Observations of Suprathermal Electrons in Mercury's Magnetosphere During the Three MESSENGER Flybys

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Mercury magnetosphere

- **Nearly all energetic particle observations inside Mercury's magnetosphere were during the first Mariner 10 flyby in 1974**
- **Many questions are still outstanding from that single ~40 minutes flyby:**
  - **Possible similarities between Earth and Hermean magnetospheres**
  - **Is there a durable magnetosphere?**
  - **Are there any energetic ions, as originally reported?**
  - **Can the magnetosphere trap energetic particles?**

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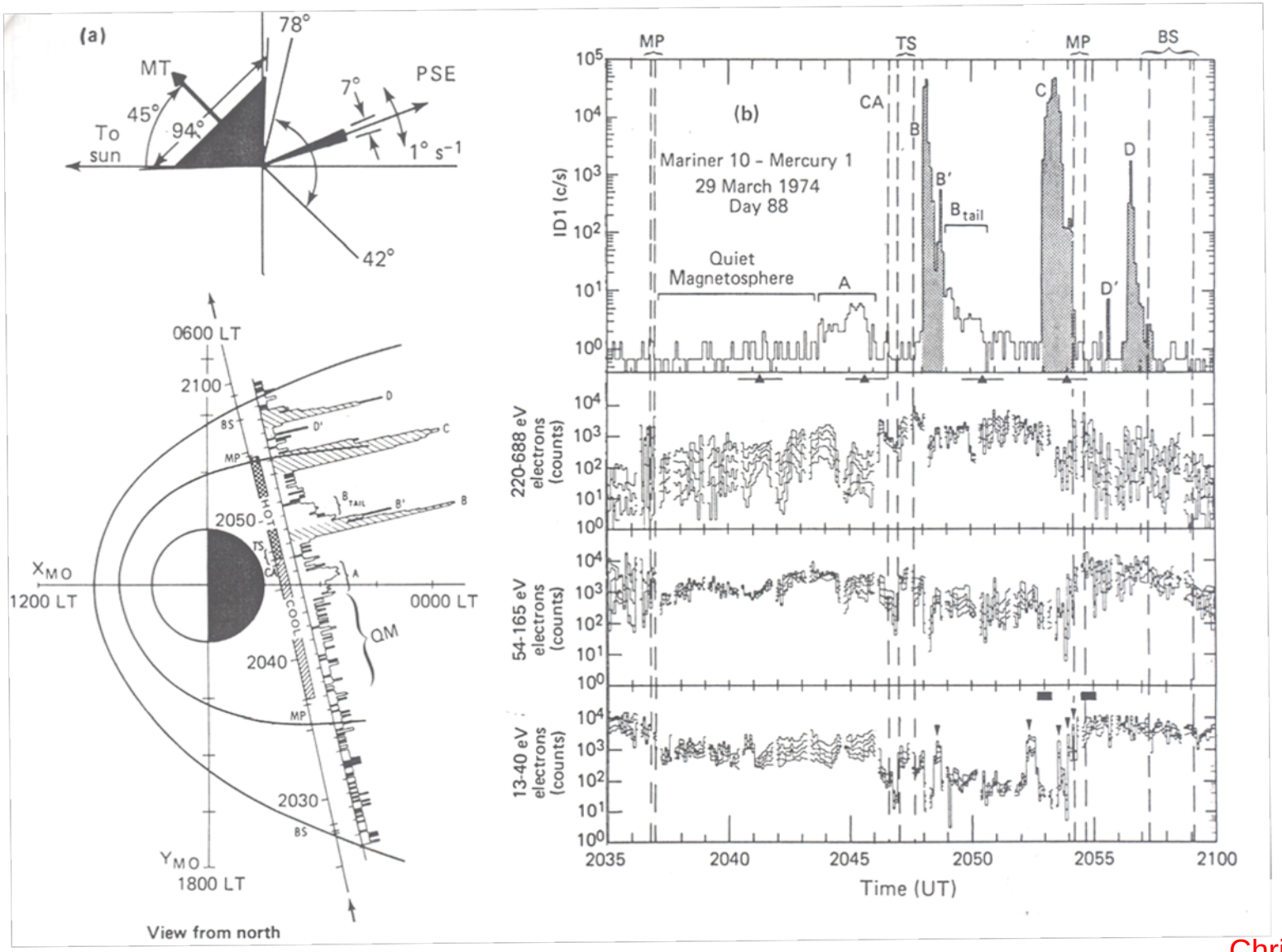
Mariner 10 Data



Christon, 1989

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Mariner 10 Interpretation

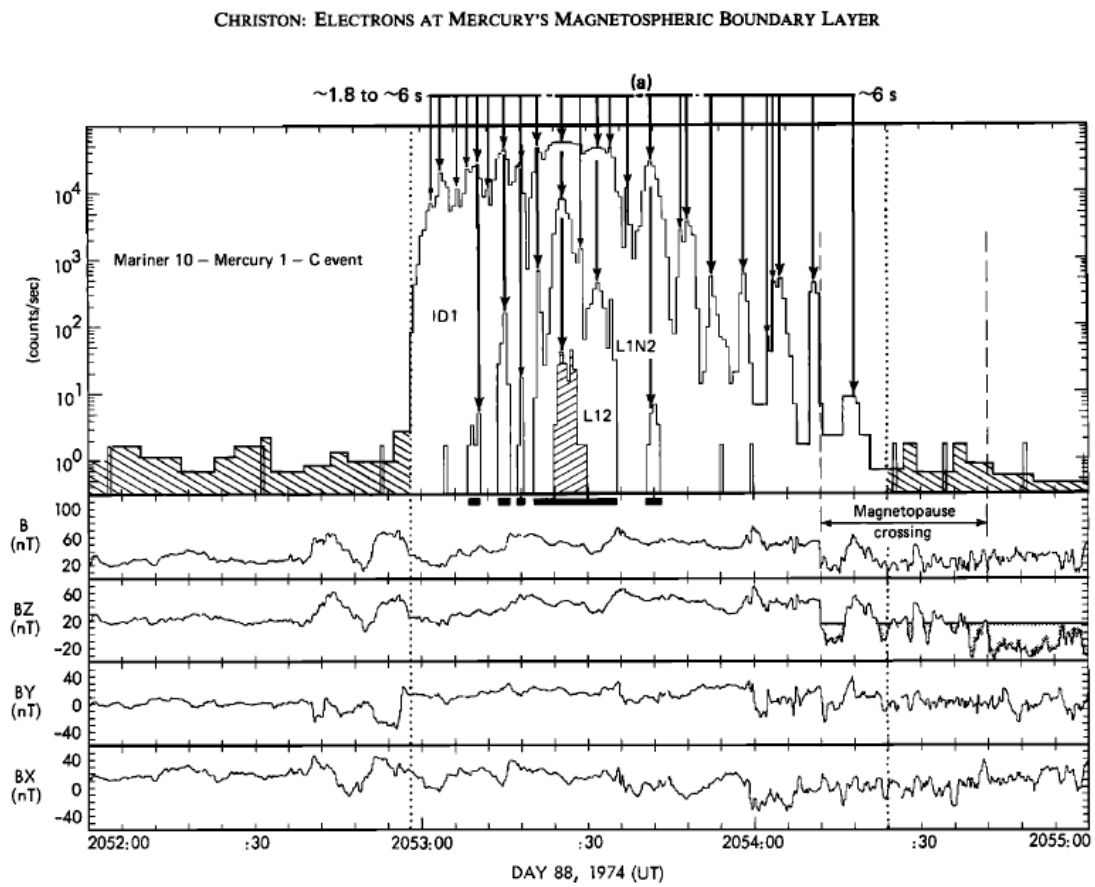

Fig. 4*b*. Information for the C event at Mercury 1 in the same format as Figure 4*a*. Stippled shading highlights the gradual decrease of BZ during the magnetopause crossing. The sequences of ID1 counting rate variations (highlighted by arrows) are discussed in the text. Dashed lines delineate the outbound magnetopause crossing MP. Higher resolution magnetic field data than in panel 4*a* are shown.

"Quasi-repetitive ~6-s decreases of the > 35 keV electron flux during the C event peak and valley interval coincide with observations of the boundary layer plasma."

