SPACESTORM

A New Model of Outer Belt Electrons for Dielectric Internal Charging (MOBE-DIC)

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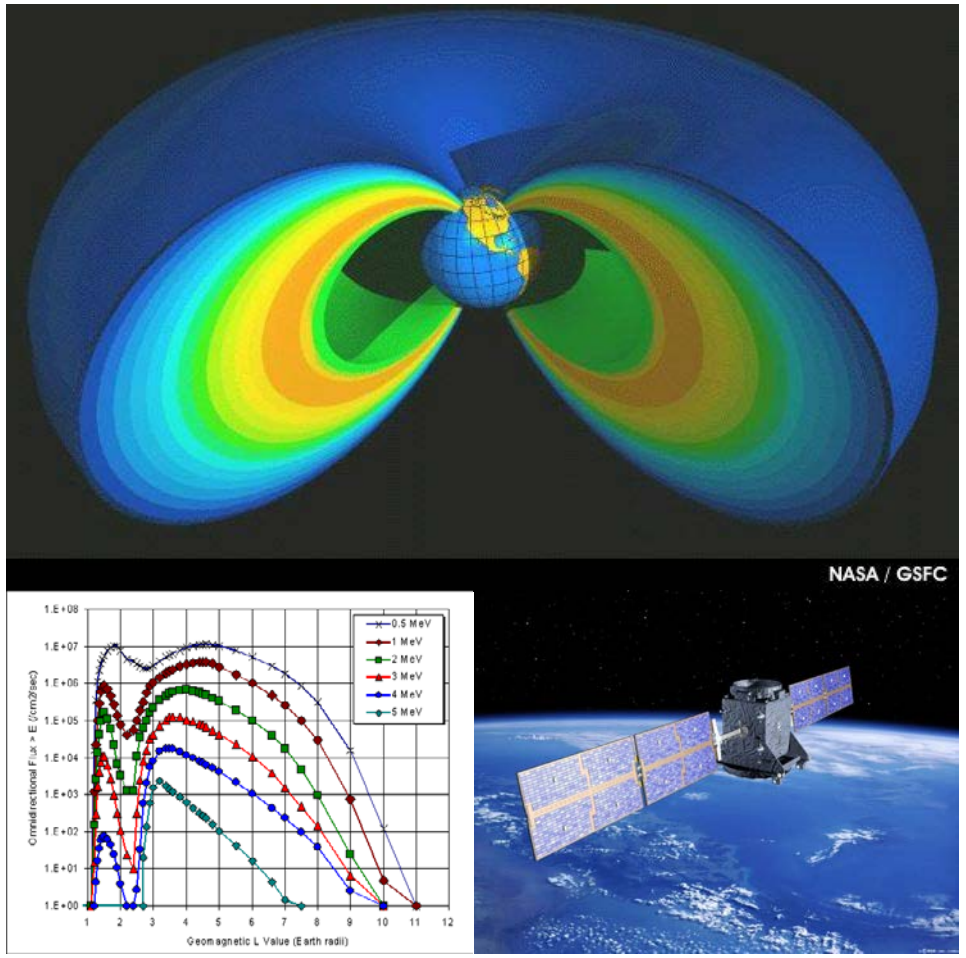
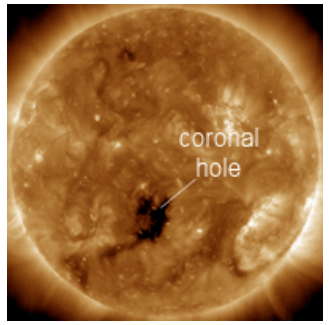
Outline

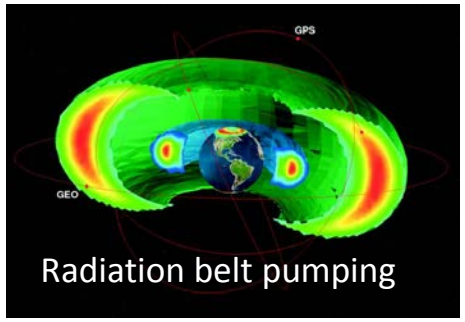
- Background
  - Internal Charging
  - Existing Models
  - The SURF Instrument
  - Electron flux determination
- The MOBE-DIC Model
  - Input Data
  - Worst-Case Estimation
  - Outer Belt Extrapolation
  - Implementation

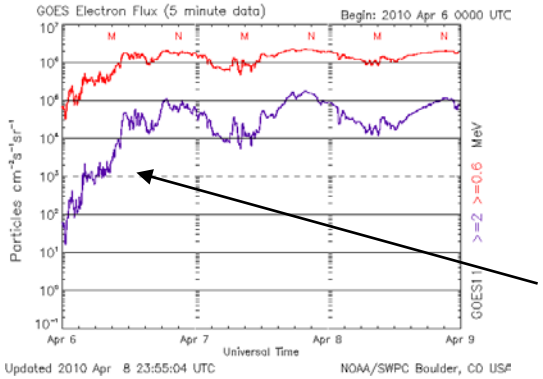


Internal Charging

- Energetic trapped electrons in Van Allen belts pose a threat to satellites through internal charging of dielectric materials:
- The outer electron belt is extremely dynamic - large changes in flux occur over short timescales, driven by coronal holes and coronal mass ejections (CMEs)



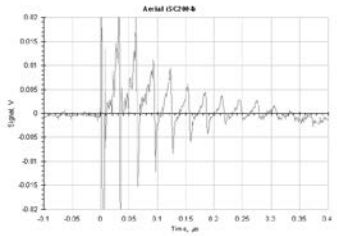




e.g. April 2010:

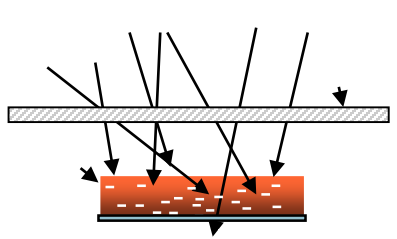
>2 MeV flux at GEO increases by ~4 orders of magnitude in a few hours!

