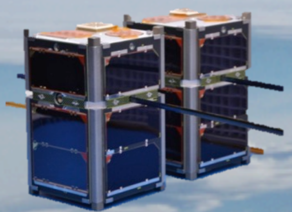
Quantifying Properties and Atmospheric Consequences of Medium Energy Relativistic Electron Precipitation from the Radiation Belts: Coordinated Studies Using FIREBIRD, Van Allen Probes Measurements and Whole Atmosphere Modeling



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And with special thanks to the FIREBIRD, RBSP-ECT, and Sun-to-Ice Teams

University of New Hampshire
Institute for the Study of Earth, Oceans, and Space

AGU Chapman Conference on Particle Dynamics in the Earth's Radiation Belts
Cascais, Portugal; Thursday, 8 March 2018, 10:30-10:50

Science Motivation

- "Missing source" of NOx in whole atmosphere climate models (Randall et al., 2015) poses a problem – what is impact of known missing source in middle atmosphere to climatalogy of whole atmosphere?

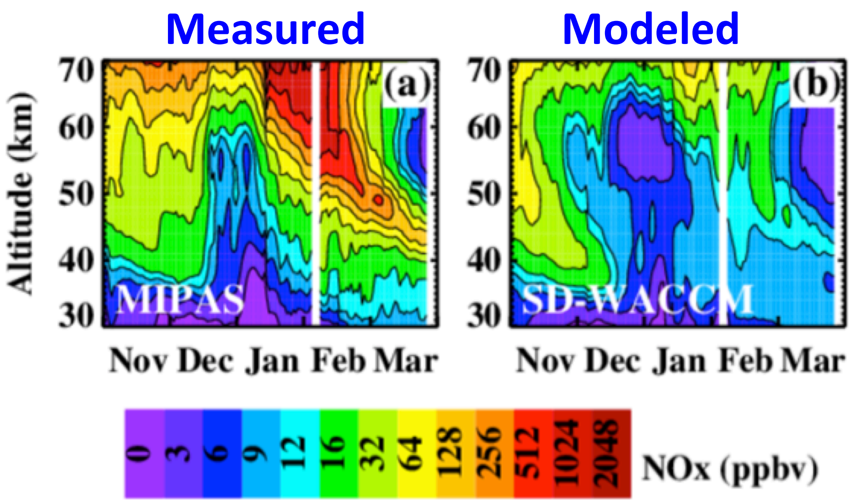


Figure 1. *NO_x from Nov 2003-Mar 2004: a) MIPAS, b) WACCM. Plots show 3-day running average poleward of 70ºN. Randall et al. [2015]*

- **Model is factor of 2-10 too low**
- **Missing source of NOx**

- Models include auroral electrons, galactic cosmic rays, and solar protons – to date, medium energy electrons NOT included
- **Might precipitating radiation belt electrons be missing source?**

Science Motivation

- **Goals of our study**
  1. Estimate the global flux and energy spectrum of medium energy radiation belt electrons precipitating into Earth's atmosphere
  2. Quantify this electron precipitation as a new source for atmospheric ionization
  3. Incorporate source into global model to assess its effects on atmospheric chemistry

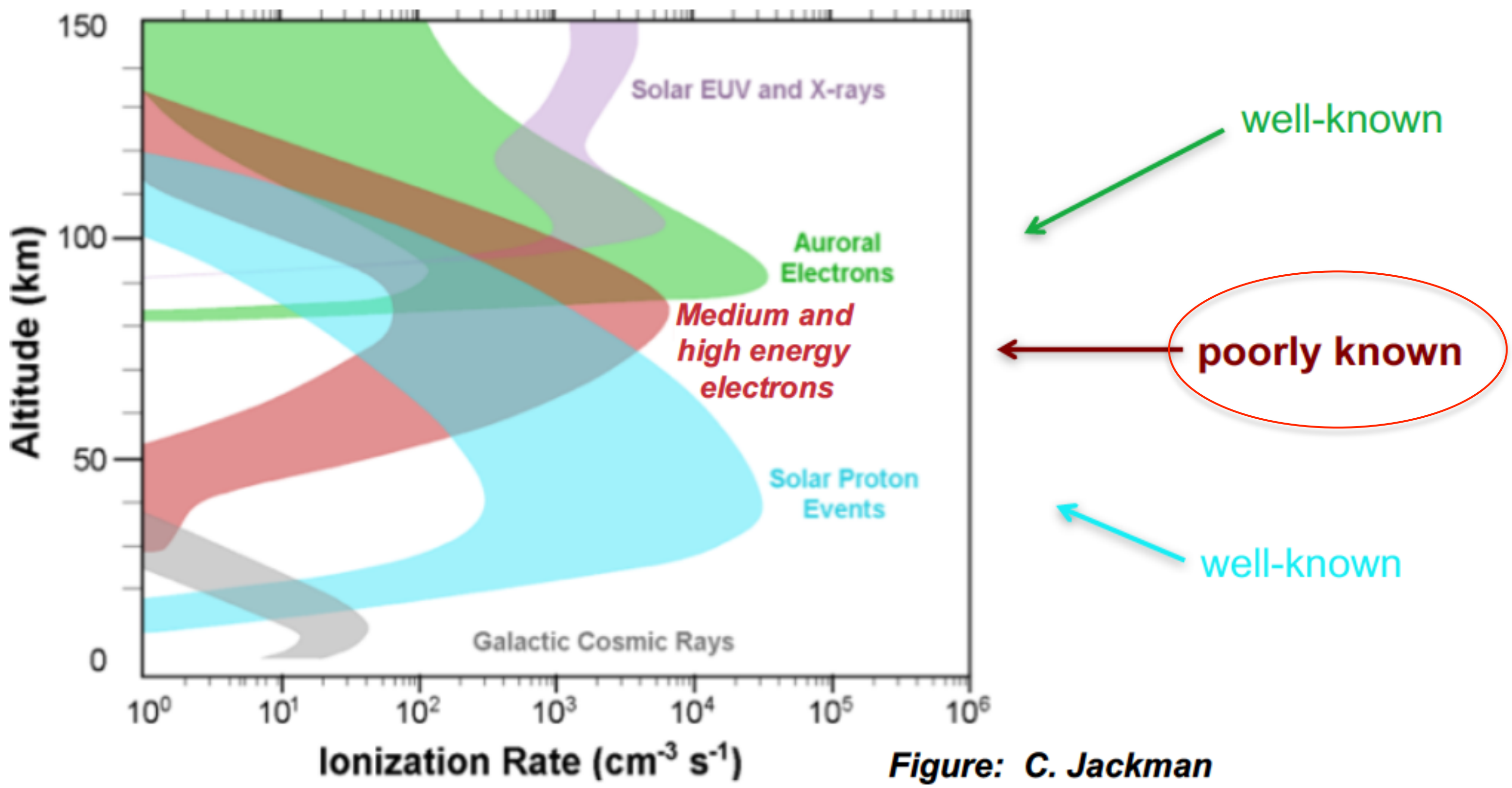


Figure: C. Jackman

Summary of NSF FIREBIRD-I and -II Missions

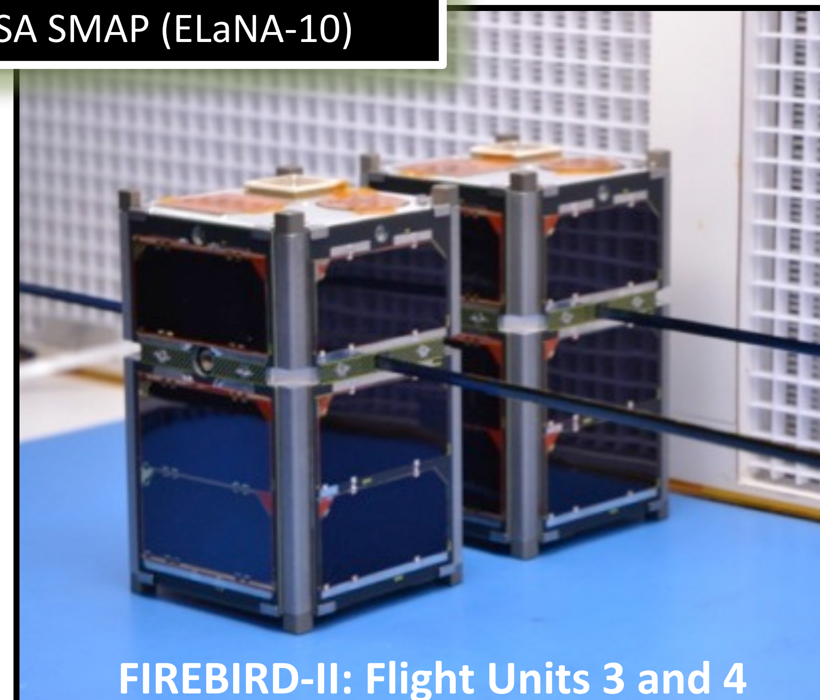
PIs: Harlan Spence (UNH) and David Klumpar (MSU)