Christon, 1989

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Energetic Particles at Mercury: Mariner 10 view

- The identity of those measured particles (ions? and/or electrons?) are questioned by others
- The existing models use Earth's magnetosphere as starting point
- However, questions remained on how similar the Mercury system to Earth
  - Ionosphere?, ring current?, etc.
- The energetic particle results initially reported by Simpson et al. (1974) sparked a major controversy that both parties now consider settled. Armstrong et al. (1975) suggested that the energetic particle measurements had been misinterpreted and really represent the measurement of lower energy electrons only. Following a terse reply by Simpson (1975), Christon et al. (1979) presented a detailed analysis of the Mariner 10 instrument response, justifying the initial claim of Simpson et al. (1974). Follow-up papers supporting the initial claims were published by Eraker and Simpson (1986) and Christon (1989) that further interpreted how these energetic particles fit within the known physics of Mercury's magnetosphere.
- Armstrong et al. (1979): "Chicago experiment was responding to large flux of low-energy electrons of unknown peak intensity and unknown but soft spectrum in some multiple pulse pileup mode"
- MESSENGER EPS was designed for these large fluxes ($A\Omega \sim 10^{-3}$ cm^2 sr)

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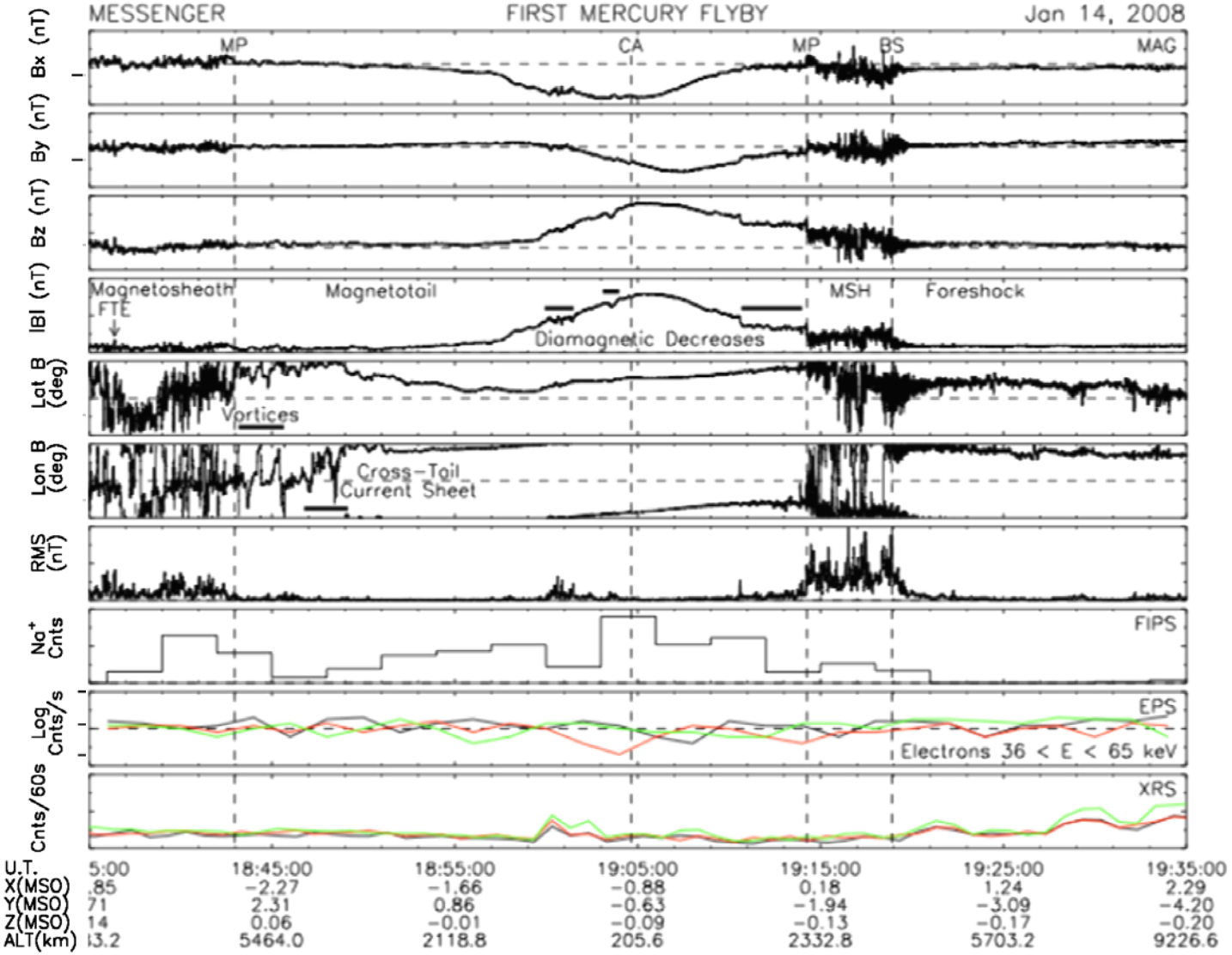
First Flyby Overview



