Overview of Missions Relevant to GEM

D. G. Sibeck
Code 674
NASA/GSFC
Greenbelt, MD 20771

Outline

1. Missions
   a) Where do NASA missions come from?
   b) Constellation, Microscale, Imaging Missions, and Highlights
   c) Orbits, Duration, Instrumentation

2. Services
   a) SPDF
   b) CCMC

3. Future
   a) Constellation and Imaging Missions
   b) Searchable data systems
   c) Global Hybrid and PIC code simulations

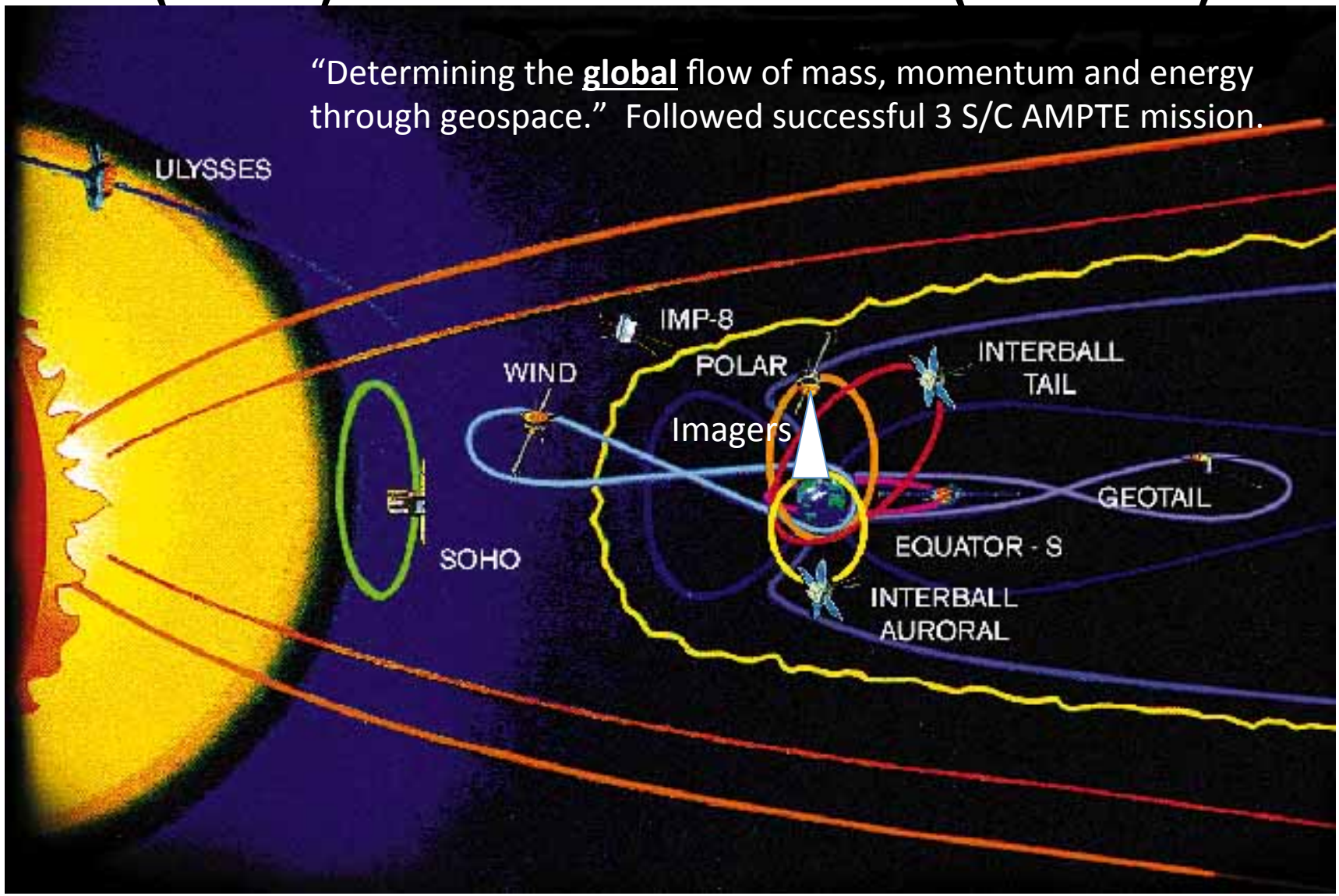
Where do NASA Missions Come From?

- Strategic Missions (STP and LWS)
  - Advisory panels like Decadal Survey and Heliophysics Roadmap consider, recommend, and prioritize
  - When individual missions get the go-ahead, Science and Technology Definition Teams work with engineers to define highest priority individual missions, prepare Announcement
  - Solar-Terrestrial Physics Program → MMS
  - LWS Program → Van Allen Probes
- Proposals from the Community
  - Explorers → IMAGE, THEMIS, TWINS
  - H-TIDES → Cubesats, e.g. CeREs
  - Others ….

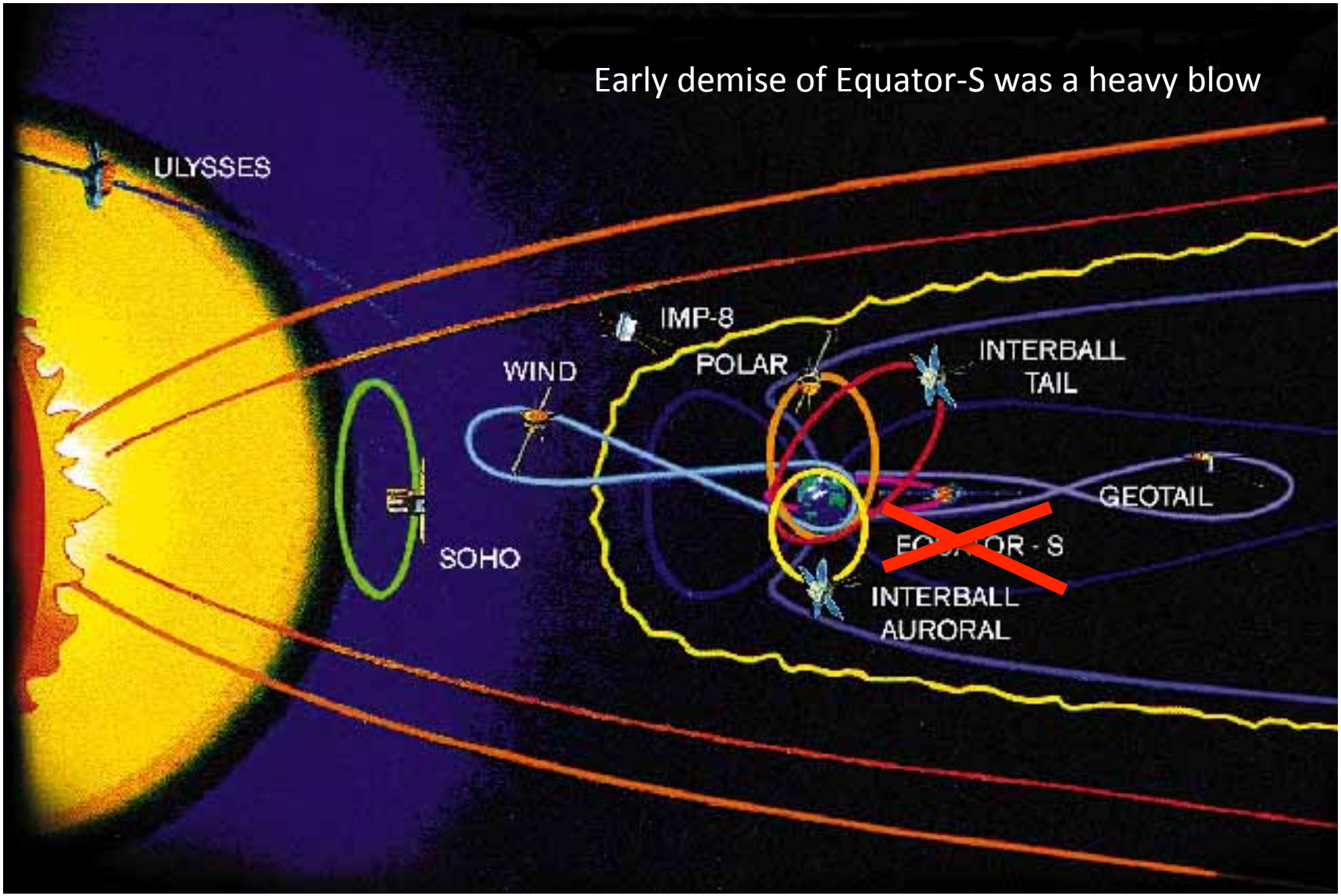
Missions

- Constellations
  - ISTP
  - THEMIS
- Multipoint microscale
  - Cluster
  - MMS
  - Van Allen Probes
- Imaging
  - IMAGE
  - TWINS
- Cubesats

International Solar-Terrestrial Physics (ISTP) Science Initiative (1990's)



ISTP Missions



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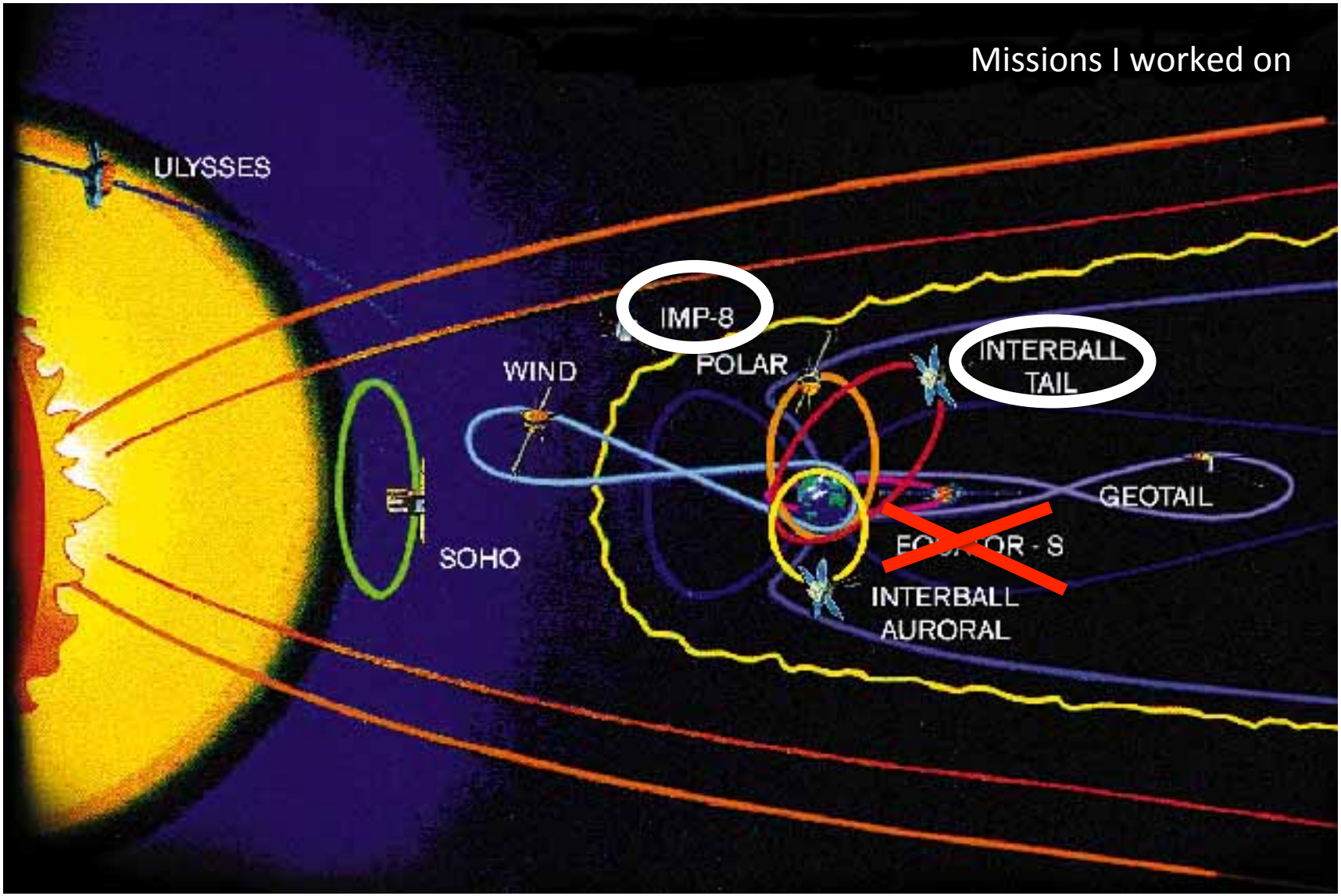
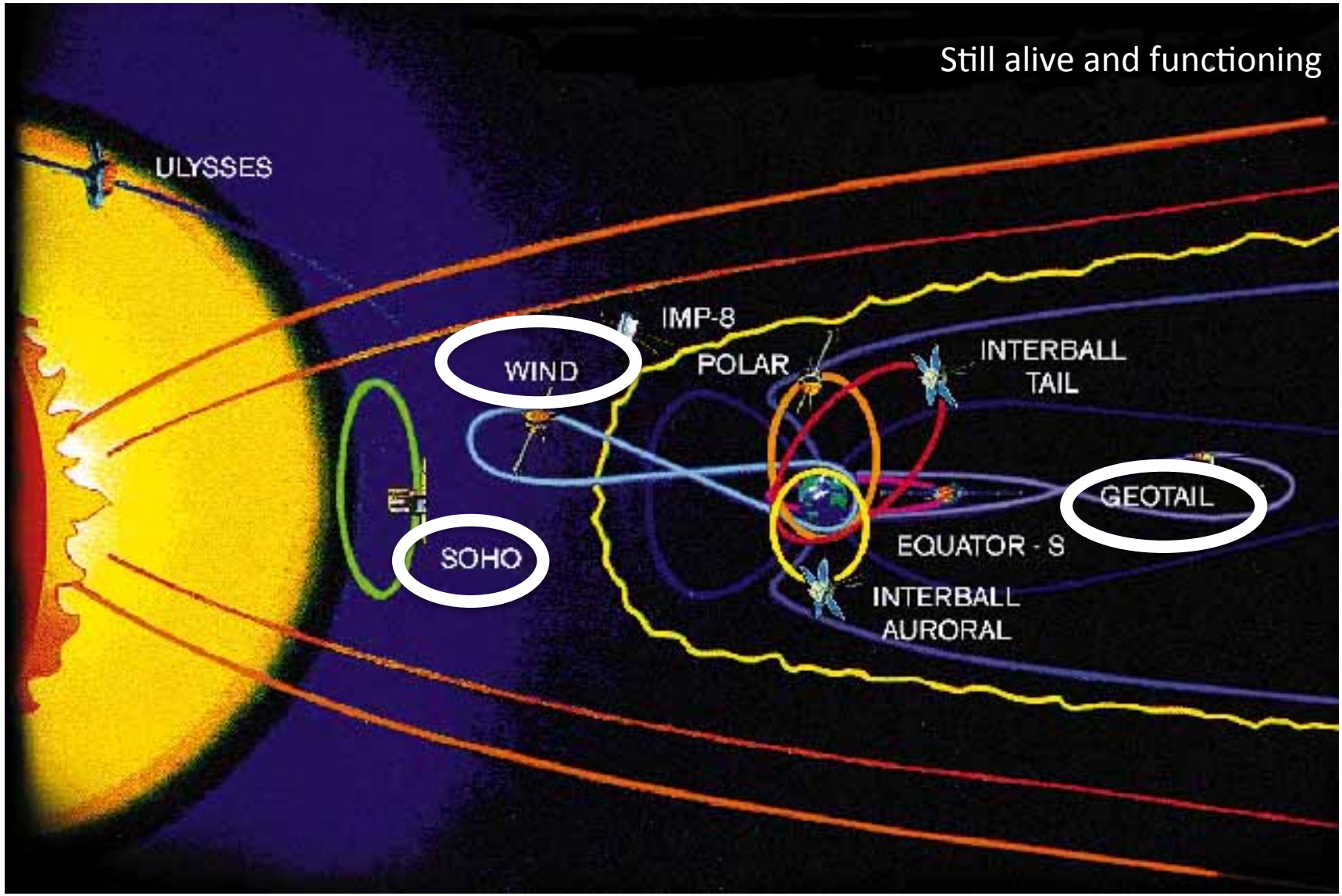
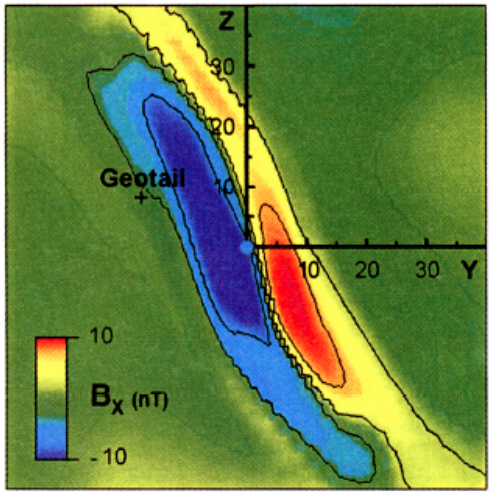


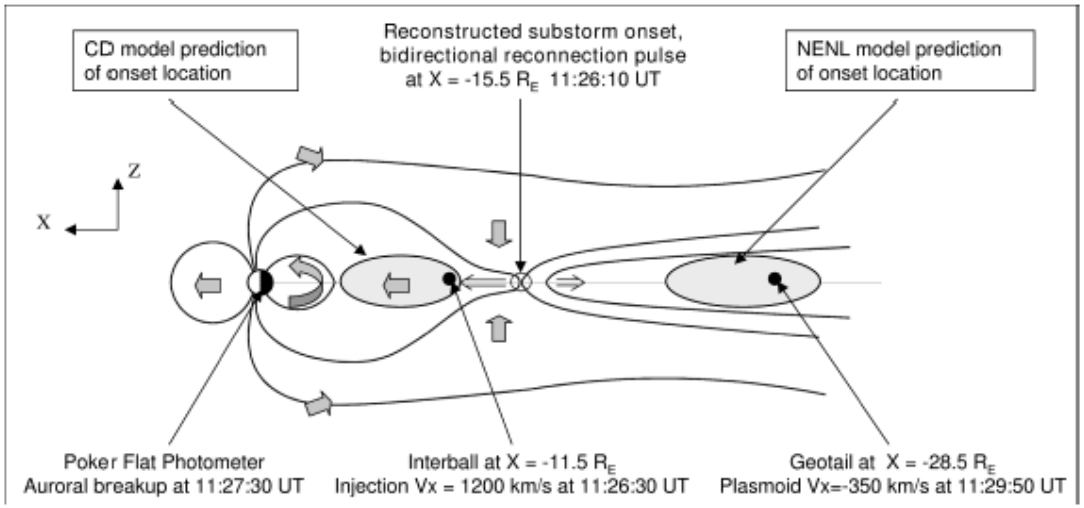
ISTP Missions



ISTP Studies

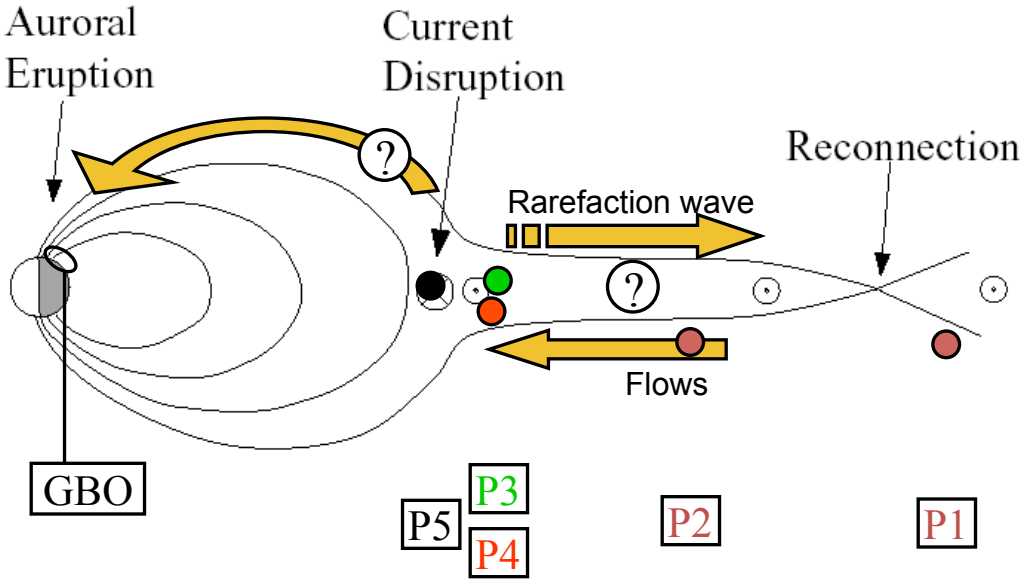
- Wind observations + MHD model predict magnetotail twisting, flattening, and field line bending observed by Geotail [Berchem et al., 1998].





- Zelenyi et al. [2004] illustrated a chance ISTP configuration in which a burst of magnetotail reconnection generated sunward flow and dipolarization at Interball-1 (12 RE) and antisunward flows, streaming ions, and a plasmoid at Geotail (28 RE) just prior to auroral break up in ground observations [Petrukovich et al. 1998].

