Quantifying Energy-Time Dispersion Properties of Relativistic Electron Microbursts: Coordinated Studies Using FIREBIRD, Van Allen Probes, and Other Assets

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Outline

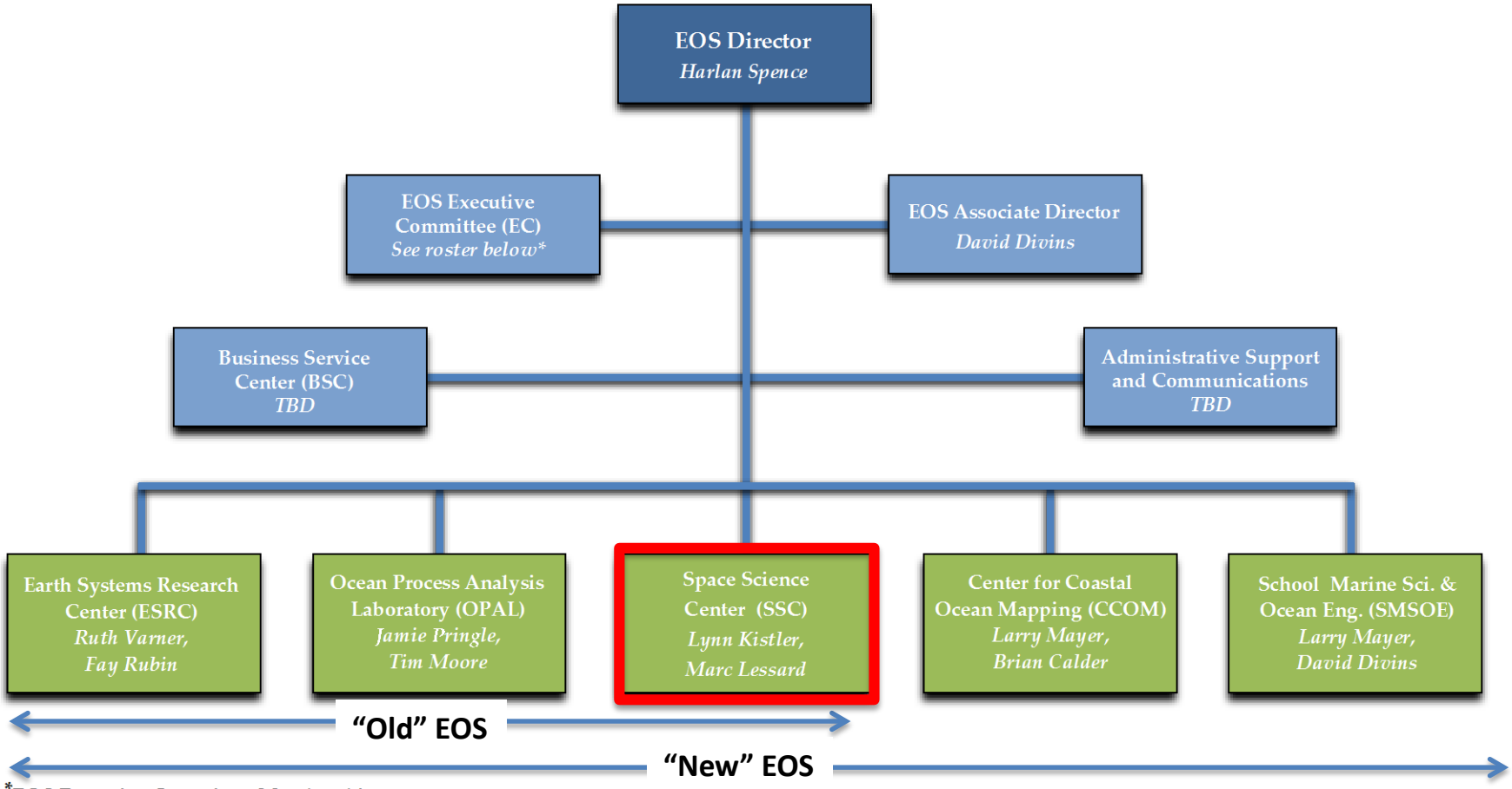
- Introduction to and overview of the Space Science Center (SSC) within EOS at UNH
- Overview of FIREBIRD mission – One example of activities within the EOS/SSC at UNH
- Accomplishing **BIG** science with *little* missions
  - Unraveling the physics of "microbursts" – using dispersion as a smoking gun
  - Impacts of relativistic electron precipitation to middle atmosphere chemistry
  - Contributions also to global electric circuit?
- Invitation to Collaborate

Introduction to and overview of the Space Science Center (SSC) within EOS at UNH

- What is EOS? It is the first (and only, so far) "University Institute"
- EOS is an academic unit of UNH (equivalent to a College) whose primary focus is interdisciplinary research
  - EOS Director (me) reports to the Provost and is a member of the Deans' Council
  - EOS is a stand-alone RCM unit administratively
- EOS PIs generate a significant fraction of all funded research on campus and account for a disproportionately large fraction of all publications

EOS Organization Chart

(v.01-09-17)



*EOS Executive Committee Membership:

- *EOS Associate Director*
- *BSC Director*
- *SwRI-EOS Director*
- *ESRC/OPAL/SSC/CCOM/SMSOE Directors and Deputy Directors*

EOS by the Numbers

- EOS currently has ~300 employees (including students)
  - 25 tenure-track faculty (representing 21 EOS FTE) and 40 research faculty (this represents <5% of all UNH faculty – big things come in little packages!)
  - ~160 technical and administrative staff
  - 80+ students work in EOS (mostly graduate students)
  - SSC has 12 TTF (joint with Physics) plus 3 very active Emeritus TTF and 12 research faculty
  - Number of proposals
    - > 1/calendar day on average
    - Accounts for ~45% of all proposal submitted at UNH
  - Number of awards
    - >100 new awards per year (NASA, NSF, NOAA, DOD, +…,etc.)
    - Accounts for ~40% of all new awards at UNH (by total $ or by #)
  - Of the 118 current PIs in EOS, 43 are from the SSC

