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Title: DREAM utilizing real-time Van Allen probe data

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DREAM utilizing real-time Van Allen Probe Data

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Outline

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  - Spacecraft Anomalies
- Motivation
- Data Sources
  - GOES
  - Van Allen Probes
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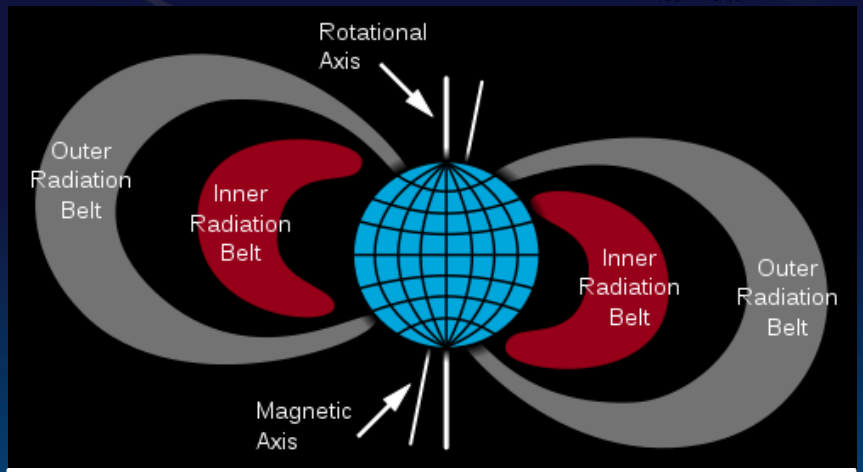
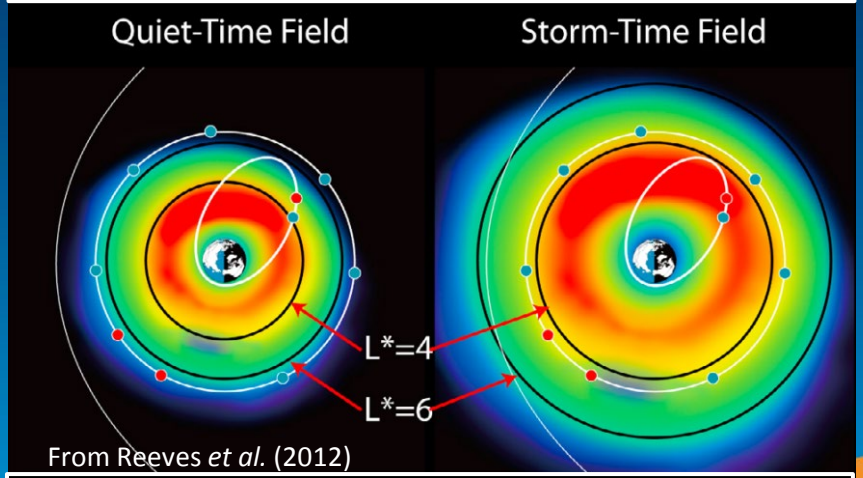
Background: Radiation Belts

- Many satellites orbit in the Earth's radiation belts which are zones of energetic charged particles trapped by the Earth's magnetic field
- The radiation belts can undergo large fluctuations from their "quiet-time" state due to geomagnetic storms created by solar activity including:
  - Solar Flares
  - Coronal Mass Ejections



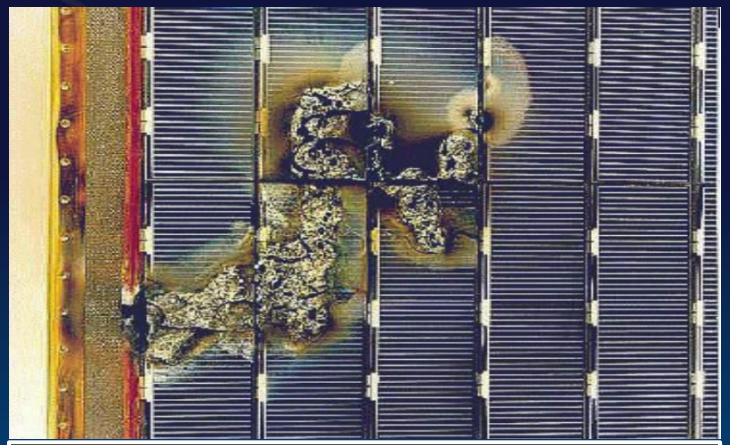
The Earth's Van Allen Radiation Belts.



Radiation belt variation due to a geomagnetic storm.

Background: Spacecraft Anomalies

- Energetic charged particles in the radiation belts can induce spacecraft anomalies such as:
  - Single event effects
  - Surface/bulk charging/discharging
  - Total dose effects
- Anomalies can:
  - Corrupt spacecraft data
  - Cause short-term system outages
  - Cause system/subsystem failures
  - Completely incapacitate a spacecraft (e.g. loss of mission)

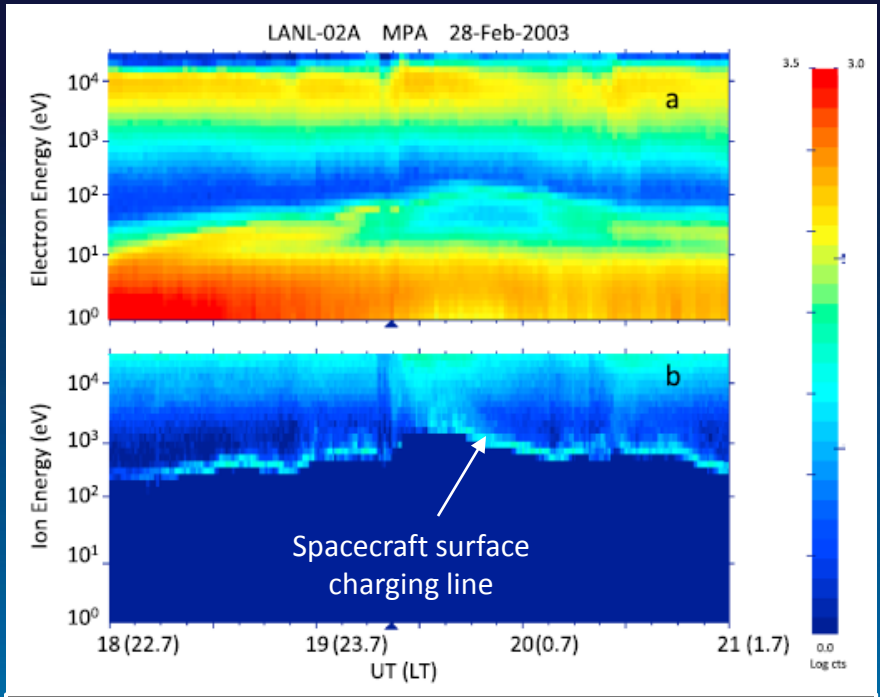


Arc damage to ESA EURECA solar array (credit: ESA)

Arc damage in laboratory tests (credit: NASA)

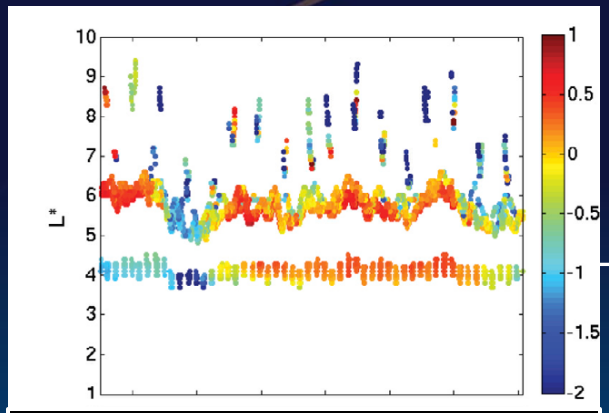
Background: Space Env. Sensors

- Some spacecraft are equipped with sensors to:
  - Monitor charged particles in the radiation belts
  - Help determine the cause and conditions under which spacecraft anomalies occur
- Most spacecraft are not equipped with space weather instruments
  - They must rely on other satellites in other orbital regimes for information on the radiation belt environment



