11:15-11:45

11 October 2017

Planetary Space Weather

Europlanet NA1 workshop @Toulouse, France

Space weather at Mercury: two point measurements with BepiColombo

Go Murakami

BepiColombo project

JAXA/ISAS

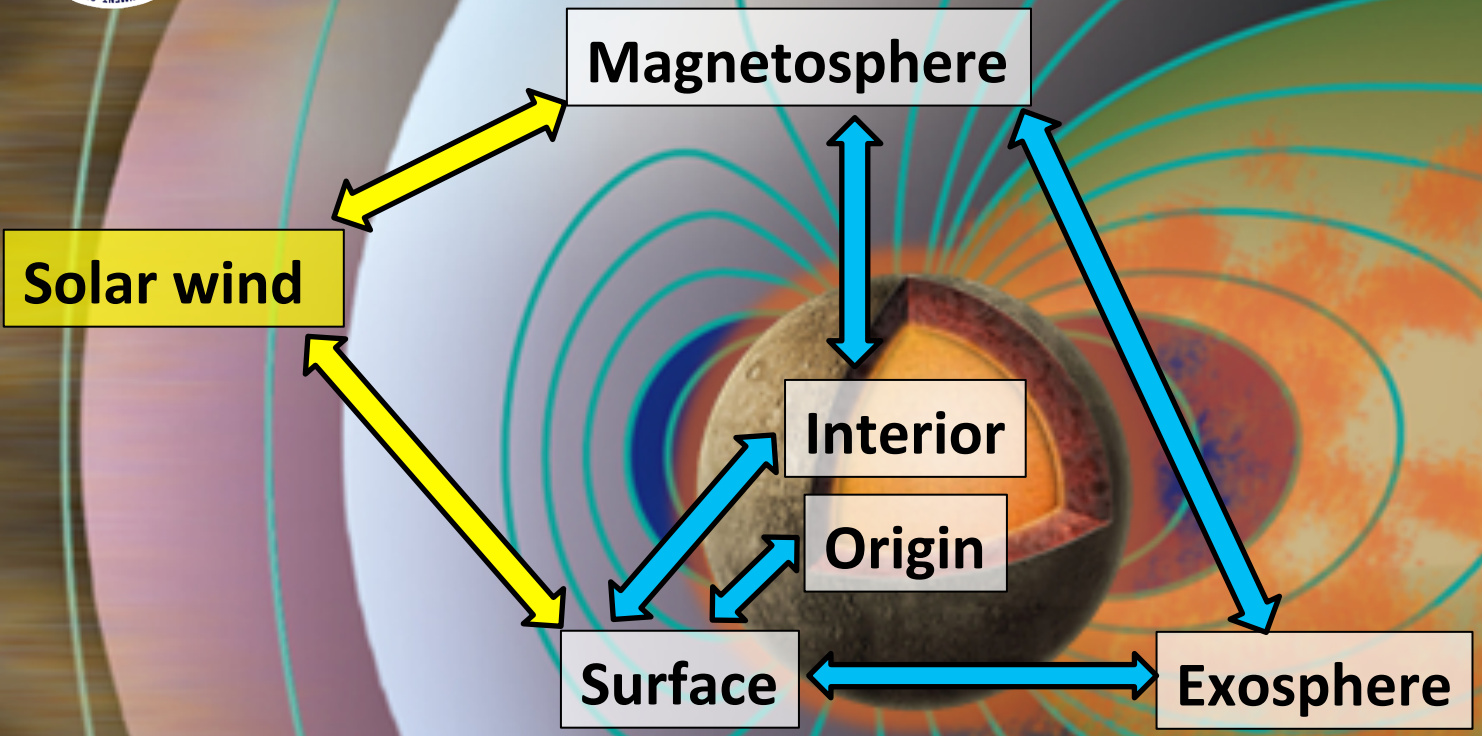
BepiColombo now: 359 days before launch

Mercury and solar wind

- **Planetary magnetic field** (~200 nT at surface = <1% of Earth)
- **Slow rotation**
- **Strong solar wind**
- -> Dynamic magnetosphere
- **No atmosphere (tenuous Exosphere)**
- -> Interaction between surface and space environment
- **Large Larmor radius of ion** (several 100 km for 1 keV at MP)
- -> Important role of heavy ions (kinetic process)
- **Innermost solar planet**
- -> Key for investigation of extreme environment (e.g., exoplanets around cool stars)

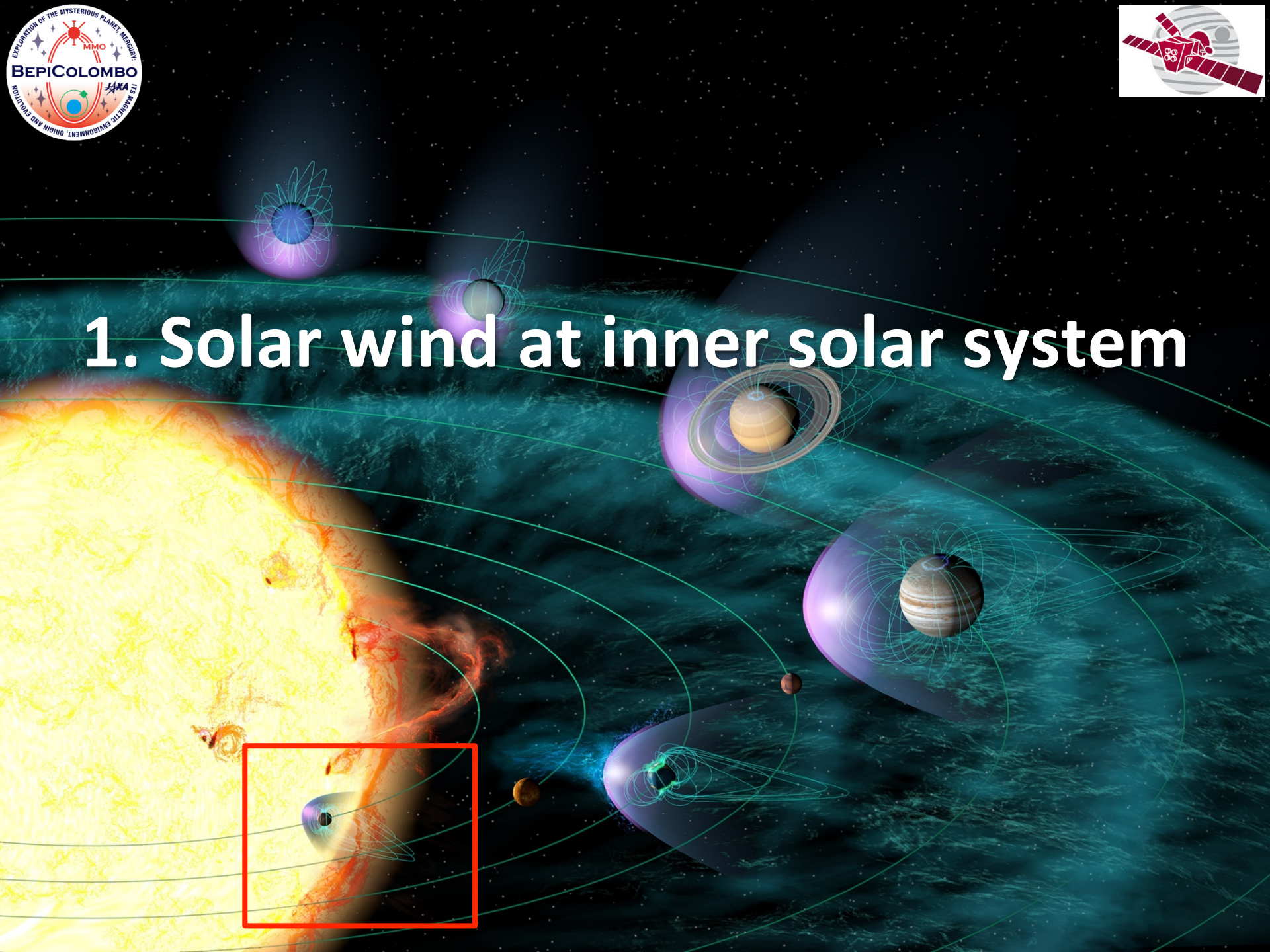
IMF |B|: **~20 nT**
Dynamic pressure: **~10 nPa**
Sunlight: 5-10 SC

Space weather at Mercury



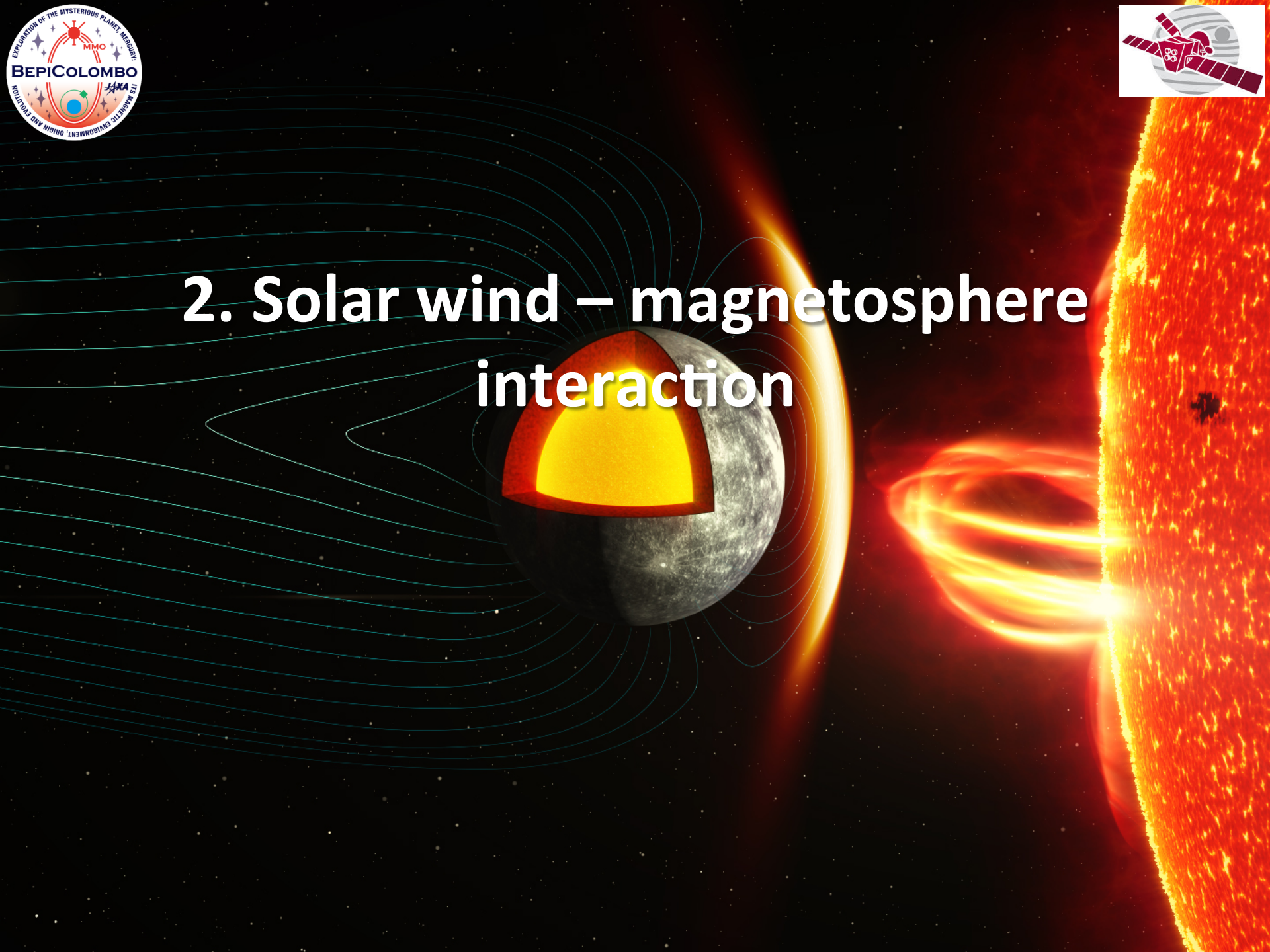
Key topics

1. Solar wind at inner solar system (0.3-0.5 AU)
2. Solar wind – magnetosphere interactions
3. Solar wind – surface interactions