EOS SSC Faculty Members

Tenure-Track Faculty

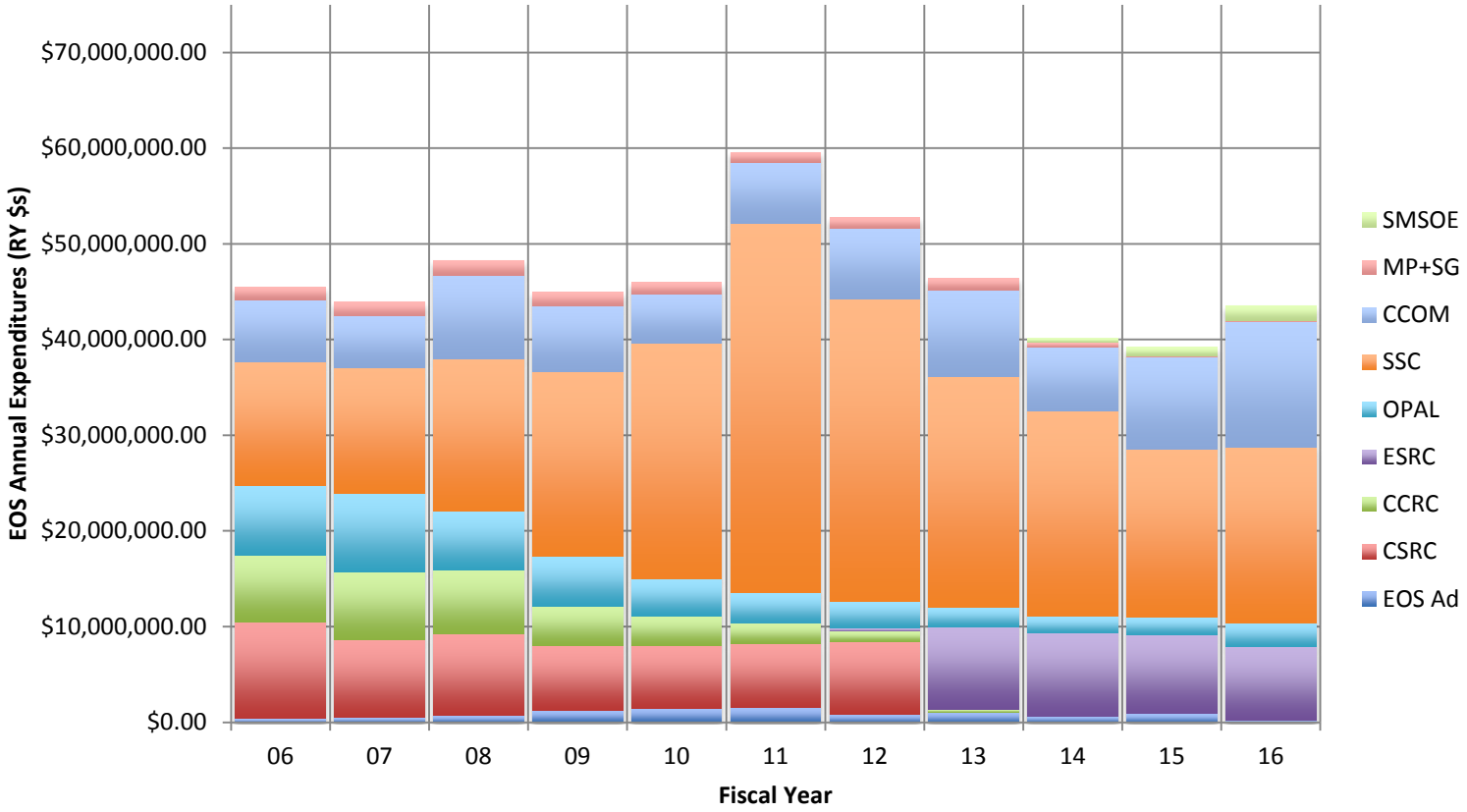
- James Connell
- Kai Germaschewski
- Marc Lessard
- Ningyu Liu
- Benjamin Chandran
- Joseph Dwyer
- Terry Forbes
- *Joseph Hollweg*
- Lynn Kistler
- *Marty Lee*
- Mark McConnell
- *Eberhard Moebius*
- Joachim Raeder
- James Ryan
- Nathan Schwadron
- Harlan Spence
- Roy Torbert

Research Faculty

- Chia-Lin Huang
- Lin Dacheng
- Jichun Zhang
- Peter Bloser
- Clifford Lopate
- Noé Lugaz
- Charles Farrugia
- Antoinette Galvin
- Philip Isenberg
- Harald Kucharek
- *Bruce McKibben*
- Charles Smith
- Bernie Vasquez

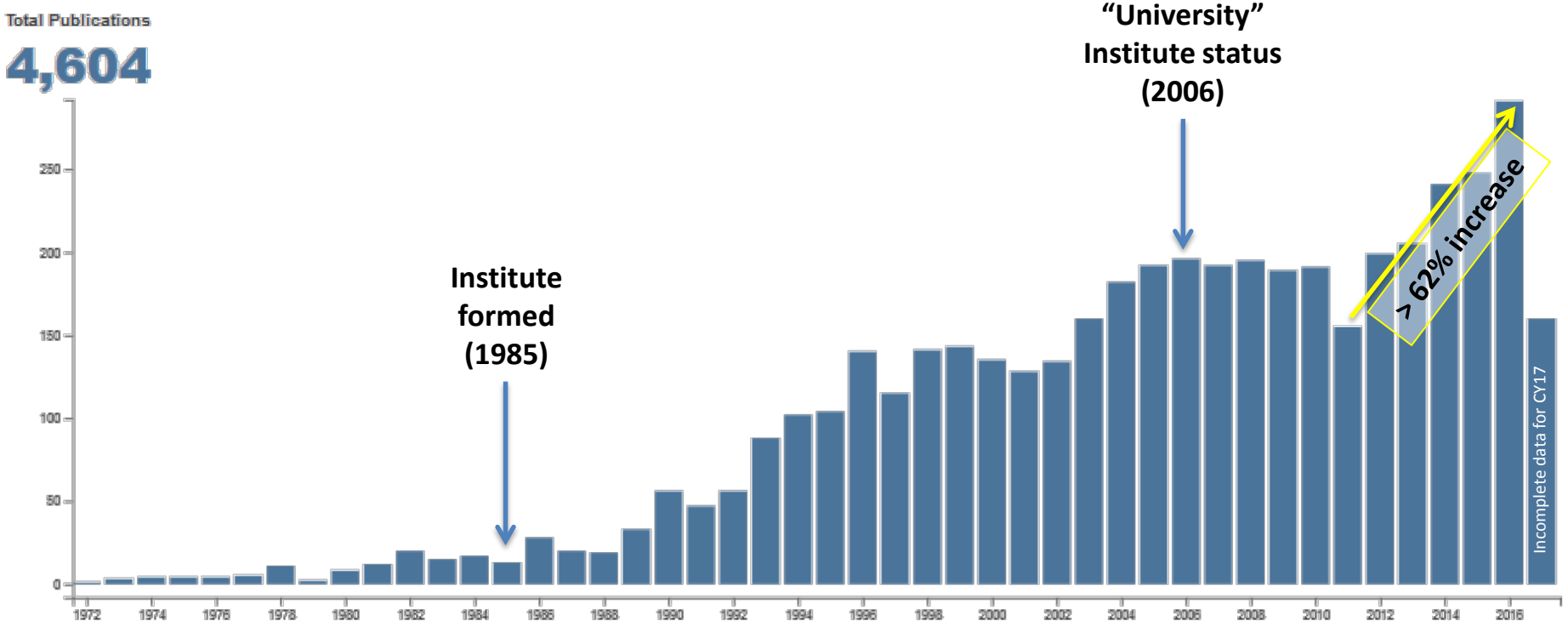
EO$ by the Number$

- **Total Expenditure$:**
  - **EO$ Overall: $45M/year**
  - **$$C: $20M/year**
- *Indirect Expenditure$ ~ $10M/year*



