Recent Space Weather Measurements from Medium Earth Orbit and their Engineering Significance

European Space Weather Week, Oostende, Belgium, 2015.

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University of Surrey
Surrey Space Centre

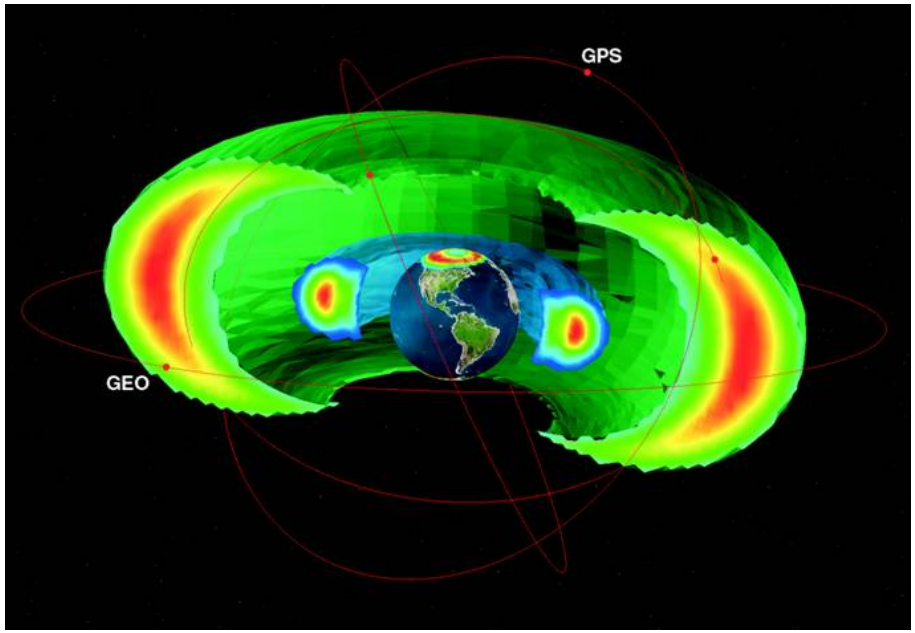

Image: NASA

Supported by:

FP7 SPACESTORM

ESA Giove Data Exploitation

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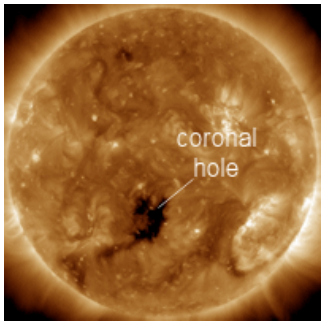
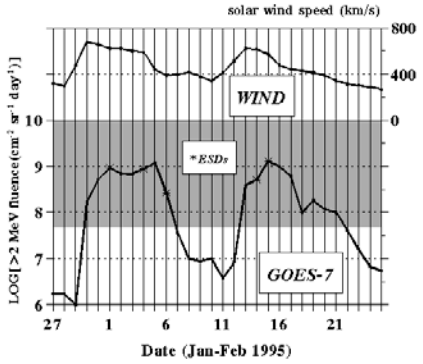
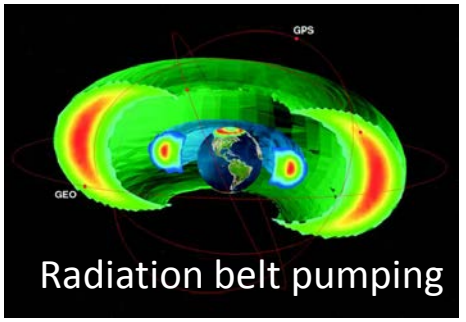
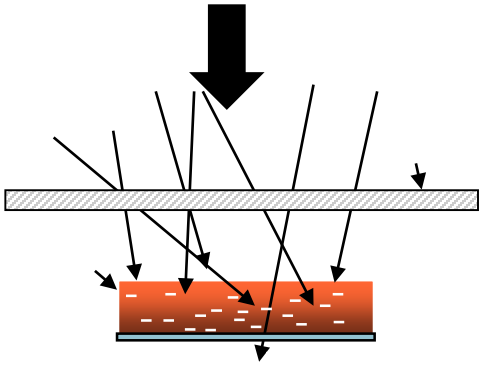
Internal charging: the chain of events leading to anomalies



Solar feature or event

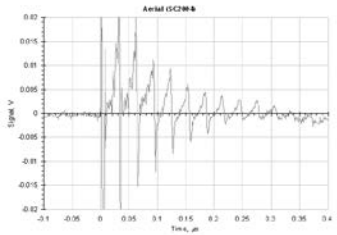




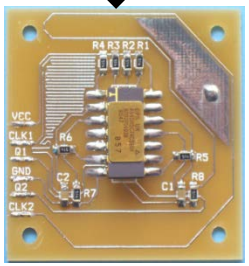


Electrostatic charging of spacecraft materials

Electrostatic discharge



Energy coupling into circuit



Circuit state change or damage

Satellite anomaly / failure/ outage

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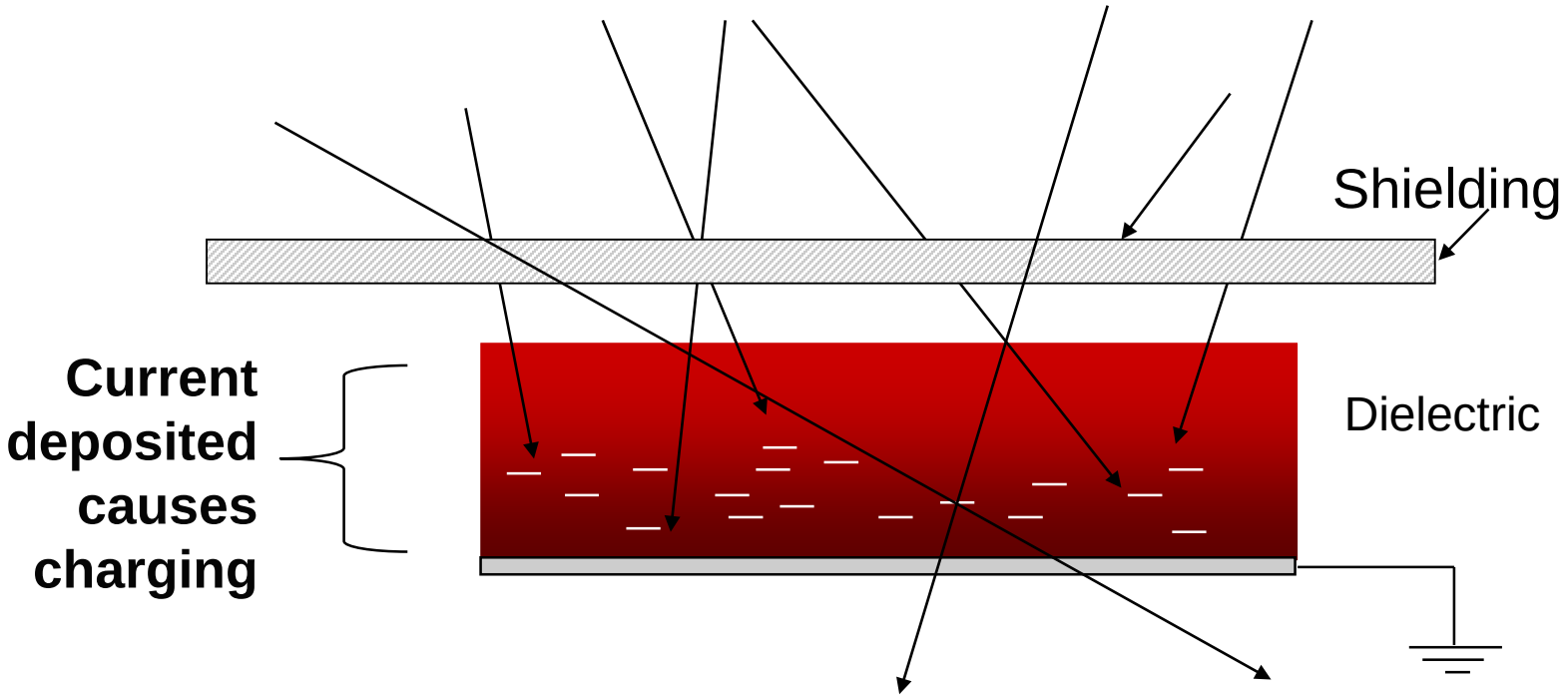
Internal charging

