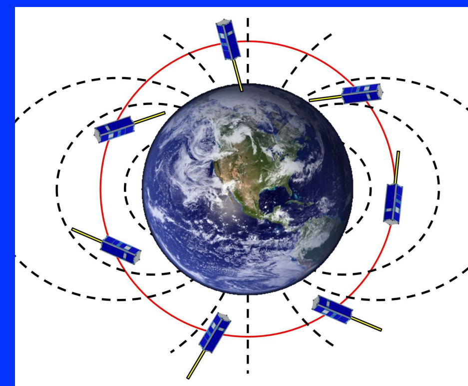
Colorado Student Space Weather Experiment (CSSWE) CubeSat: a Success in Education, Engineering, and Science



PI: Xinlin Li, Co-PIs: Scott Palo and Shri Kanekal

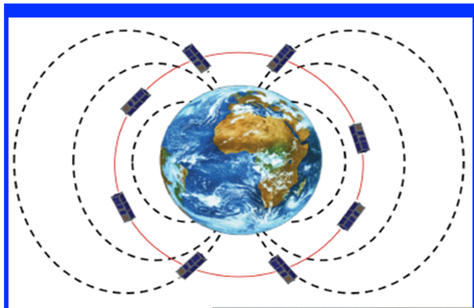
LASP Engineers: Rick Kohnert (chief technical mentor), **Gail Tate** (SW), **Vaughn Hoxie** (EE) **+ others**

Student Team: involved over 65 graduate and undergraduate students
Lauren Blum (PM), David Gerhardt (SE), Quintin Schiller (CFO and Instrument)
Other current Ph.D. students: Sam Califf and Hong Zhao
Former Ph.D. students: Drew Turner and Weichao Tu

Funded: 1/1/10 Delivered: 1/9/12

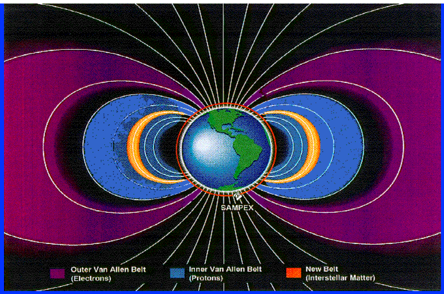
Launched: 9/13/12, NRO (Atlas V) under NASA's ELaNa program

Orbit: ~480 km x 780 km, inclination 65^0



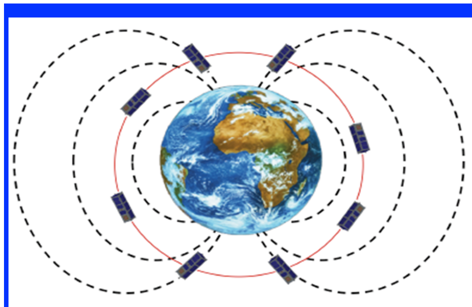
CSSWE: Colorado Student Space Weather Experiment

(Spring of 2010)



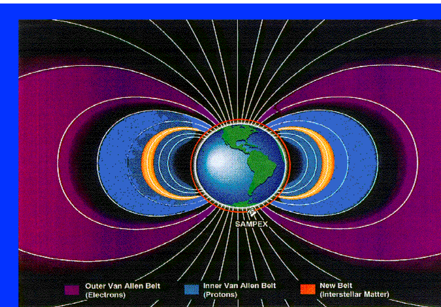
LASP
LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS

Aerospace Engineering



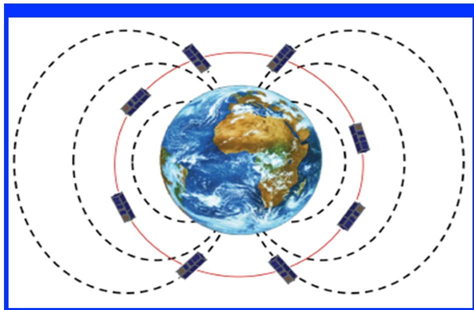
CSSWE: Colorado Student Space Weather Experiment

(Fall of 2010)



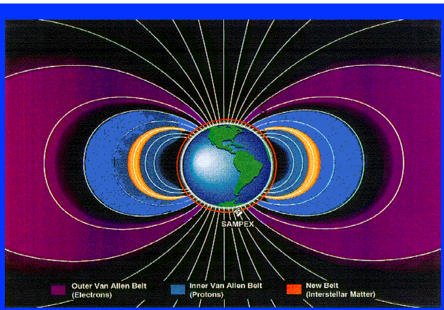
LASP
LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS

Aerospace Engineering



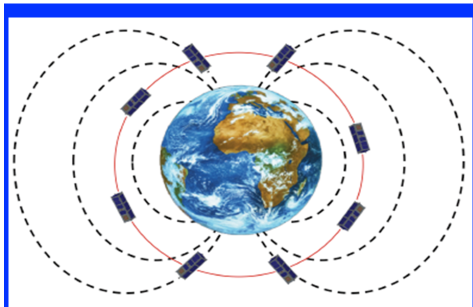
CSSWE: Colorado Student Space Weather Experiment

(Spring of 2011)



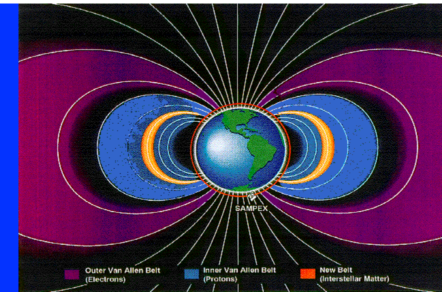
LASP
LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS

Aerospace Engineering



CSSWE: Colorado Student Space Weather Experiment

(Spring of 2010)



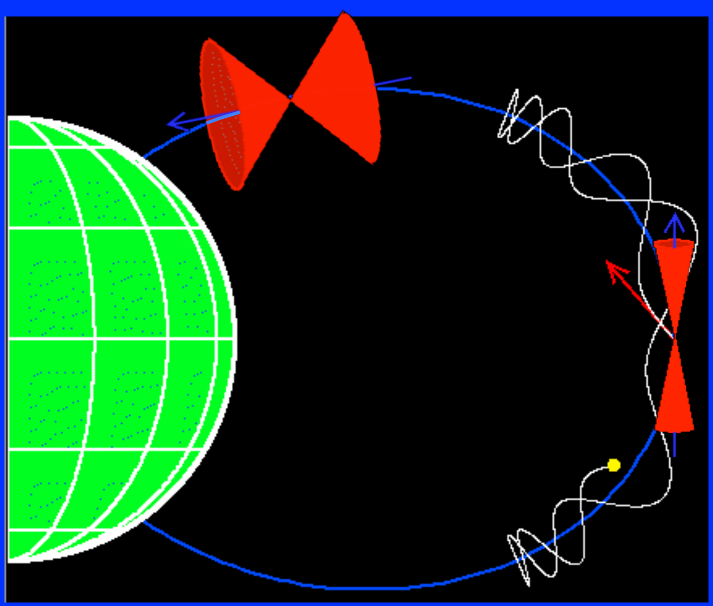
Relativistic Electron and Proton Telescope integrated little experiment (REPTile)

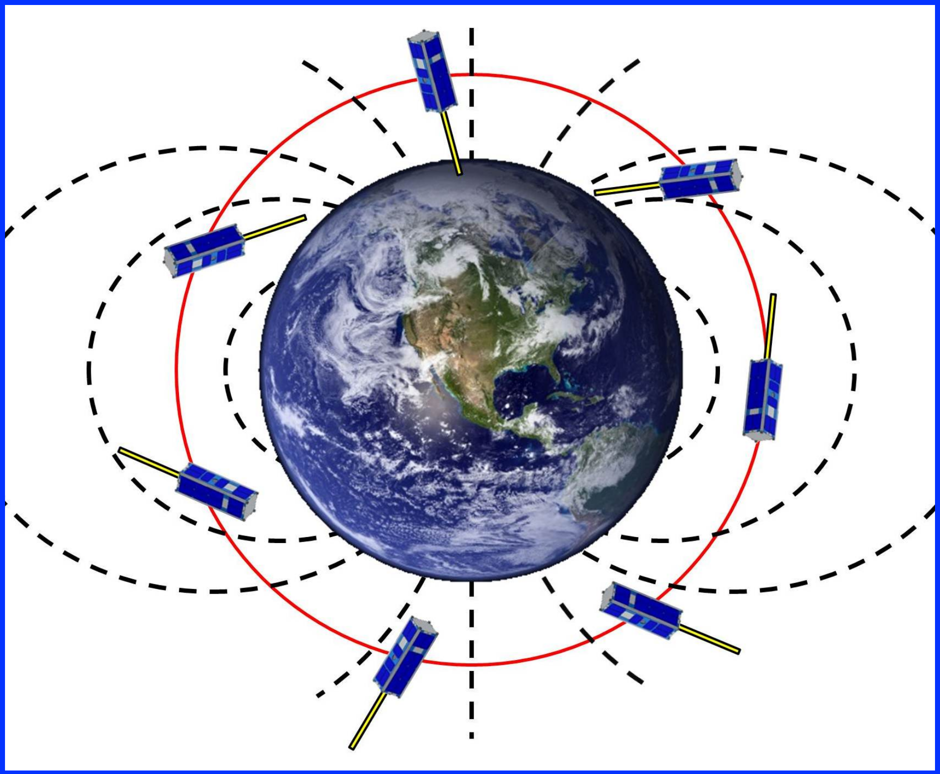
LASP
LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS

Characteristics of an electron's motion:

- Electron loss cone opens up at low altitude

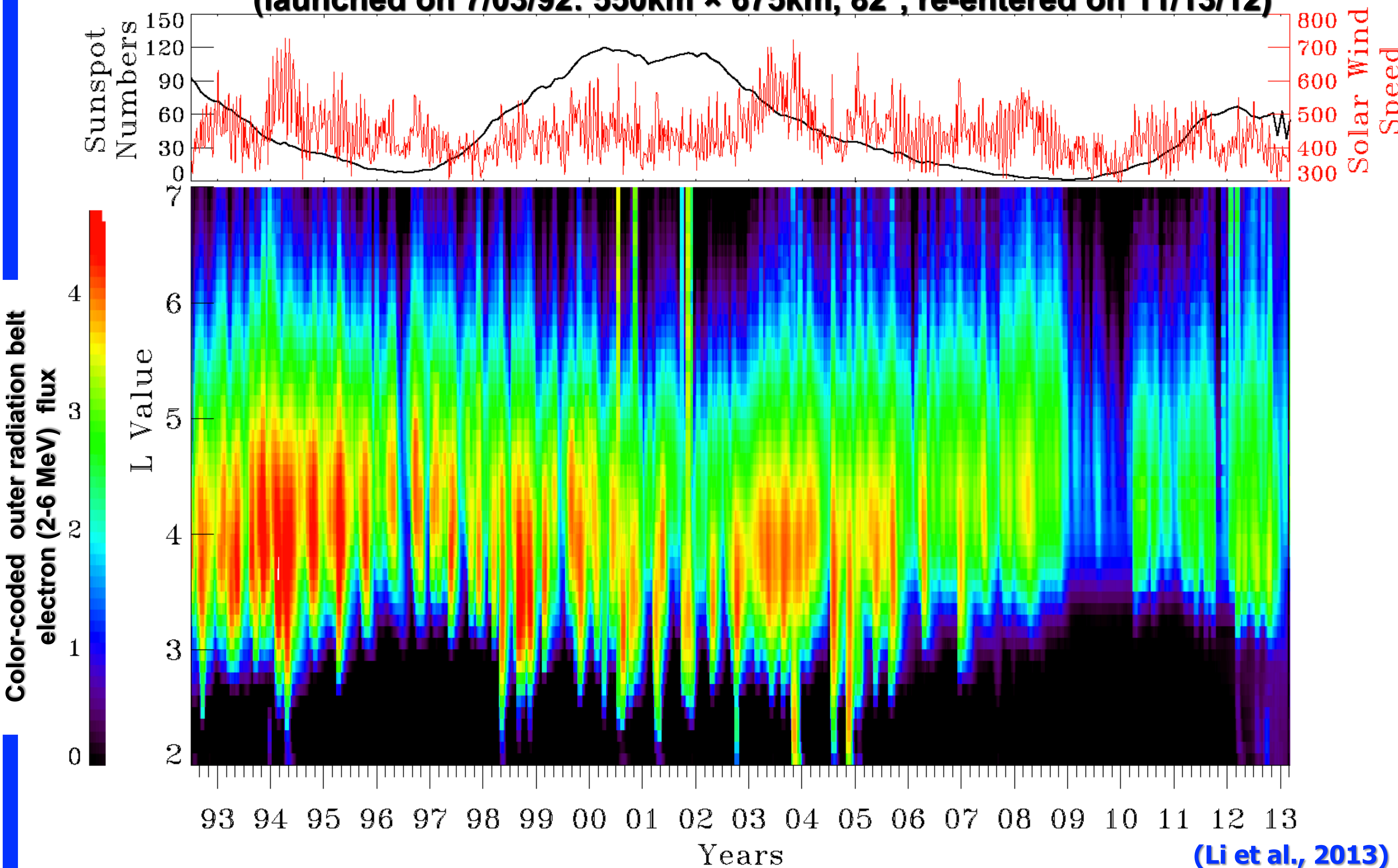
- Low altitude measurements are most useful in determining the electron loss rate





Outer Radiation Belt Electrons Measured by SAMPEX and CSSWE

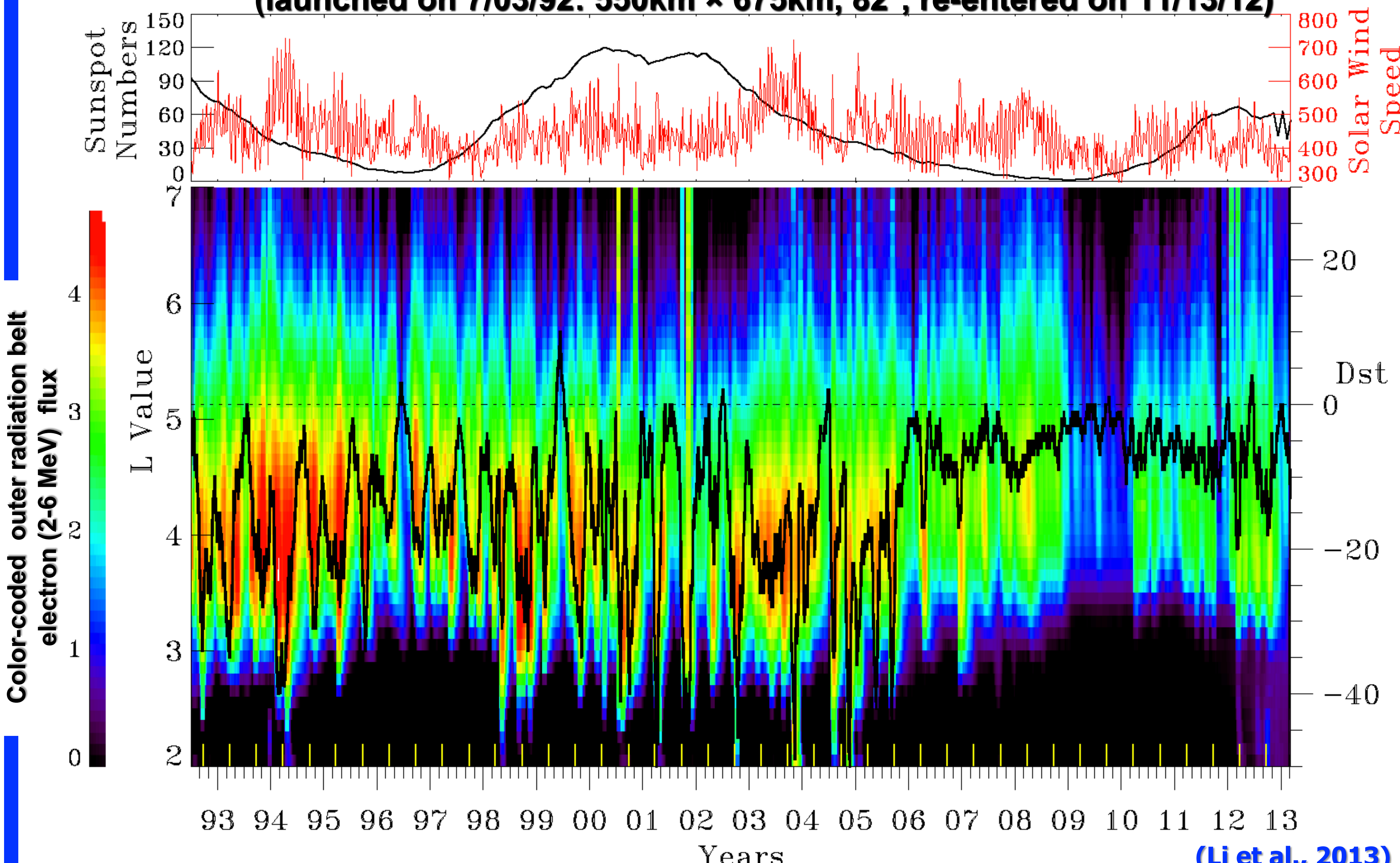
(launched on 7/03/92: 550km × 675km, 82°, re-entered on 11/13/12)



(Li et al., 2013)

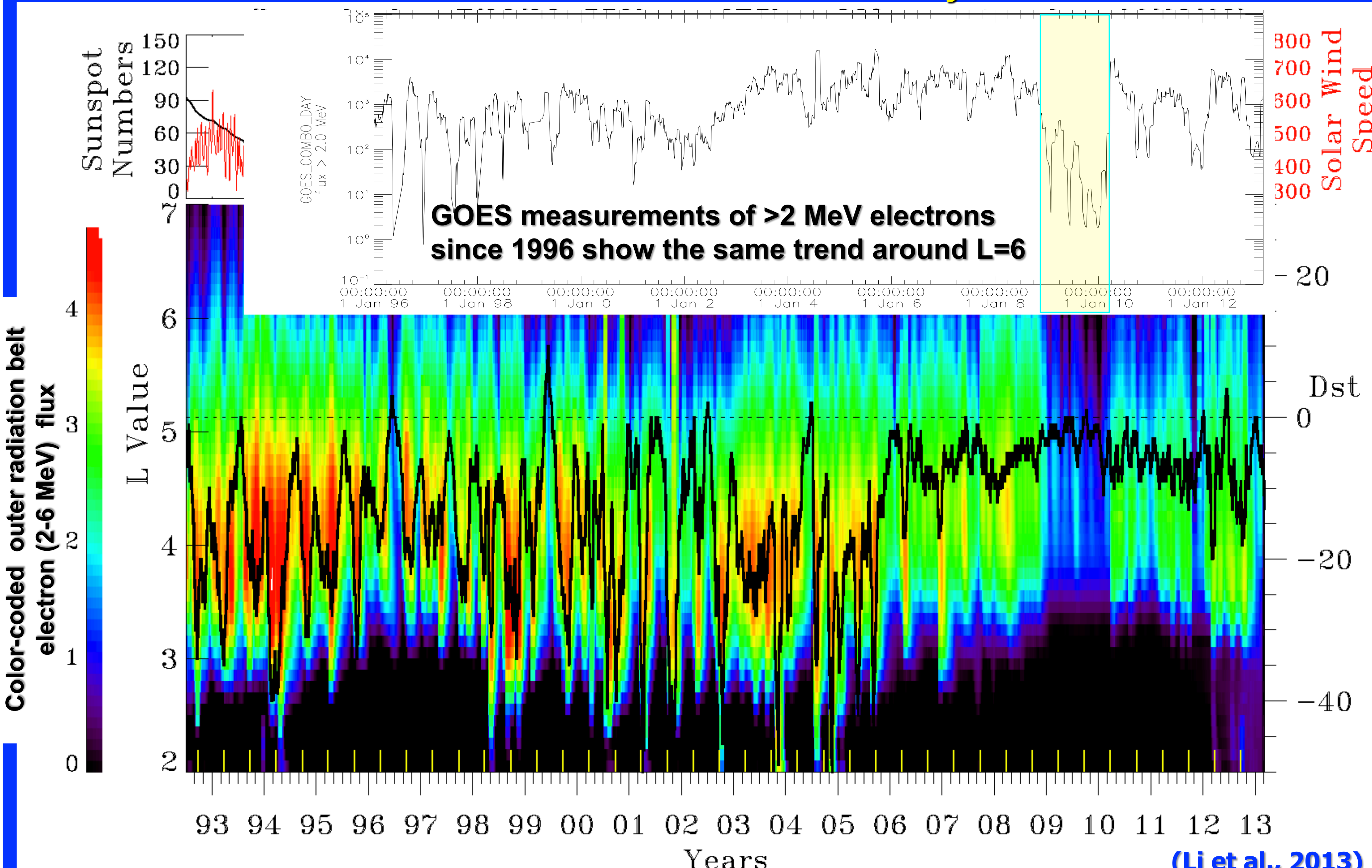
Outer Radiation Belt Electrons Measured by SAMPEX and CSSWE