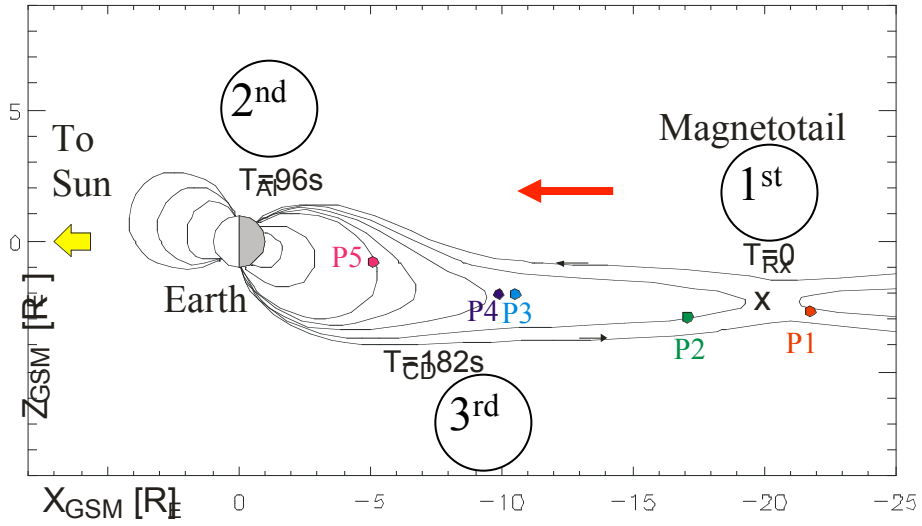
THEMIS (2007)
Systematic Configurations to Study Global Magnetospheric Dynamics



In magnetotail for substorm studies during Winter 2008 and 2009
Pinpoint when and where substorm onset begins.
Apogees lined up at 9.9, 11.8, 11.8, 19.6, and 31.7 R_E from Earth
Perigees from 1.2 to 1.5 R_E
Inclinations from 7-12°

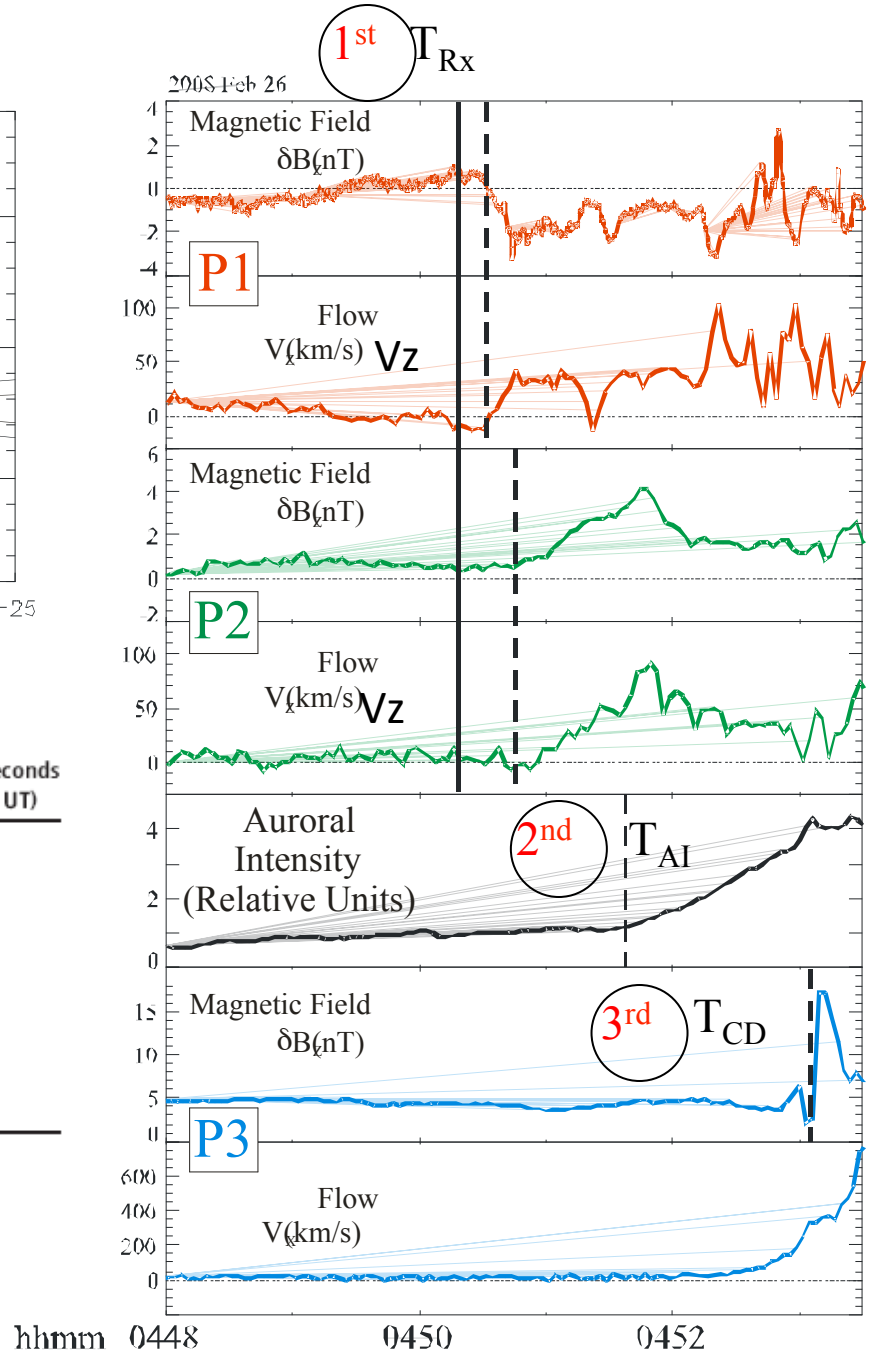
(R_E = Earth Radius)

Ground and space timing



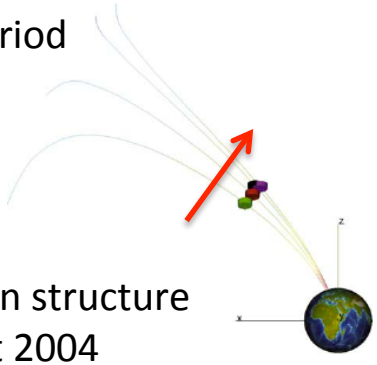
Event		Observed time (UT)	Inferred delay (seconds since 04:50:03 UT)
Reconnection onset	1	04:50:03 (inferred)	$T_{Rx} = 0$
Reconnection effects at P1		04:50:28	25
Reconnection effects at P2	2	04:50:38	35
Auroral intensification		04:51:39	$T_{AI} = 96$
High-latitude Pi2 onset	3	04:52:00	117
Substorm expansion onset		04:52:21	$T_{EX} = 138$
Earthward flow onset at P3		04:52:27	144
Mid-latitude Pi2 onset		04:53:05	182
Dipolarization at P3		04:53:05	$T_{CD} = 182$
Auroral electroject increase		04:54:00	237

Angelopoulos et al. [2008] reported evidence for the Out-to-In Model

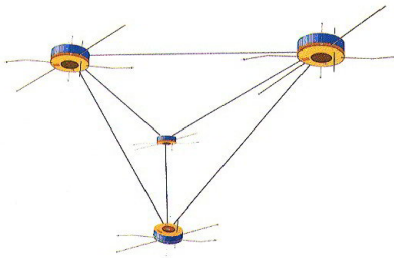


ESA Cluster (2000)

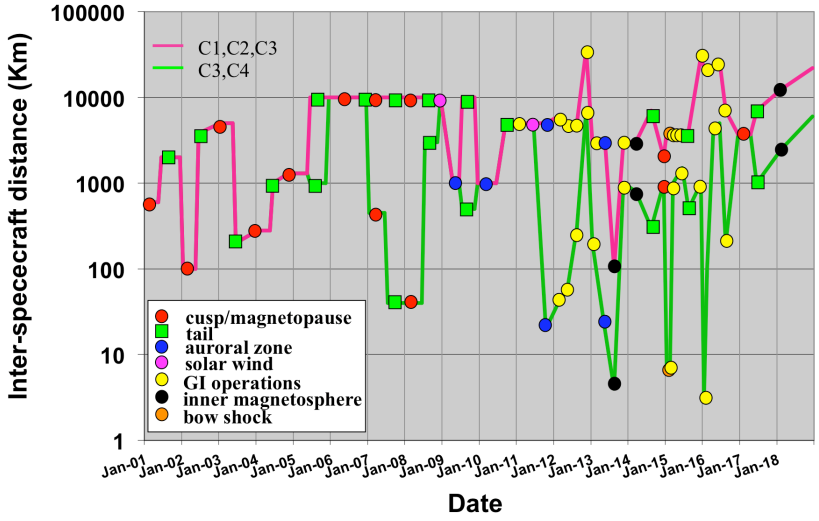
- First 4-spacecraft mission (followed exemplary 2-spacecraft ISEE-1/2 and Interball missions).
- Distinguish between spatial and temporal variations, calculate currents.
- Employ spacecraft spin to collect full particle distributions/once per 4s spin period
- Foreshock, bow shock, magnetopause, auroral zone, magnetotail…..



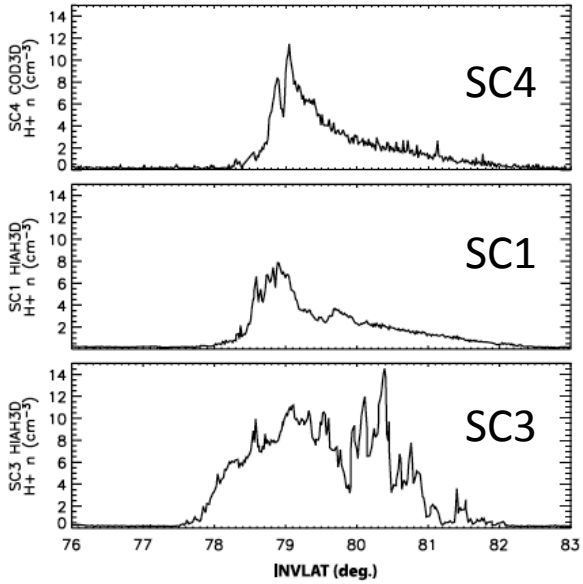
Tetrahedral configuration provides **n, V*n** at current sheets



Variable Separation Strategy

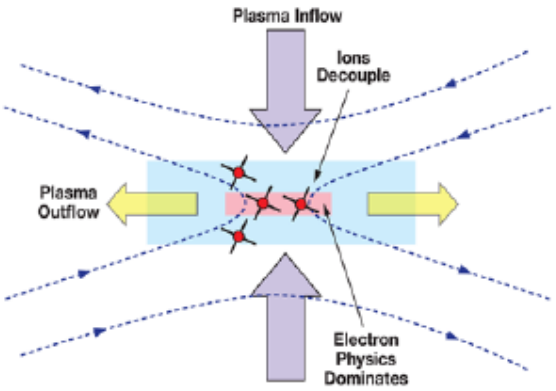


Cusp ion structure
23 Sept 2004
[Escoubet et al., 2008]



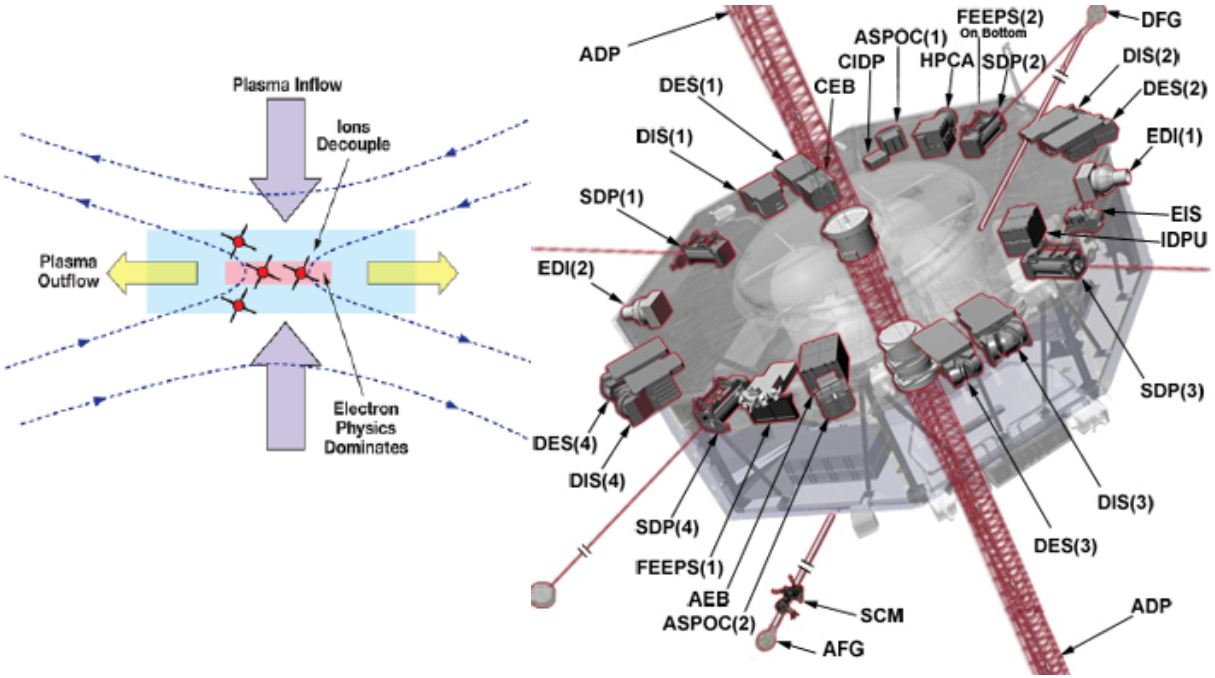
NASA MMS (2015)

- A 4-spacecraft mission to study the microphysics of reconnection



NASA MMS (2015)

- A 4-spacecraft mission to study the microphysics of reconnection
- Close separations and multiple sensors



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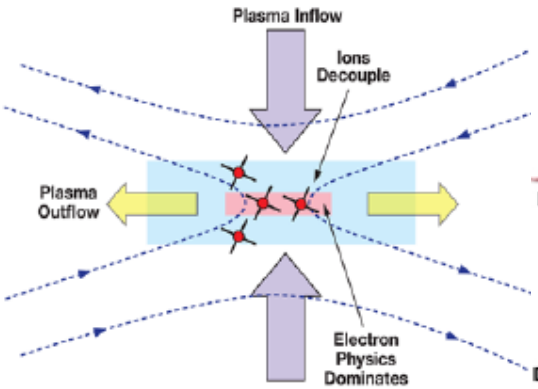
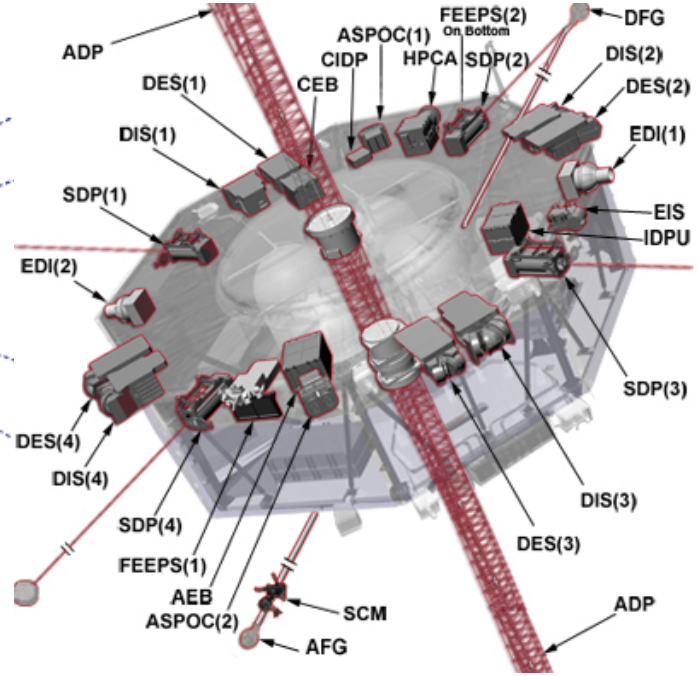
- Needed to target reconnection microphysics





Factor	Cluster	MMS
Separation Distance	>4 km	~10 km
Spin Period	4s	20s
Magnetometer Cadence	67/s burst	128/s
Plasma Cadence	4s	0.03s e- 0.150s ions

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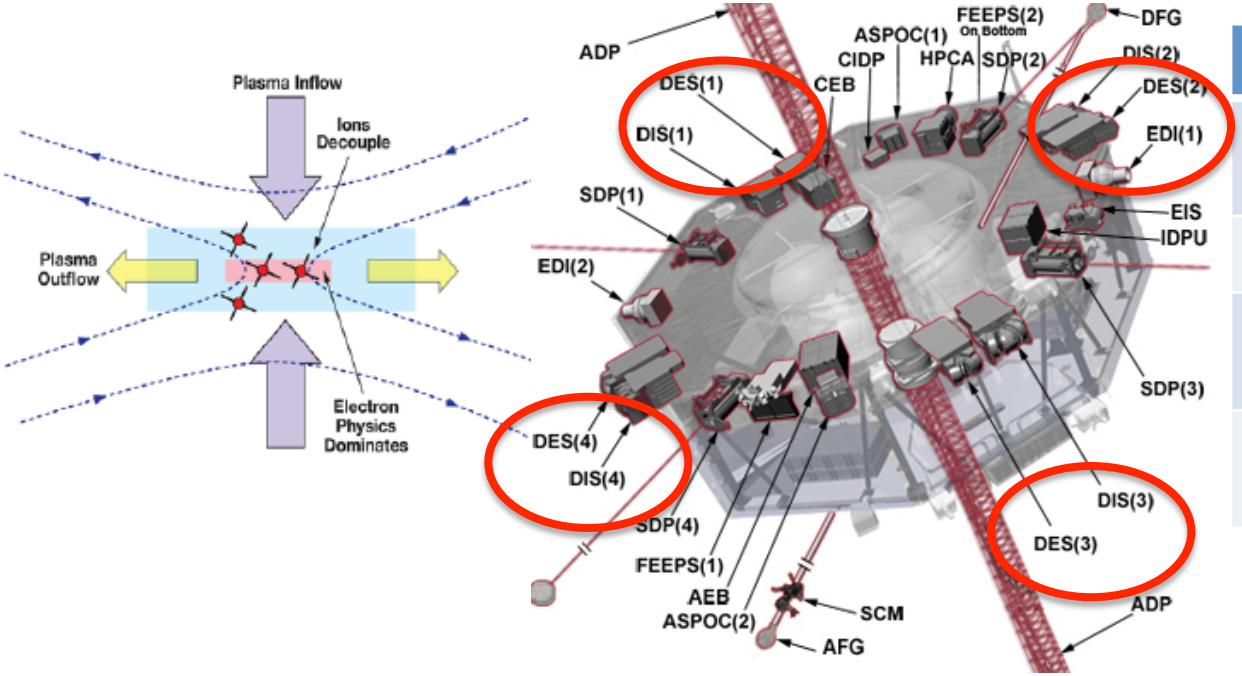

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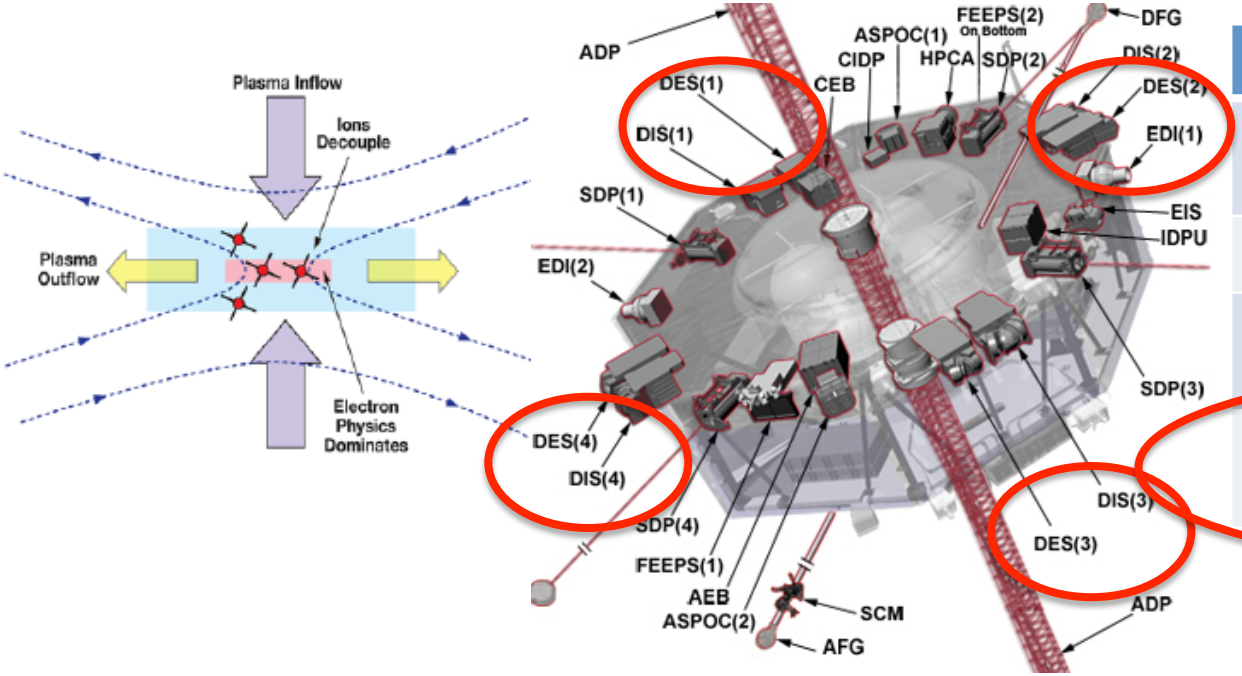