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Jan 14, 2008

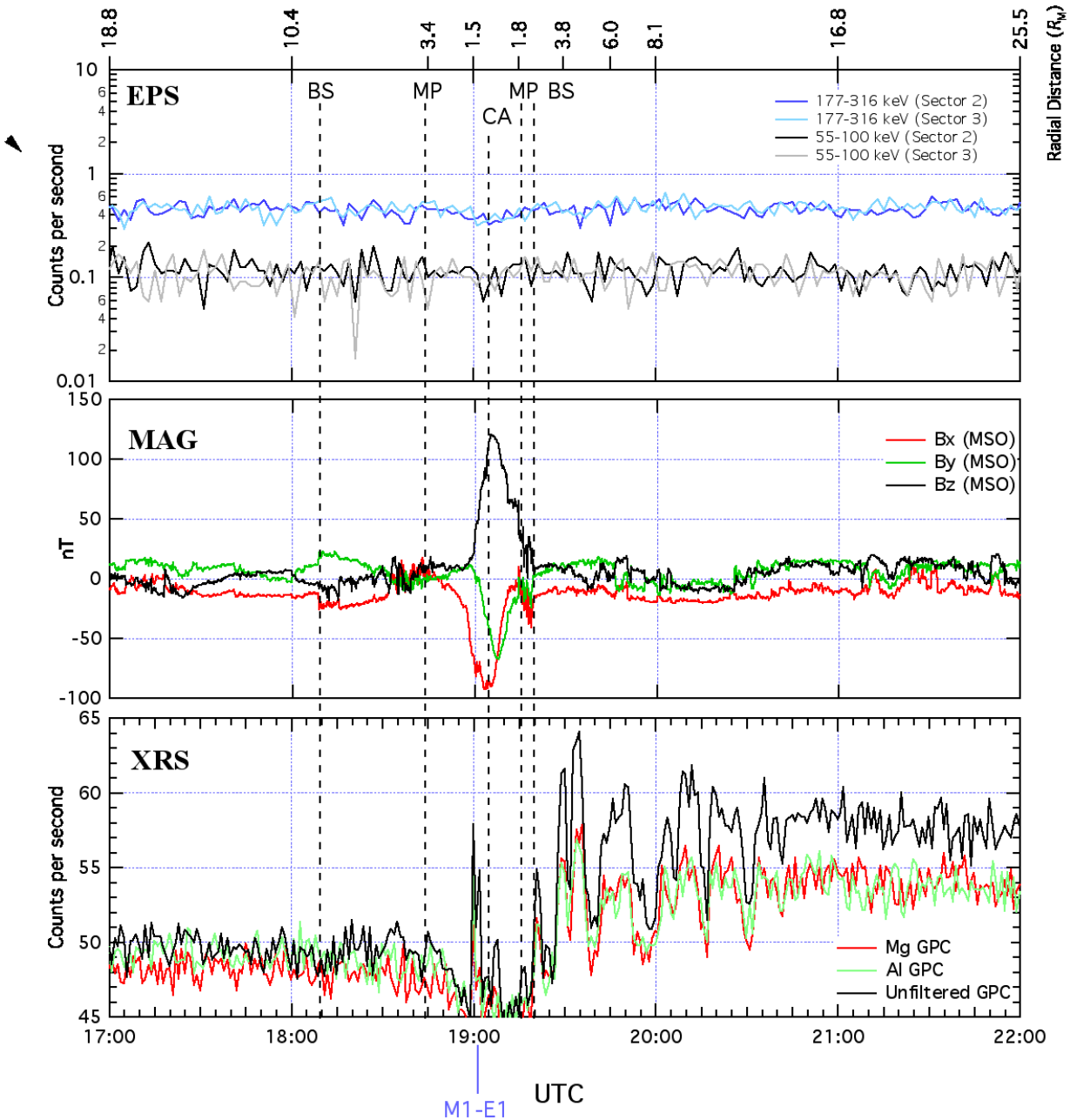

Figure 2

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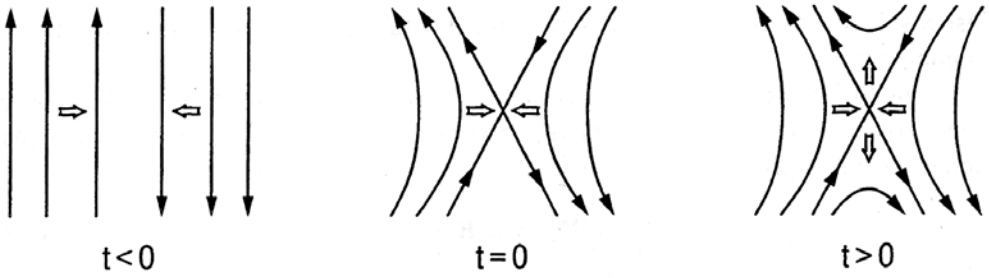
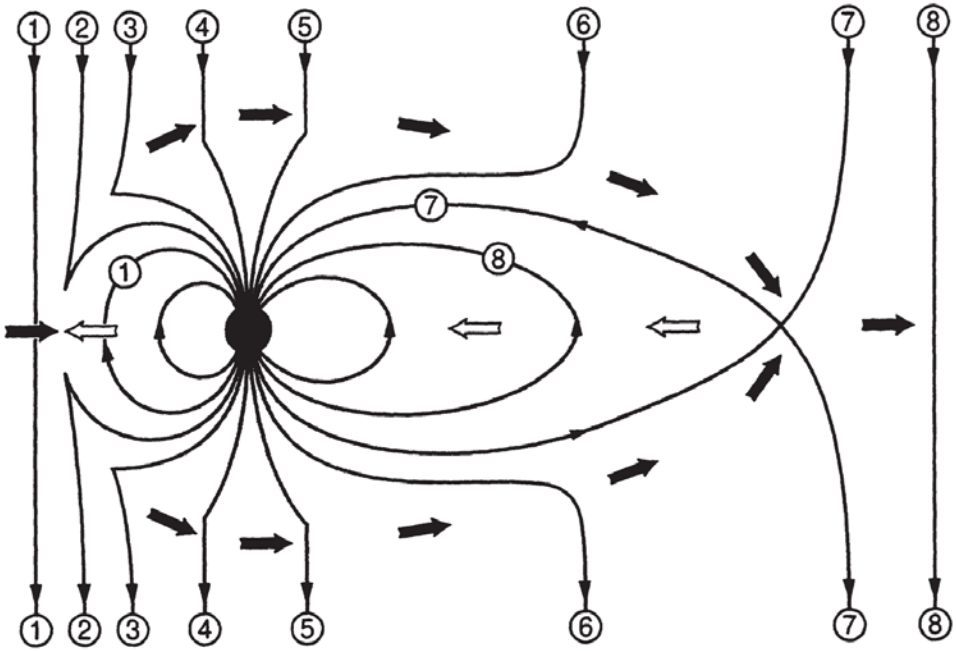
North-South IMF

- **Merging of field lines with anti-parallel component.**
- **Magnetopause reconnection creates open field lines.**
- **Magnetotail reconnection changes field line topology from open to closed.**
- **The circulation of magnetic field lines from the dayside to the nightside and back is referred to as the Dungey cycle.**





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Results from M1

- The energetic particle environment at Mercury was very different from Mariner 10
- Unlike Mariner 10, both “ions” and “electrons” were absent during the MESSENGER flyby
- Particle intensities were at background level before, during and after the magnetospheric passage
- During the MESSENGER passage, the interplanetary magnetic field Bz was northward as measured by MAG
- In fact, the last southward IMF Bz interval with a duration more than Mercury’s ~1 min convection time scale ended ~4 minutes prior to MESSENGER’s entry into Mercury’s magnetosphere
- Modelings suggest that if there were any particles energized by the southward Bz, the time constant for their loss from this small magnetosphere is < 4 minutes

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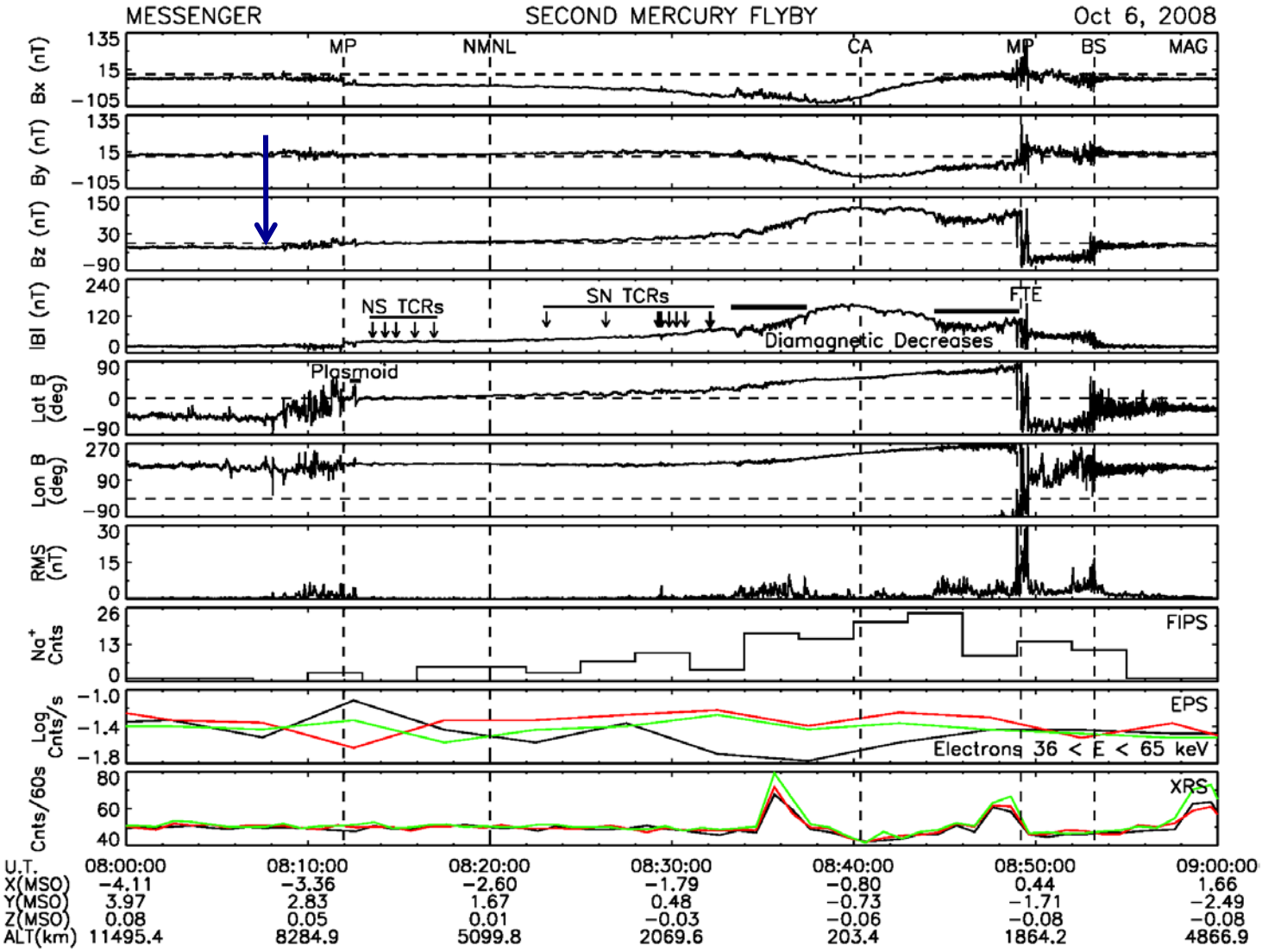
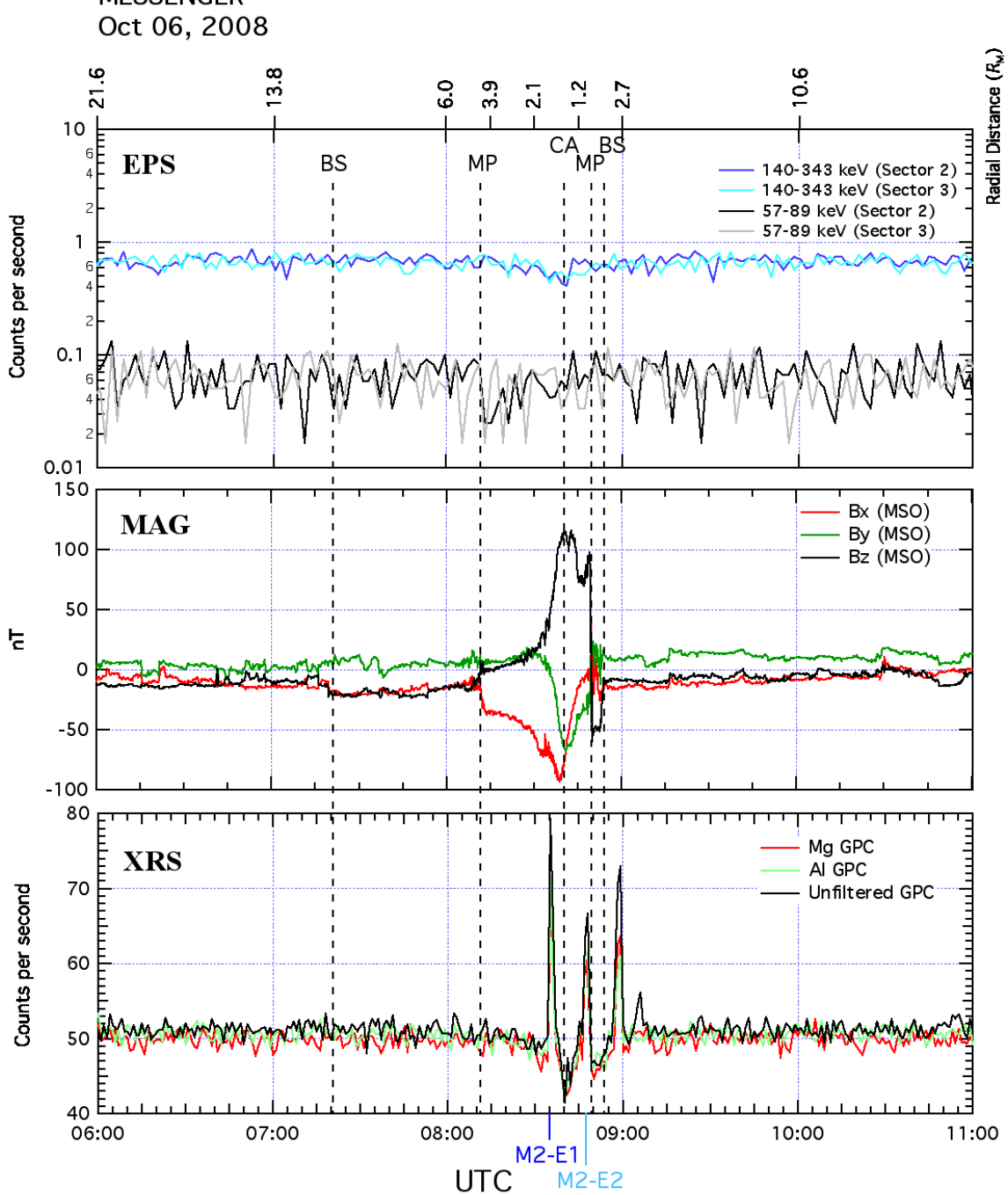
Second Flyby Overview





