Energetic charged particle absorption signatures in Saturn's magnetosphere: observations and applications

E. Roussos [1], N. Krupp [1,] P. Kollmann [1], M. Andriopoulou [1],
C. Paranicas [2], D.G Mitchell [2], S.M. Krimigis [2, 3], M.F. Thomsen[4]

1: Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany
2: John Hopkins Applied Physics Laboratory, Laurel, Maryland, USA
3: Office of Space Research and Technology, Academy of Athens, Greece
4: Los Alamos National Laboratory, USA

Electron Microsignatures

1. Localized dropouts in energetic electron fluxes, caused by particle absorption on moons or rings

2. Depth of dropout is dependent on the angular separation from the absorbing body (typically decreasing)

Jones et al. (2006)

0 deg

30 deg

Angular separation

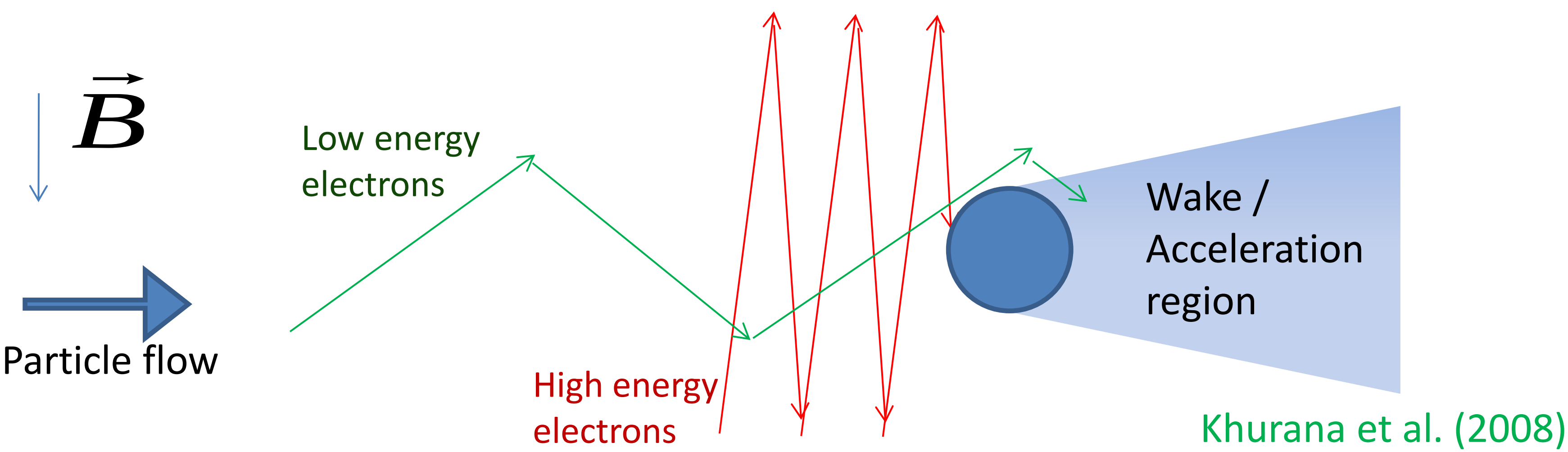
Microsignature formation

1. Plasma absorbing interaction (e.g. similar to Earth‘s Moon – S.W. interaction)
2. Plasma absorbing moons at Saturn (Mimas, Tethys, Dione, Rhea…)
3. Main features:

- Formation of plasma cavity (wake) & interaction region downstream
- Refilling processes of the wake

Wake refilling I

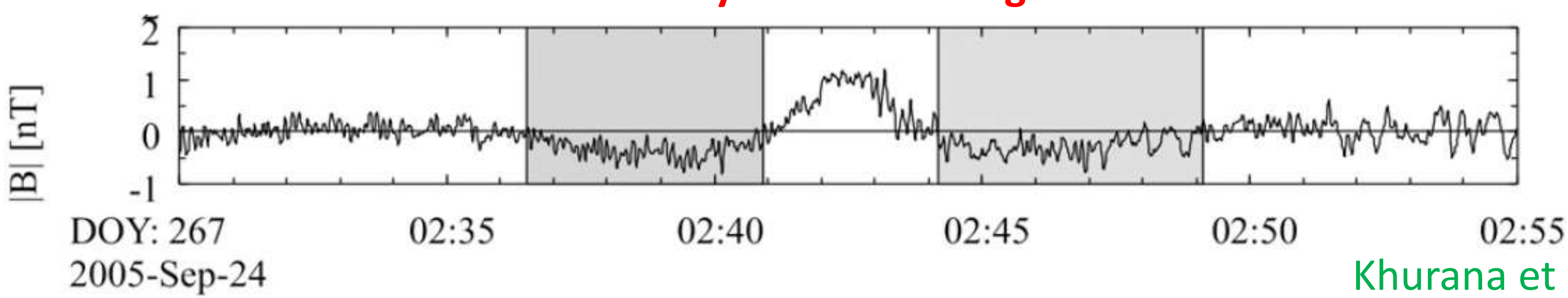
1. Along the field (most effective):
   - Potential drops, field aligned particle acceleration, two-stream instability…
   - Does not work for energetic electrons (above few keV) at Saturn´s moons:



