MESSENGER Observations of Plasma Environment Near Mercury

Jim M. Raines
University of Michigan

James A. Slavin, Thomas H. Zurbuchen
George Gloeckler, Haje Korth, Brian J. Anderson,
and Stamatios M. Krimigis

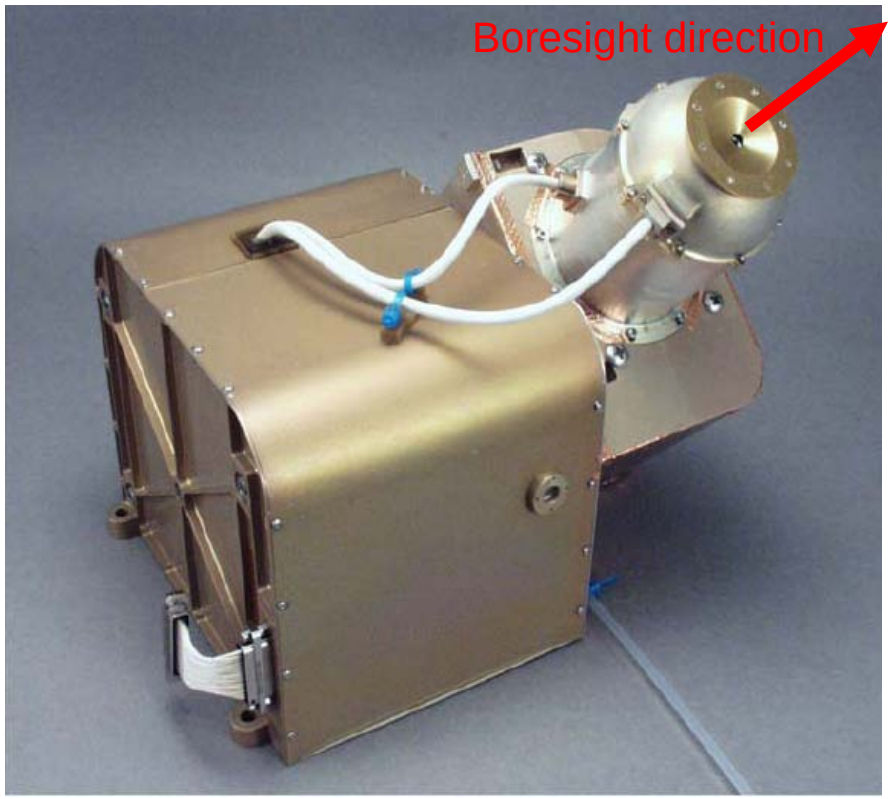
MESSENGER-BepiColumbo Joint Workshop
Boulder, CO
02Nov2010

MESSENGER

Fast Imaging Plasma Spectrometer

- Measures E/q, Time-of-flight (TOF) and incident angle for plasma ions
- E/q range: 0.5 – 13 keV/e
- m/q range: 1-60+ amu/e
- Time resolution down to 8s
- Nearly hemispherical instantaneous field of view (1.4 π steradian)
- Designed and built at University of Michigan
- Primary role: Heavy ion composition

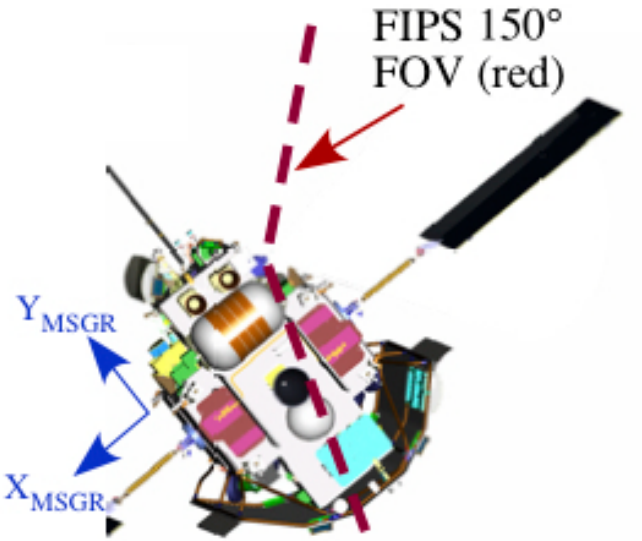
FIPS



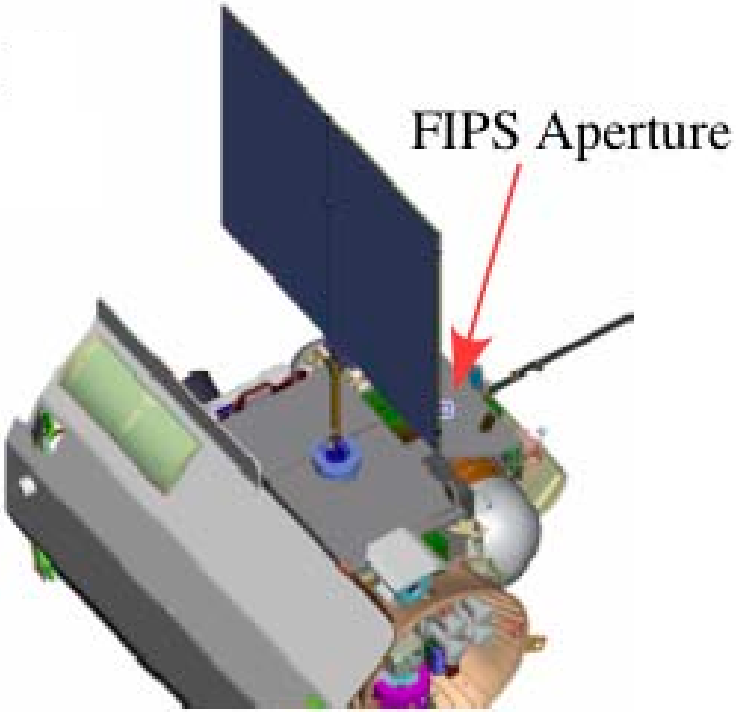
Mass: 1.41 kg Power: 1.9(ave)/2.1(max) W

