Measurements of Internal Charging Currents in Medium Earth Orbit: 2005-10

11th Spacecraft Charging Technology Conference
Albuquerque, NM, USA, 20-24th Sept 2010

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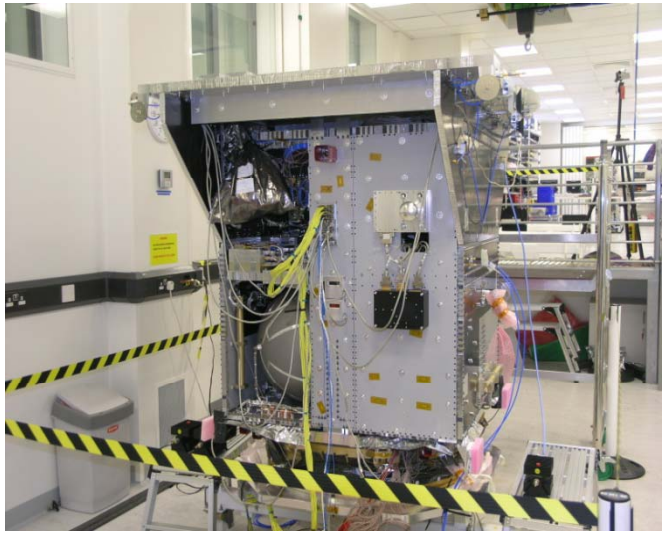
Giove-A

- Test-bed for European Galileo GNSS
  - obtain frequency filing protection
  - characterise the MEO environment
  - validate certain critical payloads
  - provide representative signal-in-space transmission
- Successfully launched in December 2005
- Orbit 23,260 km and 56 degrees inclination, 27 month lifetime
  - electron dominated: charging and total dose hazards
  - exposed to solar particle events



SSTL image

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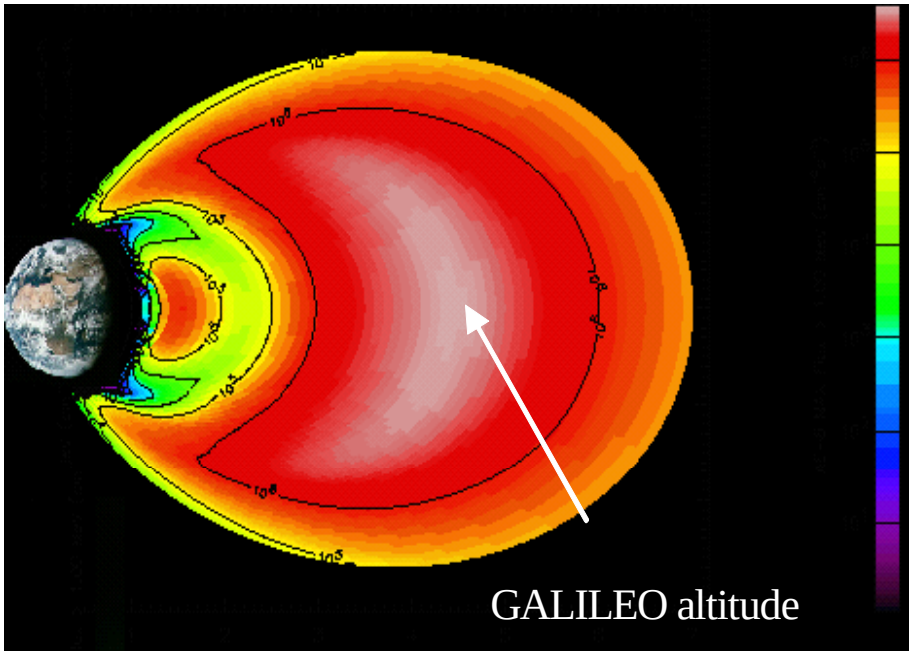
Galileo orbit

- Severe trapped electron environment
  - Charging effects
  - Total ionising dose
- Galactic cosmic rays
- Solar protons and ions



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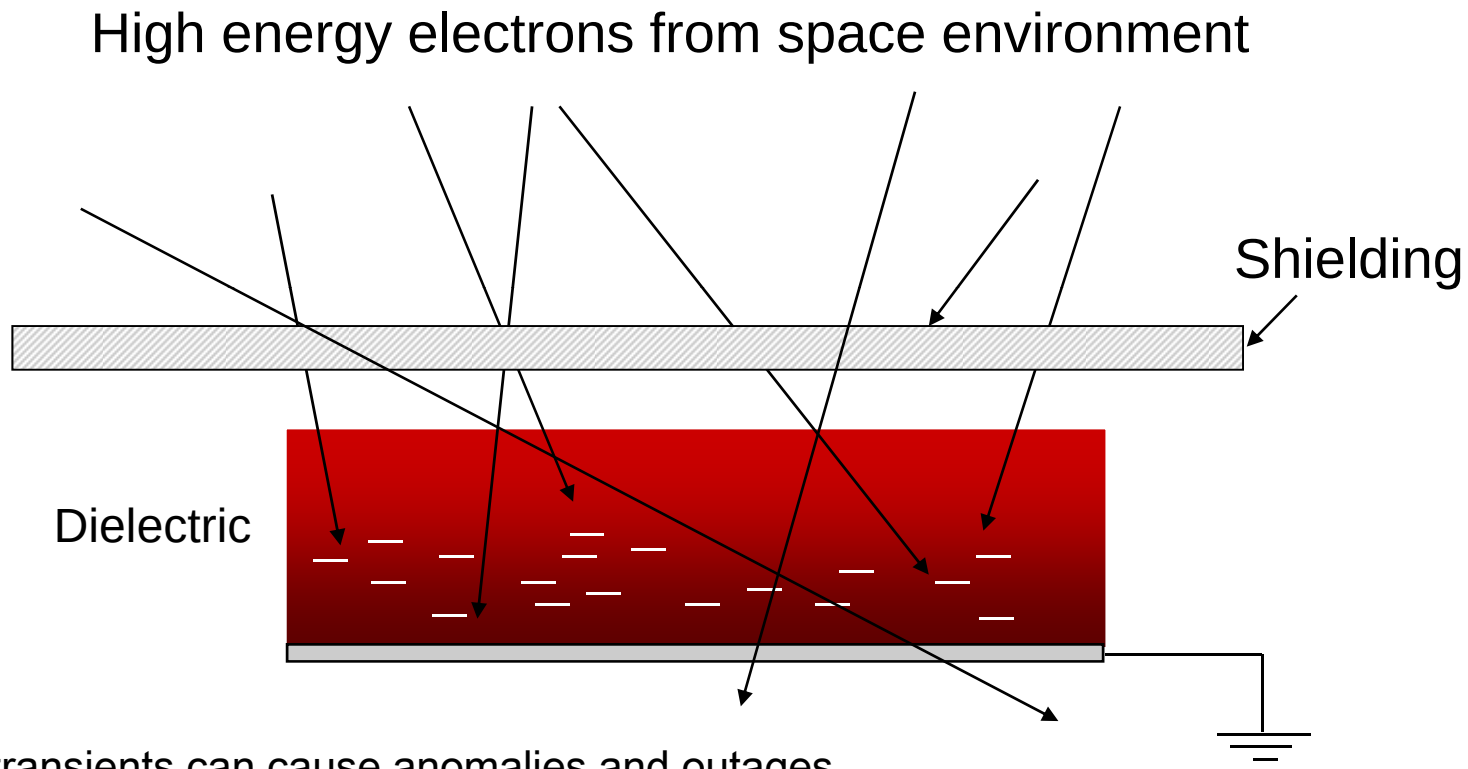
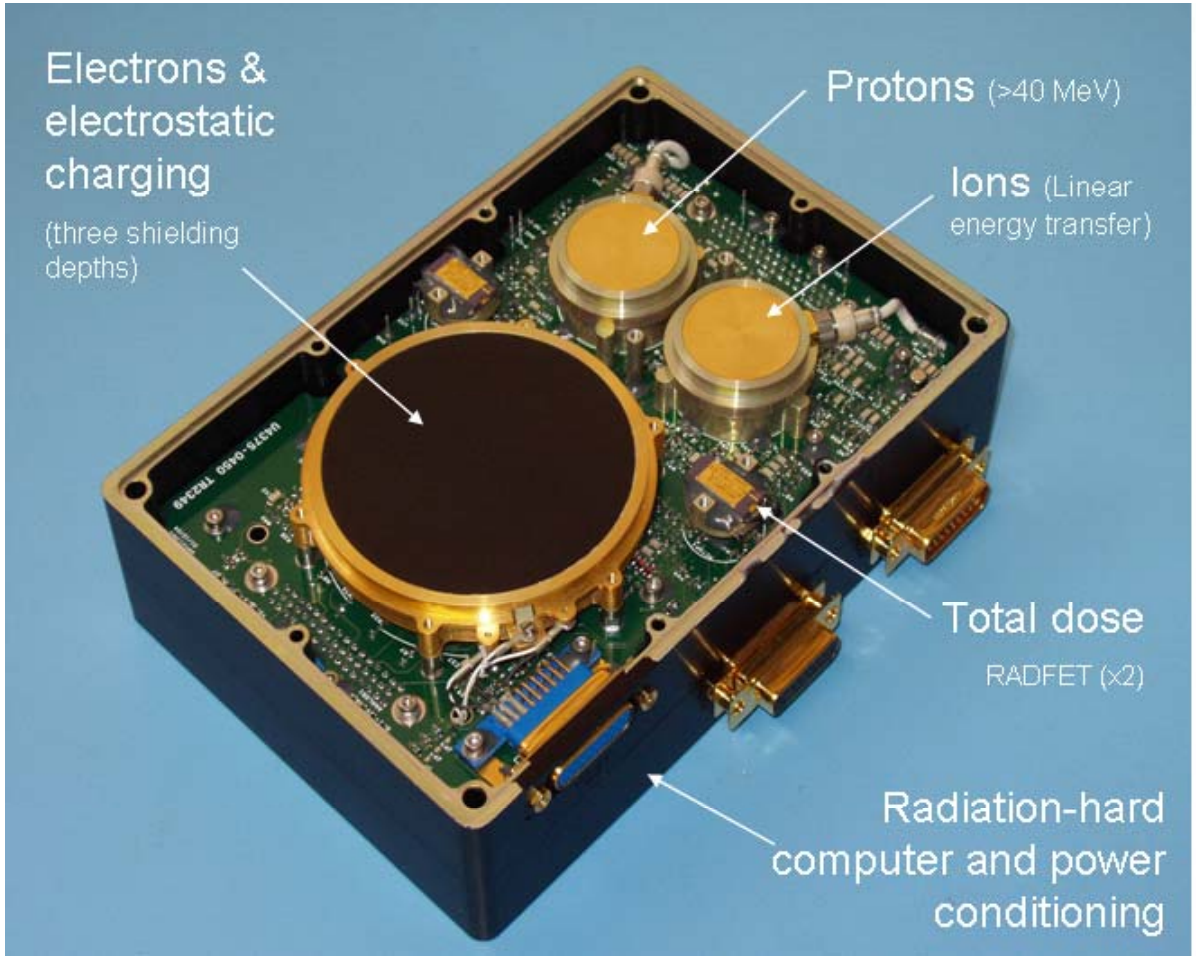
Internal charging



- ESD transients can cause anomalies and outages
- Cables, connectors, pcbs etc

Merlin-Giove-A



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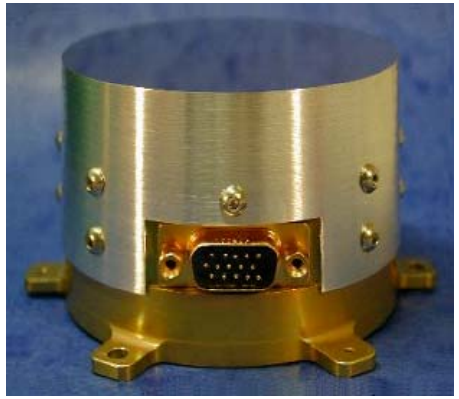
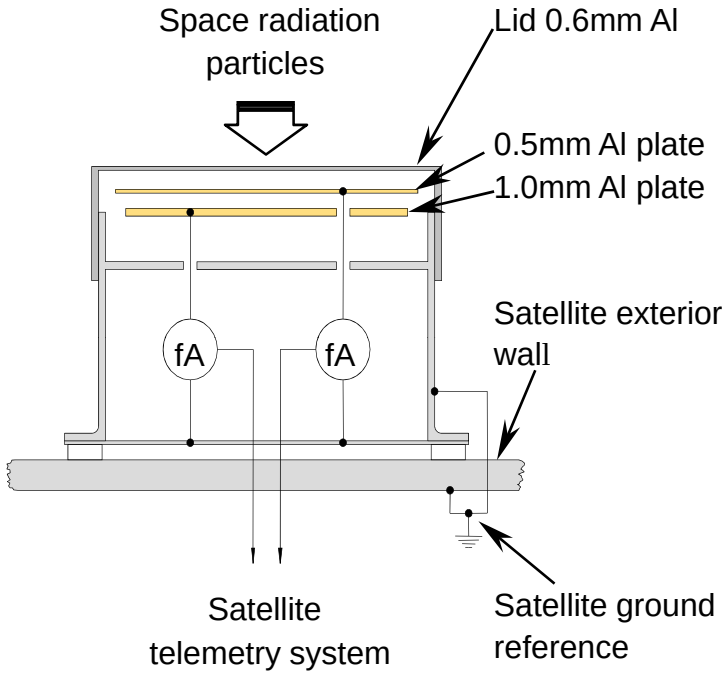
SURF charging sensor