FB-I LAUNCHED: Dec 6, 2013
VAFB Atlas-5 NROL-39

FB-II Launched late 2015
VAFB Delta-II 7320 NASA SMAP (ELaNA-10)

FIREBIRD- I: Flight Units 1 and 2

Provided excellent science results;
FU1: 12/13 - 1/14, FU2: 4/14 – 9/14



FIREBIRD-II: Flight Units 3 and 4

Improved version of FB-I mission;
Launched and beautiful data since 1/2015

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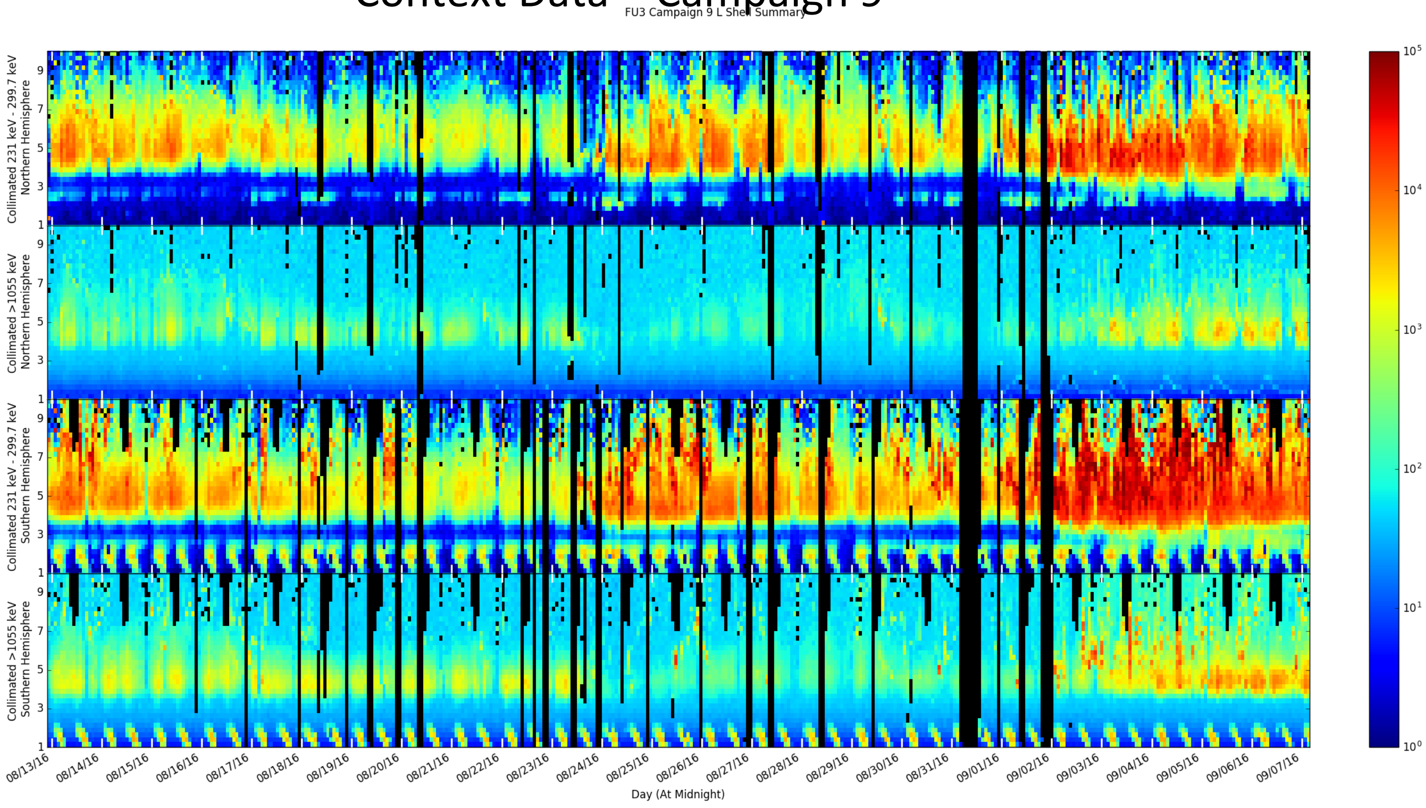
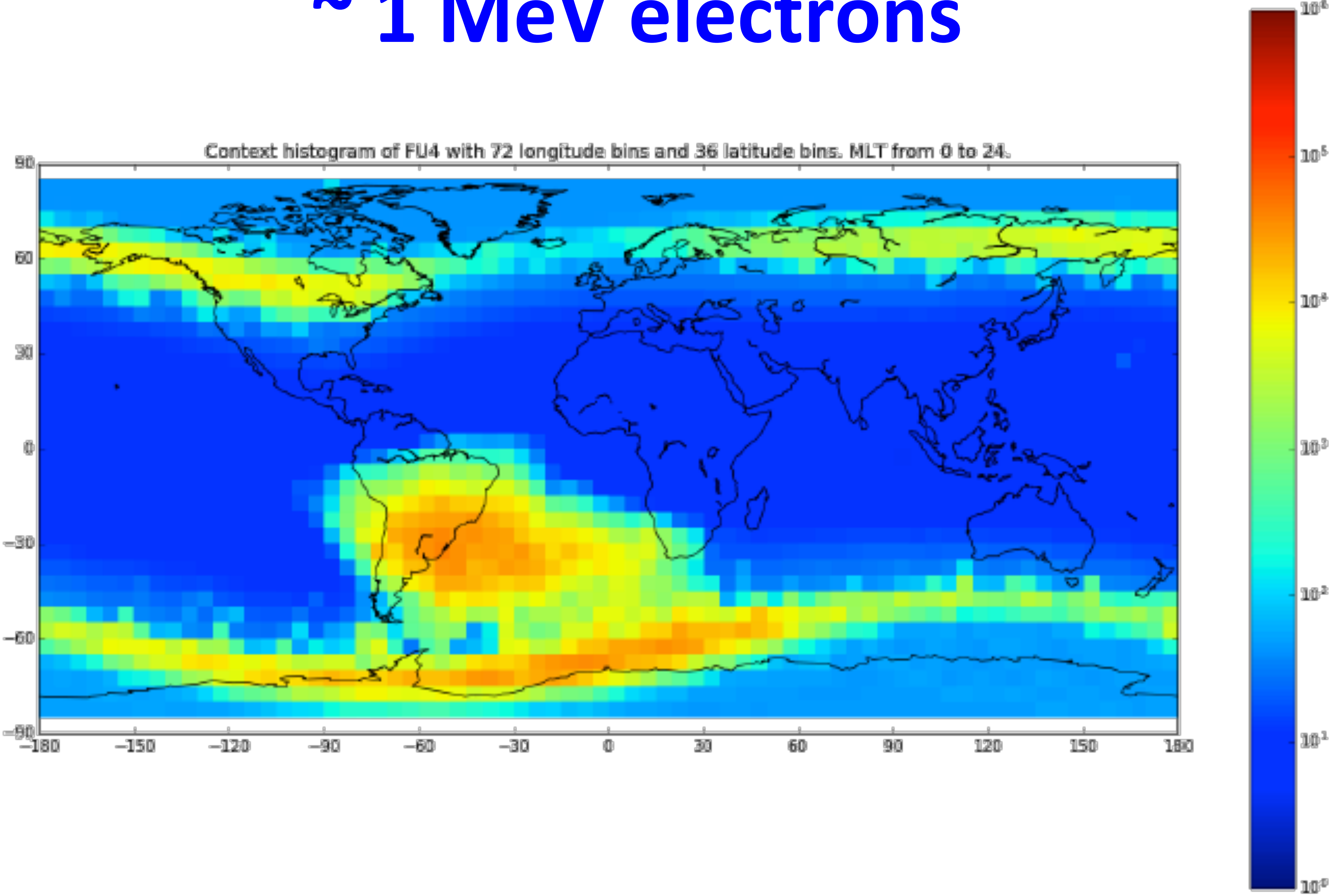
FIREBIRD-II Orbit/Data

- 650 x 430km orbit, 99 degree inclination − single ground station
- Typically one Morning (~0600-0800) and one evening (~1800-2000) pass per orbit, but morning passes are heavily prioritized
- “Context” data − low time/energy resolution − minimal volume