Ho et al., submitted, *PSS*, 2010

Figure 4

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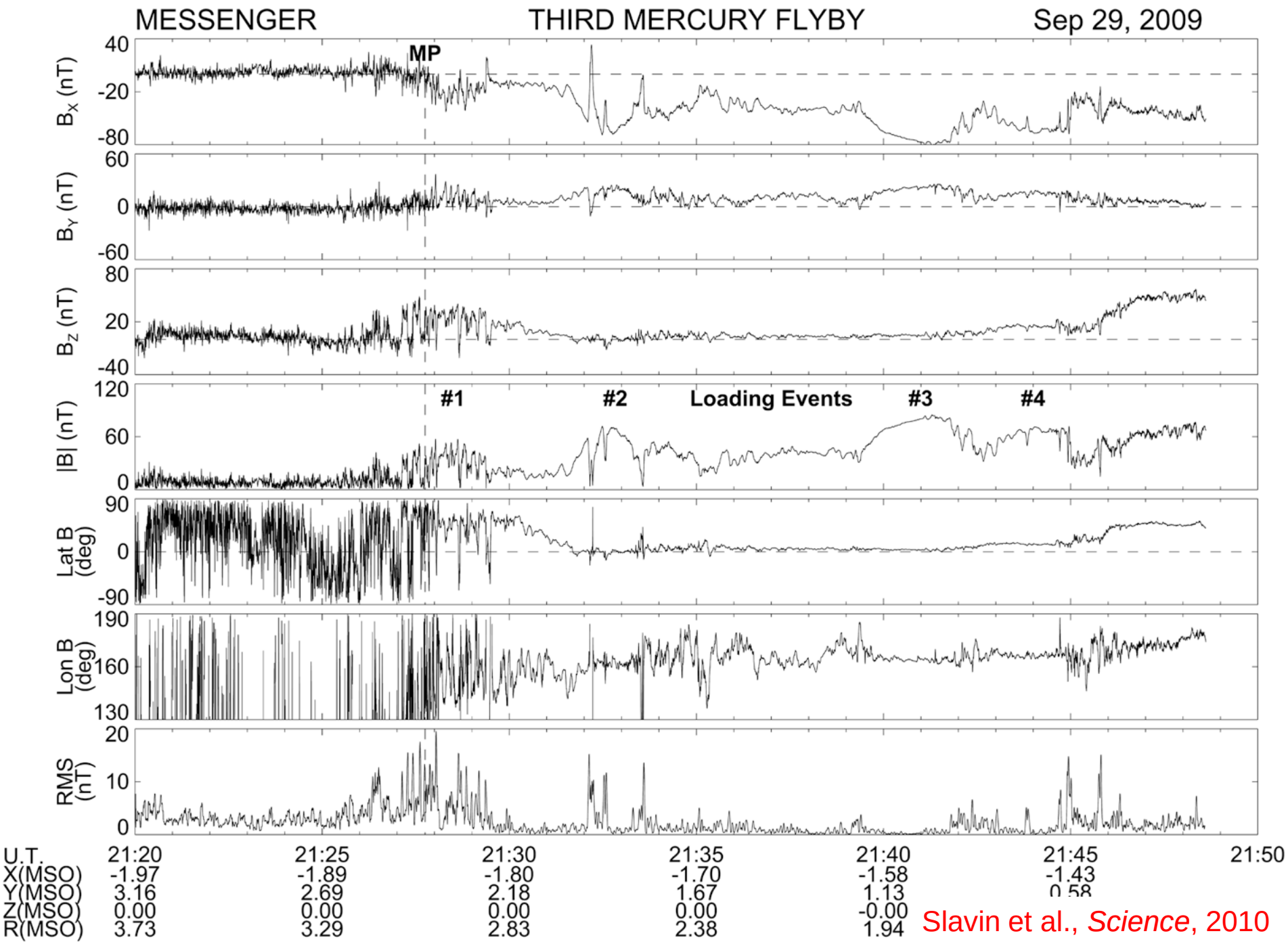
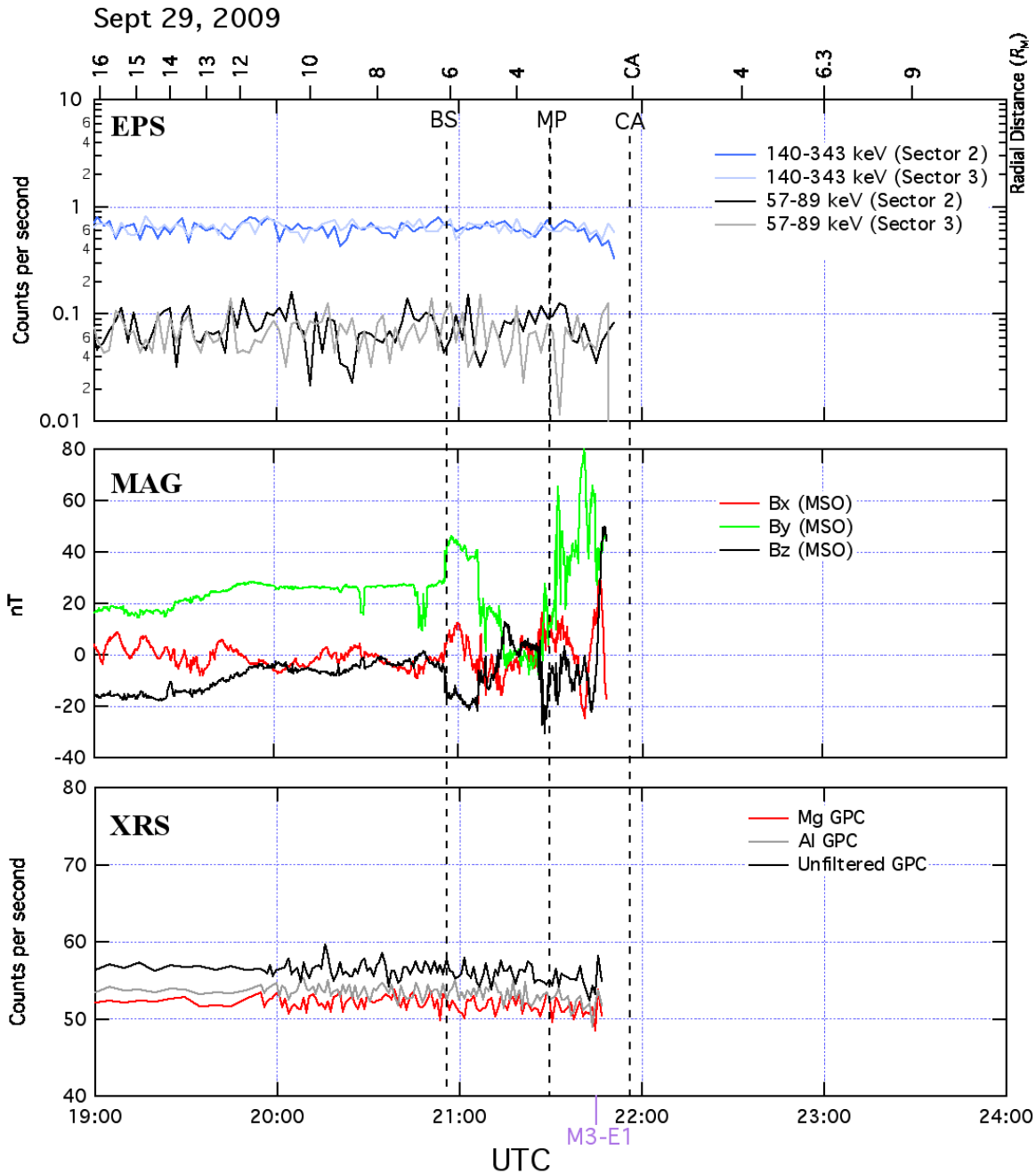
Results from M2

