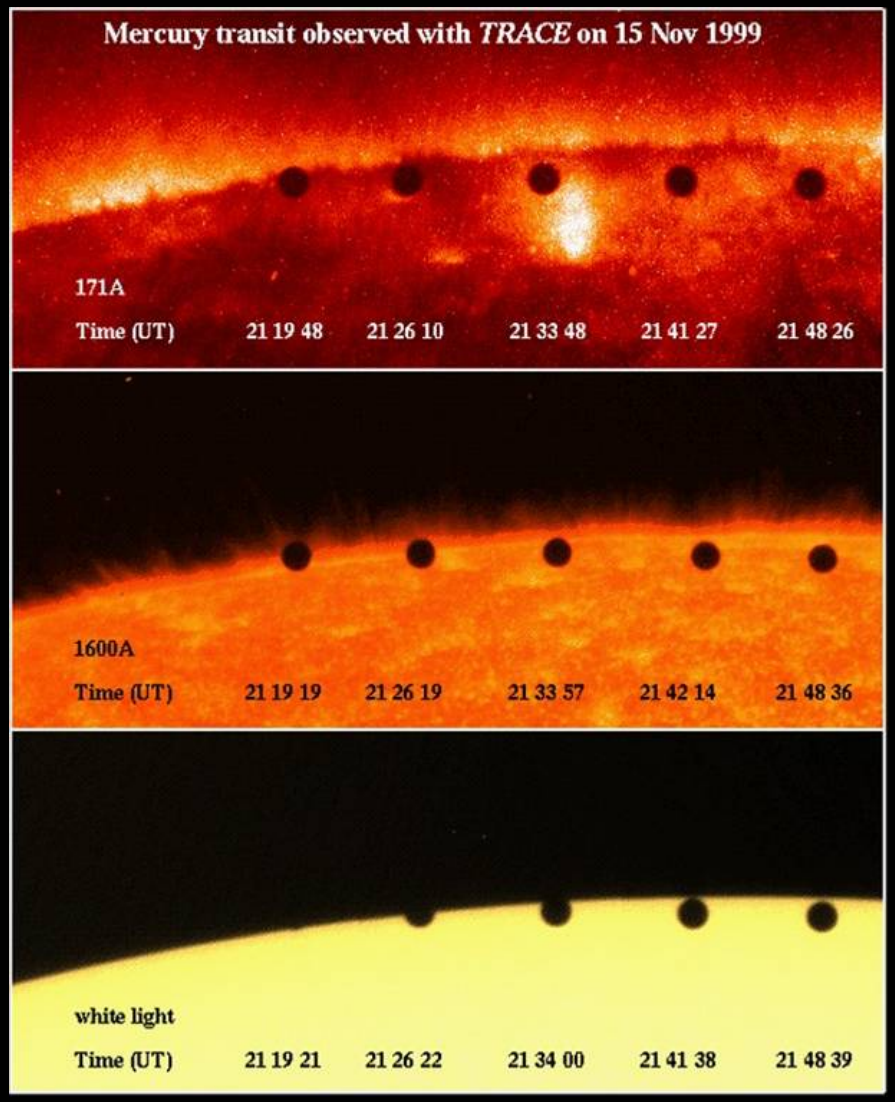
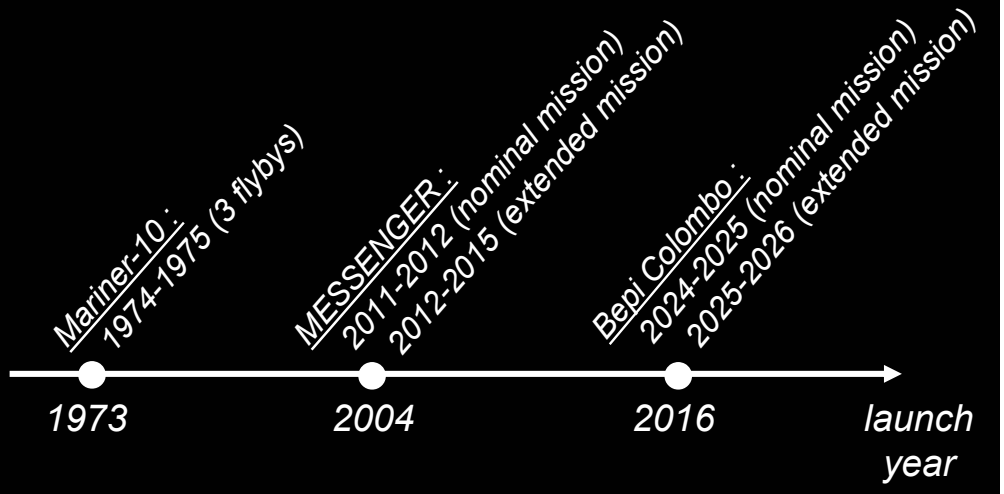



# ***La magnétosphère de Mercure avant Bepi Colombo***

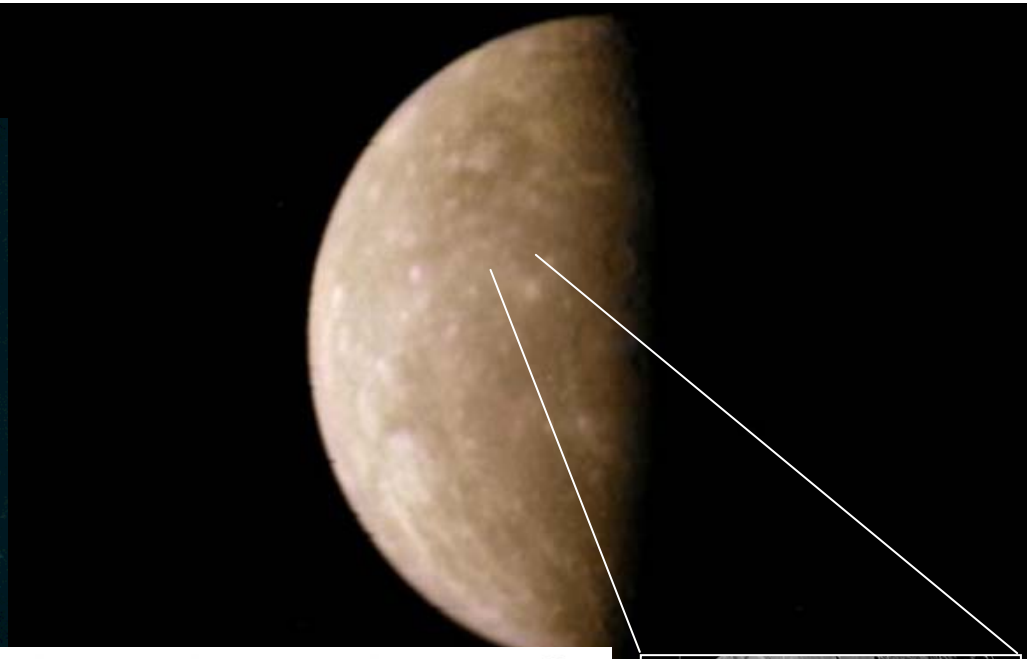
*Dominique Delcourt*

*LPP, Ecole Polytechnique-CNRS-UPMC*



***Before Mariner-10 :***

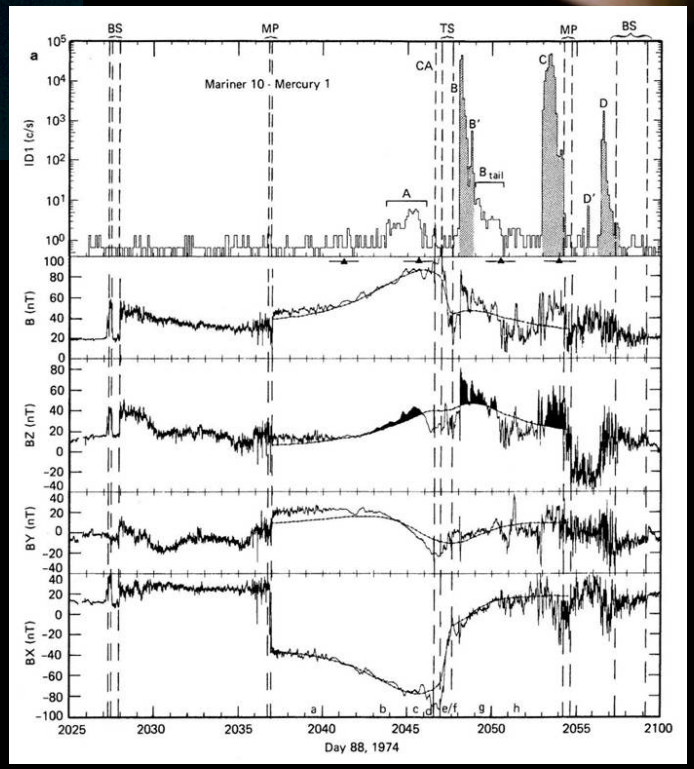
## ***Before MESSENGER :***

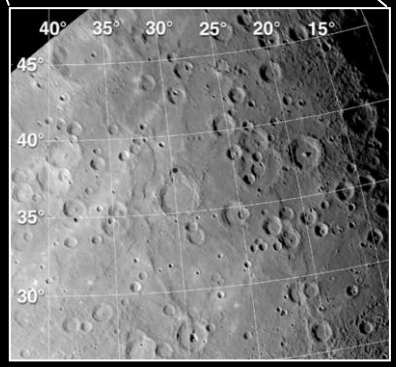


## ***Mariner-10***

*Three flybys : Mar. 29, 1974*
*Sep. 21, 1974*
*Mar. 16, 1975*

- *mapping of ~45% of Mercury's surface*
- *exospheric species : H, He, O*
- *intrinsic magnetic field*
- *energetic particle injections*

