AE9/AP9-IRENE Plasma Model: Future Development Plans and Needs

MAY 30, 2019

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Outline

- Space Plasma Model (SPM) History
  - Datasets
  - Cross-calibration
  - Templates
- SPM Issues
- SPM Future
  - MLT dimension
  - Monte-Carlo capability
  - Dataset solicitation

SPM History

- Space plasma contributes to surface dose on spacecraft; we wanted to extend the AE9/AP9 energies down to cover at least some of this hazard.
  - SPM does not describe the surface charging hazard, though it is due to the same plasma populations.
- For ease of comparison with earlier published plasma climatology's, we adopted different coordinates than AE9/AP9
  - Energy, L_m, Equatorial pitch angle (and MLT for validation).
- These choices led to a whole separate model: SPM.
- SPM has no Monte-Carlo framework because:
  - There are not many plasma instruments up simultaneously to determine covariances.
  - The plasma environment is really dynamic – those covariances will be large.
  - We decided to omit MLT in the SPM coordinates to keep it 3D like AE9/AP9; collapsing MLT increases spread of plasma distributions.
- SPM includes H^+, e^-, He^+, and O^+.
  - Not He^{++} because it has a lower flux, and we thought O^+ was more damaging to surfaces by weight and chemistry.
- Coverage issues have been incrementally worked on by including THEMIS in V1.2.

SPM Datasets

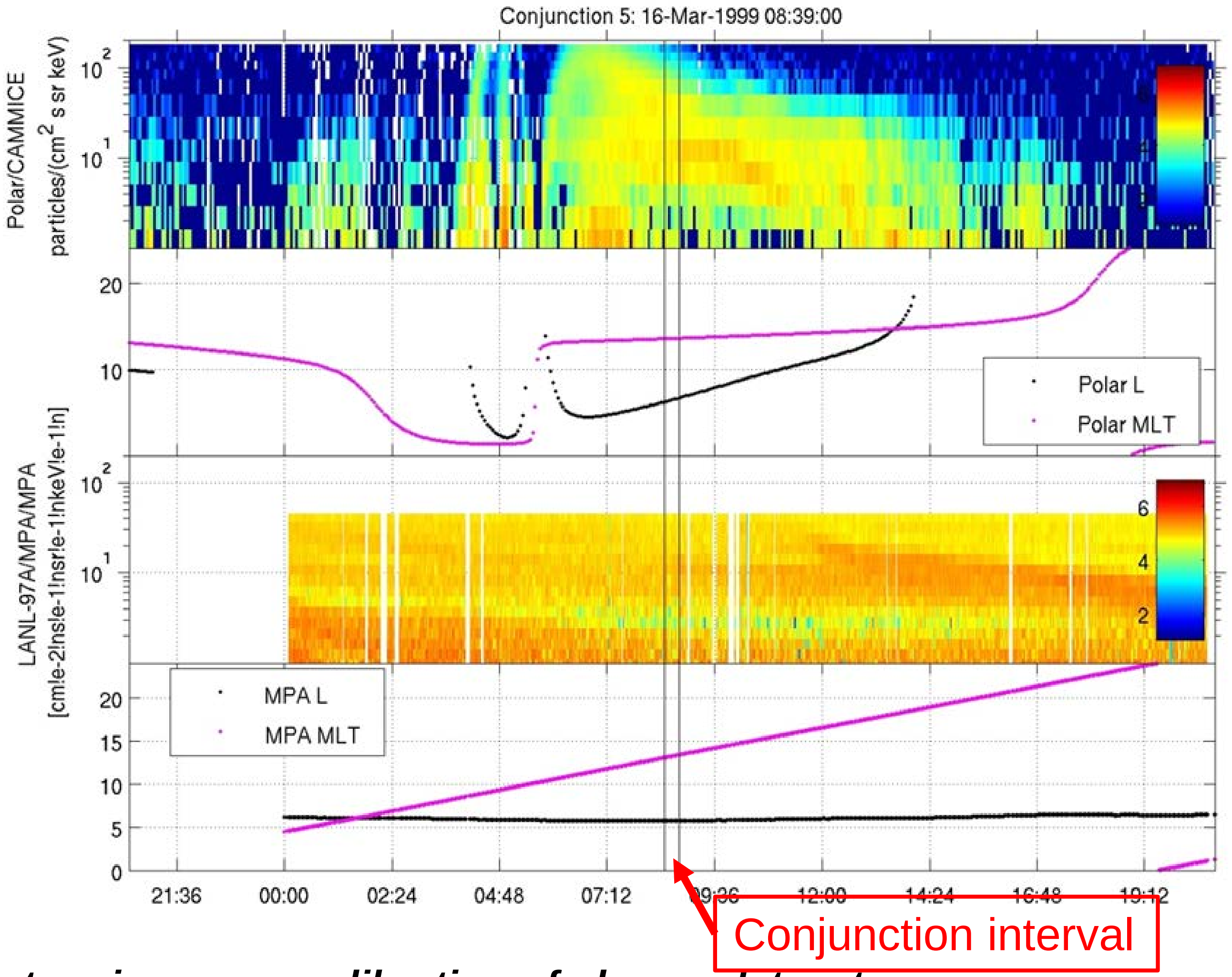
Plasma (energy in keV)					Model
POLAR/CAMMICE/MICS	5100 × 51000 km, 86°	1997–1999	1.2–1.64	V1.00	H+,He+,O+
POLAR/HYDRA	5100 × 51000 km, 86°	1997–1999	1.0–40.0	V1.00	Electrons
LANL-GEO/MPA 1990-095	36000 km circular, 0°	1990–2005	1.0–63.0	V1.00	H+, e-
LANL-GEO/MPA 1991-080	36000 km circular, 0°	1991–2004	1.0–63.0	V1.00	H+, e-
LANL-GEO/MPA 1994-084	36000 km circular, 0°	1994–2008	1.0–63.0	V1.00	H+, e-
LANL-GEO/MPA LANL-97A	36000 km circular, 0°	1997–2008	1.0–63.0	V1.00	H+, e-
THEMIS A/ESA	440 × 92000 km, 16°	2007-2013	1-60	V1.20	H+, e-
THEMIS B/ESA	440 × 92000 km, 16°	2007-2010	1-60	V1.20	H+, e-
THEMIS C/ESA	440 × 92000 km, 16°	2007-2010	1-60	V1.20	H+, e-
THEMIS D/ESA	440 × 92000 km, 16°	2007-2013	1-60	V1.20	H+, e-
THEMIS E/ESA	440 × 92000 km, 16°	2007-2013	1-60	V1.20	H+, e-

