MESSENGER at Mercury: Old Questions and New Insights

D.N. Baker, J. A. Slavin, S. M. Krimigis

and the MESSENGER Team

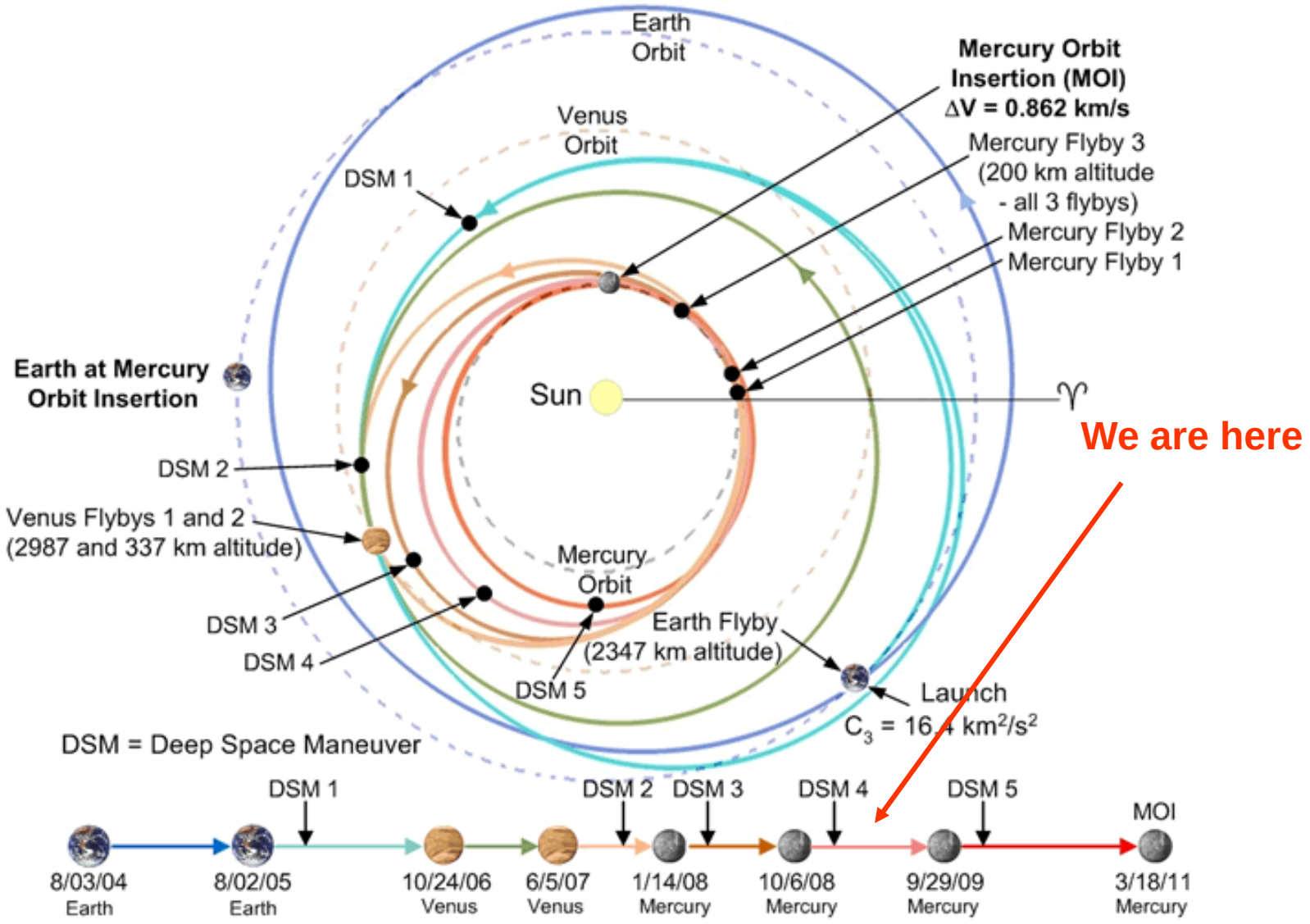
Special thanks: D. Odstrcil

Nonlinear Plasma Physics
19 June 2009

A NASA Discovery Mission

MESSENGER

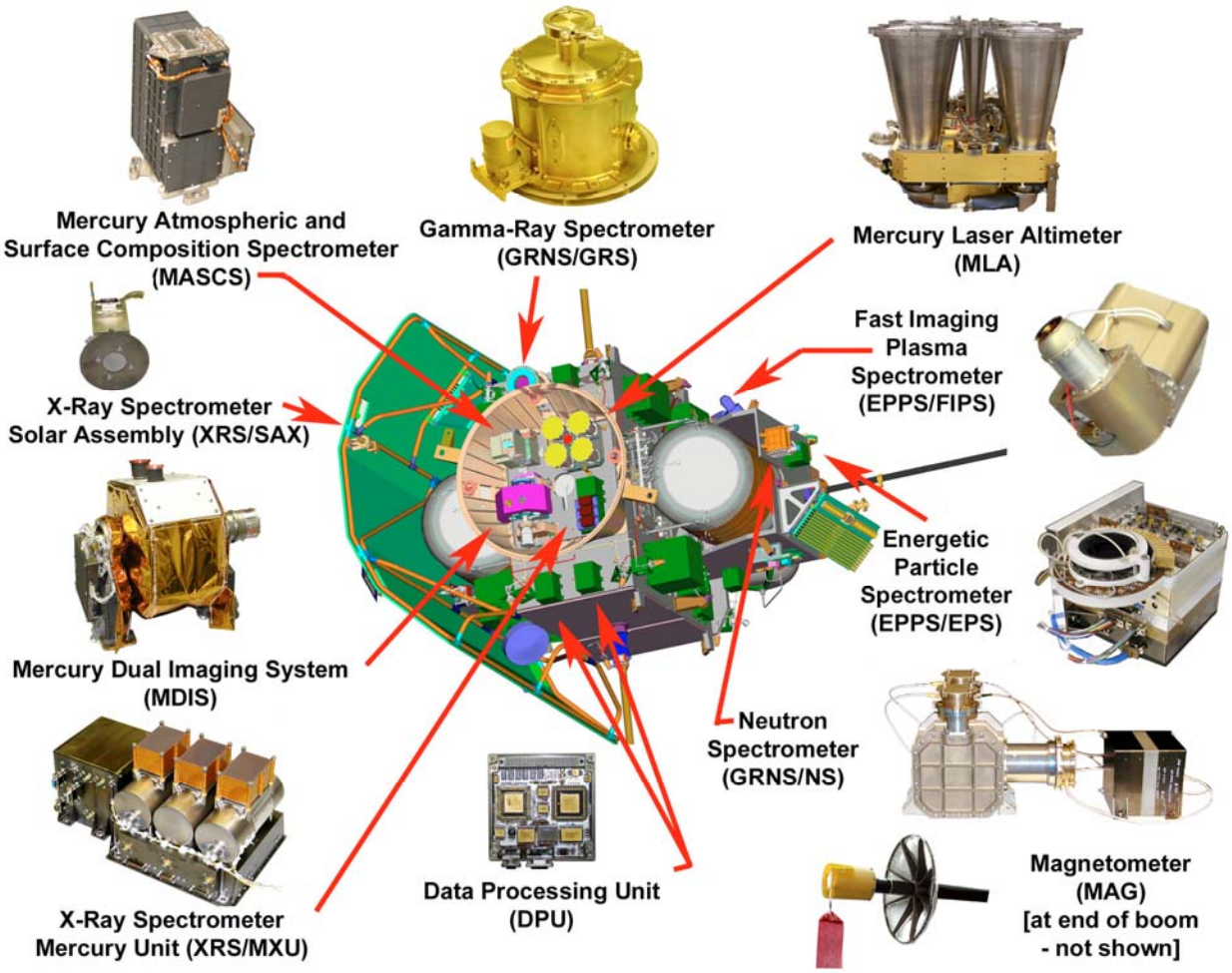
Mission Trajectory



MESSENGER

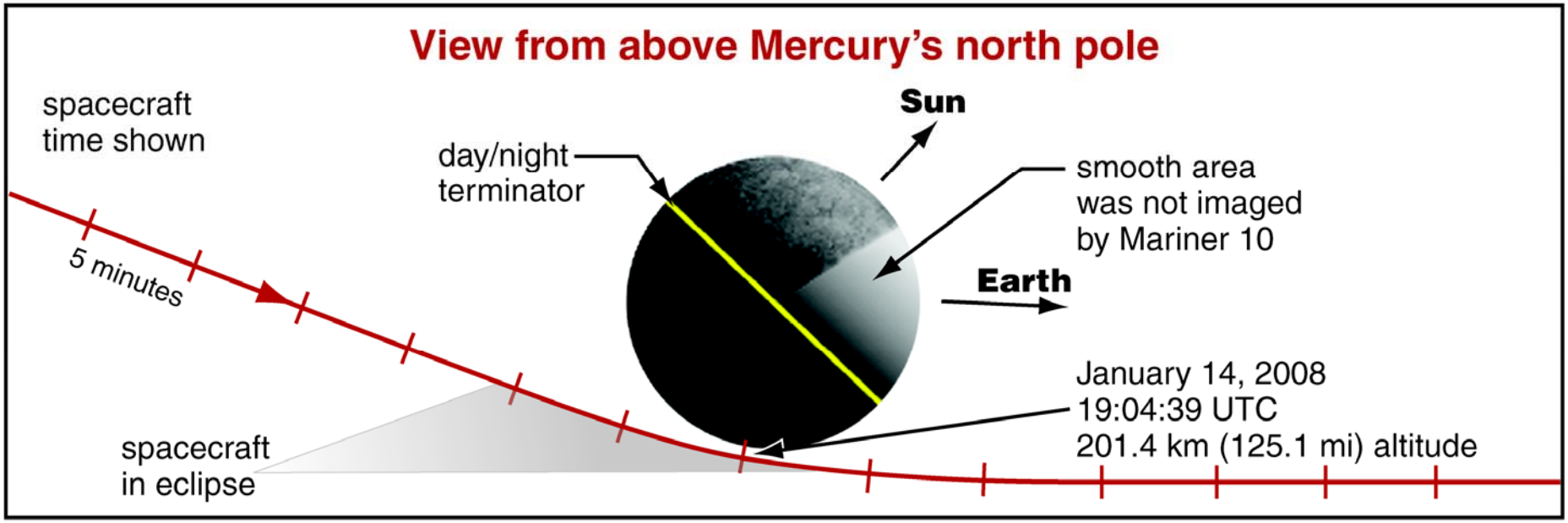
MESSENGER: Comprehensive Payload

- All instruments have operated nominally
- MDIS acquired ~2500 images
- Nearly 1000 MB of data returned



