Magnetosphere of Mercury
- Science Target for BepiColombo -

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BepiColombo Project Team

1: ISAS/JAXA

21 Feb. 2013

Mercury is :

Among the solar system planets

Smallest (Radius : 2440km)

But density is **high**

Inner most planet
Orbit around sun : 0.31-0.47AU

→ Difficult to go

Considered as **finally formed planet**

Has **intrinsic magnetic field**

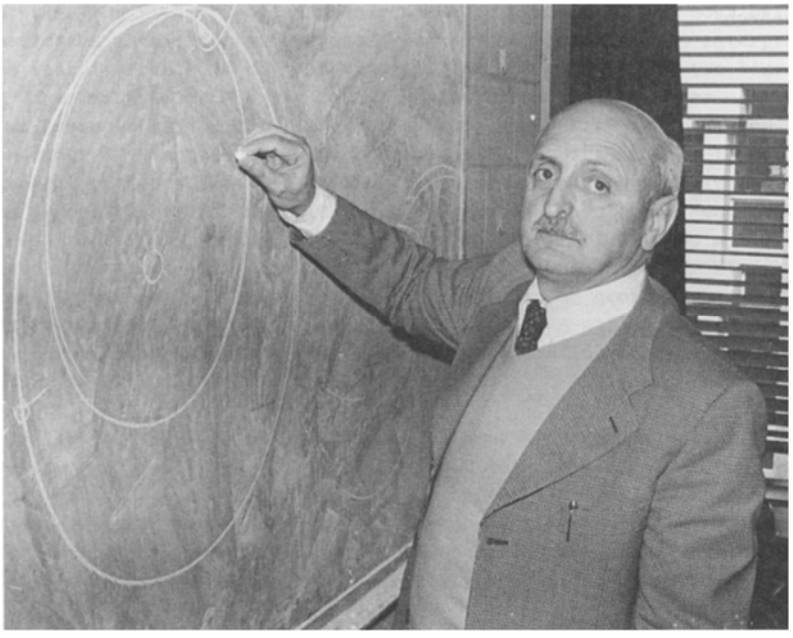
Only Earth and Mercury has intrinsic Magnetic field in solid planets

What is interesting

- How Mercury was formed
  - Planetary formation
- Why Mercury has intrinsic B-field.
  (＝Why, at least partially, Mercury has liquid core）
  - Thermal history
  - Dynamo theory
- Interaction with Solar wind
  - Particle acceleration
  - Mangnetospheric physics

etc…

Why the project name is BepiColombo



Italian mathematician and engineer of astonishing imagination.

He suggested how to put that spacecraft (Mariner-10) into an orbit that would bring it back repeatedly to Mercury.

He also explained Mercury's peculiar habit of rotating three times in every two revolutions of the Sun.

Bepi is a nickname for Guiseppe and the project name is after his name.

Prof. Guiseppe Colombo [Courtesy:BepiColombo Study Report]

BepiColombo: Two Orbiters

MPO (Mercury Planetary Orbiter) 3-axial

esa

～Low-altitude polar orbit: for Surface & Interior observations～
Study of the planetary formation near the Sun

Camera: Surface geology
IR/UV/X/Gamma/neutron spectrometer: Compositon
Magnetometer: Internal & Magnetospheric magnetic field
Precise orbit determination: Gravitational field, Relativity
etc.

MMO (Mercury Magnetospheric Orbiter) Spin

JAXA

～Elliptical polar orbit: for Magnetosphere & Exopsphere～
First comparative study of
the planetary magnetic field and Magnetosphere

Magnetometer: Internal & Magnetospheric magnetic field
Plasma particle, Electric field, Plasma waves:
Magnetosphere - Structure, Dynamics, enegetic processes
Energetic neutrals: Sputtered particles from Surface
Na imager: Exosphere – Structure & Variation
Dust: Interplanetary dust in the inner solar system

Mission Scenario

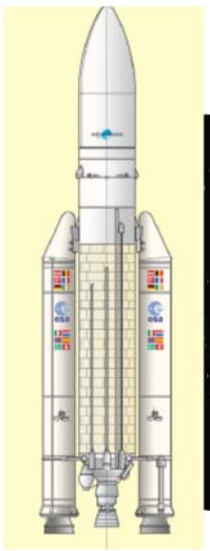
Launch: 2015 Aug.

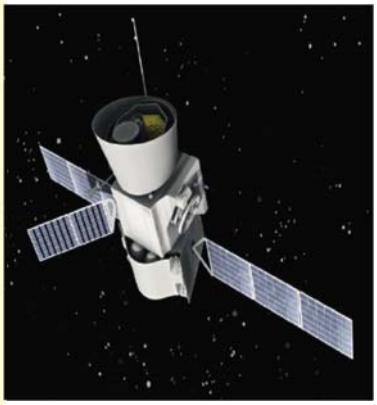
Venus swing-by x 2
Mercury swing-by x 4

Arrival: 2022

Interplanetary Cruising
Electric Propulsion
[MTM]

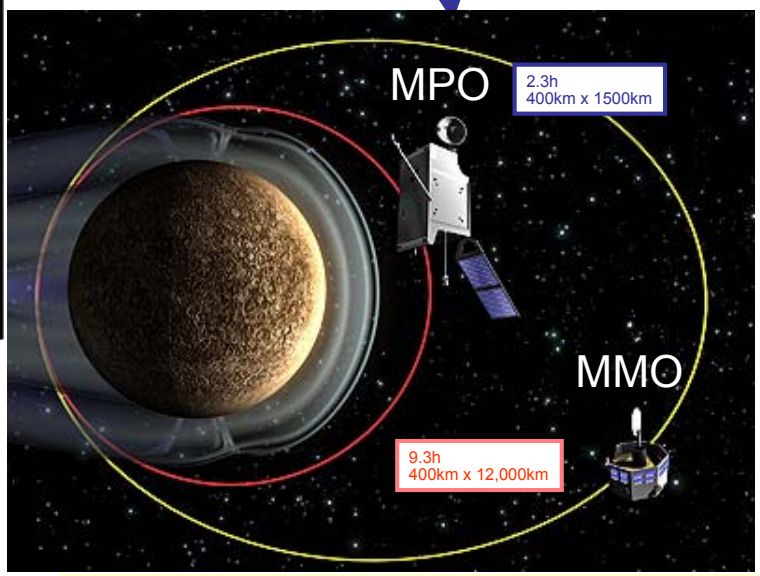
Mercury Orbit Insertion
Gravitational Capture





Ariane-5:
MPO+MMO

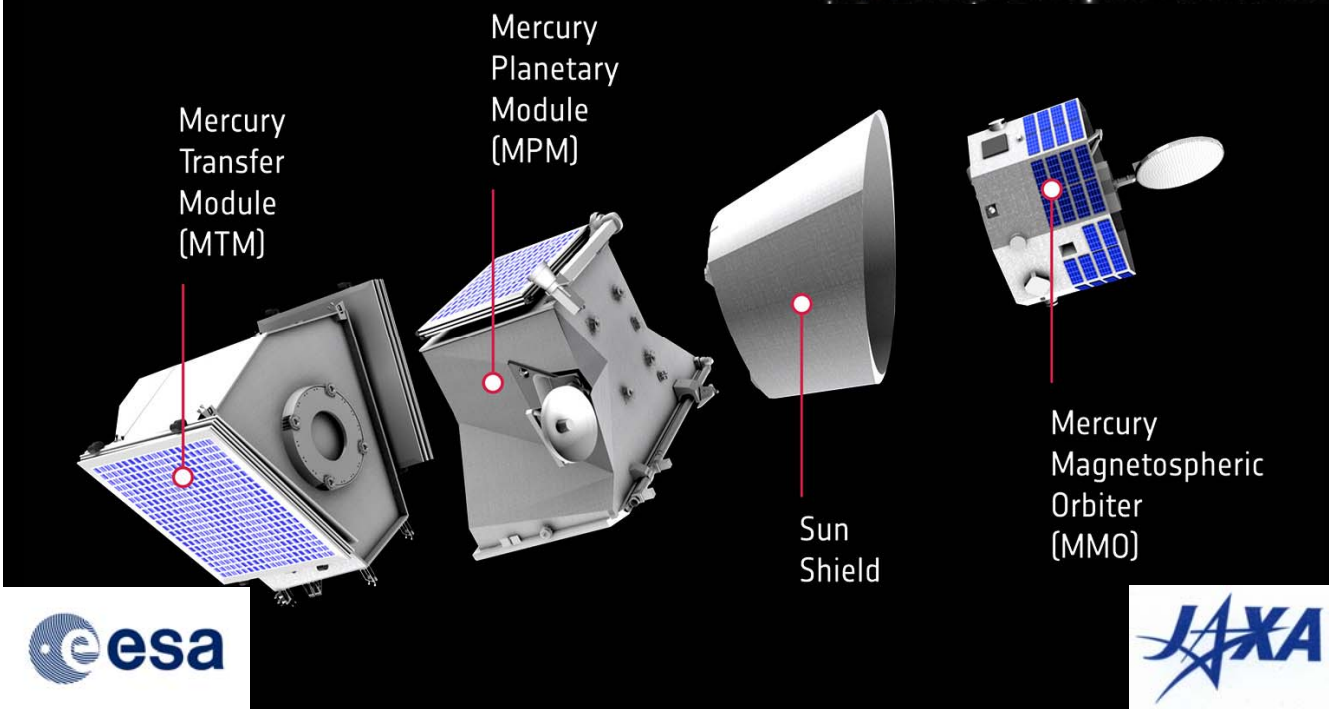
Red: JAXA
Blue: esa



Observation: 1 Earth year (+Extension)