Missing: more composition and broader energy coverage

Cross-Calibration During Magnetic Conjunction

- Using pair-wise magnetic conjunctions, we compare two plasma measurements when they should observe the "same" environment.
- Conjunction criteria are adjusted to balance conjunction size to yield sufficient statistics.
  - Criteria are shown below.
- One conjunction between CAMMICE/MICS (top two panels) and LANL-97A/MPA (bottom two panels) are shown at right.
  - Conjunction criteria satisfied at center of plot.

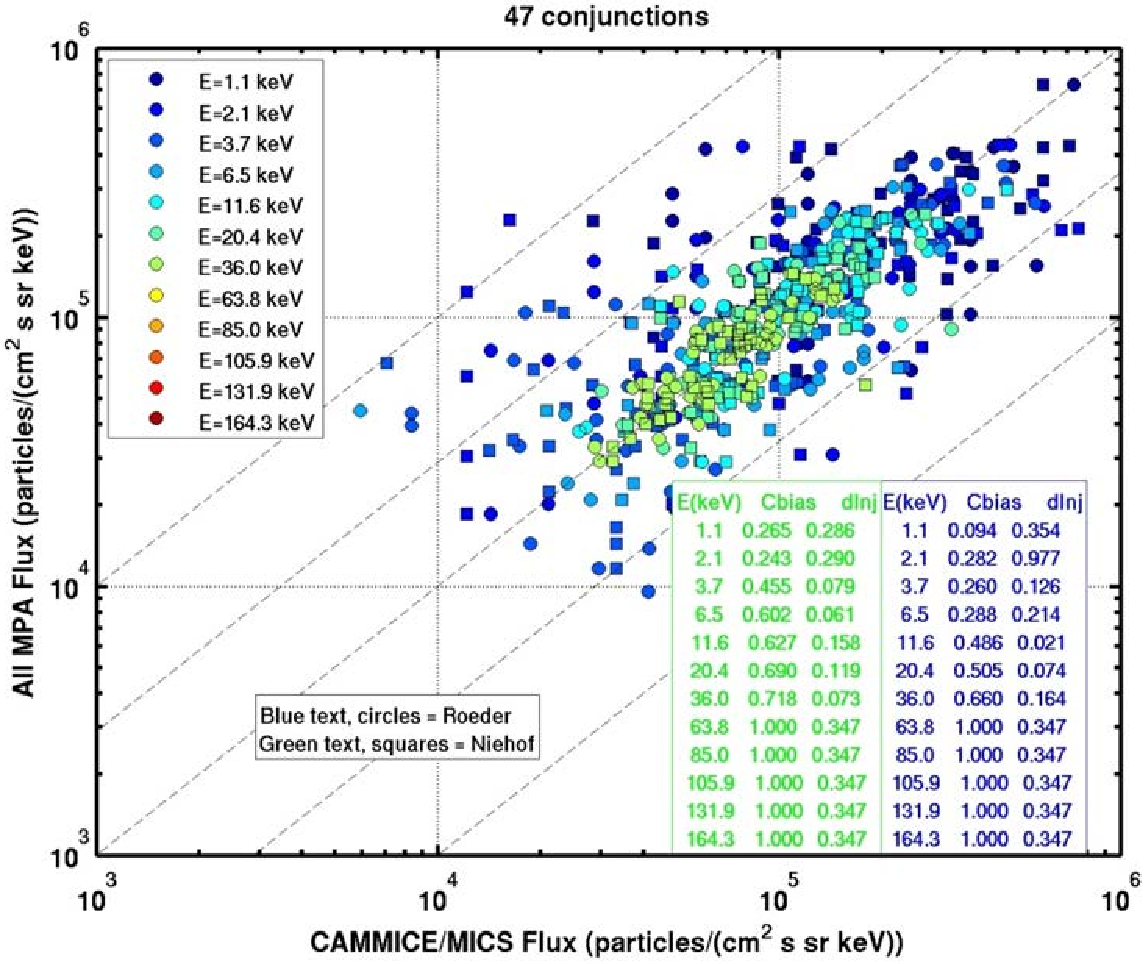
	dL	dB/B0	dMLT (hours)	dTime (minutes)	# of conjunctions
CAMMICE-MICS/1991-080	0.25	0.3	2	30	14
CAMMICE-MICS/1994-084	0.05	0.05	.5	10	19
CAMMICE-MICS/LANL-97A	0.1	0.1	.5	10	8