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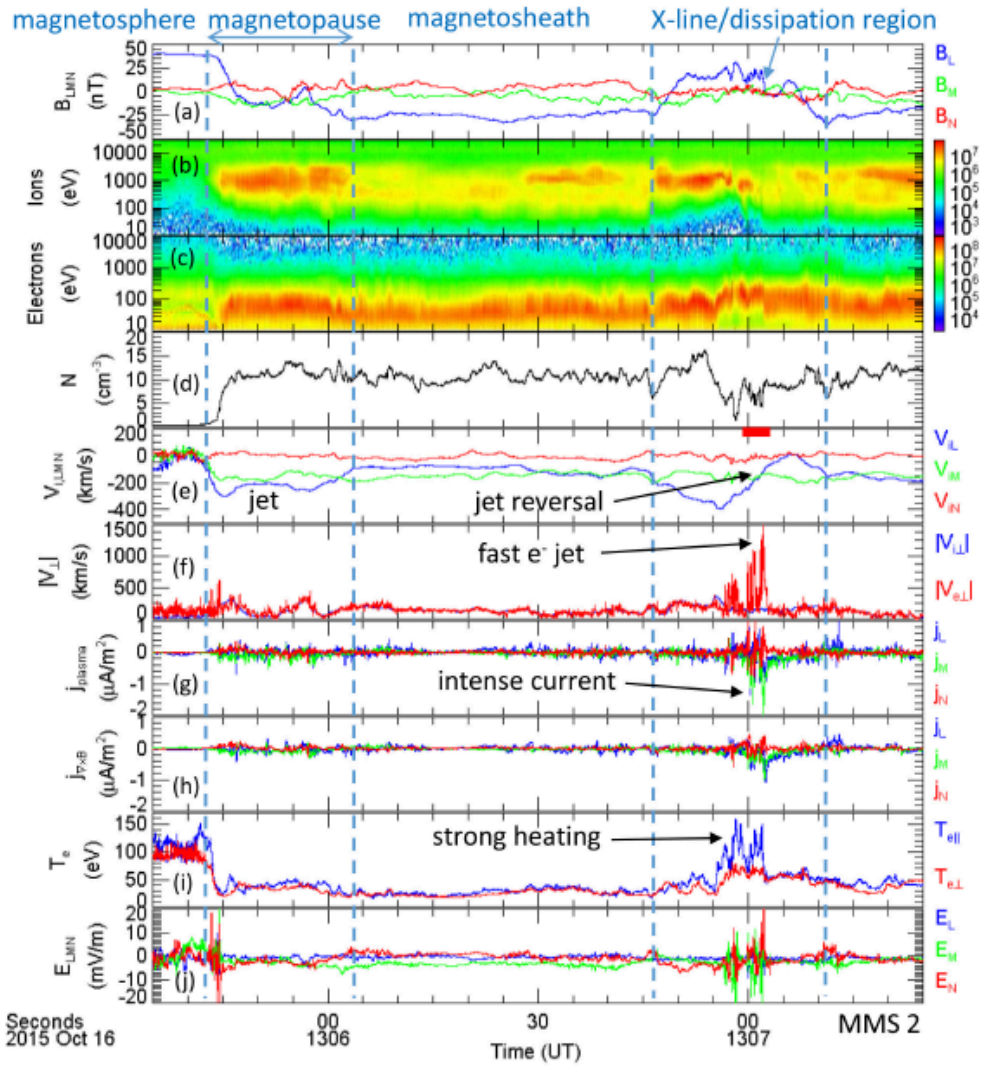
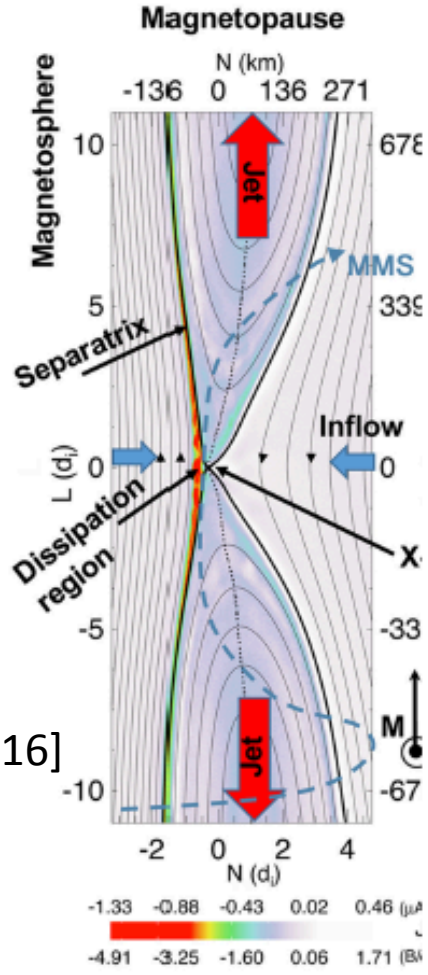


PIC simulation



Burch et al.
[Science, 2016]

Van Allen Probes

- Two identical, very well instrumented, radiation-hardened spacecraft to determine origins, transport, loss of radiation belt particles.

Comprehensive field and particle instrumentation

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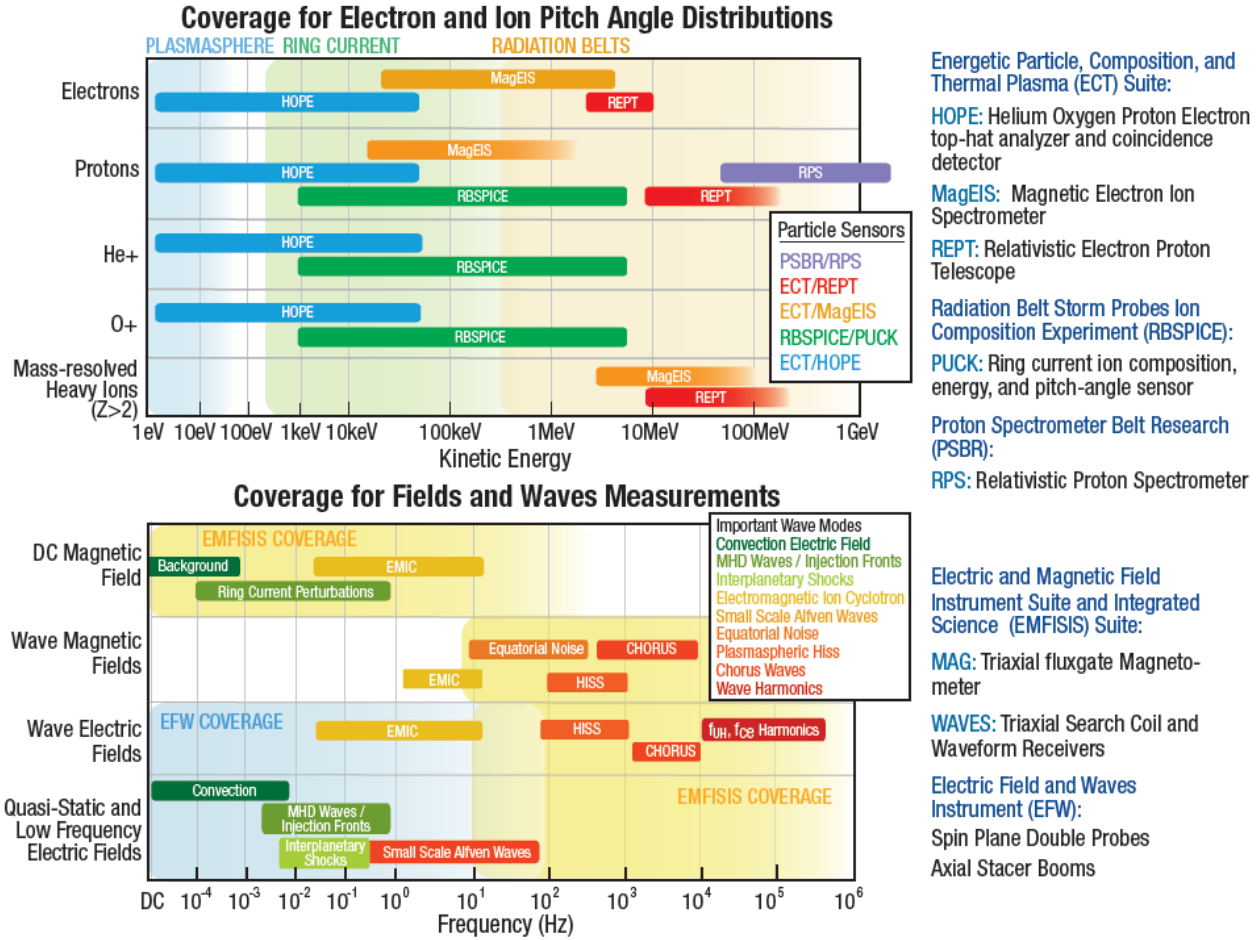


Energetic Particle, Composition, and Thermal Plasma (ECT) Suite:

HOPE: Helium Oxygen Proton Electron top-hat analyzer and coincidence detector

MagEIS: Magnetic Electron Ion Spectrometer

REPT: Relativistic Electron Proton Telescope

Radiation Belt Storm Probes Ion Composition Experiment (RBSPICE):

PUCK: Ring current ion composition, energy, and pitch-angle sensor

Proton Spectrometer Belt Research (PSBR):

RPS: Relativistic Proton Spectrometer

Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS) Suite:

MAG: Triaxial fluxgate Magneto-meter

WAVES: Triaxial Search Coil and Waveform Receivers

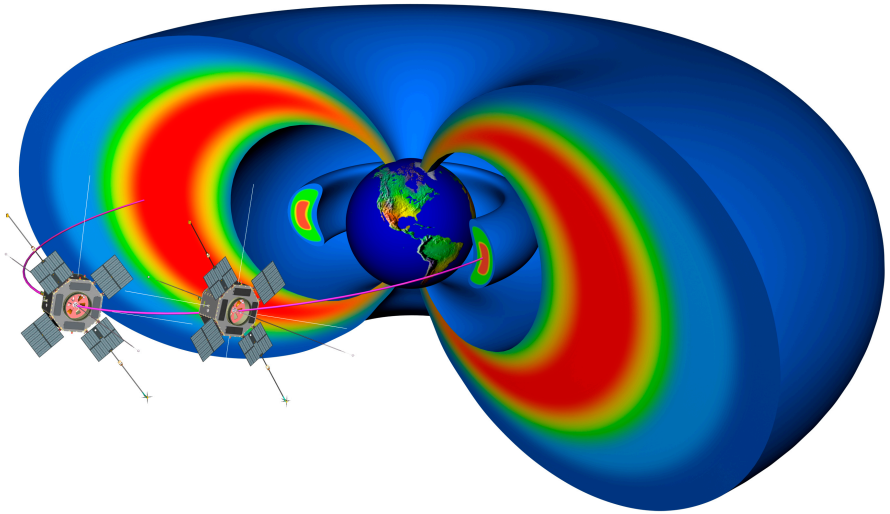
Electric Field and Waves Instrument (EFW):

Spin Plane Double Probes

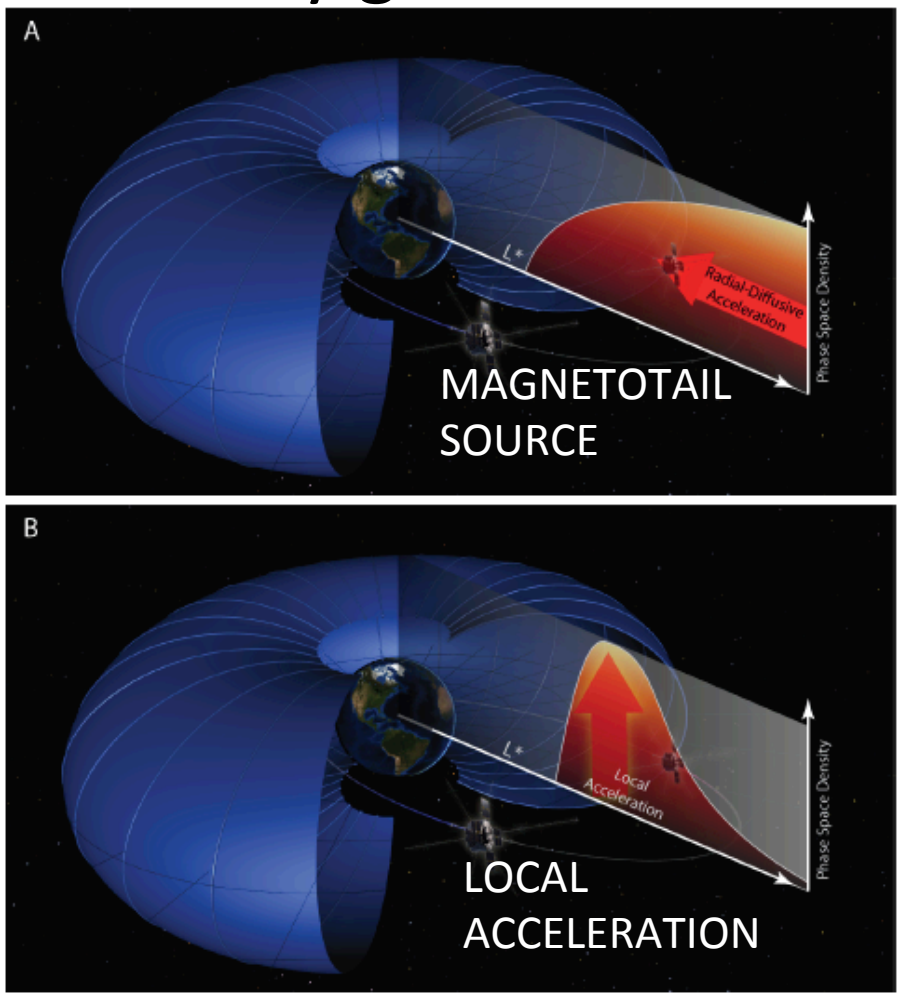
Axial Stacer Booms

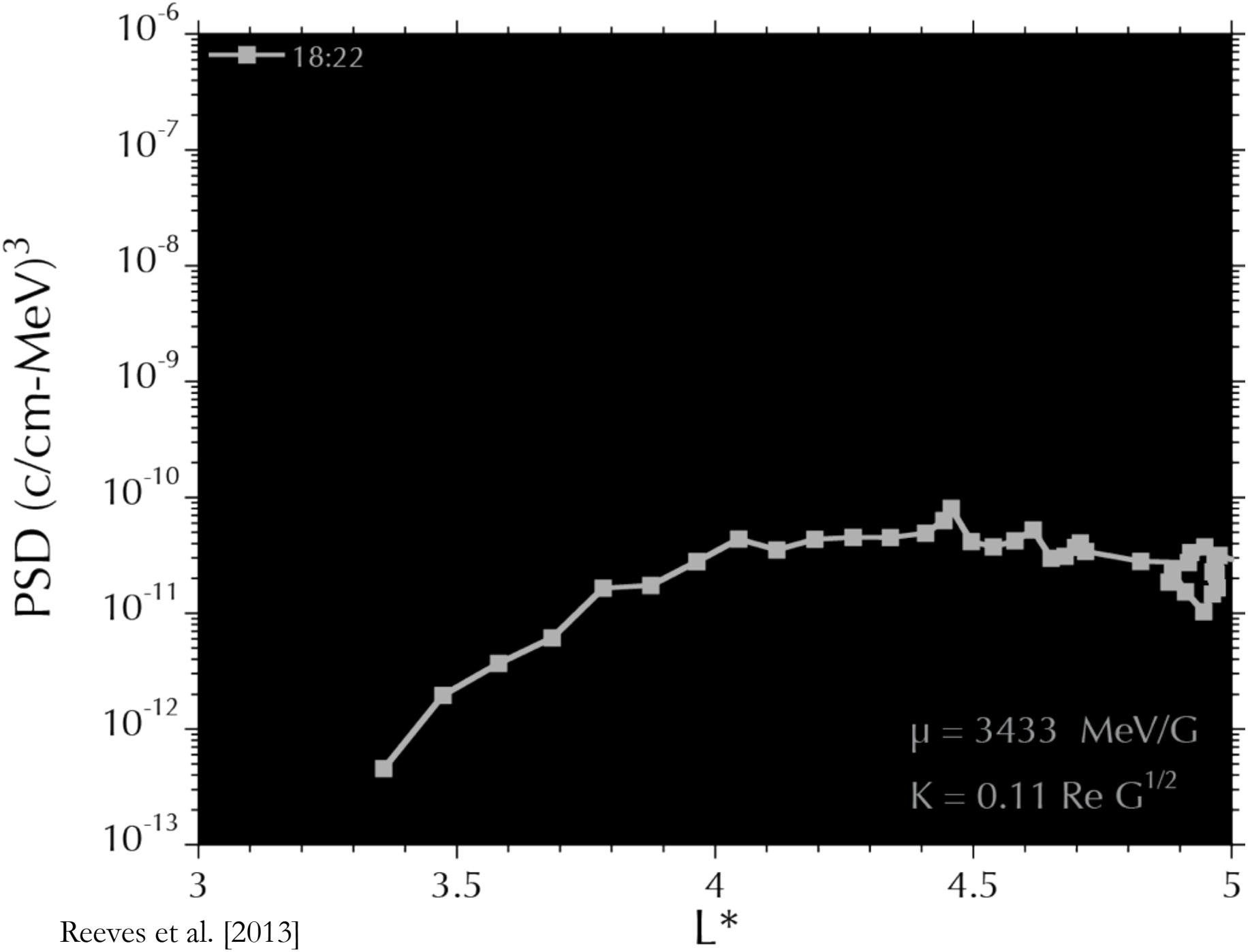
Van Allen Probes

- Two point measurements identify gradients… and sources.



Reeves et al. [2013]