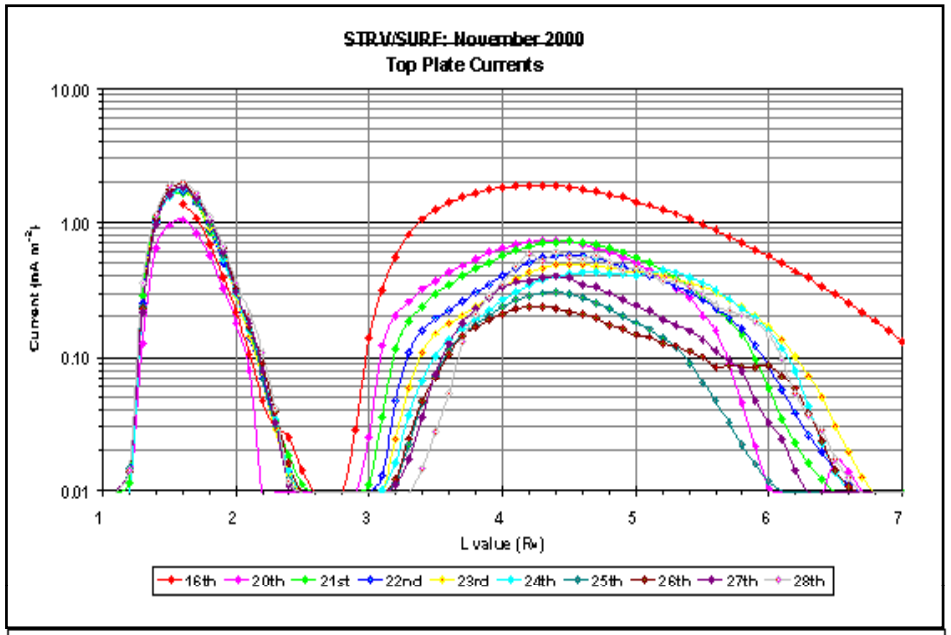
- Internal charging current *vs* depth measurement
- Each plate has unique energy response curve so spectrum can be obtained
- Virtually immune to proton contamination
- Built and flown on STRV1d
- 300g, 0.3W

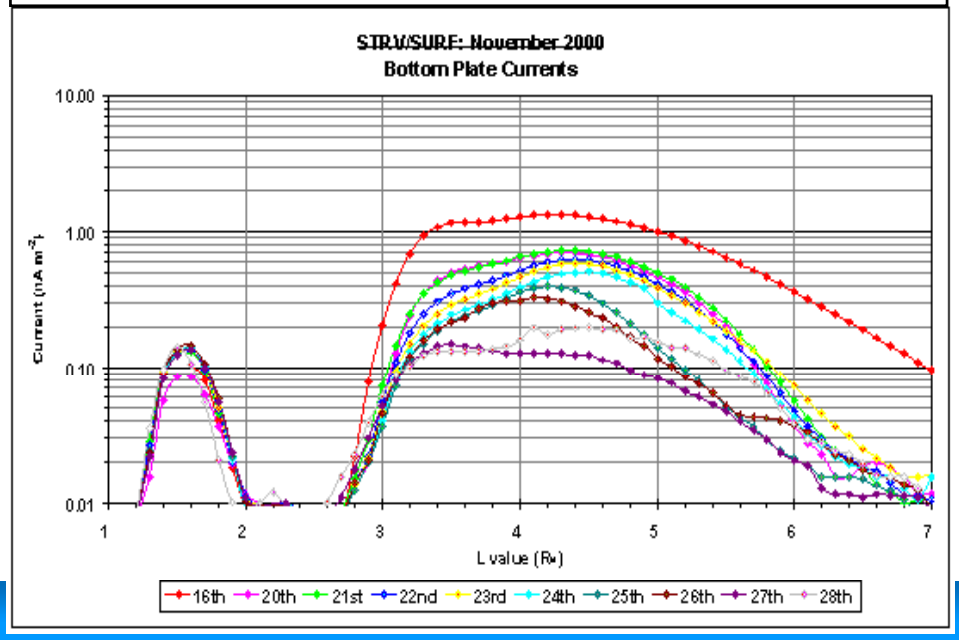




SURF results

- GTO orbit
- 500 x 36,000 km





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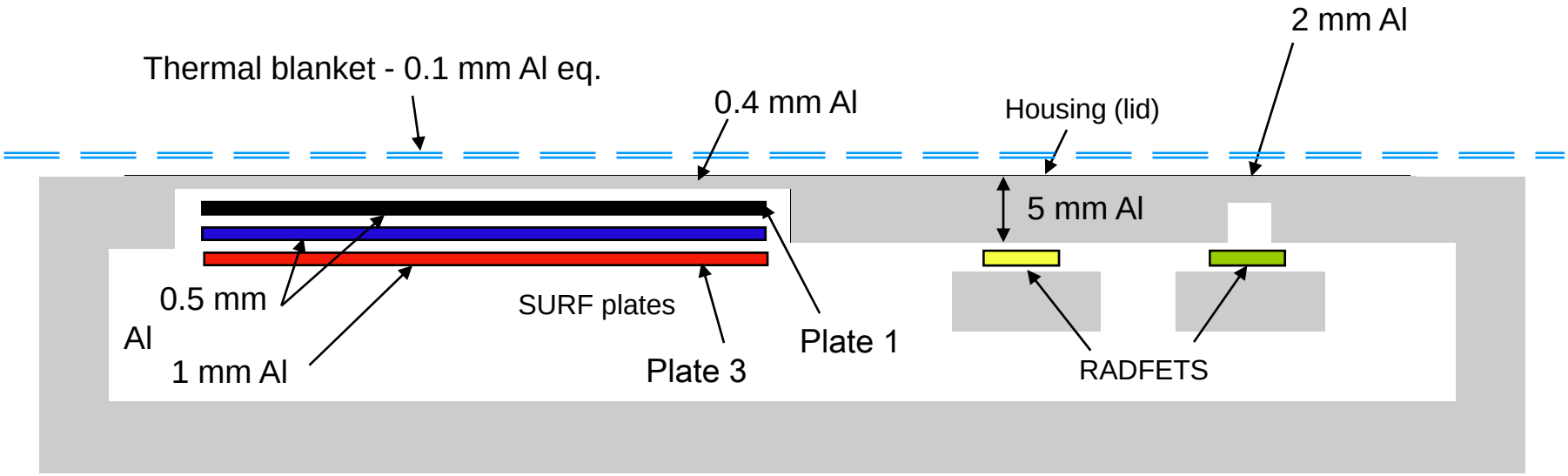
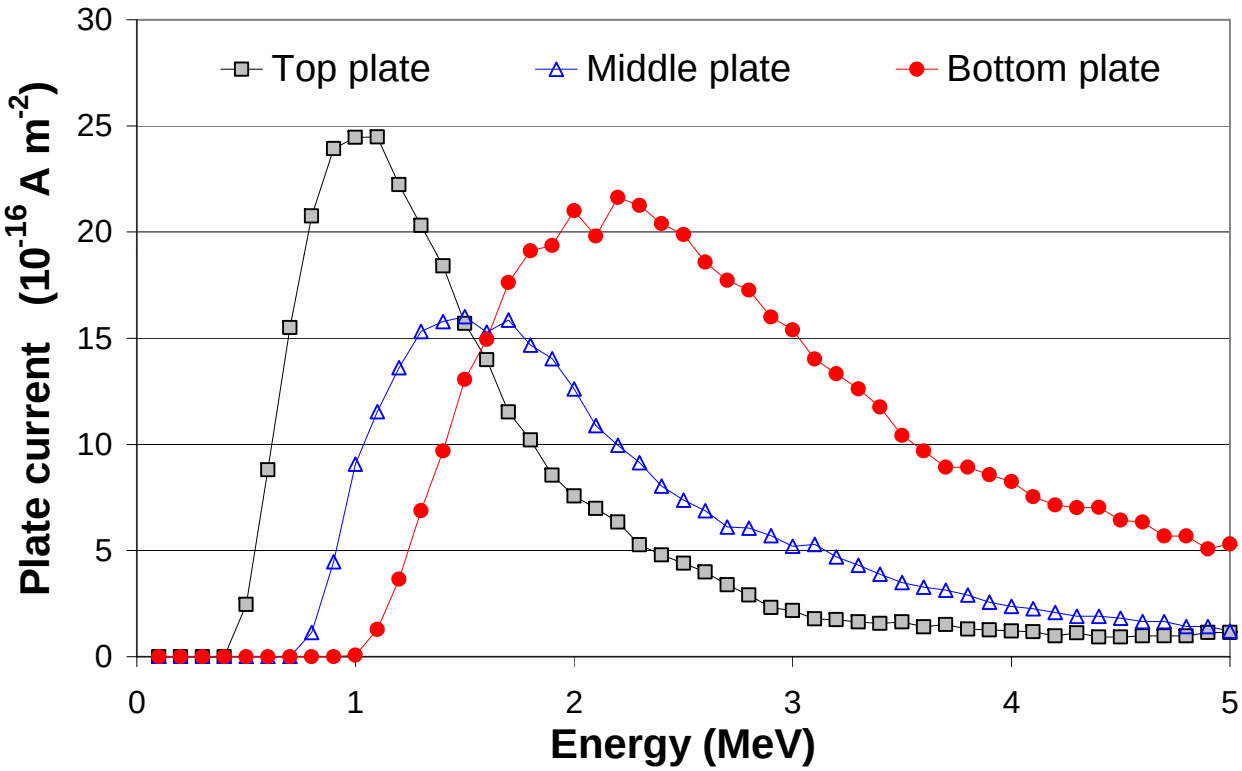
Merlin-Giove-A

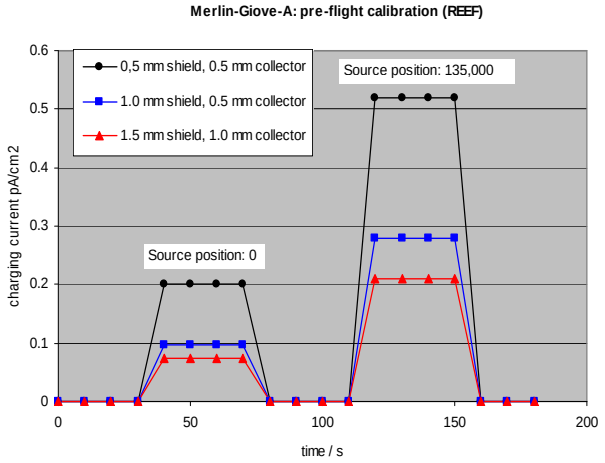
- Located externally (under thermal blanket)
- Extra box shielding incorporated (5mm thick walls) due to severity of orbit
- SURF and Radfet set-up for Giove-A:

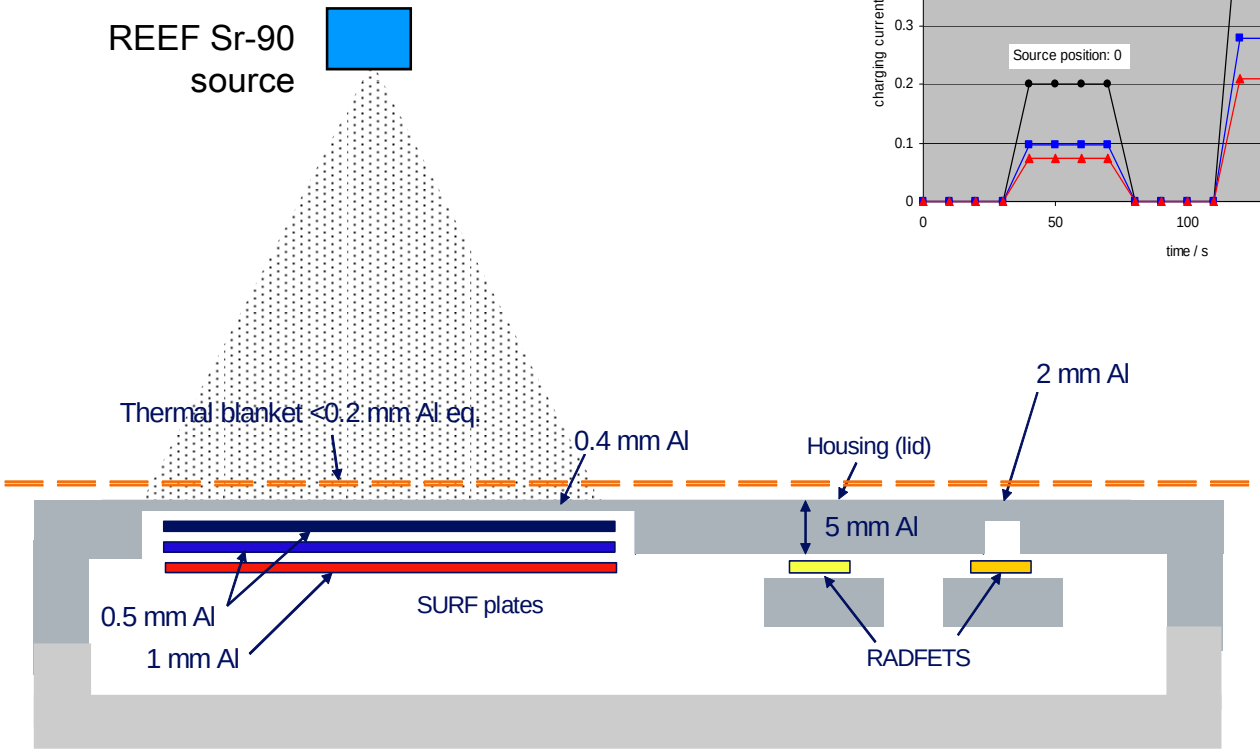


SURF response curves for each plate

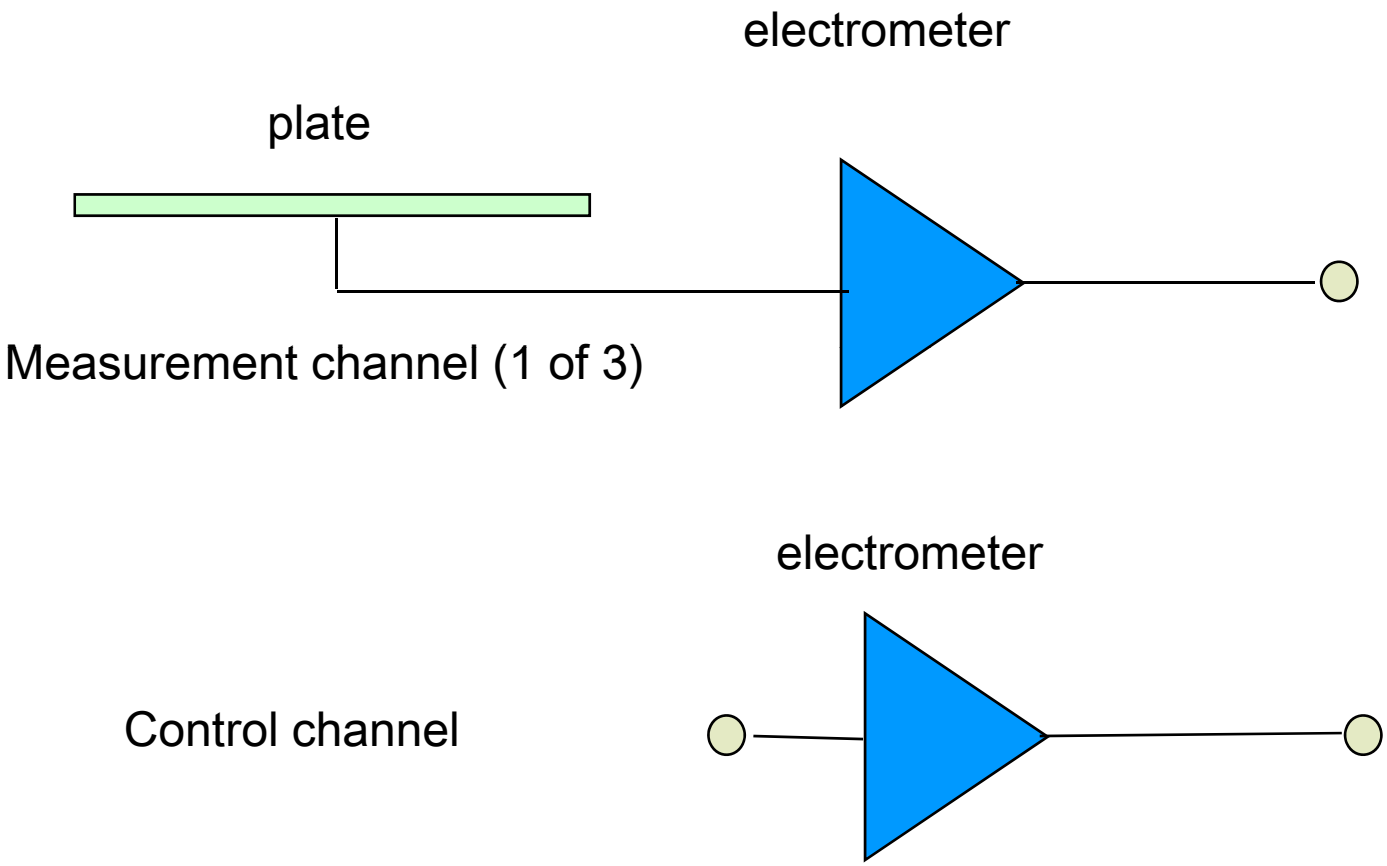


Merlin pre-flight calibration

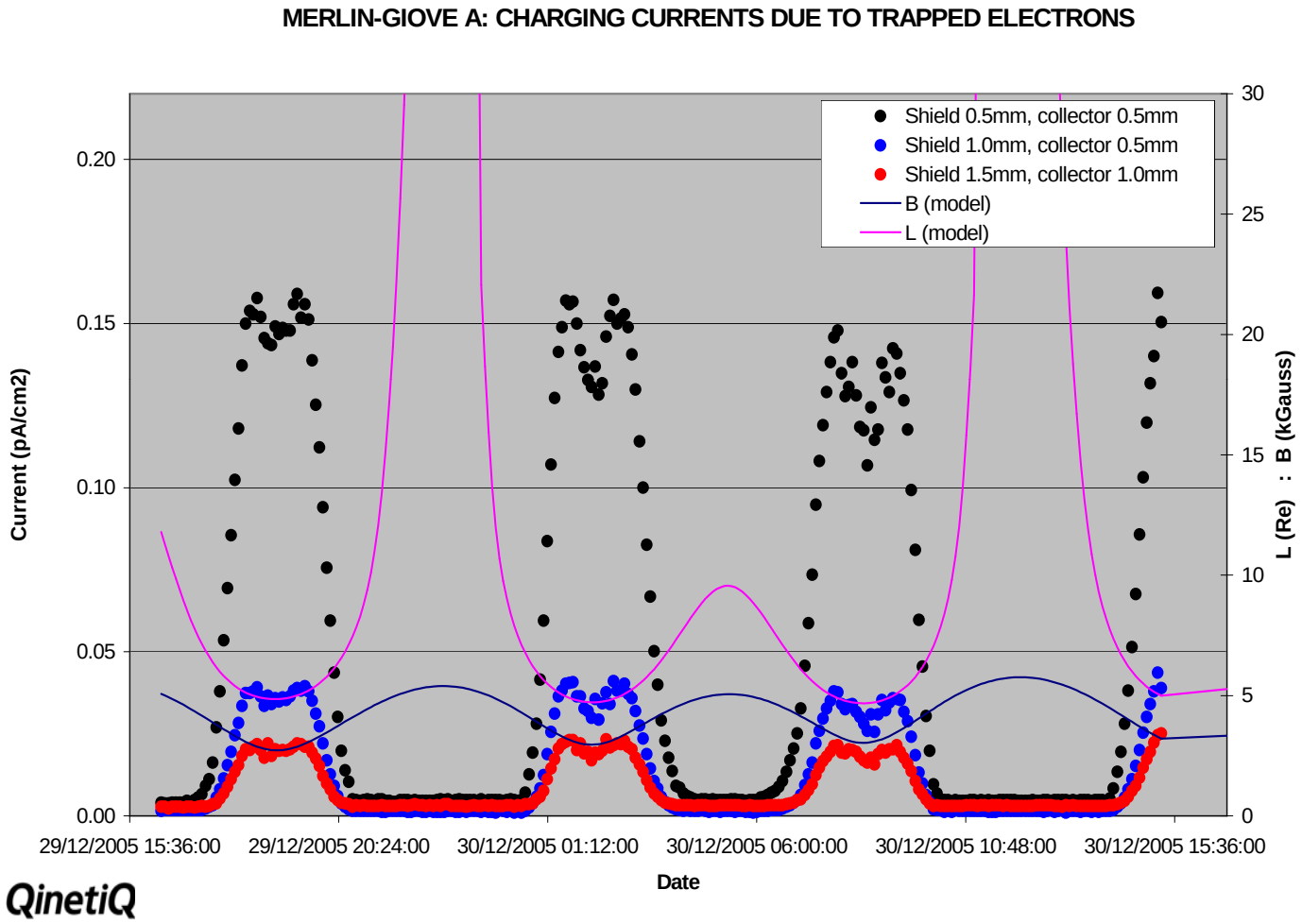




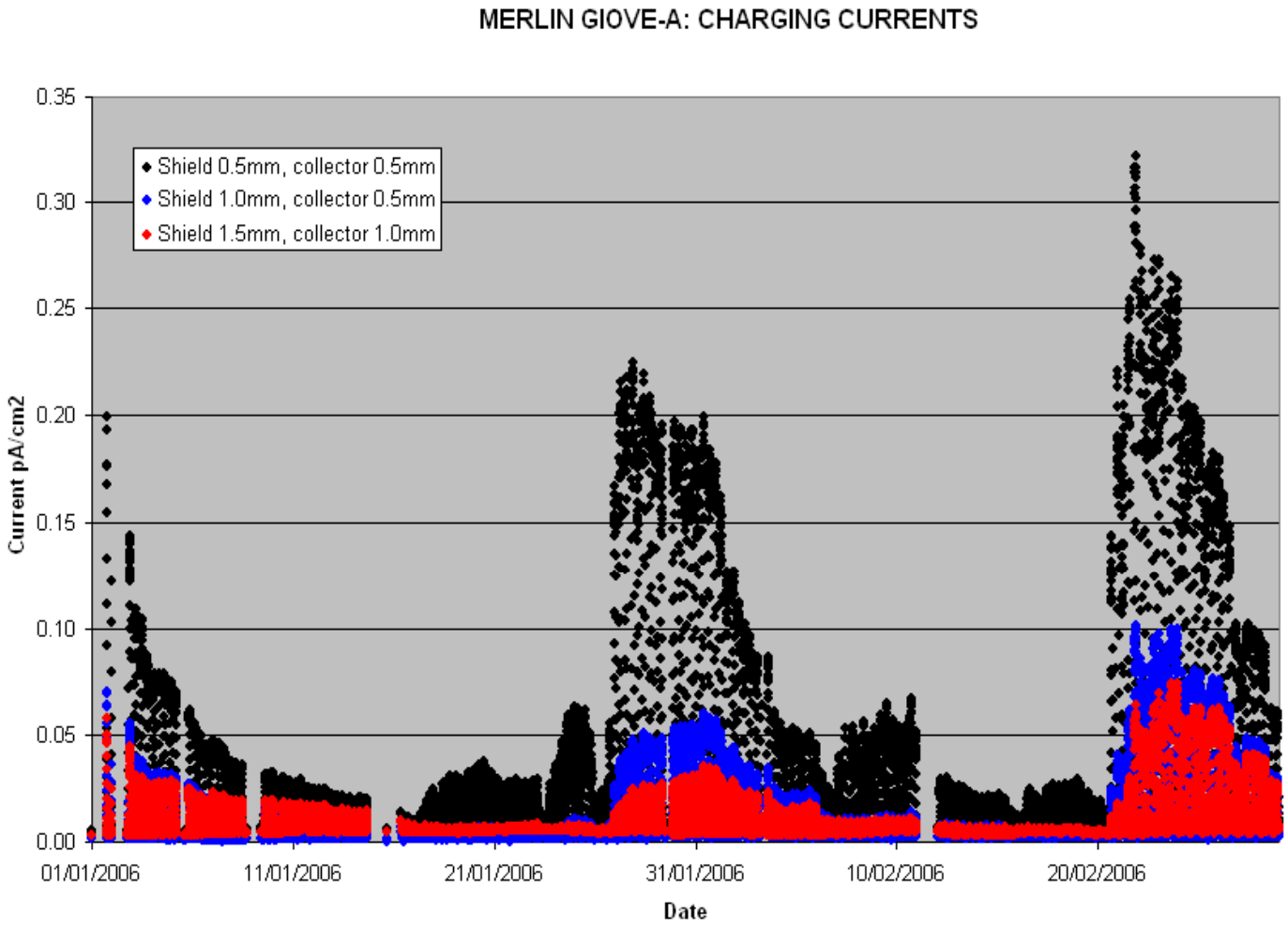
SURF control channel



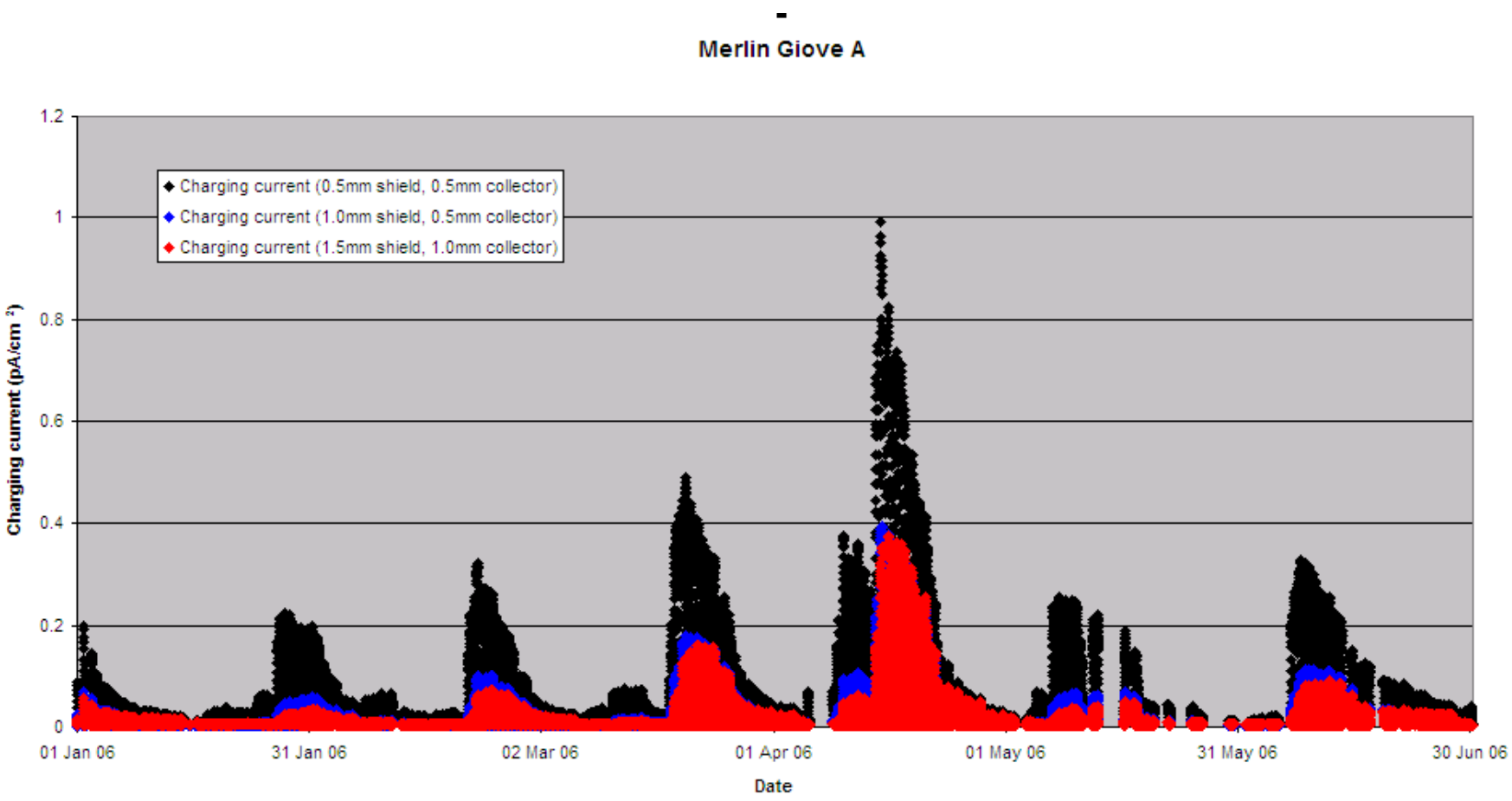
1st day of data: charging currents



Jan & Feb 2006: charging currents



January to June 2006: charging currents



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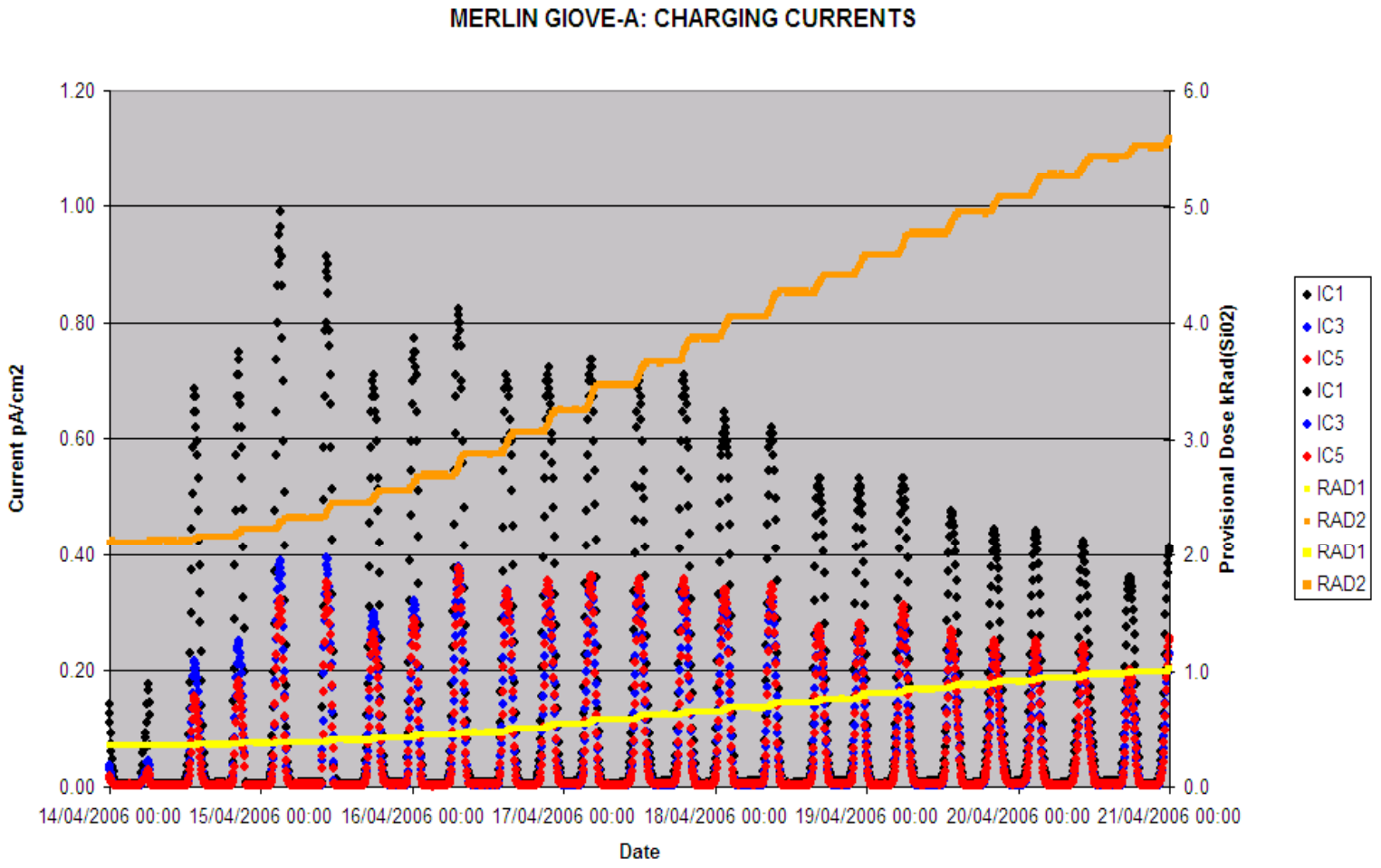
April 2006 electron event