BepiColombo

Spacecraft Configuration



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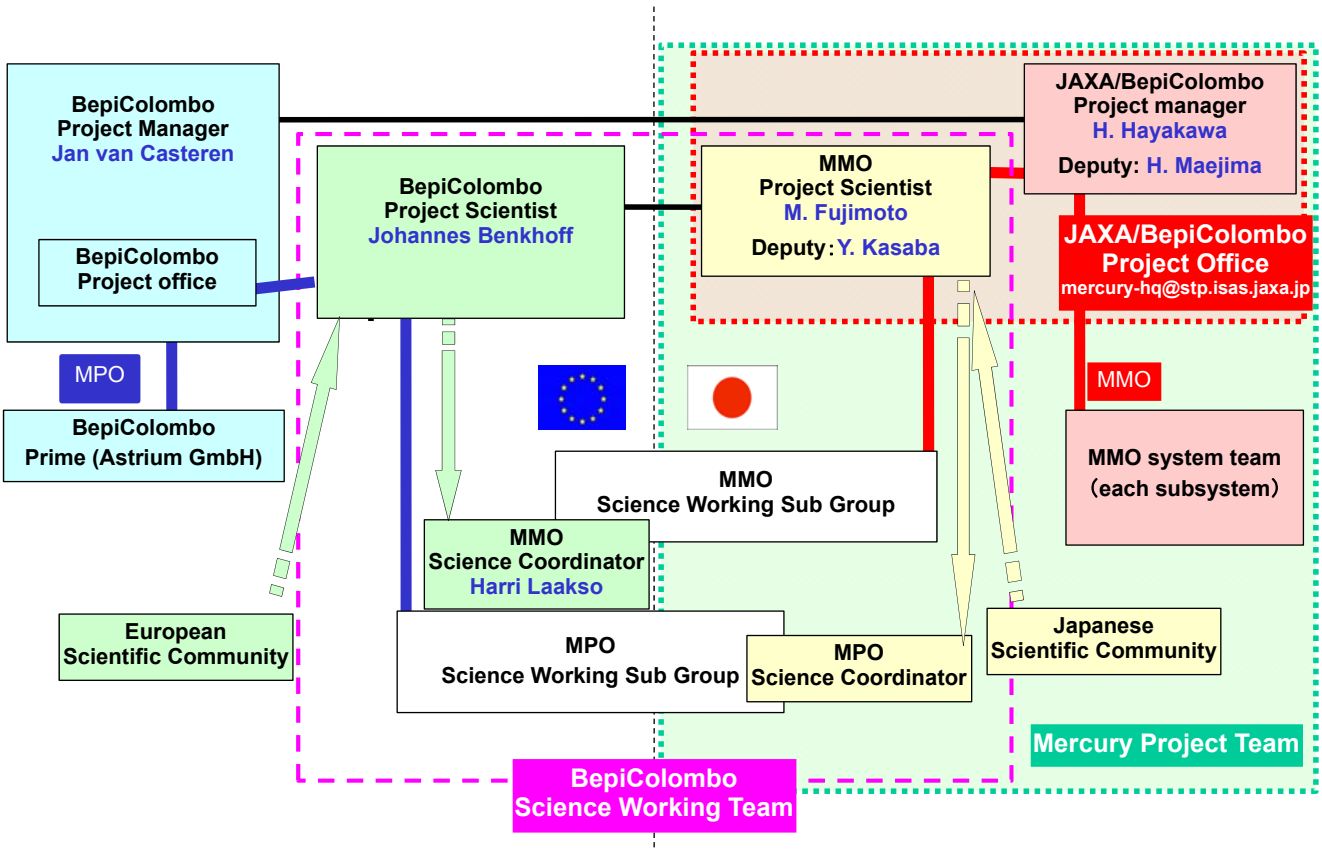
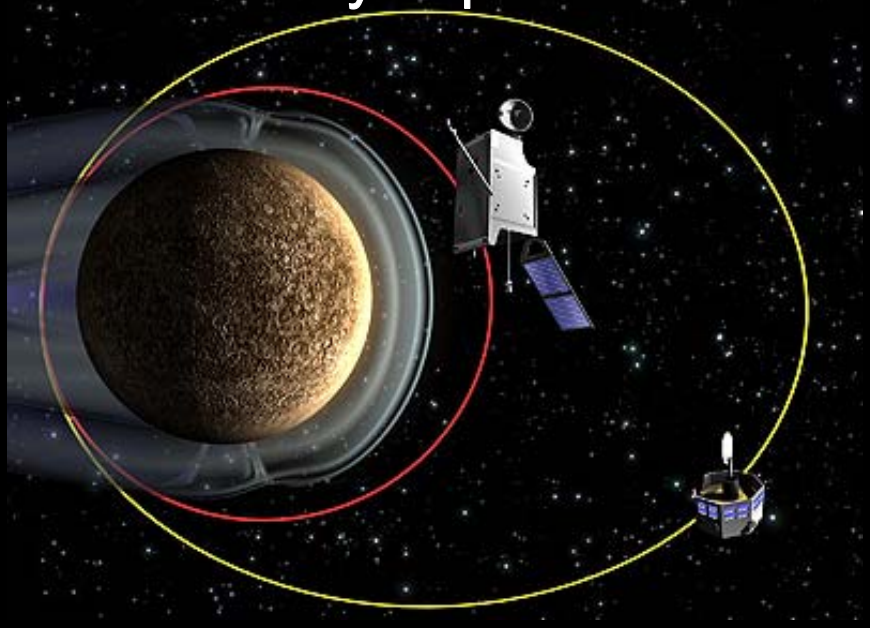
BepiColombo: Project Management Plan