Using pair-wise magnetic conjunctions, we can determine cross-calibration of plasma datasets.

Cross-Calibration During Magnetic Conjunction

- Identify conjunctions during the temporal overlap of both datasets.
  - CAMMICE / MPA protons: 47 conjunctions
  - HYDRA / MPA electrons: 291 conjunctions
  - THEMIS / MPA p^+/e^-: 79 conjunctions
- In aggregate, scatterplot CAMMICE vs MPA fluxes during conjunction.
- From this, determine the offset (C_{bias}) and residual scatter (d_{lnj}) for each dataset relative to the MPA standard.
- Barring any “gold” standard in plasma datasets, we do not apply offsets, only residual errors to weight dataset contribution to the SPM model.

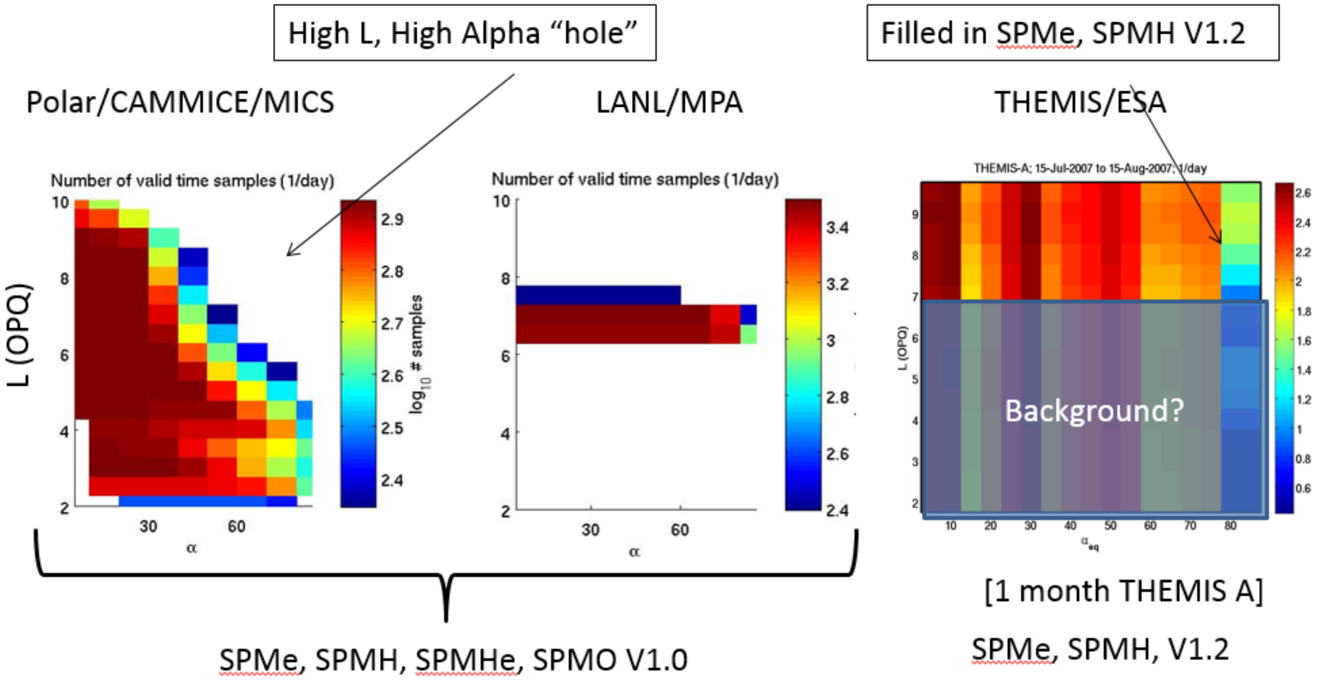


Using pair-wise magnetic conjunctions, we can determine cross-calibration of plasma datasets.

Addition of THEMIS Plasma Data

- The V1.0 plasma datasets left a high L, equatorial “hole” in coverage.
- THEMIS’ equatorial coverage and spinning spacecraft filled out L/α coverage.
- However, the plasma analyzers experienced significant background while in the radiation belts, both inner and outer belts.
- With careful selection of time without penetrating backgrounds, we could still fill the “hole”.