Context Data – Campaign 9



FU4 Context Data (Campaigns 1-9)
~ 1 MeV electrons



FIREBIRD-II Orbit/Data

- Hi-Res data – high time/energy resolution - LARGE volume
  - **VERY** limited HiRes data availability - ConOPS uses context data to hunt for proverbial scientific "needles in haystack"

Campaign #	Dates	Primary Science Goal
1	2015/2/1 → 2015/2/21	Spatial Scale of Individual Microbursts
2	2015/3/21 → 2015/4/19	St. Patrick's Day Storm
3	2015/5/16 → 2015/6/15	Van Allen Probes Conjunctions
4	2015/7/3 → 2015/8/4	July 4th Storm
5	2015/8/8 → 2015/9/4	BARREL Campaign Conjunctions
6	2015/11/15 → 2015/12/15	Conjunctions, Lightning induced precipitation
7	2016/1/15 → 2016/2/3	12.5ms time resolution, EFW and GRIPS conjunctions
8	FU3: 2016/5/20 → 2016/6/14 FU4: 2016/6/9 → 2016/6/20	50ms time resolution, context and COSI conjunctions
9	2016/8/12 → 2016/9/7	50 ms time resolution, BARREL conjunction. (Currently in data downlink phase)
10	2016/12/21 -> 2017/1/4	12 ms cadence for improved dispersion, caught geomagnetic storm, looking in the bounce loss cone.
11	2017/5/1 -> 2017/5/21	Conjunction event on May 2nd
12	2017/7/1 -> 2017/7/21	RBSP and ARASE conjunctions, July 16th shock

FIREBIRD-II Comparisons

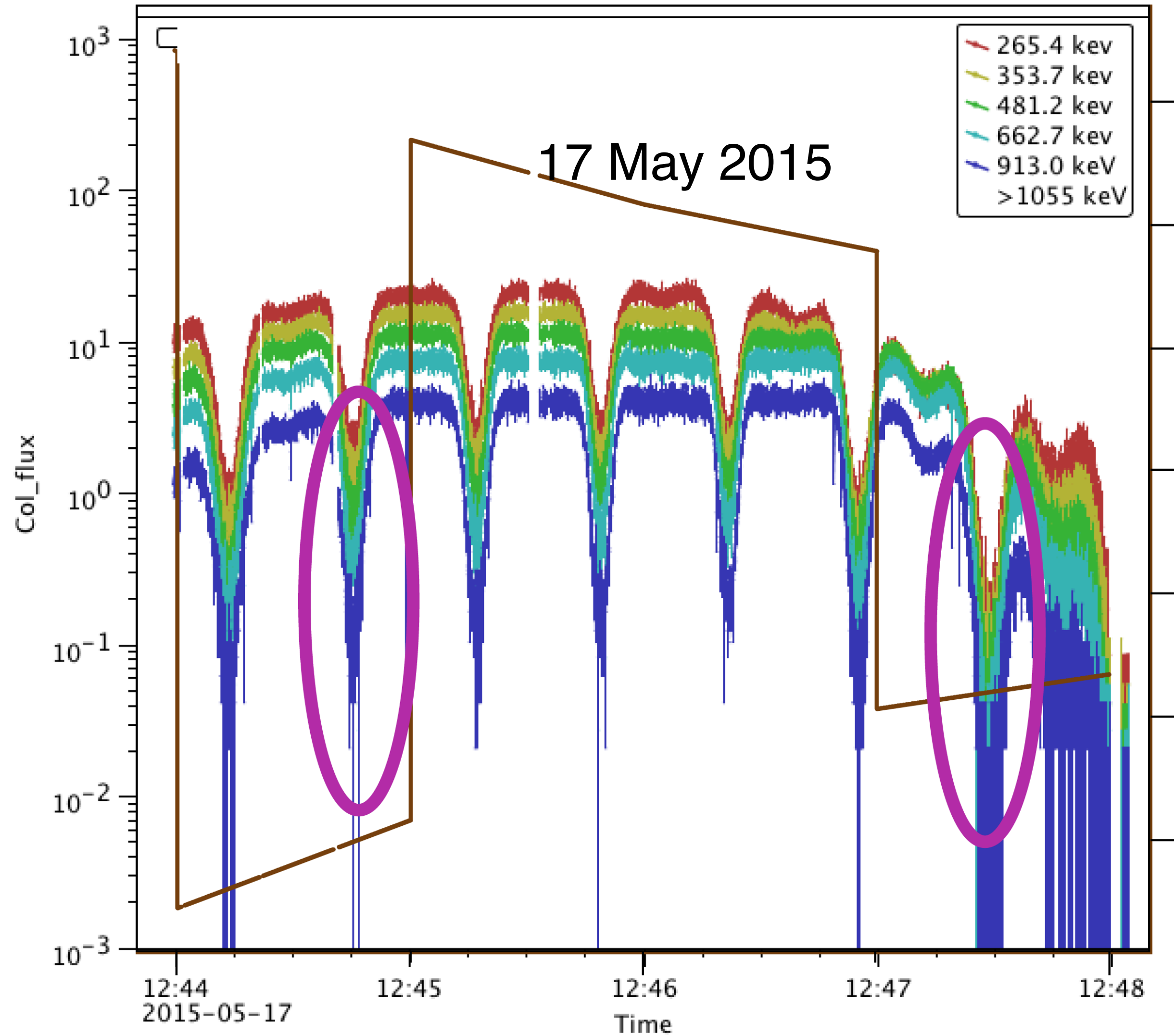
	SAMPEX	POES	FIREBIRD	Van Allen Probes
Altitude	~600 km	870 km	400 - 600 km	700 km to ~6 Re
Inclination (degree)	82	98.7	82	10
Energies	~ MeVs	> 30 keV > 100 keV > 300 keV	265 keV 354 keV 481 keV 663 keV 913 keV > 1 MeV	10s keV to MeVs (MagEIS)
Challenges	High energies	Proton contamination & sensitivity limit	*Sparse*	Equatorial “near” loss cone

Identifying Locally Precipitating Flux from FIREBIRD Measurements

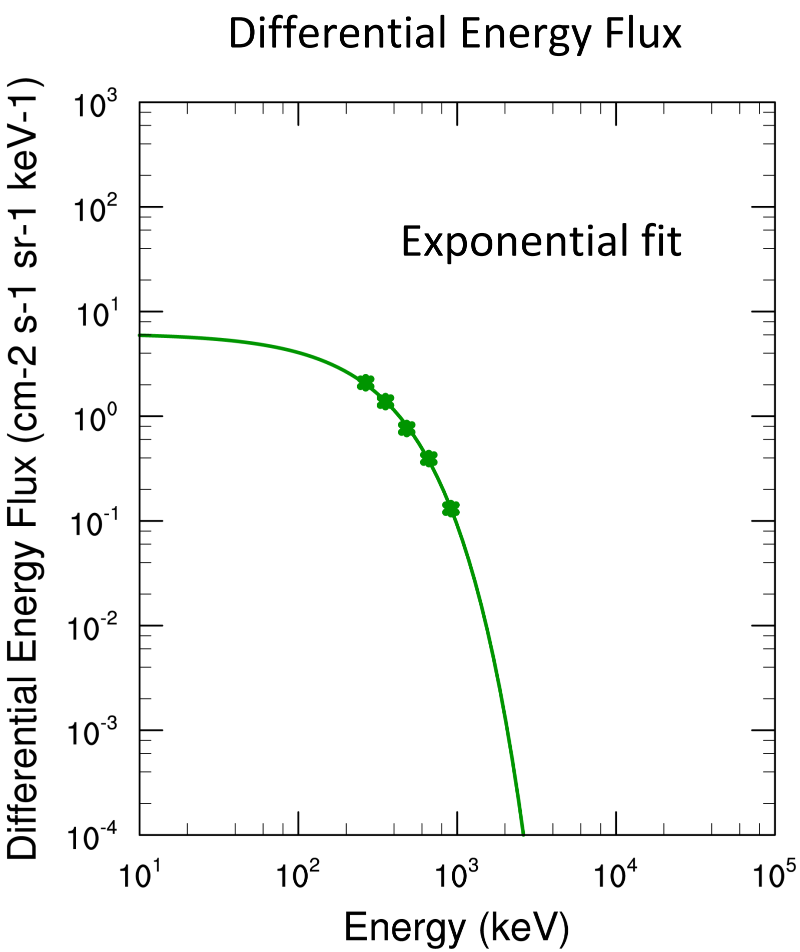
- Survey <u>collimated</u> FU2 and FU3 flux data Identify times when FIREBIRD s/c are in the bounce loss cone