- During the MESSENGER passage, the interplanetary magnetic field Bz was southward as measured by MAG
- Magnetic field data indicated plasmoid motion and reconnection signature, but no dipolarization
- Like M1, both “ions” and “electrons” were absent during the MESSENGER flyby
- Particle intensities were at background level before, during and after the magnetospheric passage

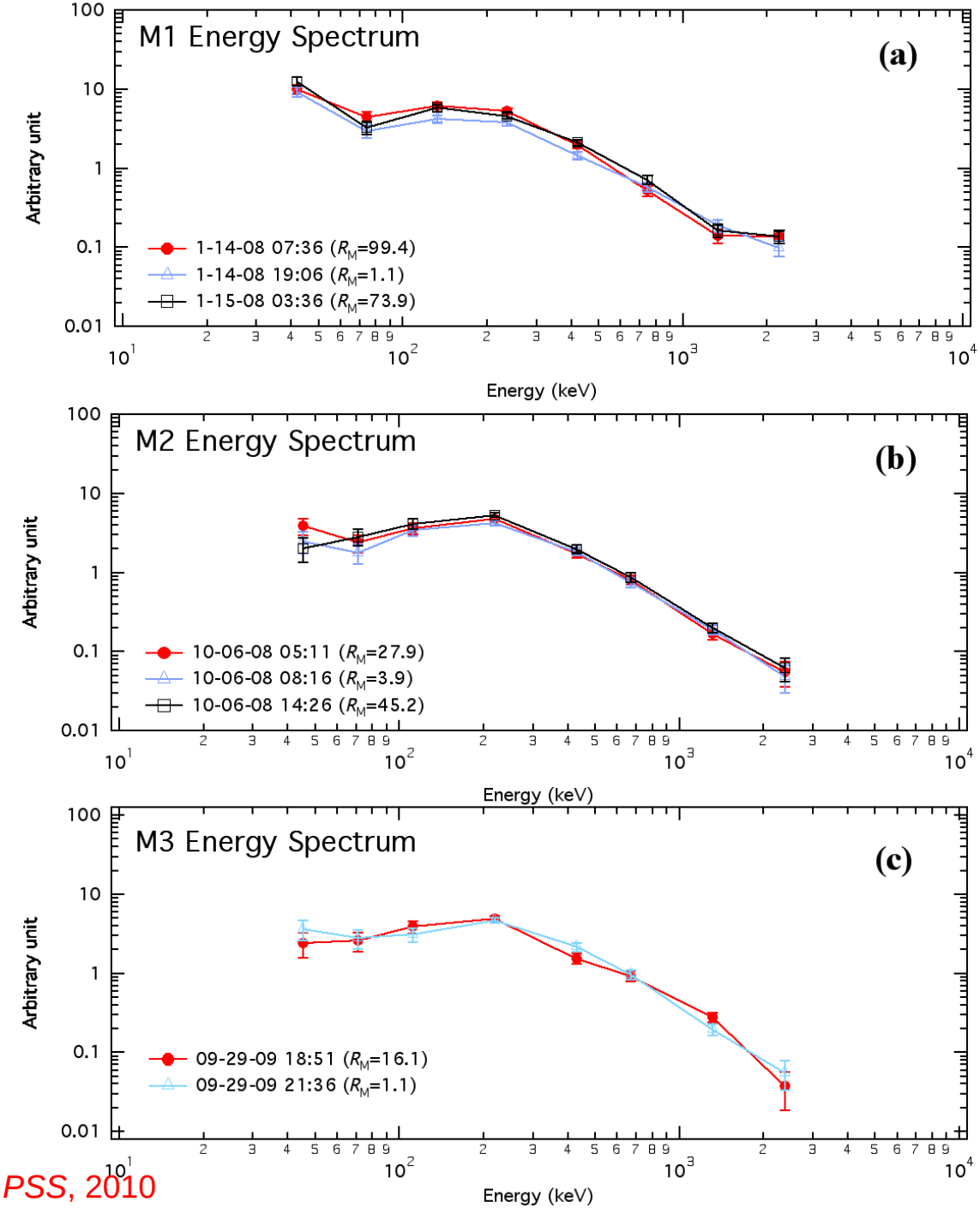


Slavin et al., *Science*, 2010



Ho et al., submitted, *PSS*, 2010

Figure 5



Ho et al., submitted, *PSS*, 2010

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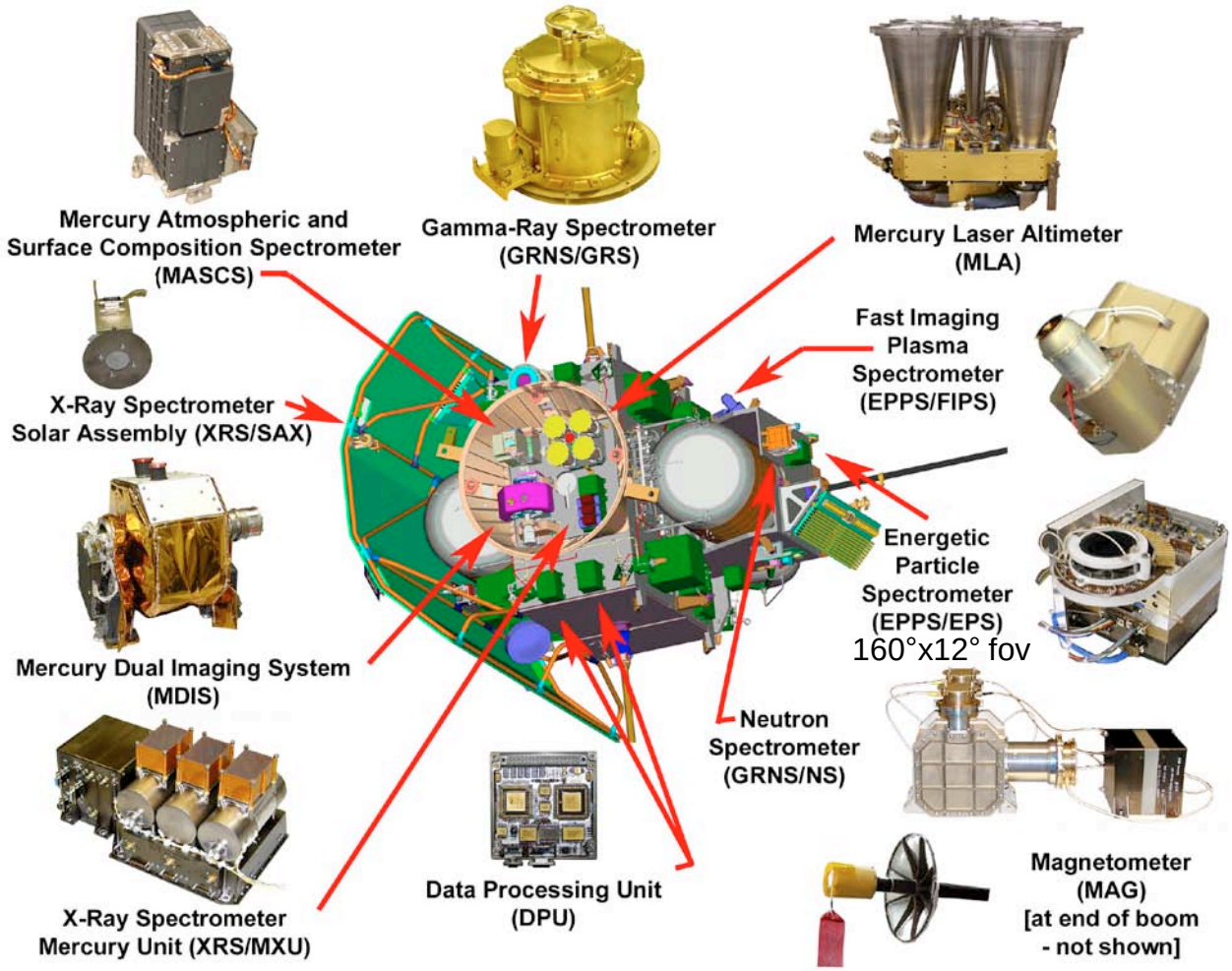
Scientific Payload