Why THEMIS coverage improves SPM V1.2



- THEMIS is an elliptical, equatorial constellation, making pitch angle resolved plasma measurements, complementary to the existing datasets in SPM.
- THEMIS ESA coverage extends to ~25 keV ions (~30 keV electrons) overlapping with MPA and HYDRA electrons, but much less than the 1-160 keV proton energy range of Polar CAMMICE/MICS.
  - We have THEMIS/SST data (ions 25 keV-6 MeV, electrons 25 keV-900 keV), but haven’t had time to include them in this effort.

SPM "Prior Knowledge": Templates

- Templates are how the SPM model interpolates or extrapolates flux maps when there are gaps in data coverage.
- We use templates based on aggregations of plasma datasets.
- AMPTE/CCE/CHEM-derived H^+ templates from Milillo et al. (2001) and DeBenedetti et al. (2005).
- Polar/CAMMICE/MICS: Roeder and Niehof
- Polar/HYDRA
- Each template included averages of these datasets over all local times, each quadrant of local time, the mean, 50th, 75th, 95th percentiles, and all species within SPM.
- For SPME (Polar/HYDRA) we also extrapolated electron flux in energy according to 4 power law exponents (-1 through -4).
- In total, our "prior knowledge" of the plasma distribution is captured in 140 unique templates.

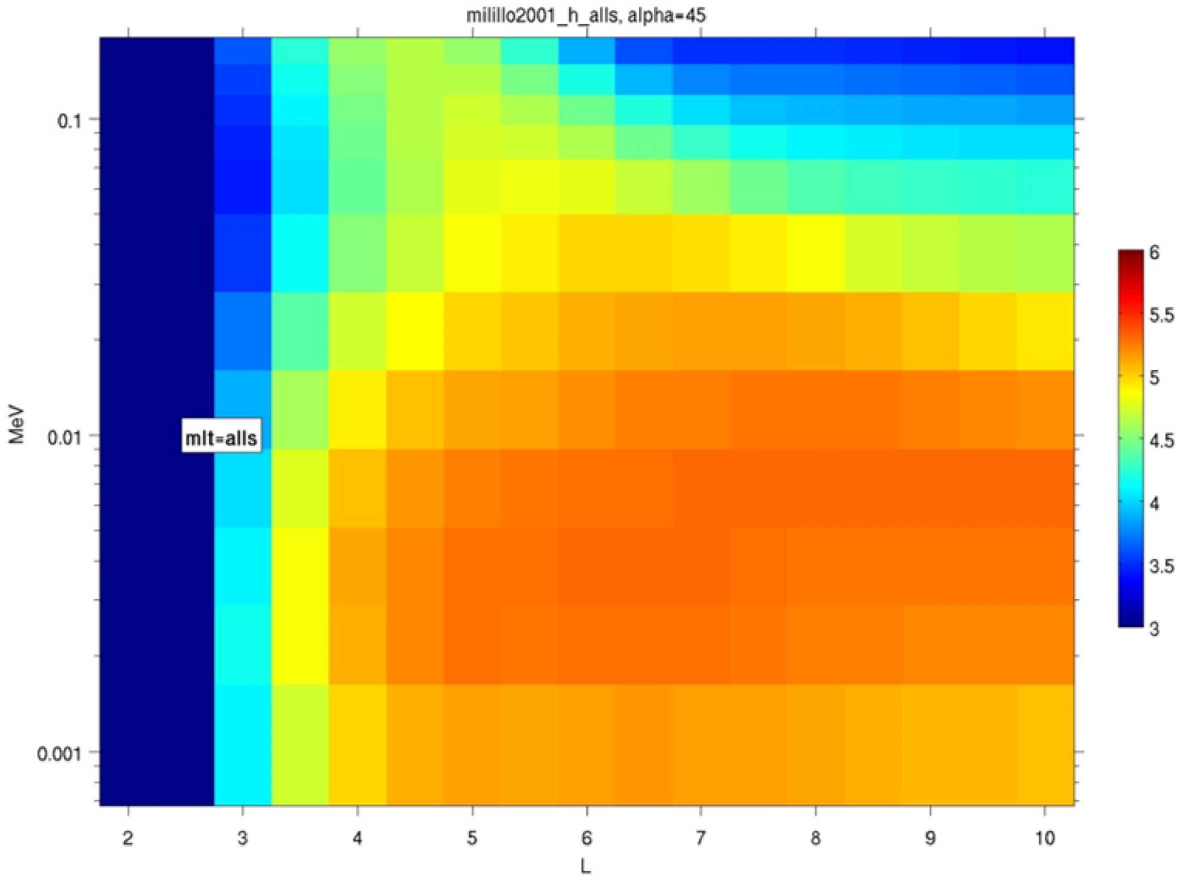


Figure 1. The AMPTE/CCE H+ template which is averaged over all local times, shown versus L (x-axis) and energy (y-axis in MeV). The color scale is log10(flux). The equatorial pitch angle for this map is 45 degrees.