17th April 2006 - single belt transit

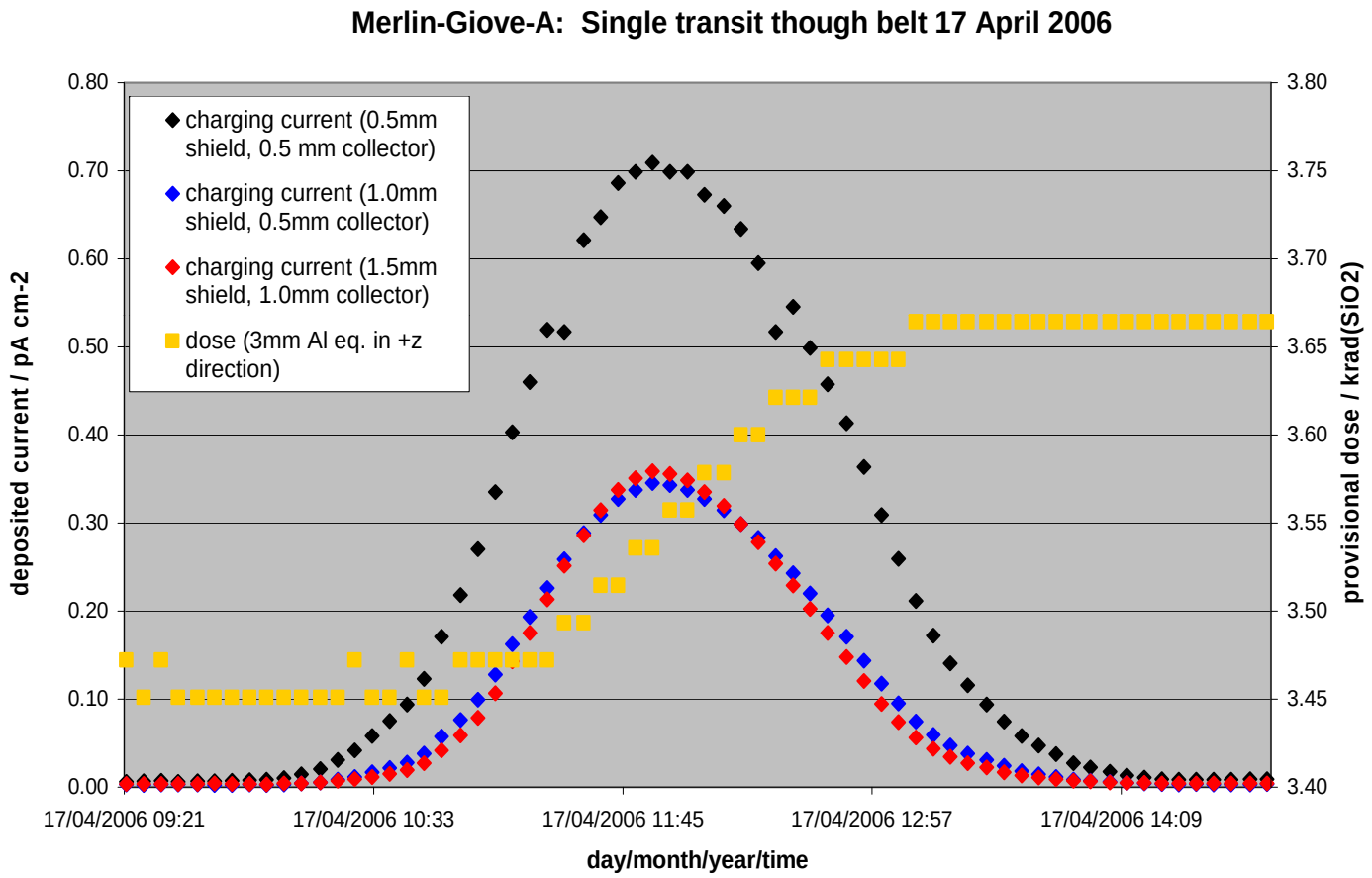


Plate 1 charging current: 2005-2009

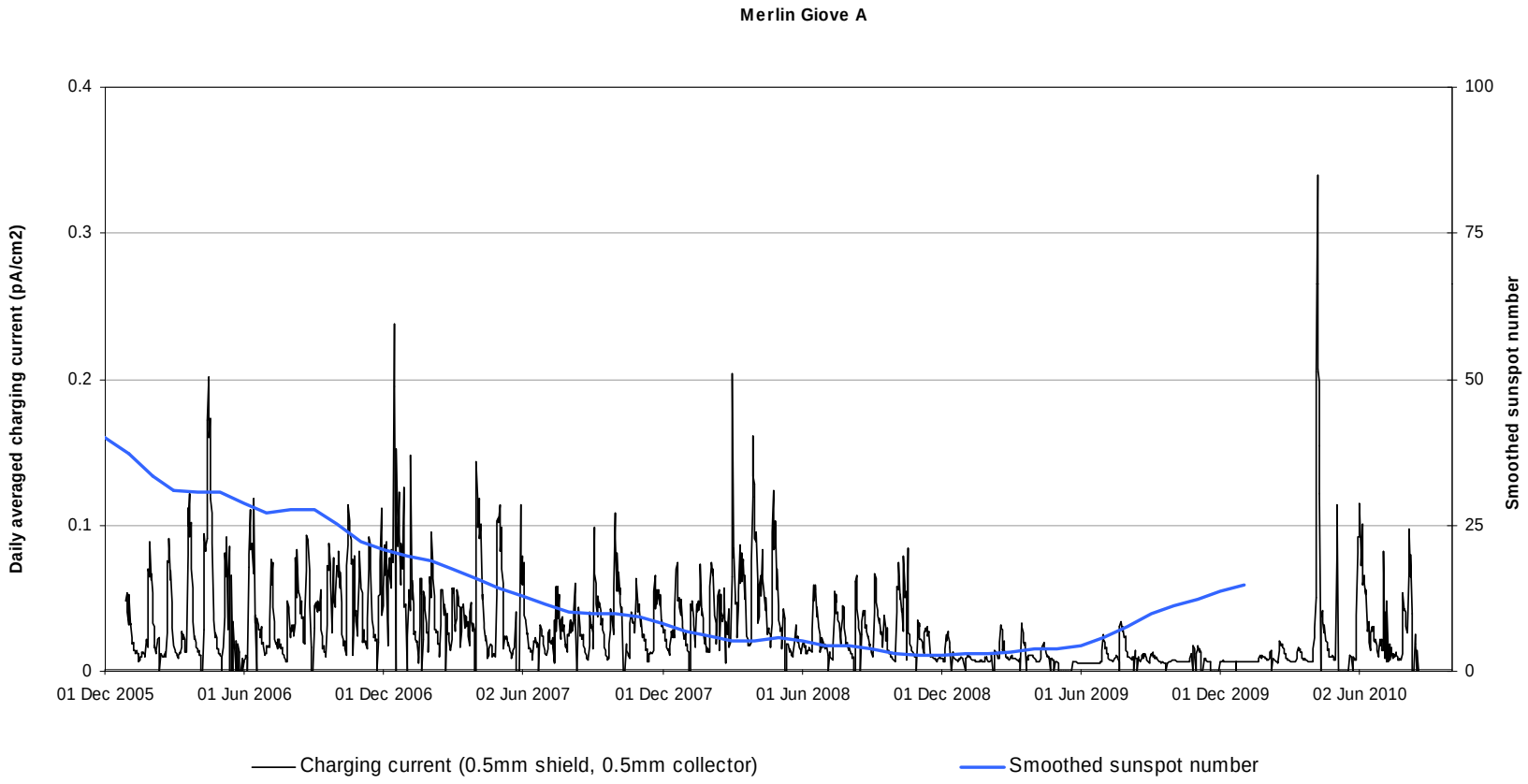


Plate 2 charging current: 2005-2009

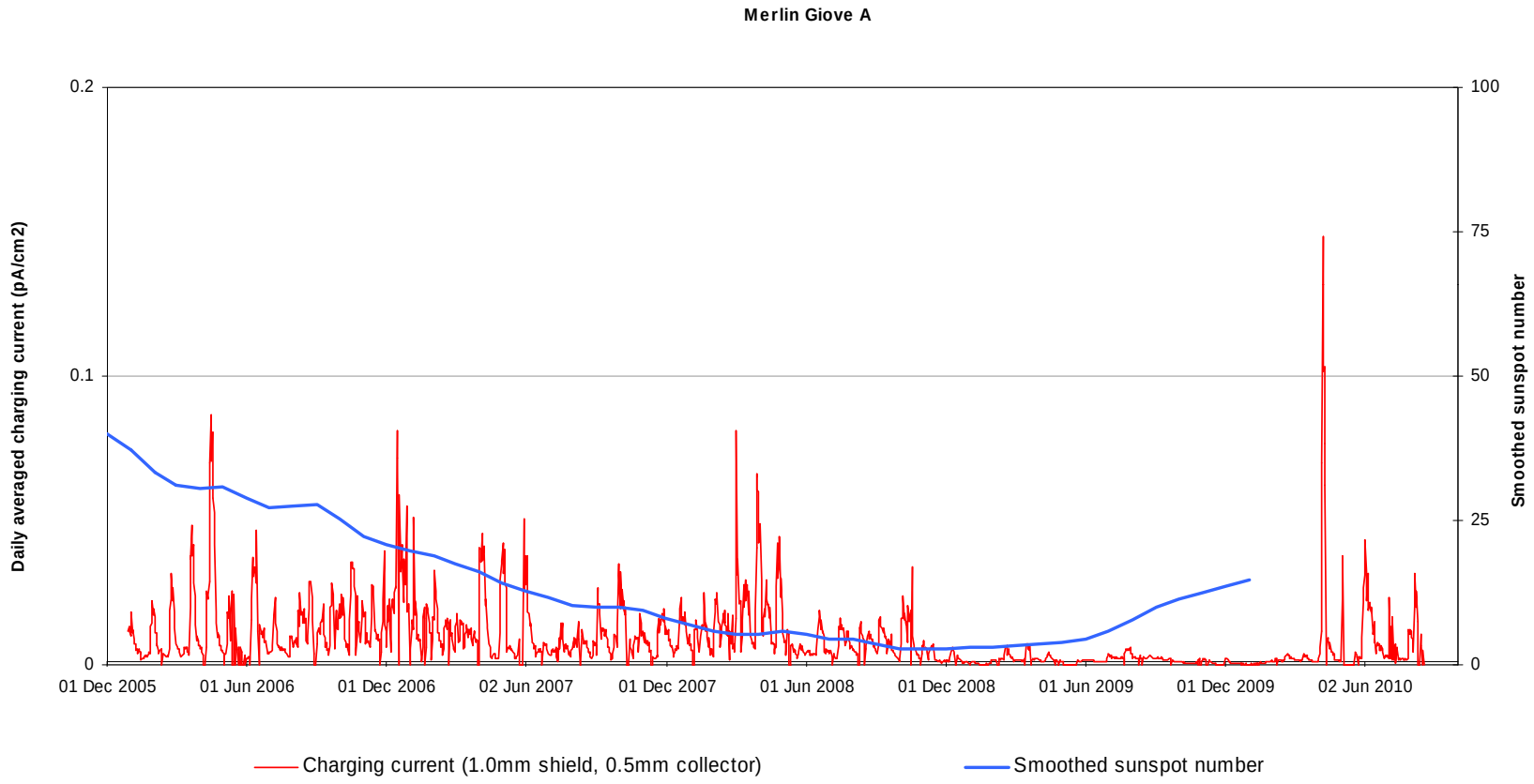
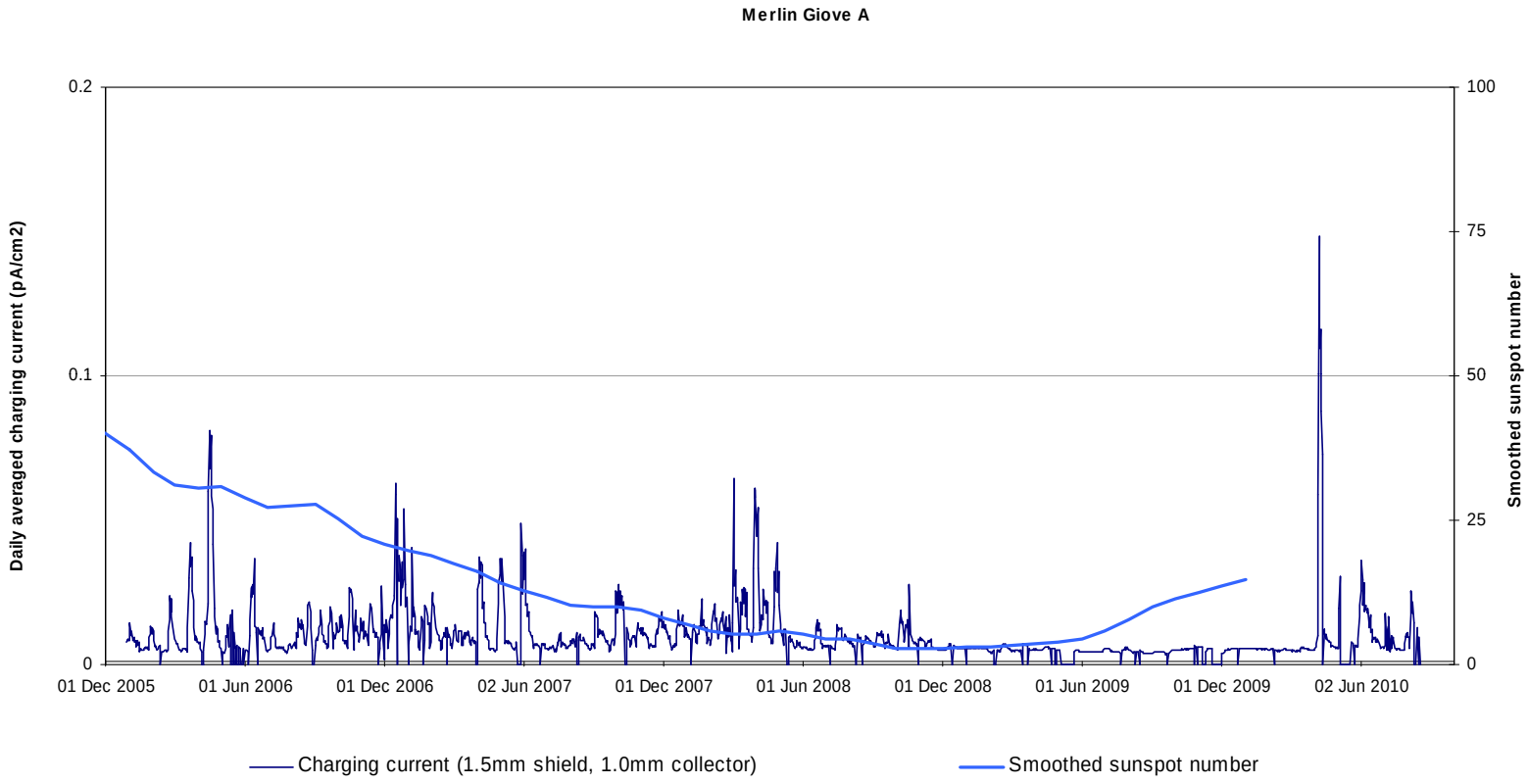
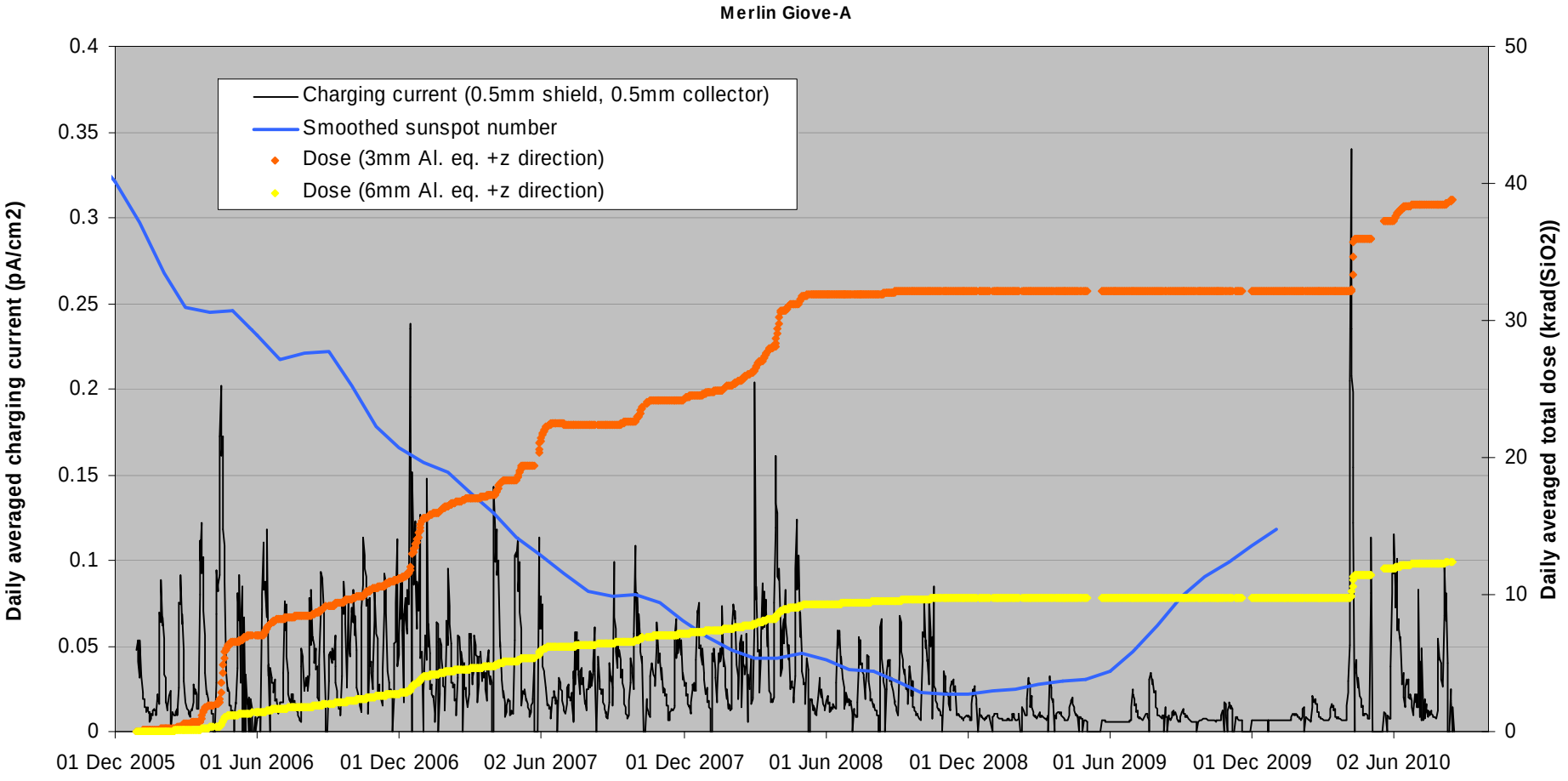