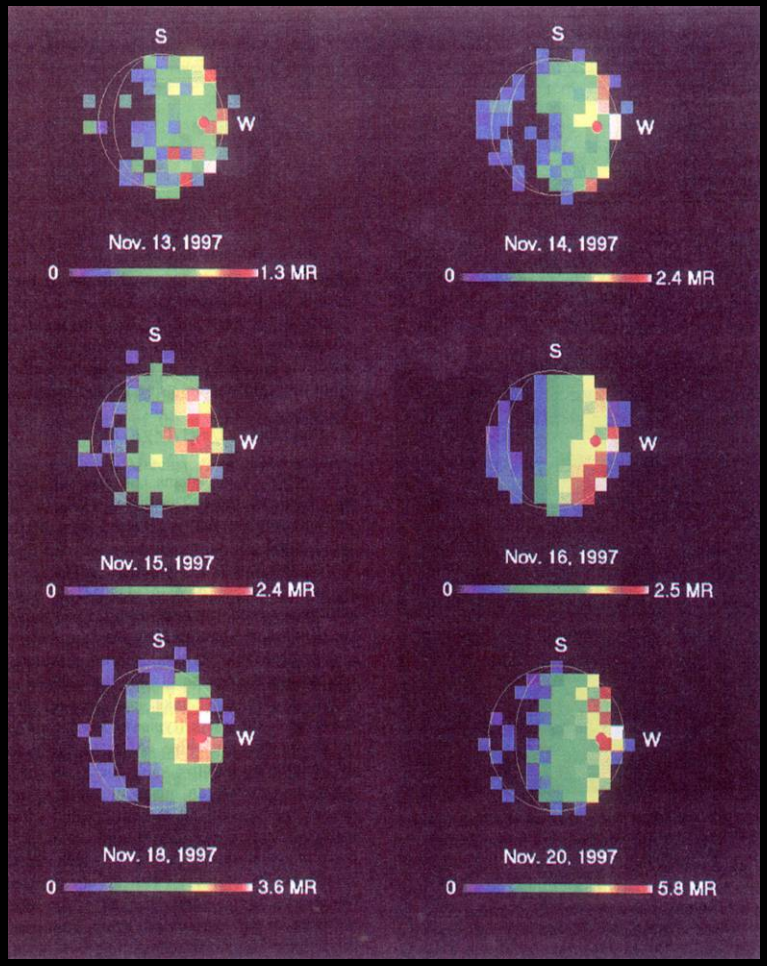


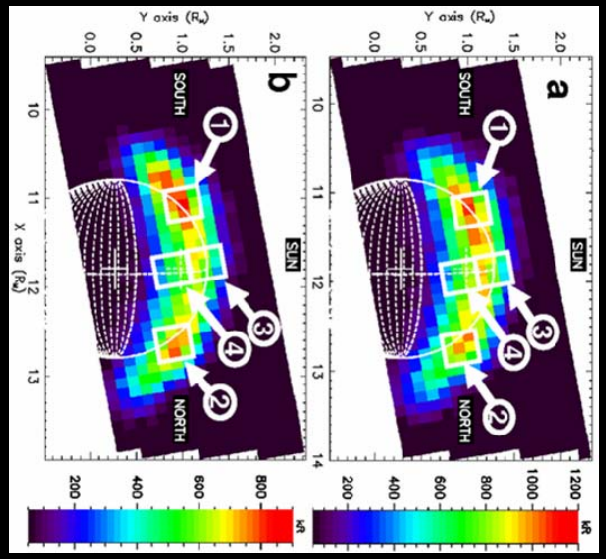

*Christon et al. [1987]*

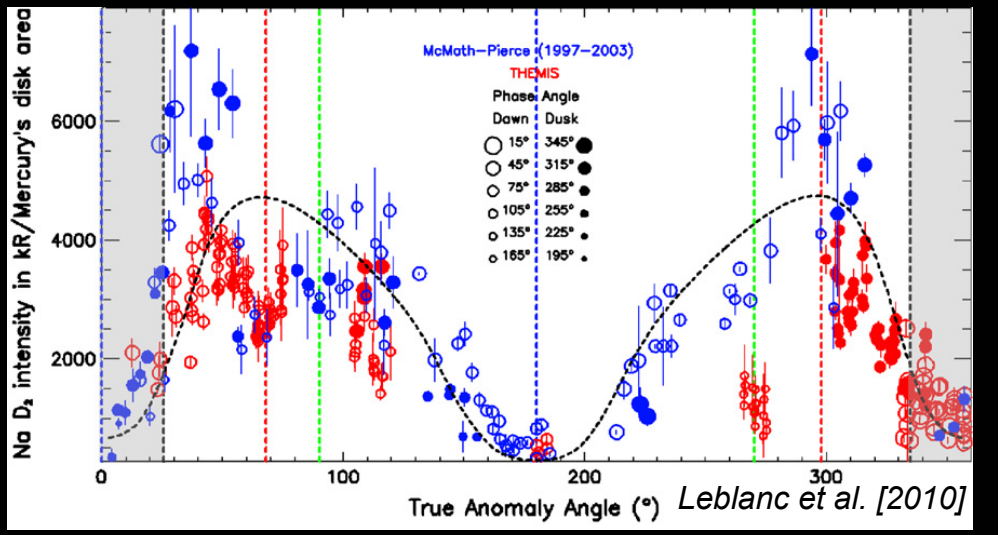
## ***Before MESSENGER :***

*Ground-based observations (e.g., $Na^+$, $Ca^+$)*



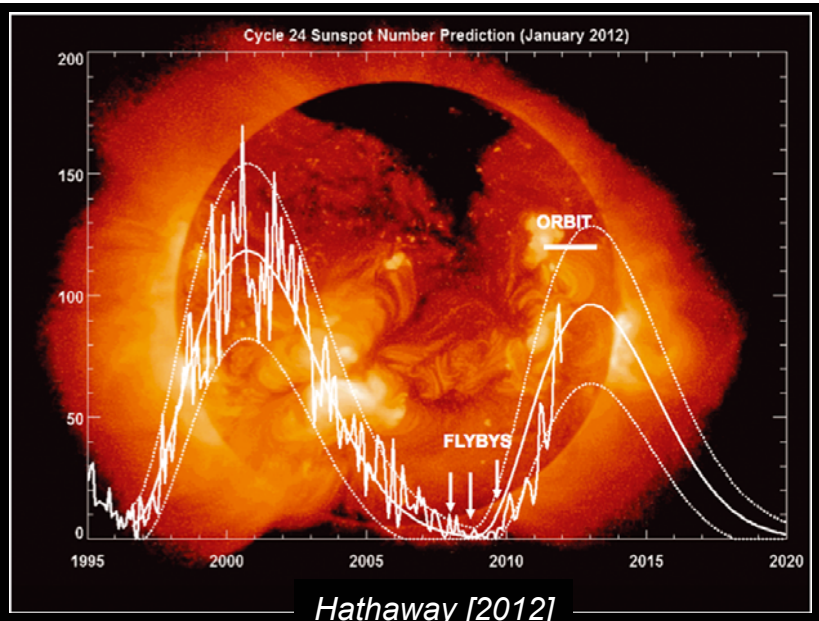

*Potter and Morgan [1985]*



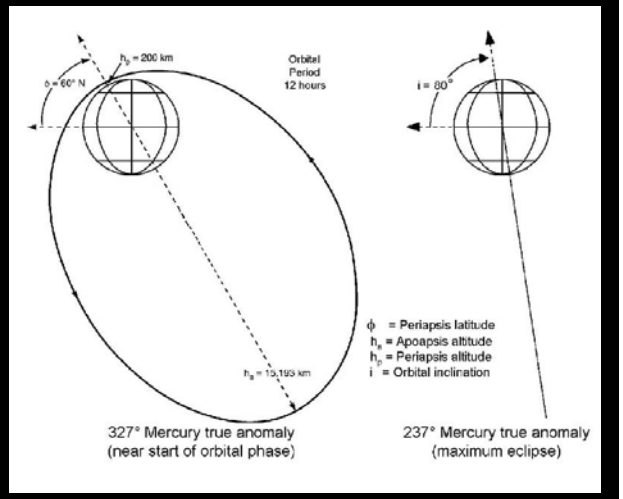




*Leblanc et al. [2010]*

☞ *Exospheric $Na^+$ content not constant over a complete Mercury's cycle*



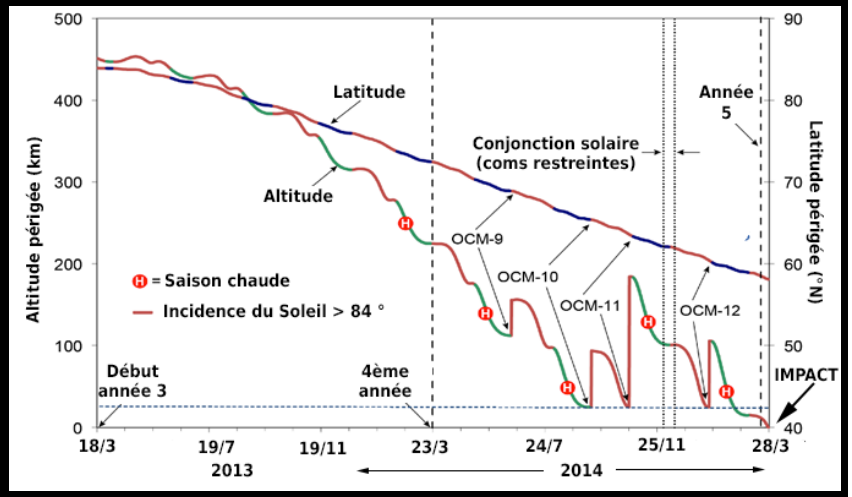

*Hathaway [2012]*




# ***MESSENGER***

*NASA Discovery mission (planetology)*

- *launch : Aug. 14, 2004*
- *3 Mercury flybys :*
  *Jan. 14, 2008 ; Oct. 6, 2008, Sep. 29, 2009*
- *(quasi-polar) orbit insertion : Mar. 18, 2011*
  *nominal mission : 200 x 15000 km, 12 hours*
  *extended mission : 200 x 10000 km, 8 hours*
- *mission end : Mar. 28, 2015*



**Sujet:** Maneuver Successfully Delays MESSENGER's Impact, Extends Orbital Operations
**De :** MESSENGER News <MESSENGER-News@APLMSG.JHUAPL.EDU>
**Date :** Thu, 22 Jan 2015 00:09:06 +0000
**Pour :** MESSENGER-ENEWS-L@listserv.jhuapl.edu

MESSENGER Mission News
January 21, 2015
http://messenger.jhuapl.edu

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**Maneuver Successfully Delays MESSENGER's Impact, Extends Orbital Operations**

MESSENGER mission controllers at the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Md., successfully conducted a maneuver today designed to raise the spacecraft's minimum altitude sufficiently to extend orbital operations and delay the probe's inevitable impact onto Mercury's surface until early next spring.

The immediately previous maneuver, completed on October 24, 2014, raised MESSENGER to an altitude at closest approach from 25.4 kilometers (15.8 miles) to 184.4 kilometers (114.6 miles) above the planet's surface. Because of progressive changes to the orbit over time, the spacecraft's minimum altitude continued to decrease.

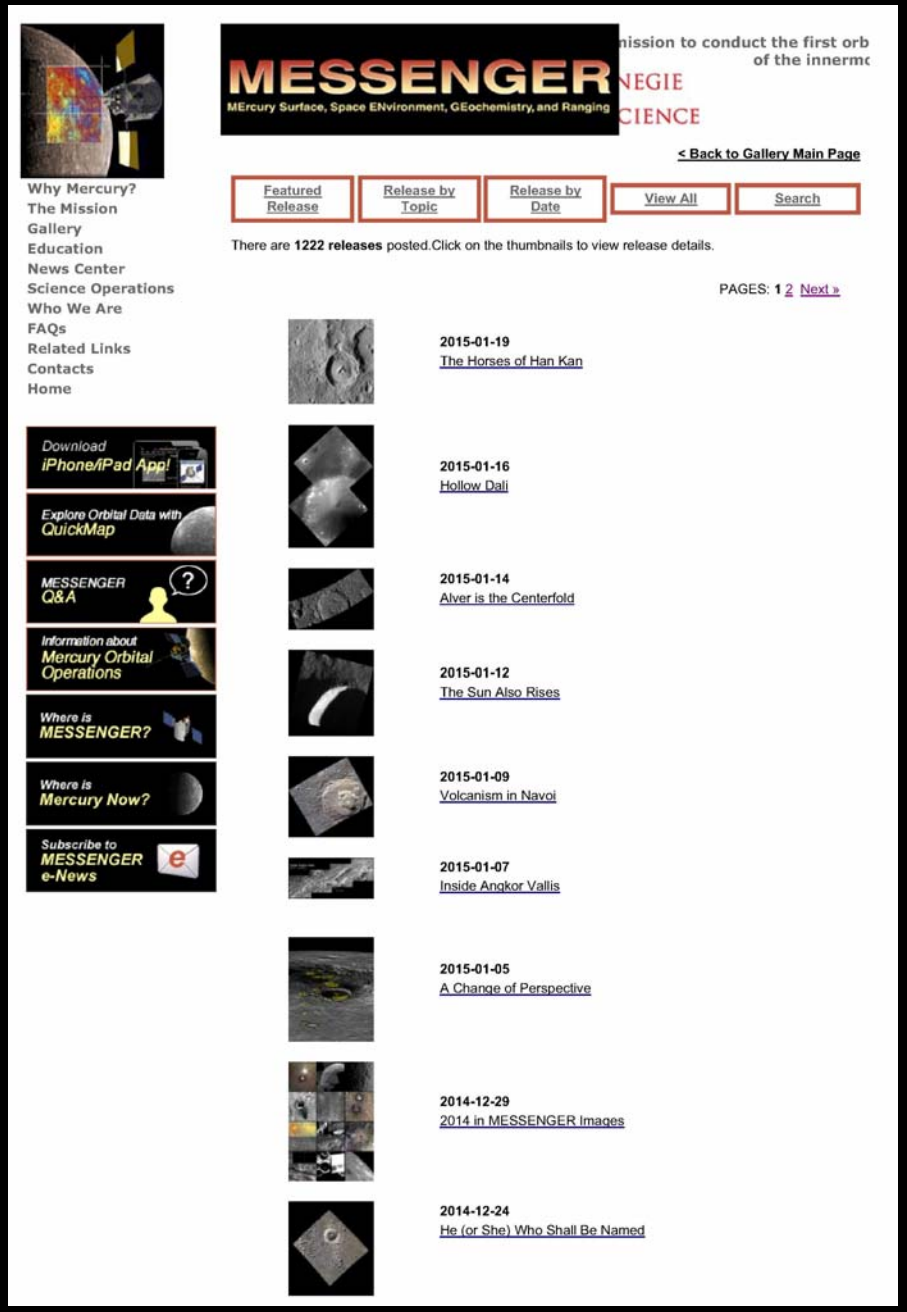
At the time of this most recent maneuver, MESSENGER was in an orbit with a closest approach of 25.7 kilometers (16.0 miles) above the surface of Mercury. With a velocity change of 9.67 meters per second (21.62 miles per hour), the spacecraft's four largest monopropellant thrusters (with a small contribution from four of the 12 smallest monopropellant thrusters) nudged the spacecraft to an orbit with a closest approach altitude of 105.1 km (65.3 miles).

This maneuver also increased the spacecraft's speed relative to Mercury at the maximum distance from Mercury, adding about 3.7 minutes to the spacecraft's eight-hour, 12.9-minute orbit period. This maneuver was the first during the mission to intentionally use both fuel and gaseous helium pressurant to impart the desired velocity change. The propellant was drawn from a small auxiliary fuel tank, and the gaseous helium was drawn from the main fuel tanks.

"This maneuver has demonstrated the safety of this concept and will allow us to characterize system performance during the use of cold gas propellant," said MESSENGER Mission Systems Engineer Dan O'Shaughnessy, of APL. "Such characterization will be necessary to forecast accurately the timing of the spacecraft's surface impact and to plan low-altitude maneuvers for the remainder of the mission."

This view shows MESSENGER's orientation soon after the start of the maneuver. The spacecraft was 118.9 million kilometers (73.9 million miles) from Earth when the 1-minute, 49-second maneuver began at 1:27 p.m. EDT. Mission controllers at APL verified the start of the maneuver 6.6 minutes later, after the first signals indicating spacecraft thruster activity reached NASA's Deep Space Network tracking station in Goldstone, California.

The next maneuver, on March 18, will again raise the spacecraft's minimum altitude, allowing scientists to continue to collect images and data from MESSENGER's instruments.


MESSENGER
MErcury Surface, Space ENvironment, GEochemistry, and Ranging
nission to conduct the first orb
of the innermc
NEGIE
CIENCE
< Back to Gallery Main Page
Why Mercury?
The Mission
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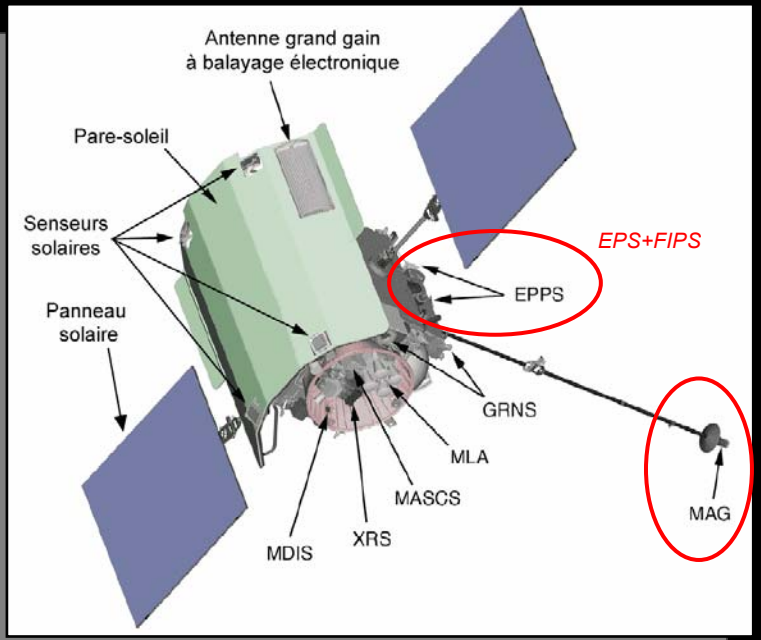
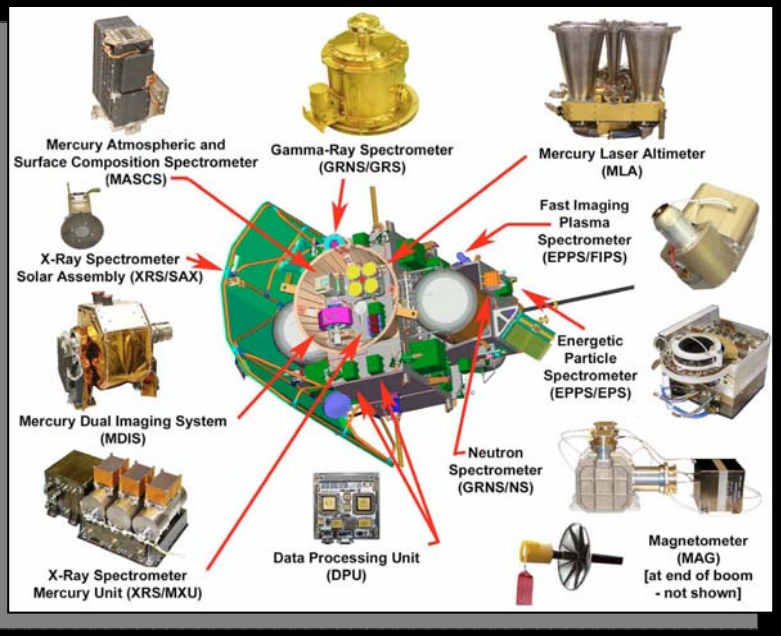
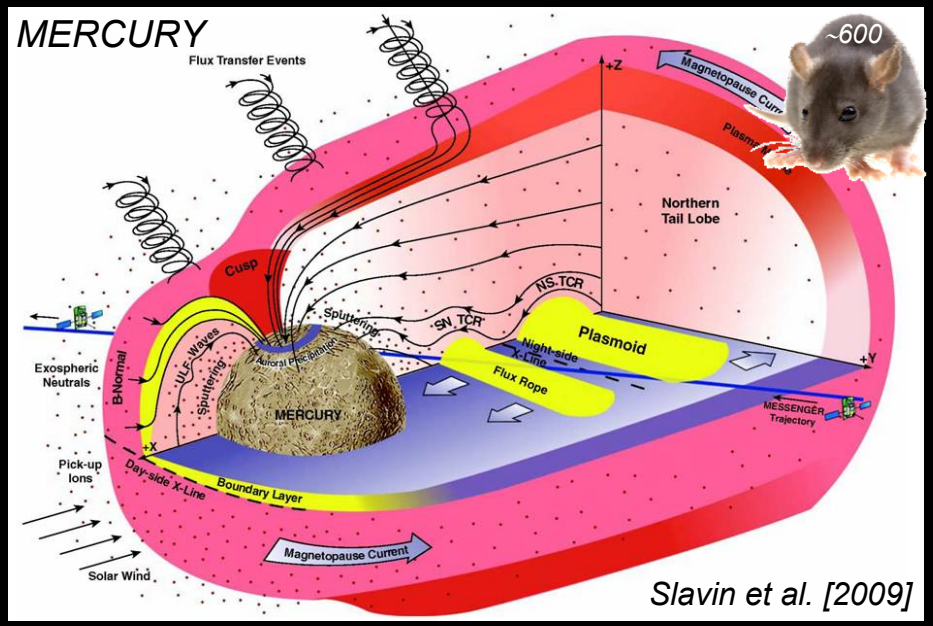
2015-01-19
The Horses of Han Kan
2015-01-16
Hollow Dali
2015-01-14
Alver is the Centerfold
2015-01-12
The Sun Also Rises
2015-01-09
Volcanism in Navoi
2015-01-07
Inside Angkor Vallis
2015-01-05
A Change of Perspective
2014-12-29
2014 in MESSENGER Images
2014-12-24
He (or She) Who Shall Be Named