1. Solar wind at inner solar system

Solar wind at inner solar system

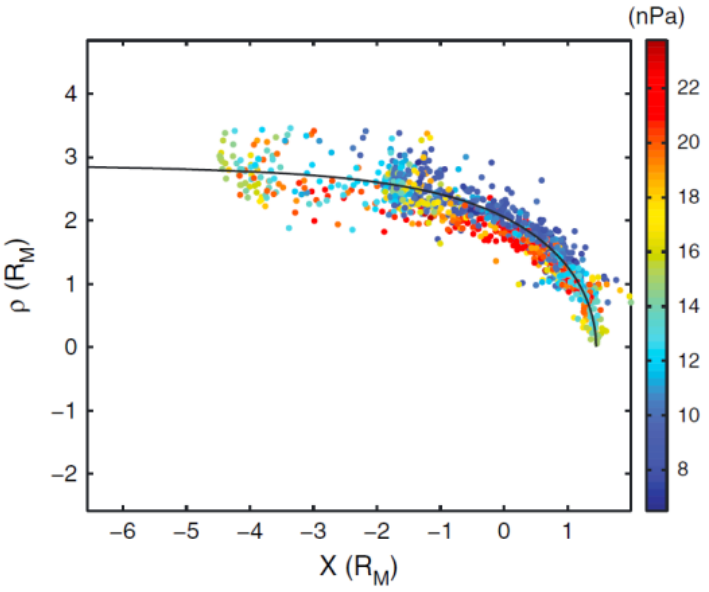
- Shocks & foreshocks: shock physics interacted with the densest solar wind environments
- Solar wind acceleration: heating mechanism of the solar wind, magnetic fluctuations (>10Hz @0.3AU)
- Solar wind model verification: possibly 4 spacecraft at inner heliosphere (MMO, MPO, Solar Orbiter, and Solar Probe Plus)

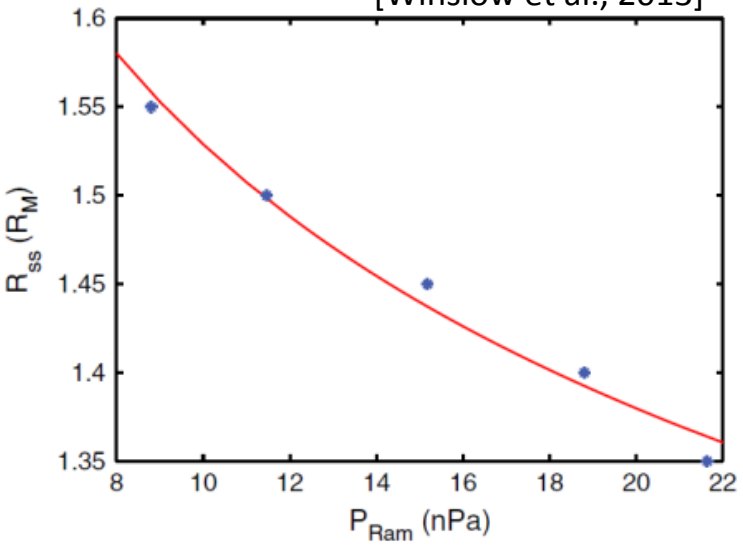

2. Solar wind – magnetosphere interaction

Dynamic magnetosphere: magnetopause

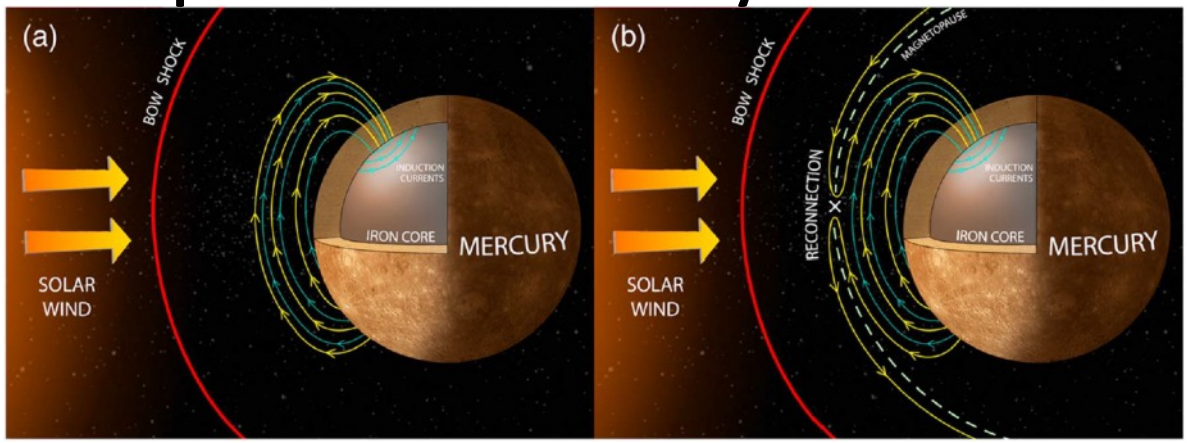
[Winslow et al., 2013]

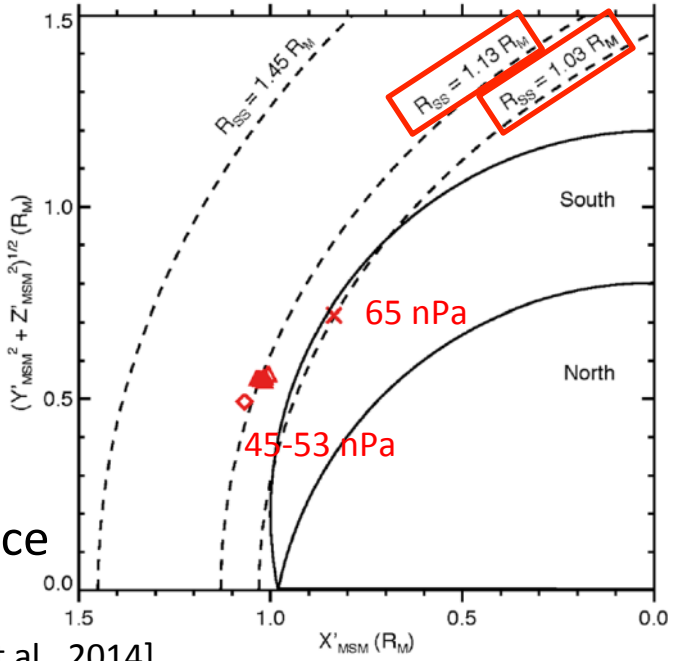
-Average: 1.45 RM
-Closer with strong solar wind





Compression or **erosion by reconnection**?





Only compression cannot explain the MP reaching surface
-> **Strong magnetic reconnection** (α = 0.1-0.2)

[Slavin et al., 2014]

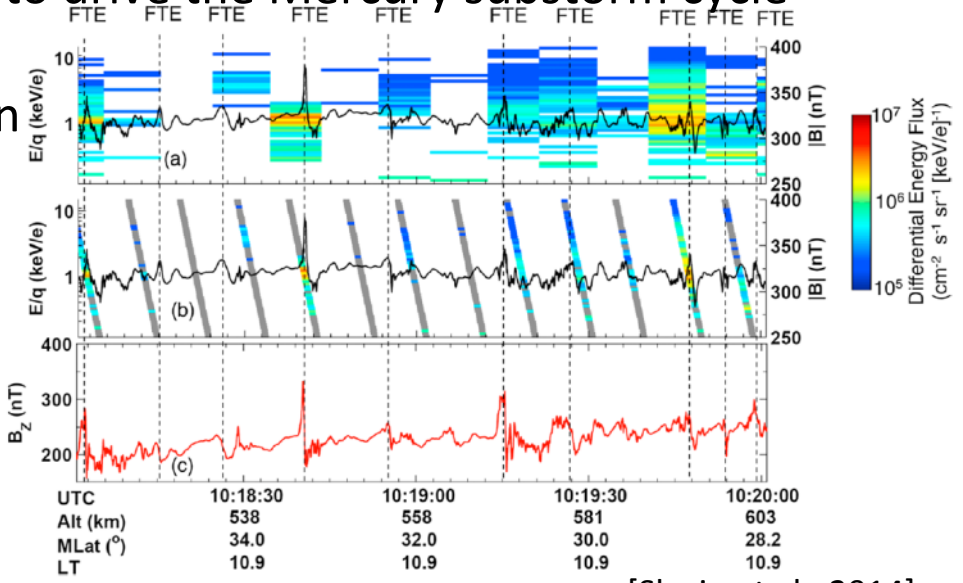
Dynamic magnetosphere: substorm

Any dependence on SW conditions?

Flux transfer events (FTEs)

-contribute >30% of flux transport required to drive the Mercury substorm cycle (<2% at Earth) [Imber et al., 2014]

-163 FTEs along tail magnetopause in 25 min

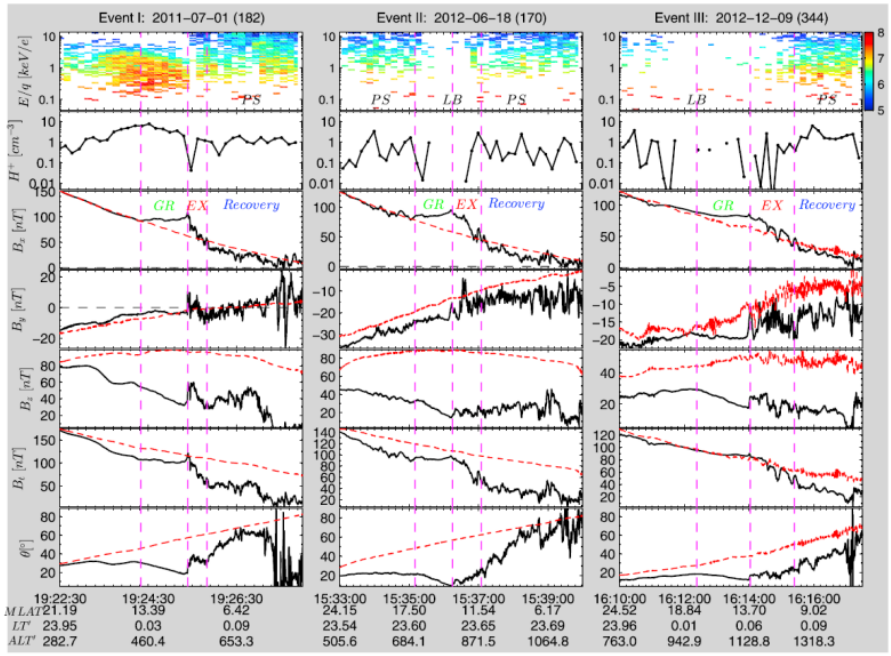


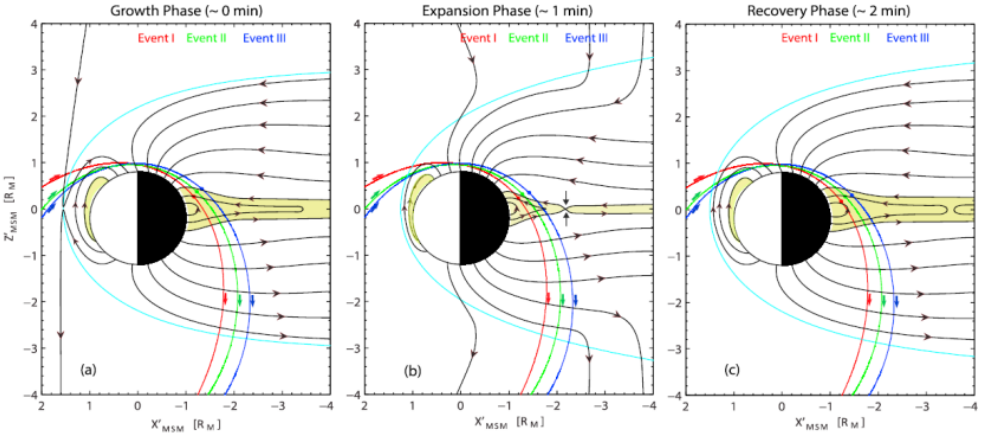
[Slavin et al., 2014]