External high energy electrons – e.g. GOES
>2MeV, >0.8MeV electron fluxes



Dielectric breakdown typically at 10^7 V/m

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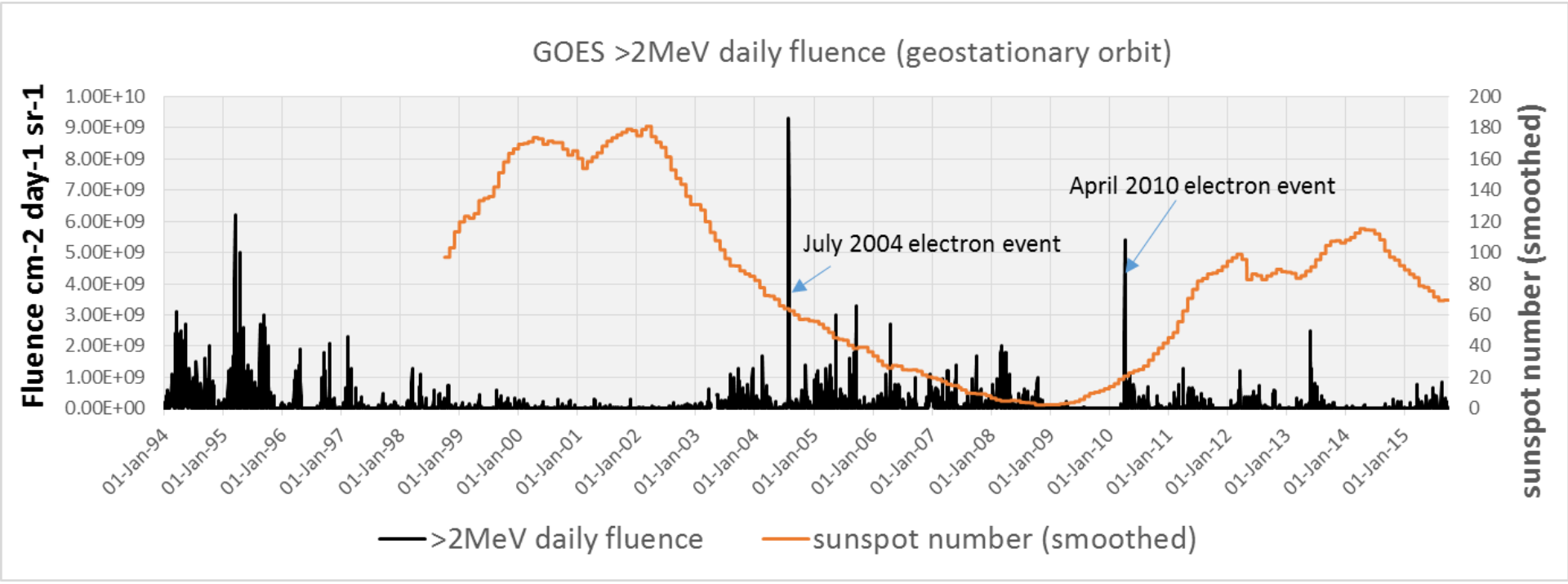
>2MeV electron daily fluences in geostationary orbit



Data from NOAA/SWPC and SIDC

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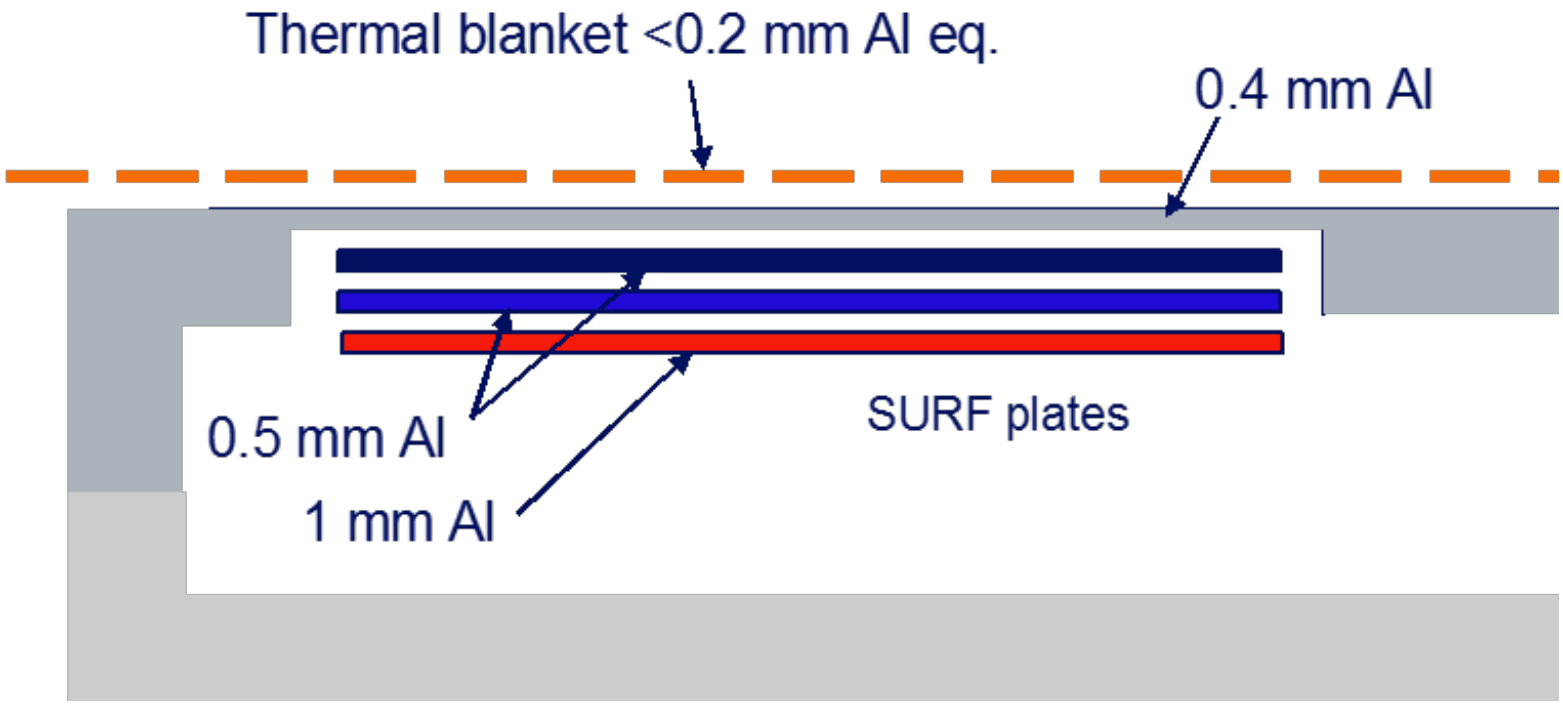
Internal charging current measurements