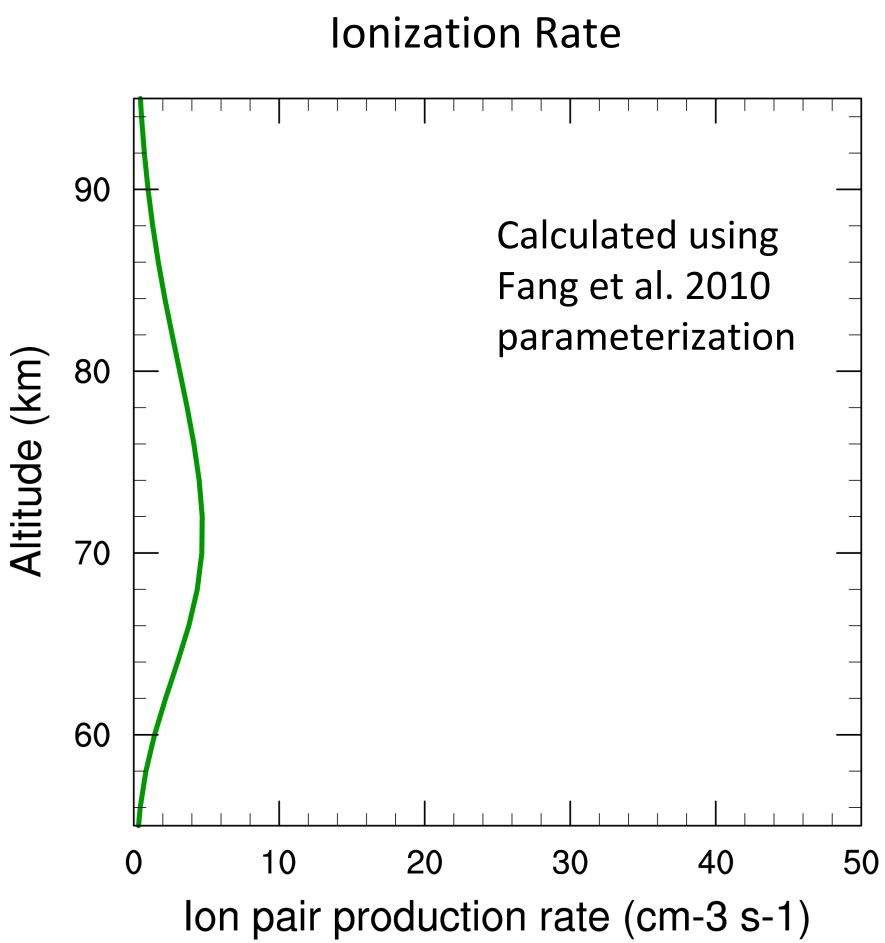
- Locate minima in flux oscillations to determine energy-resolved medium energy electrons locally precipitating

- Use energy spectra to calculate ionization (ion pair production) rates as a function of altitude