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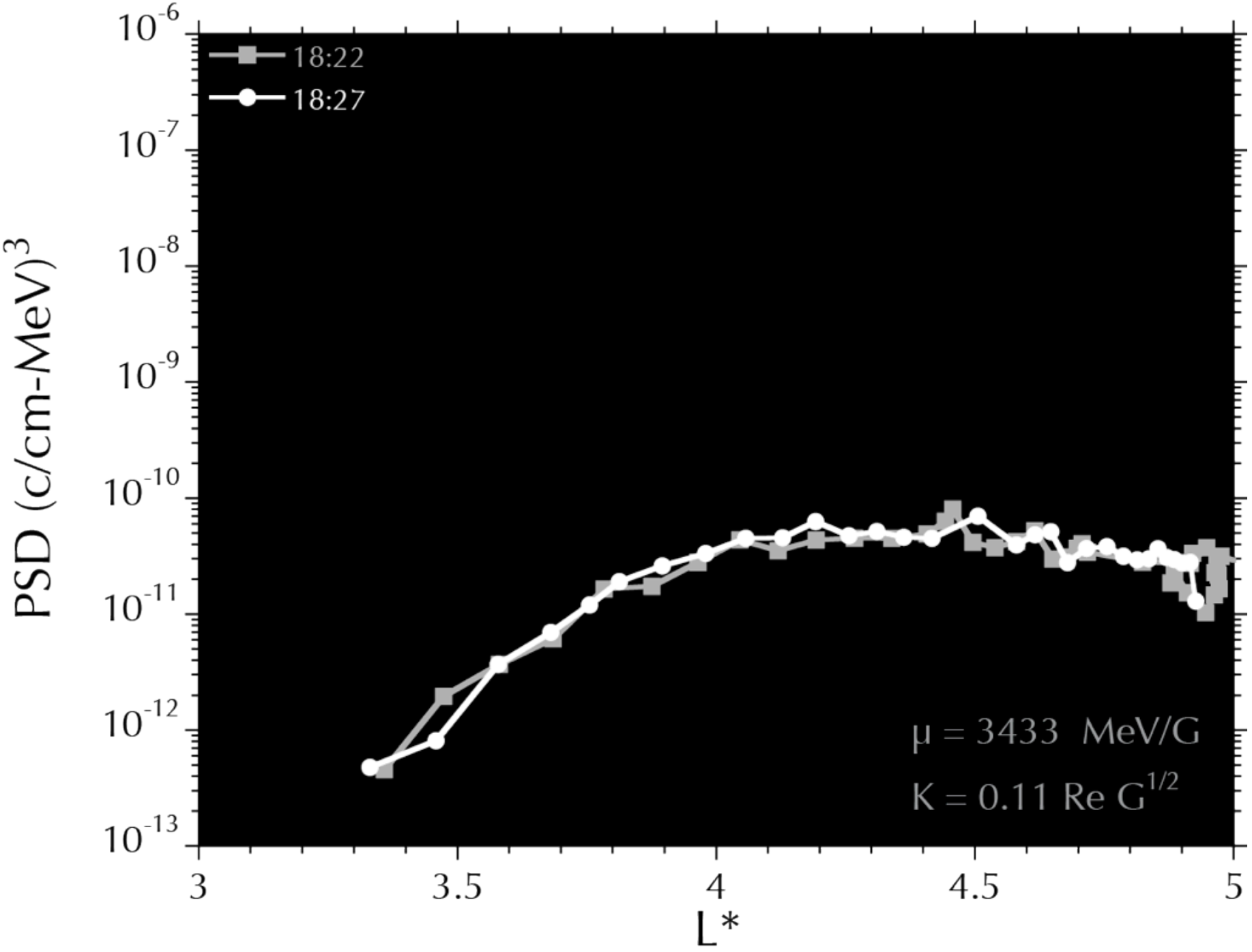
18:22
18:27
PSD (c/cm-MeV)^3
10^{-6}
10^{-7}
10^{-8}
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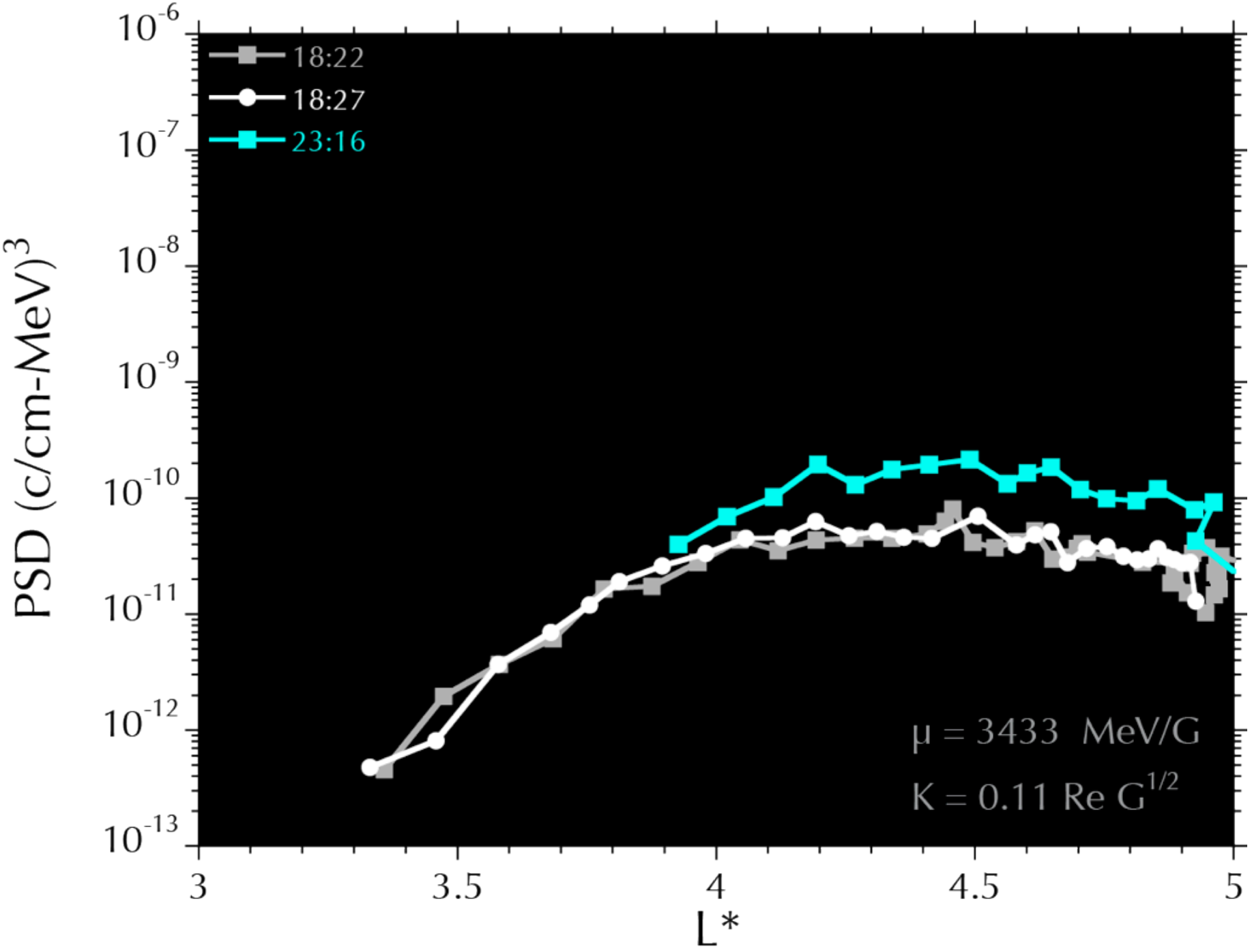
L*
μ = 3433 MeV/G
K = 0.11 Re G$^{1/2}$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PSD (c/cm-MeV)^3
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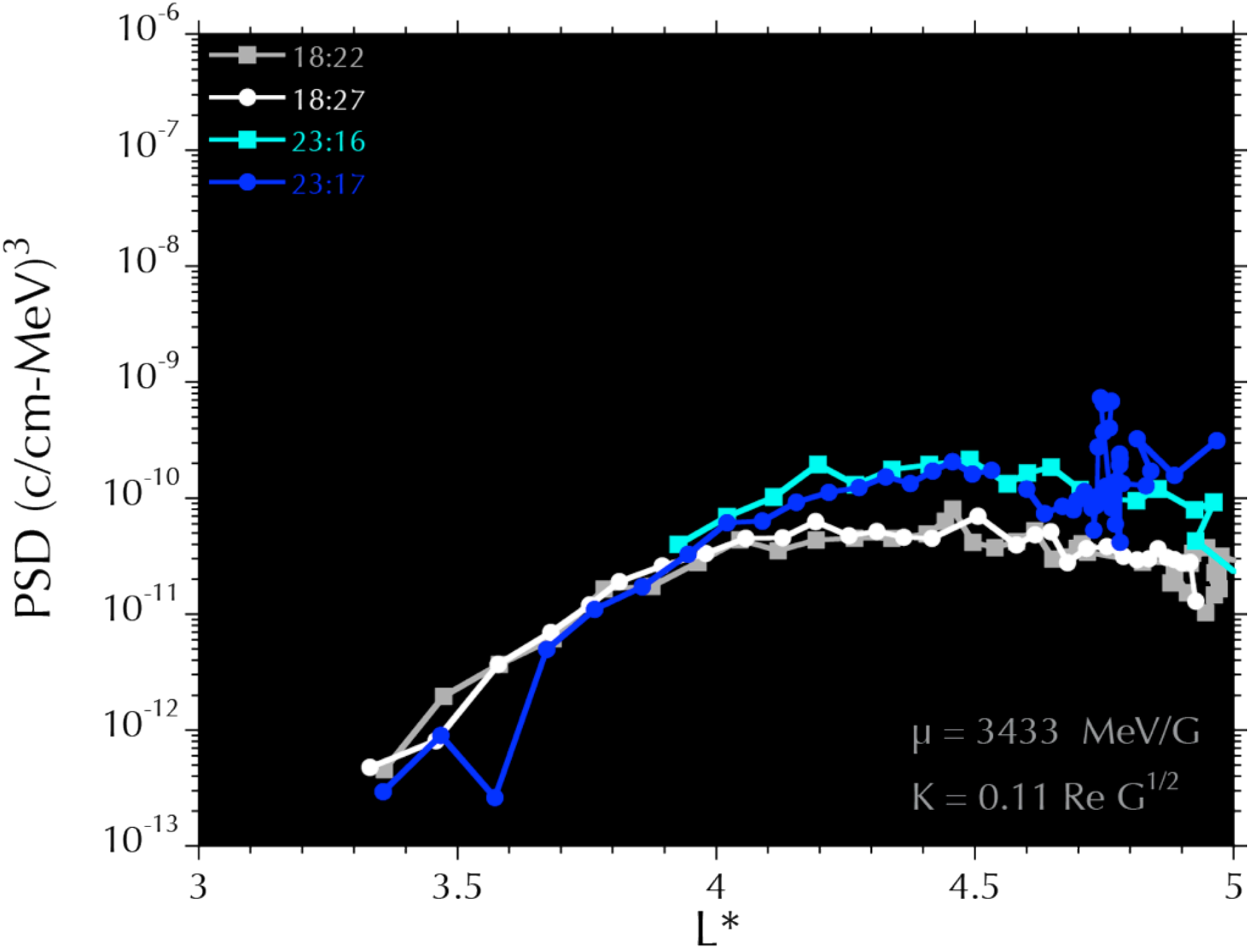
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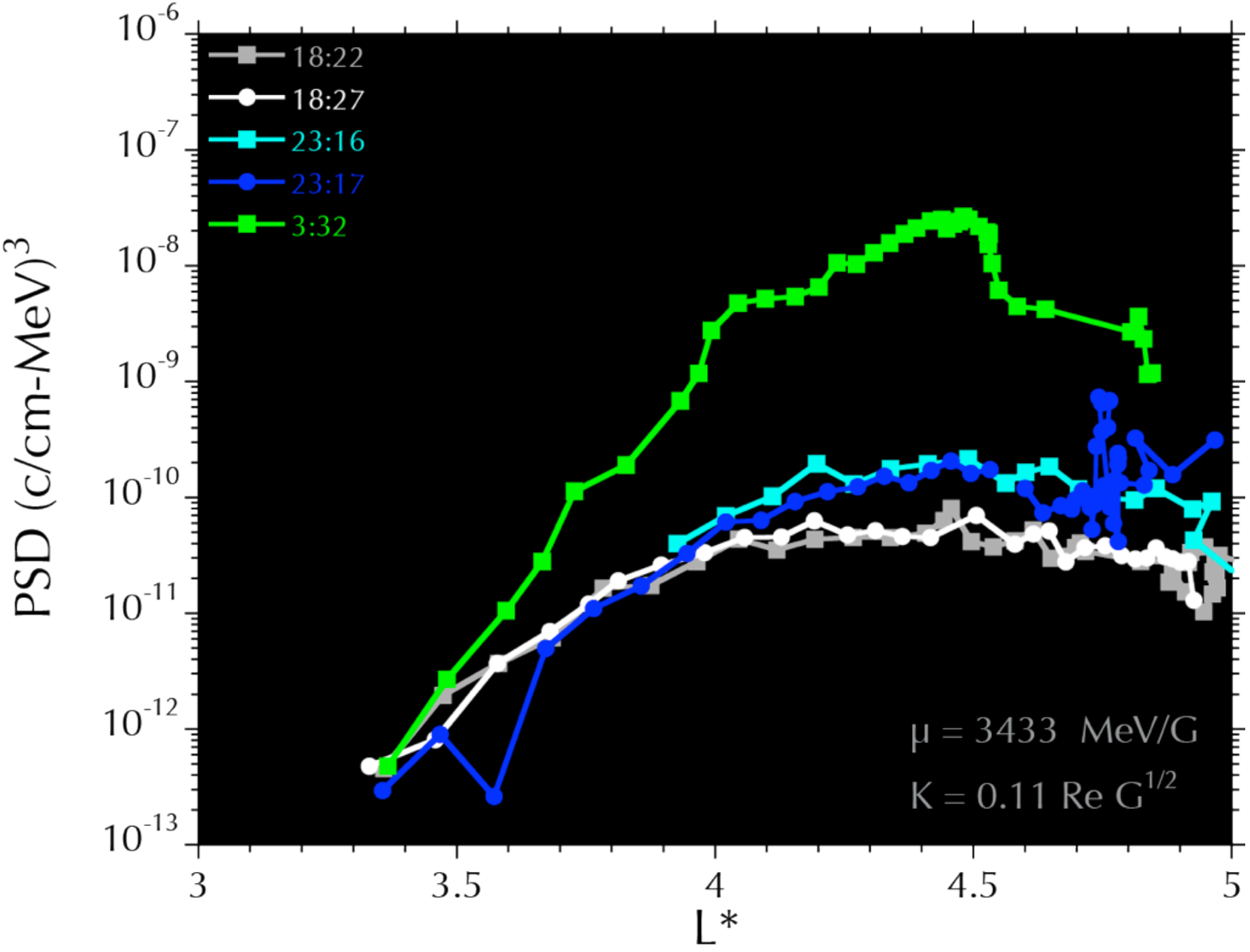
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PSD (c/cm-MeV)^3
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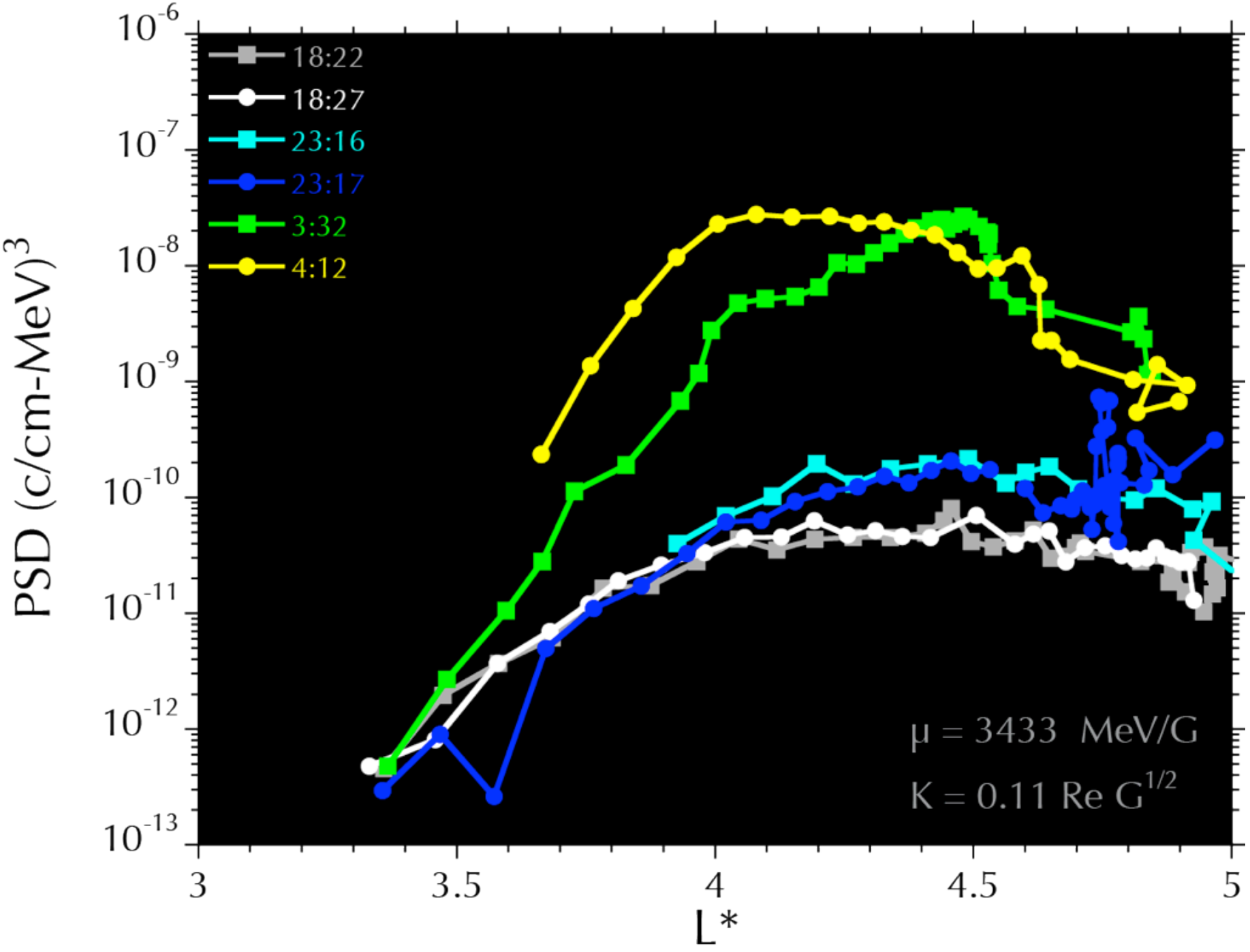
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PSD (c/cm-MeV)^3
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10^{-9}
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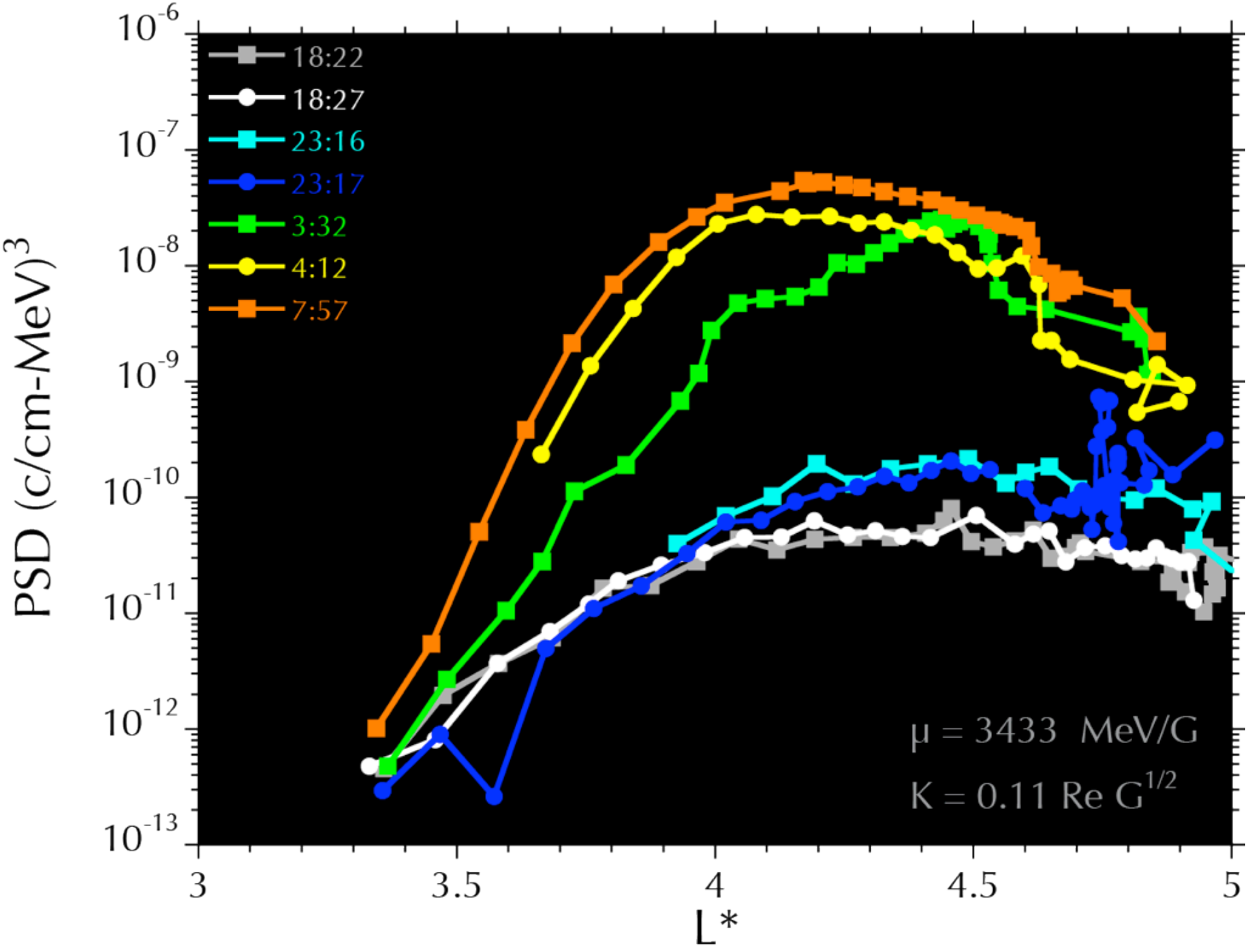
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4:12
7:57
μ = 3433 MeV/G
K = 0.11 Re G^1/2
PSD (c/cm-MeV)^3
L*
10^-6
10^-7
10^-8
10^-9
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10^-11
10^-12
10^-13
3
3.5
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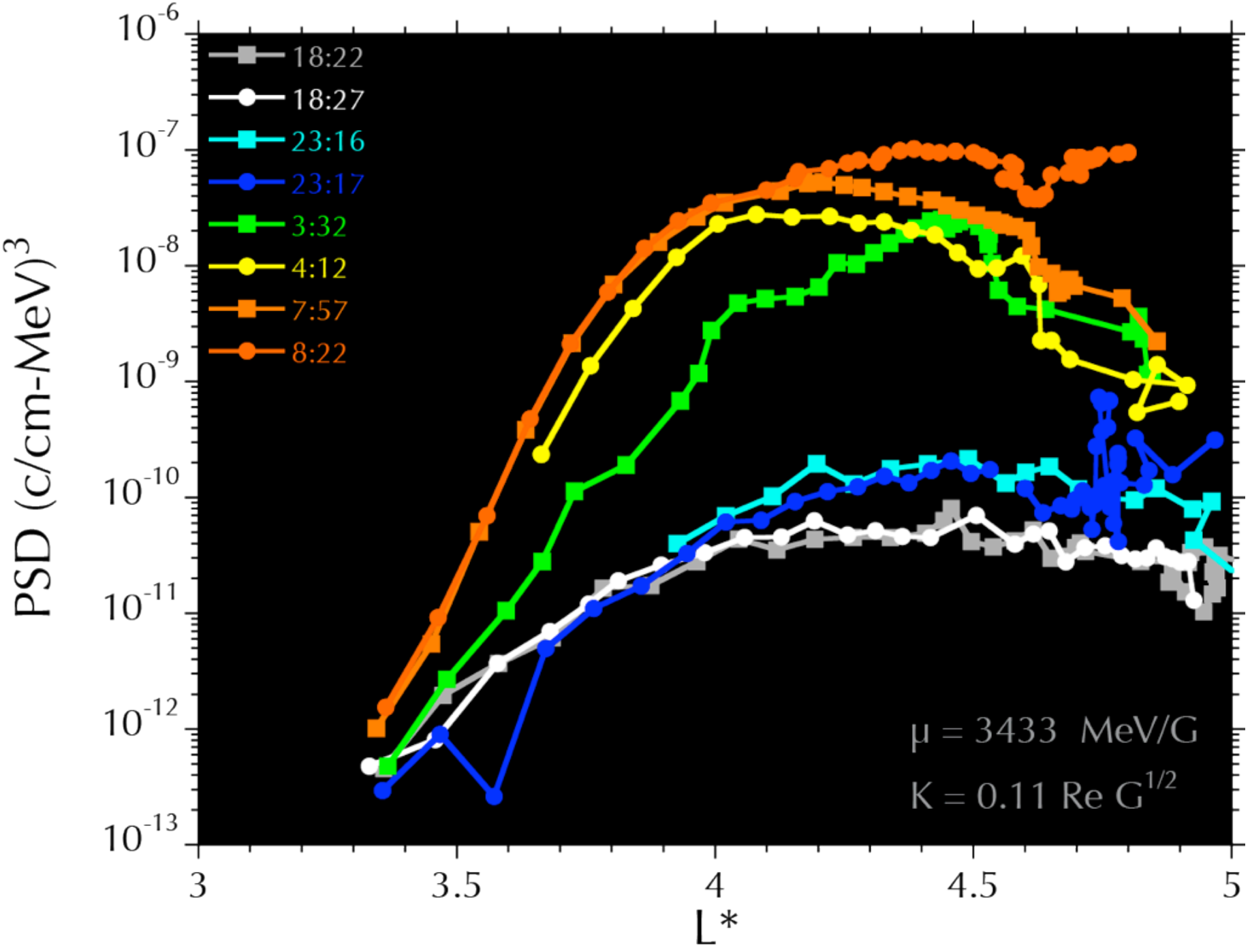
18:22
18:27
23:16
23:17
3:32
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8:22
PSD (c/cm-MeV)^3
10^-6
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10^-8
10^-9
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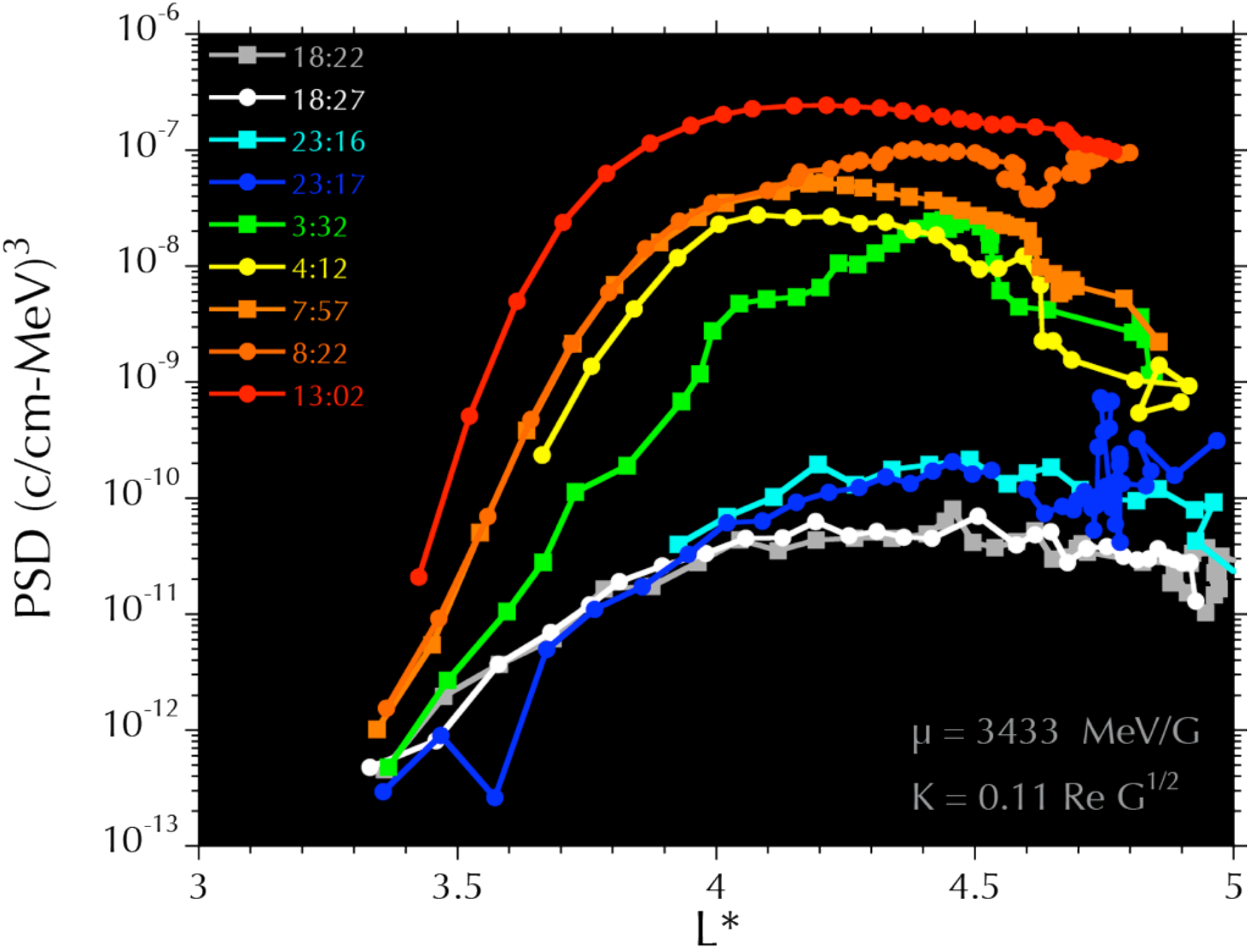
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18:27
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23:17
3:32
4:12
7:57
8:22
13:02
PSD (c/cm-MeV)^3
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10^{-7}
10^{-8}
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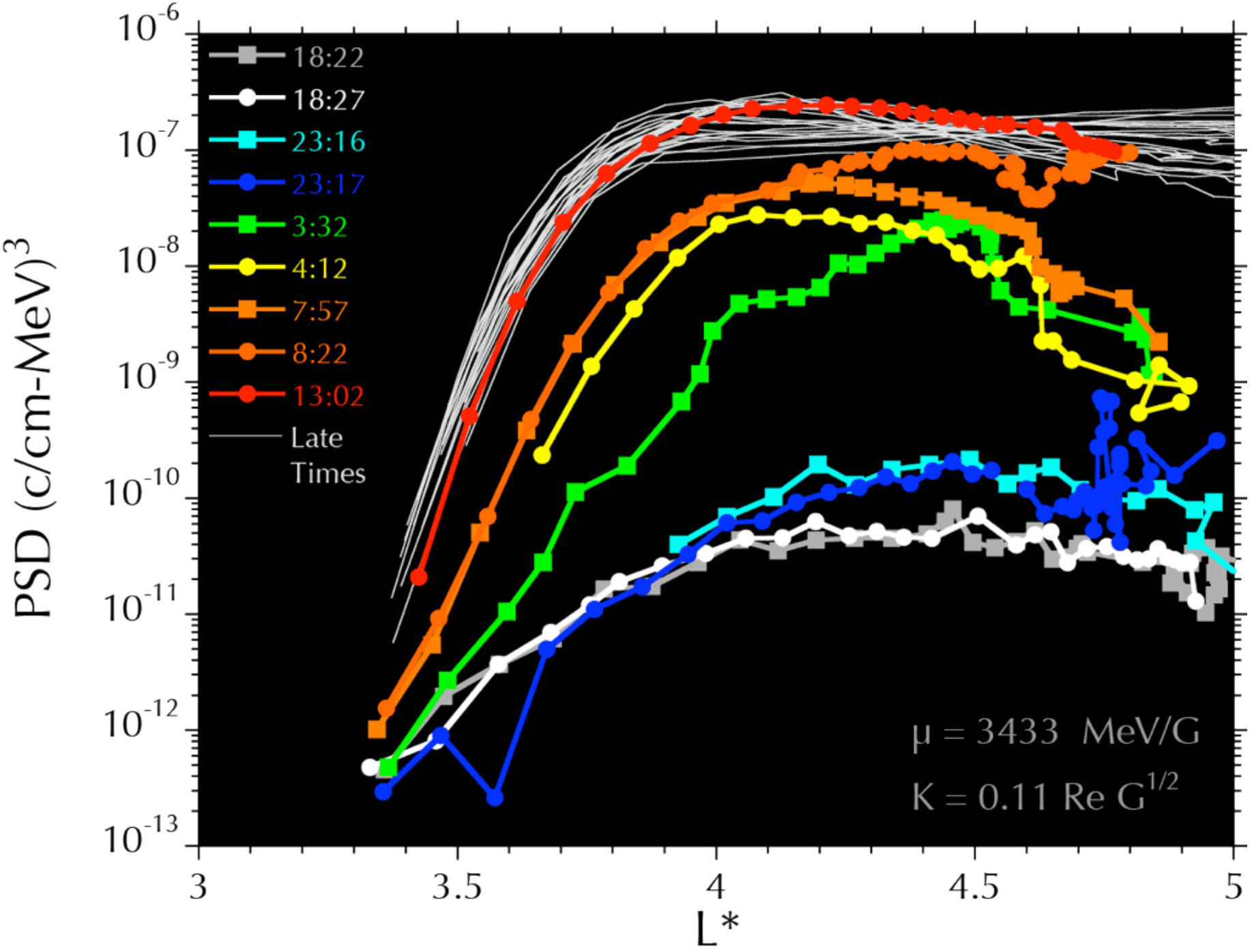
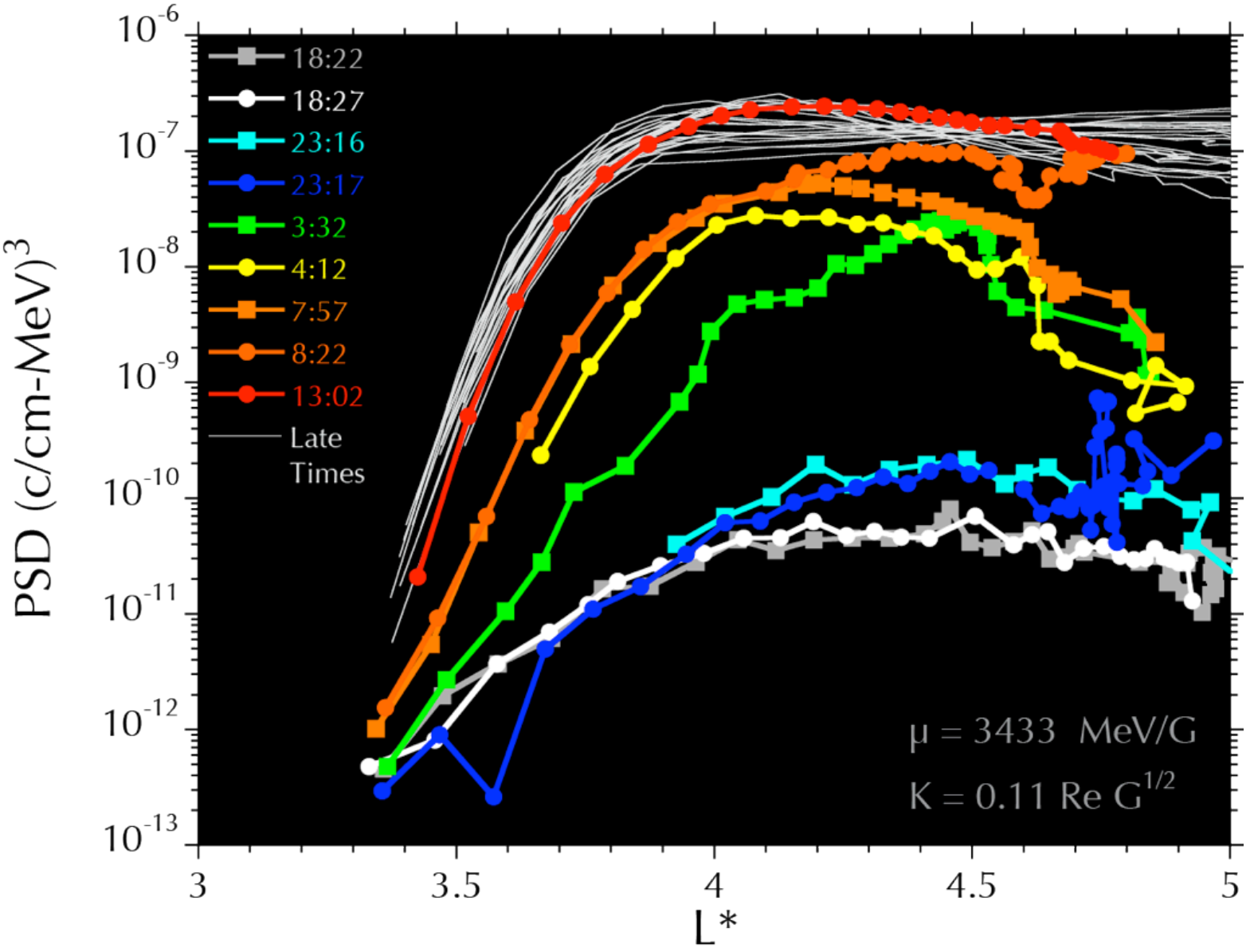
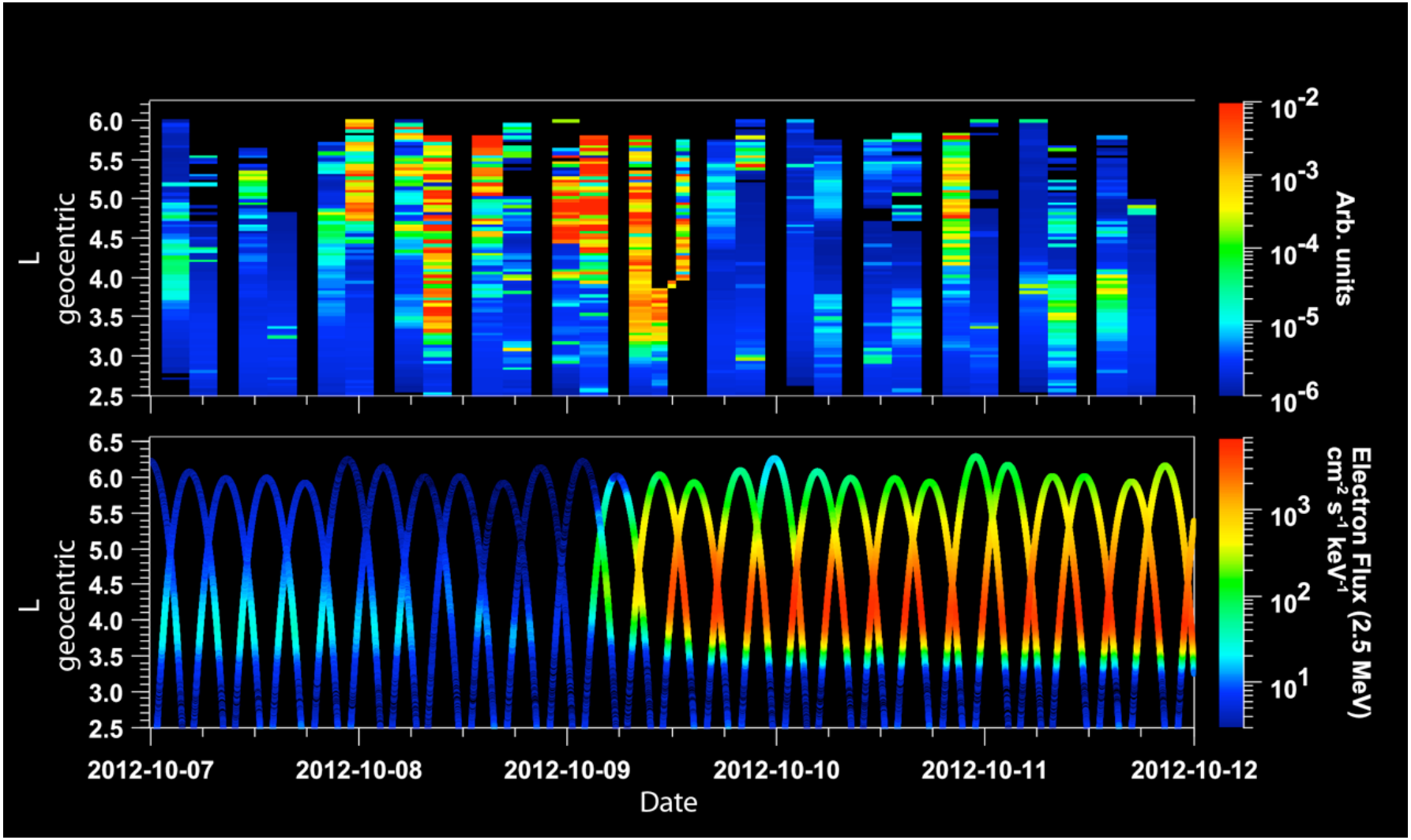