MESSENGER

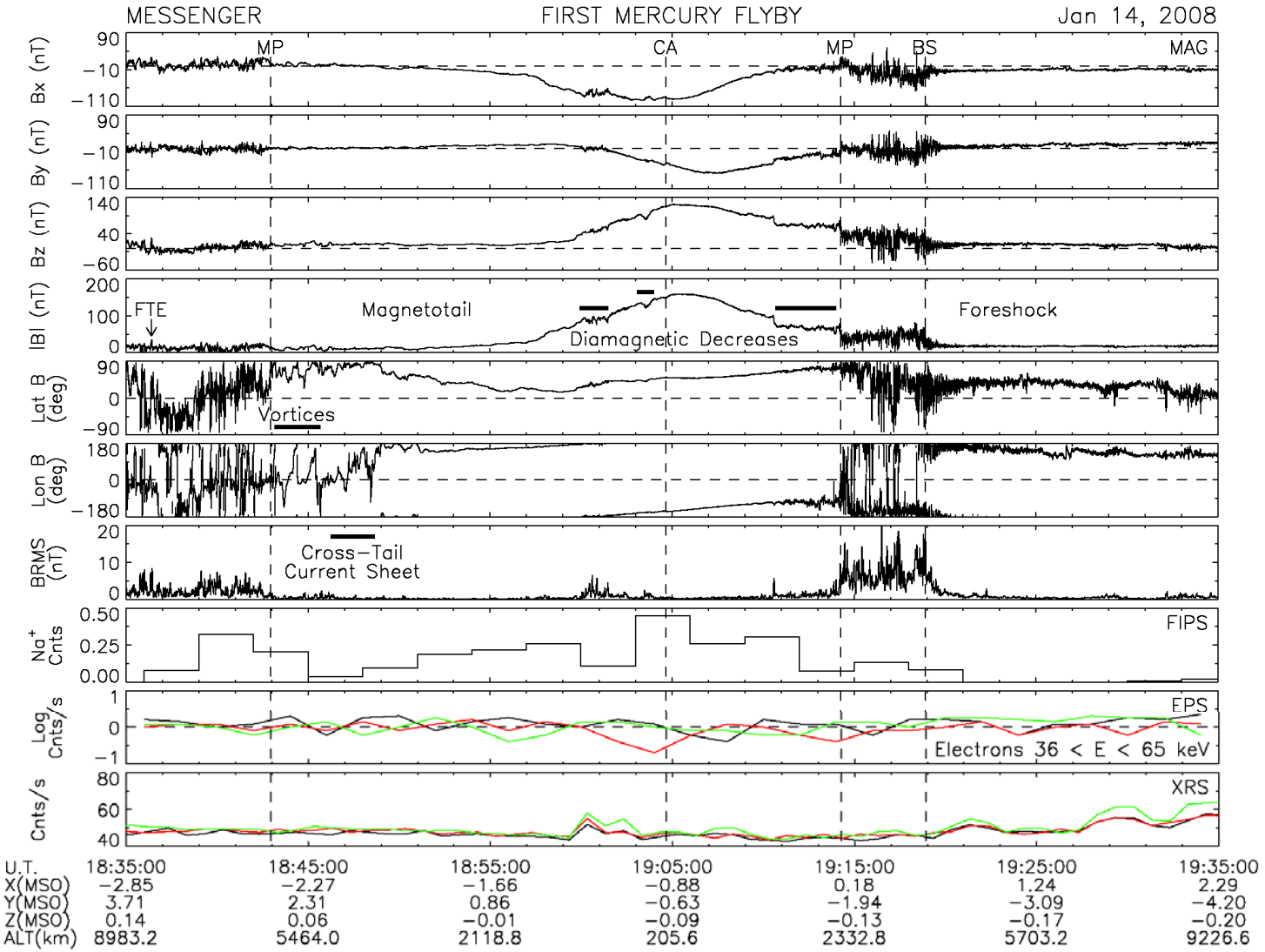
Flyby 1 Geometry



Core encounter command load ran for 55 hours
(~centered on closest approach)

MESSENGER

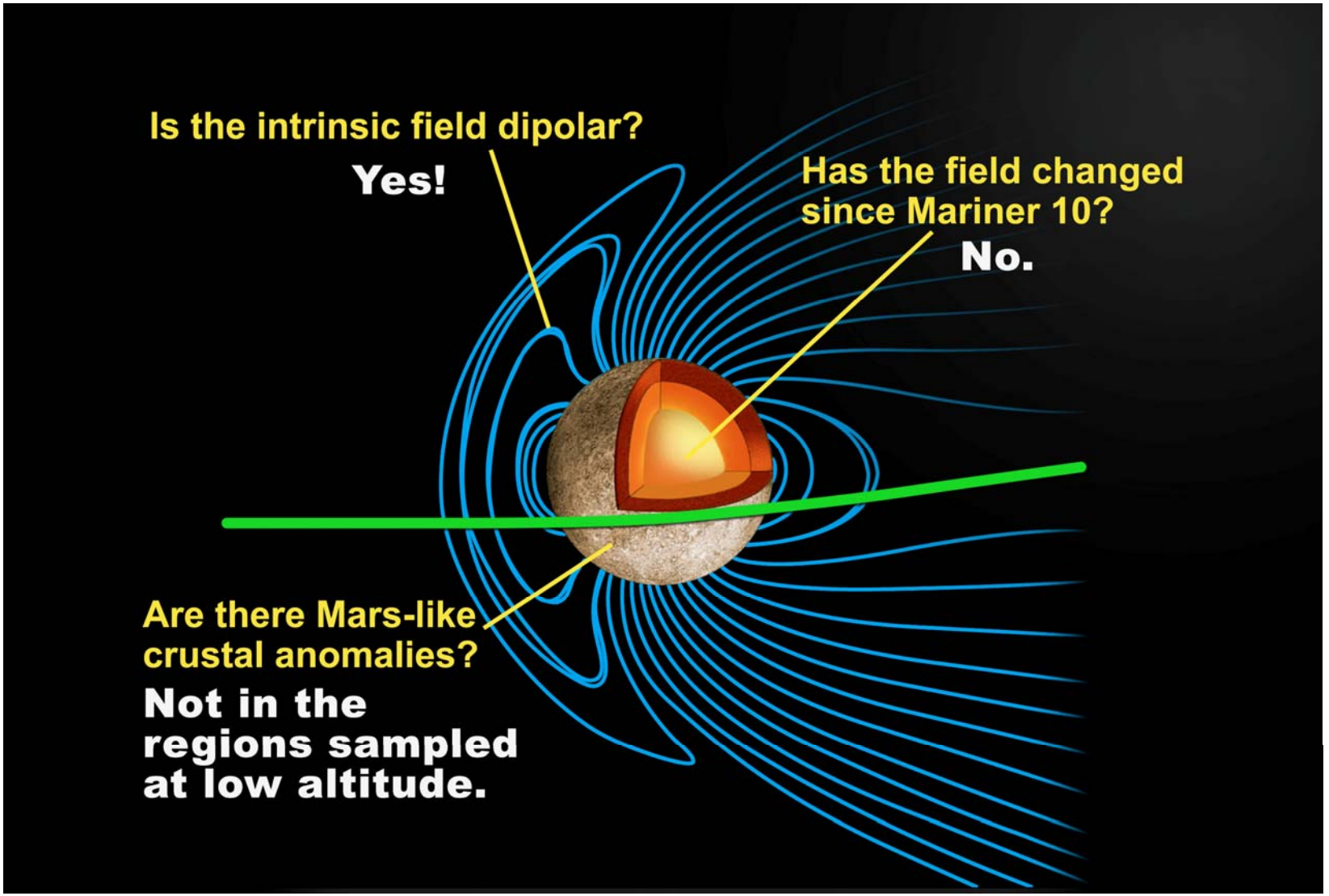
MESSENGER M1 Particles & Fields Overview



[Slavin et al., 2008]