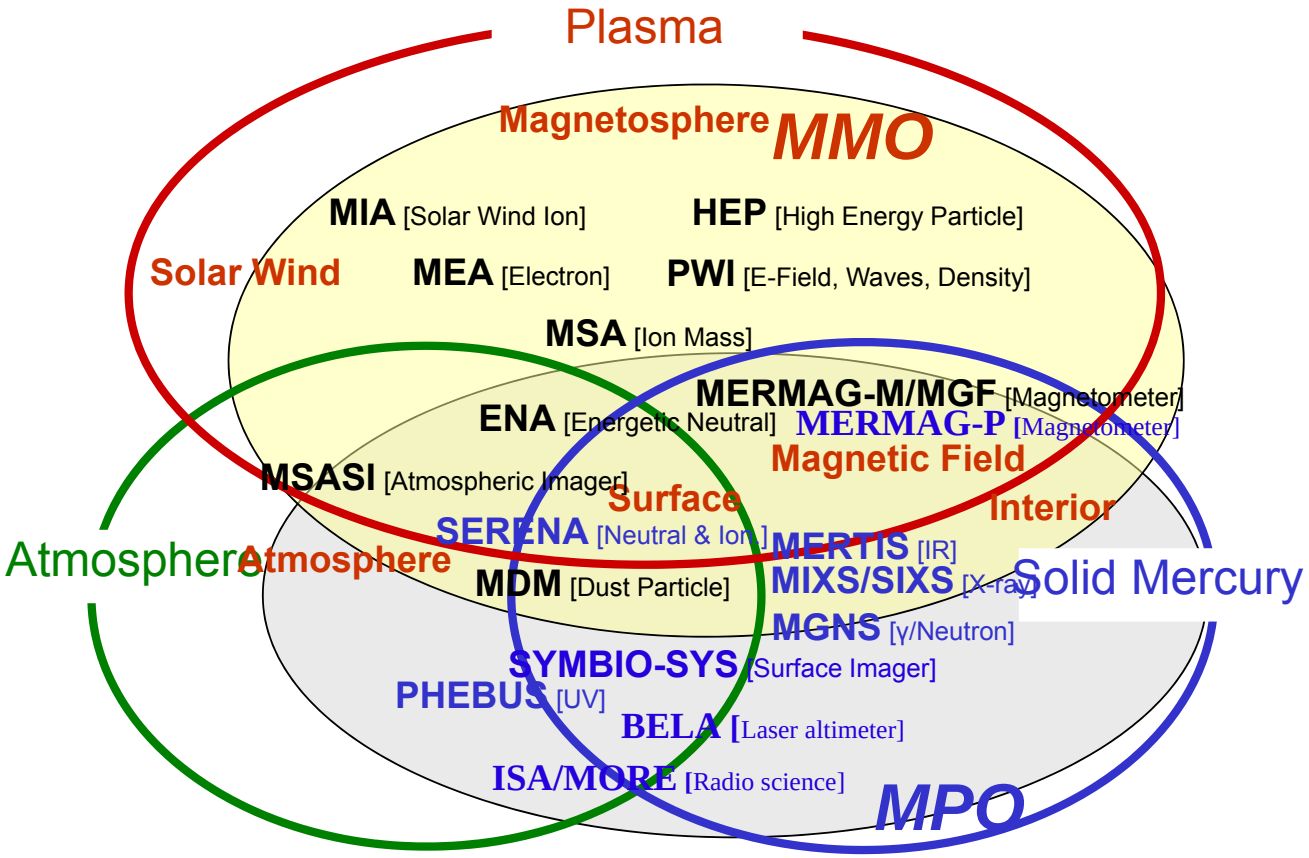


BepiColombo : Europe-Japan International Mercury Exploration



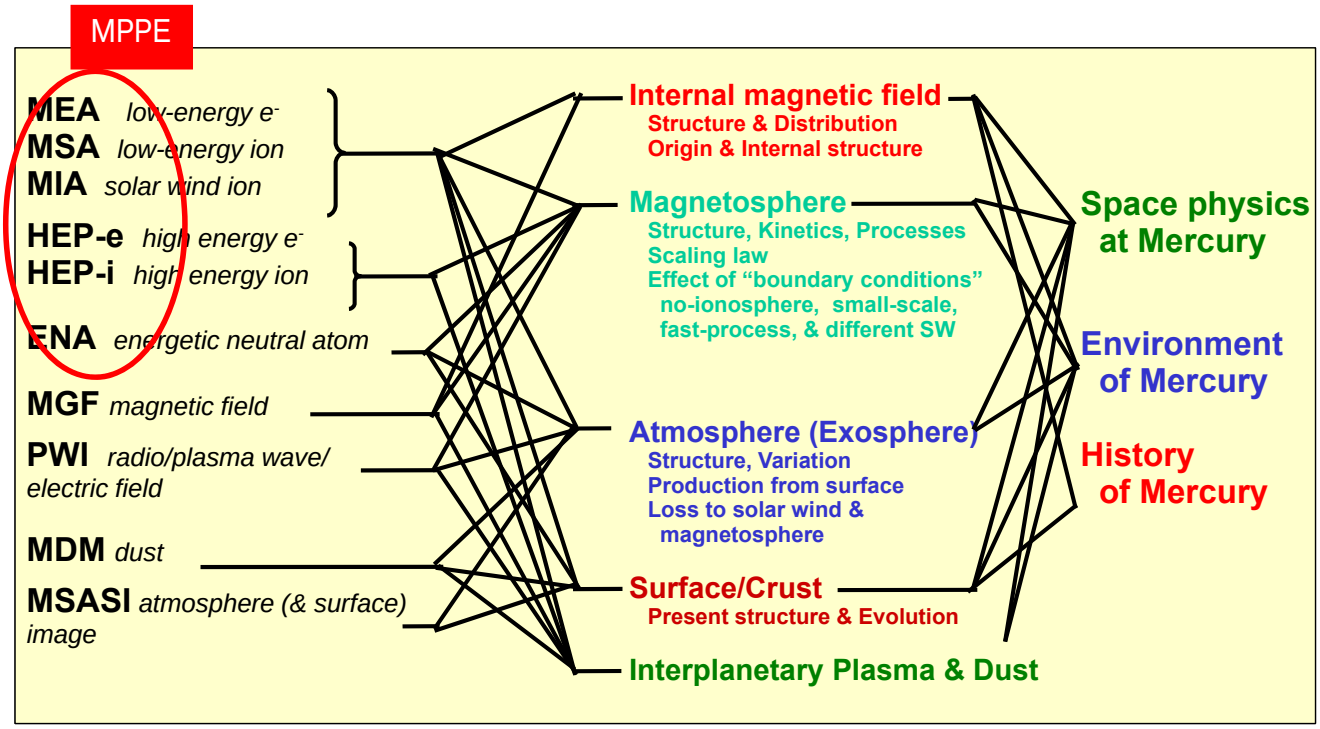
JAXA MMO: Plasma Processes
ESA MPO: Solid Mercury
MMO+MPO: Environment of Mercury with SW Interaction

BepiColombo: Science



MMO Payload: Selected

5 teams – MPPE, MGF, PWI, MSASI, MDM



MMO: Instruments

PI-Instruments

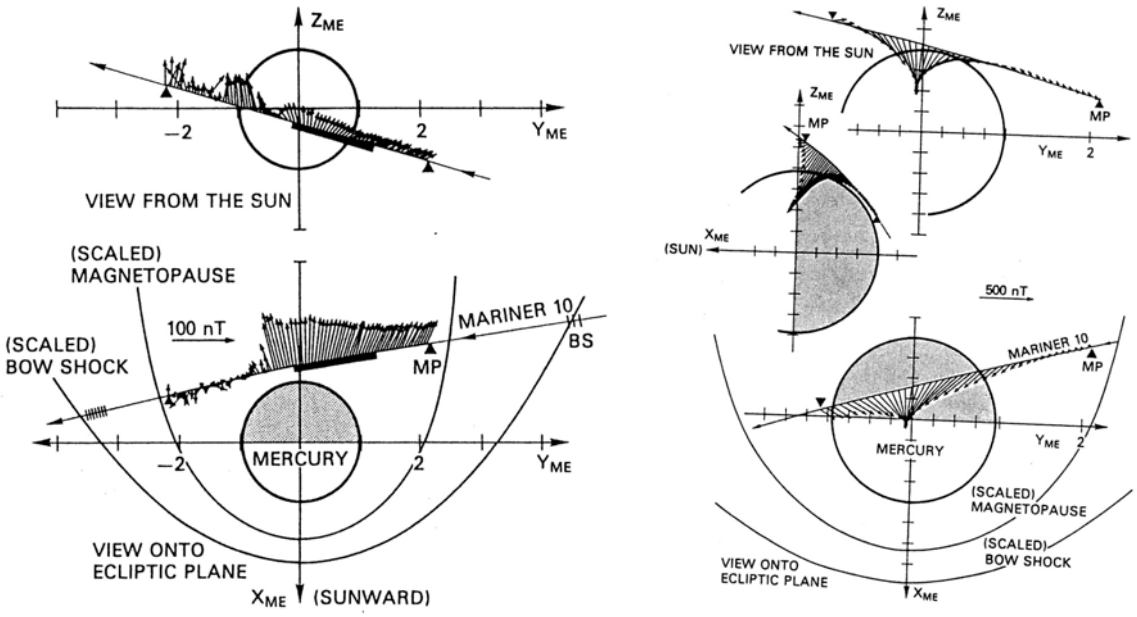
MPPE	Mercury Electron Analyzer (MEA)	Low-energy electrons	3eV ~ 30keV、dt=1sec
	Mercury Ion Analyzer (MIA)	Low-energy ions	5eV ~ 30keV、dt=2sec
	Ion Mass Spectrometer (MSA)	Ion mass spectroscopy	5eV ~ 40keV、dt=2sec m/dm=40/15
	High-Energy Ions (HEP-ion)	High-energy ions	30keV ~ 1MeV, dt=4sec
	High-Energy Electrons (HEP-ele)	High-energy electrons	30keV ~ 700keV, dt=4sec
	Energetic Neutral Atmos (ENA)	Plasma imaging	<25eV ~ 3.3keV, dt=80sec
Mermag-M	Magnetometer (MGF)	Magnetic field	DC ~ 64Hz [MAST:5m]
PWI	Plasma Wave Investigation (PWI)	Electric field, Plasma wave, Radio wave	DC ~ 10MHz (E) [probe:15m x 4] few ~ 640kHz (B) [MAST:5m]
MSASI	Mercury Imaging Camera (MIC)	Na-atmosphere image	FOV:~8°
MDM	Mercury Dust Moniter (MDM)	Interplanetary Dust	PZT

System-Instruments

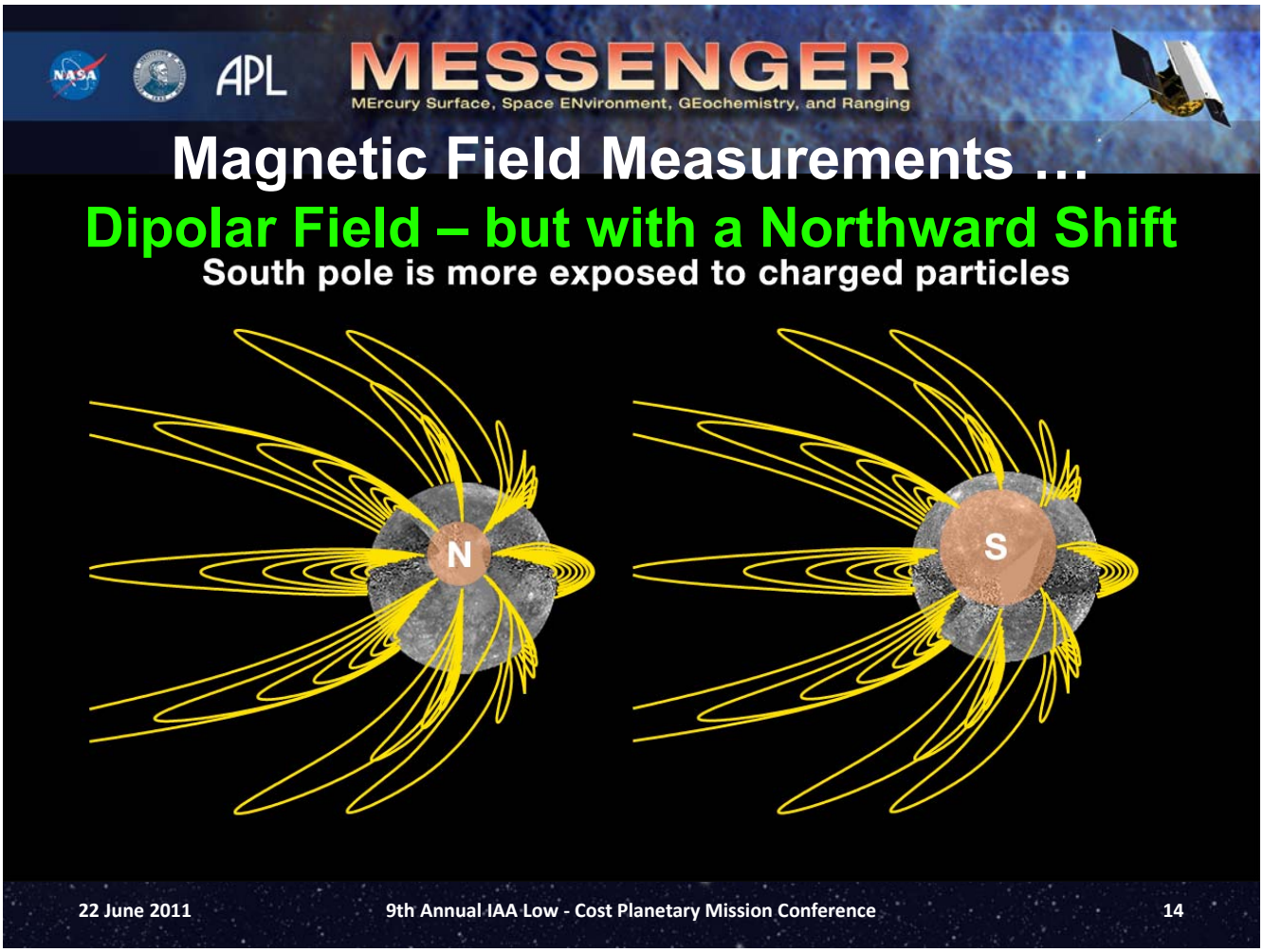
- Mission Data Processor (MDP) [2 units]
  - a. Power Conversion Unit (PCU): Supply of regulated powers
  - b. Data Processing Unit (DPU): CPU & memory unit (data processing, telemetry/command I/F, etc.)