Substorm events

-Earth-like

-Time scale: ~1 min (growth and expansion)

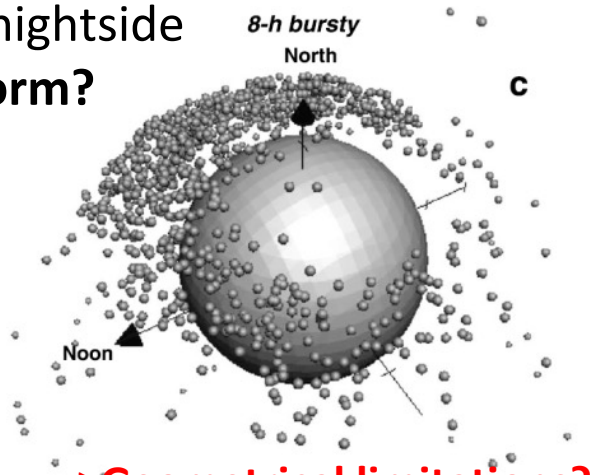




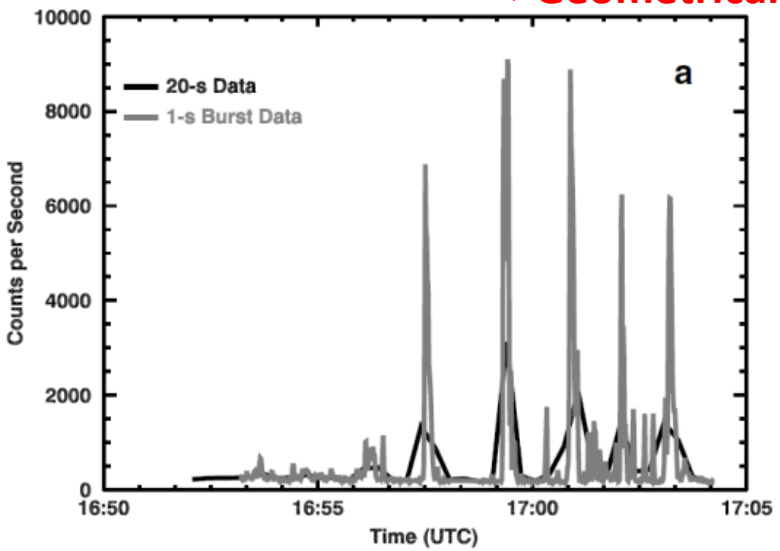
[Sun et al., 2015]

Energetic electrons

-Energy: up to ~200 keV
-Almost all are detected inside magnetosphere
-Periodicities of few minutes (Dungey cycle?)
-Injection event at nightside
-> **Linked to substorm?**

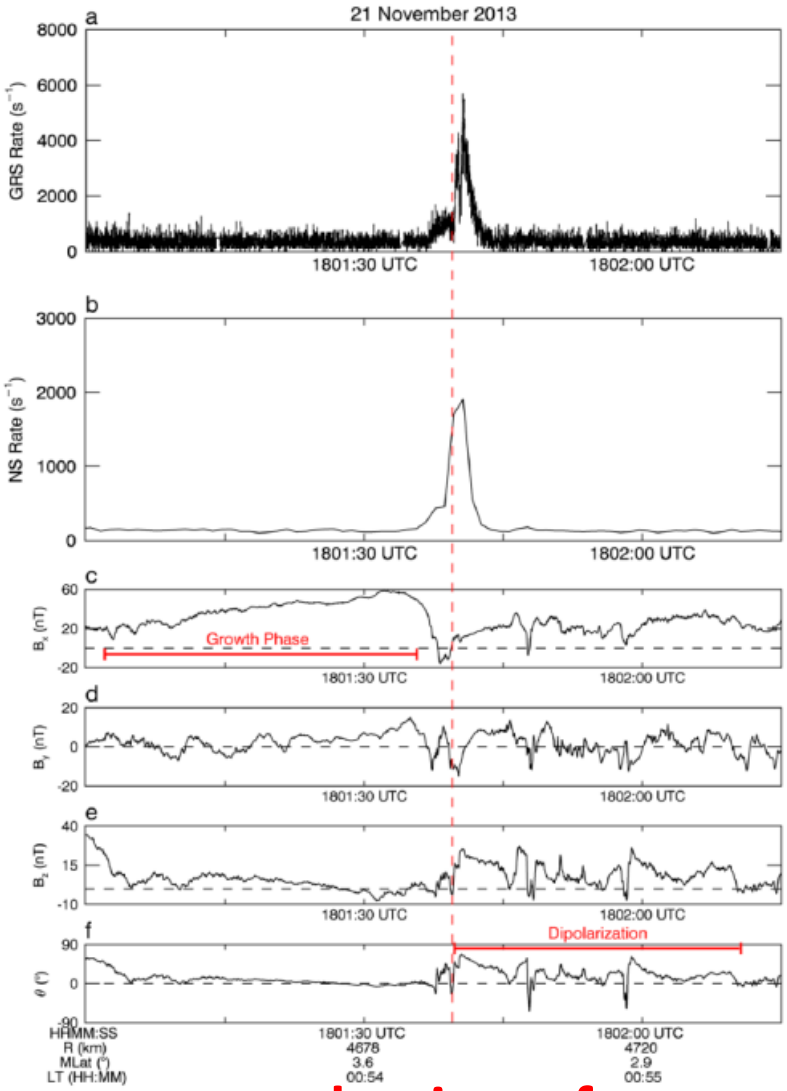


NS observation
[Lawrence et al., 2015]



->Geometrical limitations?

[Baker et al., 2016]

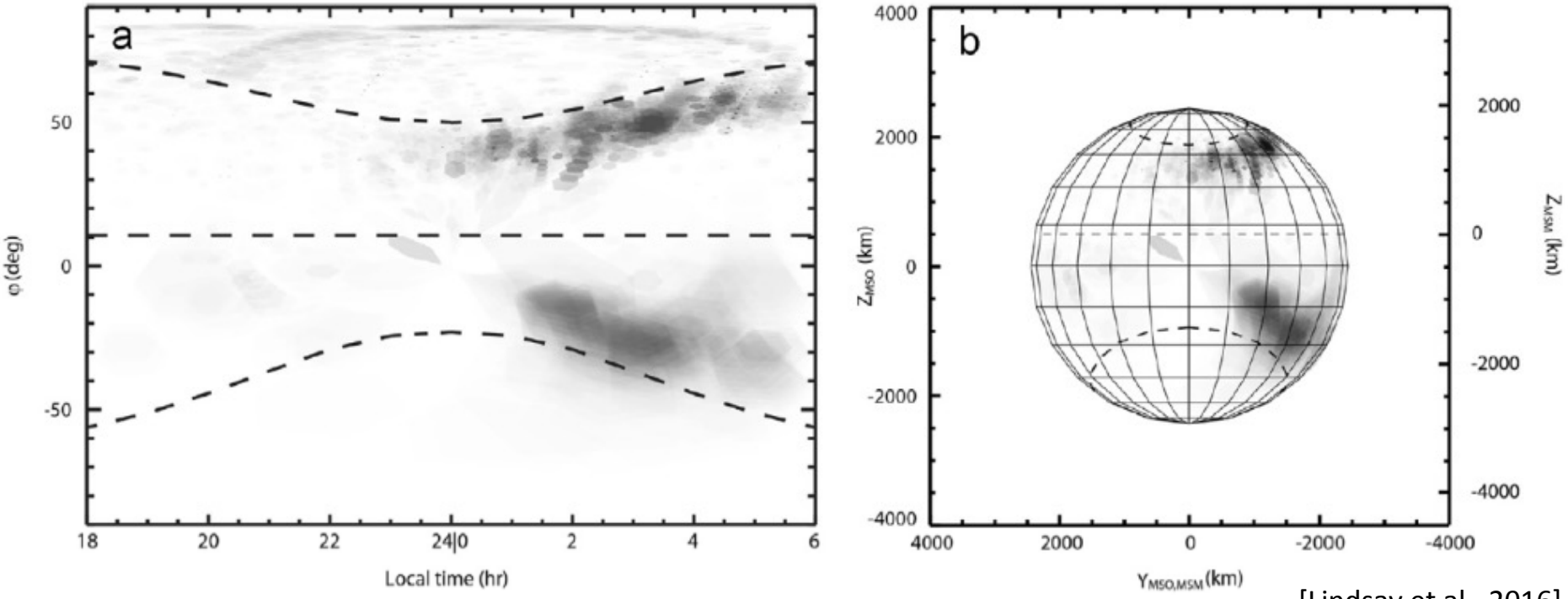


What is the source mechanism of energetic electrons?

X-ray "Aurora" by electron precipitations

XRS observation

X-ray fluorescence in the night side induced by electrons (>~4 keV)
(Event detection: ~30% of MESSENGER orbits)



[Lindsay et al., 2016]

Does solar wind effect on this precipitations?
Geometrical limitations for coverage?
Any contribution to exosphere?