MESSENGER

FIPS Field of View and Limitations

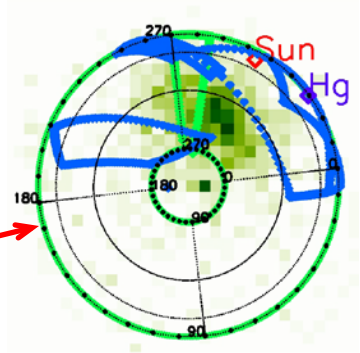


MESSENGER Top View

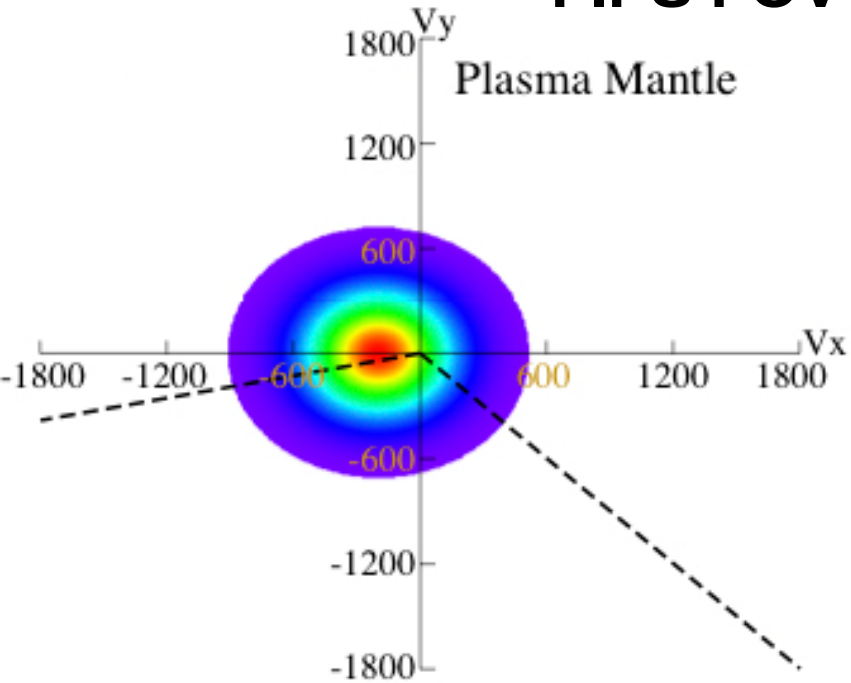


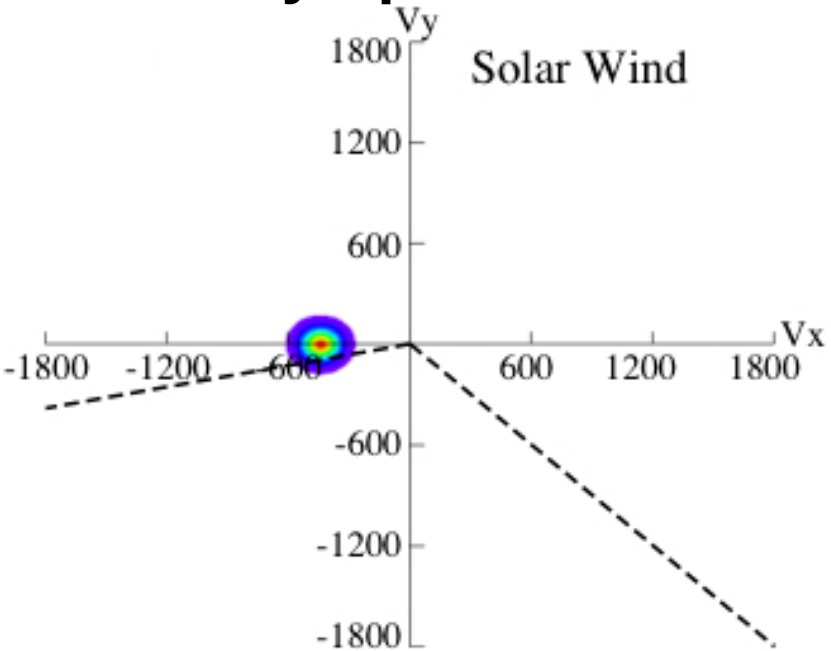
- FIPS looks out to the side of MESSSENGER, tilted down and toward front.
- FIPS FOV is blocked within 12 degrees of radial direction.

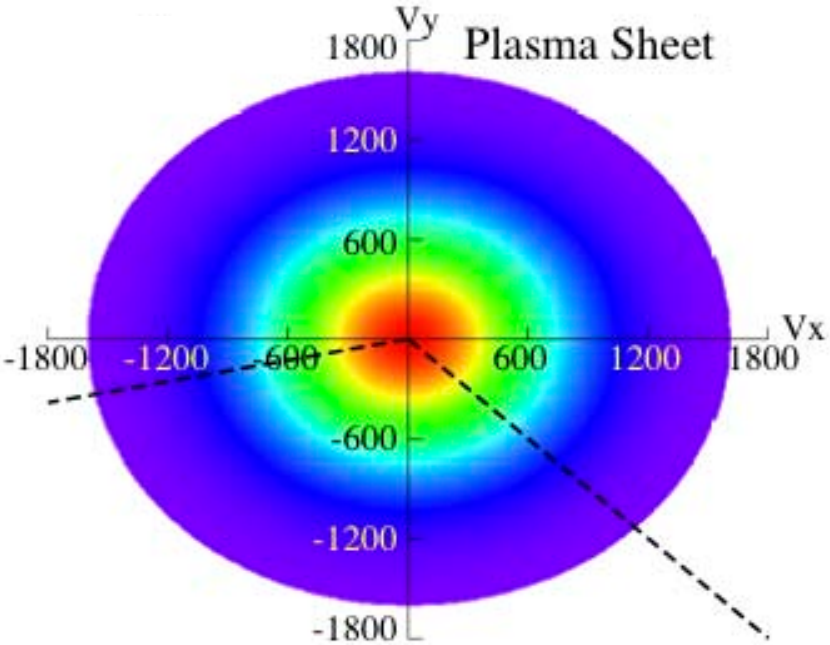
Looking **out** through FIPS aperture



FIPS FOV in Velocity Space







Issue:

Cutoff distributions complicate interpretation of FIPS measurements.

Solution:

Develop forward model recovery method which includes cutoff effects self-consistently.