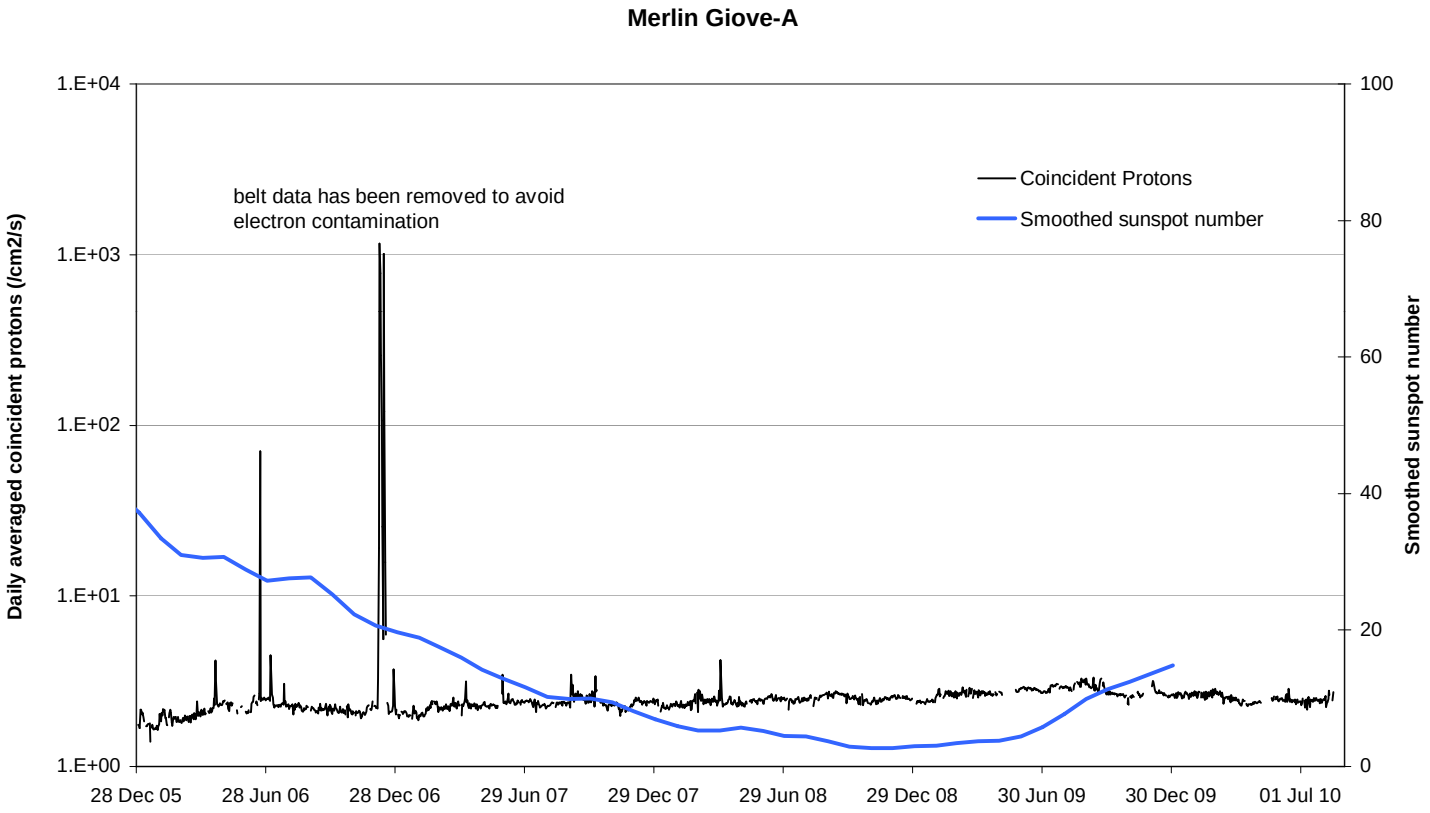
Plate 3 charging current: 2005-2009



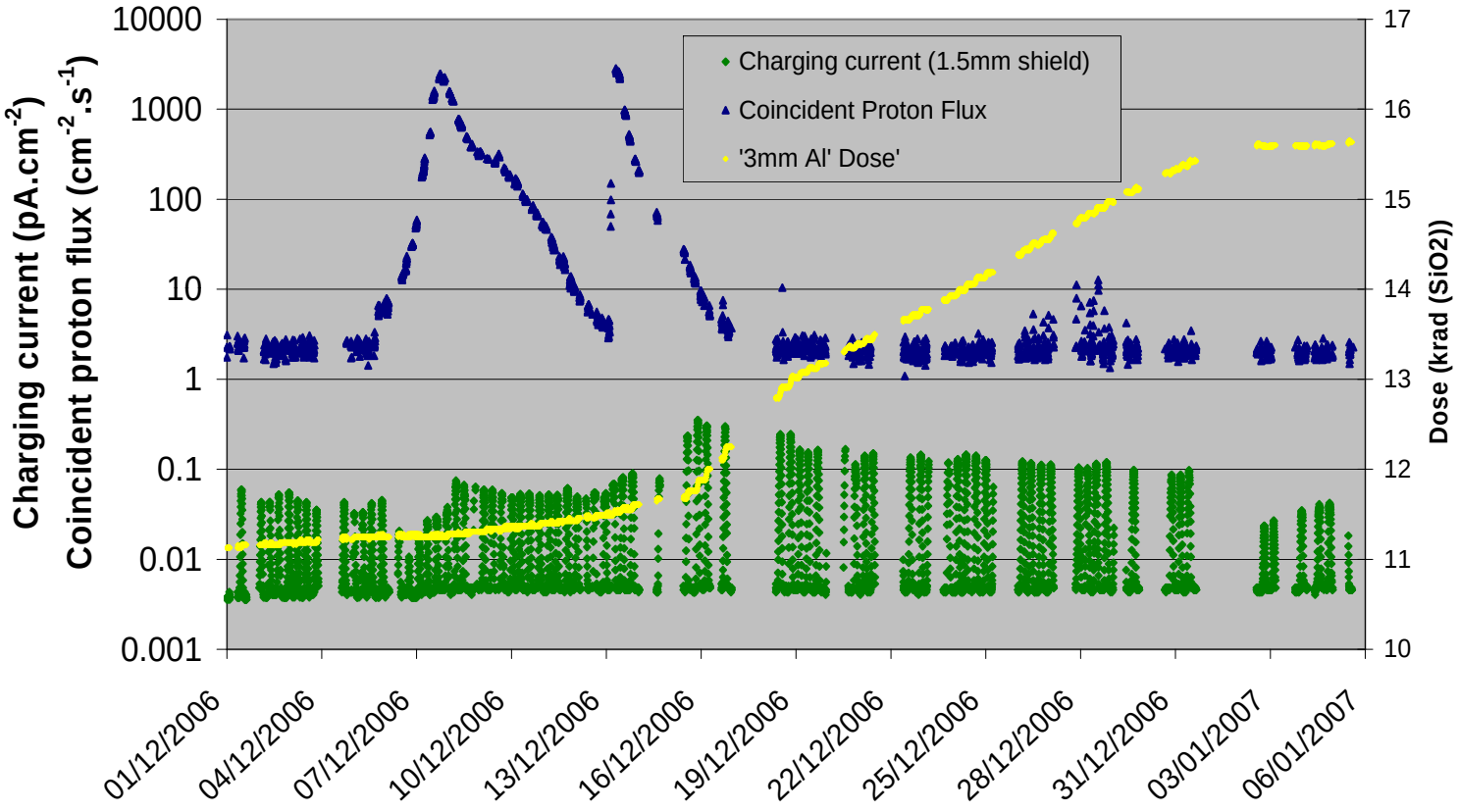
MEO electrons and ionising dose 2005-10



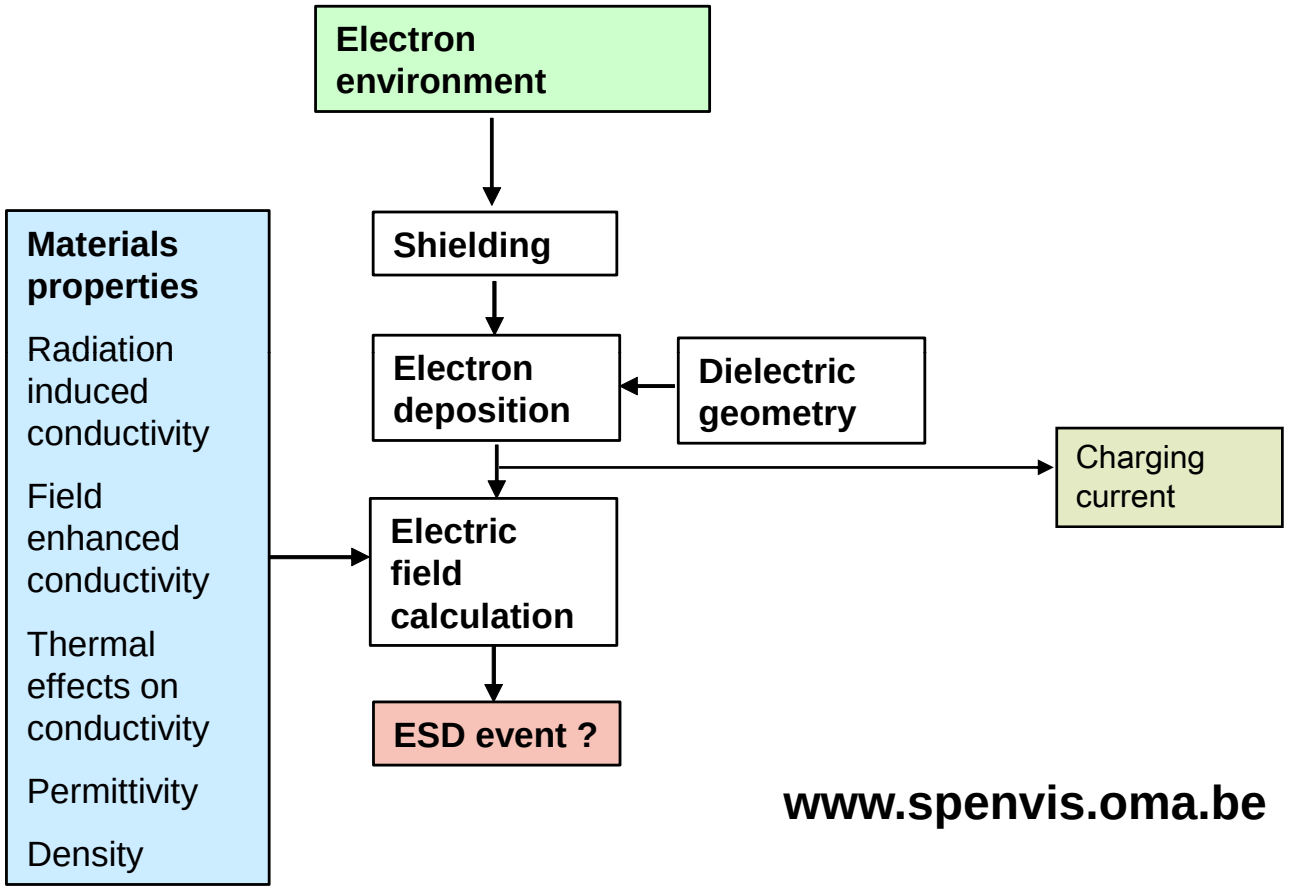
Protons (outside of the belts): 2005-2010



December 2006 ‘events’ recorded by Merlin on Giove-A



Comparison of measured currents to the FLUMIC/DICTAT prediction



FLUMIC – Flux model for internal charging

- Empirical model developed specifically for internal charging (2000)