Field aligned current

[Anderson et al., 2014]

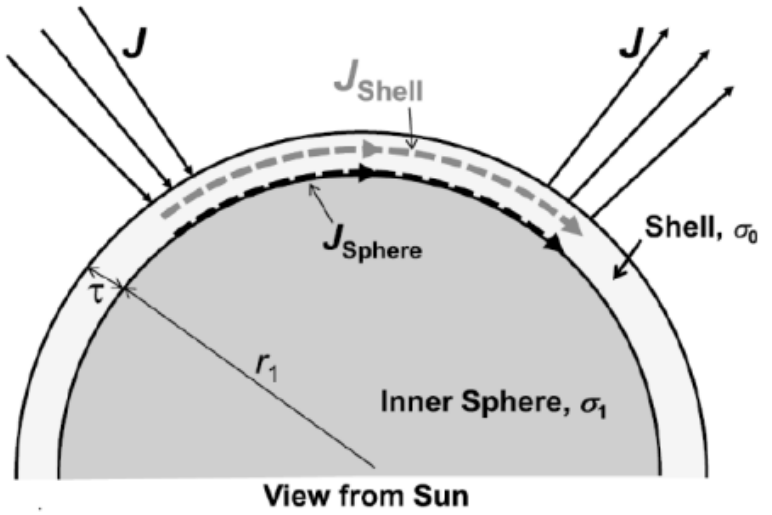
MAG observation found the evidence of field-aligned current (FAC)

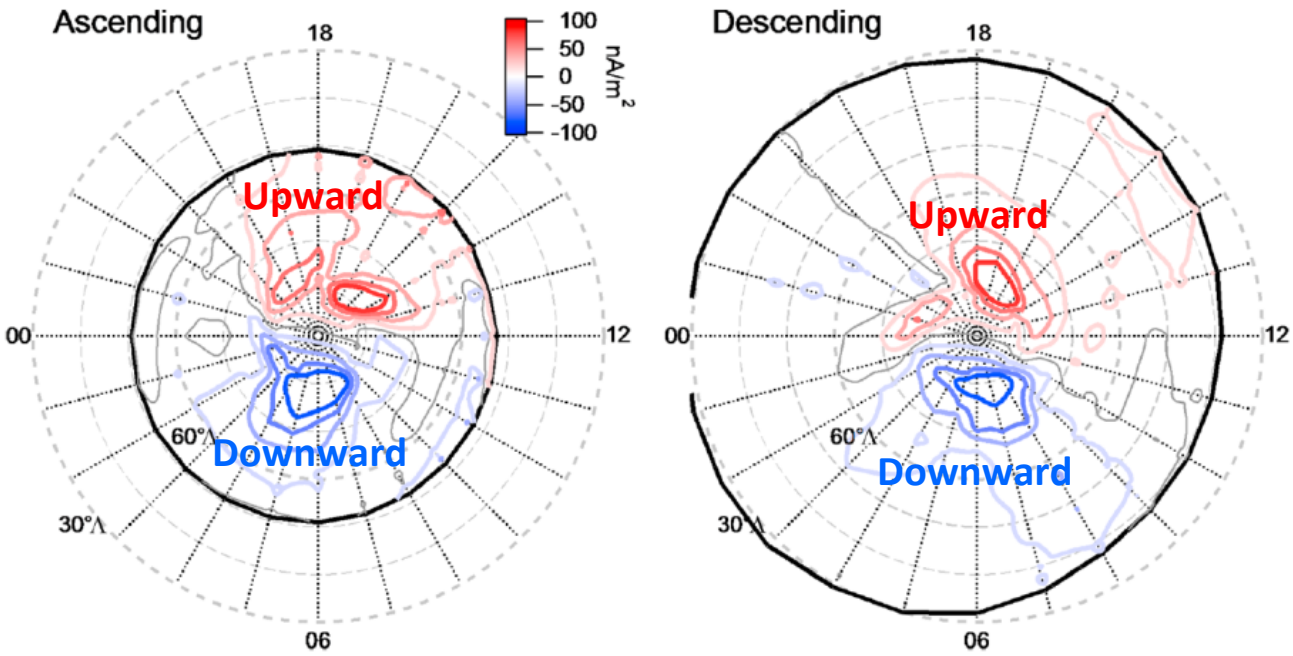
-20-40 kA (~1/100 of Earth's FAC)

-Only R1-FAC

-> Sunward convection flow may impact the surface before producing R2

-Closure should be conductive material at depth (core?)





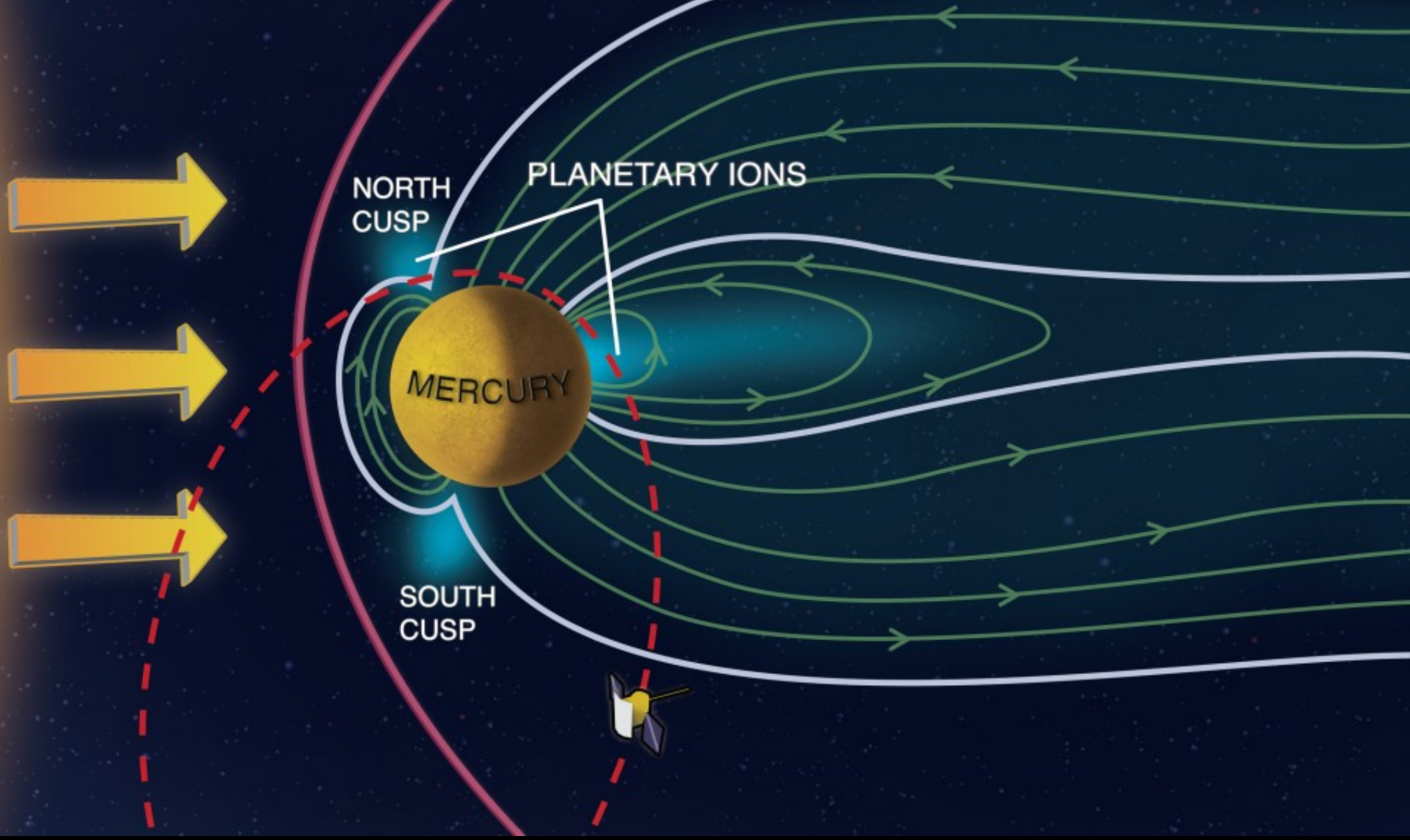
Correlation with SW?
What is Mercury's electrical conductivity structure?

[Anderson et al., 2014]

Science issues related to SW (magnetosphere)

- How can solar wind compress the magnetopause?
- Does solar wind effect on Mercury's dynamic substorms?
- What is the origin of Mercury's energetic electrons?
- Does solar wind effect on the precipitations of ions and energetic electrons at Mercury?
- How do Mercury's magnetosphere and current system respond to solar wind?

3. Solar wind – surface interaction



Mercury's exosphere

Ground-based observation

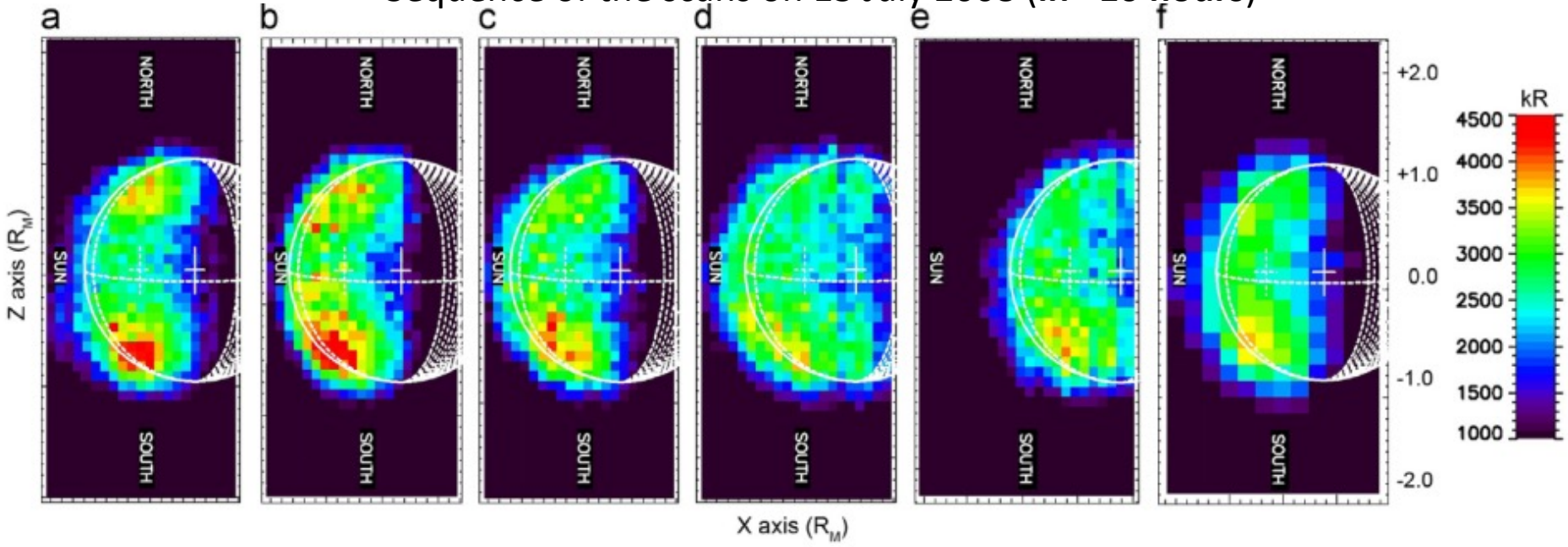
-High latitude (cusp region) enhancement

-Highly variable

-North-south asymmetry

➡ **Solar wind sputtering?**

Sequence of the scans on 13 July 2008 (**in ~10 hours**)



[Mangano et al., 2013]