18:22
18:27
23:16
23:17
3:32
4:12
7:57
8:22
13:02
Late Times
μ = 3433 MeV/G
K = 0.11 Re G^1/2
PSD (c/cm-MeV)^3
L*
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
3
3.5
4
4.5
5

→ Evidence for In Situ Acceleration

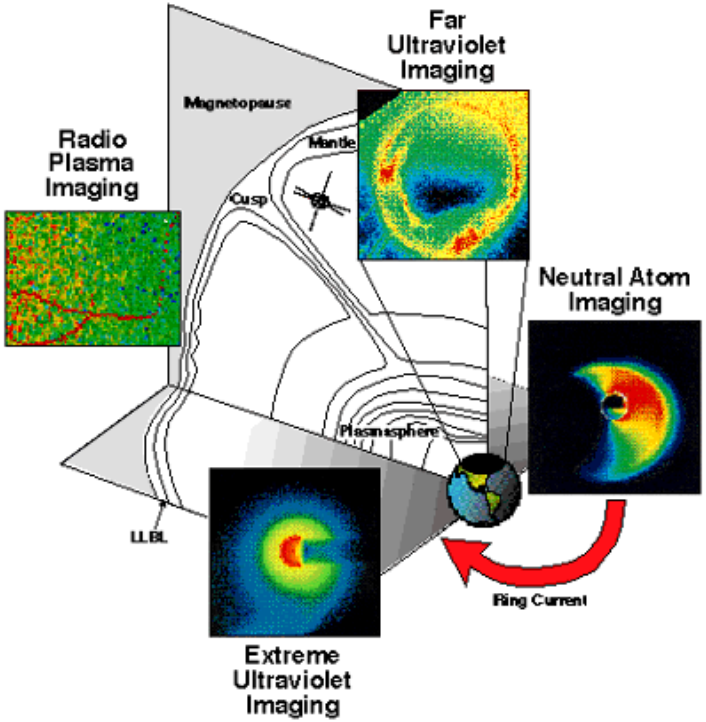


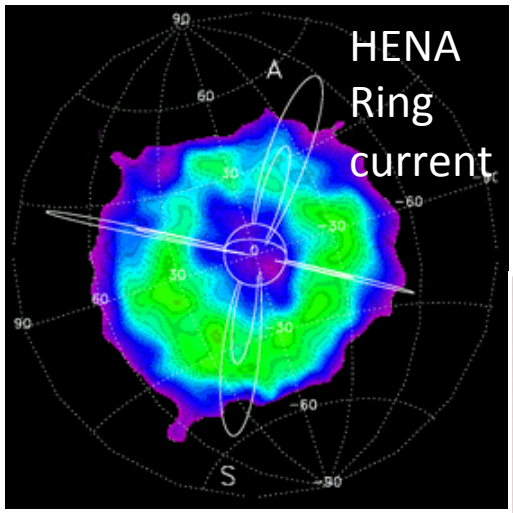
Indeed Chorus Wave Power Preceeds the Enhanced Fluxes [REPT/Spence]

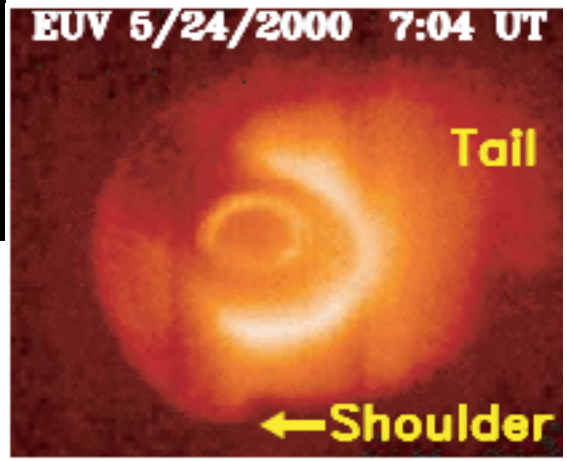


IMAGE

- Single, polar, spacecraft to understand storms, substorms, and response to solar wind
- Multi-wavelength imaging: FUV (auroral oval), EUV (plasmasphere), ENA (ring current, magnetopause)
- Efforts to contact recently rediscovered spacecraft continue!