Issues, Roughly Prioritized

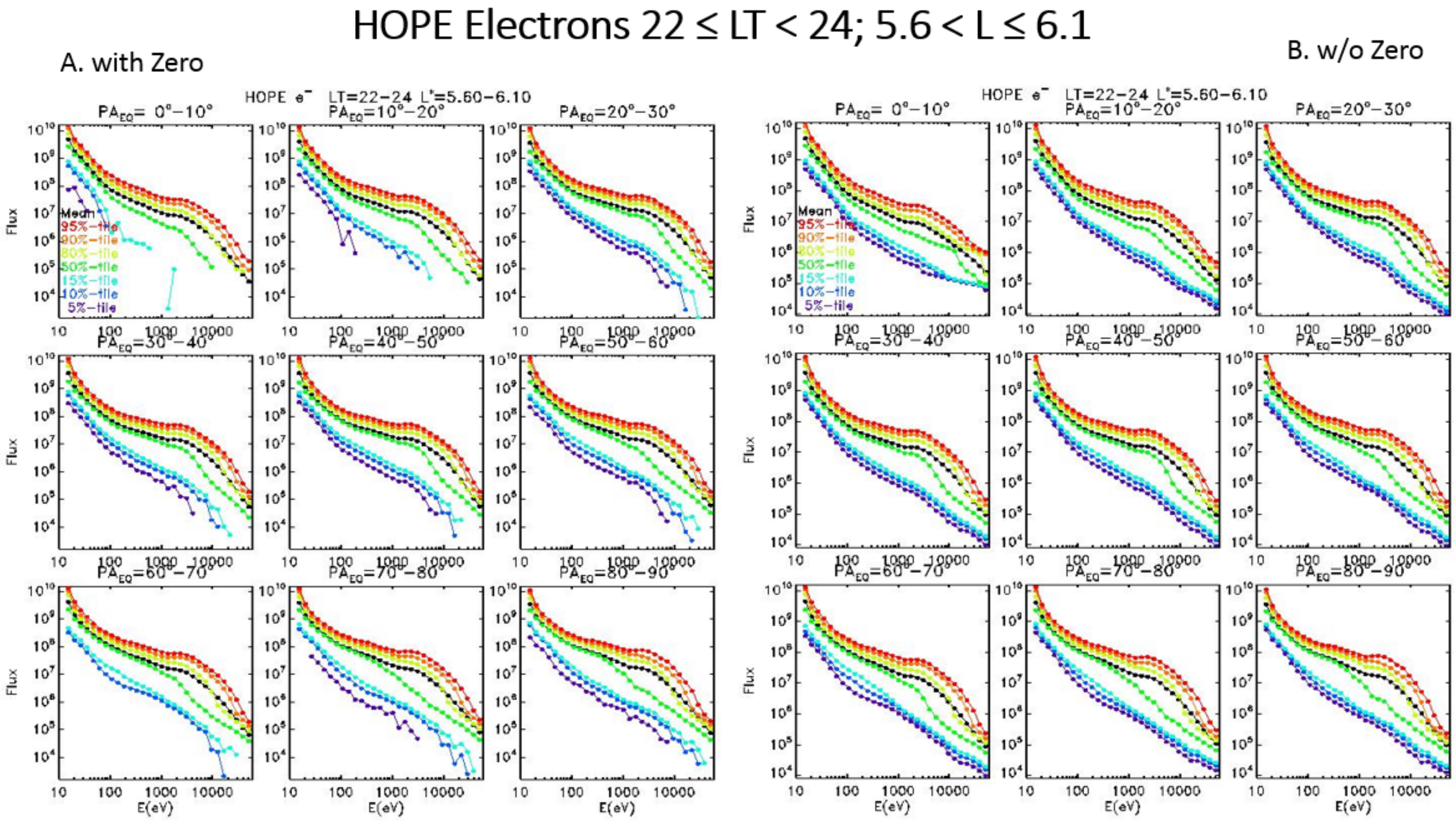
- We only have 1 dataset including composition: Polar/CAMMICE/MICS.
- MLT is ignored, and an important organizing coordinate for plasma fluxes.
- SPM has no dynamics like the rest of AE9/AP9; only perturbed mean statistics.
- Energy limits:
  - Many of our datasets don't extend to higher energy; plasma analyzers get to ~40 keV.
    - OK for electrons, AE9 starts at 40 keV. Not OK for H^+, AP9 starts at 100 keV. This introduces a "seam" between SPM and AE9/AP9.
    - S3-3 electrons spans this energy gap, but we omitted the data because it wasn't defendable.
  - Many of our datasets don't extend to lower energy; MPA host vehicle spacecraft potential limits to 1 keV.
  - Thin films, optical coatings, are susceptible to damage from energies << 1 keV.
- Solar cycle phase:
  - CAMMICE/MICS only operated for ~3 years in solar minimum, some have questioned the solar cycle dependence of plasma distributions.
  - LANL/MPA is the only long-lived plasma dataset we can bring to bear.
  - TWINS-ES/SCM possibly another, without PAD coverage.

