MMS-SMART

Magnetospheric
Solving Magnetospheric Accelera

The Fast Plasma

T E Moore[1], J L Burch[2], M R Collier[1], D J Chornay[3], M L Adrian[1], A J Coates[4], D Linder[4], T Mukai[5], Y Saito[5],

1. NASA GSFC, 2. SwRI, 3. UMCP, 4. UCL/MSSL

Abstract

A clear picture of short-scale reconnection structures and their rapid motions will require observations from closely spaced platforms at a 30ms measurement cadence. The Fast Plasma Instrument (FPI) for the MMS mission exceeds this demanding requirement by acquiring full sky, high-resolution (11˚) electron plasma velocity distributions every 25 ms. FPI also delivers four full sky, medium-resolution (45˚) distributions every 6 ms, for unprecedented access to electron scale dynamics within the reconnection diffusion region. Data compression and burst memory management provide up to 16 minutes of high time resolution data during each orbit of the four MMS spacecraft. Each spacecraft will intelligently downlink the data sequences that contain the greatest amount of temporal structure. For both electrons and ions, FPI will realize these specifications by means of eight half-top-hat energy analyzers. Each analyzer has a 180-deg x 6-deg fan-shaped field of view (FOV) aligned with the s/c spin axis, and is fitted with lateral FOV deflection electrodes. The analyzers are packaged as four Dual Electron Spectrometers and four Dual Ion Spectrometers on each spacecraft. When distributed properly around the spacecraft, these packages provide an instantaneous full-sky view that is independent of spacecraft spin rate. This approach makes available a very large instantaneous aperture for plasma measurements at the high sensitivity required for fast exposures. FPI is based on flight heritage from Cluster/PEACE, Geotail/LEP, Polar/Hydra, and Rosetta/IES.

Science Requirements and Specifications

SMART

Question 3: FPI Requirements Derivation

Science Objectives	Resolve the diffusion region features on the electron and ion inertial scales, respectively.
Payload Measurement Requirements	Analyze the full sky distribution and energy range from cold plasma (1 eV) to 30 keV (e-) or 40 keV (i+) in 25 ms Observe with 10-12˚ angular resolution and coarse energy resolution (10-30%) Avoid spacecraft sheath screening or distortions. Achieve 5% moments error: ≥ 400 counts per 0.25 msec per 128 pixels of 8 detectors = 16 kHz per angular pixel average.
Instrument Capabilities	8 ea 180˚ x 10˚ apertures, viewing radially Electrostatic deflection by ± 17˚ and ± 6˚ for each aperture for 32 Az, 16 Polar pixels. Energy resolution 17% (elec), 10% (ion), with 64 steps Fast energy scan 6 ms sweep, 25ms deflection cadence Sensitivity (GdE/E) 1 x 10^{-3} (i+), 3x 10^{-4} (e-) cm^2 sr eV/eV

FPI will observe plasma microphysics with unprecedented time resolution.

FPI	Hot Plasma	Distribution Function of Plasma Ions and Electrons	Energy Range	Ions: 1 eV - 40 keV Electrons: 1 eV - 30 keV
			Pixel Geometric Factor	Ions: 1 x 10^{-3} cm^2 sr eV/eV Electrons: 3 x 10^{-4} cm^2 sr eV/eV
			Time Resolution	Ions: 150 ms Electrons: 25 ms
			Energy Resolution	Ions: 10% Electrons: 17%
			Field of View	All Sky
			Angle Resolution	Ions: 5 x 11 deg. Electrons: 6 x 11 deg.