- Coilable MAST [2 units]
  - 5m[TBD] MAST for AC/DC magnetic field measurements

- Mercury has intrinsic magnetic field.
  （Approx. 1/150 of the Earth's B-field at Equator）
- Mercury has magnetosphere.



[Connerney and Ness, 1988]



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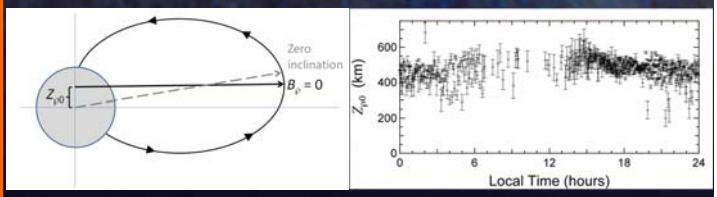
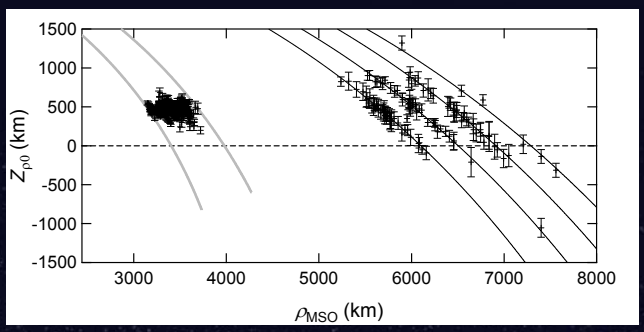
Success Criterion 3 – Accomplished and Published

- **Provide a multipole magnetic-field model resolved through quadrupole terms with an uncertainty of less than ~20% in the dipole magnitude and direction.**

- Magnetic equator determines dipole offset and quadrupole/dipole ratio.
- Plasma distribution and magnetospheric currents assumed symmetric about magnetic equator.
- Asymmetries due to interplanetary field average out over time.
- Systematic northward displacement of the dipole from the planet center shown by 479 ± 6 km (527 near-tail crossings) and 485±81 km (122 deep-tail crossings.
- Longitudinal variations limit dipole tilt to < 0.8° .



Anderson et al. [2011; 2012]



Magnetic equator crossings to March 2012
***Anderson et al.* [2012]**

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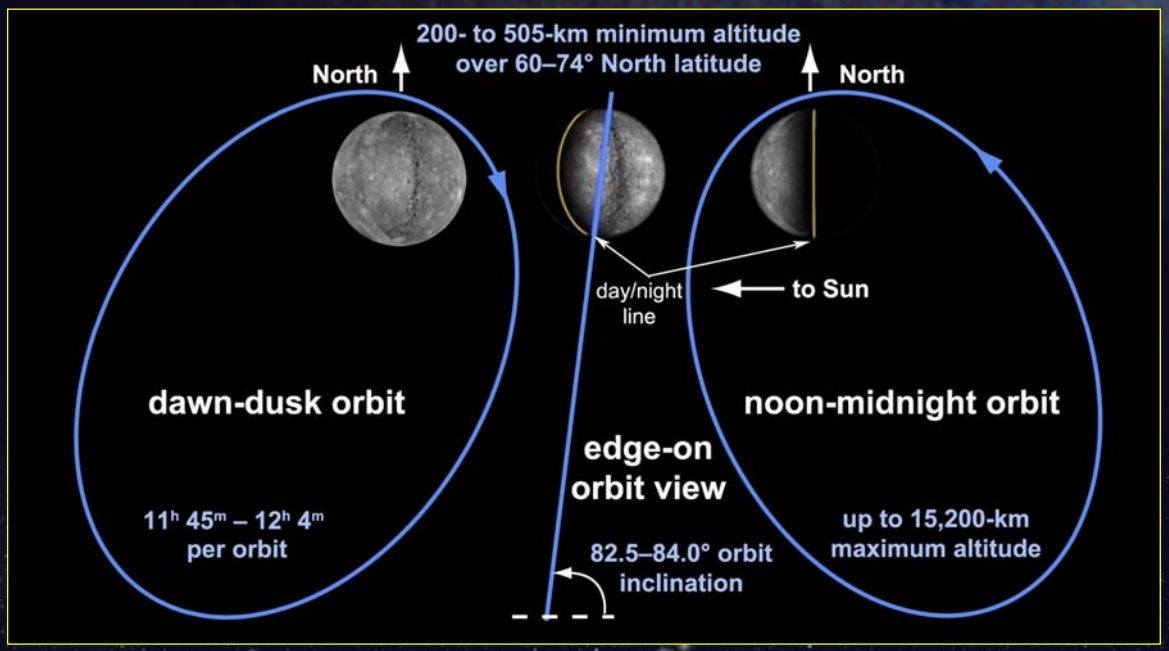
Primary mission observations were made from a highly elliptical, inertially fixed orbit.



Mercury's Magnetosphere

What is Universal / Unique of Magnetospheric Physics?

First detailed mapping of magnetosphere of other planet!

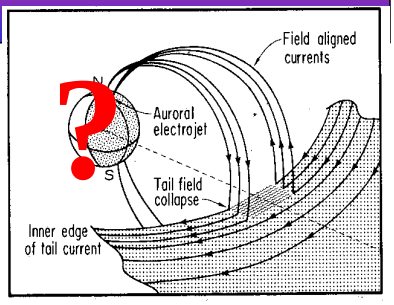
Q1) Small scale magnetosphere:
Is it similar to the Earth's?

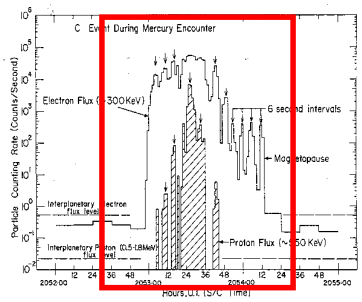
Q2) Source and Loss:
How is the plasma supplied and lost?

Q3) What is caused by the lack of Ionosphere?
How is the current closure?

Q4) Substorm & acceleration:
How is the Mercury's energetic process?

Q5) How is the interaction between surface, exosphere, and magnetosphere





Fast acceleration of electron above 200 keV

Detailed, full covered, and simultaneous E&B-Field and Particle observation is essential!

Scaling law problems

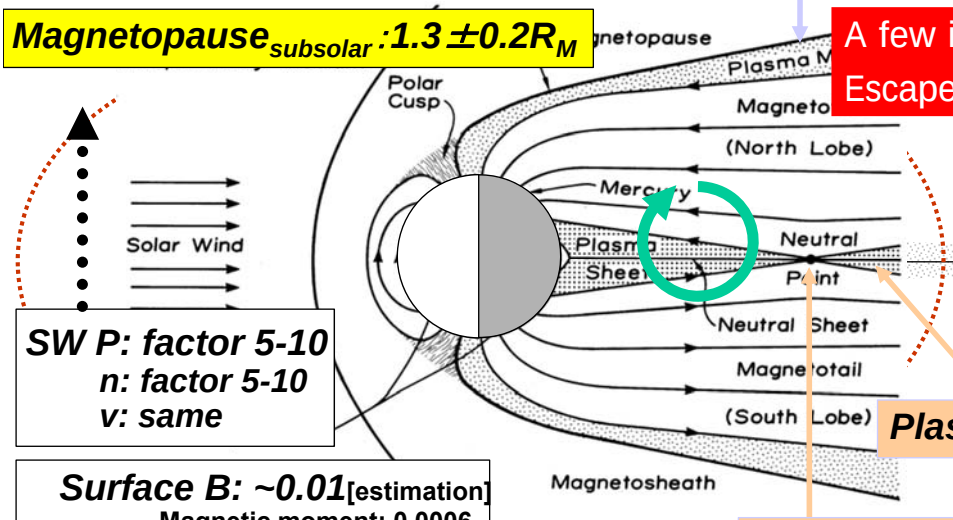
○Simple scaling law gives plasma sheet thickness as order of ion inertia length.
○"Huge" body occupies considerable part of inner magnetosphere
→ Is scaling law applicable to Mercury's magnetosphere ?