- Based mainly on data from SREM and GOES in 1980s and 1990s
- Give ‘worst-case’ 1-day flux envelope as function of:
  - B
  - L
  - fraction of solar cycle
  - fraction of year (seasonal)
- Latest version 3.0

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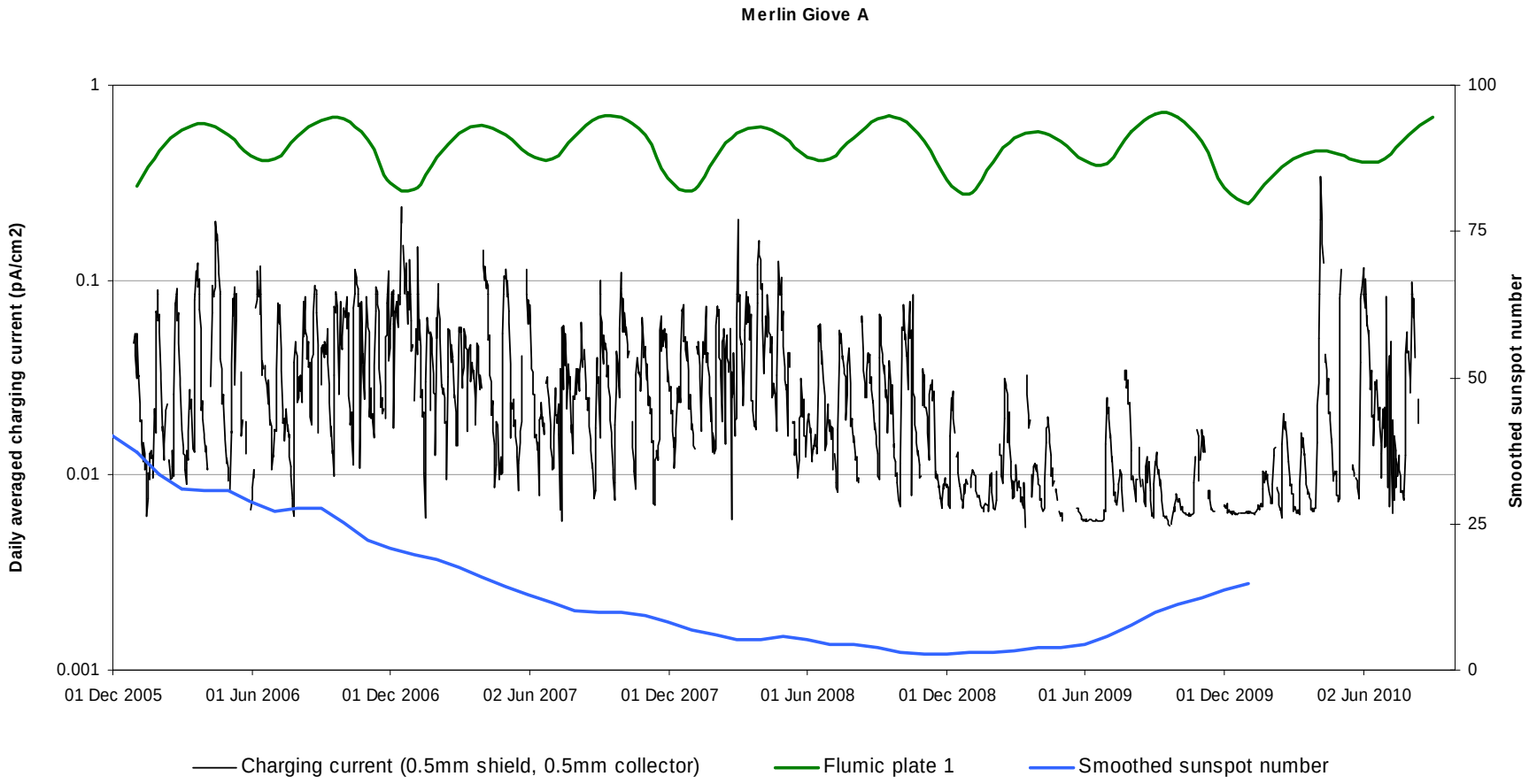
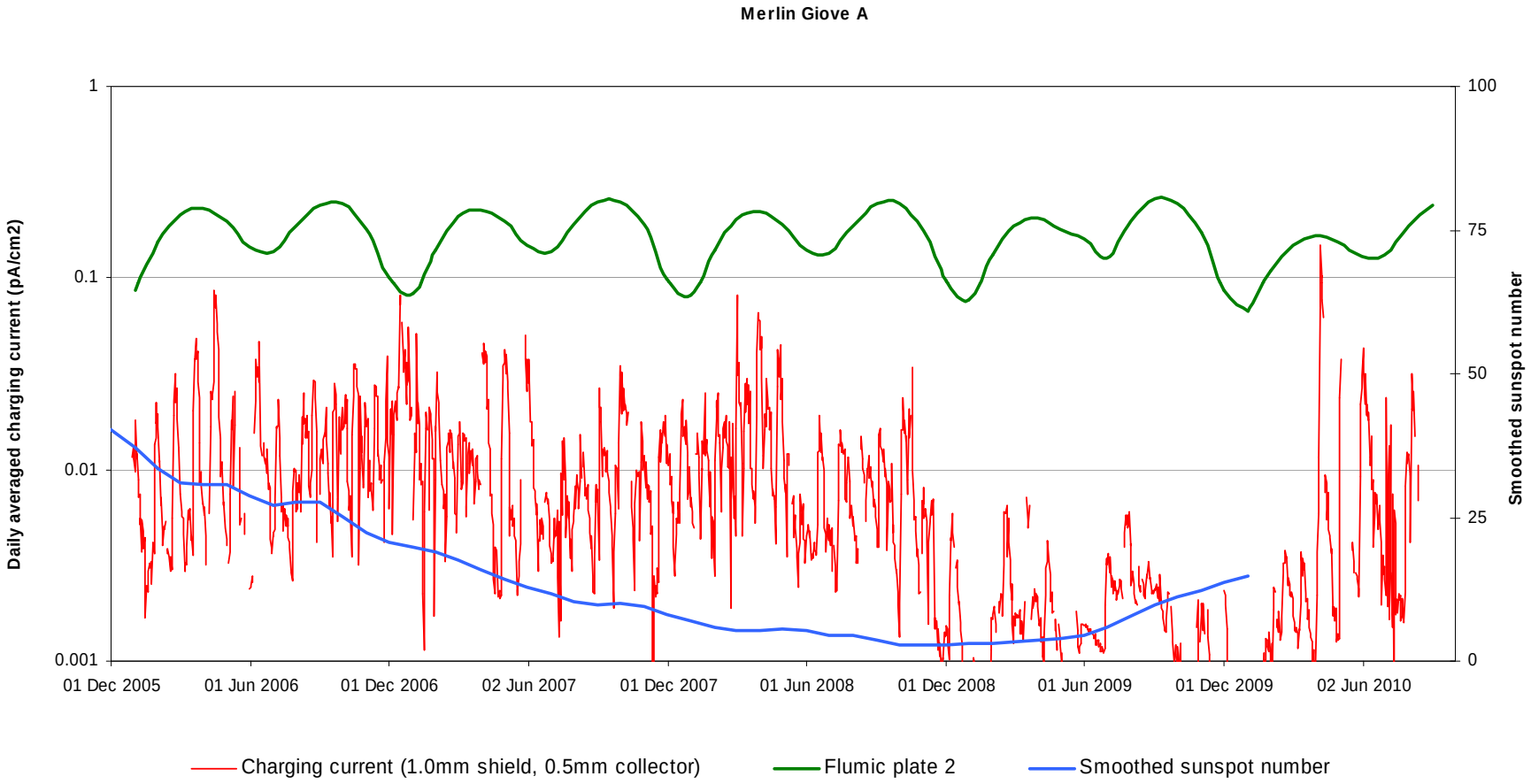
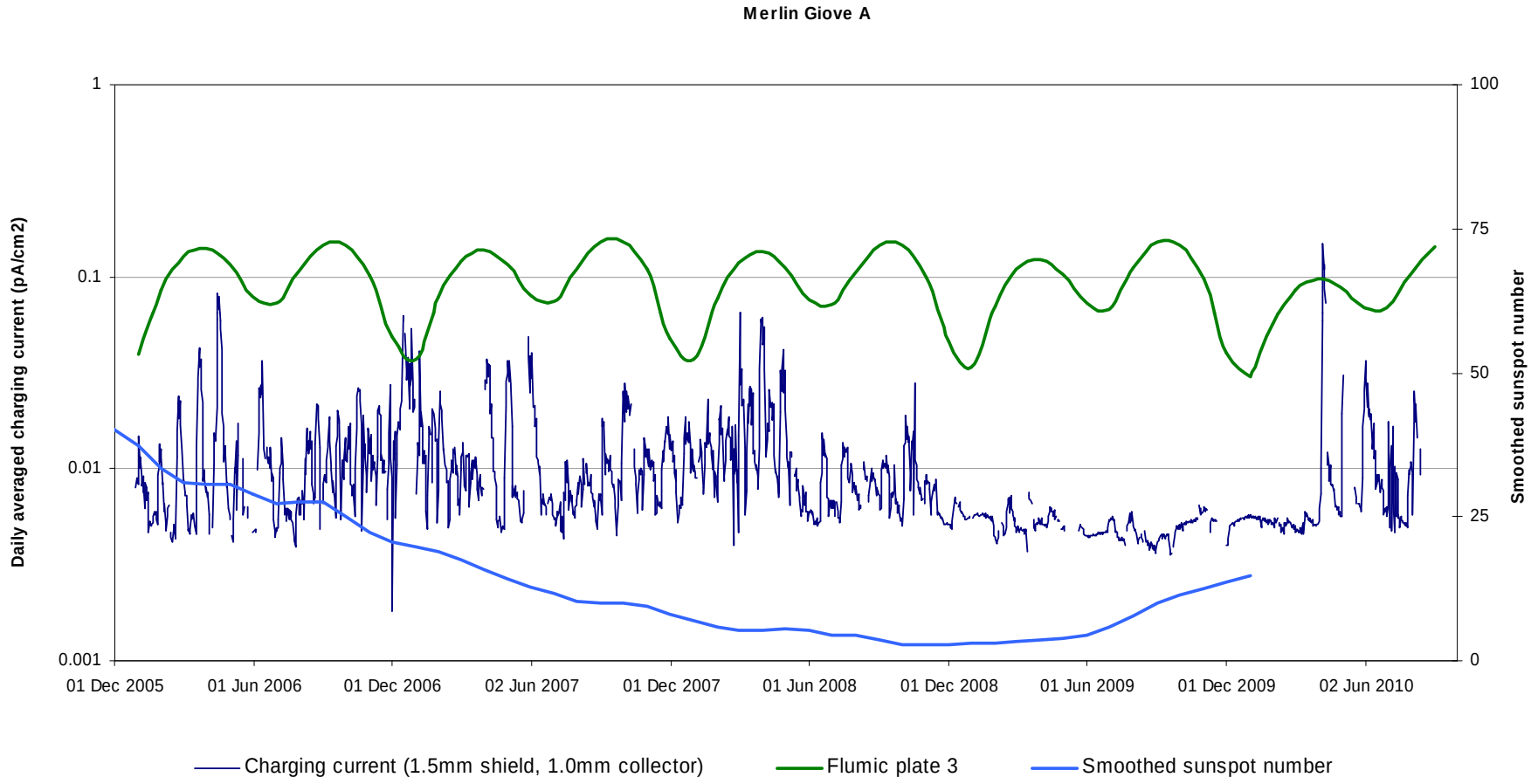
SURF plate 1 current compared to FLUMIC/DICTAT ‘worst case’ envelope