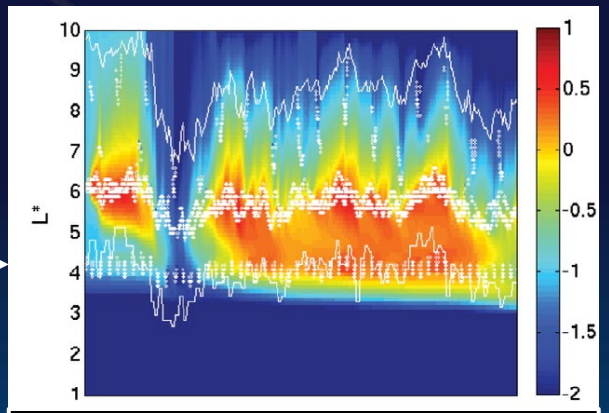
Measurements from the Magnetospheric Plasma Analyzer (MPA) aboard the geosynchronous LANL-02A satellite on Feb 28th, 2003. Spacecraft surface charging is seen in both the electrons (top) and ions (bottom). [credit: Thomsen et al., 2007]

Project Motivation



Spacecraft measurements from 1 GPS satellite, 3 LANL-GEO satellites, and Polar [Reeves et al. (2012)]

Assimilation with DREAM



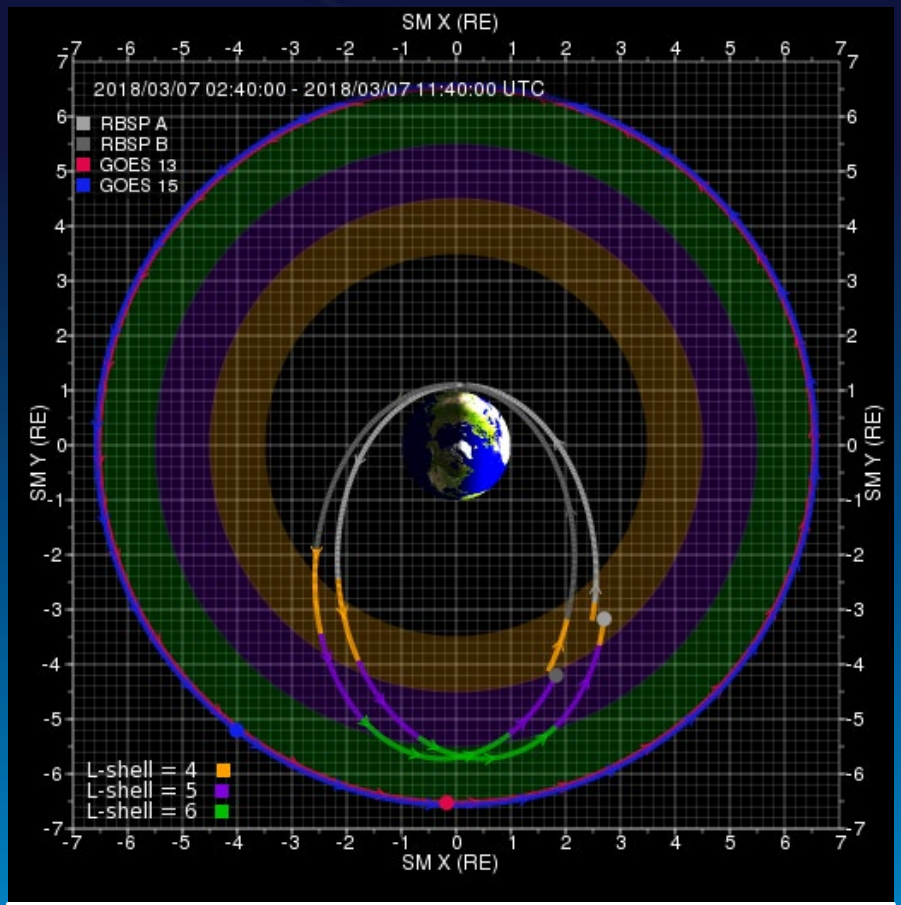
Global DREAM assimilated phase space density. [Reeves et al. (2012)]

- **Generate global estimate of radiation belts with DREAM**
  - Global estimate gives more accurate information for satellites without space environment instruments
    - Better diagnose spacecraft anomalies
    - Better predict conditions that may cause anomalies
  - DREAM is also a framework for better understanding the physical processes that control the radiation belts

Project Goal

- Currently, DREAM runs on geosynchronous data from GOES
  - Limited range of L-shell
  - Yields poor prediction for L far from ~6.6 (GEO L-shell)

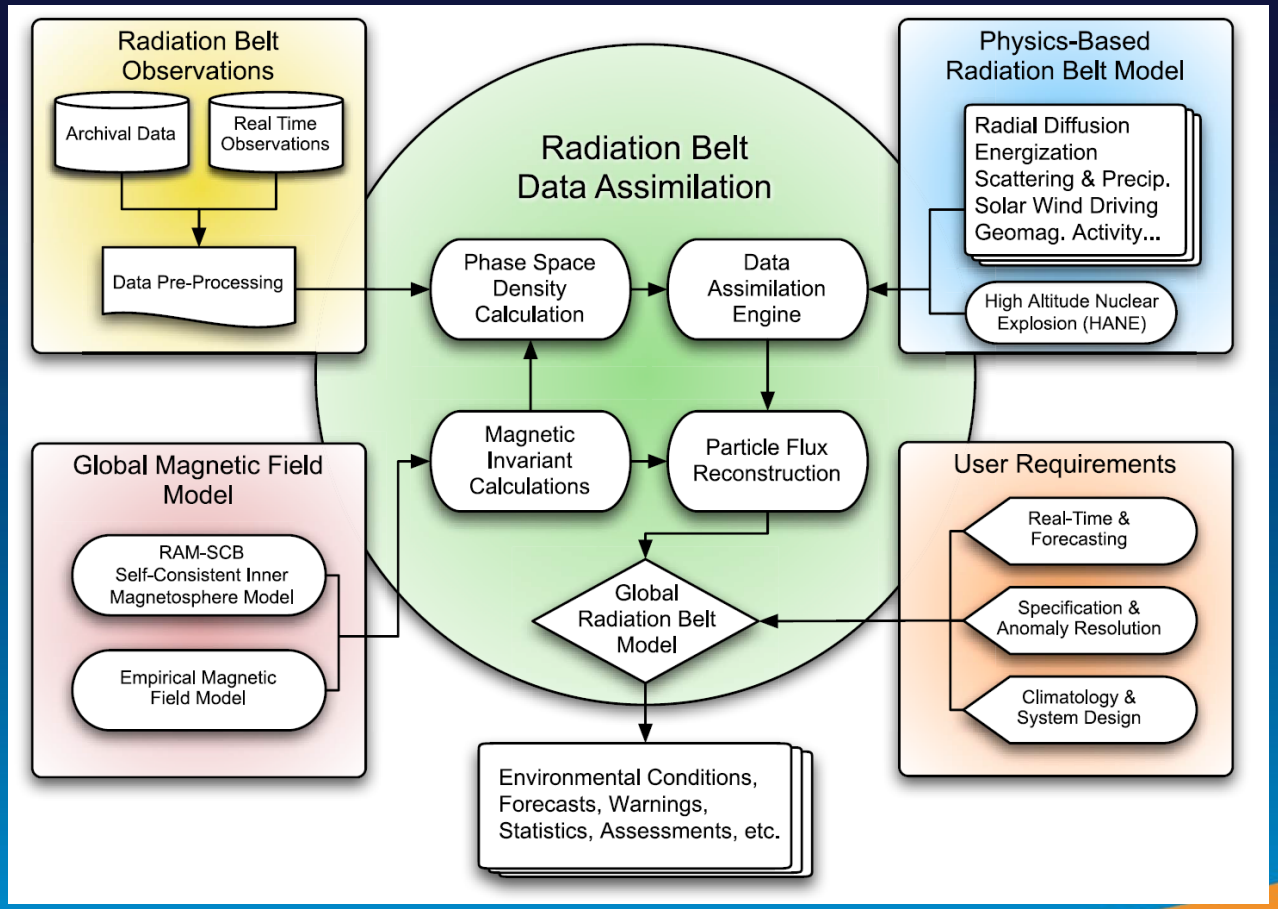
- Goal: Add the Van Allen Probe real-time data (known as beacon or space weather data) for ingestion into DREAM
  - Covers a large range of L-shell from <2 to ~6
  - Should yield better global prediction of the radiation belts



GOES and Van Allen Probes orbital trajectories on March 7th, 2018. Colors denote L-shell bands. [credit: NOAA]