MESSENGER

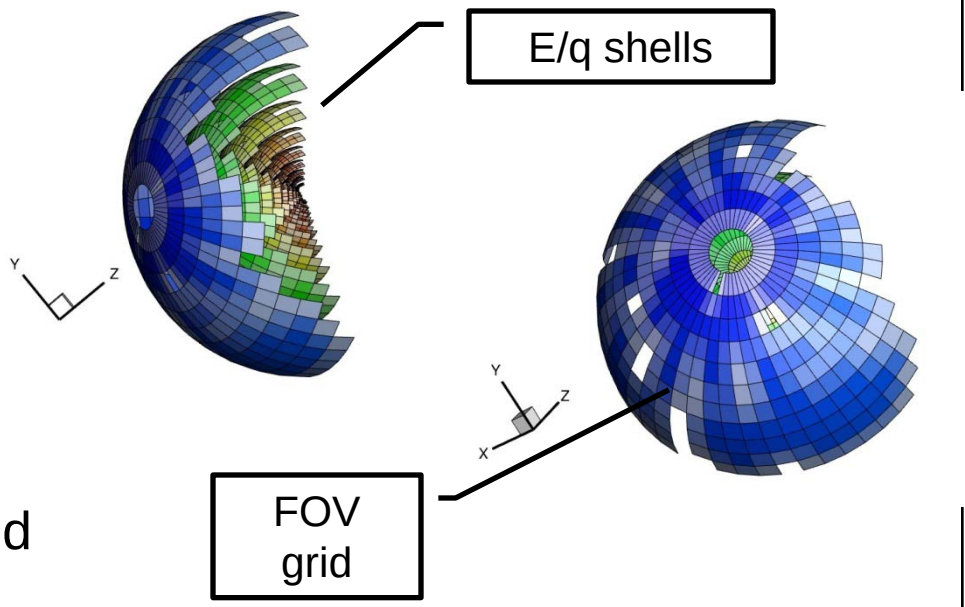
FIPS Instrument Model

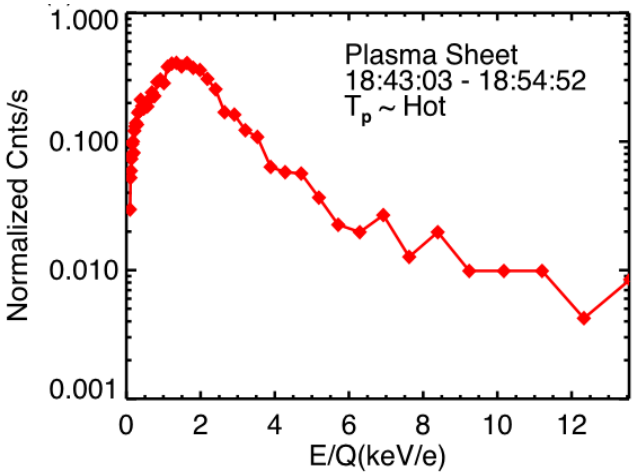
- **Input:** Plasma state and distribution function.
- **Operation:**

  1) Extract time-dependent frame transformation matrices for MESSENGER position and attitude.

  2) Raster scan over E/q values and FIPS FOV doing for each
  - FIPS frame → Input frame
  - Find phase space density from distribution function
  - Calculate counts

- **Output:** FIPS-like E/q spectrum and incident angle histogram



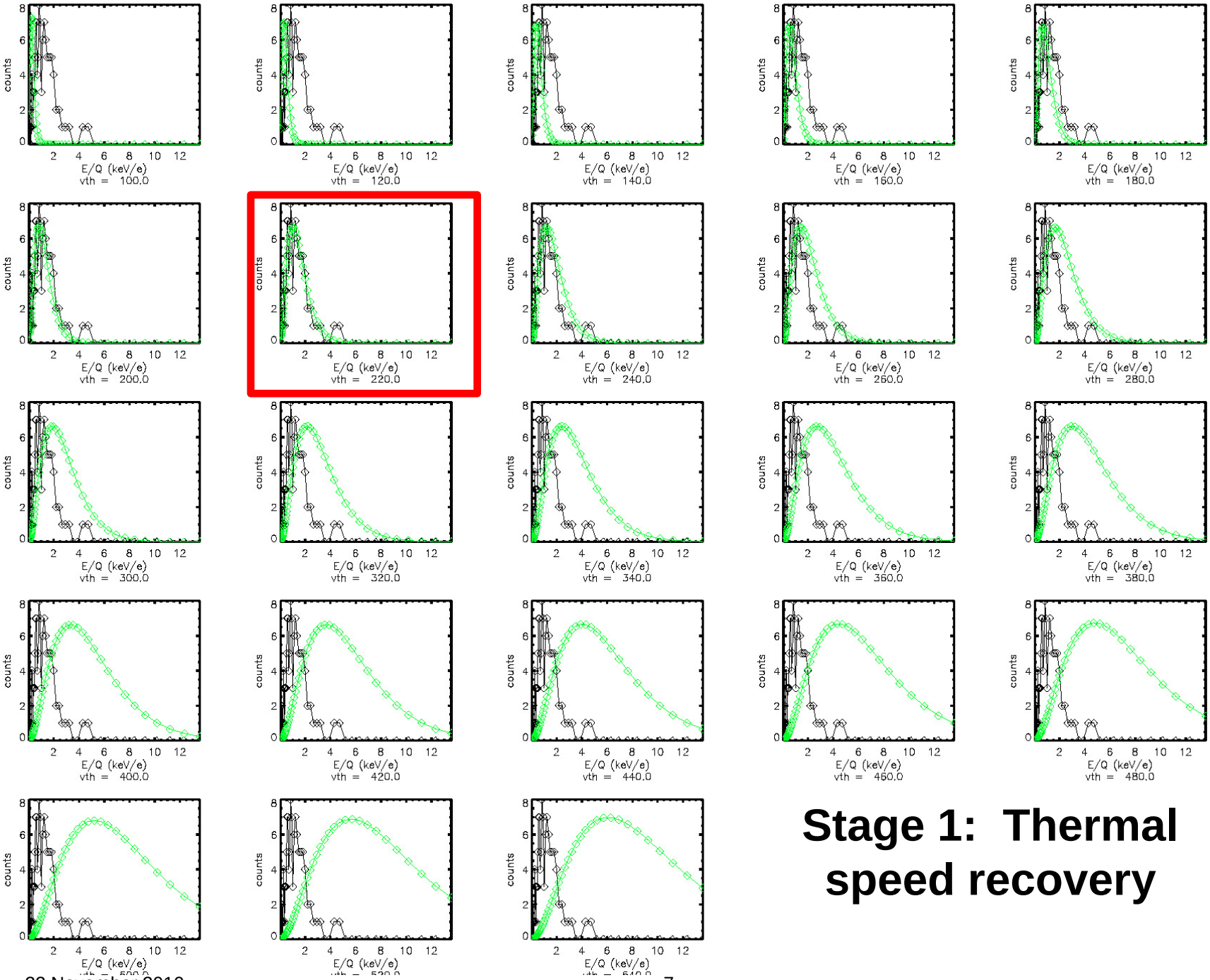


Forward Recovery Method

- Assume:
  - 3D Maxwellian velocity distribution.
  - Very low sonic Mach number
    $v_{th} >> v_{bulk}$