(launched on 7/03/92: 550km × 675km, 82°, re-entered on 11/13/12)



(Li et al., 2013)

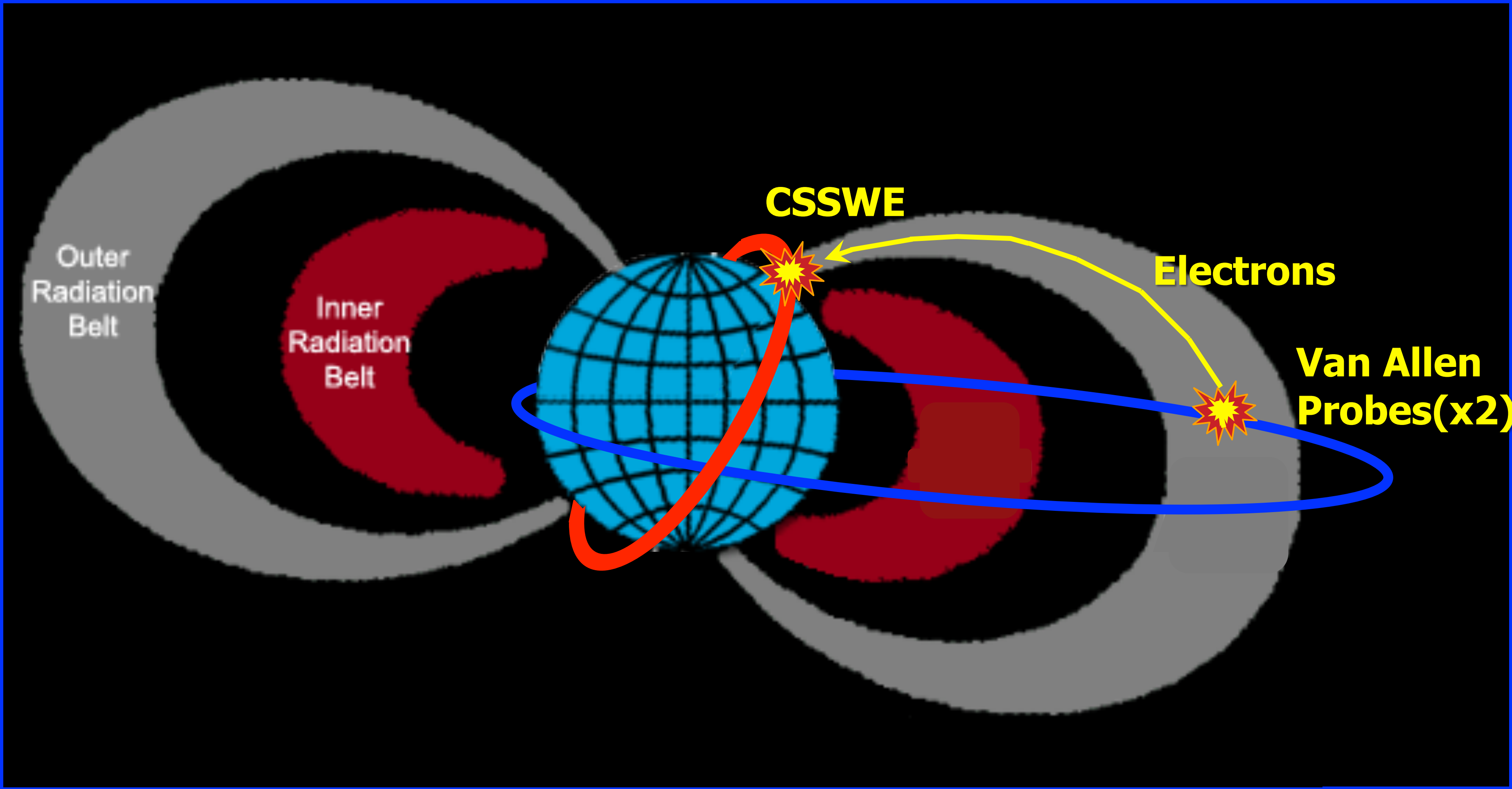
Outer Radiation Belt Electrons Measured by SAMPEX and CSSWE



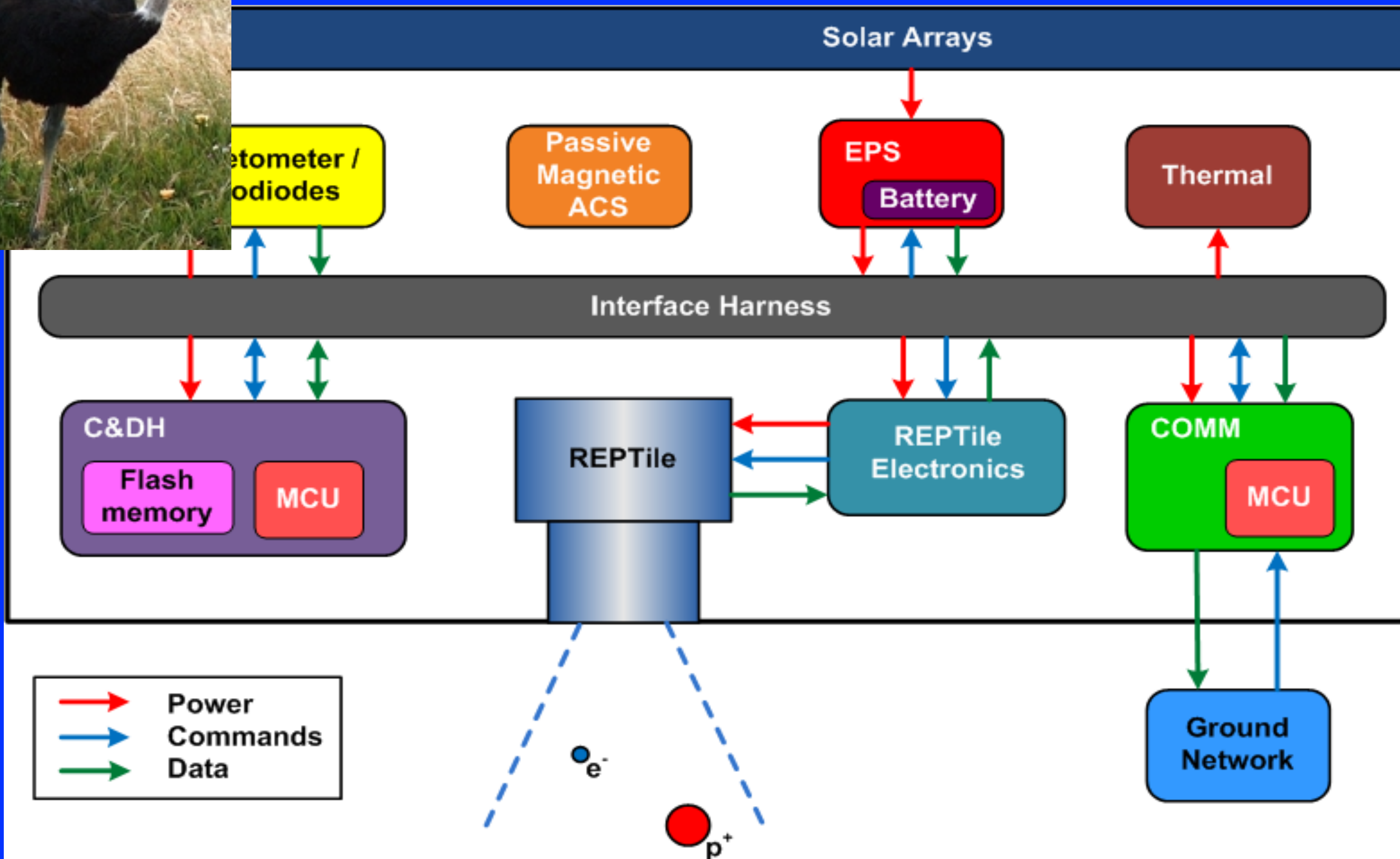
(Li et al., 2013)

Concurrent measurements with NASA/Van Allen Probes

(orbits: 605km x 30410km and 635km x 30540km , inclination: 10^0)

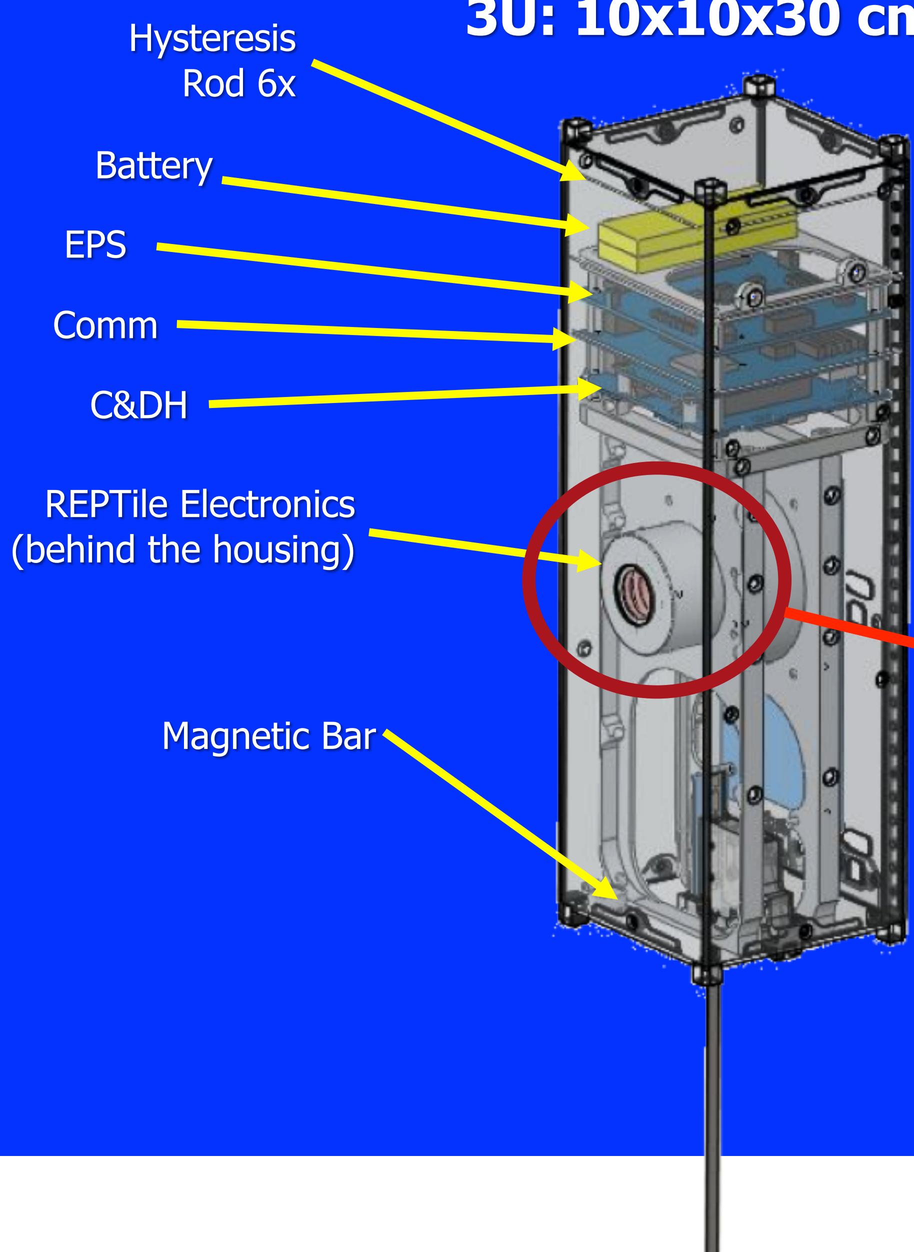


n block diagram of the subsystems and interfaces

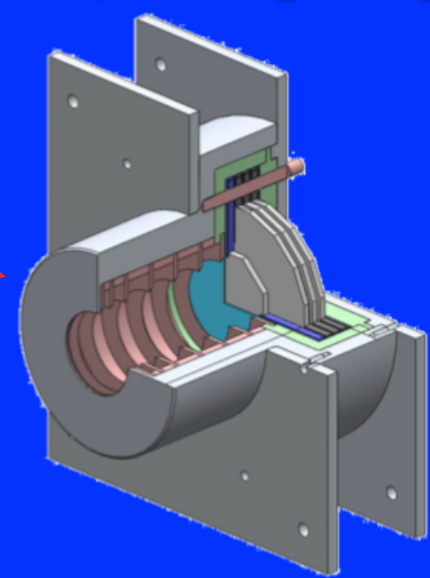


CubeSat bus, main subsystems, and the payload

3U: 10x10x30 cm^3



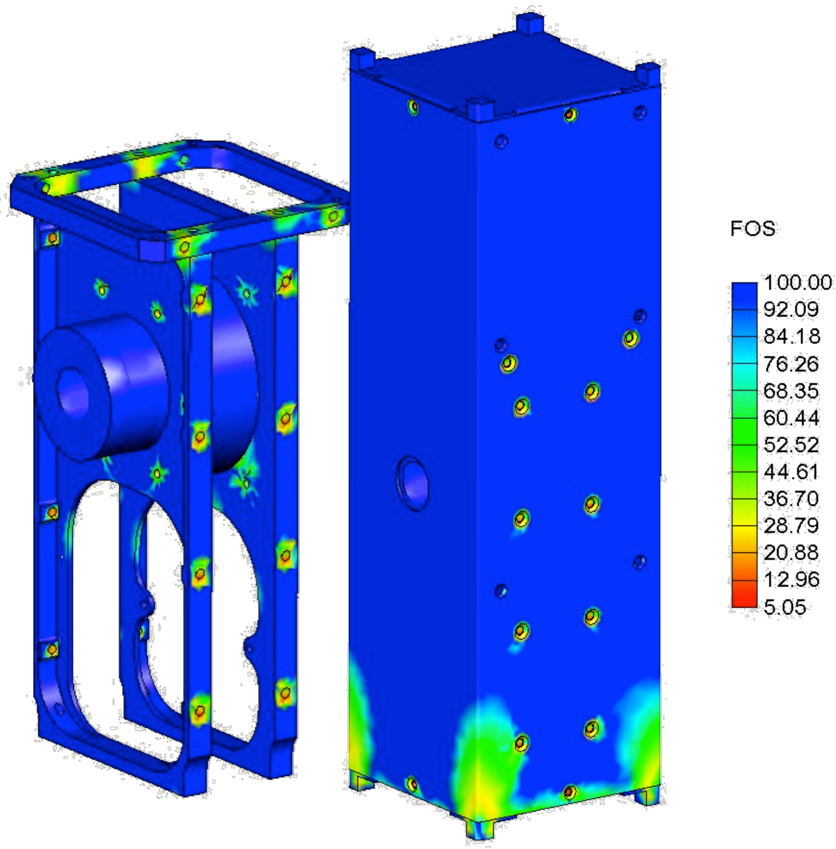
REPTile: Relativistic Electron Proton Telescope integrated little experiment

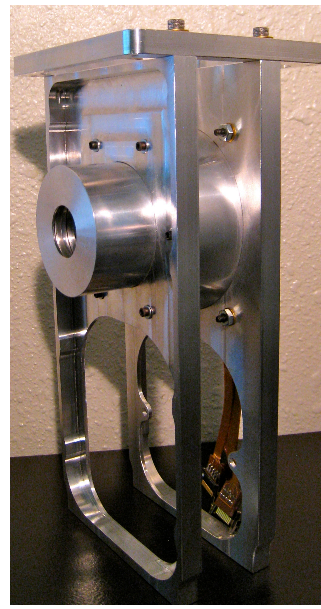


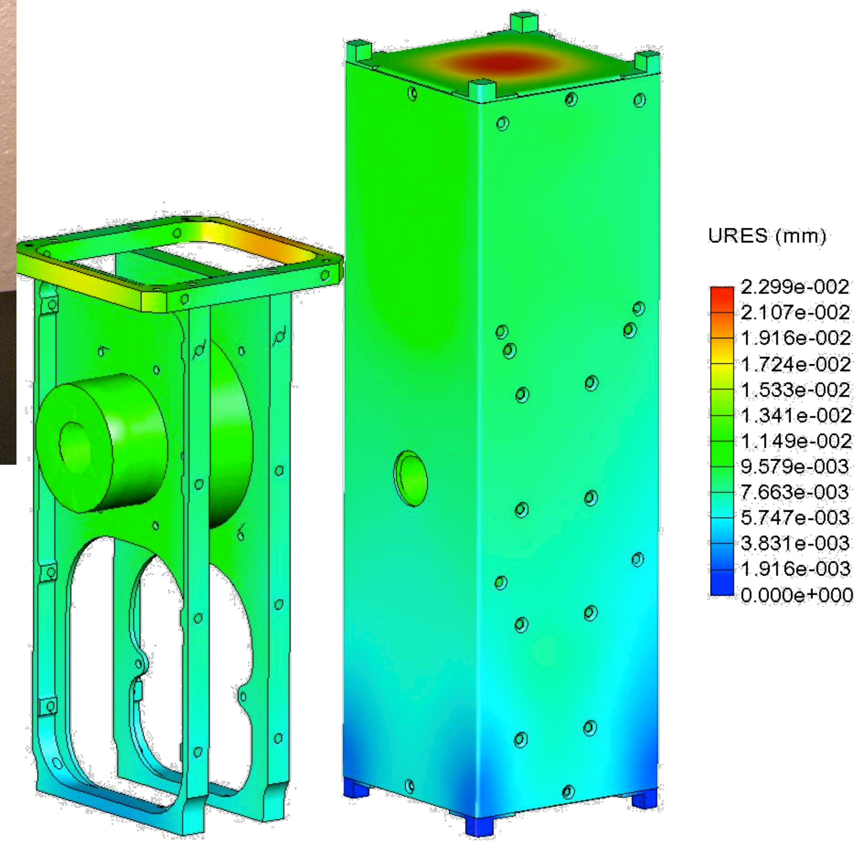
FEA Results – Factor of Safety and Displacement