SMART

Heritage / Teaming

GSFC/M. Collier, J Lobell, M Adrian

MSFC/M Chandler, V Coffey

Mission	Lead/Instrument	Applicability
Cluster	MSSL/PEACE	Sensor approach except deflection
Nozomi	JAXA/PSA-ISA	Sensor approach except deflection
Rosetta	SwRI/IES	Sensor with deflection
Triana	GSFC/Plasmag	Sensor approach with deflection
Polar	GSFC/Hydra	Hot plasma electrons, ions, 14 sensors
Selene	JAXA/SIS	Deflection of FOV
Cassini	MSSL/ELS	Sensor approach except deflection
Polar	MSFC/TIDE	Ionospheric ions, coordinated sweeps
DS-1	SwRI/PEPE	Ion composition with deflection

MSSL/A J Coates

MSSL/D R Linder

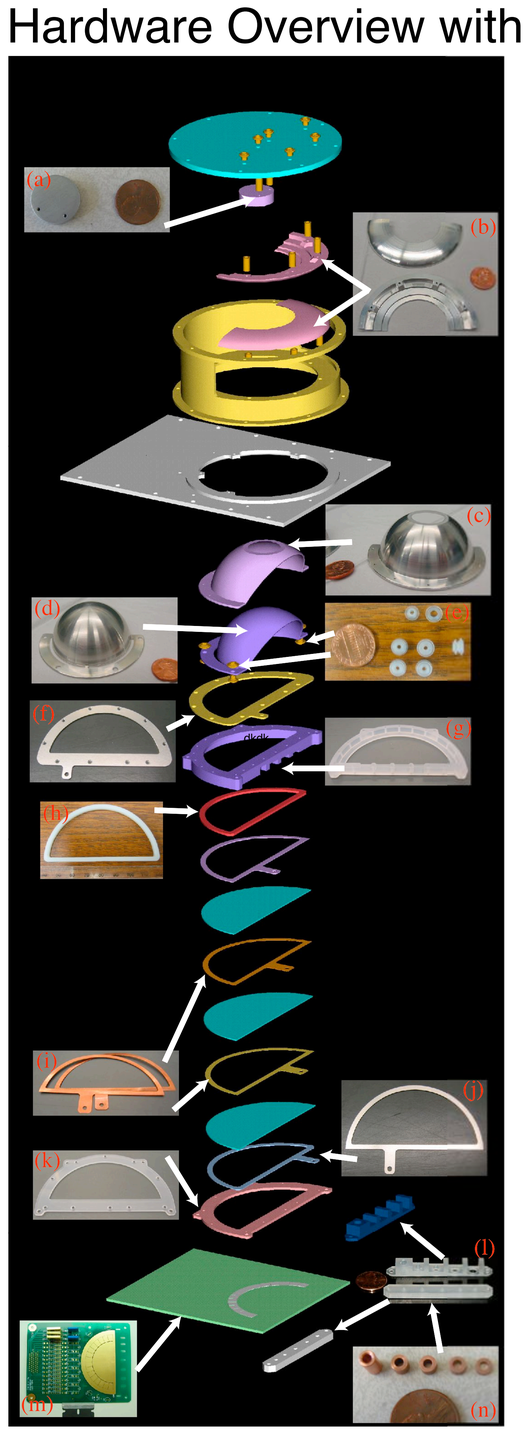
JAXA/T Mukai

JAXA/Y Saito

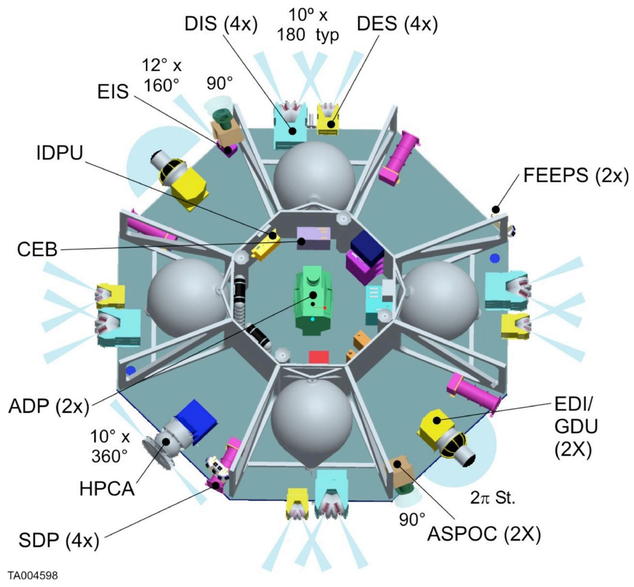
Plasmag PEACE PSA IES DDEIS PPA TIDE

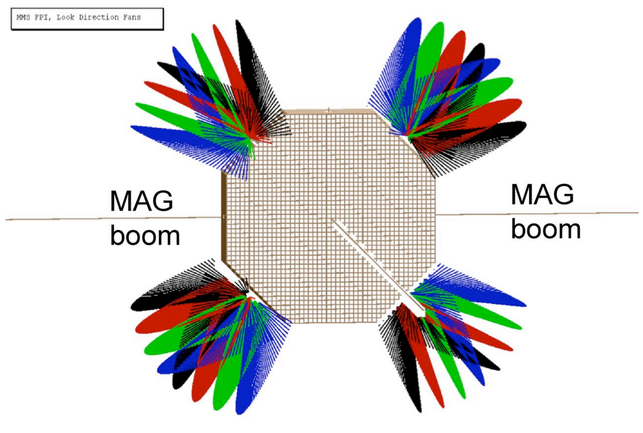
FPI is derived from the most successful plasma analyzers ever developed.

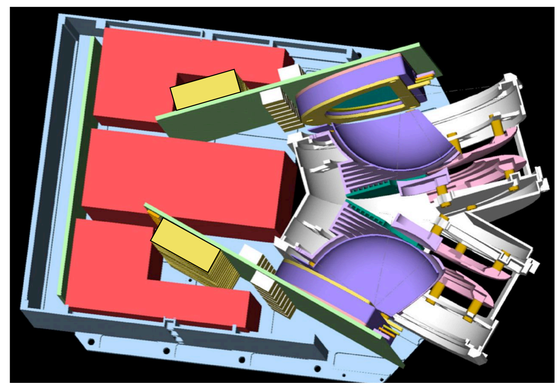
Hardware Overview with FOVs



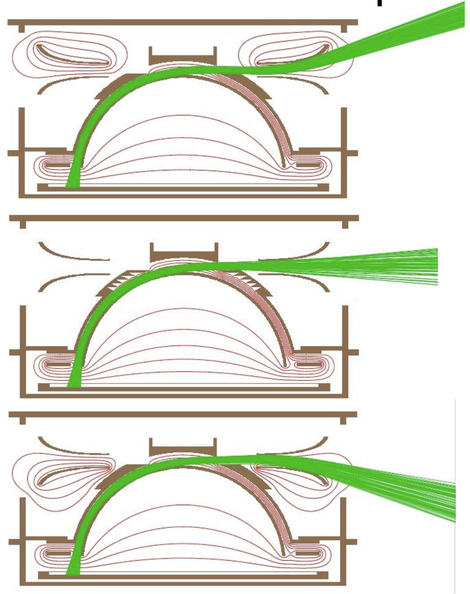
a) standoffs, b) deflectors, c) outer ESA, d) inner ESA, e) standoffs, f)upper cover, g) holder, h) spacer, i) contacts, j) contact, k) lower cover, l) terminal blocks, m) anode board, n) terminals

