



MOP 2019

Magnetospheres of Outer Planets
June 03-07, 2019
SENDAI, JAPAN



Access



Sakura Hall

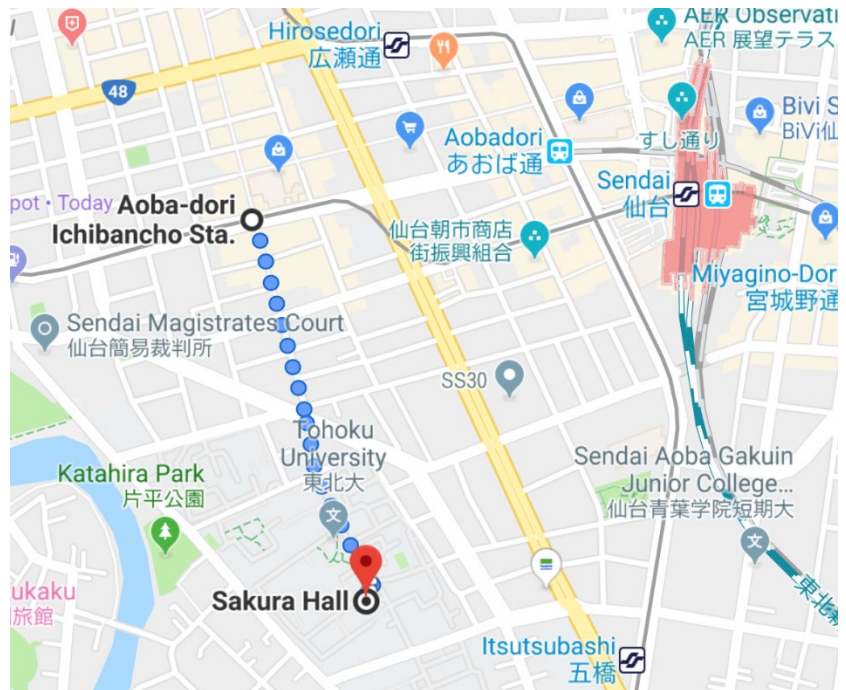
(Katahira campus)

From Jun. 3 (Mon) to Jun. 6 (Thu)

10-min walk from

Aoba-dori Ichibancho station
(subway EW line)

Route from the subway station



https://www.tohoku.ac.jp/map/en/?f=KH_E01

Google Maps <https://goo.gl/maps/VHjgQ9jumBLjexf77>



Aoba Science Hall

(Aobayama campus)

Jun. 7 (Fri)

3-min walk from Aobayama station
(subway EW line)

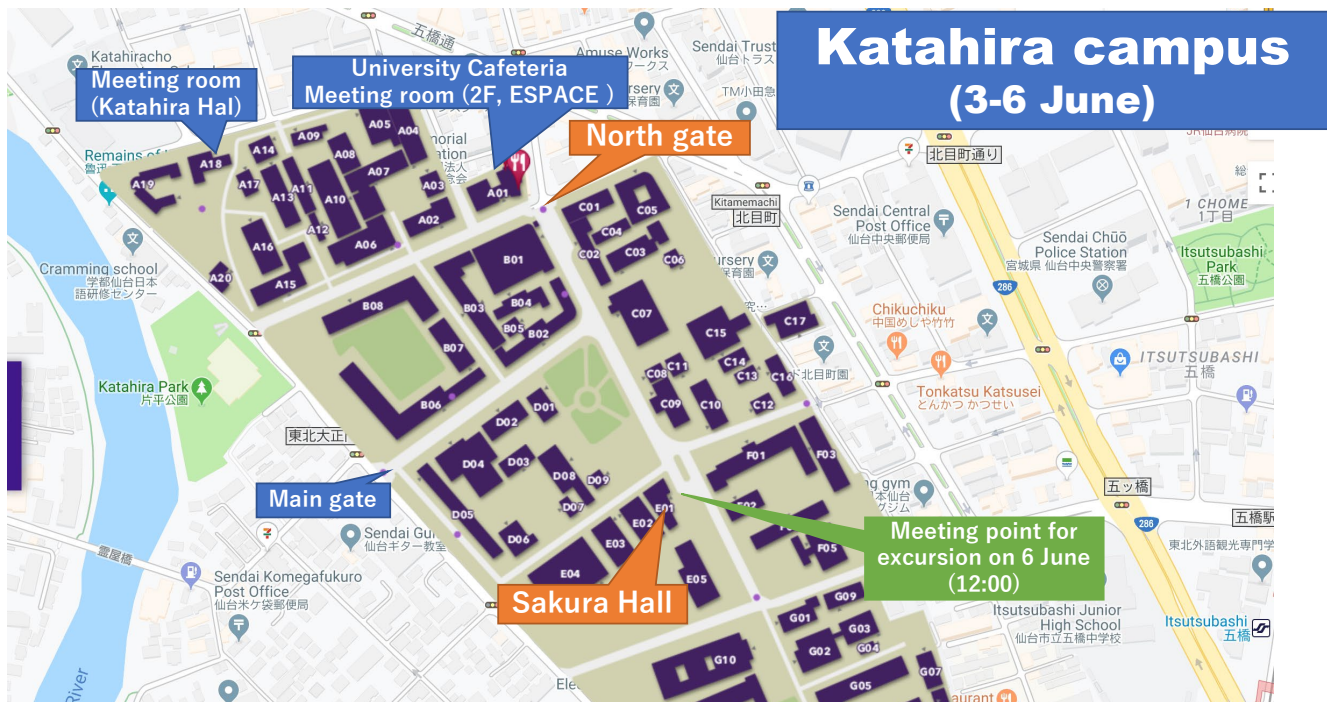
Route from the subway station



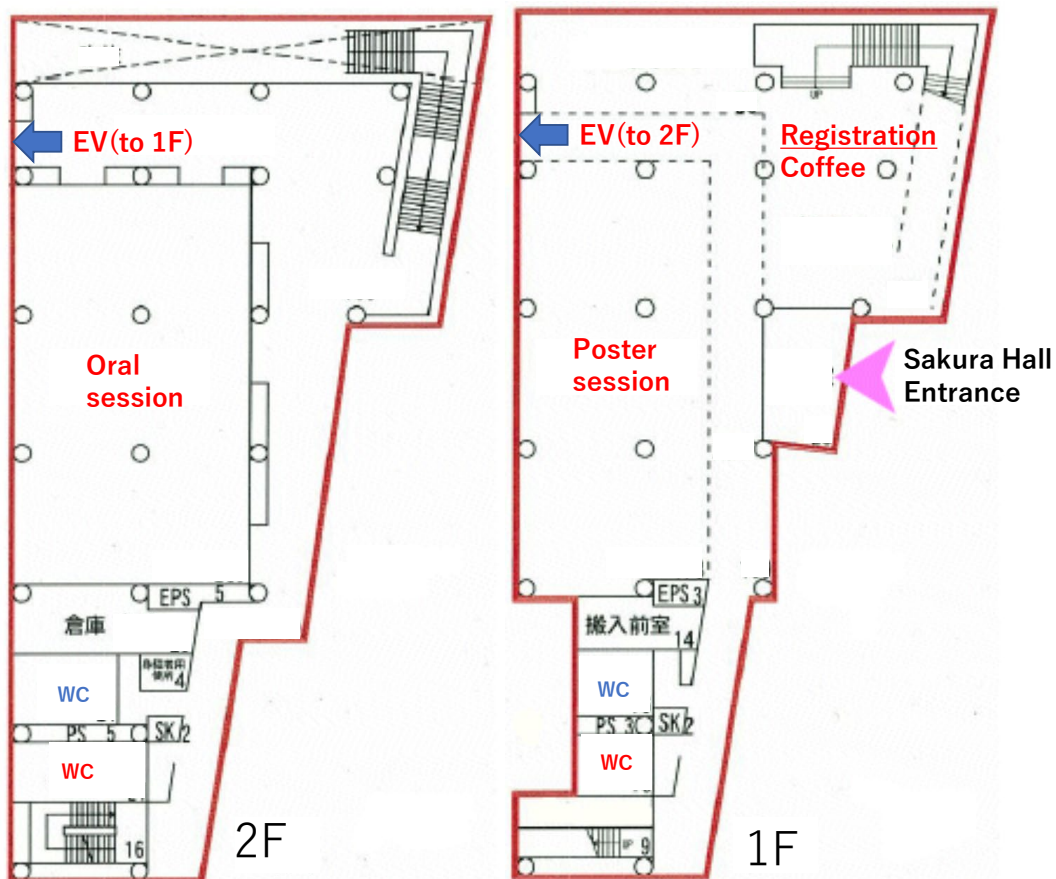
https://www.tohoku.ac.jp/map/en/?f=AY_H04

Google Maps <https://goo.gl/maps/keQ1qyWia1cc7dYw6>

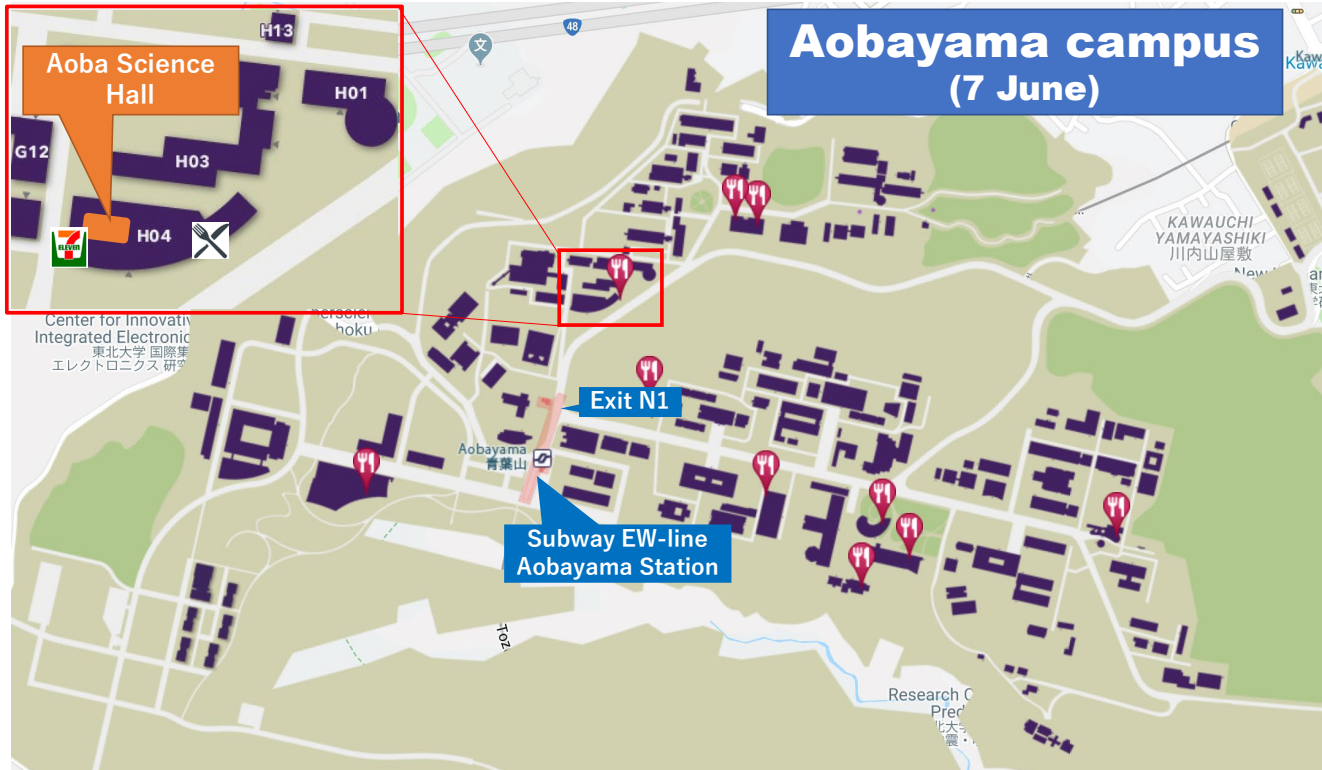
Campus map (Katahira)



(<https://www.tohoku.ac.jp/map/en/?f=KH>)



Campus map (Aobayama)



(<https://www.tohoku.ac.jp/map/en/?f=AY>)

Excursion

June 6 (Thu)

- 12:15 Getting on a bus near the venue
- 13:10 Arriving at Matsushima area
- 13:10-14:50 Lunch time

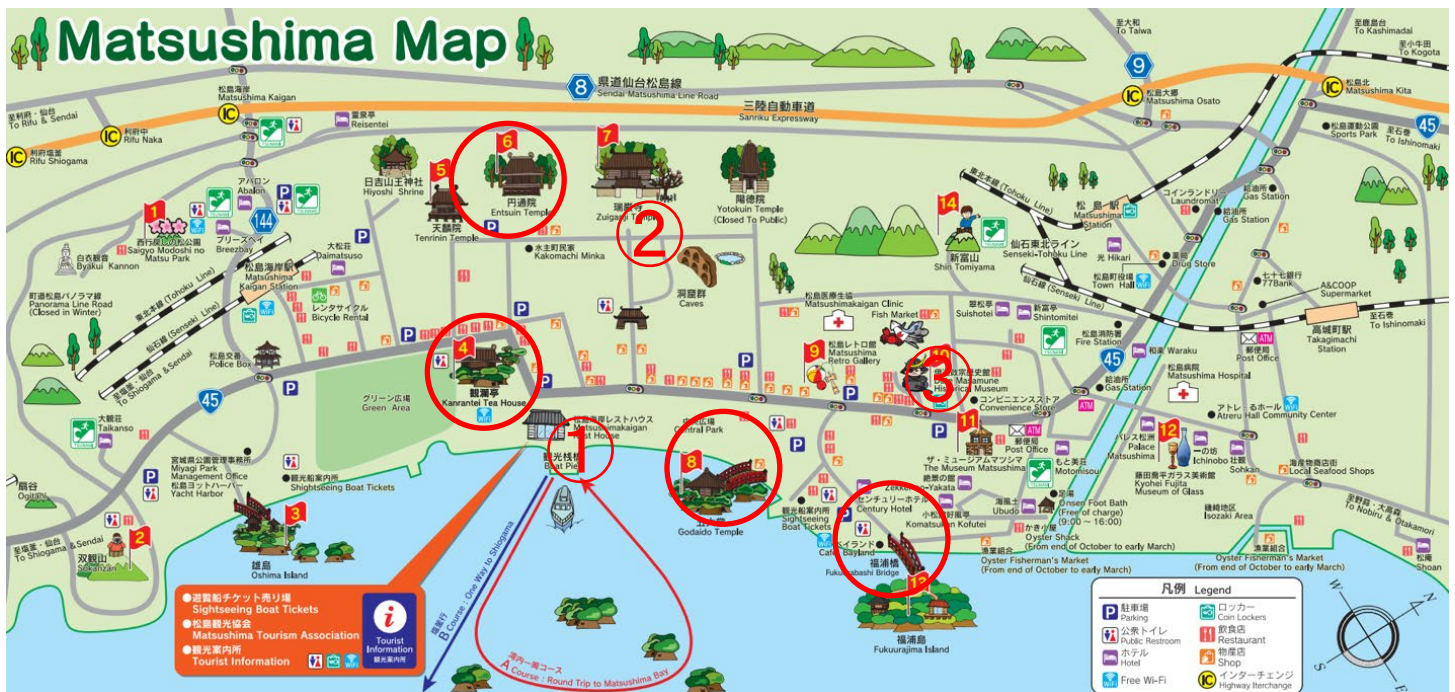
We have no reservation. There are many restaurants along the street nearby the coast.

- 15:00-16:00 Getting on a boat ①
- 16:00-17:45 Sightseeing

Tickets of the Zuiganji-temple ② and Date Masamune Historical Museum ③ will be provided.

Red circles in the map are recommended.

- 17:45 Getting on a bus
- 18:45 Arriving at central Sendai near the banquet place



<http://www.matsushima-kanko.com/uploads/Image/files/matsushimagaikokugomap2018.pdf>

Banquet

Date: Jun. 6 (Thu) 19:00-

Venue: 海鮮屋 (Kai sen ya)

[38°15'47.8"N 140°52'13.5"E]

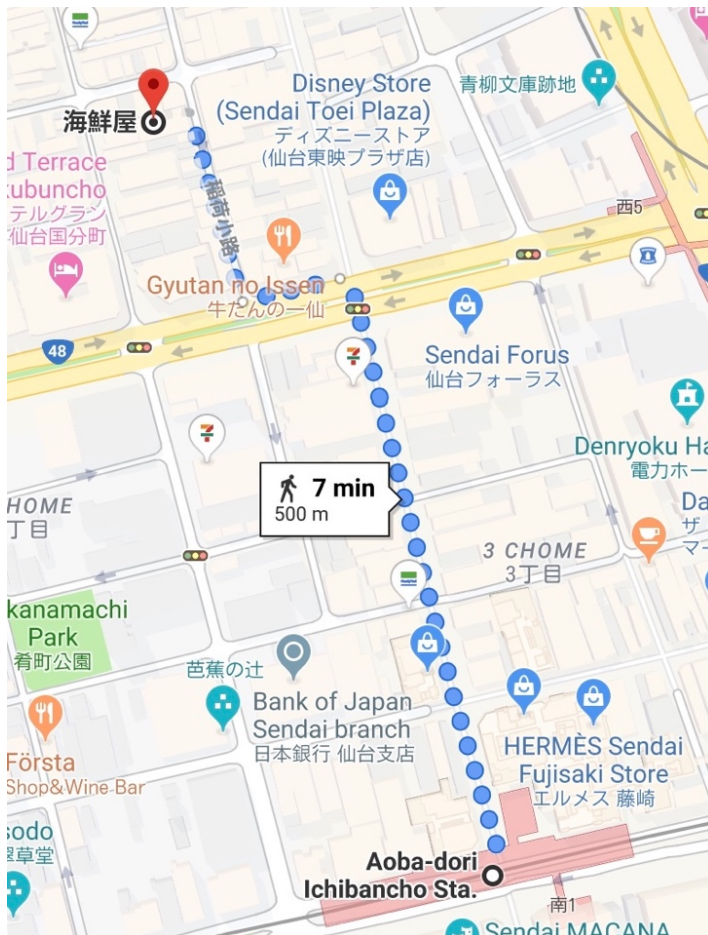
7~10-min walk from Aoba-dori

Ichibancho station
(subway EW line)

Route from the subway station



Google Maps <https://goo.gl/maps/up2QWiuMVyEGDbuPA>



Agenda

Sunday, June 2nd, Sakura Hall, Katahira Campus

15:00-18:00 **Reception**

Monday, June 3rd, Sakura Hall, Katahira Campus

Invited Talks: 25 min (20 min presentation + 5 min discussion)

Abstract

Contributed Talks: 15 min (12 min + 5 min)

(*): Presented by a co-author

page #

08:30- **Reception**

Opening

09:00-09:05 Yasumasa Kasaba Opening Remarks

Aurora - In situ, Juno's Recent Result Chair: Fran Bagenal

09:05-09:20 Scott Bolton Juno's Exploration of Jupiter's Magnetosphere 19

09:20-09:45 George Clark **(Invited)** Juno/JEDI highlights and new mysteries of Jupiter's powerful and dynamic auroras 20

09:45-10:10 Robert W. Ebert **(Invited)** Ion Properties in Jupiter's Polar Magnetosphere 21

10:10-10:25 Frederic Allegrini Energy Flux and Characteristic Energy of Precipitating Electrons Over Jupiter's Main Auroral Emission 22

10:25-10:40 Daniel Gershman Alfvén Waves in Jupiter's Polar Magnetosphere 23

10:40-11:10 **Break**

11:10-11:25 Jack Connerney Jupiter's Magnetosphere at the Midpoint of Juno's Mapping Mission 24

11:25-11:50 Sadie Suzanne Elliott **(Invited)** The Generation of Upward-Propagating Whistler-Mode Waves that Accelerate Upward-Moving Electrons in the Jovian Polar Cap Region 25

11:50-12:05 Ali Sulaiman Juno/Waves Observations of Flux Tubes Connected to Io's Orbit 26

12:05-12:20 Masafumi Imai High-Spatiotemporal Resolution Observations of Jupiter's Auroral Radiation from Juno 27

12:20-12:35 Corentin LOUIS Statistical Locus of Jovian Auroral Radio Sources Sampled in Situ by Juno/Waves 28

12:35-13:50 **Lunch**

13:50-14:25 **Poster Introduction**

	Fran Bagenal	Aurora - In situ, Juno's Recent Result	
	Fran Bagenal	Aurora - Theory and Modeling	
	Laurent Lamy	Aurora - Remote Sensing	
	Sarah Badman	Cassini Grand Finale & PPO	
	Daniel Santos-Costa	Radiation Belts	
14:25-14:50	Zhonghua Yao	(Invited) On the Relation Between Jovian Aurorae and the Loading/Unloading of the Magnetic Flux: Simultaneous Measurements from Juno, HST and Hisaki	29
14:50-15:05	Jonathan Nichols	Simultaneous Hubble Space Telescope and Juno Observations of a Jovian Auroral Enhancement Event	30
15:05-15:20	Alessandro Mura	Infrared Images of Jupiter Aurora: 3 Years of Juno Mission	31
15:20-15:35	Dale Weigt	Observations of Jupiter's Auroral Emission during Juno Apojoive June 2017	32
15:35-16:05	Break		
Aurora - Remote Sensing		Chair: Laurent Lamy	
16:05-16:30	Denis Grodent	(Invited) Jupiter is Alive! HST Observations of Jupiter's Aurora during Juno Orbits 18, 19 and 20.	33
16:30-16:45	John Clarke	The Mystery of Jupiter's Proton Aurora	34
16:45-17:00	Ben Swithenbank-Harris	Observation of a Secondary Dawn Auroral Arc at Jupiter	35
17:00-17:15	Kazumasa Imai	Jupiter's Decametric Riddle Arcs Observed by LWA and Juno	36

Tuesday, June 4th, Sakura Hall, Katahira Campus

08:55-09:00	LOC	Announcement	Abstract page #
Aurora - Theory & Modeling		Chair: Fran Bagenal	
09:00-09:25	Bob Lysak	(Invited) Structuring and Dynamics of Auroral Field-Aligned Currents by Alfvén Waves at Jupiter	37
09:25-09:50	Joachim Saur	(Invited) Wave-Particle Interaction in Jupiter's stressed Magnetosphere	38
09:50-10:15	Luke Moore	(Invited) Magnetosphere-Ionosphere Coupling at the Giant Planets: Effect of Hydrocarbon Ions on Ionospheric Electrical Conductance	39
Cassini Grand Finale & PPO		Chair: Sarah Badman	

10:15-10:40	Norbert Krupp	(Invited) The CASSINI Grand Finale in Saturn's Magnetosphere 2016-2017 in the View of Neutral And Charged Particles Measured by the MIMI Instrument	40
10:40-11:10	Break		
11:10-11:25	Michele Karen Dougherty	A Magnetic Perspective on the Interior of Saturn	41
11:25-11:40	Gregory Hunt	Currents Associated with Saturn's Intra-D Ring Azimuthal Field Perturbations	42
11:40-11:55	Omakshi Agiwal	Exploring the Sources of Variability in the Low-Latitude Field-Aligned Currents at Saturn Measured by the Cassini Magnetometer during the Grand Finale	43
11:55-12:10	Tom Stallard	A Last Look at Saturn during Cassini's Grand Finale: Maps of H3+ Emission, Temperature and Ion Winds	44
12:10-12:25	Nahid Chowdhury	Exploring Key Characteristics in Saturn's Infrared Auroral Emissions Using Adaptive Optics VLT-CRIRES Observations from 2013	45
12:25-12:40	Thomas Bradley	Solar Wind and Planetary Period Modulations of Reconnection Events in Saturn's Magnetotail	46
12:40-13:55	Lunch		
13:55-14:25	Discussion for Next MOP 1		
14:25-15:05	Poster Introduction		
	Tomoki Kimura	Hisaki Summary	
	Peter Delamere	Magnetic Flux and Plasma Transport, and Plasma Heating	
	Adam Masters	Structure	
	Lorenz Roth & Joachim Saur	Moon Interactions	
Radiation Belts		Chair: Daniel Santos-Costa	
15:05-15:30	Yoshizumi Miyoshi	(Invited) Cross-energy Coupling Process in the Terrestrial Radiation Belts; The Arase Observations	47
15:30-15:55	Satoshi Kasahara	(Invited) Pulsating Aurora from Electron Scattering by Chorus Waves	48
15:55-16:25	Break		
16:25-16:40	Heidi Becker	Mid-Mission Developments from Juno's Radiation Monitoring Investigation	49
16:40-16:55	Virgil Adumitroaie	Magnetic Field Derived Parameters for Jovian Synchrotron Radiation Modeling	50

17:10-	Poster Session
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Wednesday, June 5th, Sakura Hall, Katahira Campus

08:55-09:00 LOC	Announcement	Abstract page #
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Hisaki Summary	Chair: Tomoki Kimura
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09:00-09:25 Fuminori Tsuchiya	(Invited) Variations in Jupiter's Inner Magnetosphere Seen by Hisaki: Effects of Io and the solar wind	52
09:25-09:40 Ryoichi Koga	Spatial Distribution of Io's Neutral Oxygen Cloud During a Volcanically Quiet and Active Periods in 2014-2015	53
09:40-09:55 Reina Hikida	Increase in Hot Electron Fraction in Jupiter's Inner Magnetosphere with Io's Volcanic Event	54
09:55-10:10 Hajime Kita	Jupiter's Aurora Light Curve after 2016 Obtained from Hisaki EXCEED	55
10:10-10:25 H. Todd Smith	Resolving the Titan Torus Mystery...Finally	56

10:25-10:55	Break
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Magnetic Flux and Plasma Transport, and Plasma Heating	Chair: Peter Delamere
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10:55-11:20 Margaret G Kivelson	(Invited) Plasma Heating and Transport: Jupiter and Saturn	57
11:20-11:45 Chris Paranicas (*)	(Invited) Plasma Heating at Jupiter and Saturn	58
11:45-12:10 Abigail Azari	(Invited) A Statistical Picture of Pitch Angles of Interchange Events at Saturn and Implications for Energization and Losses	59
12:10-12:25 Vytenis M. Vasyliunas	Plasma Transport Out of the Io Torus: What Does the Observed Radial Gradient of Average Flux Tube Content Imply?	60
12:25-12:40 Peter Damiano	Modeling the Interaction of Electrons and kinetic Alfven waves in the Io plasma torus	61

12:40-13:55	Photo & Lunch
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Hisaki PSP Lunch Meeting (ESPACE room, University House Katahira)

13:55-14:25	Discussion for Next MOP 2: Vote
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14:25-15:00	Poster Introduction
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Philippe Zarka	Exoplanets and Stars
Bertrand Bonfond	MI Coupling, Ionospheres, Dust
Xianzhe Jia	Dynamics

Structure**Chair: Adam Masters**

15:00-15:15	Barry H. Mauk	A Comparative Investigation of the Leakage of Energetic Particles Across the Magnetopauses of Strongly Magnetized Planets	62
15:15-15:30	Rob J. Wilson	Electrons in the Jovian Magnetosphere as Observed by JADE-E	63
15:30-15:45	Flavien Hardy	Characterising the Structure and Compressibility of Saturn's Magnetopause	64
15:45-16:00	Ned Russell Staniland	Determining the 'Nominal Thickness and Variability of the Saturnian Magnetodisc Current Sheet	65
16:00-16:15	Hsiang-Wen (Sean) Hsu	The E-ring Asymmetry and Saturn's Noon-to-Midnight Electric Field	66

16:15-

Poster Session**Thursday, June 6th, Sakura Hall, Katahira Campus**

08:55-09:00	LOC	Announcement	Abstract page #
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Moon Interactions**Chair: Lorenz Roth and Joachim Saur**

09:00-09:25	Tom Andre Nordheim	(Invited) Charged Particle Weathering of Icy Satellites	67
09:25-09:50	Yasuhito Sekine	(Invited) How to Make a Habitable Satellite around a Gas Giant – Energy and Building Materials	68
09:50-10:15	Vincent Dols	(Invited) Interaction of Moon Atmospheres with Jupiter's magnetosphere	69
10:15-10:30	Hannes Arnold	Magnetic Signatures of a Plume at Europa During the Galileo E26 Flyby	70
10:30-10:50		Break	
10:50-11:05	Lorenz Roth	Novel HST observations of the Galilean moons Io and Ganymede, and simultaneous Juno-UVS observations of the Io footprint	71
11:05-11:20	Carley Martin	Modelling Asymmetries in Titans Flux Ropes	72
11:20-11:35	Nawapat Kaweeyanun	Favorable Conditions for Magnetic Reconnection at Ganymede's Upstream Magnetopause	73
11:35-11:50	John Leif Jørgensen	High Energy Particle Signature of the Jovian Satellites	74

11:50-

Excursion & Lunch at Matsushima

19:00-

Banquet at Kai-Sen-Ya

Friday, June 7th, **Aoba Science Hall, Aobayama**

08:55-09:00	LOC	Announcement	Abstract page #
MI Coupling, Ionospheres, Dust		Chair: Bertrand Bonfond	
09:00-09:15	William Dunn	Correlations Between Jupiter's X-ray Aurora and the Outer Magnetosphere Plasma Sheet	75
09:15-09:30	Dave Constable	Numerical Modelling of Field-Aligned Currents in the Jovian Middle Magnetosphere	76
09:30-09:45	Oleg Shebanits	Magnetosphere-Ionosphere Coupling at Saturn: Conductivities of Near-Equatorial Ionosphere	77
09:45-10:00	James O'Donoghue	The Consequences of Saturn's "Ring Rain"	78
10:00-10:15	Henrik Melin	The Ionosphere of Uranus: Long-Term Cooling and Local-Time Morphology	79
10:15-10:30	Gina A. DiBraccio	Plasmoid Observation in the Magnetotail of Uranus: Implications for Plasma Convection and Downtail Mass Loss	80
10:30-11:00	Break		
Dynamics		Chair: Xianzhe Jia	
11:00-11:25	Xianzhe Jia	(Invited) Recent Advances in Global Simulations of the Giant Planet Magnetospheres and Their Interactions with Moons	81
11:25-11:40	Binzheng Zhang	A Numerical Experiment of Global Jovian Magnetosphere: Initial Results from Multi-fluid Magnetohydrodynamics with Mass Loading	82
11:40-11:55	Harry Manners	A Global Survey of the Spatial Distribution of Ultra-Low-Frequency Waves with Periods ~1-100 Minutes in the Jovian Magnetosphere	83
11:55-12:10	Ruilong Guo	Dayside Magnetodisk Reconnection Processes on Saturn Revealed by Cassini	84
12:10-12:25	Benjamin Palmaerts	Origin and Triggers of the 1-hour Electron Pulsations in the Saturnian System	85
Closing			
12:25-12:30	Yasumasa Kasaba	Closing Remarks	

Posters, Mon-Wed, Sakura Hall, Katahira Campus

C: "Cassini Grand Finale & PPO", **J:** "Aurora - in situ, Juno's recent result", **Th:** "Aurora - Theory and Modeling", **Re:** "Aurora - Remote Sensing", **H:** "Hisaki Summary", **Tr:** "Magnetic Flux and Plasma Transport, and Plasma Heating", **Ra:** "Radiation Belts", **Mo:** "Moon Interactions", **MI:** "MI Coupling, Ionospheres, Dust", **S:** "Structure", **D:** "Dynamics", **ES:** "Exoplanets and Stars", **SI:** "Spacecraft and Instruments", (*): Presented by a co-author

Poster #	Author	Title	Session	Abstract page #
Cassini Grand Finale & PPO, Chair: Sarah Badman				
1	Gabrielle Provan	On Saturn's Rings – Planetary Period Oscillations and the Intra-D Ring Current	C	86
2	David Piša	Time Domain Structures in Cassini's Wideband Receiver Waveforms Observed Inside the Inner Magnetosphere of Saturn	C	87
3	Geraint Jones (*)	Negative Ions in Saturn's Inner Magnetosphere	C	88
4	Duane Pontius	Saturn's Multiple, Variable Periodicities: A Dual-Flywheel Model of Thermosphere-Ionosphere-Magnetosphere Coupling	C	89
5	Benjamin Palmaerts	A Nearly-Corotating Long-Lasting Auroral Spiral at Saturn	C	90
6	David Andrews (*)	The Structure of Planetary Period Oscillations in Saturn's Equatorial Magnetosphere: Results from the Cassini Mission	C	91
7	Lina Hadid (*)	Coupling between Saturn's Ionosphere and the Rings Ionosphere around 2.5 Rs	C	92
Aurora - in situ, Juno's recent result, Chair: Fran Bagenal				
8	Thomas Greathouse	A study of Local Time Variations of Jupiter's Ultraviolet Aurora using Juno UVS	J	93
9	Philippe Louarn	Electron Conics: What do They say about Auroral Acceleration Processes ?	J	94
10	Randy Gladstone	Jupiter's Average Ultraviolet Aurora Using Juno-UVS	J	95
12	Joshua Kammer	Juno-UVS 3-D Maps of High-Energy Radiation at Jupiter	J	96
13	Zhonghua Yao	Auroral Diagnosis of Solar Wind Interaction with Jupiter's Magnetosphere	J	97
14	Vincent Hue	Observation of Auroral "Raindrops" in Jupiter's Polar Region by Juno-UVS	J	98
Aurora - Theory and Modeling, Chair: Fran Bagenal				
15	Yan Song	Unified Theory of the Acceleration of Auroral Particles and the Formation of Discrete Auroras at Earth and Jupiter	Th	99
Aurora - Remote Sensing, Chair: Laurent Lamy				
16	Bertrand Bonfond	Are Dawn Storms Jupiter's auroral Substorms?	Re	100
17	Laurent Lamy	Uranus spin : Toward an Updated Rotation Period and SIII Longitude System	Re	101
18	Fabiola Magalhaes	Statistical Analysis of Long-term Variations of Jovian Radio Components Observed by Cassini.	Re	102
19	Sarah Badman	Transient Features in Jupiter's Polar Aurora: UV and X-ray Comparison	Re	103