What’s Next? SPM V1.5+

- Datasets:
    - Van Allen Probes: HOPE.
    - AMPTE/CCE/MEPA: Courtesy Kazue Takahashi, JHU/APL, 2012.
    - AMPTE/CCE/CHEM: Composition information available, but need effort from JHU/APL to make a dataset.
    - SCATHA/SC2-6.
    - CRRES/MICS: Same instrument as CAMMICE/MICS, in equatorial GTO.
    - Cluster/RAPID: International dataset.
- Coordinates:
    - MLT through the module framework.
- Algorithms:
    - Monte-Carlo statistics for SPM?
- Covariances
    - Cross-energy, L, MLT, alpha co-variances perhaps derived from climatological ring current simulations.

Highest Priority Dataset: Van Allen Probes/HOPE

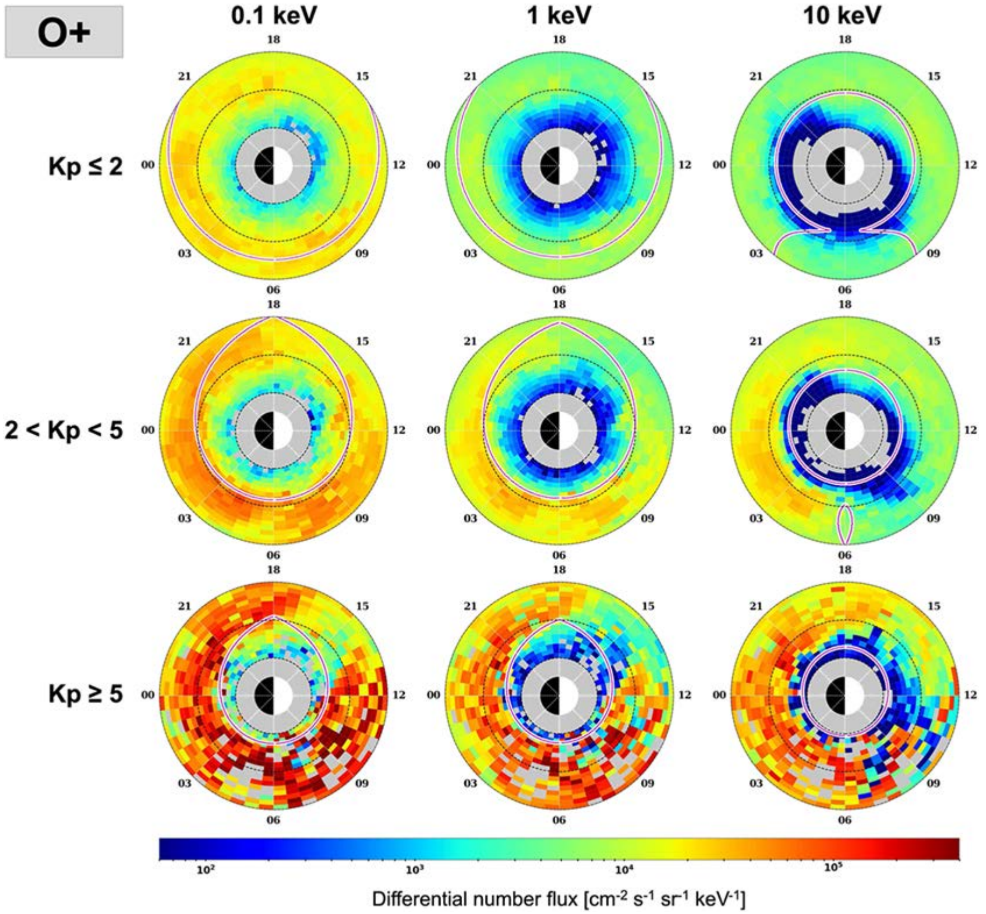
- HOPE processing begun, but abandoned for schedule.
- Two HOPE climatology analyses have just come out from different groups:
  - Jahn et al. (2017), “The warm plasma composition in the inner magnetosphere during 2012-2015”.
  - Fernandes et al. (2017), “The plasma environment inside geostationary orbit: A Van Allen Probes HOPE survey”.
- Perhaps consult with both on the data quality.
- Both find MLT features of the climatological plasma populations.