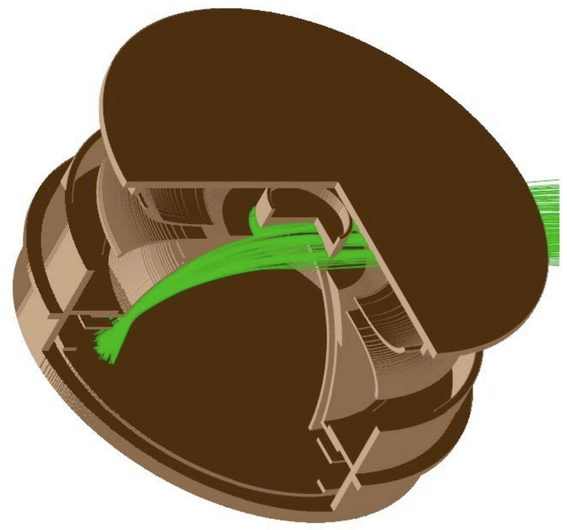






Dual Ion/Electron Spectrometer Optics (DIS, DES)

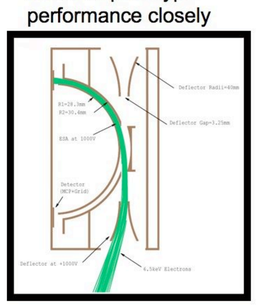


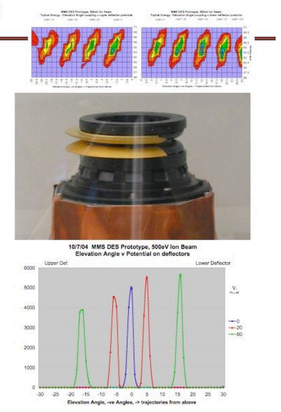


SMART

Sensors: Optics Status

- Optics raytracing matches prototype performance closely

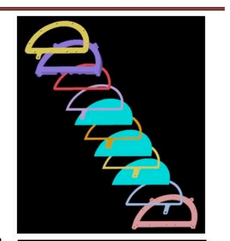


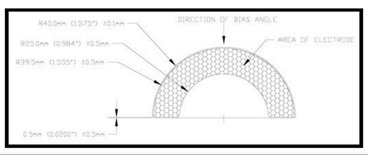


SMART

MCPs/Imaging Anode: Design and Progress

- MCP assembly designed
- MCP procurement specification
  - 60:1 channel L/d
  - 80mm nominal diameter
  - Ordered 5 Aug
- Supports evaluating Z and V stack configurations as trade





FPI will resolve electron and ion scale dynamics in the reconnection diffusion

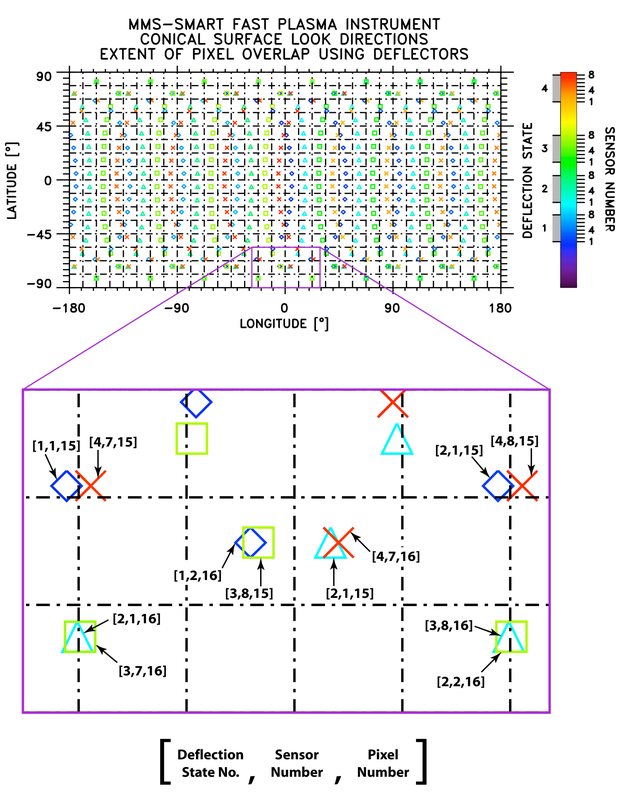
Multiscale Mission
tion, Reconnection and Turbulence