First such instrument: K. A. Ryden,et al, Profiles of Inner- and Outer-Belt Internal Charging Currents against Geomagnetic Parameter 'L': Results from the First SURF Experiment, Proceedings of 7th Spacecraft Charging Technology Conference, ESA-ESTEC, Noordwijk, The Netherlands, 23-27 April 2001.

Also see: K. A. Ryden,et al, Observations of internal charging currents in medium Earth orbit, *IEEE Transactions on Plasma Science*, Vol. 36, No.5, October 2008.

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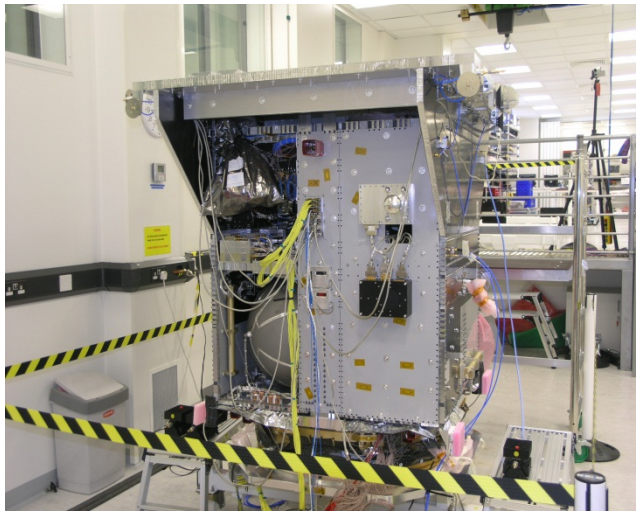
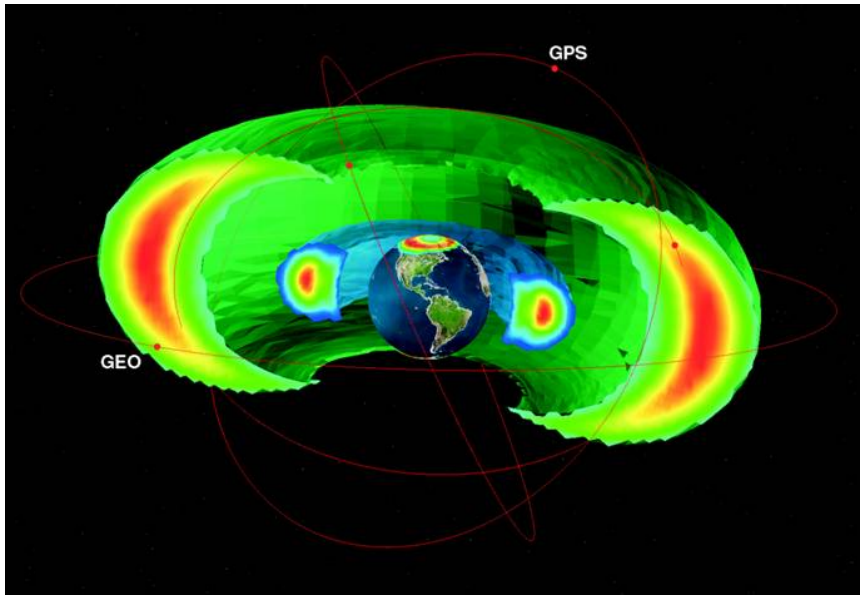
Giove-A

- December 2005 launch (built by SSTL for ESA)
- Orbit 23,260 km and 56 degrees inclination, 27 month lifetime
- Prime mission finished
- Re-orbited by +300km in 2009
  - Severe trapped electron environment
    - Charging effects
    - Total ionising dose
  - Galactic cosmic rays
  - Solar protons and ions
- Now collecting additional radiation data.



SSTL image



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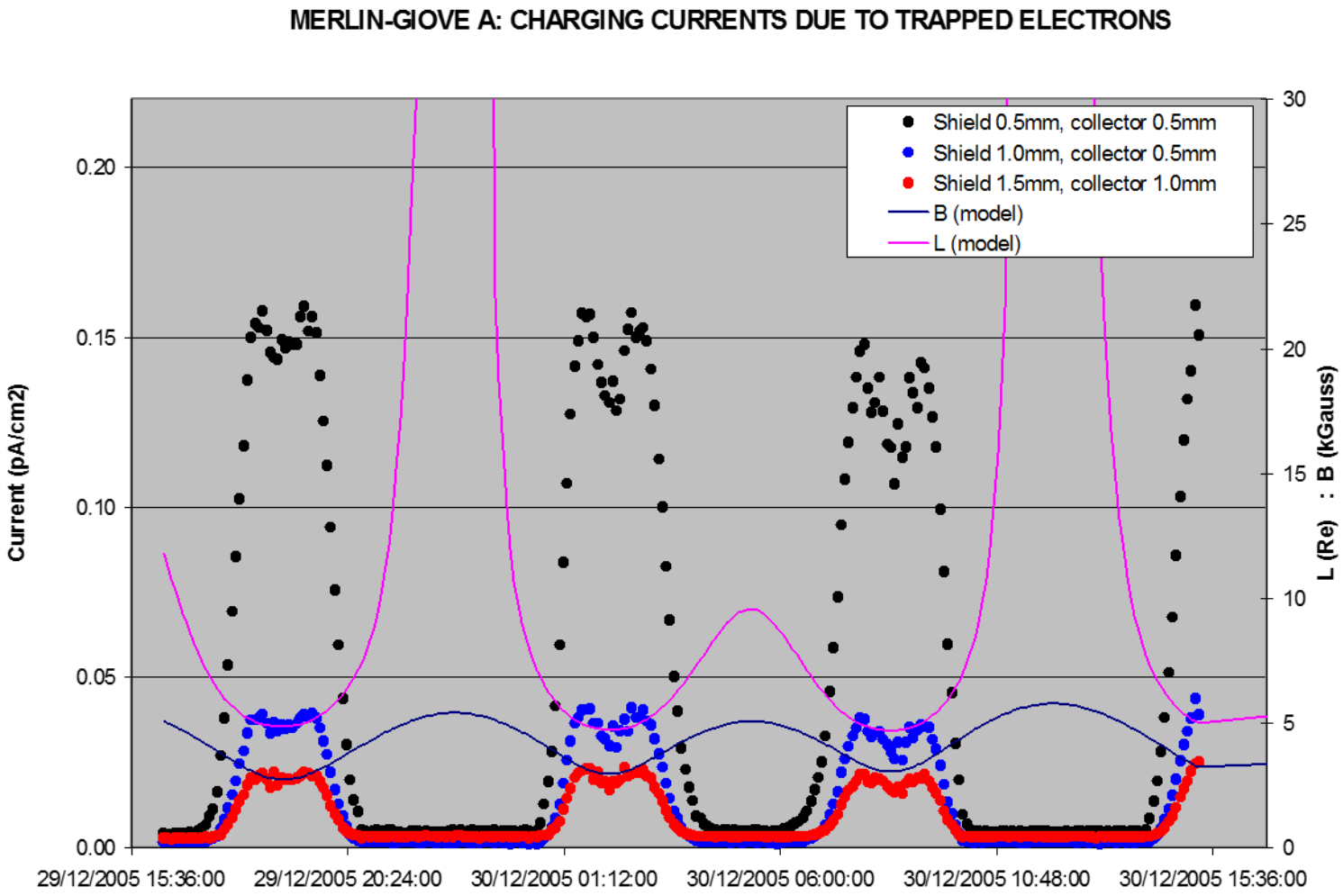
1st day of data: charging currents



