The Role of the Plasmasphere in Radiation Belt Particle Energization and Loss

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Ph.D. Research Proposal

12 September 2007

Outline

- Background
  - plasmasphere, LIT, radiation belts
- Instruments
  - DMSP, IMAGE, SAMPEX
- Method and Initial Results
  - use of DMSP observations of LIT to identify plasmapause
  - map plasmapause locations to equatorial plane
  - compare with IMAGE plasmapause observations
  - statistical studies in combination with SAMPEX observations
- Continuing Research
- Conclusion

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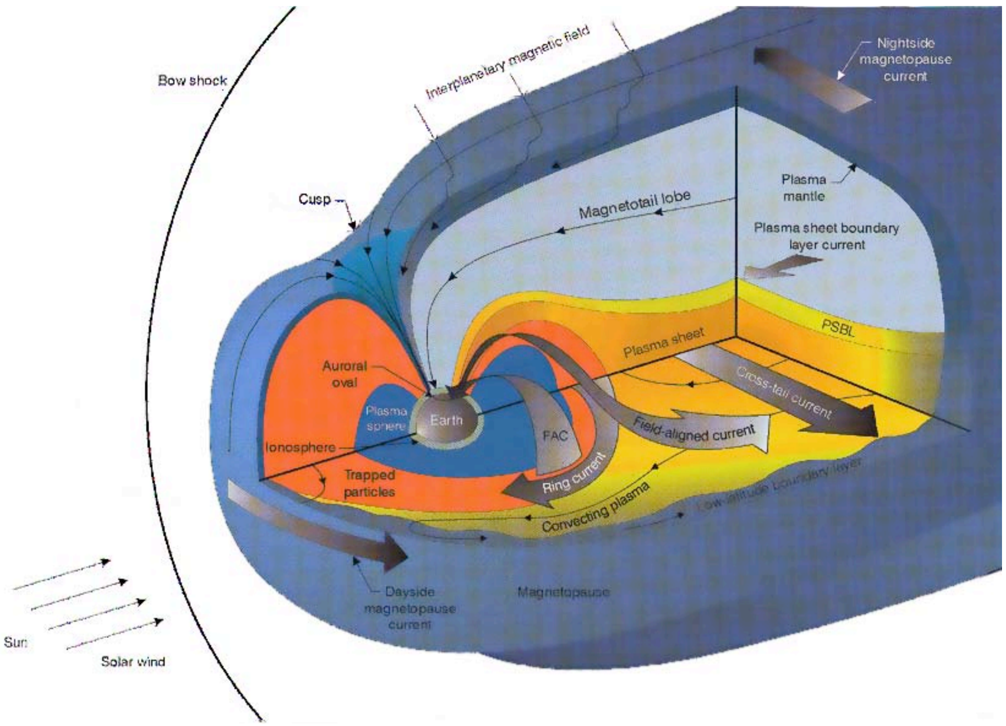
Magnetosphere

- Magnetosphere results from interaction of Earth's B field, solar wind/IMF
  - magnetotail: sunward convection, dawn to dusk crosstail electric field
  - inner magnetosphere: region of closed field lines, corotating B/E fields



IRF web site

Plasmasphere

- Plasmasphere --- a torus of cold (~1 eV), dense (10-10^3 cm^{-3}) plasma trapped on field lines in corotation region of the inner magnetosphere
  - outer boundary (plasmapause) tends to correlate with inner boundary of outer radiation belt
  - typically extends to L=3-5, but can be very structured and dynamic
  - mostly H^+, 5-10% He^+

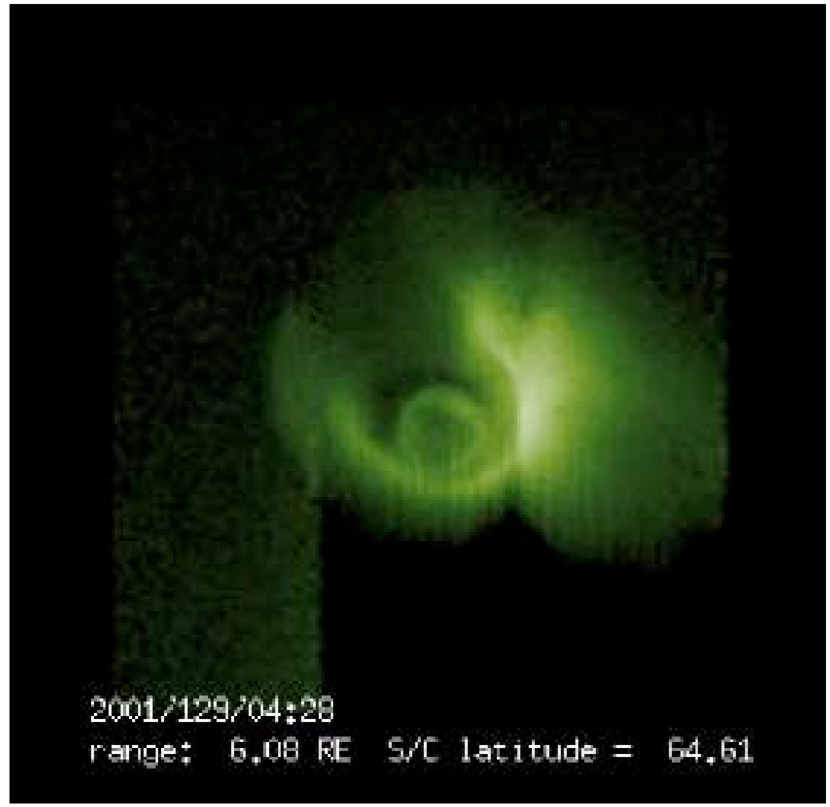
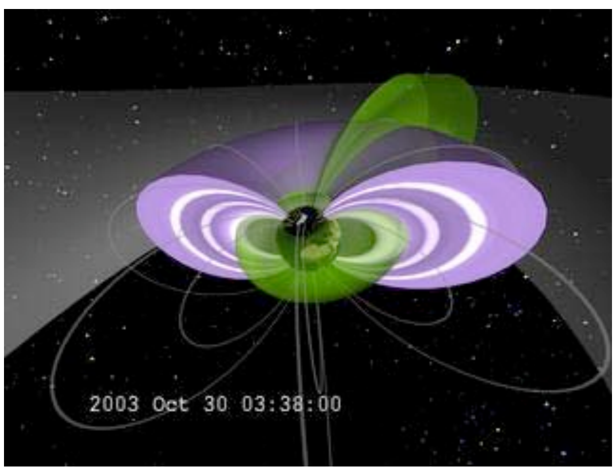