Instrument for MMS

M O Chandler[6], V N Coffey[6], J V Lobell[1], A J Ericsson[1], T Bialas[1], M Buenfill[1], M A Johnson[1], M D Shappiriol[1], P-S Yeh[1]

5. JAXA/ISAS, 6. NASA MSFC NSSTC

Sampling Strategy



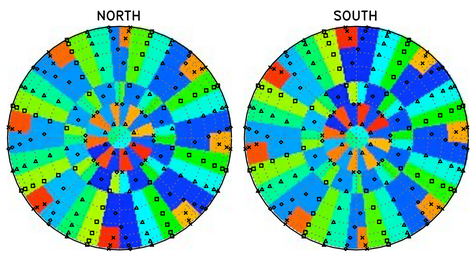
[Deflection State No. , Sensor Number , Pixel Number]

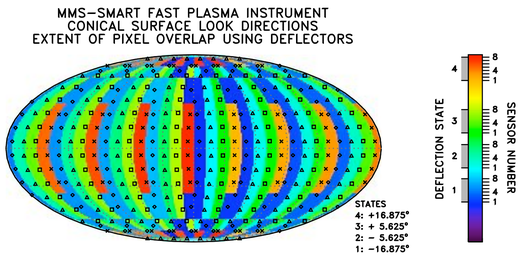
```
polar bin°  6 17 28 39 51 62 73 84 96 107 118 129 141 152 163 174
sin(theta).1 .3 .5 .6 .8 .9 .9  1  1  .9  .9  .8  .6  .5  .3  .1
collapse    4  8 16 16 24 32 32 32 32  32  32  24  16  16   8   4
```

Constant solid angle coverage

2/π = 64% of samples,

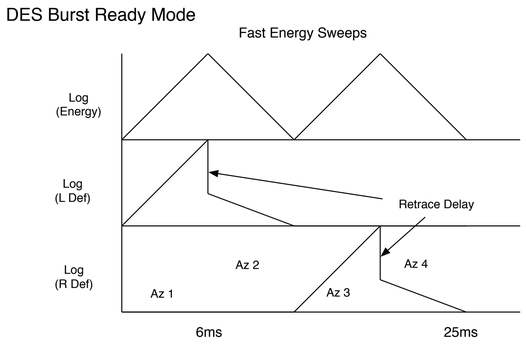
or 512 spls -> 325 spls vs 328, above



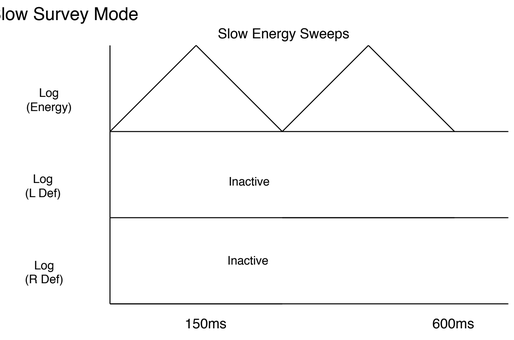


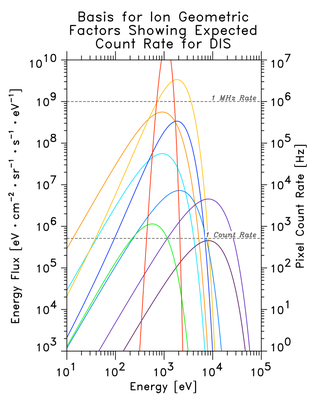
Fast Plasma Instrument
Optics Sweep Waveforms