EOS by the Numbers

- SSC authors contribute significantly to the ~300 EOS peer-reviewed publications per year



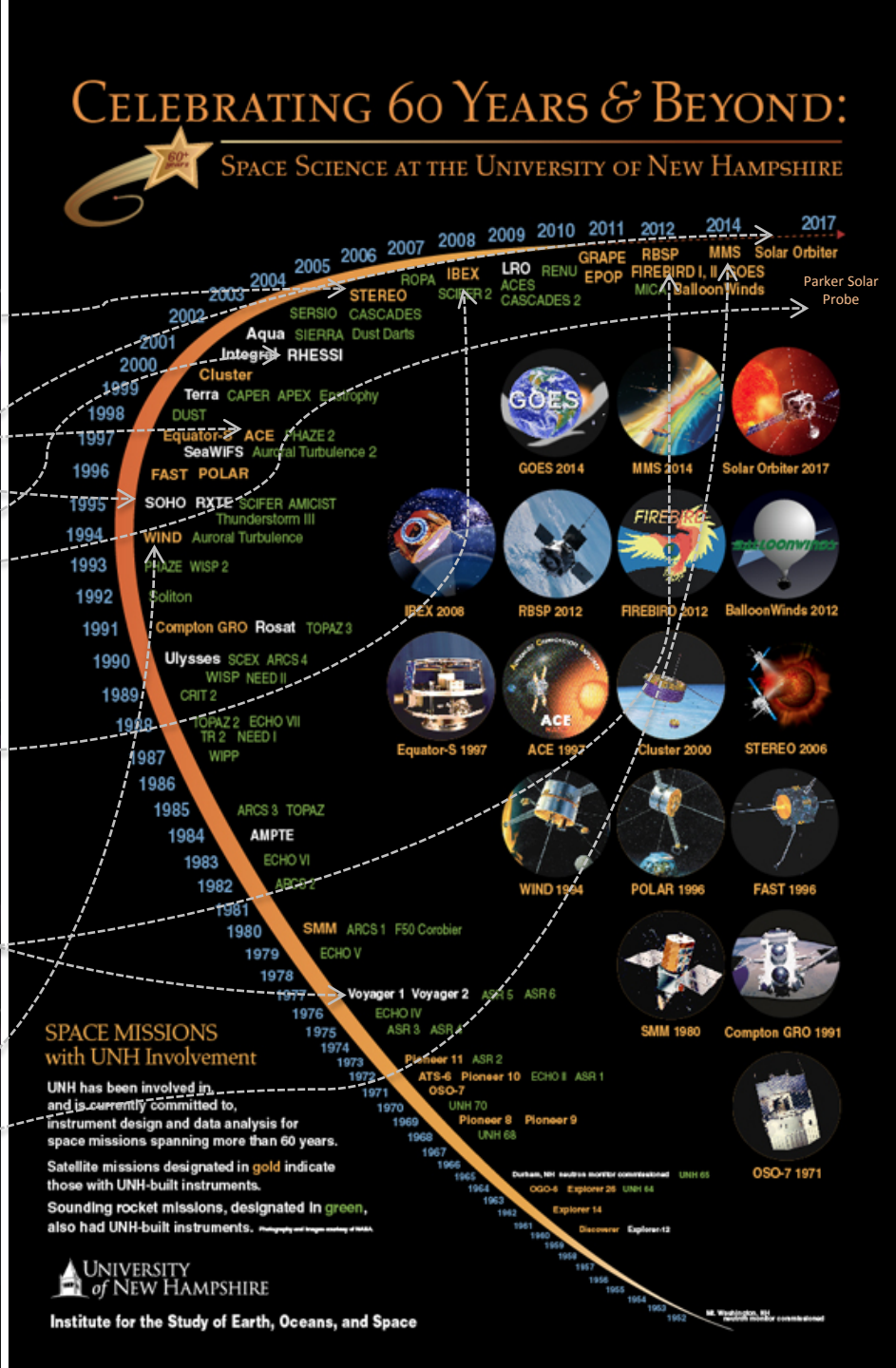
>**450 Satellite Years** on Orbit for **Currently Operating** Missions - **and Counting**!

- **SSC leadership** on:
  - **14 of all 18 active (78%) NASA Heliophysics science** missions
  - **21 overall missions** (NASA, NOAA, ESA, NSF, CSA, KARI) representing a total of **36 individual spacecraft and >450 collective years of on orbit operations**

- **SSC leadership poised to continue** with in-development (e.g., SO, SPP, et al.) and pending missions in the queue (e.g., THOR et al.)

NASA Heliophysics System Observatory (all ongoing and in-development missions)

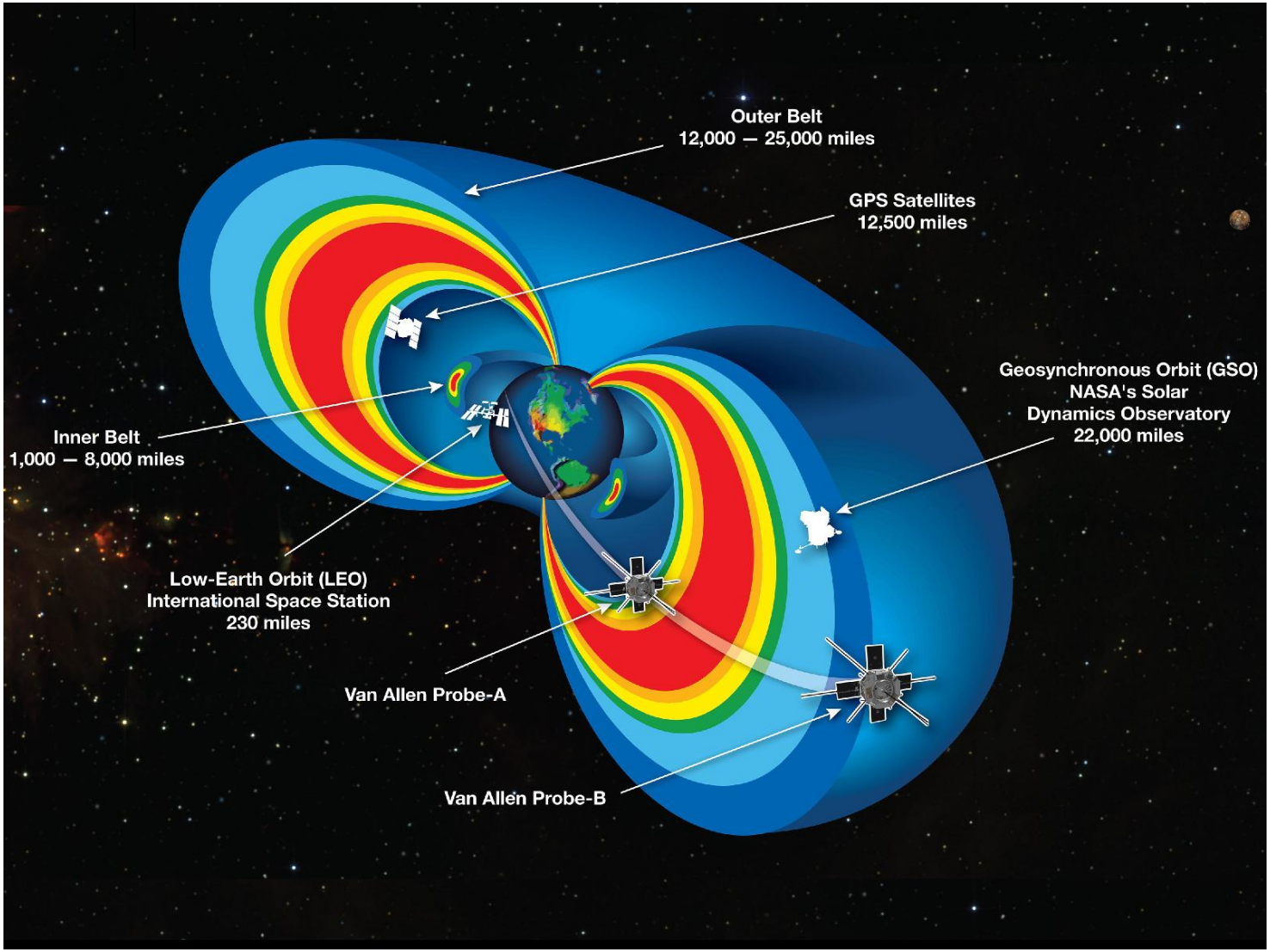
Note: UNH involvement also on THEMIS, Hinode, TWINS, and Geotail missions (not captured fully on chart to right)



