Multipoint observations of energetic particle injections from the plasma sheet into the inner magnetosphere

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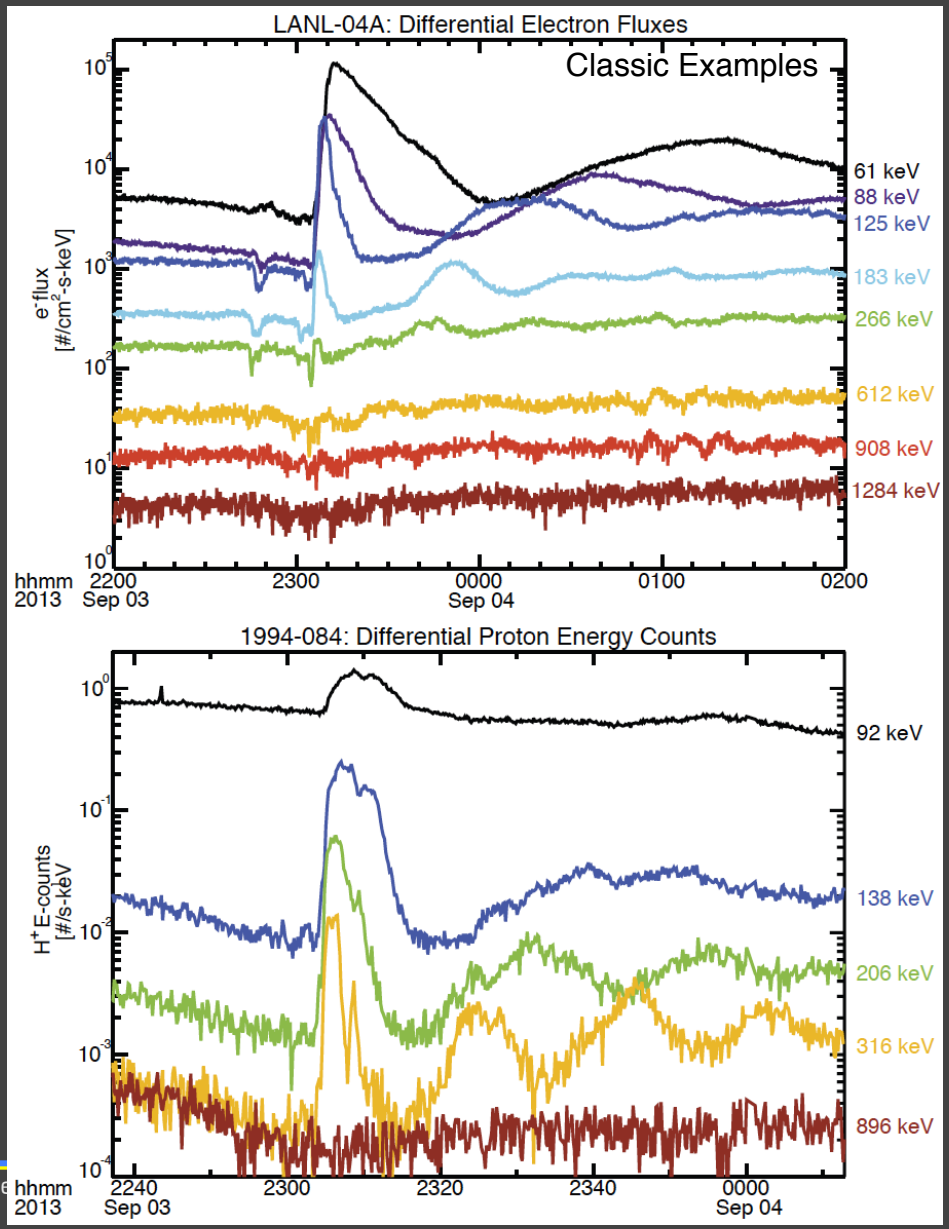
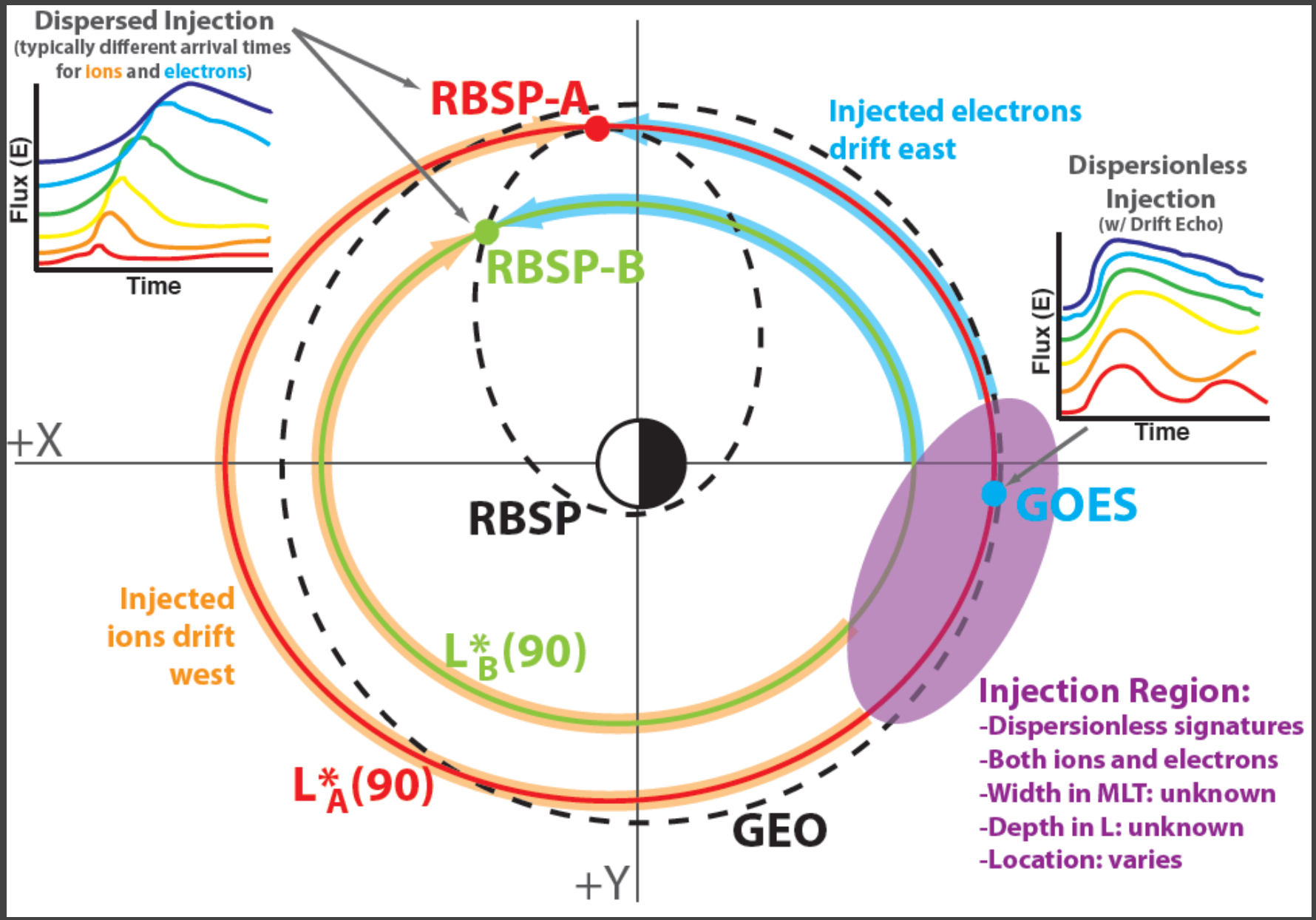
Energetic Particle Injections