Estimating Atmospheric Ionization Altitude Profile from FIREBIRD Electron Flux

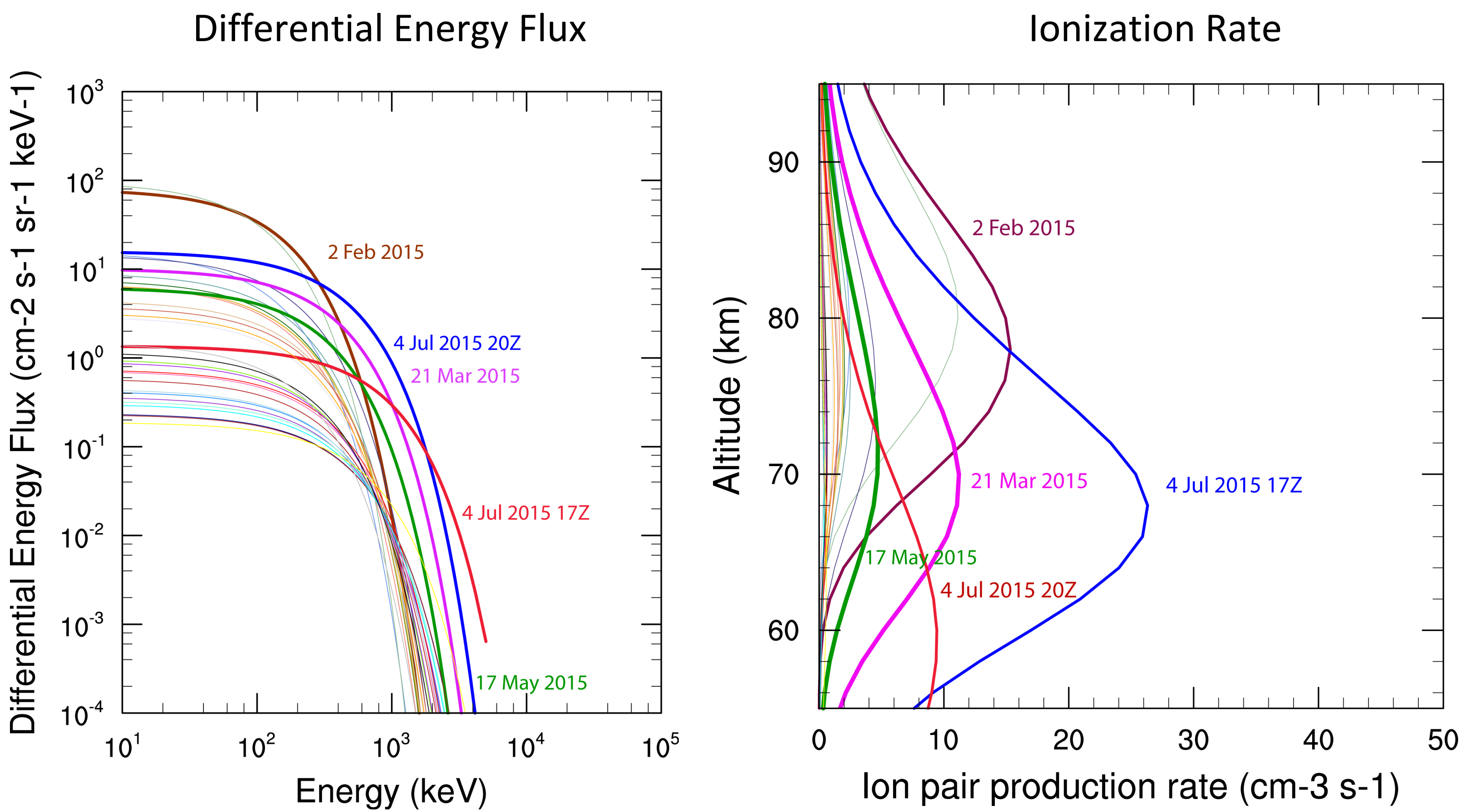




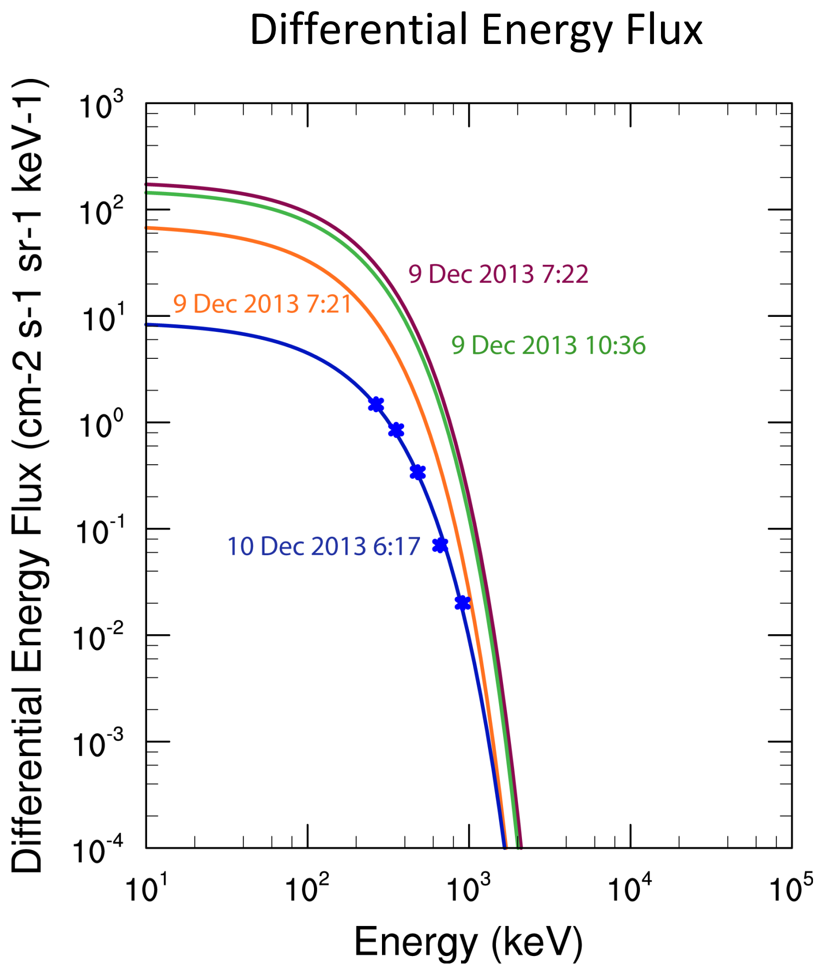
17 May 2015 12:44:45

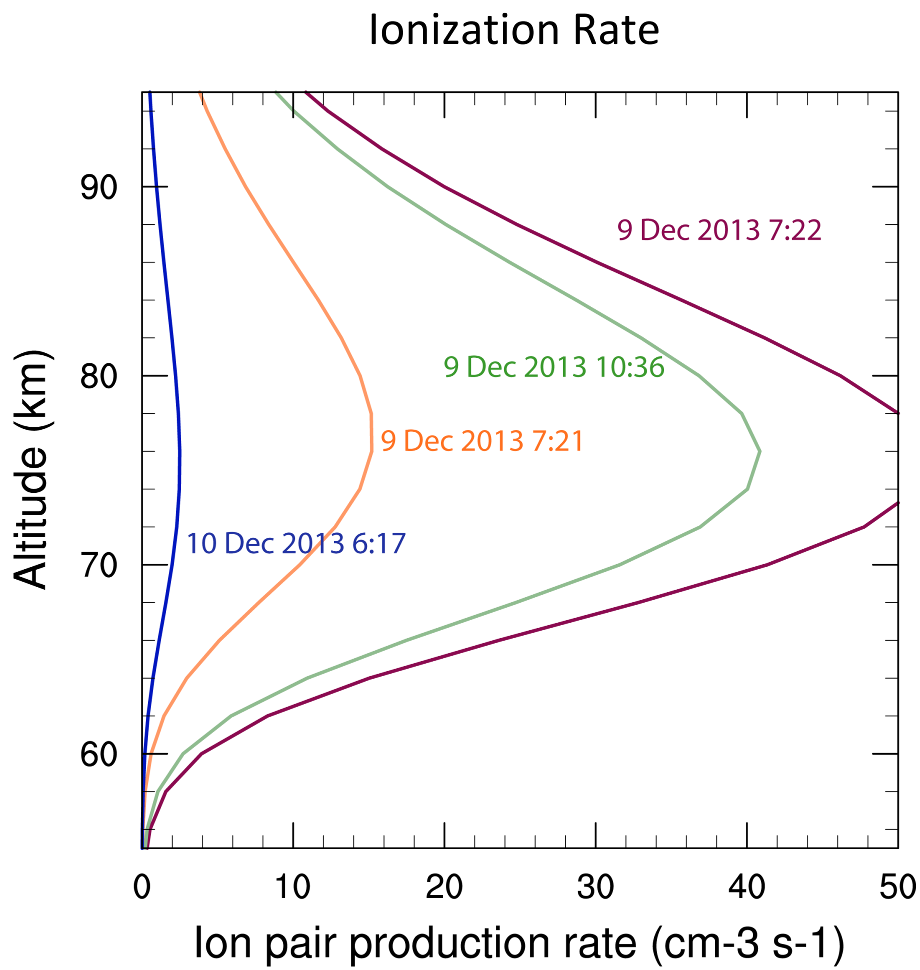
At first minimum of oscillation in BLC

Characteristic Range of Spectral Shapes (FU3)



Characteristic Range of Spectral Shapes (FU2)



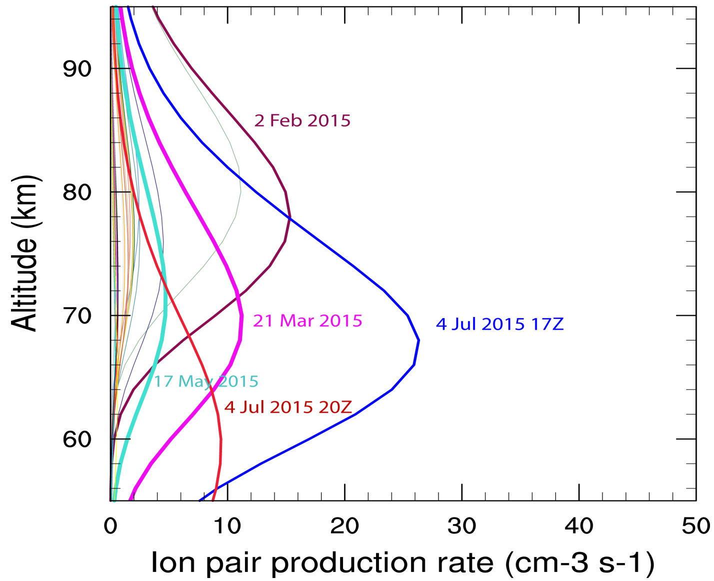


Maximum estimated ion pair production of >50 cm^3/s at 75 km

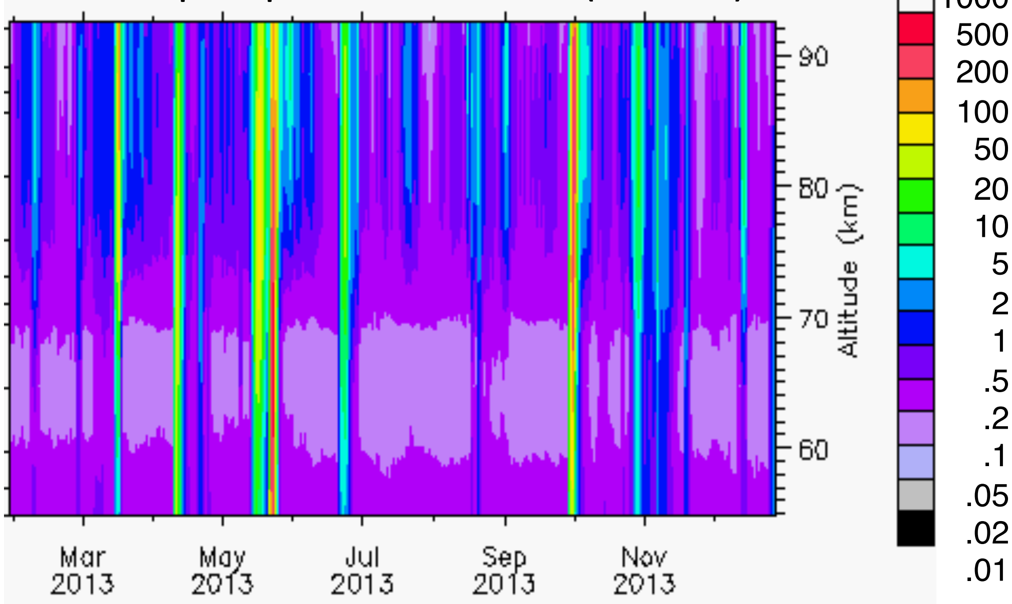
- In at least a few cases, ionization from electrons are large enough to compete with or exceed ionization from typical solar energetic proton events