Overview of FIREBIRD mission – One example of activities within the EOS/SSC at UNH

Motivating Science: Relativistic Electron Microbursts

Electron Microbursts are short (<100ms) bursts of **R**elativistic (>100's keV) **E**lectron "**P**recipitation" (**REP**) into Earth's atmosphere from the radiation belts



Motivating Science: Relativistic Electron Microbursts

- REP important to understand and quantify for two reasons:
  - Potential major source for draining radiation belts
  - Potential major missing source of middle atmosphere physics

- Initial studies in 1960s from indirect balloon x-ray measurements

- REP studied directly in LEO most notably by SAMPEX mission; long lasting mission quantified REP to a great extent (but at limited energies and with a single large spacecraft)

- Despite decades of study with **single spacecraft**, fundamental **space-time ambiguity persists** – REP scientific understanding stalled

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

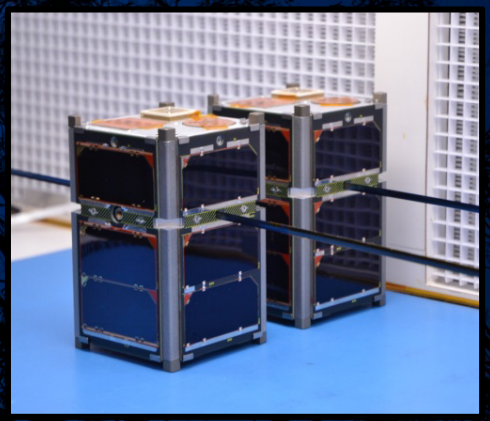
FIREBIRD-II: Flight Units 3 and 4

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

University of New Hampshire
Institute for the Study of Earth, Oceans, and Space
SSEL
MONTANA STATE UNIVERSITY
AEROSPACE
Los Alamos NATIONAL LABORATORY

FIREBIRD-II Overview

- Follow-on FIREBIRD-II mission launched 31 January 2015 from VAFB on SMAP launch (ELaNA-X) – still going strong – lessons learned