- Energetic particle injections are sudden enhancements of 10s to 100s of keV electrons and ions in the plasma sheet and inner magnetosphere associated with substorm activity
- Injected particles are thought to be transported radially inward by plasma sheet electric fields associated with tail reconnection, dipolarization signatures, and substorm activity *[e.g., Reeves et al., JGR 1991; X. Li et al., GRL 2003; Gabrielse et al., JGR 2012; Gabrielse et al., JGR 2014]*
- Injections may be able to introduce up to ~MeV electrons, as was presented in *Ingraham et al. [JGR 2001]*
- It is critical to better understand these events and include these events and their effects in improved global models [e.g., *Yu et al., GRL, 2014*]

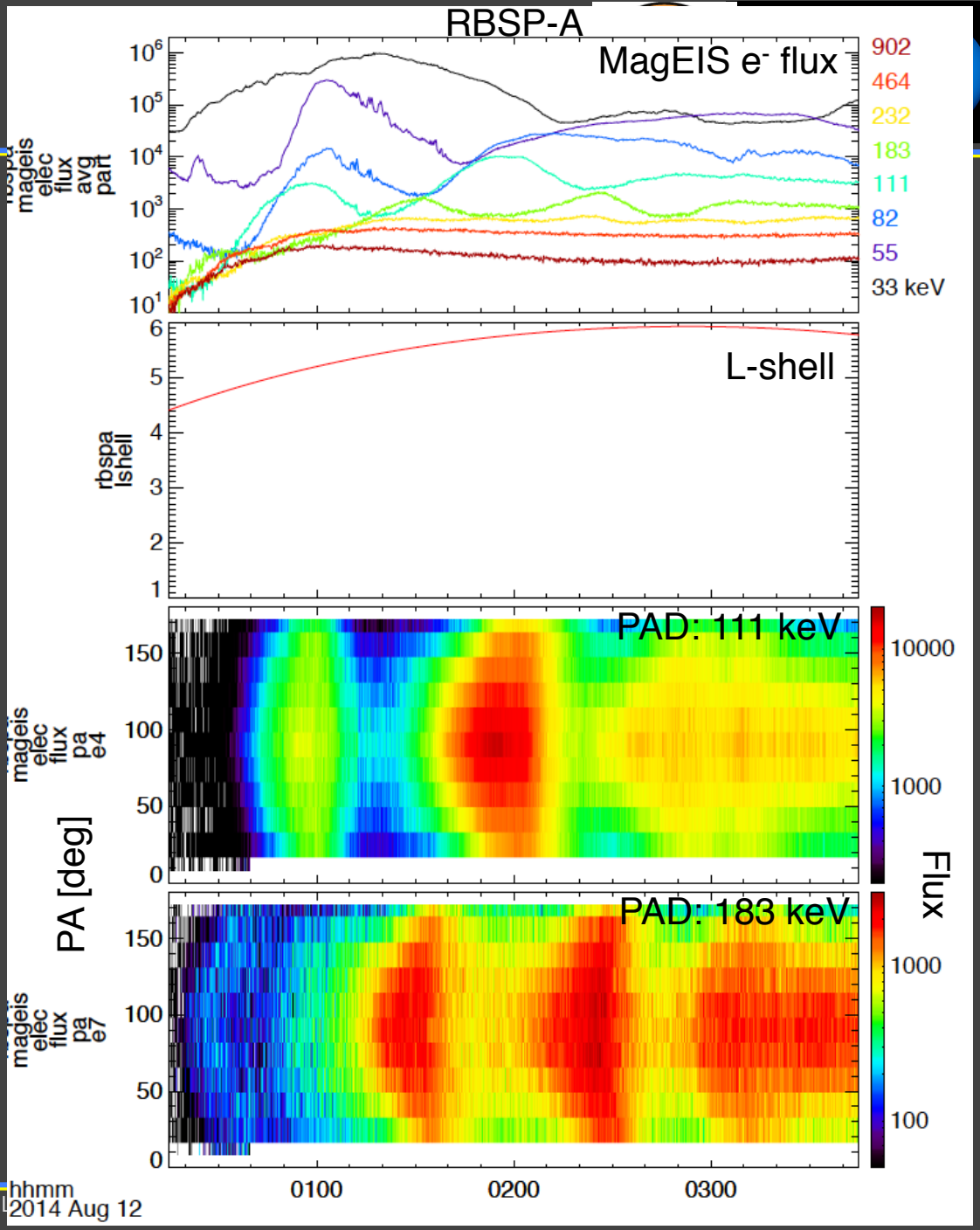


Physics of an Injection



Additional Features

- Examples of energy and pitch angle dispersion:
- Note: “bump-on-tail” and anisotropic signatures; can be ideal for wave growth
- Waves scatter the particles, further complicating the picture
- Spacecraft motion also complicates things…



Injection Theories and Stats

- Nature of the injection in the plasmasheet: agree on reconnection cause, but controversy over structure
  - *Mauk and McIlwain, JGR 1974*: injection boundary: broad swath in azimuth across much of the tail
  - *Li et al. GRL 2003; Gabrielse et al. JGR 2012*: localized injections, only a few RE in azimuth in the tail
- *Gabrielse et al. [JGR 2014]* THEMIS stats and *Birn et al. [JGR 1997]* GEO stats:
  - Reliance on definition of "dispersionless" (injection region gets narrower as dispersionless is more rigidly defined)
  - Injections happen a lot (>10 per day on avg.!)... predominantly in the pre-midnight sector