Satellite anomaly / outage /failure



Energy coupling into circuit

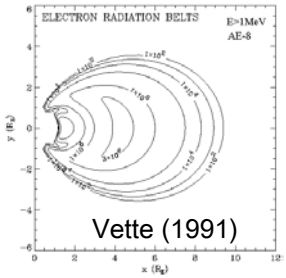
Electrostatic discharge



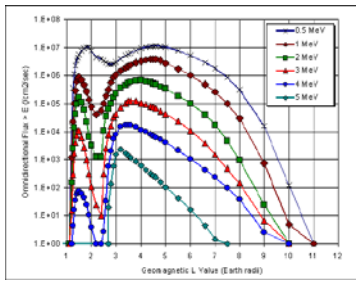
Electrostatic charging of spacecraft materials

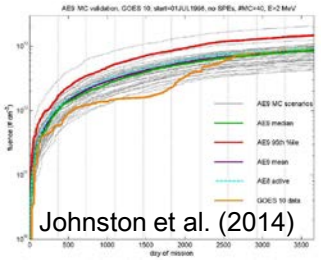
Existing Environment Models

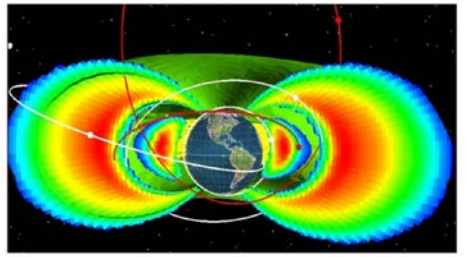
- Several models describe the Van Allen belts:
- AE8:
  - Industry standard for decades
  - Static model – no flux variability
  - Inadequate for internal charging
- AE9:
  - Successor to AE9
  - Multiple data sources
  - Comprehensive statistics
  - Complex (many input parameters & run options)
- FLUMIC:
  - Worst-case model for internal charging
  - Based primarily on GEO data (not near peak)
  - User-friendly but not up-to-date
- Various others targeted at specific environments/orbits
- Objective of this work: develop new simple model for internal charging worst case environment - successor to FLUMIC but based on medium Earth orbit (MEO) data

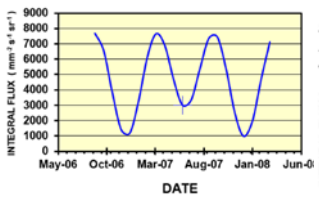


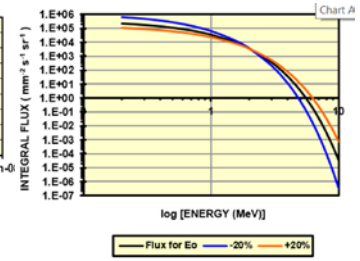
Vette (1991)

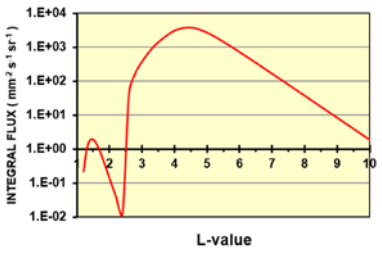



Johnston et al. (2014)



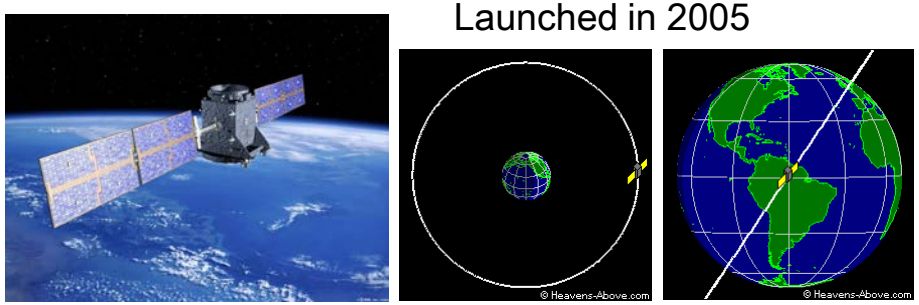


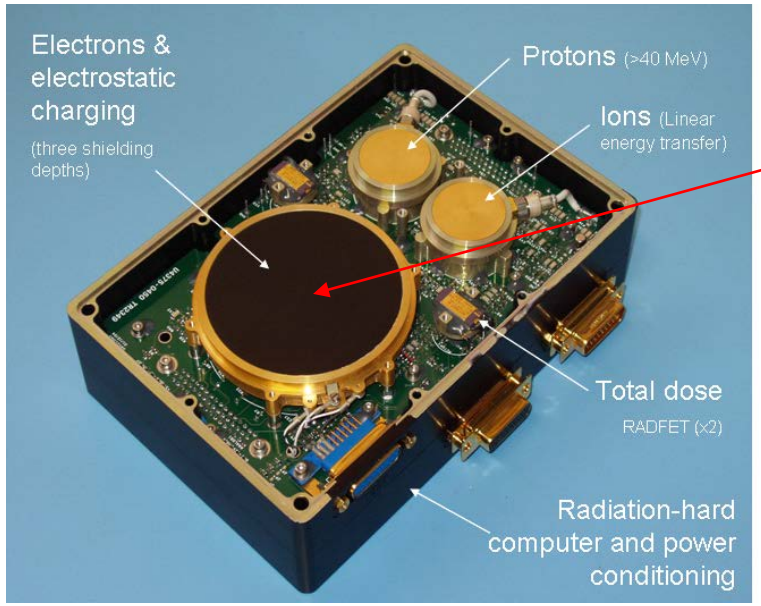




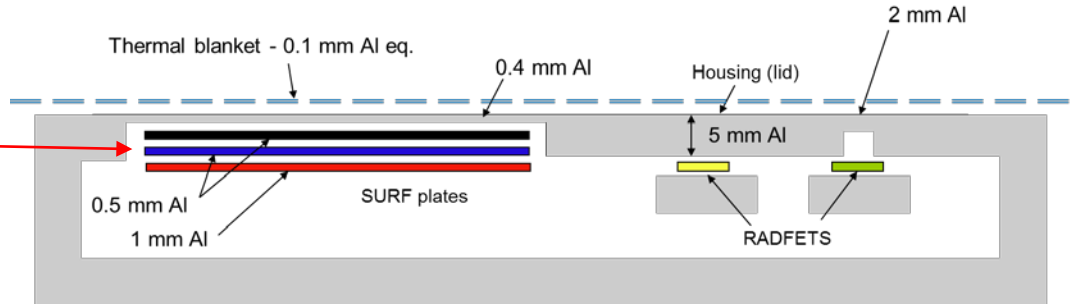
The SURF Detector

- Part of Merlin instrument suite on Giove-A (technology demonstrator for Galileo)
- Medium Earth Orbit (~23,200 km, 56°)