- Might explain the missing source of NO_x around 60-70 km altitude in models

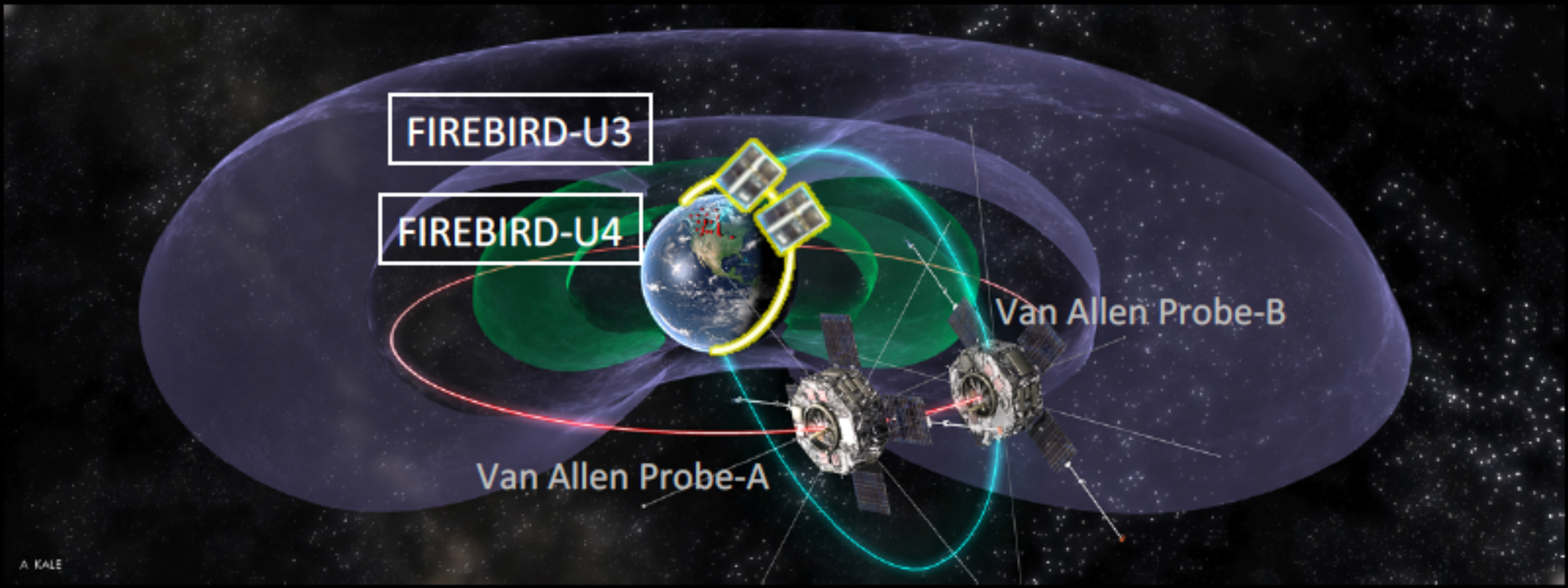
FIREBIRD electron flux



Solar Energetic Protons
Ion pair production rate ($cm^{-3} s^{-1}$)



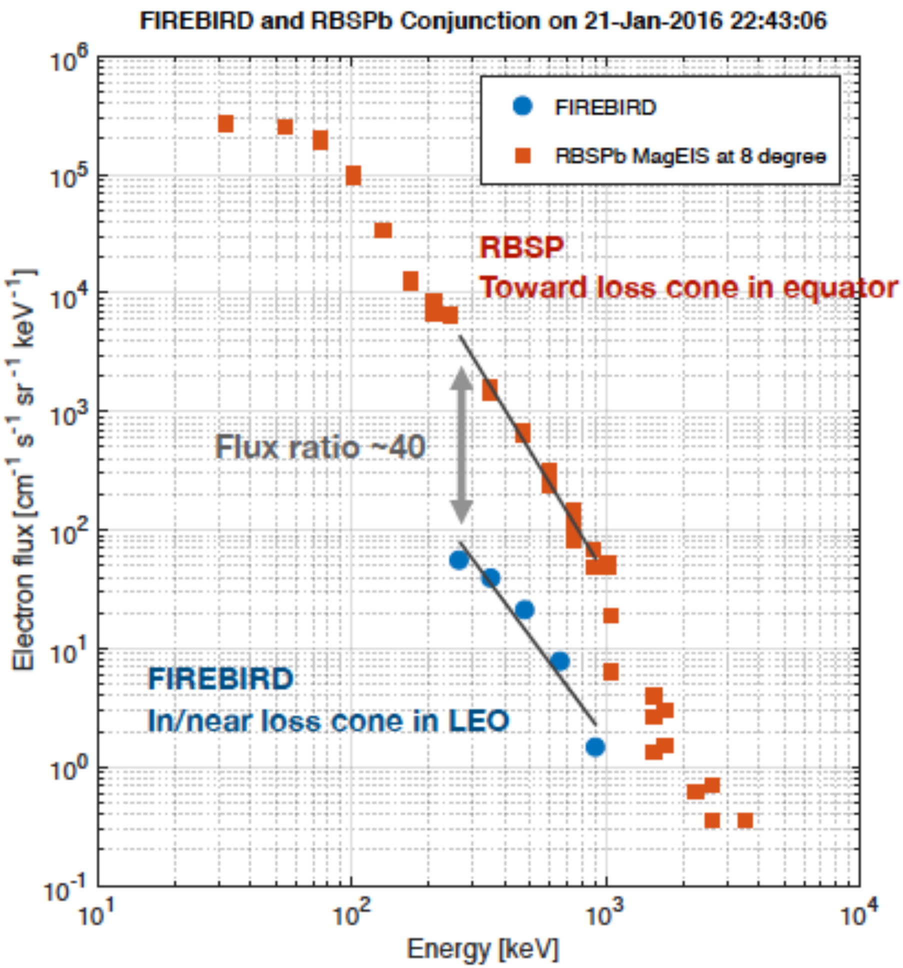
***NSF FIREBIRD:** High resolution at critical energies in the loss cone at Low Earth Orbit*



***NASA Van Allen Probes (RBSP):** Continuous coverage in the radiation belts*

FB and RBSP-ECT Energetic Electron Flux Comparison at a Conjunction

- 20 high quality conjunctions when in BLC from first 12 FB campaigns
- Estimate flux ratio between MagEIS near loss cone at equator with FB
- Some energy dependence but use average value of ~50; can range to >1000 in some cases
- Appeal to global coherence and use RBSP-ECT data to estimate losses



From Local to Global Estimates

- Create **global maps of electron flux / ionization rates** as input to 3D climate model (WACCM)

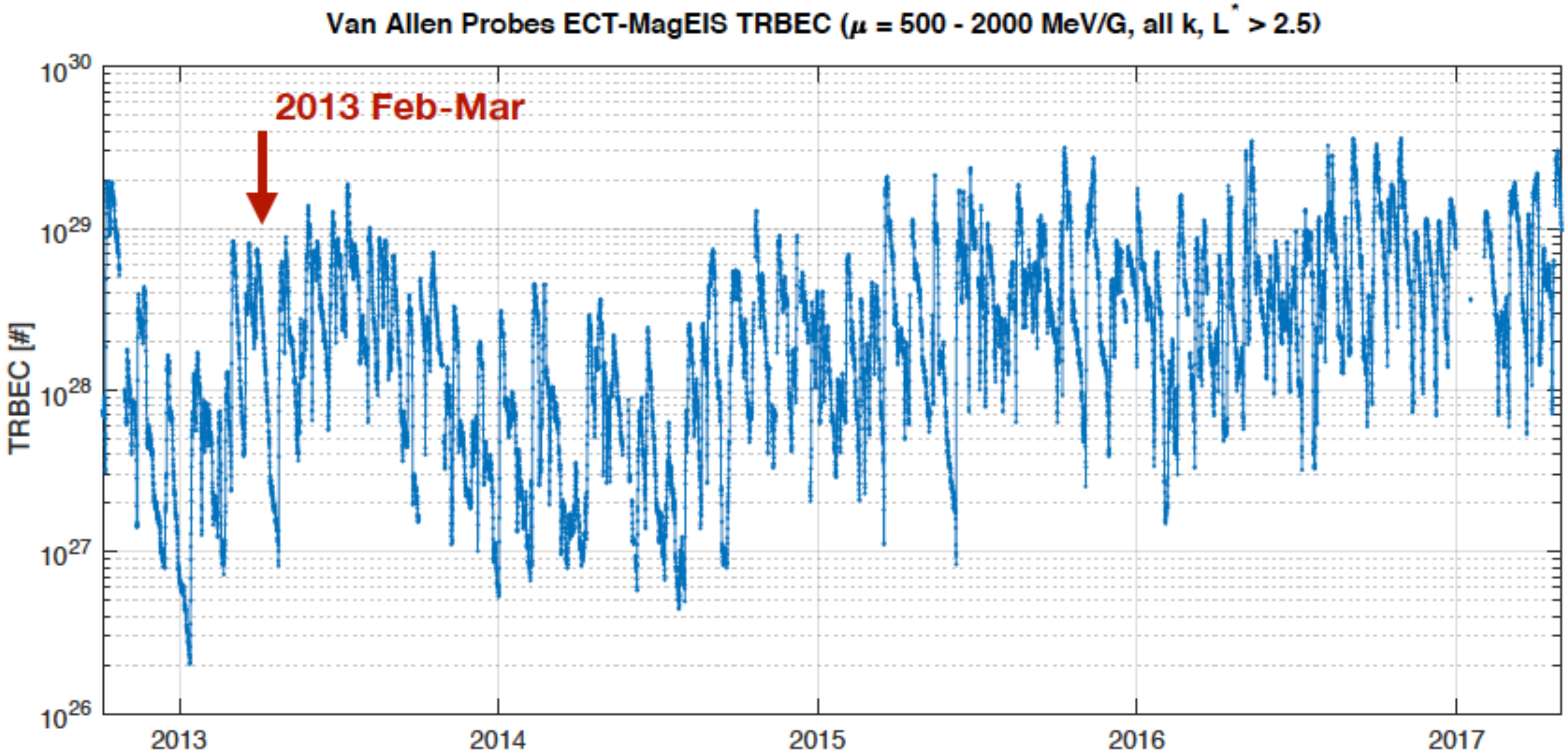
- Choose a few "representative" fluxes -- quiet times, moderate activity, and storms − here we do only one interval when conditions are ***un**-remarkable*

- Run the model to see if the ionization is large enough to explain the missing NO_x.