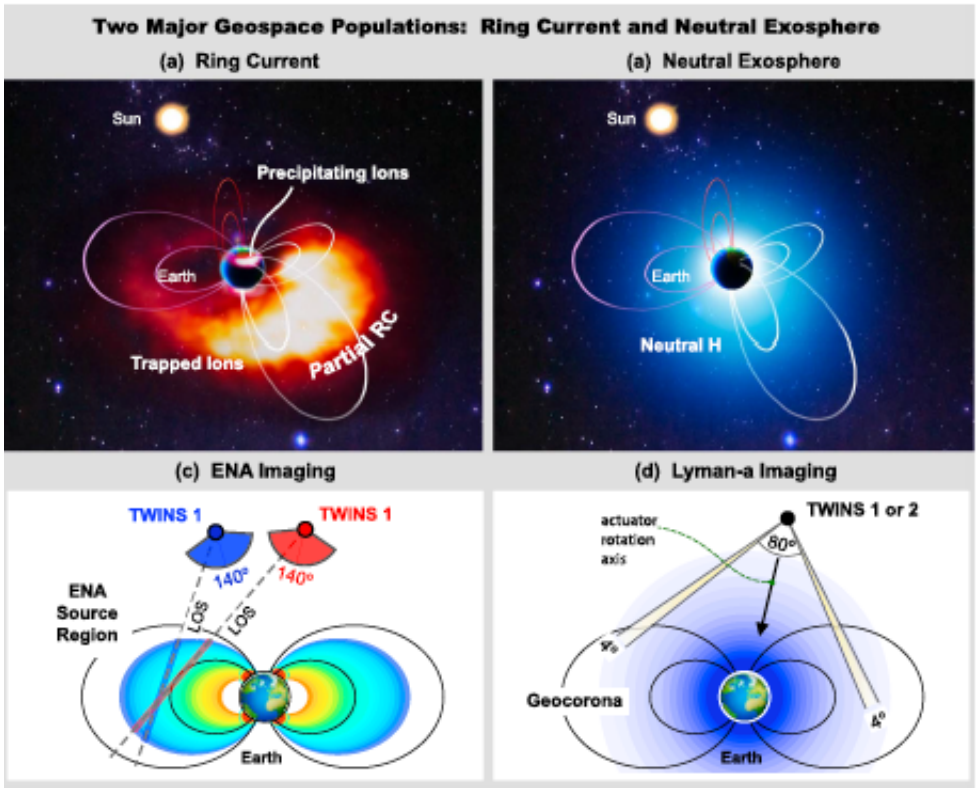


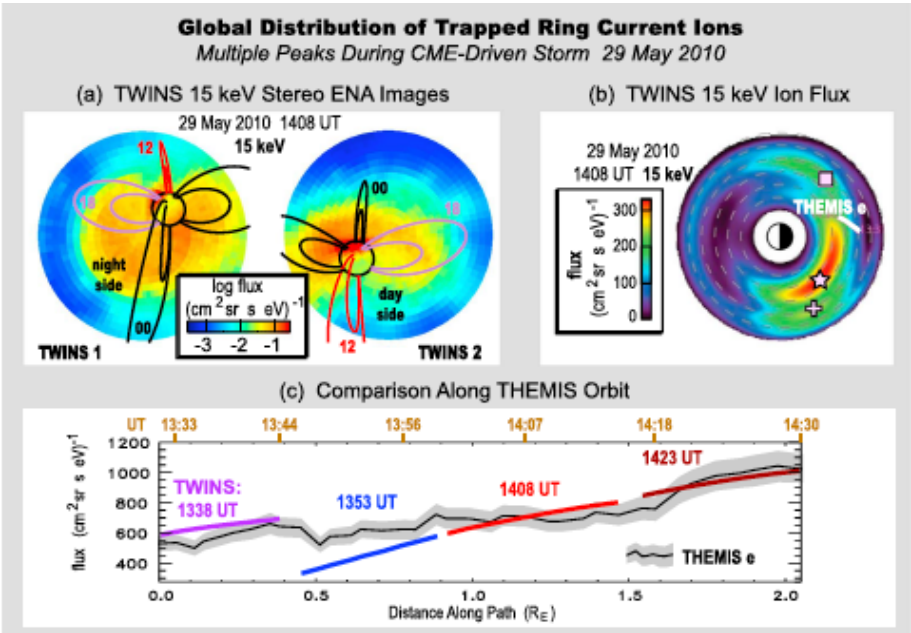
Plasmasphere
Goldstein et al. [2002]

TWINS

- 2-spacecraft mission

- Stereo imaging in ENA- catches more structure and time variations

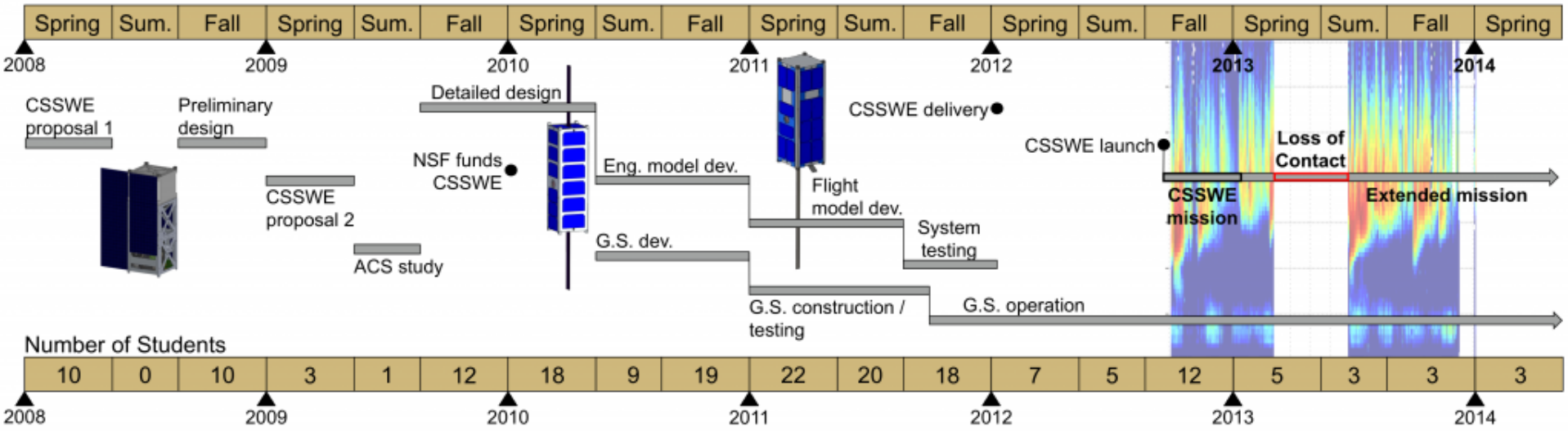




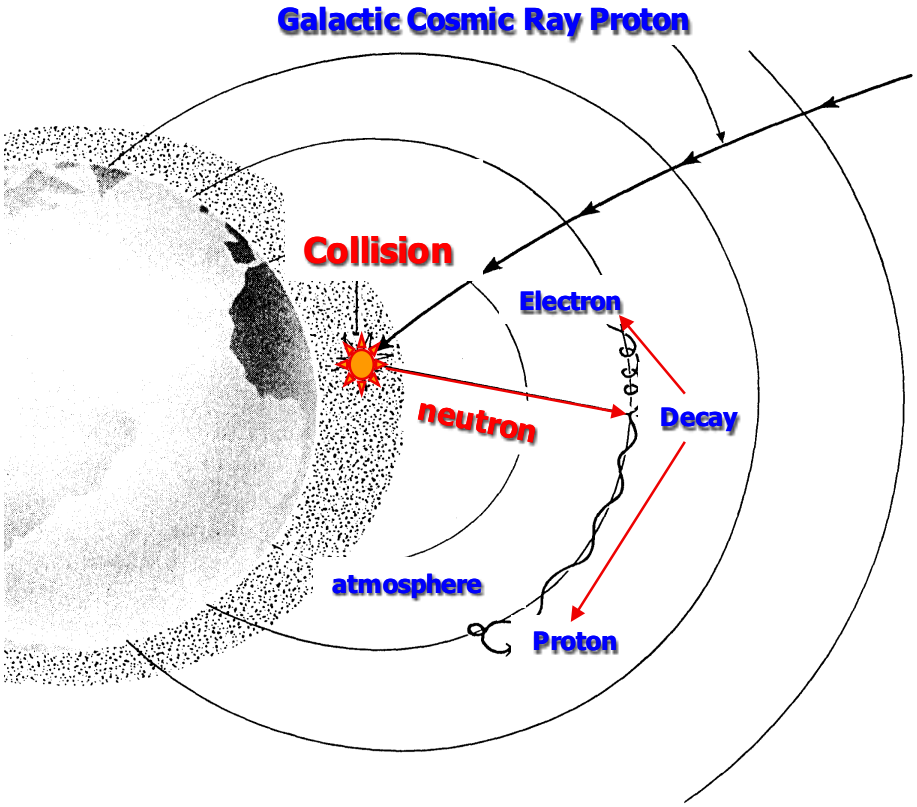
Goldstein and McComas [2018]

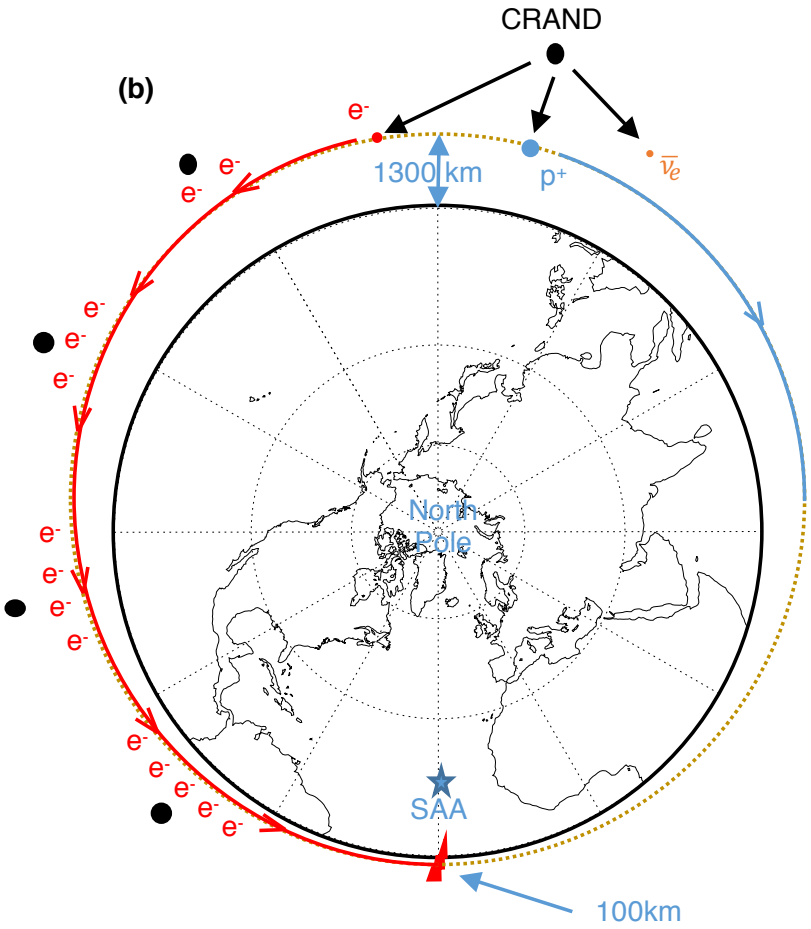
Cubesats

- Inexpensive, fast turnaround, great results. Example: U. Colorado CSSWE (Xinlin Li) observations of radiation belt electrons



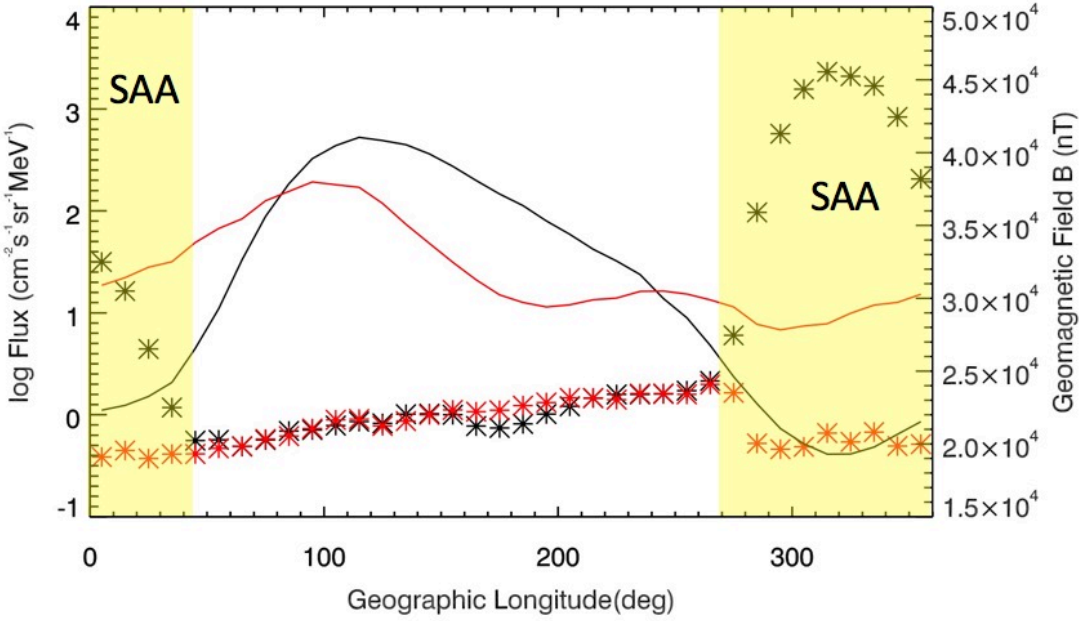
CRAND Electrons

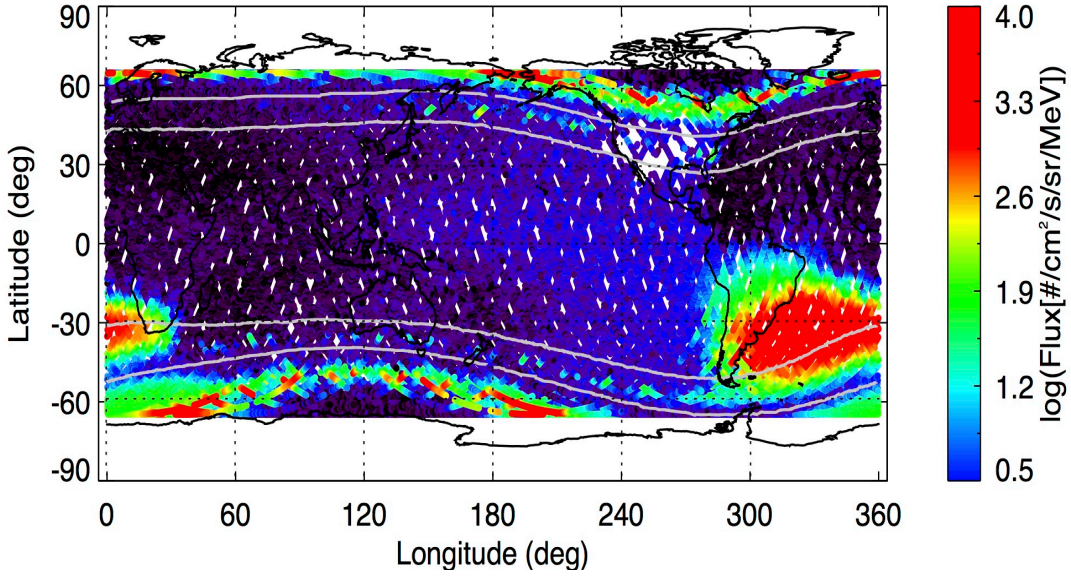




CSSWE
Li et al. [2017]

CRAND Electrons





CSSWE
Li et al.
[2017]

NASA Magnetospheric In Situ

Mission	Launch	Stop	Orbit	Inclin	P	B	E	EP	W
ARTEMIS	10/2010	Ongoing	Lunar 100 x 19000 km	Lunar 10°	X	X	X	X	X
FAST	31/07/96	1/5/09	348 x 4159	83	X	X	X		
IMP-8	26/10/73	26/7/06	22.2 x 45.3 RE	28.6	X	X		X	X
MMS	12/3/15	Operating	2550 x 70080 then X 152900	28	X	X	X	X	X
Polar	24/2/96	28/4/08	3125 x 55113	79	X	X	X	X	X
SAMPEX	3/7/92	30/06/04	512 x 687	81.7				X	
THEMIS	17/2/07	Operating	470 x 87330	16	X	X	X	X	X
Van Allen Probes	30/08/12	Operating	618 x 30414	10.2	X	X	X	X	X

Foreign Magnetospheric In Situ

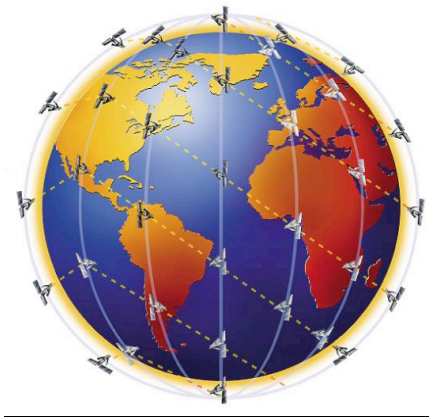
Mission	Launch	Stop	Orbit	Inclin	P	B	E	EP	W
Akebono	22/02/89	23/04/15	270 x 8000 km	75°	X	X	X	X	X
Arase	20/12/16	Ongoing	460 x 32110	31	X	X	X	X	X
CLUSTER II	16/07/00 9/8/00	Ongoing	16000 x 117000	135	X	X	X	X	X
Double Star EQU	29/12/03	14/10/07	570 x 78970	28.5	X	X		X	X
Double Star POL	25/07/04	??	700 x 39000	90	X	X		X	X
Equator-S	2/12/97	30/4/98	500 x 67300	3.75	X	X	X	X	
Geotail	24/7/92	Ongoing	51000 x 191000	10.5	X	X	X	X	X
Interball Tail/ Magion-4	3/8/95	10/00	500 x 200000	63	X	X		X	X
Interball Auroral/ Magion-5	29/8/96	Late 1998	? X 20000	63	X	X		X	X

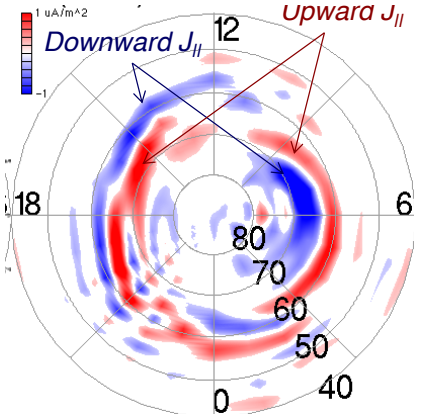
Remote Sensing Missions

Mission	Launch	Stop	Orbit	Incli	VIS	EUV	FUV	X-ray	ENA
Akebono	22/02/89	23/04/15	270 x 8000 km	75°	X		X		
IBEX	19/10/08	Operating	59000 x 312200	26					X
IMAGE	25/03/00	Still alive?	1000 x 46000	90		X	X		X
Polar	24/2/96	28/4/08	3125 x 55113	79	X		X	X	
TWINS	28/06/06 13/03/08	Operating Operating	1000 km x 7.2 RE	63.4					X

Geosynchronous and Low Altitude Measurements

Mission	Altitude	Agency	Operational Series	Plasma	Mag	Energetic Particles	FUV/EUV Imager
LANL	5.6 RE	DoE	Operating	X		X	
GOES	5.6 RE	NOAA	Operating		X	X	
DMSP	830 km	DoD	Operating	X	X	X	X
POES	807-870 km	NOAA	Operating			X	
AMPERE	780 km	Iridium	Operating		X		





Cubesats

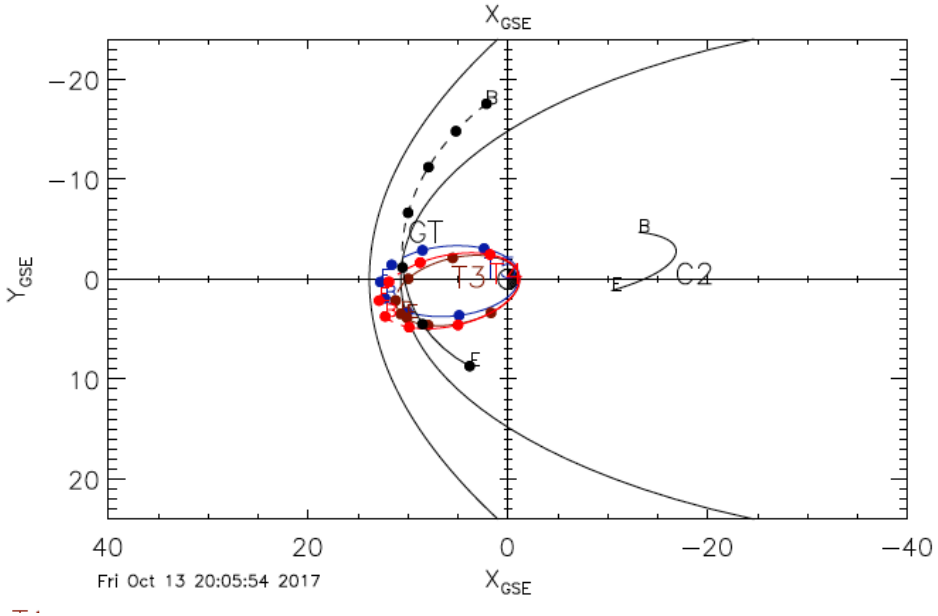
Mission	Launch	Stop	Orbit	Inclin	Measurements
CSSWE (CU- Li)	13/09/12	20/08/14	490 x 790 km	64.6°	Energetic Particles
CINEMA (UCB-Lin)	13/09/12	??	490 x 790 km	64.6	ENA, MAG
CeREs (GSFC-Kanekal)	Awaiting launch, summer, 2018		LEO	Polar	Energetic particles
CuPID (BU-Walsh)	Awaiting launch Fall 2019		LEO	Polar	Soft X-rays
ELFIN (UCLA-Angelopoulos)	Awaiting launch, Fall 2018		LEO	Polar	Energetic Particles, Magnetometer

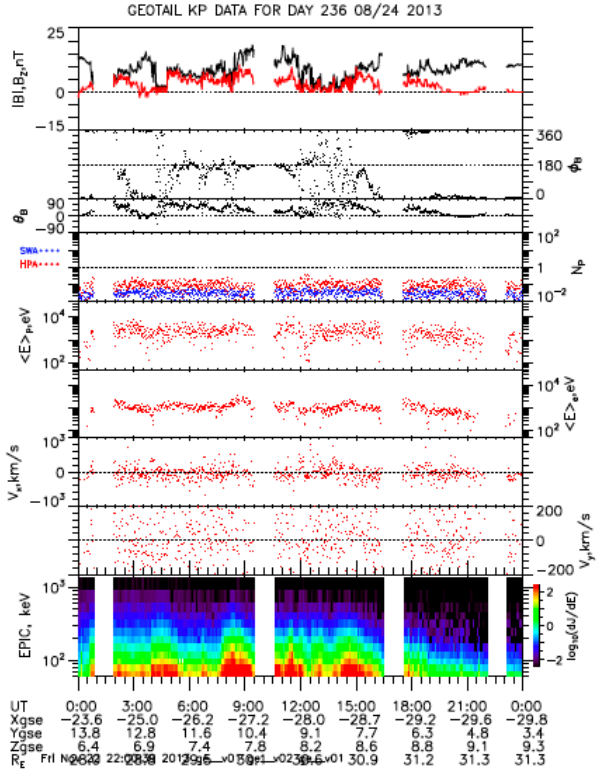
Solar Wind Measurements

Mission	Start	Stop	Plasma	Magneto meter	Waves	Energetic Particles
ACE	25/8/97	Operating	X	X		X
DSCOVR	11/02/15	Operating	X	X		
IMP-8	26/10/73	26/7/06	X	X	X	X
SOHO	2/12/95	Operating	X			
Wind	1/11/94	Operating	X	X	X	X