Sodium: seasonal variation

MESSENGER observation

Surprisingly constant year-to-year variation

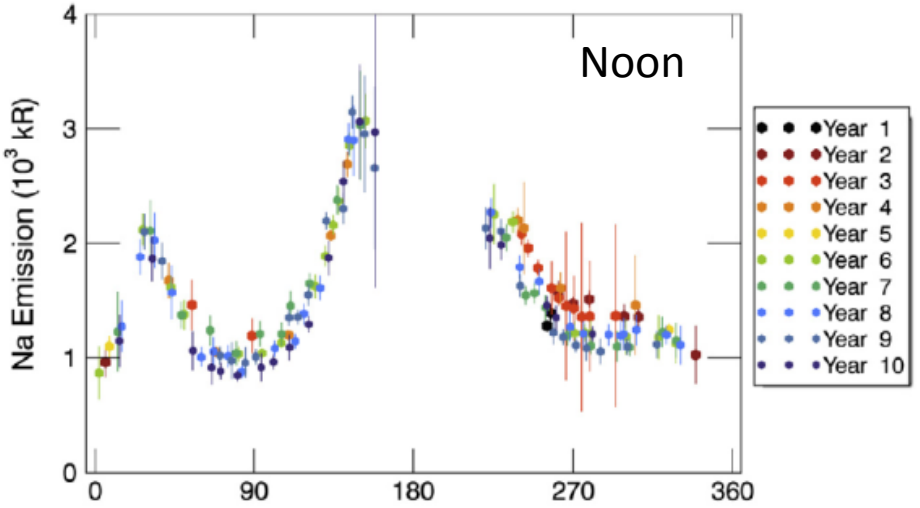
-No strong episodic variations

-No surface dependence

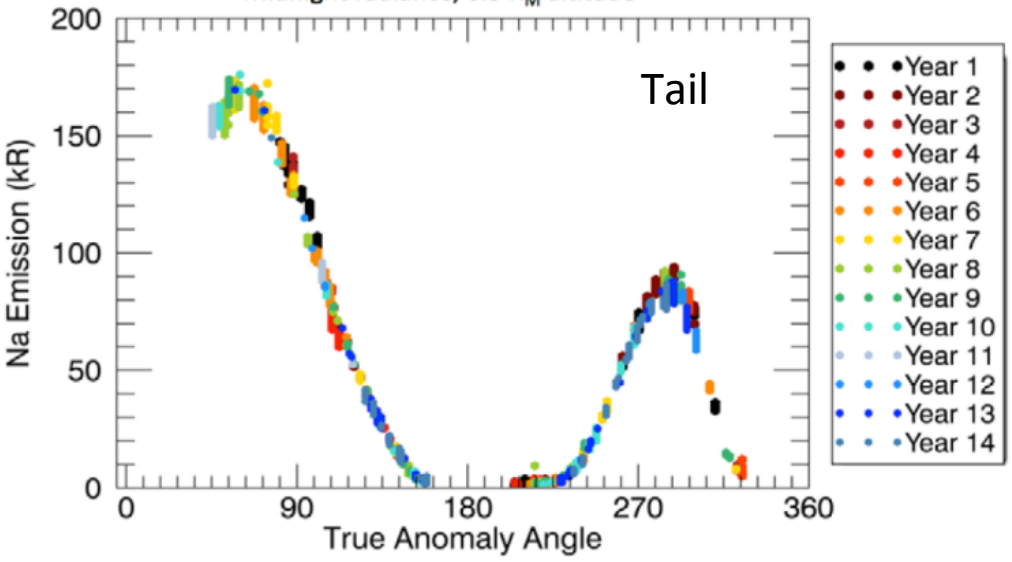
Strong seasonal variation

-> Why different from ground-based observations?

Subsolar point (300 km altitude)

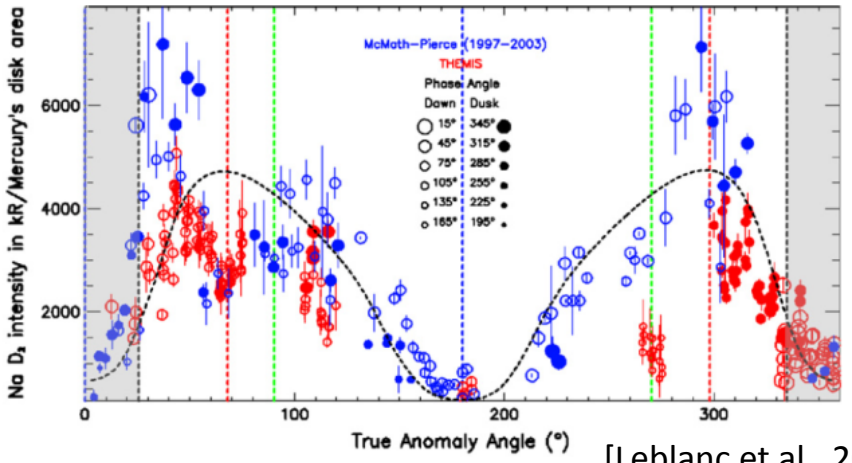


Midnight radiance, 0.5 R_M altitude



[Cassidy et al., 2015]

Ground-based observation

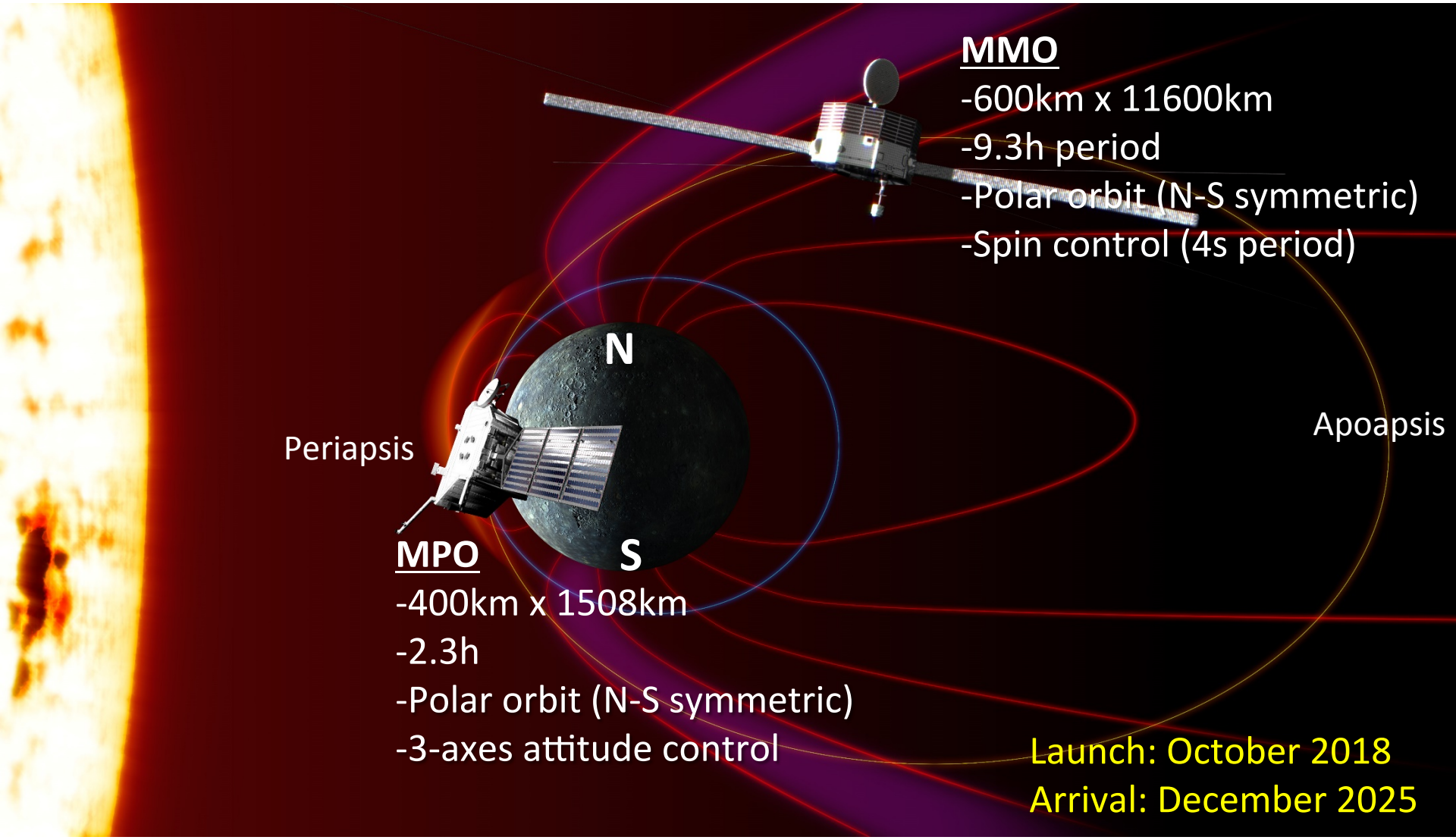


[Leblanc et al., 2010]

Science issues related to SW (exosphere)

- Is there a sporadic variations?
- Is there a high-latitude component?
- What are the consequences of precipitating ions and energetic electrons at Mercury?
- How do Mercury's exosphere respond to solar wind?

BepiColombo: two spacecraft



MMO and MPO always orbit in the same plane

BepiColombo: MPO instruments

PI	Instrument		Measurements
N. Thomas, CH; T. Spohn, D	BepiColombo Laser Altimeter	BELA	Topographic mapping
V. Iafolla, I	Italian Spring Accelerometer	ISA	Non-gravitational accelerations of MPO
K.H. Glassmeier, D	Magnetic Field Investigation	MPO/MAG	Detailed description of planetary magnetic field, its source and interaction with the solar wind
H. Hiesinger, D	Mercury Radiometer and Thermal Imaging Spectrometer	MERTIS	Global mineralogical mapping (7-14 μm), surface temperatures and thermal inertia
Mitrofanov, RUS	Mercury Gamma-Ray and Neutron Spectrometer	MGNS	Elemental surface and subsurface composition, volatile deposits on polar areas
G. Fraser, UK	Mercury Imaging X-ray Spectrometer	MIXS	Elemental surface composition, global mapping and composition of surface features
L. Iess, I	Mercury Orbiter Radio Science Experiment	MORE	Core and mantle structure, Mercury orbit, fundamental science, gravity field
E. Quèmerais, F	Probing of Hermean Exosphere by UV Spectroscopy	PHEBUS	UV spectral mapping of the exosphere
S. Orsini, I	Search for Exospheric Refilling and Emitted Natural Abundances	SERENA	In situ study of composition, vertical structure and source and sink processes of the exosphere
J. Huovelin, FIN	Solar Intensity X-ray and particle Spectrometer	SIXS	Monitor solar X-ray intensity and solar particles in support of MIXS
E. Flamini, I	Spectrometers and Imagers for MPO BepiColombo Integrated Observatory	SIMBIO-SYS	Optical high resolution and stereo imaging, near-IR (< 2.0 μm) imaging spectroscopy for global mineralogical mapping

Magnetosphere/Solar wind/Exosphere

BepiColombo: MMO instruments

Complete package to measure Mercury's plasma environment

New! 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
New!	Energetic Neutral Atoms (ENA)	Plasma imaging	<25eV ~ 3.3keV, dt=80sec
MGF	Magnetometer (MGF)	Magnetic field	DC ~ 64Hz [MAST:5m]
New! 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 Sodium Atmosphere Spectral Imager (MSASI)	Na-exosphere image	FOV:~30deg x 90-180 deg Spectral resolution: 9 pm
MDM	Mercury Dust Monitor (MDM)	Interplanetary Dust	PZT

-MMO has 5 major scientific instruments

Magnetosphere/Solar wind/Exosphere

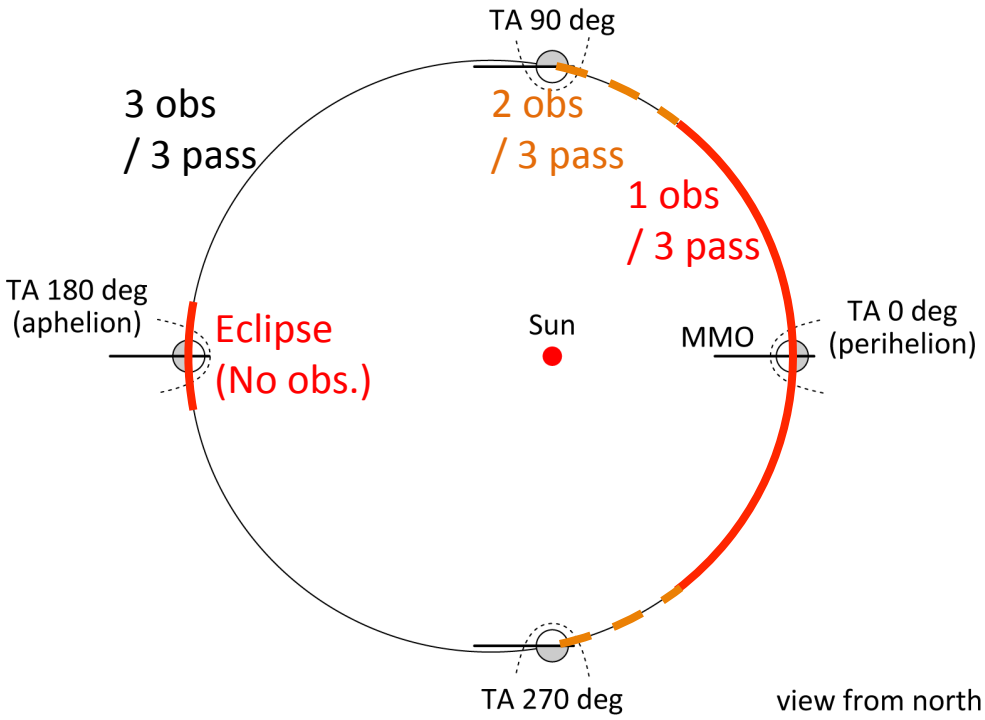
MMO observation plan

Summary of science observations

-Basically always ON (except for MSASI)