50G Static Load

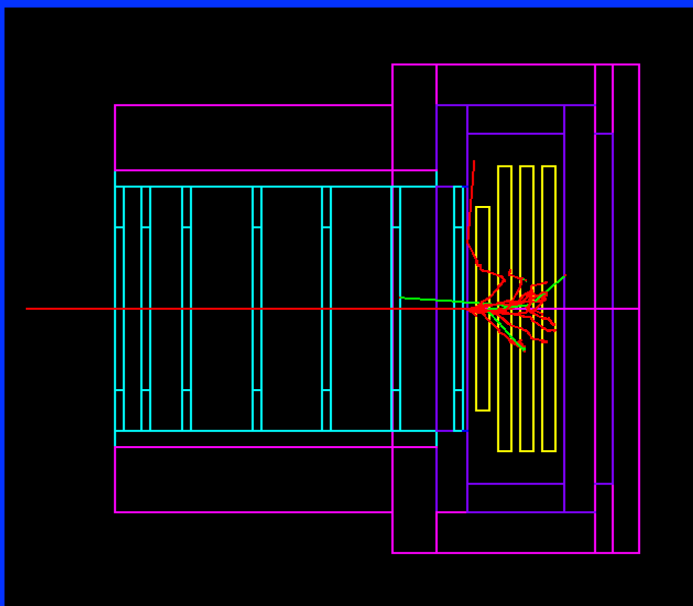
Results shown for loading along the vertical axis

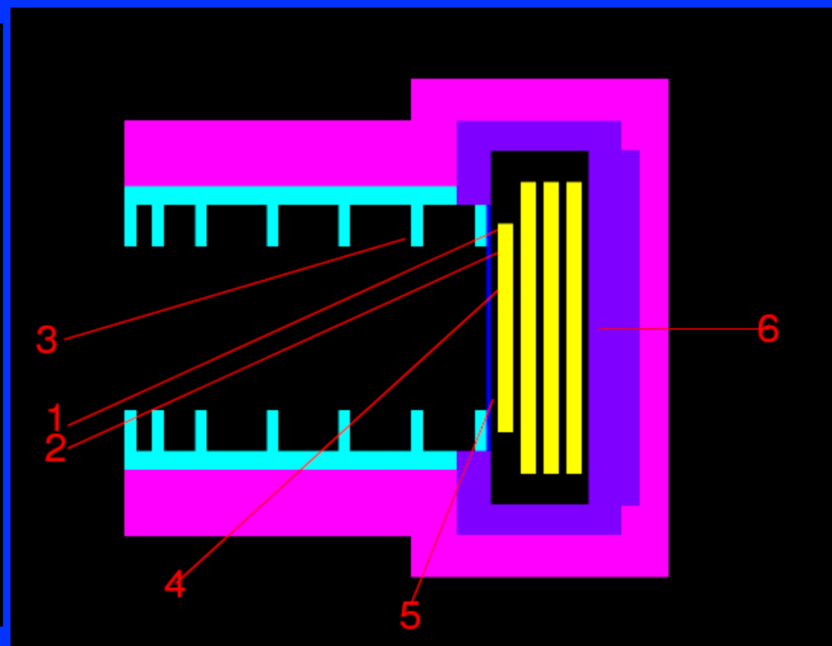






Simulation-based design of the detector





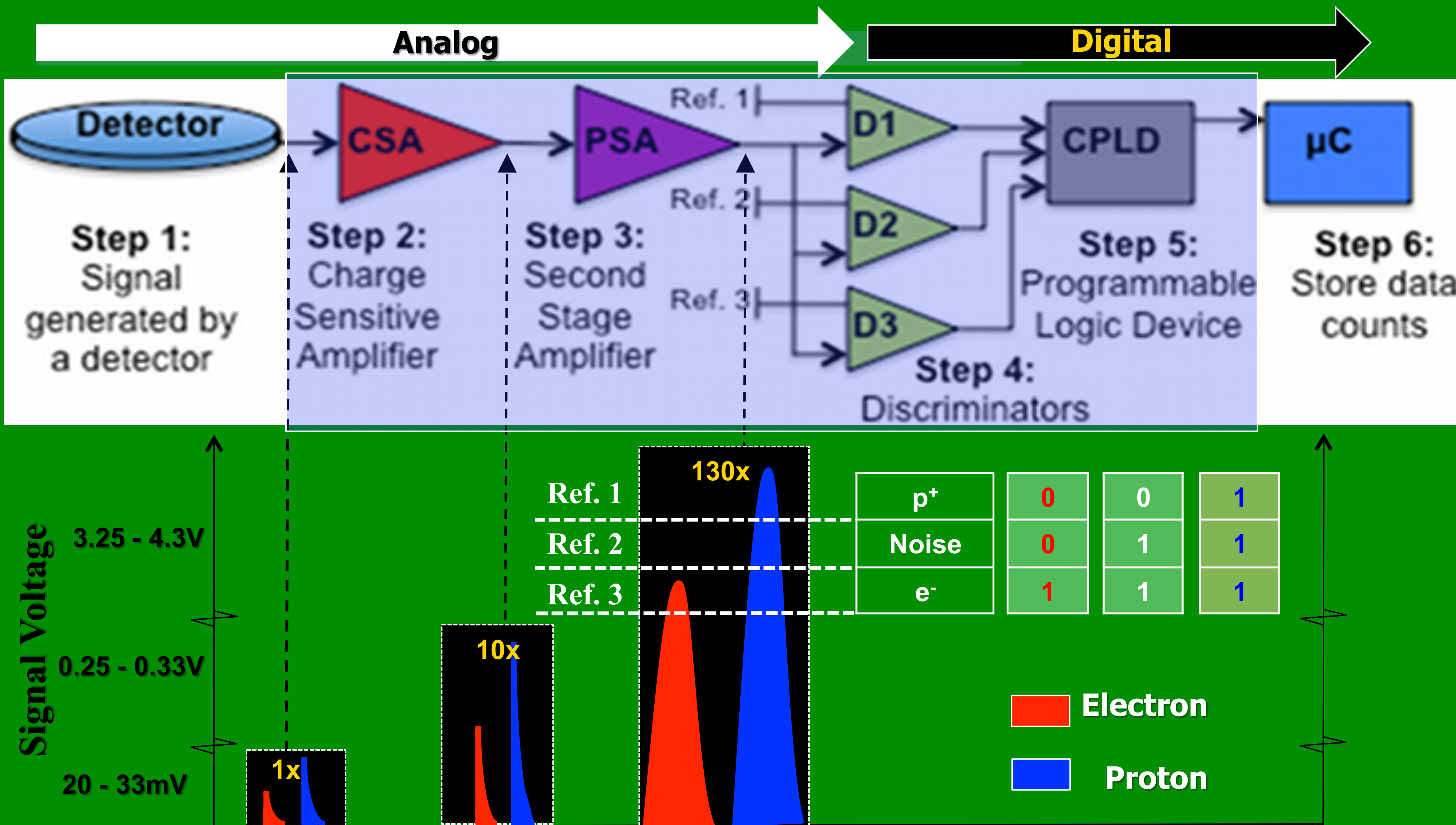
$\gamma_{signal} \approx 0.55\ Sr \cdot cm^2$

	$\gamma_{noise}[Sr \cdot cm^2]$
1	0.23
2	0.18
3	0.72
4	11.1
5	2.1
6	15.4

Table: Estimated worst-case signal-to-noise ratios (SNR)

	Detector 1	Detector 2	Detector 3	Detector 4
e: R_{sn}	87.9	42.2	28.9	23.8
proton: R_{sn}	13.6	8.5	6.4	2.2

REPTile's Signal Chain

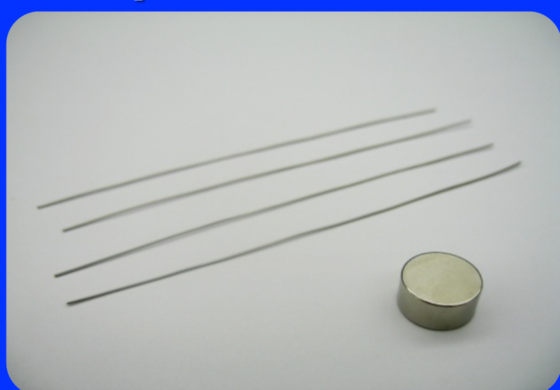


Passive Magnetic Attitude Control (PMAC)

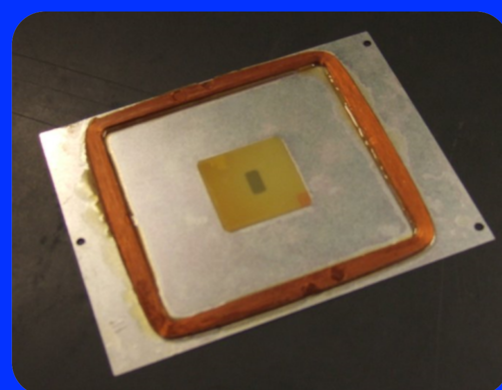
Low cost & performance, simple, robust

High cost & performance, complex

Bar Magnet & Hysteresis Rods



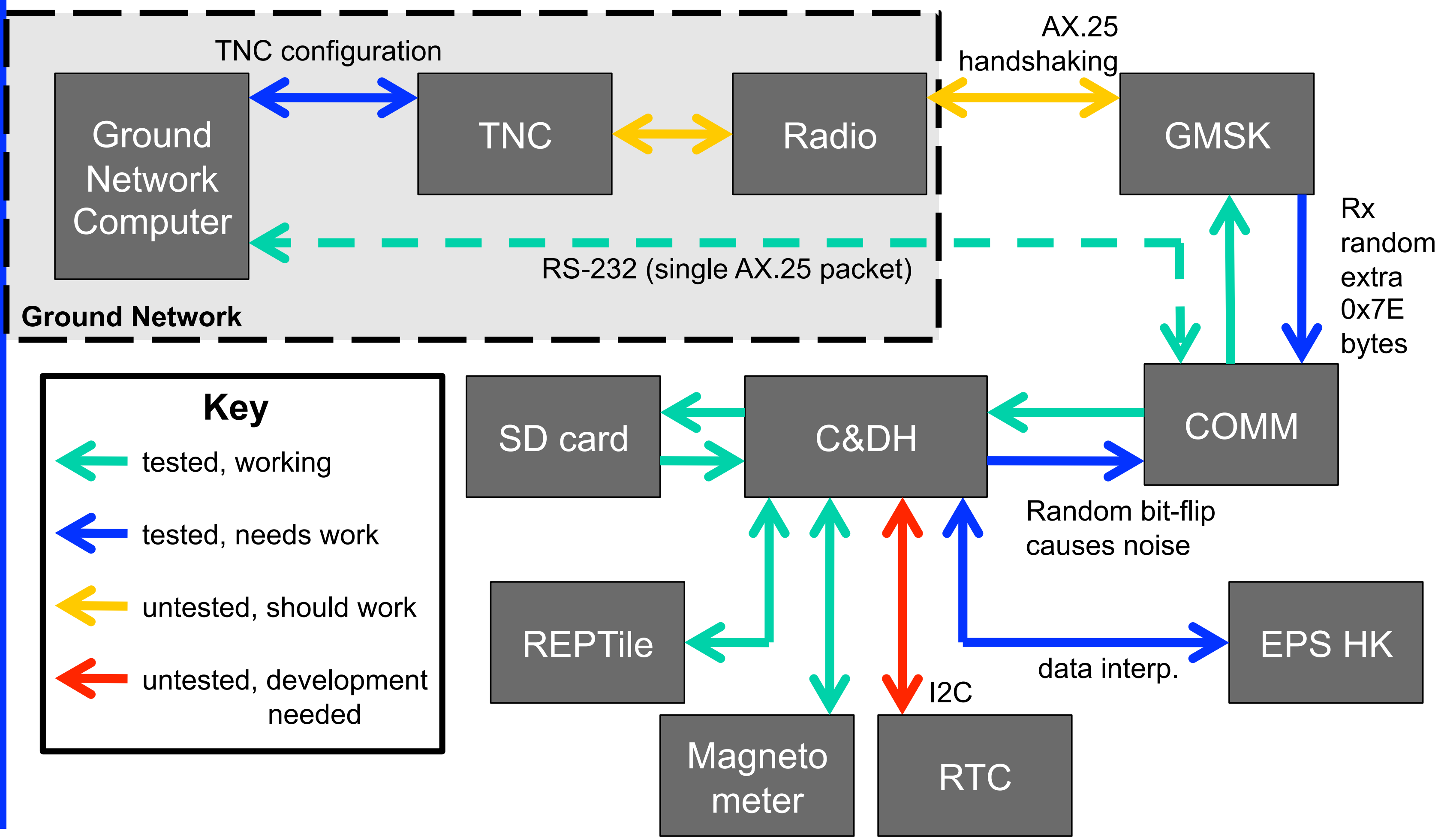
Magnetic Torque Coils



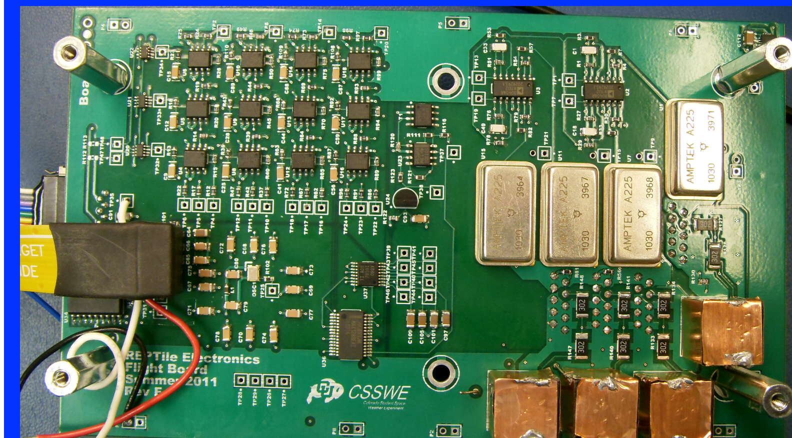
Momentum Wheels

By the early of 2011, design phase were over for most subsystems ➔ building, integration, and testing

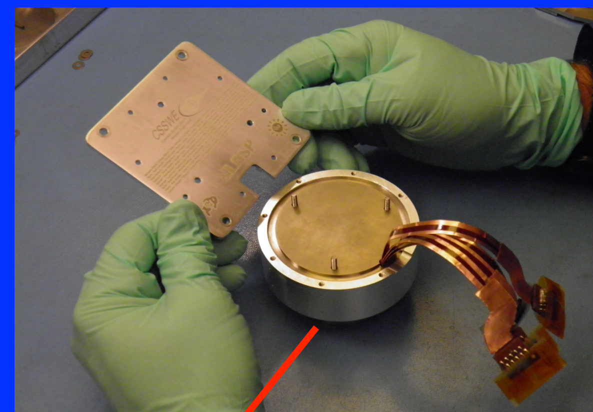
Testing – E2E Test Progress



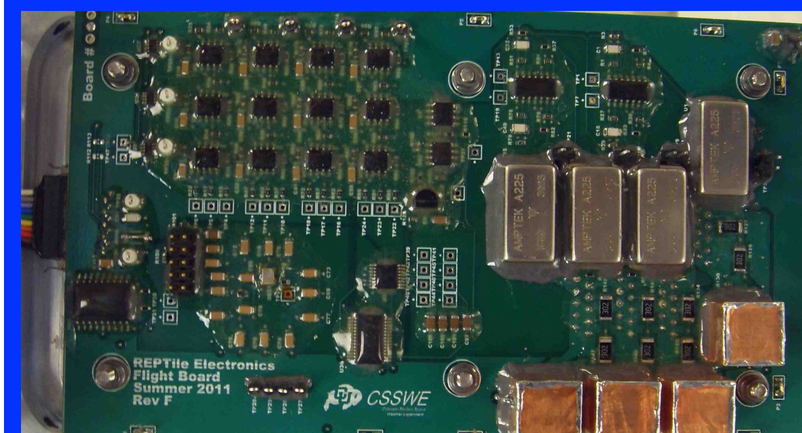
After pass the End-to-End test on flatsat → fit in check → potting all boards → integrated tests on the flight satellite