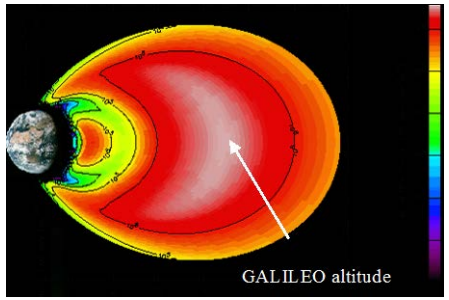
SURF



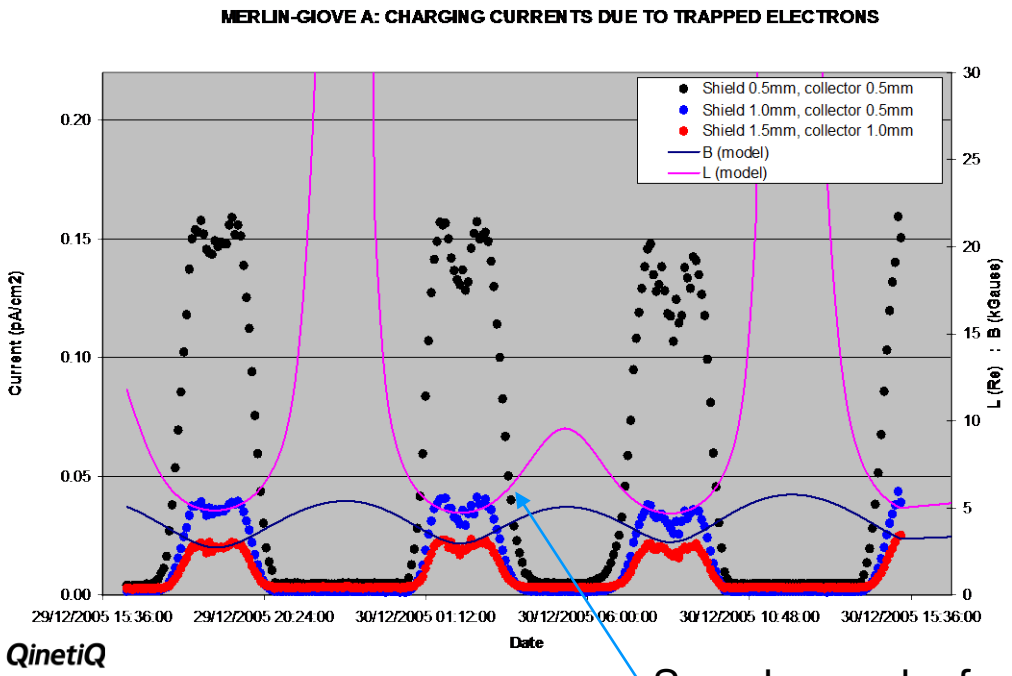
- Three stacked aluminium charge-collecting plates
- Direct measure of energetic electrons
- No proton contamination or dead-time

SURF Data

- Giove-A / Galileo orbit is in the heart of the outer belt
- Perfect location for internal charging currents

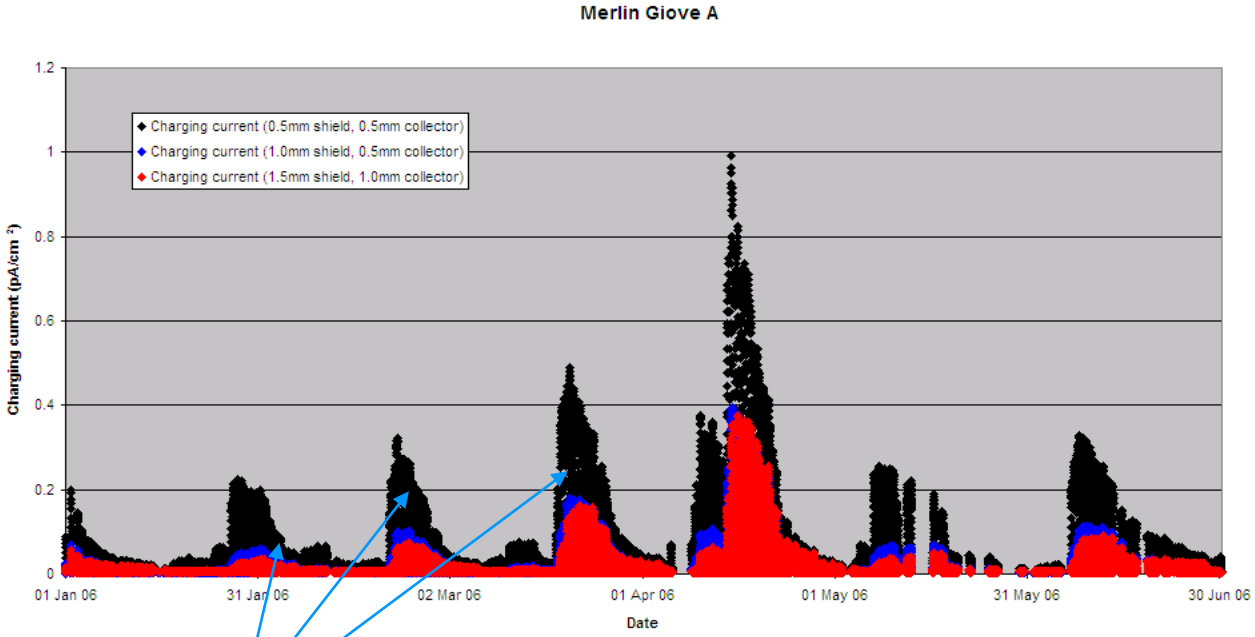


First Day:



Samples peak of belt every ~7 hours

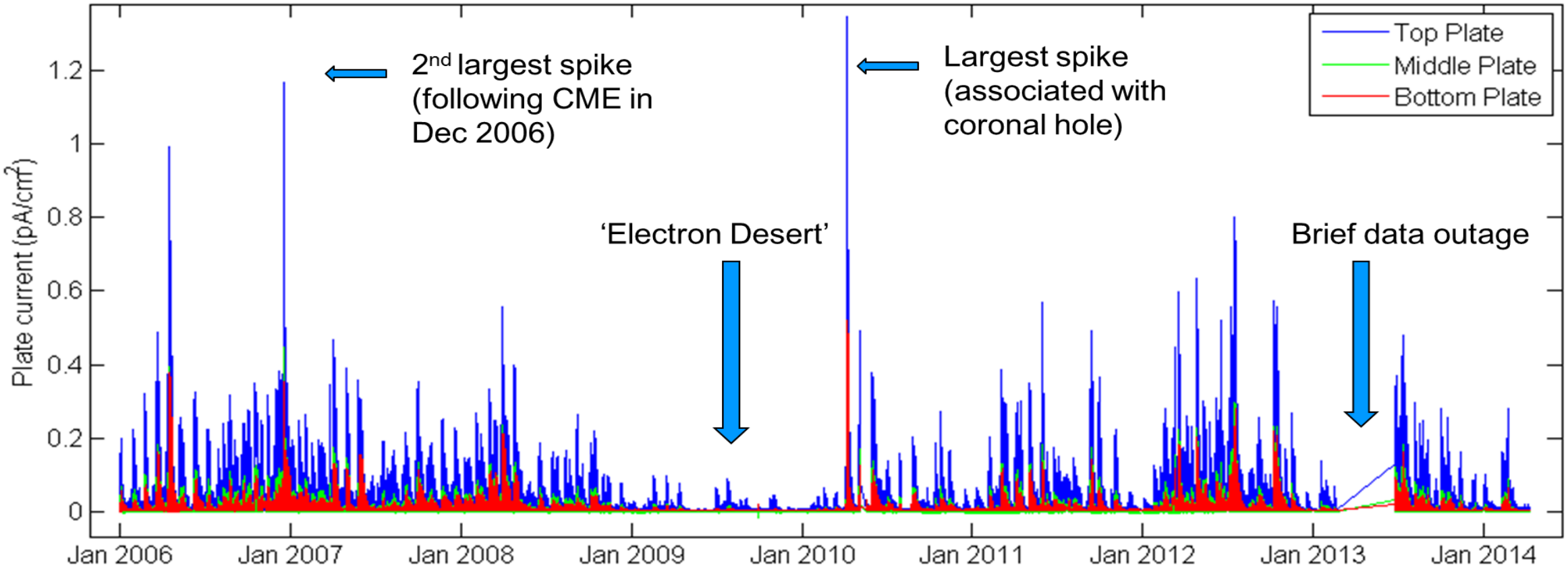
First 6 months:



Recurrence of coronal hole

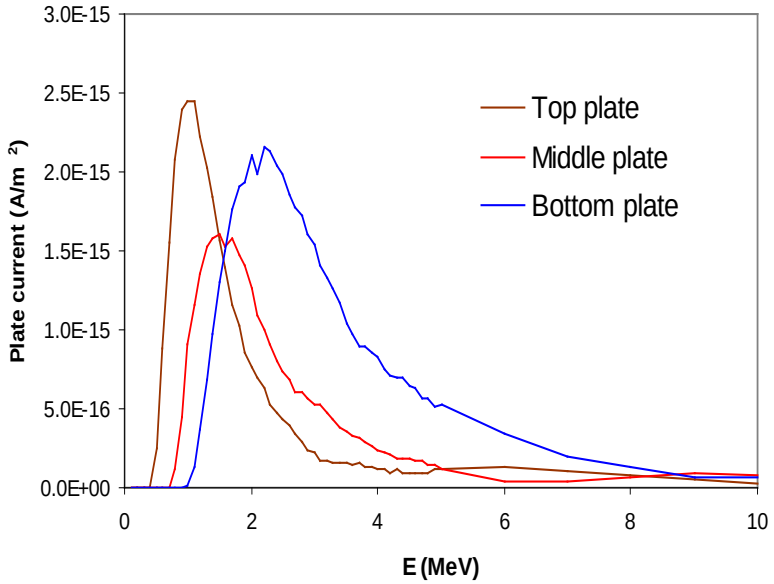
SURF Data

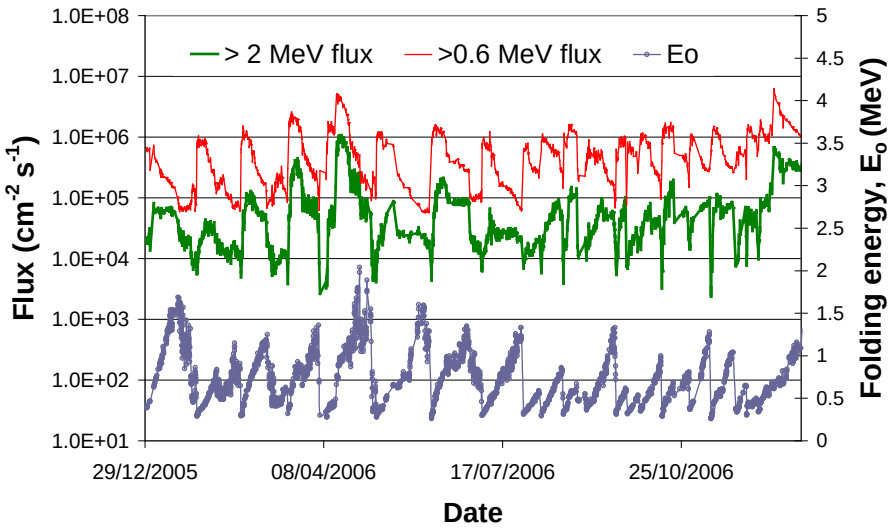
- 2005 – 2014:

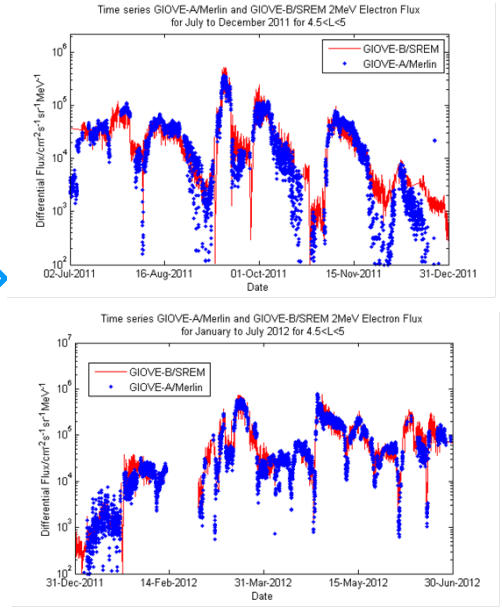


Electron Flux Determination

- Need flux, rather than current to produce model…







Instrument response functions determined by Monte Carlo simulations:

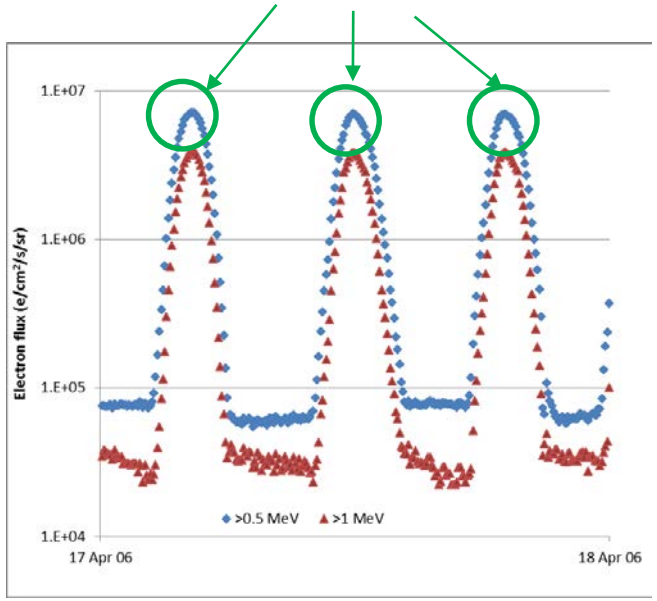
Iterative fit used to derive flux based on assumed exponential spectrum

Validated with independent fluxes from other Giove instruments (SREM, Cedex)