Courtesy of Geoff Reeves

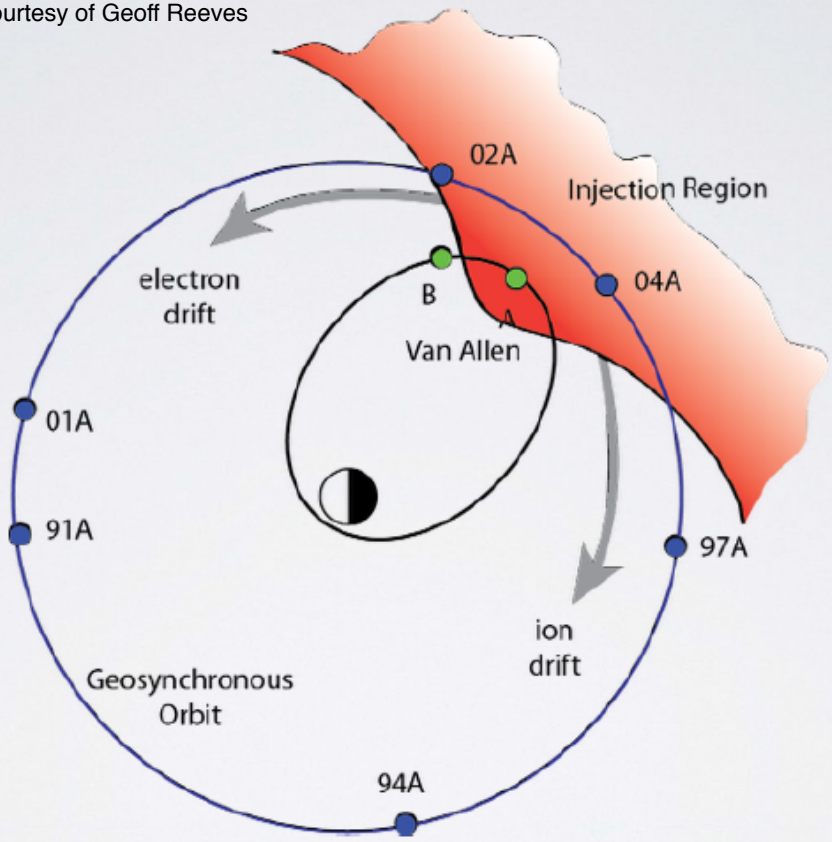
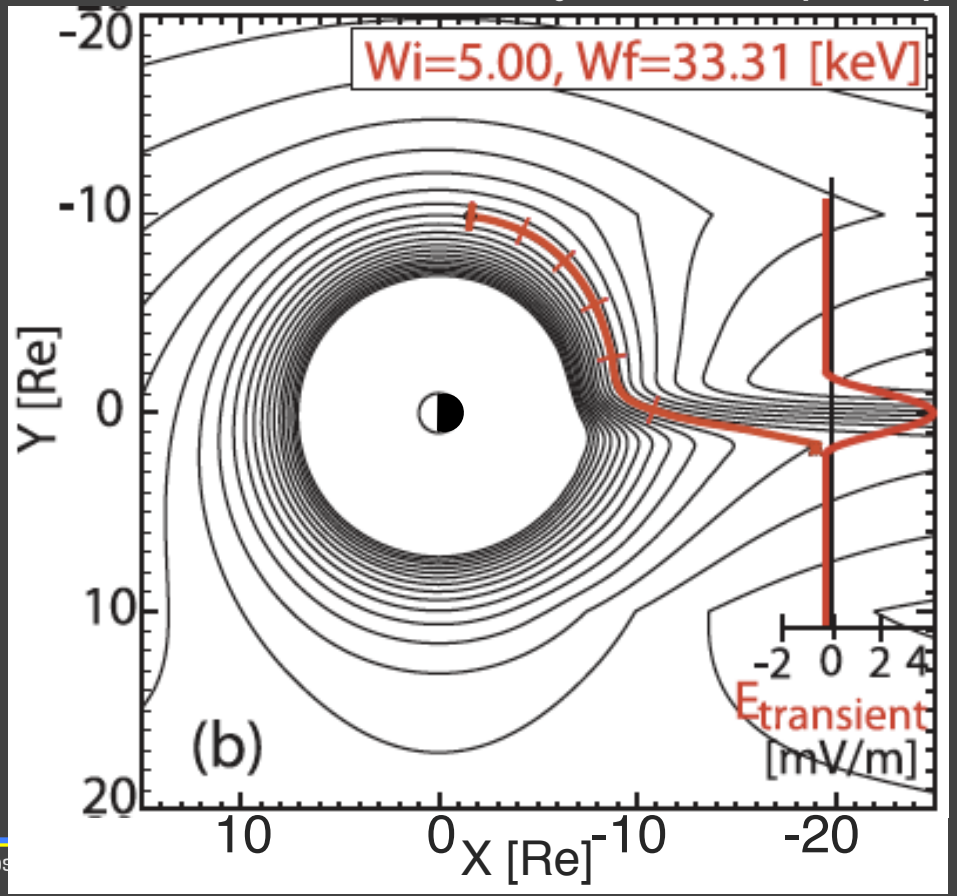


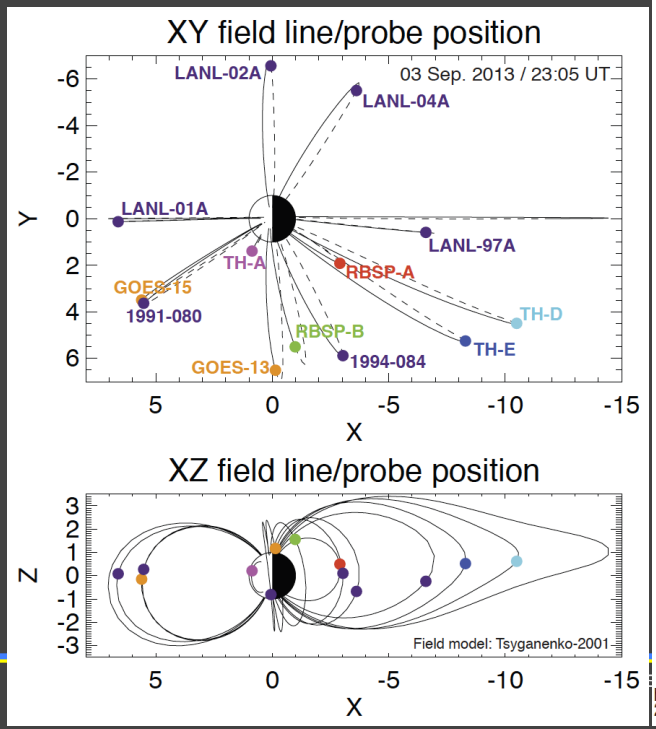
Fig. from *Gabrielse et al. [JGR, 2012]*