SURF plate 2 current compared to FLUMIC/DICTAT ‘worst case’ envelope



SURF plate 3 current compared to FLUMIC/DICTAT ‘worst case’ envelope



Ratio of 1-day mean currents: prediction/actual

	15th April 2006	15th Dec 2006	7th April 2010
Top plate	2.9	1.3	1.4
Middle plate	2.5	1.2	1.1
Bottom plate	1.6	0.7	0.65

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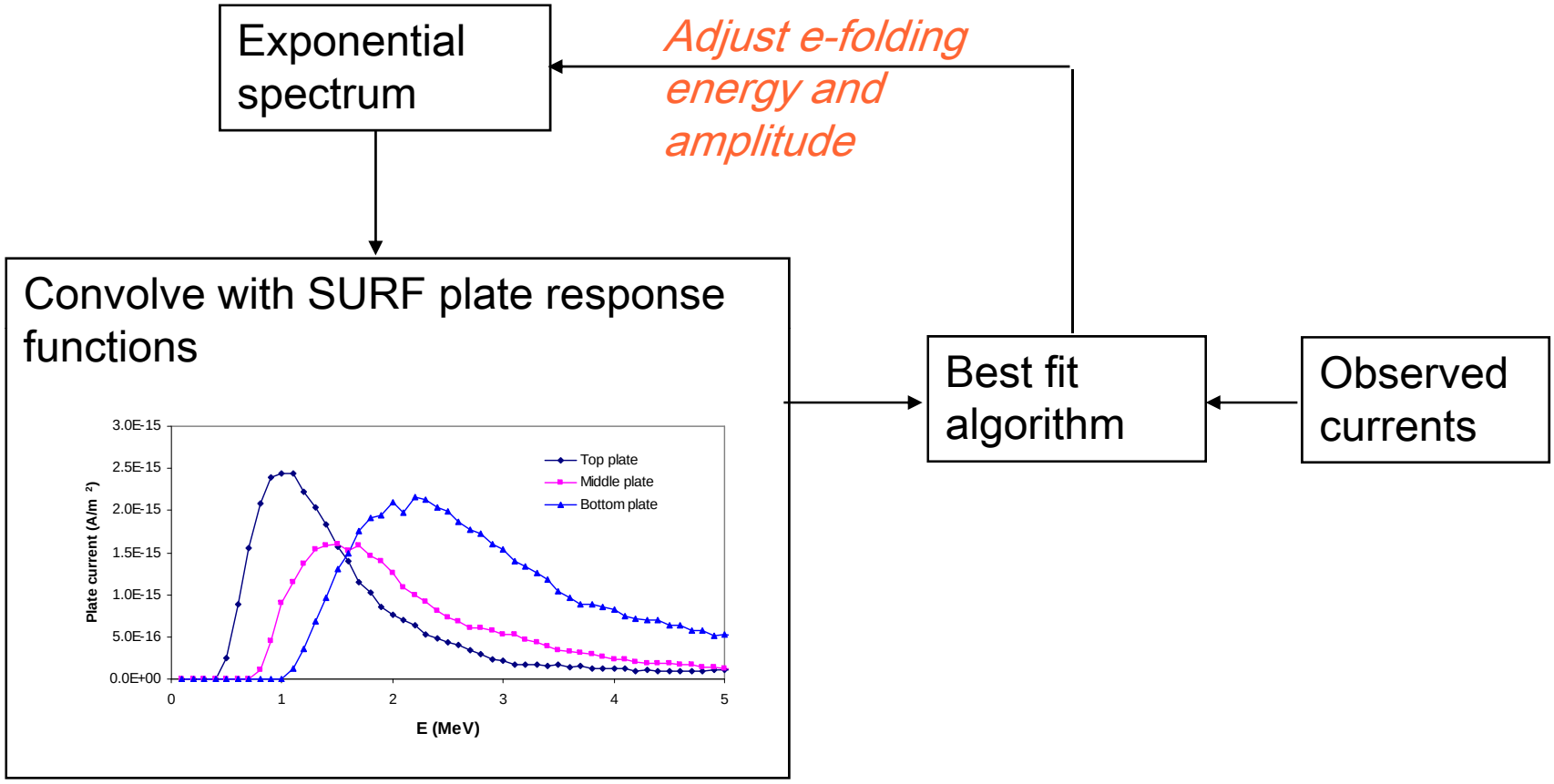
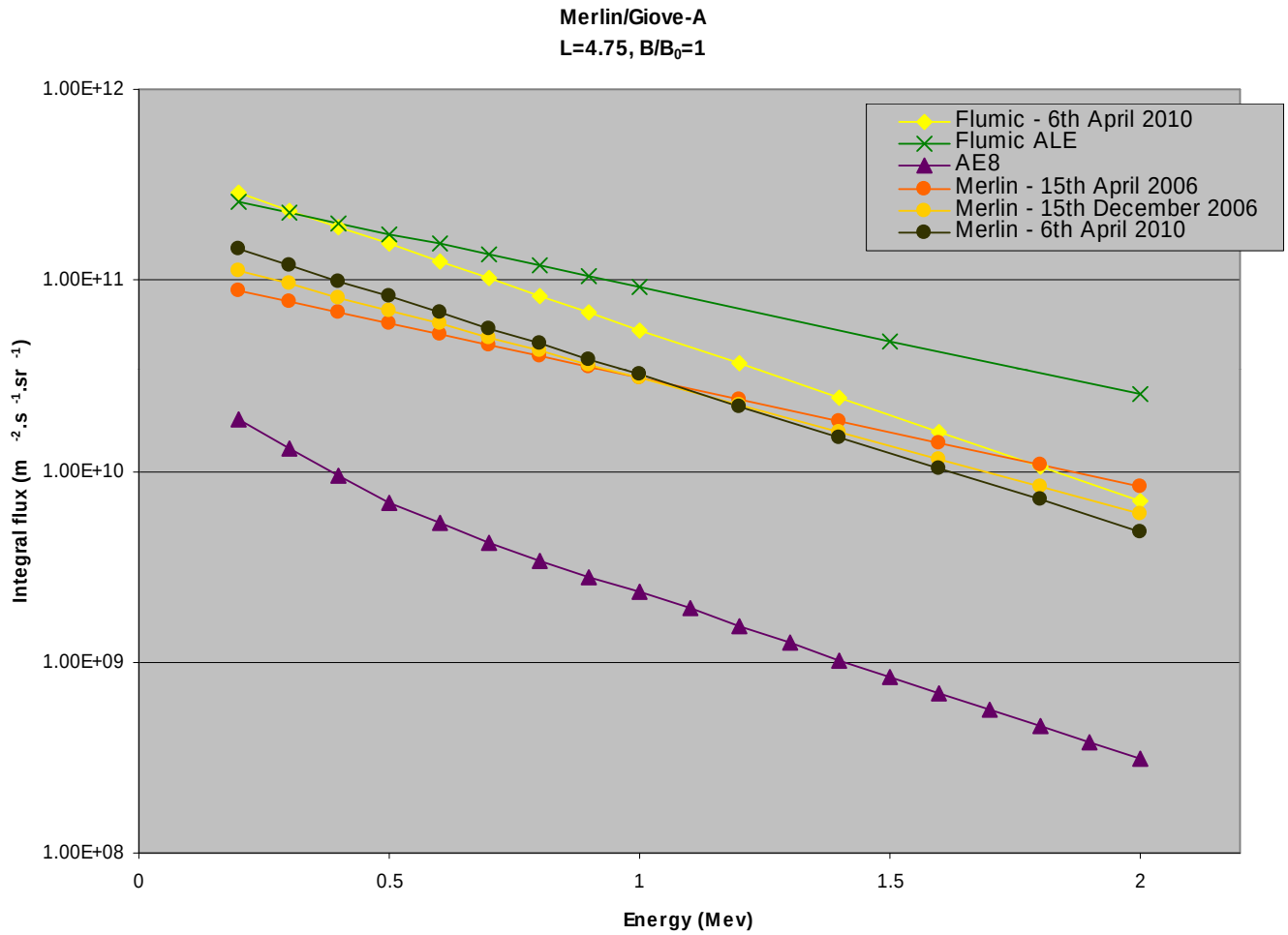
Fitting of an exponential spectrum to the results



Spectrum comparisons



Comparison of spectral hardness

	15 April 2006	15 Dec 06* * Associated with SPE/CME	07 April 2010
FLUMIC folding energy, E_0 (MeV)	0.49	0.36	0.49
Measured (fitted) folding energy, E_0 (MeV)	0.76	0.61 (0.63 for ALE)	0.53