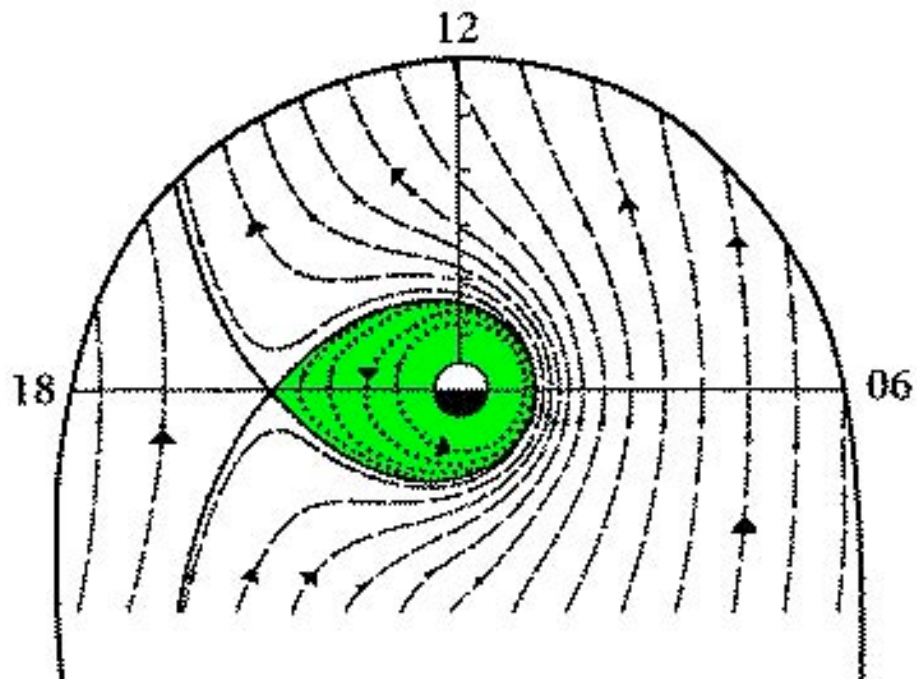
IMAGE EUV web site



NASA/GSFC web site

Plasmasphere in steady-state

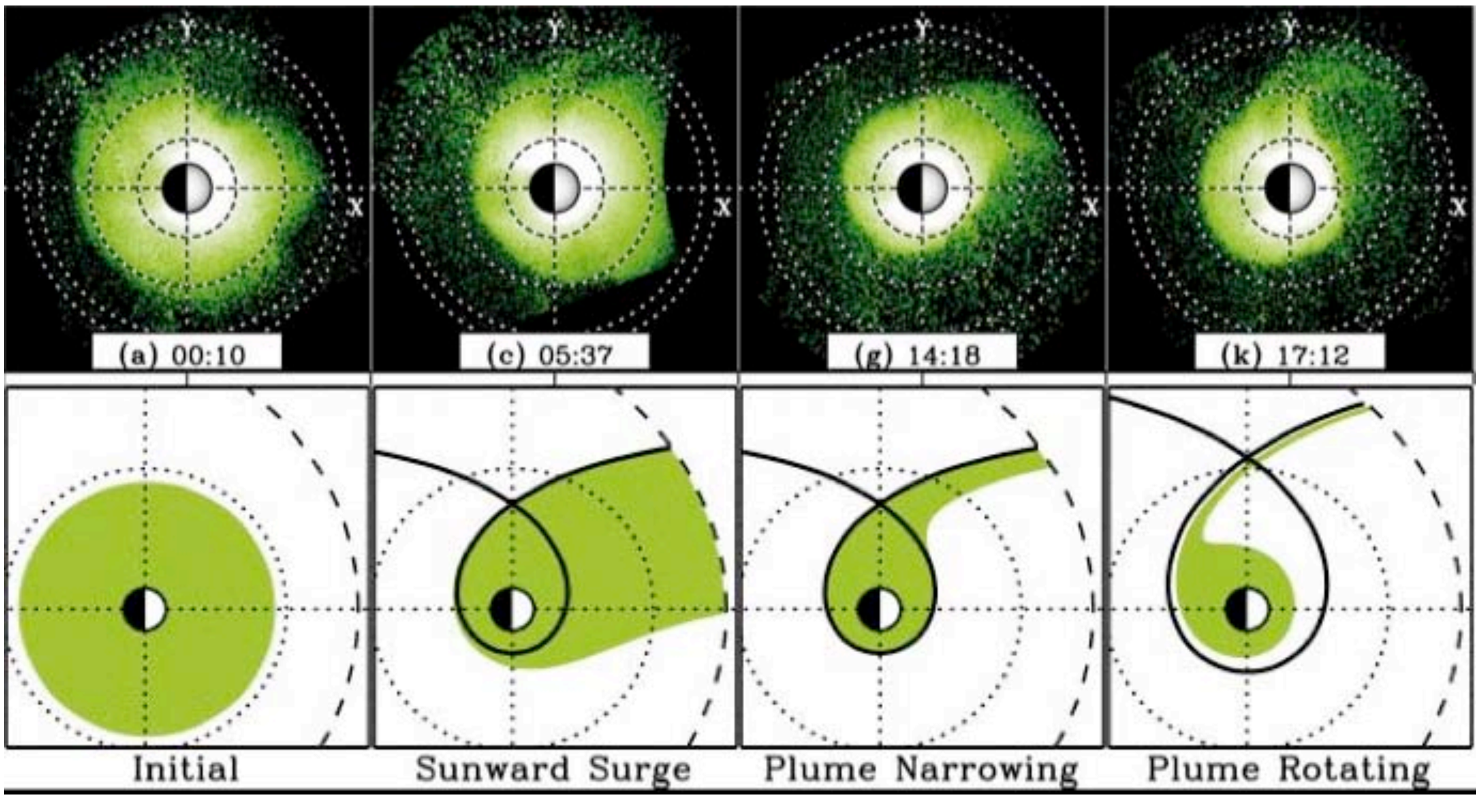
- Consider cross tail E-field plus corotation E-field
- Result is a region of closed equipotentials containing closed B field lines (Nishida, 1966, *JGR*, 71:5669; Brice, 1967, *JGR*, 72:5193)
- Plasmapause at L where $E_T = (B_0/L^3)\ L\ R_E\ \omega$
- Inside, flux tubes fill with plasma escaping from ionosphere
- Outside, flux tubes convect to magnetopause and empty



after Kavanagh et al., 1968

Plasmasphere in stormtime

- Stronger convection field -> contraction, emptying (hours)
- Weaker convection field -> refilling (days)
- Plasmapause location depends on history, not just convective E-field



Goldstein (2004) ORBITALS workshop

Plumes and notches

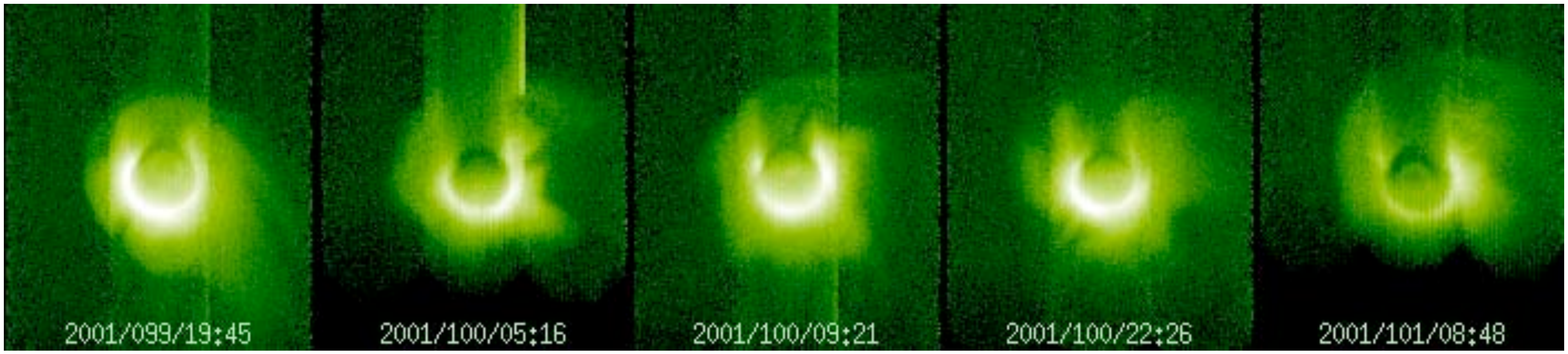


IMAGE EUV web site

- Plumes--observed on duskside during erosion phase
- Notches--radial depleted regions, lifetimes up to 60 hours, tend to slightly sub-corotate (Gallagher et al., 2005, *JGR*, 110:A09201)

Plasmapause signatures in ionosphere

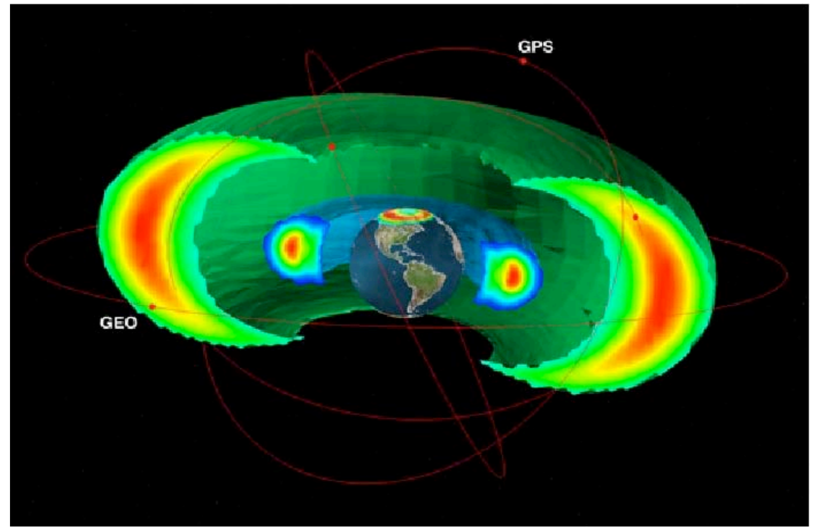
- Several ionospheric signatures of the plasmapause have been proposed, including:
  - midlatitude electron density trough - TEC - SETE
  - precipitating electron boundary - LIT - SARS
- Generally not a one-to-one correspondence between any of these and the plasmapause
- Light ion trough (LIT) is proposed as one of the more consistent signatures (Taylor and Walsh, 1972, *JGR, 77*:6716; Horwitz et al., 1990, *JGR, 95*:7949)
- Some have found the LIT tends to be equatorward of other plasmapause identifications, plus a possible LIT-plasmapause mismatch on the duskside (Foster et al., 1978, *JGR, 83*:1175; Grebowsky et al., 1978, *PSS, 26*:651)

Light ion trough

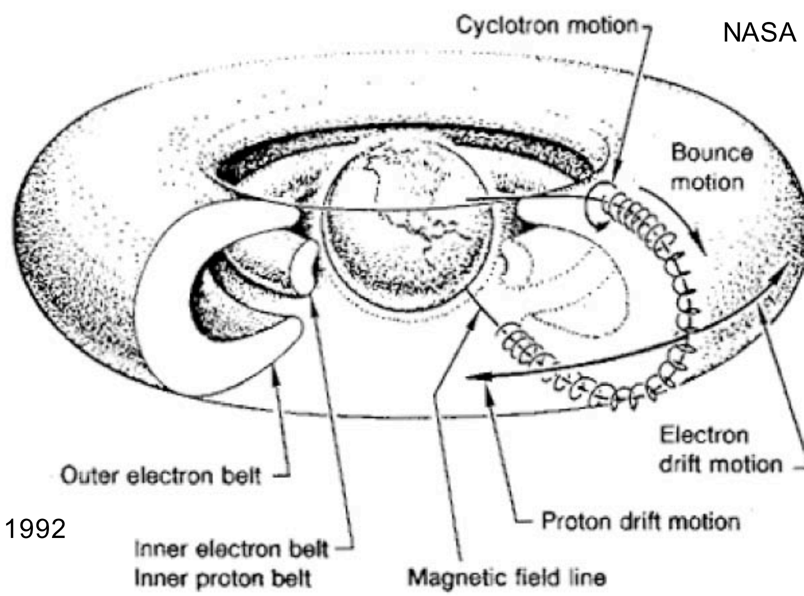
- The light ion trough (LIT) is a steep latitudinal gradient in ionospheric H^+/He^+ density near equatorial edge of auroral zone
- Simple model associates LIT with plasmapause:
  - ionospheric H^+ escapes from atmosphere due to large scale height/thermal velocity
  - equatorward of LIT, escaping light ions saturate closed flux tubes, forming the plasmasphere
  - poleward of LIT, light ions are on flux tubes that eventually empty through the magnetopause
- Reality is more complicated:
  - temperature gradient associated with LIT produces change in scale height: density gradient may not be on same field line as plasmapause
  - LIT may be generally equatorward of PP due to H^+ outflow, long refilling times for outer PP flux tubes, horizontal E fields (Foster et al., 1978, *JGR*, 83:1175).