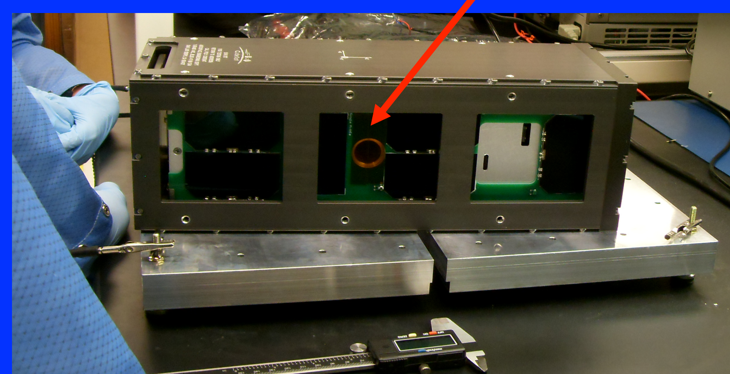
Pre-potted flight board



REPTile assembly



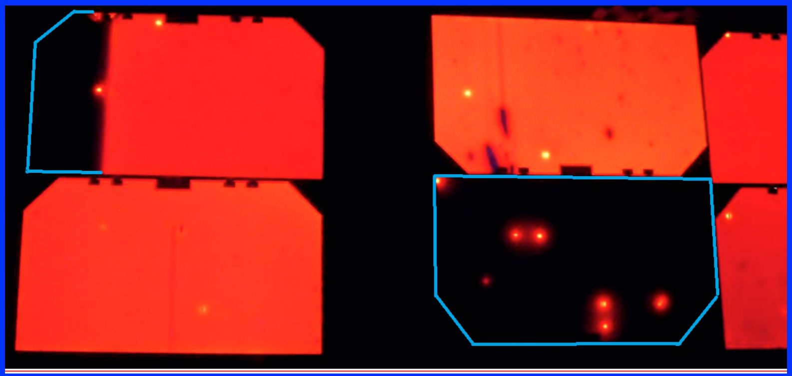
Potted flight board



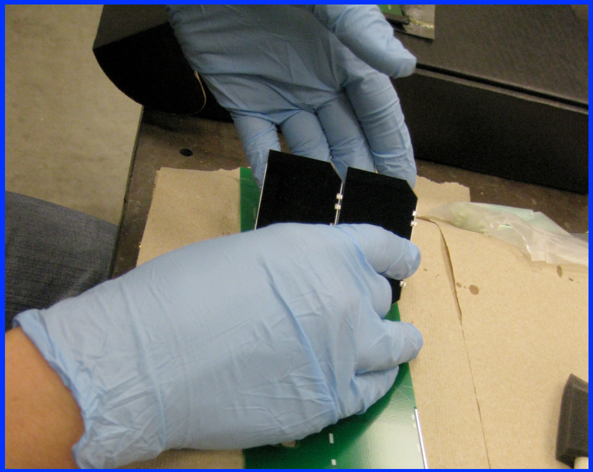
Test-POD fit check

Thorough solar cell and panel testing

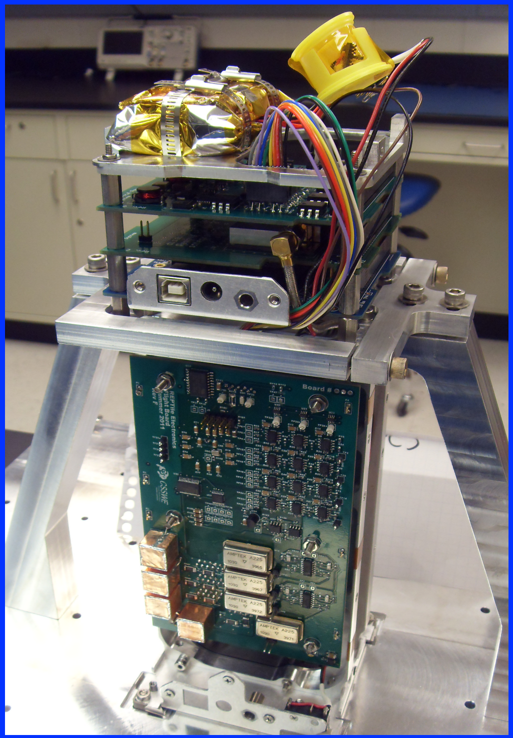
Solar cell forward bias testing

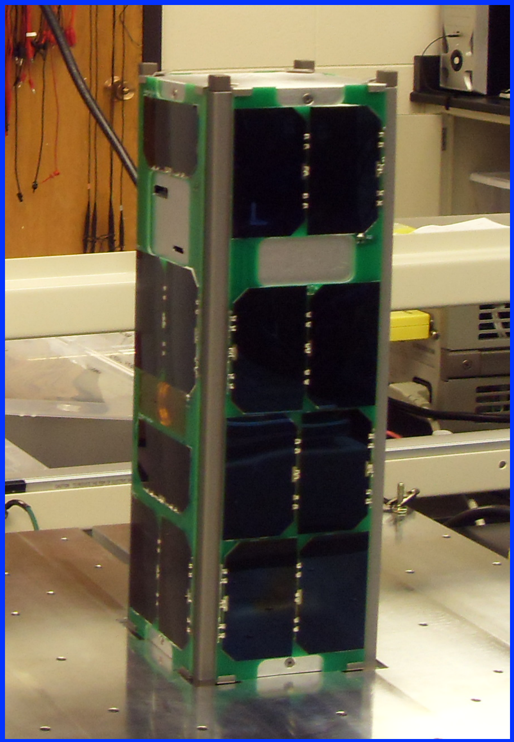


Solar cell mounting

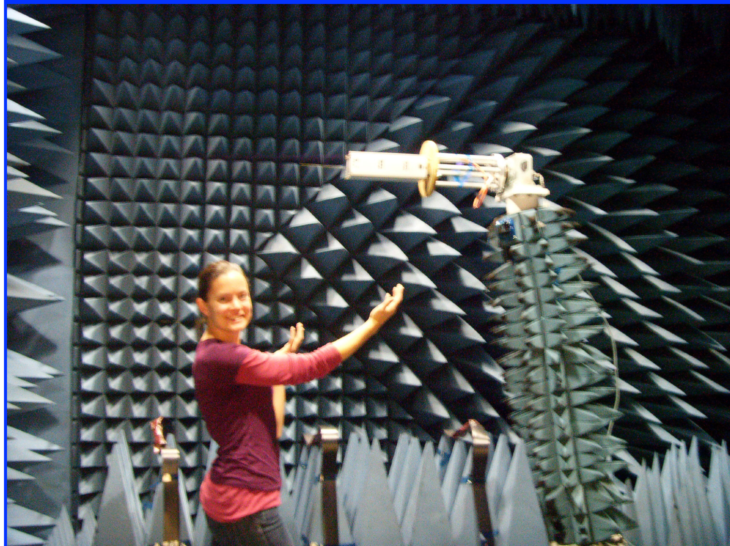


System testing and debugging

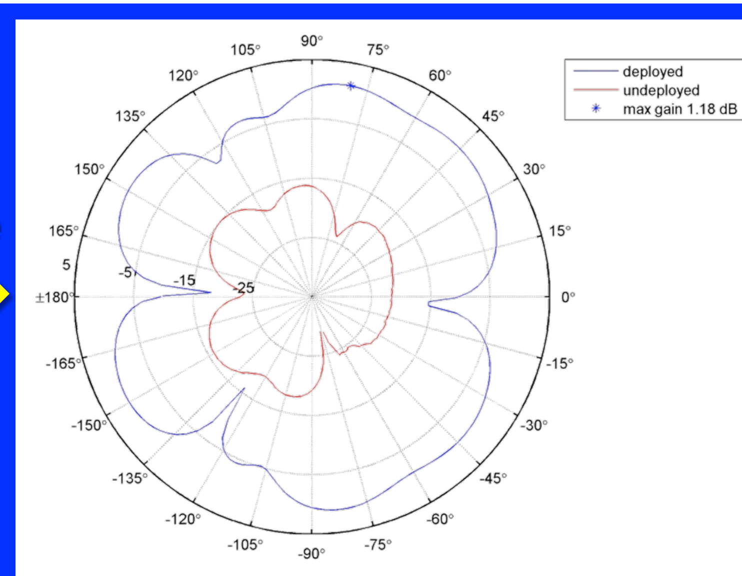




Integrated testing



Testing in anechoic chamber of FirstRF Corp. to determine the antenna gain pattern →

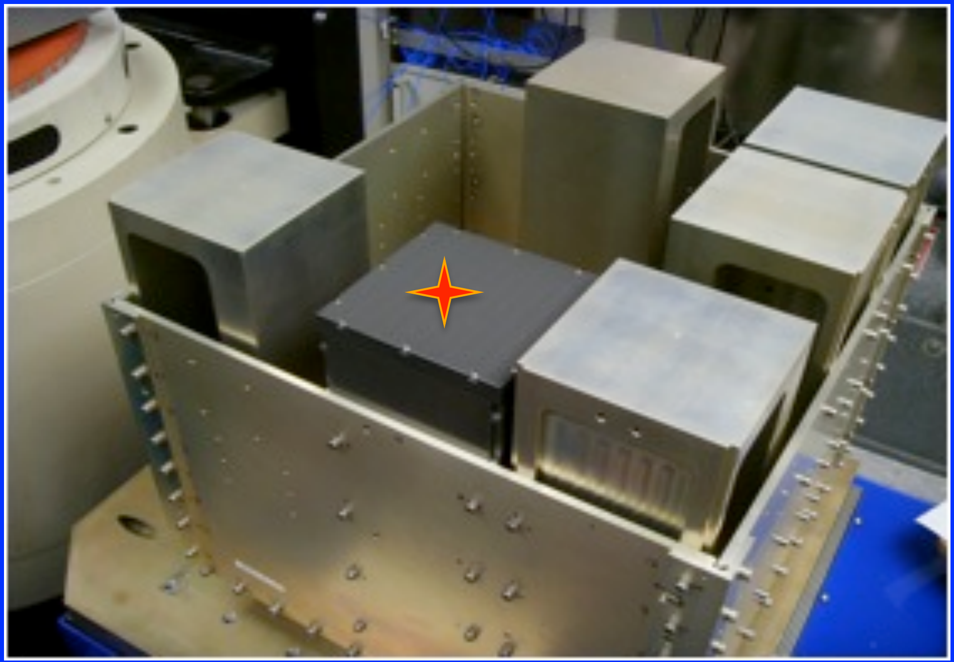


First Plugs-out Test (11/10-11/2011):

Second Plugs-out Test (after Vibe test): 11/29/2011

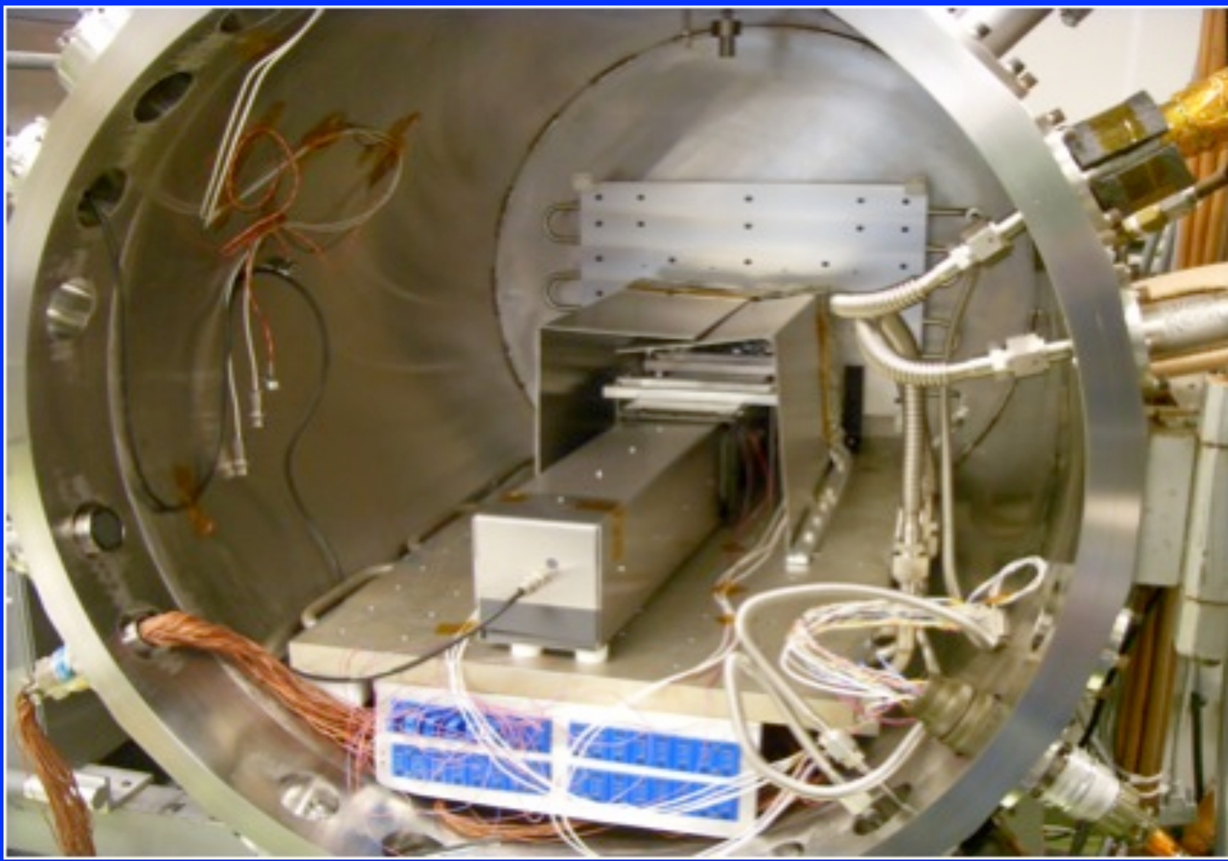
Third Plugs-out Test (after T-V test): 12/21/2011

Vibe Test at Navy Postgraduate School (11/16/2011):

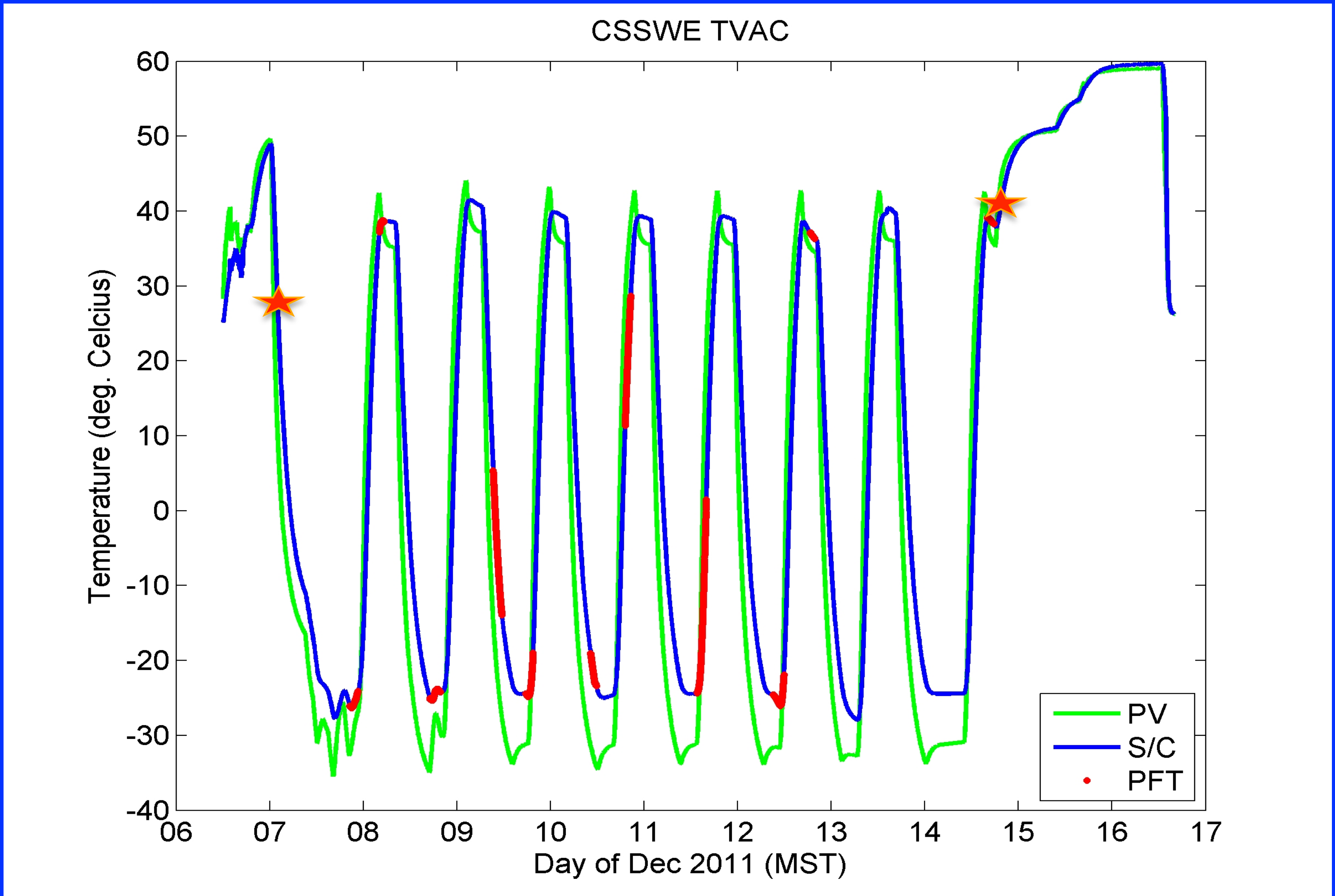


Colorado Student Space Weather Experiment (CSSWE)

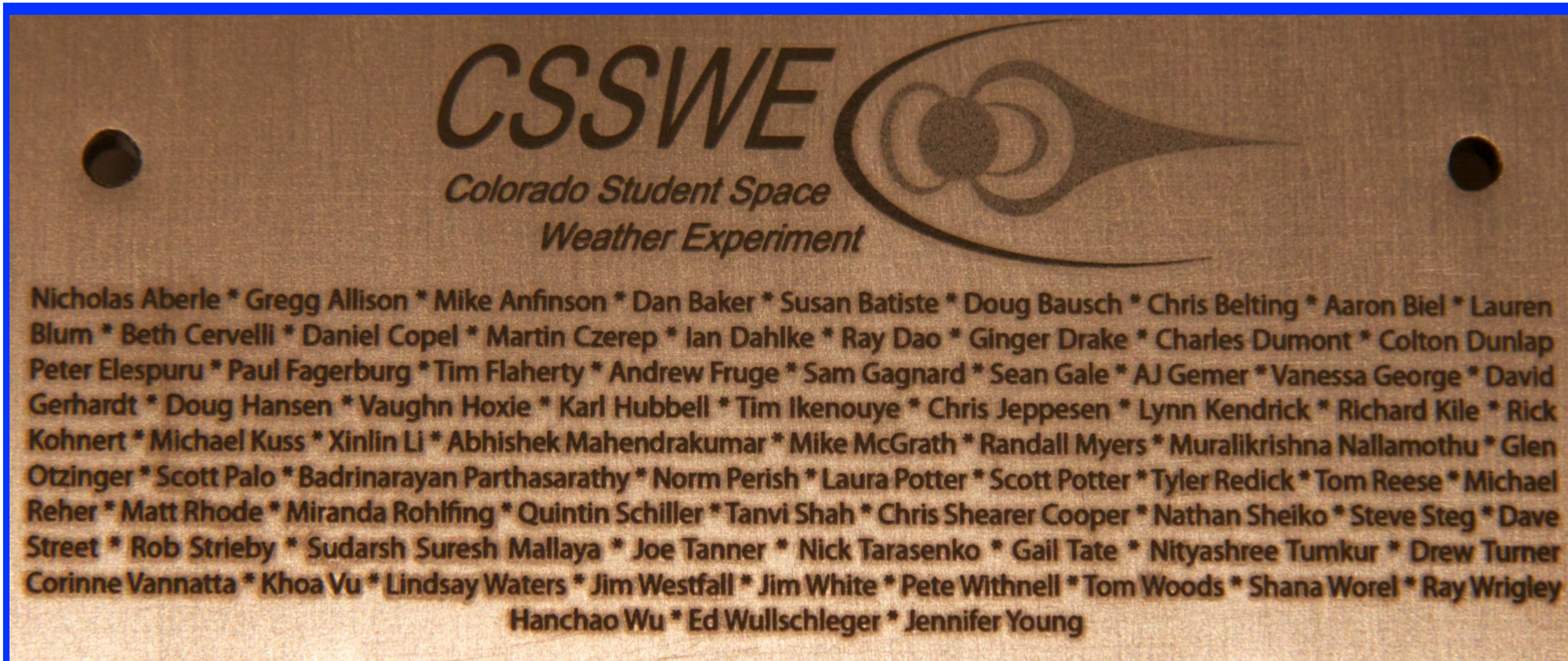
Thermo-Vac Test at LASP: 12/06-14/2011



Thermo-Vac Test: 12/06-14/2011



TVAC cycling temperature. Blue: the average of four thermistors placed on the external shell of the CubeSat; Green: on solar cell; Red portion: when PFT was performed; Red Stars: on/off.