Wake refilling II

2. Perpendicular to the field (less effective):
   - Electric fields due to pressure gradients, deviation from charge neutrality
   - Even less effective for energetic particles

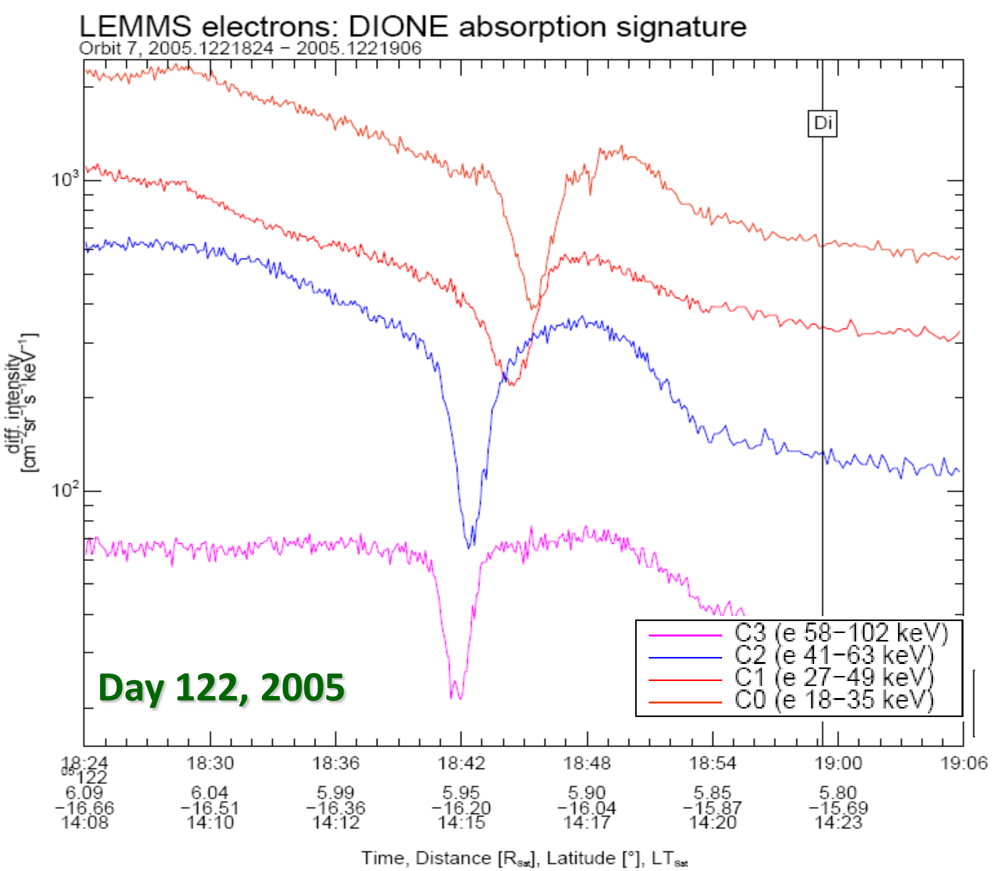
Tethys wake crossing

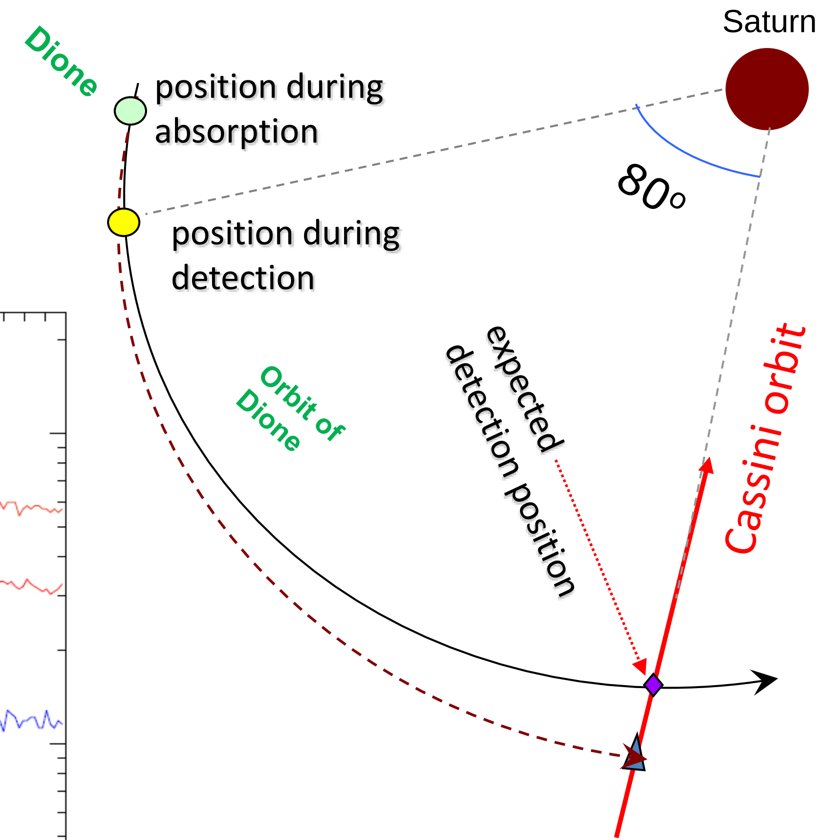


Khurana et al. (2008)