Su analysis, October 2016

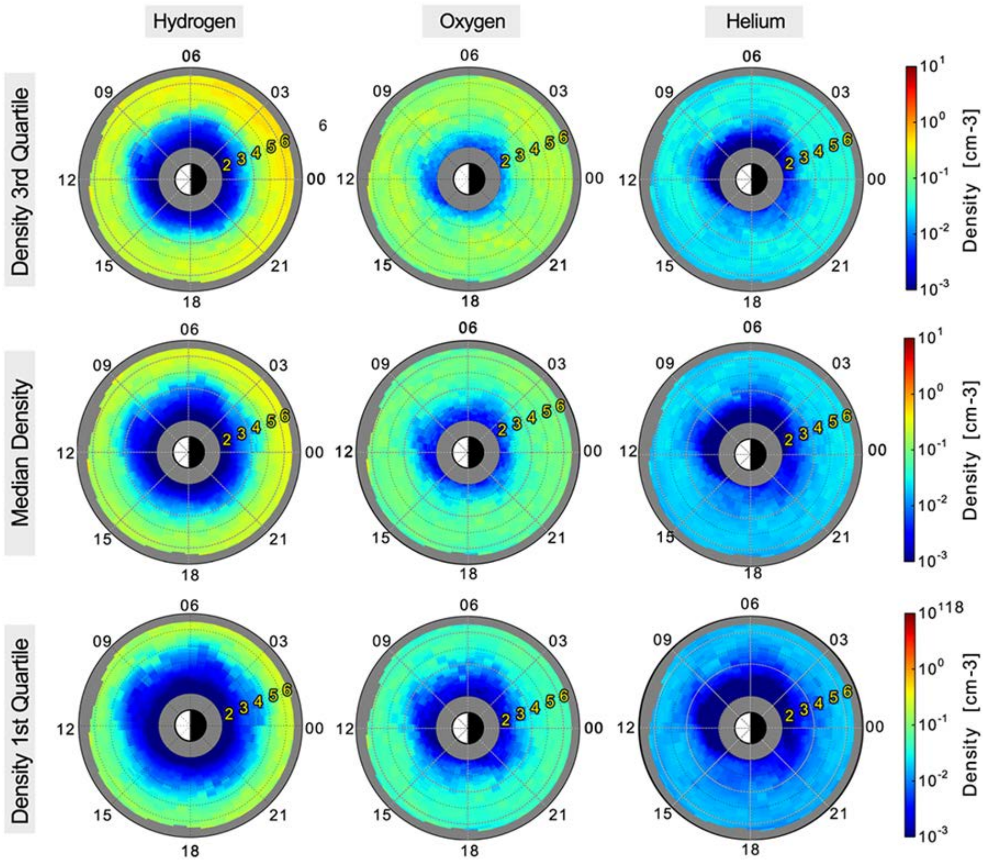
Prior Work to Build on, or Validate SPM Use of HOPE Data

Fernandes et al., 2017



Journal of Geophysical Research: Space Physics
Volume 122, Issue 9, pages 9207-9227, 4 SEP 2017 DOI: 10.1002/2017JA024160
http://onlinelibrary.wiley.com/doi/10.1002/2017JA024160/full#jgra53765-fig-0005

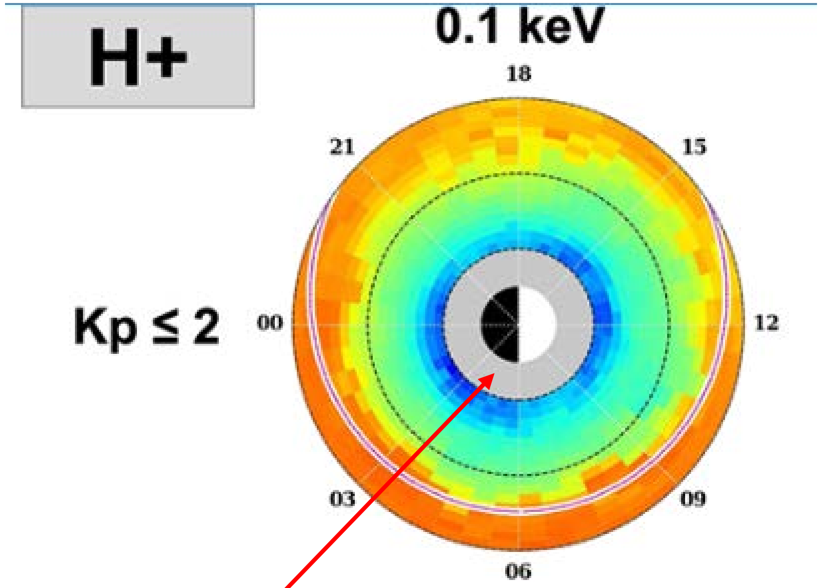
Jahn et al., 2017



Journal of Geophysical Research: Space Physics
Volume 122, Issue 11, pages 11,018-11,043, 6 NOV 2017 DOI: 10.1002/2017JA024183
http://onlinelibrary.wiley.com/doi/10.1002/2017JA024183/full#jgra53817-fig-0004

Inner Belt Plasma?

