



# The Global Positioning System as a Space Weather Monitor

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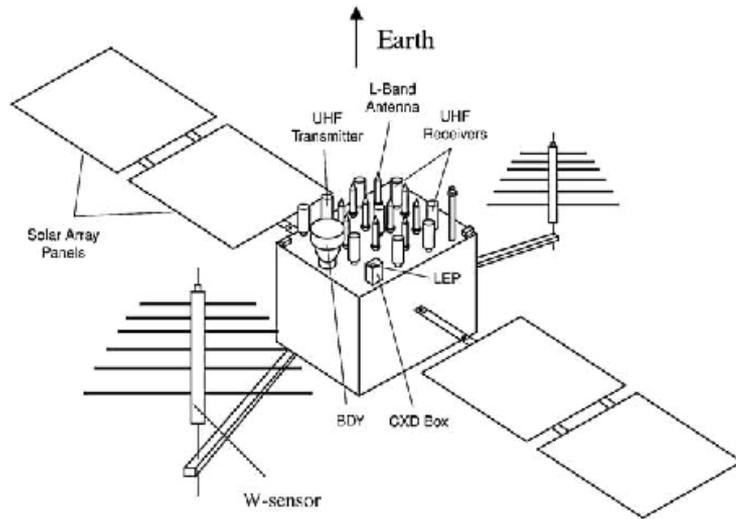
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# Slides from talk by Steve Morley

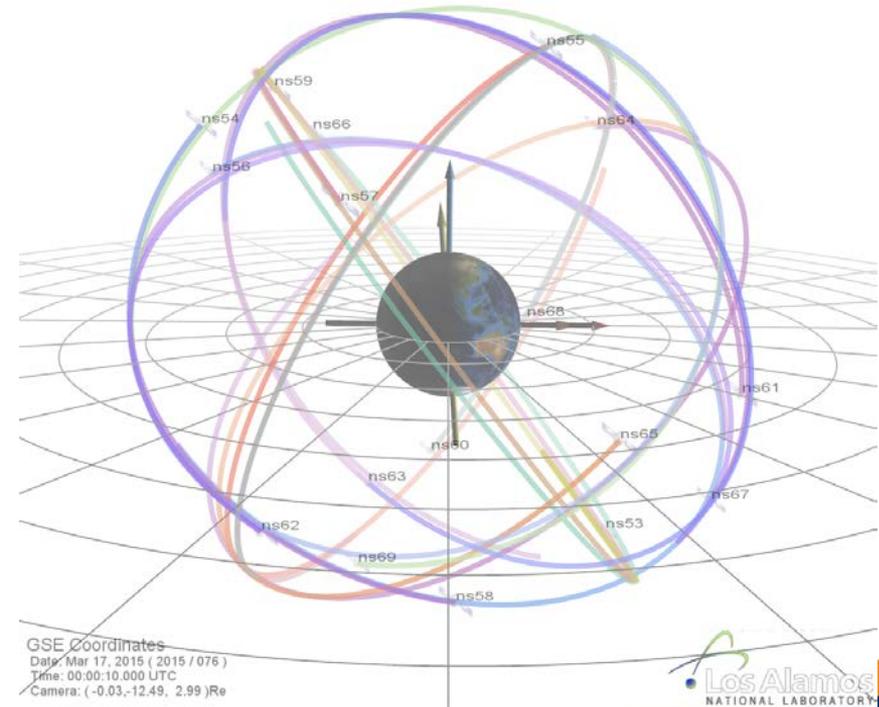
- All of the slides which follow were taken directly from a talk given by Steve Morley at the European Space Weather workshop in November 2015.
- I deleted the slides I skipped over while giving the talk at the working meeting and swapped the order of our names on the title slide

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# CXD: 19 on orbit, 6 orbital planes



From Tuszewski et al., 2004.



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# Energetic Particle Sensors on CXD



LEP

HXP

Photo: LA-UR-09-07377,  
Friedel & Cayton,  
ESWW6, 2009.