- Run model for range of densities and thermal speeds
  - thermal speed: 100-540 km/s, 20 km/s increments
  - density: 5-30 cm^{-3} , .5 cm^{-3} increments

- Two stage recovery – find best fit model E/q spectrum
  - Stage 1: thermal speed
  - Stage 2: density



Stage 1: Thermal speed recovery

Stage 1: thermal speed

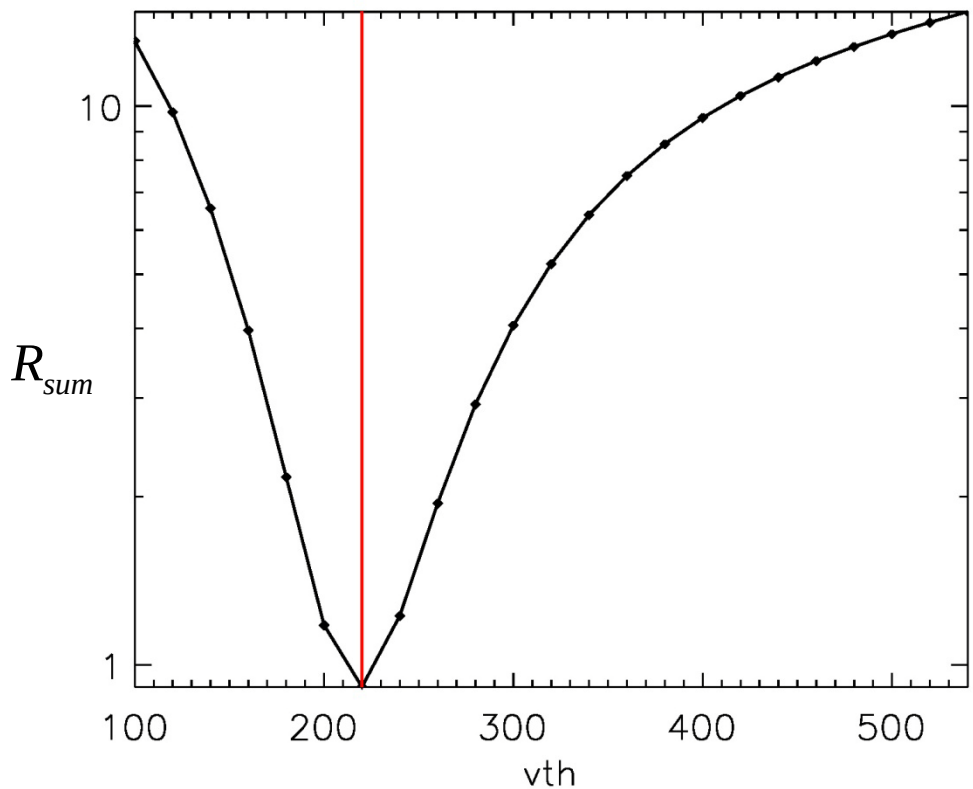
Minimize mean squared error:

$$R_{sum} = \sum_{i} (C_i - M_i)^2$$

model counts

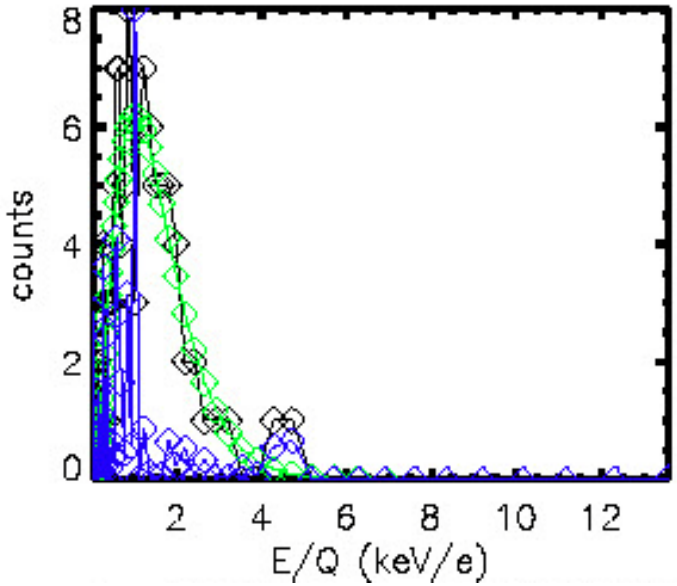
Actual counts

Sum over E/q spectrum



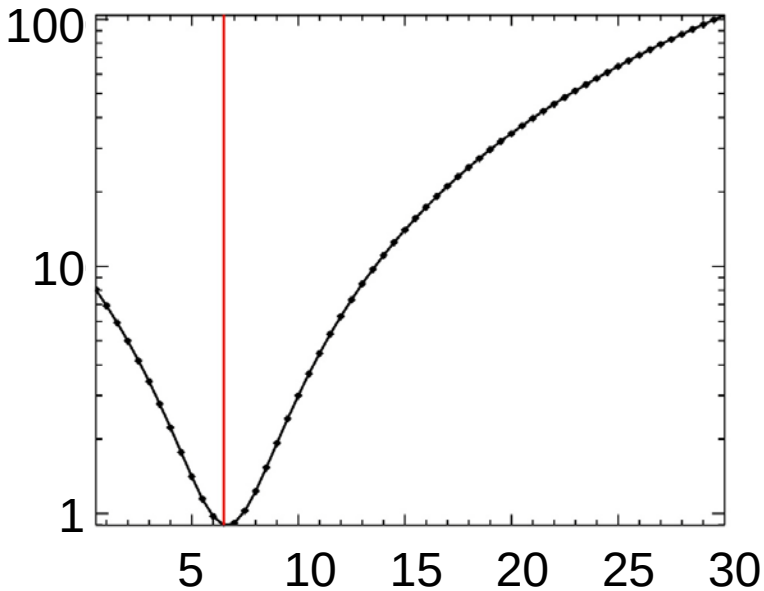
Recovered thermal speed: 220.0 km/s

Stage 2: Density Recovery



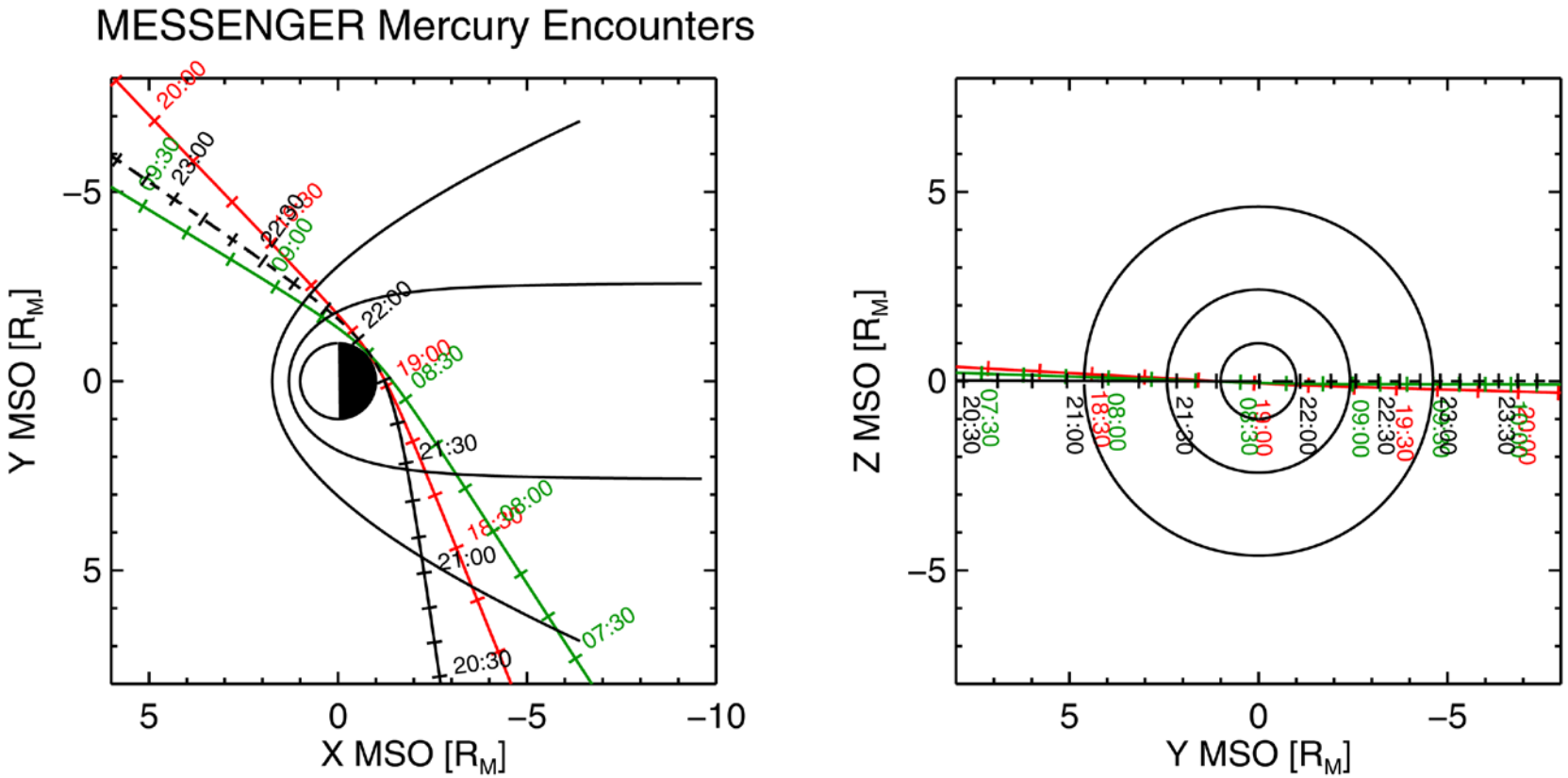
- Repeat procedure with single vth and range of densities
- No amplitude scaling this time.