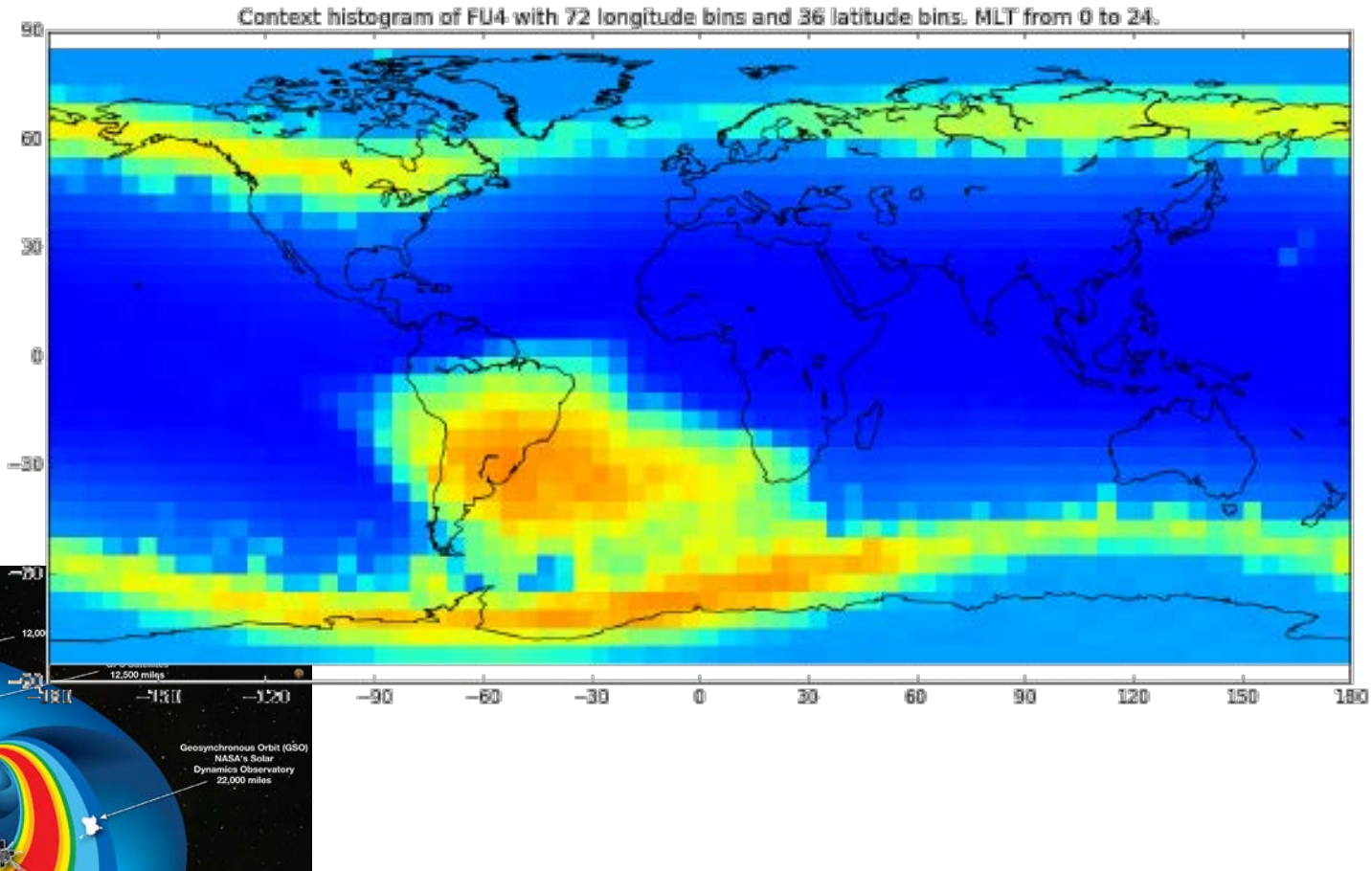


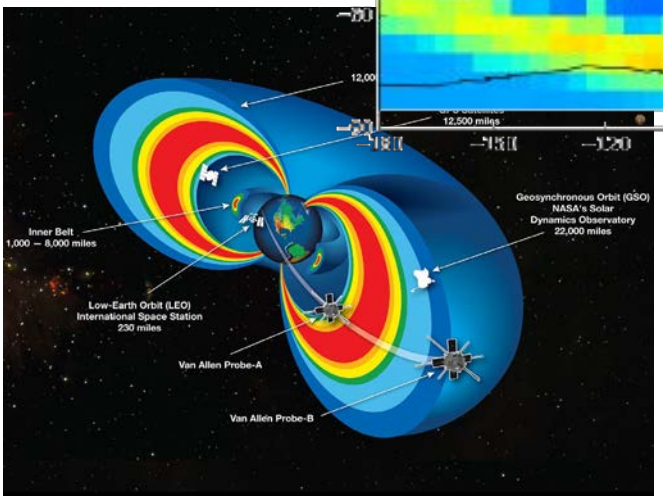
FIREBIRD-II:
Flight Units 3 and 4
Improved version of FB-I mission (lessons learned);
AWESOME DATA SINCE LAUNCH (~3 years)!!!

FIREBIRD-II Orbit/Data

- 650 x 430km orbit, 99 degree inclination – ground station at MSU
- 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

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





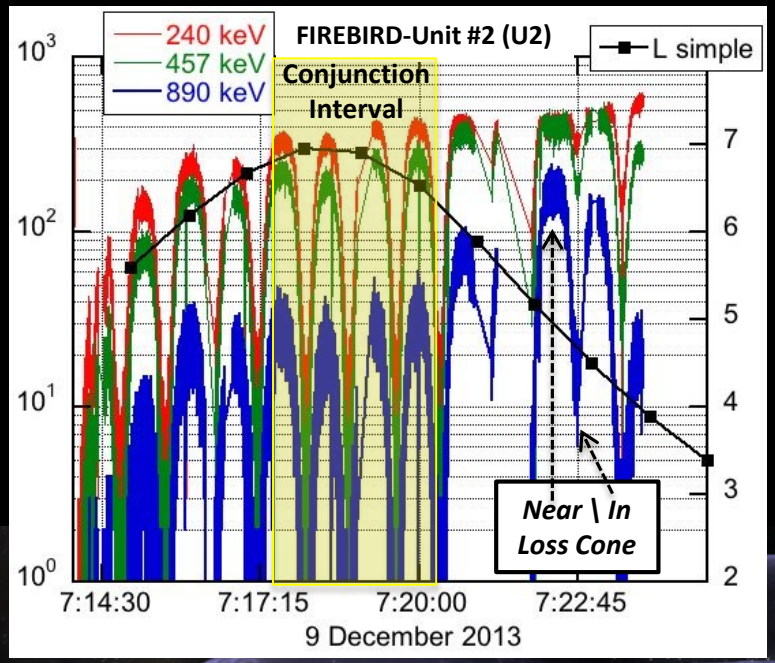
FIREBIRD-II Orbit/Data

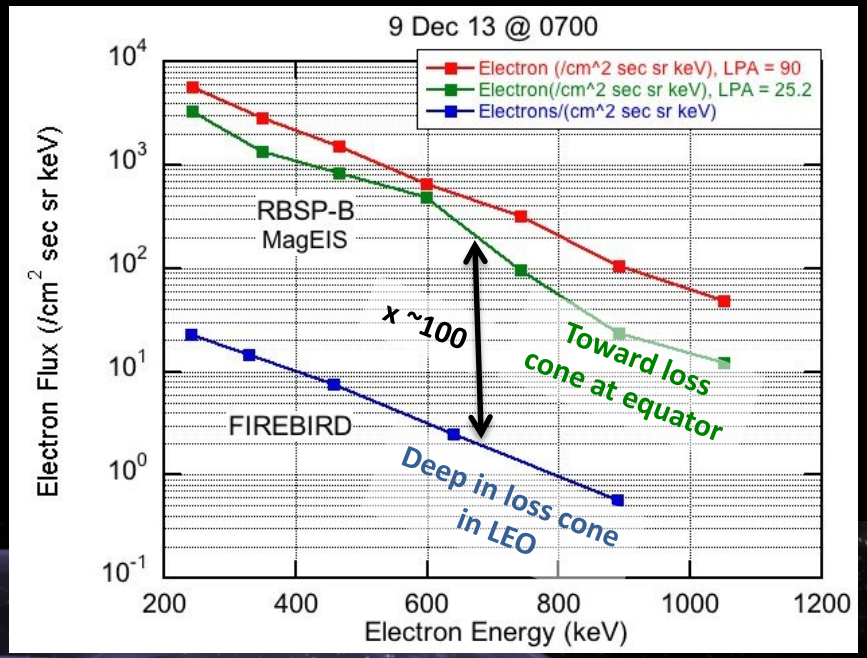
- Hi-Res data – high time/energy resolution - LARGE volume
  - **VERY** limited HiRes data availability - ConOPS uses context data to hunt for proverbial scientific “needles in haystack”

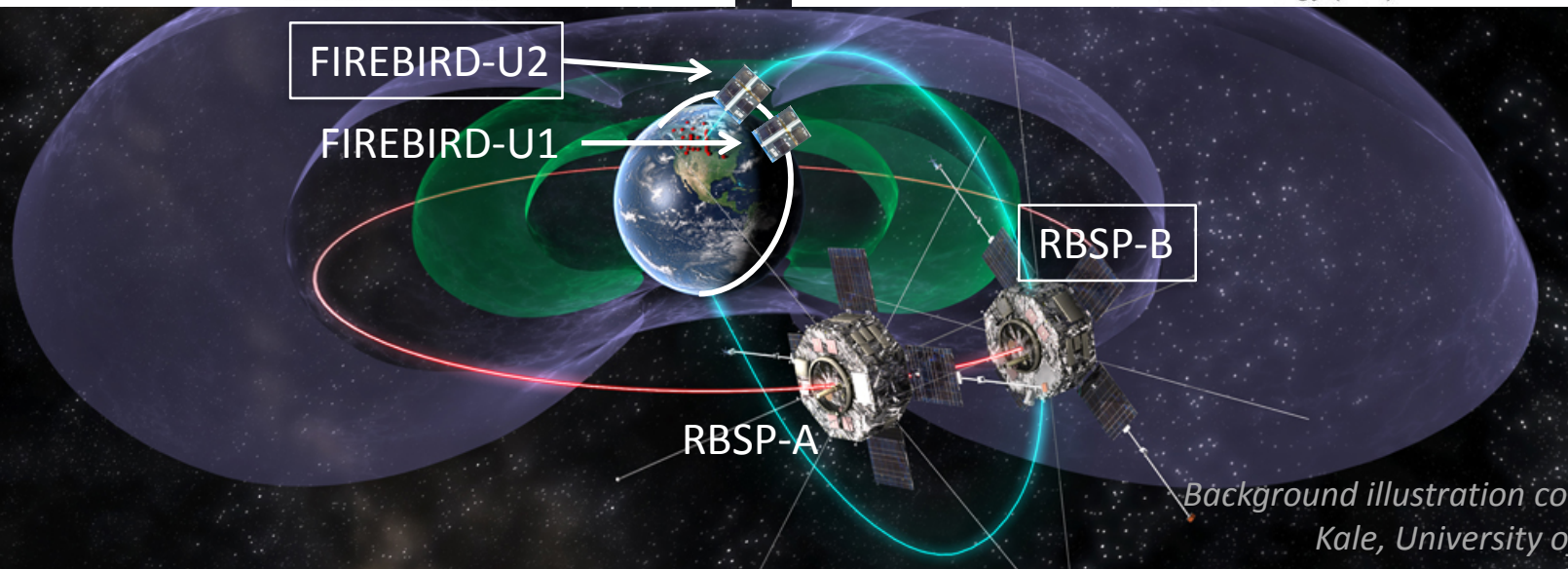
- ConOPS successful but **big lesson learned** – we return to this at the end of this talk - **need a MUCH bigger data pipe for science**!!)