20	Yasumasa Kasaba	Pulsation-like Variation of Jovian Infrared H3+ Polar Emissions Observed by Subaru 8-m	Re	104
21	Suwicha Wannawichian	Brightening Behavior of Io's Magnetic Footprint	Re	105
22	Tatphicha Promfu	Jupiter's Magnetic Field Analysis via Ganymede's Magnetic Footprint Locations	Re	106
23	Kamolporn Haewsantati	Bright Spot morphology in Jupiter's Polar Aurora	Re	107
24	Laurent Lamy	Facilitating Access to HST/Hisaki Remote Processed Observations of Saturn/Jupiter in Support to Cassini/Juno In Situ Measurements through the APIS Service	Re	108
25	Hiroaki Misawa	Expected Source Region of Jupiter's Hectometric Radiation Relating to Magnetotail Reconnection	Re	109
26	Matthew Rutala	New Insights into Jupiter's Dawn Storms	Re	110
Hisaki Summary, Chair: Tomoki Kimura				
27	Fuminori Tsuchiya	Azimuthal Variation in the Io Plasma Torus Observed by the Hisaki Satellite during Io's Volcanically Active Period	H	111
28	Nick Schneider	Ion Scale Height Variability in Hisaki Io Torus Observations	H	112
29	Seiya Nishimura	Correlation between the Io Plasma Torus and Jovian Aurora Revealed by the EXCEED/Hisaki Mission	H	113
30	Tomoki KIMURA	Development of Ground Pipeline system for High-Level Scientific Data Products of the Hisaki Satellite Mission and Its Application to Planetary Space Weather	H	114
31	Tomoki KIMURA	A Magnetic Reconnection Event at a Close Binary System Monitored by the Hisaki Satellite during the NICER-Hisaki Observing Campaign 2018-2019	H, ES	115
32	Kazuo Yoshioka	The Influence of Io's Volcanic Activity in 2015 on Jupiter's Magnetospheric Dynamics	H	116
33	Chihiro Tao	Jupiter's Aurora Observed by Hisaki: Intrinsic Periodic Variation	H	117
34	Kazuki Yamaguchi	Development of a Radial Diffusion Model of Jovian Inner Magnetospheric Plasma Aimed at Comparison with HISAKI Satellite Observation	H	118
35	Edward Nerney	A 2-D Io Plasma Torus Spectral Emission Model and Comparisons with UV and Ground-Based Observations	H	119
Magnetic Flux and Plasma Transport, and Plasma Heating, Chair: Peter Delamere				
36	Fran Bagenal	Flow of Mass and Energy Through the Magnetosphere of Jupiter: Update	Tr	120
37	Peter Delamere	Hybrid Simulations of Magnetodisc Transport driven by the Rayleigh-Taylor Instability	Tr	121
38	Bishwa Neupane	Electron Density and Temperature Fluctuations in Saturn's Magnetosphere: Implications for Transport.	Tr	122
Radiation Belts, Chair: Daniel Santos-Costa				
39	Peter Kollmann	Jupiter's Innermost Radiation Belts from Juno Measurements	Ra	123
40	Daniel Santos-Costa	Statistical Analysis of Juno Observations of $>\sim 5$ MeV Electron Beams at Jupiter	Ra	124

41	Elias Roussos	A Local-Time Confined Electron Radiation Belt Generated by Saturn's F-Ring	Ra	125
42	Elias Roussos	Relativistic Charged Particles, Neutrons and Gamma Rays at Saturn: MIMI/LEMMS Measurements and GEANT4 Simulations	Ra	126
43	Yixin Sun	Spectral Signatures of Corotation Drift Resonant Acceleration in Saturn's Electron Radiation Belts.	Ra	127
44	Chongjing Yuan	Quantifying Transient Electron Radiation Belt Extensions at Saturn	Ra	128
Moon Interactions, Chair: Lorenz Roth and Joachim Saur				
45	Hongyang Zhou	Upstream Dynamics from Embedded Kinetic Simulations of Ganymede's Magnetosphere	Mo	129
46	Marshall Styczinski	Constraining Spatial Asymmetry in Europa's Oceans	Mo	130
47	Phillip Phipps	The Centrifugal Equator as seen by Juno Radio Occultations of the Io Plasma Torus	Mo	131
48	Jeffrey P. Morgenthaler (*)	The response of the S+ Io plasma torus to the large volcanic outburst in 2018	Mo	132
50	Drew Coffin	Modeling the Hot Electron Source and System IV Modulation in the Io Plasma Torus	Mo	133
51	Camilla Harris	Multifluid MHD Simulations of Europa's Interaction with Jupiter's Magnetosphere	Mo	134
52	Frank J Crary	Europa's Interaction with the Jovian Magnetosphere: Variability in Time and Longitude	Mo	135
53	Parker Hinton	Alfvén Wave Propagation in the Io Plasma Torus	Mo	136
54	Hannes Arnold	A hybrid simulation study of the interaction between Europa's plumes and Jupiter's magnetosphere	Mo	137
55	Fabiola Magalhaes	Cassini/UVIS high-level database and application to the search for the Enceladus footprint	Mo	138
56	Masato Kagitani	Structure of Io plasma torus observed with the Tohoku 60-cm telescope	Mo	139
57	Tracy M. Becker	Constraining Europa's Exospheric Trace Abundances with HST/STIS Spectral Imaging	Mo	140
58	Gabriel Giono	A closer look at the statistics and systematics of limb anomaly detections in Europa transit observation by HST/STIS.	Mo	141
59	Aljona Blöcker	MHD Modeling of the Plasma Interaction With Europa's Asymmetric Atmosphere	Mo	142
60	Fran Bagenal	The Io-Europa Space Environment	Mo	143
61	Darci Snowden	The Impact of Magnetospheric Particle Precipitation on Titans Upper Atmosphere	Mo	144
MI Coupling, Ionospheres, Dust, Chair: Bertrand Bonfond				
62	James Sinclair (*)	Long-term and short-term and variability of Jupiter's polar stratosphere: The search of the effect from the magnetosphere	MI	145
63	Yuki Nakamura	Axisymmetric conductivities of Jupiter's middle- and low-latitude ionosphere	MI	146
64	Yuki Nakamura	Seasonal variation of north–south asymmetry in the intensity of Saturn Kilometric Radiation from 2004 to 2017	MI	147

65	Japheth Yates	Simulating the Influence of Local-Time on Magnetosphere-Ionosphere-Thermosphere Coupling at Jupiter	MI	148
66	Ayumu Kambara	Enhancement of the Jovian Thermospheric Temperature above the Great Red Spot based on the Infrared Spectroscopic Data obtained with IRTF/iSHELL	MI	149
67	Carley Martin	Polar Wind Outflow Model at Jupiter	MI	150
68	Shotaro Sakai	Plasma dynamics in Saturn's middle-latitude ionosphere and implications for magnetosphere-ionosphere coupling	MI	151
Structure, Chair: Adam Masters				
69	Flavien Hardy	Characterising the Structure and Compressibility of Saturn's Magnetopause	S	152
70	Adam Masters	Magnetospheric magnetic field models for Uranus and Neptune	S	153
71	Ivan Pensionerov	Empirical model of Jupiter's current sheet for Juno data	S	154
72	Daniel Santos-Costa	Revisiting the role of neutrals and high-latitude particle sources on the distribution of warm to energetic electrons at Saturn	S	155
73	Steven Petrinec	Magnetic shear angle estimates at the Saturn magnetopause and relation to the probable reconnection line location	S	156
74	Ezra Huscher	Plasma Sheet Properties Observed by Juno at Jupiter	S	157
Dynamics, Chair: Xianzhe Jia				
75	Jamie Jasinski	Survey of reconnection signatures at Saturn's magnetopause	D	158
76	Yash Sarkango	Impact of solar wind pressure enhancement on Jupiter's magnetosphere: Insights from global MHD simulations	D	159
77	Yuto Katoh	Cross-reference simulations by scalable communication library for the study of wave-particle interactions in planetary magnetospheres	D	160
78	Keiichiro FUKAZAWA	Development of cross-reference numerical simulation framework: macro- and micro-scale simulations of the magnetosphere	D	161
79	Ruilong Guo	Electron pulsations generated by rotating magnetospheric dynamics at Saturn	D	162
80	Michelle Thomsen (*)	Solar Wind Dynamic Pressure Upstream from Saturn: Estimation from Magnetosheath Properties and Comparison with SKR	D	163
81	Caitriona Jackman	Survey of Saturn's magnetopause and bow shock positions over the entire Cassini mission: boundary statistical properties, and exploration of associated upstream conditions	D	164
82	Kunihiro Keika	Spatio-temporal Evolution of Energy Spectra of Energetic Protons and Oxygen Ions During Large-scale Injections in Saturn's Magnetosphere	D	165
83	Patrick Guio	Effect of Magnetodisc Fields on Plasma Injection Signatures	D	166
84	Brandon Burkholder	Ubiquity of Kelvin-Helmholtz waves at Saturn's magnetopause	D	167
Spacecraft and Instruments, Chair: Go Murakami & Yasumasa Kasaba				
85	Takeshi Sakanoi	Current status and future plan of the PLANETS telescope project for planetary and exoplanetary atmospheric monitoring	D	168
86	Yoshifumi Futaana	Plasma-Neutral coupling in the Jovian magnetosphere: Low-energy Energetic Neutral Atom imaging in the Jovian system	SI	169

87	Go Murakami	Future ultraviolet observation for monitoring outer planetary systems	SI	170
88	Chuanfei Dong	A New Frontiers Uranus Orbiter Concept Study with Ten-Moment Multifluid Global Magnetosphere Modeling	SI	171
89	Fei He	Chinese Balloon-borne Optical Remote Sensing Program for Planetary Sciences	SI	172
90	Haje Korth	Investigations of Moon-Magnetosphere Interactions by the Europa Clipper Mission	SI	173
91	Kurt D Retherford	Europa-UVS and JUICE-UVS Science Planning	SI	174
92	Corey Cochrane	Multi-frequency phase and amplitude extraction of induced magnetic dipoles of icy planetary bodies via orbiting spacecraft: Application to Europa Clipper	SI	175
93	Sébastien Hess	Simulation of JUICE Plasma Measurements while Orbiting Ganymede	SI	176
94	Yasuhito Sekine	Jupiter Icy Moons Explorer-Science objectives by JUICE-Japan	SI	177
95	Yasumasa Kasaba	Japanese Participation in JUICE (Jupiter Icy Moons Explorer): Current Status and Future Plans	SI	178
96	Yasumasa Kasaba	High Frequency part in Radio & Plasma Wave Investigation (RPWI) aboard JUICE: Toward the investigation of Jupiter and Icy Moons System	SI	179
97	Atsushi Kumamoto	Passive subsurface radar for exploration of the subsurface structures of Jupiter's icy moons by JUICE/RPWI	SI	180
98	Yuto Katoh	Software-type Wave-Particle Interaction Analyzer (S-WPIA) by RPWI for JUICE	SI	181
99	Alessandro Retino (*)	The Search-Coil Magnetometer Onboard the ESA JUICE Mission: Scientific Objectives and Instrument Design	SI	182
100	Kazumasa Imai	KOSEN-1 CubeSat Mission for Jupiter's Decametric Radio Observation	SI	183

Exoplanets and Stars, Chair: Philippe Zarka

101	Philippe Zarka	Tentative Detection of the Magnetospheric Radio Emission from an Exoplanet	ES	184
102	Yuta Shiohira	The Microlensing of Exoplanet	ES	185

Abstracts

Juno's Exploration of Jupiter's Magnetosphere

S. Bolton, J. Connerney, S. Levin, A. Adriani, F. Allegrini, F. Bagenal, R. Gladstone, W. Kurth, B. Mauk and the Juno Team

* SwRI

The Juno spacecraft was launched in 2011 and arrived at Jupiter on July 4, 2016, where it now resides in a highly elliptical 53-day polar orbit. Juno's scientific objectives include the study of Jupiter's interior, atmosphere and magnetosphere with the goal of understanding Jupiter's origin, formation and evolution. The baseline mission utilizes thirty-two polar orbits to effectively map Jupiter both inside and out. Each perijove provides Juno's nine-instrument payload a close pass over Jupiter at altitudes of ~3500 km above the cloud tops. With its unique orbit and unique viewing geometry, Juno peers deep into Jupiter's atmosphere and interior to reveal for the first time the physics of giant planet interiors. The results have fundamentally changed our understanding of Jupiter and have demonstrated the utility of this new approach to solar system investigation. Juno transits both polar regions before and after perijove providing the first in-situ measurements of Jupiter's magnetosphere from above, while imaging auroral emissions in UV and IR wavelengths. An extensive campaign of Earth based observations of Jupiter complements Juno measurements during Juno's approach to Jupiter and during its orbital mission around Jupiter. This presentation will focus on an overview of results from Juno's investigation of the Jupiter's magnetosphere with summaries of scientific results on Jupiter's interior structure, magnetic field, deep atmospheric dynamics and composition.

O2

Juno/JEDI highlights and new mysteries of Jupiter's powerful and dynamic auroras

(Invited)

George Clark, B.H. Mauk, C. Paranicas, P. Kollmann, D. Haggerty, A. Rymer, J. Westlake, J. Saur, F. Allegrini, R.W. Ebert, F. Bagenal, W.S. Kurth, G. Hospodarsky, A. Sulaiman, S. Elliott, G.R. Gladstone, J.E.P. Connerney, S. Kotsiaros, D. Gershman, W. Li, S. Bolton, S. Levin

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Over the past several years, Juno observations continue to reveal new insights into the nature of Jupiter's powerful and dynamic auroras. Focusing here on the aspects revealed by energetic particle distributions measured by Juno/JEDI, previous studies have shown that Jupiter's auroral region is host to a number of different acceleration processes with unique characteristics that differ from Earth & Saturn. For example, the strong nature of Jupiter's aurora can accelerate particles to 100s or even 1000s of kilo-electron volts, which is 10-100 times more energetic than typical Earth-like processes. Likewise, the interplay between magnetic field-aligned potentials and the turbulent or stochastic like mechanisms appear to play a different and complex role in the generation of Jupiter's brightest auroral features. Juno has also passed through the footprint tails of the Jovian satellites. For Io, evidence for Alfvénic turbulence, dispersion less plasma-waves and the most intense proton distributions ever measured by JEDI appear to be the consequence of the unique coupling between the plasma environment and Jupiter's ionosphere. Jupiter's polar magnetosphere is truly a unique and dynamical region. In this presentation, we discuss the energetic particle observations in these regions and their importance to unearthing clues relating to Jupiter's aurora and satellite interactions. We focus on recent highlights and present new mysteries.

O3

Ion Properties in Jupiter's Polar Magnetosphere

(Invited)

R. W. Ebert, T. K. Kim, F. Allegrini, F. Bagenal, W. S. Kurth, P. Louarn, D. J. McComas, J. R. Szalay, M. F. Thomsen, R. J. Wilson, P. W. Valek, and S. J. Bolton

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One of the surprises of the Juno mission has been the detection of ions of magnetospheric origin, mostly protons, oxygen, and sulfur, in Jupiter's polar magnetosphere. The magnetospheric ions at high latitude reside on magnetic field lines that map to equatorial regions ranging from the inner edge of the Io torus to where corotation breaks down in Jupiter's plasma sheet [Szalay et al. 2017]. We present an overview of ion observations in Jupiter's polar magnetosphere obtained by the Jovian Auroral Distributions Experiment Ion sensor [JADE-I; McComas et al. 2017] on Juno, which measures the energy distribution of ~ 0.01 to 46 kilo-electron volts per charge (keV/q) ions with masses $< \sim 64$ amu/q. We focus on observations taken during the rapid pole-to-pole transit bounding Juno's several perijove passes where the spacecraft ranges from $\sim 1.05 - 2$ jovian radii (RJ) in jovicentric distance. A survey of parameters such as ion density, temperature and abundance are presented and compared to observations in Jupiter's equatorial magnetosphere from Juno and previous missions (e.g. Voyager and Galileo). These results provide context for understanding the structure of Jupiter's polar magnetosphere and the processes that transport the equatorial plasma to high latitudes.

Energy Flux and Characteristic Energy of Precipitating Electrons Over Jupiter's Main Auroral Emission

F. Allegrini, B. Mauk, G. R. Gladstone, G. Clark, F. Bagenal, S. Bolton, J. E. P. Connerney, R. W. Ebert, V. Hue, G. B. Hospodarsky, M. Imai, W. S. Kurth, S. Levin, P. Louarn, D. J. McComas, J. Saur, J. Szalay, R. J. Wilson

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Jupiter's powerful aurorae are caused by energetic electrons precipitating from the magnetosphere into the atmosphere where they excite the molecular hydrogen. These electrons are characterized over the auroral regions by the Jovian Auroral Distributions Experiment (JADE) and the Jupiter Energetic particle Detector Instrument (JEDI) on Juno. Derived energy spectra and pitch angle distributions help us understand how these aurorae are created and powered. Corresponding ultraviolet emissions from reconstructed images taken by the Ultraviolet Spectrograph (UVS) on Juno give us the context and allow us to match the electron observations with their impact on the atmosphere. In this study, we show how the electron energy flux and characteristic energy vary from the polar region, over the main emission, and equatorward of the main emission in relationship with the UV emissions. We focus on the closest passes which range from ~ 1.25 to 2 RJ. We find that while the >30 keV electrons dominate the energy flux in the polar regions and equatorward of the main emission, there is a region near the maximum UV brightness where: i) the characteristic energy decreases from more than ~ 100 keV to less than ~ 10 keV and ii) the maximum contribution to, or a significant fraction of, the total downward energy flux comes from <30 keV electrons. This pattern is present in all eight perijove passes for which JADE and JEDI have the best pitch angle coverage.

O5

Alfvén waves in Jupiter's polar magnetosphere

Daniel J. Gershman, John E.P. Connerney, Stavros Kotsiaros, Gina A. DiBraccio, Yasmina M. Martos, Vincent Hue, George Clark, Fran Bagenal, Steve Levin, and Scott J. Bolton

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Alfvén waves transmits field aligned currents and large-scale turbulence throughout Jupiter's magnetosphere. Magnetometer data from the Juno spacecraft have provided the first measurements of fluctuations along auroral and Jovian satellite flux tubes. Transverse magnetic field perturbations associated with Io are observed up to ~ 90 degrees away from main Io footprint, supporting the presence of extended Alfvénic wave activity throughout its tail. Additional broadband fluctuations are comprised of incompressible magnetic turbulence that maps to Jupiter's equatorial plasma sheet at radial distances within 20 RJ. These polar fluctuations are found to exhibit a power spectrum consistent with critically balanced Kolmogorov turbulence. This turbulence can generate up to ~ 100 mW/m² of Poynting flux to power the Jovian “diffuse aurora” in regions connected to the inner magnetospheres central plasma sheet.

Jupiter's Magnetosphere at the Midpoint of Junos Mapping Mission

John E P Connerney, Stavros Kotsiaros, Dan Gershman, Yasmina Martos, John L Joergensen, Jose M G Merayo, Matija Herceg, Scott J Bolton, Steven M Levin

* Space Research Corporation

The Juno spacecraft was launched in August 2011 and inserted into polar orbit about Jupiter on July 4th, 2016, performing close periJove passes (to $\sim 1.05 R_J$ radial distance) every 53 days. The Juno magnetic field investigation acquires observations throughout the magnetosphere, and maps the planetary magnetic field with unprecedented global coverage. Observations acquired during the first 9 polar passes provided a detailed (spherical harmonic of degree and order 10) magnetic field model (JRM09). A dramatic hemispherical asymmetry is evidenced in a very non-dipolar magnetic field in the northern hemisphere, and a dipolar magnetic field south of the equator, where an enigmatic “Great Blue Spot” resides within an equatorial band of opposite polarity. Here we explore implications for charged particle motion on drift shells near the planet, and models of the external field (magnetodisc) appropriate to the Juno era. It has already been noted that the magnetodisc observed by Juno is slightly less “stretched” relative to that observed in the Voyager and Pioneer era. As Junos orbit evolves, we increasingly transit magnetic latitudes that help constrain magnetodisc parameters. With 16 equally spaced longitudes now available we can begin to address the systematic mapping of Birkeland currents above the polar aurorae, and magnetodisc variability. These and other developments will be presented with Juno approximately midway through its mission, designed to collect a global map with 32 polar orbits separated by $<12^\circ$ longitude.

The generation of upward-propagating whistler-mode waves that accelerate upward-moving electrons in the Jovian polar cap region

(Invited)

S. S. Elliott, D. A. Gurnett, W. S. Kurth, B. H. Mauk, R. W. Ebert, G. Clark, P. Valek, F. Allegrini, S. J. Bolton, P. H. Yoon, J. D. Menietti, and P. Louarn

* University of Iowa

Upward-moving energetic electrons (from 100 eV to several MeV) over the entire Jovian polar region were discovered by the Juno spacecraft. These electrons were found to be associated with intense broadband whistler-mode waves, comparable to terrestrial whistler-mode auroral hiss. The waves are generated by upward-moving, magnetic field-aligned electron beams (inverted-Vs), by a beam-plasma instability at the Landau resonance. The mechanism for the generation of the waves and acceleration of the electrons, proposed by Elliott et al. [2018], will be discussed. A focus will be placed on the first step in this mechanism, wave generation by inverted-Vs. Growth rates have been computed using model distribution functions based on inverted-V observations made by the Juno JADE-E instrument. The model-generated waves are right-hand circularly polarized (as expected for whistler-mode auroral hiss). We find that the calculated growth rates are sufficient to produce the observed wave intensities. We will also discuss wave-particle interactions that occur between the upward-traveling electrons and upward-propagating whistler-mode waves. These interactions include pitch angle scattering by the waves, and stochastic electron acceleration by solitary waves. The proposed wave generation and electron acceleration mechanism will be supported by observations made by the Juno spacecraft.

Juno/Waves Observations of Flux Tubes Connected to Io Orbit

A. H. Sulaiman, G. B. Hospodarsky, W. S. Kurth, F. Allegrini, S. J. Bolton, G. Clark, J. E. P. Connerney, V. Hue, B. H. Mauk and J. R. Szalay

* University of Iowa

During each perijove pass, the Juno spacecraft crosses magnetic flux tubes connected to Io orbit at least once in each hemisphere. The Waves instrument onboard detects a variety of plasma wave emissions characteristic of the coupling between Io and Jupiter's ionosphere. These emissions have a clear upper frequency cutoff, understood to be the electron plasma frequency, thus making the electron number density calculable. Cutoffs related to other fundamental plasma frequencies are also visible. Interestingly, the ultra-high magnetic field of Jupiter makes lower frequencies in the ion and possibly Alfvénic range measurable, and provides a new view of the structure of moon-ionosphere plasma waves. Further, the total power in the plasma waves is roughly equally partitioned between the electric and magnetic components, confirming their electromagnetic nature. This offers clues to the beam speeds at play to sustain the coupling. We present such plasma wave observations pertaining to Io flux tubes and discuss their dependence with longitudinal separation (i.e. distance downtail), as well as distance from the moon. We also examine the physics of wave mode propagation and the relative contributions of particles (electrons, protons, possibly heavies) in generating plasma wave instabilities within their corresponding frequency ranges.

High-Spatiotemporal Resolution Observations of Jupiter's Auroral Radiation from Juno

M. Imai, W. S. Kurth, G. B. Hospodarsky, S. J. Bolton, and J. E. P. Connerney

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Jupiter's polar auroras present complex emissions over a broad range of electromagnetic wavelengths. In the radio regime, these sources are located on auroral radio magnetic field lines. These auroral radio emissions comprise broadband kilometric (bKOM) emissions between 10 kHz and 1 MHz, hectometric (HOM) emissions between 300 kHz and 10 MHz, and decametric (DAM) emissions between a few MHz and 40 MHz. Earth-based radio observatories and near-equatorial spacecraft revealed various types of spectral structures on the timescale of milliseconds to hours. However there remains a question of whether these structures represent an intrinsic radio generation mechanism or are due to propagation effects by high density plasmas along the observer's line of sight or both. The Juno mission provides another opportunity to address this question due to its highly-eccentric, polar orbit. Juno is equipped with the Waves instrument having high resolution recording modes of electric fields from 50 Hz to 41 MHz using a dipole antenna. During each perijove pass, Juno has identified several potential radio source crossings by comparing the lower edge of the observed emission frequency with the local electron gyrofrequency based on the measured magnetic field. The emissions tend to be composed of multiple narrow band emissions, thereby forming striated spectral structures. In this presentation, we show the details of the high-spatiotemporal resolution observations of Jovian auroral radiation from Juno's proximity to Jupiter and their physical implications by means of the Jovian radio beaming model.

Statistical locus of jovian auroral radio sources sampled in situ by Juno/Waves

C. K. Louis, L. Lamy, R. Prangé, P. Zarka, M. Imai, P. Louarn, W. S. Kurth and F. Allegrini

* IRAP

Since the discovery of the jovian auroral radio emissions, the question arises of the sources position of the different components (broadband kilometric (bKOM), hectometric (HOM) and decametric (DAM)), their eventual colocation and their association with ultraviolet (UV) auroral emissions. We surveyed the Junos fifteen first perijoves to track local radio sources from Juno/Waves in situ measurements (50 Hz–40 MHz). This allowed us to study the 3D spatial distribution of the bKOM, HOM and DAM radio sources. These are located on the same magnetic field lines, with real apexes (distance of the magnetic field lines at the equator) ranging from 10 to 62 Jovian radii. The comparison with images of the Jovian UV aurorae (quasi-)simultaneously acquired by the Hubble Space Telescope (HST) reveal a partial spatial colocation between the UV emission of the main oval and the identified local radio sources. The use of simultaneous Juno / JADE particle measurements allows us to have a better understanding of these sources.

O11

On the relation between Jovian aurorae and the loading/unloading of the magnetic flux: simultaneous measurements from Juno, HST and Hisaki

(Invited)

Z. H. Yao, D. Grodent, W. S. Kurth, G. Clark, B. H. Mauk, T. Kimura, B. Bonfond, S.-Y. Ye, A. T. Lui, A. Radioti, B. Palmaerts, W. R. Dunn, L. C. Ray, F. Bagenal, S. V. Badman, I. J. Rae, R. L. Guo, Z. Y. Pu, J.-C. Gérard, K. Yoshioka, J. D. Nichols, J. E. P. Connerney, S. Bolton and S. M. Levin

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We present simultaneous observations of aurorae at Jupiter from the Hubble Space Telescope and Hisaki, in combination with the in-situ measurements of magnetic field, particles and radio waves from the Juno Spacecraft in the outer magnetosphere, from ~ 60 RJ to 80 RJ during March 17 to 22, 2017. Two cycles of accumulation and release of magnetic flux, named magnetic loading/unloading, were identified during this period, which strongly correlate with electron energization and auroral intensifications. Magnetic reconnection events are identified during both the loading and unloading periods, indicating that reconnection and unloading are independent processes. The loading/unloading processes also correlate with MeV heavy ion fluxes, implying a potential role in Jovian X-ray emissions.

Simultaneous Hubble Space Telescope and Juno observations of a jovian auroral enhancement event

J. D. Nichols, F. Allegrini, F. Bagenal, E. J. Bunce, J.P. Connerney, S. W. H. Cowley, W.S. Kurth, D. Grodent, R. J. Wilson, Z. Yao

* University of Leicester

We present concurrent observations of Jupiter's auroras obtained with the Hubble Space Telescope and the planets magnetodisc and M-I coupling currents as observed by the Juno spacecraft, indicating an association of Jupiter's auroral intensity with current intensity. During PJ11 inbound, Juno measured in the middle magnetosphere a substantial increase in B_ϕ from a 'nominal background of ~ 2 nT to 7-9 nT between ~ 30 and $55 R_J$, implying increased equatorial radial current flowing as part of the M-I coupling current system associated with the planets auroral emission. During this interval, the B_ρ component was also enhanced from ~ 10 to ~ 20 nT, indicating increased azimuthal current and associated radial force balance in the magnetodisc. During this interval of increased radial current, the Hubble Space Telescope observed a simultaneous enhanced intensity of the main emission, peaking at ~ 2 MR. We compare these observations with the Leicester magnetodisc model, referenced to preliminary Juno JADE plasma data, and the associated theoretical M-I coupling currents.

O13

Infrared images of Jupiter Aurora: 3 years of Juno Mission

Alessandro Mura, Alberto Adriani, The JIRAM TEAM

* INAF

JIRAM (Jovian Infrared Auroral Mapper) is an imaging spectrometer on board the NASA/Juno spacecraft. The throughput of one of the imager channels (L band) is designed to observe the auroral emission due to the $H3^+$ ion; the surface resolution, when Juno is close to Jupiter's poles, is down to 10 km. Combined with the unique vantage point provided by Juno, JIRAM observed the auroral emission of Jupiter with unprecedented details.

Here we present a summary of the observations of auroral $H3^+$ images after almost 3 years since the Jovian Orbit Insertion. Because of the constraints on the observing geometry, we put particular emphasis on the south Aurora, and on the auroral footprints of the Galilean Moons.

These, when observed with high spatial resolution, consists of a regularly spaced array of emission features, extending downstream of the leading footprint.

Observations of Jupiter's Auroral Emission during Juno Apojove June 2017

D. Weigt, C. M. Jackman, W. Dunn, F. Allegrini, R. W. Ebert, P. W. Valek, M. F. Thomsen, G. Clark, R. Gladstone and R. Kraft

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We present a case study of Jovian X-ray observations from a joint Chandra and XMM-Newton campaign on June 18th - 19th 2017. The 10-hour Chandra observation and 28-hour XMM-Newton observation overlapped by ~ 9 hours, allowing both spatial and spectral X-ray analysis of Jupiter in tandem. We showcase dynamic new X-ray auroral videos demonstrating the time-varying spatial morphology of the highest energy auroral emission over a 10 hour continuous observation. Alongside the X-ray auroral videos, we present light curves from Chandra; timing analysis of significant quasi-periodic oscillations detected in the north polar region and further discuss the morphology of the emission with new polar plots of the Chandra observations. In addition, we show spectra taken from XMM-Newton and frame the X-ray observations in the context of Juno in situ observations. During this X-ray observation interval Juno was near its apojove on the dawn flank, close to the expected nominal position of the magnetopause. Juno data can be used to infer the state of compression or expansion of the magnetosphere and to place these observations in context of possible magnetospheric drivers linked to boundary dynamics.

Jupiter is alive!

HST observations of Jupiter's aurora during Juno orbits 18, 19 and 20.

(Invited)

D. Grodent, Z. Yao, B. Bonfond, J.-C. Gérard, A. Radioti, S. Badman, E.J. Bunce, J.D. Nichols, L. Roth, J. Saur, W. Dunn, C. Schmidt, J.T. Clarke, J.E. Connerney, G.R. Gladstone, T. Kimura, W.S. Kurth, B. Mauk, D.J. McComas, A. Mura, G.S. Orton

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The terawatts of ever-changing ultraviolet auroral emissions that are always observed with HST at both poles of Jupiter demonstrate that Jupiter's planetary system is "alive." The characteristics of the different components of Jupiter's UV aurora provide information on the evolution of the overall state of the portion of the Jovian magnetosphere to which they connect. During the present medium-size HST campaign (HST GO-15638, cycle 26), precession of the line of apsides of Juno's orbit makes it possible to probe different regions of the magnetosphere, compared to Juno orbits during previous HST cycles. Solar wind dynamics and internal processes are known to have strong influence on Jupiter's aurora, but their relative contributions and the way they couple with each other are still under debate. Cycle 26 falls during the expected minimum of the 11-year solar activity cycle. Current measurements suggest that the solar activity is already exceptionally low, with very few solar events, like CMEs, reaching Jupiter. This provides an unprecedented opportunity to observe Jupiter's aurora during a period when its magnetosphere is mainly controlled by internal processes, therefore revealing Jupiter's natural "breathing." The present HST campaign is meant to observe Jupiter's bright FUV auroral emissions in time-tag imaging mode during Juno orbits 18 to 22 (Feb-Sep 2019). We focus on the 5-day periods prior to and during Junos perijove, when Juno is sampling the current sheet region within 60 RJ, which is expected to contain the plasma source responsible for most bright auroral components, but is in a location where these aurorae cannot be observed with Juno-UVS. We sample Jupiter's emissions at a frequency of ~ 1 HST visit per Jovian rotation, with typically 10 HST visits for each of the 5 Juno orbits. Here we present preliminary results inferred from HST observations and concurrent Juno in situ data, obtained during Juno orbits 18, 19 and 20.