Recovered density:
6.5 cm^{-3}



MESSENGER

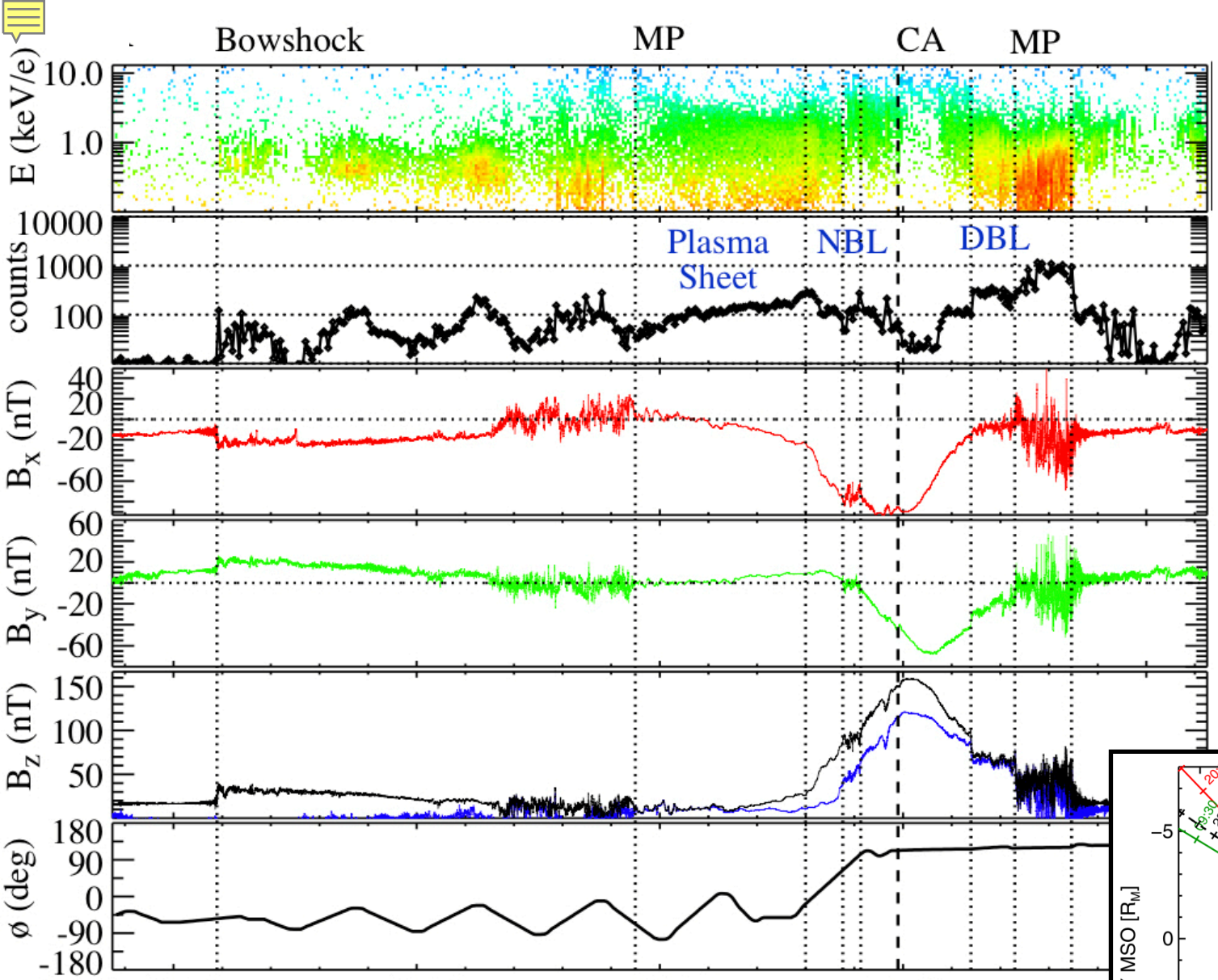
Flyby Geometry



Mercury Flybys: M1 (14 Jan 2008), M2 (6 Oct 2008), M3 (29 Sep 2009).

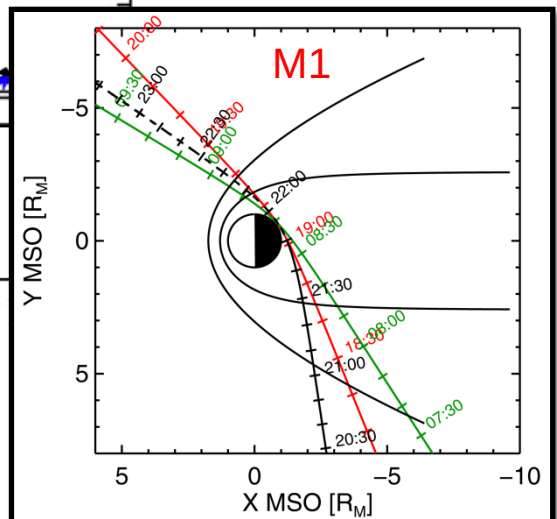
Flyby 1

14 Jan 2008



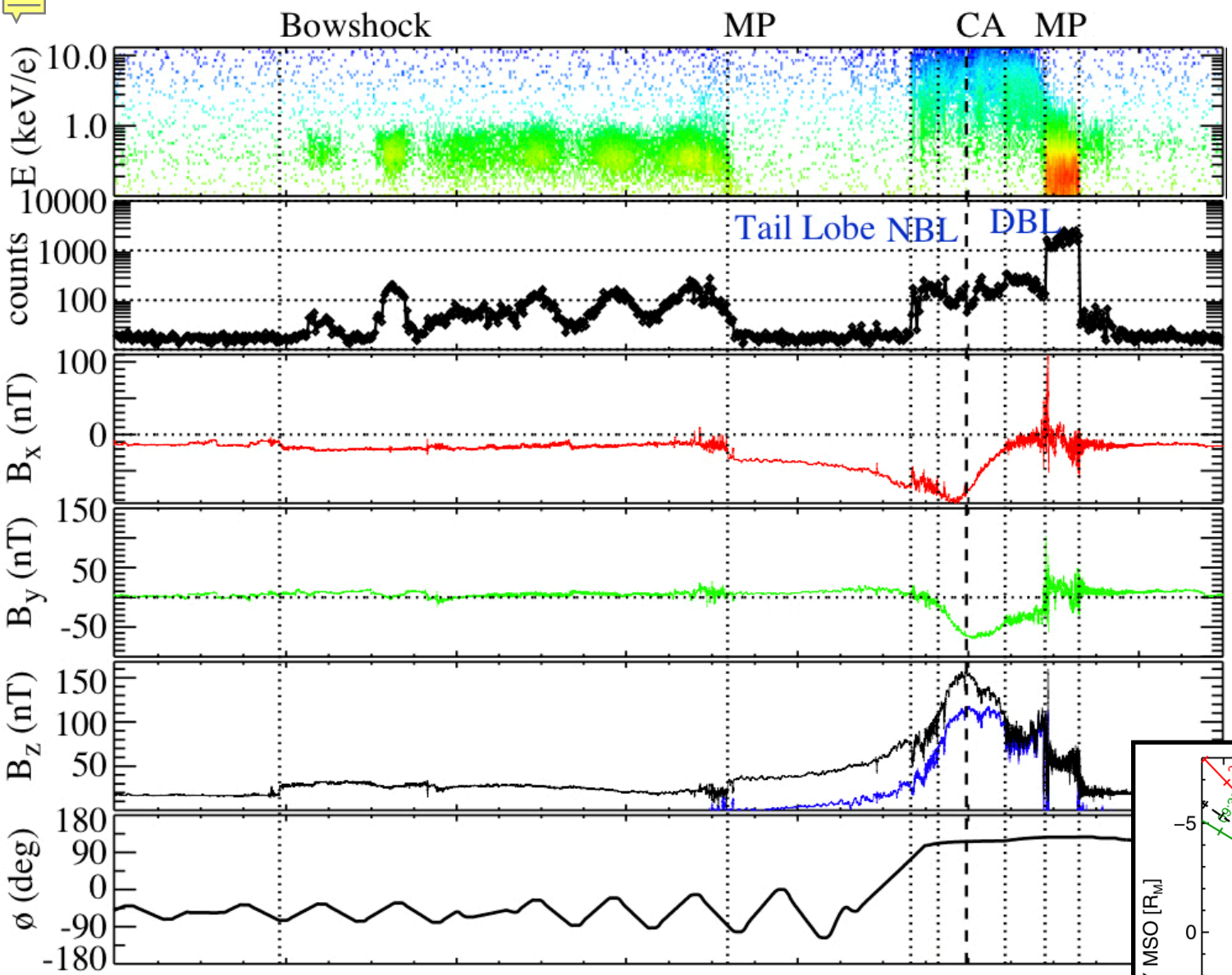
UTC	18:05	18:25	18:45	19:05
MSO X	-4.51	-3.41	-2.27	-0.88
MSO Y	7.83	5.10	2.31	-0.63
MSO Z	0.37	0.22	0.06	-0.09
ALT	8.05	5.13	2.24	0.08