Radiation belts

- Radiation belts comprise energetic charged particles (keV to MeV) trapped by the Earth's magnetic field
- Two belts, slot region in between
  - inner belt of electrons/ions, very stable
  - outer belt of electrons, very dynamic
- Trapped particles have three types of periodic motion
- Steady-state radiation belts are a dynamic balance of various sources, diffusion mechanisms, and losses
  - including a variety of wave-particle interactions



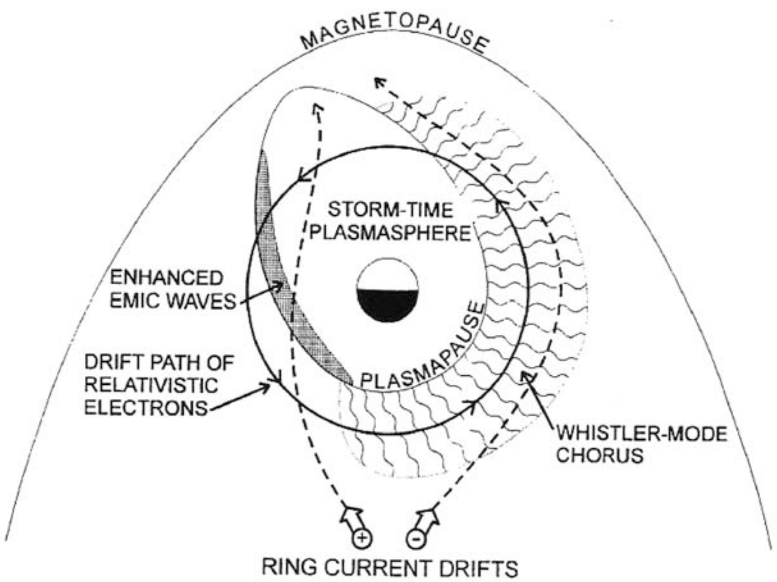
NASA web site



McKay et al., 1992

Plasmasphere-radiation belt connection

- Plasmapause (PP) correlates with inner edge of outer radiation belt
- Wave-particle interactions are proposed as the casual link:
  - stormtime EMIC waves inside duskside PP scatter radiation belt particles into loss cone, rapidly depleting outer belt
  - whistler-mode chorus outside PP energizes radiation belt particles over multiple orbits, slowly repopulating belt (Summers et al., 1998, *JGR,* 103:20487)



Summers et al., 1998

Instruments

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DMSP

- DMSP satellites: sun-synchronous circular orbits near 840 km alt., 101 min. period, 99° inclination
- 3-4 satellites in operation continuously over 10+ years
- Plot illustrates polar coverage in one day from four DMSP satellites (F11-F14) in MLAT-MLT
  - provides ~50% MLT coverage at 40°, ~75% coverage at 60°
- Instruments include
  - Retarding Potential Analyzer providing ion density, composition, temperature
  - Ion Drift Meter providing cross track ion velocity
  - SSJ/4 providing energy spectra/flux of precipitating electrons and ions

DMSP Coverage October 19, 1998

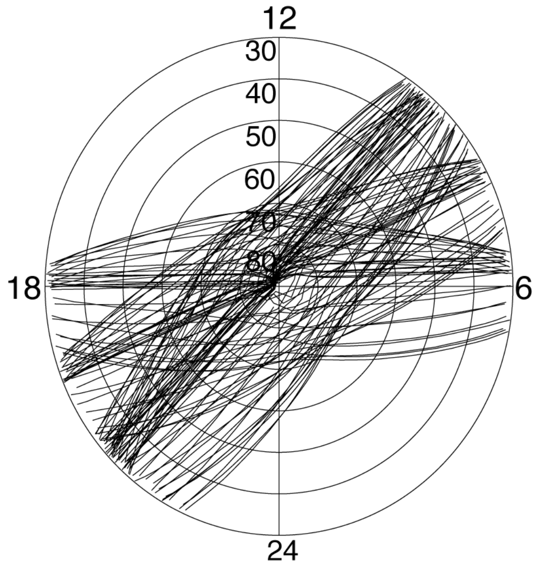
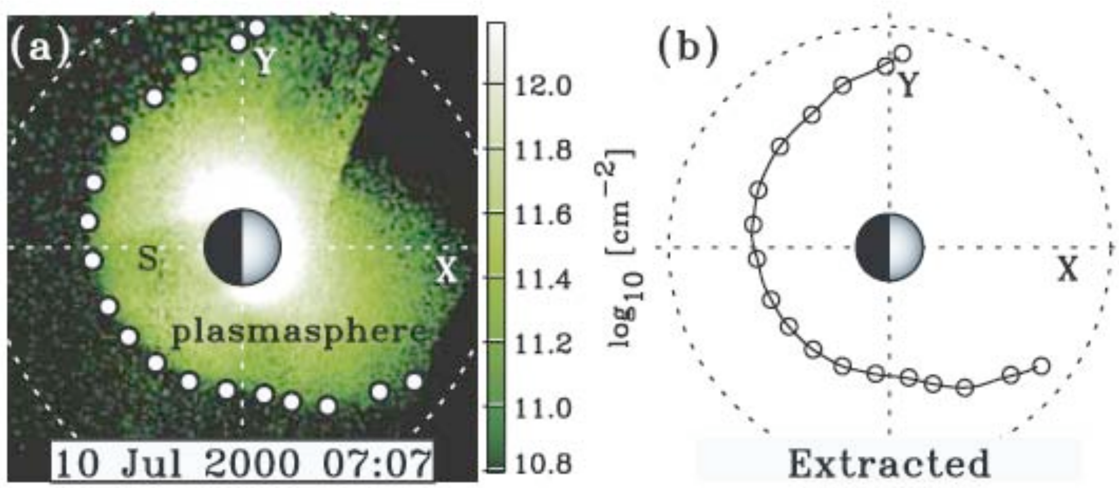


IMAGE EUV

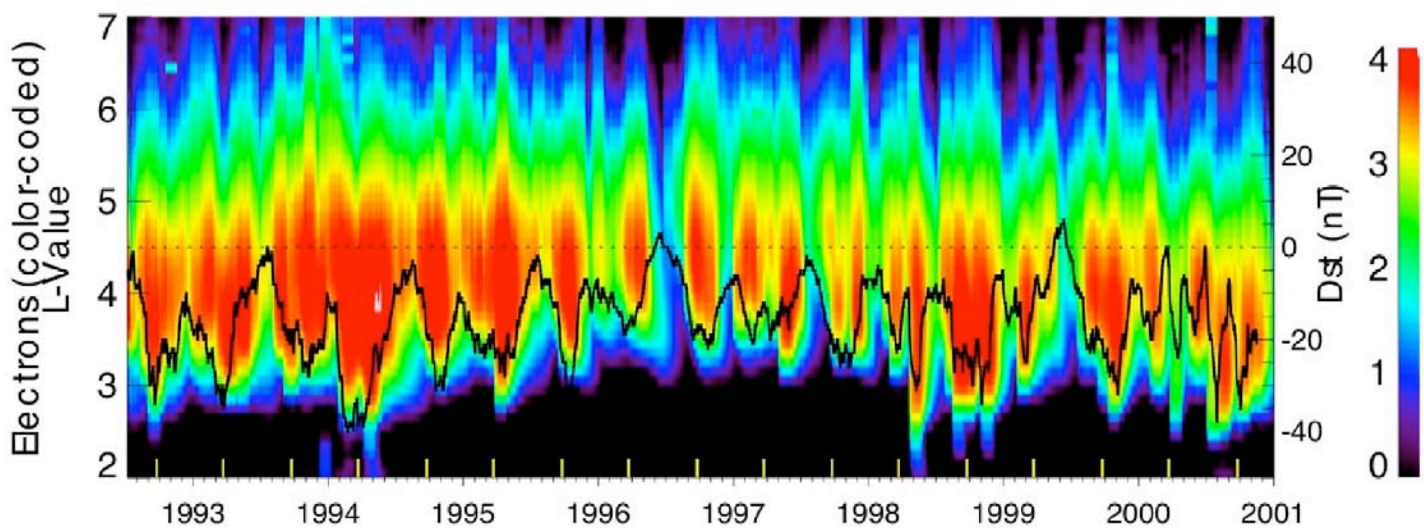
- IMAGE spacecraft:
  - eccentric polar orbit, from 1400 km alt. to 8 R_E
  - operational 3/2000 to 12/2005
- EUV imager
  - directly imaged 30.4 nm UV scattered by He^+
  - could image plasmasphere by its He^+ component
- Sample of extracted plasmapause locations from reprojected EUV image (from J. Goldstein)--