LEP: Low Energy Particle  
subsystem has 5 electron  
channels

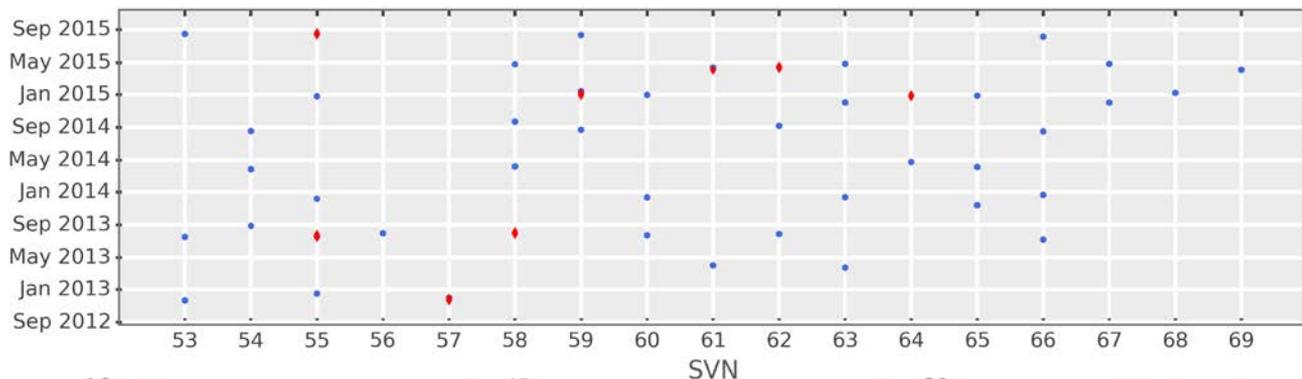
HXP: High-energy X-ray and  
Particle subsystem has 7 electron  
channels

Eleven electron channels on 19  
block IIR and IIF satellites

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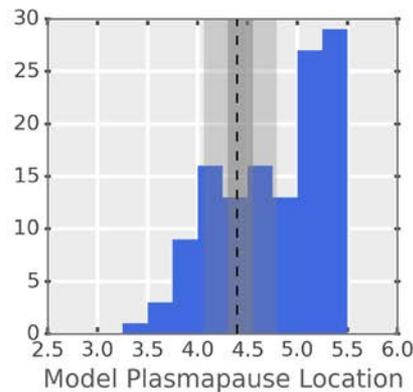
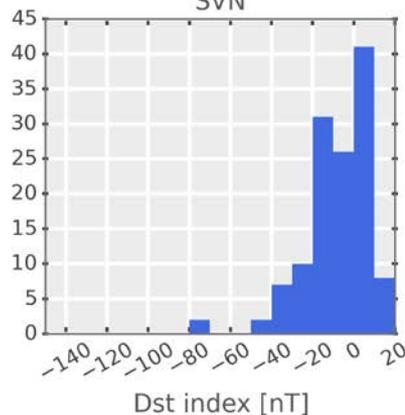
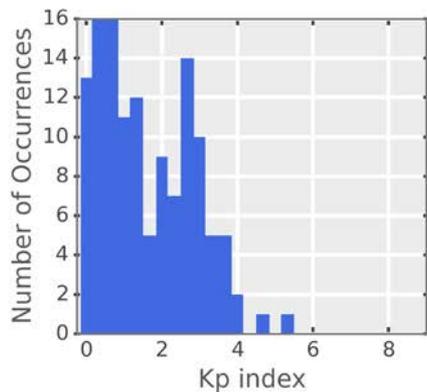