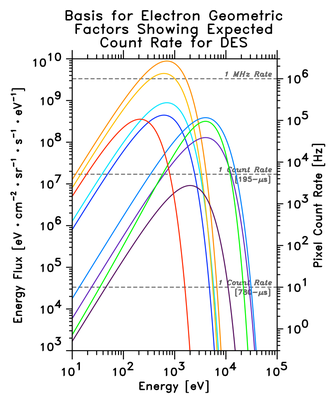
DES Burst Ready Mode



Slow Survey Mode







Region	Density [cm⁻³]	Bulk Velocity [km · s⁻¹]	T_i [eV]
Magnetosheath	16.00	100.0	350.0
Dense Magnetosheath	160.00	100.0	350.0
Magnetopause	8.00	400.0	300.0
Dense Magnetopause	80.00	400.0	300.0
Outer Magnetosphere	0.10	20.0	4000.0
Plasma Sheet	1.00	20.0	4000.0
Cold, Dense Plasma Sheet	3.00	20.0	1000.0
LLBL 0°	0.32	100.0	200.0
Solar Wind Protons	10.00	450.0	15.0

$G_0 = 1.0 \times 10^{-3}$ cm² · sr · eV · eV⁻¹

Region	Density [cm⁻³]	Bulk Velocity [km · s⁻¹]	T_e [eV]
Magnetosheath	16.00	100.0	350.0
Dense Magnetosheath	160.00	100.0	350.0
Magnetopause	8.00	400.0	300.0
Dense Magnetopause	80.00	400.0	300.0
Outer Magnetosphere	0.10	20.0	1000.0
Plasma Sheet	1.00	20.0	2000.0
Cold, Dense Plasma Sheet	3.00	20.0	2000.0
LLBL Electrons	0.32	18 755.0	1000.0
Solar Wind Electrons	10.00	450.0	100.0

$G_0 = 3.0 \times 10^{-4}$ cm² · sr · eV · eV⁻¹

Measurements and Modes

DES

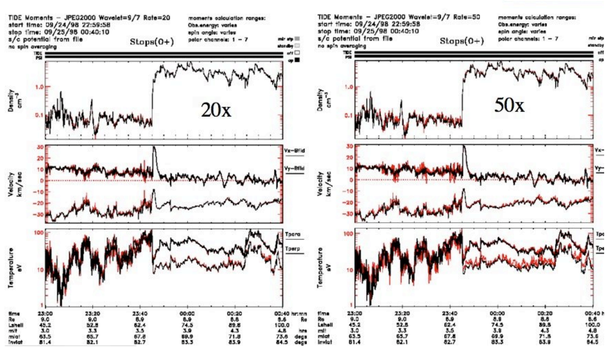
Dual Electron Spectrometer (DES) Survey Modes			
	Slow Survey	Fast Survey	Burst
time/day in mode	14.4 hours (60%)	9.6 hours (40%)	173 seconds (0.2%)
angular resolution (spacecraft)	22.5 deg x 11.3 deg	11.3 deg x 11.3 deg	11.3 deg x 11.3 deg
active heads	1	4	4
total angular pixels	256	512	512
post-polar angle collapse pixels	128	256	256
energies	32	32	32
total transmitted elements	4,096	8,192	8,192
cadence (s)	64.0	4.0	0.025
sampling period (s)	64.0	0.025	0.025
word length (bits)	8	8	4 (see note below)
data rate to s/c if uncompressed	8 bits/elem*4,096 elem/64s = **0.512 kbits/s**	8 bits/elem*8,192 elem/4.0s = **16.4 kbits/s**	4 bits/elem*8,192 elem/0.025s = **1311 kbits/s**
telemetry allocation	0.128 kbits/s	4.10 kbits/s	700 kbits/s
compression factor	4.0	4.0	1.9
ASPOC cadence (s)	1.0	0.063	0.008