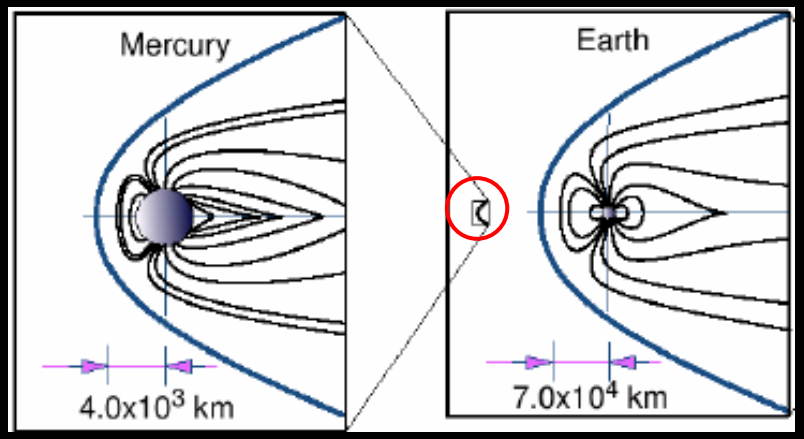

Antenne grand gain
à balayage électronique
Pare-soleil
Senseurs solaires
Panneau solaire
EPS+FIPS
EPPS
GRNS
MLA
MASCS
MAG
MDIS
XRS


Mercury Atmospheric and Surface Composition Spectrometer (MASCS)
Gamma-Ray Spectrometer (GRNS/GRS)
Mercury Laser Altimeter (MLA)
Fast Imaging Plasma Spectrometer (EPPS/FIPS)
X-Ray Spectrometer Solar Assembly (XRS/SAX)
Energetic Particle Spectrometer (EPPS/EPS)
Mercury Dual Imaging System (MDIS)
Neutron Spectrometer (GRNS/NS)
Magnetometer (MAG) [at end of boom - not shown]
Data Processing Unit (DPU)
X-Ray Spectrometer Mercury Unit (XRS/MXU)

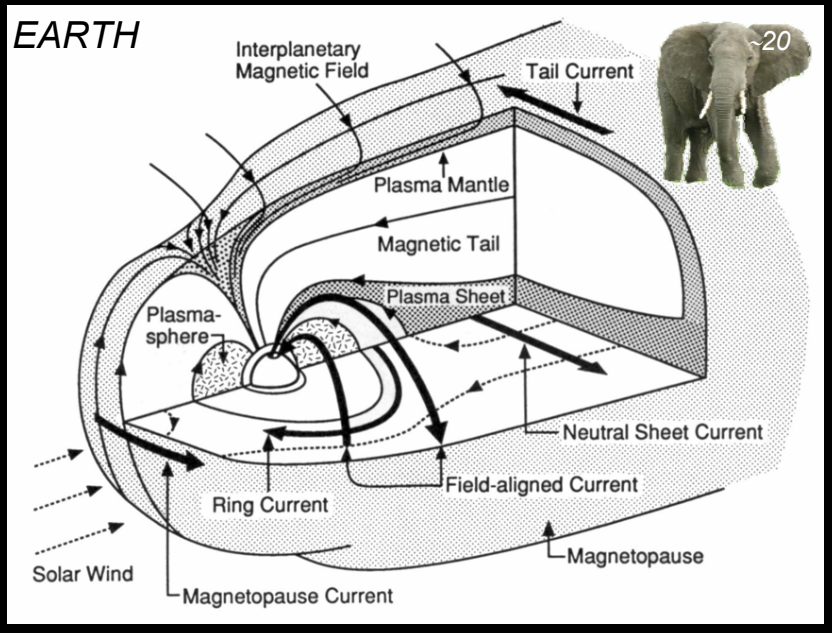
# MESSENGER



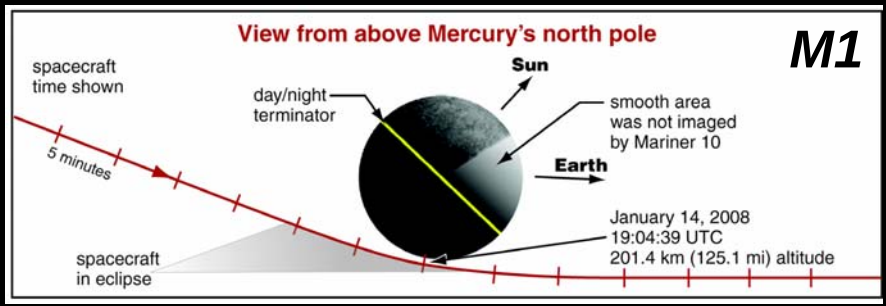

Slavin et al. [2009]

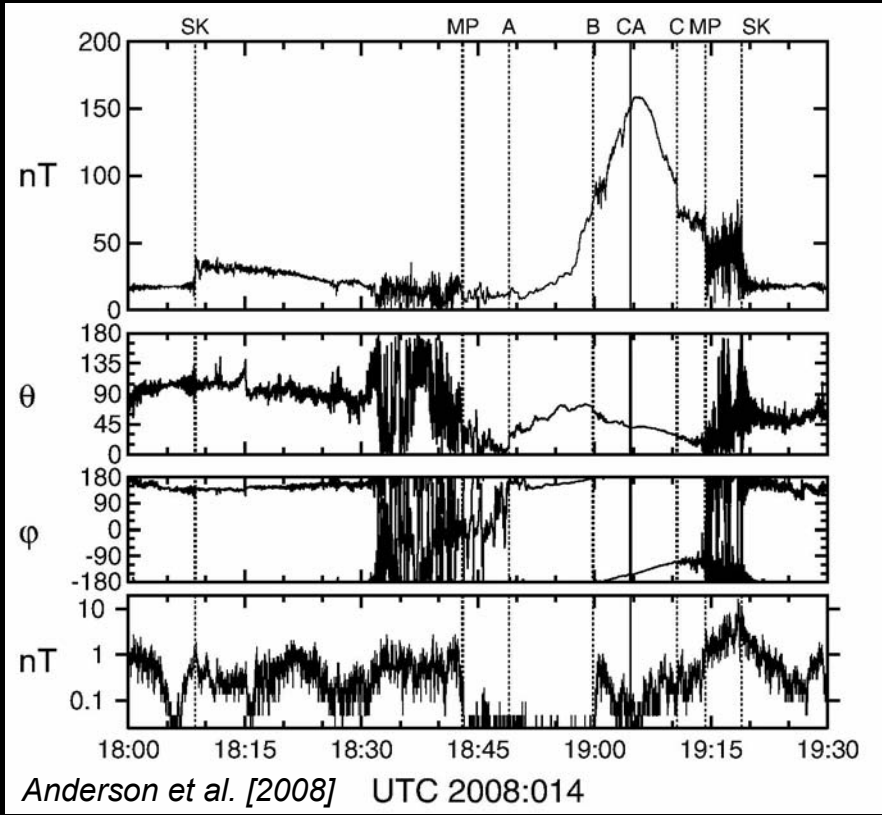



- *Different boundary conditions (tenuous atmosphere, solar wind parameters)*
- *Different spatial and temporal scales (~1:8 and ~1:30, respectively)*