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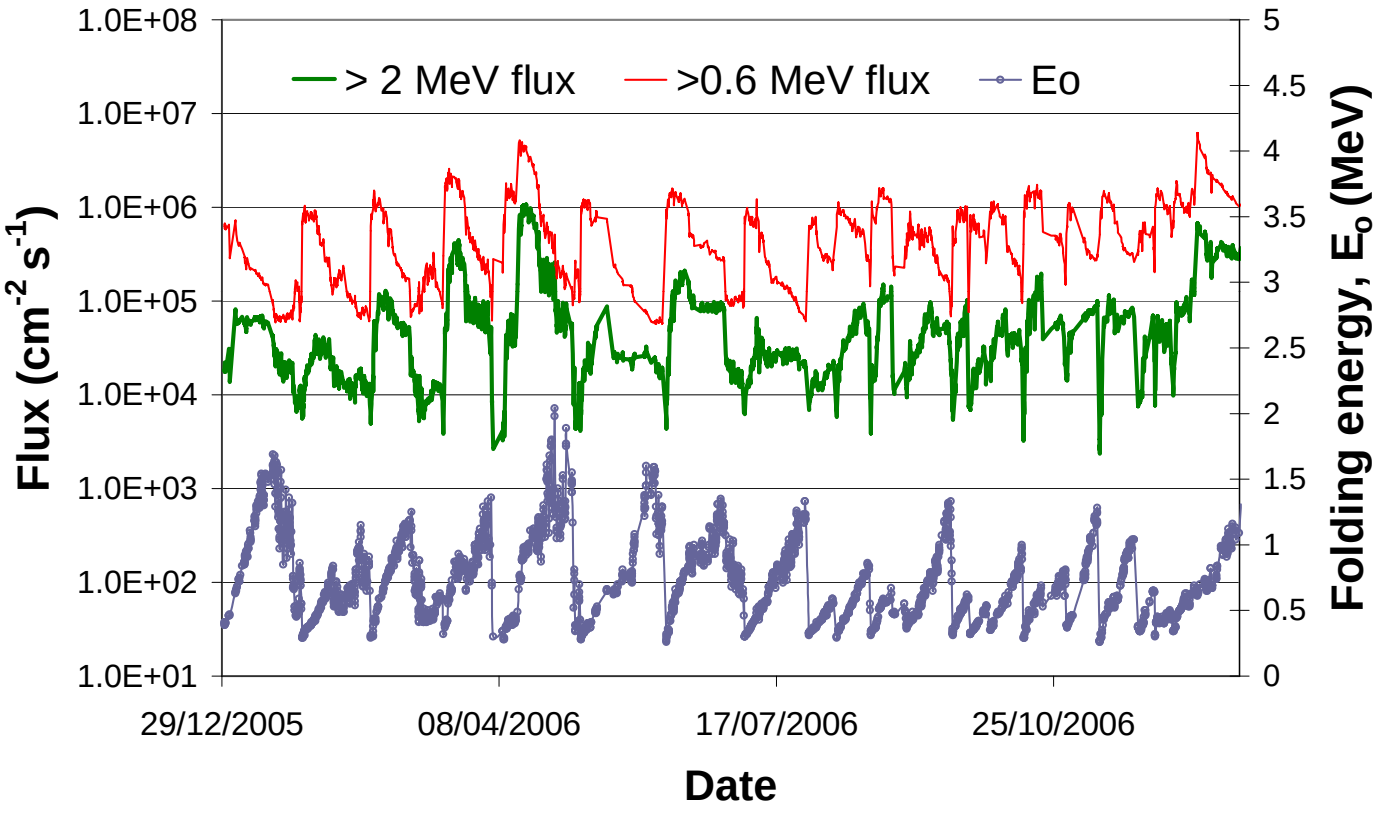
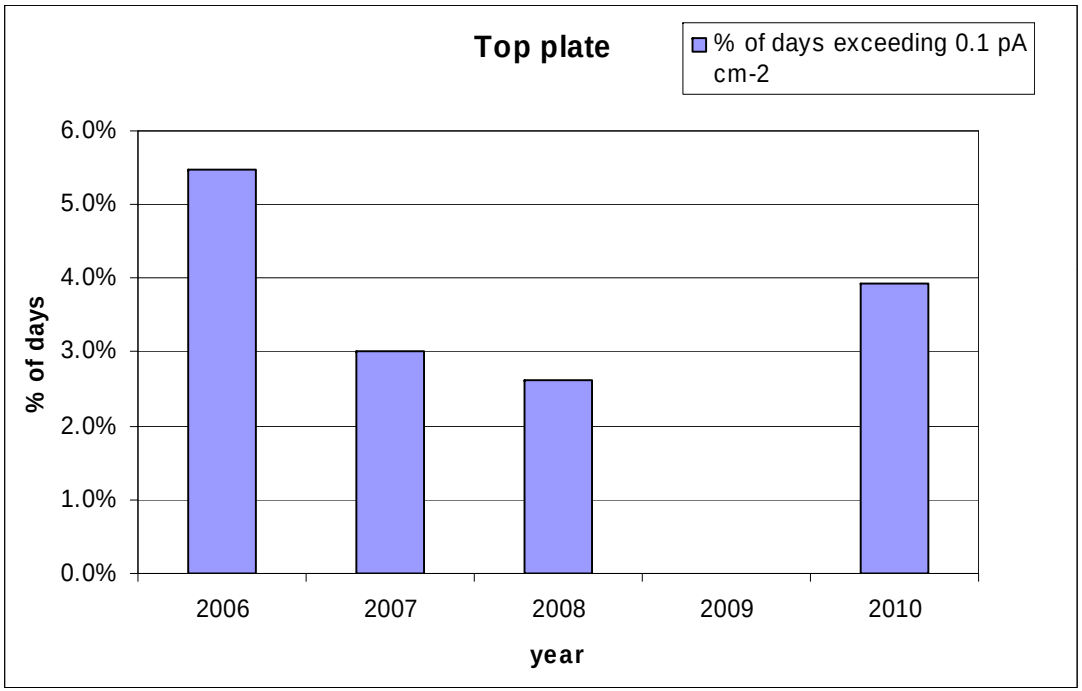
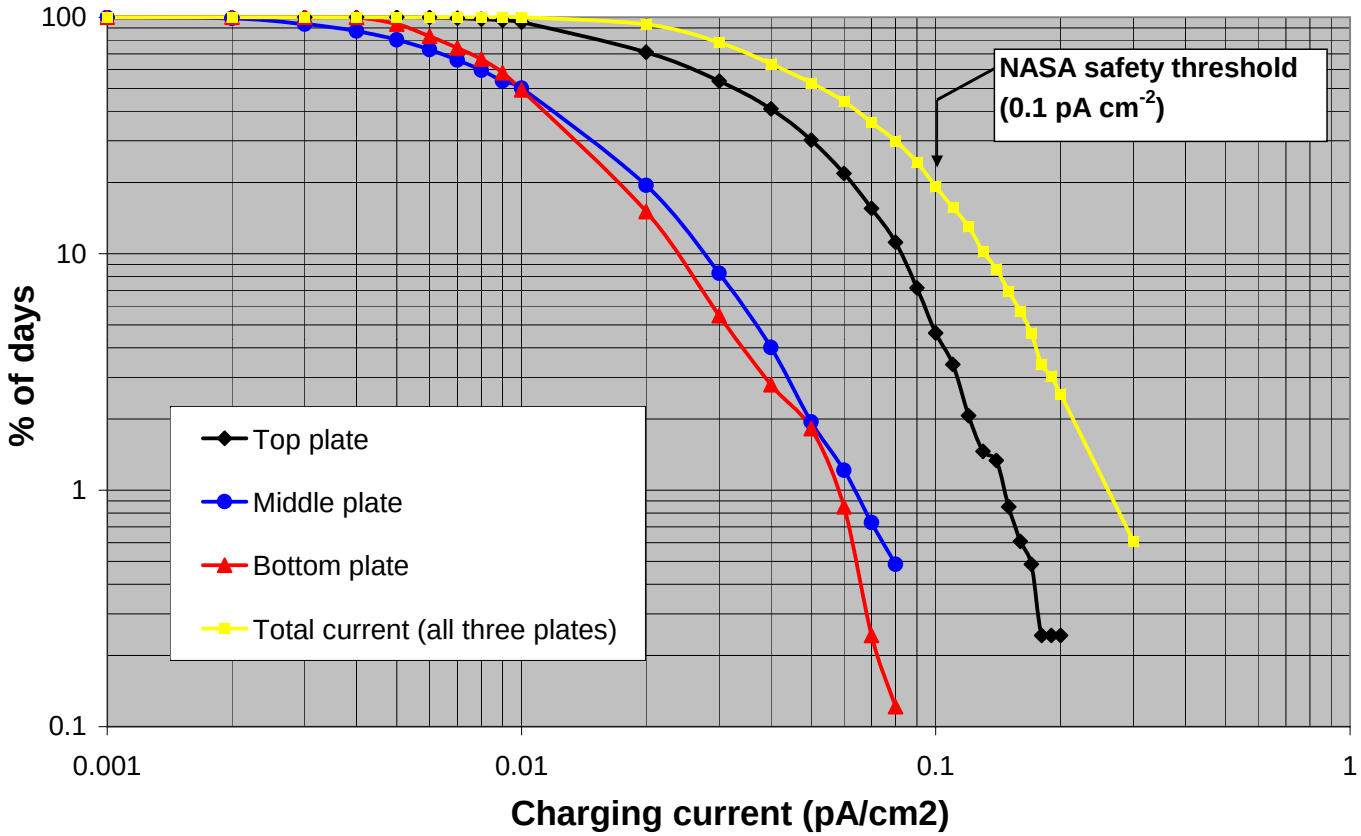
Fitted flux and hardness (assuming exponential spectrum)



Top plate - number of days for which daily mean of 0.1 pA cm^{-2} is exceeded.

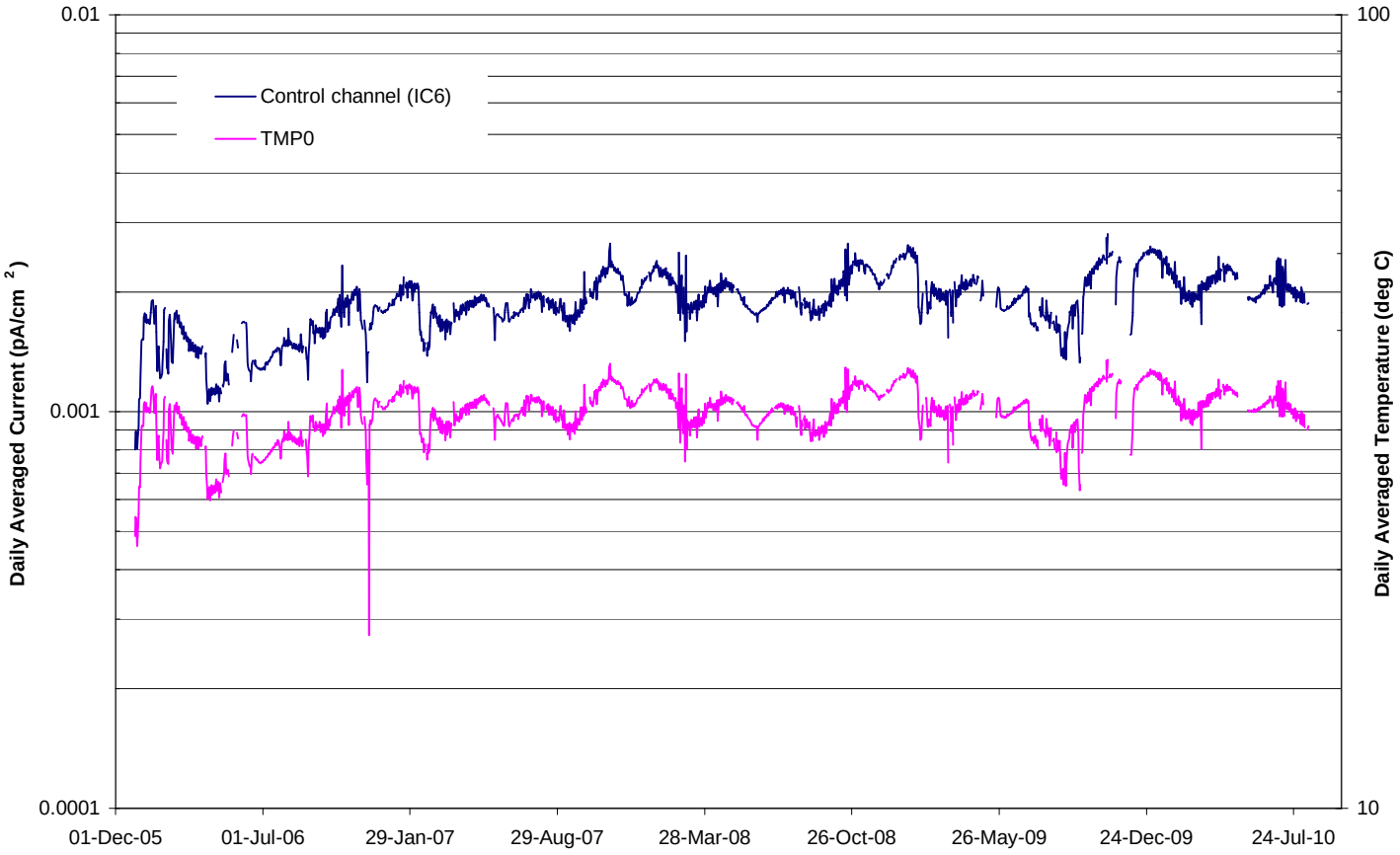


% of days exceeding a given charging current

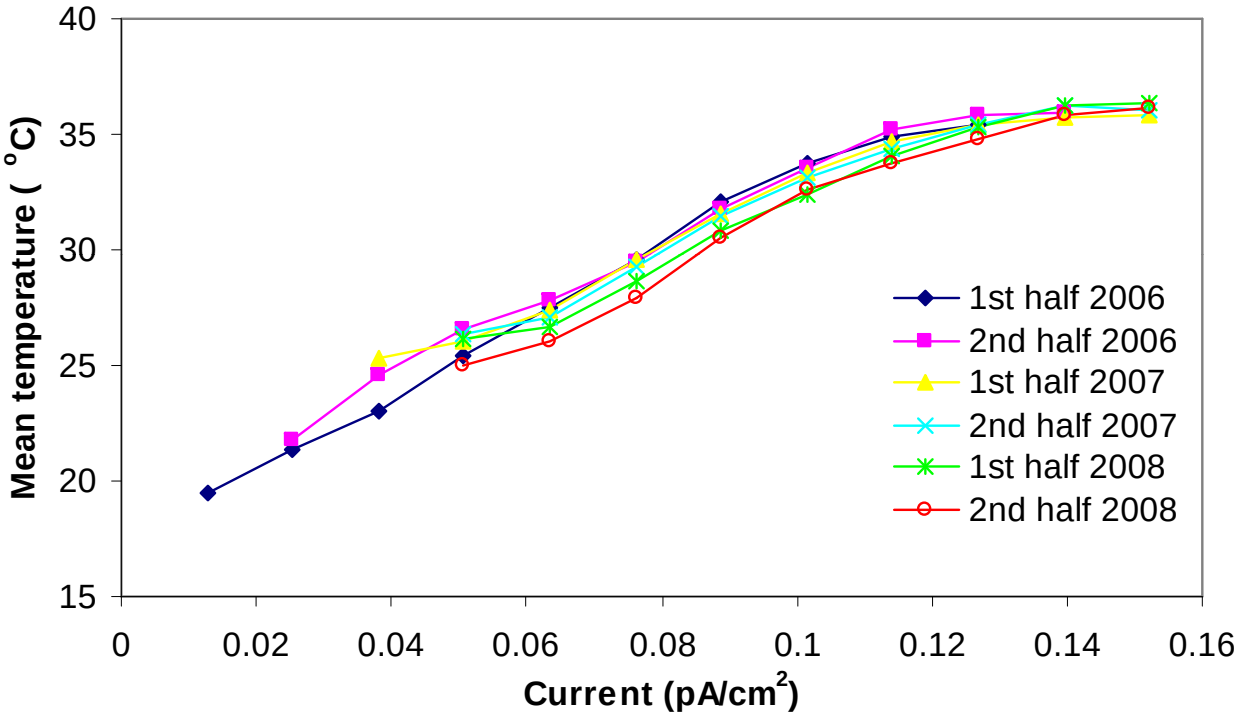


(Includes data up to April 2009.)

Control amplifier current and temperature



Temperature and control channel offset correlation (2005-2008)



Conclusions

- Merlin has now operated successfully in MEO from 2005-2010 which includes the solar minimum
- A number of significant charging events were observed in the declining phase 2005-2008 as would be expected
- An ~18 month quiet period was observed after the minimum of the smoothed sunspot number in Dec 08.
- New solar cycle has started with a significant electron belt enhancement event in April 2010.
  - appears to be the largest internal charging current for mission to date (though may ultimately be revised since some data was missing around this time).
- DICTAT3.5/FLUMIC3.0 for charging currents has proved to be a sensible 'worst case' design envelope so far.
- For the top plate 5% of days have exceeded the 0.1 pA cm^{-2} threshold (NASA Handbook 1999).

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