# Conjunction: RBSP & GPS within 1000km



140 conjunctions

All at L~4,  
equatorial



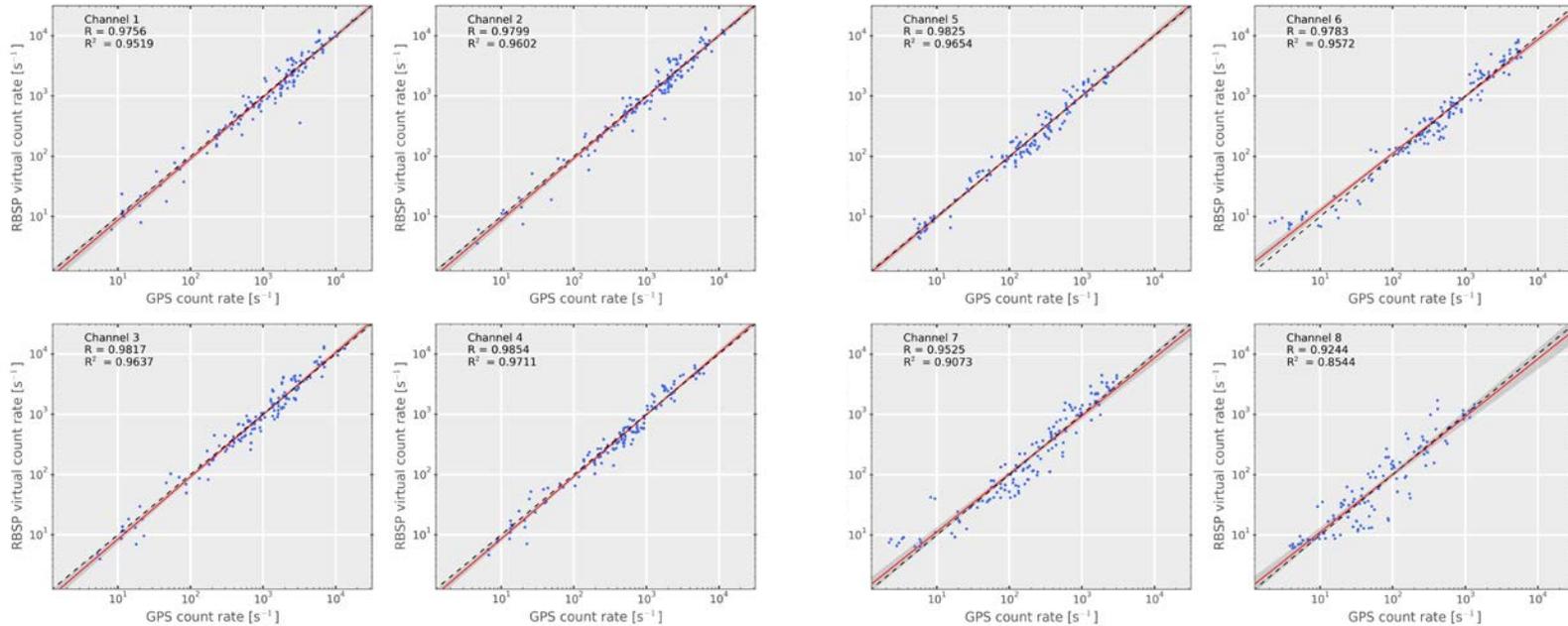
# Comparing counts with counts

- For each CXD channel,  $i$ 
  - Van Allen Probes energy spectrum used to estimate “expected counts”,  $C$ , by folding with CXD response functions,  $G_i$

$$C_i = \int_E j(E)G_i(E)dE$$

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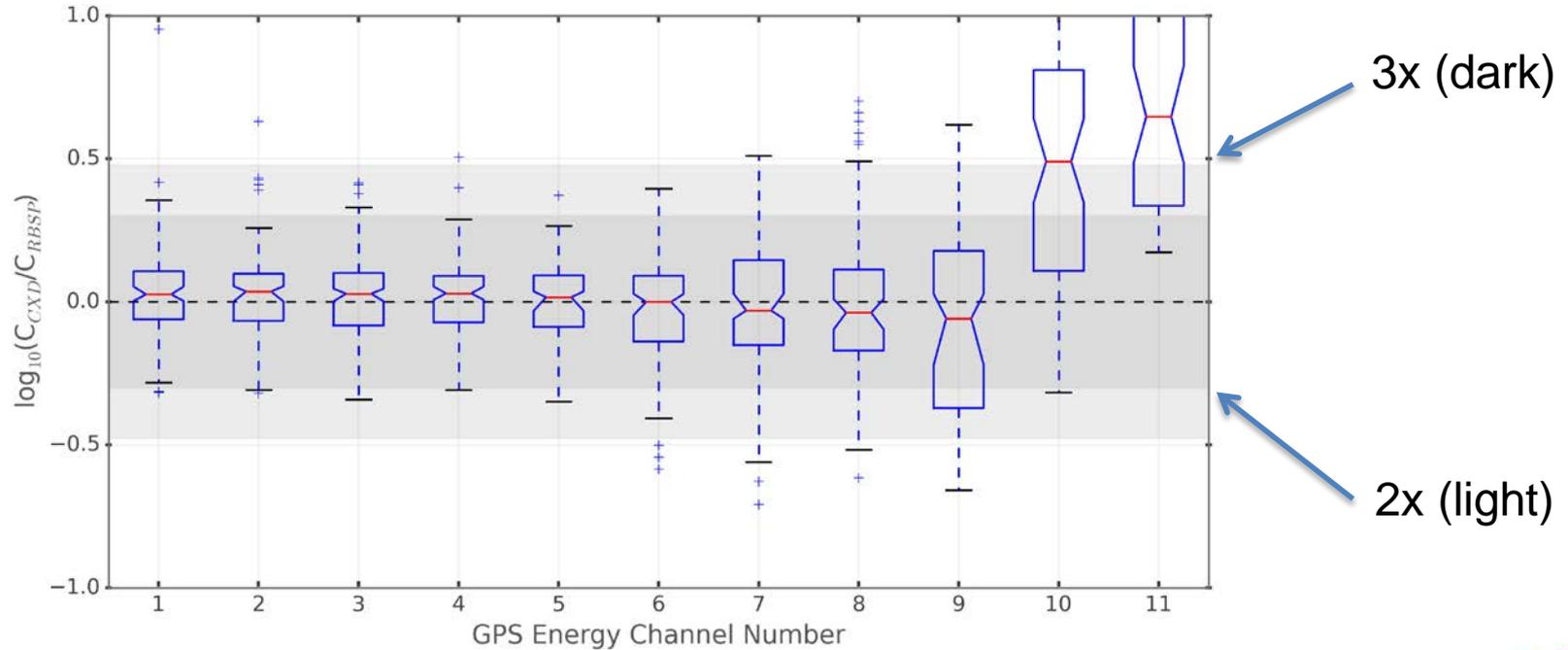
# CXD counts vs “expected” counts