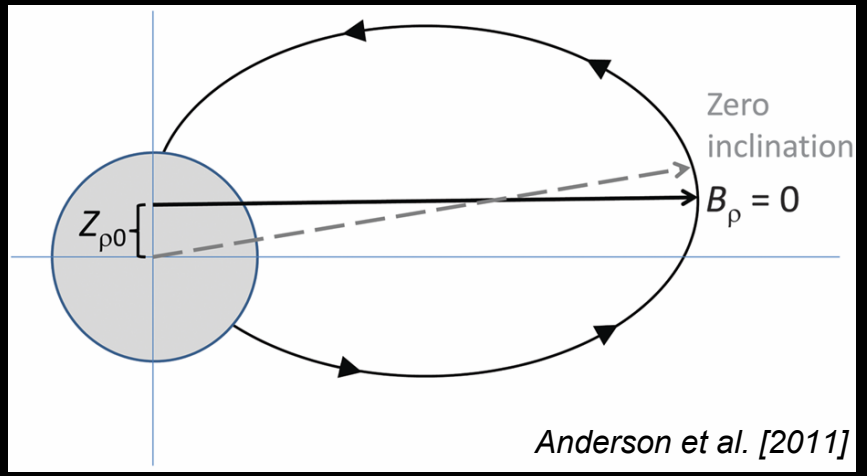


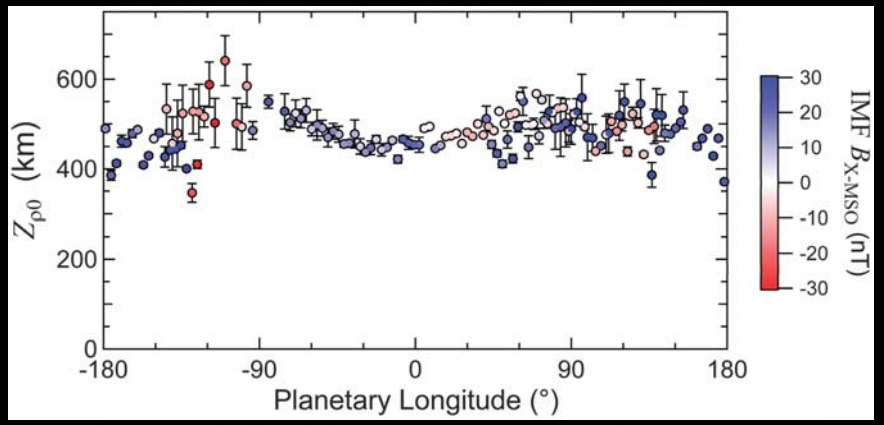
# Intrinsic magnetic field

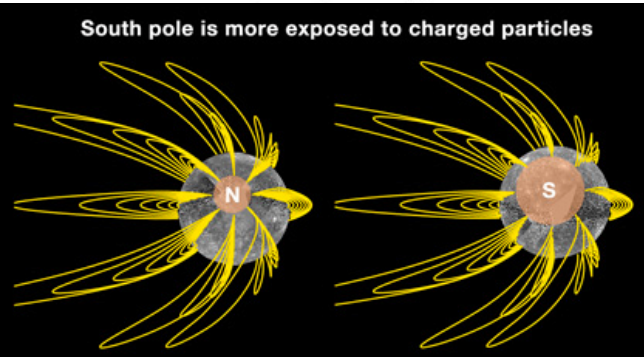


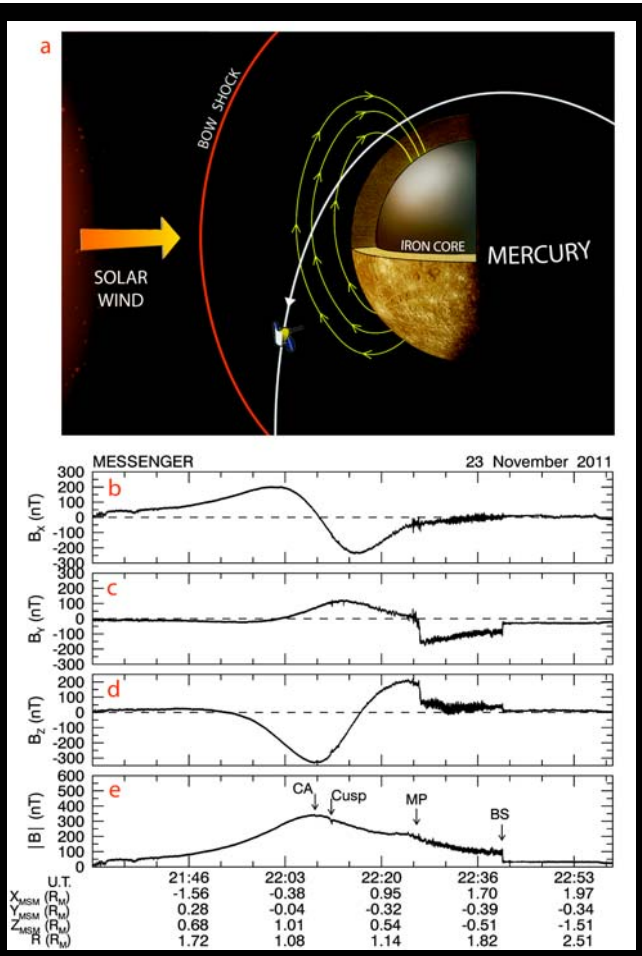

*Northward offset of magnetic equator of ~480 km*

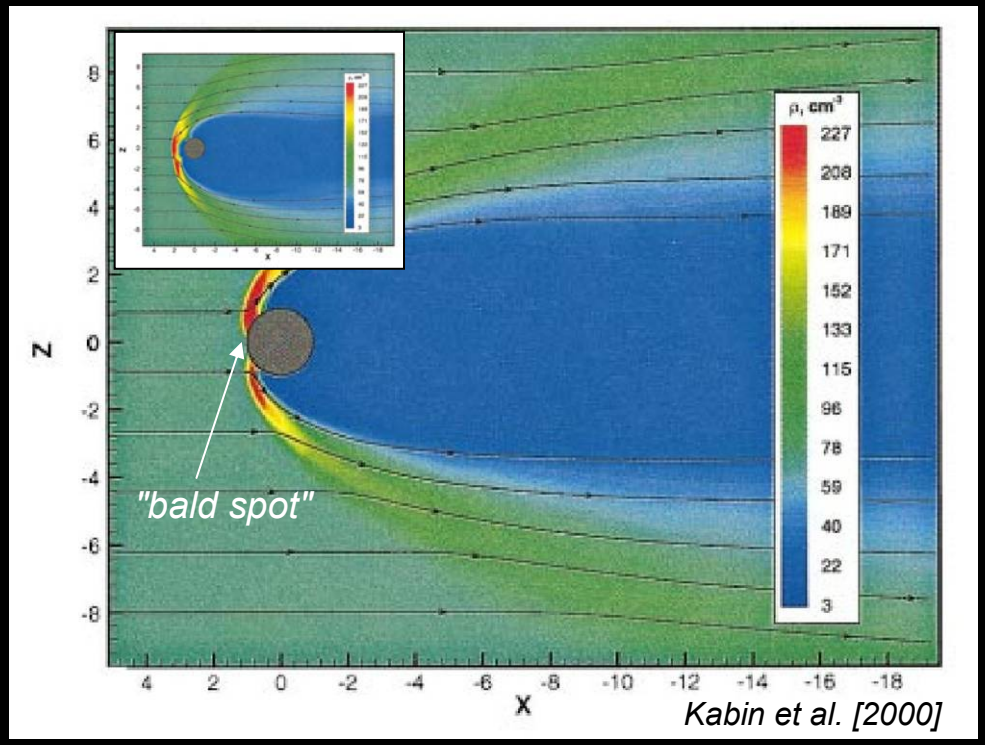


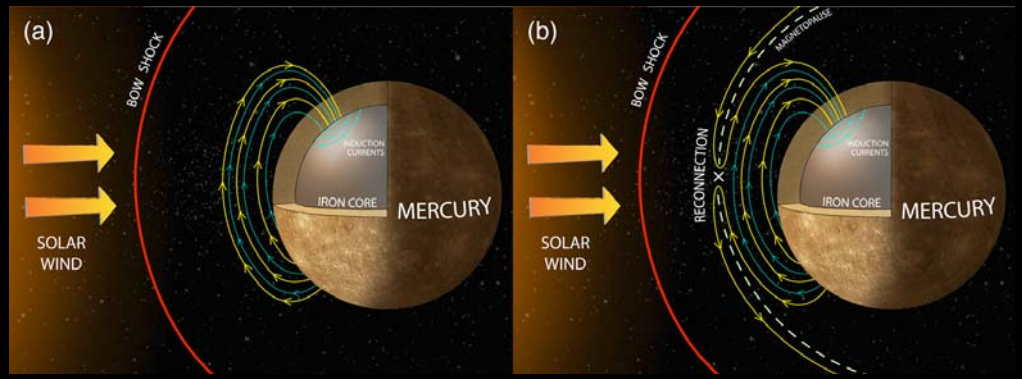



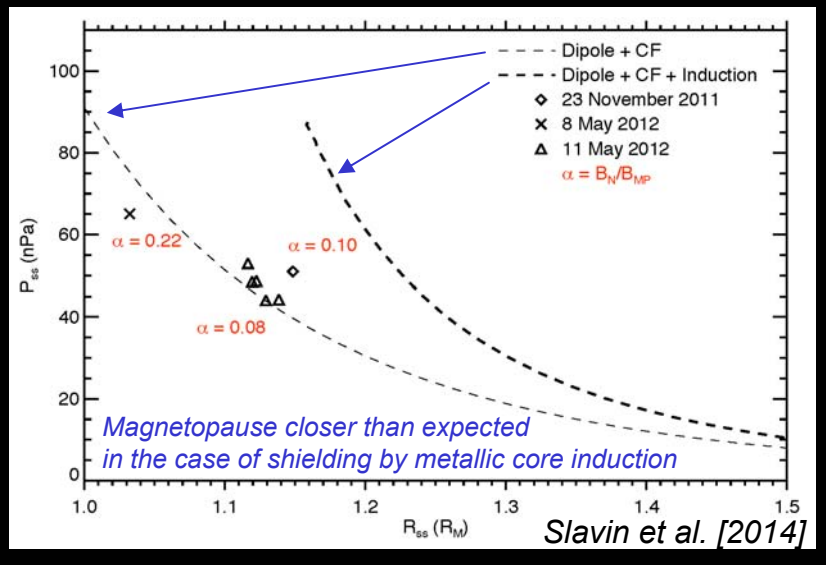



# Erosion of dayside magnetosphere

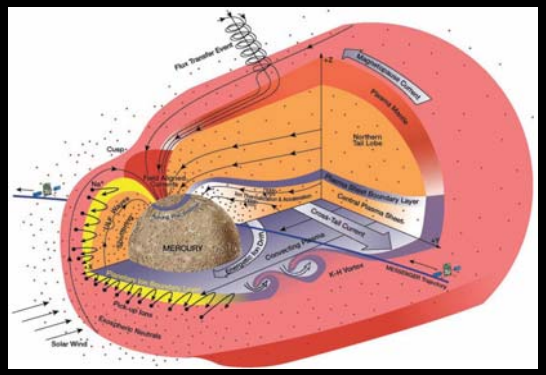


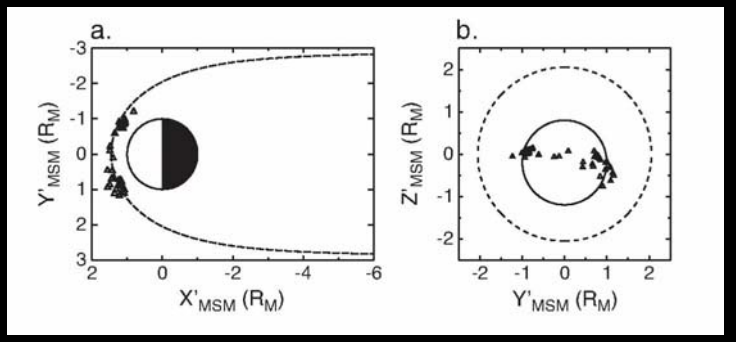



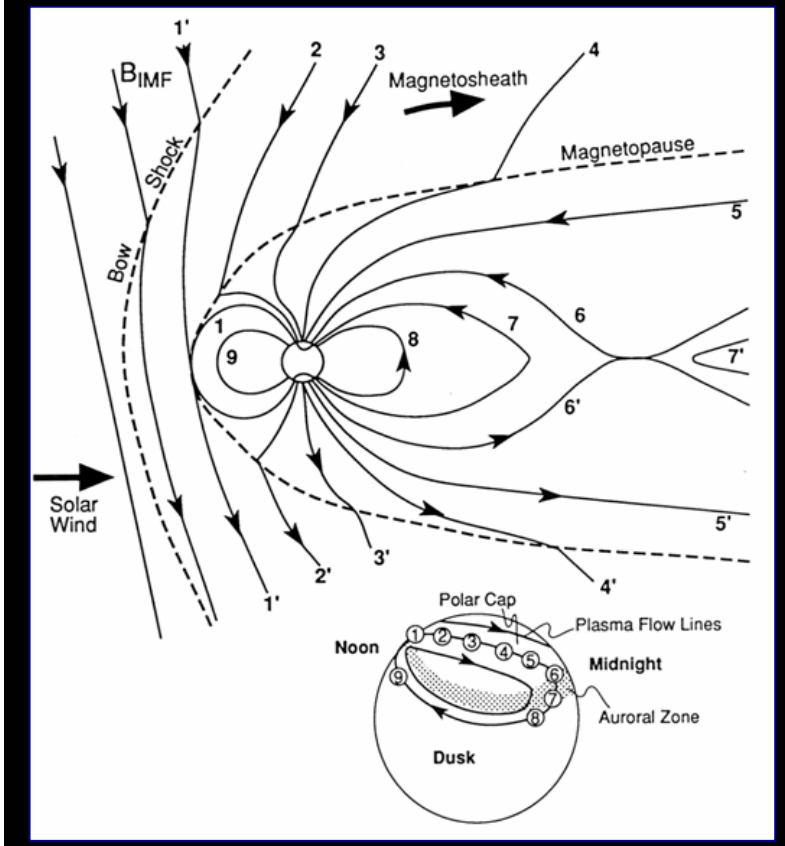



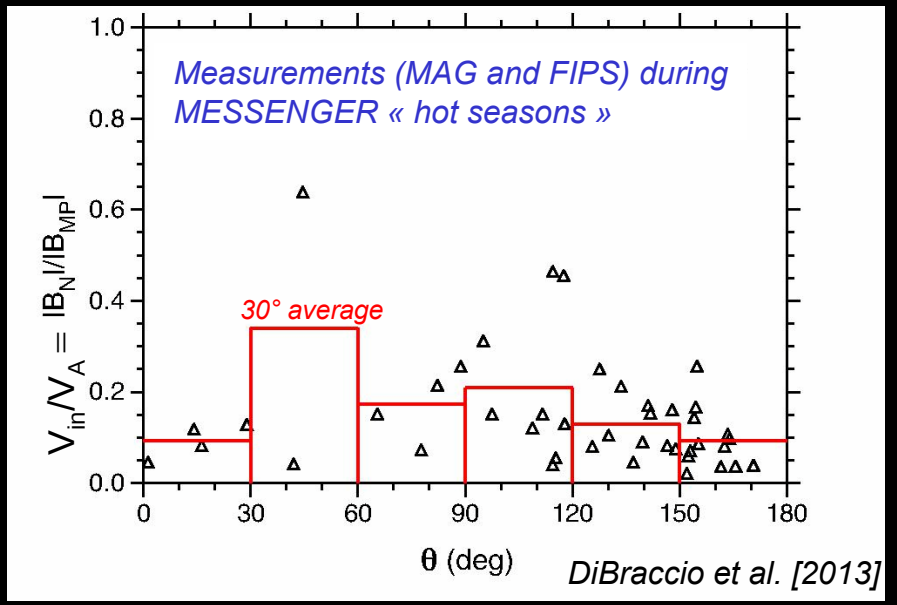
# Dayside reconnection



*Dungey cycle :*
*Earth : a few hours*
*Mercury : several minutes*



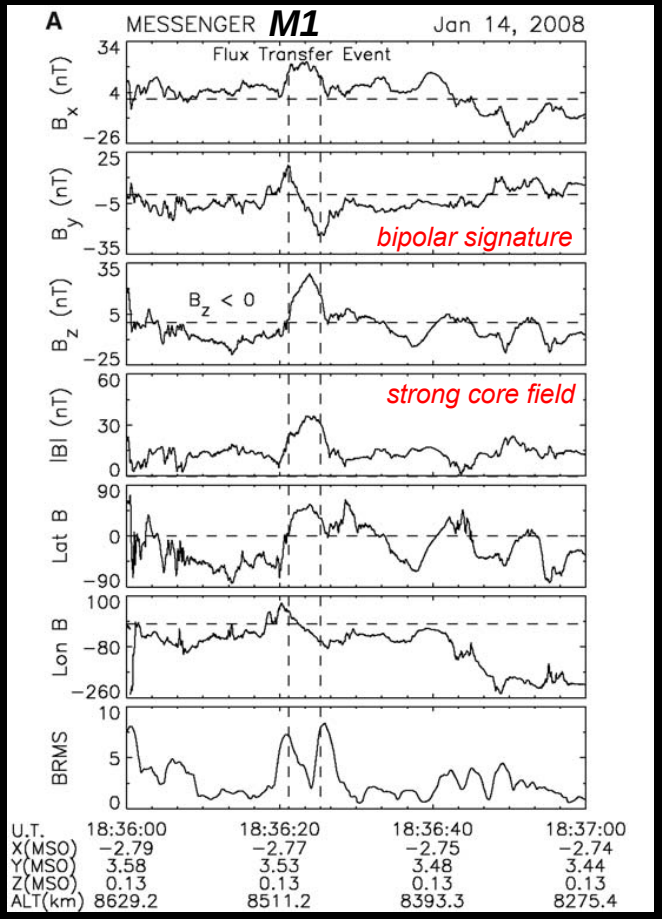



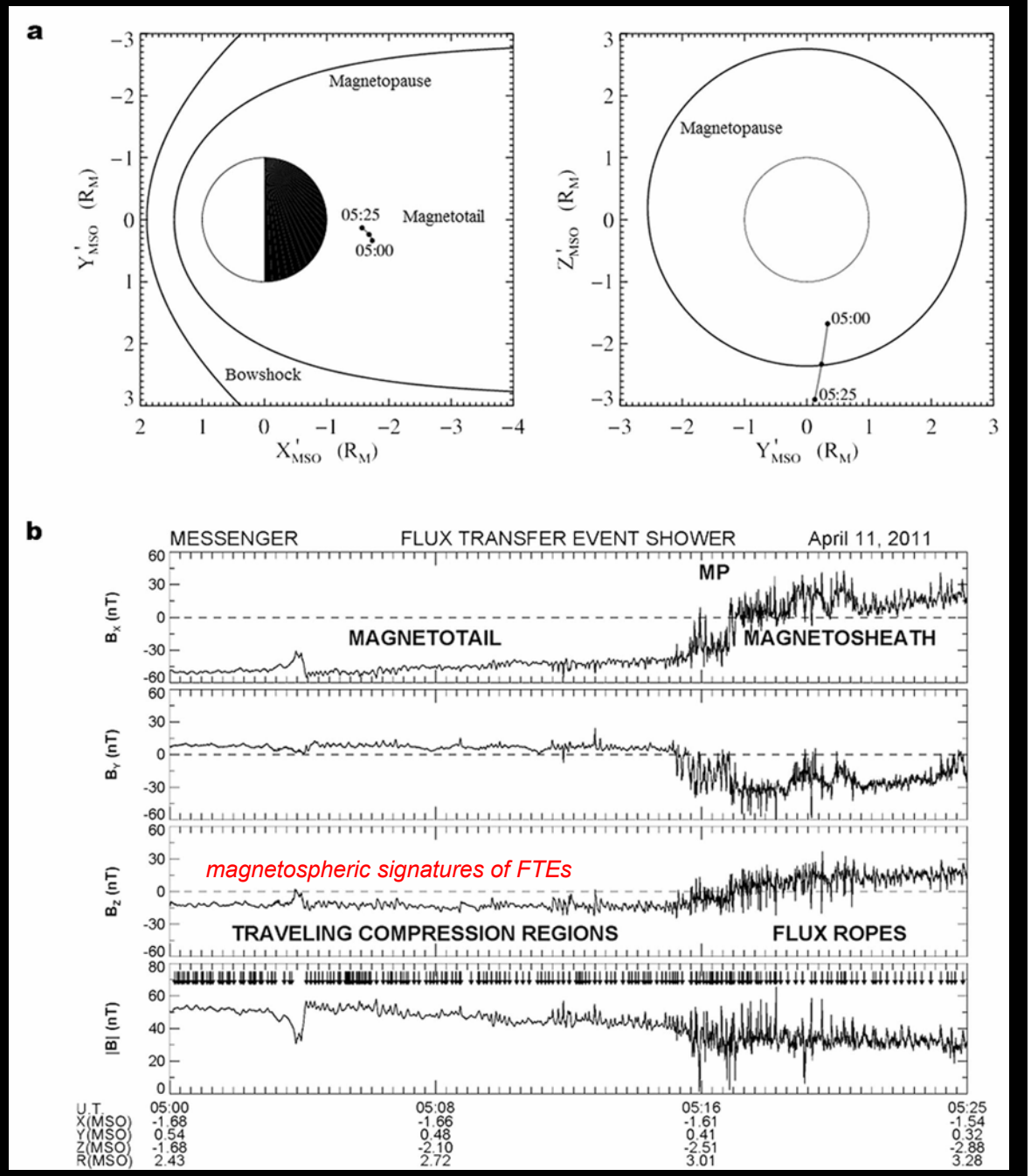

☞ *Upstream of Mercury, low Alfven Mach number (low beta) as compared to Earth*