Distant Neutral Line :~16R_M ?

Tail radius: ~3R_M~8000km

Magnetopause$_{subsolar}$:1.3±0.2R_M

A few ion gyro-radius:
Escape with heating ?



SW P: factor 5-10
n: factor 5-10
v: same

Surface B: ~0.01 [estimation]
Magnetic moment: 0.0006
Planetary radius: 0.38

[Adopted fromj Russell et al., 1988]

~Ion inertia length:
unstable ?

Plasma sheet : ~400km?

Near Earth Neutral Line :~5R_M ?

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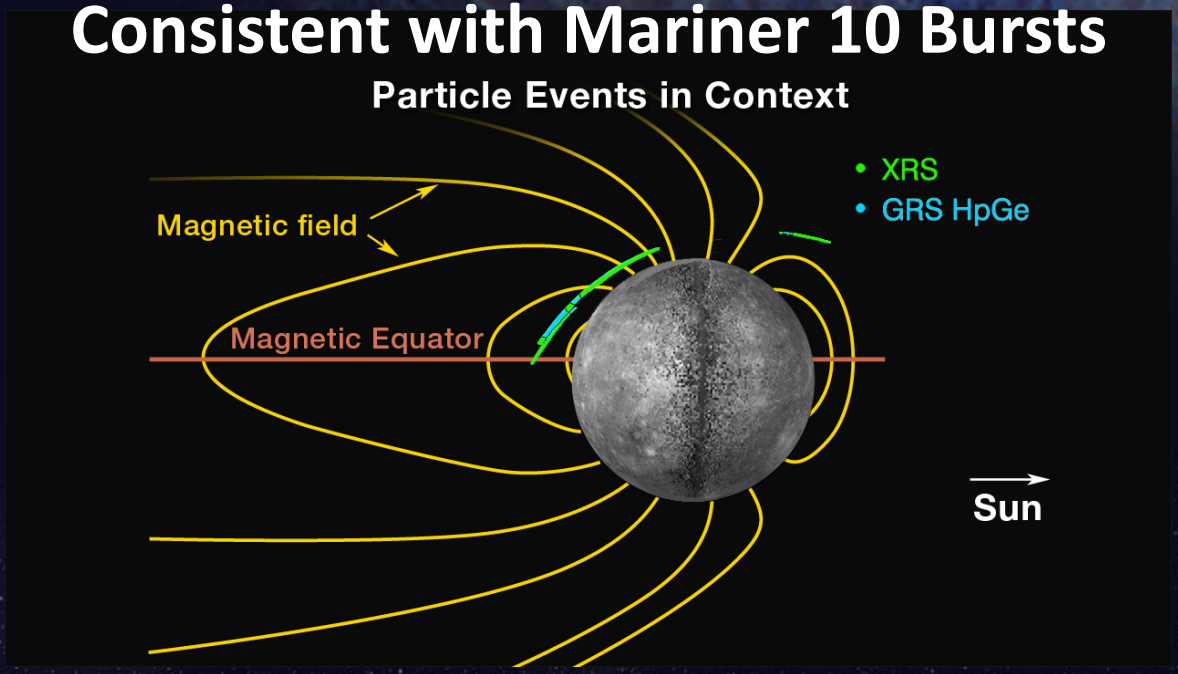
Locations of ~30 keV Electrons Consistent with Mariner 10 Bursts



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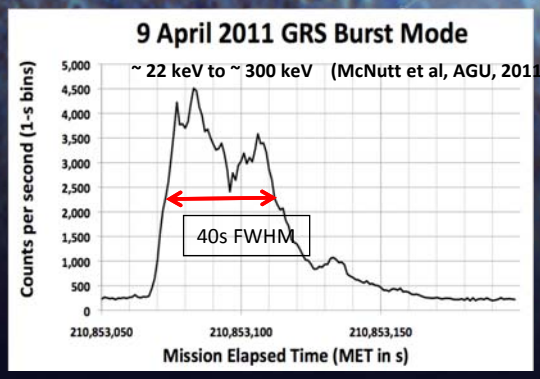
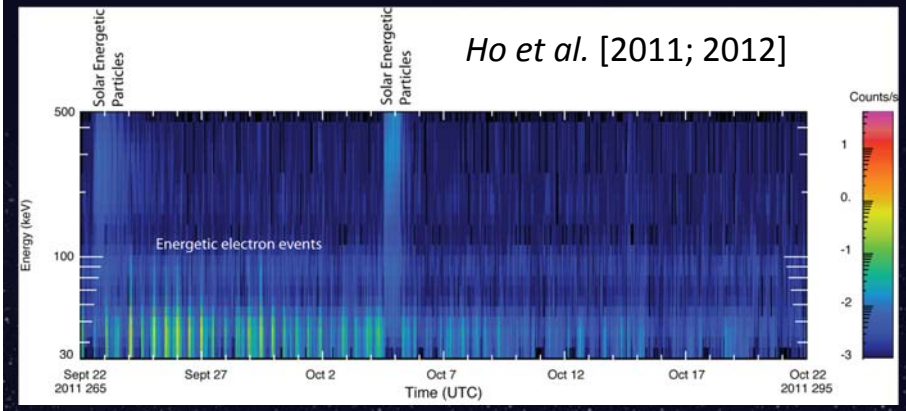
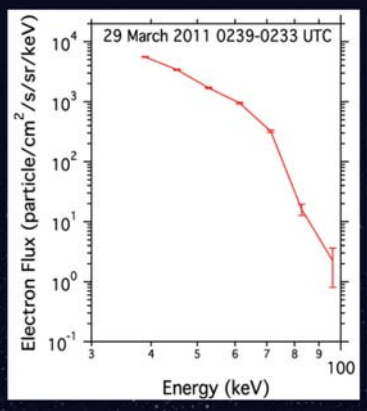
Energetic Electron Bursts

- Energetic electrons are observed on most orbits but with varying intensity and temporal history.
- Similar to Mariner 10 observations.
- Typically at high northern latitudes, consistent with only marginal detection (in XRS) during MESSENGER's Mercury flybys.



Ho et al. [2011; 2012]

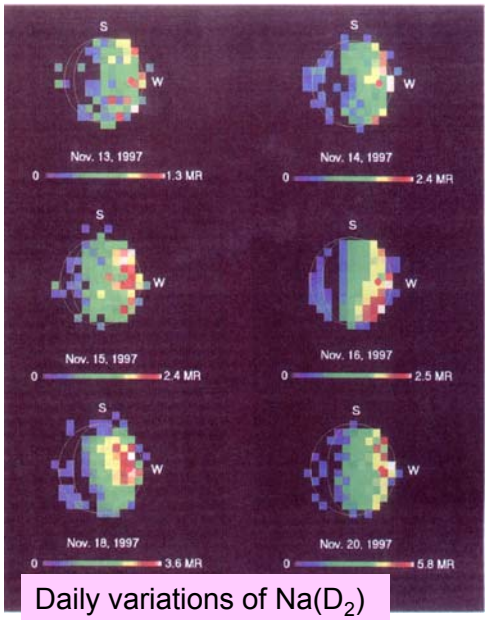




Mercury's Exosphere

- Na density (~10^6/cc) is almost same as H density.
- Large daily variation : Affected by solar wind/magnetosphere ?
- Affects to magnetosphere as temporal ionosphere and heavy particles with large gyration radius ?

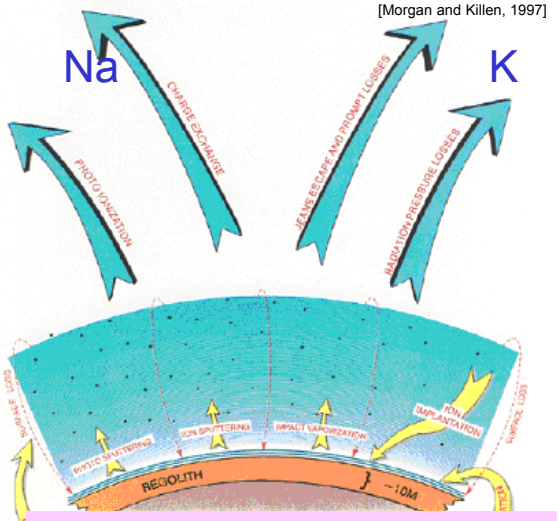
→ How to relate with magnetosphere ?



Daily variations of Na(D_2)

[Potter et al., 1999]

[Morgan and Killen, 1997]



Generated by sputtering with particles from magnetosphere ?
Affects magnetosphere as heavy ion ?