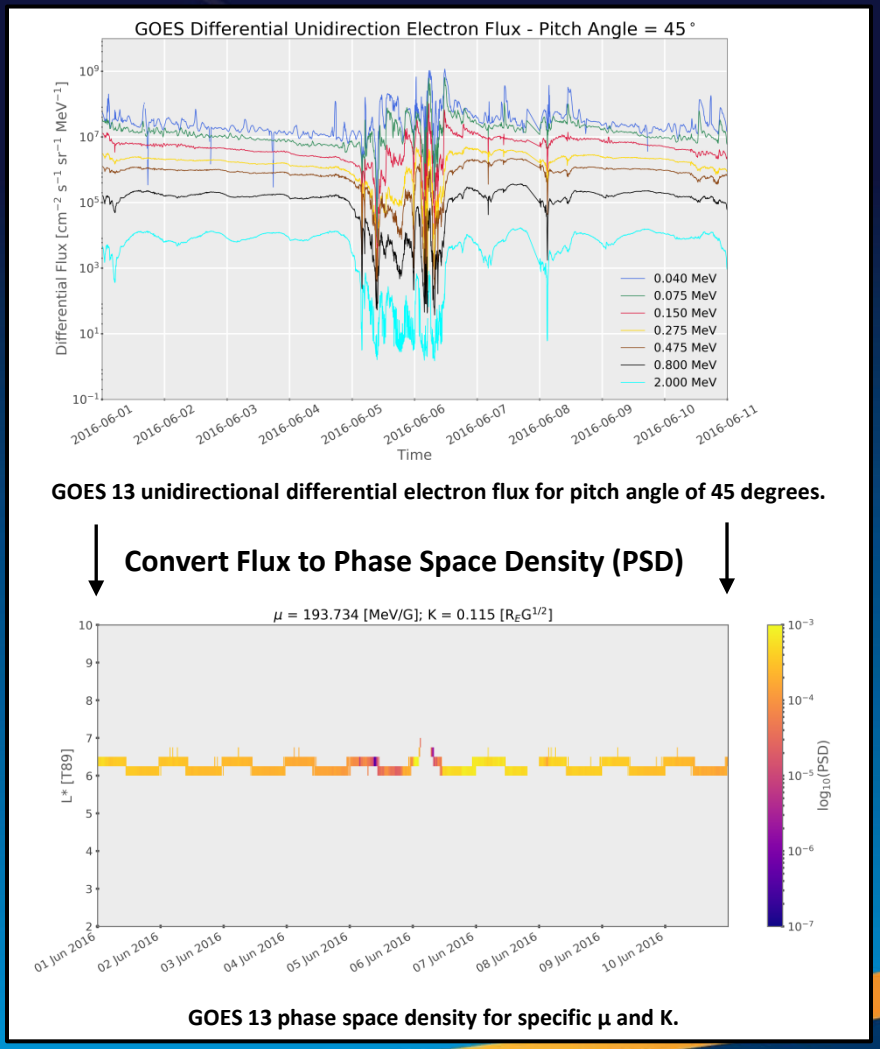
DREAM Framework

- Inputs: Radiation Belt Observations
  - GOES 13
  - Van Allen Probes
    - Beacon
    - Science
- Models
  - 1D Radial Diffusion Radiation Belt Model
  - Tsyganenko 1989 (T89c) Magnetic Field Model
- Output
  - Global phase space density estimate
  - Flux along arbitrary satellite orbit



Data Sources: GOES 13

- GOES = Geostationary Operational Environmental Satellite
- Orbital longitude = 60° W
- Electron data from 2 sensor types
- Limited pitch angle coverage
- EPEAD
  - Energetic Proton, Electron, and Alpha Detectors
  - High energy integral fluxes
    - (>0.6 MeV, >2 MeV, >4 MeV)
- MAGED
  - Magnetospheric Electron Detector
  - Low energy differential fluxes
    - 30-50 keV, 50-100 keV, 100-200 keV, 200-350 keV, 350-600 keV



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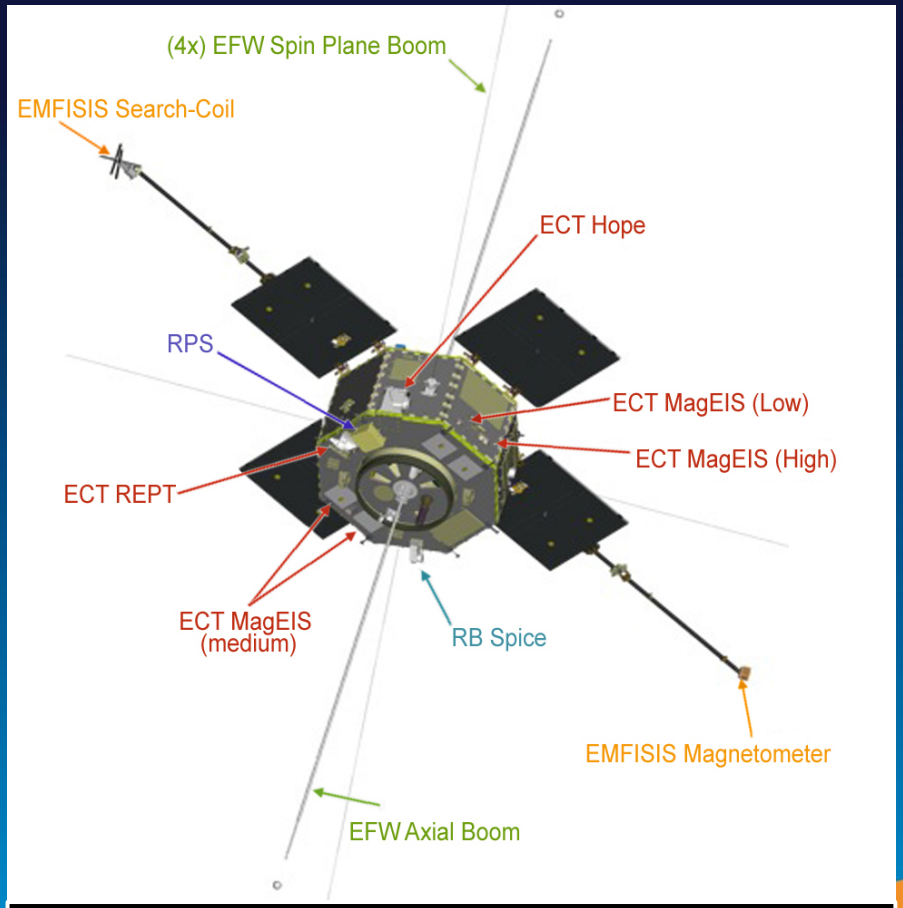
Data Sources: Van Allen Probes

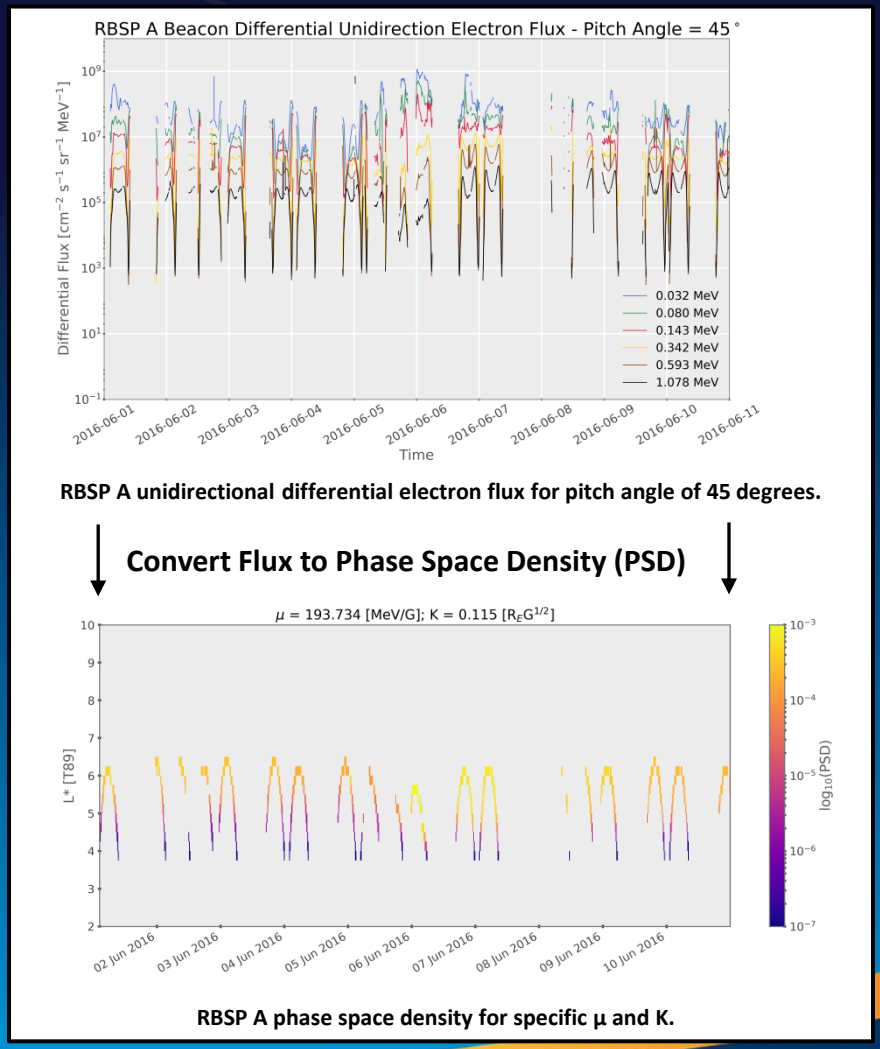
- Also known as the Radiation Belt Storm Probes (RBSP)
- Two satellites (A and B)
- Highly elliptical orbits (HEO)
- Electron data from 3 instruments
- MagEIS
  - Magnetic Ion Electron Spectrometers
  - Four types: Low, M35, M75, and High
  - Energy range = ~20 keV to ~5 MeV
- HOPE (Not used in this work)
  - Helium, Oxygen, Proton, and Electron Mass Spectrometer
  - Low energy sensor – 1 eV to ~50 keV
- REPT (Not used in this work)
  - Relativistic Electron-Proton Telescope
  - High energy sensor - ~1.5 MeV to ~20 MeV