⇒ *large reconnection rate regardless of shear angle (« delta beta - shear condition », e.g., Phan et al. [2013])*

☞ *Intense solar wind forcing*

# ***Flux Transfer Events (reconnection bursts)***

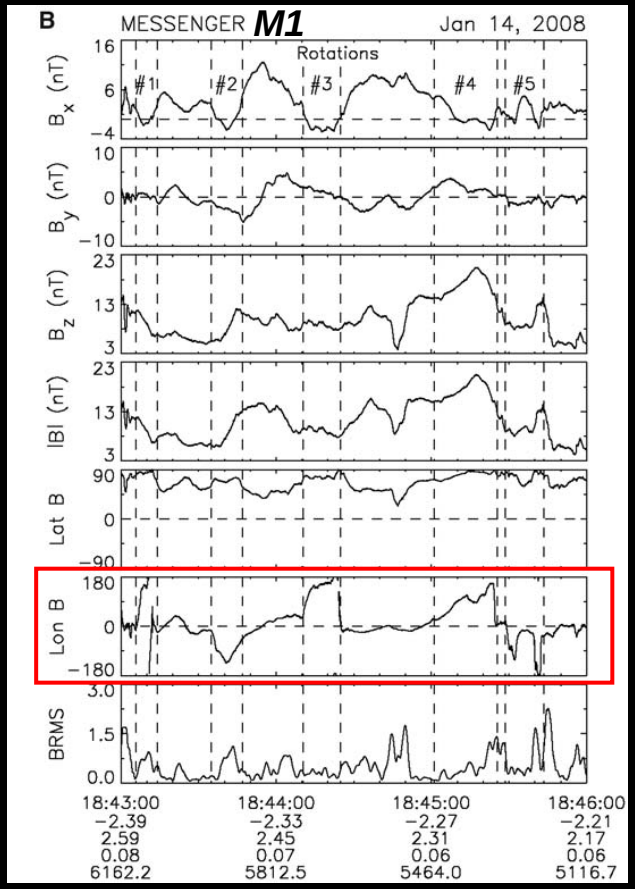



*Slavin et al. [2008]*



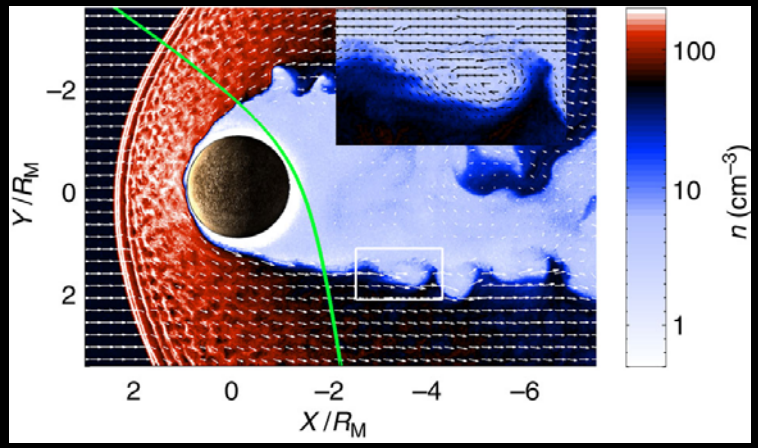

*Slavin et al. [2012]*

# Kelvin-Helmholtz instability

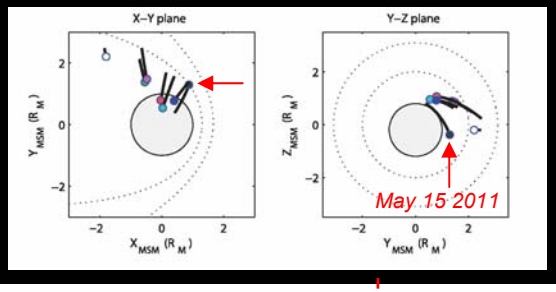


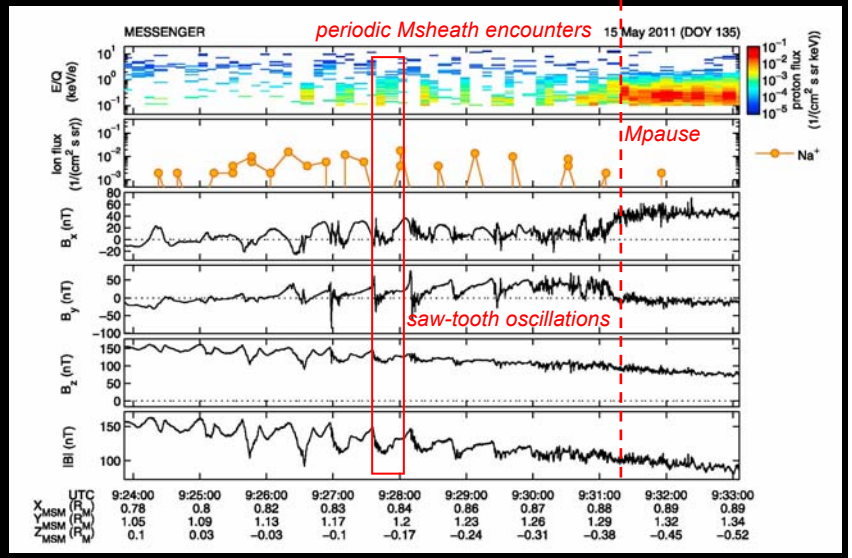

Slavin et al. [2008]

- *Repeated B rotations in dusk flank characteristic of K-H driven vortices*




Paral and Rankin [2013]

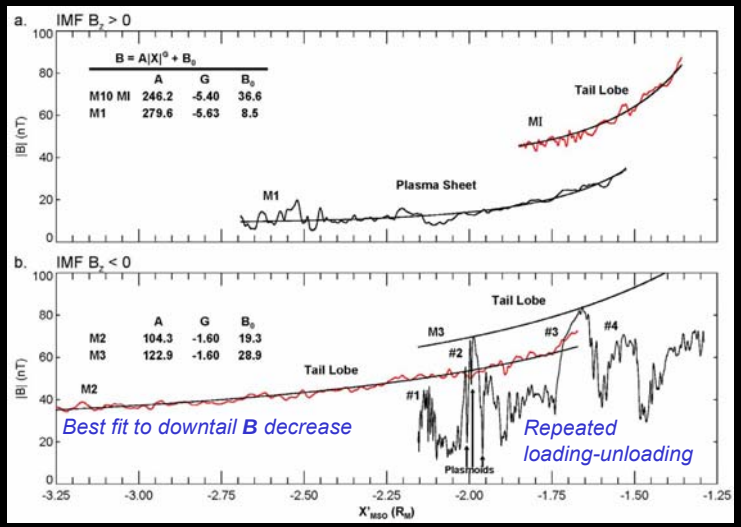


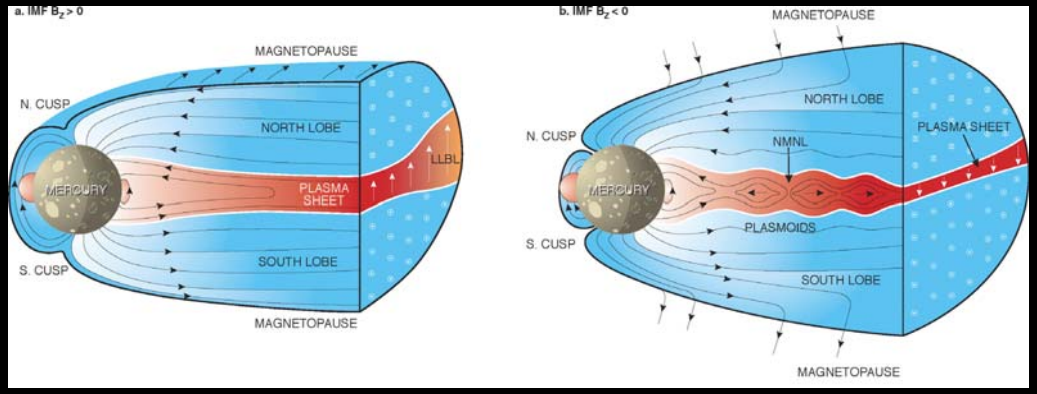

Sundberg et al. [2012]

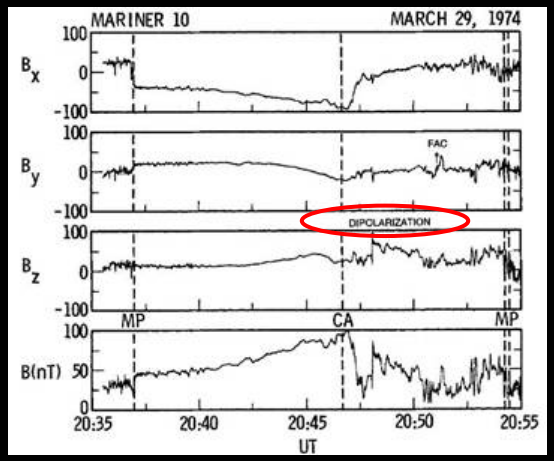
- *Larger/smaller velocity shear layer with smaller/larger K-H growth rate on dawn/dusk sides ?*
- *Mass loading (e.g., $Na^+$) in dawn sector ?*
- *…*