Accomplishing **BIG** science with *little* missions

Comparison of e- Energy Spectral Shape and Intensity (0.25 – 1 MeV) In/Near Loss Cone at LEO (FB-FU2) & Equator (RBSP-B) at L ~ 6.5





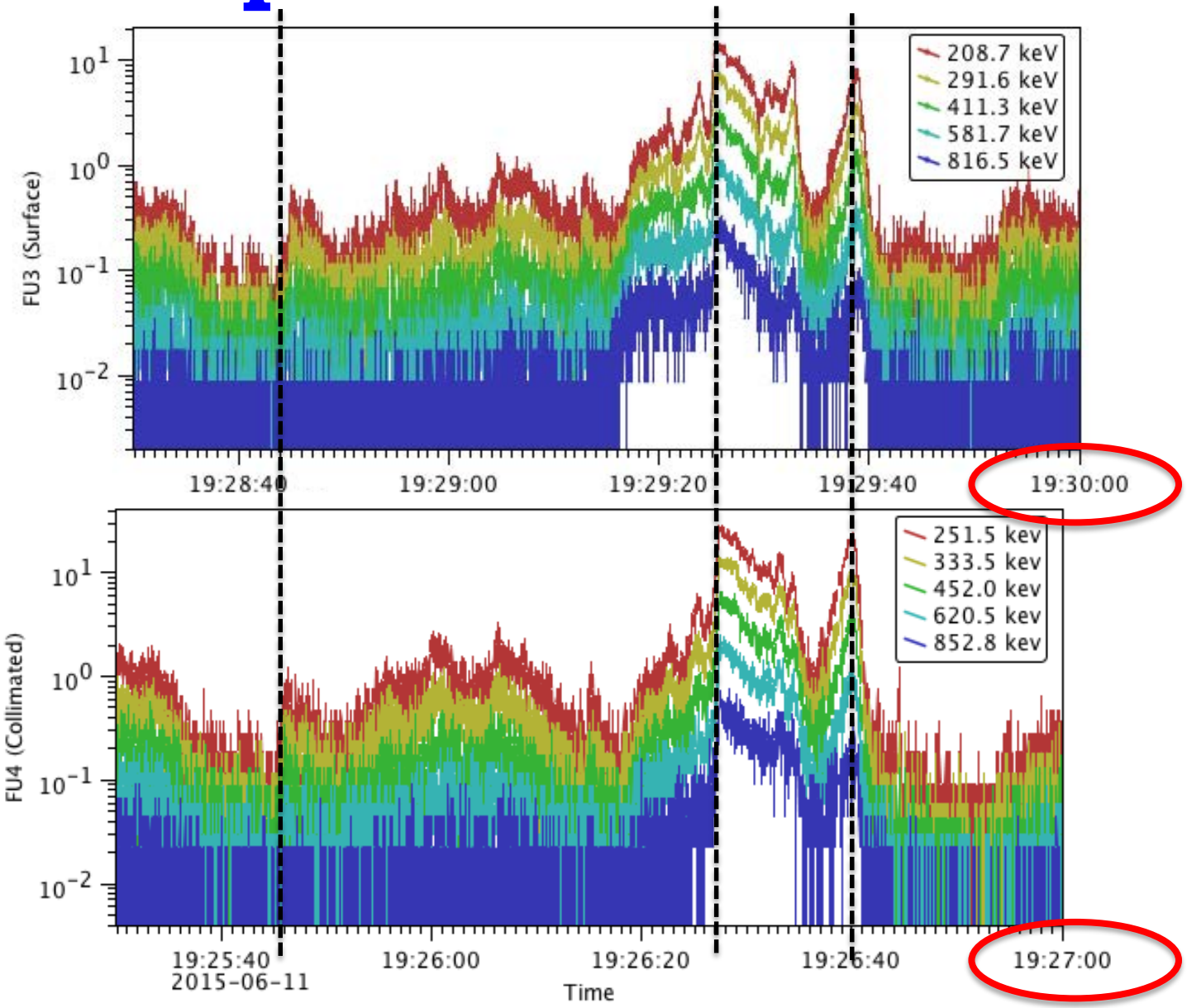


Background illustration courtesy A. Kale, University of Alberta

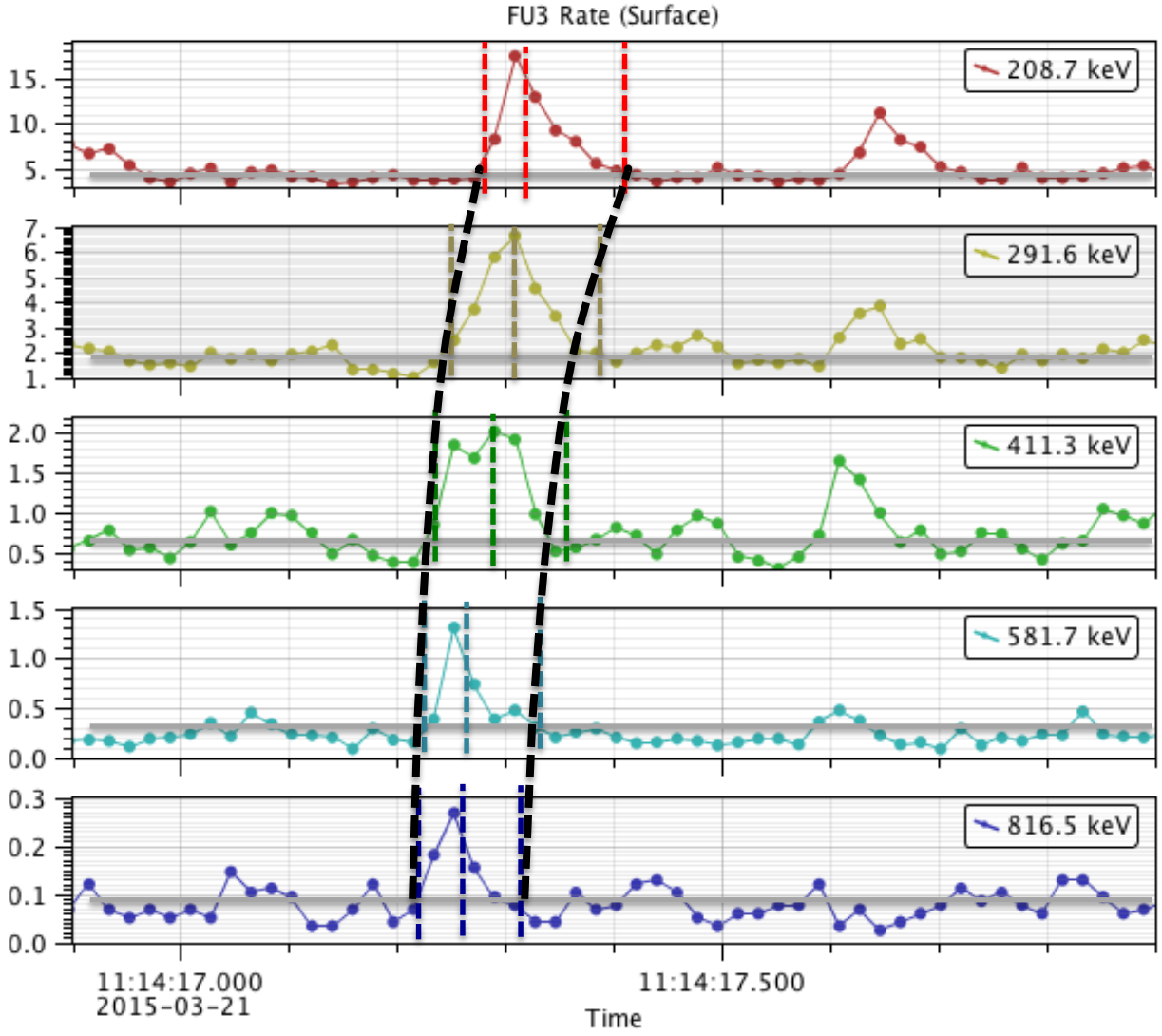
A KALE

First unambiguous evidence of REP spatial structure

- Examples of temporally persisting (3 minutes) spatial REP bands
- A single s/c interprets REP as temporal
- Similar REP spatial structures seen also by AC-6