Northward IMF



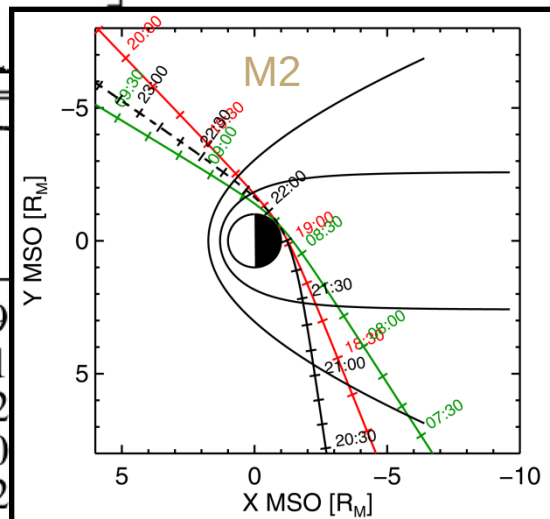
Flyby 2

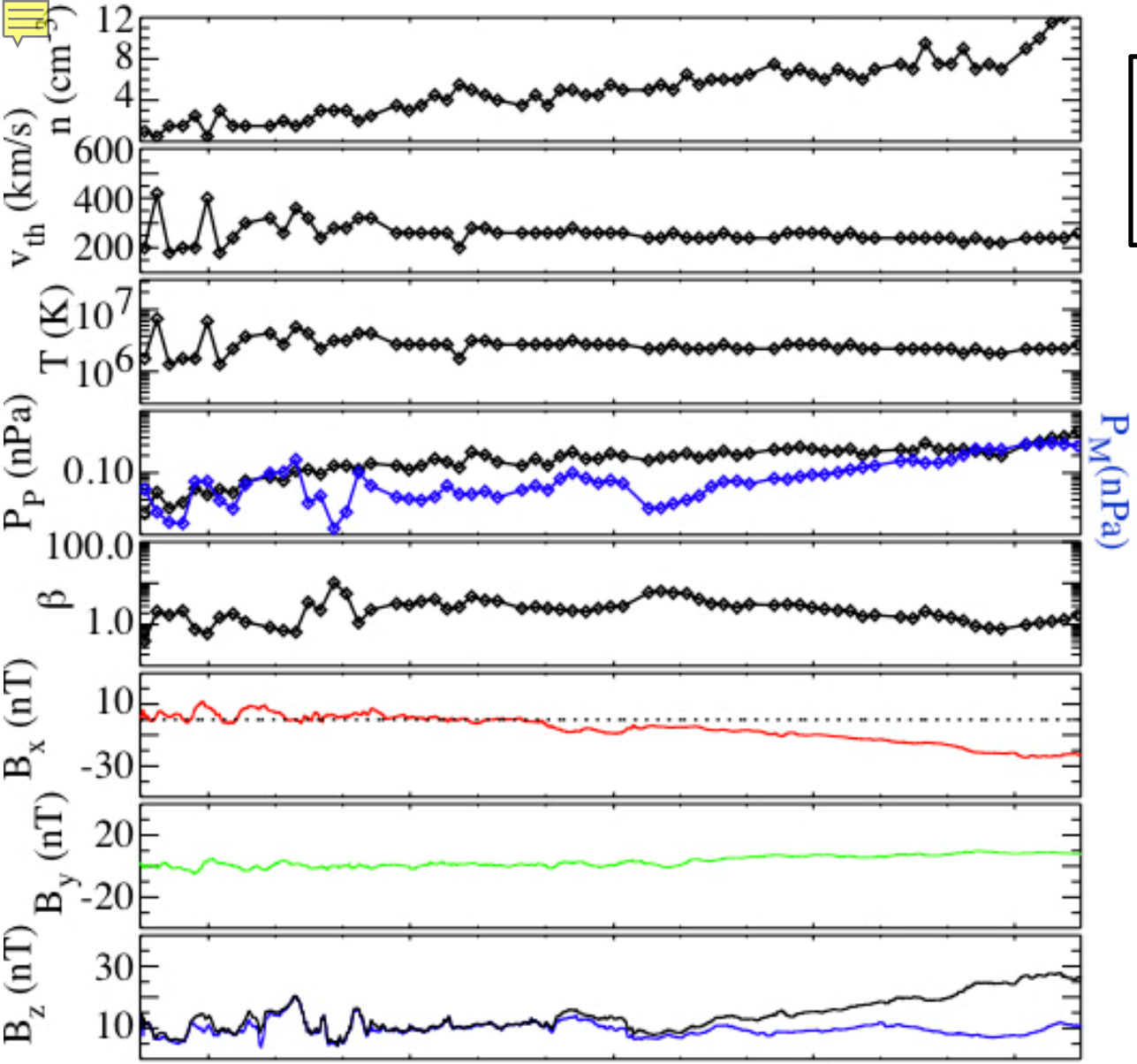
06 Oct 2008



UTC	07:20	07:40	08:00	08:20	08:40	09
MSO X	-6.98	-5.55	-4.10	-2.59	-0.78	1
MSO Y	8.42	6.20	3.97	1.65	-0.75	-2
MSO Z	0.23	0.16	0.08	0.01	-0.06	-0
ALT	9.94	7.32	4.71	2.07	0.08	2