# Loading-unloading and dipolarisation

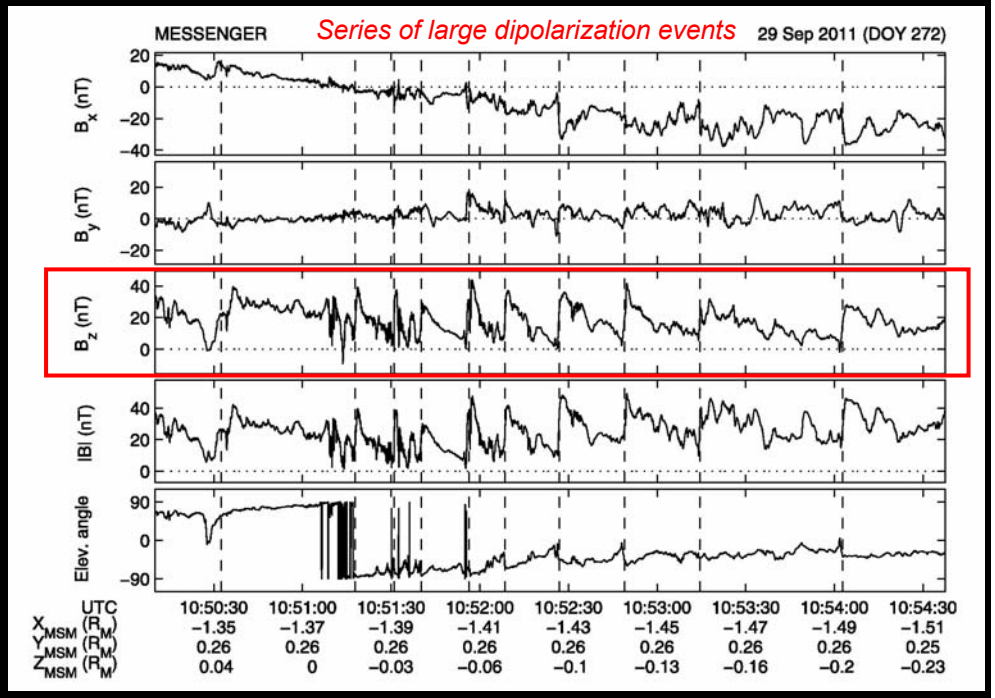



*Slavin et al. [2012]*



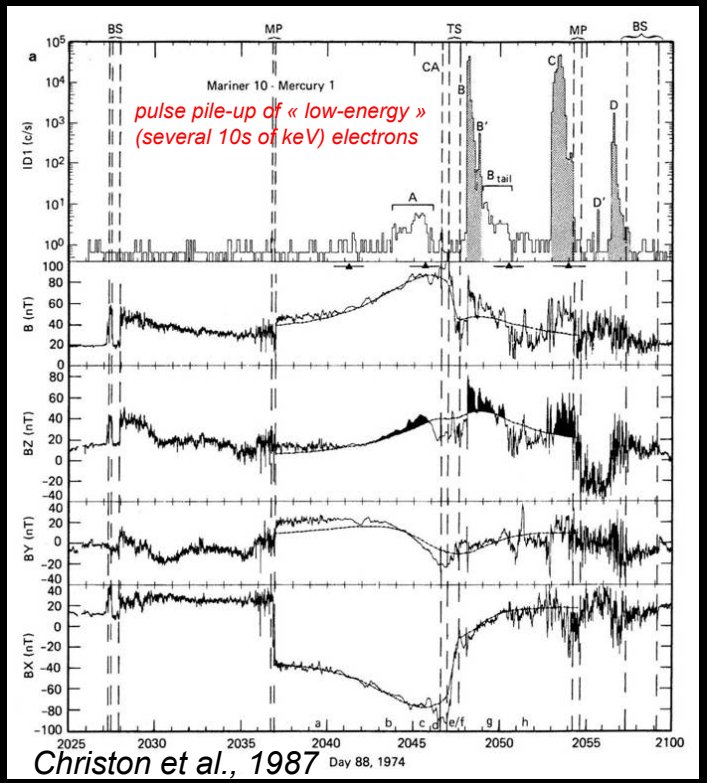

*Christon et al. [1987]*



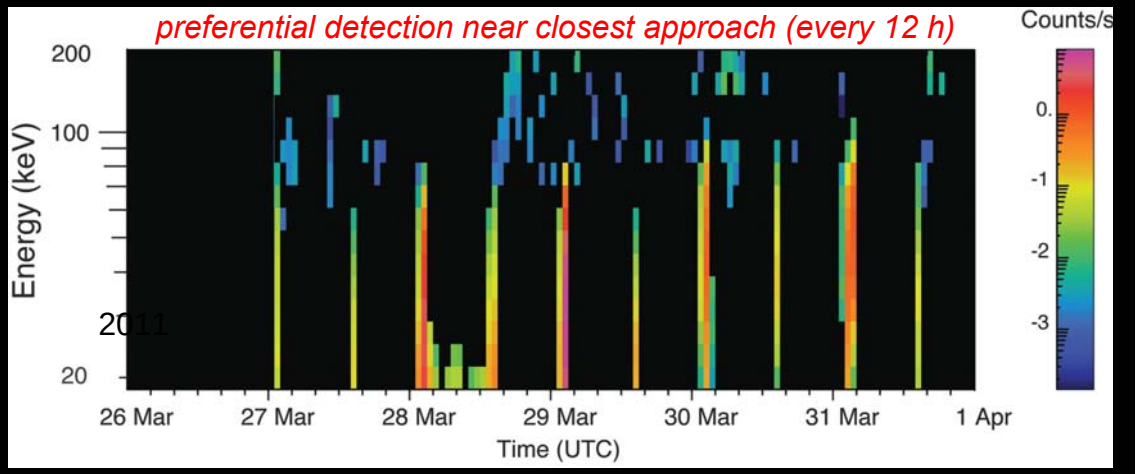

*Sundberg et al. [2012]*

- ☞ *Field line reconfiguration over short time scales (~2 s dipolarization risetime, ~10 s lifespan)*
- ☞ *Efficient (nonadiabatic ?) heating of plasma sheet populations*

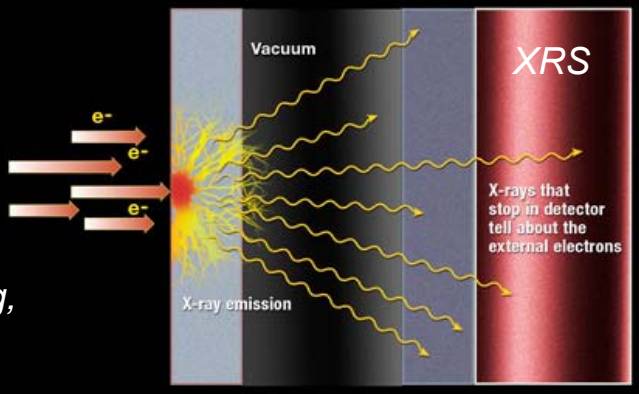
# Energetic particles

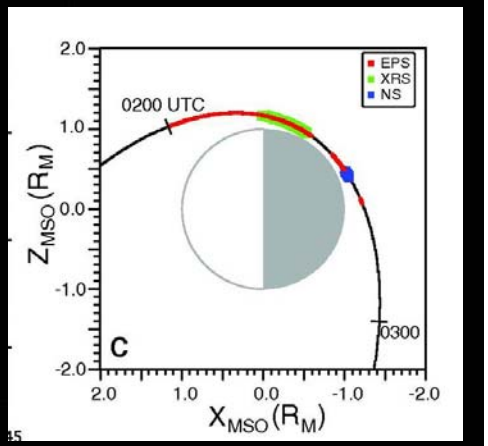



Christon et al., 1987



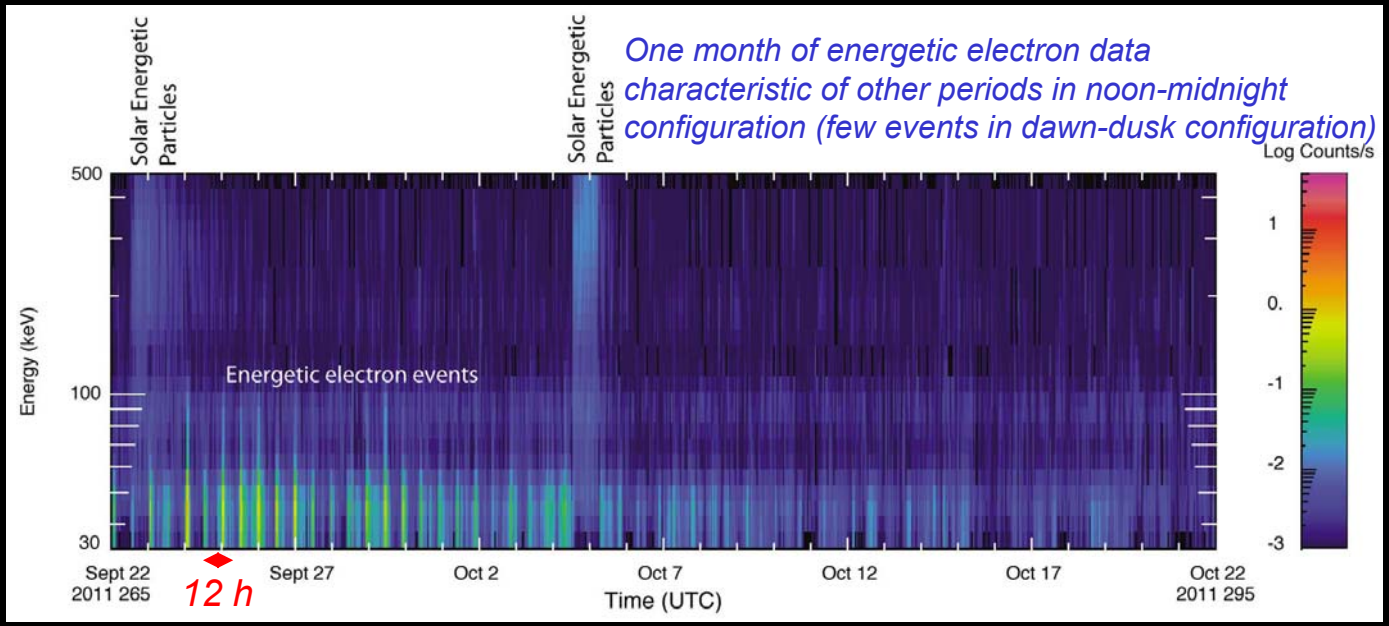

- *No evidence of stably trapped high-energy particles*
- *No energetic particle measurements from EPS during MESSENGER flybys (despite observations of loading-unloading, e.g., during M3) but indirect evidences from XRS (caused by bremsstrahlung of ~10 keV electrons, i.e., below EPS threshold).*
- *EPS measures only the high-energy tail of energetic electron bursts.*



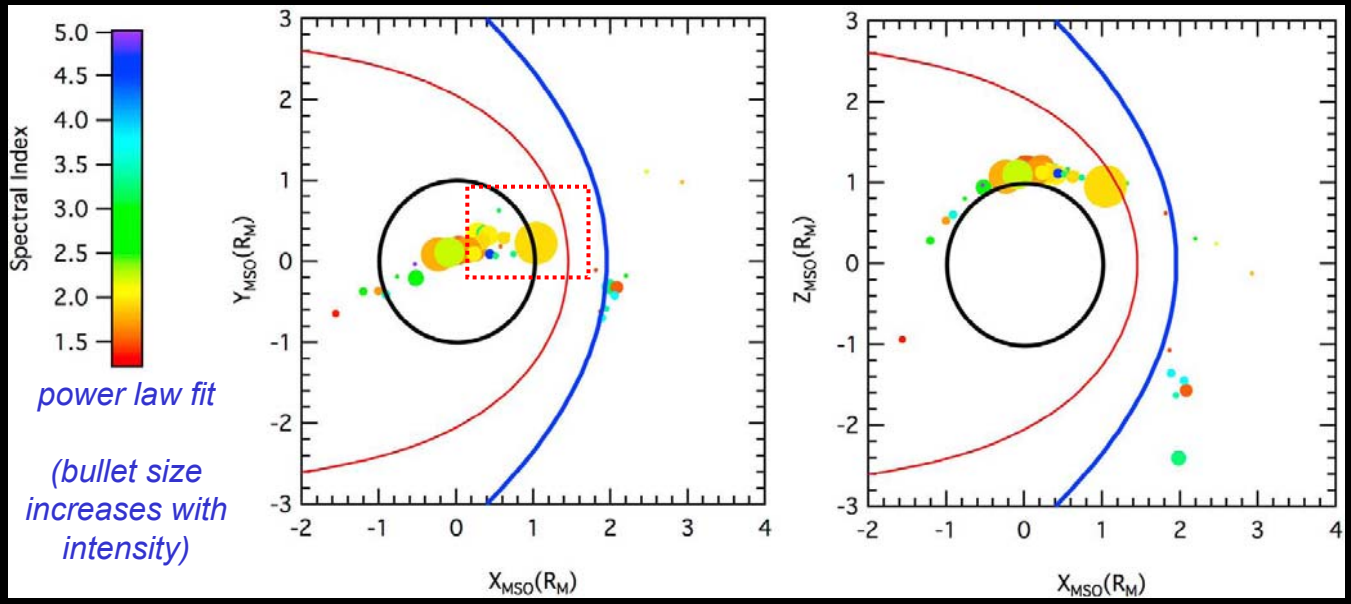




Ho et al. [2011]

# Energetic particles

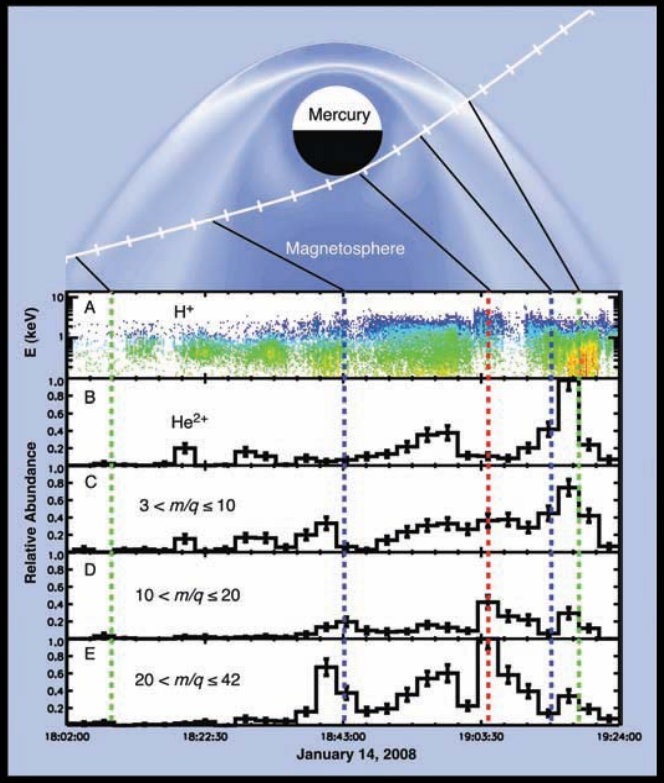


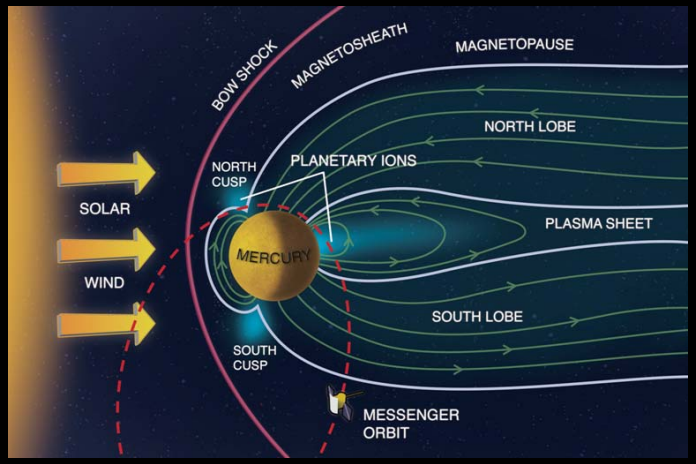

- *Most intense energetic electron events near northern dayside cusp*
- *Some moderate-size events near local midnight*