From: K. A. Ryden,et al, Observations of internal charging currents in medium Earth orbit, *IEEE Transactions on Plasma Science*, Vol. 36, No.5, October 2008.

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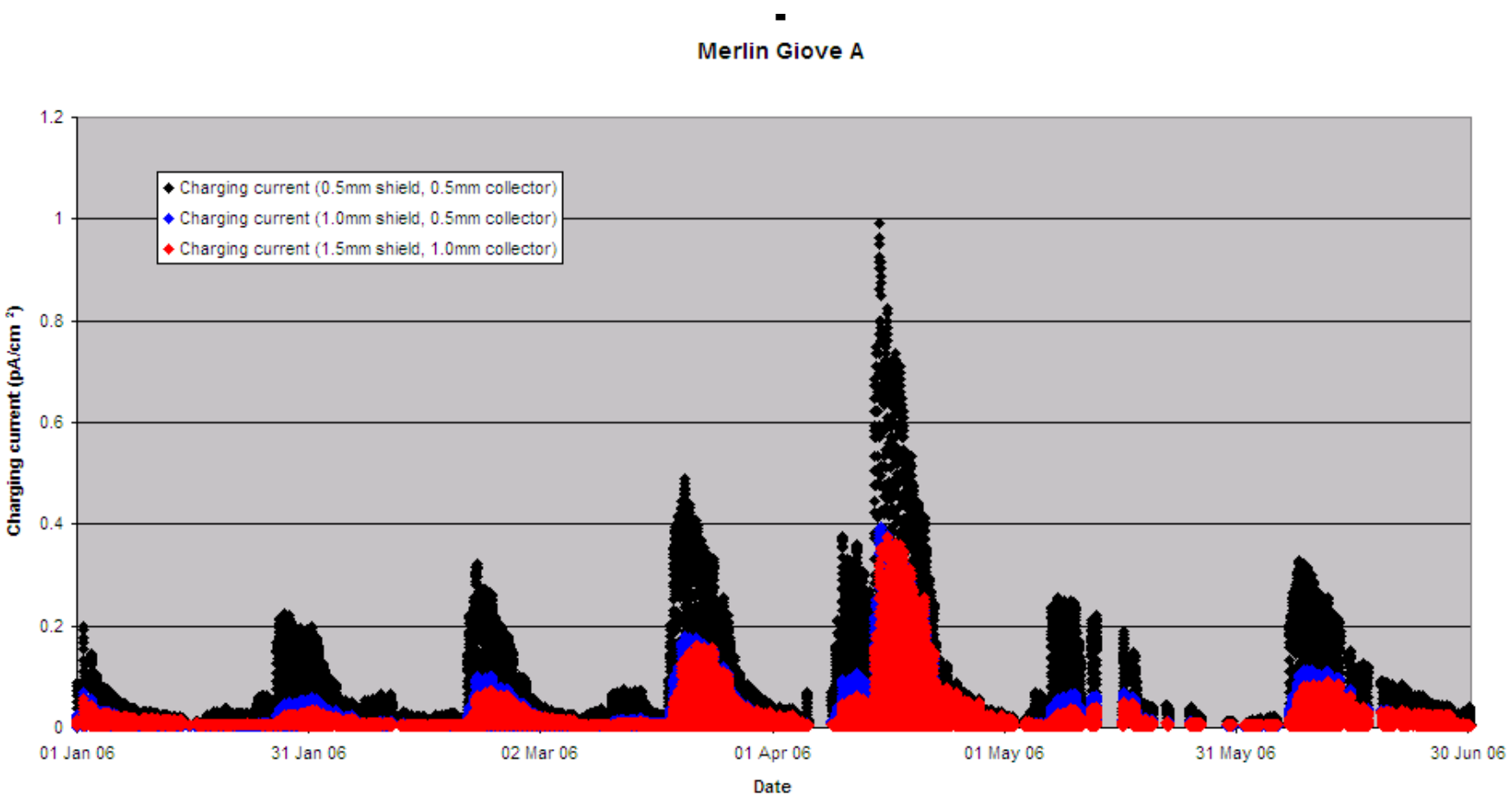
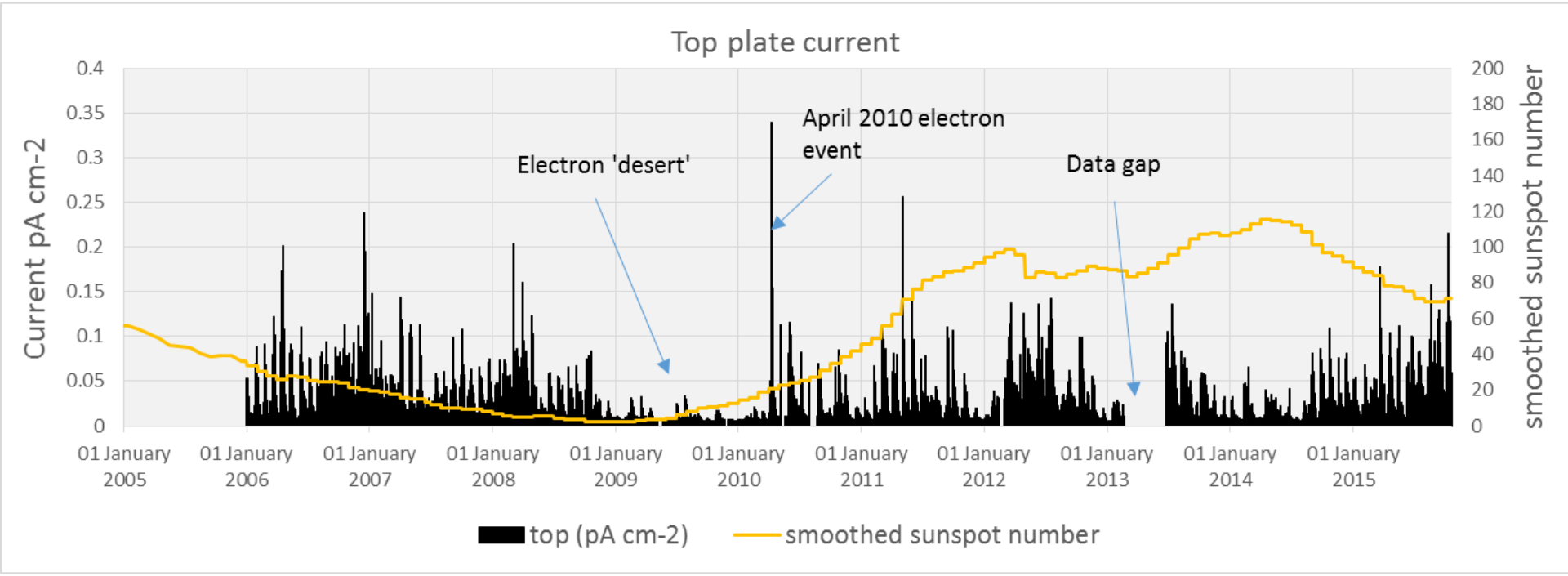
January to June 2006: charging currents