- The MESSENGER payload weighs 47.2 kg including mounting hardware, captive thermal control components, purge system, payload harnesses, and magnetic shielding for the spacecraft reaction wheels. The mass for MDIS includes the calibration target. The MAG mass includes a 3.6-m boom.
- Nominal average power consumption per orbit is 84.4 W; actual values will vary with instrument operational mode and spacecraft position in orbit.



Instrument details can be found at http://messenger.jhuapl.edu/instruments/index.html

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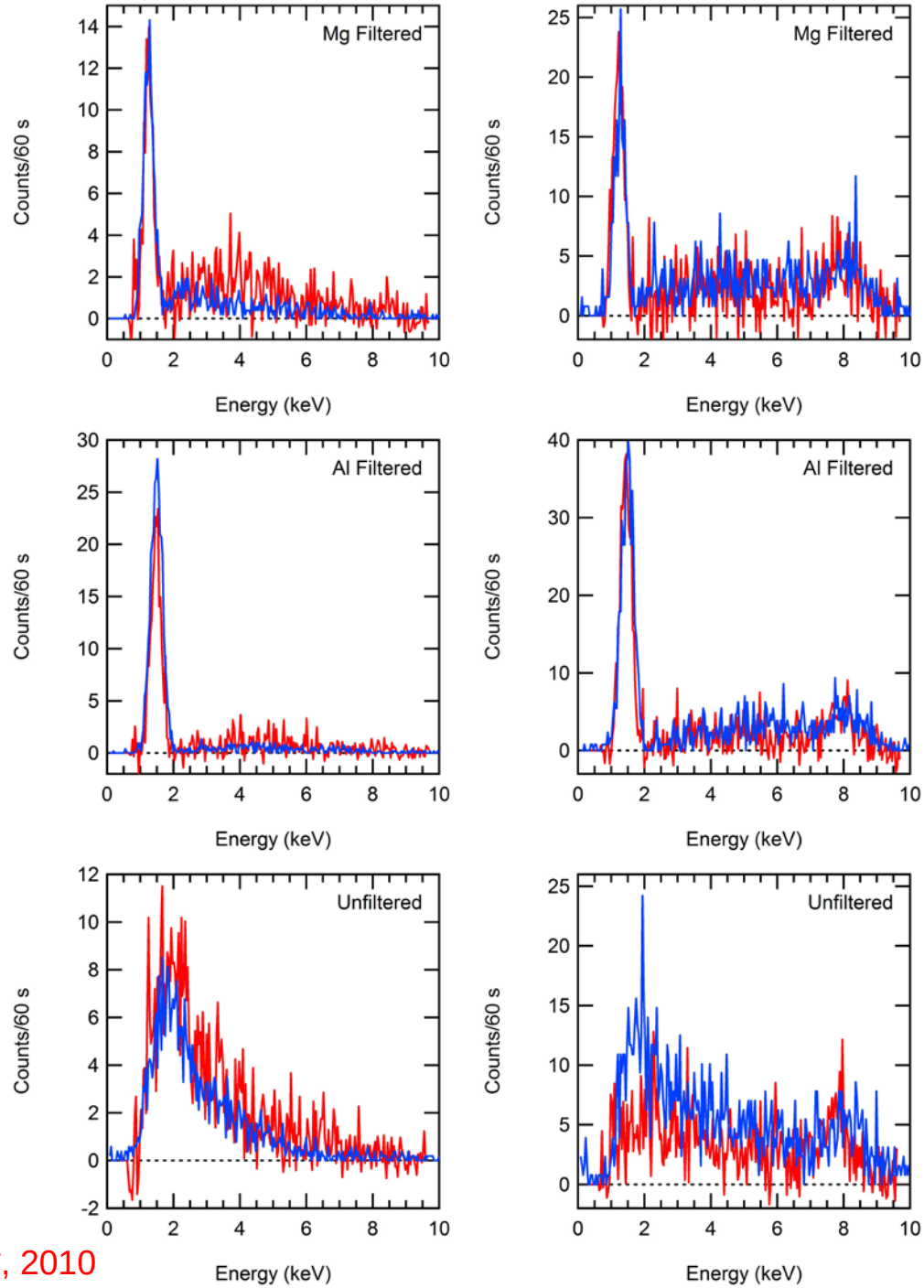
Electron Distribution Fitted

Table 1. Parameters used to fit the XRS electron events detected during M1 and M2.

Event	Date	Time of event (UTC)	Duration (s)	N (electrons/cm^2-sr-s-keV)	Best-fit K	Best-fit E_o
M1-E1	14 January 2008	18:59:49	180	1.35×10^7	8	0.7
M2-E1	6 October 2008	08:35:08	60	5.39×10^7	8	0.7
M2-E2	6 October 2008	08:47:08	120	3.06×10^8	7	1.0
M3-E1	23 September 2009	21:45:39	60	3.85×10^6	8	0.7

Note: A kappa distribution (Christon, 1987) is assumed, where the flux

$j = N[E/E_o][1 + E/KE_o]^{-K-1}$, and N, E_o and K are the normalization factor, modal energy, and kappa, respectively.