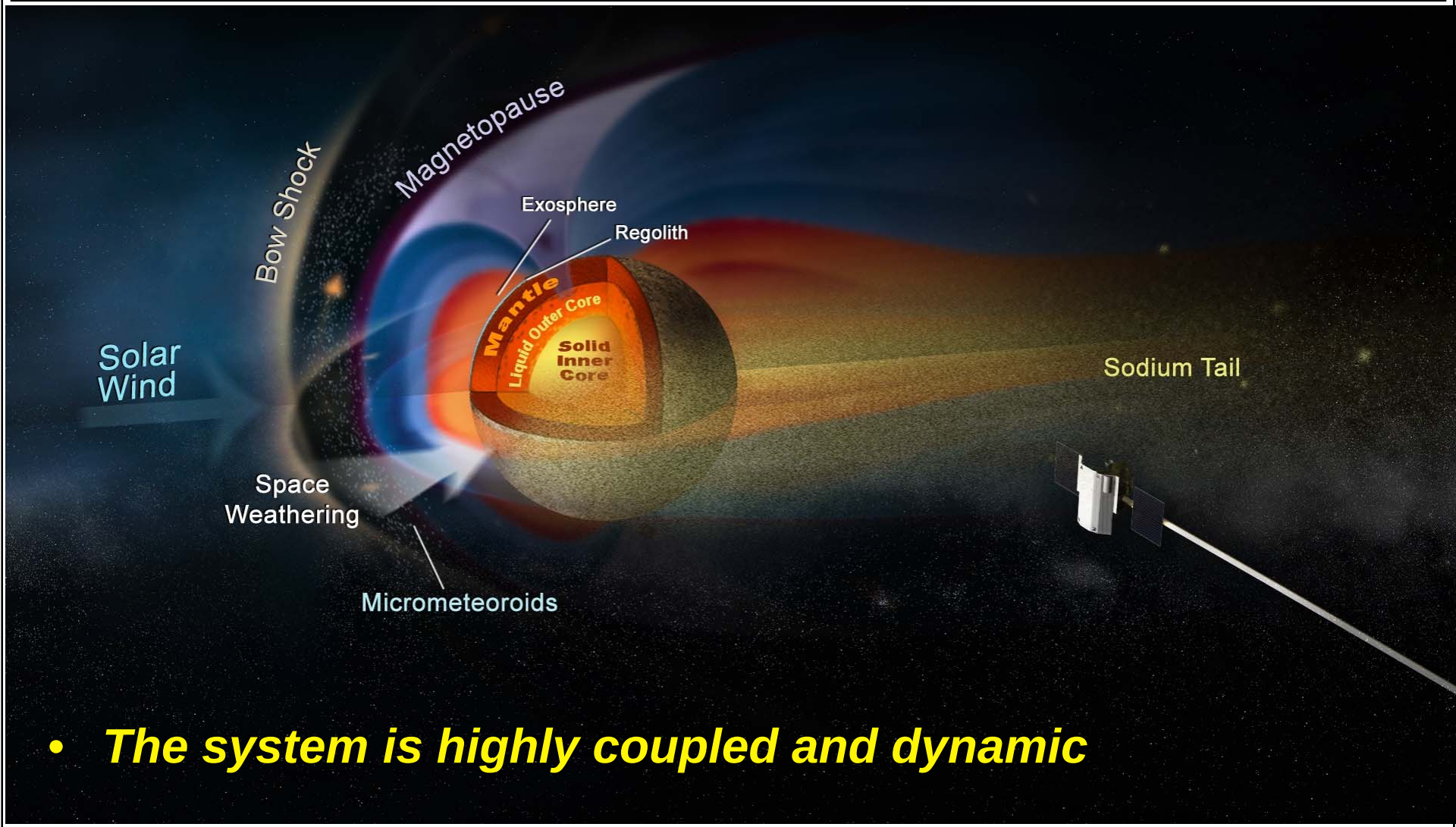
MESSENGER

Magnetic Field



MESSENGER

Interconnections are Complex



- ***The system is highly coupled and dynamic***

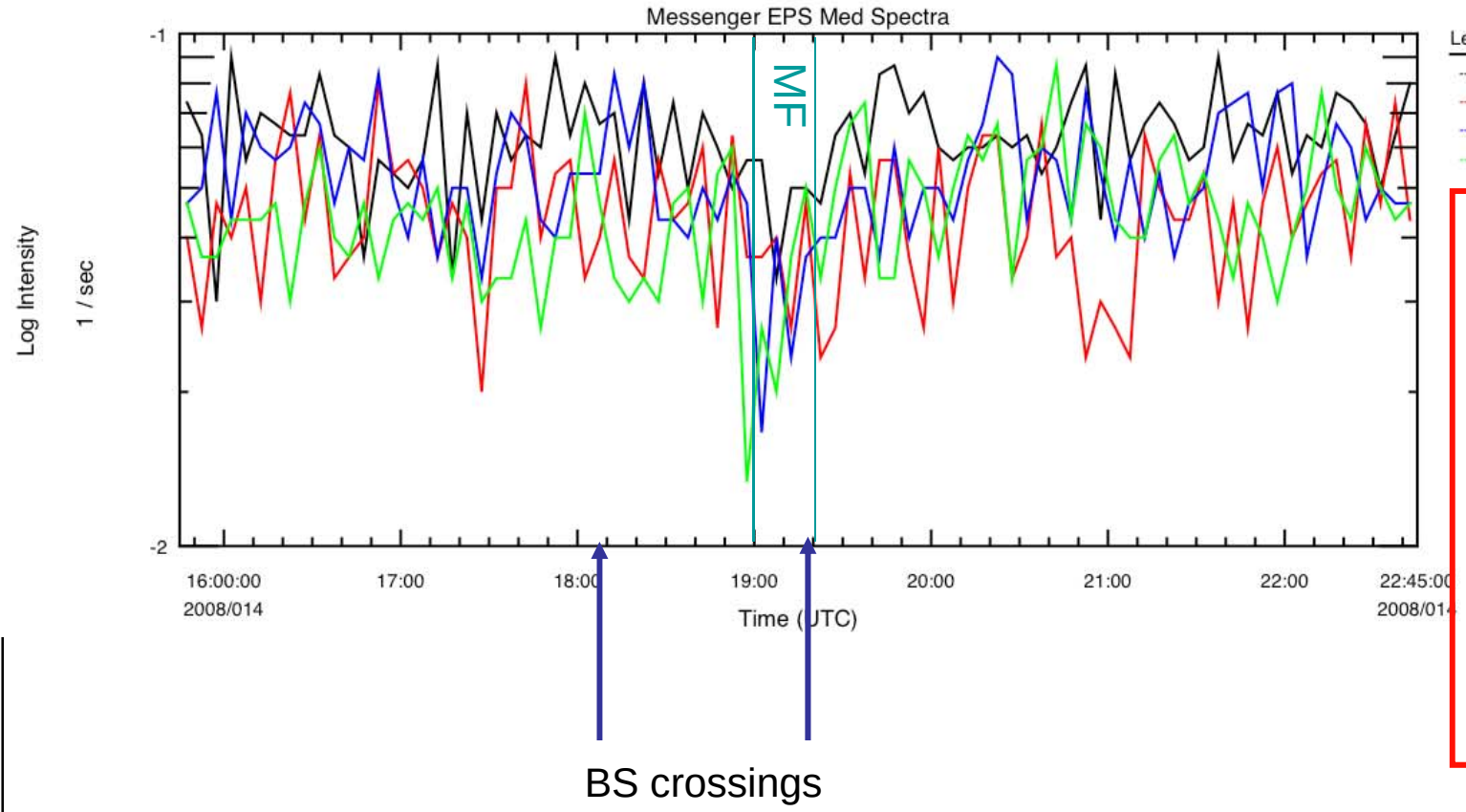
MESSENGER

M1: Plasma and Fields

MESSENGER

Energetic Electrons (E> 36 keV)

Quiescent magnetic field – consistent with lack of energetic electrons (2007:365 solar event clearly seen in EPS).