Top plate charging current (daily averages)



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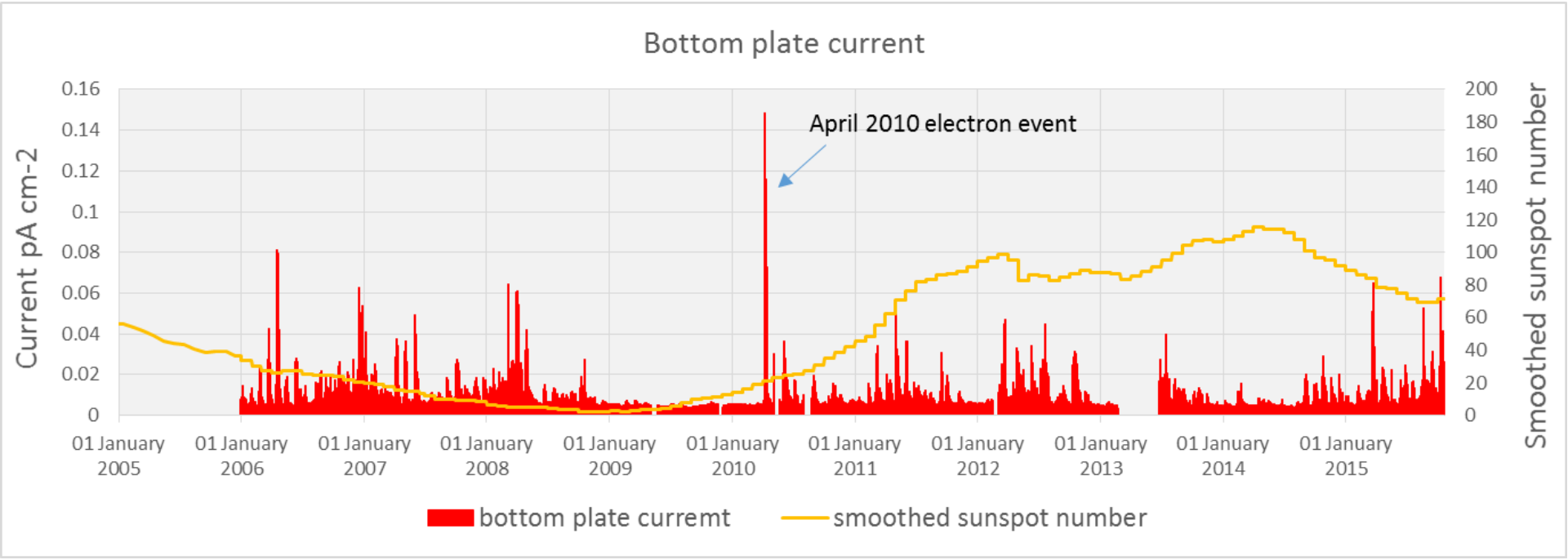
Bottom plate charging current (daily averages)



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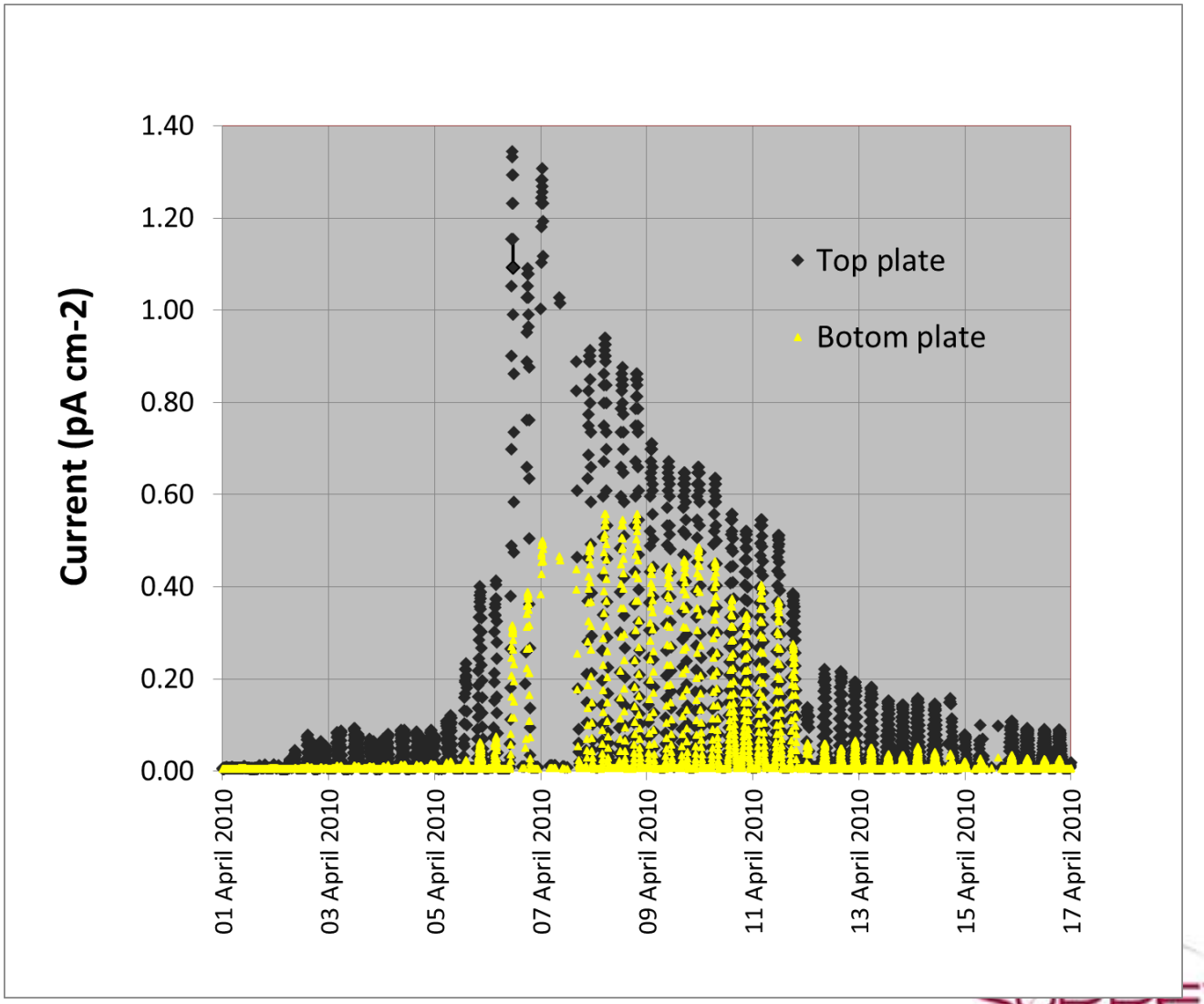
April 2010 – largest internal charging event in our data set



From: K. A. Ryden et al, Internal Charging Measurements in MEO using the SURF sensor: 2005-2013, IEEE Trans. Plasma Sci., Vol. 43, No.9, Sept 2014.