Van Allen Probe satellite model with space environment sensors labeled [credit: NASA]

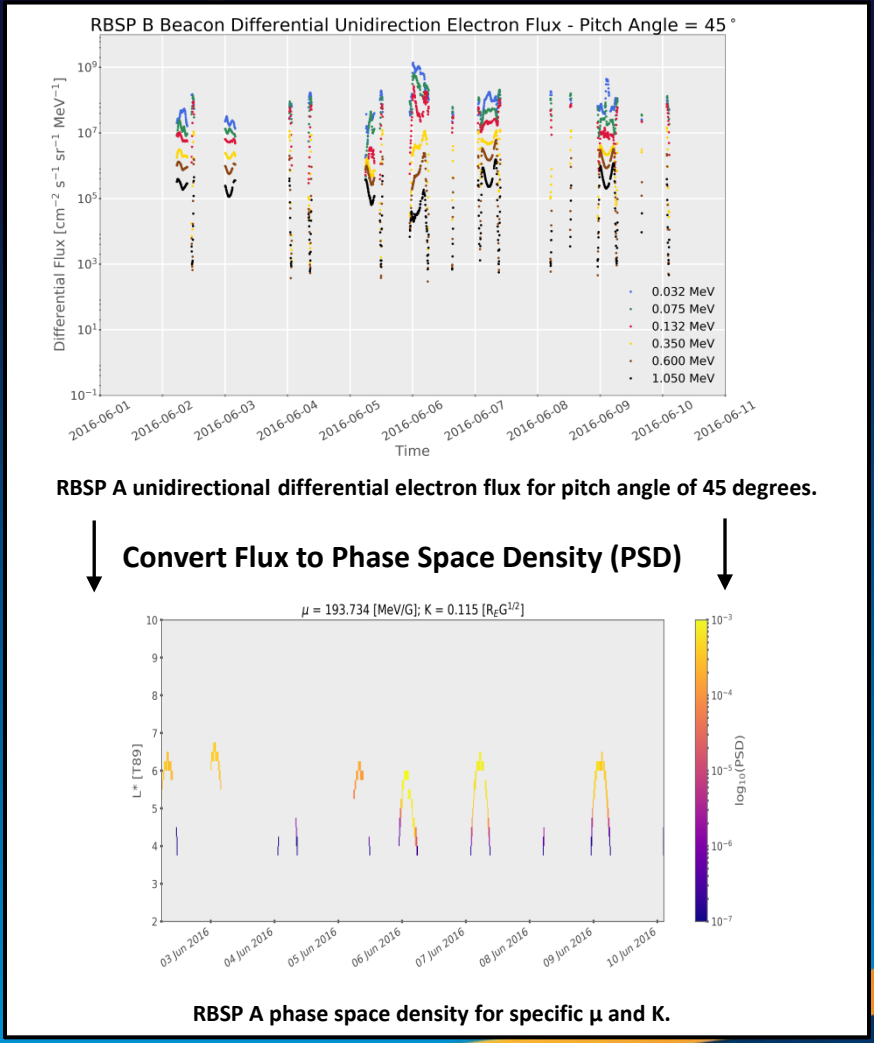
Data Sources: RBSP A Beacon

- Real-time Van Allen Probe data
- Also known as “Space Weather” data
- Available for MagEIS, REPT, and HOPE
- MagEIS
  - Only Spin-averaged Electron Flux
  - Must be processed with REPAD to generate pitch angle tagged fluxes
  - Limited temporal coverage
    - ~85% coverage for RBSPA
    - ~35% coverage for RBSPB
- HOPE & REPT
  - Format and lack of compute information make real-time data make it difficult to use



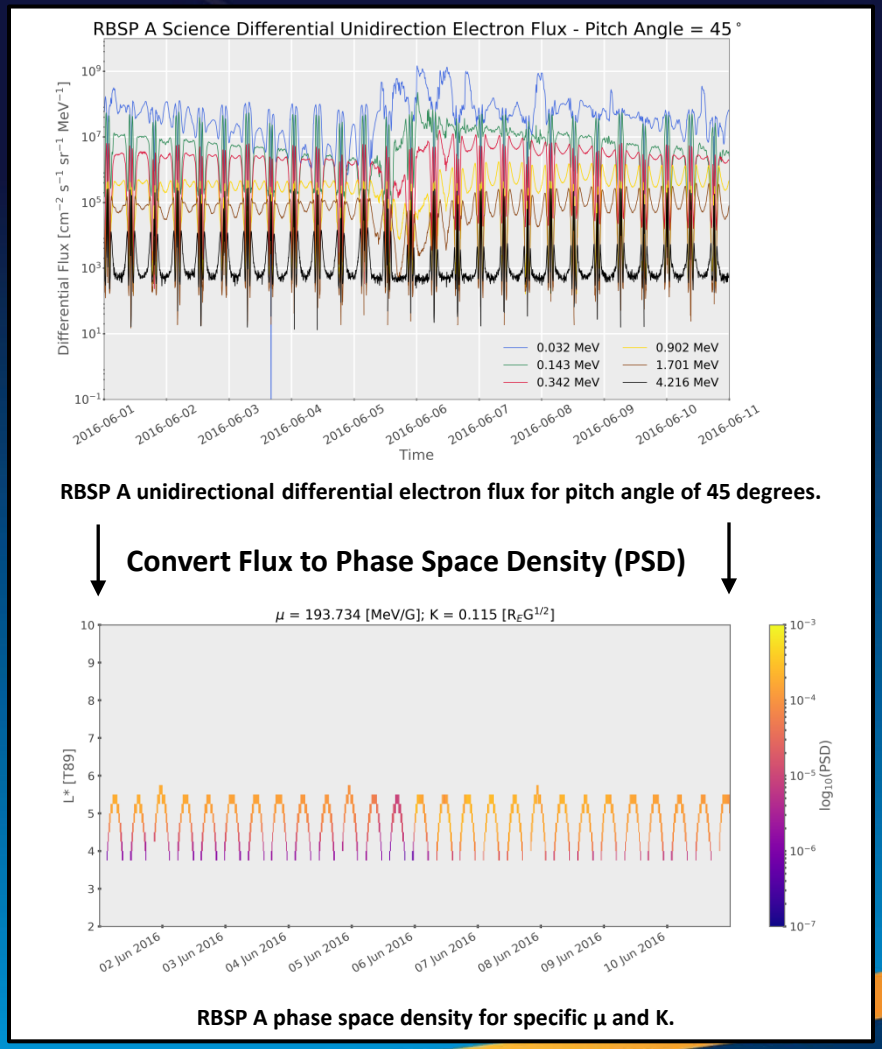
Data Sources: RBSP B Beacon

- Real-time Van Allen Probe data
- Also known as “Space Weather” data
- Available for MagEIS, REPT, and HOPE
- MagEIS
  - Only Spin-averaged Electron Flux
  - Must be processed with REPAD to generate pitch angle tagged fluxes
  - Limited temporal coverage
    - ~85% coverage for RBSPA
    - ~35% coverage for RBSPB
- HOPE & REPT
  - Format and lack of compute information make real-time data make it difficult to use