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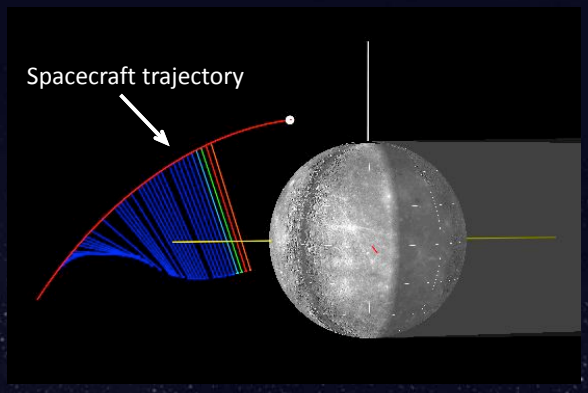
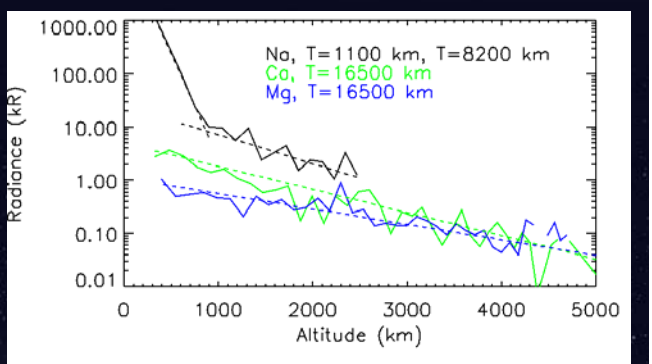
Success Criterion 6 – Part 1 – Accomplished

- **Provide altitude profiles at 25-km resolution of the major neutral exospheric species**
- Major neutral exospheric species have been identified: sodium, calcium, and magnesium
  - 1206 altitude profiles of Na
  - 1185 altitude profiles of Ca
  - 1187 altitude profiles of Mg
- Statistics for the three major species are similar
  - **Sodium exhibits a two-component structure**
  - **Magnesium and calcium are more energetic**

McClintock et al. [2011]





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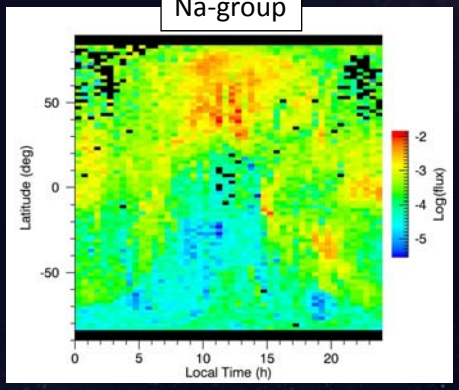
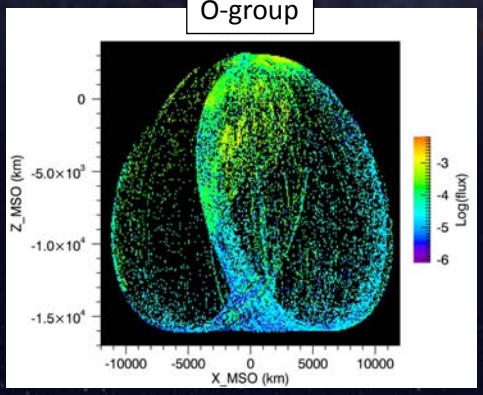
Success Criterion 6 – Part 2 – Accomplished

- **Characterize the major ion-species energy distributions as functions of local time, Mercury heliocentric distance, and solar activity**

Na-group



O-group



- Five ion species have been characterized for 3 Mercury years: H^+, He^{2+}, He^+, O-group (O^+, water group), Na-group (Na^+, Mg^+, Si^+); spatial and temporal behavior of the ionized exosphere-magnetosphere system has been documented.
- Reference: MESSENGER observations of the spatial distribution of planetary ions near Mercury, T. H. Zurbuchen et al., *Science, 333*, 1862–1865 (2011).

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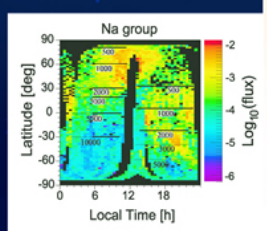
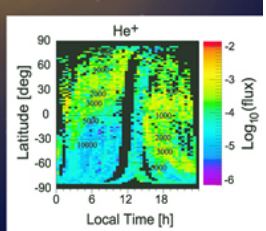
Heavy ion observations

Sodium (Na)



Helium (He)



Courtesy of NASA, JHU/APL, Carnegie Institution of Washington

SW parameters at Earth and Mercury

M_A around Mercury may be lower than that around Earth

Planet	R, AU	V_{sw}, Km/S	n_p, cm^{-3}	B, nT	T_p, 10^4°K	T_e, 10^4°K
Mercury	0.31	430	73	46	17	22
	0.47	430	32	21	13	19
Venus	0.72	430	14	10	10	17
Earth	1.00	430	7	6	8	15
Mars	1.52	430	3.0	3.3	6.1	13
(Scaling)	•••	R^0	R^{-2}	$R^{-1}(2R^{-2}+2)^{1/2}$	$R^{-2/3}$	$R^{-1/3}$

A set of 'typical' long term mean parameters at 1 AU have been scaled to the orbits of the other terrestrial planets by using the approximate radial dependencies displayed in the last row. The least certain scalings are those for temperature where the values of *Gazis et al.* [1981] for T_p and *Sittler and Scudder* [1980] for T_e have been adopted.

Planet	R, AU	P_{sw}, 10^{-8} dynes/cm^2	M_s	M_A	β	Q	c/ω_{pi}, km	Spiral Angle, deg
Mercury	0.31	26	5.5	3.9	0.5	15	27	17
	0.47	11	6.1	5.7	0.9	32	40	25
Venus	0.72	5.0	6.6	7.9	1.4	62	61	36
Earth	1.00	2.5	7.2	9.4	1.7	88	86	45
Mars	1.52	1.1	7.9	11.1	2.0	120	130	57

Using the basic parameters from the first table a series of plasma quantities relevant to planetary bow shocks have been computed; $P_{sw} = 1.16 n_p m_p V_{sw}^2$, $M_s = V_{sw}/(2k_B(1.14T_p + 1.08T_e)/1.16m_p)^{1/2}$, $M_A = V_{sw}(1.16 n_p m_p 4\pi)^{1/2}/B$, $\beta = 8\pi n_p k_B(1.14T_p + 1.08T_e)/B^2$, $Q = M_A = \frac{1}{2}P_{sw}8\pi/B^2$, $c/\omega_{pi} = 228/n^{1/2}$, and IMF spiral angle = $\tan^{-1}(R)$. In all cases, the solar wind plasma has been assumed to contain 4% He^{++} with $T_{He} = 3.5T_p$.

Slavin and Holzer, JGR, 1981

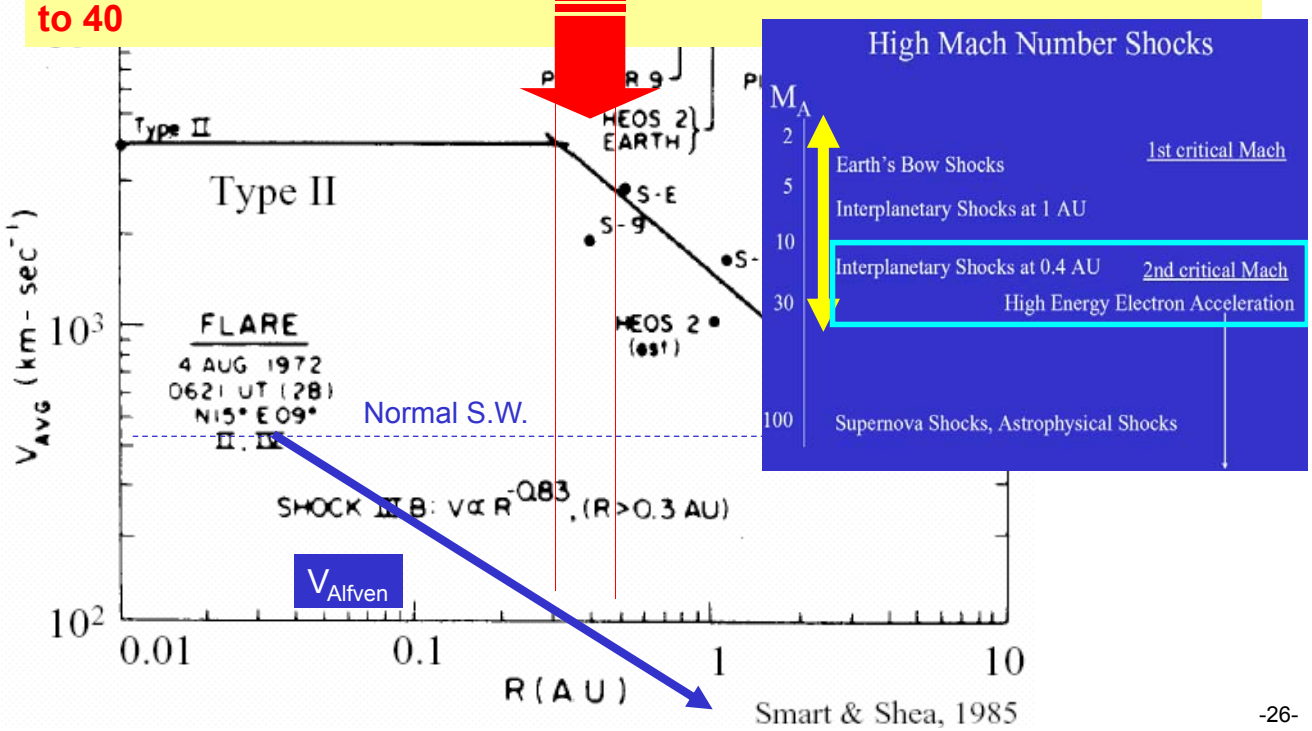
esa

Interplanetary Space: Solar Wind & Dust

JAXA ISAS

Shock speed do not decrease until perihelion of Mercury.