Tools

- At GSFC:
  - Gifwalk
  - https://cdaweb.gsfc.nasa.gov/cgi-bin/gif_walk



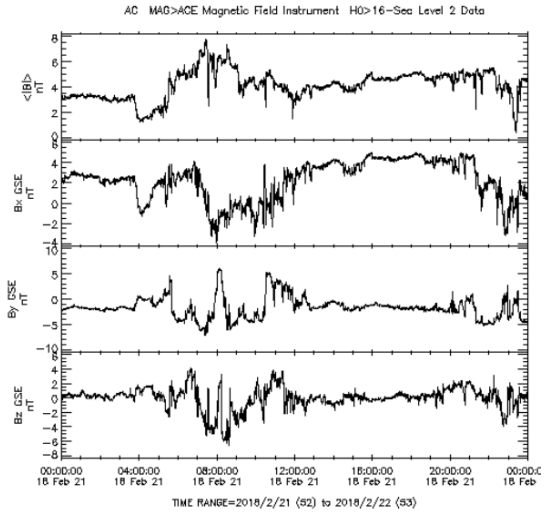


Data Servers

- At GSFC
  - CDAWeb
  - SSCWeb
  - OmniWeb
- Elsewhere
  - MMS
  - THEMIS
  - Van Allen Probes
  - …

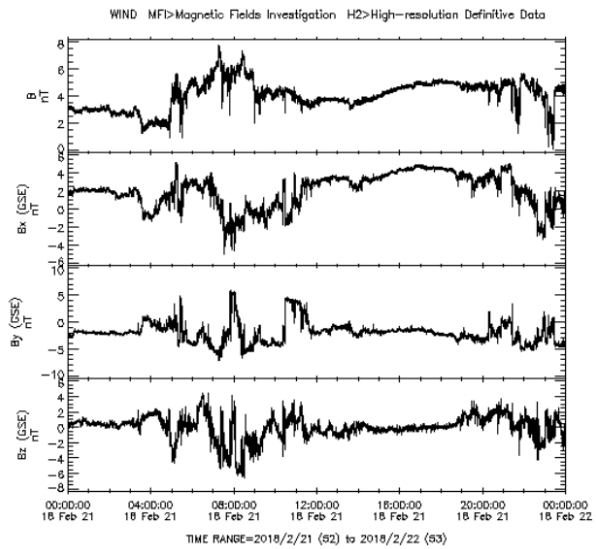
Data Servers

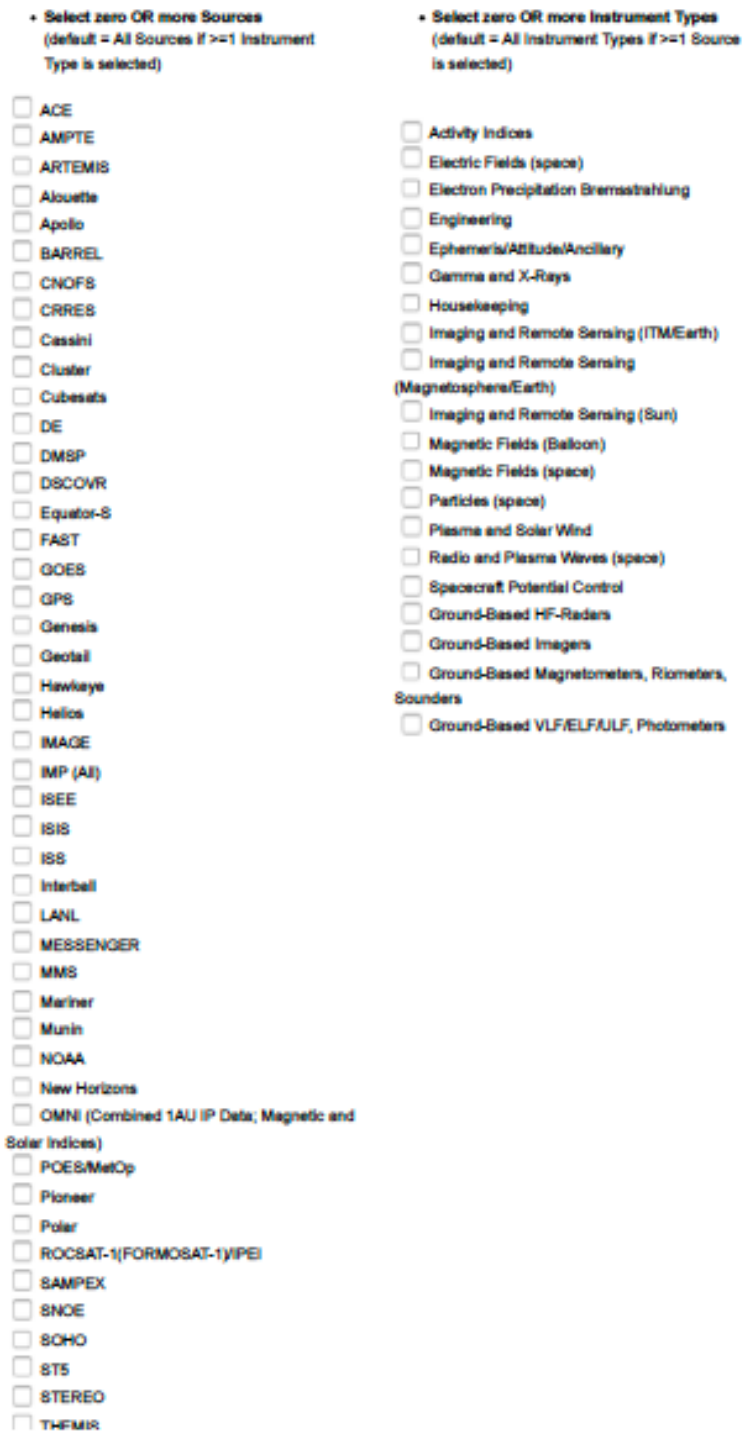
- Cdaweb.gsfc.nasa.gov



ACE

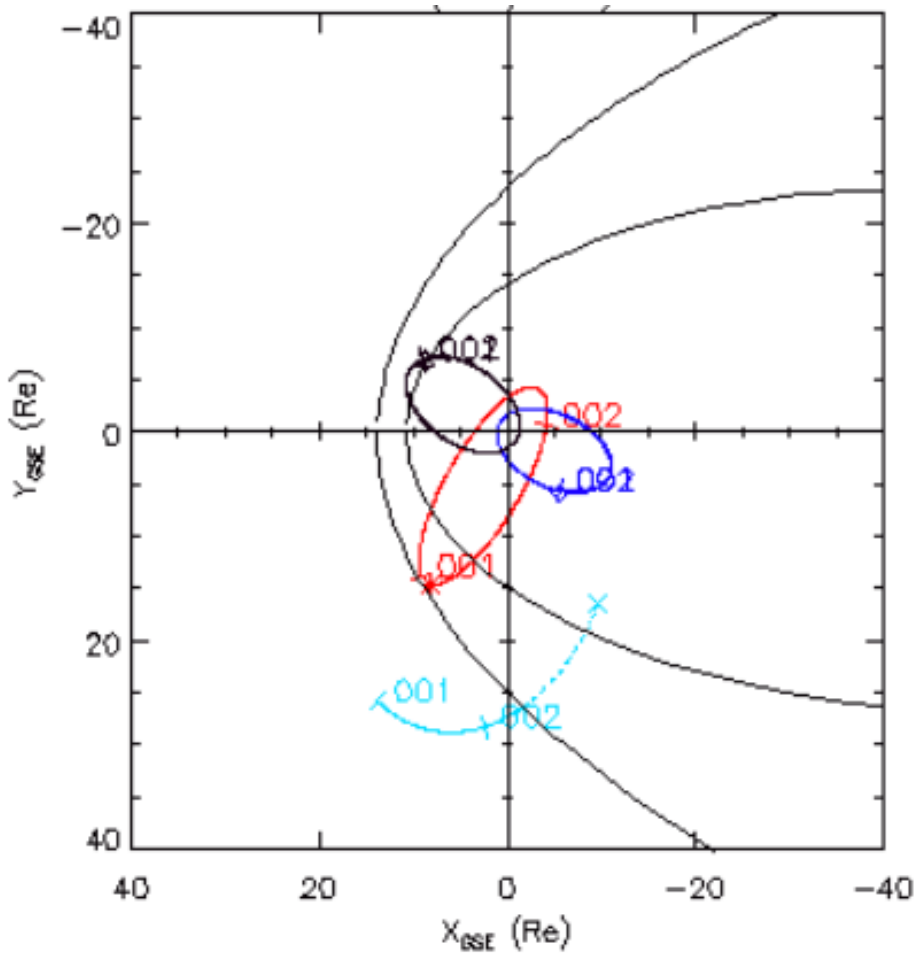
Wind





Data Servers

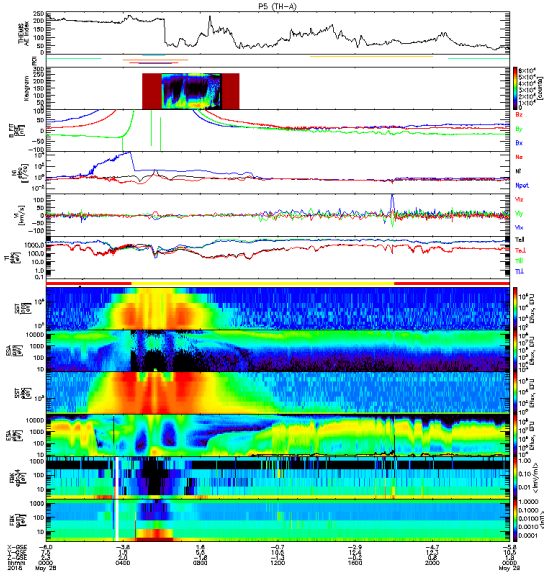
- Sscweb.gsfc.nasa.gov



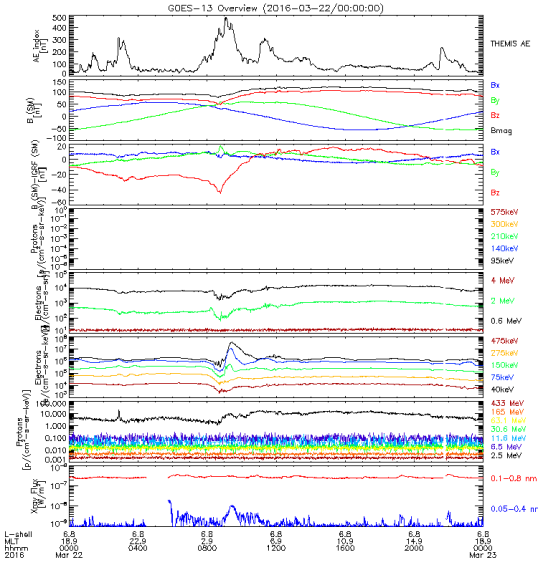
Other Data Servers

- MMS
- THEMIS (Includes GOES/POES)
- Van Allen Probes

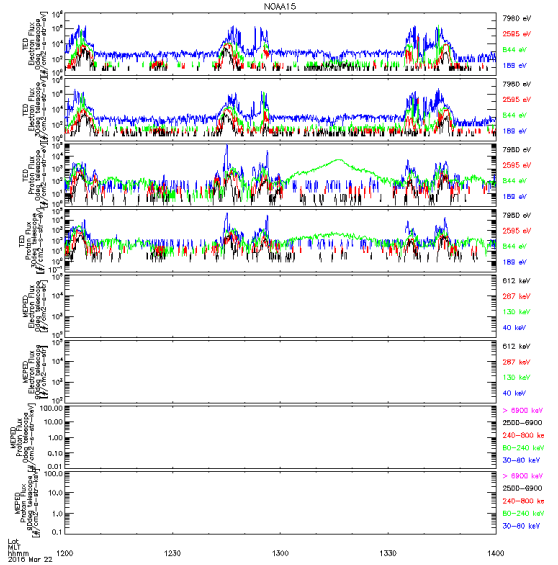
Themis.ssl.berkeley.edu



THEMIS
Themis.ssl.berkeley.edu



GOES

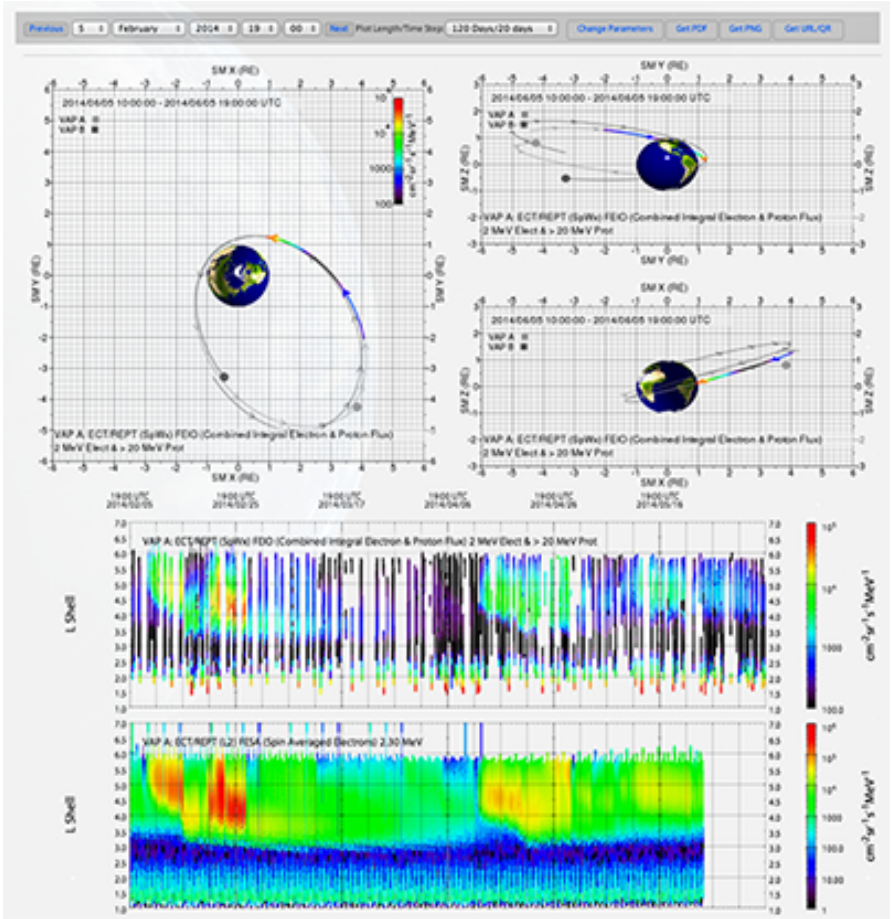


POES

Other Data Servers

- MMS
- THEMIS (Includes GOES/POES)
- Van Allen Probes

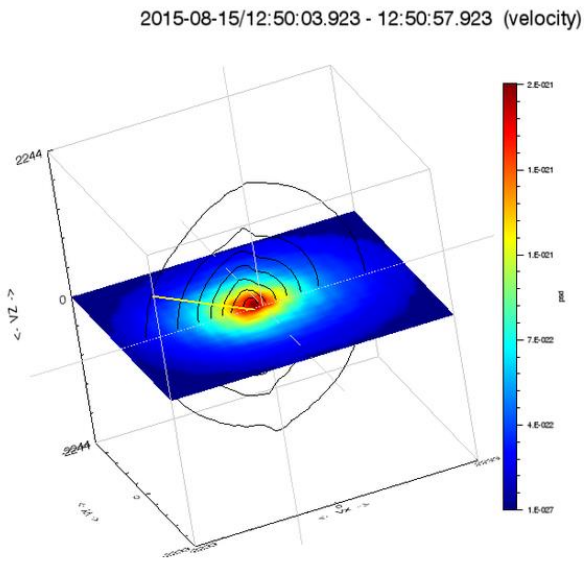
Van Allen Probes
Vanallenprobes.jhuapl.edu



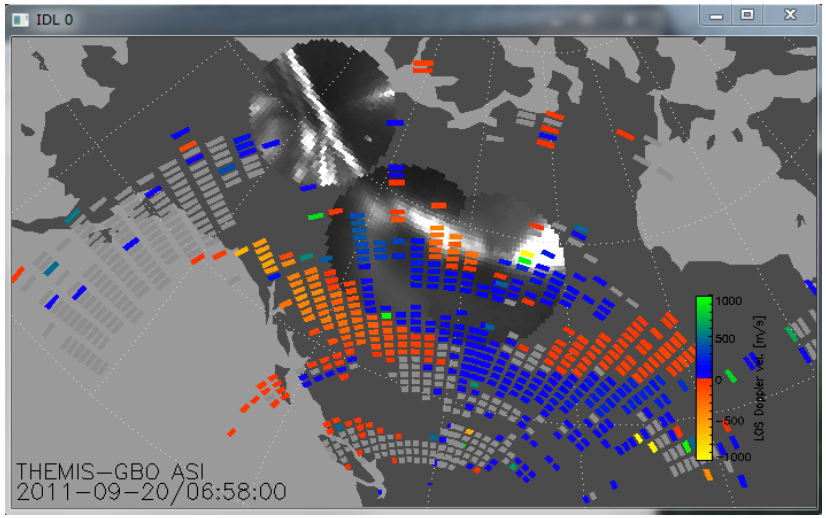
Other Tools

- SPEDAS/TDAS (THEMIS/CDAWeb, ERG, MMS, other missions)

SPEDAS MMS
Ion Distribution
Function

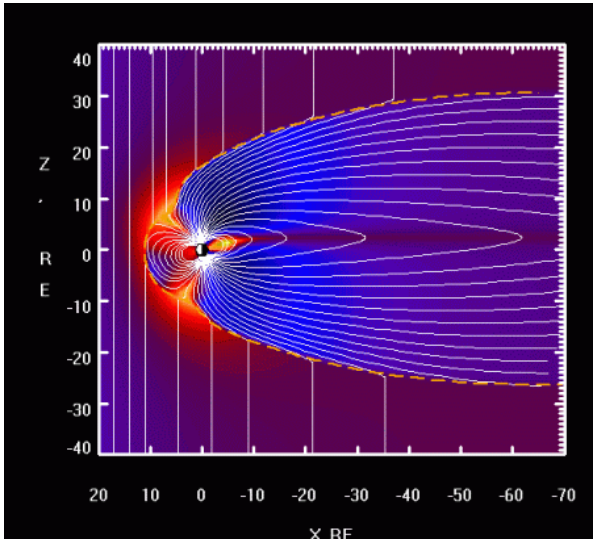


SuperDARN radar

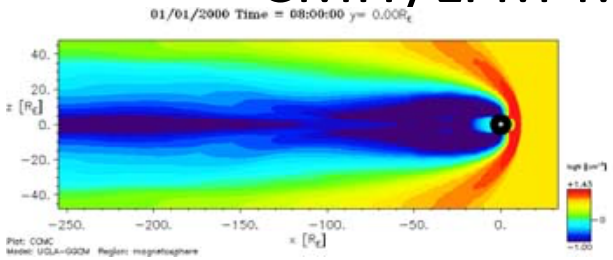


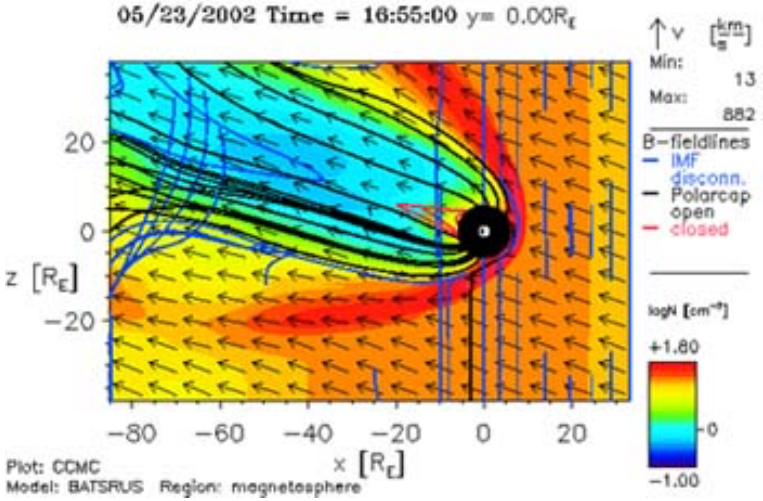
CCMC Services

- Instant Runs
  - Tsyganenko Magnetic Field
  - And others…



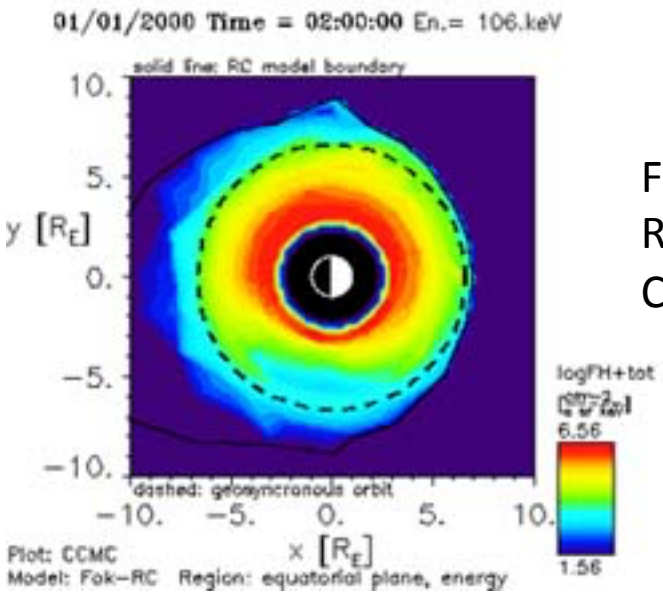
- Runs on Request (Global MHD Models)
  - BATS-R-US
  - Open GGCM
  - GUMICS
  - CMIT/LFM-MIX