The Mystery of Jupiter's Proton Aurora

John Clarke, Randy Gladstone, Jean-Claude Gerard, Matthew Rutala

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Jupiter displays the brightest aurora in the solar system, and has the strongest and most extensive magnetospheric and ionospheric current systems. Field-aligned currents are mainly carried by electrons, owing to their high mobility, but part of the currents will also be carried by protons in the hydrogen-rich jovian environment. In addition, cross-field currents in the dynamo region of the ionosphere are carried mainly by ions, not electrons. Collisions of protons with atmospheric neutrals produce bright auroral H Lyman-alpha emissions at UV wavelengths, characterized by their doppler-shifts from the proton velocity. Such proton aurora have been observed at both the Earth and Mars, but to date there have been no reported proton aurora observed at Jupiter, a hydrogen planet. The mystery in the title is, why do we not commonly observe the proton aurora at Jupiter? This topic is of particular interest with the JUNO measurements of bright aurora at the magnetic footprints of flux tubes where the expected accelerated electrons were not found. This talk will give a brief overview of the physics of proton auroral production, a review of past observations that could have detected the proton aurora, and a discussion of the current systems expected to produce proton aurora at Jupiter.

O17

Observation of a Secondary Dawn Auroral Arc at Jupiter

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Ultraviolet images of Jupiter's northern aurora captured by HST-STIS on the 18th July 2016 revealed an unusual auroral morphology in the form of a second main auroral arc forming on the dawnside just poleward of the main emission. Simultaneous measurements made by the Juno spacecraft reveal that the magnetosphere was highly compressed for ~ 2 days prior to this interval, and additional HST orbits reveal enhancement of the main emission in the days preceding the event. This auroral form has not been previously observed at Jupiter and presents a unique challenge to our current understanding of the dynamics at work in the magnetosphere. Here we analyse the evolution and structure of the aurora during this interval, and consider possible conditions under which this morphology may arise.

Jupiter's Decametric Riddle Arcs Observed by LWA and Juno

K. Imai, C.A. Higgins, T.E. Clarke, M. Imai and W.S. Kurth

* National Institute of Technology, Kochi College

The Riddle arcs were found in the dynamic spectrum of Jupiter's decametric radio emissions observed by the Voyager spacecraft [Riddle, 1983]. The Riddle arcs have the same slope at the same frequency and System III longitude on a frequency time plot. An isolated Riddle arc can be easily recognized inside of the Io-A arc structures. The emission of the Riddle arcs was determined to be from the instantaneous Io flux tube.

The modulation lane method [Imai et al., 1992, 1997, 2002] is based on the slope measurements of modulation lanes on the dynamic spectrum of Jupiter's decametric radio emissions. We usually measure the slope with a 1 MHz bandwidth and determine the most probable value of the lead angle between activated flux tubes to fit the value of the slope. We use this lead angle to calculate the longitudinal location of the magnetic field line of the radio emitting sources.

The Long Wavelength Array (LWA) is a low-frequency radio telescope designed to produce high-sensitivity, high-resolution spectra in the frequency range of 10-88 MHz. Using LWA data we analyzed the modulation lanes and the Riddle arcs and found that almost all of the Riddle arcs correspond to a zero-degree lead angle. This means that the radio sources related to the Riddle arcs are located along the instantaneous Io flux tube. This result is consistent with Riddle's conclusion.

With the advantage of Juno's unique polar orbit, the Waves instrument [Kurth et al., 2017] observed for the first time the polar beaming patterns and geometry of Jupiter's decametric radio emission sources. The dynamic spectra recorded by the Waves instrument show the Riddle arcs very clearly. We are analyzing the Juno Waves data to find the Riddle arcs in an effort to understand the latitudinal beaming patterns of Jupiter's decametric radio emissions and the location of radio sources. We present the preliminary results of this unique and important study.

Structuring and Dynamics of Auroral Field-Aligned Currents by Alfvén Waves at Jupiter

(Invited)

Robert L. Lysak, Yan Song

* School of Physics and Astronomy, University of Minnesota

Observations from Juno have indicated that the field-aligned current system at Jupiter is weaker than expected and filamentary in nature, in contrast to expectations. This suggests that the field-aligned current system is more dynamic than assumed in previous models. The evolution of the current system is governed by the propagation of Alfvén waves, which may form natural resonant cavities due to the extreme gradients in plasma parameters in the magnetosphere. In addition, the large gradients in the Alfvén travel time from the plasma sheet to the ionosphere will lead to phase mixing, which can filament the currents, leading to small scale structures. In addition, periodicities in the aurora with periods of about 10 minutes have been observed, which may be interpreted in terms of reflections of Alfvén waves propagating between the plasma sheet and ionosphere (e.g., Nichols et al., 2017). We have developed a model for the propagation of kinetic Alfvén waves between the plasma sheet and ionosphere at Jupiter. The model describes a three-dimensional flux tube based on the Connerney et al. (1981) model of the magnetic field due to the Jovian current sheet. The mass density necessary to determine the Alfvén speed is determined using the model of Bagenal and Delamere (2011). This model illustrates the processes of phase mixing and Alfvén wave reflection in the evolution of field-aligned currents at Jupiter.

Bagenal, F., and P. Delamere (2011), *J. Geophys. Res.*, 116, A05209, doi:10.1029/2010JA01624.

Connerney, J., et al. (1981), *J. Geophys. Res.*, 86, 8370.

Nichols, J., et al. (2017), *Geophys. Res. Lett.*, 44, 9192, doi: 10.1002/2017GL074824

O20

Wave-Particle Interaction in Jupiter's stressed magnetosphere

(Invited)

Joachim Saur

* University of Cologne

We review wave-particle interactions in Jupiter's middle magnetosphere focusing mostly on the Alfvén wave branch of the plasma wave modes. The radial transport of plasma outward from Io and Europa's orbits causes the magnetospheric plasma to sub-corotate, which generates large scale magnetic stresses that couple the magnetosphere to the ionosphere. These stresses are the root cause for the reacceleration of the magnetospheric plasma towards corotation. The magnetic stresses also include small scale, non-force balanced magnetic field fluctuations, which partly travel as Alfvén waves along Jupiter's magnetospheric field lines. We show that wave-particle interaction of these Alfvén waves occurs within distances of approximately $L = 30$ dominantly at high latitudes leading to auroral electron acceleration. Further outside the waves are more prone to experience ion cyclotron damping in the plasma sheet leading to heating of the heavy ion populations. We also compare general magnetospheric wave-particle interactions with those associated with the Alfvén wings of the Galilean moons.

Magnetosphere-Ionosphere Coupling at the Giant Planets: Effect of Hydrocarbon Ions on Ionospheric Electrical Conductance

(Invited)

L. Moore, M. Galand, and J.I. Moses

* Center for Space Physics, Boston University

Particles, energy and momentum are exchanged between planetary upper atmospheres and magnetospheres via currents that flow through the high magnetic latitude ionosphere. This coupling is important for both aeronomy and magnetospheric physics, and can, for example, supply angular momentum to the magnetosphere or drive Joule heating in the atmosphere. Ionospheric Pedersen and Hall currents allow closure of the magnetospheric current system, and they in turn are strongly affected by the enhanced ionization brought by Birkeland currents.

Here, we briefly review past giant planet magnetosphere-ionosphere coupling studies, focusing on the impact on the ionosphere and thermosphere. Next, we present preliminary results from ionospheric model calculations in Jupiter's auroral region using inputs based on Juno data. Whereas previous estimates of ionospheric electrical conductances are based entirely on H^+ and H_3^+ ion distributions, we find conductances at Jupiter are dominated by hydrocarbon ions. The dependence of conductivity on ion mass means that accurate conductance calculations are intimately linked to comprehensive hydrocarbon ion chemistry. Calculations that do not include hydrocarbon ions will underestimate ionospheric electrical conductivities, as a majority of energetic particles in Jupiter's auroral region appear to be deposited at or below the methane homopause.

The CASSINI Grand Finale in Saturn's Magnetosphere 2016-2017 in the View of Neutral And Charged Particles Measured by the MIMI Instrument

(Invited)

N. Krupp, E. Roussos, P.Kollmann, D.G. Mitchell, A. Kotova, C.P. Paranicas, D. Hamilton, S.M. Krimigis, M.K. Dougherty

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Cassini ended its mission to explore the Saturnian magnetosphere with a set of high-latitude orbits close to the planet in 2016/2017 called the “Grand Finale”. After a set of 22 ring-grazing orbits near the F-ring (November 2016-April 2017) the spacecraft reached the region between Saturn's atmosphere and the innermost D-ring during the 22.5 proximal orbits (April 2017-September 2017) before finally crashing into Saturn on 15 September 2017.

The MIMI suite of particle detectors onboard recorded data continuously during the Grand Finale and measured the first in-situ particle responses in that region of the Kronian magnetosphere besides of the variability of the overall magnetospheric conditions during the various one week long orbits.

A major discovery was the detection of a radiation belt of protons with energies above 25 MeV between Saturn's atmosphere and its D-ring originating in the CRAND (cosmic ray neutral albedo decay) process. We will discuss the Galactic Cosmic Ray access to the Saturnian magnetosphere, its atmosphere and rings during the last phase of the Cassini mission. This interaction plays a major role in understanding the sources and sinks of the high-energy particles. The existence of a low-energy ion belt in the same region was confirmed by Energetic Neutral Atom (ENA) emissions. The location of the low-energy belt was constrained further to altitudes below 1800 km above the 1 bar cloud level.

In addition, measurements of MeV electrons near Saturn's A-ring outer edge and the F-ring, Saturn showed asymmetries between the northern and the southern hemisphere and in Saturn local time. In the post-noon sector a locally produced electron microbelt was discovered. This microbelt is colocated with the F-ring and contains electrons drift resonance with corotation.

A Magnetic Perspective on the Interior of Saturn

Michele K. Dougherty, Hao Cao and the Cassini Magnetometer Team

* Imperial College London

Magnetic fields are windows into planetary interiors and Saturn's internal magnetic field following the Cassini Grand Finale orbital phase continues to surprise us. The unique geometry of these orbits provided an opportunity to measure the internal magnetic field at closer distances to the planet than ever encountered before. The surprising close alignment of Saturn's magnetic axis with its spin axis (known about since the early Pioneer 11 observations) has been confirmed, however external effects, observed even around periaspse are masking some of the magnetic field signals from the interior. The varying northern and southern magnetospheric planetary period oscillations and field aligned currents at both high and low latitudes are contributing to the magnetic signals observed. We show the directly determined northward offset of Saturn's magnetic equator and its "longitudinal" variations, small-scale yet highly consistent magnetic structures along the latitudinal direction detected along every Grand Finale orbit. Observational constraints on the electromagnetic induction response from the semi-conducting region and time variation of Saturn's internal magnetic field will also be presented. We will discuss how these latest measurements provide a new perspective on answering some key questions concerning Saturn's interior: level of differential rotation, the existence and extent of stable stratification, and the size and nature of the central core. We also report new features in the external planetary magnetic field, which not only enhanced our view of the auroral current systems but also revealed a new inter-hemispheric currents flowing in the magnetospheric plasma near the inner edge of the D ring.

Currents Associated with Saturn's Intra-D Ring Azimuthal Field Perturbations

G. J. Hunt, S. W. H. Cowley, G. Provan, H. Cao, E. J. Bunce, M. K. Dougherty, and D. J. Southwood

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During the final 22 full revolutions of the Cassini mission in 2017, the spacecraft passed at periapsis near the noon meridian through the gap between the inner edge of Saturn's D ring and the upper layers of the planets atmosphere, revealing the presence of an unanticipated low-latitude current system via the associated azimuthal perturbation field peaking typically at $\sim 10\text{--}30$ nT. Assuming approximate axisymmetry, here we use the field data to calculate the associated horizontal meridional currents flowing in the ionosphere at the feet of the field lines traversed, together with the exterior field-aligned currents required by current continuity. We show that the ionospheric currents are typically $\sim 0.5\text{--}1.5$ MA per radian of azimuth, similar to auroral region currents, while the field-aligned current densities above the ionosphere are typically $\sim 5\text{--}10$ nA m⁻², more than an order less than auroral values. The principal factor involved in this difference is the ionospheric areas into which the currents map. While around a third of passes exhibit unidirectional currents flowing northward in the ionosphere closing southward along exterior field lines, many passes also display layers of reversed northward field-aligned current of comparable or larger magnitude in the region interior to the D ring, which may reverse sign again on the innermost field lines traversed. Overall, however, the currents generally show a high degree of north-south conjugacy indicative of an interhemispheric system, certainly on the larger overall spatial scales involved, if less so for the smaller-scale structures, possibly due to rapid temporal or local time variations.

Exploring the sources of variability in the low-latitude field-aligned currents at Saturn measured by the Cassini Magnetometer during the Grand Finale

O. Agiwal, H. Cao, G. J. Hunt, M. K. Dougherty

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The Cassini spacecraft traversed magnetic field lines which connect the planet Saturn to its main ring system during the 22 Grand Finale orbits. The magnetometer (MAG) measurements from these orbits revealed the presence of a highly variable low-latitude field-aligned current (FAC) system, which is predominantly confined to the magnetic field lines mapping to the D-ring of Saturn. There is also evidence of the low-latitude FACs on field lines which map to the B-ring in the southern hemisphere, however the FACs are suppressed along the other field lines mapping to the A-C rings. The orbit-to-orbit variability in the fine structure of the measurements can be understood by considering the spatial and temporal variability of the Pedersen conductivities and/or neutral wind speeds in the day-side ionosphere of Saturn. Implications of interaction between the planet and the 'ring ionosphere from the MAG measurements will be discussed.

A last look at Saturn during Cassini's Grand Finale: Maps of H₃⁺ emission, temperature and ion winds

Tom S. Stallard, Kevin Baines, Henrik Melin, Tom Bradley, Luke Moore, James O'Donoghue, Steve Miller, Nahid Chowdhury, Sarah Badman, Hayley Allison

* Department of Physics and Astronomy, University of Leicester

In August 2017, as Cassini took its final orbits around Saturn, we observed Saturn's infrared aurora from the Keck telescope in Hawaii. This unprecedented Cassini Grand Finale support programme scanned Saturn's auroral region from Earth over seven separate orbits, providing the first ever 2d images of temperature and ion wind structure. The observation technique used produces details of how these parameters vary across the aurora in the same way as our recently published measurements at Jupiter (Johnson et al., 2017; 2018).

The temperature images show a thermosphere with highly localised hotspots, with temperatures varying by as much as 300K spatially across the aurora on each night, but with underlying temperature structure (once smoothed out over seven nights) broadly following the H₃⁺ emission brightness, with an apparent cooling at the pole.

The ion wind images show very localised ion wind flows across the auroral region, suggesting that past observations had smoothed out these small scale jets, likely indicating a combination of both local time and planetary frame ion flows. The seven-night average velocities provide a view of the overall local time flows, allowing us to map out the location of the core of co-rotating field lines (described as the three-tier structure in past papers) from noon to midnight across the pole of the planet.

If there is time, we also intend to measure the intensity and neutral wind flows associated with the upper stratospheric emission at 600km altitude - potentially providing the first ever measure of ionosphere-neutral atmosphere coupling at Saturn.

Exploring Key Characteristics in Saturn's Infrared Auroral Emissions Using Adaptive Optics VLT-CRIRES Observations from 2013

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We present a study of Saturn's H3+ northern auroral emission using data taken on 19 May 2013 with the Very Large Telescopes long-slit spectrometer Cryogenic Infrared Echelle Spectrograph (VLT-CRIRES) situated at Paranal, Chile. Adaptive optics, combined with the high spectral resolution of VLT-CRIRES ($\sim 100,000$), mean that this dataset offers an unprecedented spatially and spectrally resolved ground-based view of Saturn's infrared aurora. We have used discrete H3+ emission lines to derive dawn-to-dusk auroral intensity, ion line-of-sight velocity, and thermospheric temperature profiles.

Our data reveal a dawn-enhanced auroral intensity with an average auroral temperature of 361 K and evidence for a localised dark polar region in the aurora. This dark feature is at the same location as a strong noon-midnight flow in the ion velocity on the scale of ~ 1.2 km per second – far exceeding other ion flow velocities nearby inside the polar cap – and resembles an ionospheric polar vortex. The thermospheric temperature profile reveals a subtle and previously undetected gradient which increases across the polar cap going from dawn to dusk. We also find that a temperature hotspot of 379 K drives a region of emission near the pole, corresponding to a location where, unlike at Jupiter and Uranus, H3+ is failing to cool the thermosphere.

The findings of this work will aid ongoing investigations into the processes driving the energy mechanisms in Saturn's upper atmosphere and also inform models of the coupling between Saturn's upper atmospheric layers and its magnetic field.

Solar Wind and Planetary Period Modulations of Reconnection Events in Saturn's Magnetotail

T.J. Bradley, S.W.H. Cowley, E.J. Bunce, G. Provan, E. Roussos, N. Krupp, M.K. Dougherty, L. Lamy, H. Melin, C. Tao, J.D. Nichols, W. Pryor

* University of Leicester

Tail reconnection (RCN) at Saturn can be detected with the Cassini spacecraft via deflections of the magnetic field, low frequency extensions of Saturn's kilometric radiation, and plasma injections observed via charged particle counts, e.g., Bunce et al. [2005GL022888]. Cassini's 20 F-ring orbits and 22 proximal orbits, with apoapses at approximately 21 Saturn radii on the nightside of the planet, provide ideal conditions to view such features over a period of 9.5 months to identify any preferential conditions for their occurrence. We identify several large-scale tail RCN events with the Cassini spacecraft during this interval which we support with UVIS and HST auroral observations, showing clear night-side plasma injections associated with such tail activity. These events are then compared with planetary period oscillation (PPO) phases, propagated Solar wind (SW) models, and solar energetic particle and galactic cosmic ray counts. Results show that large-scale RCN takes place during magnetospheric compressions caused by coronal mass ejections and corotating interaction regions with separations between each event of approximately one solar rotation. However, we also find that these SW modulated events have a preference to take place during near-ideal PPO anti-phase conditions for which the tail current sheet will be thinned and stretched out, in conformity with the results of Bradley et al. [2018JA025932], for smaller scale closed field line Vasyliunas type RCN events. This is validated via the lack of RCN detections during solar wind compressions when the PPO perturbations are in phase. Furthermore, we find that the large-scale RCN events are mostly triggered at ideal, dominant northern PPO phases of 0 degrees. We propose that the triggering of large-scale Dungey cycle type tail RCN at Saturn is favored by optimum conditions from the SW external to the magnetosphere in concert with the PPO phasing internally, rather than being dependent on one condition or the other.

Cross-energy coupling process in the terrestrial radiation belts; The Arase observations

(Invited)

Y. Miyoshi, I. Shinohara, T. Takashima, K. Asamura, S-Y. Wang, Y. Kazama, S. Kasahara, S. Yokota, T. Miatni, N. Higashi, Y. Kasahara, Y. Kasaba, S. Yagitani, A. Matsuoka, H. Kojima, Y. Katoh, K. Shiokawa, K. Seki, Geospace Exploration ERG project Group

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The radiation belts exist the magnetized planets except for Mercury in our solar system. In the terrestrial magnetosphere, there are radiation belts for both electrons and ions. The electron outer radiation belt is highly variable associated with solar wind disturbances. Enhancement and decrease of the relativistic electrons are mainly caused by interactions with different kind of plasma waves. For example, MHD fast mode waves and whistler mode waves contribute to acceleration of relativistic electrons, while EMIC waves and whistler mode waves cause decrease of energetic electrons through pitch angle scattering. Whistler and EMIC waves are generated through plasma instability of tens keV electrons and ions, and cold plasma populations including heavy ions controls wave characteristics as an ambient media, so that cross-energy coupling process via wave-particle interactions is essential to cause dynamical evolutions of the radiation belts. In order to understand the dynamics of the terrestrial radiation belts and reveal their physical processes, the Arase (ERG) satellite was launched in 2016 and the satellite has observed various phenomena since March 2017. The satellite observes wide energy electrons from 20 eV to 20 MeV and ions 10 eV/q to 180 keV/q with mass discrimination. The satellite also observes wide frequency range of electric fields (DC-10 MHz) and magnetic fields (DC-100 kHz). In this presentation, we would like to show some highlight results from the Arase observations, especially for focusing on wave-particle interactions on the electron accelerations and decrease. Moreover, we will discuss comparative studies among planetary radiation belts.

Pulsating aurora from electron scattering by chorus waves

(Invited)

S. Kasahara, Y. Miyoshi, S. Yokota, T. Mitani, Y. Kasahara, S. Matsuda, A. Kumamoto, A. Matsuoka, Y. Kazama, H. U. Frey, V. Angelopoulos, S. Kurita, K. Keika, K. Seki & I. Shinohara

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Auroral substorms, dynamic phenomena that occur in the upper atmosphere at night, are caused by global reconfiguration of the magnetosphere, which releases stored solar wind energy. These storms are characterized by auroral brightening from dusk to midnight, followed by violent motions of distinct auroral arcs that suddenly break up, and the subsequent emergence of diffuse, pulsating auroral patches at dawn. Pulsating aurorae, which are quasiperiodic, blinking patches of light tens to hundreds of kilometres across, appear at altitudes of about 100 kilometres in the high-latitude regions of both hemispheres, and multiple patches often cover the entire sky. This auroral pulsation, with periods of several to tens of seconds, is generated by the intermittent precipitation of energetic electrons (several to tens of kiloelectronvolts) arriving from the magnetosphere and colliding with the atoms and molecules of the upper atmosphere. A possible cause of this precipitation is the interaction between magnetospheric electrons and electromagnetic waves called whistler-mode chorus waves. However, no direct observational evidence of this interaction has been obtained so far. Here we report that energetic electrons are scattered by chorus waves, resulting in their precipitation. Our observations were made in March 2017 with a magnetospheric spacecraft equipped with a high-angular-resolution electron sensor and electromagnetic field instruments. The measured quasiperiodic precipitating electron flux was sufficiently intense to generate a pulsating aurora, which was indeed simultaneously observed by a ground auroral imager.

Mid-Mission Developments from Juno's Radiation Monitoring Investigation

Heidi N. Becker, James W. Alexander, Martin J. Brennan, Alexandre Guillaume, Virgil Adumitroaie, John L. Jorgensen, Troelz Denver, Randy Gladstone, Thomas K. Greathouse, Vincent Hue, Joshua Kammer, Maarten H. Versteeg, Alberto Adriani, Alessandro Mura, Andrea Cicchetti, Raffaella Noschese, Roberto Sordini, John E.P. Connerney, Scott J. Bolton, Steven M. Levin

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Juno's Radiation Monitoring (RM) Investigation uses penetrating particle signatures in data from multiple science and engineering instruments to measure >5 MeV and >10 MeV electron fluxes at Jupiter. Now more than half way through Juno's prime mission, RM's observations of Jupiter's inner radiation belts have consistently revealed lower than anticipated >10 MeV electron fluxes, often with unexpected spatial distributions. The new JRM09 magnetic field model from Juno's first nine orbits (Connerney et al., 2018) has provided considerable insight into the deviations from pre-arrival predictions. Work is underway with RM models and count rate observables to explore additional spectral explanations.

RM has also extended the capabilities of the investigation to include Stellar Reference Unit (SRU) imaging of the dark side of Jupiter (an opportunity afforded by the geometry of Juno's 53-day orbit in the last year). The SRU is a low-light visible wavelength engineering camera used to support spacecraft attitude determination and the RM radiation investigation. During perijove 13 (May 24, 2018) the SRU collected high resolution imagery of Jupiter's northern auroral oval while Juno was less than 60,000 km from the cloud tops; the closest view of Jupiter's aurora with a visible wavelength imager.

Our presentation will discuss these developing facets of the RM Investigation.

Magnetic Field Derived Parameters for Jovian Synchrotron Radiation Modeling

V. Adumitroaie, J. Arballo, S. Brown, S. Gulkis, S. Levin, M. Janssen, G. Orton, F. Oyafuso, C. Li, A. Ingersoll, Z. Zhang, P. Steffes, S.J. Bolton, D. Santos-Costa

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The Juno spacecraft arrived at Jupiter July 4, 2016 and is now in a 53.5-day polar orbit. Synchrotron radiation generated by ultra-relativistic electrons trapped in Jupiter's magnetosphere are detected and measured by Juno's MWR Radiometer over a range of wavelengths from 2 cm to 50 cm. An extension of the Levin et al. (2001) multi-zonal, multi-parameter model to simulate synchrotron emission using assumed electron distributions and Jovian magnetic field models (VIP4 and the latest incarnation, JRM09) generates the four Stokes parameters of the synchrotron emission. The model depends on magnetic-field-derived quantities such as L-shell and B critical, the minimum magnetic field amplitude for a given L-shell at which electrons that mirror at or below the upper boundary of the atmosphere are lost. This study describes the modeling issues associated with above-mentioned derived parameters and results for the JRM09 model.

CRAND injection coefficients at Saturn

Anna Kotova, Leonardo Regoli, Elias Roussos, Peter Kollmann, Norbert Krupp, Iannis Dandouras

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During Cassinis Proximal Orbits, the Magnetospheric Imaging Instrument (MIMI) confirmed earlier predictions about the existence of the innermost radiation belt of Saturn, residing between the atmosphere of the planet and the Main Rings. The interpretation of the MIMI observations indicated a dominance of protons with energies in the MeV-GeV range, which is consistent with the main particle source for this region being the Cosmic Ray Albedo Neutron Decay (CRAND) process. The layered structure of the proton component of the main radiation belt of Saturn with the clear depletions on the L-shells corresponding to the location of the moons also confirms that the local source of the energetic ions like CRAND should be present there.

In order to estimate the efficiency of the CRAND process we calculated the so-called injection coefficients, which determine the fraction of ejected neutrons with the correct geometrical propagation such that they can have the possibility to contribute to the belts population. We evaluate the relative contribution of the different source areas on the rings and for different angular source emission functions for the neutrons, which convert into the protons that sustain the radiation belts. We will also consider multiple cascades of secondaries between the atmosphere and the rings. Having already a calculated spectra and flux of incoming GCRs that power CRAND, we are going to evaluate neutron production rate using the GEANT4 simulation of the particle beam interaction with rings matter /atmosphere and from there we can use the injection coefficients for estimation the CRAND input over the time.

A quantitative analysis of the energetic proton measurements can be used to constrain densities of Saturn's D-ring and exosphere as well as shedding light on the details of the CRAND process and particle diffusion. Such an analysis, for example through a physical model of the radiation environment, requires information on the injection coefficient, as it can be directly determined from information about Saturn's magnetic field.

Variations in Jupiter's inner magnetosphere seen by Hisaki: Effects of Io and the solar wind

(Invited)

F. Tsuchiya, K. Yoshioka, T. Kimura, I. Yoshikawa, G. Murakami, H. Kita, C. Tao, R. Koga, F. Suzuki, R. Hikida, S. Han, M. Kagitani, Y. Kasaba, H. Misawa, T. Sakanoi, M. Kuwabara,, A. Yamazaki

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The innermost Galilean satellite, Io, supplies a large amount of volcanic gases to the Jovian magnetosphere. The plasma supply from the satellite has a primary role in the characterization of the Jovian magnetosphere. Using a continuous data set of the Io plasma torus obtained from an extreme ultraviolet spectroscope onboard the Hisaki satellite, we found that significant variations of the neutral and charged particle populations in the inner magnetosphere which were caused by the volcanic eruptions at Io in early 2015. The time evolution of the Io plasma torus radial distribution showed that the outward transport of plasma was enhanced for approximately 2 months. Intense short-lived auroral brightenings, which represent transient energy releases in the outer part of the magnetosphere, occurred frequently during this period. The short-lived auroral brightenings accompanied sporadic enhancements of the ion brightness in the plasma torus. The brightening in the plasma torus appeared, on average, 11–12 hours after the onset of auroral brightening, indicating a rapid inward transport of energy from the outer part of the magnetosphere and the resultant enhancement of hot electron population in the inner magnetosphere. This shows that the change in a plasma source in the inner magnetosphere affects a large-scale radial circulation of mass and energy in a rotationally-dominant magnetosphere. The Hisaki observation also showed that the solar wind effect on the inner magnetosphere was not negligible but provides visible changes through electric field fluctuation. Hisaki found that the dawn-dusk electric field that causes the dawn-dusk brightness asymmetry of the torus changed by the dynamic pressure of the solar wind. The fluctuation of the electric field also acts as a driver of radial diffusion of high energy trapped electrons and could cause long-term change in the Jovian synchrotron radiation.

Spatial distribution of Io neutral oxygen cloud during a volcanically quiet and active periods in 2014-2015

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Io has a thin atmosphere created by volcanism and sublimation from the surface frost. Io atmospheric oxygen atoms are heated by atmospheric sputtering, and escape from Io gravity, forming a neutral oxygen cloud around Io orbit. The neutral cloud is important as a source of the Io plasma torus. Previous modeling studies showed the distribution of the equilibrium neutral oxygen cloud, and showed that changes in Io volcanism can lead to increase densities of both neutral sodium cloud and Io plasma torus. However, the structure and variations of Io neutral oxygen cloud were not observed. The extreme ultraviolet spectrograph called EXCEED installed on the Hisaki satellite observed the Io plasma torus continuously in 2014–2015, and we derived the spatial distribution of atomic oxygen emissions at 130.4 nm. The azimuthal distribution observed from November to December in 2014 showed the equilibrium neutral oxygen cloud consists of a dense region distributed around Io (the “banana cloud”) and a longitudinally uniform, diffuse region distributed along Io orbit. The dense region mainly extends on the leading side of Io and inside of Io orbit. The neutral oxygen cloud spreads out to 7.6 Jupiter radii (R_J), where the brightness drops below $\sim 1 R$.

We also observed the OI brightness started increasing from Day of year 20 in 2015, and the enhancement of OI emission continued between 3 months. The radial distribution shows the oxygen cloud spread outward during the volcanically active period (8–8.6 R_J). The number density at Io orbit (where north-south thickness is 1.2 R_J) increased to about 90 cm^{-3} during the active period that is more than twice bigger than the number density during the quiet period (40 cm^{-3}). The azimuthal distribution shows the neutral oxygen cloud during the active period also consists of the banana cloud and diffuse region distributed along Io orbit, but both of the regions that enlarges. The observation results show the neutral escape rate from Io significantly increases during a volcanically active period.

Increase in hot electron fraction in Jupiter's inner magnetosphere with Io's volcanic event

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The satellite Io, which has many volcanoes and is located at 5.9 RJ from the center of Jupiter, is a powerful plasma source in the magnetosphere. The resulting specificity of the Jupiter's magnetosphere is the magnitude of energy that circulates internally. Previous researches, using data obtained by Voyager and Cassini spacecraft and chemical models complementarily, showed that the pickup energy of heavy ions originating from volcanoes on Io and the energy of hot electrons are converted into radiation reaching ~ 3 TW. However, the origins of hot electrons, that is, heating and/or transport mechanisms are still unrevealed. Therefore, in this research, we focus on the response to the change in the amount of plasma supplied to the magnetosphere and explore the above problem. In this study, the radial distributions of plasma density and temperature were derived from the intensities of emission lines in the extreme ultraviolet range obtained by Hisaki satellite. In this presentation, we will show the results using data obtained from DOY 331 in 2014 to DOY 134 in 2015. The activation of volcanoes on Io was confirmed by ground-based infrared observations in early January 2015. We found that plasma density changed dynamically with the activation of volcanoes during the volcanic event. We found that hot electron fraction increased from DOY ~ 50 to DOY ~ 120 in 2015. Prior to that, the short-lived auroral brightening associated with reconnection with mass loading frequently occurred. This finding suggests that the increase in hot electron fraction in the torus is caused by the active radial circulation.

Jupiter's aurora light curve after 2016 obtained from Hisaki EXCEED

Hajime Kita, Tomoki Kimura, Fuminori Tsuchiya, Go Murakami, Atsushi Yamazaki, Ryoichi Koga, Reina Hikida, Kazuo Yoshioka, Ichiro Yoshikawa

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Hisaki is an Earth-orbiting satellite launched in 2013. The purpose of this mission is to observe UV emission from planetary atmospheres and magnetospheres by the spectrometer EXCEED (Extreme Ultraviolet Spectroscope for Exospheric Dynamics). Hisaki EXCEED began its monitoring of the Jovian system in December 2013 with a 140 arcsec – 20 arcsec “dumbbell” slit which is designed to observe the Io plasma torus and Jovian aurora simultaneously. Hisaki EXCEED can continuously observe the Jovian system along the 106 min orbit for several months, which is a feature never available for large facilities such as Hubble Space Telescope.

The guide camera of Hisaki broke down around mid-2016. From 2016 to 2017, we tried to observe the aurora and torus simultaneously without the guide camera. The location of Jupiter was set to in the narrow slit region, however, sometimes aurora moved away from the narrow slit region. Therefore, we use two observing modes, “torus mode” and “aurora mode” since 2017. The Jovian disk is located in the wide-slit region for the aurora mode. Both north and south auroras are observed, and only one side of the torus can be seen. For the torus mode, we set the location of Jupiter to the narrow slit region, and the torus fit within the wide-slit region. We will show the time series of the total auroral power over 900-1480 Å as well as the torus emission over 650-780 Å.

