Causalities of occurrence features of Io-related Jupiter's radio emission

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The following question; 'How Jupiter's auroral radio emissions are generated?' has been long years of subjects. Especially the Io-related auroral emission component (Io-DAM) has shown mysterious nature of characteristic occurrence probability, that is, the occurrence strongly depends on both Io's positional angle and Jupiter's magnetic longitude to an observer. We have investigated this subject based on ray-tracing analyses using several kinds of magnetic field and plasma density models including a new magnetic field model 'JRM09' based on the JUNO explorations (Connerney et al., 2018). The analyses show that JRM09 gives more natural explanations for the observed occurrence probabilities, however a hypothesis of some special energy transportation to some limited longitudinal regions is needed to restrict radio emissions to be solely from Io-DAM source regions and to exclude non Io-DAM radio emissions.

We have examined whether this hypothesis is really needed based on the analyses of observation results for Io magnetic footprint aurora (IFA) brightness on the assumption that auroral brightness reflects intensity of Io-DAM emission. In this examination, we have referred the ten-year data of IFA observed by the far ultraviolet imaging instruments on board the Hubble Space Telescope (Wannawichian et al., 2013). As the result, IFA brightness at non-Io-DAM source longitudes is rather larger than those at Io-DAM source longitudes, which implies the hypothesis can be ruled out and demands some other processes/conditions to fulfill the Io-DAM occurrence nature.

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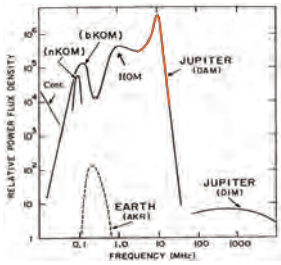

Fig. Schematic plot of Jupiter's non-thermal radio emissions.(Kaiser, 1993)

DAM: >10MHz

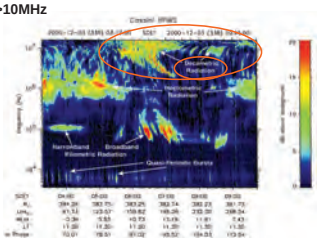

Fig. f-t diagram obs. by Cassini.(Gurnett+, 2002)

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ABSTRACT

The following question; 'How Jupiter's auroral radio emissions are generated?' has been long years of subjects. Especially the Io-related auroral emission component (Io-DAM) has shown mysterious nature of characteristic occurrence probability, that is, the occurrence strongly depends on both Io's positional angle and Jupiter's magnetic longitude to an observer. We have investigated this subject based on ray-tracing analyses using several kinds of magnetic field and plasma density models including a new JUNO based magnetic field model 'JRM09'. The analyses show that JRM09 gives more natural explanations for the observed occurrence probabilities, however a hypothesis of some special energy transportation to the Io-DAM source region is needed to restrict radio emissions to be solely Io-DAM emissions. We have examined whether this hypothesis is really needed based on the analyses of observation results for Io footprint aurora (IFA) brightness on the assumption that auroral brightness reflects intensity of Io-DAM emission. As the result, IFA brightness at non-Io-DAM source longitudes is rather larger than those at Io-DAM source longitude, which implies the hypothesis can be ruled out and demands the some other ideas to explain the Io-DAM occurrence nature. In this presentationr we would like to discuss with you what this result means.

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1. Introduction: Obvious Occ. Characteristics of Io-DAM

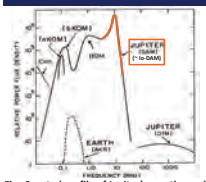

Fig. Spectral profile of Jupiter's non-thermal radio emission (Kaiser, JGR, 1993)

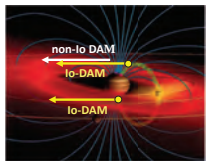

Fig. DAM & Io-DAM (after J. Spencer)

●Obvious Char.1: Occurrence probability

➔ Localized Sources

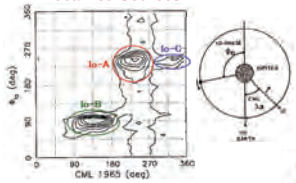

Fig. Occurrence prob. for DAM (obs. by Tohoku U. in 1974-1994)

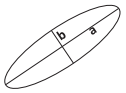

Fig. Polarization ellipse: Axial ratio (AR) is defined as b/a ～ (L-R)/(L+R)

●Obvious Char.2: Polarization

➔ Excellence of RH elliptical pol.