Ho et al., submitted, *PSS*, 2010

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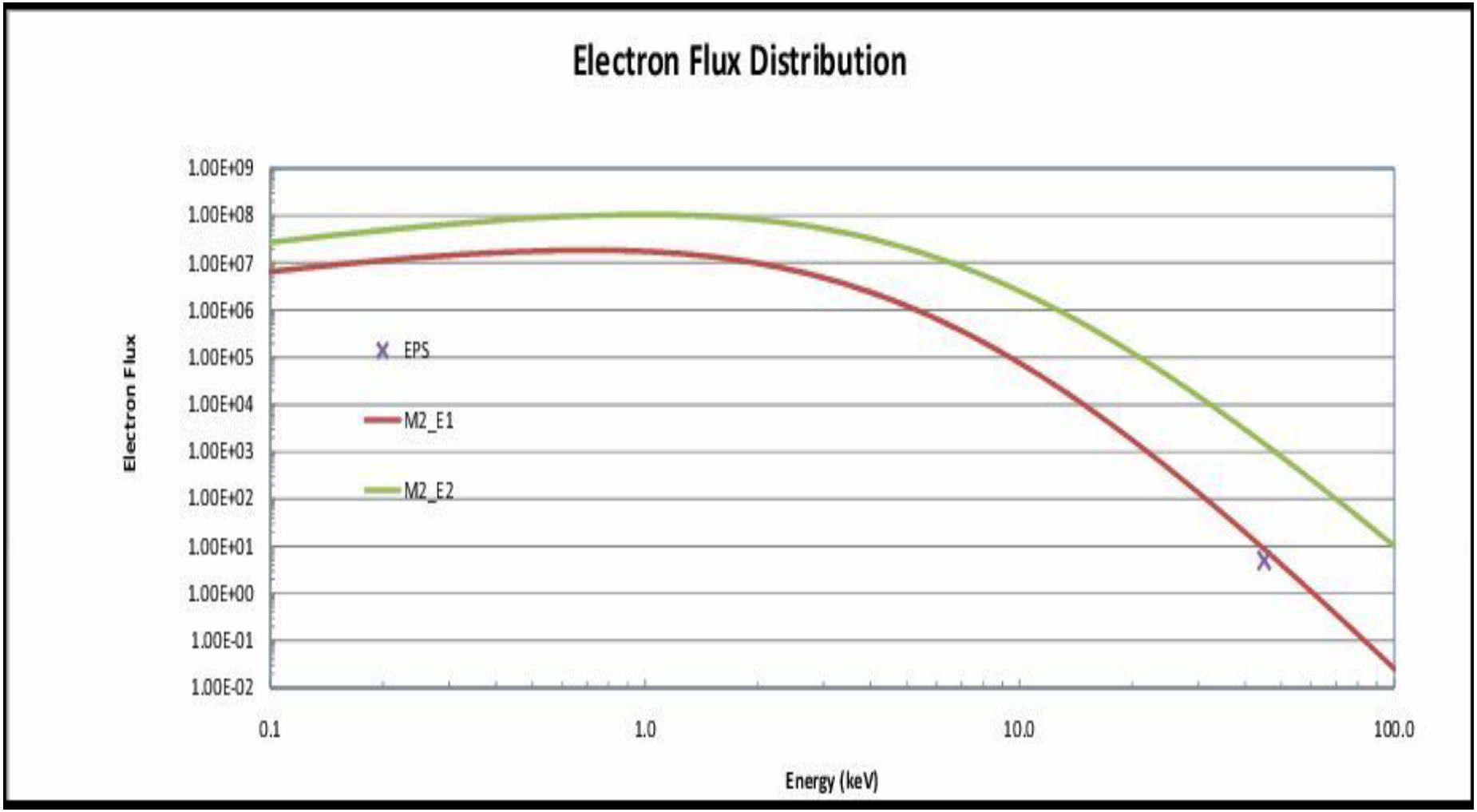

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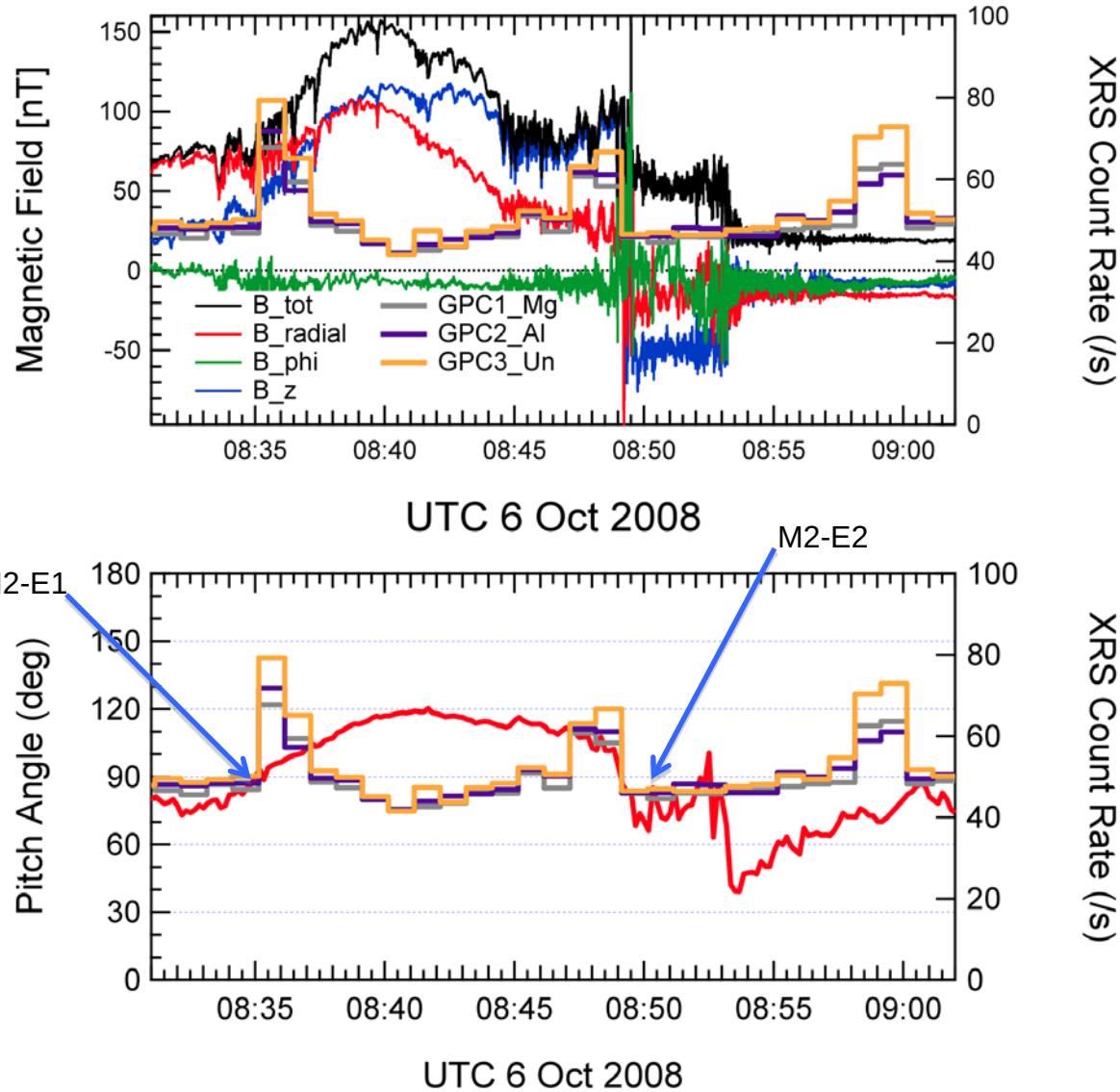
Magnetic Field [nT]
XRS Count Rate (/s)
B_tot
B_radial
B_phi
B_z
GPC1_Mg
GPC2_Al
GPC3_Un
08:35
08:40
08:45
08:50
08:55
09:00
UTC 6 Oct 2008
M2-E1
M2-E2
Pitch Angle (deg)
XRS Count Rate (/s)
UTC 6 Oct 2008

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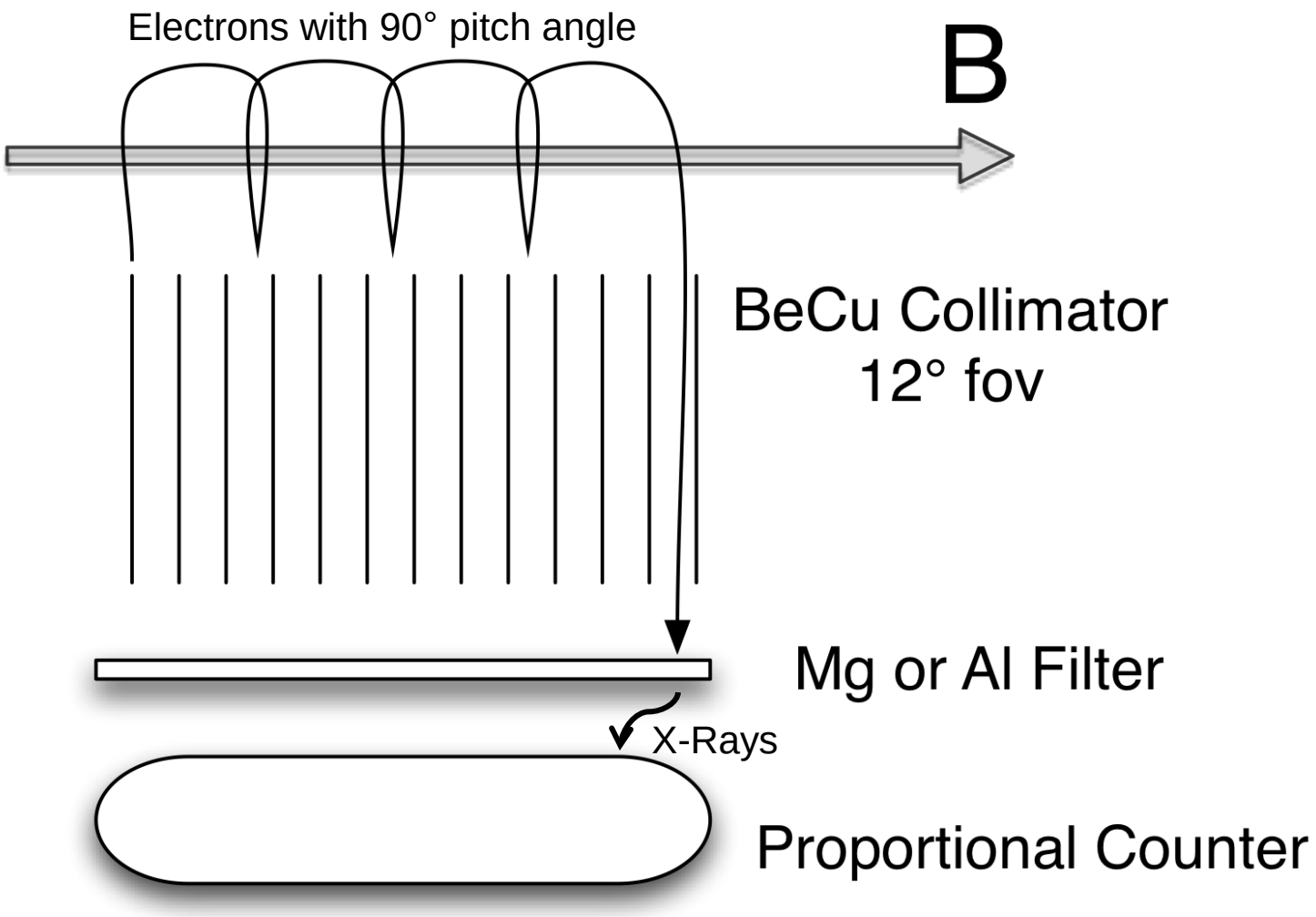
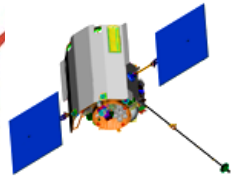
X-Ray Event Geometry