Goldstein et al., 2004

SAMPEX PET

- SAMPEX spacecraft:
  - LEO (500-620 km), polar
  - operational 7/1992 to present
- Proton/Electron Telescope (PET)
  - has series of eight solid state detectors
  - detects energetic electrons (0.4-30 MeV) and H^+/He^+ (18-250 MeV)
- SAMPEX provides pitch angle information only when in spin mode
  - this mode periodically 5/1996-5/1998, 12/1999-2/2000
- Sample spectrogram of SAMPEX electron observations with Dst--



Li et al., 2001

Method and Initial Results

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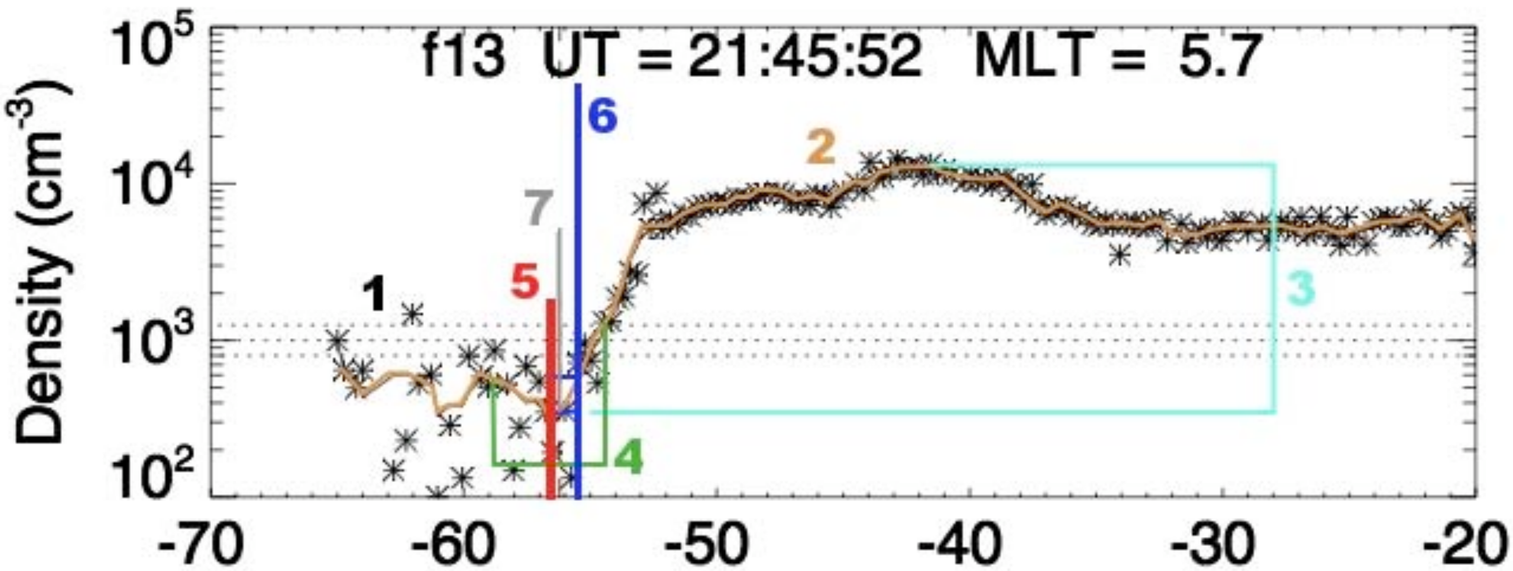
Method and Initial Results

- Initial results from two case studies:
  - 1 day, 18 June 2001 (day 169)
  - 72 days, 21 March-31 May 2001 (days 80-151)
  - these periods selected to match availability of processed IMAGE data (J. Goldstein)

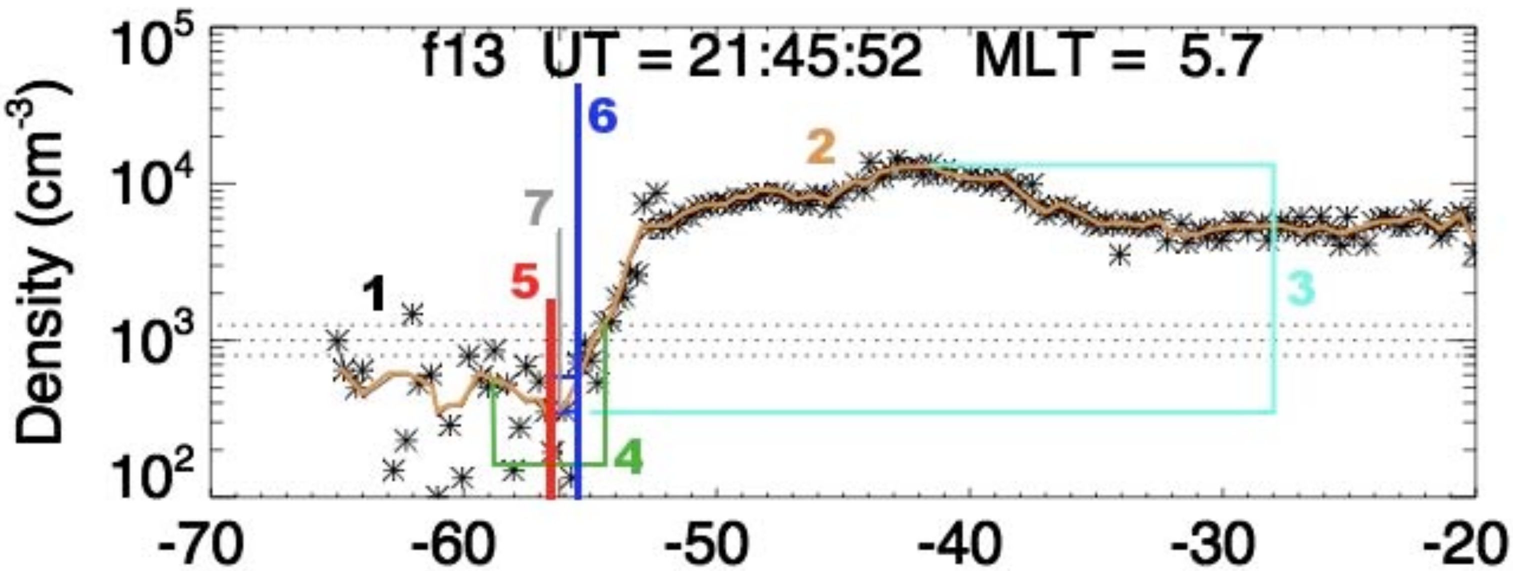
Method: algorithm for LIT ID

- [1] use DMSP [H^+] data from 20-65 deg MLAT N/S
- [2] smooth data with N-pt. average (N=5)
- [3] if maximum dynamic range is less than a factor of 10, ignore pass
- some passes rejected manually (too noisy, no LIT, etc.)



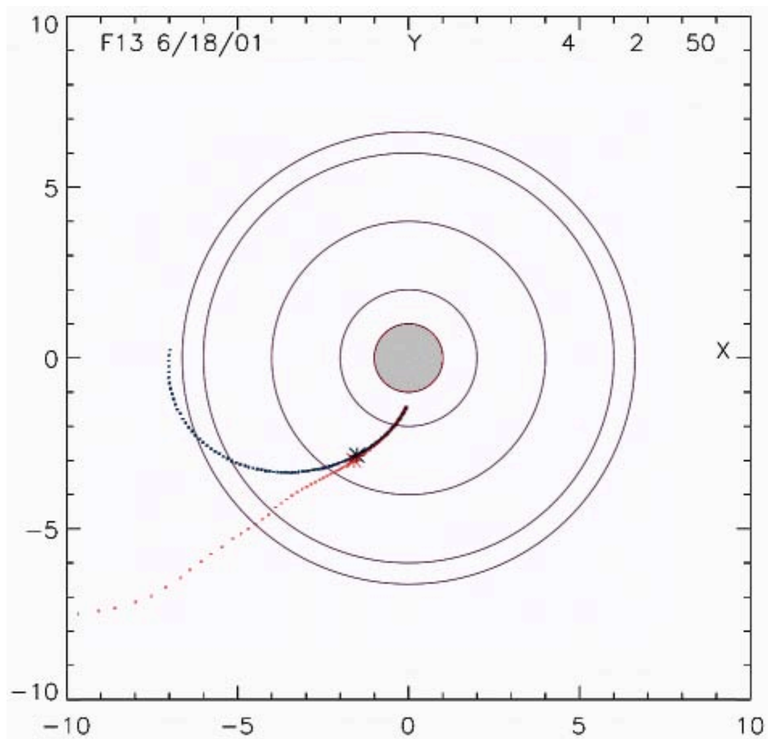
Method: algorithm for LIT ID

- [4] manually select range near LIT minimum
- [5] algorithm picks density minimum within range
- [6] moving equatorward, PP is where density is factor of *F* greater than at minimum (*F*=1.5)
- [7] manually select boundary as check on automatic ID