Resolving the Titan torus mystery...finally

H.T. Smith, R.E. Johnson, A.M. Rymer and A.K. Woodson

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Saturn's largest moon, Titan, has been the topic of much interest and mystery. This moon possesses no intrinsic magnetic field which leaves its dense nitrogen-rich atmosphere relatively unprotected from direct interaction Saturn's magnetosphere. Therefore, before Cassini, it was logically assumed that nitrogen particles would escape from Titans atmosphere and form a large toroidal gas cloud near Titans orbit (in the outer magnetosphere) constituting the dominant species in the magnetosphere. Cassini observations detected nitrogen ions, however these particles exist in the inner magnetosphere and water-group particles (from Enceladus plumes) actually dominate Saturn's heavy magnetospheric particle population. These results appear inconsistent with the expectation that Titan's exposed atmosphere should provide a significant source of heavy particles to Saturn's magnetosphere. Therefore, Titan was demoted to having a relatively minor impact on Saturn's magnetosphere.

However, UVIS observations detect $<0.5\%$ N_2 in the Enceladus plumes. Further modeling and observations confirm that the observed nitrogen in the inner magnetosphere cannot be produced by Enceladus. These issues led to the "Titan torus mystery" involving the unresolved source of the nitrogen which has a large bearing on our fundamental understanding of Enceladus, Titan and how they interact with the Saturn's magnetosphere. Resolving this inconsistency could also provide import insight into atmospheric loss. With the significant increase in data and improved analysis techniques, it is now possible to conduct a comprehensive analysis. For this talk, we present observations, analysis and modeling results to examine how Titan interacts with Saturn's magnetosphere and also present a theory called "torus erosion." All of these results lead to the conclusion that Titan is producing a neutral torus that is difficult to directly detect. In this case, Titan is actually having a larger impact on Saturn's magnetosphere than currently expected.

Plasma Heating and Transport: Jupiter and Saturn

(Invited)

Margaret Galland Kivelson

* EPSS, UCLA and CLASP, University of Michigan

Some people think that physicists don't really work. Indeed, what we do is much like play. We love puzzles; we find them in data and we try to solve them. When we find solutions, we are delighted, but it is even more interesting to identify questions. Only then can we speculate on answers.

Questions arise in interpreting plasma dynamics at Jupiter and Saturn. One long-standing puzzle, referred to as the energy crisis, relates to the plasma torus (also Enceladus's). In the inner magnetosphere, radial transport satisfies requirements of adiabaticity. Thus the warm plasma temperature should decrease outward as the background field weakens. But the plasma temperature increases with radial distance. Heating by pickup of neutrals is insufficient to account for the thermal profile. Inward transport of flux tubes filled with the hot plasma of the outer magnetosphere should provide heat for the torus plasma. Is it enough?

In both the Io and Enceladus torus, a small population of hot (\sim keV) electrons must be present, but the source of these electrons is uncertain. A similar problem is faced in understanding the sources of energetic electrons in Earth's inner magnetosphere. At Earth, a "double whammy" of wave-particle interactions accounts for the energization. Could analogous processes act at the outer planets?

Still not understood are the sources of strong dawn-dusk asymmetries of field configuration and associated plasma properties in both magnetospheres. Mechanisms have been suggested to account for the asymmetries, but not yet tested. From dusk, the plasma rotates into the magnetotail, where some is lost through processes that ultimately couple to the solar wind; details remain uncertain. Possible loss mechanisms include decoupling of ions from the weak field of the distant tail or ejection in plasmoids whose azimuthal flow removes them on the morning side tail. Some of these processes are seen in computer simulations but no spacecraft data are available to test the results. So puzzles remain; playful physicists will keep looking for answers.

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Plasma Heating at Jupiter and Saturn

(Invited)

C. Chris Paranicas, P. Kollmann, M. F. Thomsen, E. Roussos, N. Krupp, G. Clark, and R. Allen

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_ : presenter

Jupiter and Saturn both contain a satellite deep within their magnetospheres that is a strong source of neutrals. Some of these neutrals are ionized in the inner magnetosphere and this new plasma must be shed from the system. For magnetic flux conservation, flux tubes move inward to balance those moving outward. As flux tubes move in, the hotter plasma and particles that can stay within the radially moving structures are energized in a way that approximately conserves the first adiabatic invariant of motion. At Saturn, these discrete, inward moving distributions, injections, may be responsible for the dominant flux of some particle species and energies. This is because the neutral density is high enough to significantly limit the lifetimes of energetic particles, leaving behind mostly the newly injected particles. This fact can be used to help understanding plasma heating in planetary magnetospheres. At Jupiter, recent injections may also be important for the observed flux close to the planet, where neutral densities are higher. Farther out, the situation changes, and circulation takes place in the context of the magnetodisk, which is known to stretch magnetic field lines very strongly. In this talk, we will review these subjects, discussing sources and loss of hot plasma and particles using observations mostly from the Galileo and Cassini spacecraft.

A Statistical Picture of Pitch Angles of Interchange Events at Saturn and Implications for Energization and Losses

(Invited)

A. R. Azari, M. Liemohn, X. Jia, R. C. Allen, R. M. Dewey, D. G. Mitchell, C. Paranicas, & N. Sergis,

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In 2004 the Cassini spacecraft arrived at Saturn and for the next 13 years collected large amounts of plasma and magnetic field data. We utilize data from the CHEMS instrument to present a statistical review of pitch angles of interchange injections. Interchange events are a primary mass transport process similar to a Rayleigh-Taylor like instability within $\sim 5\text{--}12$ Saturn radii (R_s). This instability is from: (1) a flux tube gradient in the plasma population arising from Enceladus located at 4 R_s which outgasses ~ 250 kg/s of H_2O into the magnetosphere and (2) Saturn's rapid rotation, leading to a co-rotating plasma environment in <11 hours per rotation. This forces dense plasma resulting from the H_2O into less dense plasma (energetic H^+). The observed transport of energetic H^+ toward Saturn is termed interchange injections and can characterize dynamics of the magnetosphere.

We use H^+ flux CHEMS to calculate an anisotropy ratio, which compares flux at perpendicular pitch angles to flux at parallel and antiparallel pitch angles. We compare this ratio within interchange events to global distributions. By reviewing pitch angles of interchange events we obtain information about energization (primarily through betatron acceleration), and losses. We build off a survey to identify and classify interchange injections over the mission from high-energy (3–220 keV) ion fluxes. This survey was created through a trained, tested, and automated process; providing events which are statistically classed by severity against the background plasma.

We observe greatly anisotropic interchange events between 7–8 R_s (upwards to >10 times higher perpendicular flux) in the 47–72 keV energy range. Outside of 7–8 R_s we see a decrease of anisotropy to near parity at 12 R_s . We compare energization to expectations of betatron acceleration. Inside of 7–8 R_s we observe depletion of perpendicular flux, which we compare and attribute to expected charge exchange lifetimes for H_2O , O, and H to H^+ .

Plasma Transport Out of the Io Torus: What Does the Observed Radial Gradient of Average Flux Tube Content Imply?

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A widely accepted view of outward plasma transport by interchange motions in giant planet magnetospheres is that flux tubes with high mass density flow outward slowly over broad longitudinal regions, and the magnetic flux is returned by flux tubes with low mass density flowing inward rapidly over narrow longitudinal regions. The observed so-called "injection events" are adduced as direct evidence for the narrow return flow regions. With the flux tube content (mass per unit magnetic flux) assumed constant following individual flow lines, the longitudinally averaged flux tube content is predicted to change only very slightly with increasing radial distance outward from the source region. The empirical model of plasma mass distribution in the magnetosphere of Jupiter derived from Voyager and Galileo observations by Bagenal and Delamere (JGR 116, A05209, doi:10.1029/2010JA016294, 2011) shows, however, that flux tube content decreases monotonically with radial distance, at a rate that between 6 and 15 Jovian radii can be represented as a power law $1/(R^{3.3})$. Such a decrease can be consistent with the usually accepted view only if one postulates that the narrow high-velocity inflow and broad low-velocity outflow regions change with increasing distance into broad low-velocity inflow and narrow high-velocity outflow. Alternatively, one must question the assumption of constant flux tube content along flow lines.

O43

Modeling the interaction of electrons and kinetic Alfvén waves in the Io plasma torus

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Observations of the Galileo satellite illustrated small scale magnetic field fluctuations near Io (e.g. Chust et al., 2005) suggesting the presence of kinetic Alfvén waves (KAWs) in the Io plasma torus. In the terrestrial magnetosphere, both in observations and simulations, the presence of KAWs have also been linked to the formation of electron distribution functions elongated in the direction parallel to the magnetic field. This plateau is associated with the trapping of electrons within the KAW potential. In this presentation, we summarize initial simulation results of KAWs in the Io plasma torus using a 2D gyrofluid-kinetic electron model in a dipolar geometry (Damiano, 2019). We consider realistic heavy ion mass and temperature and illustrate the formation of plateaued electron distributions within the propagating KAWs that are qualitatively consistent with both the observations seen in the terrestrial magnetosphere and the Galileo observations of Frank and Patterson (2000) taken in the torus. We find that the presence of heavy ions acts to enhance the magnitude of the electron trapping and hence the length of the observed plateau in the electron distribution function. While trapped electrons propagate with the travelling KAW mode, the ambipolar electric fields at the torus boundaries can act to de-trap some electrons even as wave energy propagates through. We infer that electrons energized in interactions with KAWs will contribute to the local generation of the supra-thermal electron population which in-turn has important implications for the System IV modulation in the Io plasma torus.

A Comparative Investigation of the Leakage of Energetic Particles Across the Magnetopauses of Strongly Magnetized Planets

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We performed a comparative examination of the leakage of energetic charged particles (> 10 s of keV) across the magnetopauses of Earth and Jupiter using observations of the MMS mission at Earth and the Juno mission at Jupiter. This analysis revealed a simple ordering of the escape processes also supported by a simple kinetic model of the magnetopause interactions. Specifically, charged particles (e.g. singly charged heavy ions) with gyroradii much larger than the structures (e.g. thickness) associated with the boundary tend to stay with the boundary and are impeded from fully escaping, with or without the presence of boundary-normal magnetic fields engendered by reconnection. On the other hand, energetic charged particles with intermediate-sized gyro-radii (e.g. H^+) tend to be scattered by boundary structures and are much more likely to escape fully across the boundary, again with and without boundary-normal magnetic fields. The escape of small gyro-radii particles (e.g. electrons) is more strongly regulated by the presence of boundary-normal magnetic fields, although models show that escape is still possible at times even in the absence of such fields through gradient drift processes. Here we present the evidence at both Earth and Jupiter that supports the ordering of escape described here. We also place these results into the context of observations made with other missions and at other planets.

O45

Electrons in the Jovian Magnetosphere as Observed by JADE-E

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Juno has now completed half its mapping mission, and the electron sensors on JADE (JADE-E) have recently undergone extensive inflight cross-calibration and analysis for removing the background noise, making now the perfect time to begin surveying electron properties in Jupiter's magnetosphere. JADE-E consists of two nearly identical sensors measuring ~0.05 to 100 keV/e electrons. These are mounted along the azimuth of the spacecraft and observe a 2-dimensional slice of phase-space. During high rate science (selected hours near perijove) the sensors are able to deflect in spacecraft elevation up to ± 35 degrees in order to track the magnetic field direction, but when in low rate science (almost all of the middle/outer magnetosphere) there is no deflection so the slice is around a spacecraft elevation of ~ 0 degrees, which can limit pitch angle coverage. Anisotropic electron temperatures can only be calculated with good pitch angle coverage, but where it is possible they will be surveyed. A hot-electron fraction will also be inferred from the data. We will make a preliminary survey of electron properties (e.g. densities, pressures, temperatures) in the Jovian magnetosphere.

Characterising the Structure and Compressibility of Saturn's Magnetopause

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We report work in progress on the construction of a numerical model for a magnetopause boundary, based on using local balance between exterior (solar wind) and interior (magnetospheric field and plasma) sources of pressure. We demonstrate how the model can be applied to the Saturn system, and illustrate the following related points:

- Magnetopause crossings from the Cassini spacecraft can be used to compute local solar wind pressure estimates. Combining this information with our magnetopause surface model, one can deduce the compressibility of Saturn's magnetosphere; this procedure yields results that are consistent with previous studies, based on more empirical surface models.

- The modelled boundary can be used to compute the corresponding shielding field which is produced by the magnetopause surface currents. The resulting magnetospheric field model could then help characterise the space environment of particular moons – eg. Titan, which orbits near the magnetopause of Saturn.

- Our modelling technique retains enough flexibility to be open to numerous improvements, such as introducing variable hot plasma pressure, contributions of a co-rotating partial ring current, and configurable dipole tilt for studies of seasonal effects.

Determining the 'Nominal Thickness and Variability of the Saturnian Magnetodisc Current Sheet

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In the magnetosphere of Saturn, the dominant magnetic field contributors are the internal field and the magnetodisc current sheet. The co-rotating plasma, sourced from the moon Enceladus, that carries the azimuthal current in this equatorial sheet stretches the magnetic field into the characteristic magnetodisc geometry. This current sheet is observed at all local times but has a highly dynamic configuration due to multiple factors, including planetary period oscillations, variable solar wind conditions and the obliquity of Saturn.

In this study, we use the complete magnetic field dataset collected by the Cassini spacecraft to determine the north-south thickness of the magnetodisc current sheet. We identify crossings of the current sheet where a clear signature in the radial field component allows us to constrain the boundaries of the current layer. We begin by investigating the factors that are controlling the variability of the thickness. We then determine how the thickness varies both spatially and temporally with respect to these dynamical processes that are continuously perturbing the current sheet. Finally, we calculate the average thickness as a function of these parameters. Our results are essential for understanding the global configuration of the Saturnian system and how it is modified by the magnetodisc current sheet. They also enable us to better model the most significant current system in the Saturnian magnetosphere.

O48

The E-ring asymmetry and Saturn's noon-to-midnight electric field

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The asymmetric structure of Saturn's diffuse E ring is the most significant, yet puzzling, Cassini finding about the dynamics of the diffuse ring originated from Enceladus. Azimuthally, the E ring appears to be an egg-shaped structure with the blunt side facing sunward. The rings vertical structure, however, shows a global warpage that is symmetric with respect to Saturn's rotation axis. In other words, the ring is both symmetric and asymmetric.

Here we show that the recently discovered noon-to-midnight electric field in Saturn's inner magnetosphere is the main cause of the observed asymmetry. We found that, the noon-to-midnight electric field essentially reduces, cancels, or even reverses the effect of the Solar radiation pressure on charged E ring particles. This electric field modifies and confines the longitude of particles orbital periapses differently from the "classic" E ring grain dynamics, leading to a size-dependent, day-night asymmetric structure.

We will present the latest E ring dynamics simulation results including the effects of the noon-to-midnight electric field and the day-night plasma temperature asymmetry. For comparison, in situ measurements carried out by the Cassini Cosmic Dust Analyser as well as the Radio and Plasma Wave Science instruments will be used to provide observational constraints on the E ring dynamical evolution. Finally, we will address the implications regarding the E ring deposition pattern on embedded icy moons and the dynamics of the diffuse mu ring of Uranus.

Charged particle weathering of icy satellites

(Invited)

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Most icy satellites are embedded within the magnetosphere of their host planet, and are thus exposed to charged particle bombardment, from thermal plasma to more energetic particles at radiation belt energies. Bombarding charged particles are capable of affecting surface material, in some cases down to depths of several meters (Johnson et al., 2004; Parancias et al., 2009, 2002). Examples of radiation-induced surface alteration include sputtering, radiolysis, compaction and grain sintering; processes that are capable of significantly altering the physical properties of surface material. Radiolysis of surface ices containing sulfur-bearing contaminants from Io has been invoked as a possible explanation for hydrated sulfuric acid detected on Europas surface (Carlson et al., 2002, 1999) and radiolytic production of oxidants represents a potential source of energy for life that could reside within Europas sub-surface ocean (Chyba, 2000; Hand et al., 2007; Johnson et al., 2003; Vance et al., 2016). Regions of anomalous thermal inertia on the saturnian moons Mimas, Tethys and Dione have been interpreted as being due to sintering caused by high energy electrons, which preferentially bombard their leading hemispheres.

Here we will present an overview of charged particle weathering effects at icy satellites by comparing theoretical predictions with observations. We will present modelling results of energetic ion and electron bombardment of Europa (e.g. Cooper et al., 2001; Parancias et al., 2001, 2002; Nordheim et al., 2018) and discuss the possible implications for observable surface properties as well as for future surface sampling missions. In particular, we will focus on the effect of local electromagnetic fields on energetic particle access to Europas surface. We will also discuss energetic electron bombardment and associated surface effects at the saturnian satellites Mimas and Tethys (e.g. Howett et al., 2010, 2011; Nordheim et al., 2017; Schaible et al., 2017).

O50

How to make a habitable satellite around a gas giant – Energy and building materials

(Invited)

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Life requires energy. In this regard, a habitable planetary body can be defined as a planetary system that provides disequilibrium energy to the hydrosphere continuously. On a geologically-active icy satellite around a gas giant, oxidants can be generated on the icy crust through dissociation of surface molecules via photo-/ionchemistry and subsequent hydrogen escape. In the subsurface ocean, high-temperature water-rock reactions on the seafloor can form reductants. Hydrological cycles within the ocean and icy crust can transport and mix these chemical products, generating disequilibrium energy within the hydrosphere. In the present study, we compare the availability of these disequilibrium energy on the icy moons around the gas giants in the Solar System, including Europa and Enceladus. Based on the comparison, we discuss the factors that can control the habitability of the icy moons in the Solar System and beyond.

O51

Interaction of Moon Atmospheres with Jupiter's magnetosphere

(Invited)

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The underlying processes of atmosphere-plasma interactions is similar for all Galilean moons. These interactions were observed by the Galileo between 1995-2001. The interaction produces perturbations of the flow and magnetic field caused by collisions of the incoming plasma with the neutral atmosphere resulting in ionization and momentum-loading. But each moon adds a specific flavor to this interaction that makes each of them an intriguing research topic. I review the global concepts of plasma-atmosphere interactions and mainly address the cases of Io and Europa. I briefly highlight some specific issues at Ganymede and Callisto to set the scene for others. Io, is remarkable for its intense volcanism, the ultimate source of its dense atmosphere (compared to other jovian moons). Io is the archetype of a strong local interaction. As the main source of the heavy ion plasmashet, it is the root cause of the plasma interaction at other moons. Orbiting the poles of Jupiter, from time to time Juno crosses the foot of field lines intersecting Ios orbit. Junos observations reveal puzzling details of the distant consequences of the local interaction at Io. Europas atmospheric source results from plasma sputtering its icy surface. Although its local interaction is weaker than Ios, the presence of a subsurface liquid ocean and potential plumes exposing its composition are main objectives of the future JUICE and Clipper missions. With a permanent magnetic field, Ganymede presents a case of continuous reconnection with the surrounding jovian field, also to be explored by JUICE. Callisto, has been claimed by some to possess from time to time the densest O₂ atmosphere of the solar system beyond Earth. Consequently, its interaction with the corotating plasma might be surprisingly strong. It is probably very variable and depends on solar illumination by and the hemisphere impinged by the highly variable magnetospheric ions fluxes in the plasma sheet.

Magnetic Signatures of a Plume at Europa During the Galileo E26 Flyby

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We analyze the magnetic field perturbations observed near Jupiter's icy moon Europa by the Galileo spacecraft during the E26 flyby on 3 January 2000. In addition to the expected large-scale signatures of magnetic fieldline draping and induction, the E26 data set contains various prominent structures on length scales much smaller than the moon's radius. By applying a hybrid (kinetic ions and fluid electrons) model of Europa's interaction with the impinging magnetospheric plasma, we demonstrate that these fine structures in the magnetic field are consistent with Galileo's passage through a water vapor plume whose source was located in Europa's orbital trailing, southern hemisphere. Considering the large-scale asymmetries of Europa's global atmosphere alone is not sufficient to explain the observed magnetic signatures. Combined with the recent identification of a plume during the earlier E12 flyby of Galileo, our results provide strong evidence that plume activity at Europa was a persistent phenomenon during the Galileo era.

Novel HST observations of the Galilean moons Io and Ganymede, and simultaneous Juno-UVS observations of the Io footprint

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Within two Hubble Space Telescope (HST) campaigns in support of the NASA Juno mission (GO14634 & GO15638, PI D. Grodent), spectra and spectral images of the moons Io and Ganymede were obtained by HST's Space Telescope Imaging Spectrograph (STIS) and Cosmic Origins Spectrograph (COS) on several occasions between 2017 and 2019.

On one occasion around Juno's perijove #14 in July 2018, the Juno Ultraviolet Spectrograph (UVS) observed Io's footprint simultaneously to the HST imaging of Io. We compare the temporal variability of the local moon aurora and the footprint brightness. Through this comparison, we investigate how the amplitude and phase of the periodically changing brightness of Io's aurora and the footprint are correlated.

Additionally, we present results from two novel far-UV observations of Ganymede: High-sensitivity spectra of the moon going into eclipse as well spectral images of the moon while transiting Jupiter. Both Ganymede observations are used to constrain the optical depth of the moon's atmosphere in the far-UV.

O54

Polar Wind Outflow Model at Jupiter

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Polar wind is an important source of plasma in the magnetosphere at Earth, and it has been shown to be a contributor to the magnetospheric population at Saturn and Jupiter. We are developing a semi-kinetic, non-classical polar wind model for rapidly rotating systems to characterise the material escaping the upper atmosphere and the physical processes that dominate the escape, including evaluating with the auroral current systems. We present early results from the model and compare to in situ data at Jupiter and Saturn.

Favorable Conditions for Magnetic Reconnection at Ganymedes Upstream Magnetopause

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Ganymede is the largest moon in the solar system, and the only satellite to maintain a permanent magnetic field. Jovian plasma can enter the moons magnetosphere via magnetic reconnection at the upstream magnetopause, where Ganymedes magnetic field lines are nearly anti-parallel to the Jovian field. Despite relatively steady magnetopause conditions, MHD simulations have shown evidence of unstable reconnection events such as flux ropes. Nevertheless, viable locations for magnetic reconnection have not been formally assessed under fundamental plasma theory. Here we present an analytical model parametrising typical steady-state conditions at Ganymedes upstream magnetopause, which are then used to evaluate magnetic reconnection onset conditions. We find that the onset is satisfied where the adjacent magnetic fields are partially anti-parallel, which is the case across the entire magnetopause. The estimated reconnection electric field magnitude is ~ 3 mV/m, with an associated voltage of order 10-100 kV. The loose constraint on reconnection indicates the possibility of multiple X-lines consistent with MHD simulations. This conclusion does not change under variations of the model input parameters. Understanding magnetic reconnection structure will improve our understanding of plasma convection within Ganymedes magnetosphere. Further model development may include dynamical effects, which will provide insights into Ganymedes internal liquid ocean.

High energy particle signature of the Jovian satellites

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Since its insertion into a highly elliptical 53-day polar orbit in July 2016, NASA's Juno spacecraft has repeatedly passed through the inner part of the Jovian magnetosphere. Several of these traverses brought Juno close to field lines which also pass through the Galilean satellites, enabling direct observations of their influence upon the charged particle flux trapped on these field lines. The Magnetometer experiment, mounted on the outer extremity of one of Juno's solar arrays, consists of two vector magnetometer platforms each equipped with two ASC star tracker sensors. The star trackers are heavily shielded in order to deliver accurate attitude information when Juno passes the fierce trapped radiation belts of Jupiter; by design, only high energy particles ($>15\text{MeV}$ for electrons and $>80\text{MeV}$ for protons) may penetrate to the star tracker focal plane detector CCDs where they leave a measurable ionization charge. By counting these, the ASC delivers an accurate measurement of the high energy particle flux every 250ms covering more than four decades of flux. These ancillary measurements are valuable for generating nearly continuous measurements of Jupiter's trapped particle population. However, every time Juno passes through the magnetic field lines connecting to one of the Galilean moons, we obtain a detailed characterization of the effect the moons have on the trapped particle population. We present the particle populations as measured, from bow shock to cloud tops, and discuss the scatter and diffusion of energetic particles as measured in the vicinity of Jupiter's satellites.

Correlations Between Jupiter's X-ray Aurora and the Outer Magnetosphere Plasma Sheet

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Jupiter produces dynamic X-ray auroral emissions at both of its poles [e.g. Gladstone et al. 2002; Cravens et al. 2003; Elsner et al. 2005; Branduardi-Raymont et al. 2004; 2007; Dunn et al. 2017]. These consist of two main components: 1. a lower latitude bremsstrahlung emission from precipitating electrons along the UV main emission [Branduardi-Raymont et al. 2004; 2008] and 2. a more dominant poleward emission from the precipitation of highly energetic ions [e.g. Elsner et al. 2005; Branduardi-Raymont et al. 2007]. These emissions are often observed to pulse, sometimes erratically and sometimes with a regular beat (e.g. Jackman et al. 2018). For much of the last two decades, these remote signatures of energetic ion precipitations have been interpreted as indicators of the processes at Jupiter's cusp and/or Jupiter's return current system [e.g. Bunce et al. 2004; Cravens et al. 2003]. Here, we report on an extensive campaign totalling hundreds of hours of Jupiter observations by XMM-Newton that were conducted coincident with in-situ measurements of Jupiter by NASA's Juno mission. By comparing data from XMM-Newton and Juno's JEDI, WAVES and MAG instruments, we identify strong correlations between events at 50-70 Jupiter radii in the outer magnetosphere and Jupiter's X-ray auroral emissions. Strangely, these correlations connect the dawn and night-side magnetosphere with the aurora and not the expected noon magnetosphere [Dunn et al. 2016; Kimura et al. 2016]. We finish by leveraging our understanding of the UV emissions to interpret the triggers of these processes.

Numerical modelling of field-aligned currents in the Jovian middle magnetosphere

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Jupiter's main auroral oval is driven by upward directed field-aligned currents which originate in its middle magnetosphere, at radii of $\sim 20R_J - 50R_J$. Investigating the particle dynamics in such a region will allow several unanswered questions to be examined: what are the density and potential structures along high-latitude field lines, extending to the middle magnetosphere? How much energy is deposited into the planetary atmosphere due to precipitating electrons?

Previous 1-D spatial kinetic models of the Jovian system have been limited to examining the Io flux tube. This is due to computation cost of modelling the large-scale sizes and magnetic mirror ratios present in the middle to outer magnetosphere. To that end, a 1-D spatial, 2-D velocity, hybrid kinetic/fluid model, designed to examine the high latitude regions of the Jovian magnetosphere is under development. Through the use of code parallelisation and a non-uniform spatial grid, finer mesh can be prescribed towards the ionosphere, allowing small-scale features to be resolved without impacting on computational runtimes. The model outputs include high-latitude electron densities, altitude of the auroral acceleration region and precipitating electron intensity. Comparison of the model output with data from the Juno spacecraft will allow validation and refinement of magnetosphere-ionosphere coupling theory. An overview of the model, along with initial results of the upward current region of the Jovian middle magnetosphere will be presented.

Magnetosphere-Ionosphere coupling at Saturn: conductivities of near-equatorial ionosphere

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Using the in-situ measurements from the last 6 orbits of Cassinis Grand Finale (288 – 293), the Pedersen, Hall and field-parallel conductivities of the top ionosphere (10:50 – 12:17 Saturn Local Time, 10N – 20S planetocentric latitude) are derived from the combined datasets of the RPWS/LP, INMS and Cassini magnetometer. Considering the known underestimation of the plasma densities and masses by the RPWS/LP in dusty plasma environments (derived in absence of the negative ion/dust mass information), the Pedersen and Hall conductivities are constrained to 10^{-4} – 10^{-3} S/m at ionospheric peak (or close to), 5.5-122 S height-integrated. These conductivities decline from orbit 288 through 292 (propagating from a decline in the ion densities), suggesting temporal variations possibly driven by the ring dust influx. We also show that the ionospheric dynamo region is 575-1050 km thick, situated between 770 and 1900 km above 1 bar level.

The consequences of Saturn's "ring rain"

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Saturn's upper-atmospheric H_3^+ emissions have been previously studied using ground-based observations, and found to exhibit peaks in emissions at specific latitudes. The cause of these peaks is due to an influx of charged water products originating from Saturn's rings known as 'ring rain'. Subsequent modeling using the Saturn Thermosphere Ionosphere Model (STIM) has indicated that these peaks in H_3^+ emissions are likely driven by an increase in H_3^+ density, rather than temperature, as a local reduction in electron density (due to charge exchange with water) lengthens the lifetime of H_3^+ . However, a direct observation of the H_3^+ density is required to estimate the flow rate of material into Saturn with models. Calculation of ring rains flow rate into Saturn is a highly important input for determining the age, lifetime and evolution of Saturn's rings. Here we present the first ever derivation of H_3^+ density, temperature and radiance in the nonauroral regions of Saturn, using data taken from the 10-meter Keck telescope in 2011. H_3^+ density is enhanced near 45 degrees north planetocentric latitude and strongly reduced near 39 degrees south. When compared to STIM modeling results, these densities indicate a small 50kg/sec water influx in the north and an enormous 1500kg/sec influx in the south. The charged grains are pulled in along the magnetic field by gravity, but the southward-inclination of the magnetic field (in the vicinity of the ring plane) means that the grains are preferentially drawn southwards into the planet. Assuming that our (Saturn northern Springtime) measurement represents all seasons, and that the rings are able to disperse over time, the ring rain mechanism alone will drain Saturn's rings to the planet within 300 million years. If we also add the recent Cassini-spacecraft measured ring-material detected falling into Saturn's equator (and assume it is constant), then the rings have under 100 million years to live. Recent measurements by Cassini again have estimated a ring age of ~50 million years, so it seems that Saturn's rings are short-lived.

The ionosphere of Uranus: long-term cooling and local-time morphology

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The upper atmosphere of Uranus is known to have previously demonstrated to be slowly cooling between 1993 and 2011. New analysis of near-infrared observations of emission from H₃⁺ obtained between 2012 and 2018 reveals that this cooling trend has continued, showing that the upper atmosphere has cooled for 27 years, longer than the length of a nominal season of 21 years. The new observations have offered greater spatial resolution and higher sensitivity than previous ones, enabling the characterisation of the ionospheric emission as a function of local-time. These profiles peak between 13 and 15 hours local-time, later than models suggest. The NASA Infrared Telescope Facility (IRTF) iSHELL instrument also provides the detection of a bright H₃⁺ signal on 16 Oct 2016, rotating into view from the dawn sector. This feature is consistent with an auroral signal. We also discuss the future James Webb Space Telescope observations of the atmosphere and ionosphere of Uranus, planned as part of the Guaranteed Time Observing (GTO) programme.

Plasmoid Observation in the Magnetotail of Uranus: Implications for Plasma Convection and Downtail Mass Loss

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We report on a plasmoid observed in the magnetotail of Uranus during the Voyager 2 flyby in January 1986. The presence of a plasmoid signature in the Magnetometer data indicates that magnetic reconnection was occurring in the cross-tail current sheet during the spacecraft's tail traversal. The magnetic field measurements represent a classic loop-like plasmoid signature, similar to what has been reported at the outer planets of Jupiter and Saturn: a bipolar signature indicative of the looped outer magnetic field wraps and a decrease in total field magnitude at the center of the structure due to trapped plasma. Further analysis demonstrates that the plasmoid was moving downtail, away from the planet and therefore, contributing to the total loss in the overall mass budget of the system. The location of the plasmoid at ~ 54 RU (where RU is the radius of Uranus) downtail provides constraints on the tail reconnection X-line location, consistent with previous modeling results. We provide estimates of the plasmoid size in order to infer the amount of plasma ejected. By assuming one plasmoid event over a convection cycle of ~ 17 hr, we calculate the contribution of a single plasmoid to balance the total mass budget of the system. Observations of a ~ 30 -s duration postplasmoid plasma sheet following the plasmoid signature indicates that magnetic reconnection continued between the open-field tail lobes. We find that ~ 3.69 MWb of open-tail flux was detached following the plasmoid ejection, suggesting that either a higher plasmoid occurrence rate or additional convection loss mechanisms are necessary to balance the ~ 3.29 GWb of magnetic flux in the Uranian magnetotail. This plasmoid observation provides significant evidence of magnetic reconnection and flux transport processes at Uranus in order to understand this Ice Giants magnetospheric dynamics.

Recent advances in global simulations of the giant planet magnetospheres and their interactions with moons

(Invited)

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Global simulations have now been widely used in studies of planetary magnetospheres, becoming a valuable tool for interpreting satellite observations, discovering new physics or processes, or, in general, for understanding the basic behavior of the magnetosphere. When it comes to the giant planet magnetospheres, because of their relatively large system sizes, presently magnetohydrodynamics (MHD) remains the only feasible approach for simulating the global system. However, important properties common to the giant planets call for global models that go beyond the single-fluid, ideal MHD approach. For example, the strong internal plasma sources associated with the moons (Io at Jupiter; Enceladus at Saturn) require global MHD models to be able to take into account the effects of mass-loading, either through boundary conditions or adding source/loss terms in the MHD equations. At the giant planets, the typical high Mach number solar wind leads to a magnetosheath with high-beta plasma, which has been suggested to suppress magnetopause reconnection. Under such conditions, to quantify how efficiently the solar wind is coupled to the giant planet magnetospheres requires a global model that can simulate kinetic effects that are not captured by a fluid approach. A similar situation exists when it comes to modeling the plasma interaction with planetary moons. In this presentation, we provide an overview of the recent progress made on global simulations of the giant planet magnetospheres and their interactions with the major satellites. We will discuss how mass-loading is treated in global simulations and how it affects the plasma transport and large-scale structure. We will present results from a coupled fluid-kinetic model (MHD-EPIC) applied to the giant planets as well as the magnetized moon, Ganymede, to illustrate how a kinetic treatment allows us to better understand magnetopause dynamics. Examples of global simulations that incorporate localized neutral sources due to plumes at the Galilean moons (e.g., Io, Europa) will also be discussed.