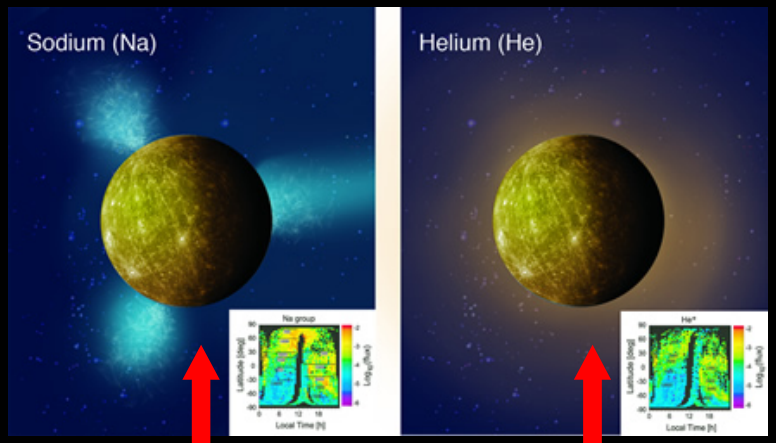


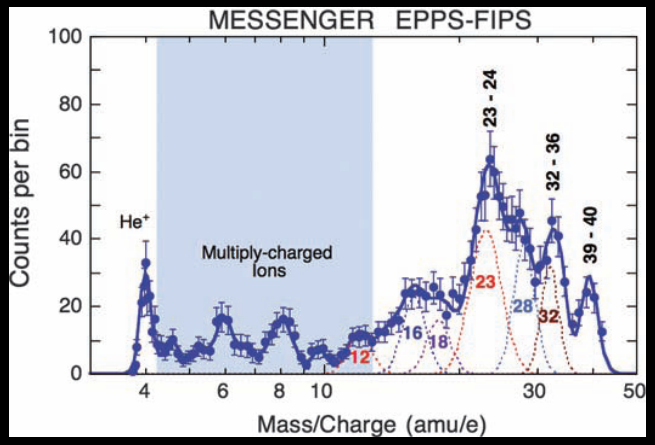

*Ho et al. [2012]*

# Magnetospheric populations

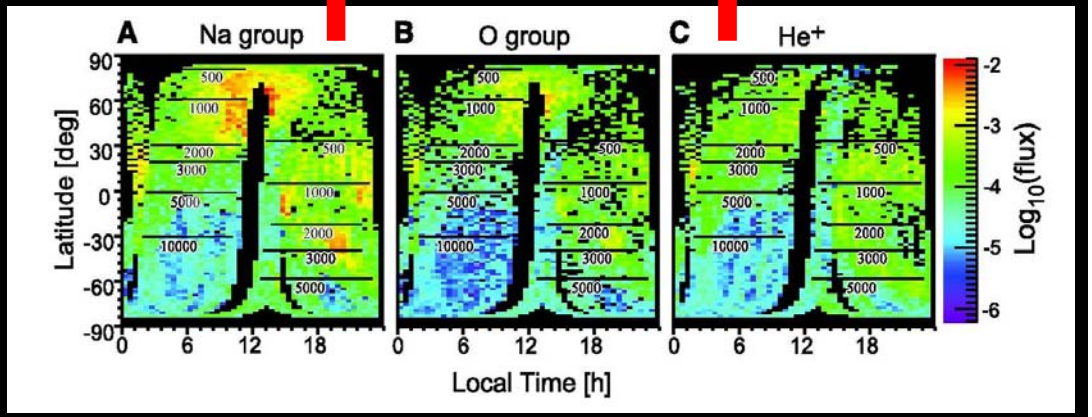


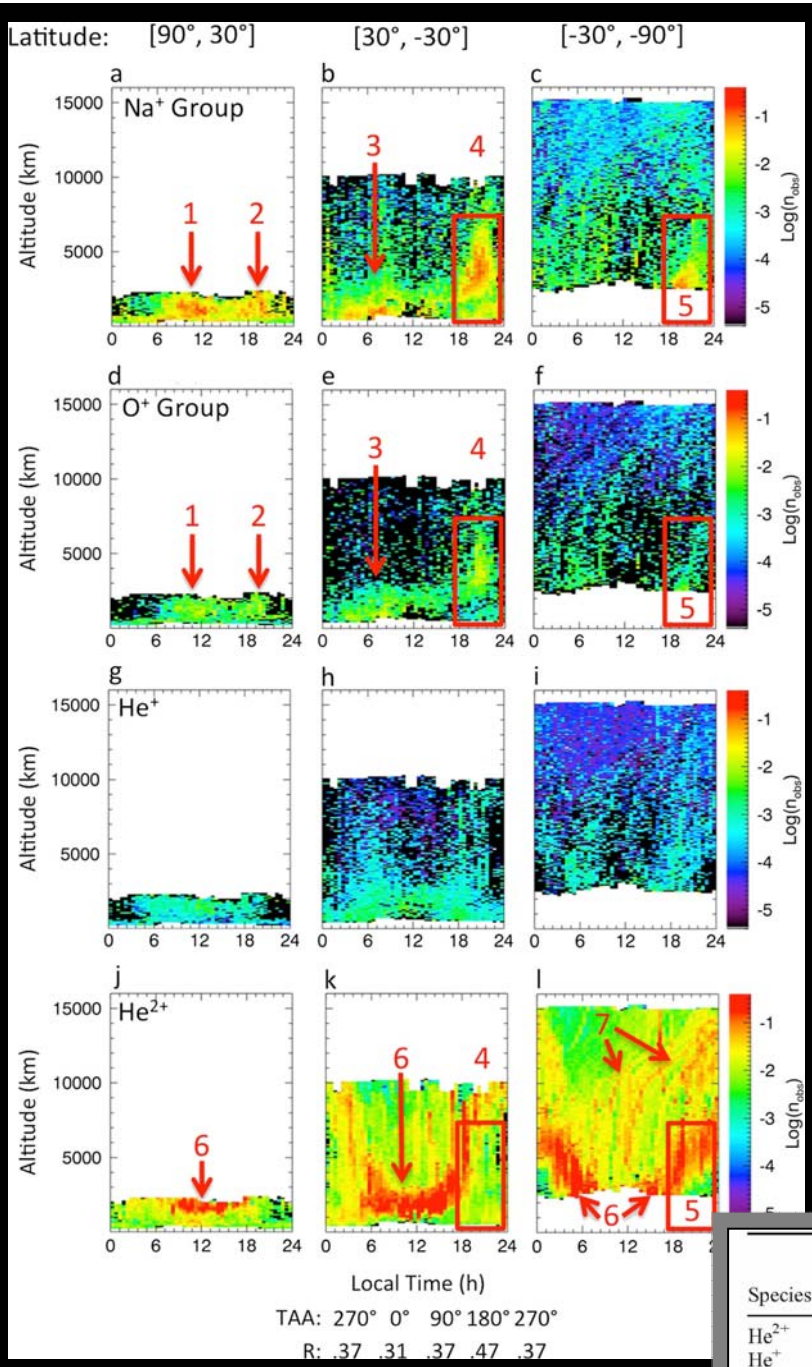



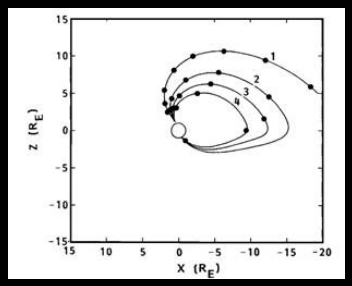

Zurbuchen et al. [2008]

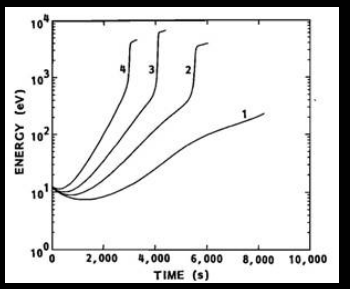


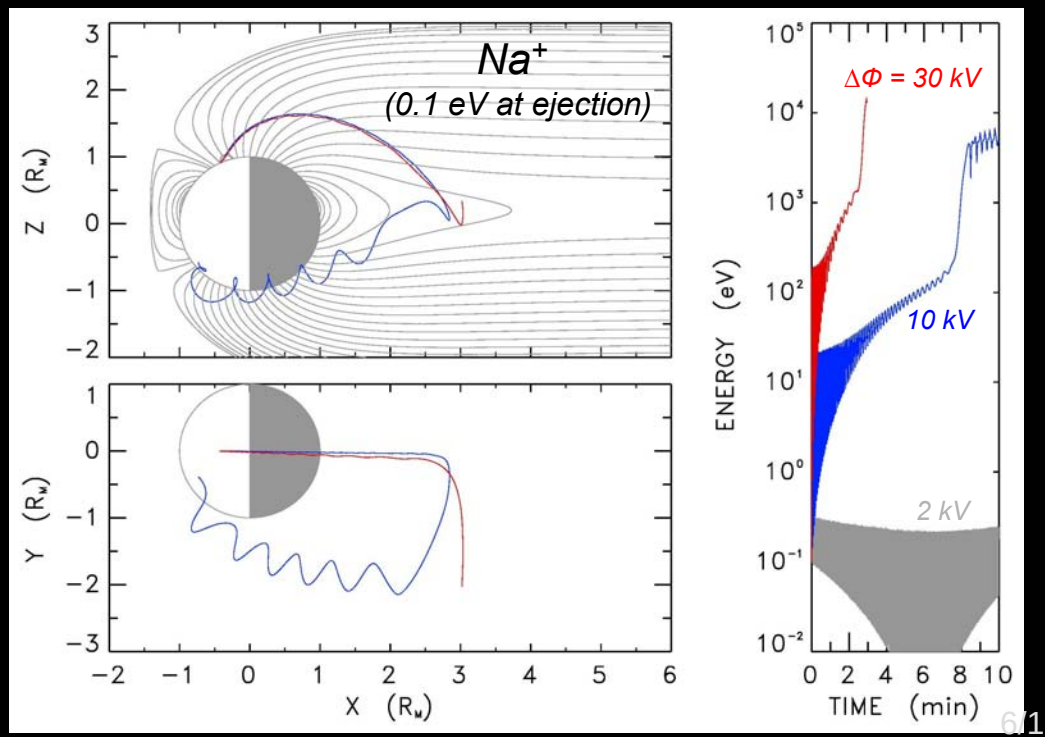

Zurbuchen et al. [2011]

# Magnetospheric populations



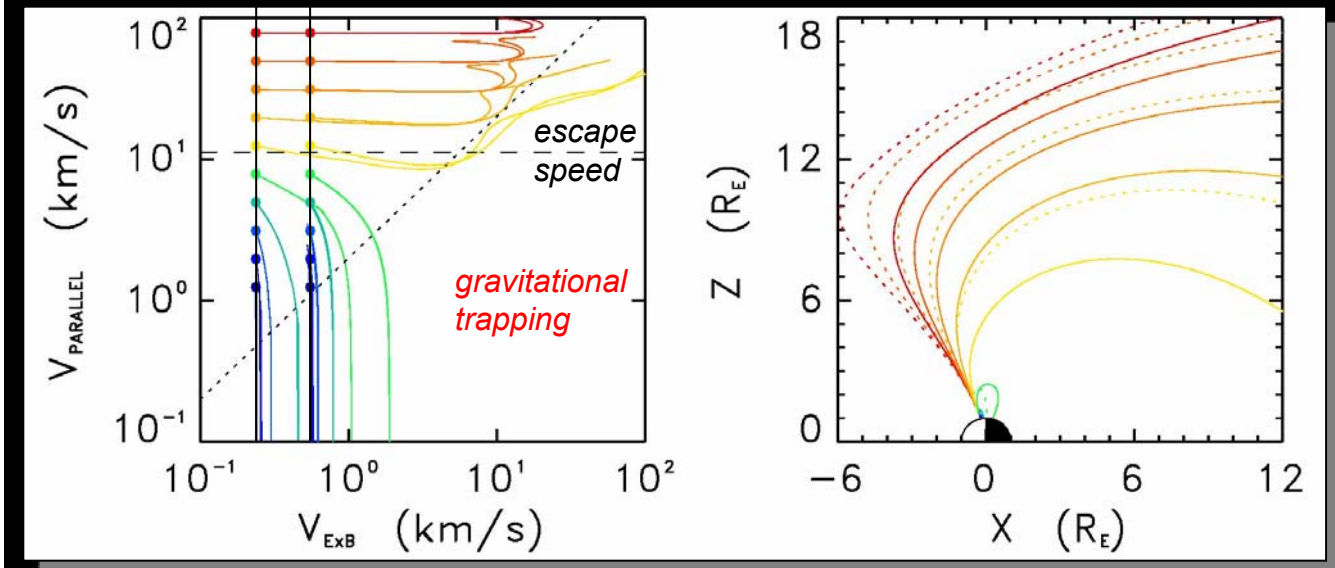




Raines et al. [2013]

| Species | Orbital $\langle n_{obs} \rangle$ (cm$^{-3}$) | Orbital Ratio | M1 + M2 $\langle n_{obs} \rangle$ (cm$^{-3}$) | M1 + M2 Ratio |
|---|---|---|---|---|
| $He^{2+}$ | $(3.9 \pm 0.0012) \times 10^{-2}$ | 7.7 | $(1.0 \pm 0.012) \times 10^{-3}$ | 0.31 |
| $He^{+}$ | $(3.4 \pm 0.0035) \times 10^{-4}$ | 0.067 | $(2.2 \pm 0.23) \times 10^{-3}$ | 0.68 |
| $O^{+}$ group | $(8.0 \pm 0.010) \times 10^{-4}$ | 0.16 | $(1.0 \pm 0.18) \times 10^{-3}$ | 0.31 |
| $Na^{+}$ group | $(5.1 \pm 0.0043) \times 10^{-3}$ | 1 | $(3.3 \pm 0.047) \times 10^{-3}$ | 1 |

# Centrifugal acceleration : Mercury vs. Earth

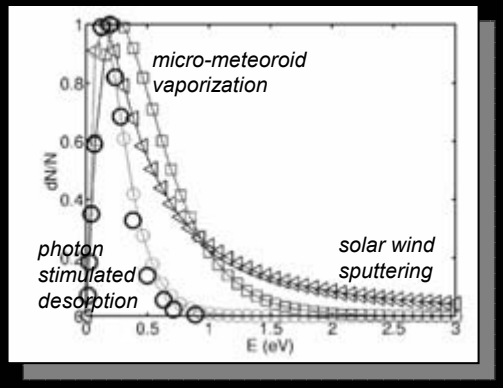



**EARTH**

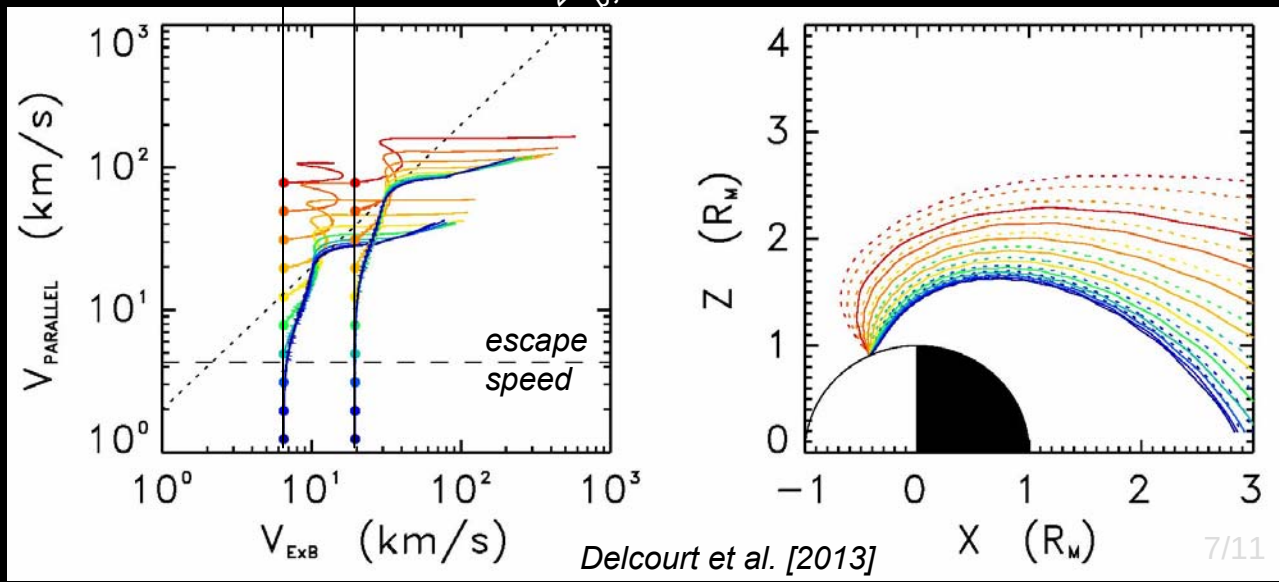
*different centrifugal energization schemes*