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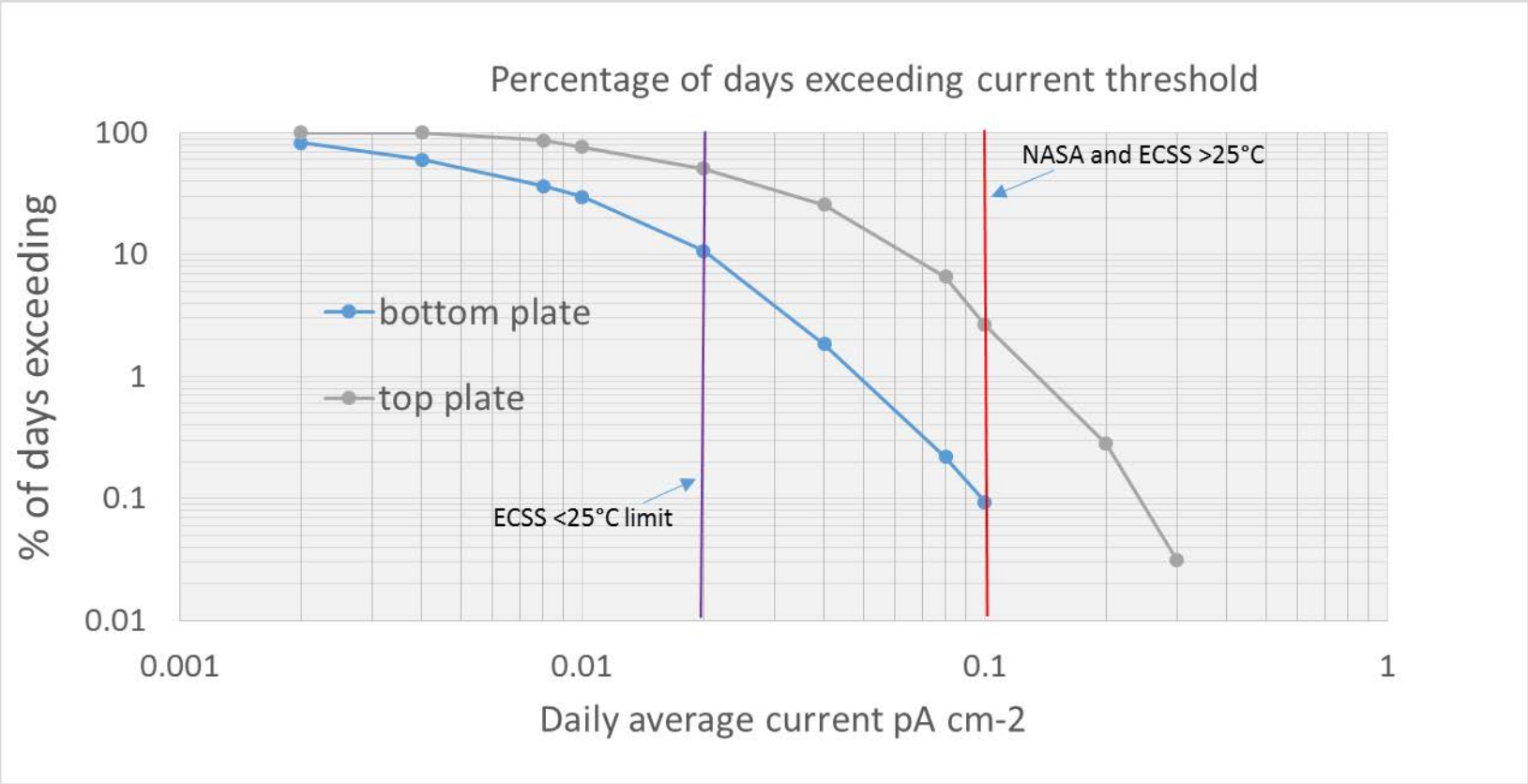
Currents deposited



Engineering limits (1-day averages):

- 0.1pA cm^{-2} deposited current (NASA, ECSS>25ºC)
- 0.02pA cm^{-2} (ECSS <25ºC)

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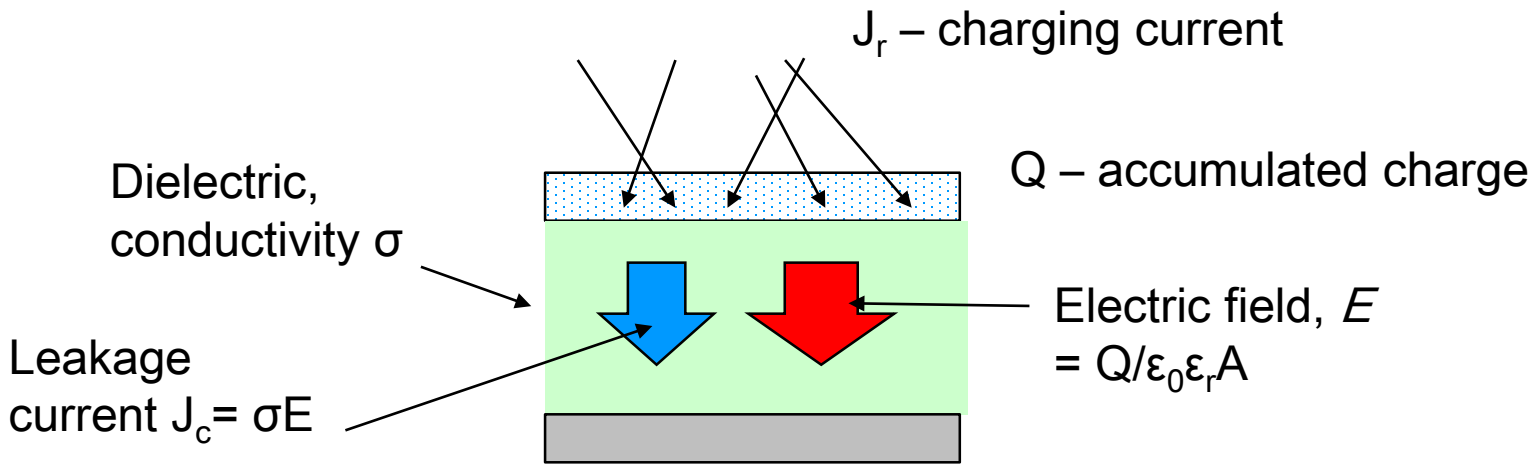
Model of electric field in dielectrics

Bodeau* examined charge/field build up using simple 'leaky capacitor' model (using external fluxes in GEO to estimate charging currents)

We take similar approach, but use measured charging currents as the input to calculation (MEO)



$$E(t+\Delta t) = E(t)\cdot e^{-\frac{\Delta t}{\tau}} + \frac{J_r}{\sigma}\left(1 - e^{-\frac{\Delta t}{\tau}}\right) \quad \text{where} \quad \tau = \frac{\varepsilon_0 \varepsilon_r}{\sigma}$$

*M Bodeau, 48th AIAA Aerospace Sciences Mtg, January 2010, Orlando, Florida.