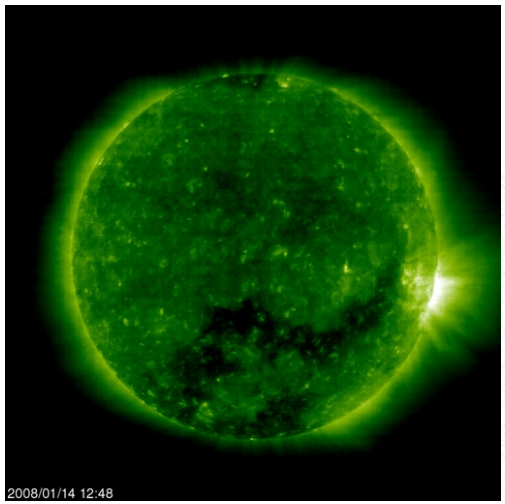
BS crossings

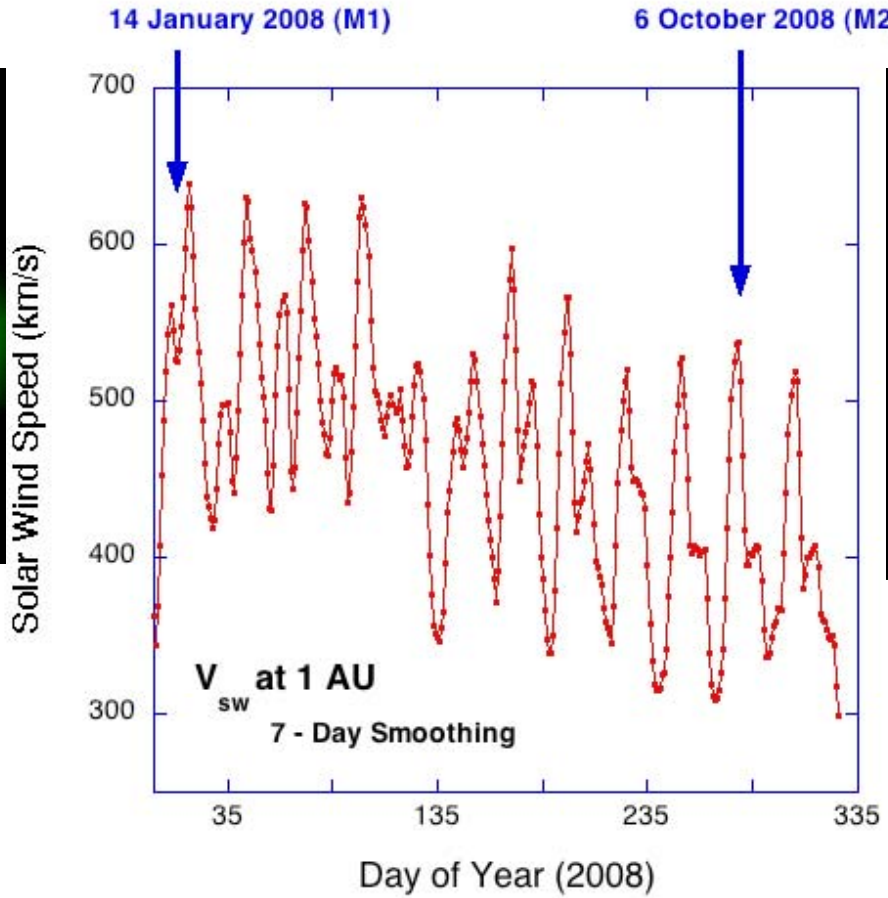
EPS

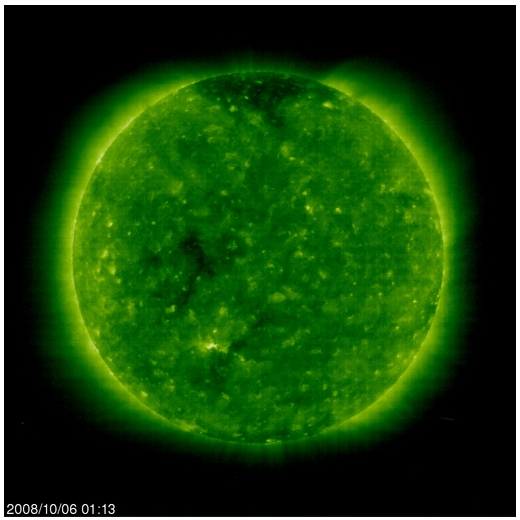
1.7 kg 5.8 W

MESSENGER

Solar & Solar Wind Conditions



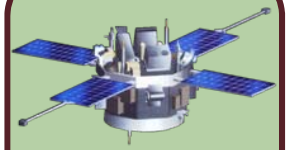




MESSENGER

Real-Time Solar Wind Forecast Model

Daily synoptic maps



Real-time Solar Wind Data at L_1

WSA

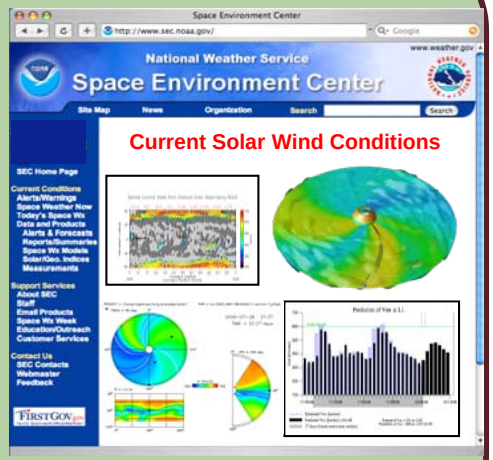
- Pre-processing of synoptic maps
- Potential field source surface (PFSS) + Heliospheric current sheet (HCS)
- Mapping to ENLIL inner boundary or L_1

ENLIL

- Generation of inner boundary from WSA
- Propagation of SW structures with MHD code in heliosphere
- Post-processing of simulation for L_1 prediction

AR Linear filter to predict SW speed at L_1

V Validation of SW parameters at L_1



Space Weather Forecast (SWPC)

Real-time Inputs

- **Initial:** Daily solar magnetograms
- **Future:** 3 hourly solar vector magnetograms from various instruments

Coupled Coronal Heliospheric model (WSA 1.5-ENLIL 2.5)

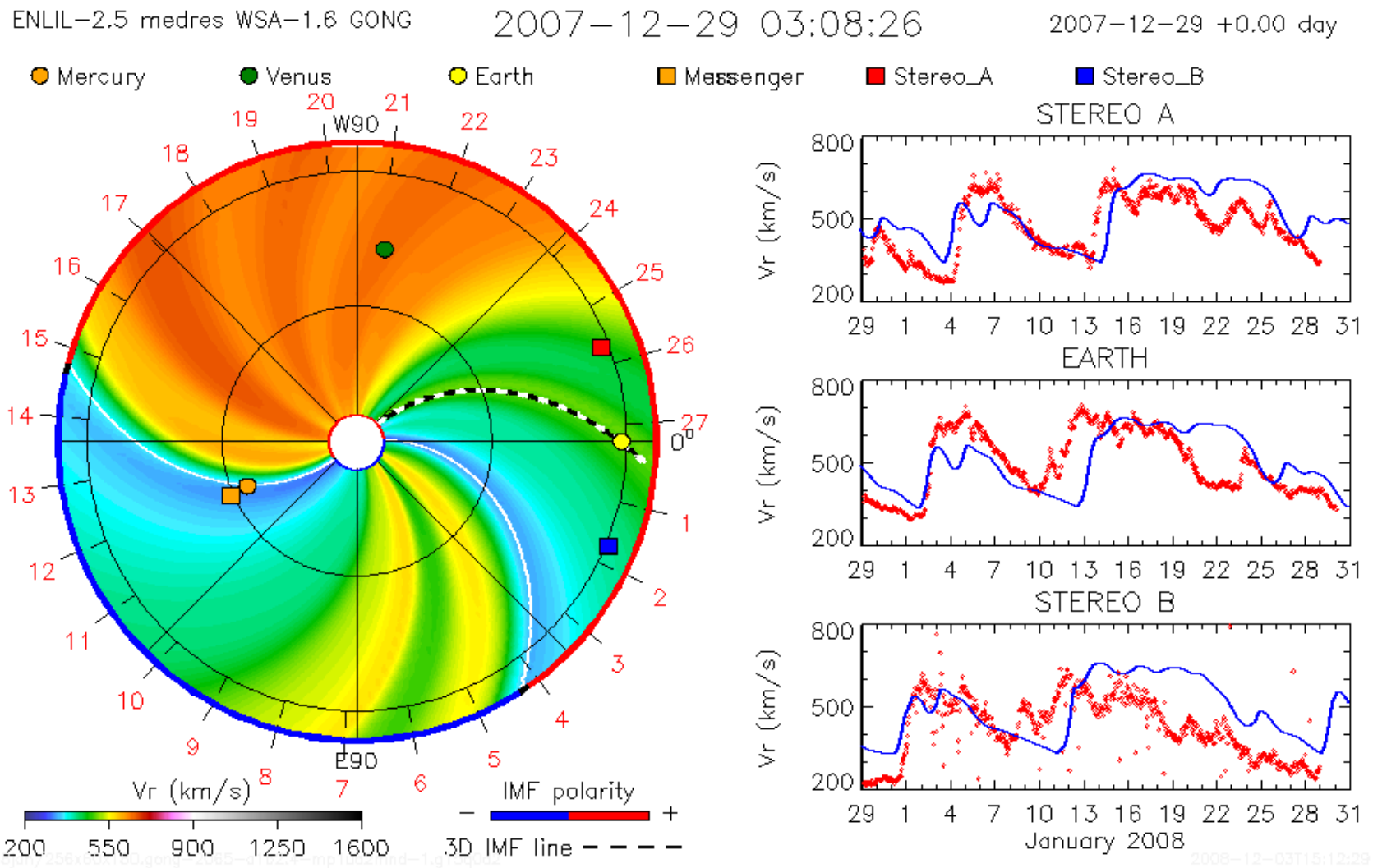
- **WSA-ENLIL:** Wang-Sheeley-Arge empirical coronal model (WSA) and first priniciples, physics-based, 3D MHD heliospheric model (ENLIL)
- **Present:** Low resolution stationary-mode. Running on high-end LINUX workstation
- **Future:** Medium resolution quasi time-dependent mode (MPI). Next generation multi-processor computing resources

Output Products, User Benefits

- **Initial:** 3 day forecast of solar wind parameters at L1 and their geoeffectiveness
- **Users:** Satellite operators, space exploration, input to geospace models
- **Future:** 3 day forecast of high-speed events, characterization of solar sub-earth point