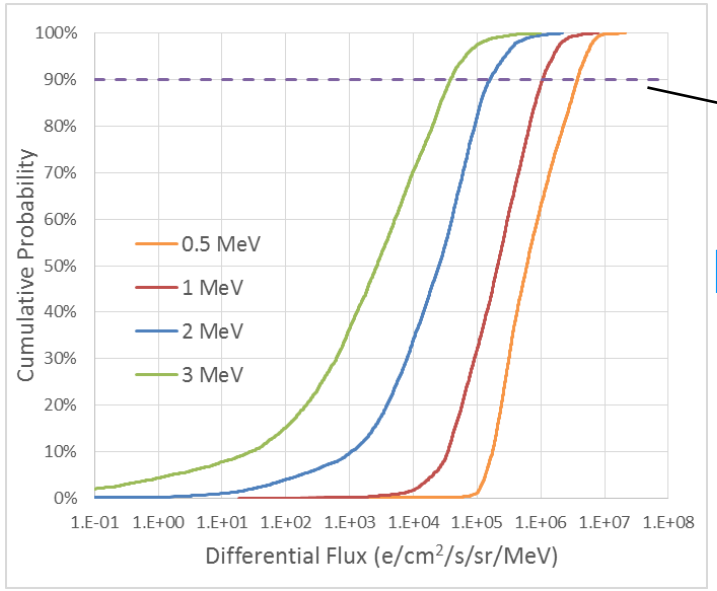
Worst Case Statistics

- Use derived flux time series to create cumulative distribution functions (CDFs) at discrete energies in the range 0.5 – 3 MeV (peak of instrument response)

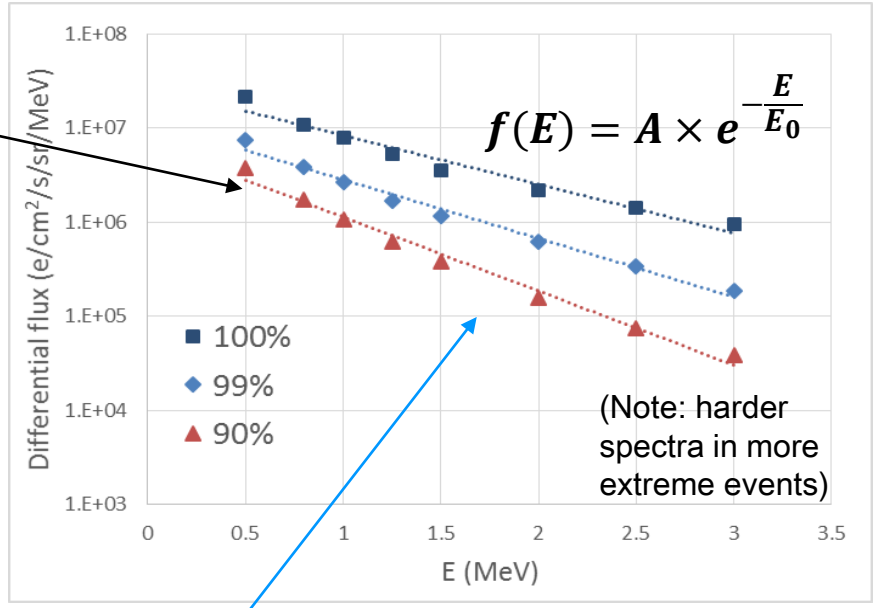
Create reduced series of average flux at equatorial peaks (L≈4.7)



CDFs based on equatorial flux:



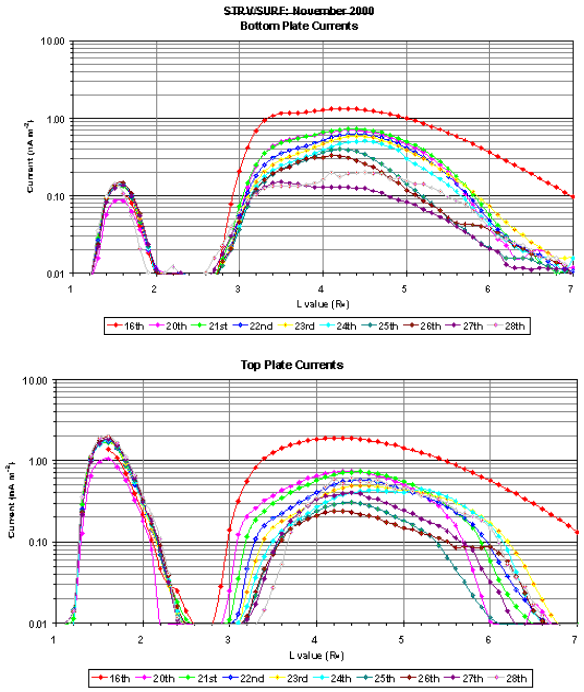
Fit baseline spectra at three confidence levels - 90%, 99% & 100%:



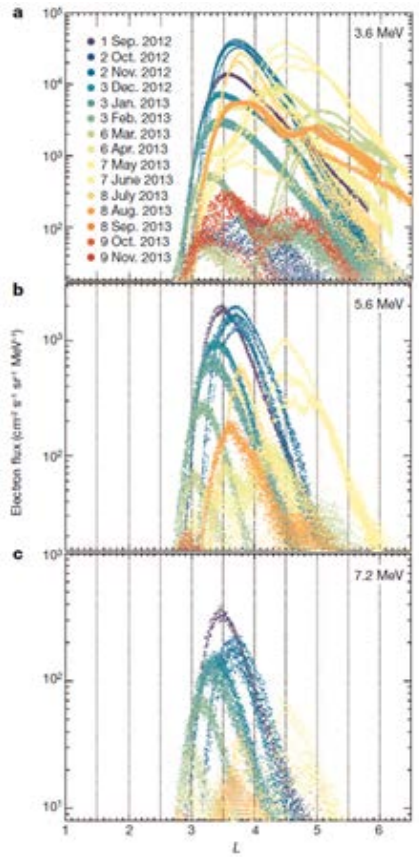
These three spectra form the basis of the MOBE-DIC model

Extrapolating to other L-Shells

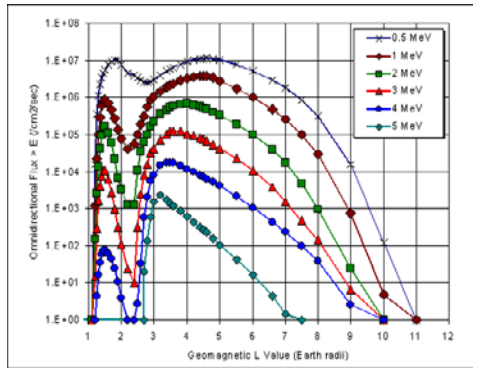
- Equatorial spectra at L≈4.7 form the basis of the model
- Need to derive profile of L-shell to extrapolate, however…
- L-Shell profile is not stable, e.g.:



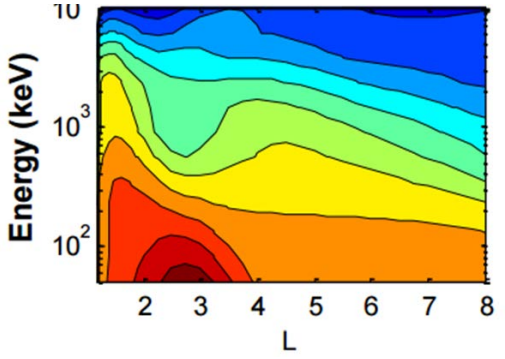
SURF on STRV1d (Ryden et al. 2001)