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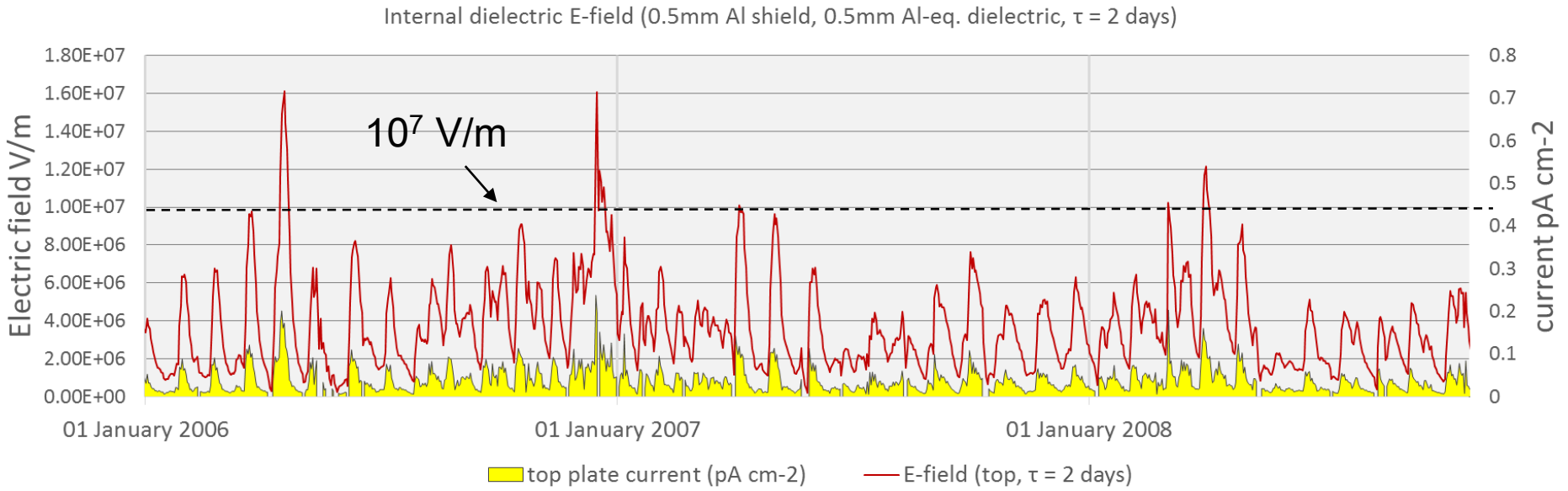
Dielectric internal field modelling (2006 - 2009)

0.5 mm Al shielding

0.5mm Al-eq. thickness absorber

Dielectric conductivity 1E-16 ohm^{-1} m^{-1}

Relaxation time constant: **2 days**



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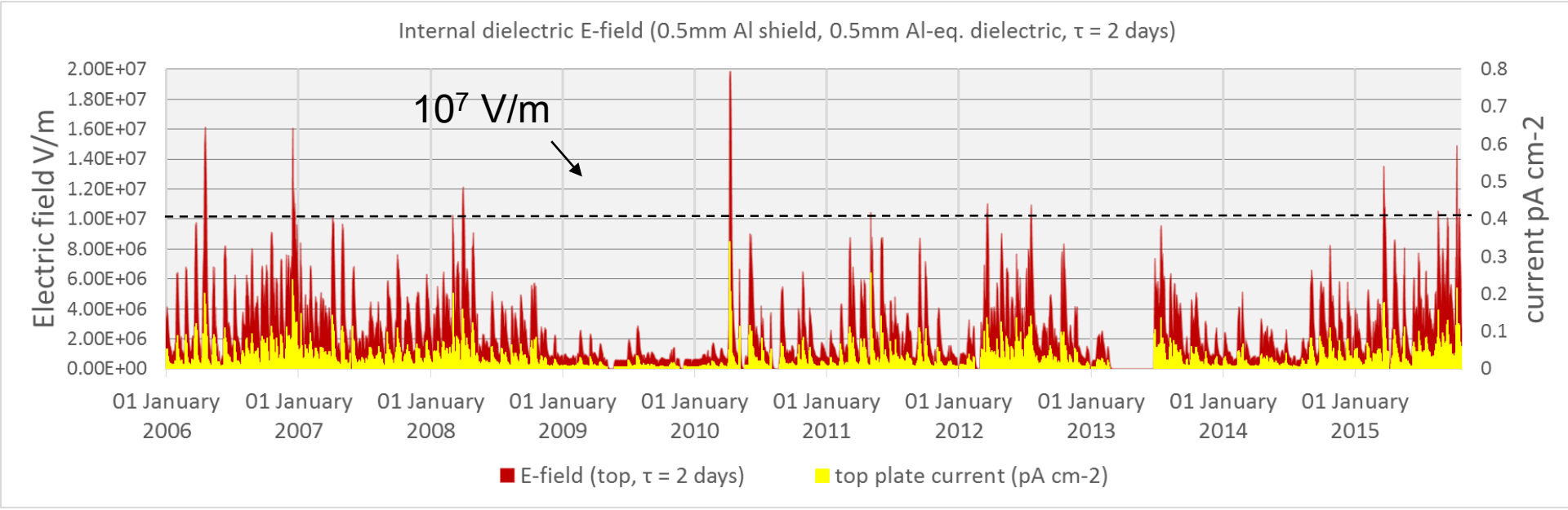

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Dielectric internal field modelling (2006 – 2009)