・・・ Its interpretation:

Next opportunity

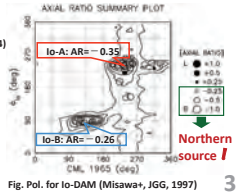

Fig. Pol. for Io-DAM (Misawa+, JGG, 1997)

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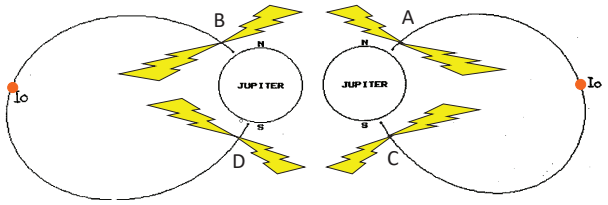
Appendix. Explanation of Io-DAM source configuration



Io-B (,D) @dawn source Io-A(,C)@dusk source

Fig. Schematic plots of wave source regions of Io-A~D DAM emissions

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1. Introduction: Purpose of this study

Clarification of Origin of Io-DAM ・・・ No reliable direct obs.

➔ Investigation of origin (generation & propagation processes) of Io-DAM using numerical analyses ("ray trace", "polarization trace") with comparison of observed occurrence nature

- Magneto-ionic mode ? (R-X or L-O?)
- Generation conditions? (Source location, Initial ray direction, Energy supply process..)
- Plasma conditions in source & propagation regions? ・・・➔ next step (polarization analysis)

1. Introduction: Latest numerical (Ray-tracing) analysis for Io-DAM

Method: 3D Ray-tracing (Misawa+, Planet. Radio Emissions IX meeting, 2022):

- model of magnetic field : JRM09 (Connerney+, GRL, 2018)
- model of plasma density : Ne_{max}~6×10^5[cm^{-3}], T~1300K (Grodent+, JGR, 2001)
- wave mode : R-X & L-O

Results:

- wave mode : "R-X"
- wave direction : ～90° to B
- lead angle : ～20° ～
- special requirements : "selective energy input" for the longitudes of northern Io-DAM sources

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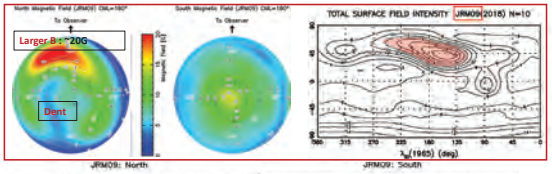
2. Magnetic field model of Jupiter for Ray-tracing

● Magnetic field model: "JRM09 (Juno Reference Model through Perijove 9)" (Connerney+, GRL, 2018)



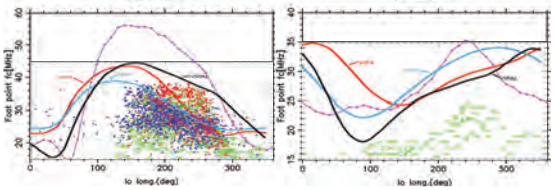


Fig. [top] Total magnetic field intensity map of the JRM09. [bottom] Previous mag. models vs. JRM09 with respect to Io-DAM freq. Green: Genova & Aubier, 1985./Blue(Io-A) & Red(Io-B) Zarka+, 2002. (after Hess et al., 2011(VIP4, VIT4, VIPAL))

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2. Plasma density model of Jupiter's ionosphere

・ Diffusive equilibrium $Ne(z)=Ne_0\times\exp(-z/H)$, $H=2K_BT/m_Hg(z)$

※T:1300K(Grodent+, 2001) or more(1600K by Voyager2:Eshleman+, 1979)

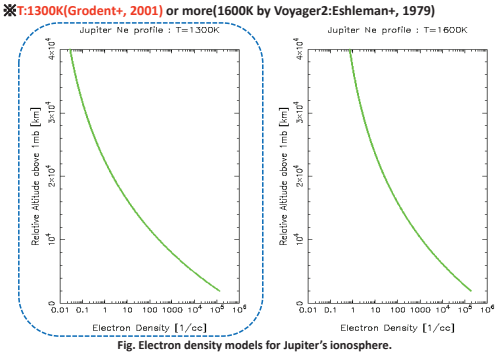

Fig. Electron density models for Jupiter's ionosphere.