Confirms that instrument responses are well-modelled

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# CXD counts are as “expected”



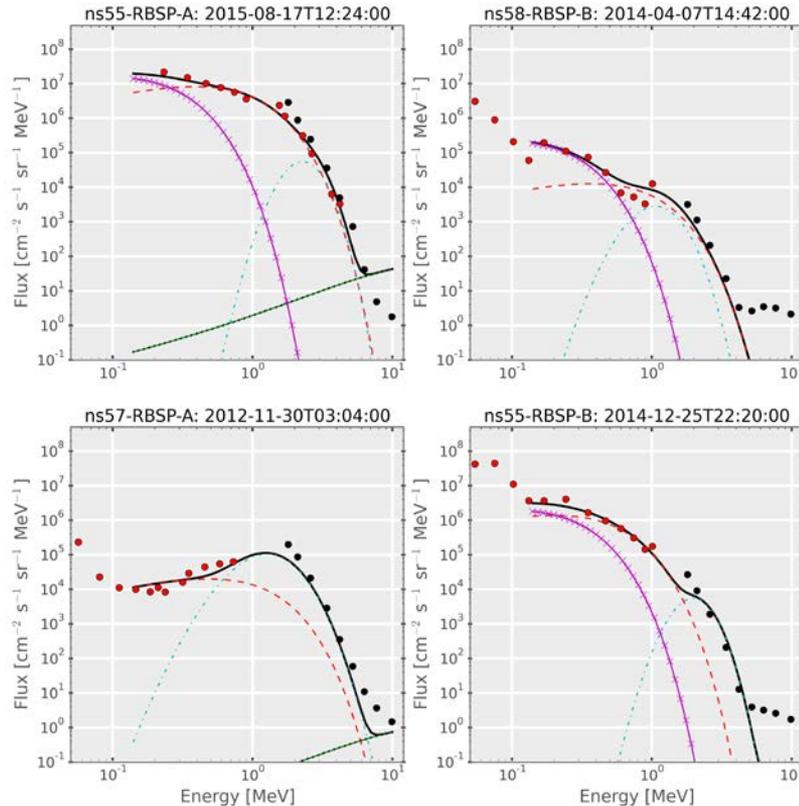
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# Flux: Forward modelling

- Constrained fit using:
  - 3 Maxwell-Juttner distributions, in  $E$
  - 1 Gaussian distribution in  $\log(p)$
- Multi-parameter fits performed using TMinuit in CERN's ROOT package
  - Minimizer is variant of Davidon-Fletcher-Powell method
  - Minimizes MSE of counts from estimated flux spectrum