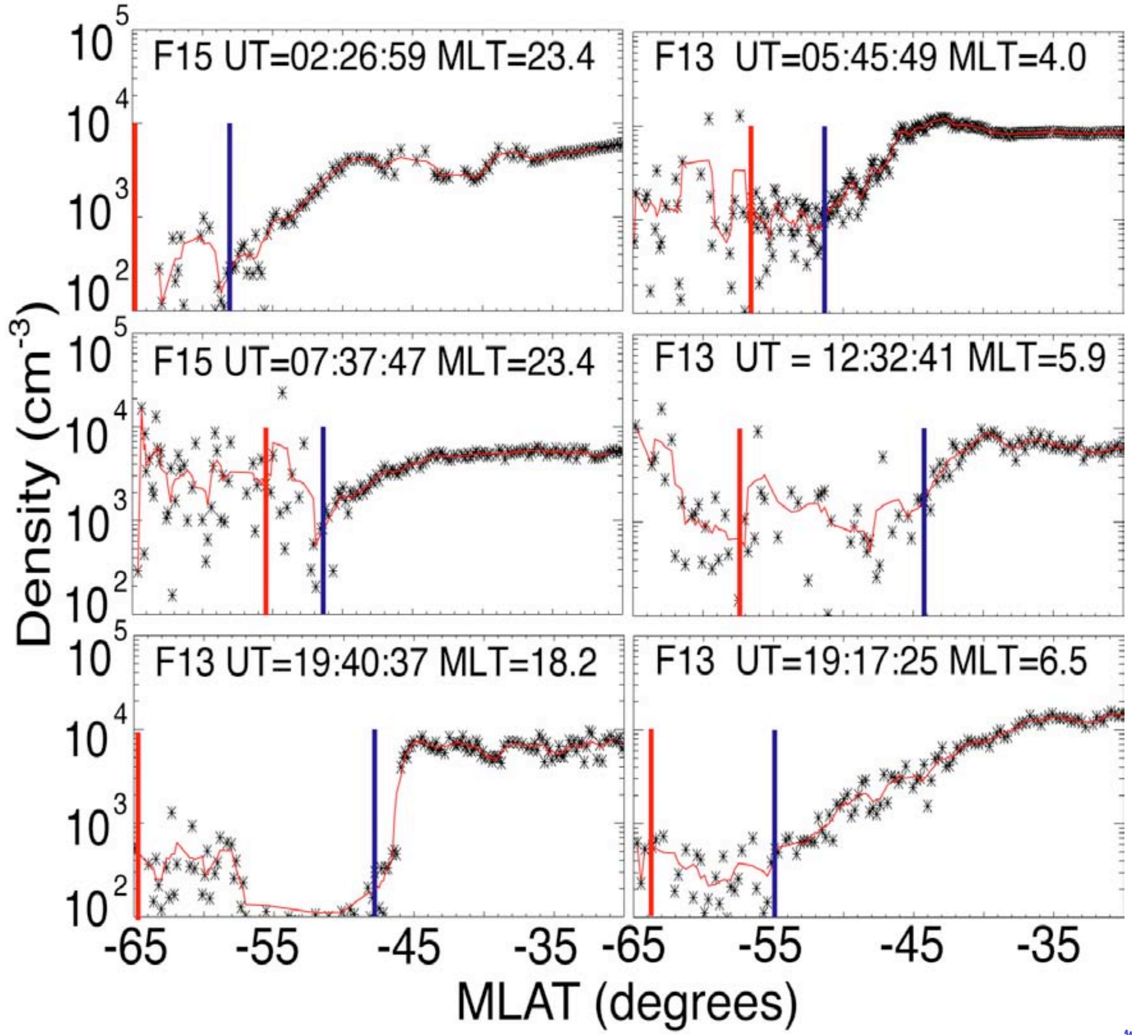
Method: mapping to equatorial PP

- Map plasmapause ID along field lines from DMSP location to high altitude plasmapause
- Use both internal and external fields from GEOPAK
  - internal: IGRF 2000
  - external: Tsyganenko 2001 (with ACE data for input)
- Figure shows orbit track from one DMSP pass mapped to SM X-Y plane with (red) and without (blue) external field



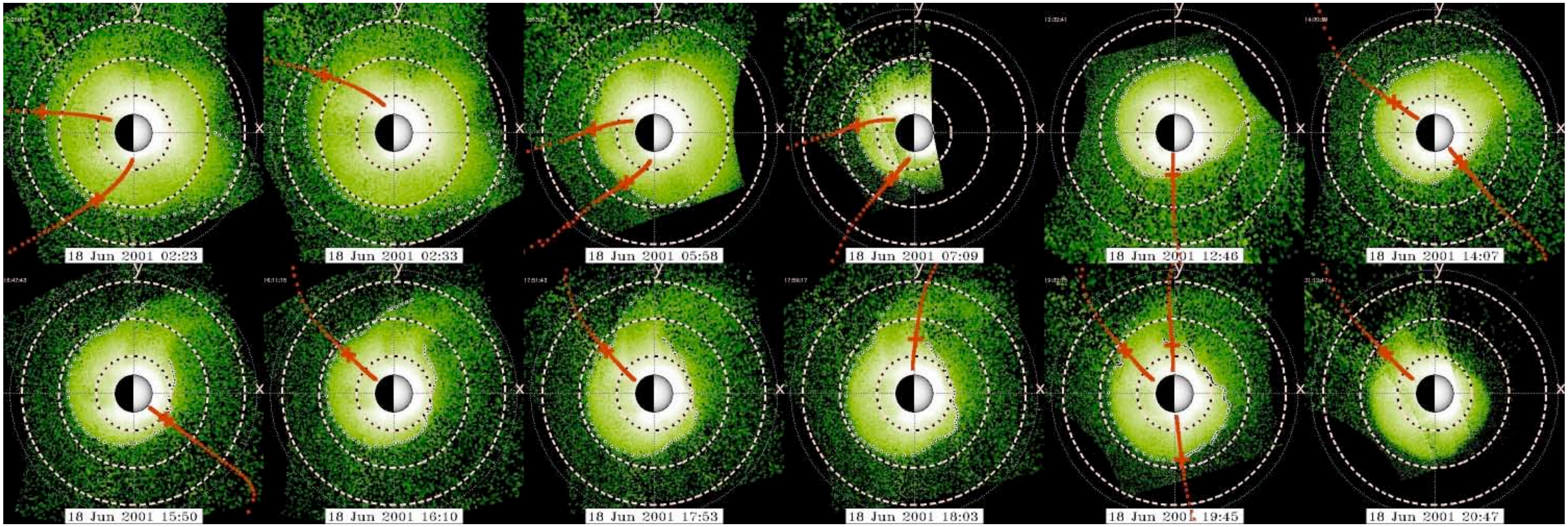
Initial results: LIT identifications

- Plots show DMSP H^+ density vs. MLAT, smoothed density in red
- Vertical red line is equatorward electron precipitation boundary
- Semi-automatic procedure picks PP identification at blue line



Initial results: mapped IDs from 1-day study

- For 18 June 2001, plots show IMAGE EUV images of plasmasphere projected to SM X-Y plane, Sun at right
- Red lines show mappings of DMSP orbit track to SM X-Y plane, red cross shows identified plasmapause



Initial results: IDs from 72-day study

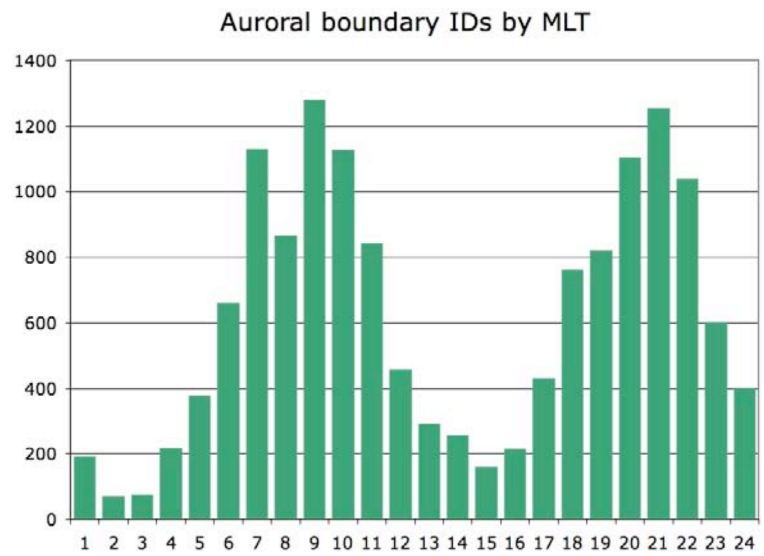
- Statistics for 72-day study (2001 days 80-151):