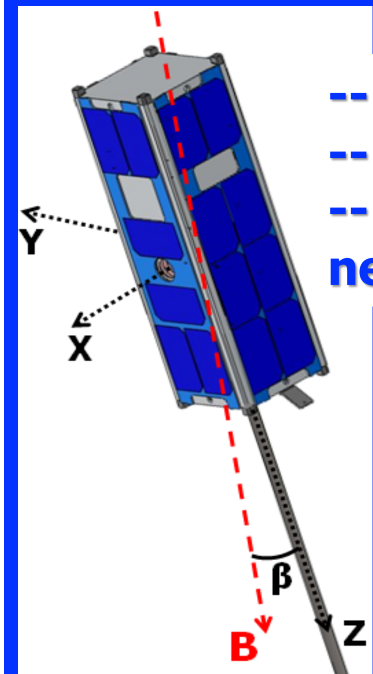
Additional Reviewers: Bill Possel, Bret Lamprecht, Andrew Jones, Beth McGilvray, Heather Reed, Darren Osborne
ASE: Trudy Schwartz, Diane Dimeff
Roof Antenna: Paul deFalco, CU Fac-man
QA and ESD Training: Doug Vincent, Jon Thiede, Dwight Reinhardt
CPLD: Magnus Karlsson
T-Vac and REPTile testing: James Mason, Hong Zhao, David Hall, David James, Matt Carton
Mission Operation & Software: Colin Stewart, Wayne Russell, Samantha Pettus, Tyler Fox, Scott Taylor, Tyler Traver, Mike Dorey, Steve Roughton, Chris Pankratz, Sean Ryan, Jennifer Reiter
EPO and Website: Stephanie Renfrow, Tom Mason, Marisa Lubeck, Ransom Christofferson, Nick Diorio, *http://lasp.colorado.edu/home/csswe/*
Business Analysts: Peter Wise, Jason LaClair, Zak Eaton, Nina Davis

Launched on 9/13/12, we received beacon packets during its first over pass

Commissioning phase completed on 10/04/12 and Particle detectors were turned on

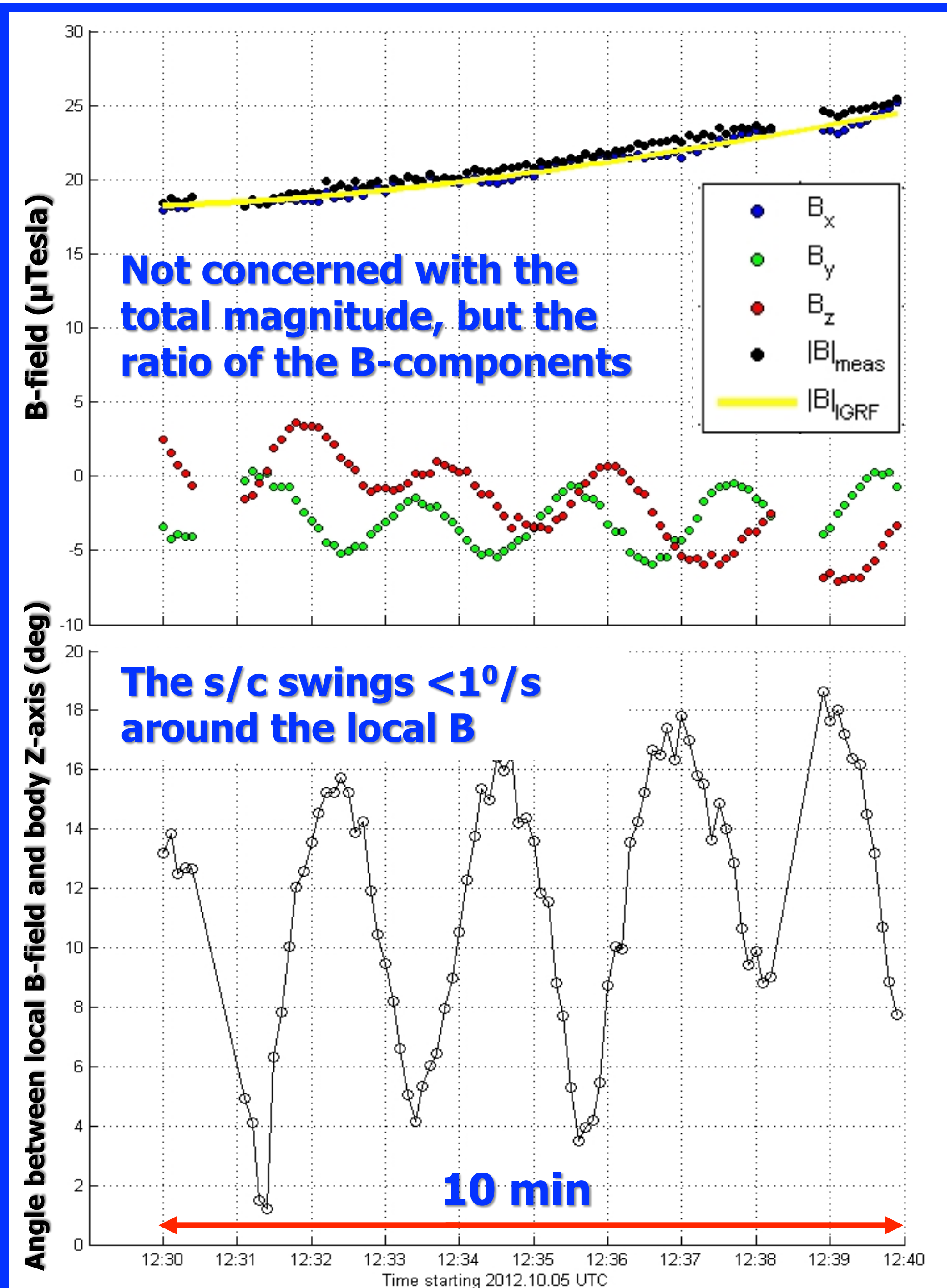
The data are clean, exceeding our expectation!

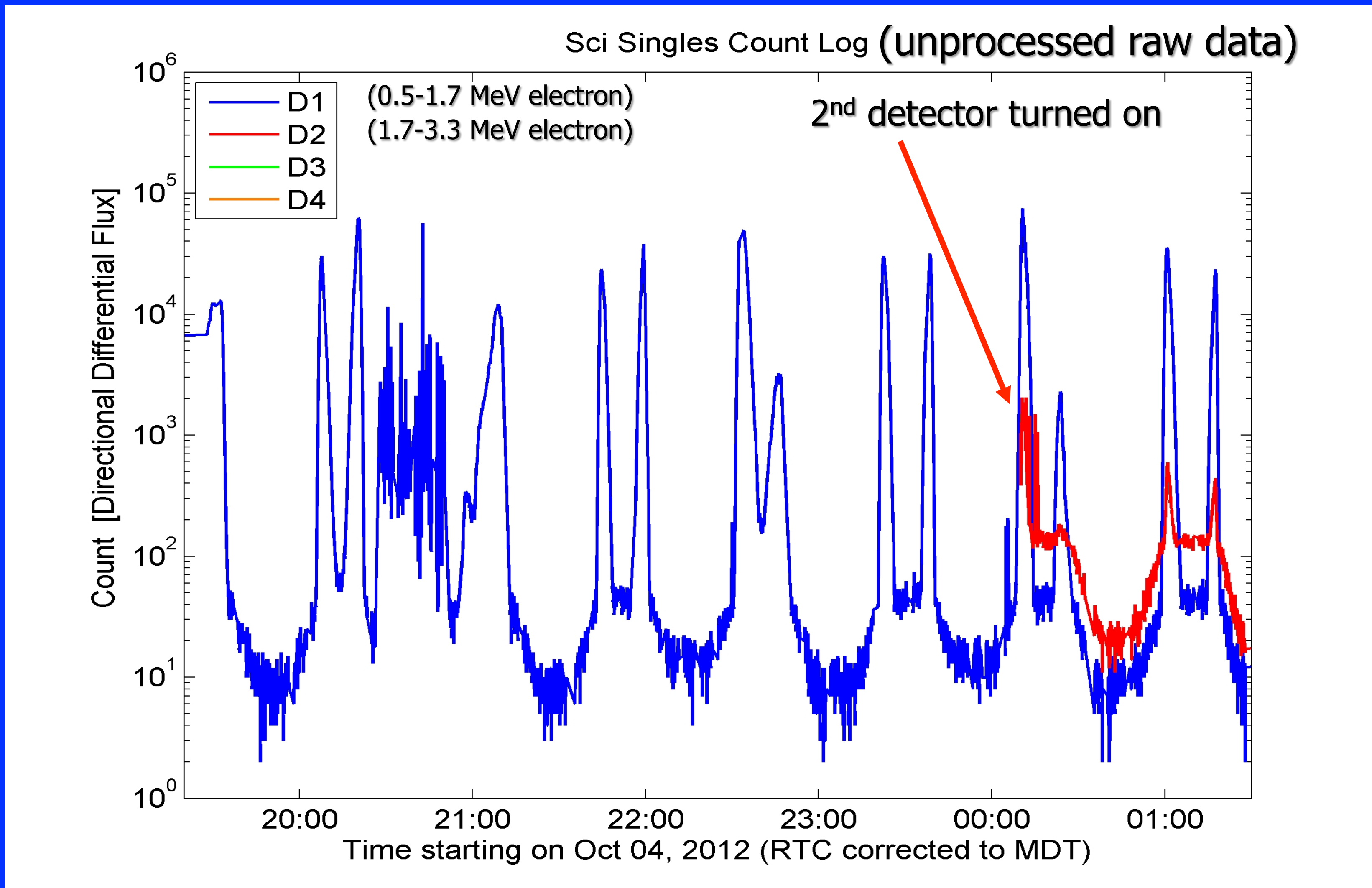
	Channel 1	Channel 2	Channel 3
Electrons	0.5-1.7 MeV	1.7-3.3 MeV	>3.3 MeV
Protons	9-18 MeV	18-30 MeV	30-40 MeV



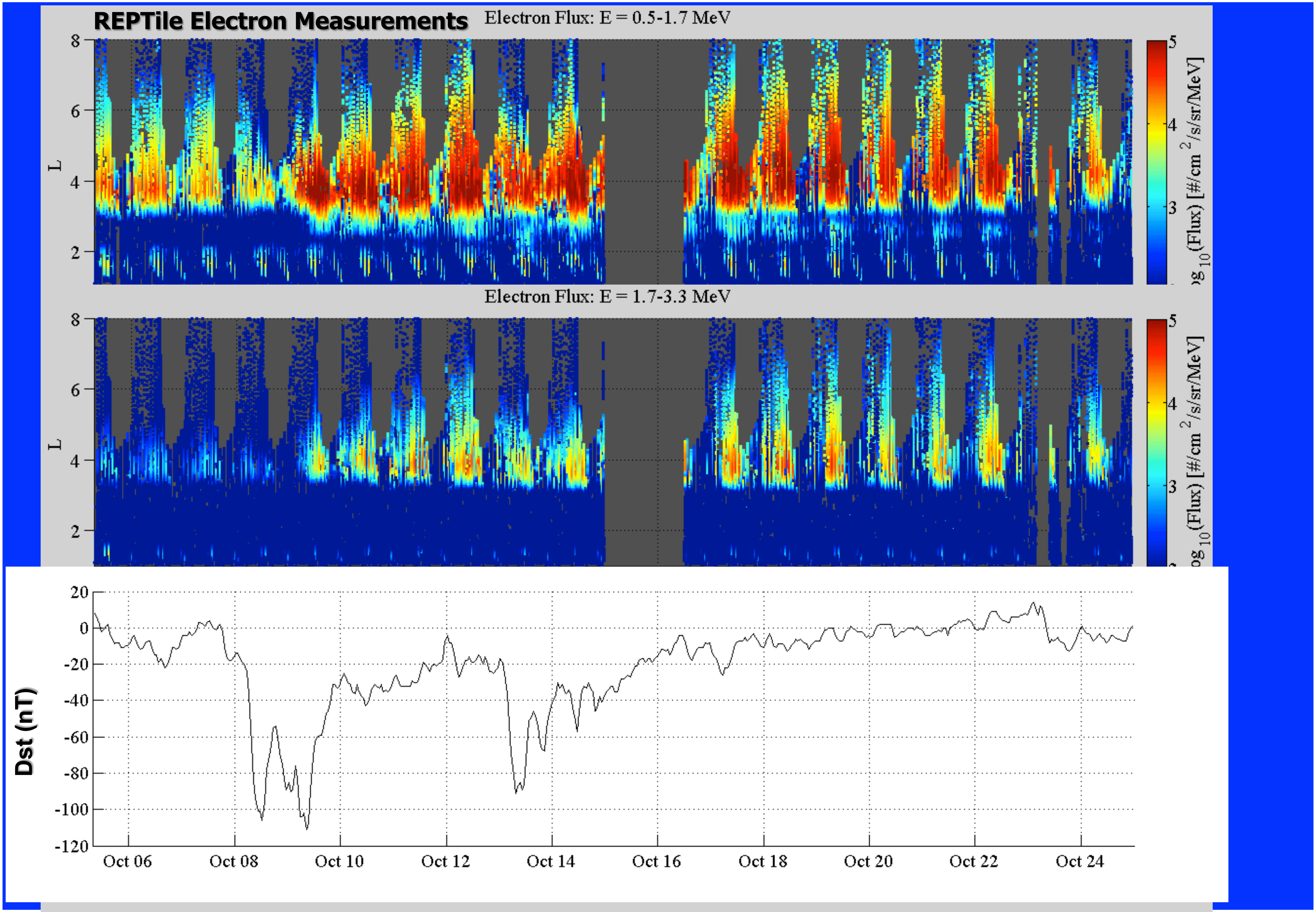
-- **Passive Attitude Control**
-- **No pointing requirement**
-- **Only the knowledge is needed**

Onboard magnetometer + photo sensors + temperature sensors ➔ s/c attitude

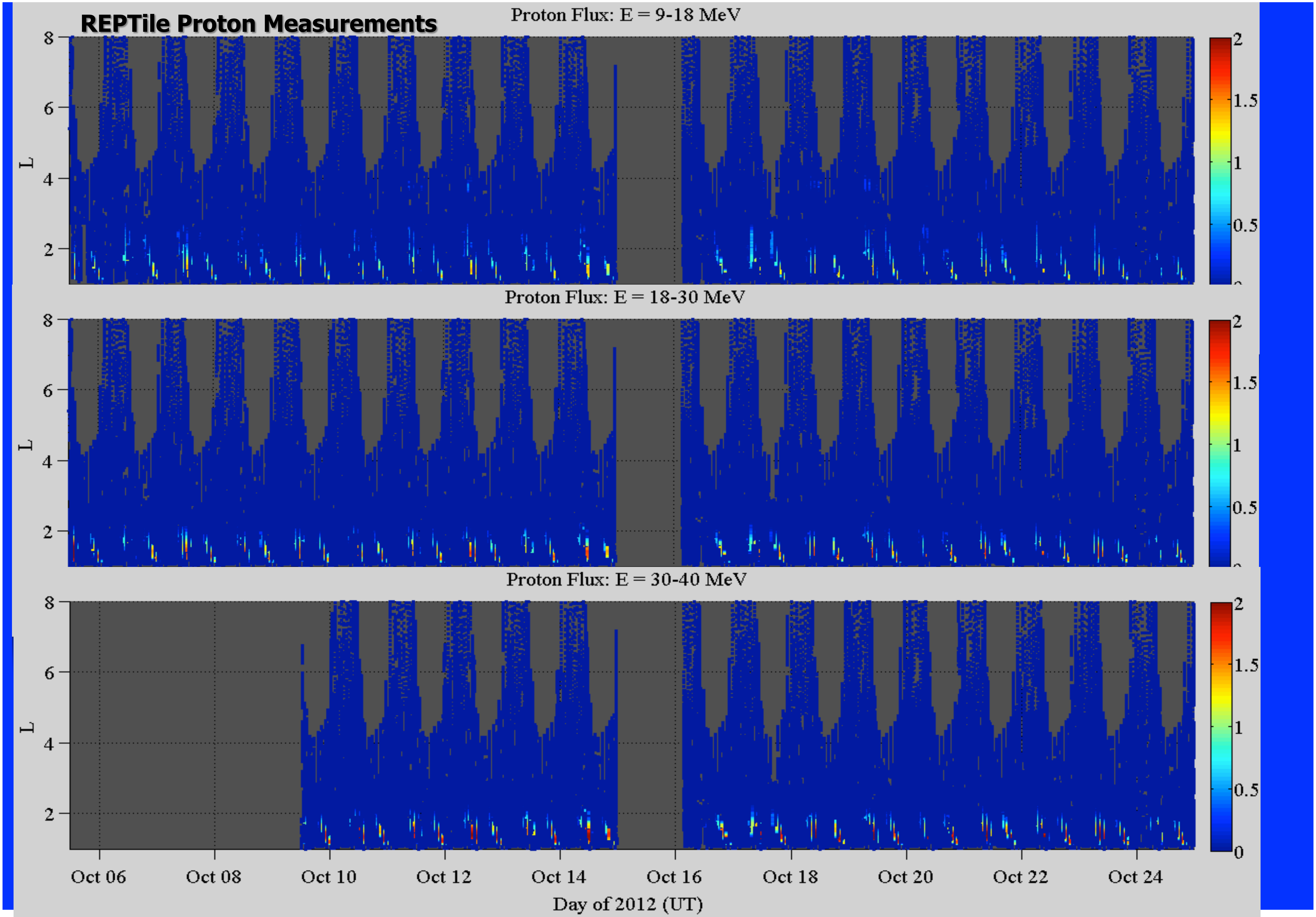




Orbit: ~480 km x 780 km, inclination ~65⁰



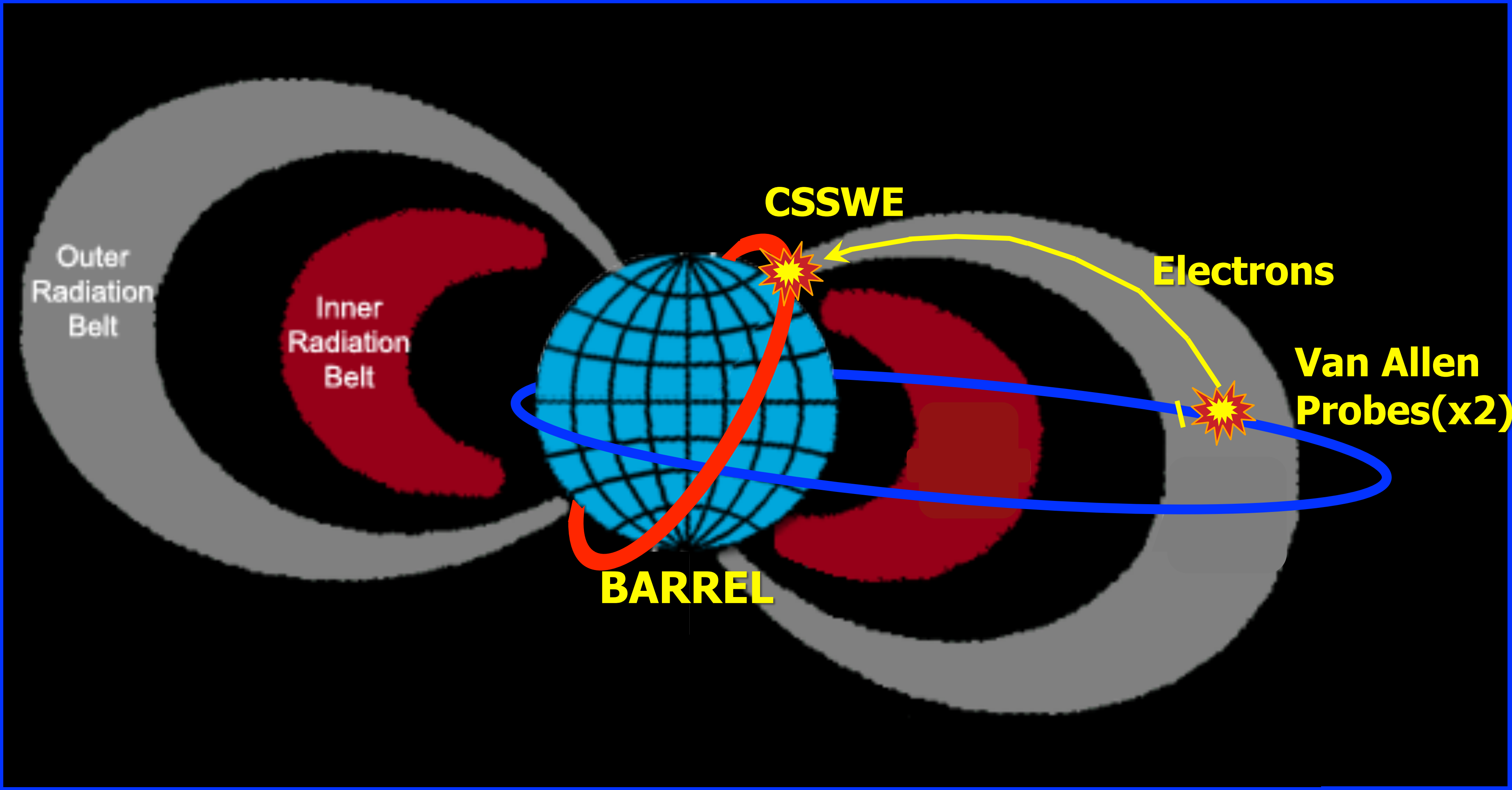
REPTile Electron Measurements
Electron Flux: E = 0.5-1.7 MeV
Electron Flux: E = 1.7-3.3 MeV
L
log10(Flux) [#/cm2/s/sr/MeV]
Dst (nT)
Oct 06
Oct 08
Oct 10
Oct 12
Oct 14
Oct 16
Oct 18
Oct 20
Oct 22
Oct 24