→ Rare opportunity to measure shock with Mach number up to 40

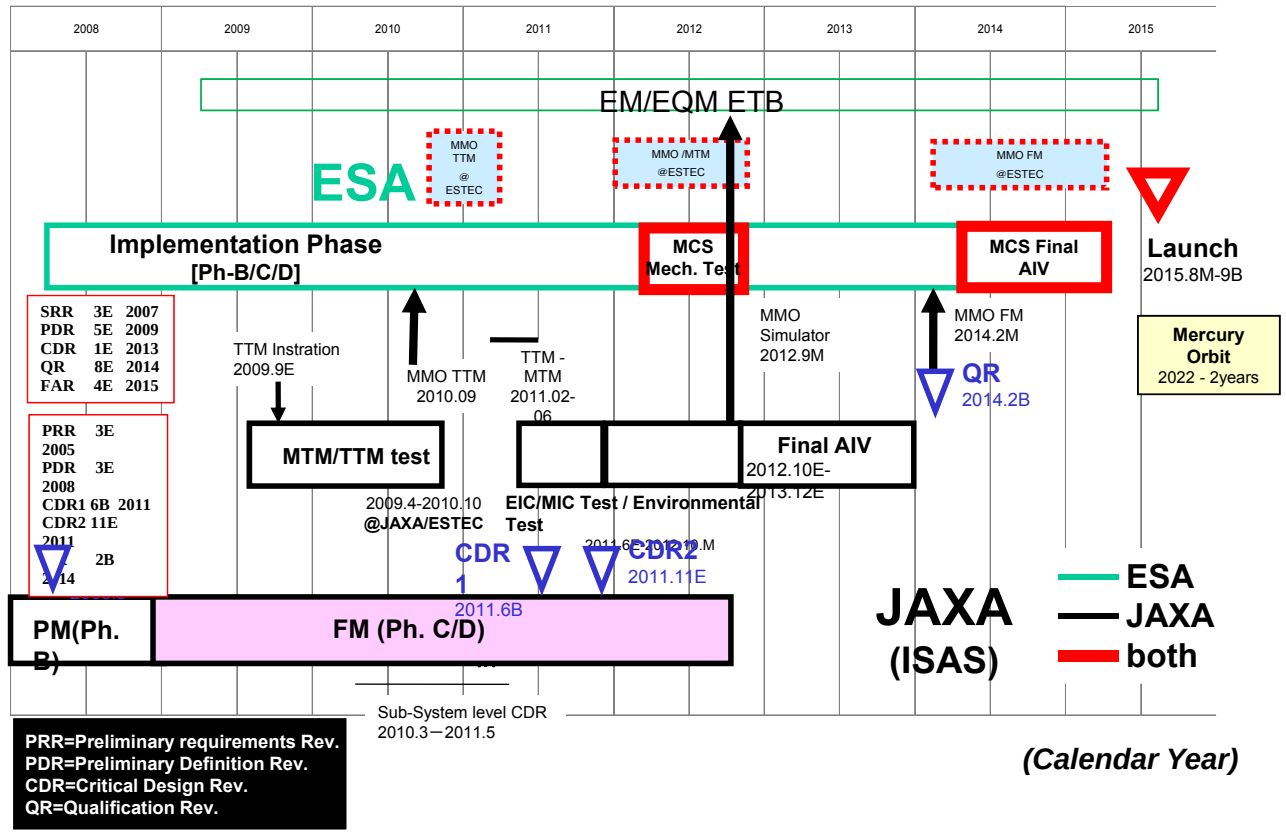


Target for BepiColombo MMO

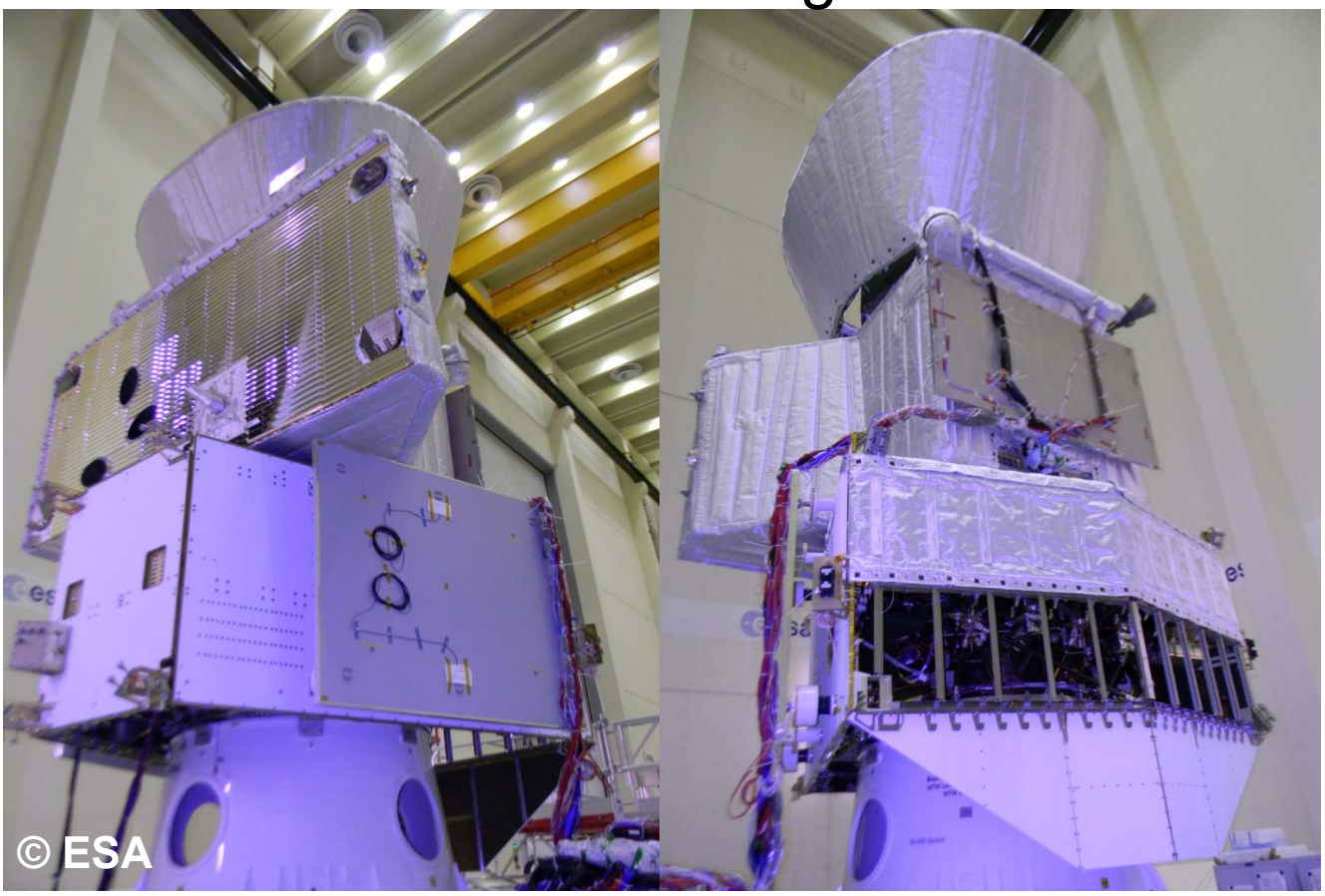
- Magnetic Field :
  - Offset dipole ? Higher term effect ?
  - How dynamo works.
- Neutral particles (Na …) :
  - Solar wind interaction ? Meteorite ? Or other mechanism ?
  - Tail distribution
- Plasma
  - Acceleration mechanism for the high energy electrons observed near Mercury
  - How to maintain tail plasma
  - Bow shock, Interplanetary shock
  - Instability

…

BepiColombo MMO Schedule (Oct. 2012)