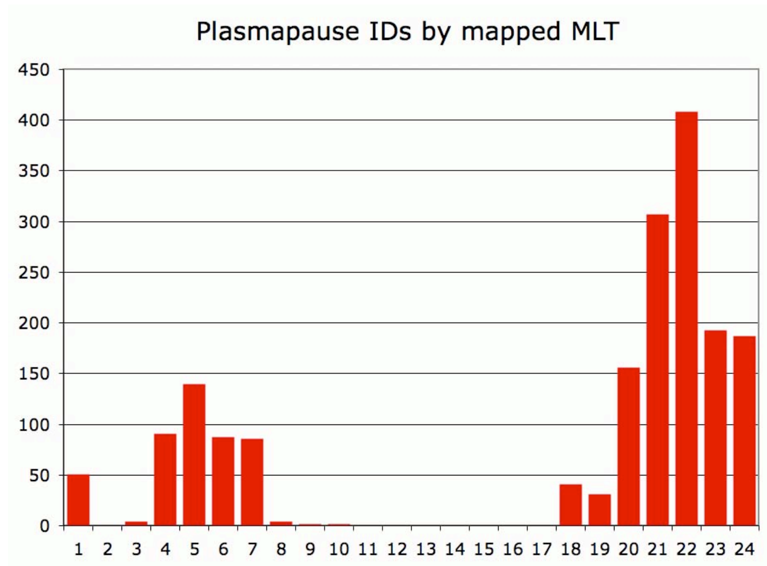
all passes	14,894 (100%)
rejected by program (dynamic range too low)	8,286 (55.6%)
rejected manually before analysis (data too noisy, no visible LIT)	4,631 (31.1%)
rejected manually after analysis (>2 deg difference from manually chosen ID)	187 (1.3%)
retained plasmapause IDs	1,790 (12.0%)

- Average of 25 plasmapause IDs per day (range 0-47)

Initial results: IDs from 72-day study

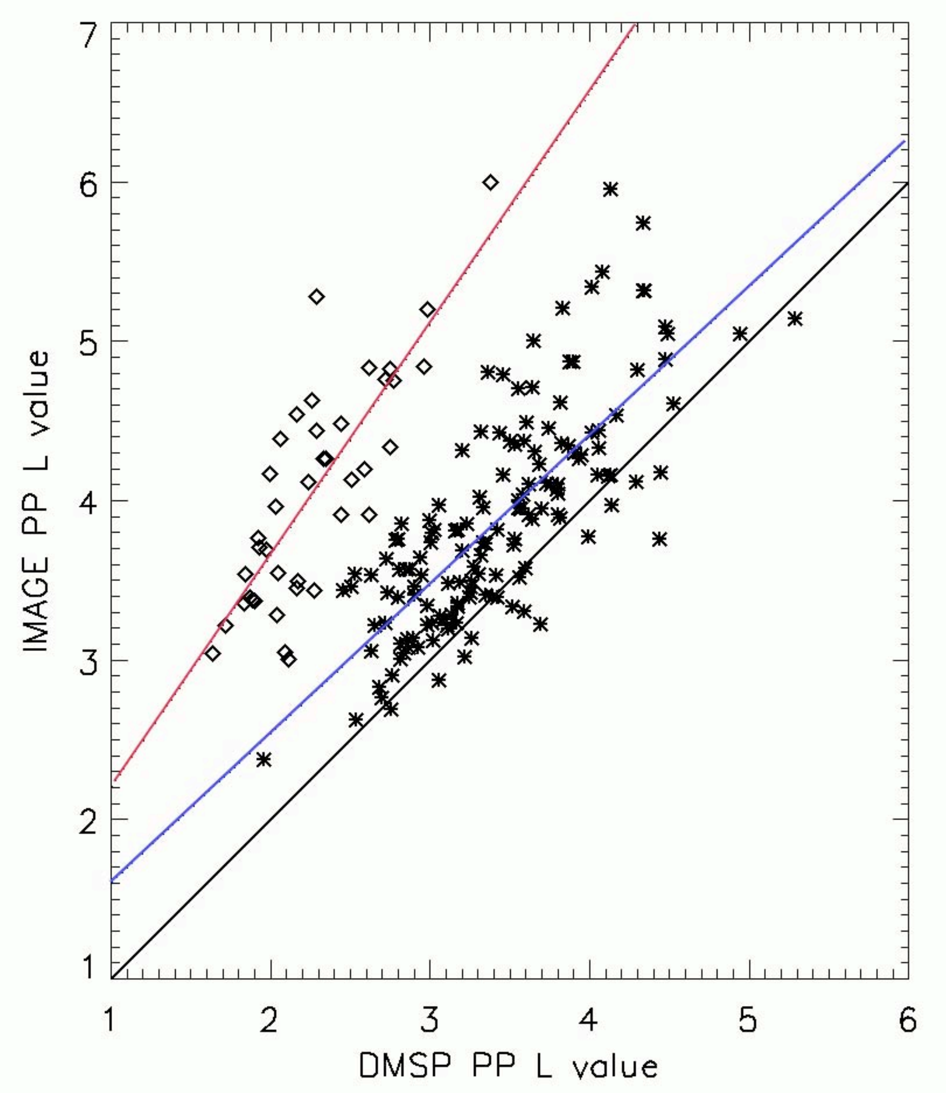
- DMSP orbit orientation imposes preferred MLT distribution
  - dusk-dawn or 0930-2130 at equator
- For LIT to be identified, must be above O^+ transition height and have >~5% H^+
  - winter and/or nightside passes preferred
- Magnetic fields lines at high altitudes tend to be stretched anti-sunward
- Results--preferred locations for equatorial mappings of PP IDs





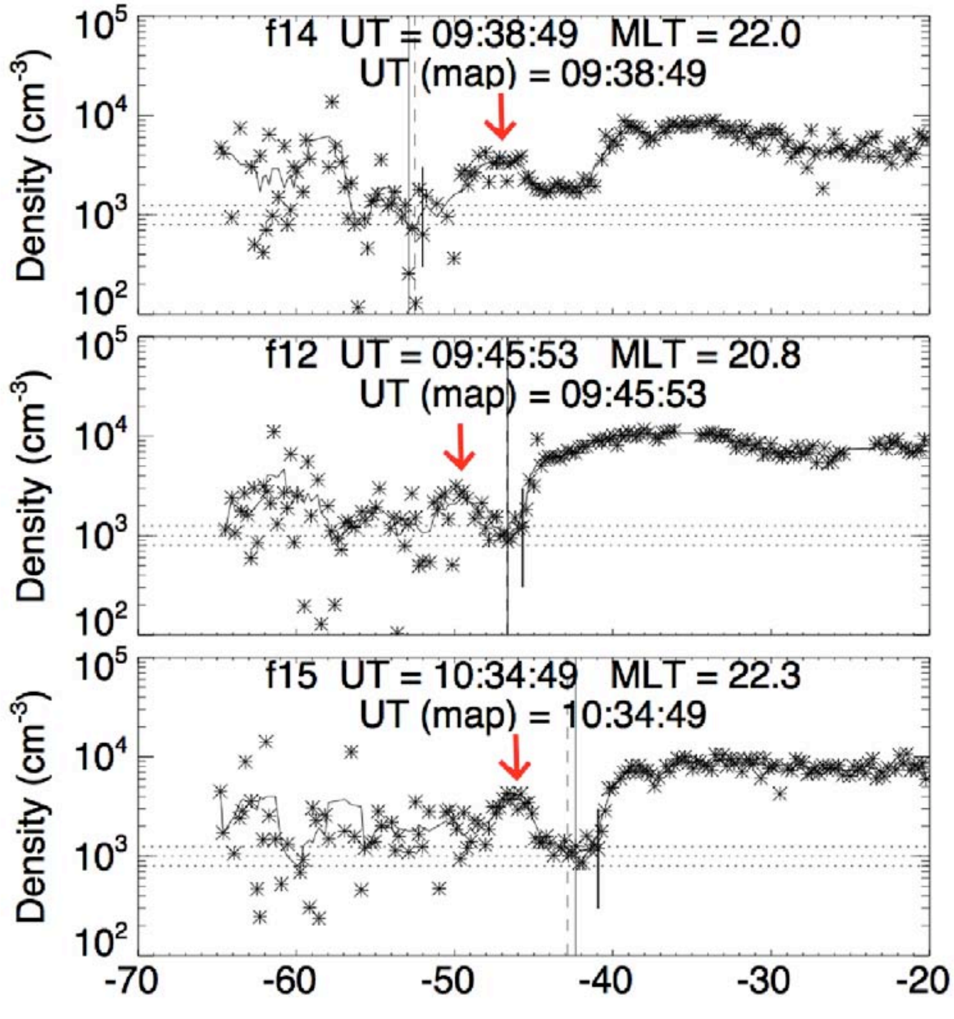
Initial results: comparison to IMAGE

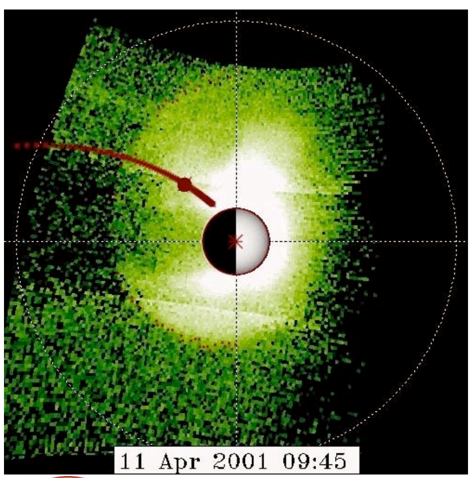
- 72-day study yielded 187 comparisons to IMAGE
- two clusters in data:
  - good match cluster, N=147 (79%), mean difference ~0.5 L
  - mismatch cluster, N=40 (21%), mean difference ~1.7 L
- examination of mismatches suggests DMSP method is observing plasmasphere structures (plumes, notches, etc.)