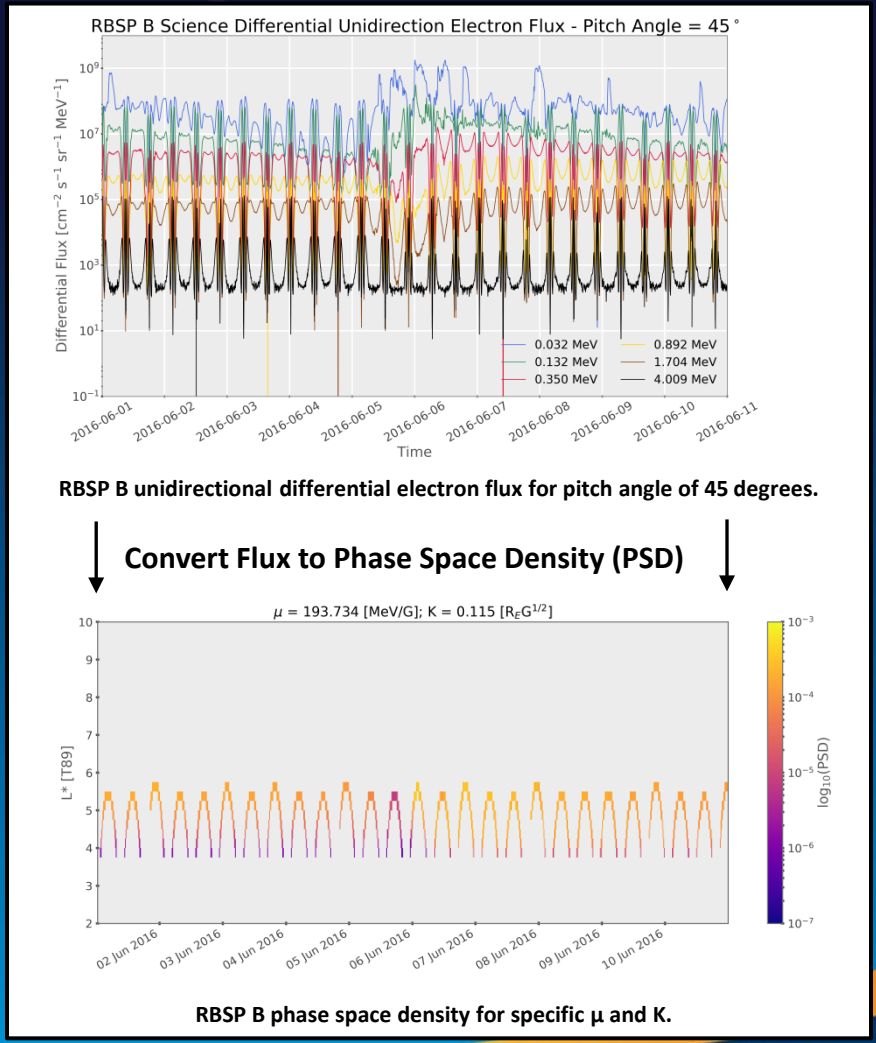
Data Sources: RBSP A Science

- Definitive Van Allen Probe data
- Considered the “gold standard” of space environment data
- Available for MagEIS, REPT, and HOPE
- Not a real-time data source
  - Preliminary Level 3 flux files are available in ~12 hours
  - Definitive Level 3 flux files are available in ~1 week



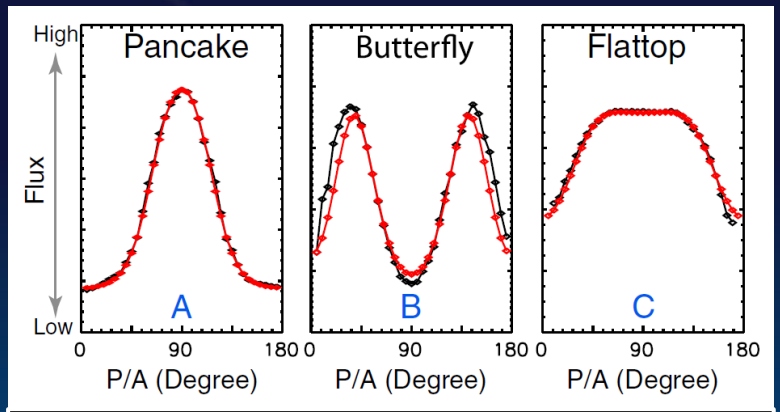
Data Sources: RBSP B Science

- Definitive Van Allen Probe data
- Considered the “gold standard” of space environment data
- Available for MagEIS, REPT, and HOPE
- Not a real-time data source
  - Preliminary Level 3 flux files are available in ~12 hours
  - Definitive Level 3 flux files are available in ~1 week

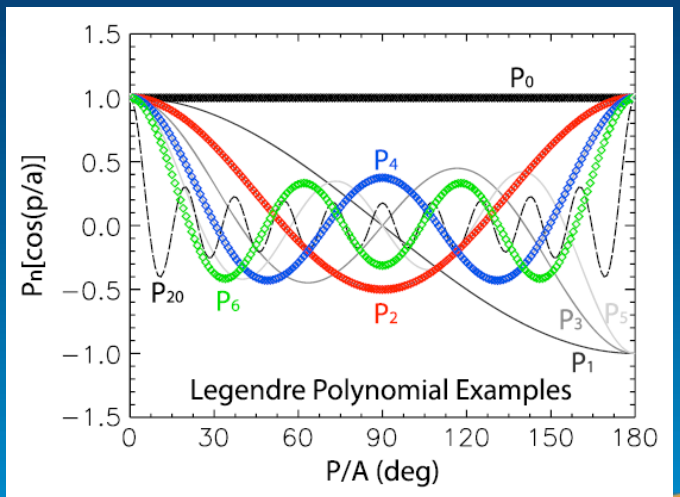


Beacon Data Processing

- Van Allen Probe beacon data must be converted from spin-averaged flux to pitch angle tagged flux
  - Conversion utilizes REPAD
  - REPAD = Relativistic Electron Pitch Angle Distribution Model
- REPAD Model
  - Uses Legendre polynomials to fit pitch angle distributions
  - Trained using data from CRRES, Polar, and LANL-97A
  - Legendre polynomial coefficients depend on:
    - L-shell
    - AE index
    - Magnetic local time
    - Electron energy



REPAD pitch angle distribution fits on real data. [credit: Chen et al., 2014]



Legendre polynomials used in REPAD pitch angle distribution fitting. [credit: Chen et al., 2014]

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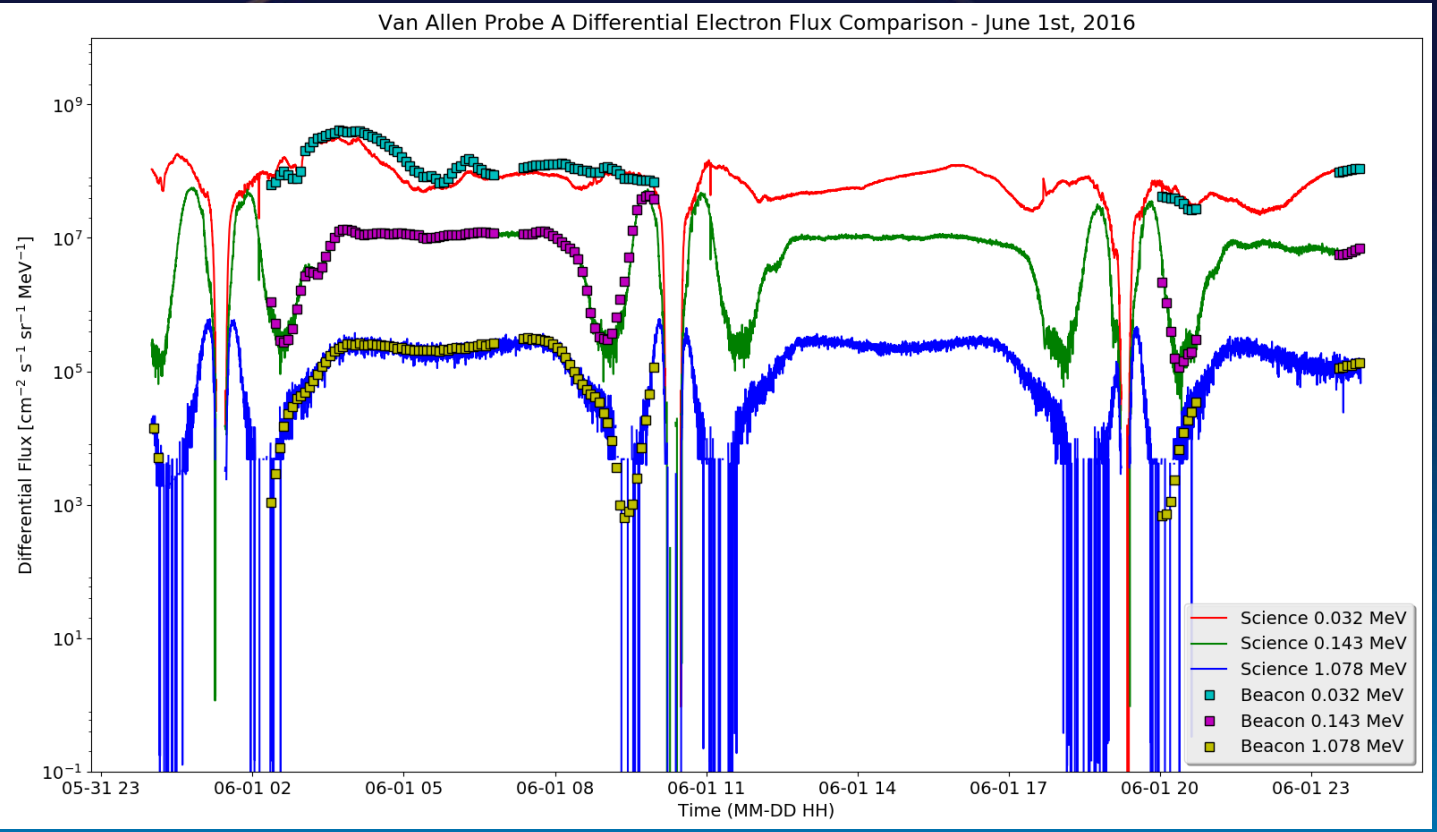
Beacon vs. Science: Energy