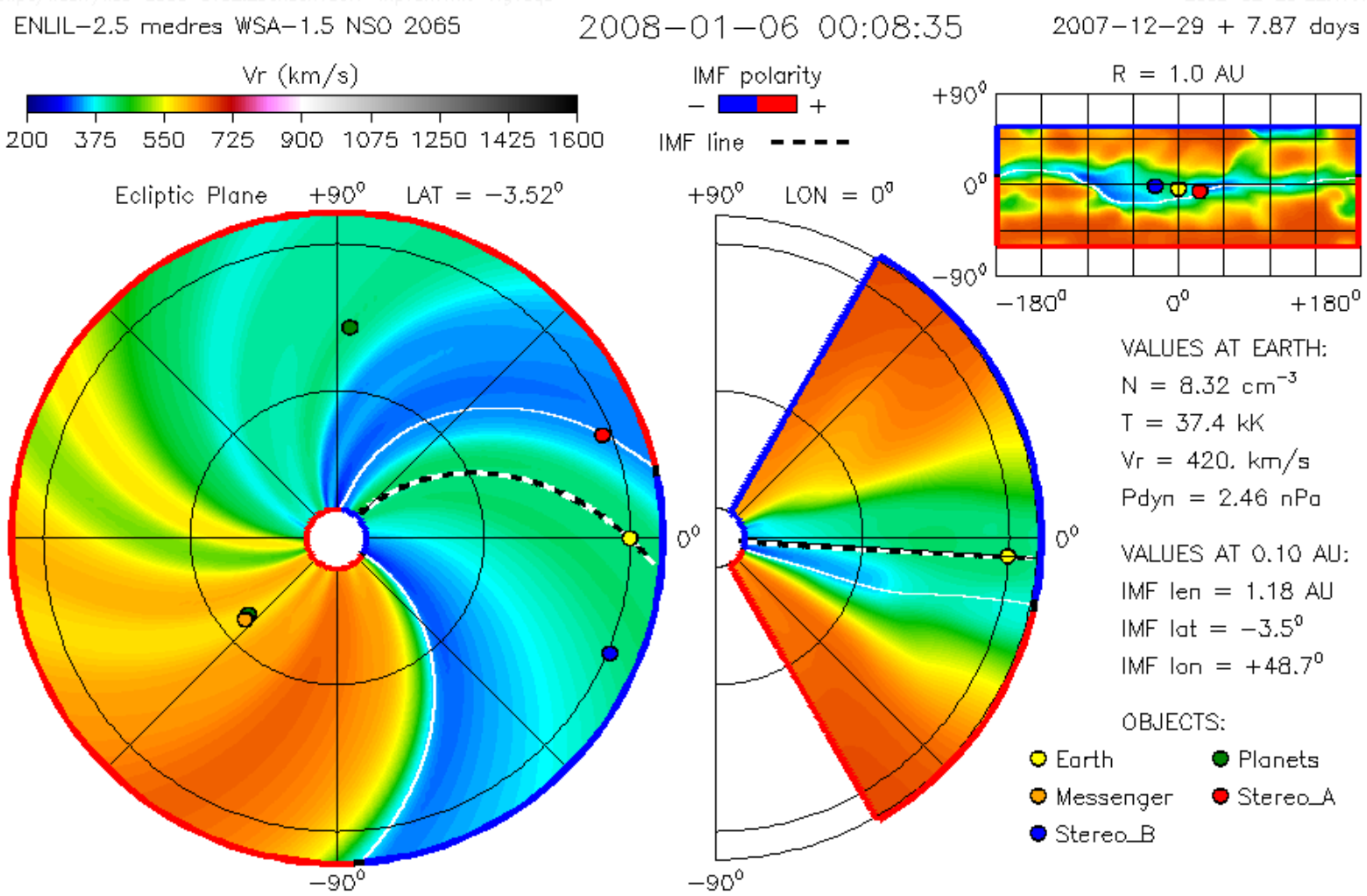
MESSENGER

Comparisons: STEREO & ACE



MESSENGER

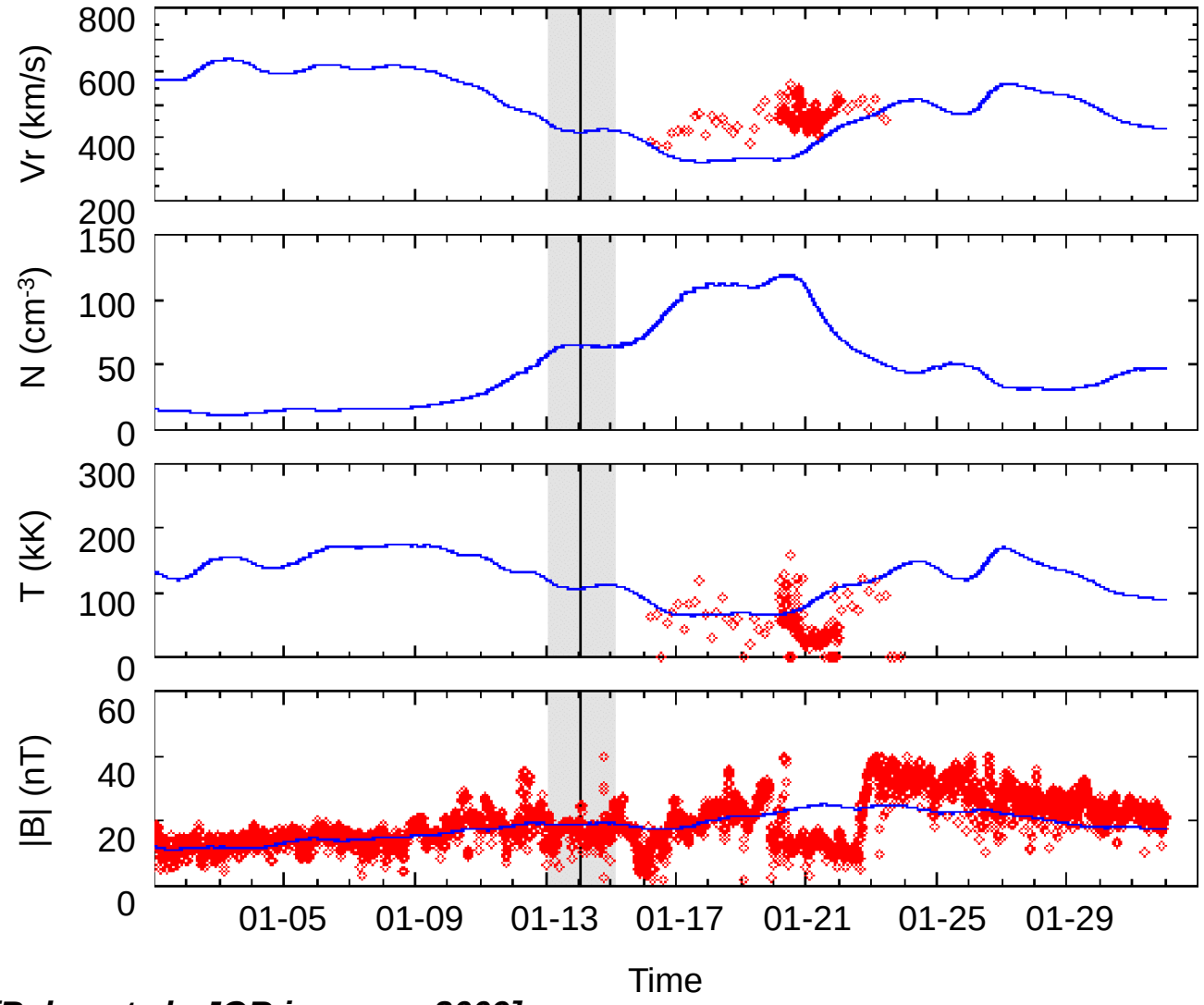
2008 January 6-15 – Flow Velocity



[Baker et al., JGR in press, 2009]

MESSENGER

Model Results and MESSENGER



[Baker et al., JGR in press, 2009]

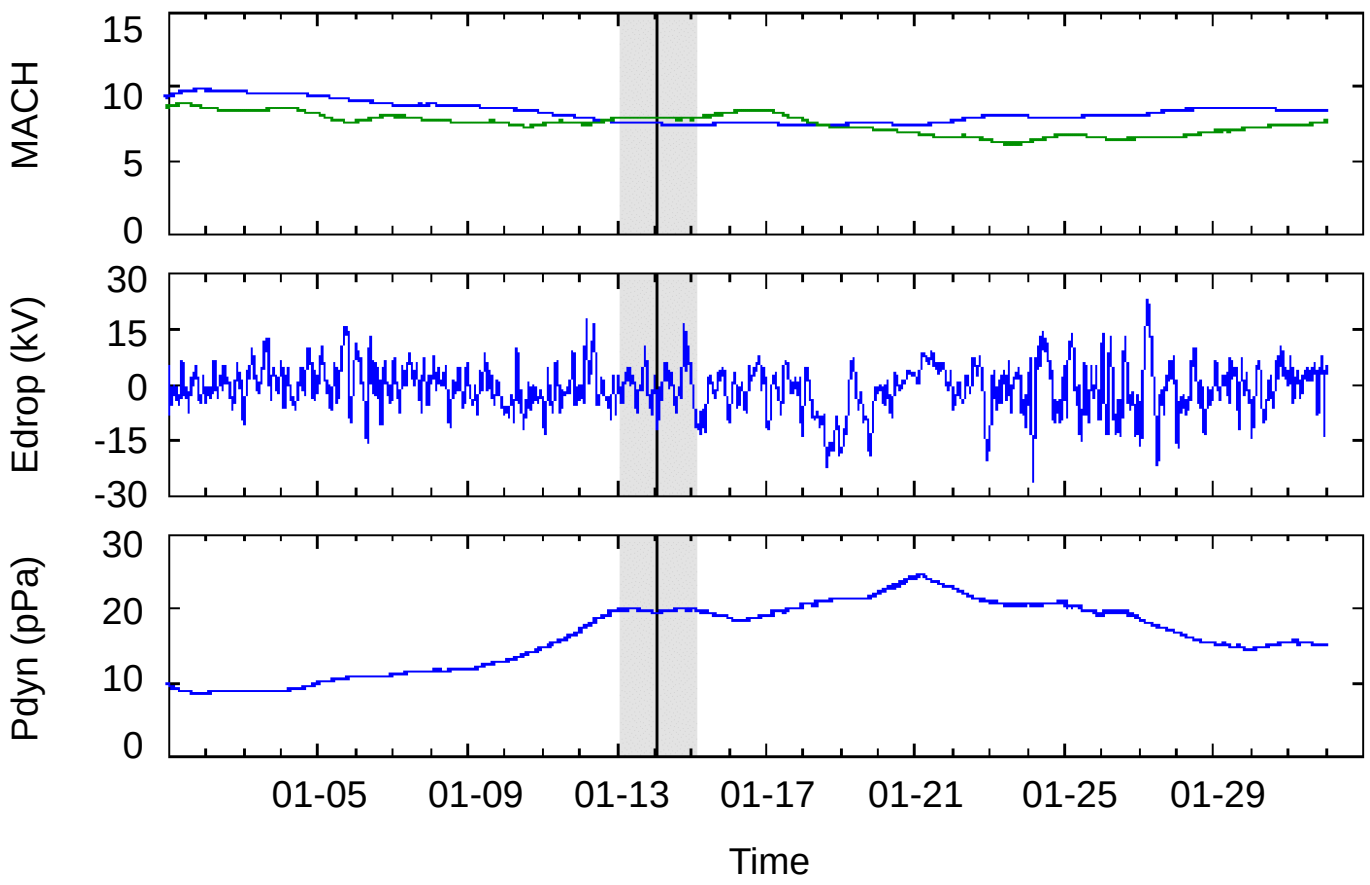
Only very limited *in situ* solar wind plasma data are available (due to FIPS mounting on S/C)

SW/Mag feature on 20-22 Jan?