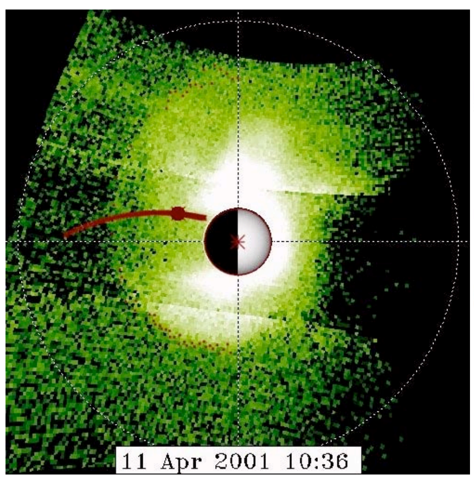


Initial results: mismatches day 101

- day 101: 6 mismatches
- three density plots (2 mismatches, 1 good) show structure, possible plume
- IMAGE EUV images suggest some density structure within the outermost density gradient

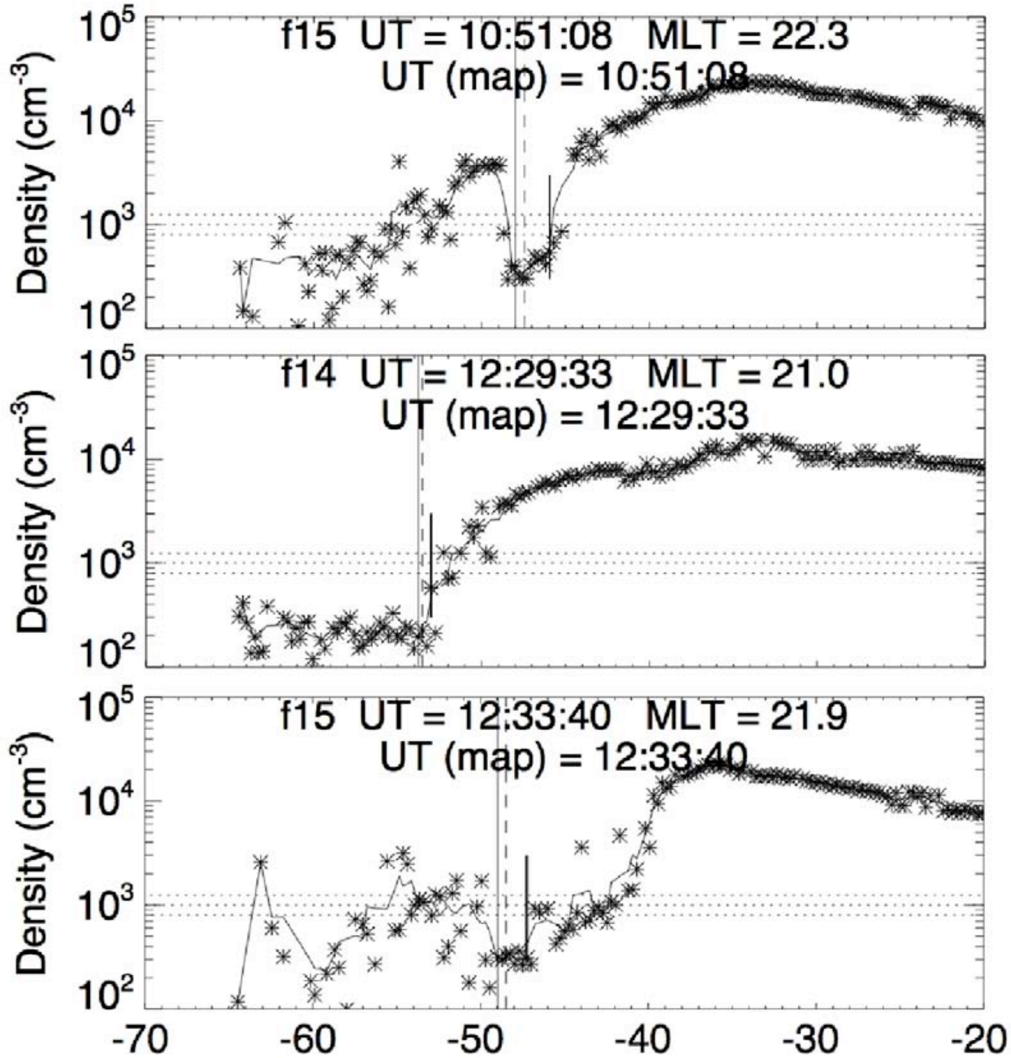


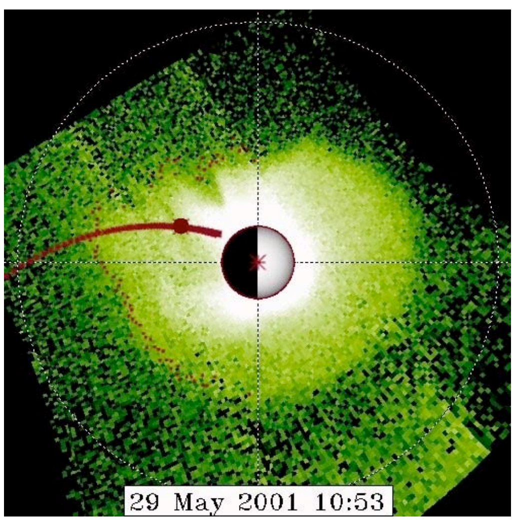




Initial results: mismatches day 149

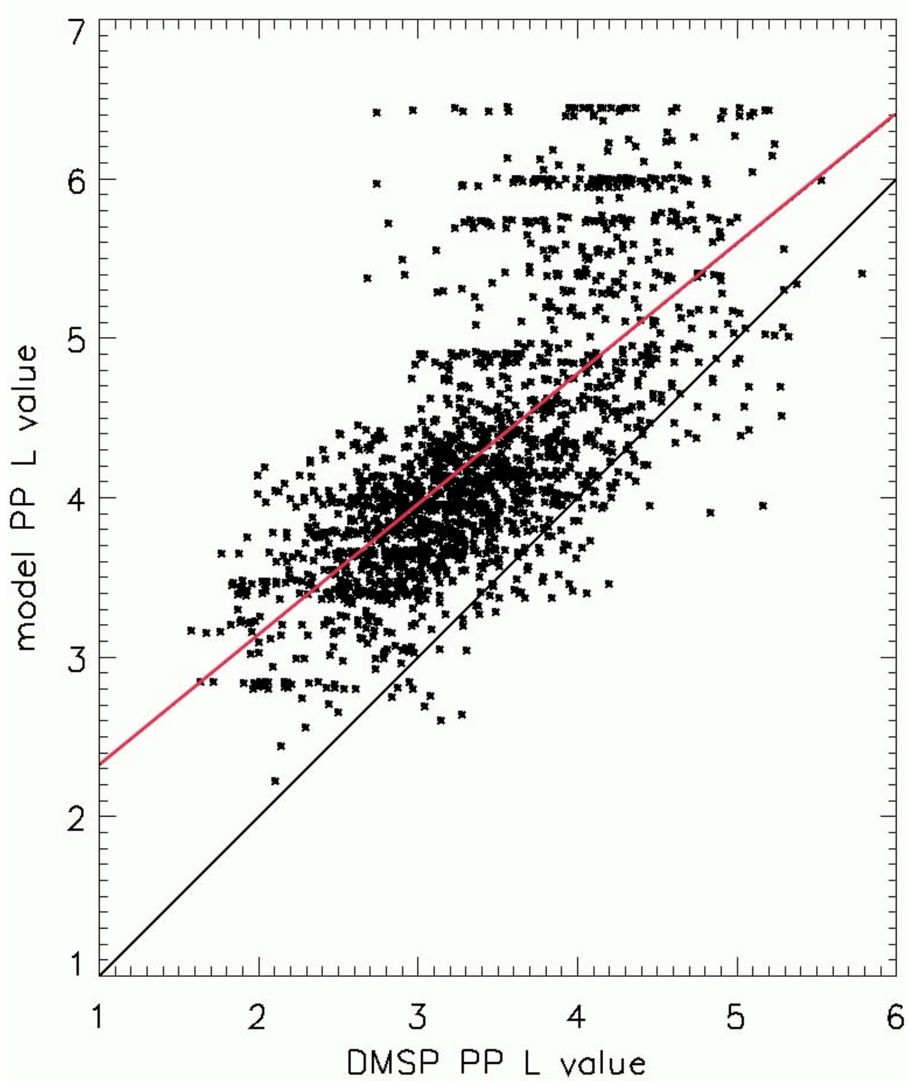
- day 149: 2 mismatches, several good matches at nearby times/MLTs
- several DMSP density plots show structure
- IMAGE EUV image clearly shows one notch
- appears that some DMSP passes mapped to inside of notch, some to outside