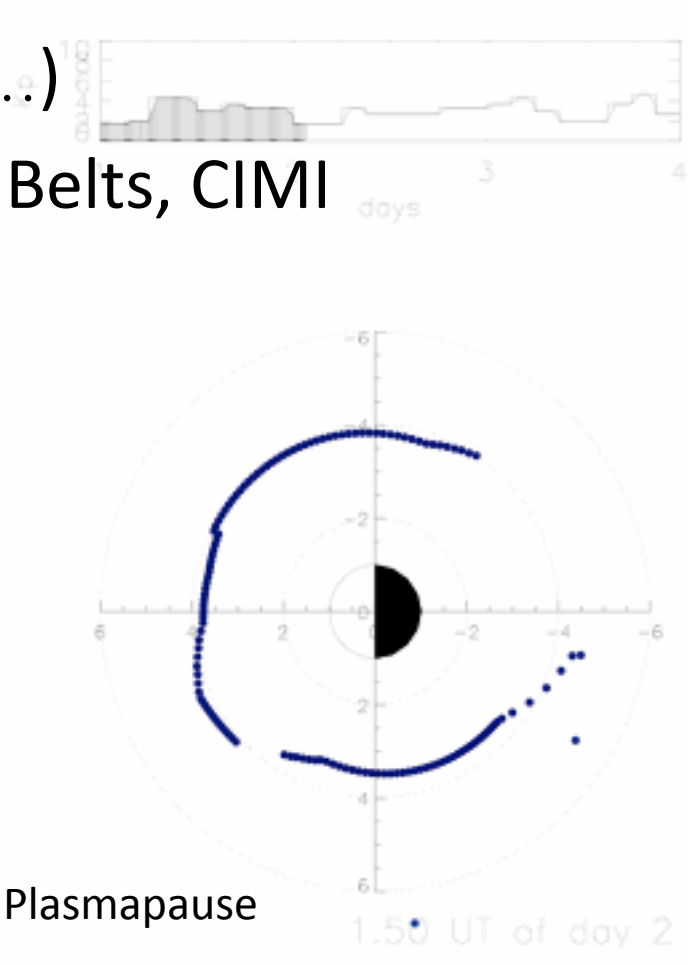


CCMC Services

- Inner Magnetosphere
  - Plasmasphere
  - RCM (PSD moments, Φ, $J_{//}$,…)
  - Fok Ring Current, Radiation Belts, CIMI
  - VERB (rad belt electrons)



Fok Ring Current



Plasmapause

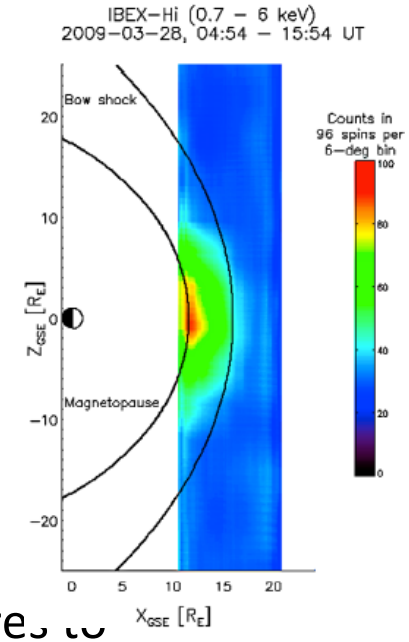
Future

- New missions
  - Global imaging and Constellation missions
- More cubesats
- Searchable data bases
  - Pattern recognition algorithms for use on large on-line data sets
- Global simulations on demand
  - Hybrid and PIC codes

New Missions

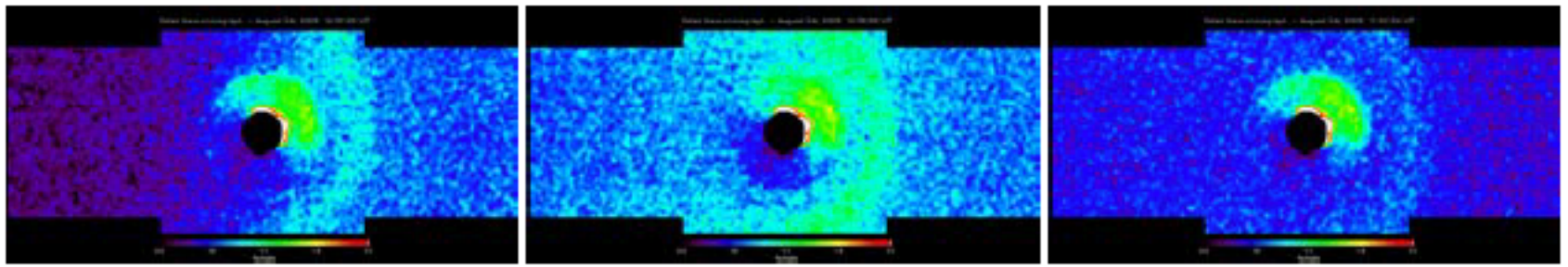
- Global Imaging
  - Not just FUV auroral, EUV plasmasphere, and 10's of KeV ENA ring current but also
  - 1 keV ENAs from magnetosheath

IBEX images Sheath [Fuselier et al., 2010]



  - Simulations show Thomson scattering allows electron structures to be imaged over 7.5 min integration times at 490-870 nm (NRL/ Damien Chua)

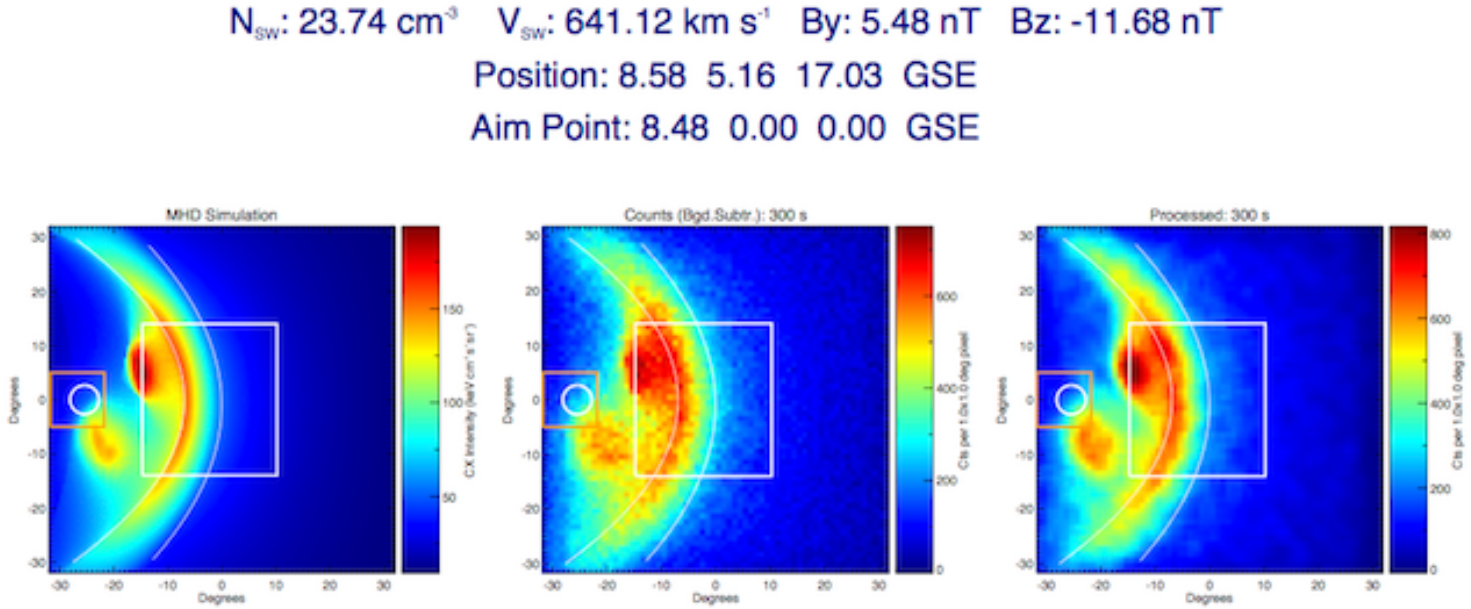
Plasmasphere and Magnetosheath



New Missions

- Global Imaging
  - Not just FUV auroral, EUV plasmasphere, and 10's of KeV ENA ring current but also

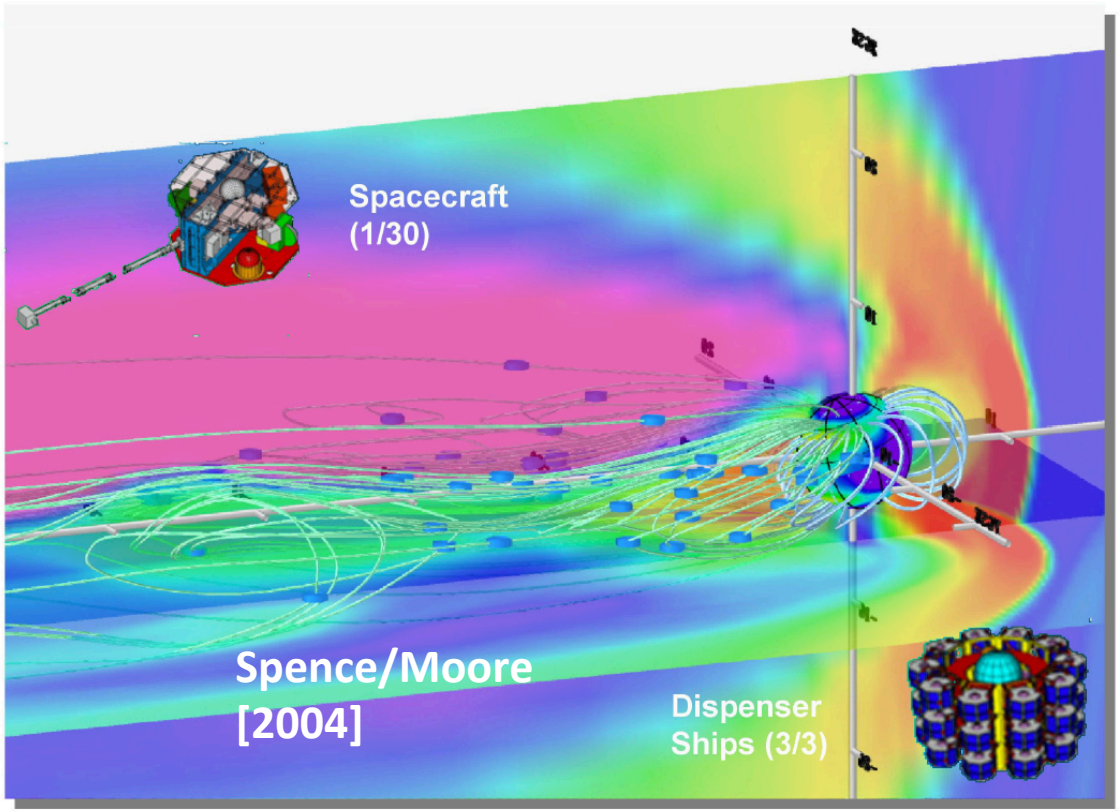
  - 0.1-1 keV soft X-rays from the magnetosheath and cusps (SMILE)



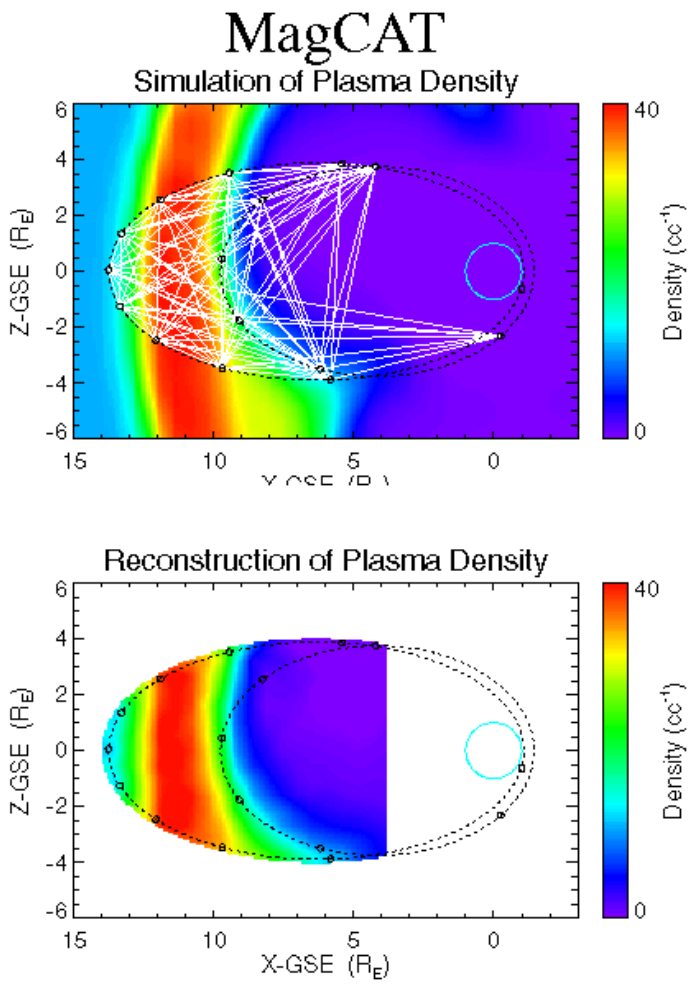
New Missions

- Constellation class missions

"Magnetospheric Constellation DRACO:
Dynamic Response and Coupling Observatory"



Ergun, Tomography



Searchable Data Bases

- Large searchable data bases at the Virtual Magnetospheric Observatory and VIRBO +
- Automated pattern recognition tools to identify events →
- Large event data sets for statistical analysis
- vmo.nasa.gov
- virbo.org

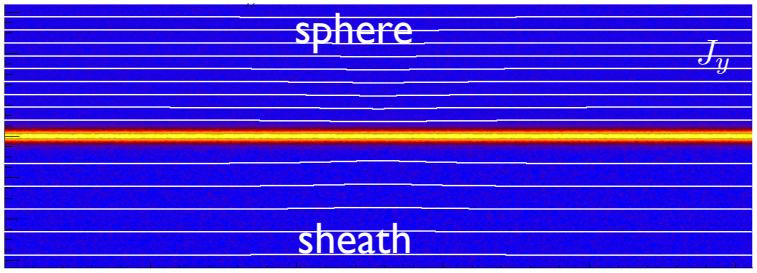
PIC and Hybrid Simulations

- CCMC PIC code runs on request
- Global Hybrid codes

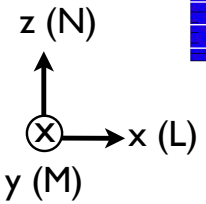
Run on Request

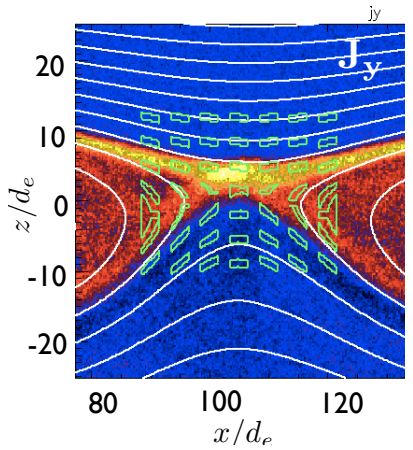
We have generalized the initial condition

B_{x2} B_{y2} n_2 T_2 V_{x2} V_{y2}

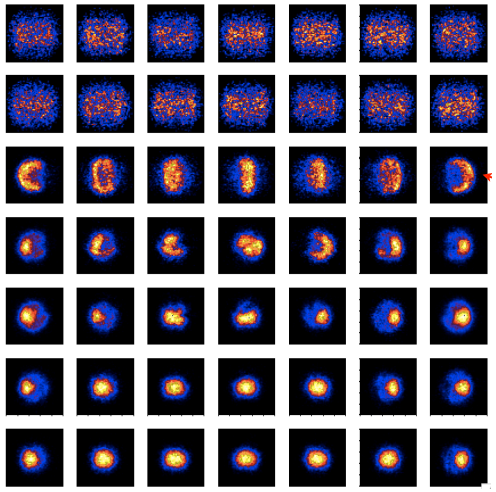


B_{x1} B_{y1} n_1 T_1 V_{x1} V_{y1}



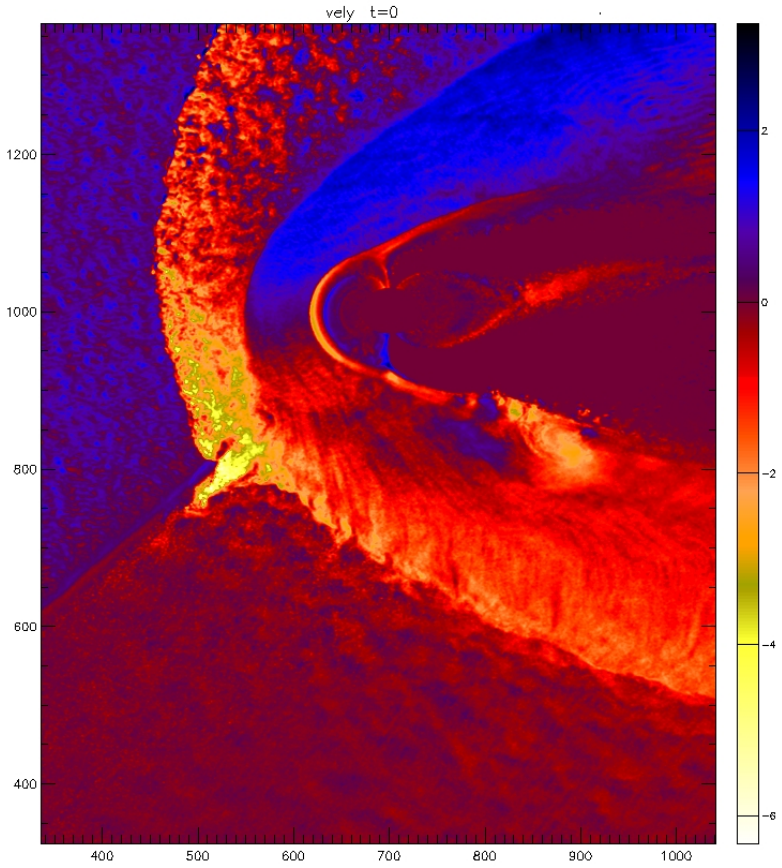


Distribution functions

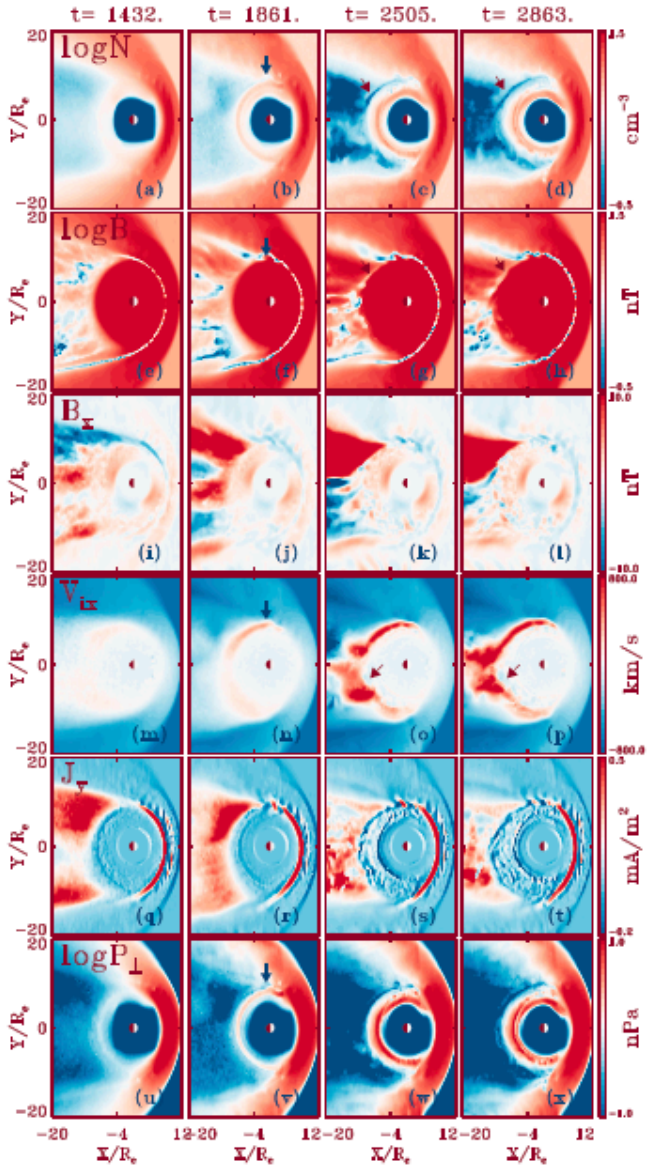


- An user can request a run with customized upstream conditions.
-- CCMC generates particle distribution & field & moment.
-- All data is published on-line & can be analyzed interactively using tools on CCMC.

Hybrid Code Simulations



2.5 D
HFA at
Bow Shock
[Omidi and
Sibeck,
2008]



3D
Injections feed
ring current
Lin et al. [2014]

Conclusion

- This is a golden era for magnetospheric research. Many resources available to help you study the magnetosphere.
- In conjunction with ever improving simulations and data mining services, the observations we take now will serve as the basis of studies for years to come.

Conclusion

- This is a golden era for magnetospheric research. Lots of resources to study the magnetosphere. Enjoy it!
- In conjunction with ever improving simulations and data mining services, the observations we take now will serve as the basis of studies for years to come.
- **What are you doing to plan and prepare for the next generation of missions?**