Model magnetic field (|**B**|) is spot-on prior to 20 Jan, but too low after

MESSENGER

Model Results and MESSENGER



Sonic and Alfven Mach numbers from model ~ 8

Cross-tail potential using model V and measured **B**

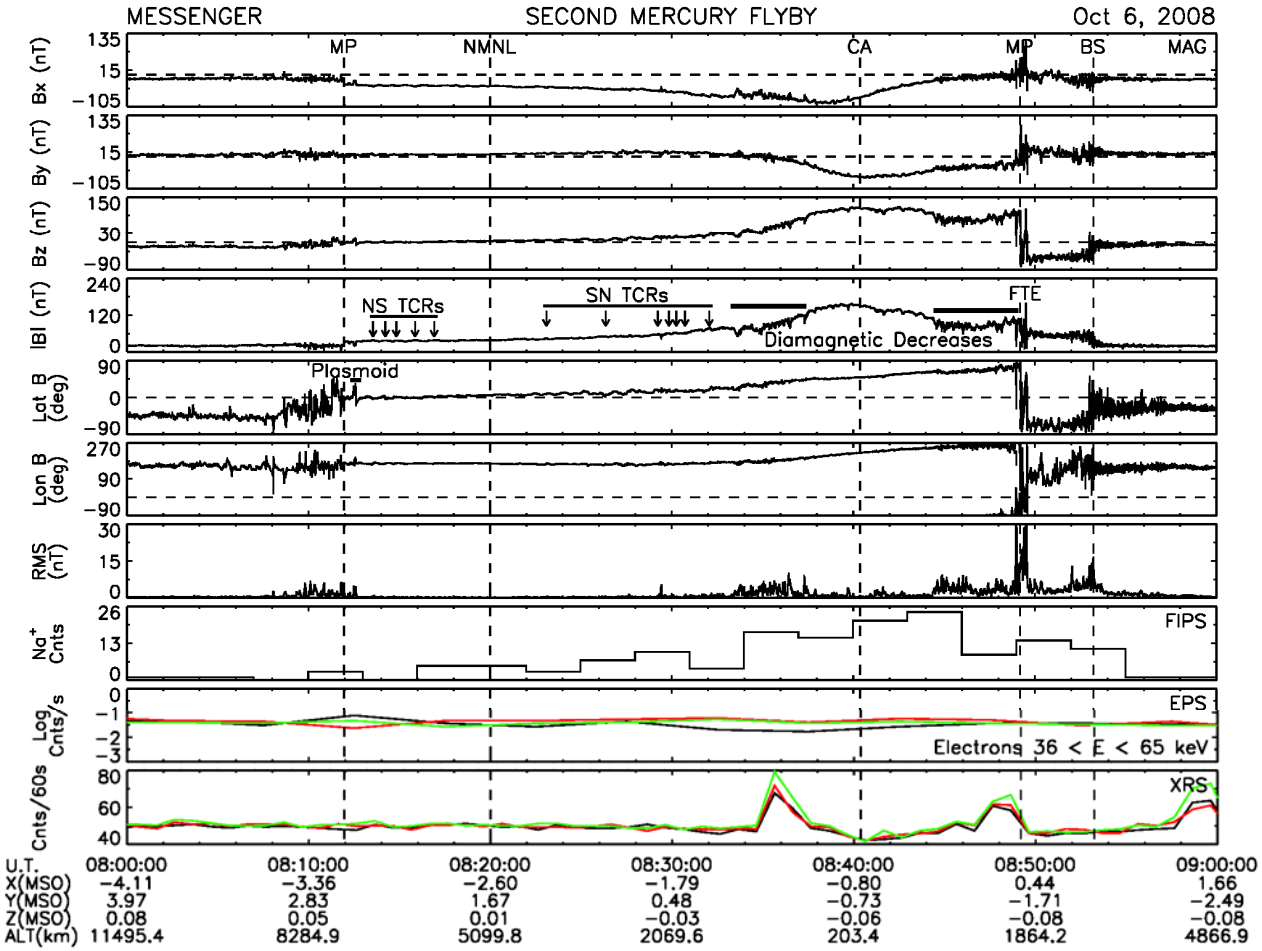
Dynamic solar wind pressure from model V and ρ: Local max

[Baker et al., JGR in press, 2009]

MESSENGER

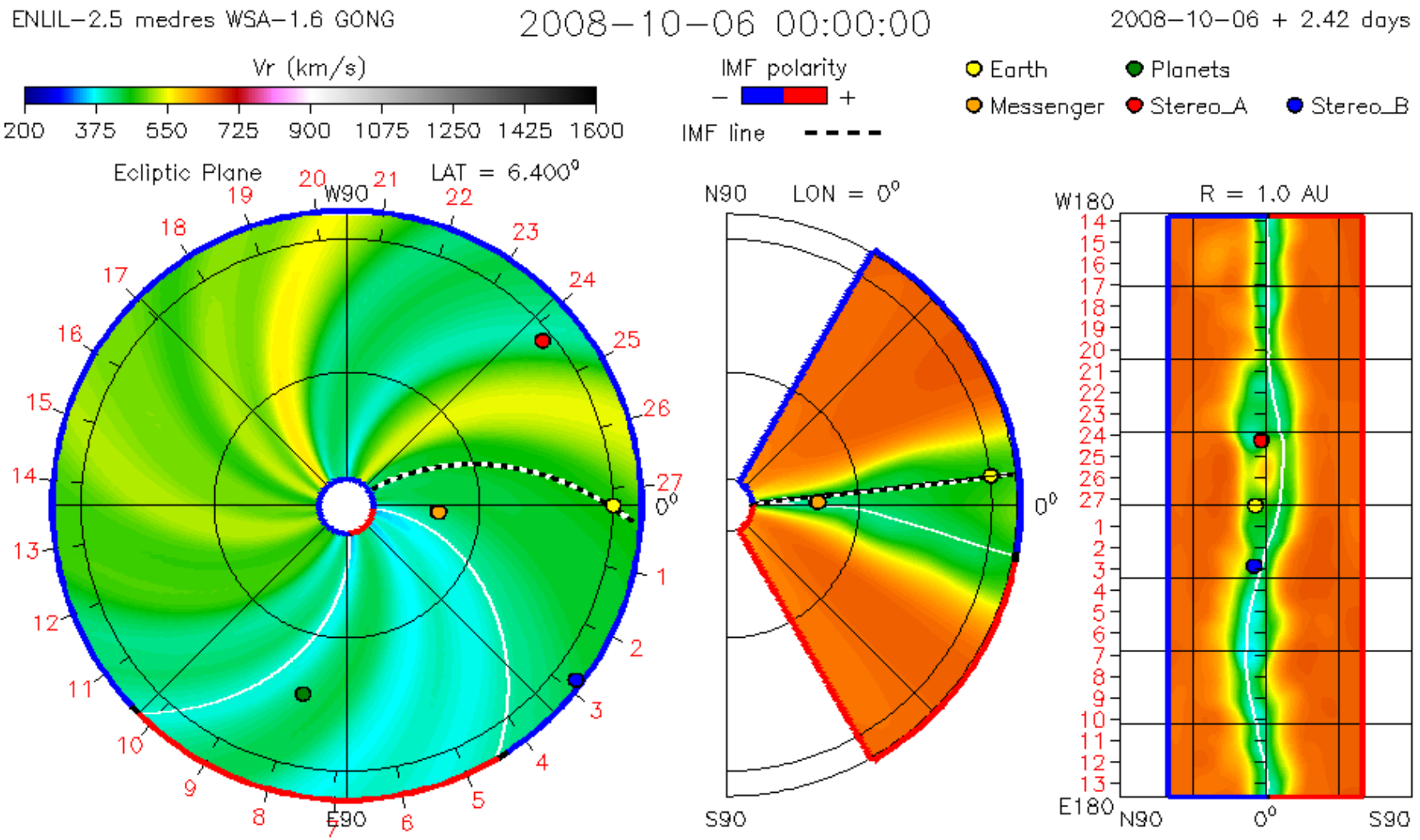
Second Flyby Overview

[Slavin et al., Science, 2009]



Strong reconnection signatures – Plasmoid, TCRs, Magnetopause B_N, and FTE!