A Numerical Experiment of Global Jovian Magnetosphere: Initial Results from Multi-fluid Magnetohydrodynamics with Mass Loading

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We present initial results of modeling the dynamics of global Jupiter magnetosphere driven by steady solar wind and interplanetary magnetic field using three-dimensional simulations based on multi-fluid, ideal magnetohydrodynamics (MHD). Two non-ideal processes, mass loading and co-rotation, are implemented in the global model. The mass loading is implemented in a conservative way with a fixed rate of 1000 kg/s at the low-altitude (inner) boundary of the simulation domain (6 RJ). Co-rotation is introduced as a time-stationary electric field varies as a function of latitude at the inner boundary. Initial results show that the results are resolution-dependent, and the high-resolution simulations are capable of reproducing the profiles of measured density, thermal pressure, temperature and scale height in the Jupiter magnetosphere to some extent. The radial and azimuthal transport of magnetospheric plasmas are also in agreement with theoretical and observational estimations. In the simulation, Kelvin-Helmholtz instability occurs throughout the simulation with significant dawn-dusk asymmetries along the magnetopause, caused by the fast co-rotation of the magnetospheric plasma. Non-linear centrifugal-driven instability also occurs in the inner region of the simulation domain between 15-40 RJ after five simulation days (120 hours). However, the simulated size of the Jupiter magnetosphere is significantly smaller than observations, especially in terms of locations of magnetopause and bow shock. The reason of size discrepancy is possibly related to the missing of a non-thermal, hot plasma population observed by satellites, which requires further investigation including the implementation of hot plasma populations through physics-based, empirical, and/or ad-hoc non-adiabatic heating rates for magnetodisk plasmas.

A Global Survey of the Spatial Distribution of Ultra-Low-Frequency Waves with Periods ~ 1 -100 Minutes in the Jovian Magnetosphere

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Ultra-low-frequency (ULF) waves of unknown origin have been observed throughout Jupiter's magnetosphere since the Pioneer era. The enormous Jovian magnetospheric cavity is capable of supporting magnetohydrodynamic waves of periods of order tens of minutes, with a widely reported range of ~ 1 -100 minutes. Previous studies of such waves are scattered between different datasets and often focus on individual case studies, leaving the spatial distribution and source mechanisms of these waves an ongoing mystery.

We have performed a global survey identifying large-amplitude ULF wave events using magnetometer data from the Galileo spacecraft and several near-equatorial flyby missions. We found over 400 ULF wave events, consisting of a combination of compressional and alfvénic wave packets. Compressional and Alfvénic events were often coincident in space and time, which may be evidence for the driving of global Alfvénic resonances known as field-line-resonances. The results confirm that 15, 30- and 40-minute periods dominate the Jovian ULF wave spectrum, encompassing the entire range of periods reported in the established literature. Additionally, we present the first evidence for multiple harmonics in the equatorial plasma sheet. Events occurred predominately in the outer magnetosphere close to the magnetopause, supporting hypotheses that magnetospheric ULF wave power may be driven by Kelvin-Helmholtz instabilities and other large-scale compressive perturbations on the magnetopause.

Dayside magnetodisk reconnection processes on Saturn revealed by Cassini

R. L. Guo, Z. H. Yao, Y. Wei, N. Sergis, L. C. Ray, I. J. Rae, C. S. Arridge, A. J. Coates, P. A. Delamere, P. Kollmann, D. Grodent, W. R. Dunn, J. H. Waite, J. L. Burch, Z. Y. Pu, B. Palmaerts, M. K. Dougherty, D. Mitchell, E. Roussos, A. Radioti, N. Krupp, W. X. Wan

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Magnetic reconnection is a fundamental plasma process that energizes charged particles explosively, generating phenomena such as nebular flares, solar flares, and stunning aurorae. In planetary magnetospheres, magnetic reconnection has often been identified on the dayside magnetopause and in the nightside magnetotail and/or magnetodisk. For giant planets, the dayside magnetodisk is usually considered thicker than the nightside due to the compression of solar wind, and thus not an ideal environment for reconnection. However, in this work, we report a series of evidences of near-noon reconnection within Saturn's magnetodisk using measurements from the Cassini spacecraft. An ion diffusion region is well defined based on the analysis of the Hall magnetic field and the electron pitch angle distribution. The results suggest that the rotationally driven reconnection process plays a key role in producing energetic electrons (up to 100 keV) and ions (several hundreds of kiloelectron volts). In particular, we find that energetic oxygen ions are locally accelerated at the reconnection sites, which shed light to understanding of Jovian X-ray aurorae caused by MeV ion precipitations.

Origin and Triggers of the 1-hour Electron Pulsations in the Saturnian System

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Phenomena displaying a periodicity of around one hour have been frequently observed in Saturn's magnetosphere during the Cassini era. In particular, flux of energetic electrons can exhibit 1-hour quasi-periodic pulsations. While these pulsations have been well characterized, their origin and the processes triggering them remained uncertain at the end of the Cassini mission. Using long imaging sequences of the auroral emissions at Saturn, we report the first direct observational evidence that the 1-hour periodicities arise from a global 1-hour oscillation of the Kronian magnetosphere. This natural oscillation acts independently of the local magnetospheric conditions and can have multiple triggering processes. Many 1-hour quasi-periodic electrons were encountered close to the magnetopause, suggesting that magnetopause processes could trigger them, such as magnetic reconnection and Kelvin-Helmholtz (KH) instabilities. We now report simultaneous presence of KH instabilities and 1-hour electron pulsations, supporting this scenario. Pulsed electrons are also encountered much deeper in the magnetosphere and may originate from reconnection in the magnetodisk, on both the day and night sides of the magnetosphere.

P1

On Saturn's Rings – Planetary Period Oscillations and the Intra-D Ring Current

G. Provan, S. W. H. Cowley, E. J. Bunce, T. J. Bradley, G. J. Hunt, H. Cao, and M. K. Dougherty.

* University of Leicester

We examine Saturn's magnetic fields observed during the periapsis passes of Cassini's final 23 orbits which passed north-south through the equatorial plane on field lines inside of Saturn's D ring. We focus on two phenomena, the planetary period oscillations (PPOs) and the intra-D ring currents. The intra-D ring currents begin and end near-symmetrically at some point on field lines threading the D ring, consistent with the effect of interhemispheric field-aligned currents, and the currents generally extend to larger values within the interior region. Total currents are ~ 1 MA per radian of azimuth (MA/rad) comparable with auroral values. The signatures are variable in form and amplitude, this is not connected with pass altitude, local time, planetary period oscillation phase, or D68 ringlet phase, but may relate to variable structured thermospheric winds and ionospheric conductivities suggesting a dynamical D ring-atmosphere interaction. Although the variation of the intra-D ring currents is not connected with the PPO phase, these fields are superposed on PPO oscillations of smaller amplitude which are found to be present throughout the periapsis pass data, from the auroral regions through to the field lines inside of the D ring. PPOs are thus observed throughout Saturn's magnetosphere without exception. Associated ionospheric meridional currents decrease from ~ 1 MA/rad in the auroral region to ~ 0.1 - 0.2 MA/rad throughout the ring region, increasing to ~ 0.2 - 0.4 MA/rad inside the D-ring. We also determine the mean residual fields on these passes, and show that the persistent "lagging" azimuthal fields found previously in the dayside subauroral region on F ring orbits remains essentially unchanged on field lines threading the main ring system, even inside of field lines passing through synchronous orbit. This finding calls into question the usual dynamical interpretation of such "lagging" field geometries in this case.

Time Domain Structures in Cassini's Wideband Receiver Waveforms Observed Inside the Inner Magnetosphere of Saturn

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Time domain structures manifesting as striking mono-, bi- or tri-polar structures are observed inside Saturn's inner magnetosphere. These structures can be characterized as electrostatic/magnetic solitary waves, double layers, dust impacts or instrumental effects. The RPWS/Wideband Receiver (WBR) detects the time domain structures in waveform snapshots in both 10- and 80-kHz modes. In this study, we focus on electrostatic solitary waves (ESWs) exhibiting bipolar structures in the waveform snapshots. Previous work of Williams et al. (2006) showed ESWs in plasma boundary regions or regions with abrupt changes in the magnetic field. Pickett et al. (2015) made the ESW observations from Cassini's orbit insertion through 2008 and distances $<10 R_s$ and identified ESWs with very low occurrence rates (up to 0.1%) mostly close to the equatorial plane of Saturn and in the vicinity of Enceladus. We surveyed ESWs during the last phases of Cassini's mission (Dec 2016 - Sep 2017) and identified more than 70 events at the ring plane in the vicinity of the planet ($R < 2 R_s$). A few events were also observed along auroral field lines at higher latitudes near or inside an SKR source region. ESW signatures can be missed for two possible reasons. First, ESWs can be superposed with a different wave with the amplitude of the same order or misinterpreted as other phenomena, especially as dust impact signatures. Second, the temporal scale of ESWs cannot be resolved by the WBR instrument. These instrumental constraints of the ESWs detection are shown. We also revisit the previously identified events in more detail and discuss their possible generation processes. Finally, examples of ESWs and dust impacts are provided to show their properties and differences.

Negative Ions in Saturn's Inner Magnetosphere

G. H. Jones, A. J. Coates, A. Wellbrock, W. Dunn, and the Cassini CAPS Team

* UCL Mullard Space Science Laboratory, UK

_ : presenter

Cassinis CAPS electron spectrometer was capable of detecting negative ions in addition to electrons. These had been detected by the instruments within the Saturn system at Titan, Enceladus, Rhea, Dione, and near the main rings, where they could be observed as a cold population in the local ram direction, or as localised pickup ion populations. It is however otherwise difficult to recognize the negative ions unambiguously in data from an instrument designed for electrons. The possibility remained that negative ions are common in the magnetospheric population, but they are difficult to identify. A work by Thomsen et al. (doi:10.1002/2017JA024147, 2017) provided the means to identify negative ions in at least one context. Thomsen and colleagues reported the presence of H⁺ bands consistent with protons having undergone a bounce-resonant interaction within the standing wave structure of a field line resonance in Saturn's inner magnetosphere. During the same periods, we found that CAPS-ELS data show the presence of negative ions following the same behaviour, and the energies of the negative ion signatures are entirely consistent with them being O⁻ ions. Here, we report on the initial results of a survey of the distribution of these negative oxygen ions, which almost certainly originate at the E-ring and its neutral particle torus (and hence ultimately from Enceladus). Oxygen is strongly electronegative, so the formation of these ions can be explained. However, it is surprising that water group positive ions were apparently not present in similar numbers. The negative ion signatures appear most common around midnight and post-midnight local times. This suggests that they are transient in nature, and associated with corotation plasma having spent time in darkness in the shadow of the planet.

P4

Saturn's Multiple, Variable Periodicities: A Dual-Flywheel Model of Thermosphere-Ionosphere-Magnetosphere Coupling

E. L. Brooks, C. Fernandez, and D. H. Pontius Jr.

* Birmingham-Southern College

_ : presenter

The Jovian flywheel model was developed to explain the remarkable steadiness of the observed corotation lag in Jupiter's magnetosphere [Pontius, 1995, following Huang and Hill, 1989]. The key conclusion of that research was that the observed lag is primarily due to slippage within the neutral atmosphere, with only a small fraction of it arising from slippage between the thermosphere and magnetosphere. Moreover, the neutral wind profile in the atmosphere responds very slowly, so it acts as a mechanical flywheel to dampen out temporal variations with timescales less than several months. We adapt the model for Saturn by allowing the Pedersen conductance to differ in the northern and southern hemispheres. In steady state, the two neutral thermospheres then have different rotation rates that can slowly vary with the season on Saturn as solar illumination of the poles varies.

A Nearly-Corotating Long-Lasting Auroral Spiral at Saturn

B. Palmaerts, Z. Y. Yao, R. L. Guo, N. Sergis, D. Grodent and A. Radioti

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The main ultraviolet auroral emission at Saturn consists of multiple structures of various sizes forming a discontinuous ring of emissions around Saturn's poles. For decades, it is known that the main emission is occasionally organized in a global spiral surrounding the pole. In August 2016, the Ultraviolet Imaging Spectrograph (UVIS) on board the Cassini spacecraft proceeded to a 7h-long imaging of Saturn's northern aurora. During this observing sequence, the main emission displayed a spiral wrapping around the pole by more than 370° in longitude. The spiral was in rotation around the pole at $\sim 90\%$ of rigid corotation, which is an unusually high velocity for extended auroral structures. A spiral was again observed during a shorter UVIS sequence, sixteen hours after the end of the first sequence. Simultaneously to the first UVIS sequence, imaging of the energetic neutral atom (ENA) emissions revealed a hot plasma population in the same local time sector as the extremity of the UV spiral. The leading edge of the plasma population follows the spiral structure around the planet. This correspondence suggests that the presence of the hot plasma distorted the magnetospheric current system, resulting in the spiral shape of the main emission. Furthermore, simultaneous in-situ measurements of the ion fluxes exhibit enhancements recurring every ~ 10.5 hours. The nearly corotating aurora, ENA emissions and ions revealed by this multi-instrument dataset are likely three signatures of a magnetosphere-ionosphere coupling current system and of the associated hot plasma population corotating with the planet.

The Structure of Planetary Period Oscillations in Saturn's Equatorial Magnetosphere: Results from the Cassini Mission

D. J. Andrews, S. W. H. Cowley, G. Provan, G. J. Hunt, L. Z. Hadid, M. W. Morooka and J.-E. Wahlund.

* Swedish Institute of Space Physics

_ : presenter

Saturn's magnetospheric magnetic field, planetary radio emissions, plasma populations and magnetospheric structure are all known to be modulated at periods close to the assumed rotation period of the planetary interior. These oscillations are readily apparent despite the high degree of axi-symmetry in the internally produced magnetic field of the planet, and have different rotation periods in the northern and southern hemispheres. In this paper we study the spatial structure of (near-) planetary period magnetic field oscillations in Saturn's equatorial magnetosphere. Extending previous analyses of these phenomena, we include all suitable data from the entire Cassini mission during its orbital tour of the planet, so as to be able to quantify both the amplitude and phase of these field oscillations throughout Saturn's equatorial plane, to distances of 30 planetary radii. We study the structure of these field oscillations in view of both independently rotating northern and southern systems, finding spatial variations in both magnetic fields and inferred field-aligned currents that are common to both systems.

Coupling between Saturn's ionosphere and the rings ionosphere around 2.5 Rs

L. Z. Hadid, J.-E. Wahlund, M. W. Morooka, A. M. Persoon, W. M. Farrell, M. K. G. Holmberg, O. Shebanits, W. S. Kurth, J. D. Menietti, E. E. Woodfield

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_ : presenter

Based on the Cassini proximal orbits, we show the presence of electron density enhancements at latitudes around $\pm 45^\circ$ in Saturn's ionosphere which are connected to magnetic field lines around 2.5 Rs. This preliminary study is based on the wave and the Langmuir probe in-situ measurements from the Radio and Plasma Wave Science investigation. Combining some of the F ring grazing orbits, we show evidences of a plasma transport from the ring ionosphere around 2.5 Rs into Saturn's ionosphere. Different transport mechanisms that could lead to the formation of such structures are being discussed. These processes include an ambipolar diffusion moving the plasma upward along the field lines [Persoon et al. 2009], wave-particle interaction which could also accelerate the electrons upward [Woodfield et al. 2017] and pick-up processes associated with newly born ions forming adjacent to the rings. Other than the ring plane as a main source, those electron density enhancements could also be produced locally in the ionosphere of Saturn.

P8

A study of Local Time Variations of Jupiter's Ultraviolet Aurora using Juno UVS

T. K. Greathouse, G. R. Gladstone, M. H. Versteeg, V. Hue, J. A. Kammer, M. W. Davis, S. J. Bolton, S. Levin, J. E. P. Connerney, J.-C. Gérard, D. Grodent, B. Bonfond, E. J. Bunce

* Southwest Research Institute

With 19 successfully completed Perijoves, Juno UVS has collected an enormous amount of data with unprecedented views of the northern and southern auroras spanning all local time geometries. Juno UVS, with its spectral and spatial mapping capabilities allows for the retrieval of both UV brightness as well as color ratio information. Maps of both the brightness and color ratio of the main ovals and polar emissions display strong local time variations, some suggestive of ionospheric local time control while others magnetosphere local time drivers. In this presentation we bring together all the UVS observations to date to show and catalogue the many local time phenomena evident therein.

Electron conics: what do they say about auroral acceleration processes ?

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* CNRS/IRAP

Electron conics are often observed in the Jovian auroral regions, when Juno crosses the sources of radio emissions. These particular distributions are characterized by maximum fluxes at oblique pitch angles, $\sim 20^\circ$ - 30° from the B-field, both in the upward and downward directions and provide considerable free energy for the cyclotron maser instability (Louarn et al, 2018). They can also be used to probe the auroral acceleration processes. They indeed appear difficult to explain by quasi-static E-fields and their formation likely requires an interaction with a stochastic field. We explore a scenario based on the existence of a low frequency electric field turbulence, for example linked to inertial Alfvén waves. We deduce the characteristics of this turbulence that would be consistent with the formation of the observed conics.

Jupiter's Average Ultraviolet Aurora Using Juno-UVS

G. R. Gladstone, T. K. Greathouse, M. H. Versteeg, V. Hue, J. A. Kammer, M. W. Davis, S. J. Bolton, S. M. Levin, J. E. P. Connerney, J.-C. Gérard, D. C. Grodent, B. Bonfond, J. D. Nichols, F. Bagenal

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Using the best UVS data from each of Junos completed perijoves, we have created average (and variance) maps for the northern and southern auroras of Jupiter. The individual maps for each perijove contain a variety of auroral forms and represent many different levels of activity at a variety of local times. In contrast, the average maps allow features that are nearly always present, but at a lower brightness level, to stand out. The variance maps, on the other hand, tend to highlight auroral structures which occur only rarely. In this presentation we examine what can be learned from these ensemble maps which provide a new look at Jupiter's always surprising auroras.

Juno-UVS 3-D Maps of High-Energy Radiation at Jupiter

J. A. Kammer, G. R. Gladstone, T. K. Greathouse, V. Hue, M. H. Versteeg, M. W. Davis, H. N. Becker, S. J. Bolton, J. E. P. Connerney, S. M. Levin

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Juno-UVS is an ultraviolet spectrograph that primarily observes Jupiter's auroral emissions, but is also sensitive to penetrating high-energy particles (generally >10 MeV electrons), which are a source of white noise during UV observations. Based on the measurements made by Juno-UVS during 19 perijove passes so far (PJ1 and PJ3-20), we find that the level of background radiation observed by the instrument consistently reaches a maximum in certain regions around Jupiter, and we use this data to map the 3-D spatial distribution of the radiation, as well as to create an empirical model to predict levels during future perijoves. These maps reveal the highly asymmetric nature of the near-Jupiter magnetic field, which results in broad regions of anomalously low radiation when the spacecraft crosses certain field lines in the northern latitudes of Jupiter. In particular, we find that field lines connecting the northern magnetic pole and a large negative radial B-field anomaly near the equator (a.k.a. the "Great Blue Spot") are largely empty of >10 MeV electrons. We present comparisons of the Juno-UVS data from each of the perijove passes so far and discuss what future perijoves might further reveal about the nature and extent of high-energy radiation around Jupiter.

Auroral diagnosis of solar wind interaction with Jupiter's magnetosphere

Z. H. Yao, B. Bonfond, D. Grodent, W. S. Kurth, W. R. Dunn, B. Palmaerts, A. Radioti, G. B. Hospodarsky, J. E. P. Connerney and S. J. Bolton

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Jupiter has the brightest aurorae in the polar atmospheres in our solar system, allowing the visualization of energy dissipation in deep space. The solar wind and Jupiter's moon Io are the two main sources in driving the auroral dynamics. However, the relation between auroral morphologies and their drivers is poorly understood, and therefore the application of auroral images to examine the energy circulation in the space is still very limited. Using the unprecedented simultaneous measurements from the current Juno mission and the coordinated research campaigns from the Hubble Space Telescope, we find that both the solar wind and internal processes can drive the auroral intensifications on Jupiter's dawn arc. Furthermore, by analysing the morphological features of these aurorae, we can diagnose the interaction between solar wind and Jupiter's magnetosphere directly from the remote sensing of its aurorae. Our results demonstrate that auroral processes have direct implications for understanding space environments of a planet, which is also potentially applicable to understanding space environments of exoplanets where in-situ detection is not likely possible.

Observation of auroral “raindrops” in Jupiter's polar region by Juno-UVS

V. Hue, T. K. Greathouse, G. R. Gladstone, M. H. Versteeg, J. A. Kammer, M.W. Davis, S. J. Bolton, S. Levin, J. E. P. Connerney, M.J.-C. Gérard, D. Grodent and B. Bonfond

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Juno-UVS has observed Jupiter's FUV auroral emissions during 19 close flybys following Juno orbital insertion on 5 July 2016. Each perijove provides a different snapshot of the Jovian auroral emissions recorded at different system III longitude and local time conditions. During PJ6 (19 May 2017), UVS recorded several transient auroral features located within Jupiter's northern polar auroral region. These auroral “raindrops” are characterized by bright spots of H₂ emission (typically ~100 kR), which expand into concentric circles over tens of seconds, and seem to appear most often at local times close to noon. In this study we characterize where the raindrops occur in Jupiter's polar region, their spectral characteristics, and their typical expansion rates.

Unified Theory of the Acceleration of Auroral Particles and the Formation of Discrete Auroras at Earth and Jupiter

Yan Song, R. L. Lysak

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Junos observations show that Jupiters aurora is significantly different from Earths aurora. It is suggested that the intense auroral emissions are caused by broadband acceleration (Mauk et al., 2018). It has also been suggested that large amplitude electromagnetic waves may be tied to the stochastic acceleration of auroral particles (Kurth et al., 2018). In addition, field-aligned currents in the Jupiters magnetosphere seem to be too weak to explain the generation of the powerful Jupiter auroral emissions. In this presentation we will focus on the understanding of two observed phenomena using a recently-developed dynamic theory.

(i) Field-aligned current and displacement current: In fact, auroral accelerations are not directly caused by field-aligned currents, but by parallel electric fields. The parallel displacement current describes the generation of the electric field, which is likely to be important at Jupiter. We will discuss the relationship between the field-aligned current, the displacement current and the generation of electrostatic fields, and explain the observed weak field-aligned currents in the Jupiters magnetosphere.

(ii) The creation of Alfvénic electrostatic plasma structures: We propose that the nonlinear interaction of incident and reflected Alfvén wave packets in the acceleration regions can create Alfvénic electrostatic plasma structures such as Alfvénic double layers in the region. These structures consist of localized electrostatic fields, which are embedded in low density cavities and surrounded by enhanced reactive stresses. The generated electrostatic fields will deepen the seed low density cavity, which can further enhance the stronger electrostatic fields, causing auroral particle acceleration to high energy. The Poynting flux carried by Alfvén waves can continuously supply energy to the auroral acceleration region, sustaining double layers with a long-lasting electrostatic field. The structure acts as powerful high energy particle accelerators, which may related to intense broadband Jupiter auroral acceleration.

Are Dawn Storms Jupiter's auroral Substorms?

B. Bonfond, Z. Yao, R. Gladstone, D. Grodent, J.-C. Gérard, A. Radioti, J. Kammer, V. Hue, T. Greathouse, M. Versteeg, W. Kurth, P. Louarn, G. Hospodarsky, M. Imai, J.E.P. Connerney, D. Gershman, S. Kotsiaros, A. Adriani, A. Mura, B. Mauk, F. Allegrini, S. Levin, S. Bolton

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There are multiple evidences that mass and energy rarely circulate smoothly in planetary magnetospheres. To the contrary, these systems tend to accumulate them until they fall out of balance through reconfiguration events. The source of mass and the source of energy can differ, as well as the trigger that initiates the collapse. However, despite some fundamental differences between the planets, the auroral signatures of the global reconfigurations bear many similarities that inform us on the common physical processes at play. For the first time, Juno has granted us a complete and global picture of one type of such reconfigurations, the auroral dawn storms, from their initiation to their vanishing. Juno actually captured views of dawn storms at different stages of development in approximately half of the cases.

For example, on PJ11 and PJ16, Juno-UVS caught the brief appearance of small elongated spots located poleward of the main emission in the midnight sector. In both cases, a few hours later, the main emission began to brighten and broaden in the same sector. Then the main arc split into two parts, one moving towards the pole and the other moving equatorward. The whole feature also started to rotate towards the dawn sector, progressively accelerating to co-rotation. On PJ6, Juno-UVS observations missed the beginning of the event, but they allowed us to examine the next phase. After the broadening and the splitting of the main emission, the outer arc transformed into large blobs. During the same time interval, subsequent Hubble Space Telescope images confirmed that the blobs kept on evolving, forming latitudinally extended fingers. All these auroral features resemble auroral morphologies observed at Earth during substorms. The Jovian elongated spots look like terrestrial poleward boundary intensifications (PBIs), the poleward motion of the arc indicates a dipolarisation/current disruption and the blobs in the outer emissions suggest massive plasma injections.

Uranus spin : toward an updated rotation period and SIII longitude system

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The official inner rotation period of Uranus of 17.24 ± 0.01 h was determined from unique remote radio auroral observations and in situ magnetic observations during the flyby of the planet by Voyager 2 in Jan. 1986. The poor uncertainty on the rotation period yielded the associated SIII Uranian Longitude System (ULS) defined at that time to be valid only for a couple of months aside the flyby.

25 years later, the Earth-based re-detection of Uranus ultraviolet aurora with the Hubble Space Telescope provided a new mean to remotely track the magnetic poles. By fitting the bright southern auroral features observed late 2014 with model auroral ovals, we could determine the longitude of the southern magnetic pole with a 26° uncertainty and reference again the longitude system. The observational campaign was however too short to sample the rotation period with an improved accuracy.

We therefore applied the same method to the other auroral features detected in 2011 and, most recently, in 2017 to provide milestones aimed at updating the inner rotation period and determining a SIII longitude system valid over an extended time interval.

While a more accurate rotation period better characterises the planetary core, an updated SIII longitude system is essential to design any future exploration of the Uranian magnetosphere.

Statistical analysis of long-term variations of Jovian radio components observed by Cassini.

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Jupiter has a strong magnetic field and a complex magnetosphere. As consequence, it has a very diverse zoo of intense radio emissions. The high latitude emissions extend from kilometric to decametric wavelengths (bKOM, HOM and DAM). The DAM component is itself split in emissions that are controlled by satellite-Jupiter interaction (Io, Europa, Ganymede) and auroral emissions resulting from solar wind-magnetosphere or ionosphere-magnetosphere interactions. The relation between these components, and their link to magnetospheric dynamics is not fully understood. From Cassini/RPWS measurements it is possible to obtain instantaneous direction of arrival, flux density and polarization degree of the observed radio waves. We present a statistical analysis of the Jovian low-freq spectrum as recorded by the RPWS, over the range 3.5 kHz to 16.1 MHz, during the Cassini-Jupiter fly-by (Oct. 1st, 2000 to April 1st, 2001). The data were reduced, calibrated and detrended (for distance-related variations), and a catalog of all occurrences for the detected radio components (Jovian ones and solar Type III bursts) was created from a meticulous visual selection based on time-frequency distribution of their flux density and circular polarization. Combination of these two informations permitted a better selection of the components and separation of their hemisphere of origin (northern for RH and southern for LH circular emissions). Based on these selections, stacked longitude-versus-frequency polarized intensities of HOM, bKOM and non-Io-DAM are presented. These stacked dynamic spectra provide 'signature of each radio component that we attempt to interpret in terms of source location and beaming properties, in relation with magnetospheric dynamics. Also from the catalog it is possible to build robust correlations between the components (even when they share the same freq. range) and harmonic analysis of their time series, making it possible to address the periodicities related to Sys III versus Sys IV modulations, as well as longer periods related to Io's volcanism and the solar wind.

Transient Features in Jupiter's Polar Aurora: UV and X-ray Comparison

R. L. Gray, S.V. Badman, W. Dunn, G. Branduardi-Raymont, R. Gladstone, P. Ford, R. Elsner, and J. Kinrade

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_ : presenter

We examine observations of Jupiter's UV aurorae taken by the Hubble Space Telescope during the New Horizons flyby in 2007 and characterise the variability of features poleward of the main aurora. We show that the intensity of arcs parallel to the main oval in the dusk sector varies on a timescale of several minutes. These arcs are detected under solar wind compression conditions, associated with corotating interaction regions. In one case the UV arcs vary with the same period as the soft X-rays detected by Chandra from the same spatial region later on the same day. We therefore suggest that the X-rays are associated with the same process that drives the UV auroral arcs. The flashing of the features on these timescales suggests they are more likely to be associated with a transient magnetospheric process (e.g. magnetodisk reconnection pulses) rather than a relatively steady process (e.g. stepwise breakdown in corotation). We also identify a prolonged (~15 min) polar enhancement in the UV, which may be the counterpart of a similar-duration enhancement identified in X-rays, and suggest this could be related to cusp activity, which is expected to drive upward and downward currents in this region.

Pulsation-like variation of Jovian infrared H3+ polar emissions observed by Subaru 8-m

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In previous observational studies, the observed shortest timescale of H3+ emission changes was ~30 min, in ~16-min step imaging. We searched the shorter timescale variations. Our observation was executed as the narrow band-filtered imaging of the Jovian H3+ 3.4- μ m emission using the IRCS (infrared camera and spectrograph) on the Subaru 8-m telescope on 25 May 2016. Approximately 1 hr of continuous data was taken at intervals of 45–110 s, with high spatial resolution (~0.2 arcsec) using adaptive optics. In the northern polar region, we found bright patch-like emissions on the poleward side of the main oval. One of them had a pulsation period of ~10 min. On the other hand, the slit viewer image taken on 31 January 2015 did not show such periodic variations. (Time intervals of images was longer, ~10–30 min, and were not optimized to this detection.)

In order to investigate the mechanism of such fast variability, we utilized an H3+ emission model to investigate the response time of the H3+ emission to abrupt and periodic variations of the precipitating electron flux. The model could show that the H3+ emission could pulsate with this timescale due to a modulated flux of the precipitating electrons in the kilo-electron-volt to tens of kilo-electron-volt energy range.

(The paper: Watanabe et al., 2018 [doi:10.1029/2018GL079264])

Brightening Behavior of Io's Magnetic Footprint

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The interaction between Io's extended atmosphere and Jupiter's fast rotating magnetospheric plasma causes picked up currents to travel along the magnetic field lines from interaction region toward the planet's ionosphere. The precipitating particles accordingly result the emission, in auroral region, which is called Io's magnetic footprint. With the 9.4 degrees tilt angle between magnetic axis and rotation axis, Io experiences different plasma environment, in the plasma torus, throughout its orbital path. At system III longitudes near 110 degrees and 290 degrees, Io is expected to feel very dense surrounding plasma, since it should be near the center of plasma torus. Previous studies of Io's auroral magnetic footprints brightness showed there is general brightness variation trend suggesting strong interaction in those longitudes. However the picked up currents travel along the magnetic flux as a form of Alfvén waves, which perform waves properties, e.g., refraction and reflection. As a result, there were clear observations of multiplicity and swirling patterns of Io's auroral magnetic footprint. In this work, the size and the brightness of Io's Main Alfvén wing spot (MAW), will be analyzed based on FUV imaging by STIS (Space Telescope Imaging Spectrograph) and Advanced Camera for Surveys (ACS) instrument on Hubble Space Telescope (HST). The analysis will focus on images of Jupiter's auroral regions, which were taken in 1998, 2000, 2001, and 2007 during HST's campaigns. The short-time variations of Io's magnetic footprint, when Io was near 110 degrees and 270 degrees will be investigated in detail. The result would show the development of Io's footprint emission, in size and brightness, when strong interactions at the satellite was expected.

Jupiter's Magnetic Field Analysis via Ganymedes Magnetic Footprint Locations

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Ganymedes magnetic footprint is connected to plasmas around the moon, in which the magnetic field disturbance occurs causing charge particles to be picked up and move along the magnetic flux tubes into Jupiter's ionosphere resulting in the auroral emission. The shifted locations of Ganymedes magnetic footprint from the prediction by magnetic field model can be used to study the magnetic field structure of Jupiter by considering the variance of plasma in Jupiter's middle magnetosphere. In this work, we present the observation data of Ganymedes magnetic footprint using Hubble Space Telescope (HST) in 2007. These data are compared with the numerical results from the magnetodisc model. In the model, we investigate the hot plasma parameter (K_h) which is observed by Voyager and Pioneer along with the variation of hot plasma pressure anisotropy. We study the effect of these two parameters at the locations of Ganymede, which accordingly will be mapped to Jupiter's ionosphere. Furthermore, we analyze the correlation between the locations of main oval aurora and Ganymedes magnetic footprint including with the footprints brightness by considering the nearest location of the footprint and main oval aurora in Jupiter's ionosphere. In order to study the correlation, we consider the fluctuation of hot plasma pressure anisotropy in the middle magnetosphere which could affect the stretching of Jupiter's magnetic field lines resulting in the shift of Ganymedes magnetic footprint and main oval locations.