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Conclusions

- During the three MESSENGER flybys, the IMF exhibited all three possible conditions (North, South, Varying)
- At M3, the magnetometer measured several substorm-like signatures of extreme loading of Mercury's magnetotail
- But EPS measured no energetic ions or electrons above instrument background (~5 particles/cm^2-sr-s-keV at 45 keV)
- MESSENGER's X-Ray spectrometer nonetheless observed photons resulting from low-energy (~10 keV) electrons impinging on its detectors during each of the three flybys
- The estimated electron distribution agree well with the upper limit put for by EPS
- Questions remain about what acceleration processes are operating at Mercury and what Mariner 10 particle instrument had measured
- During the first two flybys, MESSENGER only caught a glimpse of what is to come in 2011

Backup slides

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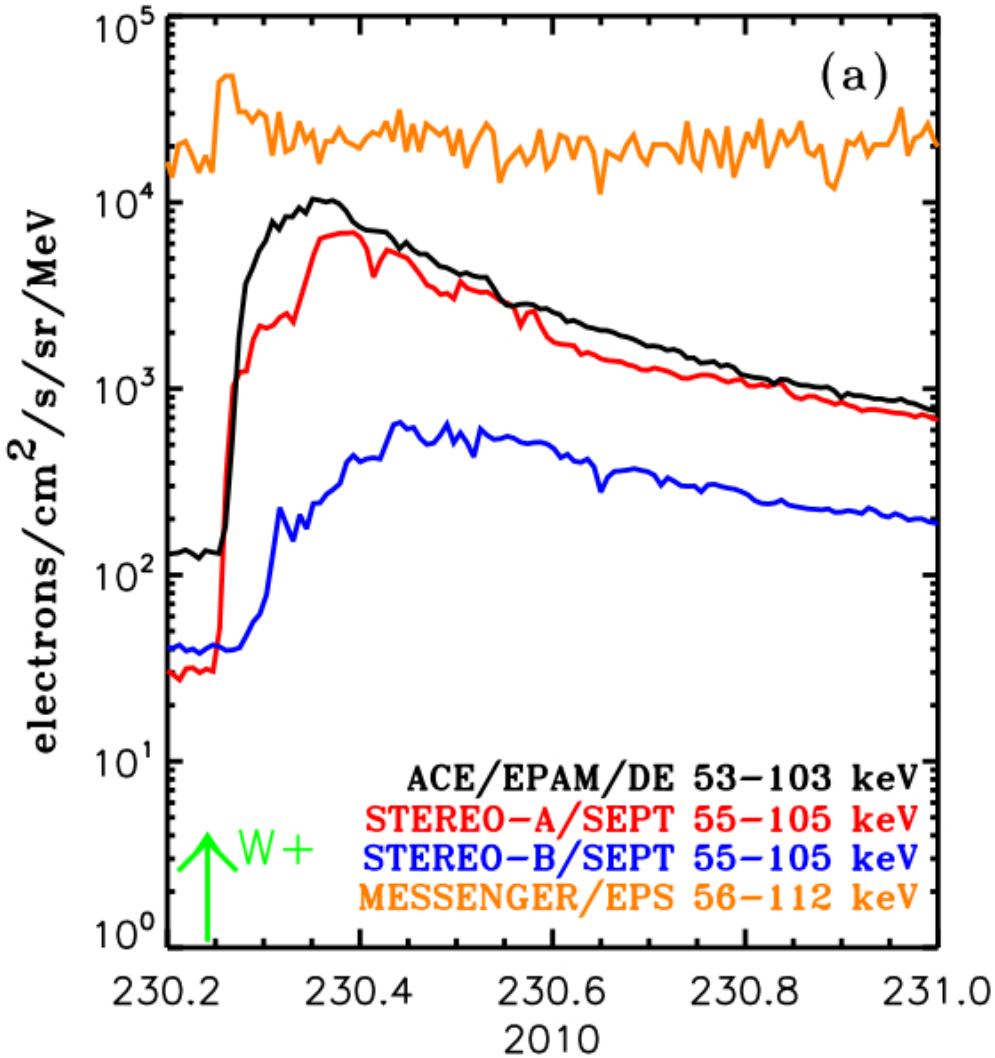
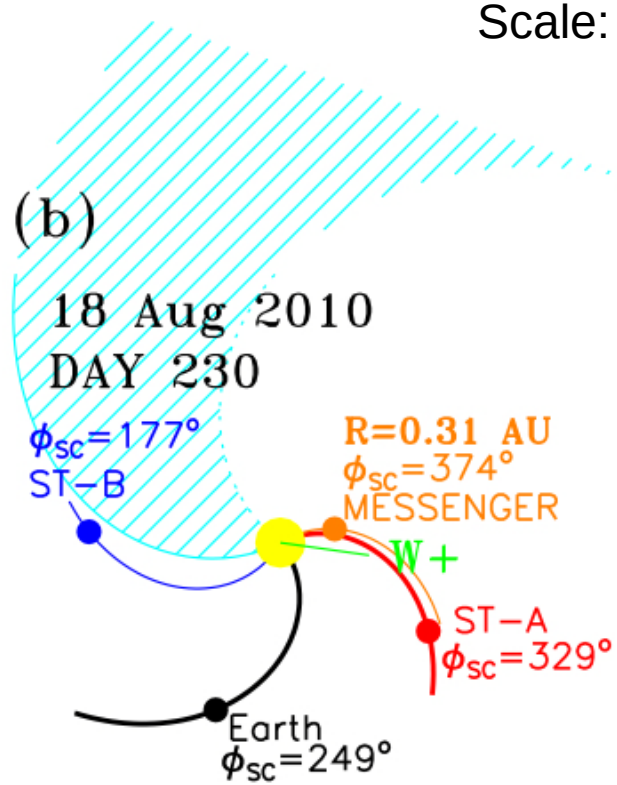
August 18, 2010



Peak Intensity:
MSRG: ~5x10^4 pf
ACE: ~ 1x10^4 pf

Scale: 1/r$^{1.3}$



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Conclusions

- Mercury's magnetosphere resemble Earth's magnetosphere in several ways but more importantly;
- Mercury's magnetosphere is different in some key aspects (size, ring current, etc)
- Mariner 10 particle measurements only provided a snap shot of a highly dynamic couple system
- Questions remained on what acceleration processes are operating at Mercury and what Mariner 10 particle instrument had measured
- MESSENGER only caught a glimpse on what to come in 2011 during the first two flybys

Mariner 10 / MESSENGER Observations

- Mariner 10/MT geometric factor ~10 cm^2-sr
- Large EPS pixel geometric factor is 10^{-3} cm^2-sr
- Mariner 10 energetic particle detector was designed to measure >170 keV e^-
- Questions remain today on what was measured:
  - Scattering of the Ti foils (>0.36 for)
  - Single electron detection efficiency (~10^{-2})
  - Pile-up effect?
- EPS will have similar or slight better detection efficiency for 36 keV electrons