DIS

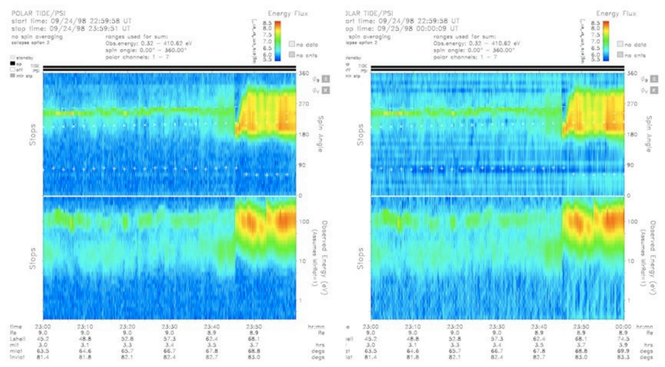
Dual Ion Spectrometer (DIS) Survey Modes			
	Slow Survey	Fast Survey	Burst
time/day in mode	14.4 hours (60%)	9.6 hours (40%)	173 seconds (0.2%)
angular resolution (spacecraft)	22.5 deg x 11.3 deg	11.3 deg x 11.3 deg	11.3 deg x 11.3 deg
active heads	1	4	4
total angular pixels	256	512	512
post-polar angle collapse pixels	128	256	256
energies	32	32	32
total transmitted elements	4,096	8,192	8,192
cadence (s)	64.0	4.0	0.250
sampling period (s)	64.0	0.250	0.250
word length (bits)	8	8	4 (see note below)
data rate to s/c if uncompressed	8 bits/elem*4,096 elem/64s = **0.512 kbits/s**	8 bits/elem*8,192 elem/4.0s = **16.4 kbits/s**	8 bits/elem*8,192 elem/0.250s = **262 kbits/s**
telemetry allocation	0.128 kbits/s	4.10 kbits/s	100 kbits/s
compression factor	4.0	4.0	2.6

Data Compression and Burst Quality

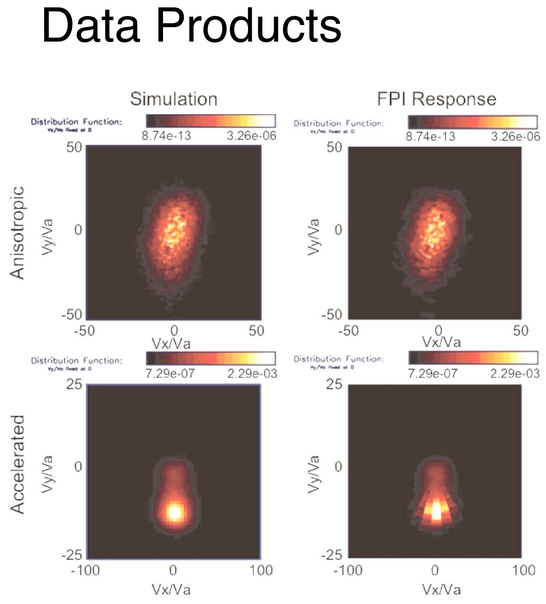
JPEG 2000 WT Compression on Flight Data
Moments vs Compressed/Decompressed