Bright Spot morphology in Jupiter's Polar Aurora

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The bright spot is a feature of aurora emission which is usually found in the polar region of Jupiter's aurora. The auroras in the polar region have unstable behaviors. Accordingly, unclear developments are typically found for these emissions. Therefore, the bright spot is chosen to study for more understanding about this region. Images of Jupiter's aurora were observed by the Advanced Camera for Surveys (ACS) on board the Hubble Space Telescope (HST). Specifically on Jupiter's auroras in the northern hemisphere, eight bright spots were clearly found in Jupiter's aurora images taken during May-June 2007. There were two bright spots appearing on the same day. The variation of locations and the approximated sizes of the bright spots were analyzed to study its evolution. The ionospheres location of eight spots was found to vary within 10 degrees. There was noticeable that bright spots have certain formation development, starting from an unclear shape, taking the form of a spot and then dropping in brightness until reaching totally disappear. The spots mapped locations in magnetosphere were usually found at distances more than 70 Jovian radii at the local time near noon. These results suggested that the bright spots were related to polar cusp process.

Facilitating access to HST/Hisaki remote processed observations of Saturn/Jupiter in support to Cassini/Juno in situ measurements through the APIS service

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The Auroral Planetary Imaging and Spectroscopy (APIS) online service <http://apis.obspm.fr> was released at the occasion of the MOP meeting hold in Athens, in Aug. 2013. This service provides an open and interactive access to processed auroral observations of the outer planets and their satellites, especially Saturn and Jupiter, which are of peculiar interest for the magnetospheric community. Precisely, APIS enables the user to access a conditional search interface which queries : (a) a high level database made of quasi-all public HST auroral observations - now extending to data acquired in support to Cassini Grand Finale and Juno (with polar projections including the spacecraft magnetic footpath), (b) external databases - now including Hisaki/EXCEED planetary long-term observations acquired since 2013. The APIS interface also enables the user to interactively work with the data online through plotting tools developed by the Virtual Observatory (VO) community, such as Aladin for images - and now Cassis for spectra. This service is VO compliant and the associated databases can therefore be queried by external VO portals such as VESPA or CDPP/AMDA. The diversity of available data and the capability to sort them out by relevant physical criteria shall in particular facilitate statistical studies, on long-term scales and/or multi-instrumental multi-spectral combined analysis.

Expected Source Region of Jupiter's Hectometric Radiation Relating to Magnetotail Reconnection

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It has been known that Jupiter's auroral radio emission in the hectometric wave range (HOM) is roughly classified into two type occurrence components. One is a component relating to solar wind variations (sw-HOM) appearing around CML (Central Meridian system III Longitude of an observer) $\sim 180^\circ$ when solar wind pressure enhances. The other one is generally more intense than sw-HOM and has no or weak relation with solar wind variations (nsw-HOM) appearing around CML $\sim 110^\circ$ and $\sim 280^\circ$ for major components when De (Jovicentric declination of an observer) $\sim 1^\circ$ (Nakagawa et al., ASR, 2000). Recently, we found one more nsw-HOM component appearing around CML $\sim 340^\circ$, which highly correlates occurrence of magnetic reconnection events in the magnetotail region based on the WIND/WAVES data analyses. This new component is an important role for the studies of global magnetospheric dynamics of Jupiter since it is a possible remote marker of the reconnection events occurring in the magnetotail. However, due to difficulty in precise direction finding in the hectometric wave range, the radio source of the new component, that is, location of transported energy input originated from reconnection events, has been still unrevealed.

In order to investigate source location of the new nsw-HOM we have made a comparison study of the new component with appearance features of Jupiter's aurora observed by the Hubble Space Telescope and the Hisaki spacecraft, and also have surveyed expected source regions by calculating observable rays using a magnetic field model ('VIPAL' proposed by Hess et al., JGR, 2011). The result shows that the occurrence of the new component well correlate with intensification of Jupiter's internally driven type aurora, and expected radio sources are located around dawn (spot) region and/or polar region.

New Insights into Jupiter's Dawn Storms

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Jupiter's aurora can be broken into three independent domains: the footprint emission caused by the Galilean moons, the main auroral oval, and the diffuse polar emission. These domains are driven by different plasma sources, have different behaviors, and appear in distinct areas of the planets surface. Our interest lies in the dawn storms of Jupiter—an interesting auroral phenomenon which straddles the domains of the different aurora. This bright emission appears on the main oval, indicating a plasma origin in the middle magnetosphere, but is apparently controlled by the Jupiter-Sun geometry at dawn, indicating control in the outer magnetosphere. The formation and evolution of these storms must be tied to some fundamental aspect of Jupiter's magnetosphere which is not yet fully understood. Now, with the largest set of HST UV observations of Jupiter ever available due to Juno mission support, we can characterize the morphology and development of the dawn storms in order to determine the interplanetary and Jovian conditions required for these storms to form.

Azimuthal variation in the Io plasma torus observed by the Hisaki satellite during Io's volcanically active period

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In the Jovian magnetosphere, sulfur and oxygen ions supplied by the satellite Io are distributed in the Io plasma torus. The plasma torus is located in the inner area of magnetosphere and plasma generally corotates with the planet. The density and temperature of plasma in the torus have significant azimuthal variations that are coupled with the energy flows in the Jovian inner magnetosphere. In this study, 3 years of data obtained by the Hisaki satellite, from December 2013 to August 2016, were used to investigate statistically the azimuthal variations and to find how the variations were influenced by the increase in neutral particles from Io. The azimuthal variation was obtained from a time series of sulfur ion line ratios, which were sensitive to the electron temperature and the sulfur ion mixing ratio S^{3+}/S^{+} . The major characteristics of the azimuthal variation in the plasma parameters were consistent with the dual hot electron model, proposed to explain previous observations. On the other hand, the Hisaki data showed that the peak System III longitude in the S^{3+}/S^{+} ratio was located not only around 0° – 90° as in previous observations, but also around $\sim 180^{\circ}$. The rotation period, the so-called System IV periodicity, was sometimes close to the Jovian rotation period. A persistent input of energy to electrons in a limited longitude range of the torus is associated with the shortening of the System IV period.

Ion Scale Height Variability in Hisaki Io Torus Observations

Nicholas McCord Schneider, Carl Schmidt, Masato Kagitani, Yasumasa Kasaba, Tomoki Kimura, Go Murakami, Fuminori Tsuchiya, Hajime Kita, Reina Hikida, Ichiro Yoshikawa, Kazuo Yoshioka

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Ion temperature is a critical variable in Io plasma torus energetics, but is difficult to derive from remote sensing measurements. The relative importance of hot ions vs. hot electrons in powering the torus emissions remains an open question. Torus brightenings, whether caused by episodic changes in the volcanic supply to the torus or periodic System III/IV enhancements, offer the best chance to search for driving variations in hot electrons or ions. Much attention has been paid to hot electron populations, derivable from detailed spectral modeling, but less work has been done on ion temperature. Ground-based studies have successfully derived T_{\perp} from very high resolution spectra, and TII from scale height measurements in images, both over limited datasets. Schneider et al. 1997 found strong longitudinal variations in TII during a week-long dataset, and anti-correlated System III brightness, but more extended followup datasets have not previously been available.

The Hisaki dataset presents the possibility of an unparalleled opportunity to study long-term and short-term variations in ion temperatures. The instrument is not designed to take images of specific emissions, but its large entrance slit accepts the full height and width of the torus. In the ideal case, each spectral emission feature would appear as an image of the torus at its appropriate position in the spectrum, creating an “overlapogram” (as did the Cassini UVIS instrument). In reality, the emissions are blurred due to instrumental resolution and aberrations, and multiple spectral feature overlap. Furthermore, the changing opening angle of the rotating torus adds a spurious apparent scale height variation which must be removed, with special attention to asymmetries introduced by Jupiter's changing tilt. With allowances for all these effects, we will report on our search for ion temperature variations during the first two years of Hisaki observations, and compare our results to a previous independent study by M. Shishido (M.S. thesis, U. Tohoku).

Correlation between the Io Plasma Torus and Jovian Aurora Revealed by the EXCEED/Hisaki Mission

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While an explosive energy release event in the mid-magnetosphere is manifested as a transient aurora, its connection to the inner-part has not been investigated due to sparsity of observations. By EXCEED/Hisaki, we have taken the advantage of long-term (2013-2019) and quasi-continuous monitoring of the aurora and the Io-plasma-torus (IPT), and found simultaneous brightening at the IPT and aurora. Studies on temporal characteristics of the both regions enable us to see slow coupling between the mid- and the inner-magnetosphere as well as to quantify the hot electron temperature in the IPT. In this study, we will show light curves of the IPT and discuss temporal and spatial scales of the IPT's brightening events.

Development of ground pipeline system for high-level scientific data products of the Hisaki satellite mission and its application to planetary space weather

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The Hisaki satellite is the first-ever space telescope mission that is dedicated to planetary sciences. Atmospheres and magnetospheres of our solar system planets are continuously monitored by the extreme ultraviolet (EUV) spectrometer onboard Hisaki. Here we describe a data pipeline system developed for processing high-level scientific and ancillary data products of the Hisaki mission. The telemetry data downlinked from the satellite is stored in a ground telemetry database, processed to imaging spectral data with a 1-min temporal resolution and ancillary data products in the pipeline, and archived in a public database. The imaging spectra are further reduced to higher-level data products for practical scientific use. For example, light curves of the power emitted from Jupiter's aurora and plasma torus with a temporal resolution of 10 minutes are reduced from the imaging spectral data. The reduced light curve revealed transport process of energy and mass in Jupiter's magnetosphere and associated interplanetary solar wind conditions. The continuous monitoring with Hisaki largely contributes to understanding of space weather the planets in our solar system.

A magnetic reconnection event at a close binary system monitored by the Hisaki satellite during the NICER-Hisaki Observing Campaign 2018-2019

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Stellar magnetic reconnection process during flare is still not well understood compared to those of the sun and planetary magnetospheres because of lack of continuous monitoring of distant stars in multiple wavelengths. Here we present a flare event at a close binary system, UX Arietis, monitored with the planetary extreme ultraviolet (EUV) space telescope Hisaki during the coordinated observing campaign with the NICER X-ray Telescope from late 2018 to early 2019. Time variability in the EUV spectrum of the binary was successfully monitored from the beginning to the end of flare. Emission power at the EUV wavelengths peaked at $\sim 10^{25}$ W, which is comparable with that measured in the previous X-ray observations by e.g., the Advanced Satellite for Cosmology and Astrophysics (ASCA) (Gudel et al., 1999). The EUV spectrum showed emission lines of carbon, nitrogen, oxygen, and silicon ions. Electron temperature and density, volume emission measure, and ion balance were reduced from the emission lines by EUV spectral diagnostics. Dynamics of the stellar magnetic reconnection will be discussed based on comparison of the reduced plasma parameters with the X-ray spectrum measured with NICER.

The influence of Io's volcanic activity in 2015 on Jupiter's magnetospheric dynamics

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The Jovian moon Io has active volcanos. Jovian magnetospheric dynamics are driven by the expulsion of Io's plasma in the strongly-magnetized fast-rotating system and should vary in response to Io's volcanic activity. In early 2015 when various observations indicated an increase in volcanic activity, the Hisaki spacecraft continuously observed the Jovian magnetosphere via the aurora emission and the emission from the Io Plasma Torus. The plasma diagnosis of the enhanced torus spectrum along with a physical chemistry model for deducing plasma parameters revealed a higher plasma density and a 2-4 times faster radial flow as compared with a volcanically quiet period. Aurora emissions reflecting mid-magnetospheric activities showed multiple highly-elevated brightness peaks about a month later. In this presentation, the influence of Io's enhanced volcanic activity on the Jovian magnetosphere deduced by the long-term and continuous monitoring by Hisaki will be shown.

Jupiter's aurora observed by Hisaki: Intrinsic periodic variation

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Several parameters of Jupiter magnetosphere, i.e., plasma flow and appearance of auroral spots, show intrinsic periodic variation with a few day to several days. Magnetospheric global re-configuration following periodic magnetotail reconnections is proposed for producing these periodicities. Observed auroral power integrated over the pole region shows gradual increase and decrease over 5–10 days with the peaks corresponding to magnetotail magnetic field disturbed periods. Hisaki is a space telescope launched by JAXA in 2013 and provides continuous observations of emissions from Jupiter auroral and Io plasma torus. We analyzed Jupiter aurora taken by a spectrometer EXCEED (Extreme Ultraviolet Spectroscope for Exospheric Dynamics) onboard Hisaki and investigate the statistical feature of the auroral periodic variation.

Auroral power revised by the rotational appearance shows periodic variation with gradual increase and decrease. We analyzed data observed over 2014–2015 which includes periods when Io's volcanic activity was quiet (in 2014–2015) and high (in 2015). The auroral periodicity spreads from 0.8 to 8 days, which is comparative with the periodicity seen in other observations. The periodicity does not change significantly between the two volcanic activity periods. The periodicity does not show clear correlation with solar wind dynamic pressure, auroral power, central meridional longitude (CML), nor Io phase angle. These suggest that the periodicity is intrinsic and independent of solar wind variation, magnetospheric plasma variation, magnetic field topology, and relative position of Io. A super-epoch analysis shows the symmetric increase and decrease trends of auroral power and magnetospheric source current, while the color ratio, which is a proxy for auroral electron energies, does not show significant variation associated with this periodic variation. This symmetric variation of auroral power is contrasting to asymmetric increase and decrease variations seen in the ion flux and spectral slope. We will discuss these characteristics and relationships.

Development of a radial diffusion model of Jovian inner magnetospheric plasma aimed at comparison with HISAKI satellite observation

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We developed a radial diffusion model of the Io plasma torus that describes interaction and radial transport of various ions and electron in Jovian inner magnetosphere to understand balances of mass and energy of plasmas and their temporal changes.

The radial distribution model of steady state Jovian magnetospheric plasma was developed based on observation results of Voyager 1, Voyager 2, Galileo, and Cassini spacecraft. However, there is no report on a model that explains time variation of radial distribution of ions and electrons.

In this study, we are developing a radial diffusion model based on the Fokker-Planck equation that can track mass and energy balances of major heavy ions of Io origin (O^+ , O^{2+} , S^+ , S^{2+} , and S^{3+}) and time evolution of radial transport. Physical chemistry models which include radial transport have been developed by Schreier et al. (1998) and Delamere et al. (2005). We applied the similar approach to estimate time variations of mass and energy transports in Jovian magnetosphere and use the Forward Time Central Space (FTCS) scheme to solve the transport equations. We compared the model results in the region of 6-9 RJ under the steady state conditions with the HISAKI's observation in November 2013 when the volcano activity was quiet [Yoshioka et al., 2018]. We obtained that the number density of ions with higher valence number tend to be greater than that of observation result. The model estimated the electron temperature to be 6 to 8 eV that was several eV higher than observation value. We considered that the increase in number density of high valence number ions may be due to overestimation of electron impact ionization. In addition, we obtained that the temperature with low valence ions was higher than observation value, for example, O^+ temperature was higher than 260 eV at 9 RJ. This discrepancy may be caused by the heating of pick-up ion gained by high electron temperature. In this presentation, we give detailed comparison between model and observation and quantitative verification.

A 2-D Io Plasma Torus Spectral Emission Model and Comparisons with UV and Ground-Based Observations

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In recent work re-analyzing UV emissions observed by Voyager, Galileo, & Cassini, we found plasma conditions consistent with a physical chemistry model (Delamere et al. 2005) with a neutral source of dissociated sulfur dioxide from Io (Nerney et al. 2017). Previously, we used a cubic cm emission model to simulate a UV spectrum as a function of the local ion and electron density as well as the electron temperature using the CHIANTI atomic database version 8 (Del Zanna and Badnell 2016). We are developing a 2-D torus emission model (adapted from Steffl et al. 2004b) that combines latitudinal and radial variations assuming azimuthal symmetry. Given the location and pointing of the detector and a model of the density and temperature as a function of radius and latitude of the Io plasma torus we can integrate the emissivity along the line of sight to simulate a UV or visible spectrum for comparison with observations. We will compare model output with UV spectroscopic observations of the Io plasma torus from Cassini, JAXAs Hisaki mission, and ground-based optical observations from Apache Point Observatory and Kitt Peak National Observatory. Our goal is to better understand and constrain both the temporal and spatial variability of the flow of mass and energy from Ios volcanic atmosphere to Jupiter's dynamic magnetosphere.

Flow of Mass and Energy Through the Magnetosphere of Jupiter: Update

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The Bagenal and Delamere (2011) study of the flow of mass and energy through the jovian magnetosphere presented average plasma conditions and calculated typical mass and energy budgets. Since 2011 additional data have been provided by the Hisaki satellite measuring the UV emissions from the Io plasma torus since 2013 and the instruments on Juno have made in situ measurements of magnetospheric conditions over 19 orbits. In this paper we provide updated budgets, including new data as well as considering the time variability of the system.

Hybrid simulations of magnetodisc transport driven by the Rayleigh-Taylor instability

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Plasma transport in the rapidly rotating giant magnetospheres is thought to involve a centrifugally-driven flux tube interchange instability, similar to the Rayleigh-Taylor (RT) instability. In three dimensions, the convective flow patterns associated with the RT instability can produce strong guide field reconnection, allowing plasma mass to move radially outward while conserving magnetic flux (Ma et al., 2016). We present hybrid (kinetic ion / fluid electron) plasma simulations of the RT instability using high plasma beta conditions appropriate for the inner and middle magnetosphere at Jupiter and Saturn. A density gradient, combined with a centrifugal force, provide appropriate RT onset conditions. Pressure balance is achieved with a temperature gradient in a fixed magnetic field. The three-dimensional simulation domain represents a local volume of the magnetodisc resonant cavity. Simulated RT growth rates compare favorably with expectation, where the fundamental mode of the resonant cavity determines the largest (stabilizing) parallel wavelength. We suggest that the perpendicular scale of RT structures is determined by the fundamental mode, which limits growth due to magnetic tension. The scale of modeled and Cassini-observed magnetic field fluctuations (i.e., distance between current sheet crossings) compare favorably. Finally, we will discuss strong guide field magnetic reconnection and diffusive processes as plausible mechanisms to facilitate kinetic-scale radial transport.

Electron Density and Temperature Fluctuations in Saturn's Magnetosphere: Implications for Transport.

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The rapidly rotating magnetodisc of Saturn has its own plasma source. The outward transport of the internally produced plasma is due to the centrifugally driven interchange instability, determined by the gradient of the flux tube content and flux tube entropy. The stability of the magnetodisc is determined by flux tube entropy and flux tube content. The electron density and temperature fluctuations were observed in the outer magnetosphere of Saturn by Voyager-1 and Voyager-2. Goertz [1983] suggested that the fluctuations might be due to the formation of plasmoids via a centrifugal instability. The Cassini CAPS instrument also shows thermal electron density variations in the outer magnetosphere. The electron temperature is similar to the ion temperature [Ma. et. al., 2019], showing a dawn-dusk asymmetry where the dawn is hotter than dusk region. This dawn-dusk asymmetry in the magnetosphere could be associated with the generation low-density flux tubes in the midnight to dawn sector. Lyon - Fedder - Mobarry (LFM) simulations suggest a Raleigh Taylor (RT) –type instability and/or tail reconnection in the midnight to dawn sector, leading to injections. We will compare the observed electron density fluctuation with the results of the LFM global MHD simulation. We will also talk about transport associated with the generation of the low flux tubes from midnight to dawn sector in the outer magnetosphere.

Jupiter's Innermost Radiation Belts from Juno Measurements

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The region inward of Europas orbit shows the highest intensities in Jupiter's magnetosphere of the very energetic ions and electrons and therefore offers a testbed to study transport and acceleration processes to high energies. The inner radiation belts have not been extensively sampled by earlier missions. Also with Juno studying these belts remains challenging because the intensities are in parts too high to be measured reliably and also because Jupiter's complex and asymmetric magnetic field makes it difficult to map the measurements in a way different orbits can be compared fairly.

Jupiter's innermost ion radiation belt is a relatively unusual region as it appears that the corotating plasma is absent and there are few energetic electrons: The electron radiation belt stops at Jupiter's main ring as electrons are not able to diffuse through it. We do find ionospheric plasma but the next higher energy population is not at corotation energies but peaks around 100keV. We performed a phase space density analysis based on Junos 18 orbits to date. The results suggest that these ions originate from larger distances in the magnetosphere. They only suffer minor losses while being radially transported across the orbits of Amalthea and the main ring, and are adiabatically accelerated in the process.

There is a third ion population peaking around 1MeV. Phase space density analysis suggests that this population requires a local source. Especially for oxygen and sulfur ions this population seems time variable. Such variability is unusual because a major driver of time variability of trapped particles, the interchange instability, cannot act here for the lack of corotating plasma. A mechanism that can both populate the inner ion belt as well as explain its dynamics is the stripping of energetic neutral atoms (ENA) in the exospheres of Jupiter and the main ring. The dynamics of the inner belt would then be a reflection of the dynamics of the magnetosphere that produces varying ENA intensities.

Statistical analysis of Juno observations of $>\sim 5$ MeV electron beams at Jupiter

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A meticulous multi-instrument analysis of Juno observations for the first ten science orbits (PJ1, PJ3-11) had demonstrated the capability of Juno/MWR instrument to detect the signature of (mainly downward) MeV electron beams ($>\sim 5$ MeV). These radio signatures are typically observed when Juno is in the process of crossing intense bi-directional electron flux tubes (JEDI and JADE observations) connected to the main auroral emissions or poleward auroral spots. Juno/UVS maps of auroral regions at 158-162 nm (and color ratio maps) and > 10 MeV electron fluxes inferred from Juno/ASC and JEDI, along with JADE radiation background counts, support Juno/MWRs observations of highly energetic electrons ($>> \text{keV}$ to 10s of MeV) precipitating into the upper atmosphere. The statistical distribution of downward MeV electron beams places these events at no particular SIII longitudes, although they have been observed in the AM sector ($\text{LT} \sim 5\text{-}10.5$) and linked to field lines mapping onto the equator at M-shells of $\sim 30\text{-}70$ so far. We propose to further analyze Juno observations of $>\sim 5$ MeV electron beams, by including the latest science orbits (PJ12-PJ18). We will examine their statistical distribution in different coordinate systems (magnetic and with respect to sub-solar point), both when observed at high latitudes close to the planet and mapped onto the equator in the middle magnetosphere. Resonant electron scattering caused by diverse waves have been considered to predict pitch-angle scattering phenomenon for MeV electrons at Jupiter [e.g. Ciurera-Borcia et al., *Physics of Plasma* 8, 266 (2001), *Physics of Plasma* 6, 4597 (1999)]. We will present our progress in analyzing Juno particle, field, and radio data and understanding the origins of $>\sim 5$ MeV electron beams at Jupiter.

A Local-Time Confined Electron Radiation Belt Generated by Saturn's F-Ring

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Energetic electron data collected during Cassini's Proximal orbits from regions just outward Saturn's dense A-ring (2.27 Rs), contain signatures of highly confined MeV electron intensity enhancements which we call microbelts. These microbelts map persistently near the planets narrow F-ring at 2.32 Rs and they have an average L-shell extent of 0.02 Rs. Their occurrence probability in local time is not uniform, as for every orbit they were either occurring inbound (pre-noon) or outbound (post-noon). 80% of the detections took place few hours post-noon and only 20% pre-noon. We demonstrate that these microbelts contain local time stationary MeV electrons, trapped in local-time and L-shell confined trajectories which result from the presence of a local electron source in a region where corotation is superposed with weak, dawnward plasma flows. These flows are associated to the well-established noon-midnight convective electric field at Saturn. The source process for the microbelts' electrons is likely secondary electron production due to Galactic Cosmic Ray collisions with F-ring dust, as implied by the microbelts' colocation with the F-ring. The formation and stability of the microbelts against the variability of the convective flows is demonstrated through test particle simulations.

Relativistic charged particles, neutrons and gamma rays at Saturn: MIMI/LEMMS measurements and GEANT4 simulations

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MIMI/LEMMS was the energetic particle detector of the Cassini spacecraft, originally designed to measure electrons between 20 keV and ~10 MeV, and ions between 20 keV/nuc and ~100 MeV/nuc. The instrument's highest energy responses were difficult to characterise, especially in Saturn's radiation belts, where due to high fluxes of instrument penetrating radiation, particle counts were recorded also from "out of passband" particles that mimic the energy deposition of the species/energies a LEMMS channel was nominally designed for. Effects of penetrating radiation are also difficult to disentangle from an actual foreground signal due to limitations in downlinking diagnostic measurements, such as PHA from LEMMS solid-state detectors. For all these reasons, only a fraction of LEMMS's 56 rate channels is commonly used for analysis in the literature, while the interpretation of some of the measurements in the radiation belts remains up to this date challenging and ambiguous. In order to overcome all these limitations, we review and utilise the enormous, >17-year dataset of LEMMS measurements from a variety of environments (heliosphere, Saturn's magnetosphere/radiation belts, Earth and Jupiter flybys, moon-magnetosphere interaction regions), together with detailed GEANT4 simulations of the instrument, and provide angular and energy response functions of all 56 LEMMS rate channels to protons, heavy ions and electrons. The analysis extends LEMMS's measurement capabilities to >>300 MeV/nuc for ions and up to ~40 MeV for electrons. These extended measurement capabilities are demonstrated with selected LEMMS observations. In addition, we provide response functions to secondary gamma rays and neutrons. As these species can be produced in high fluxes by GCR impacts on Saturn's rings and atmosphere, we explore whether their signal can be resolved during Cassini's SOI and Proximal orbits. This detailed LEMMS calibration opens up a broad range of new opportunities and capabilities for investigating and understanding energetic particles in the heliosphere and Saturn's magnetosphere.

Spectral signatures of corotation drift resonant acceleration in Saturn's electron radiation belts.

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The energetic electron spectra of Saturn's electron radiation belts are studied using Cassini's 13 years measurements by the MIMI/LEMMS detector. We find that within L-shells from 4 to 10 the differential flux of electrons with energy above few hundred keV up to ~ 1.5 MeV can be described with two power law functions separated at a cutoff. Statistics show that in the inner magnetosphere, this cutoff energy tends to follow the energy of corotation drift resonance consistently, that is the energy at which magnetic electron drifts cancel out the azimuthal corotation. This confirms that corotation drift resonant electrons can be transported radially very efficiently, by e.g. variable noon-midnight electric fields, indicating this acceleration mechanism to be the most effective for energies around 1 MeV. Furthermore, a local time asymmetry in spectral parameters further testifies to the existence of the noon-midnight electric field. Converted to the first adiabatic invariant, the cutoff agrees with the corotation drift resonance value fairly well inside $L \sim 7$. For higher L-shells (and μ), the spectral cutoff deviates systematically from corotation drift resonance, which indicates a different acceleration mechanism dominating. The double power law indices show different tendency: the lower energy power law index increases with L while the higher energy power law index decreases with L.

Quantifying Transient Electron Radiation Belt Extensions at Saturn

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The L-shell distribution of MeV electrons in Saturn's radiation belt is investigated orbit by orbit during the 13-years exploration of Cassini spacecraft at Saturn, as this can be indicative of convective processes, whether internally or externally driven, within the planets magnetosphere. It is found that in addition to the normal monotonic decrease of count-rates towards higher L-shells, there are orbits showing transient extensions superimposed on the monotonic distribution. These extensions are variable both in L-shell extent and intensity. Their extent can reach as low as $L \sim 3$, just outside the main rings, and up to $L \sim 10$, while their peak intensity is centered around $L = 5-6$. Excluding few cases, these extensions don't persist for more than a single Cassini orbit (typically 1-3 weeks). The occurrence and evolution of transient extensions will be also investigated in the context of solar wind transients (e.g. CMEs, CIRs) or other magnetospheric indices (e.g. energetic ion composition), and to factors that strongly affect the radial transport of relativistic electrons in the magnetosphere, such as variable convective flows.

Upstream Dynamics from Embedded Kinetic Simulations of Ganymede's Magnetosphere

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The largest moon in the solar system, Ganymede, is also the only moon known to possess a strong intrinsic magnetic field and a corresponding magnetosphere. This provides an excellent opportunity to study plasma interactions and dynamics in a sub-Alfvenic system using the improved version of the semi-implicit particle-in-cell (PIC) code iPIC3D embedded into the BATS-R-US Hall magnetohydrodynamic (MHD) model. With a self-consistently coupled resistive body representing the electrical properties of the moon's interior, improved inner boundary conditions, and the flexibility of coupling different grid geometries in BATS-R-US, we successfully validated our model for all six Galileo flybys. The coupled MHD-EPIC model provides information about the ion phase space distributions near the upstream reconnection sites, which can be used to guide interpretation of future in-situ measurements. Furthermore, we have derived the energy flux associated with the upstream magnetopause reconnection based on our model results and quantified its contribution to the observed auroral emissions. We also studied the global reconnection rate. Our analysis quantifies the dependence of the reconnection rate on magnetic shear angle and Alfven Mach number, and the temporal dependence suggests a chaotic energy-cascading system.

Constraining Spatial Asymmetry in Europa's Oceans

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Strong evidence for extant liquid water oceans under Europa's icy crust comes from magnetic measurements by the Galileo spacecraft. The best explanation for the time-varying magnetic moments of Europa is a subsurface ocean with a high dissolved salt content. Previously published research has assumed that the ice–ocean boundary is spherically symmetric. To first order, this assumption is likely correct, as Europa is differentiated. However, the shape of the boundary between the conductive, saline ocean and the non-conducting ice shell has a significant effect on the magnetic moments induced by the time-varying field applied by Jupiter. Assuming spherical symmetry in the ice–ocean boundary limits the information about the spatial distribution of Europa's oceans that may be obtained from magnetic measurements.

From Maxwell's laws and boundary conditions, a spherically symmetric boundary and a spatially uniform excitation field from Jupiter induce only an oscillating dipole moment for Europa. For a more general boundary, we expand the radius in spherical harmonics, so it is a function of colatitude and longitude. This allows calculation of induced magnetic moments for a given inducing field and boundary shape; quantifying asymmetry is accomplished by identifying maxima in expansion terms that still permit consistency with Galileo MAG data.

This method yields constraints on how asymmetric the ice–ocean boundary may be. Due to the many degeneracies involved in forward modeling of magnetic induction signals, it is not possible to determine specific values for ocean properties without far more data than is currently available. This is why we aim to quantify the maximum spatial asymmetry that may be present—to place limits on the uncertainty of the ice–ocean boundary shape, and thereby the thickness of the icy crust. Europa's ice crust may be thinner in some regions than others, which would have major implications for future exploration and ocean access to the surface.

The Centrifugal Equator as seen by Juno Radio Occultations of the Io Plasma Torus

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The Io plasma torus is the dominant source of plasma in the magnetosphere of Jupiter. About a ton of neutral material per second is released into the area surrounding Jupiter and subsequently ionized. Once the material, mainly Sulfur and Oxygen, is ionized it becomes a plasma which is picked up by Jupiter's magnetic field and distributed into a torus around Jupiter called the Io plasma torus. The particles are trapped on the magnetic field and the fast rotation of the magnetic field causes the plasma to be trapped around the centrifugal equator. The centrifugal equator is defined by the locus of points along the magnetic field lines that are the furthest away from the rotation axis. Here we present measurements of the location of regions of the torus from radio occultations of the Io plasma torus by Juno and compare the observed locations to the centrifugal equator predicted by the VIP4 and JRM09 internal field models. We find that the JRM09 internal field model alone reasonably predicts the location of the inner torus region but not the outer torus. When a current sheet model is added to the JRM09 model, the predicted location of the outer torus region is significantly improved. We conclude that the Io plasma torus is indeed located in the centrifugal equator, as expected. We suggest that remote observations of the Io plasma torus location may provide a method to constrain current sheet properties.

P48

The response of the S+ Io plasma torus to the large volcanic outburst in 2018

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_ : presenter

In 2018, PSI's Io Input Output facility (IoIO) observed an enhancement in the the Jovian sodium nebula that started at the beginning of the year and lasted for 6 months, indicating a large volcanic event on Io (Morgenthaler et al. ApJL 2019). In this presentation, we will report on our ongoing reductions of IoIO observations of the Io plasma torus in S+ 6731A, which were recorded contemporaneously with the sodium observations. Very preliminary reductions suggest the torus started brightening in mid March (at the peak of the Na brightness), reached peak brightness in mid to late May and returned to baseline in early July. This slow onset and fast recovery and shift relative to sodium nebula brightness profile is similar to that observed by Brown & Bouchez (1997). Our ongoing reduction efforts are improving the accuracy of both Na nebula and S+ torus surface brightness and extracting the torus ansa positions. The IoIO project is funded by an NSF grant to the Planetary Science Institute to record observations of the sodium nebula and S+ torus through the 2020 Jovian opposition.