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# Sample Flux Comparisons



Energy spectra can be far from Maxwellian in the heart of the radiation belt

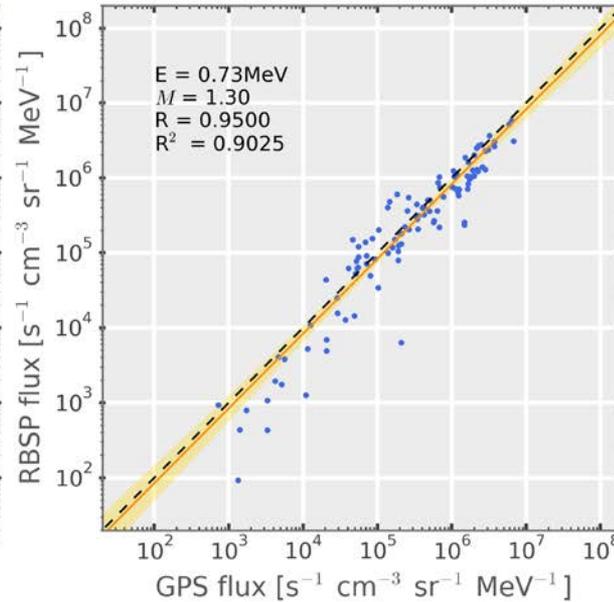
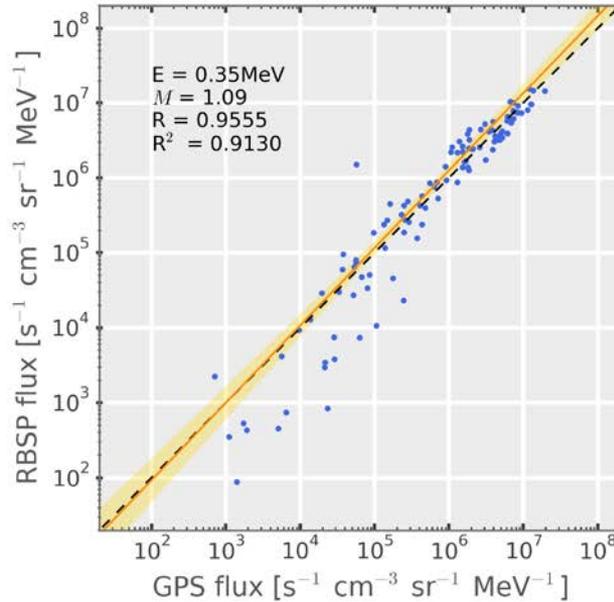
Data points – RBSP

- Red: MagEIS
- Black: REPT

Curves – CXD fitted spectra

- Black: Total
- Red/Magenta/Green: M-J
- Blue: Gaussian

# CXD fluxes close to “gold standard”

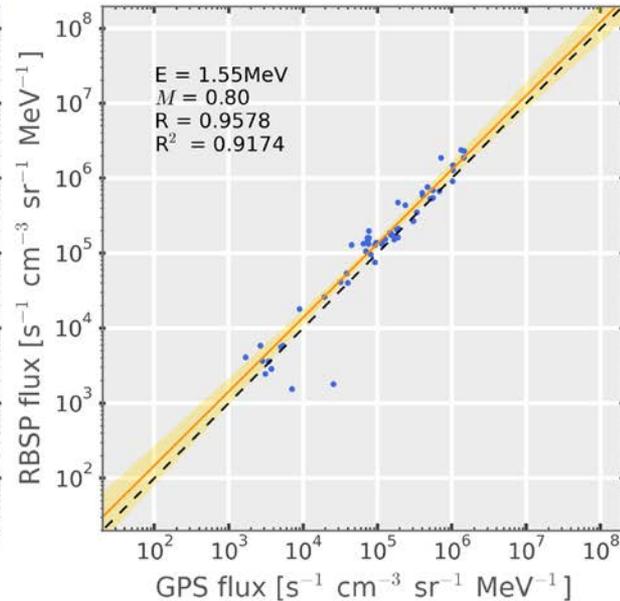
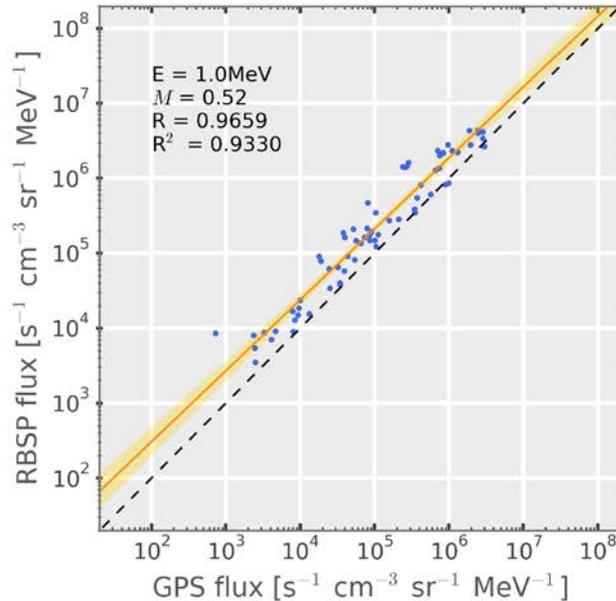


0.35 MeV

0.73 MeV

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# CXD fluxes close to “gold standard”