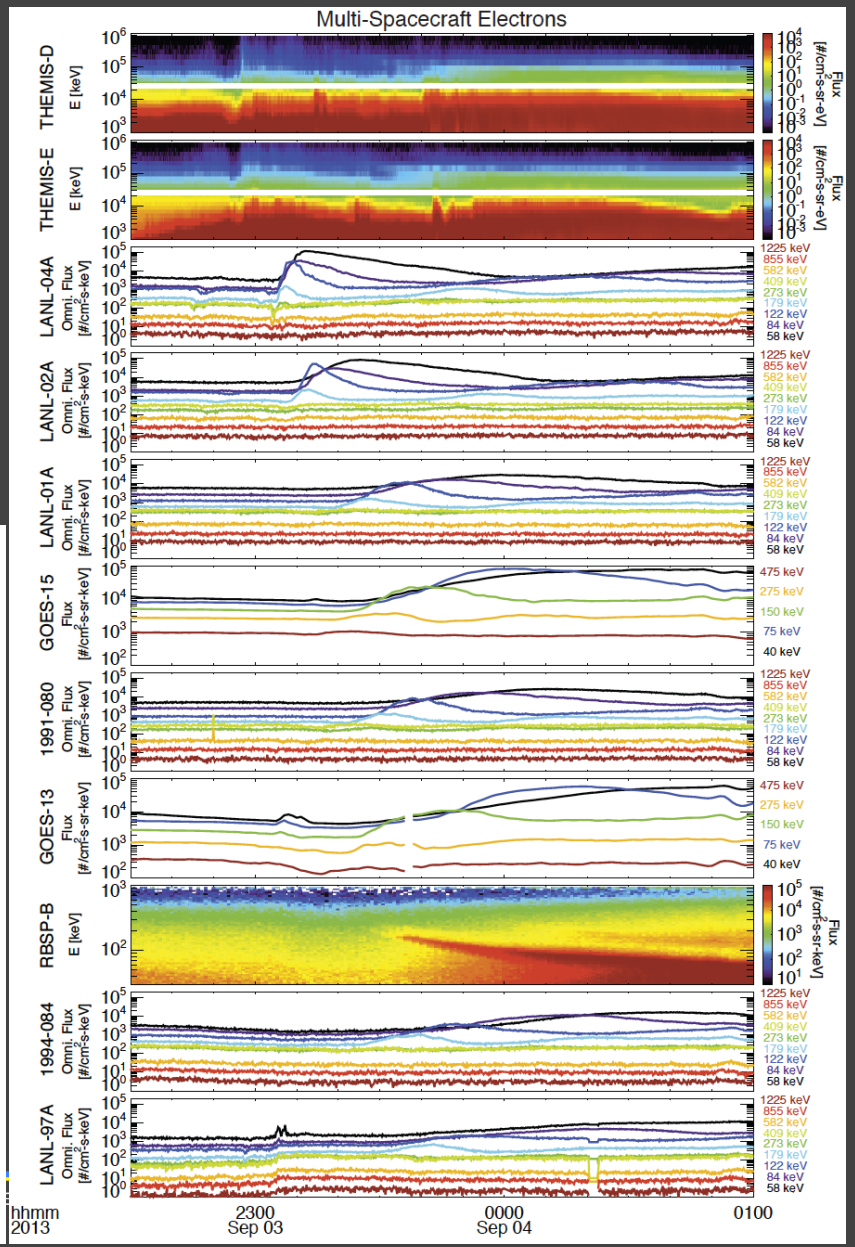


Understanding Injections

- ***We are now using multipoint (>10 s/c) in situ observations to better understand these events***

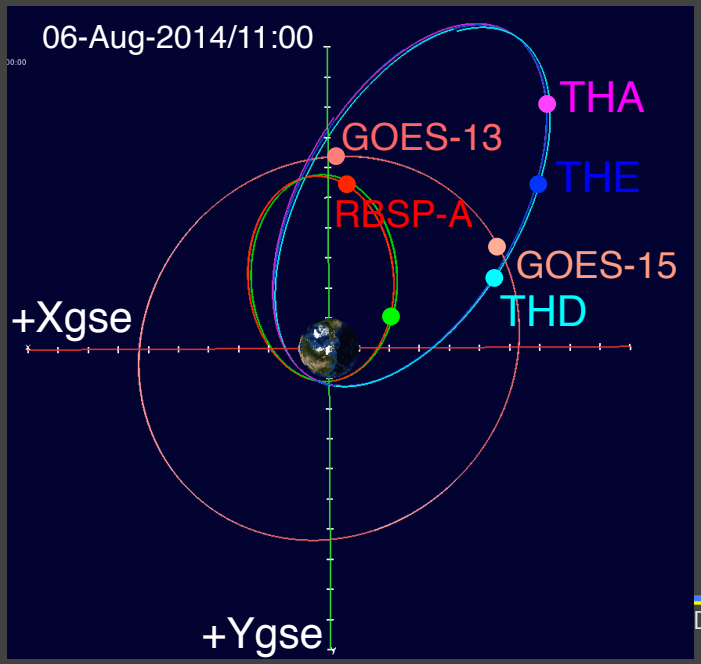
- Some topics we are investigating:
  - Size of injection region: Localized injections vs. broad injection fronts
  - Occurrence rates of injections as a function of L-shell in the inner magnetosphere
  - Finer structure within injections
  - Injection propagation through the braking region (~8-10 RE) and into the inner magnetosphere
  - Energy thresholds of injections and how these change with activity
  - Species dependencies
  - Assoc. wave activity
  - Accuracy of global field models