Modeling the Hot Electron Source and System IV Modulation in the Io Plasma Torus

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Jupiter exhibits a fundamental rotational periodicity known as System IV that has no widely-accepted explanation, yet is easily observed in ultraviolet emission from the Io plasma torus. We demonstrate, using a physical chemistry model [Copper et al., 2016], that the combination of a prescribed System III superthermal electron modulation [Steffl et al. 2008] and a hot electron modulation governed by the radial flux tube content gradient [Hess et al., 2011] generate a radially independent beat periodicity consistent with System IV. We seek to explore the origin of this second electron modulation by simulating the transport of hot electrons from the outer torus, and show that their lifetimes are insufficient to populate the inner torus. Instead, we suggest that kinetic Alfvén waves generated by interchange provide a local origin for the superthermal electrons. We will explore this idea using a gyrofluid-kinetic electron model [Damiano, et al., 2019].

Multifluid MHD Simulations of Europa's Interaction with Jupiter's Magnetosphere

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Jupiter's moon Europa lies on the outer edge of Jupiter's inner magnetosphere, where corotating magnetospheric plasma flows past the moon and perturbs the electromagnetic fields and ionospheric plasma of Europa. We have developed a 3D multifluid magnetohydrodynamic model of this interaction between Europa's neutral exosphere, ionosphere, and Jupiter's magnetosphere. Our simulations solve for the bulk properties of 3 ion fluids (magnetospheric O^+ , exospheric O^+ and O_2^+) and one electron fluid, and the electromagnetic fields near the moon. We include a static distribution of neutral O_2 representing Europa's exosphere that, through ionization and charge-exchange, generates the ionospheric and pickup ions in our simulation. We present idealized simulations to demonstrate the nominal state of the plasma interaction as well as simulations for the Galileo E4 and E15 flybys, with which we validate the model. We have mapped the distribution of magnetospheric plasma that reaches Europa's surface, which represents the contribution of thermal plasma to the sputtering of Europa's icy surface that replenishes the O_2 exosphere. We find that while the majority of downward flux impinges on the upstream hemisphere, the surface impact by the magnetospheric O^+ ions is offset towards the anti-jovian hemisphere due to the influence of the convective electric field. We investigate the influence of the neutral atmosphere and the ambient magnetospheric plasma on this precipitation pattern by varying these two elements of the model throughout a set of simulations of the plasma interaction. We find that most of the magnetospheric plasma is diverted around the moon due to the plasma interaction with Europa's ionosphere. We find that this diversion is more efficient when the neutral exosphere density is high. The resulting ionosphere is then denser and better able to obstruct the impinging magnetospheric plasma.

Europas Interaction with the Jovian Magnetosphere: Variability in Time and Longitude

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The interaction between Europa and the Jovian magnetosphere depends on several upstream conditions, most importantly the Alfvén Mach number and conductance, and the orientation of the background magnetic field. These quantities vary both in time and with the longitude of Europa. The varying magnetic field also produces an induced magnetic signature from the subsurface ocean within Europa. Measuring this induced signature as a function of longitude would be a highly informative way to study this ocean.

However, the ocean signature must be separated from the magnetic perturbations from the magnetospheric interaction. Here, we use Galileo measurements of the plasma conditions (Bagenal et al., 2015) and magnetic field (this work) around Europas orbit to assess the longitudinal variability of the interaction. We also investigate the effects of other sorts of variability. The origins of this variability are unclear, but the Galileo data clearly show it. For example, a factor of two to four in electron density at different crossings of Europas orbit occurring at similar longitudes (figure 10, Bagenal et al.)

To quantify the magnetospheric interaction, we will apply a simplified model, similar to the wire current model of Khurana et al. 1997 and Shilling et al., 2004. This provides easily-calculated estimate of the magnetic field perturbations from an Alfvén wing and the currents closing through Europas atmosphere. From this we calculate the apparent dipole a spacecraft would observe, i.e. the dipole which would be calculated if the perturbations were fit with a dipole. This value represents the systematic error (for longitudinal variations) and uncertainty (for other sorts of variability) introduced in measurements of the internal ocean.

Alfvén Wave Propagation in the Io Plasma Torus

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We apply diffusive equilibrium to derive a 3D model of the Io plasma torus using in situ Voyager PLS data, Cassini UVIS observations, and the Juno-based JRM09 magnetic field model. Hinton et al. (2019) used this model to derive the locations of the first bounce of iogenic Alfvén waves, which accurately matched the location of the MAW, RAW and TEB spots in HST observations of Bonfond et al. (2017). The close match suggests a good level of accuracy for the magnetic field geometry, strength, and density of the Io plasma torus. Furthermore, this work suggests that the Alfvén waves remain coherent for at least one bounce off the ionosphere and an additional traversal through the plasma torus. We expand on this work by calculating the power transmitted from Io to the ionosphere of Jupiter along a density profile from our 3D model. The power transmitted is calculated for different wavelengths, providing evidence for which wavelengths may be carrying the power across the torus and ultimately exciting the satellite footprint aurora.

A hybrid simulation study of the interaction between Europas plumes and Jupiter's magnetosphere

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Europa is exposed to a time-varying sub-Alfvénic plasma flow impinging on its tenuous atmosphere. The interaction between Europas induced dipole, its global atmosphere, and localized inhomogeneities by plumes of water vapor generates Alfvén wings which carry field-aligned currents along the background field and a magnetic pileup region in front of the moon. The sub-Alfvénic plasma interaction therefore results in a complex, highly non-linear behavior of the plasma flow and its frozen-in magnetic field. The goal of our study is to identify inhomogeneities generated by Europas plumes in the magnetic field data from the Galileo mission and we plan to build a database to identify plumes in magnetic field data from future missions (e.g., the European Space Agency's upcoming JUICE mission and the National Aeronautic and Space Administration's Europa Clipper mission). We apply the highly parallelized, three-dimensional hybrid simulation code A.I.K.E.F. (kinetic ions, fluid electrons) to investigate the effect of inhomogeneities in Europas atmosphere (plumes) on the plasma interaction with the Jovian magnetosphere. Our code treats ions as kinetic particles by solving the Newtonian equations of motion, whereas the electrons are treated as a massless, charge-neutralizing fluid. In addition, we implement state of the art techniques such as including ion production rates for multiple ion species (including oxygen and water vapor) by integrating over their energy dependent cross sections, resulting in a model for Europas ionosphere that is consistent with observations. Further, dissociative ion-electron recombination is included in our model of Europas ionosphere. To systematically assess the magnitude and structure of the magnetic perturbations associated with the plume-plasma interaction at Europa, we vary the plume location across Europas surface whilst considering different symmetric and asymmetric density profiles of Europas global atmosphere. To isolate the impact of a plume on Europas magnetospheric environment, we also conduct runs without any global atmosphere

Cassini/UVIS high-level database and application to the search for the Enceladus footprint

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The Cassini/UVIS spectro-imager onboard the Cassini spacecraft has monitored the UV aurora of Saturn for more than a decade (and those of Jupiter during the planet flyby late 2000). In this work, we present an automated processing pipeline aimed at building a high level database to feed APIS (<http://apis.obspm.fr>) service, thus allowing statistical analyses, long-term studies and an easier way to cross-search of events of interest.

Cassini/UVIS past observations have for instance revealed the auroral Enceladus footprint, probing the electrodynamic interaction between Saturn and its moon, at three occasions only over the course of the Cassini mission. We investigated the presence of the Enceladus footprint in Cassini/UVIS processed pseudo-images acquired during the Cassinis 'Grand Finale, a set of high-inclination orbits sampling the northern and southern auroral regions which provided unprecedented vantage views on both hemispheres.

Structure of Io plasma torus observed with the Tohoku 60-cm telescope

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Ion pickup of volcanic gases is the most significant energy source in the Io plasma torus though, distribution of pick-up region and its variability is still unclear. Density profiles of ions along the magnetic field line are determined under condition of diffusive equilibrium. Based on the diffusive equilibrium, plasma equator is close to the centrifugal equator though, higher ion anisotropy moves the plasma equator toward the magnetic equator. Measuring ion distribution with sufficient spatial resolution enables us to derive ion anisotropy which is tightly related to the amount of fresh pickup ion. On this study, we focus on variability of latitudinal structure of Io plasma torus as well as its radial structure using ground-based observation over six month period in 2018. The ground-based observation of sulfur ion emission, [SII] 671.6nm and 673.1nm was made at Haleakala observatory in Hawaii during March through August 2018 using a monochromatic imager attached onto the Tohoku 60-cm telescope which enables us to measure distribution of S⁺ with spatial resolution of 0.03 jovian radii (RJ). We also made observation of neutral sodium cloud extending up to several hundred of RJ as a proxy of supply of neutral particles from Io (Yoneda et al., 2015). Based on observation over the six month, [SII] brightness increases from DOY 80 through 140, then gradually decreases though DOY 230 in 2018 as the neutral sodium cloud seems to increase from DOY 50 through 135. The result suggests that increased volcanic activity from DOY 50-135 caused increase of S⁺ and brightening of [SII] emission. We also find variation of latitudinal structure of Io plasma torus. Longitudinal peak of S⁺ emission at the same system III longitude 279 degree are -0.73, -0.80 and -0.79 RJ on 26, 29 July 7 and August, respectively. The shift of S⁺ density peak toward magnetic equator implies higher anisotropy on 29 July and 7 August compared with 26 July. One of the possible explanation of the latitudinal shift of S⁺ plasma is an increase of fresh pickup ion which makes higher anisotropy.

P57

Constraining Europas Exospheric Trace Abundances with HST/STIS Spectral Imaging

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In order to understand the complex interactions between Jupiter's magnetosphere and the tenuous exosphere of Europa, it is critical to constrain the constituents that make up that exosphere. We aim to place upper limits on the abundance of several trace species in Europas exosphere through direct observations of the auroral emissions as well as through detection and mapping of any observable species across the surface of Europa. Observations using the Space Telescope Imaging Spectrograph (STIS) on the HST produce high spectral resolution UV images of Europa with spatial resolutions of ~ 80 km/pixel, and therefore spatially resolve Europa across ~ 40 pixels. Utilizing this data, we are developing surface reflectance maps of the satellite in the UV to detect and constrain the abundances of available species to be delivered to the exosphere through sputtering.

A closer look at the statistics and systematics of limb anomaly detections in Europa transit observation by HST/STIS.

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The detection of the Lyman-alpha emission from potential water plumes emanating from cracks in Europas icy surface by Roth et. al. (2014) greatly increased the general interest for future exploration of the moon as well as for searching for hints of plumes in existing data. Indeed, the possibility of probing Europas sub-surface ocean from orbit or flyby is a compelling argument for a future probe, and confirming this detection has become of prime importance. Since then, Sparks et. al. (2016) reported detections of limb anomalies in three of multiple observations of Europa transiting in front of Jupiter, interpreted as water vapor absorption. Sparks et. al. (2017) reported a re-detection of one putative plume signal using the same measurement technique. More recently, Jia et al. (2018) and Arnold et. al. (2019) indirectly concluded the presence of water plumes by comparing magnetic field measurements from Galileo flybys to numerical simulations.

A closer look at systematic and statistics of detecting plume anomalies at the limb of Europa is presented in this poster. We identify several potential systematic sources that affect the signal derived for the limb regions. The impact of these effects on the resulting statistical significance were investigated, revealing limitations of such observing methods and nuancing the certitude of the plume detections.

MHD Modeling of the Plasma Interaction With Europas Asymmetric Atmosphere

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The global distribution of Europas near-surface oxygen atmosphere is likely spatially nonuniform. There are several predictions about global asymmetries in the sputtering atmosphere. We apply a 3D MHD model to analyze the effects of Europas asymmetric atmosphere on the plasma interaction. Therefore, we use different atmosphere models with longitudinal dependencies. We compare our model results with Europas magnetic field environment measured with the Magnetometer of the Galileo spacecraft during several flybys. Specifically, we are interested in how the atmospheric density varies between day- and nightside as well as between upstream and downstream side. Additionally, we constrain changes in the atmosphere between the different flybys.

The Io-Europa Space Environment

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The components of the Io-Europa system are generally discussed in isolation. To understand physical processes and the interconnections of the components, we need to look at the whole system. Our goal is to summarize the current understanding of this multi-component system and to present the outstanding questions. We compare their atmospheres, and summarize what is known about the interaction with the plasma in which they are embedded. These interactions produce clouds of escaping neutrals that extend for a substantial fraction of Ios and Europas orbits around Jupiter. Electron impact ionization of these neutral clouds produces the plasma that is trapped in Jupiter's strong magnetic field. It is the intriguing feed-back systems between the moons and the magnetospheric plasma that begs understanding. The magnetospheric plasma primarily corotates with the planets 10-hour spin period, but also moves radially outwards over several weeks. Only about 10% of the torus material moves inwards from Ios orbit. The inward flows are about a factor 50 slower than the outward flow. Charge exchange reactions between the corotating plasma and the neutral clouds produces energetic neutral atoms that escape Jupiter to form a neutral disk that extends 100s of RJ around Jupiter. Recent observations by the Juno spacecraft of heavy ions in Jupiter's upper ionosphere suggest that some of the neutrals hit the planets atmosphere and form a source of heavy ions close to the planet. As the iogenic plasma moves out through the giant magnetosphere, it is heated to 10s-100s keV energies. When the energetic ions move inward through the neutral cloud around Europas orbit, they charge exchange, making very energetic neutral atoms which have high speeds in all directions and likely spread into a huge sphere around the Jupiter system. This system of ~ten coupled components comprises a wide range of physics and extends from 10s of kilometers to AU scales.

P61

The Impact of Magnetospheric Particle Precipitation on Titans Upper Atmosphere

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We describe how magnetospheric particle precipitation affects Titans upper atmosphere based on three-dimension modeling of ion and electron precipitation and in-situ measurements in Titans plasma environment and atmosphere. In particular, we use models to calculate heating, ionization, sputtering, and auroral emission. Upper boundary conditions for each model are based on CAPS measurements of magnetospheric plasma outside of Titans atmosphere and, when possible, simulation results are ground-truthed by comparing them with INMS and Langmuir Probe data inside Titans atmosphere. We will present model-data comparisons for specific flybys and simulations that are representative of average and extreme plasma environments observed near Titan by Cassini. We find that energy deposition rates and ion production rates due to thermal ion precipitation and electron precipitation have a similar magnitude and are sufficient to explain electron densities observed by RSS and Cassini's Langmuir Probe on the nightside of Titans atmosphere. Globally, thermal plasma deposits less energy in Titan's atmosphere than solar EUV.

Long-term and short-term and variability of Jupiter's polar stratosphere: The search of the effect from the magnetosphere

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We present an analysis of multiple datasets, which capture the mid-infrared stratospheric emission of Jupiter's polar regions on different timescales. A time series of 7.8- μ m CH₄ emission images measured by Subaru-COMICS, as well as high-resolution spectral measurements of CH₄, C₂H₂, C₂H₄ and C₂H₆ emission measured by TEXES on NASA's Infrared Telescope Facility and Gemini-North will be presented and analysed. We find the magnitude and morphology of emission, and thus the thermal structure and chemistry of the stratosphere, to exhibit both a short-term (daily) and longer-term (> 1 year) variability. On short-term timescales, we find the magnitude of CH₄, C₂H₂ and C₂H₄ emission within the polar region to be variable on daily timescales in accordance with the external solar wind dynamical pressure. Over longer timescales, retrieved 1-mbar temperatures in the northern auroral region indicate a net cooling over the 2014 to 2018 period, which we attribute to the overall decrease in solar activity following solar maximum in 2014 and the approaching solar minimum in 2020-2021.

Axisymmetric conductivities of Jupiter's middle- and low-latitude ionosphere

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Ionospheric Hall and Pedersen conductivities are important parameters in determining the electric potential distribution and plasma convection in a magnetosphere-ionosphere system. At Jupiter, meteoric ions deposited by meteoroid ablation are expected to play a major role in the ionospheric conductivities [e.g., Cloutier et al., 1978]. This study evaluates the contribution of meteoric ions to ionospheric conductivities and electric field in the inner magnetosphere.

We have developed a meteoroid ablation model, a photochemical model and an ionospheric potential solver. Our simulation results reveal that the largest contributions to the Hall and Pedersen conductivities occur in the meteoric ion layer because of the strong surface magnetic field at Jupiter. The conductance is axisymmetric in the middle and low latitudes because the lifetimes of meteoric ions in the lower ionosphere are sufficiently longer than half a Jovian day. At high latitudes, the conductance is enhanced at dawn side associated with the Region 2-like upward field-aligned current. The dawn-to-dusk electric field is 4 - 27 [mV/m] around Io orbit. For comparison, we model another case of ionosphere without H⁺ and meteoric ions. In this case, the conductance is entirely smaller than the former case, and diminished at night side. The dawn-to-dusk electric field is 45 - 270 [mV/m] around Io orbit.

In order to evaluate the validity of our results, we compare our results to observations. Previous studies showed that dawn-dusk brightness asymmetry in the Io plasma torus and dawnward shift of the position were caused by dawn-to-dusk electric field imposed on the inner magnetosphere [Ip and Goertz, 1983, Barbosa and Kivelson, 1983]. Observations by the Hisaki satellite revealed the existence of dawn-to-dusk electric field of ~4 - 9 [mV/m] around Io orbit [Murakami et al., 2016]. Our model results are almost consistent with the Hisaki observations in the case with meteoric ions in the lower ionosphere.

Seasonal variation of north–south asymmetry in the intensity of Saturn Kilometric Radiation from 2004 to 2017

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This study investigates the long-term variation of Saturn Kilometric Radiation (SKR) intensity observed by the Radio and Plasma Wave Science (RPWS) instrument on board the Cassini spacecraft from 2004 (southern summer) to 2017 (northern summer). The results showed that the SKR intensity was brighter on the summer side than on the winter side, which was clearly seen in the south-to-north SKR intensity ratio. In the long-term variations, the southern SKR intensity became 100 times smaller at northern summer than at southern summer, while the northern SKR intensity was not largely changed. It means that the reversal in the intensity ratio was mainly caused by the long-term reduction of the southern SKR intensity in winter, not the enhancement of northern SKR in summer. We also investigated the possible contributions from the long-term solar EUV flux and solar wind dynamic pressure in the solar cycle 23 and 24, but found that their clear contribution on the SKR long-term variations were less than the Saturn's seasonal changes associated with the variation of its rotational axis to the Sun. We also compared the long-term variation of the SKR intensity and the SKR period in half a Kronian year. The former showed more systematic variations and was not same with the ones seen in the SKR periods. Including the differences of variations in northern and southern polar emissions, further studies should be needed.

Simulating the Influence of Local-Time on Magnetosphere-Ionosphere-Thermosphere Coupling at Jupiter

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Jupiter's upper atmospheric temperature is considerably higher than that predicted by Solar Extreme Ultraviolet (EUV) heating alone. Simulations incorporating magnetosphere-ionosphere coupling effects into general circulation models have, to date, struggled to reproduce the observed atmospheric temperatures under simplifying assumptions such as azimuthal symmetry and a spin-aligned dipole magnetic field. Here we present the first full three-dimensional thermosphere model coupled to a tilted magnetosphere model – breaking the aforementioned assumptions. We discuss the influence that using a tilted magnetosphere model with local time dependence has on Jupiter's upper atmospheric dynamics and energetics, and aurorae.

Enhancement of the Jovian Thermospheric Temperature above the Great Red Spot based on the Infrared Spectroscopic Data obtained with IRTF/iSHELL

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The thermospheric temperature of all giant planets is several hundred kelvins higher than that expected from solar heating [Yelle and Miller, 2004]. At mid- to low-latitudes, one candidate for the heating is energy transportation by atmospheric waves from the lower atmosphere. Recently, O'Donoghue et al. [2016] revealed the heating in the thermosphere above the Great red spot from the intensity ratio of two emission lines (3.383 μ m/3.454 μ m) of thermospheric H₃⁺ taken by IRTF/SpeX (R~2500) in December 2012. They estimated the temperature above the Great red spot to be 1644 \pm 161K, and that on surrounding region to be 900 \pm 42K. As the reason, they suggested the propagation of atmospheric waves generated in the Great red spot to the thermosphere.

In this study, we observed the thermospheric temperature in the Jovian mid-latitude region near the Great red spot by IRTF/iSHELL on January 11, 2017. This observation was performed with the iSHELL's Lp1-mode (3.265-3.657 μ m), and the data reduction was performed with NASA's data reduction tool, Spextool ver. 5.0.1. Similar to O'Donoghue et al. [2016], we derived the intensity ratio of two emission lines of H₃⁺ (3.3839 μ m/3.4548 μ m), and estimated the temperature precisely distinguished from CH₄ line by iSHELL's higher wavelength resolution (R~75000) than SpeX. As a result, we estimated the thermospheric temperature above the Great red spot to be 910 \pm 132K, and that on the surrounding region to be 583 \pm 30K. We revealed the temperature above Great red spot is about 300K higher than that on the surrounding region. This suggests the existence of energy transport from the lower to the upper atmosphere in the Great red spot. In addition, the estimated temperature was lower than that in O'Donoghue et al. [2016]. We suggest there is a possibility of time variation of the thermospheric temperature and the effect of changing an observation instrument. In this presentation, we report details about the observation and data analysis.

P67

Modelling Asymmetries in Titans Flux Ropes

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85 flux ropes are detected in Titans ionosphere using Cassini magnetometer data from 2005-2017. A force-free and non-force-free model have been utilised previously to fit the data and extract properties of these flux ropes, however the models can not fit pronounced asymmetries. We deform the force-free model to show that the asymmetries can be produced and better fitted by bending the flux rope and changing the cross-section from circular to elliptical. We also explore the possibilities of helical flux ropes and their expected signatures along with an analysis of the differences between the flux ropes found at Titan and the other planetary bodies.

Plasma dynamics in Saturn's middle-latitude ionosphere and implications for magnetosphere-ionosphere coupling

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Saturn's magnetosphere-ionosphere (MI) coupling is active in the auroral region at high latitude between 75° and 80° . The coupling process between the inner magnetosphere less than $10 R_S$ and the ionosphere at latitude lower than $\sim 70^\circ$ is not well understood. However, the interaction between ionosphere and Saturn's ring particles was recently observed by studying patterns in the emissions of H_3^+ in the low-latitude ionosphere below 50° . These emissions were likely due to the called "ring rain". Ring rain consists of ion fluxes that are generated by photoionization of the ring surface and then precipitate into the ionosphere. A similar phenomenon is expected to occur in the inner magnetosphere in the region of E ring. Sakai et al. (2013) showed that the magnetospheric electric field generated by the ion-dust collisions slows ions with respect to the co-rotation speed and suggested that the dust-plasma interaction occurs via MI coupling. This magnetospheric electric field also strongly depends on the ionospheric Pedersen conductivity. A multifluid model is used to investigate how Saturn's magnetosphere affects ionosphere. The model includes a magnetospheric plasma temperature of 2 eV as a boundary condition. The results are: (1) H^+ ions are accelerated along magnetic field lines by ambipolar electric fields and centrifugal force, and have upward velocities of about 10 km/s at 8000 km; (2) the ionospheric plasma temperature is 10000 K at 5000 km, and is affected by magnetospheric heat flow at high altitudes; (3) modeled electron densities agree with densities from occultation observations if the maximum neutral temperature at a latitude of 54° is about 900 K or if electrons are heated near an altitude of 2500 km; and (4) electron heating rates from photoelectrons can also give agreement with observed electron densities when the maximum neutral temperature is lower than 700 K. The ionospheric height-integrated Pedersen conductivity varies with local time with values between 0.4 and 10 S. We suggest that the sub-corotating ion velocity in the inner magnetosphere depends

Characterising the Structure and Compressibility of Saturn's Magnetopause

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We report work in progress on the construction of a numerical model for a magnetopause boundary, based on using local balance between exterior (solar wind) and interior (magnetospheric field and plasma) sources of pressure. We demonstrate how the model can be applied to the Saturn system, and illustrate the following related points:

- Magnetopause crossings from the Cassini spacecraft can be used to compute local solar wind pressure estimates. Combining this information with our magnetopause surface model, one can deduce the compressibility of Saturn's magnetosphere; this procedure yields results that are consistent with previous studies, based on more empirical surface models.

- The modelled boundary can be used to compute the corresponding shielding field which is produced by the magnetopause surface currents. The resulting magnetospheric field model could then help characterise the space environment of particular moons – eg. Titan, which orbits near the magnetopause of Saturn.

- Our modelling technique retains enough flexibility to be open to numerous improvements, such as introducing variable hot plasma pressure, contributions of a co-rotating partial ring current, and configurable dipole tilt for studies of seasonal effects.

Magnetospheric magnetic field models for Uranus and Neptune

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The ice giant planets Uranus and Neptune possess the most complex planetary magnetic fields in the Solar System. The combination of highly dynamic magnetic environments and extreme solar wind conditions means that the ice giant magnetospheres are distinct from the magnetospheres of all other planets. We know very little about how Uranus and Neptunes magnetospheres work, and we expect there to be important differences between them. Here we present an analytical, three-dimensional magnetospheric magnetic field model and apply it to both Uranus and Neptune. Inputs to the model are the location and orientation of the planetary magnetic dipole, within a simple magnetopause surface geometry. The model then assumes steady state and uses magnetic scalar potential theory to calculate the magnetic field created by magnetopause currents to confine the planetary field to the magnetospheric cavity, before superposing this with the planetary field to determine the total magnetospheric magnetic field. We model the Uranian and Neptunian magnetospheric fields during the Voyager 2 flybys and compare to observations. We then employ this low-resource modelling approach to examine the inducing magnetic field at different moons within each system, with implications for electromagnetic induction in any electrically conducting regions such as subsurface oceans.

P71

Empirical model of Jupiter's current sheet for Juno data

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Juno spacecraft provided plenty of new valuable data on the magnetic field inside the Jovian magnetosphere. We use this data to develop a new empirical model of the Jupiter's current sheet. Our model combines successful elements from several previous models. It has a disk-like current with constant north-south thickness and a piecewise current density dependence on the cylindrical distance. The model also takes into account the lagging of the magnetodisc from magnetic equator. We test the model using the Juno spacecraft magnetometer data and compare performance of our model with the results of previous ones.

Revisiting the role of neutrals and high-latitude particle sources on the distribution of warm to energetic electrons at Saturn

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Cassini observations of eV-keV electron Pitch-Angle Distributions (PADs) at Saturn have revealed a spatial structuring, with little temporal and longitudinal dependence, that can be broken up into three distinct regions [Clark et al., *Planetary and Space Science*, Volume 104, p. 18-28 (2014)]: (1) a region dominated by field-aligned PADs from ~12-15 Rs, (2) a transition region, in which PADs evolve from mostly field-aligned to pancake and isotropic, from ~8 to ~12 Rs with observations of butterfly distributions, and (3) a region inside ~8 Rs that is dominated by trapped PADs. Although Cassini had unveiled Enceladus' dense and extended neutral cloud, little had been done to gauge its role on the energy and spatial distributions of electrons. Neither the role of polar sources was investigated to explain the observed PADs. We have subsequently combined multi-instrument data analyses of Cassini observations (2005-2012) and a diffusion theory model of charged particle fluxes to further investigate the origins of electrons' PADs in the 100s of eV to keV energy range and pinpoint the different mechanisms that control their evolution throughout the magnetosphere of Saturn (< 15 Rs). Cassini CAPS/ELS, MIMI/LEMMS and MAG are used to both constrain the model at its boundary conditions and discuss our simulation results with in-situ data. Our radial transport is initially constrained by MIMI/LEMMS observations of micro-signatures and assumed to be adiabatic. The interaction with neutrals is both radiative (Bremsstrahlung) and collisional (ionization, excitation, and elastic). The source term of electrons with energies < 10 s of keV, small pitch-angles, and for $L > 10$ Rs is constrained by Cassini ELS and LEMMS data. Data-model comparisons show some good agreements beyond ~7-8 Rs, while the incorporation of other mechanisms (such as particle source of 1-100 keV energy electrons from injections, interactions with dust, waves, and cold plasma) into our model is needed to improve our results closer to the planet.

Magnetic shear angle estimates at the Saturn magnetopause and relation to the probable reconnection line location

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In this work, a semi-empirical Tsyganenko magnetic field model has been modified to represent that of Saturn's outer dayside magnetosphere, utilizing a simple asymmetric magnetopause shape to shield the internal magnetic field as determined from Cassini magnetometer observations (Dougherty et al., Science, 2018). An analytic magnetosheath magnetic field model is also employed to estimate the external magnetic field along the magnetopause. The magnetic fields interior and exterior to the model magnetopause are used to create maps of the magnetic shear angle over the magnetopause surface. With such maps, the probable location of the reconnection line along the dayside magnetopause is estimated and compared with Cassini observations of accelerated electrons tangential to this boundary (indicative of reconnection occurrence).

P74

Plasma Sheet Properties Observed by Juno at Jupiter

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Using 14 inbound passes through the jovian system, we combine measurements from the fields and particles instruments on the Juno spacecraft to make a preliminary map of the properties of Jupiter's plasma sheet. Junos orbit is particularly useful for exploring the variation in plasma conditions with latitude as well as radial distance (from ~ 10 to ~ 50 RJ). We compare basic plasma properties (density, temperature, composition, magnetic field strength) as well as derived quantities (pressure, plasma beta, gyroradius, Alfvén speed) with those from previous observations (specifically Voyager and Galileo) and estimate the flow of mass and energy through the system. We also quantify locations of plasma blobs and other deviations from uniform plasma sheet conditions.

P75

Survey of reconnection signatures at Saturn's magnetopause

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Magnetic reconnection at the magnetopause is an important process that occurs at planetary magnetospheres and is the main driver of magnetospheric dynamics at Earth. We present a survey of magnetopause crossings at Saturn using Cassini magnetometer and plasma data (using MAG, CAPS and MIMI). We have analysed magnetopause crossings in regards to signatures of reconnection such as flux transfer events (FTEs), travelling compressions regions (TCRs) and energised/mixed plasma.

Impact of solar wind pressure enhancement on Jupiter's magnetosphere: Insights from global MHD simulations

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Although it is widely accepted that Jupiter's magnetosphere is rotationally driven, remote observations of Jupiter's UV aurorae have shown that the main emission responds to changes in solar wind dynamic pressure. In this work we use a global magnetohydrodynamic model that includes the Io plasma torus centered around $\sim 6 R_J$ to investigate the influence of the solar wind and IMF on the large-scale structure of Jupiter's magnetosphere, such as the corotation-enforcement current system and the magnetic topology. We conducted different runs in which we vary the upstream parameters to simulate the impact of forward interplanetary shocks on the magnetosphere under southward and Parker-spiral IMF orientations. We found that a dynamic pressure enhancement drastically decreases the ionospheric current density on the day side and marginally increases it on the night side, which is consistent with previous theoretical predictions and global MHD simulations. Our 3D field line tracing through the simulation domain indicates that for a Parker-spiral IMF, all open field lines in the high-latitude region lie poleward, by at least 4-5 degrees, of the upward field-aligned currents of the corotation-enforcement current system, which is commonly assumed to be associated with Jupiter's main oval. In our simulation, plasmoid release in the tail occurs in a non-periodic fashion with a separation time what appears to depend on the upstream solar wind pressure. We find that plasmoid release is well-correlated with reduction in the overall strength of the corotation-enforcement current system as well as the net open flux in the polar region. Based on the time rate of change of the open flux variation, we have determined the total voltage of the reconnection-induced potential drop across the magnetosphere, which is in agreement with empirical models of Jupiter's dayside magnetopause reconnection.

Software-type Wave-Particle Interaction Analyzer (S-WPIA) by RPWI for JUICE

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We describe the principles of the Wave-Particle Interaction Analyzer (WPIA) and the implementation of the Software-type WPIA (S-WPIA) on the spacecraft. The merit of WPIA has been demonstrated by numerical experiments (Katoh et al., AnG 2013), THEMIS (Shoji et al., GRL 2017), and MMS data analysis (Kitamura et al., Science 2018). S-WPIA has been implemented in the Arase (ERG) satellite (Katoh et al., EPS 2018) for the investigation of wave-particle interactions in the Earth's radiation belts and will be realized as a software function of running on the DPU of RPWI (Radio and Plasma Waves Investigation) for the ESA JUICE mission. S-WPIA conducts onboard computations of physical quantities indicating the energy exchange between plasma waves and energetic ions. Onboard inter-instruments communications are necessary to realize S-WPIA, which will be implemented by efforts of RPWI, PEP (Particle Environment Package) and J-MAG (JUICE Magnetometer). The prime target of S-WPIA in JUICE is ion cyclotron waves and related wave-particle interactions occurring in the region close to Ganymede and other Jovian satellites. Low-Frequency receiver (LF) and Langmuir Probes (LP) data will be used for electromagnetic waveform of ion cyclotron waves in the frequency range of a few Hz. For the particle data, S-WPIA uses particle counts detected by Jovian plasma Dynamics and Composition (JDC) of PEP in the energy range from 1 eV/q to 25 keV/q. By providing the direct evidence of ion energization processes by plasma waves around Jovian satellites, S-WPIA increases the scientific output of JUICE while keeping its impact on the telemetry data size to a minimum.