Total Radiation Belt Electron Content

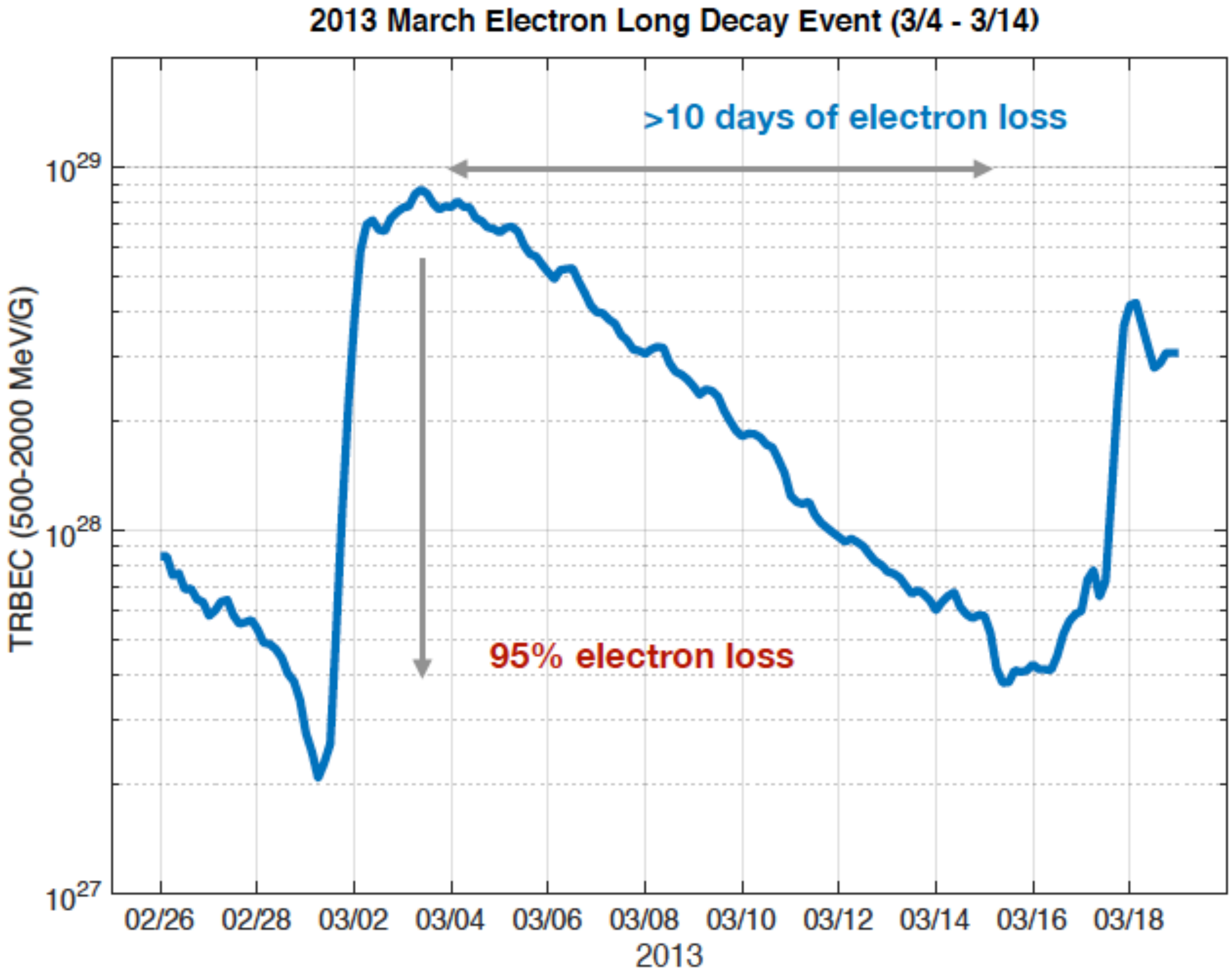
- Integrate number of electrons in an elemental phase space:

$$dN \approx 8.134 \times 10^{29} \, \bar{f}(\mu, K, L^*) \frac{\sqrt{\mu}}{L^{*2}} d\mu dK dL^*.$$