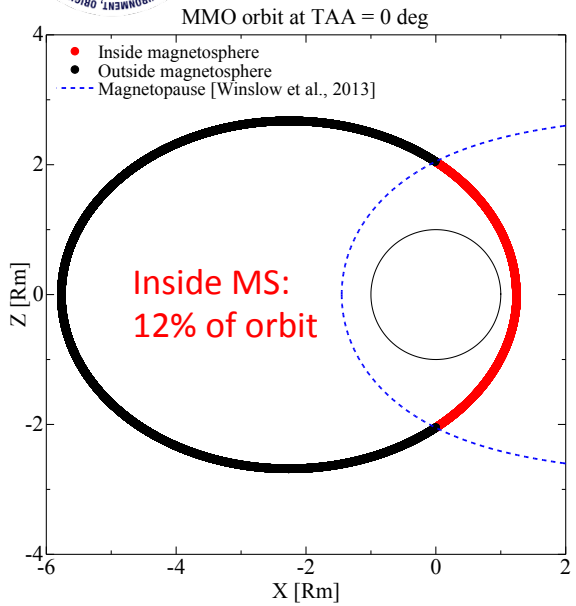
-Constraints: thermal (TAA = 0 ± 90 deg) and electrical (5 days around TAA = 180)

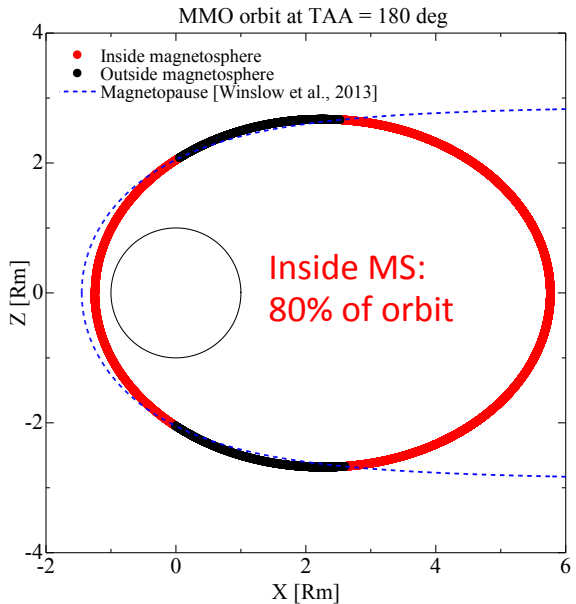
-Observations mode: basically depends on geometry



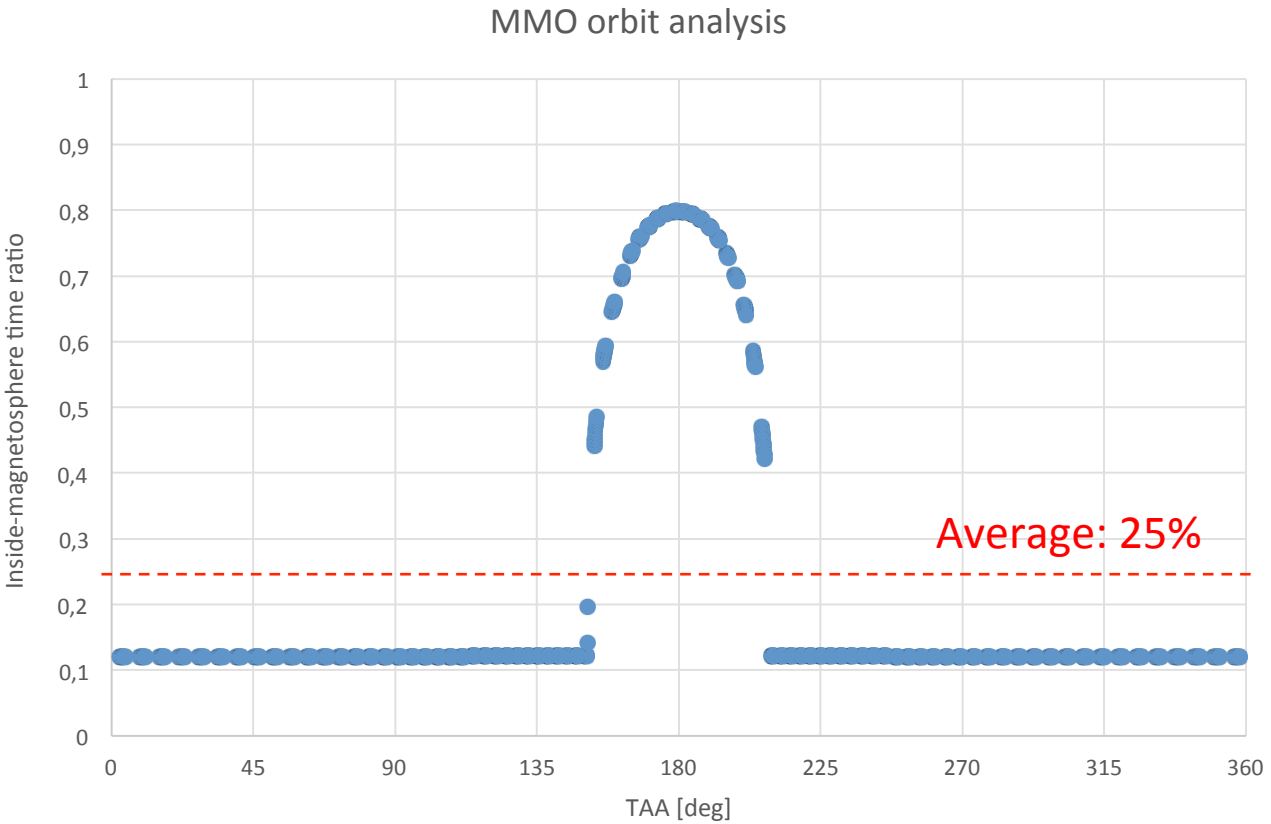
Observation plans will be updated in 2018 by new thermal analysis

Solar wind vs magnetosphere





How long MMO is inside the magnetosphere?



-Northward shift of dipole center is not included
-Margin of magnetopause location is not yet considered

This calculation will be performed and updated by MS modeler

How can BepiColombo address to SW-related science issues?

Solar wind

- MMO can monitor the solar wind with complete plasma measurements onboard spinning spacecraft

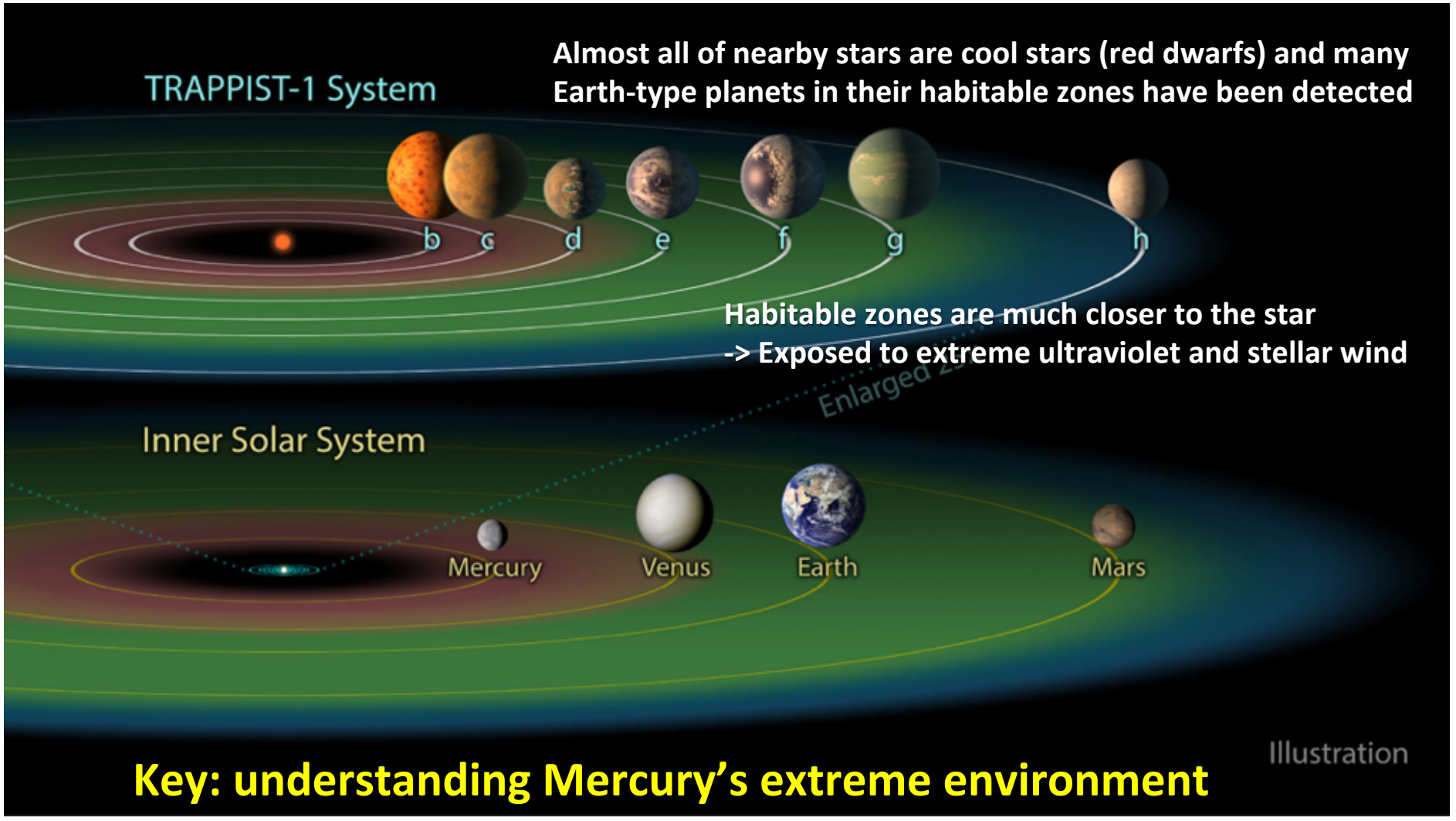
Magnetosphere

- Two spacecraft: simultaneous observation of solar wind and Mercury's magnetosphere or two points in magnetosphere
- Complete package for plasma environment measurement on MMO: magnetic and electric fields (DC and AC), ions and electrons

Exosphere

- MSASI can monitor the global distribution of the exosphere (including cusp regions) at least every 9h
- Simultaneous observation of the solar wind and the exosphere

Science after Mercury: habitable planets around cool stars



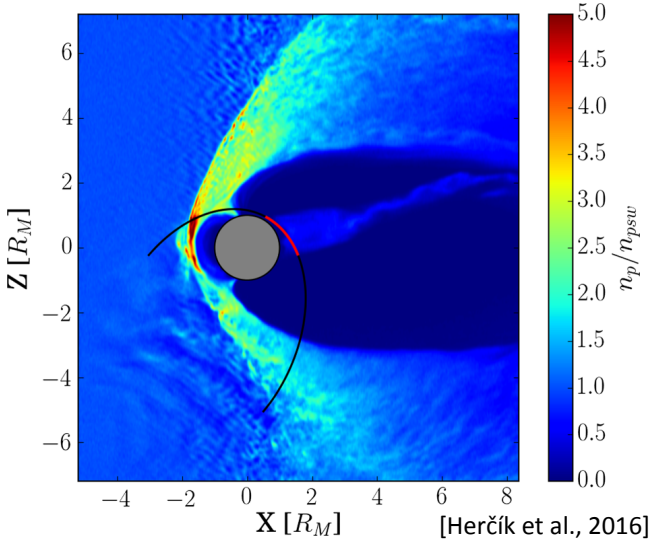
Key: understanding Mercury's extreme environment

Thank you!