MESSENGER



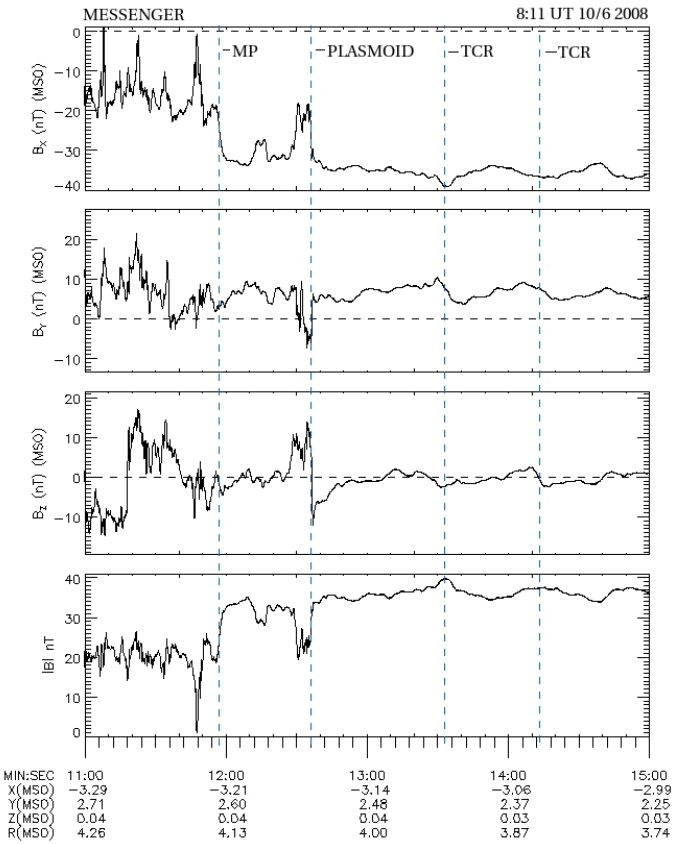
Values at Earth: N = 4.96 cm^{-3} T = 34.5 kK Vr = 466. km/s Pdyn = 1.80 nPa IMF line at 0.10 AU: N06.0 W35.0

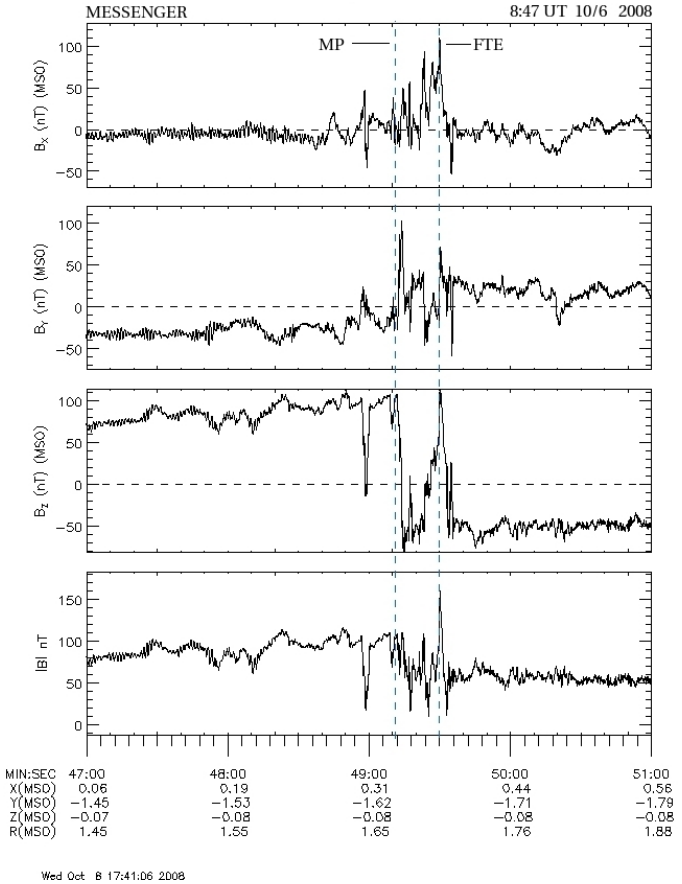
wsadu–1.6–gong/200x60x180.a1b2.1–mp1um1mt–1.g15q0.2008–10–06

2008–10–07T00:30:03

MESSENGER

Plasmoids, TCRs, and FTEs

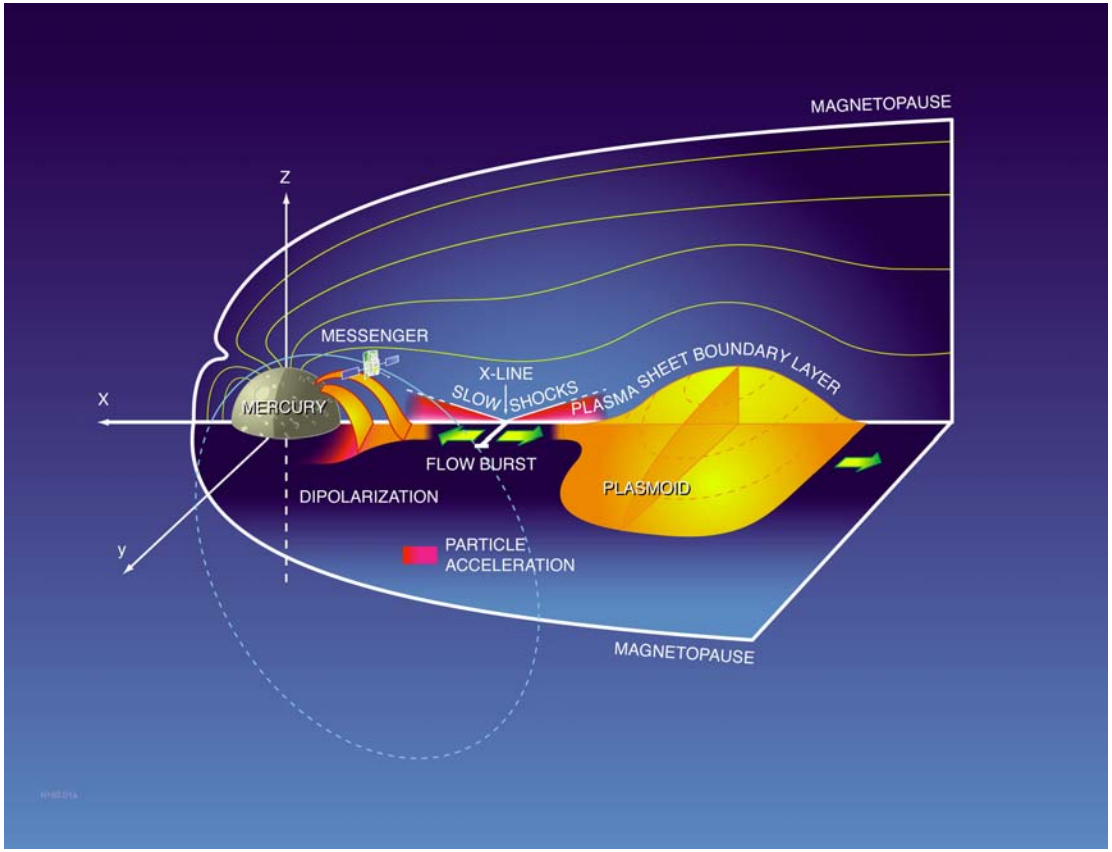




MESSENGER observed Strong *Dayside & Nightside* Reconnection Signatures!!

MESSENGER

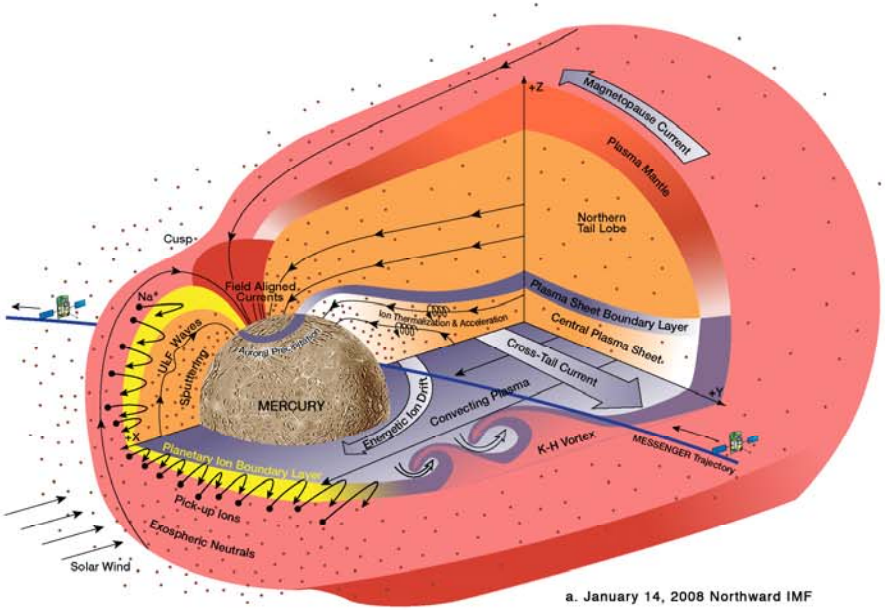
Plasmoid Ejection at Mercury

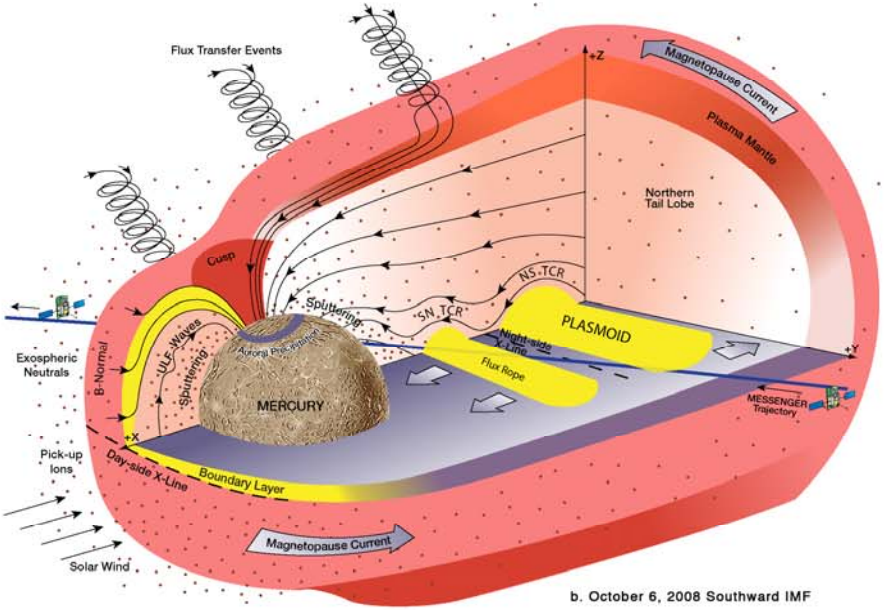


The mean X ~ -25 R_e distance to Reconnection X-line at Earth, scales to X ~ -3.5 R_m at Mercury…only M2 provides X < -3 R_m tail observations!