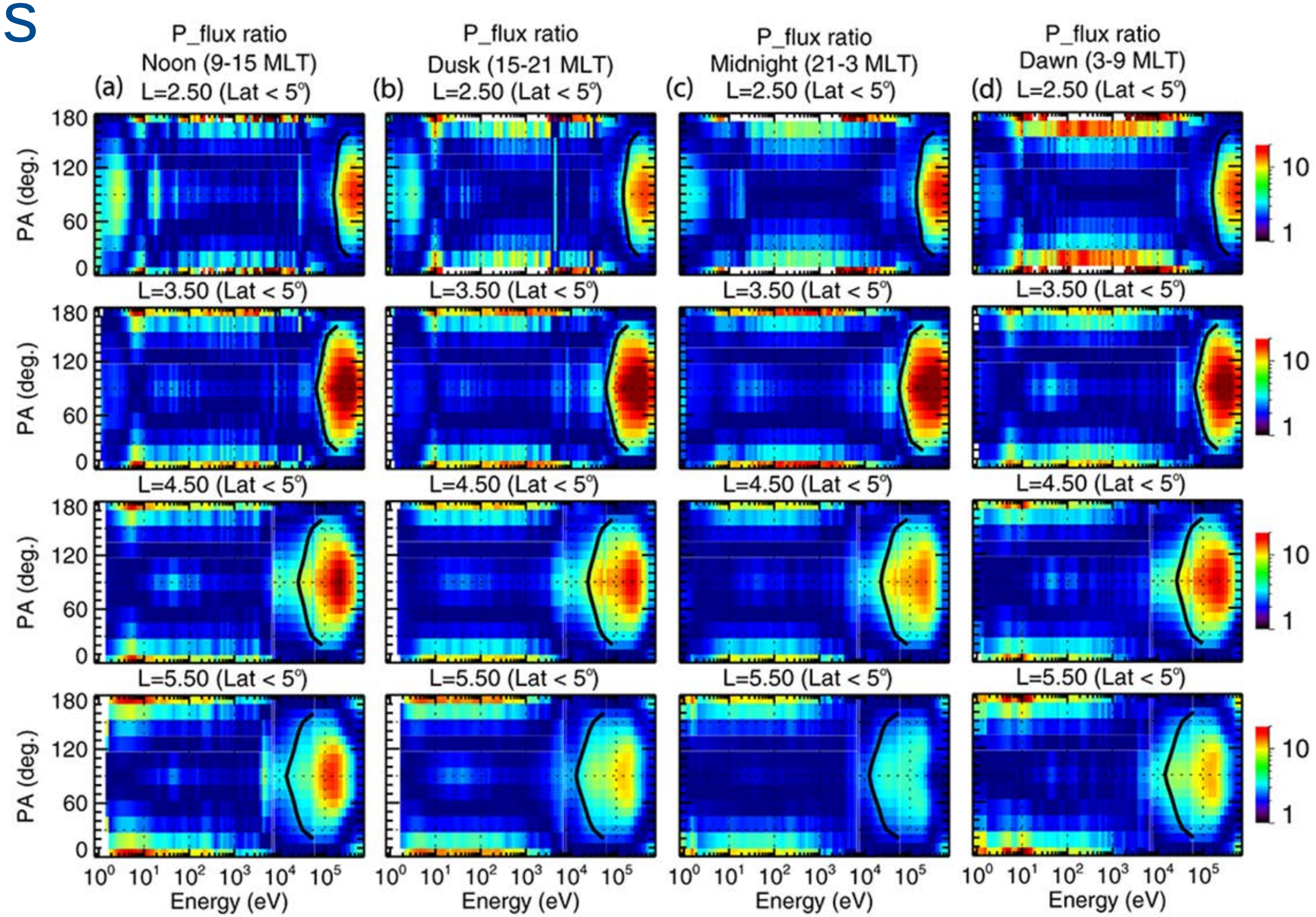
- Much like measuring electrons in a penetrating proton background (MagEIS), cleanly measuring plasma in the inner belt requires hardware designed for such purposes.
- No one has tried this, really.
- Fernandes et al. 2017 excise L<2 for penetrating proton reasons:



Reduction of background counts in HOPE by penetrating radiation is achieved by a combination of shielding and coincidence measurement (through time-of-flight) of plasma ions and electrons that enter the detector subsystem. Background count rates from penetrating radiation are negligible in all regions except in the inner zone, where the random coincidence event rate from penetrating protons, which are identified using regularly reported time-of-flight spectra, can be comparable to the lowest measured event rates from plasma particles during these intervals. $\boxed{\text{This study examines } L \geq 2\text{, which lies outside this region.}}$ For this survey, we

Pitch Angle Distributions

- By combining HOPE and RBSPICE, Yue et al. have determined characteristic pitch angle distrubutions from 1 - 600 keV for protons.
- Yue et al. have normalized the fluxes, but we could omit that step.
- Again uses MLT as a primary dimension.



Journal of Geophysical Research: Space Physics
Volume 122, Issue 9, pages 9464-9473, 21 SEP 2017 DOI: 10.1002/2017JA024421
http://onlinelibrary.wiley.com/doi/10.1002/2017JA024421/full#jgra53799-fig-0002

The Role of Ring Current Simulations

- In order to derive the spatio-temporal covariances necessary to drive Monte-Carlo scenarios using SPM, we need far more data than we have.
- Ring current simulations can fill this role.
  - Long term simulations of the ring current can be used to derive cross-L, cross-Energy, cross-Pitch Angle, cross-MLT and time-lagged covariances in SPM fluxes.
  - There are a few groups with capable models to attempt this.

Simulations can fill an important gap in the SPM models

The future of the IRENE Plasma Model

- Van Allen Probes / HOPE data is highest next priority
  - Collaboration is essential on data interpretation.
- Add modules, with SPM/MLT as a first attempt.
- New datasets with composition are needed
- Simulations can play a unique role enabling plasma Monte-Carlo scenarios.