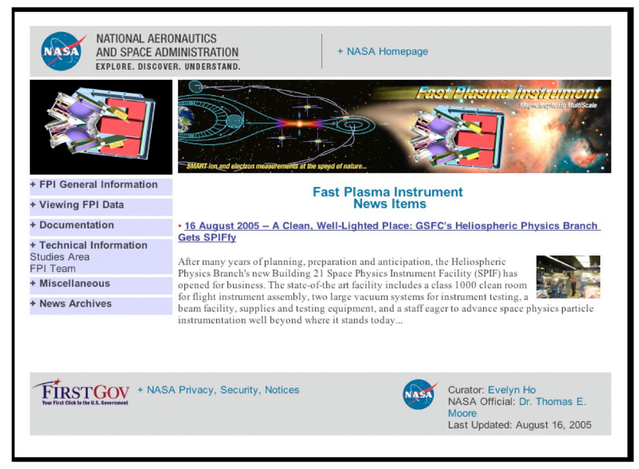


Spectrograms: Raw vs Compressed 20x

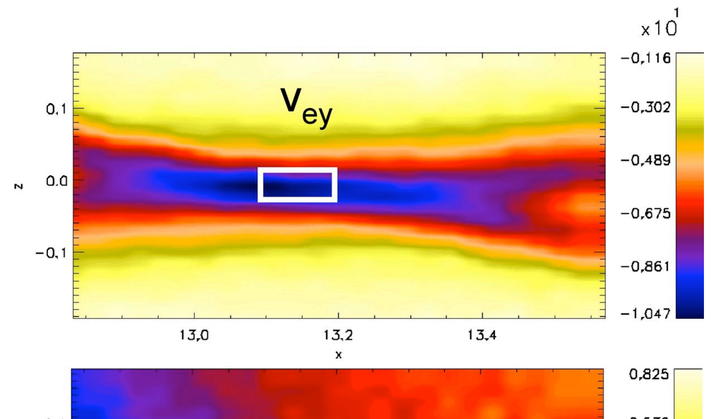


Data Products





- Clear resolution of off-diagonal pressure tensor elements
- Clear depiction of beams and heat fluxes
- 6 ms (8 az bins) or 25 ms (32 az bins) cadence, depending on required completeness of angular sampling
- Capability to map subtle features of the diffusion region

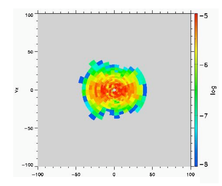


Science Closure

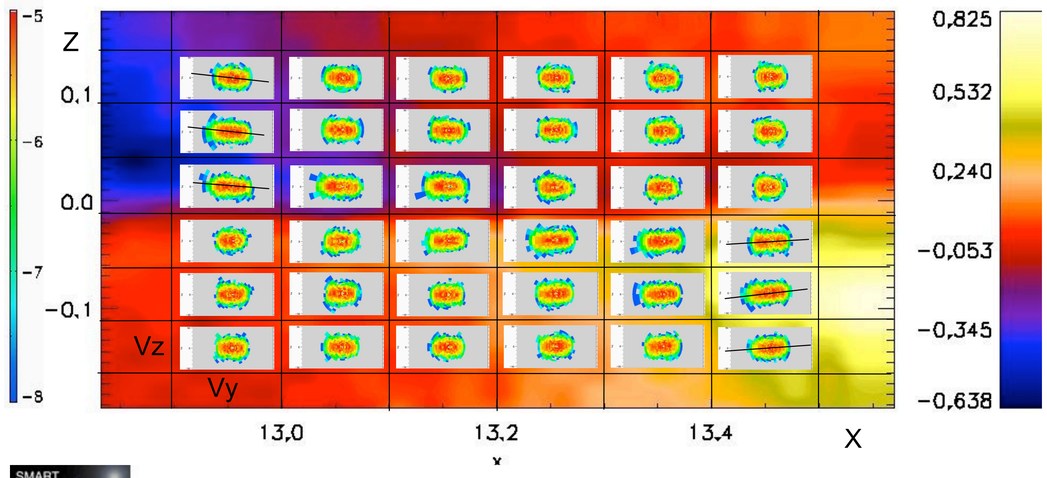
Diffusion Region Pressure Tensor

Simulated data values in Vy-Vz plane on left color bar,
Background map of Pyz values per right color bar
Vx-Vz plane distributions are ~ circular

PSD



P_{yze} x10⁻²



Summary

- **The FPI Team provides:**
  - "Fastest full sky plasma analyzer ever developed…"
  - Fully resolves the reconnection diffusion region
  - Instantaneous all-sky plasma sampling
  - Strong heritage from experienced partners
  - Prototype-proven optimizations
  - Recent production environment experience
  - Meets or exceeds Level 1 Science Requirements

region using multiple distributed sensor apertures and fast energy/angle sweeping.