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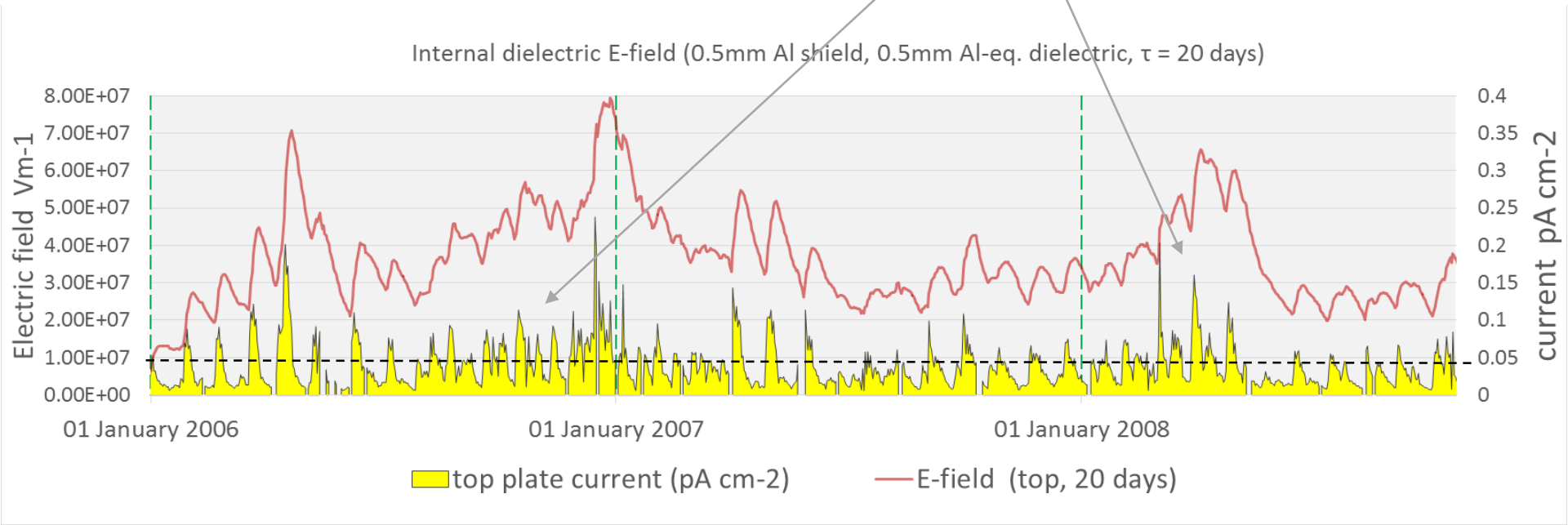
0.5mm Al-eq. thickness dielectric

Dielectric conductivity 1E-17 ohm^{-1} m^{-1}

Time constant **20 days**

Periods with multiple coronal holes



E-field much larger and peaks not co-incident with peak fluxes

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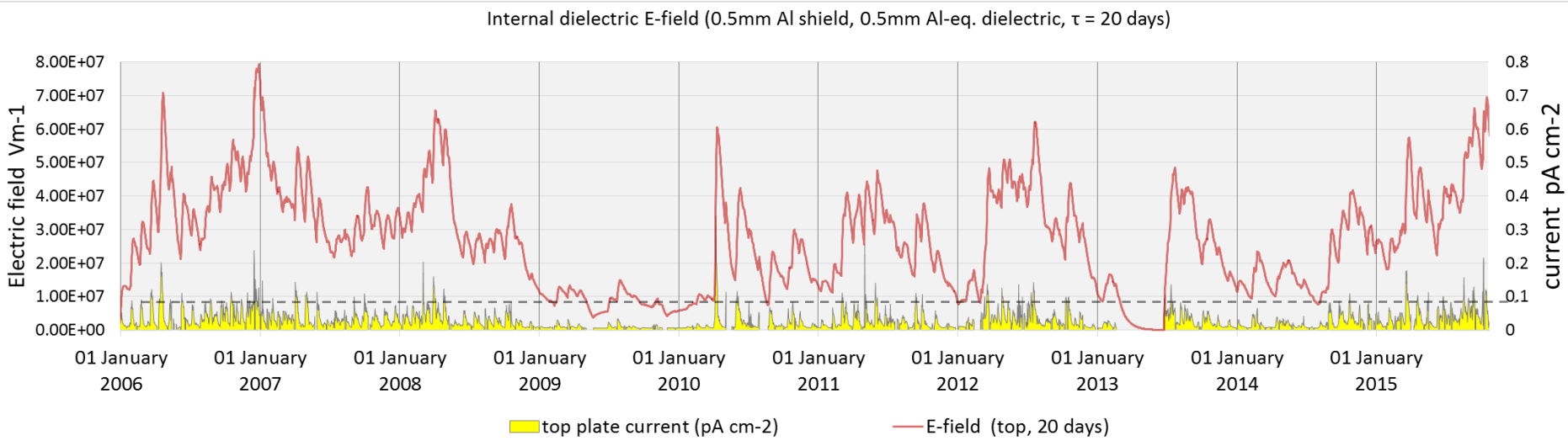
0.5mm Al-eq. thickness dielectric

Dielectric conductivity 1E-17 ohm^{-1} m^{-1}

Time constant 20 days



April 2010 E-field no longer the peak

December 2006 is peak time.

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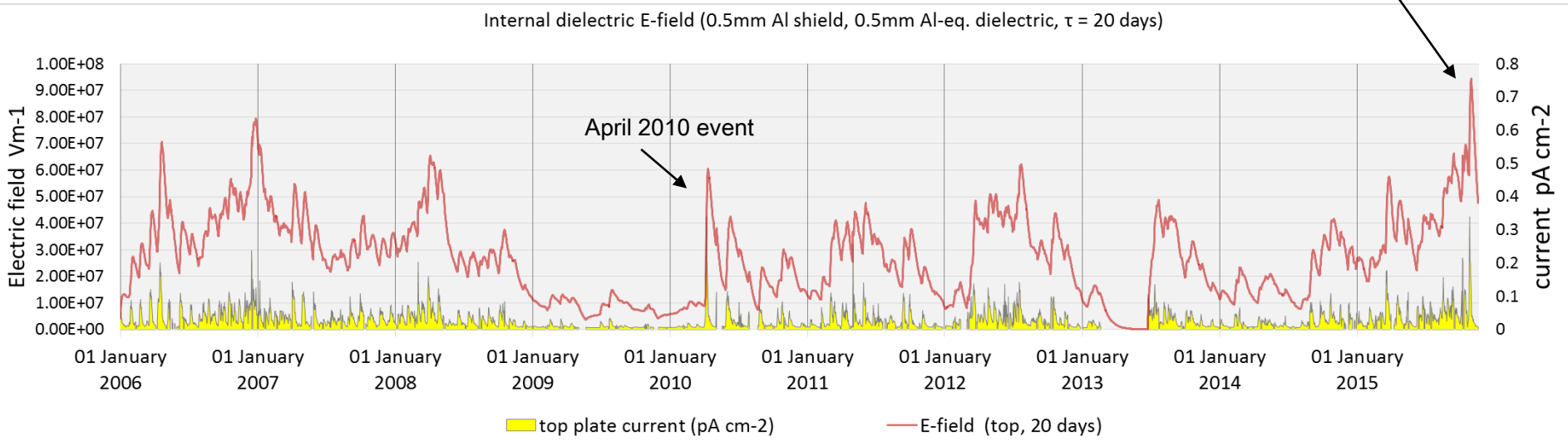
What if April 2010 event occurred now?

Repeat of April 2010 inserted at 21st October 2015



- More threatening now (given the recent history of multiple electron events).

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Conclusions

Current measurements enable improved insights into the charging process:

- 1.5 mm Al shielding insufficient to supress currents to below the 0.1pA cm^{-2} daily mean
- Monitoring at greater shielding depths would be advantageous (e.g. 2mm, 4mm etc)

Electric field modelling (long time constant materials) indicates:

- Peak field (Dec 2006) occurred 3 years before peak daily current (April 2010)
- Periods with multiple coronal holes are central to increasing threat level
- E-fields increasing at present due to increased coronal hole activity

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