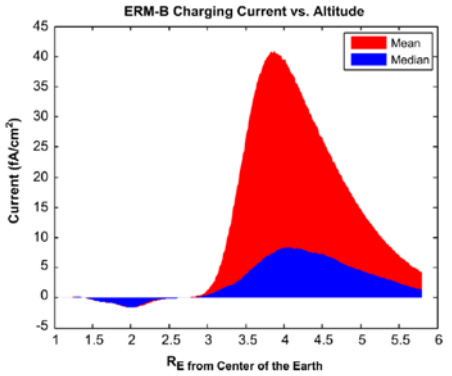
Van Allen Probes, REPT (Baker et al. 2014)



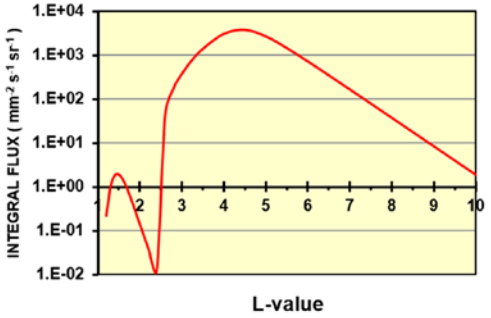
AE8



AE9



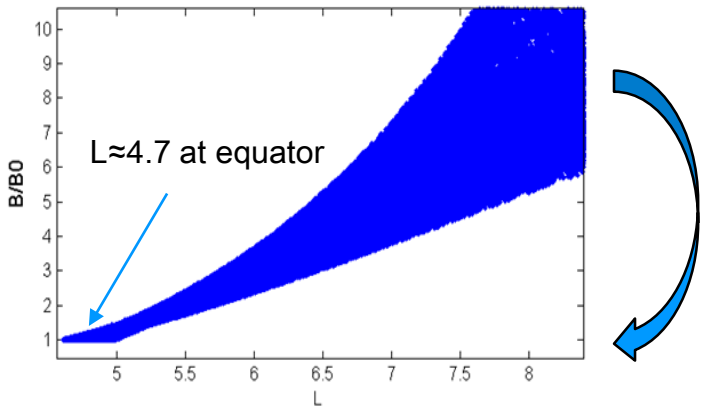
Van Allen Probes, ERM (Maurer et al. 2013)



FLUMIC

Extrapolating to other L-Shells (2)

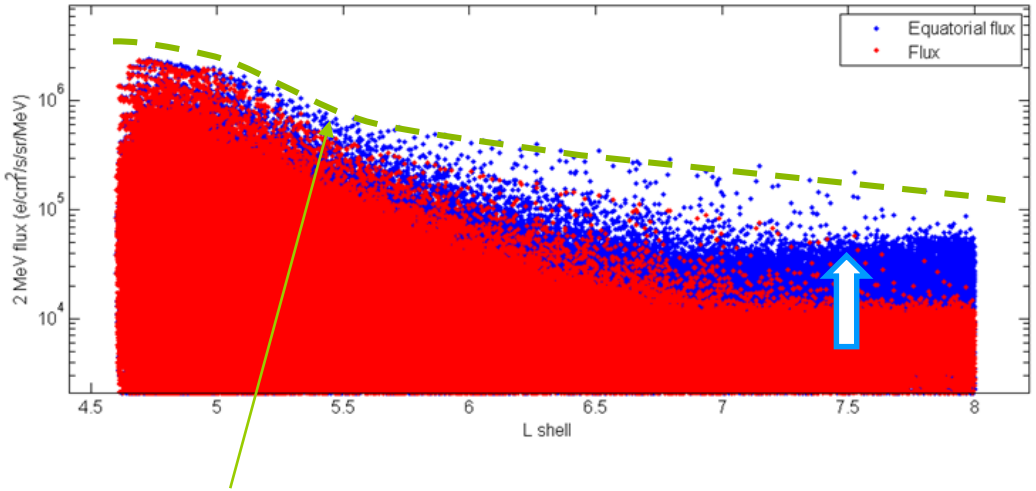
- Our approach is to use high-latitude SURF data
- Inclination of Giove-A orbit means higher L shells only encountered at higher latitudes
- Need to renormalise non-equatorial fluxes:



Assume Vette function (like AE8 and FLUMIC)

[Scaling is (slightly) L-dependent but not energy-dependent]

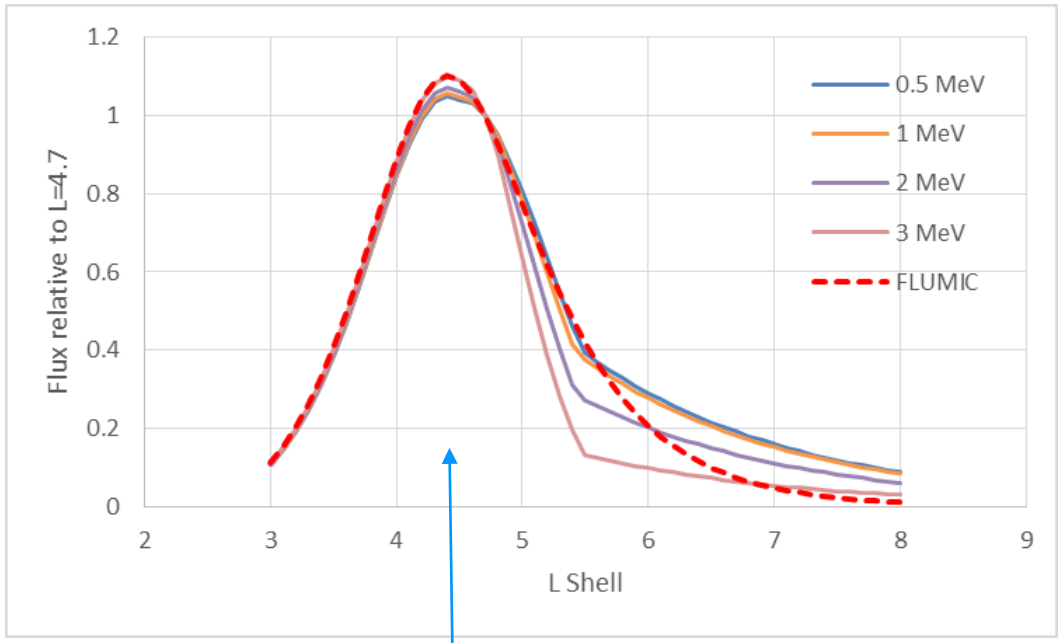
All Flux → Equatorial Flux



Fit 'envelope' to renormalised data (at each energy)
→ Energy-dependent L-Shell profile