MCS Stack Configuration



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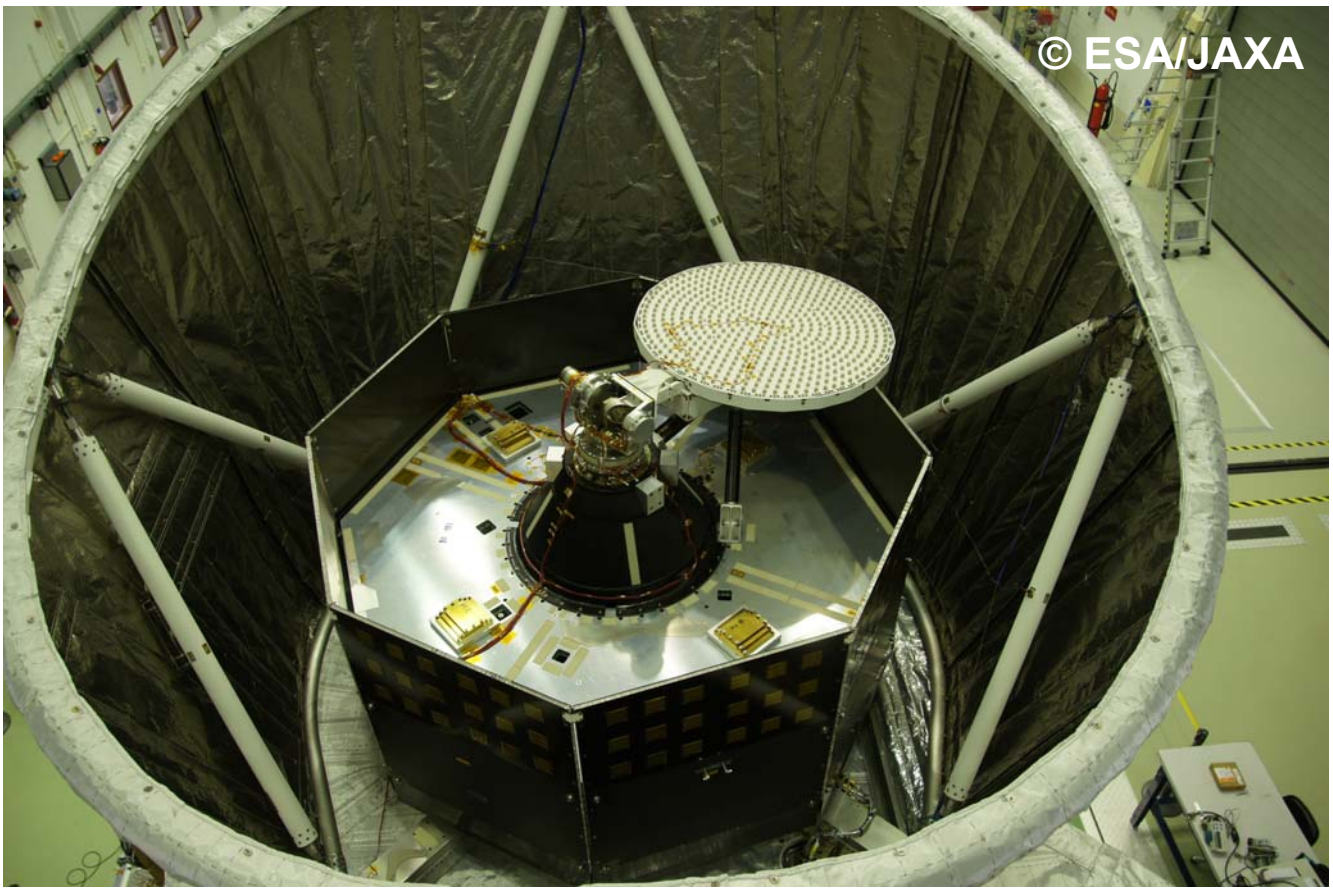
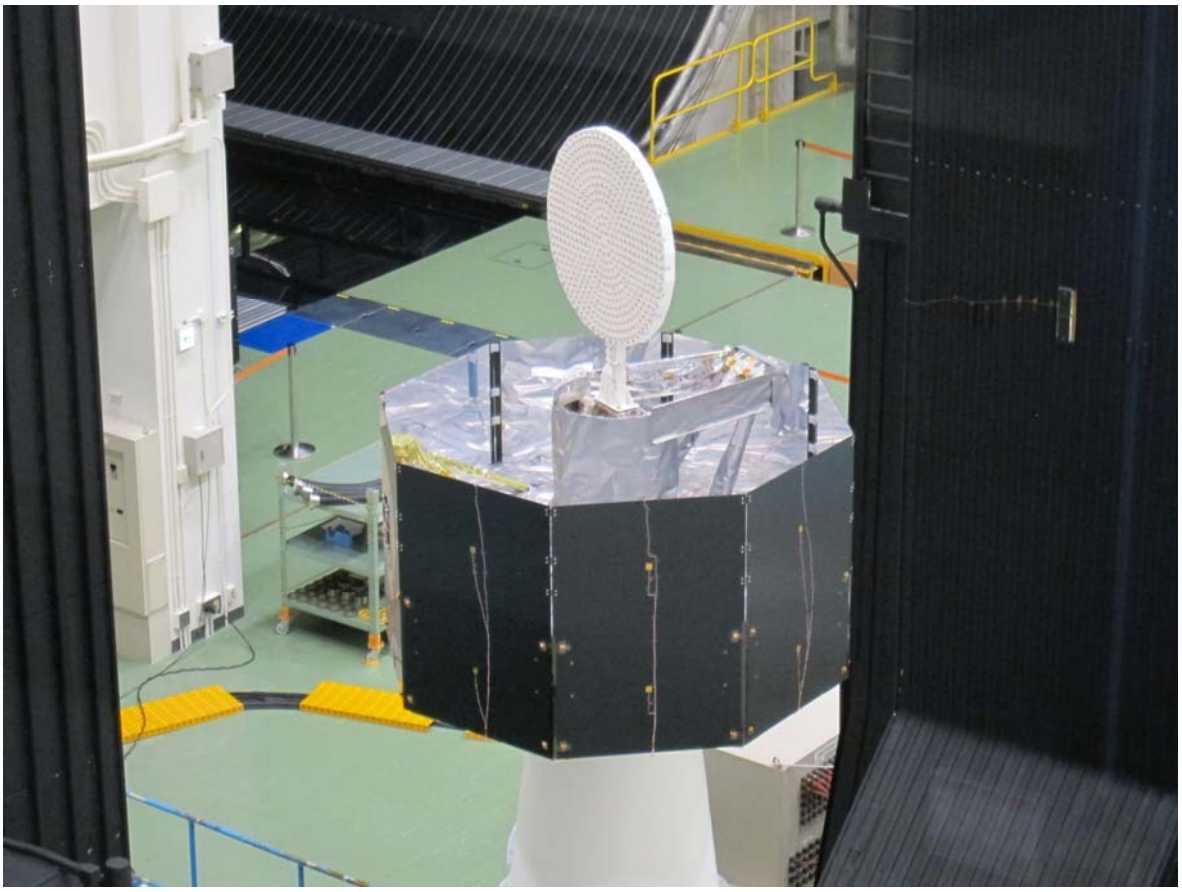
MCS Stack Configuration

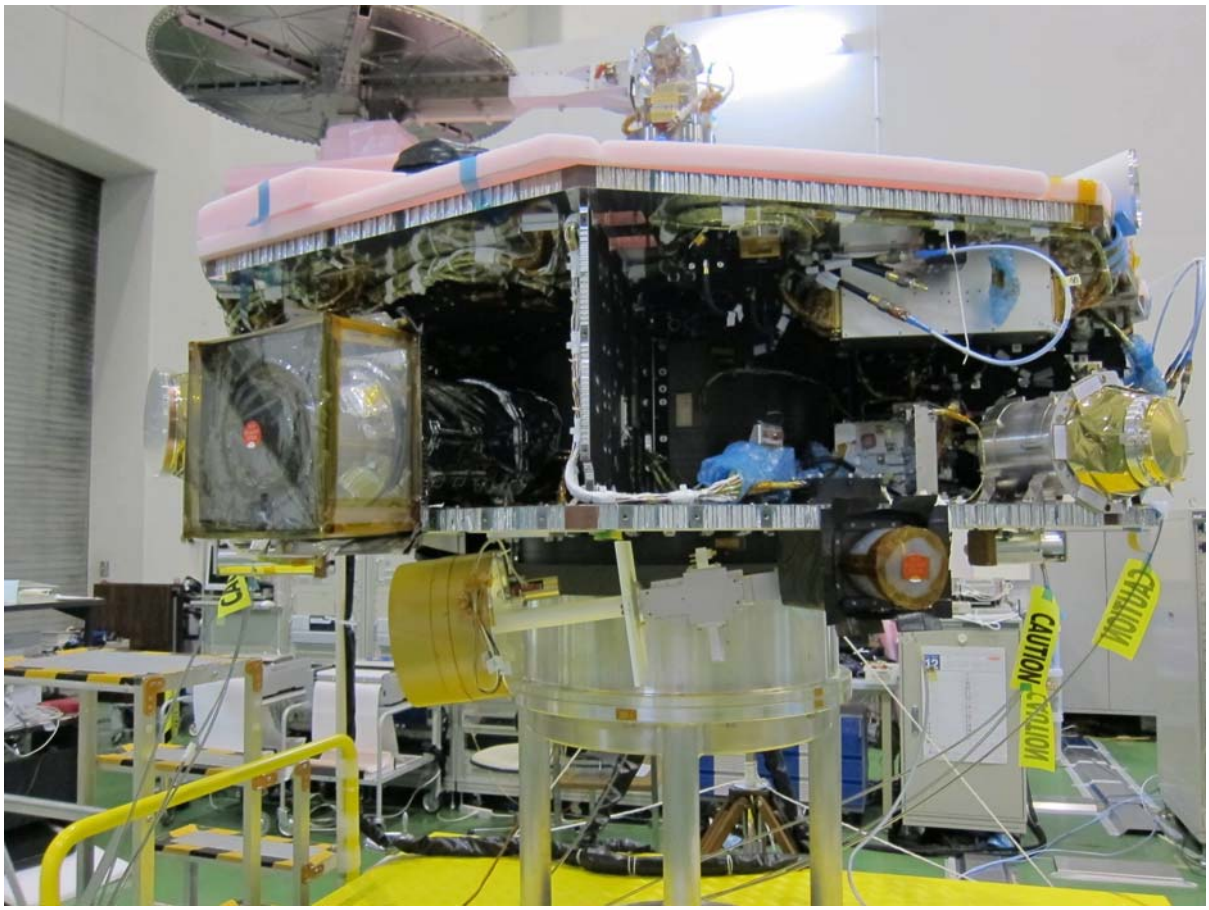




Additional 1SC TTM Test@TKSC

EIC/MIC on the Table Test Setup@ISAS

EIC/MIC Test Setup@ISAS



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EIC/MIC Test Setup@ISAS