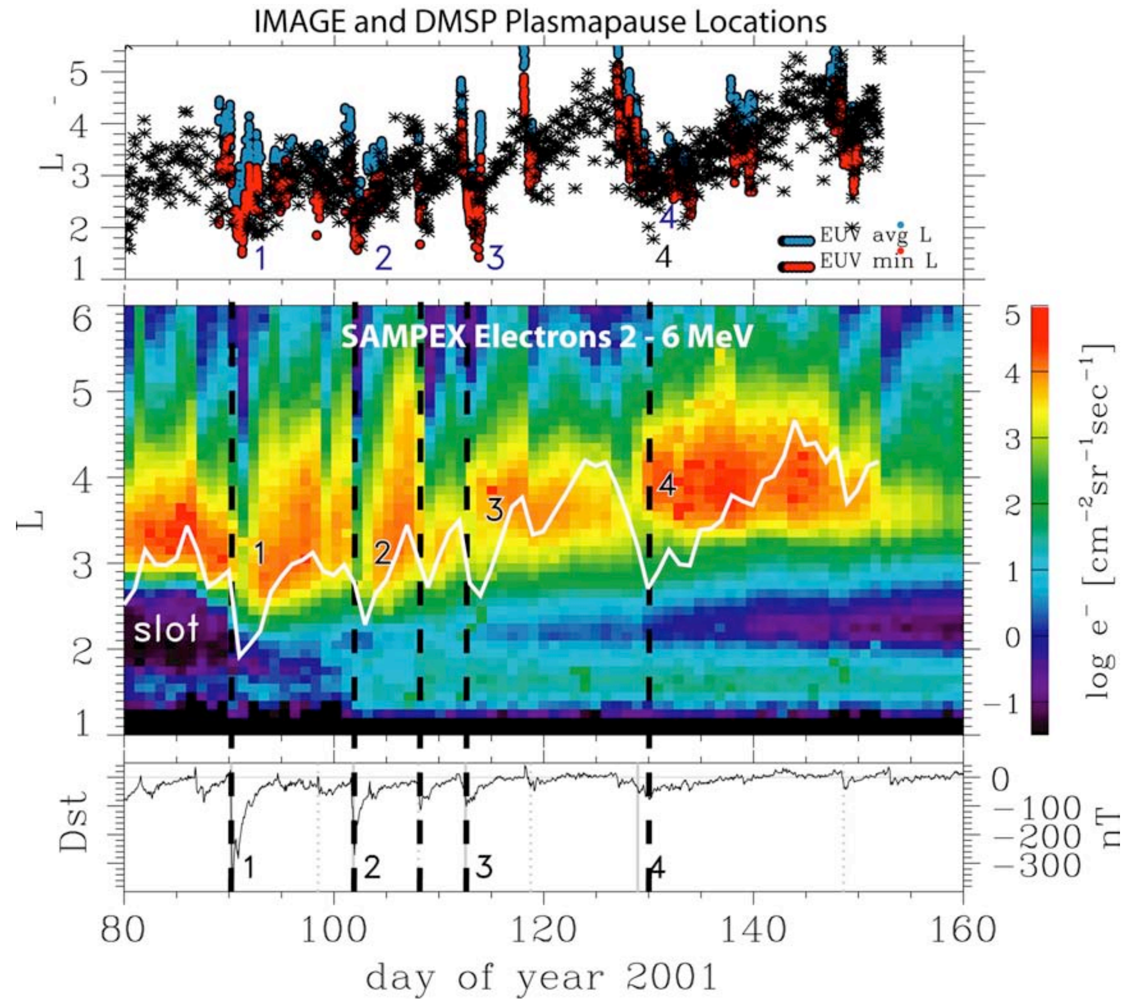
Initial results: comparison to PP model

- comparison to O'Brien-Moldwin model (2003, *GRL*, 30:1152), parameterized by Dst and MLT
- for lower L, model PP is about 1 L value greater than DMSP PP
- for L>~4, results diverge
  - model may not extend to Dst ~ 0; DMSP ID method may have difficulty with diffuse plasmapause



Initial results: comparison to SAMPEX

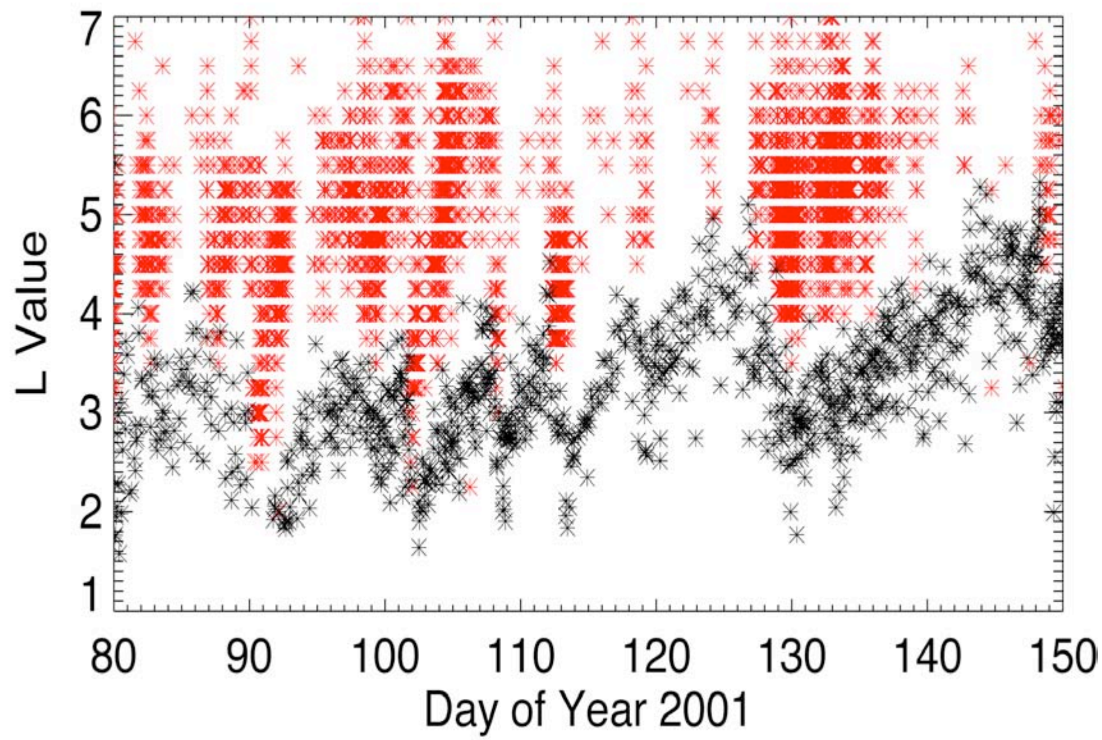
- Using 1790 plasmapause IDs from 72-day study
- top: PP IDs from DMSP (black) compared to IMAGE
- middle: daily average of our PP IDs (white) compared to SAMPEX electron flux
- Correlation in PP movement and Dst, movement of inner edge of outer radiation belt



base image from Goldstein et al., 2005

Initial results: comparison to SAMPEX

- red: SAMPEX-identified microbursts
  - microbursts are short (~1 s) bursts of precipitating relativistic electrons observed at low altitudes; found associated with whistler chorus (O'Brien et al., 2003, *JGR,* 108:1329)
- black: all DMSP-based plasmapause IDs
- shows strong correlation in radial dynamics



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Continuing Research (1)

- LIT identification algorithm
  - make the process more automated
  - revise selection criteria
- mapping to equatorial plasmapause
  - automate processing of ACE source data
  - investigate possible sources of propagated data
- comparisons to IMAGE, other datasets
  - complete examination of 72-day study comparisons
  - compare to other IMAGE data as available
  - possible comparison to POLAR in situ observations of high altitude plasmapause (limited to coincident observations on same field line)

Continuing Research (2)

- build multi-year database
  - potentially over 100,000 PP IDs for 10+ years (one full solar cycle)
- statistical studies using plasmapause IDs and SAMPEX observations
  - case studies/epoch analyses
  - long-term correlation/time offset analyses
  - correlation studies for loss cone populations/microbursts
  - possible data assimilative studies

Continuing Research (3)

- case studies/epoch analyses
  - average PP/radiation belt response to stormtime perturbations
- statistical comparison of mean PP, mean radiation belt location with time offset
  - different characteristic response times for erosion/recovery phases
  - can evaluate response times to address PP/radiation belt linkage
- correlate PP location to locations/times where loss cones are populated
  - pitch angle observations available for periods in 1996-1998, 2000
  - correlate PP location to locations of observed microbursts
- combine PP locations with empirical PP model to estimate fractions of electron drift orbits inside/outside plasmasphere
  - interest from LANL RAM team in this
  - prospective theoretical investigation: constraint wave characteristics contributing to particle energization/loss

Plan of work

- fall 2007--complete algorithm; continue comparisons to IMAGE (and POLAR?); continue building database
- spring 2008--conduct case studies of comparisons to SAMPEX
- summer 2008--analyze trends/biases; complete database
- fall 2008--complete database, multiyear statistical study with SAMPEX; finish dissertation
- output:
  - PP database, available for other groups
  - two journal articles (case studies with SAMPEX; long-term statistical study with SAMPEX)
  - one article submitted to *GRL* (Anderson et al., 2007)

Conclusion

- We have obtained initial results from a method of identifying the plasmapause using DMSP observations of the LIT.
- Comparisons show good correlation with IMAGE plasmapause IDs and SAMPEX radiation belt flux and microburst observations.
- This approach will be applied to full DMSP database: 10+ years of observations--covering full lifetime of SAMPEX.
- Database will be used for event studies and to statistically analyze correlation of plasmapause-radiation belt dynamics.

Acknowledgements

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- Greg Earle, Marc Hairston, Rod Heelis, Xinchou Lou, Brian Tinsley
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- my wife