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3. Numerical analysis: Explan. of 'Observable Ray Map' & 'Lead Angle'

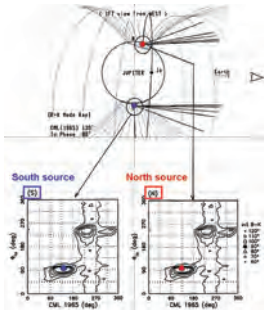

Fig. 'Observable Ray Map'

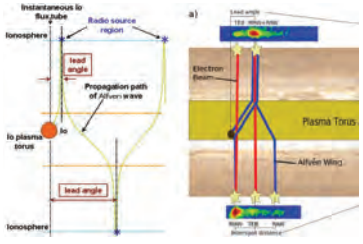

Fig. Observed 'Lead Angle'. (Bonfond+, GRL, 2008 (after Hess+, JGR, 2011))

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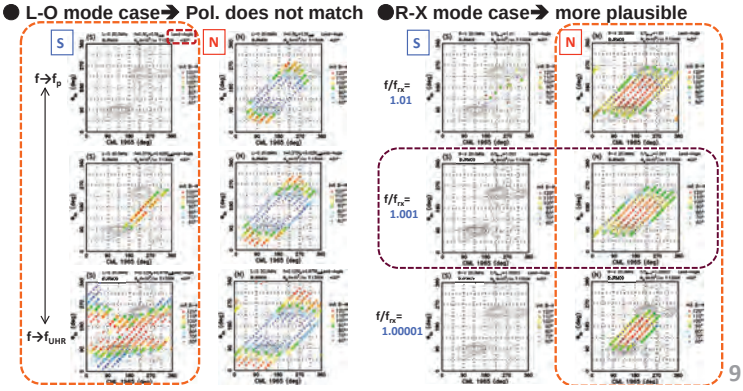
4. Ray-tracing result: L-O/R-X difference – observable source position

● L-O mode case➔ Pol. does not match ●R-X mode case➔ more plausible



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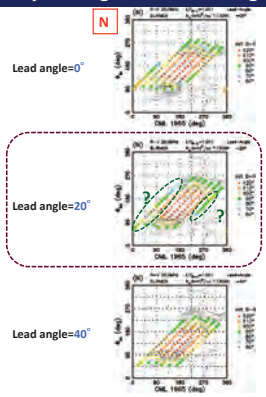
4. Ray-tracing result: Lead angle depend. & Required conditions for 'Io-DAM'



・RH pol. from N-hemis.
・DAM only from N-hemis. (condition: $f/f_{R\text{-}X}$<1.0005)
➔ meet with obs.

・Lead Angle ~ 20° ~
・Cone half angle ~ 90±10° ~
➔ meet with theoretical expectations.

◎R-X mode is more preferable as Io-DAM
◎JRM09 gives more natural explanation for origin of Io-DAM

BUT

・Still remaining a bit 'non Io-DAM' for adopting the Io-DAM conditions
➔➔ some special energy inputs to solely the Io-DAM source region may be needed???
・Origin of Io-C
➔➔ need some L-O mode Io-DAM???

Fig. Results for R-X Io-DAM with lead angles.

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5. Discussion: Special energy input to Io-DAM source region?