Development of cross-reference numerical simulation framework: macro- and micro-scale simulations of the magnetosphere

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For some years we have studied the magnetospheres of Jupiter, Saturn and Earth by using 3-dimensional magnetohydrodynamic (MHD), electro-hybrid, and Particle-In-Cell (PIC) simulations. These simulations are not able to connect each other due to large differences of the spatial and temporal scales which their simulations should treat. However, thanks to the recent development of supercomputer, the coupling simulations come close to be achieved in a few years. On the other hand, these simulation codes are developed independently so that the implementation and construction of code are quite unlike and hard to understand for each simulation code developer. As a result, it is difficult to connect these simulation codes.

Recently the communication library (ACP), which can transfer the data between different programs easily using RMA (remote memory access), is developed for parallel computing in the high-performance computing (HPC). That is, the data generated by the different simulation codes can be transferred between those simulation codes easily using ACP. Thus, we have started the development of cross-reference simulations framework for macro and micro scale with ACP.

The main concepts of this framework are that we do not add modifications to the simulation codes as possible without data transfer and we do not need to know the referred simulation code without data format. These concepts allows for many simulation codes to participate in this framework. In this study, we will show the design of this framework in detail and status of development. In particular, we focus on coupling MHD and electro-hybrid simulations. The magnetic field data of MHD simulation is transferred to the cross-reference framework and the magnetic field lines are calculated then these lines are transferred to the electro-hybrid simulation. Some implementations and results of this simulation will be shown.

Electron pulsations generated by rotating magnetospheric dynamics at Saturn

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Quasi-periodic pulsations of energetic electrons have been frequently observed in Saturn's magnetosphere. The mechanisms for the electron pulsations are far from conclusive, although generally believed to be associated with field-line resonance due to their similar periodicities. Here we report an electron pulsation event that is related to aurora beads and energetic neutral atom (ENA) emissions. The perturbation of the magnetic field indicates that Cassini spacecraft encountered a series of field-aligned currents (FACs) connected to the aurora beads. The fluxes of energetic electrons were enhanced when the spacecraft crossed the FACs. Both aurora beads and ENA emission were rotating. Given that the FACs interconnect the aurora beads and the active region at equator, a hot plasma population associated with the ENA enhancement, we conclude that the FACs were rotating with Saturn and had finite extent in the azimuthal direction. The periodic features also manifested in the whistler-mode auroral hiss emissions in the same event. We proposed that the electron pulsations we studied are spatial effect of the rotating magnetosphere. The rotation of the whole magnetosphere transfers the spatial effect to the temporal effect, i.e., the pulsation sequences observed by Cassinis multiple instruments.

Solar Wind Dynamic Pressure Upstream from Saturn: Estimation from Magnetosheath Properties and Comparison with SKR

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_ : presenter

An analytical method is developed by which measurements made by the Cassini spacecraft in Saturn's magnetosheath can be used to infer the upstream solar wind parameters, specifically the solar wind speed and the dynamic pressure. The method is validated by comparing the results with other estimates of these parameters, including the mSWIM MHD model and magnetopause and bow shock models applied to observed boundary crossings. The comparisons suggest the new inferred solar wind speeds and dynamic pressures may be on average somewhat low (~ 40 km/s and perhaps a factor of 2, respectively), but systematic temporal variations such as interplanetary shocks do seem to be captured well. Comparison of the inferred dynamic pressure with observed SKR emissions reveals several episodes of very good temporal tracking between dynamic pressure and SKR intensity, with relatively short time delays (4-5 hours), suggesting rather direct driving. Where the tracking is good, the SKR fluxes vary roughly as the square of the dynamic pressure.

Survey of Saturn's magnetopause and bow shock positions over the entire Cassini mission: boundary statistical properties, and exploration of associated upstream conditions

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The Cassini spacecraft orbited the planet Saturn from July 2004 – September 2017, and its varied orbital trajectory took it across the magnetopause and bow shock boundaries multiple times, at varying radial distances, local times, latitudes, and phases of the solar cycle. Here we present a comprehensive list of these boundary crossings, derived primarily using data from the Cassini magnetometer instrument, with cross-validation against the electron spectrometer data where available. There are a multitude of scientific avenues for exploitation of this list. In this work, we examine the variability in boundary location and use the crossing times in concert with models of the bow shock and magnetopause to infer the upstream solar wind dynamic pressure at the times of crossings. This analysis allows us to understand the limitations of the Cassini trajectory for studying boundary physics under a range of solar wind driving conditions. In addition, rapid traversals of the magnetosheath are used to estimate the range of speeds of boundary motion.

Spatio-temporal Evolution of Energy Spectra of Energetic Protons and Oxygen Ions During Large-scale Injections in Saturn's Magnetosphere

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It is believed that radial transport with sharp, localized filamentary structures due to interchange instabilities is the main transport process in Saturn inner magnetosphere [e.g., Hill et al., 2005, GRL; Paranicas et al., 2016, Icarus; Azari et al., 2019, JGR]. Global injections of energetic particles (>10 keV, non-thermal) were also observed, associated with large-scale reconfigurations of the magnetotail magnetic field probably caused by reconnection [c.f., Mitchell et al., 2015, AGU Monograph]. The pressure of the non-thermal plasma becomes comparable to and dominates thermal pressure outside 9 Rs and 12 Rs, respectively [e.g., Sergis et al., 2010, GRL]. The large-scale injections therefore play an important role in transport and acceleration. Our study focuses most on generation and transport of non-thermal H^+ and O^+ during the large-scale reconfiguration. Observations showed different responses (e.g., relatively high O^+ temperature) to the reconfiguration between the two species [e.g., Dialynas et al., 2009, GRL]. However, the dominant mechanism(s) of selective/mass-dependent acceleration is(are) not fully understood.

Using observations of energetic neutral atoms by the Ion Neutral Camera (INCA) of the Magnetospheric Imaging Instrument (MIMI), we examine the spatio-temporal evolution of energy spectra for hydrogen and oxygen atoms with energies of ~ 10 to ~ 300 keV. The time sequence of the spectral evolution during large-scale injections is of our particular interest. To characterize the relation of the spectral evolution to the magnetic field dipolarization, we utilize in-situ ion observations by INCA and Charge Energy Mass Spectrometer (CHEMS) and magnetic field measurements by the Cassini magnetometer (MAG). We will also compare the results with observations at Earth to understand how universal the ion acceleration during the magnetic field reconfiguration is to the magnetospheres of different magnetized planets.

Effect of Magnetodisc Fields on Plasma Injection Signatures

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Studies of plasma injection signatures at the giant planets commonly interpret these events in terms of a longitudinally localized 'bundle' of hot plasma or a more radially-extended flow channel. In either picture, the hotter plasma moves radially inward toward the planet and gains energy. These structures also entrain energetic charged particles. But charged particles have important secondary drifts and in our view don't 'stay with' the injecting hot plasma indefinitely but instead drift azimuthally at different, energy-dependent velocities, leading to the 'dispersed' signature in observed energy spectra. In this study, we describe work in progress on revisiting the modelling of azimuthal gradient and curvature drift rates for injected particles, using a magnetodisc field rather than the pure dipole which is often assumed. We comment on the quantitative effect of the magnetodisc on the energy dispersion, according to typical radial distances of origin, and inward radial velocities, for injection events at Saturn.

Ubiquity of Kelvin-Helmholtz waves at Saturn's magnetopause

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Cassini encountered Saturn's magnetopause boundary ~2000 times during the time period 2004-2012 when the Cassini Plasma Spectrometer was operational. The observed plasma and magnetic field properties at these boundary crossings vary strongly, and the prime suspect for the source of this variability is the presence of Kelvin-Helmholtz waves. We classify each boundary crossing as Kelvin-Helmholtz active or inactive based on major deviations from the expected flow pattern, and also by quantifying magnetic field fluctuations in the vicinity of the magnetopause. Hybrid simulations of the Kelvin-Helmholtz instability suggest that heating and transport can be significant within an actively growing vortex. A comparison of the Cassini data and hybrid simulations give values for the mass diffusion coefficient and turbulent heating rate density which compare favorably. The Kelvin-Helmholtz occurrence rate is estimated and their importance for the global mass and energy budgets of Saturn's magnetosphere is quantified. Previous studies have confoundingly concluded that the dusk sector is Kelvin-Helmholtz active more often than the dawn. The results here show the greatest frequency of Kelvin-Helmholtz instabilities occurs in the pre-noon sector where the flow shear is maximized.

Current status and future plan of the PLANETS telescope project for planetary and exoplanetary atmospheric monitoring

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We are conducting an international collaboration for the 1.8-m aperture off-axis telescope project PLANETS. In this presentation, we focus on the current status of PLANETS project and future plans to promote planetary/exoplanetary sciences. PLANETS is characterized by low-scattering and high-contrast optics with off-axis mirror system, and also by monitoring observation. We mainly concern variations in planetary atmospheres, faint gases produced from satellites, exoplanetary atmosphere, and also welcome other targets that match to the advantages of PLANETS. Continuous monitoring is essential to understanding the planetary atmospheric phenomena, and therefore, own facility with even small-telescope and own instruments are important as we demonstrated with T40 and T60 telescopes at the summit of Haleakala, Hawaii (3050m).

To achieve precise spectroscopy and polarimetry for faint emissions/absorption in planetary/exoplanetary atmospheres and satellites, PLANETS a 1.8-m aperture with low-scattered light optics is necessary. PLANETS project is managed by the PLANETS Foundation (www.planets.life), which is an internationally organized entity whose board members are from several institutes in Japan, USA, Germany, Brazil, and France. This off-axis optical system brings us unrivaled high-dynamic range scientific capabilities on coronagraphy and polarimetry. It will have a Gregoian focus with a FOV of 6' ($F_{no}=13$) with diffraction limited image with a diameter of approximately 1'. The main mirror is Clearceram Z-HS with a diameter of 1850 mm, which is now on the final polishing process. We are designing mechanical structure of telescope for both cases of equatorial mount and azimuthal-elevation mount. We are also designing a mirror support structure in two ways, active support and passive support. We are aiming to get first light with PLANETS telescope within next several years.

Plasma-Neutral coupling in the Jovian magnetosphere: Low-energy Energetic Neutral Atom imaging in the Jovian system

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Physics in the Jovian magnetosphere include numerous plasma–neutral coupling processes. We will overview the science questions related to the plasma–neutral couplings in the Jovian magnetosphere, focusing on the low-energy processes related to the corotating plasma.

The Io volcanic material is a main source of the magnetospheric plasma. The corotating Io torus plasma (~ 74 km/s) is neutralized via the charge-exchange mechanisms with the Io neutral torus atoms and molecules. The generated energetic neutral atoms (ENAs) are transported outwards, forming a disk (Mendillo et al., 2007) with a "spiral form" embedded (Futaana et al., 2015). The ENA fluxes from the Io plasma torus directly quantify the mass and energy balances in the tori. The Jovian magnetospheric plasma also interacts with the surfaces of moons. Without significant atmospheres for Ganymede and Callisto, the corotating plasma impinges on their surfaces. ENAs are emitted from the surfaces via the backscattering and sputtering processes. Such ENAs have been observed at the Moon (Wieser et al., 2009) and in the laboratory (Wieser et al., 2016). The flux of the backscattered ENAs and the energy distributions will quantify the flux and energy of the plasma impinging on the surfaces (Futaana et al., 2013). The expected higher flux of plasma precipitation at the cusps may hypothetically manifest the surface albedo differences via space weathering (Khurana et al., 2007). The scattered ENA measurements will give direct answer, similar to the study at our Moon (Wieser et al., 2010). Furthermore, the characteristics of the surface materials are also inferred from the sputtered ENAs.

The European JUICE mission is equipped with the plasma package, PEP (Particle Environment Package). As a part of PEP, the innovative ENA sensor, JNA (Jovian Neutrals Analyzer), will conduct the low-energy ENA measurements in the Jovian magnetosphere for the first time. We will also introduce the PEP/JNA experiment in the presentation.

Future ultraviolet observation for monitoring outer planetary systems

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Ultraviolet (UV) observation has been a powerful tool for investigating the magnetospheres of outer planets. For example, Japans UV space telescope dedicated to planetary spectroscopy succeeded to monitor the variations of Io plasma torus and Jupiter's aurora for long time and continuously. It enabled us to detect Ios volcanic activities and magnetospheric responses to them. However, due to its low sensitivity and low spatial resolution, Hisaki cannot detect other Jupiter's and Saturn's moons, especially icy moons such as Europa and Ganymede. In 2026, NASAs Europa Clipper will arrive at Europa and start its flyby observations. ESAs leading JUICE spacecraft will also start its observations of Jovian system in 2029. If Hubble Space Telescope will be retired in early 2020s, no UV monitoring missions can cover outer planetary systems in the period of Europa Clipper and JUICE. Therefore, we are now studying the concept of future UV space telescope mission. One of the main targets is Europas water plume. In this study we introduce the initial results of our concept study, especially capability and required specifications for Europas plume detection. In addition, we will also introduce the capabilities with Russian space telescope, World Space Observatory-Ultraviolet (WSO-UV).

A New Frontiers Uranus Orbiter Concept Study with Ten-Moment Multifluid Global Magnetosphere Modeling

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Future study of the ice giants in our solar system remains a flagship mission priority as outlined in the current Visions and Voyages Decadal Survey. However, Discovery and New Frontiers class mission proposals are capable of measuring a preponderance of the desirable scientific observables are of great interest to the (exo-)planetary science community. With this in mind, we present the Quest to Uranus to Explore Solar System Theories (QUEST) mission concept to study the complex features found in the Uranus system. The QUEST platform is a spin-stabilized spacecraft powered by two eMMRTG's in a polar orbit around Uranus with a scheduled one-year lifetime. The magnetometer enables vector measurements of Uranus' magnetic field and thus will facilitate our understanding of dynamos that drive magnetospheres of ice giants. The plasma wave receiver measures the wave activities in the magnetosphere and helps constrain the global magnetic field configuration. The microwave radiometer probes the deep atmosphere by providing data on spatial cloud structure, gas volume mixing ratios, and patterns in global circulation. A wide-angle camera with an additional methane filter is included to study the global distribution of stratospheric methane and to take images of the larger Uranian satellites. The Radio Science Antenna is used to transmit and receive radio signals in X and Ka bands to and from Earth allowing us to obtain atmospheric temperature, pressure, and density profiles as well as measurements of the gravitational moments of Uranus. With substantial mass, power, and cost margins, this mission represents a compelling option for sub-flagship budget exploration of a high priority target. Finally, we will present ten-moment multifluid simulations of Uranus' magnetosphere. The new model is akin to a fluid version of PIC code, where non-ideal effects like the Hall effect, electron inertia and pressure tensor are self-consistently embedded without the need to explicitly solve a generalized Ohm's law.

Acknowledgments: QUEST was supported by NASA/JPL through the PSSS program.

Chinese Balloon-borne Optical Remote Sensing Program for Planetary Sciences

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Deep space exploration is one of the Chinese scientific strategies in the future. As two examples, China has successfully implemented the ChangE Project and approved the Mars in-situ detection program. Orbiter exploration programs to Jupiter are being discussed in Chinese communities. Moreover, Earth-based planetary optical remote sensing, such as balloon-borne telescopes and ground-based telescopes, could also provide unique value in resolving planetary environments. Compared with space-based missions, the advantages of these telescopes include low costs, maintainability, long-term continuous observation, and rapid response to space events. As supported by the Strategic Priority Research Program of Chinese Academy of Sciences, that is the Scientific Experimental system in Near-Space (SENSE), the Institute of Geology and Geophysics, CAS (IGGCAS) is leading a project to carry out coordinated balloon-borne planetary optical remote sensing and ground-based monitoring of planetary geological activity. In this program, a balloon-borne planetary atmospheric spectral telescope (PAST) with 0.8-m aperture in spectral range from 280 nm to 680 nm will be floated at 35-40 km altitude to observe and investigate the global space environment of Mercury, Venus, Mars, and Jupiter. At the same time, two ground-based telescopes both with 1-m aperture will be established to monitor the geological activities of Jupiter's moons (e.g., the volcanic activity on Io). Using the coordinated observations by PAST and ground-based telescopes and other satellite measurements when available, we will investigate mass transport and energy dissipation in space environments for solar system planet.

Investigations of Moon-Magnetosphere Interactions by the Europa Clipper Mission

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The influence of the Jovian space environment on Europa is multifaceted, and observations of moon-magnetosphere interaction by the Europa Clipper will provide an understanding of the satellites interior structure and compositional makeup among others. The variability of Jupiter's magnetic field at Europa induces electric currents within the moons conducting ocean layer, the magnitude of which depends on the oceans location, extent, and conductivity. Europa is also embedded in a flow of corotating plasma, which continuously impacts and sputters the surface to produce the moons atmosphere. In addition, micrometeorite impacts eject particles of the surface to wrap Europa in a cloud of dust. The neutral atmosphere is readily ionized by energetic particles to produce an ionosphere, which gives rise to current systems electromagnetically connecting Europa to Jupiter. The Europa Clipper mission will observe the causes and effects of Europas interaction with its space environment using a suite of in-situ and remote-sensing instruments. The Interior Characterization of Europa using Magnetometry (ICEMAG) investigation will measure magnetic fields generated by currents induced in Europas subsurface ocean and the electromagnetic coupling of the moon to Jupiter. The Plasma Instrument for Magnetic Sounding (PIMS) will measure ions and electrons in Europas ionosphere to infer plasma currents and coupling between Europa and Jupiter. The MAss Spectrometer for Planetary Exploration (MASPEX) measures trace neutral species to determine the composition of Europas atmosphere. Finally, the SURface Dust Analyzer (SUDA) will map the chemical composition of particles ejected from Europas surface and identify the makeup of potential plumes by directly sampling microscopic particles. We present the highlights of the moon-magnetosphere interaction science we seek to unravel with the Europa Clipper mission and the primary investigations involved in these studies.

Europa-UVS and JUICE-UVS Science Planning

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Present and upcoming exploration of the Jupiter system includes Ultraviolet Spectrograph (UVS) investigations all sharing the same basic instrument design. NASA's Europa Clipper mission (2023 launch), ESA's Jupiter Icy Moons Explorer (JUICE) mission (2022 launch), and their Europa-UVS and JUICE-UVS instruments are being built at the time of this meeting. These UVS instruments closely follow the Juno-UVS design in terms of using a modern microchannel plate (MCP) detector and including robust shielding from intense MeV electron radiation. These new instruments are the fifth and sixth instruments in a series, starting with Rosetta-Alice, New Horizons Pluto-Alice, the Lunar Reconnaissance Orbiter (LRO) Lyman Alpha Mapping Project (LAMP), and Juno-UVS. Photons in the 50-210 nm wavelength range (slightly expanded relative to Juno-UVSs 70-200 nm range) are observed at moderate spectral and spatial resolution along a 7.5° slit. Initial lab calibrations for JUICE-UVS confirm that enhanced spectral and spatial capabilities relative to previous instruments are achieved as planned, with a well-focused alignment completed earlier this year. JUICE-UVSs science goals encompass the whole Jupiter system: 1) Exploring the atmospheres, plasma interactions, and surfaces of the Galilean satellites; 2) Determining the dynamics, chemistry, and vertical structure of Jupiter's upper atmosphere; and 3) Investigating the energetics and dynamics of the atmosphere, neutral clouds, and torus. The science goals of Europa-UVS, as for Europa Clipper, are focused on Europa habitability goals specifically: 1) Search for and characterize any current activity, notably plumes or thermal anomalies, in regions that are globally distributed; and 2) Characterize the composition and sources of volatiles, particulates, and plasma, sufficient to identify the signatures of non-ice materials, especially organic compounds, in globally distributed regions of the atmosphere and local space environment. We describe the UVS science plans and basic concepts of operations.

Multi-frequency phase and amplitude extraction of induced magnetic dipoles of icy planetary bodies via orbiting spacecraft: Application to Europa Clipper

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There are many icy bodies within our solar system that are thought to have a planetary scale subsurface ocean with life-harboring potential, a prime example being the Jovian moon of Europa. One goal of the Europa Clipper mission is to constrain the ice shell thickness, ocean depth, and salinity of the subsurface ocean. The magnetometer, in unison with field correction measurements made by the plasma instrument, will accomplish this task by accurately measuring the induced response from the ocean at multiple driving frequencies. While it is somewhat straight forward to interpret measurements made from a stationary source located at the bodys center, it is not commonplace to interpret the frequency of the magnetic field measurements from a non-stationary source like the Clipper spacecraft which will be passing Europa at velocities of up to 3-4 km/s in an elliptical orbit around Jupiter. Here, we present a frequency decomposition method which allows for retrieval of the induction parameters, namely the amplitude and phase for each of the dominant induced dipoles, which are essential for constraining the shell and ocean properties. This analysis does not only apply to Europa, but also to any icy satellite thought to contain a subsurface ocean in the presence of a time-varying magnetic field such as Ganymede, Callisto, Enceladus, or even Triton.

Simulation of JUICE Plasma Measurements while Orbiting Ganymede

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ESAs JUICE spacecraft will explore the Jovian system in the early 2030s, finally orbiting Ganymede for several months. While a great care is brought to the electrostatic cleanliness of JUICE, the solar powered spacecraft still presents some dielectric surfaces that will charge and perturb the scientific payload, in particular the instruments measuring the ambient plasma. Even though charging studies are performed by the spacecraft manufacturer, these studies do not directly simulate the perturbation of the scientific plasma measurements, nor do they take into account the environment variability along the Ganymede orbits. We present here a study associating two simulations codes: LatHyS for the environment simulation and SPIS for the spacecraft simulation, that allow an accurate modeling of the sensitivity of JUICE measurements to the spacecraft interaction with its environment. This study prepares the future observations of JUICE as well as the framework allowing to compare simulations to measurements to better analyze the later.

P94

Jupiter Icy Moons Explorer - Science objectives by JUICE-Japan

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JUpiter ICy moons Explorer (JUICE) is the first L-class mission by European Space Agency (ESA). Japan participates into the JUICE mission as a junior partner. In this presentation, we discuss the roles of the Japanese planetary science community in JUICE and future outer Solar System missions, especially focusing on the planetary formation and habitability.

Japanese Participation in JUICE (Jupiter Icy Moons Explorer): Current Status and Future Plan

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In the JUICE mission, an ESA's L-class mission to Explore Jupiter Icy Moons, four Japanese groups are providing some parts of RPWI (radio and plasma waves), GALA (laser altimeter), PEP (particle), and SWI (submm). And two Japanese groups are also participating as science Co-Is of JANUS (imager) and J-MAG (magnetic field). Science Objectives of the participation from Japan in JUICE are as follows (Sekine et al., in this conference):

(1) to understand "Origin and Evolution of Gas Giants" by answering to the question "How are planets formed?"

(2) to understand Conditions for Forming Subsurface Liquid Ocean by answering to the question "Where can we find extra-terrestrial liquid oceans?"

(3) to understand "Jupiter Magnetosphere as the Most Powerful Accelerator in Our Solar System" by answering to the question "What is the environmental change occurring in our solar system?"

They are linked to our activities in past space missions, especially BepiColombo, the Euro-Japan joint mission to Mercury, Hisaki UV/EUV space telescope which continuously run the Jovian observations, radio / IR / VIS ground-based observations, and multiple modeling studies related to outer planets. In this poster, we summarize the current status and future plans of those activities.

High Frequency part in Radio & Plasma Wave Investigation (RPWI) aboard JUICE: Toward the investigation of Jupiter and Icy Moons System

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In 2019 we are developing the PFM/FM of Radio & Plasma Wave Investigation (RPWI) aboard ESA JUICE. RPWI provides an elaborate suite for electromagnetic fields and plasma environment around Jupiter and icy moons, with 4 Langmuir probes (LP-PWI; 3-axis E-field -1.6 MHz, and cold plasmas), a search coil magnetometer (SCM; 3-axis B-field -20 kHz), and a tri-dipole antenna system (RWI; 3-axis E-field 0.08-45 MHz, 2.5-m tip-to-tip length).

RWI with High Frequency Receiver (HF) provide the highest sensitivity reaching the galactic background for the highly-resolved Jovian radio emissions from magnetosphere (aurora etc.), atmosphere (lightning), and icy moons. Its direction and polarization capabilities enable us to identify the source locations and characteristics. In this paper, we introduce the observation and telemetry plans. It includes the survey of harsh magnetosphere around Jupiter and its interaction with icy moons, and the plasma environment and subsurface characteristics of icy moons. For the subsurface, we will use the passive subsurface radar (PSSR) technique to sound the icy crusts of Galilean satellites, by the reflections of Jovian HOM/DAM.

Passive subsurface radar for exploration of the subsurface structures of Jupiter's icy moons by JUICE/RPWI

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Expected performance of the passive subsurface radar sounding of Jupiter's icy moons by using JUICE/RPWI has been investigated. In passive radar observation, the Jovian radio waves are used as radar pulse. So it could be a complimentary observation to active radar. Jovian radio waves is noise for active radar while they becomes signal for passive radar. Passive radar with RPWI is possible to use wide frequency range. The roughness of the surface and subsurface reflectors with respect to the wavelength will be smaller in lower frequency range. We should note demerits such that it is possible only in Jupiter side, and we can not control the radar pulse in order to apply usual radar techniques. In order to perform passive radar with RPWI, we prepare two kind of operation modes: PSSR-1 for continuous waves with long duration and PSSR-2/3 for burst waves with short duration. In PSSR-1, RPWI measures spectrogram including interference patterns caused by direct waves and reflected waves from the moon's surface and subsurface reflectors. In PSSR-2/3, RPWI measures waveforms and perform the cross correlation analysis among the waveforms. In estimation of detection depth, we have to confirm several parameters. The intensities of the Jovian radio waves and galactic noise were determined based on the previous spacecraft and ground-based observations. The noise level of the RPWI receiver was determined based on test results with the preamplifier engineering model. Based on Moore [2000], attenuation rate in ice with rock/sulfate impurities are estimated to be $\sim 7\text{dB/km}$. We assumed a melt as subsurface reflector. The roughness of the surface and subsurface was also considered (30 to 10 m for 1km-baseline). In the analysis, we obtain 100 cross correlations from 4096-point waveforms, and calculate their ensemble average. Based on the above parameters, the detection depth of passive radar by RPWI is estimated to be ~ 5 km around 10 MHz, ~ 8 km around 1MHz, and ~ 11 km around 0.1 km.

Cross-reference simulations by scalable communication library for the study of wave-particle interactions in planetary magnetospheres

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We have been developing a cross-reference simulation code by scalable communication library for the study of wave-particle interactions in planetary magnetospheres. We use Advanced Communication Primitives (ACP; http://ace-project.kyushu-u.ac.jp/main/jp/01_overview/) library for the communication among the simulation codes, which enables us to carry out 'strong' cross-reference simulations; the data exchange among simulation codes is conducted by direct memory access, instead of file output as has been used in conventional 'weak' cross-reference simulations.

By a series of electron-hybrid and MHD cross-reference simulations, we study the generation and propagation of whistler-mode chorus emissions in the planetary magnetosphere. Chorus emissions are electromagnetic plasma waves commonly observed in planetary magnetospheres and are a group of coherent wave elements changing their frequency in time. While the generation process of chorus has been reproduced by numerical experiments [e.g., Katoh and Omura, GRL 2007a] and has been explained by the nonlinear wave growth theory [Omura et al., JGR 2008, 2009], previous studies revealed similarities and differences of the spectral characteristics of chorus in planetary magnetospheres, which has not been understood yet.

In the cross-reference simulations, we use the MHD code for the investigation of the range of variation of the spatial scale of the planetary magnetosphere. The electron hybrid code is used to reproduce the generation process of chorus emissions under the initial conditions provided from the MHD simulations. An electron fluid code [Katoh, 2014] is also used for the study of the propagation of chorus emissions in the meridional plane of the magnetosphere. We describe the simulation models used in the developing code and show their initial results.

The Search-Coil Magnetometer Onboard the ESA JUICE Mission: Scientific Objectives and Instrument Design

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_ : presenter

The JUperiter ICy moons Explorer (JUICE) mission is the first large-class (L1) mission in ESA Cosmic Vision. JUICE is planned for launch in 2022 with arrival at Jupiter in 2029 and will spend at least four years making detailed observations of Jupiter's magnetosphere and of three of its largest moons (Ganymede, Callisto and Europa). The Radio and Plasma Wave Investigation (RPWI) consortium will carry the most advanced set of electric and magnetic fields sensors ever flown in Jupiter's magnetosphere, which will allow to characterize the radio emission and plasma wave environment of Jupiter and its icy moons. Here we present the scientific objectives and the instrument design of the Search Coil Magnetometer (SCM) of RPWI. SCM will provide, for the first time, high-quality three-dimensional measurements of magnetic field fluctuations vector in the frequency range 0.1 Hz – 20 kHz within Jupiter's magnetosphere. High sensitivity ($\sim 4 \text{ fT} \cdot \text{Hz}^{-1/2}$ at 4 kHz) will be assured by combining an optimized (20 cm long) magnetic transducer with a low-noise ($4 \text{ nV} \cdot \text{Hz}^{-1/2}$) ASICs pre-amplifier for the front-end electronics. Perturbations by the spacecraft will be strongly reduced by accommodating SCM at $\sim 10 \text{ m}$ away from the spacecraft on the JUICE magnetometer boom. The combination of high sensitivity and high cleanliness of SCM measurements will allow unprecedented studies of waves and turbulence down to electron scales, in particular in key regions such as the Jupiter magnetodisk as well as the magnetopause, the auroral region and the magnetotail current sheet of Ganymedes magnetosphere. This will lead to important advances in understanding plasma energy conversion and particle energization mechanisms in Jupiter's magnetosphere.

KOSEN-1 CubeSat Mission for Jupiter's Decametric Radio Observation

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Since the discovery of Jupiter's decametric radio emissions in 1955, important details of its radiation mechanism have not yet been determined. In order to investigate the beaming structure of Jupiter's radio emission to clarify aspects of the emission mechanism, we plan to launch a 2U-size CubeSat for observation of Jupiter's radio waves and observe simultaneously in outer space and on the Earth. The purpose of this project is to measure the emission delay time by using a correlation analysis method. The delay time can be measured by the correlation analysis of waveform data obtained by simultaneous observations of Jupiter's radio S-bursts between this satellite and the ground. If the beam of Jupiter's radio S-bursts is moving together with the rotation of Jupiter, we can calculate a time difference of about 70 milliseconds at the baseline length of 8000 km. Using the proposed simultaneous observations, it is possible to test whether the Jovian S-bursts are emitted like a 'beacon', rotating with Jupiter's magnetic field and sweeping by the Earth, or like a 'flashlight', an instantaneous emission with a 0 millisecond time delay. This information is very important to determine the nature of Jupiter's radio emission mechanism.

Our application was selected on Dec. 12, 2018, as a CubeSat candidate for JAXA's innovative satellite technology demonstration program. The 2U-CubeSat project, named KOSEN-1, is planned to be launched by a JAXA Epsilon rocket at the end of 2020. The worldwide ground-based observations together with the KOSEN-1 satellite will be supported by the NASA Radio JOVE project, an education and outreach program for planetary radio astronomy.

The KOSEN-1 project is supported by the Coordination Funds for Promoting AeroSpace Utilization of the Ministry of Education, Culture, Sports, Science and Technology (MEXT), JAPAN.

P101

Tentative Detection of the Magnetospheric Radio Emission from an Exoplanet

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After recalling the motivations for searching radio emissions from exoplanetary magnetospheres, and the predictions made about their possible detectability, I will summarize recent tentative detections. I will present in more details the most recent one, that we have obtained with the European low frequency radiotelescope LOFAR, and the physical parameters that it provides on the emitting system. Further observations will be necessary both to confirm the detection and to draw more detailed information about the emitter, as illustrated by simulations based on the cyclotron maser mechanism. Finally, I will outline observation plans for the near future.

The Microlensing of Exoplanet

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Giant planets in our solar system are known to have intrinsic magnetic field. The information of a magnetic field around a planet is considered as one of the diagnostic indicators of probing the interior structure(, which are strongly involved in the formation history). A hot Jupiter akin to our giant planets, but in the proximity to a host star should have intrinsic magnetic fields. The practical method that can remotely detect magnetic fields of exoplanets utilizes planetary auroral emission. However, no obvious detections of auroral emission from hot Jupiters. Here, we propose a new method that is using the gravitational microlensing for exoplanet studies at radiofrequencies. In general, the gravitational microlensing method can be used to detect variations of source star's luminosity induced by the presence of a planet orbiting around lens star with optical telescopes. In this study, we instead consider the variations of source exoplanet's radio emission, as the expected radio emission from hot Jupiters could exceed the emission of the host star. In this method, we regard the planet orbiting around the star as source object, and the source object passes behind the lens star along the trajectory like the cycloid curve. While source object does that, the angle between the source object and the lens star is changed periodically, so that the change similarly affects the amplification of object's luminosity. And the light curve is obtained in which the periodical increase and decrease of luminosity are added to the microlensing that both the source star and the lens star are stars. We simulated this method and found that some of exoplanets show periodic peaks of amplification due to planetary motion. Furthermore, in this poster, we discuss the detectability of remote hot Jupiter at radio frequency to use Square Kilometre Array (SKA) and its pathfinder, low frequency array (LOFAR).