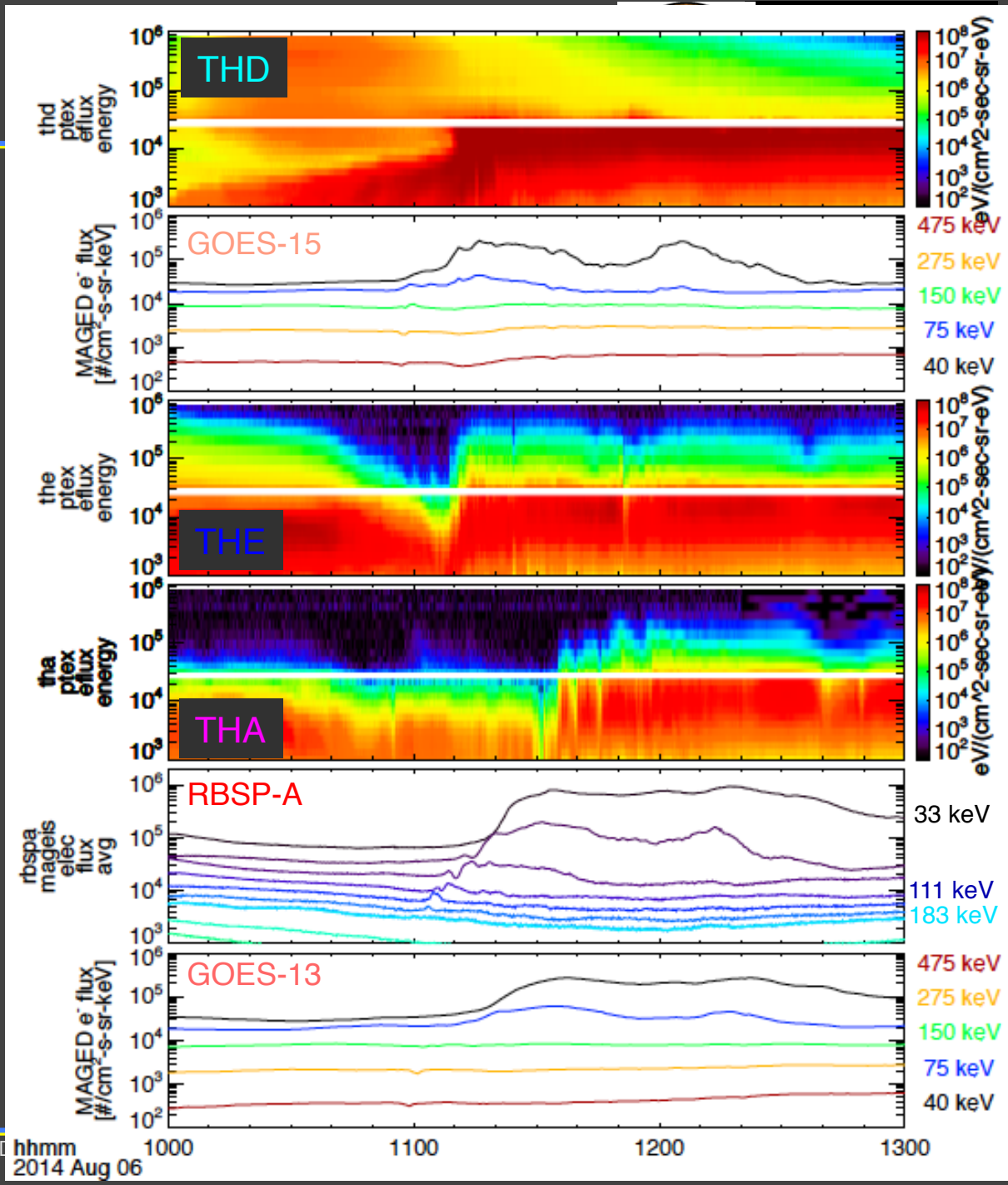




Size of an Injection Region

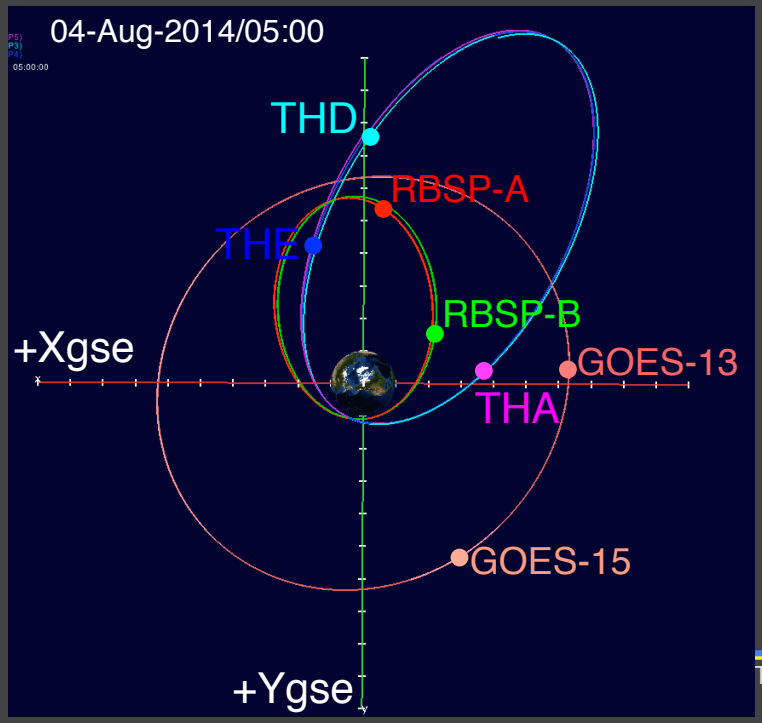
- From event statistics compiled from THEMIS *[e.g., J. Liu et al. JGR 2014]*, dipolarization fronts and EPIs in the tail are only ~3 RE wide in azimuth
- Example multipoint case here does not support broad, cross-tail injection: note THA only sees a weak, dispersed injection but a strong, dispersionless injection is clearly observed by THE
- Individual injections localized, but.... can they coalesce during substorms?