Southward IMF



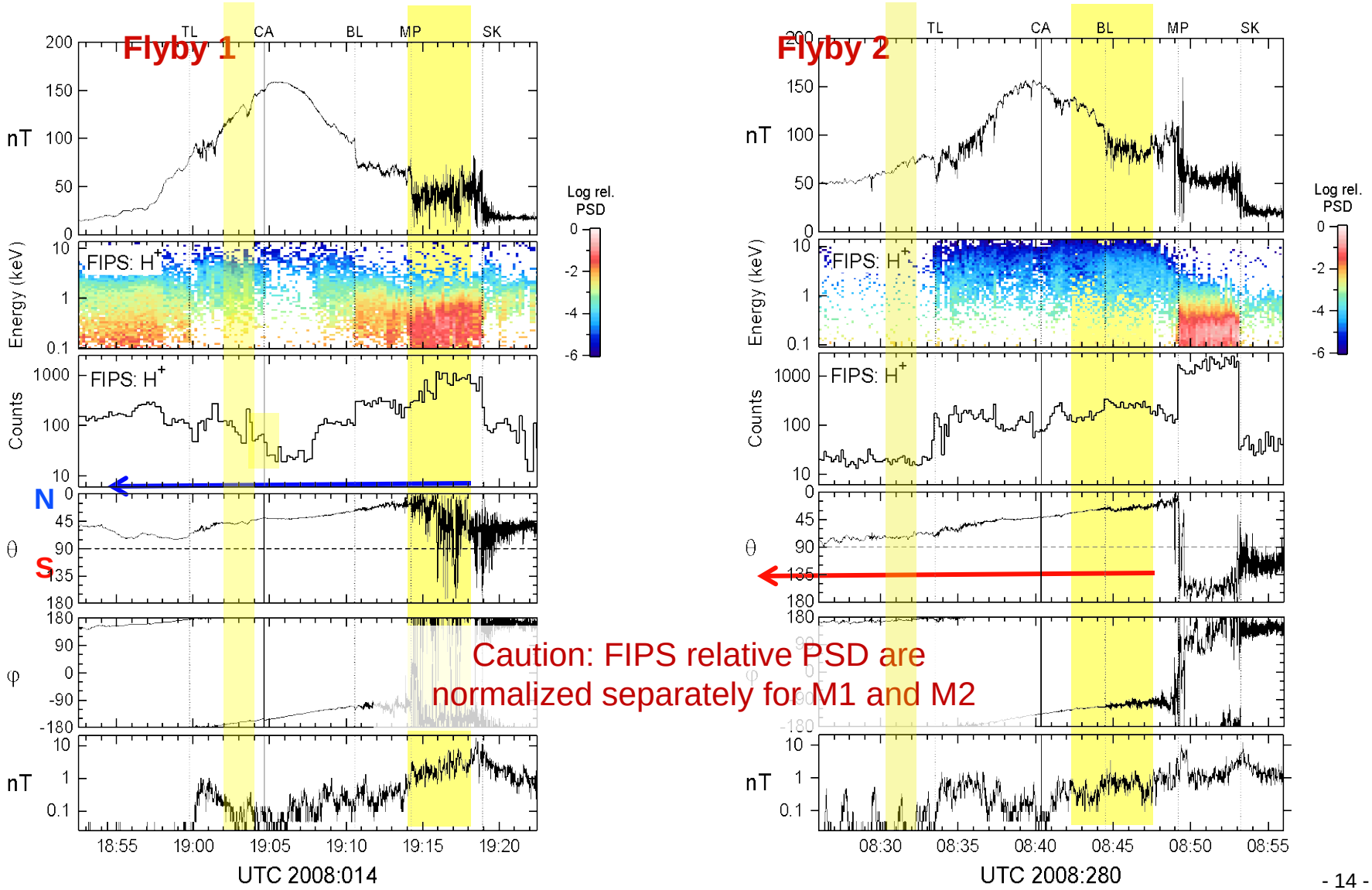


M1 Plasma Sheet Recovered Data

- Density spans the 1 cm^{-3} reported from Mariner 10. (Ogilvie et al. 1977)
- Density range is consistent with Earth, given 1/r^2 scaling law: ~10x Earth plasma sheet density is expected and observed. (Ogilvie et al. 1977, Baumjohann and Paschmann 1989)
- Plasma β within range reported at Earth. (Baumjohann and Paschmann 1989)
- Proton pressure increased ~2x with approach to planet, consistent with observations at Earth. (Shiokawa, et al., 1997)

MESSENGER

Boundary Layer Detail



Caution: FIPS relative PSD are normalized separately for M1 and M2

MESSENGER

	Dayside Boundary Layer		Nightside Boundary Layer	
Flyby:	M1	M2	M1	M2
<n> [cm^{-3}]	16	8	4.3	5.2
<T> [K]	8.7×10^5	4.7×10^6	2.4×10^6	4.1×10^6
$< P_P >$ [nPa]	.19	.51	0.14	0.28
$< P_M >$ [nPa]	1.9	3.01	3.1	2.7
$< \beta >$	0.1	0.2	0.5	0.1
<|B|> [nT]	69.1	91.2	88.4	81.4

Strong differences are observed in proton densities, temperatures and pressures for Northward IMF M1 vs. Southward IMF M2.

MESSENGER

Dayside Boundary Layer Comparison

Flyby:	M1	M2
$\langle n \rangle$ [cm^{-3}]	16	8
$\langle T \rangle$ [K]	$.87 \times 10^6$	4.7×10^6
$\langle P_P \rangle$ [nPa]	.19	.51
$\langle P_M \rangle$ [nPa]	1.9 (2.53)	3.01 (4.62)
P_M drop [nPa]	-1.63	-1.61
$\langle \beta \rangle$	0.1	0.2
$\langle \lvert B \rvert \rangle$ [nT]	69.1	91.2

- P_M drop is the difference in magnetic pressure upon entry into the dayside boundary layer, calculated from 20 s averages of the field on each side.
- Proton pressure in depressions is not sufficient to balance decreased magnetic pressure.

Where is the missing pressure?

- Flyby showed a peak in Na^+ ions in the dayside boundary layer region (Zurbuchen 2008).
- Ions picked-up near dayside boundary layer would not yet be thermalized (non-Maxwellian, ring velocity distribution).
- Estimate:
  - Assume: Thermal speed = convection speed = 300 km/s
  - ➔ Temperature of ~10^8 K
  - ➔ Density of **~ 1 cm^{-3}** Na^+ ions required to make up the missing pressure.
- Cannot calculate density of Na^+ ions observed by FIPS (yet!)
- Observed flux not likely to account for that high of a density
- However, substantial Na^+ could have gone undetected during flybys
  - Small solid angle
  - Tail-ward convection

Orbit data required to answer these questions.

Key Results/Discussion

Key Results

- Plasma sheet parameters within expected ranges, as compared to Earth.
- Strong differences are observed in proton densities, temperatures and pressures for Northward IMF M1 vs. Southward IMF M2.
- Proton pressure in diamagnetic depressions is not sufficient to balance decreased magnetic pressure.

Discussion

- FIPS measurement geometry presents significant challenges for bulk plasma moments.
- We have developed a method to recover density and temperature via a software instrument model and can be applied in various areas.
- Next steps: Increase applicability by using full 3D info