- Van Allen Probe beacon data processed with REPAD compares quite well with the science data (example shown for June 1st, 2016)
  - 3 energies: 32 keV, 143 keV and 1.078 MeV
  - Pitch angle = 45 degrees

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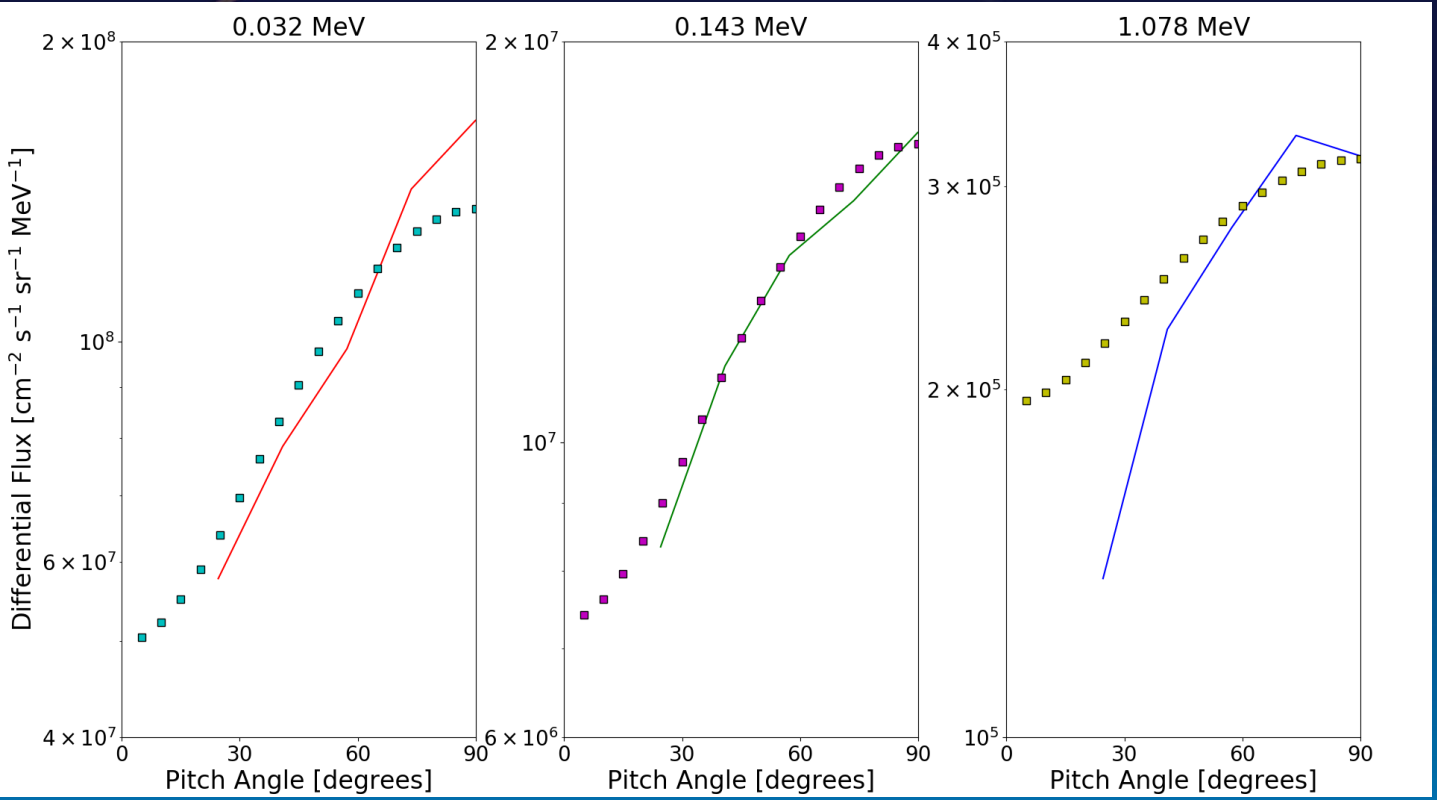
Beacon vs. Science: Pitch Angle



- Van Allen Probe beacon data processed with REPAD compares well with the science data at lower energies (example shown for June 1st, 2016)
  - 3 energies: 32 keV, 143 keV and 1.078 MeV
  - Time: June 1st, 2016 at 06:00:00