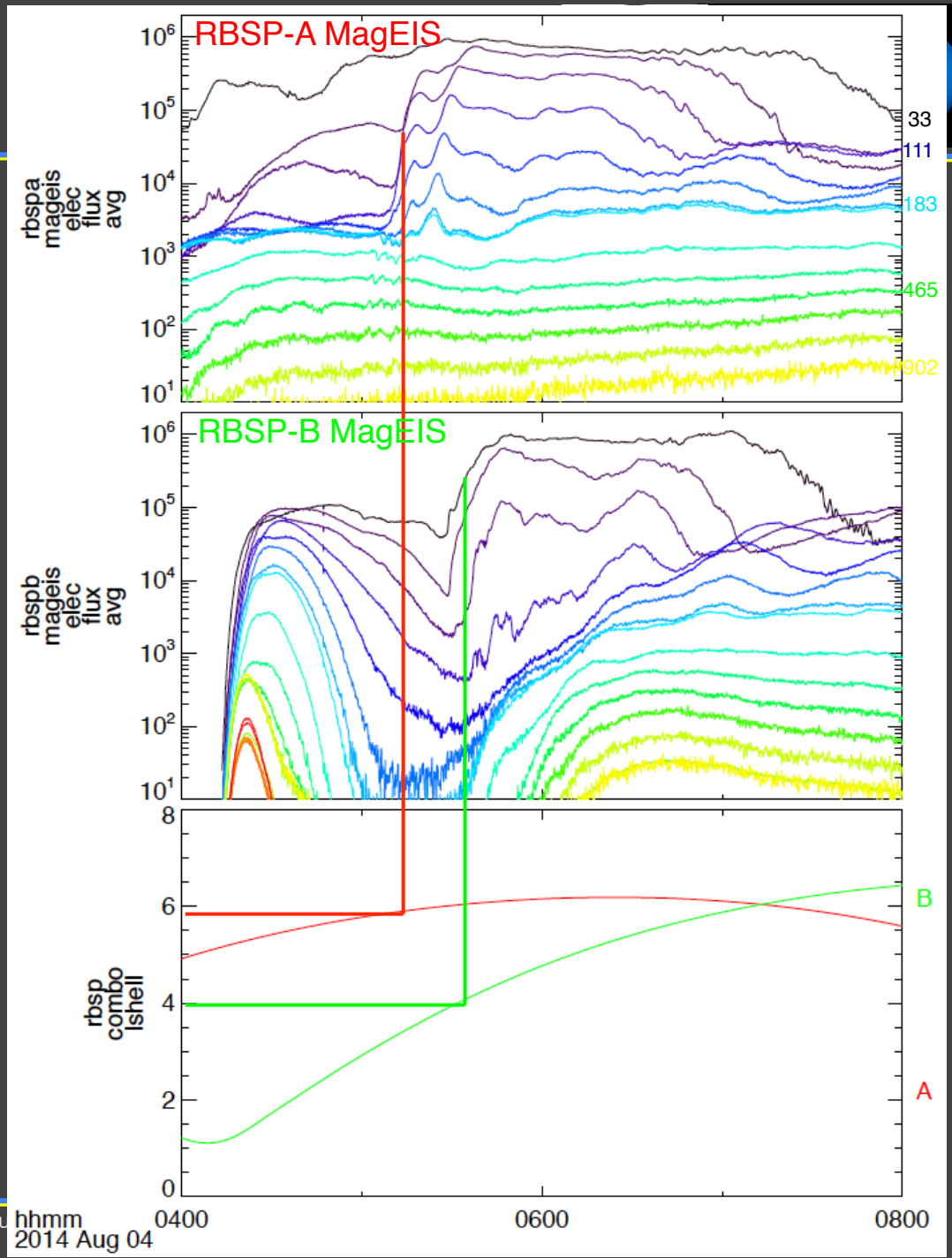




Depth of Injections

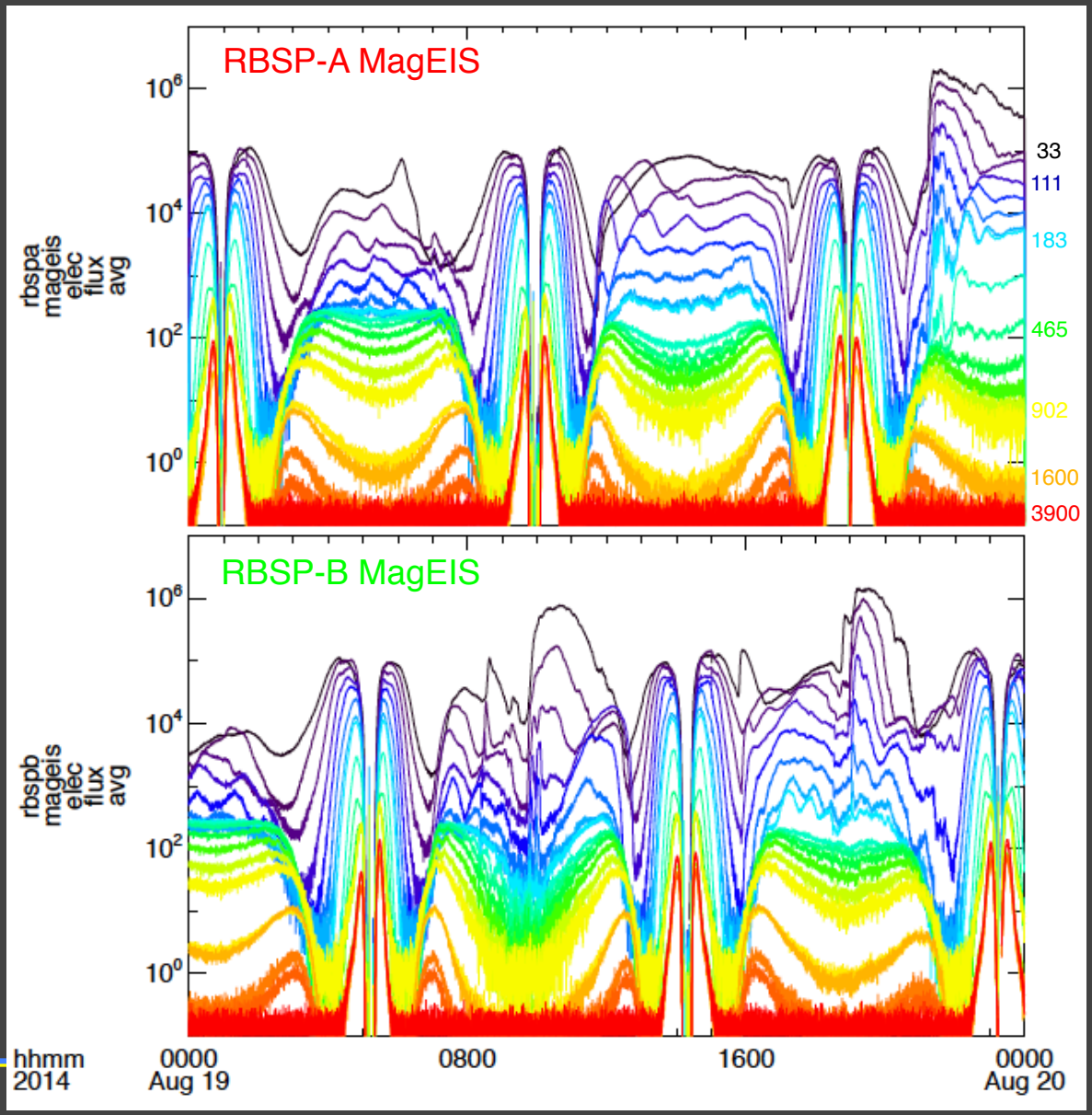
- Energetic particle injections can penetrate deep into the inner magnetosphere, even down to L = 4!
- Injections slow as they move to lower L-shells (here only ~10-20 km/s) [see also *Reeves et al., ICS 1996*]
- See also: *Gkioulidou et al. [JGR, 2014]*, EPIs can penetrate into the heart of the storm-time ring current and significantly contribute to it