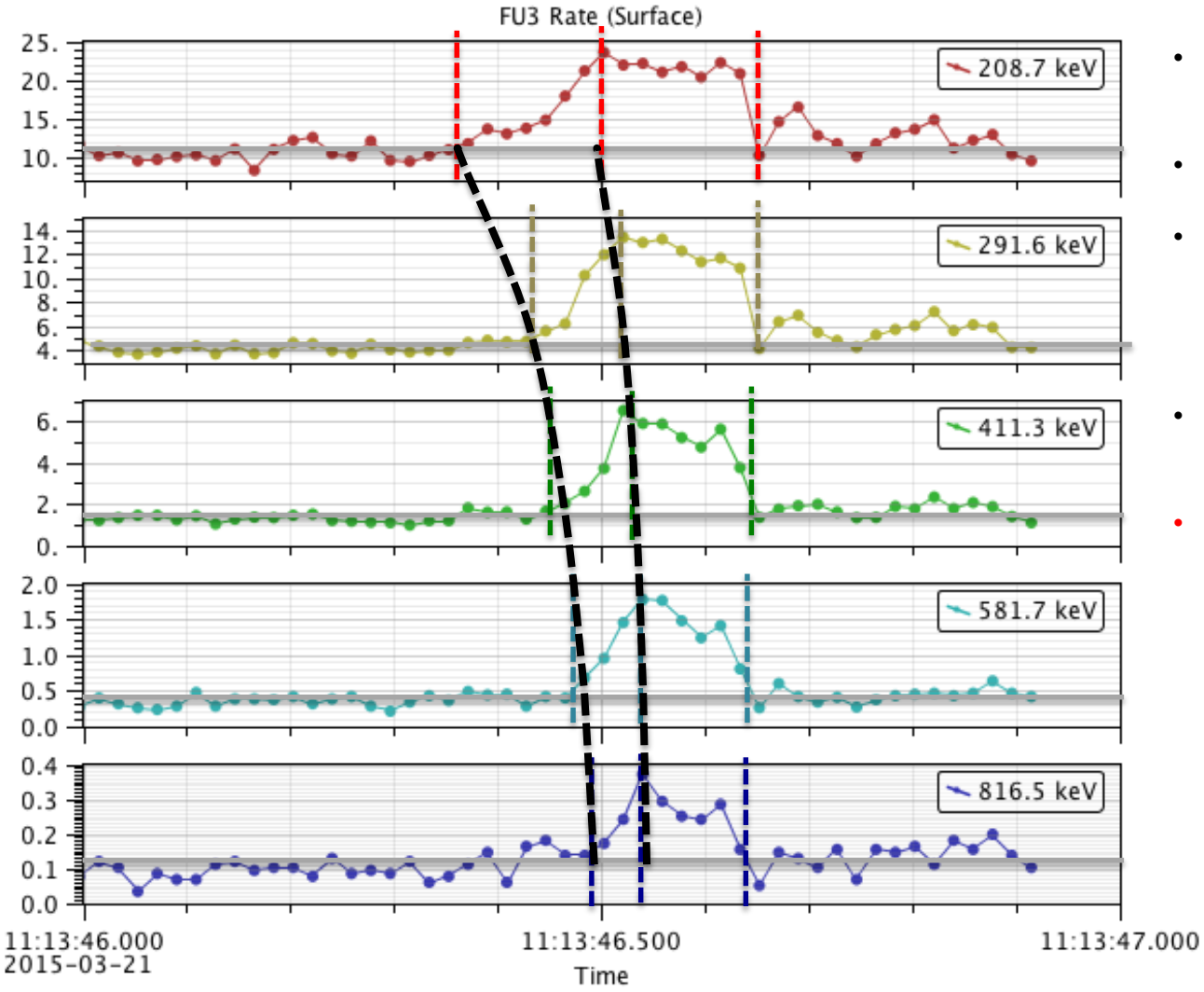


FB-II For First Time Quantifies REP Dispersion - "Regular TOF" Style



- 1 second of data (18.75 ms resolution) at ~11:14:17UT on 21 Mar 2015
- FB-II FU3 passing through outer zone electron belt
- Isolated burst reveals time-of-flight (TOF) style dispersion, with highest energy electrons arriving first, followed successively by lower energies
- Lowest energy (~200 keV) arrives ~60 ms later than highest energy (~800 keV)
- **Mapping back suggests common point only ~ 1.2 Re away**
- **But source of dispersion is complex….!**