●Exam. of brightness of Io footprint aurora

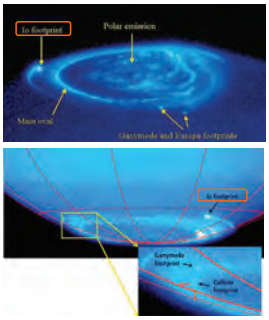

Fig. HST images of Jupiter's UV aurorae.
(Top: Clarke+, 2004, Bottom: Bhattacharyya+, 2018)

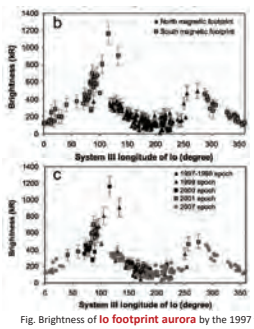

Fig. Brightness of Io footprint aurora by the 1997 – 2007 HST obs. (Wannawichian+, 2013)

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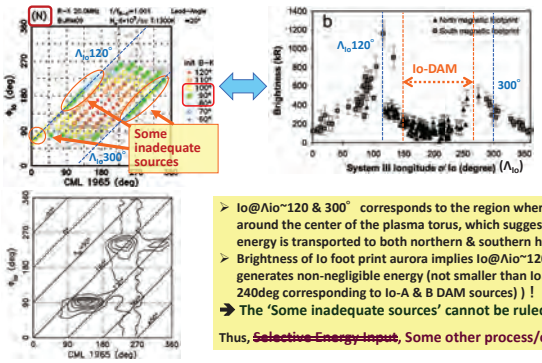
5. Discussion: Special energy input to Io-DAM source region?

"Result of ray tracing" vs. "Brightness of Io footprint aurora"



➢ Io@Λio~120 & 300° corresponds to the region where Io locates around the center of the plasma torus, which suggests Io-genic energy is transported to both northern & southern hemispheres.
➢ Brightness of Io foot print aurora implies Io@Λio~120 & 300deg generates non-negligible energy (not smaller than Io@Λio~150-240deg corresponding to Io-A & B DAM sources)) !
➔ The 'Some inadequate sources' cannot be ruled out !

Thus, ~~Selective Energy Input~~, Some other process/condition?

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5. Discussion: Special energy input to Io-DAM source region?

Then, what does this result mean?

- Possibility 1: Auroral brightness does not reflect DAM intensity ?
  ➔ Need precise comparison of intensities between Io-DAM and Io footprint aurora
  ・・・now requesting the timing data of Io footprint auroral intensity to S. Wannawichian
  c.f. There was comparison among X-ray, UV and (Non Io-) DAM (Dunn+, 2020), that result seems to be correlative but not quantitative…

- Possibility 2: Actual Jupiter's magnetic field is still different from 'JRM09'?
  ➔ Maybe 'No'?
  ・・・The newest magnetic field model 'JRM33'(Connerney+, 2022) is not so different from 'JRM09', but need confirmation using the ray-tracing

- Possibility 3: Some other reasons???
  ➔ ex. critical wave generation conditions, such as generated ray direction depending on input particle energy (energy dependent hollow cone) meeting with Io-DAM…

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6. Summary

●Purpose: Investigation of origin (Source location, Wave mode, Generation conditions, Energy supply process) of Jupiter's Io-DAM emission

●Method: 3D raytracing & Examination on 'Selective Energy Input' for solely Io-DAM source longitudes
Conditions(Ray-tracing): ・R-X & L-O mode waves from both S & N hemis.
・Including Lead-angle
・Diffusive equilibrium Ne model (T=1300K)
・New Mag. Field Model "JRM09"
Method of 'Selective Energy Input' Examination: Evaluation of brightness of Io footprint aurorae

●Results & Discussions:
Ray-tracing: R-X mode from the N-hemis. with Lead-angle ~20deg, cone half angle~90deg are plausible.
・・・'JRM09' like mag.-field gives more natural exp. for Io-DAM,
BUT some special energy inputs to solely the Io-DAM source region may be needed.
Examination on possibility of 'Selective Energy Input': Io@'some inadequate (non Io-DAM) sources' generates non-negligible energy (not smaller than Io@'Io-DAM sources) !

・・・There still remaining questions on causalities of Io-DAM occ. probab. Any other processes/conditions?
➔ FUTURE SUBJECT.

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