REPTile Proton Measurements
Proton Flux: E = 9-18 MeV
Proton Flux: E = 18-30 MeV
Proton Flux: E = 30-40 MeV
L
8
6
4
2
0
0.5
1
1.5
Oct 06
Oct 08
Oct 10
Oct 12
Oct 14
Oct 16
Oct 18
Oct 20
Oct 22
Oct 24
Day of 2012 (UT)

Concurrent measurements with NASA/Van Allen Probes

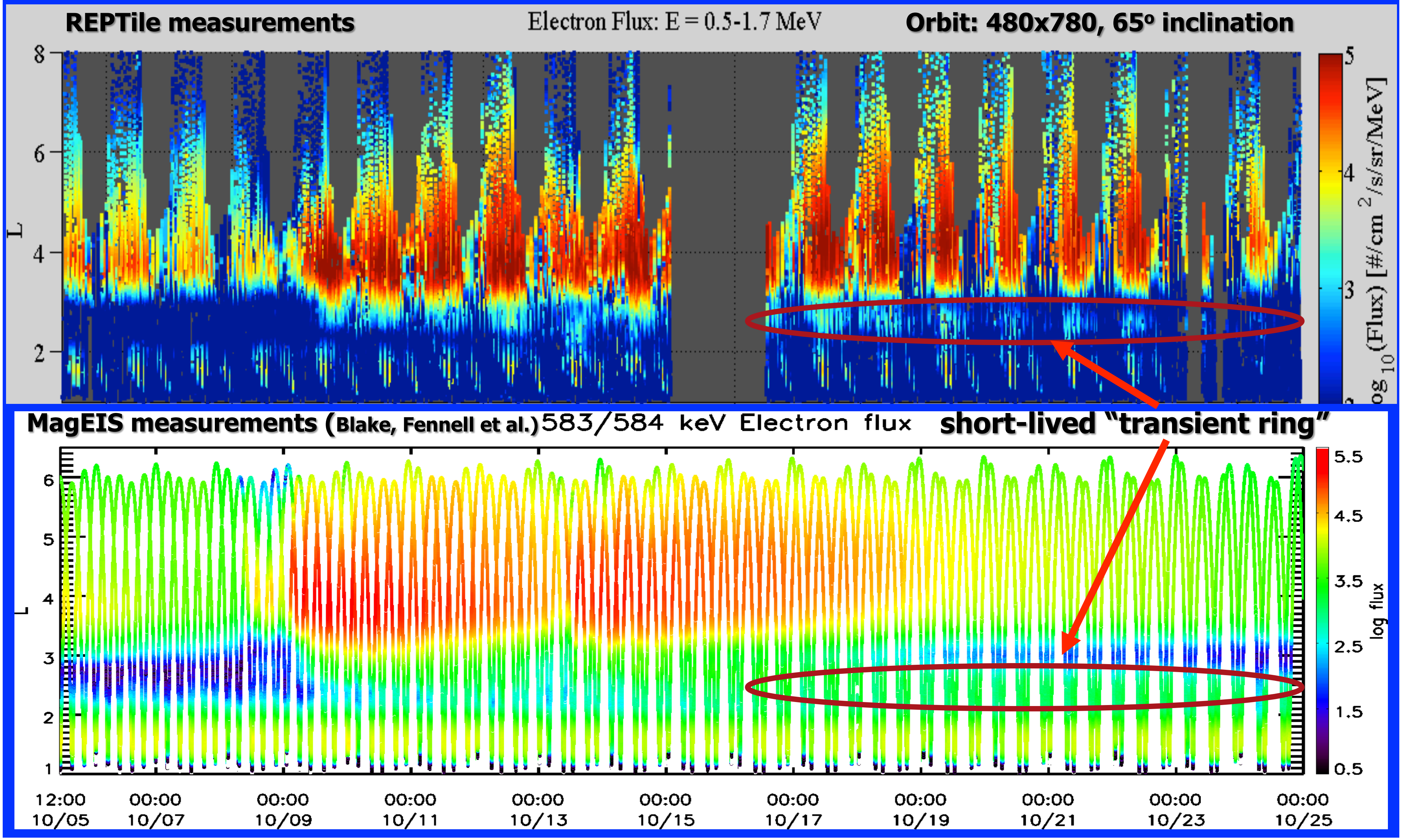
(orbits: 605km x 30410km and 635km x 30540km, inclination: 10^0)



Comparison REPTile and MagEIS (~ 0.5 MeV):

(1) ~ 0.5 MeV electrons go deep, pass slot region and merge with inner belt

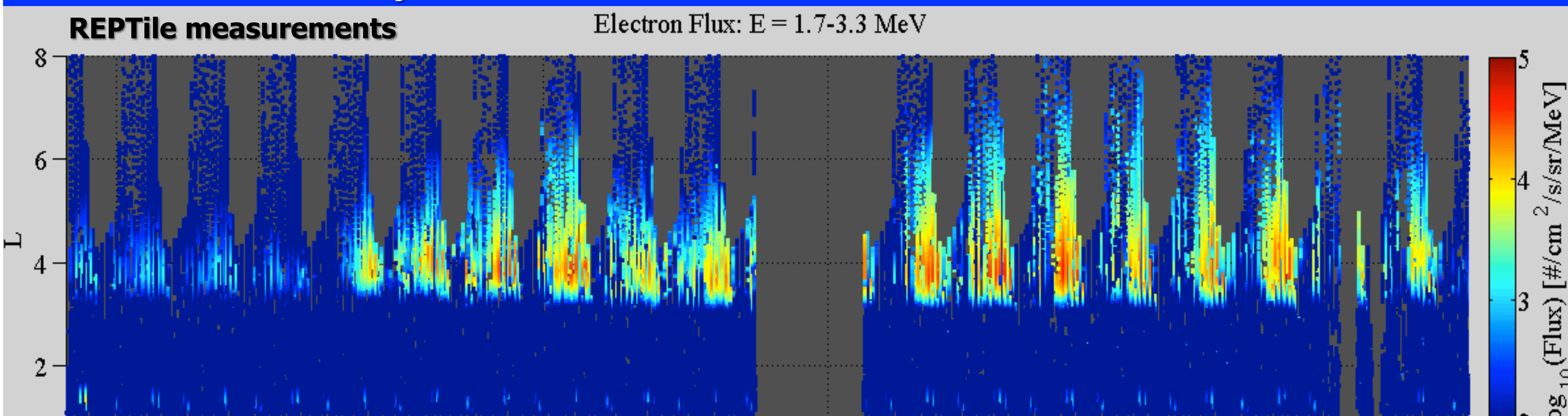
(2) Detailed structures: including so called "transient ring"

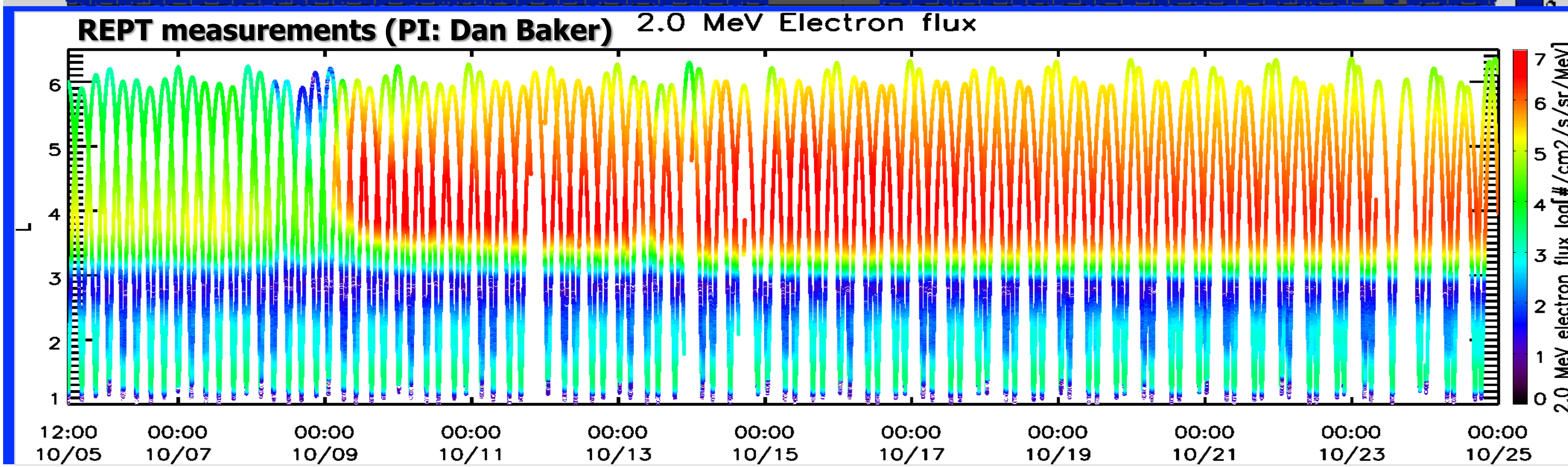


Comparison REPTile and REPT (>1.77 MeV):

(1) Outer belt electrons dynamic with continuous PA scattering, but stayed at L≥3, and no “transit ring”

(2) Inner belt electrons stable, confined to the equatorial region, only detectable by REPTile over SAA

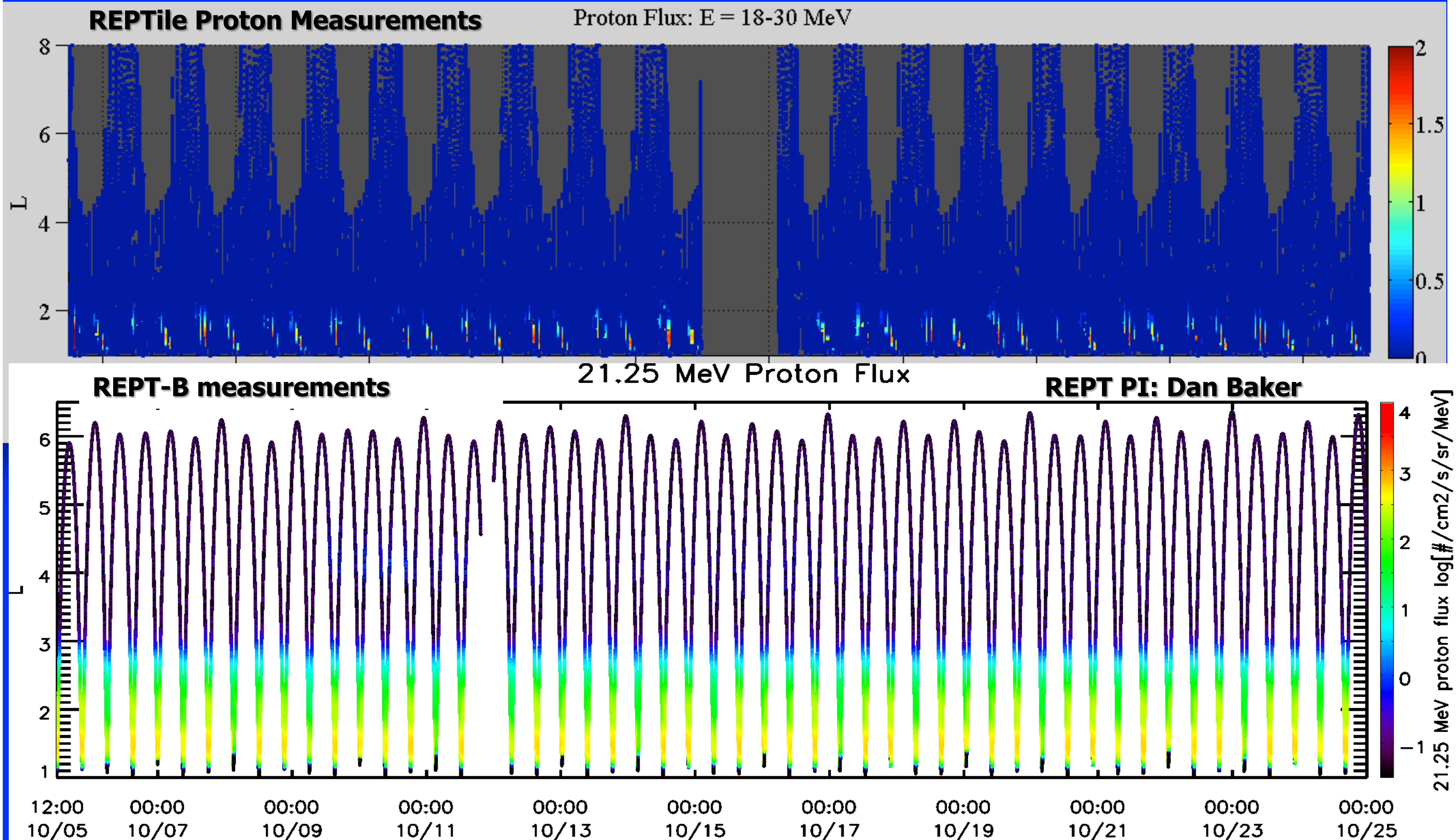




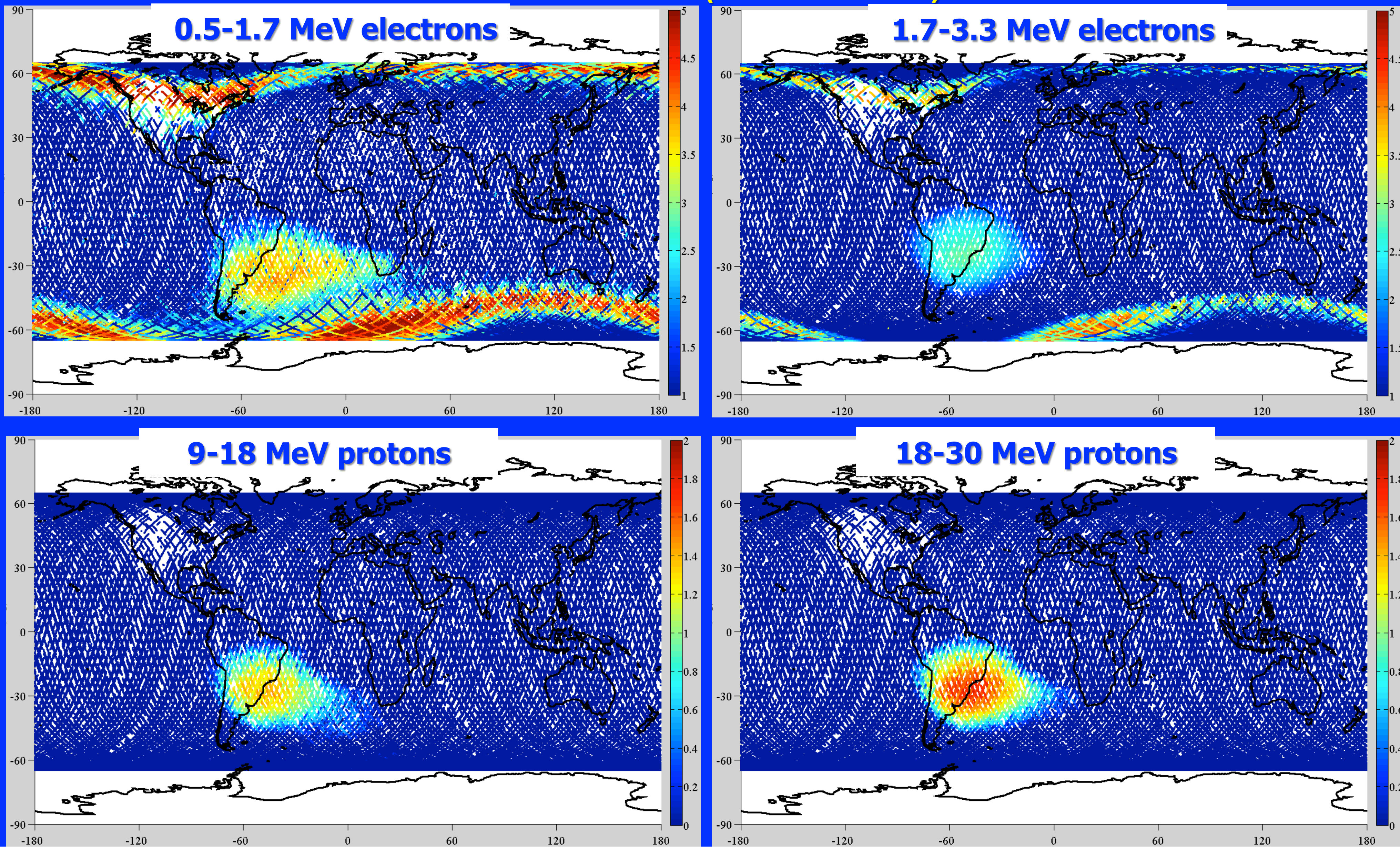
Comparison between REPT and REPTile:

(1) Very few energetic protons in the outer belt

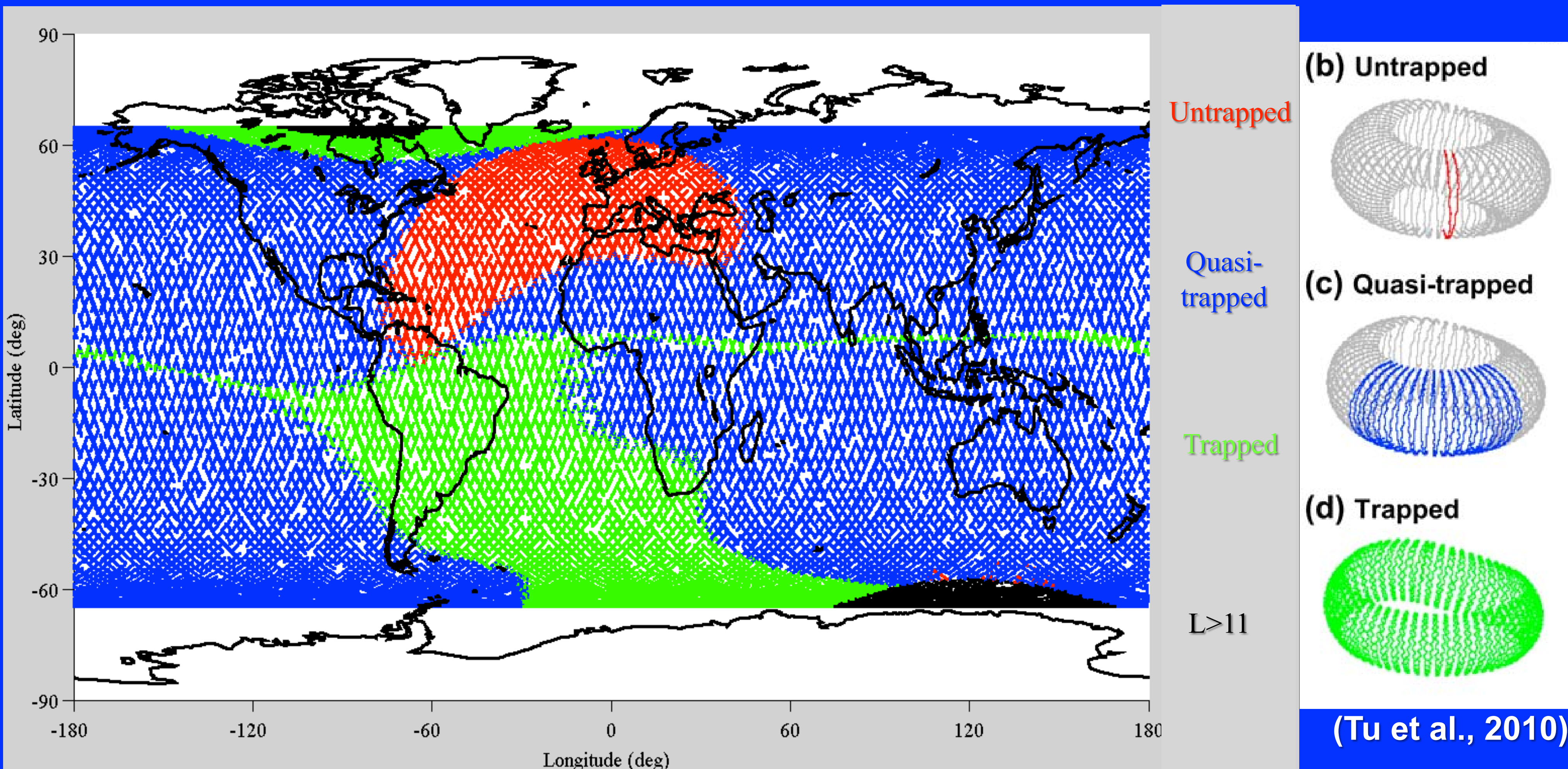
(2) Inner belt protons stable, confined to the equatorial region



Measurements of electrons & protons from REPTile provide a clear picture of energetic particles (electrons and protons) in the near Earth environment (10/5-25/2012)

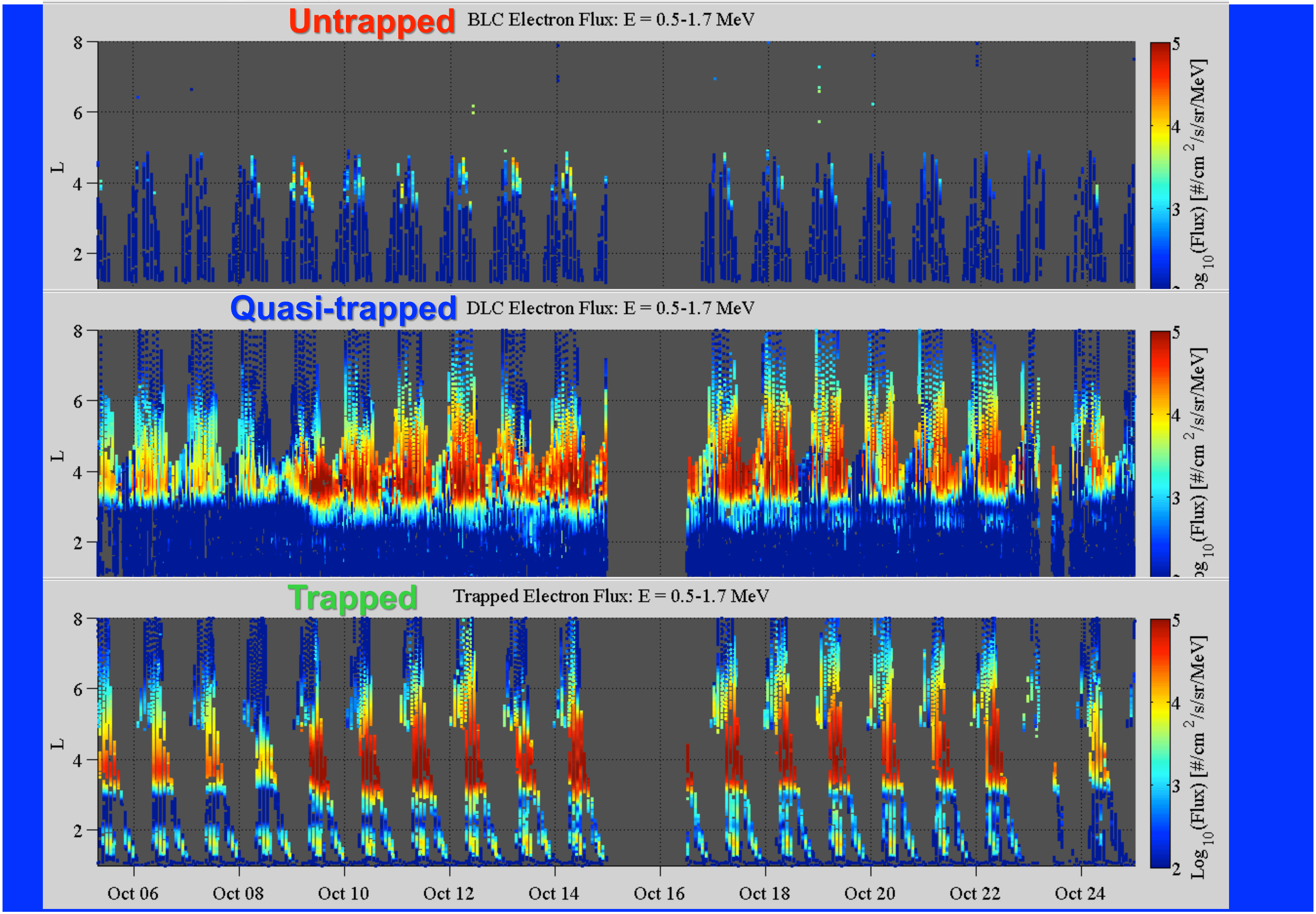


Based on where the measurements are made, we can classify the electron populations: Untrapped (BLC), Quasi-trapped (DLC), and Trapped



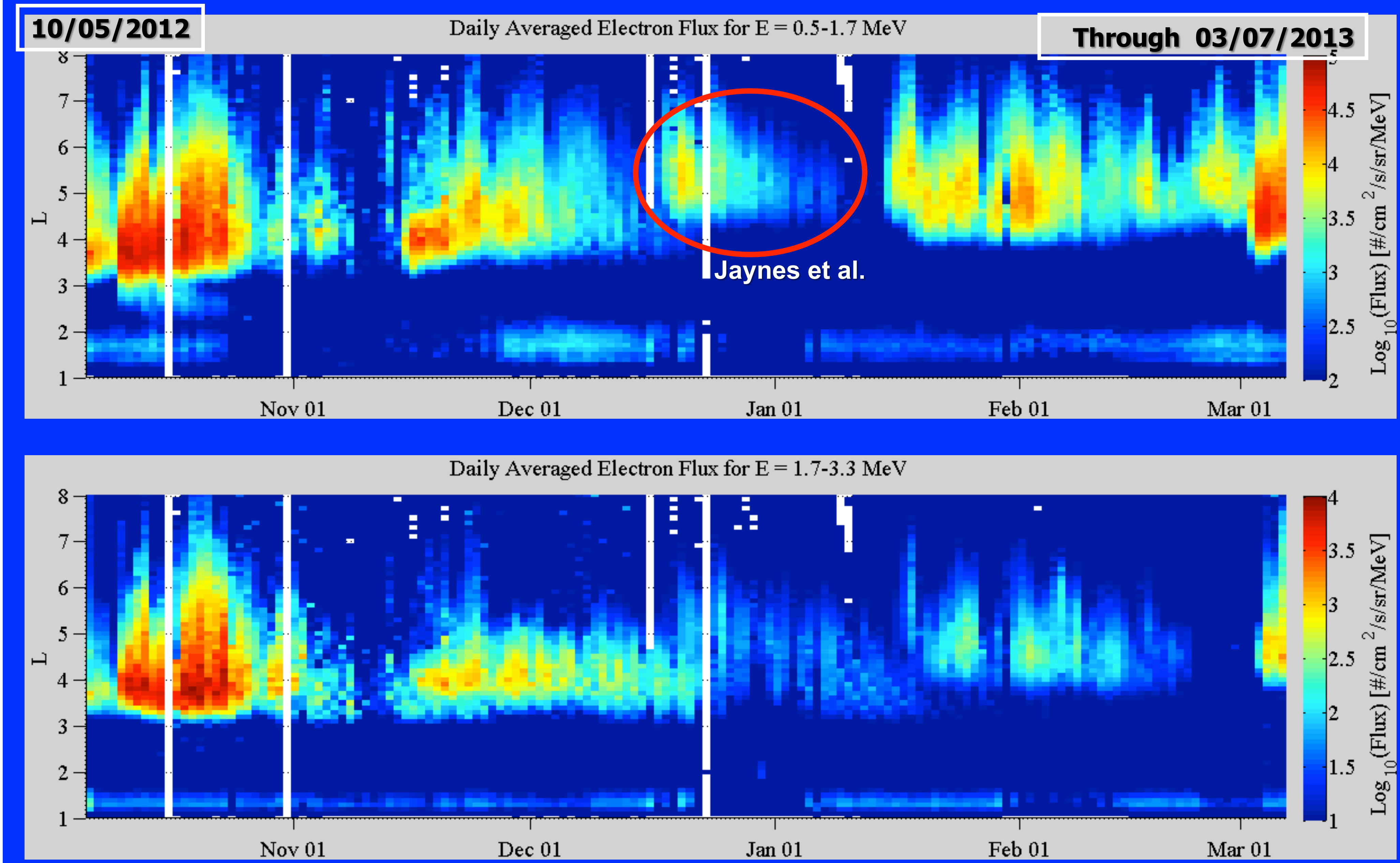
(Tu et al., 2010)

(Suggested by Richard Selesnick, Hong and Quintin made the above figure)

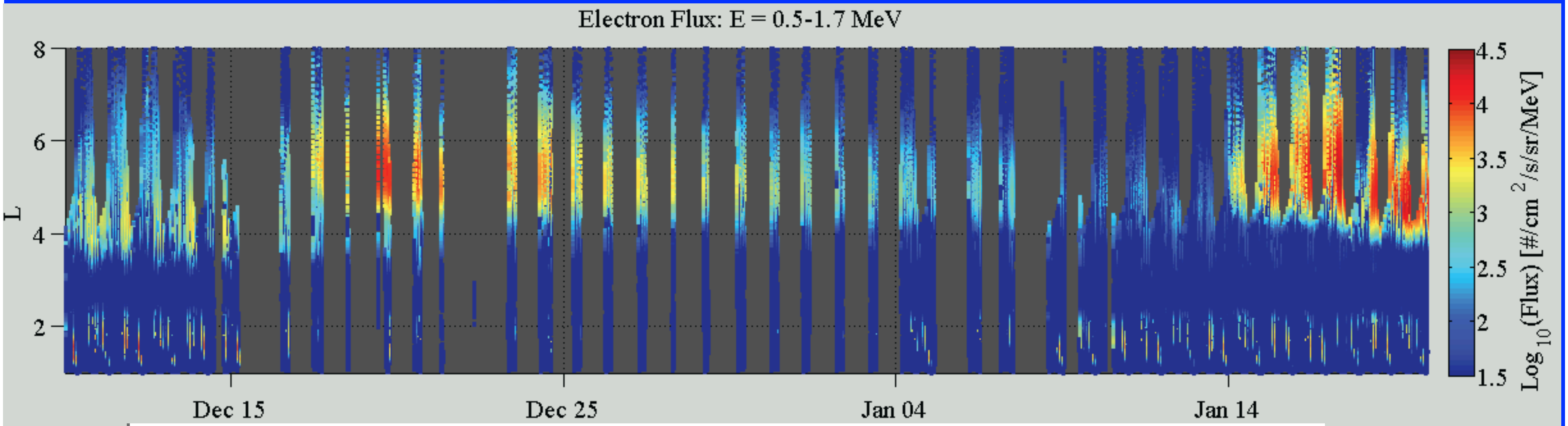


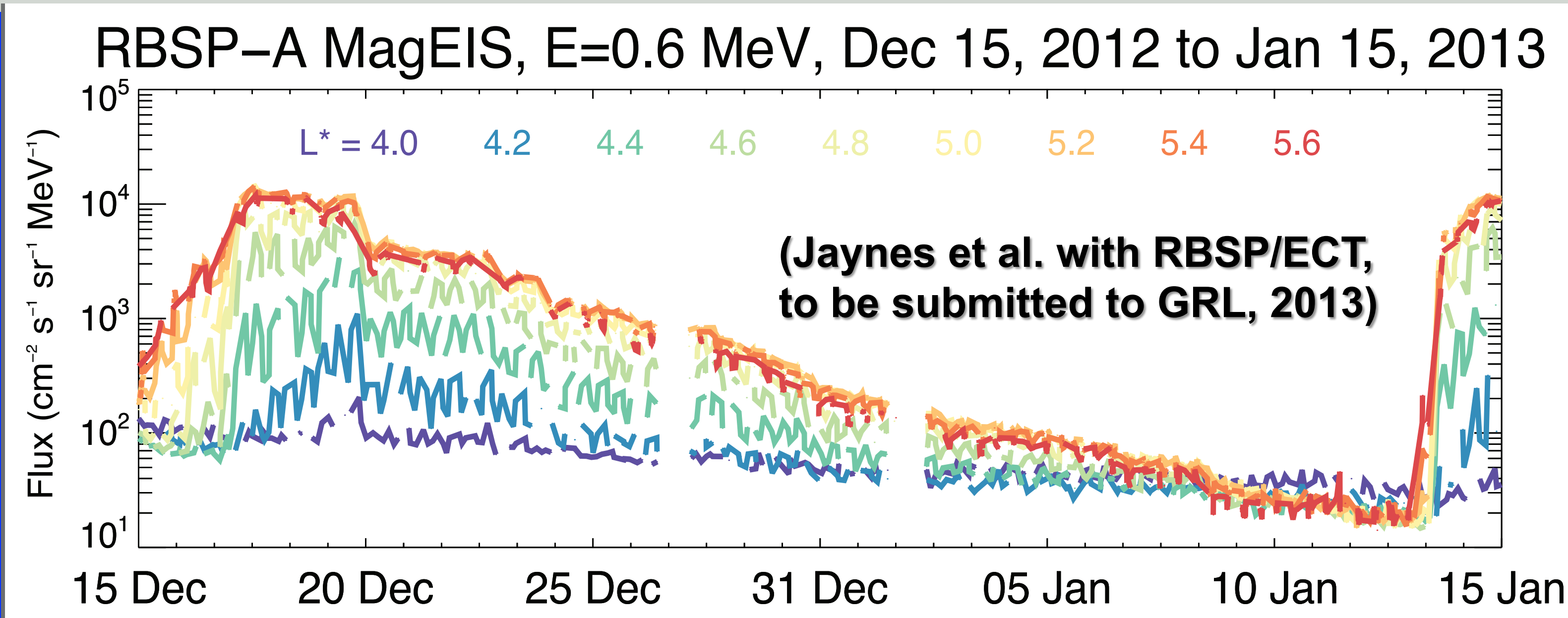
Untrapped
BLC Electron Flux: E = 0.5-1.7 MeV
Quasi-trapped
DLC Electron Flux: E = 0.5-1.7 MeV
Trapped
Trapped Electron Flux: E = 0.5-1.7 MeV
L
Log10(Flux) [#/cm2/s/sr/MeV]
Oct 06
Oct 08
Oct 10
Oct 12
Oct 14
Oct 16
Oct 18
Oct 20
Oct 22
Oct 24