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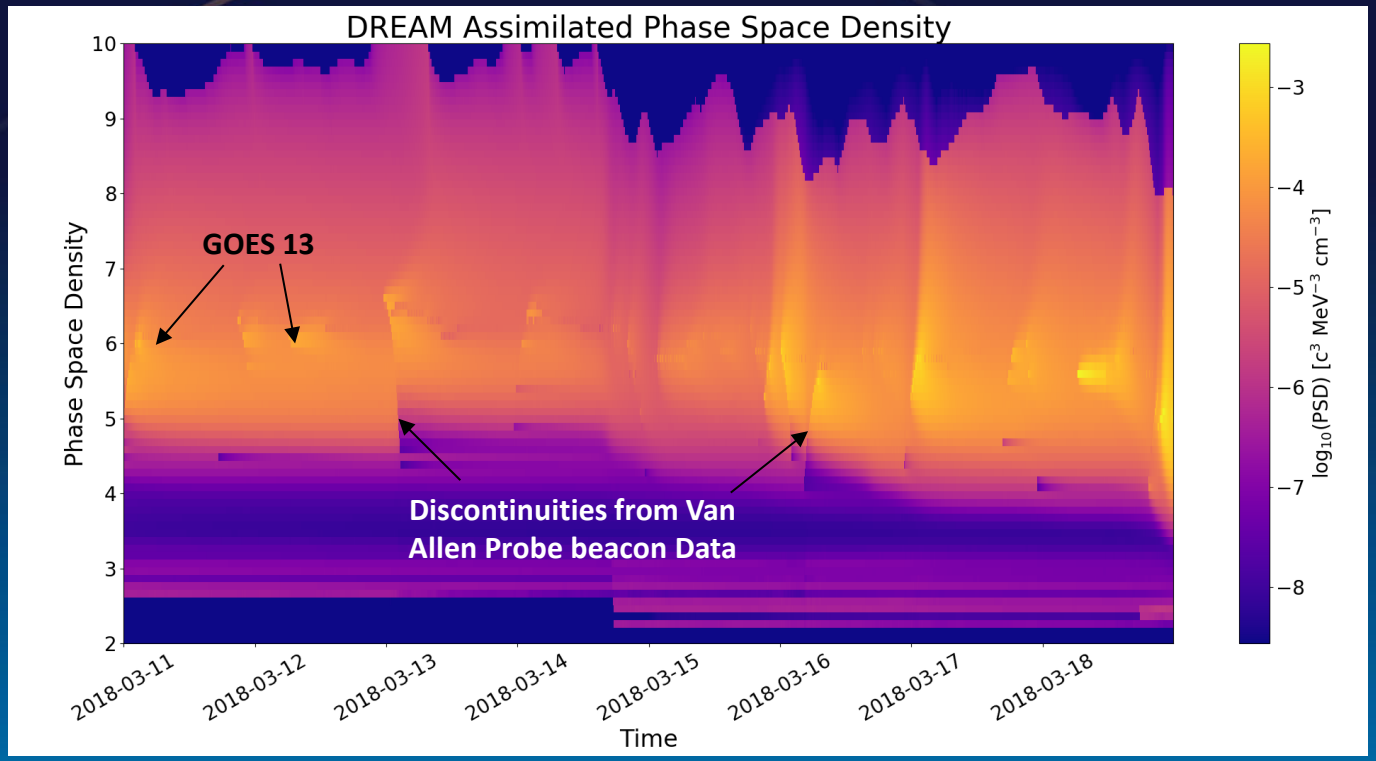
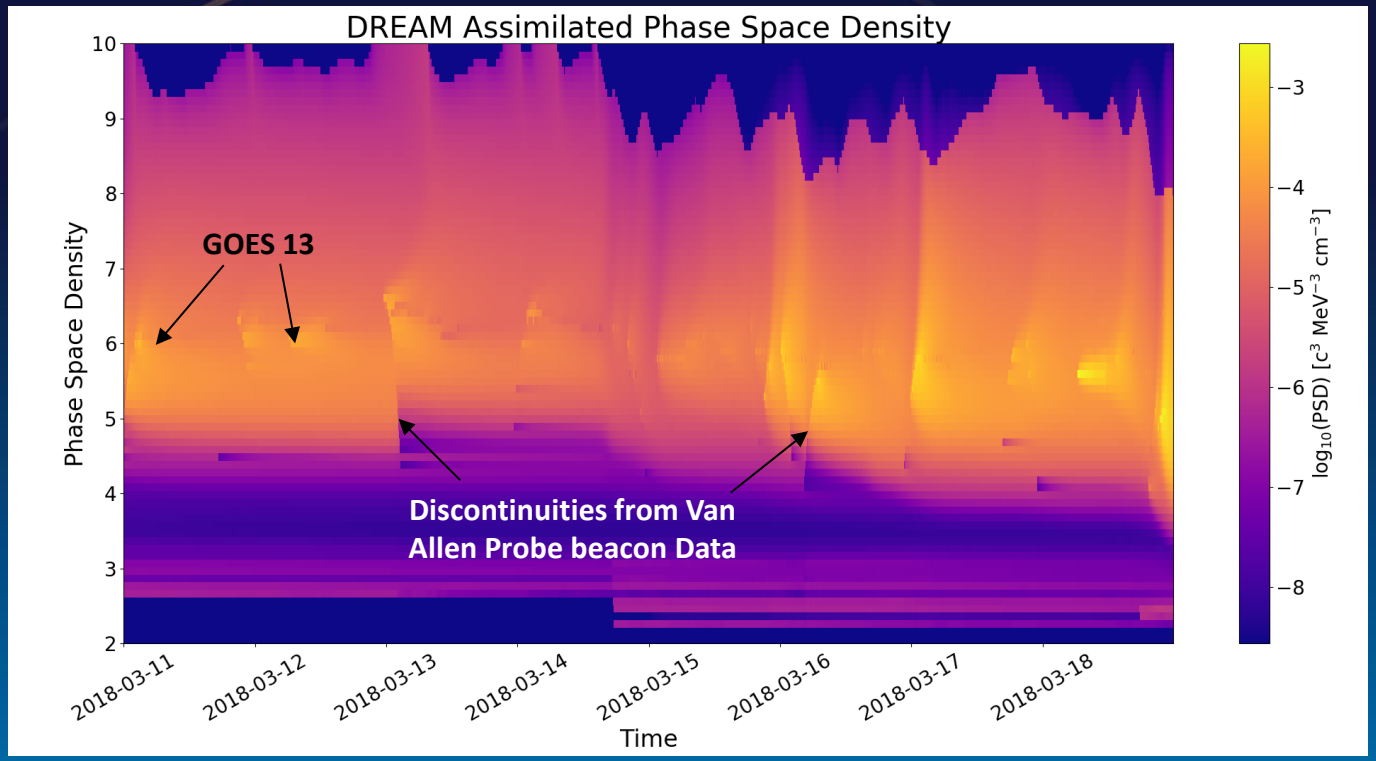
Real-time DREAM



- GOES 13 and Van Allen Probe beacon data is now ingested into DREAM in real-time
  - Global phase space density is updated every 30 minutes

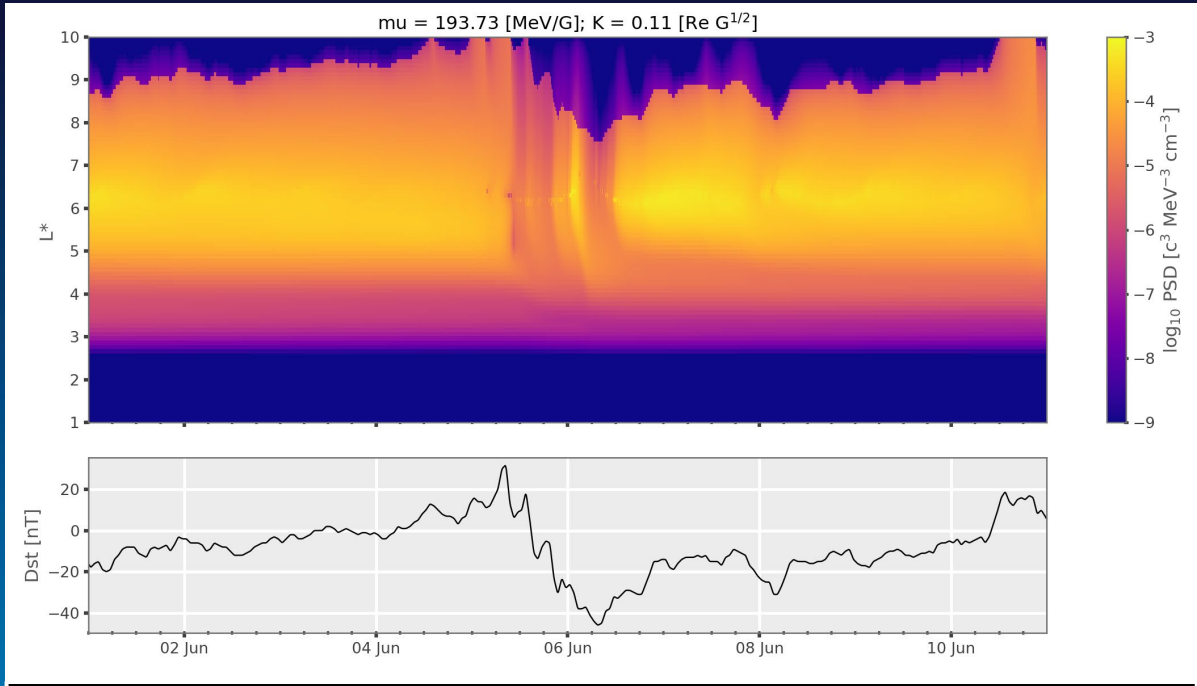
Real-time DREAM



- Cut-in / cut-out times of Van Allen Probe data lead to discontinuities in the assimilated phase space density
  - Diffusion timescale is much shorter than the longest cut-out time period (~24 hour) in the Van Allen probe beacon data