MESSENGER

Mercury's Magnetosphere
Post-Flyby View





Northward IMF

- Magnetopause Boundary Layer
- Kelvin-Helmholtz Waves on Flanks

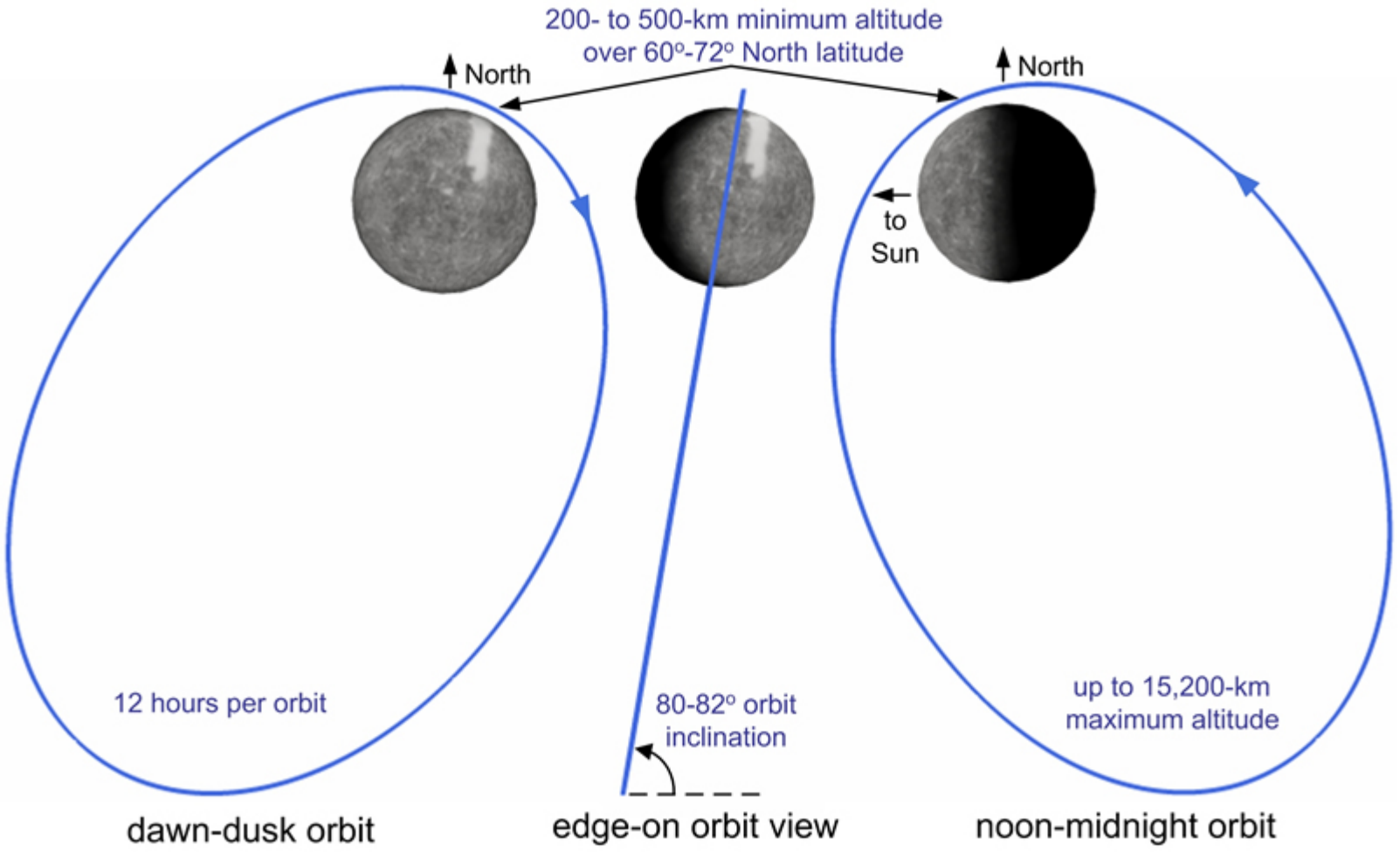
Southward IMF

- Magnetopause B-normal is ~ 10 times Earth values; Dungey Cycle Time is ~ 2 min;
- Large Flux Transfer Event when IMF $B_z < 0$
- Plasmoid and TCRs imply NMNL X ~ -2.6 R_M


The first space mission designed to orbit the planet closest to the Sun
MESSENGER
MErcury Surface, Space ENvironment, GEochemistry, and Ranging
MERCURY:
The Key to Terrestrial Planet Evolution
MESSENGER will start a yearlong study of its target planet in March 2011. Understanding this "end member" among the terrestrial planets is crucial to developing a better understanding of how our own Earth formed, how it evolved, and how it interacts with the Sun.
http://messenger.jhuapl.edu/
The Journey Continues…
Mercury Flyby 3
29 September 2009
Mercury Orbit Insertion
18 March 2011
(643 days from now)
Mission Elapsed Time
1774 days
Distance Traveled
5,384,000,000 km (~36 AU)

MESSENGER

MESSENGER Orbital Phase



MESSENGER

Summary and Future Plans

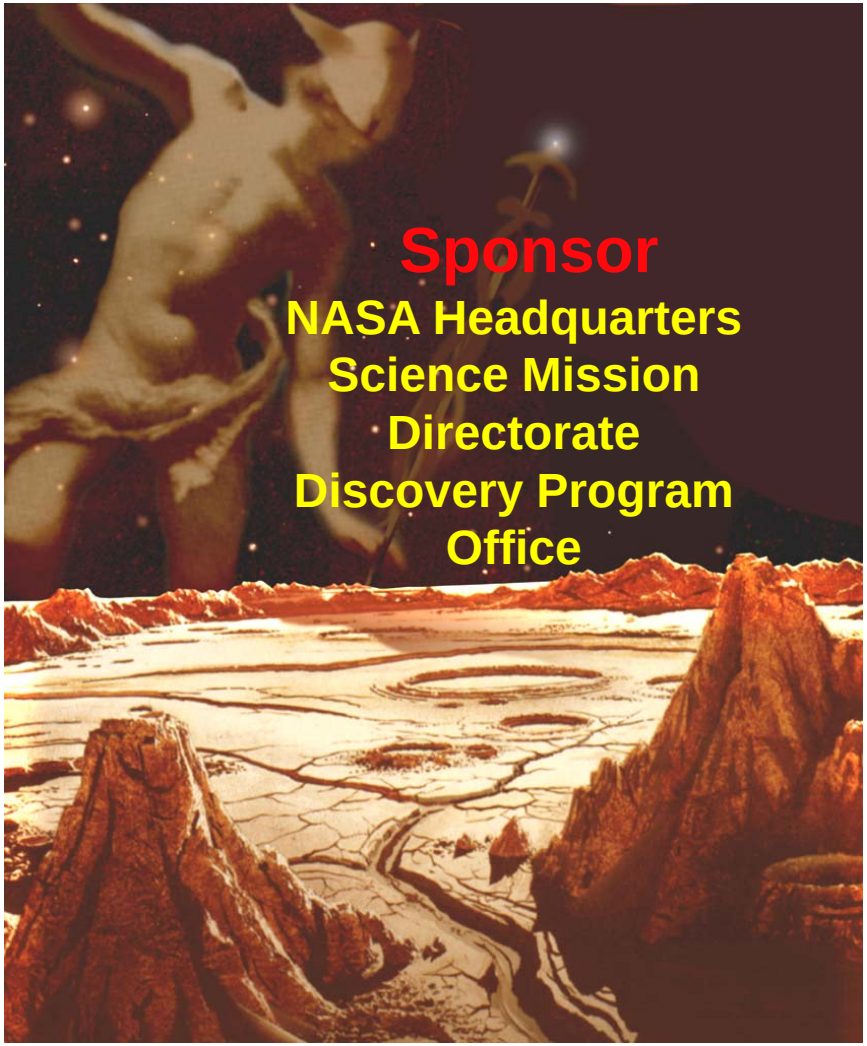
- Results for M1 encounter show that Mercury was in an extensive region of low speed, quiet solar wind; M2 was modeled to be at high-density sector boundary
- MESSENGER magnetic field and plasma data show vastly different magnetospheric conditions for the two flyby passes; Neither pass showed energetic particles??
- Third MESSENGER flyby (September 2009) may help resolve enigma of substorm behavior and particle properties
- Future solar wind modeling can provide continuous estimate of magnetospheric driving conditions for orbital phase and for ground-based observing

MESSENGER
Programmatics

Scientific investigation of the planet Mercury -

Team members

- **Principal Investigator**
  Sean C. Solomon, Carnegie Institution of Washington
- **Project Management - APL**
- **Spacecraft Development/Operations - APL**
  - **Propulsion - Aerojet**
  - **Structure - Composite Optics**
- **Instruments**
  - **APL, GSFC, UColorado (LASP), UMichigan (SPRL)**



MESSENGER

2008 January 6-15 – Plasma Density