REPTile electron measurements since launch

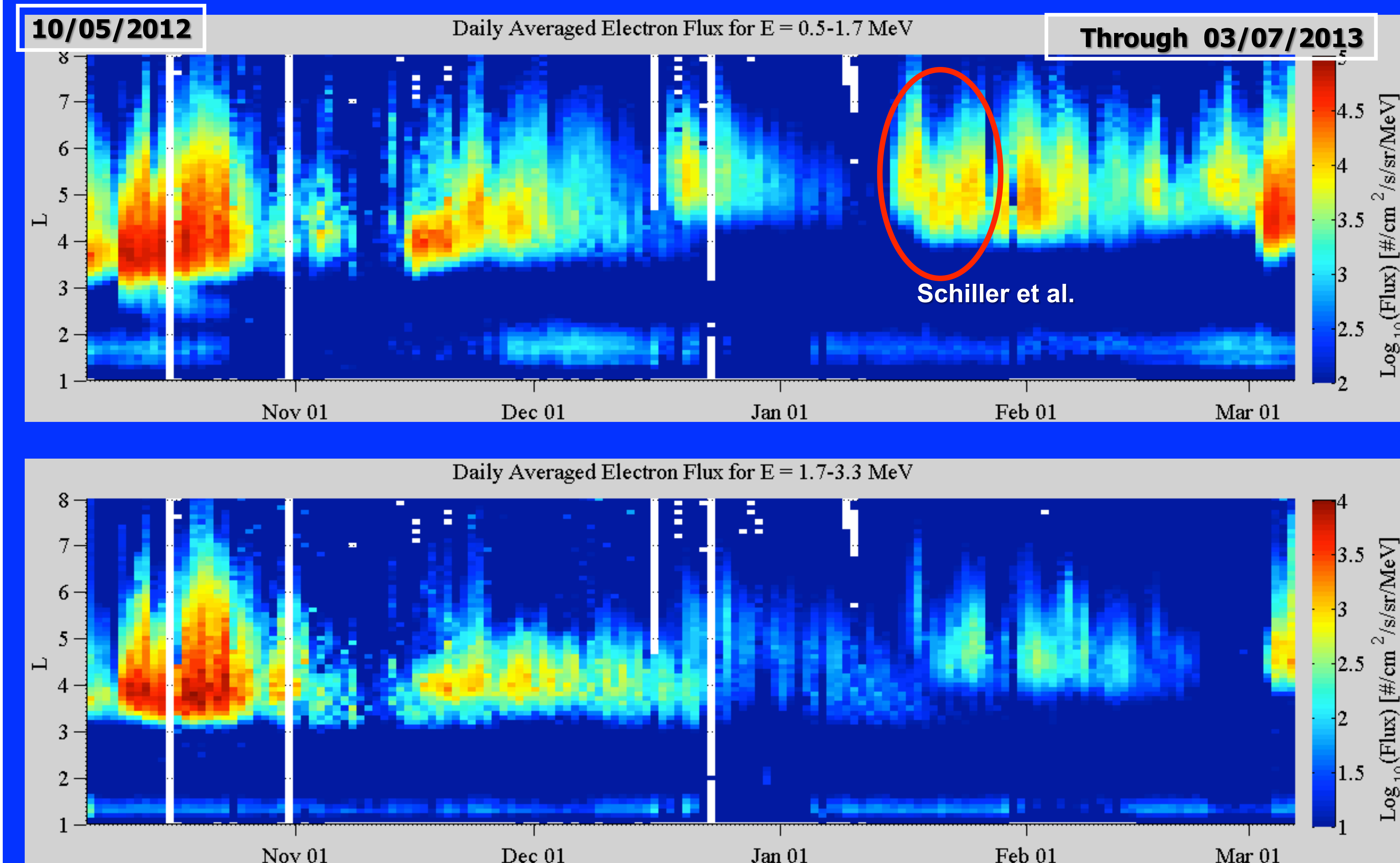


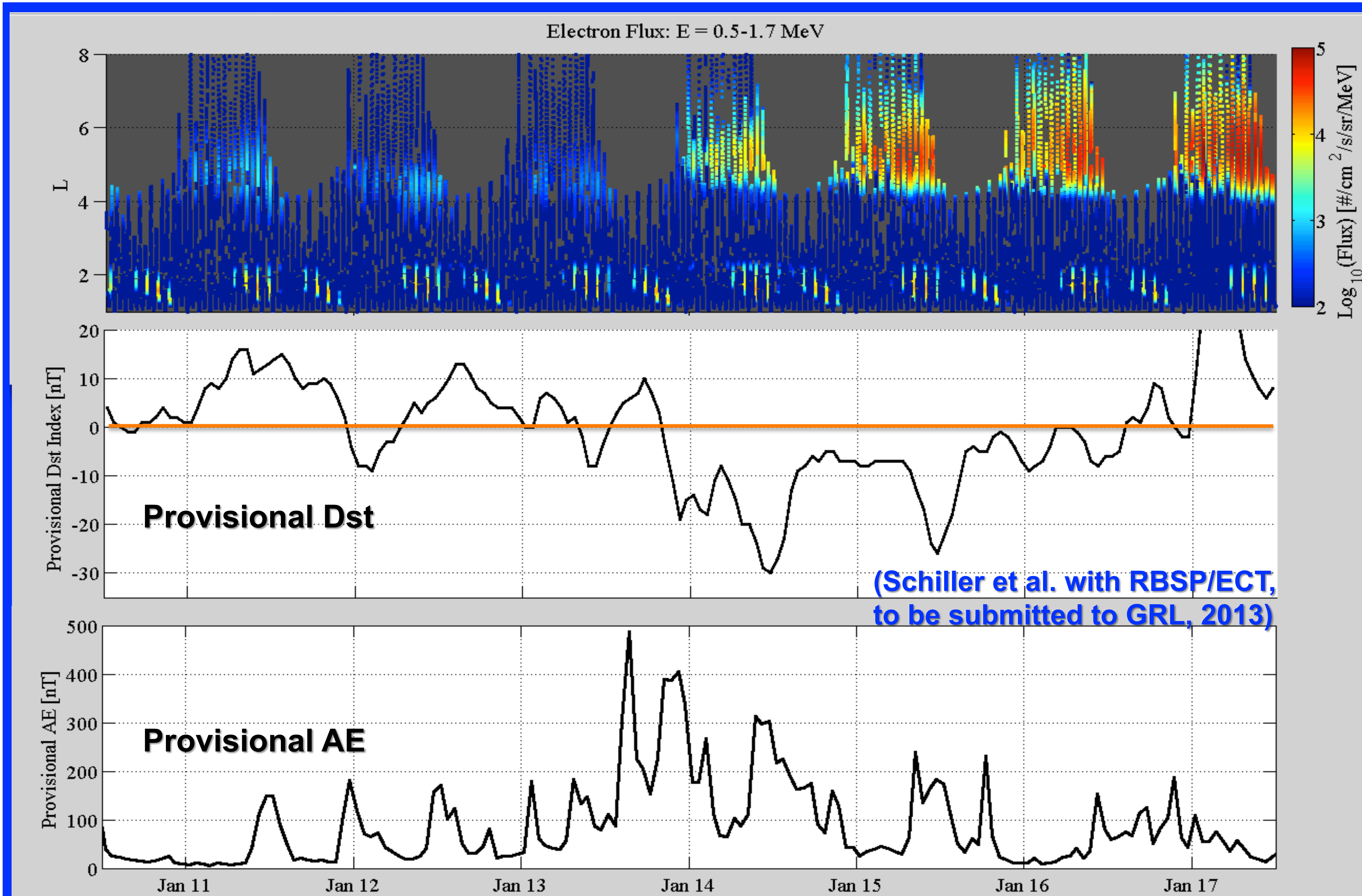
Evolution of relativistic outer belt electrons during extended quiescent period





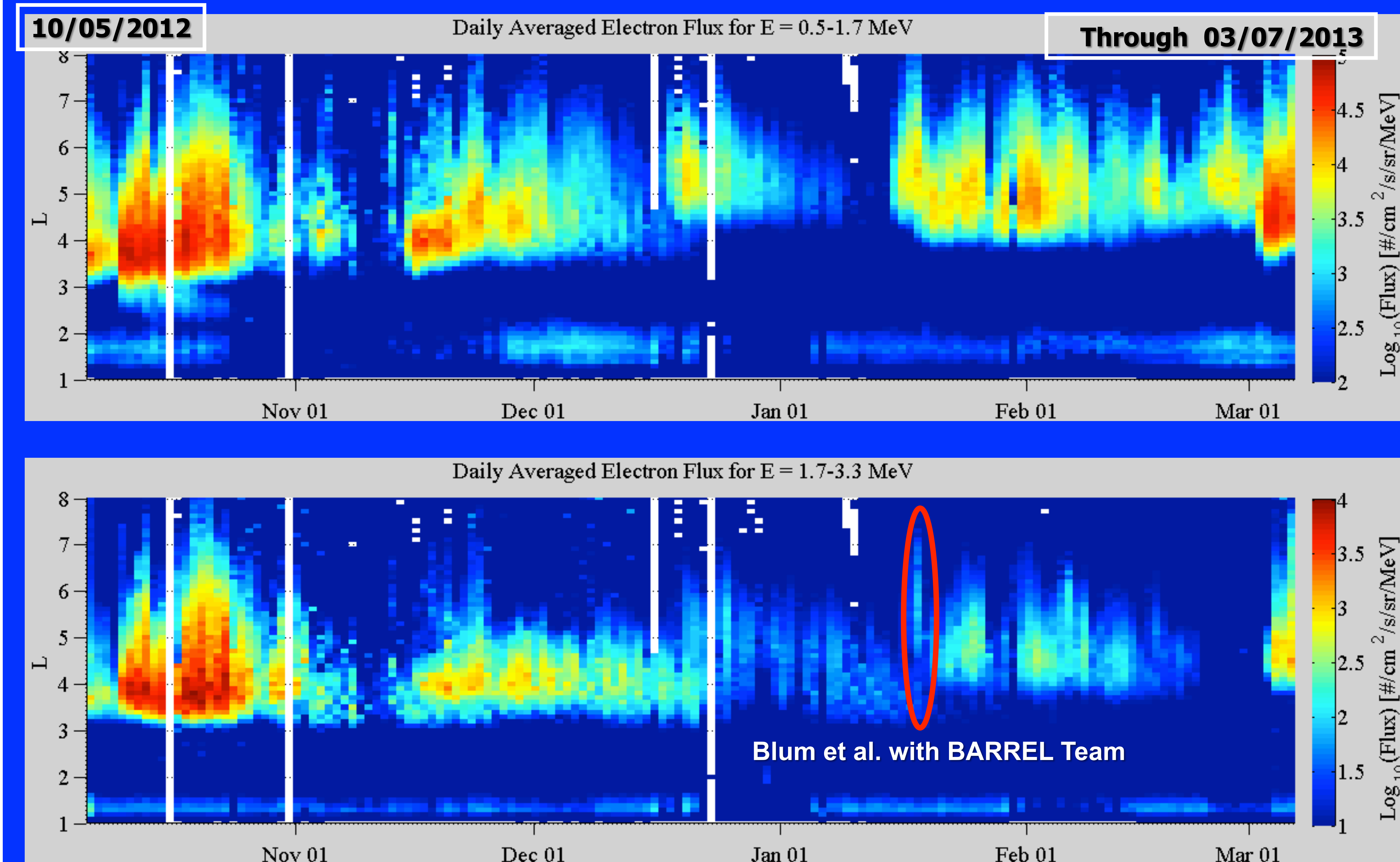
REPTile electron measurements since launch





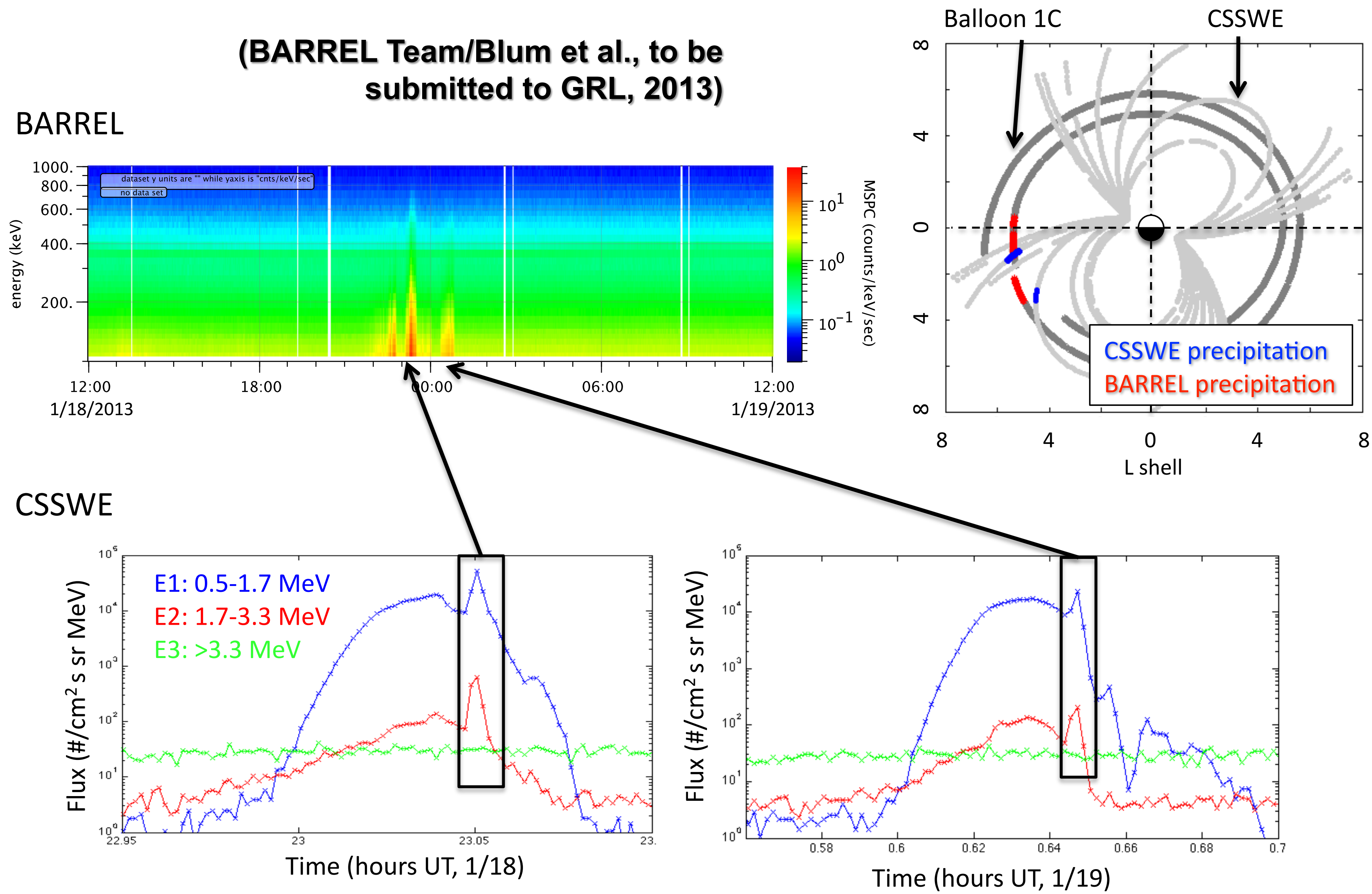
Enhancement during non-storm time, but with some substorm activity

REPTile electron measurements since launch

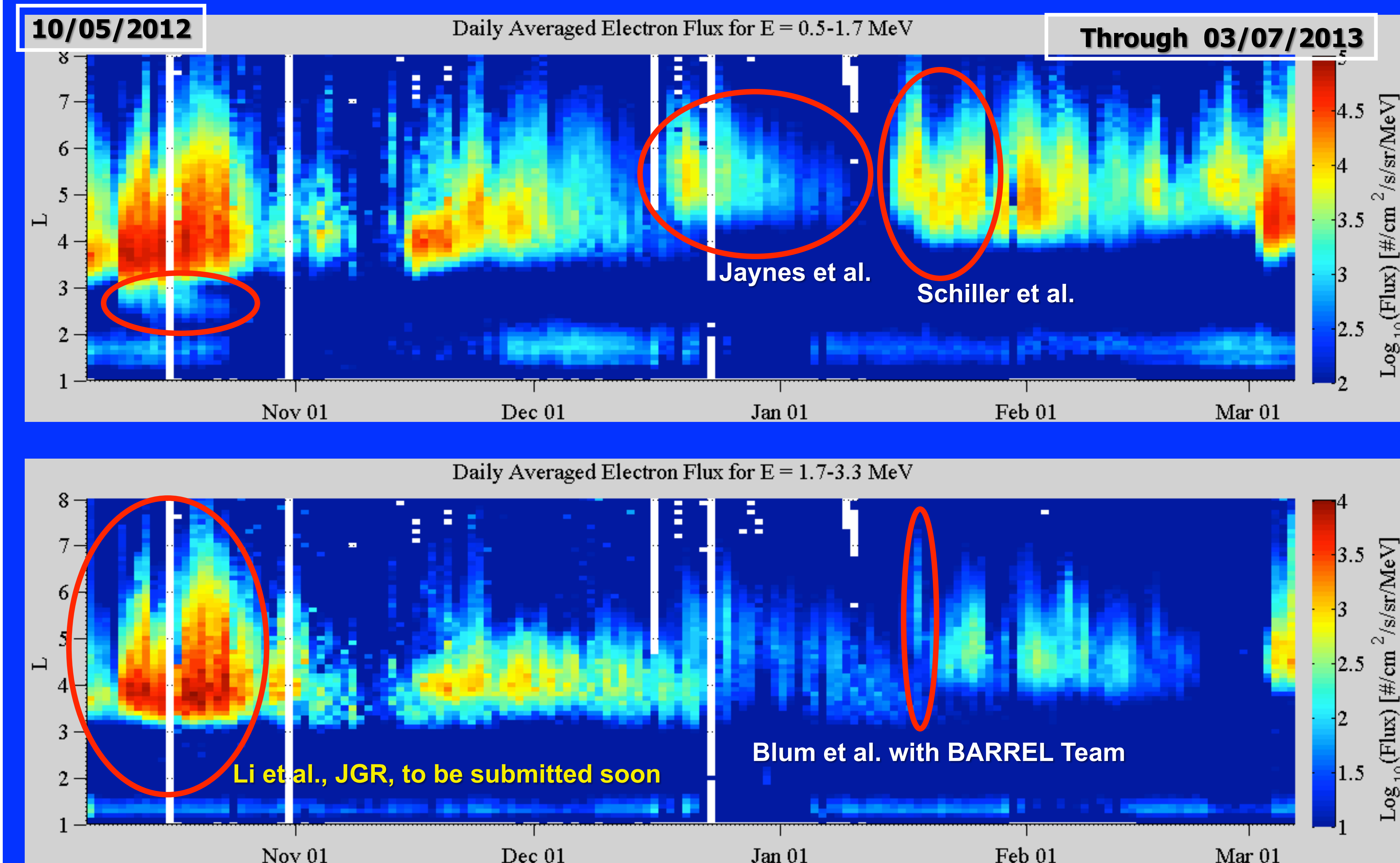


BARREL-CSSWE Conjunctions – 01/18-19

(BARREL Team/Blum et al., to be submitted to GRL, 2013)



REPTile electron measurements since launch



The satellite went silent on 3/08/13.

Data analysis and modeling efforts have been continuing …

Then on 6/18/13 (Tuesday), 23 beacons were recorded by the automated system, bi-directional communications with the satellite were re-established yesterday …

Publications

Li, X., S. Palo, R. Kohnert, L. Blum, D. Gerhardt, Q. Schiller, and S. Callif (2013), Small Mission Accomplished by Students - Big Impact on Space Weather Research, *Space Weather Journal, 11*, doi:10.1002/swe.20025, 2013.

Li, X., S. Palo, R. Kohnert, D. Gerhardt, L. Blum, Q. Schiller, D. Turner, W. Tu, N. Sheiko, and C. S. Cooper (2012), Colorado Student Space Weather Experiment: Differential flux measurements of energetic particles in a highly inclined low Earth orbit, in Dynamics of the Earth's Radiation Belts and Inner Magnetosphere, Geophys. Monogr. Ser., vol. 199, edited by D. Summers et al., 385–404, AGU, Washington, D. C., doi: 10.1029/2012GM001313.

Li, X., S. Palo, and R. Kohnert (2011), Small Space Weather Research Mission Designed Fully by Students, *Space Weather Journal 9, S04006, doi:10.1029/2011SW000668*

Title: Conducting Science with a CubeSat: The Colorado Student Space Weather Experiment, Scott Palo, Xinlin Li, David Gerhardt, Drew Turner, Rick Kohnert, Vaughn Hoxie and Susan Batiste, *24th Annual AIAA/USU Conference on Small Satellites*

Title: Characterization and Testing of an Energetic Particle Telescope for a CubeSat Platform, Lauren Blum, Quintin Schiller, with advisor Xinlin Li, *26th Annual AIAA/USU Conference on Small Satellites*

Title: REPTile: A Miniaturized Detector for a CubeSat Mission to Measure Relativistic Particles in Near-Earth Space, Quintin Schiller, Abhishek Mahendrakumar, with advisor Xinlin Li, *24th Annual AIAA/USU Conference on Small Satellites*

Title: Passive Magnetic Attitude Control for CubeSat Spacecraft, David T. Gerhardt with advisor Scott Palo, *24th Annual AIAA/USU Conference on Small Satellites*

Conclusions

Our tiny CubeSat has been operating over five months, providing clean measurements of energetic electrons and protons → a success in education, engineering, and science! → A Proof!

Combined measurements with other missions such as Van Allen Probes and THEMIS provide a better characterization of the inner and outer belts (for both e^- and p^+):

(1) penetration depth is energy dependent
(2) energy spectrum is L dependent
(3) inner belt is well confined to the equatorial region
(4) quantify the net enhancements measured near the equator
(5) refine the spatial and temporal scopes of precipitation

In-depth science results have been harvested …

CubeSat Mission Website: *http://lasp.colorado.edu/home/csswe/*

Mission Overview From NSF:

"The success of the CSSWE mission exemplifies everything we hope to achieve with the NSF CubeSat program. The CSSWE CubeSat has provided unique and highly valuable scientific data for space weather research.

At the same time, the project is an extraordinary demonstration that this can be done successfully with a student-built satellite in an educational setting. This data is an outstanding resource that will be aiding scientific advances for years to come."

Therese Moretto Jorgensen, PhD
Program Director, Space Weather Research
National Science Foundation