2011-2015

MESSENGER

2016-2024



[Herčík et al., 2016]

What should we do now?

2025-

BepiColombo

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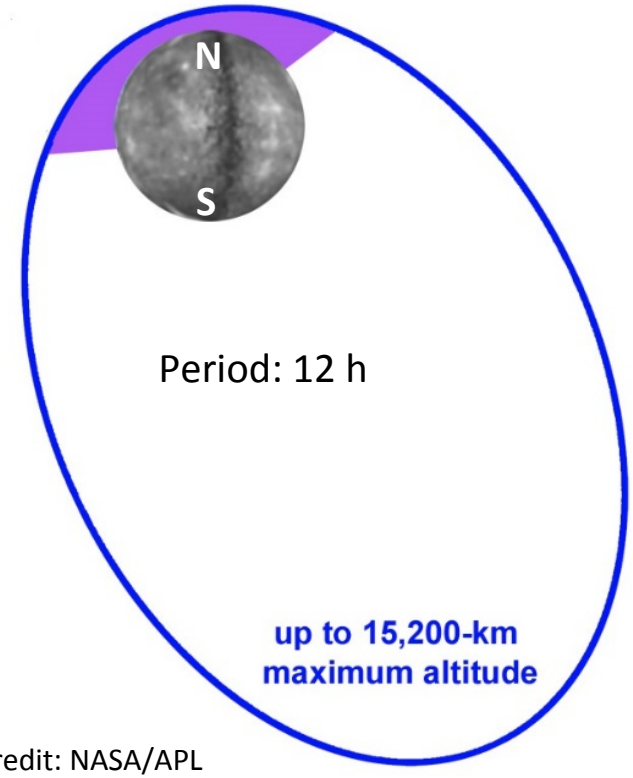
MESSENGER: overview

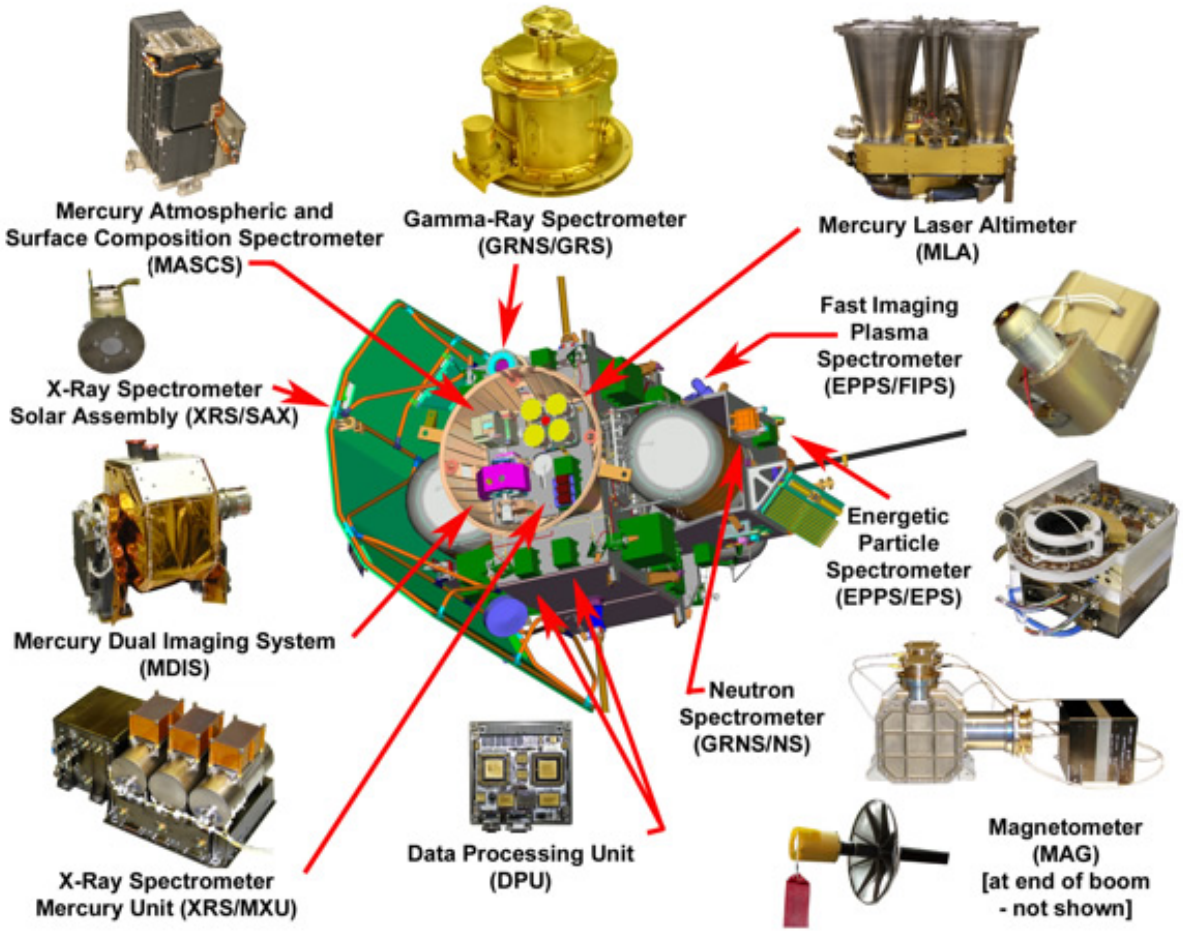
Orbit

200- to 500-km
minimum altitude
over 60-75° North latitude



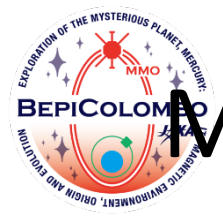
Credit: NASA/APL

Instruments



Credit: NASA/APL

"Total" Mercury observations



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MESSENGER Top Ten Science Results

Summarized in MESSENGER-BepiColombo WS 2015

1. **Volatile rich planet** –Surprisingly abundant K, S, Na, and Cl
2. **Polar deposits of water ice** in the permanently shadowed craters
3. **Offset magnetic field** toward the north pole by ~0.2 RM
4. **Hollows** –Evidence that Mercury is still geologically active
5. **Volcanic deposits** have played a critical role in shaping Mercury's surface
6. **Global contraction** of 7 km in radius, larger than previously believed
7. **Seasonal exosphere**
8. **Dynamic magnetosphere** because of Mercury's small magnetic field and proximity to the Sun
9. **Energetic electrons** from several keV to several 100 keV
10. **Field-aligned currents** from the magnetosphere to low altitudes

Internal/Surface/Exosphere/Magnetosphere

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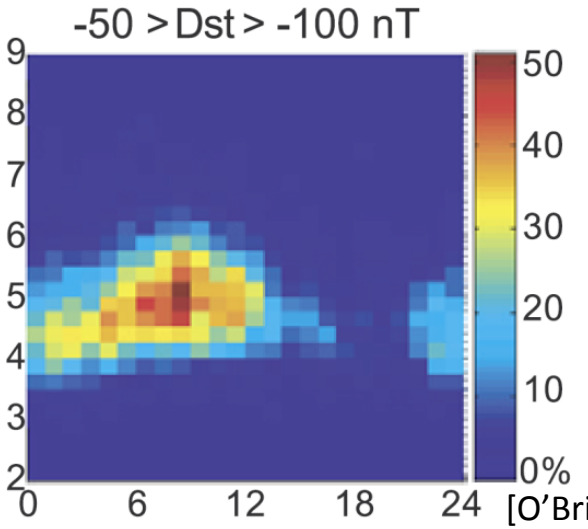
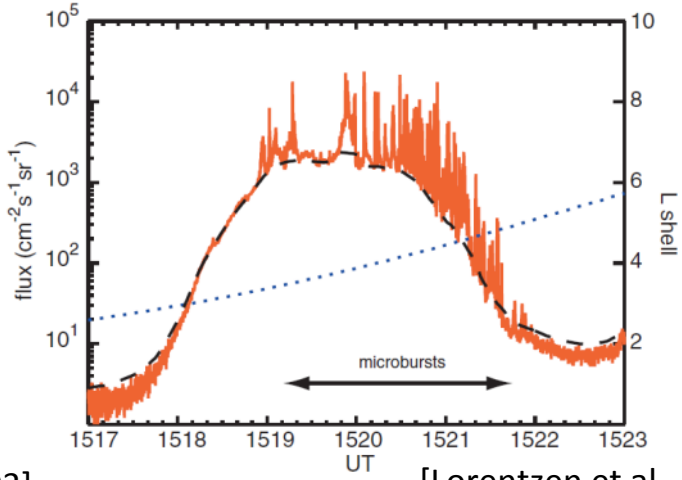
Are there plasma waves? (e.g., Chorus)

Micro burst: precipitations of high energy electrons by chorus waves

Earth

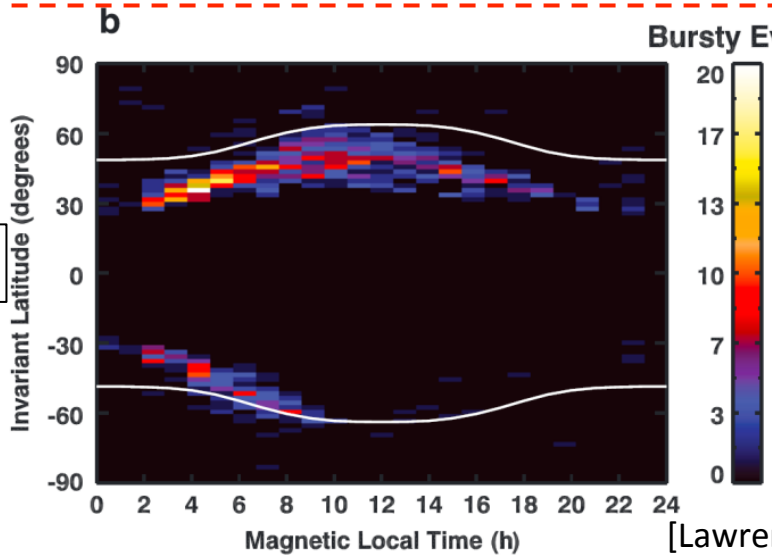


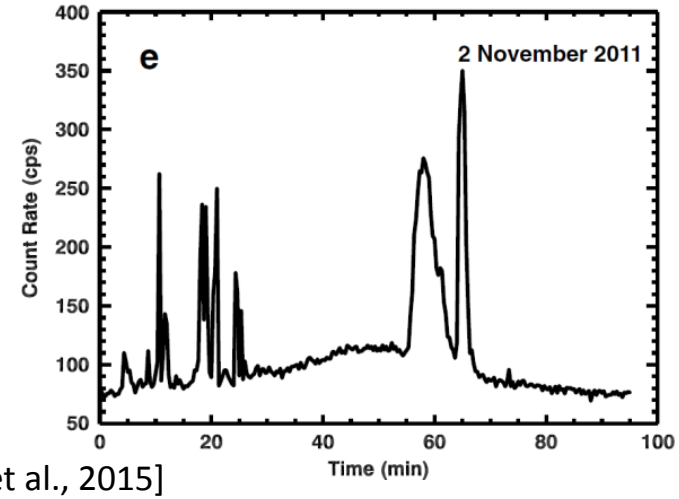
[O'Brien et al., 2003]



[Lorentzen et al., 2001]

Mercury





[Lawrence et al., 2015]

Similarity between the Earth and Mercury -> Chorus waves at Mercury?