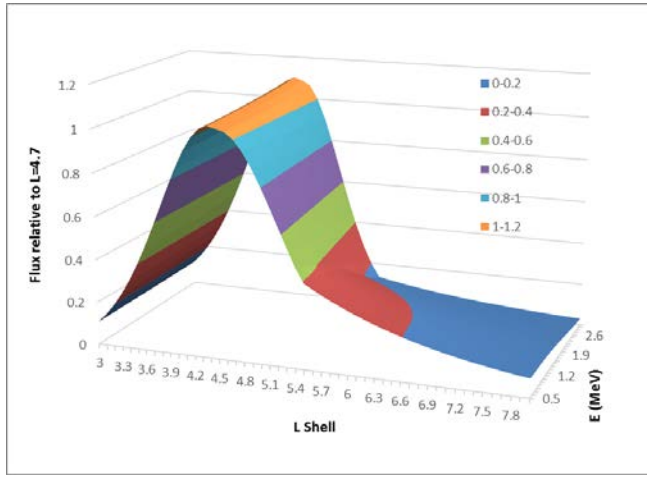
Extrapolating to other L-Shells (3)

- Final (energy-dependent) L-shell profile (3 < L < 8)

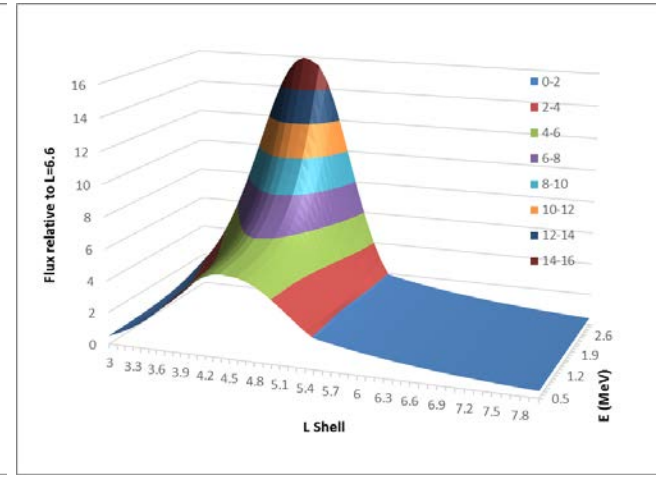


FLUMIC function used below L=4.5 (no Giove data)

Normalised to L=4.7:



Normalised to L=6.6:



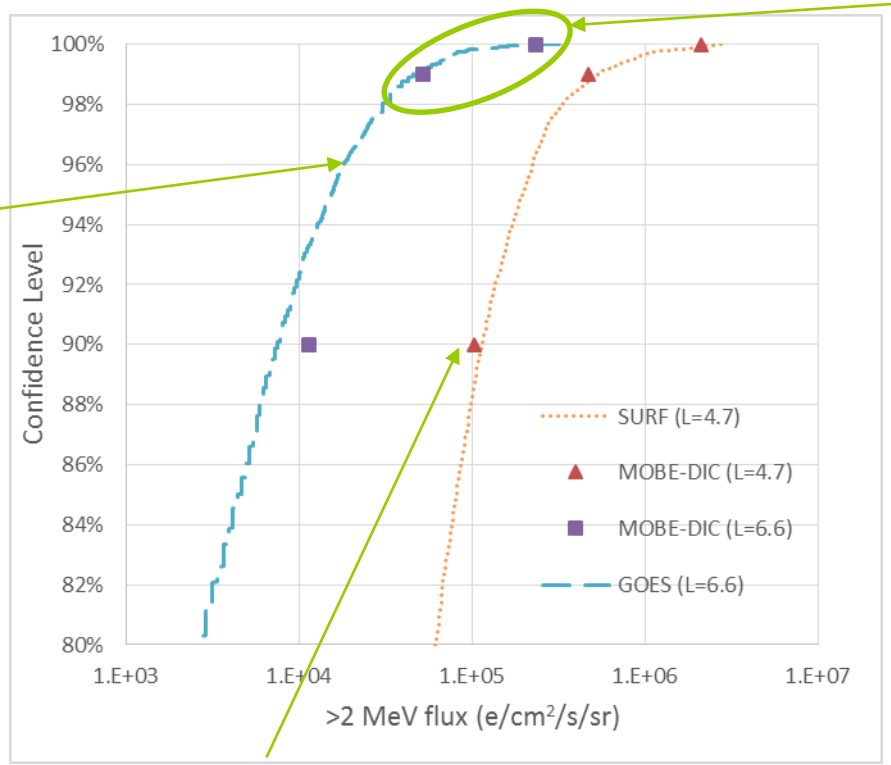
(NB slightly modified version used for integral flux)

Comparison to GOES data

- Equivalent CDFs constructed from GOES (geostationary) electron flux data
- Compare with MOBE-DIC prediction at L=6.6:

>2 MeV flux adjusted to L=6.6 and for dead-time effects

(Meredith et al., 2015)



Unsurprisingly, excellent consistency at L=4.7 (MEO)

Good agreement between MOBE-DIC and GOES at 99% and 100% (slightly worse at 90% due to conservative L-shell envelope)

MOBE-DIC prediction for '100%' (worst case) at GEO for >2 MeV flux is:

2.34×10^5 e/cm^2/s/sr

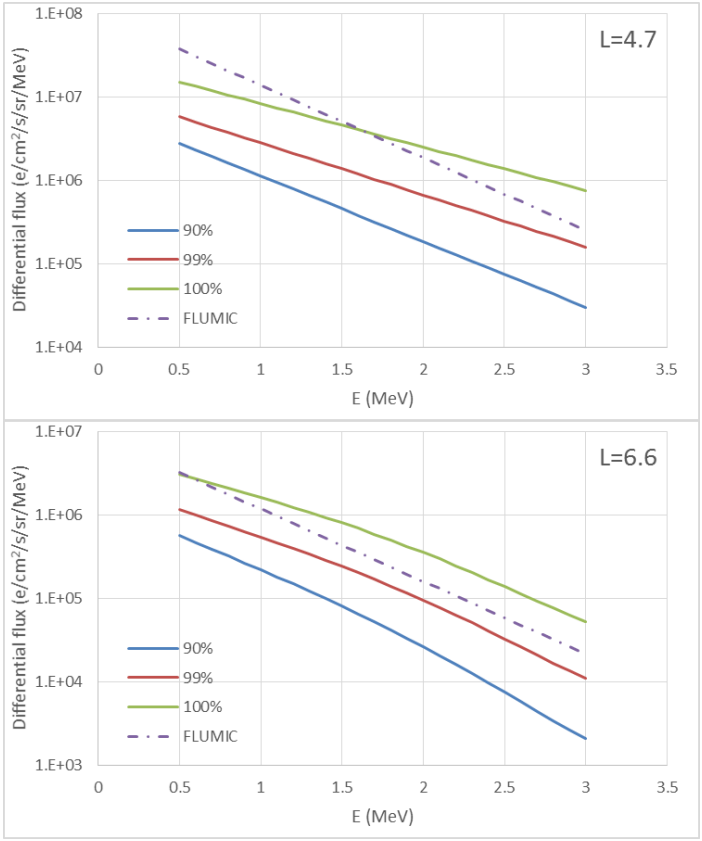
Theoretical upper limit (Koons et al. 2001)…

2.34×10^5 e/cm^2/s/sr !!