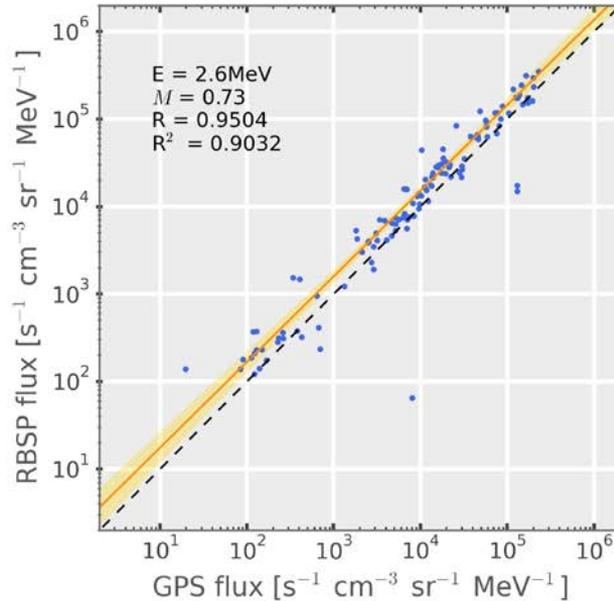


1.00 MeV

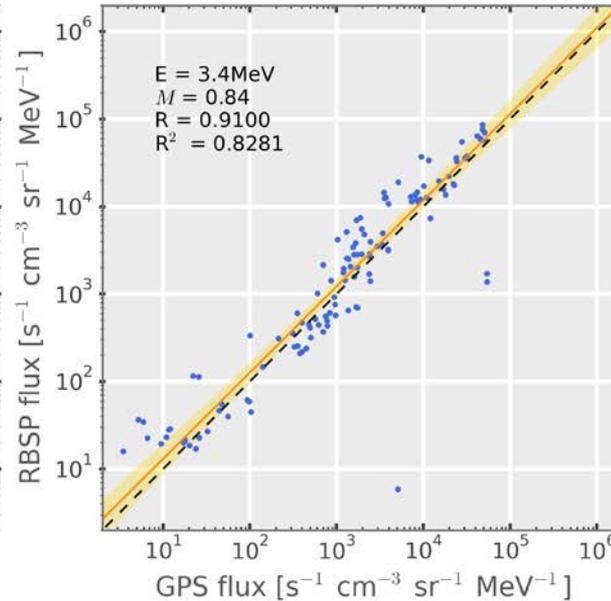
1.55 MeV

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# CXD fluxes close to “gold standard”