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MMO observation plan: Observation modes

PWI
- -Solar wind mode
- -Magnetosphere mode

MPPE (MIA/MSA/MEA)
- -Solar wind mode
- -Magnetosphere mode

MPPE (ENA)
- -Periapsis mode (periapsis ± 70 min)
- -Apoapsis mode (apoapsis ± 60 min)
- -Low resolution mode (other)

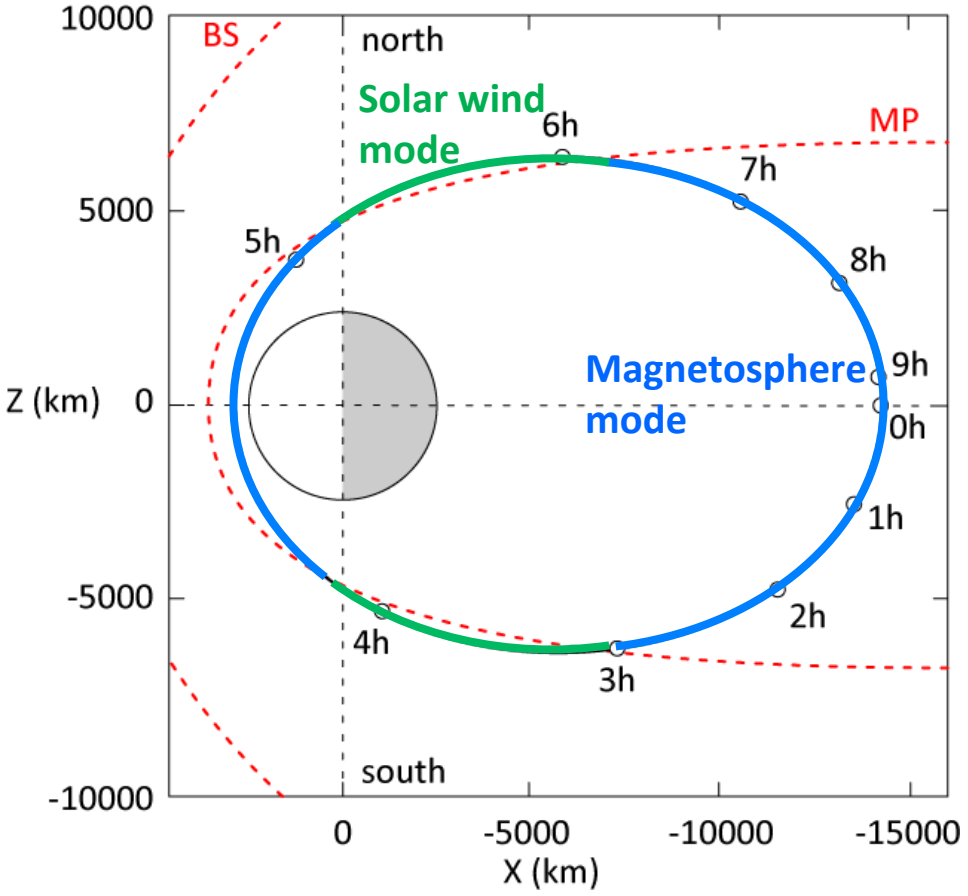
MPPE (HEP): only one mode

MSASI
- -Normal mode (FOV: 45 deg for spin scan)
- -Wide mode (FOV: 90 deg for spin scan)

MGF: only one mode

MDM: only one mode

TA = 180°
PWI and MPPE (MIA/MSA/MEA)



The timing of mode change will basically depends on the geometry and will be optimized 1 Mercury Year (MY) after orbit insertion

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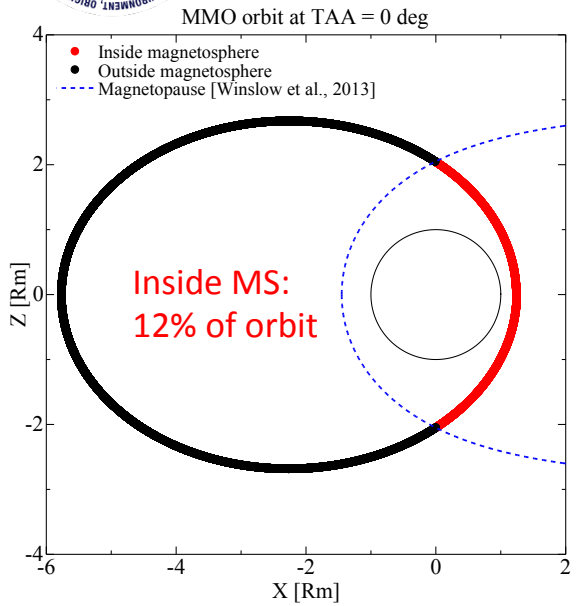
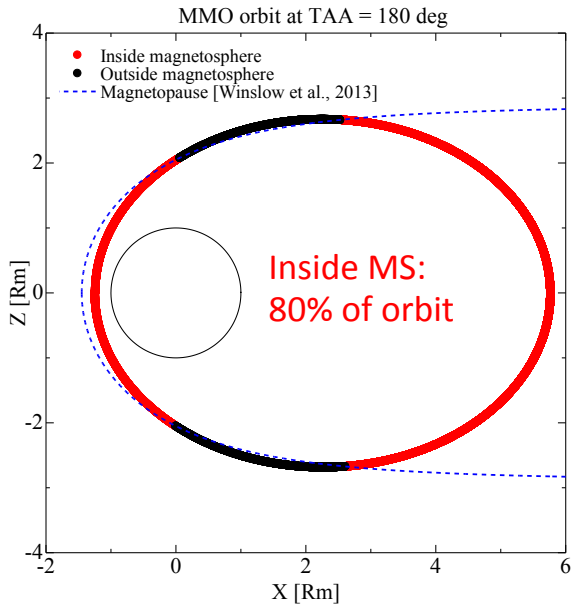
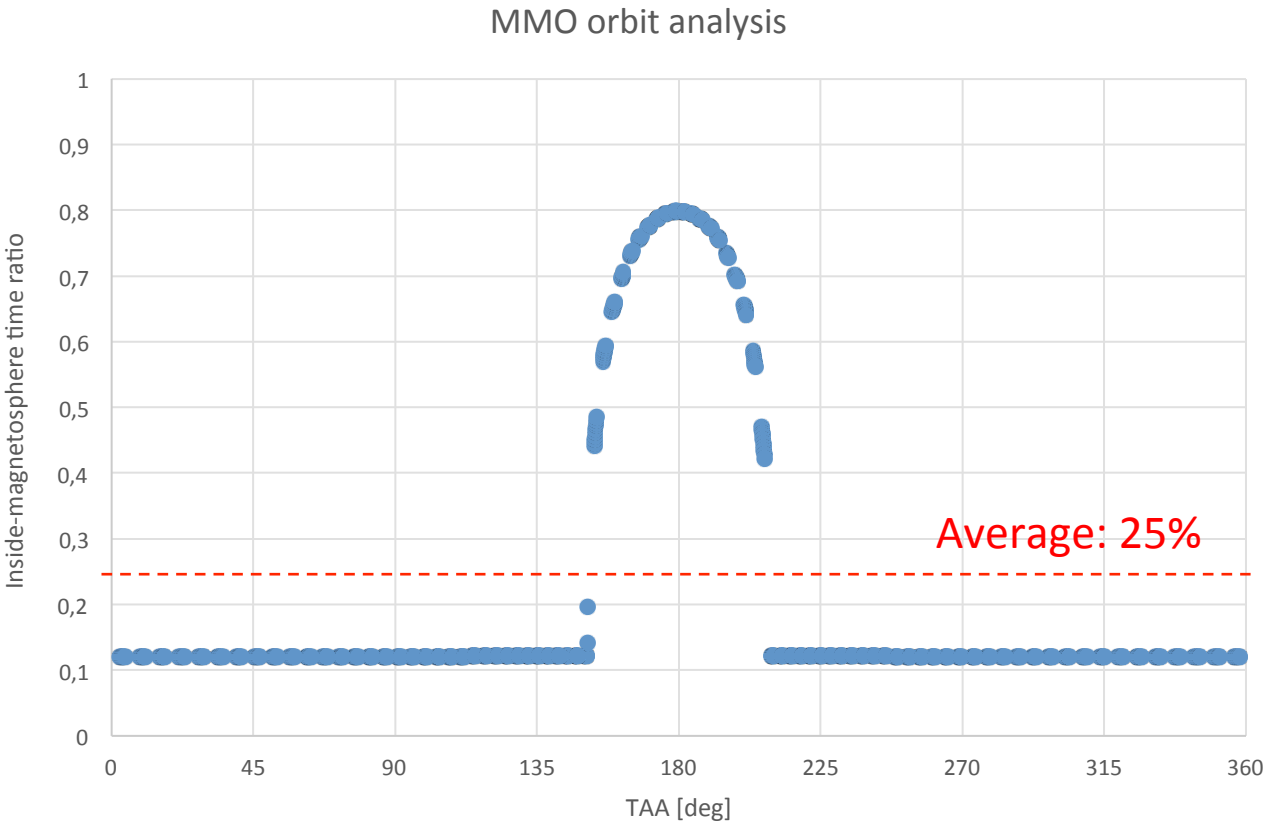
MMO downlink plan: strategy





How long MMO is inside the magnetosphere?



-Northward shift of dipole center is not included
-Margin of magnetopause location is not yet considered

This calculation will be performed and updated by using latest Mercury's magnetospheric models

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MMO downlink plan: strategy

MPPE-ENA, MDM, MSASI, PWI-AM2P

- L: 100%, M: as much as possible

Data mode	Resolution	Generation
L-mode	Low	Always
M-mode	Nominal	Always
H-mode	High	Partially (4 min)

MPPE (others), PWI, MGF

<Assumptions>

- L-mode data of the period when M-mode data are downlinked are not required to be downlinked (except for MPPE-LEP)
- Three cases depending on DL rate:
- Case 1 (Low DL rate): DL rate < L-mode 100% # This case rarely happens (only a few days)
- Case 2 (Mid DL rate): L-mode 100% < DL rate < L + M inside magnetosphere
- Case 3 (High DL rate): L + M inside magnetosphere < DL rate

<DL plan>

- Case 1 plan : L-mode only
- Case 2 plan : L + M (all of observation period should be covered)
- M-mode data selection: several sub-plans → Need to be discussed in the future
- Case 3 plan : L + M (magnetosphere) + H and/or M (solar wind)
- H-mode and M-mode (solar wind) data selection: several sub-plans → Need to be discussed in the future