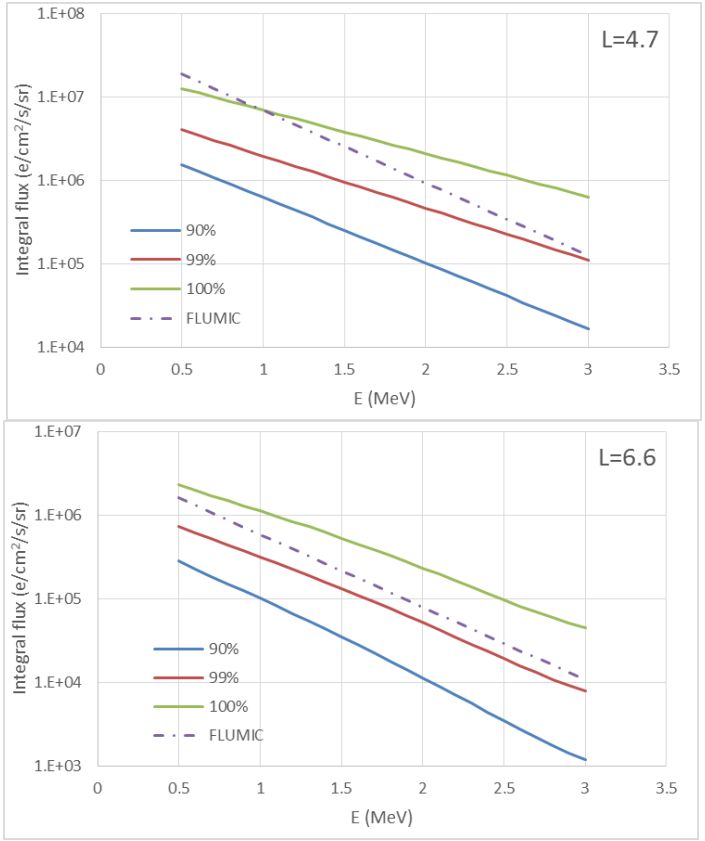
Comparison to existing models

- Comparison to FLUMIC model (other comparisons in paper):

Differential Spectra



Integral Spectra



MOBE-DIC gives harder spectrum at MEO

Good agreement at GEO (FLUMIC in between 99% & 100% MOBE-DIC level)

MOBE-DIC: Implementation

- MOBE-DIC model is defined by a set of parameters and simple equations
- At present simple spreadsheet implementation:

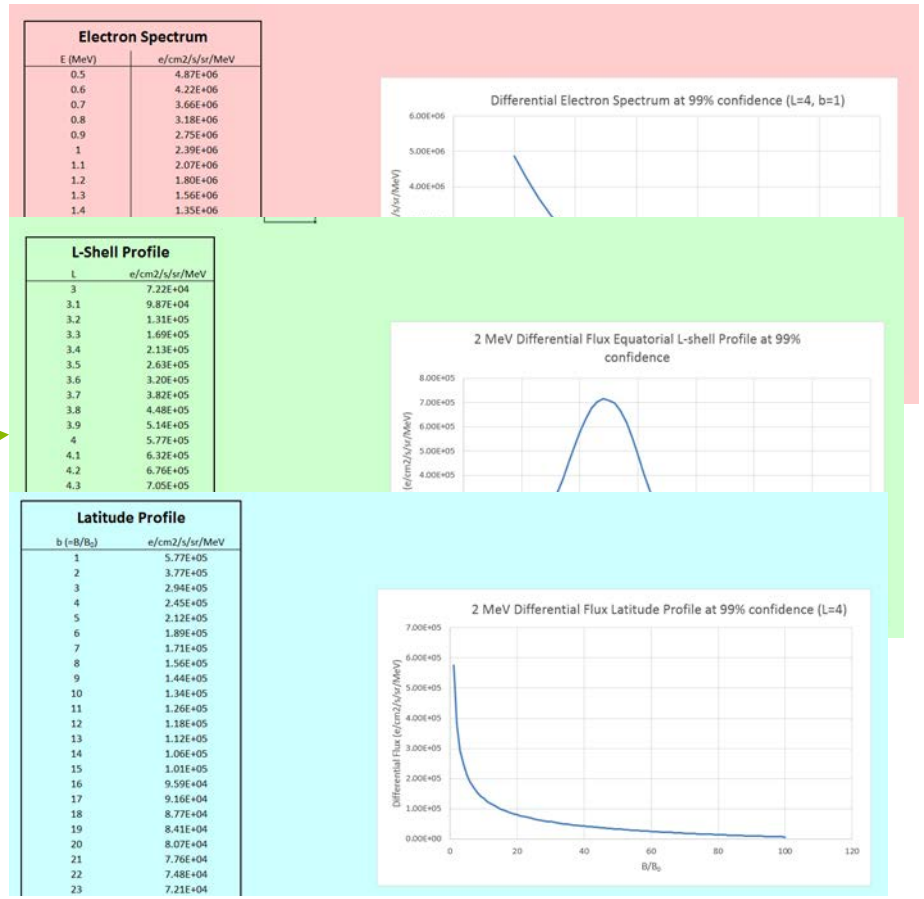
Model of Outer Belt Electrons for Dose and Internal Charging (MOBE-DIC)

INPUTS	Allowed Range	
Confidence Level	100%, 99% or 90%	99%
Spectrum Type	Differential or Integral	Differential
Energy	0.5 < E (MeV) < 3	2.0
L-shell	3 < L < 8	4.0
Magnetic Latitude	1 < b < 100	1.0

OUTPUTS

- Electron Spectrum Plot
- L-shell Profile Plot
- Latitude Profile Plot

Differential Flux: 5.77E+05 e/cm2/s/sr/MeV



- Public version available on request (a.hands@surrey.ac.uk)
- To be made available via Spenvis…

Summary

- Data from Giove (A & B) satellites analysed and cross-correlated
- Spacecraft now graveyarded, SREM and Cedex instruments ceased in 2012
- Merlin instrument (including charging current, proton telescope and RadFETs) continues to collect useful data on Giove-A
- SURF charging currents used to calculate electron flux (free from proton contamination)
- ‘Worst case’ fluxes derived as function of confidence level at MEO
- Non-equatorial fluxes used to extrapolate to other L-shells
- Implemented in new Model of Outer Belt Electrons for Dielectric Internal Charging (MOBE-DIC) (successor to FLUMIC)
- Aimed at spacecraft engineering community, specifically for concerns over internal charging during enhanced environments
- To be made publically available via Spenvis