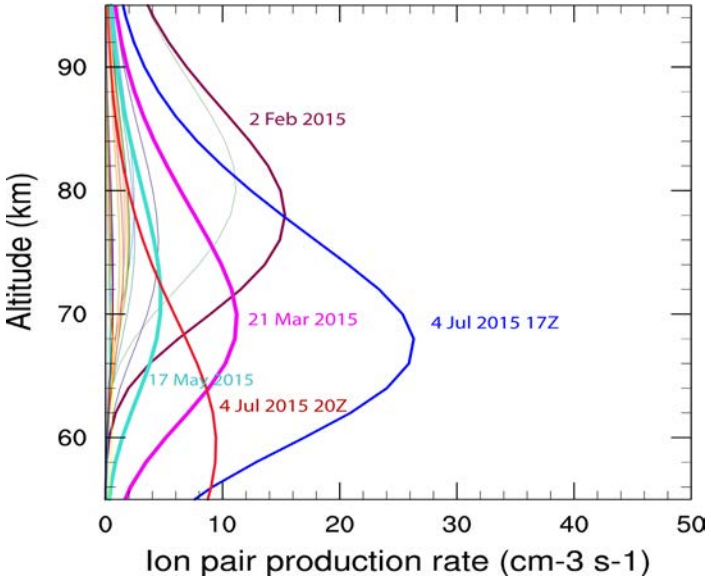
FB-II "Inverse Velocity" REP Energy Dispersion – Test of Theories



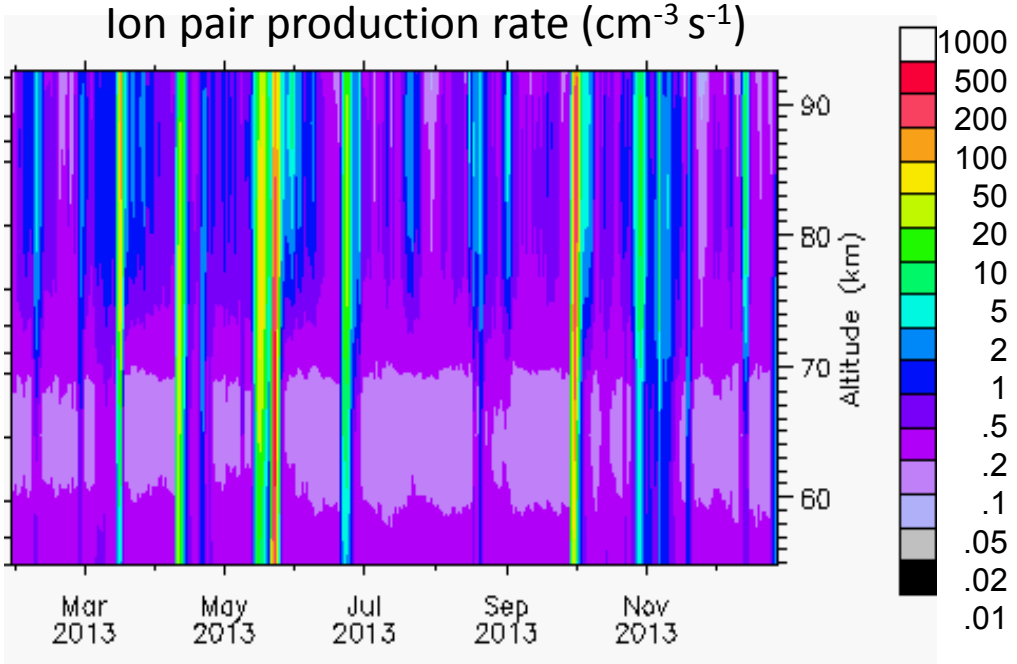
- 1 second of data (18.75 ms resolution) at ~11:13:46UT on 21 Mar 2015
- FB-II FU3 was passing through outer zone electron radiation belt
- Isolated burst reveals inverse velocity style dispersion, with LOWEST energy electrons arriving first, followed successively by HIGHER energies
- Lowest energy (~200 keV) arrives ~100 ms earlier than highest energy (~800 keV)
- **Consistent with model predictions of Saito et al., Miyoshi et al. !! - whistler chorus resonance varies as wave propagates from equator (lower energies) to higher latitudes (higher energies)**

Ionization from electrons are large enough to compete with background ionization from solar energetic protons….and might explain the missing source of NO_x around 60-70 km in models.

FIREBIRD electron flux



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



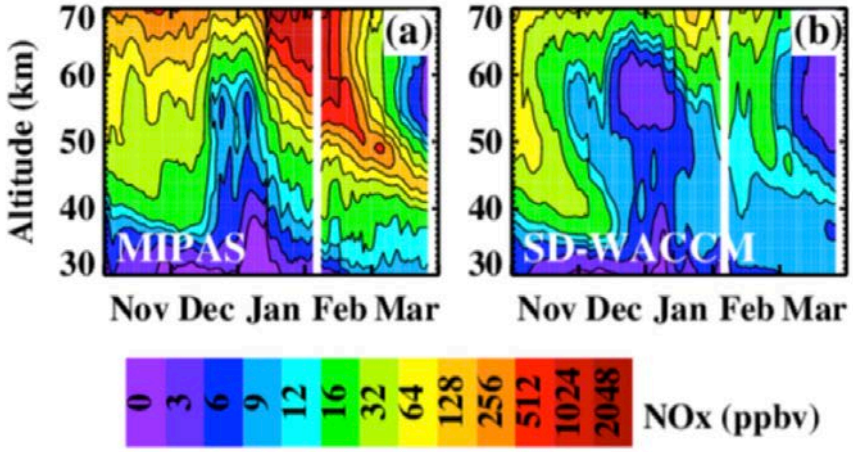


Figure 1. *NO_x from Nov 2003-Mar 2004: a) MIPAS, b) WACCM. Plots show 3-day running average poleward of 70°N. Randall et al. [2015]*

Invitation to Collaborate

(harlan.spence@unh.edu)

FIREBIRD-II Pair Launched January 31, 2015

They are in good health, data from Campaign 12 is being downloaded

- FB-II operating as a pair from immediately after turn-on (10-km separation) to present. They are currently about 3,800 km apart.
- Campaign duration set by quality and quantity of science data stored onboard satellites
  - Science data storage capacity allows northern hemisphere operation for ~4 weeks
  - Between campaigns selected high-value science data is downloaded to ground
- Data is uploaded daily at https://ssel.montana.edu/ Navigate to Missions: FIREBIRD and FIREBIRD-II

Campaign #	Dates	Primary Science Goal
1	[illegible]	Spatial Scale of Individual Microbursts
2	[illegible]	[illegible]
3	[illegible]	Van Allen Probes Conjunctions
4	[illegible]	July 4th Storm
5	[illegible]	BARREL Campaign Conjunctions
6	[illegible]	Conjunctions, Lightning induced precipitation
7	[illegible]	12.5ms time resolution, EFW and GRIPS conjunctions
8	[illegible]	50ms time resolution, context and COSI conjunctions
9	[illegible]	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