Comparisons: Test Case

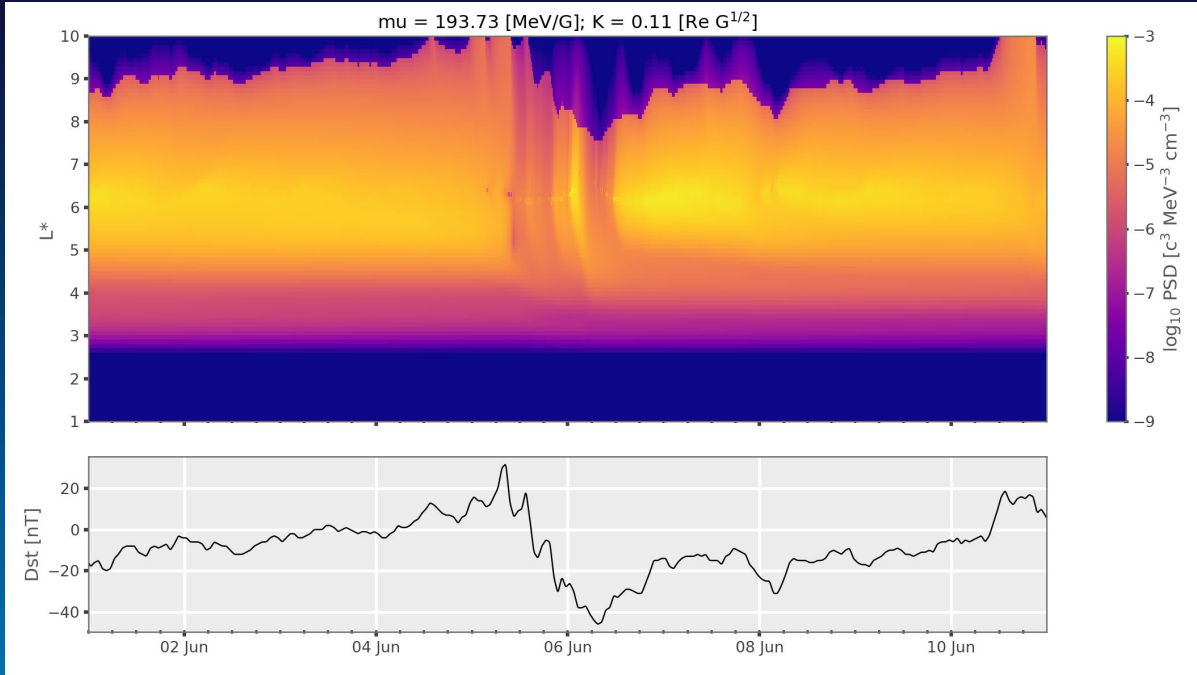
- **Assimilated PSD is compared between:**
  - GOES Only
  - GOES + Beacon
  - GOES + Science
- **Time Period**
  - Start: 2016-06-01
  - End: 2016-06-10
- **Moderate Geomagnetic Storm**
  - K_p: 1 to 6
  - DST: ~-40 to +30 nT



Real-time DREAM assimilated phase space density based only on GOES 13 local measurements.

Comparisons: GOES Only

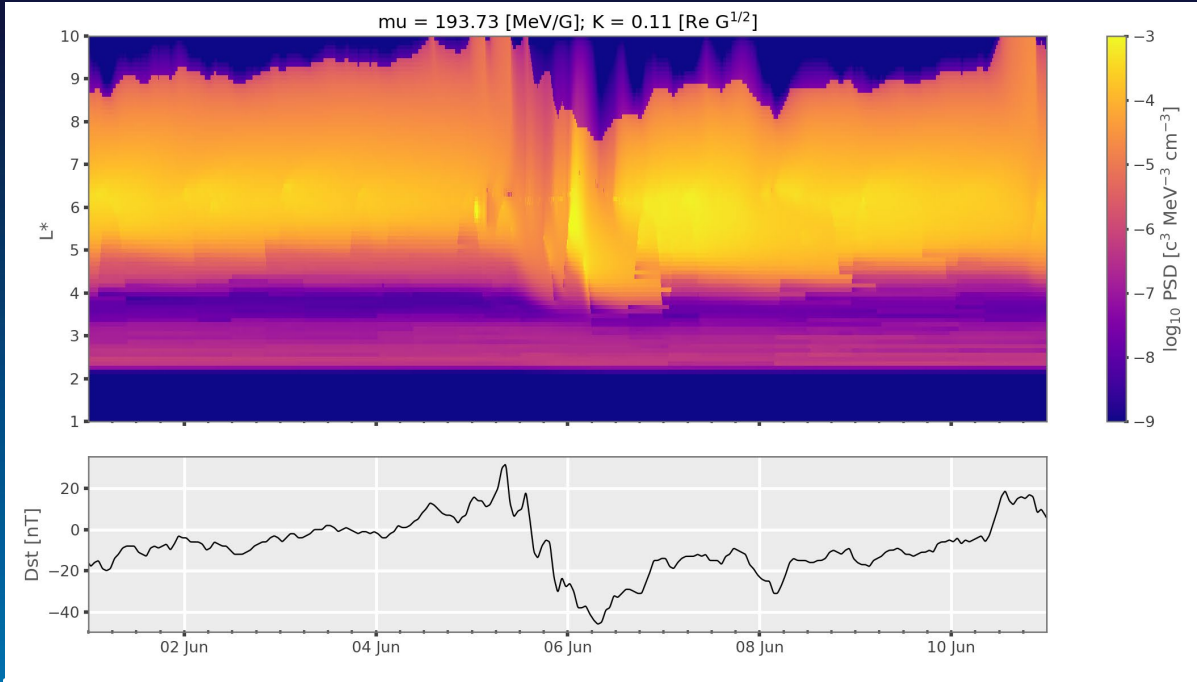
- With only GOES, there is no radial structure other than provided by the model
- Storm onset near June 5th is clearly visible in DREAM PSD
- Reduction in PSD quickly diffuses away from GEO L-shell



Real-time DREAM assimilated phase space density based only on GOES 13 local measurements.

Comparisons: GOES + Beacon

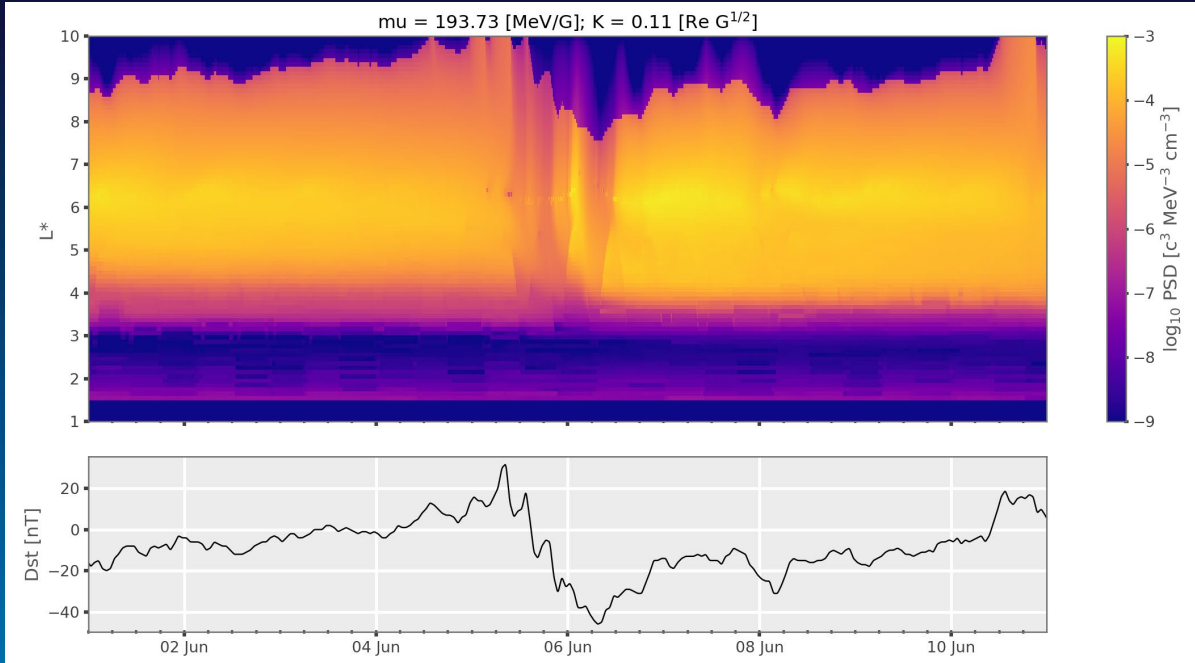
- Van Allen Probe Beacon adds additional radial structure at the cost of discontinuities in PSD
- Structure of low L-shell (3 to 4) is significantly enhanced
- Structure of L-shell from 4 to 6 is also enhanced but diffusion occurs at a faster rate in this region so discontinuities are more noticeable



Real-time DREAM assimilated phase space density based on GOES 13 and Van Allen Probe beacon local measurements.

Comparisons: GOES + Science

- Van Allen Probe Science data provides the best assimilated PSD but is not an option for real-time processing
- Some discontinuities are still visible, but they are significantly diminished compare to the Beacon data



Real-time DREAM assimilated phase space density based on GOES 13 and Van Allen Probe science local measurements.

Conclusions

- **Van Allen Probe beacon data processed and ingested by DREAM**
  - Spin-averaged flux converted to pitch angle distribution by REPAD
  - ~85% coverage for RBSP A; ~35% coverage for RBSPB
  - Only utilizing data from MagEIS (~20 keV to ~5 MeV)
- **DREAM PSD compared**
  - GOES only: Little radial structure but does capture PSD drop during storm
  - GOES + Beacon: Adds radial structure but leads to discontinuities in PSD
  - GOES + Science: Most representative PSD but not available for real-time
- **DREAM is running in real-time on GOES 13 and Van Allen Probe beacon data. PSD products are available at:**
  - **/n/space_data/dream/DREAM_PSD**