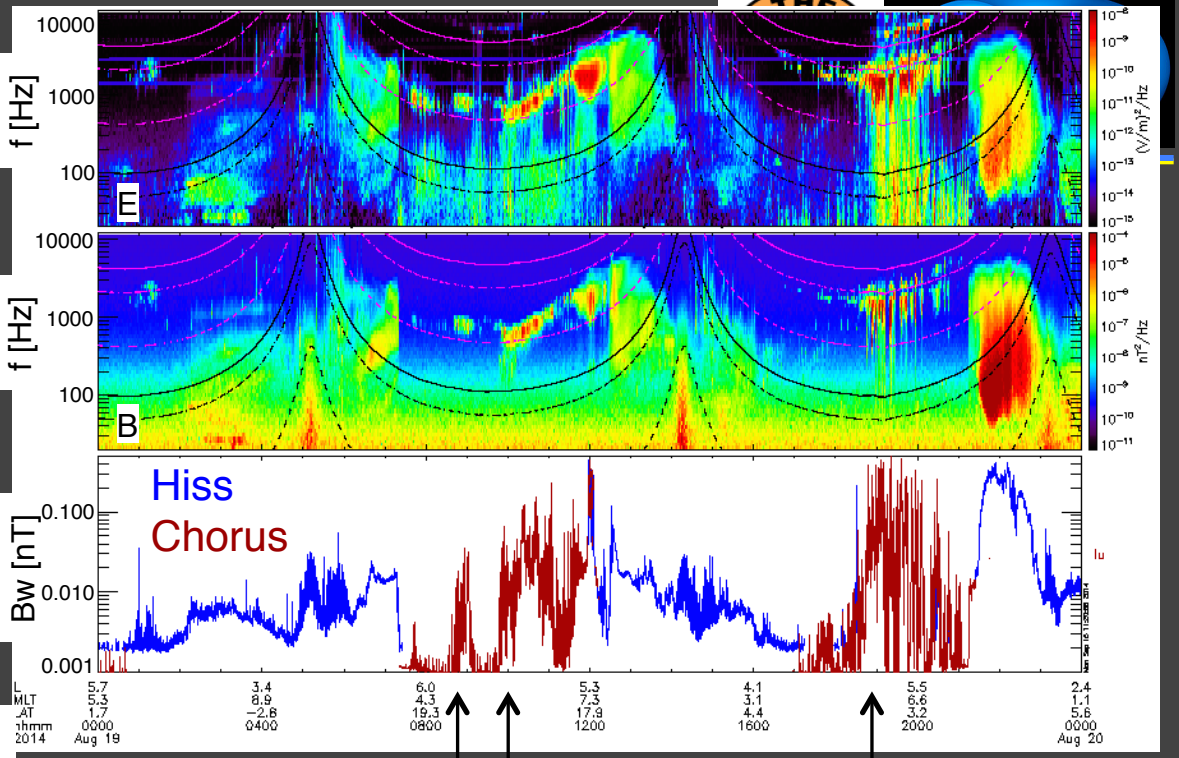
Energy Range of Injections

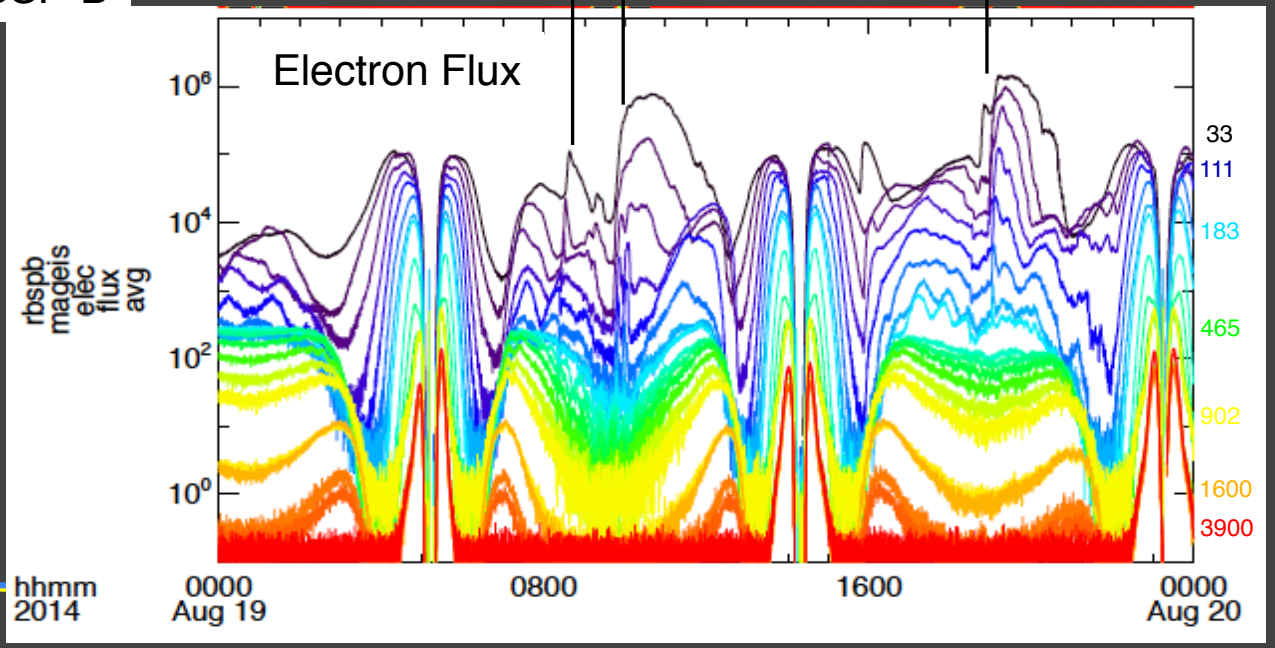
- Typically, electron injections range in energy from 10s < E < ~200 keV
- However, with increasing substorm activity, the upper energy threshold increases… e.g.:
- This implies either:
  - An active acceleration/ heating process in the tail during substorm activity *AND/OR*
  - Recirculation after local acceleration in the inner magnetosphere…



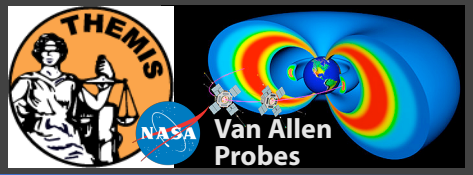
Wave Activity

- There is a 1:1 correspondence between electron injections and enhanced chorus wave activity:
- Plasmaspheric hiss also enhanced during this period of activity…
- EMIC wave growth may also be associated with ion injections
- This is expected based on statistical results of *Meredith et al. [JGR 2001; 2002; 2014]*





Closing Thoughts…



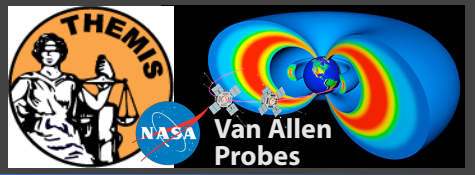
- Energetic particle injections are tail dynamics that prove to be very important for inner magnetospheric processes:
  - Contribute to the storm-time ring current
  - Provide the seed population for the outer radiation belt
  - Provide the source populations for EMIC and chorus waves

- They can also be a tool to help us to better understand cross-species and -energy interactions in the inner magnetosphere, plus the accuracy of global field models

- Many outstanding questions remain, *particularly for EPIs in the inner magnetosphere*, but we are now well poised to better understand energetic particle injections with multipoint observations (using dozens of events for ions in Summer/Fall 2013 and electrons in Summer/Fall 2014 with THEMIS + GEO + RBSP + Cluster + …)

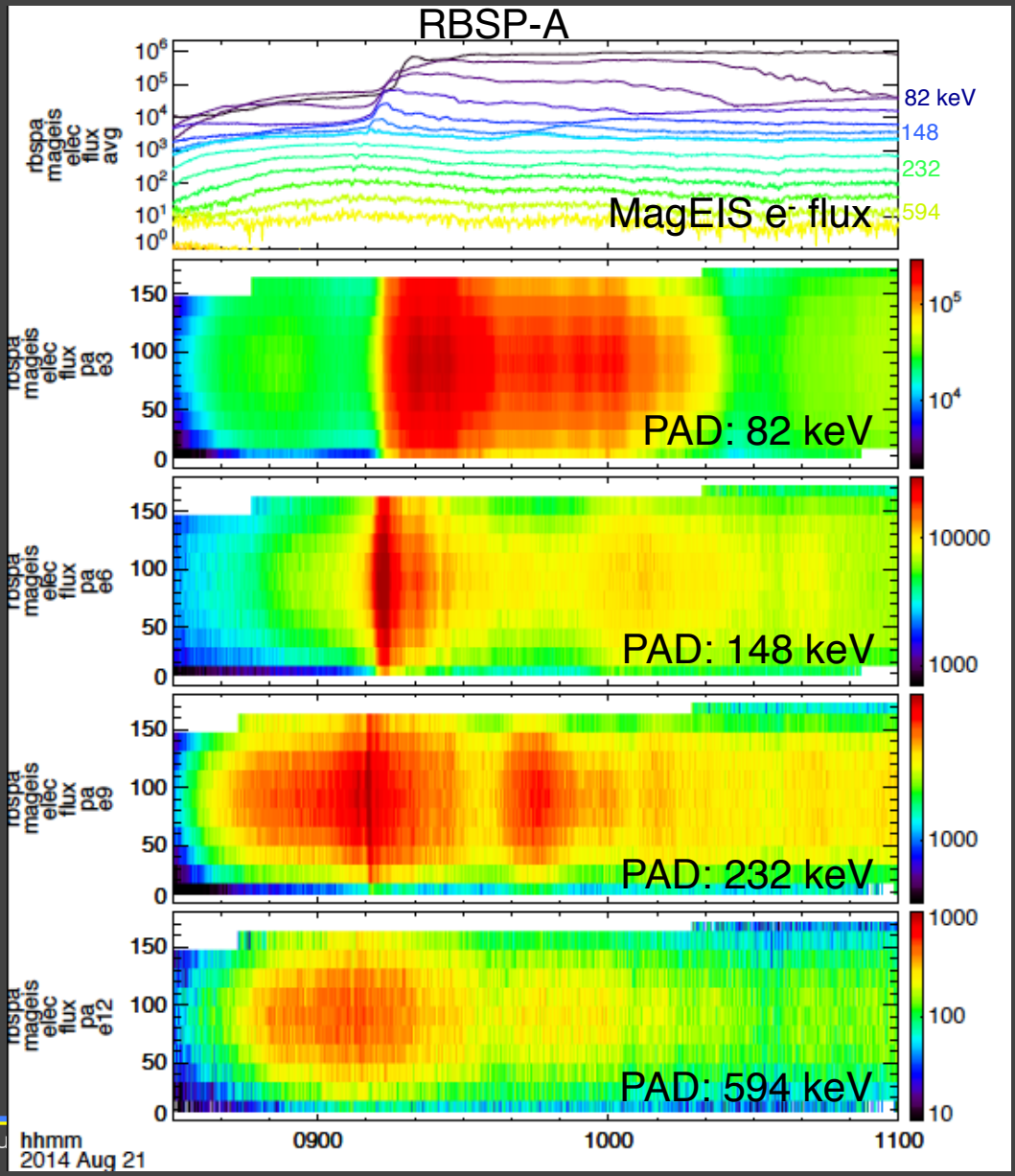
- This is all very preliminary… more actual conclusions to come at AGU!