Electron Long-Quiet Decay Event

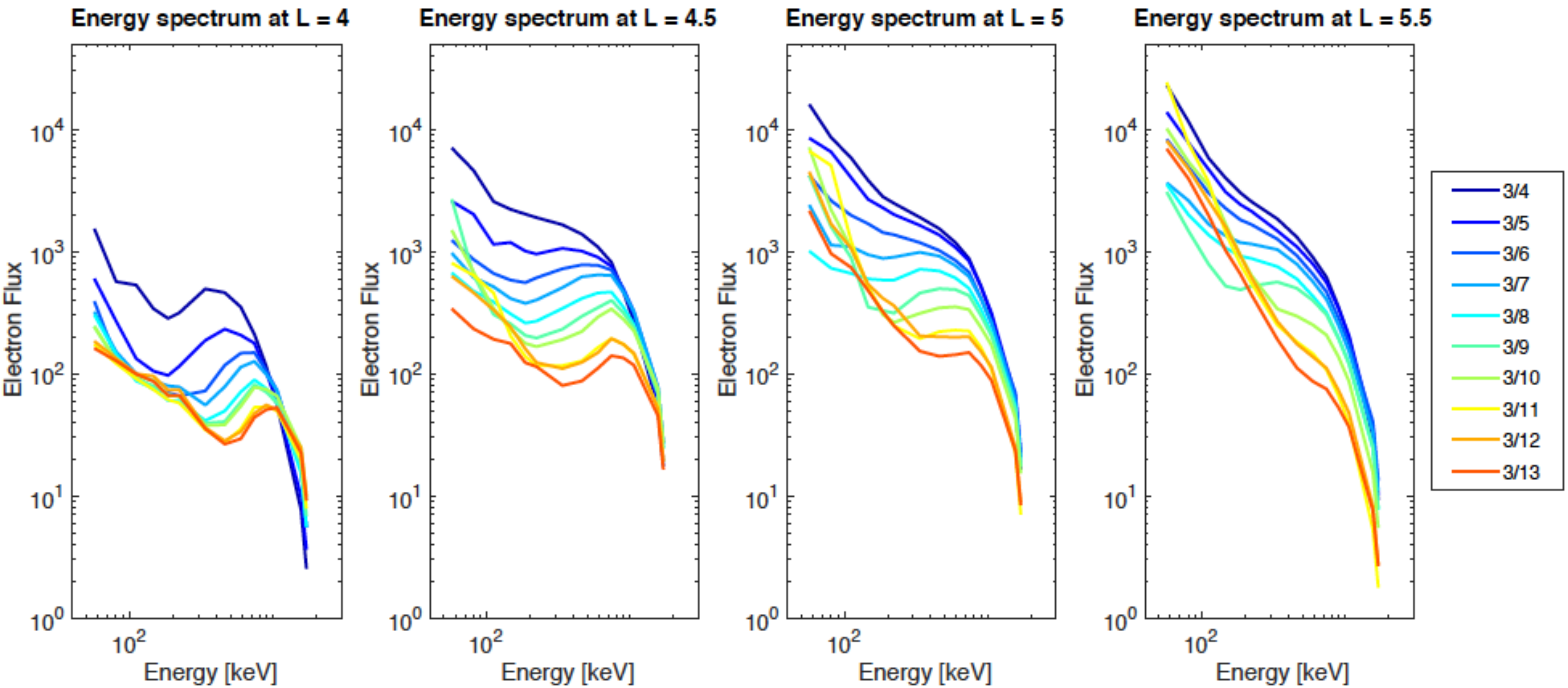
2013 February-March



Electron Long-Quiet Decay Event

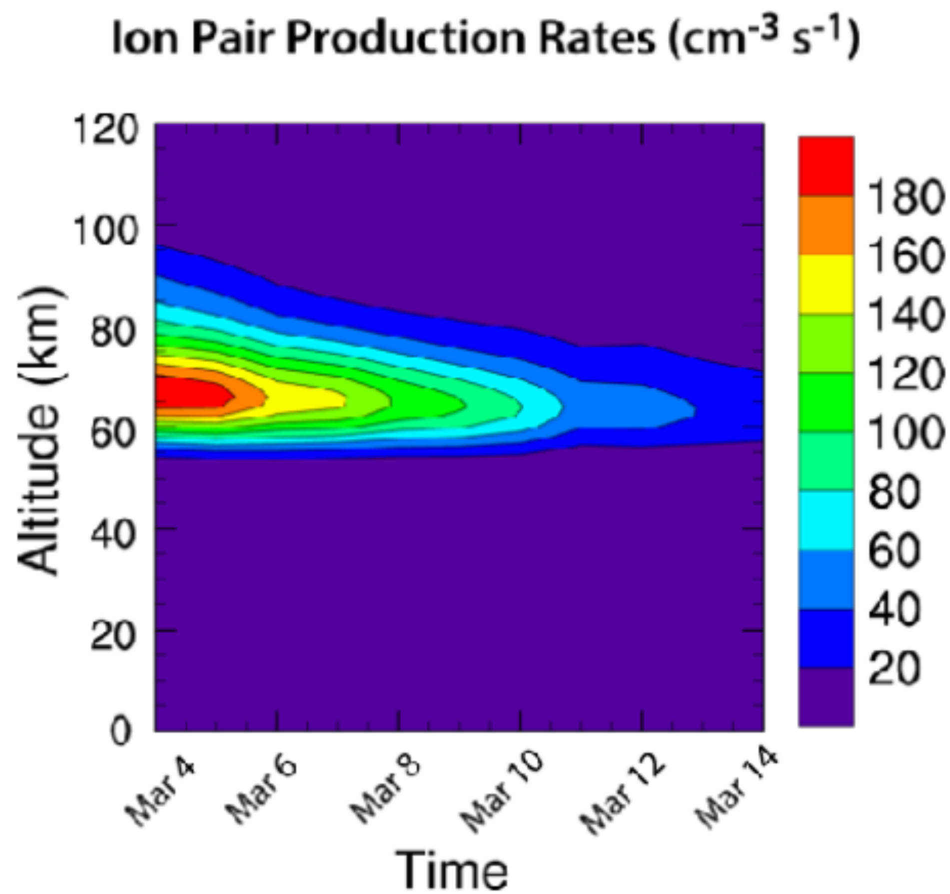
2013 February-March

- Electron flux and energy spectrum for simulating RBE impact on atmosphere



Whole Atmosphere Community Climate Model (WACCM)

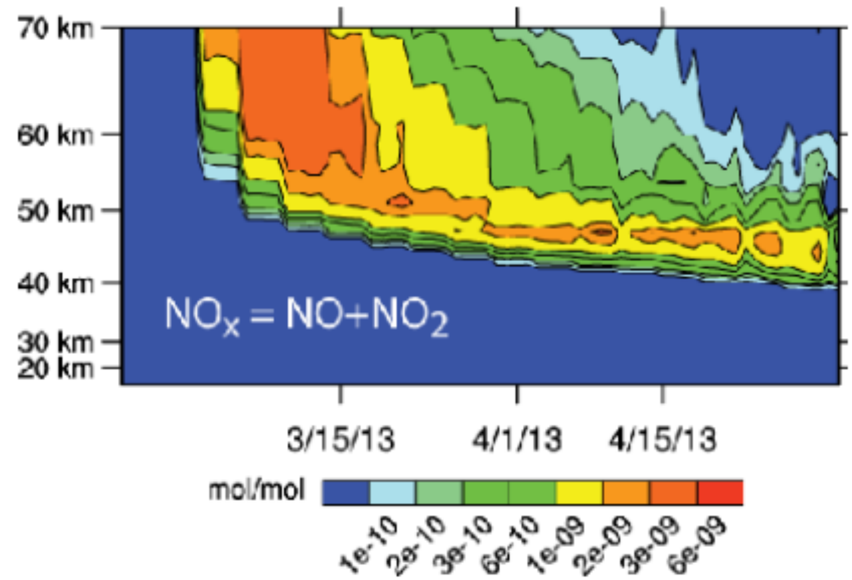
- Compute the effects of energetic particle precipitation on atmosphere and address the contribution of upper atmospheric dynamics and chemistry to climate
  - Assume RB electron precipitation between L = 3 and 7
  - Atmospheric ionization input: > 50 keV electron flux from 2013 Feb-Mar event (moderate condition)
  - Average flux ratio = 50



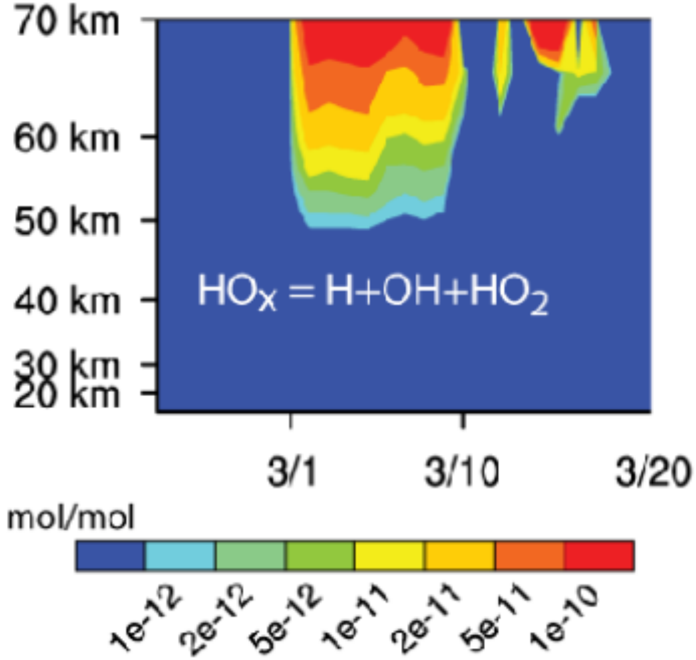
WACCM Results

- Northern Hemisphere HOx and NOx enhancements and O3 reductions compared to simulations without radiation belt electrons

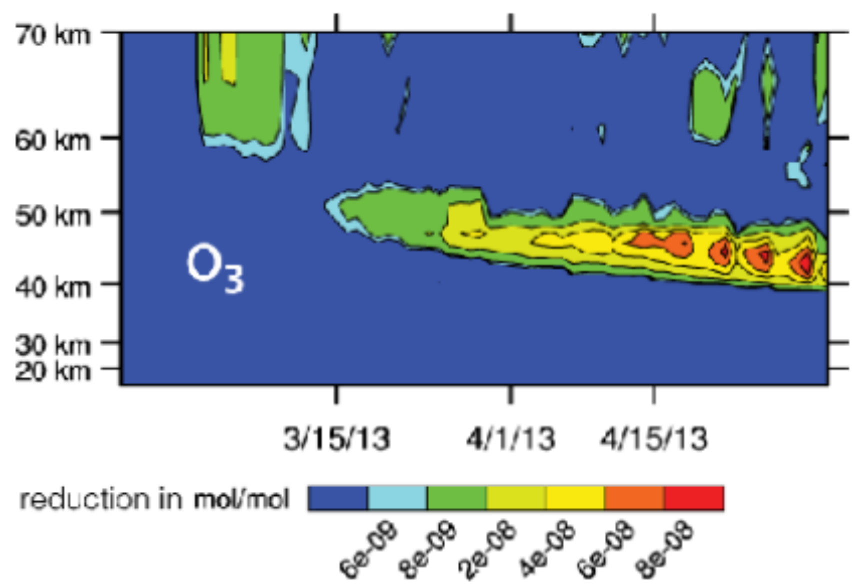
~50-100% peak enhancements



~5% peak enhancements



~2-3% peak reductions



Summary and Future Work

- We estimated radiation belt electron precipitation
  - Ratio between MEO (RBSP-ECT) /LEO (FB) loss cone flux
  - Use TRBEC to identify a "clean" period of loss
  - Use scaled MEO to estimate global e- precipitation flux
- We quantified contribution of radiation belt electron precipitation to middle atmospheric chemistry
  - HOx (few %) and NOx (50-100%) increases; O_3 decrease (few %)
  - NOx increase narrows gap between observations and model, but not clear if enough generally; **rad belt e-'s probably important**
- Next: Explore times/cases when we can compare data–driven models with simultaneous NOx measurements