**MERCURY**

$2V_{ExB}$ parallel acceleration by "moving magnetic mirror"

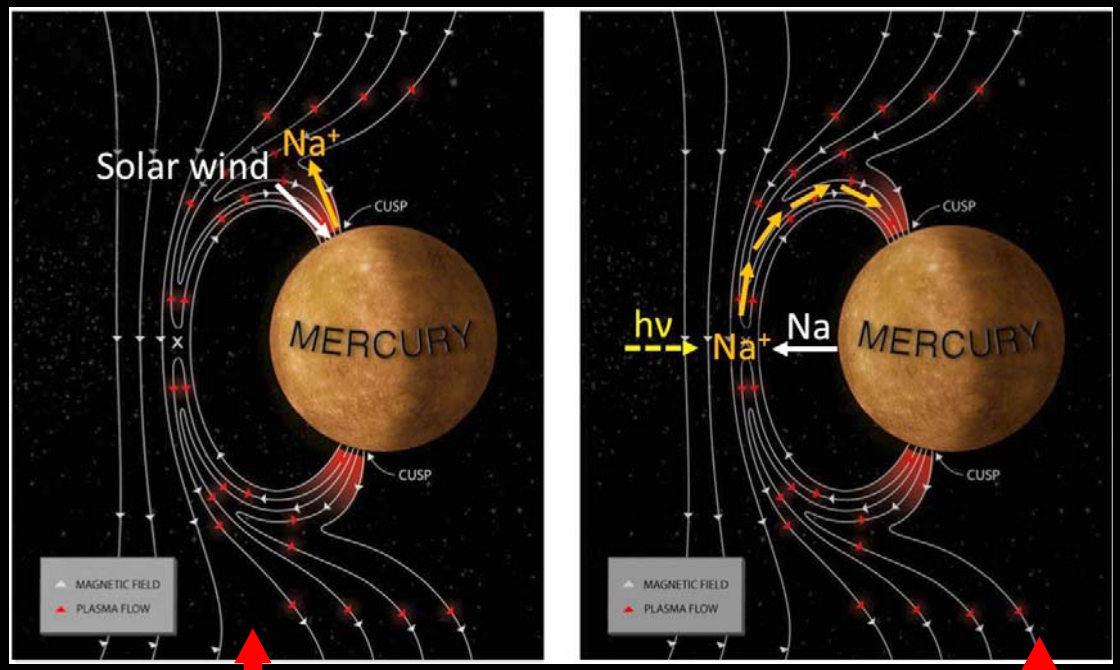


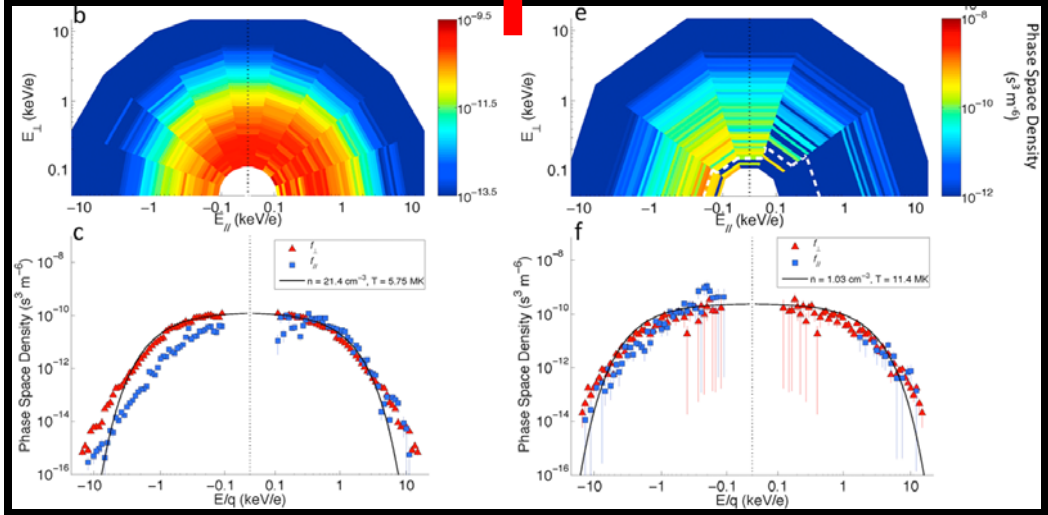

*Yakshinskiy and Madey [1999]*

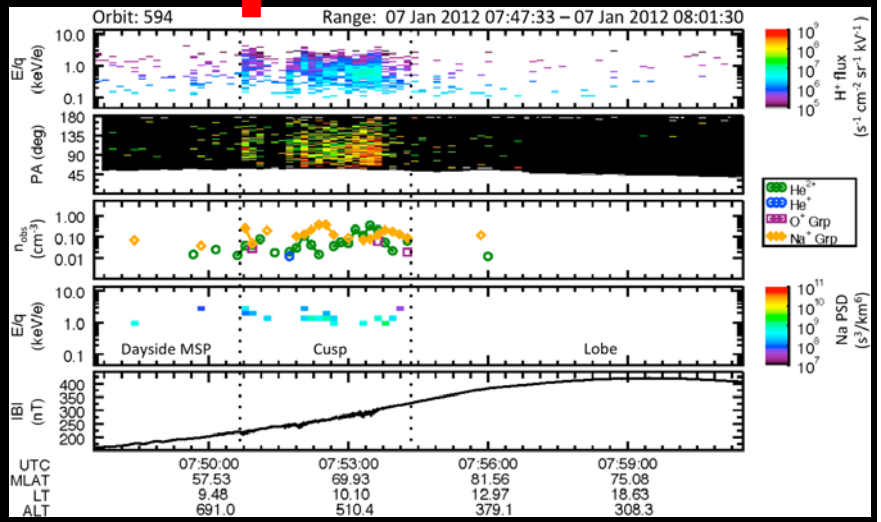



*Delcourt et al. [2013]*

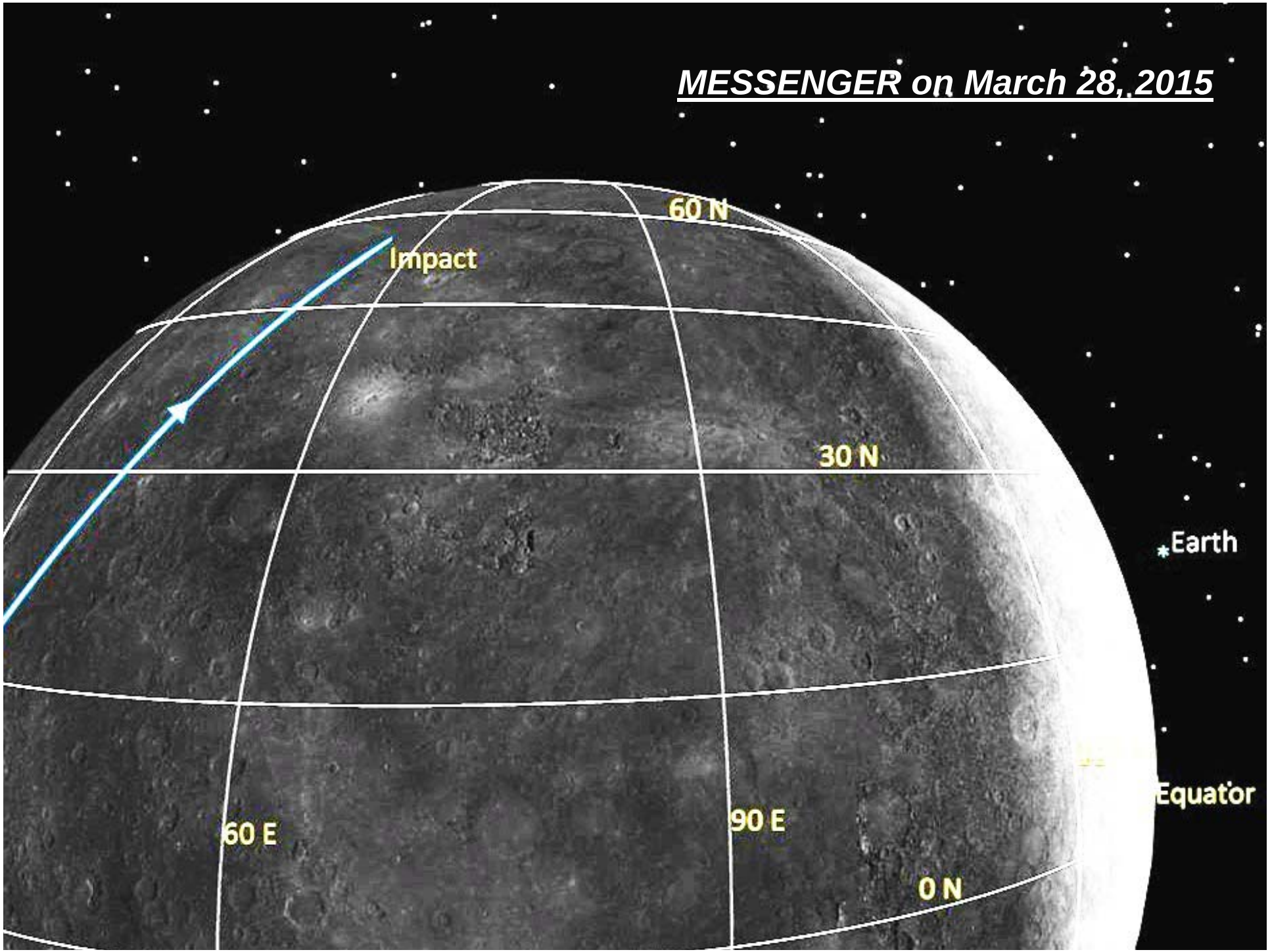
# Cusp $Na^+$




*Raines et al. [2014]*


MESSENGER on March 28, 2015
60 N
Impact
30 N
Earth
Equator
60 E
90 E
0 N

# Bepi Colombo

## Mercury Planetary Orbiter (MPO)

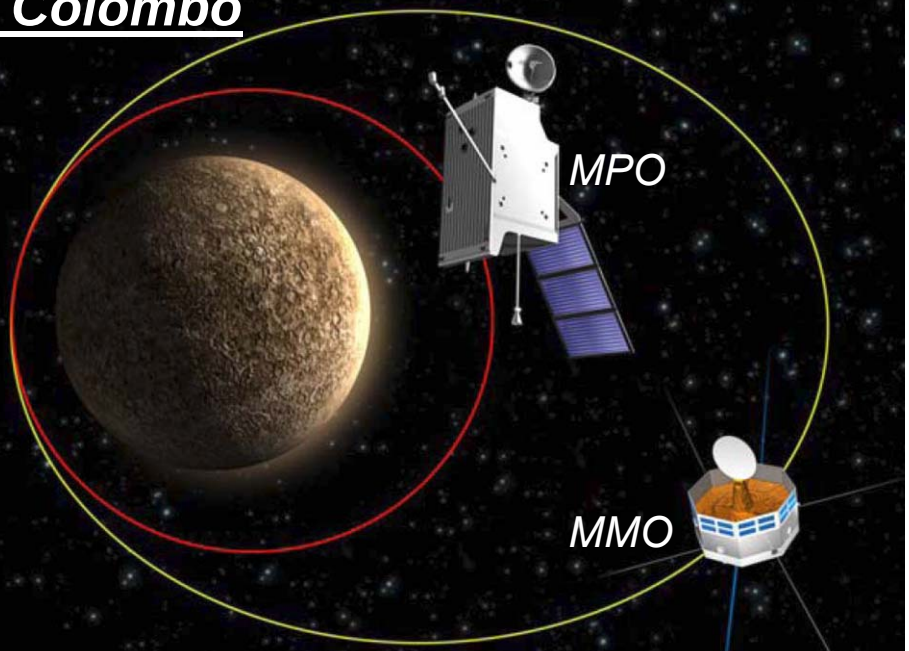
*(ESA, 400 x 1500 km, 2.3 h)*

| | |
|---|---|
| BELA | altimètre laser |
| ISA | radio science |
| MERMAG | magnétomètre |
| MERTIS | spectromètre IR |
| MGNS-MANGA | spectromètre $\gamma$-neutrons |
| MIXS / SIXS | spectromètre X |
| PHEBUS | spectromètre UV |
| SIMBIO-SYS | imageurs, spectro visible-NIR |
| SERENA | Search for Exospheric Refilling and Emitted Natural Abundances (ELENA, MIPA, **PICAM**, STROFIO) |

## Mercury Magnetospheric Orbiter (MMO)

*(JAXA, 400 x 12000 km, 9.3 h)*

| | |
|---|---|
| PWI | Plasma Wave Investigations (**SORBET**, MEFISTO, EWO, LF-SC, **DB-SC**, WPT, **AM2P**) |
| MPPE | Mercury Plasma Particle Experiments (**MEA**, MIA, **MSA**, HEP, ENA) |
| MERMAG | magnétomètre |
| MSASI | imageur exosphère |
| MDM | analyseur poussières |




**Intérieur** noyau / manteau
composition
champ magnétique

**Surface** morphologie
composition
température

**Exosphère** composition
dynamique
sources / puits

**Magnétosphère** structure
composition
dynamique
couplages

***« End member » magnetosphere :***

- *Proximity to the Sun (IMF)*
- *Tenuous atmosphere*
- *Weak planetary magnetic field (North-South asymetry)*
- *Slow rotation (58.6 days)*

*Magnetosphere similar to that of Earth*
***but very dynamical***

***Contribution from Bepi Colombo :***

- *Intrinsic magnetic field*
- *Wave, plasma and energetic particle measurements*
- *Multi-point measurements (?)*
- *…*