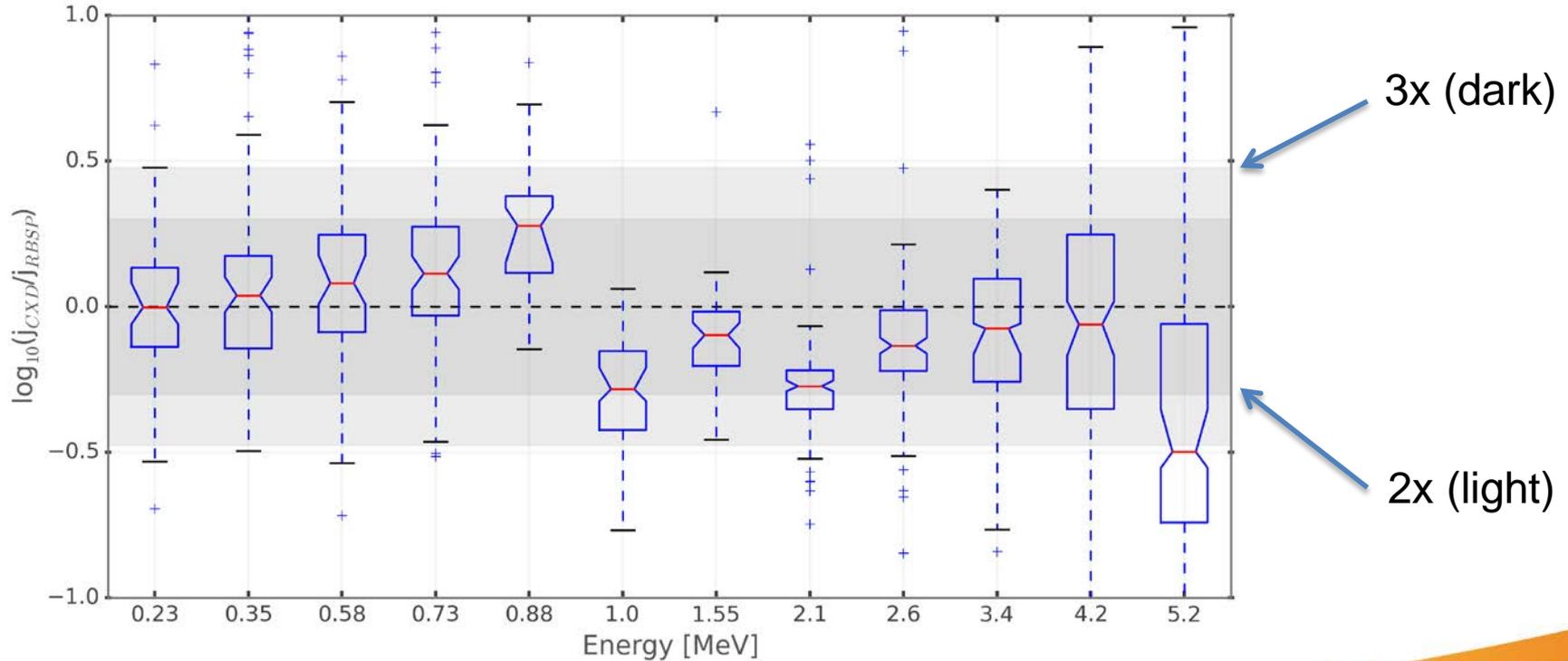
2.60 MeV



3.40 MeV

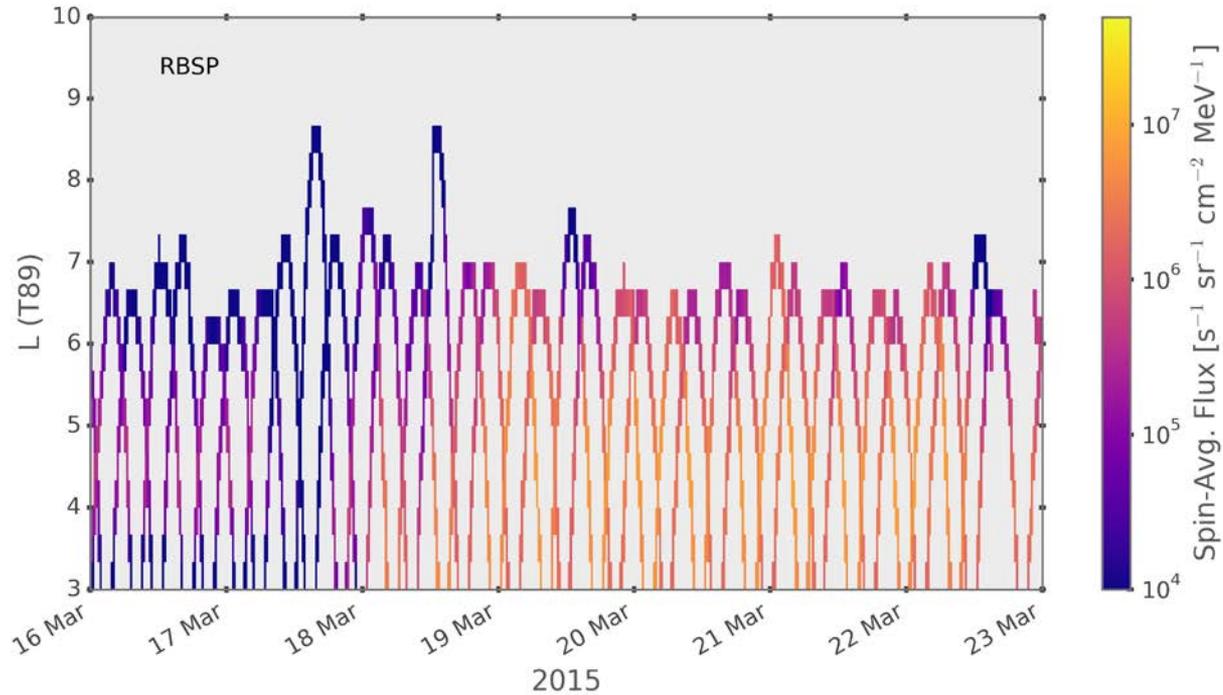
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# Typically within factor of 2