Backups



Pitch Angle Distributions

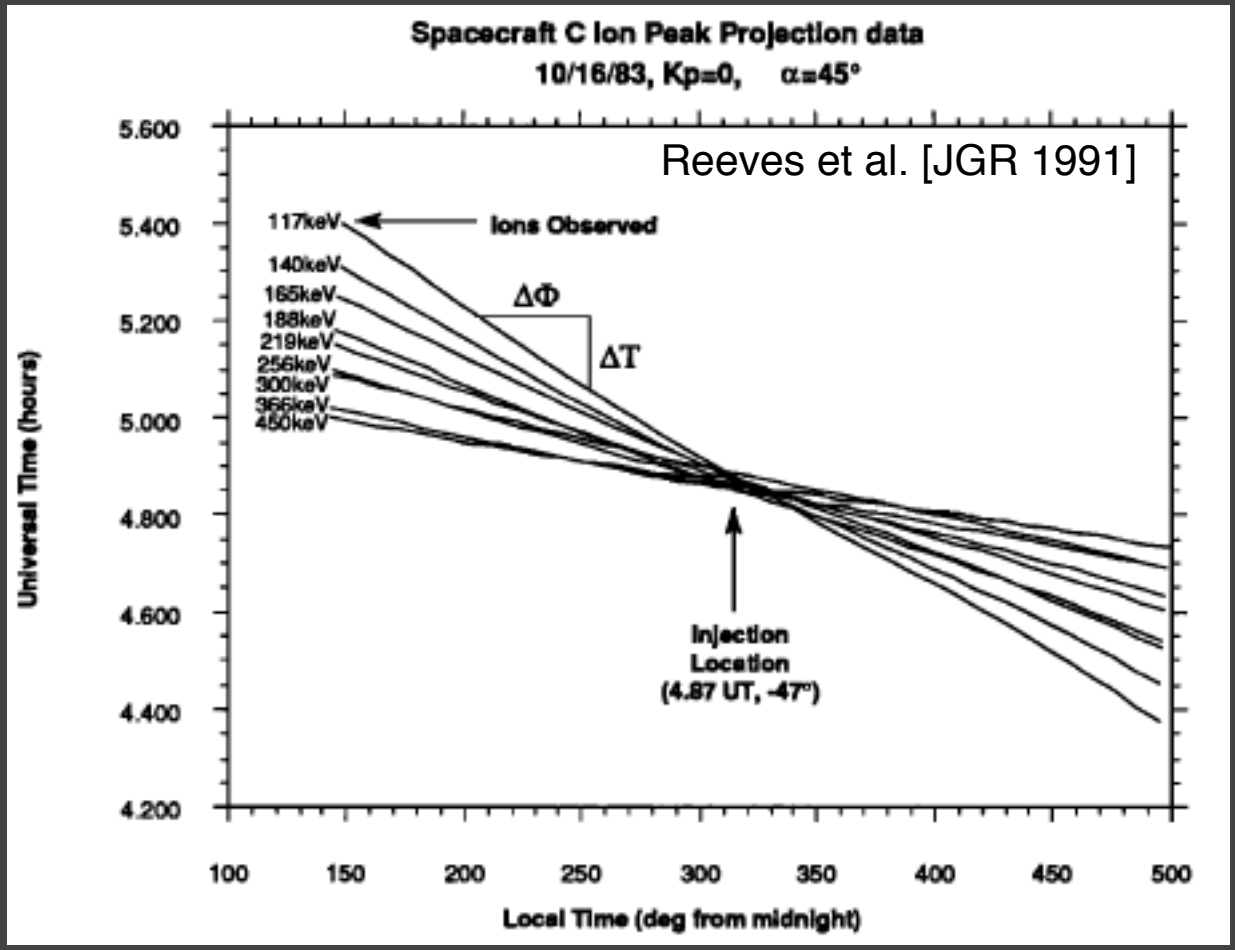
- PADs from dispersed and dispersionless injections:
  - They are different, as expected
  - Is there a "typical" dispersionless injection or are the all different? We need stats...
  - How do PADs evolve as injected particles drift... not an easy question considering pitch angle drift dispersion PLUS diffusion from ongoing wave activity... can these be separated?
- Broad pitch angle distributions imply enhanced precipitation, which is indeed observed associated with injections [e.g., Turner et al., Nat Phys 2012; JGR 2014]
- Rapid pitch angle scattering likely due to strong wave activity (EMIC and chorus) associated with them...

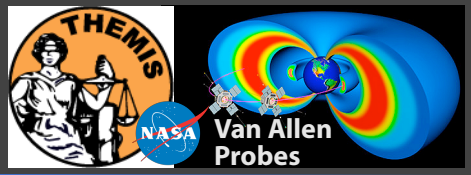


Size of the Injection Site

- Get western injection boundary from ions [e.g., Reeves et al., JGR 1991] and eastern boundary from electrons

- **Discuss this with Geoff!**





- Use presentation to introduce controversies, difficulties, and benefits
- Series of cases showcasing key points:
  - Injections can go deep within inner magnetosphere: 2014-08-04/05:00
  - Injections are apparently localized in MLT or not distributed right across tail: 2014-08-21/09:00 and/or 2014-08-06/11:00 and/or 2014-08-19/09:00; what is going on in the tail is very complex, localized, and dynamic (2014-08-21/09:00)
  - Increasing energy with increasing activity: 2014-08-19 events (stormtime), also showcases how substorm activity can result in outer belt enhancement
  - PAD of injected particles in: 1. dispersionless 2014-08-19 and 2. dispersed injections: 2014-08-21/09:00
  - Diffusion in drift echoes: 2014-08-12 and/or 2014-08-21/09:00
  - Wave activity corresponding to drifting electrons?: list sent to Wen Li
  - Ion injections too and THEMIS + GEO + RBSP also good for these! (2013 example)
- Recap and future work