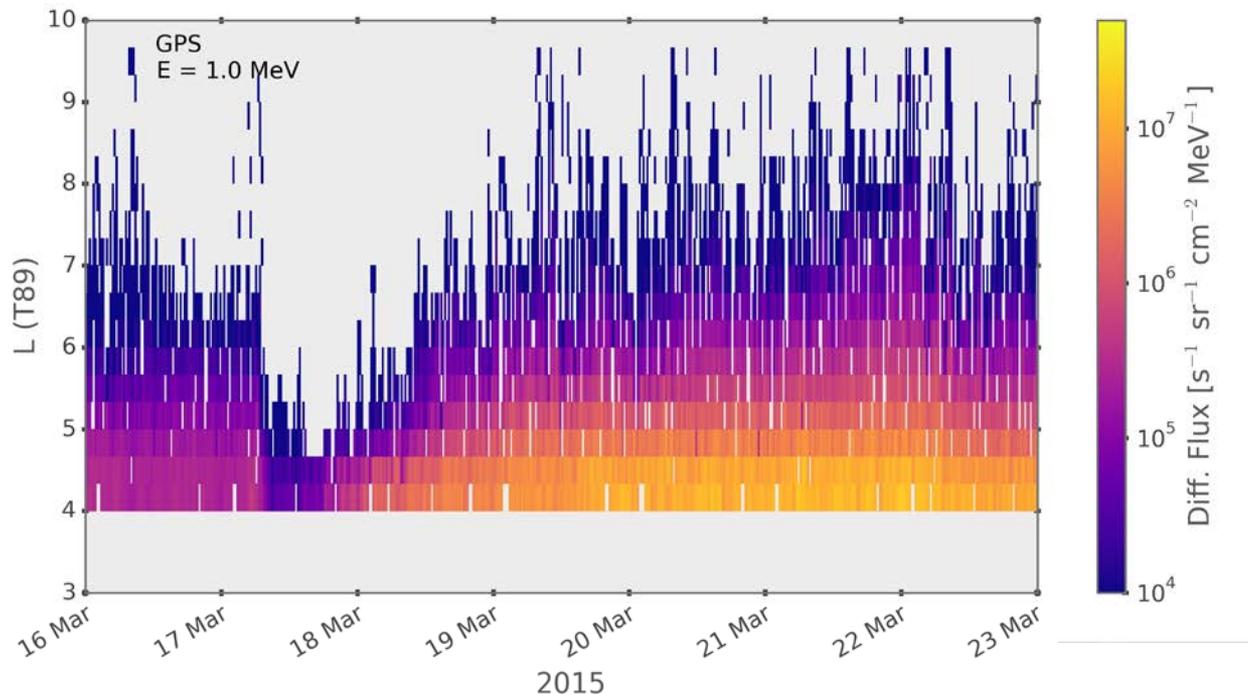
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# RBSP: March 17<sup>th</sup> storm @ 1MeV



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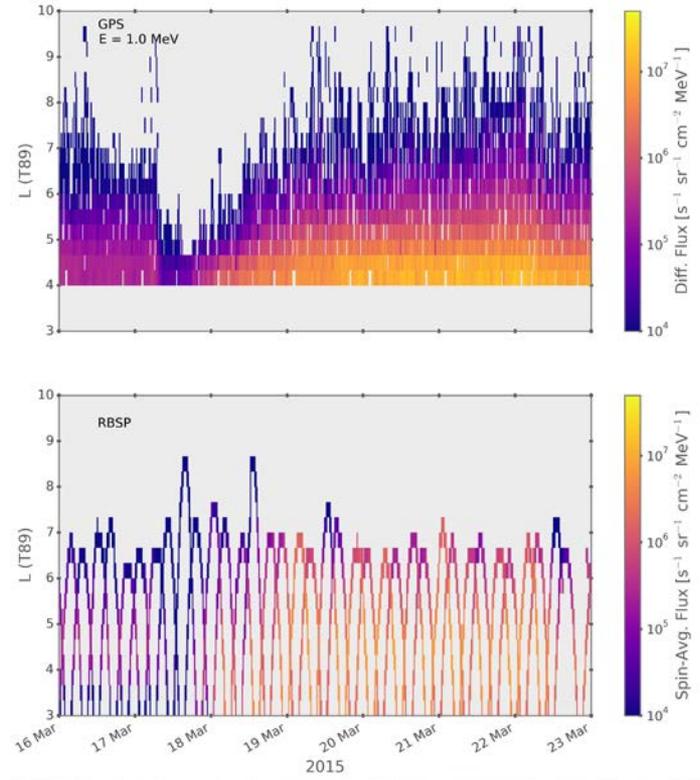
# CXD: March 17<sup>th</sup> storm @ 1MeV



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# GPS is a unique Space Weather capability

- 19 CXD on orbit, more coming...
- More than 118 satellite-years of CXD data since 2001
- Current data density allows new discovery
- CXD validated against Van Allen Probes
- CXD fluxes typically within factor of 2 of Van Allen Probes at conjunction



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