- Magnetic drifts of energetic particles occur on lines of equal B_m
- Energetic particles have the tendency to be excluded from the wake

Electron microsignatures

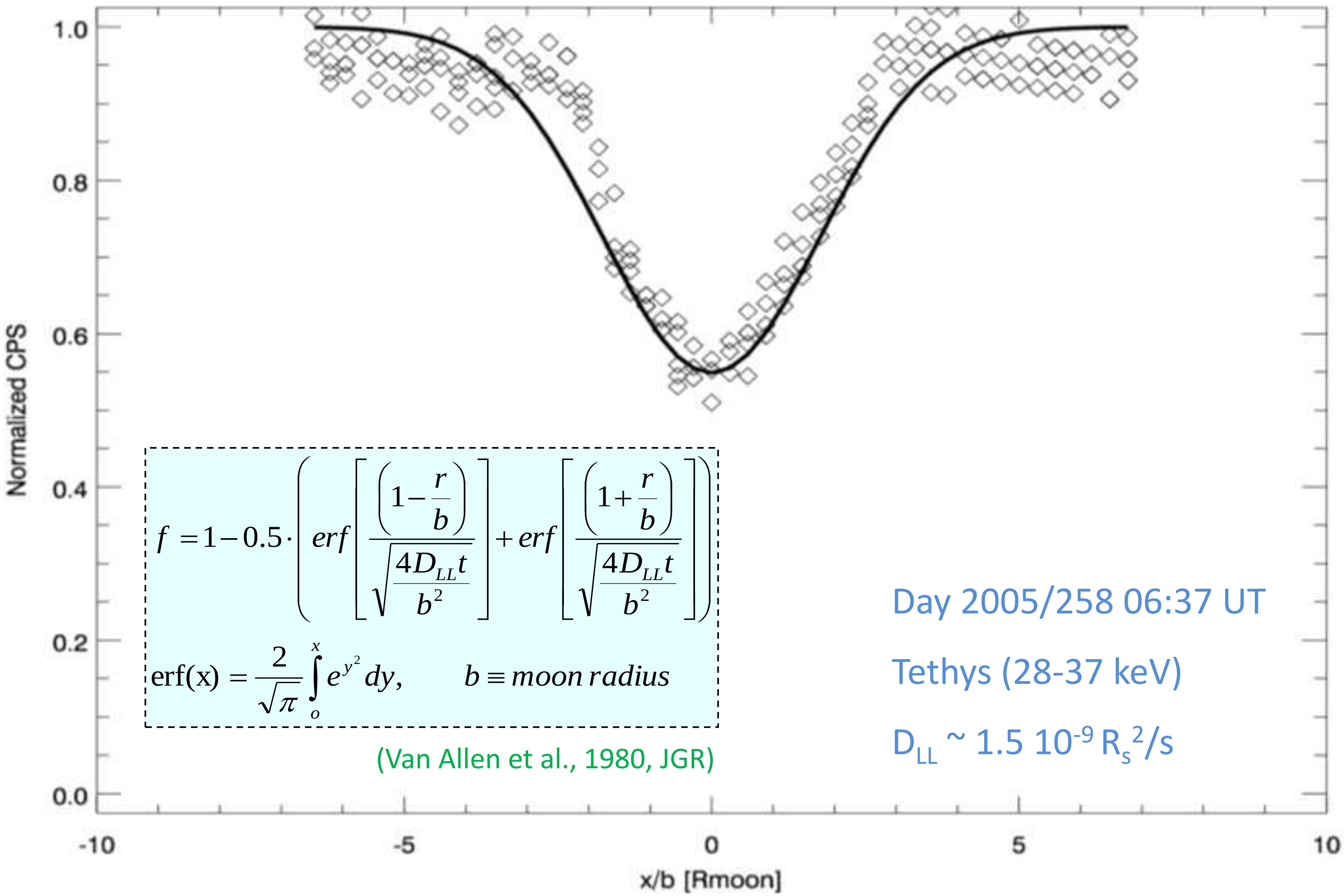




Studies

1. Refilling of microsignatures
2. Displacement of microsignatures

Magnetospheric diffusion (I)



$$f = 1 - 0.5 \cdot \left(erf\left[\frac{\left(1 - \frac{r}{b}\right)}{\sqrt{\frac{4D_{LL}t}{b^2}}} \right] + erf\left[\frac{\left(1 + \frac{r}{b}\right)}{\sqrt{\frac{4D_{LL}t}{b^2}}} \right] \right)$$

$$\mathrm{erf(x)} = \frac{2}{\sqrt{\pi}} \int_o^x e^{y^2} dy, \qquad b \equiv moon\, radius$$

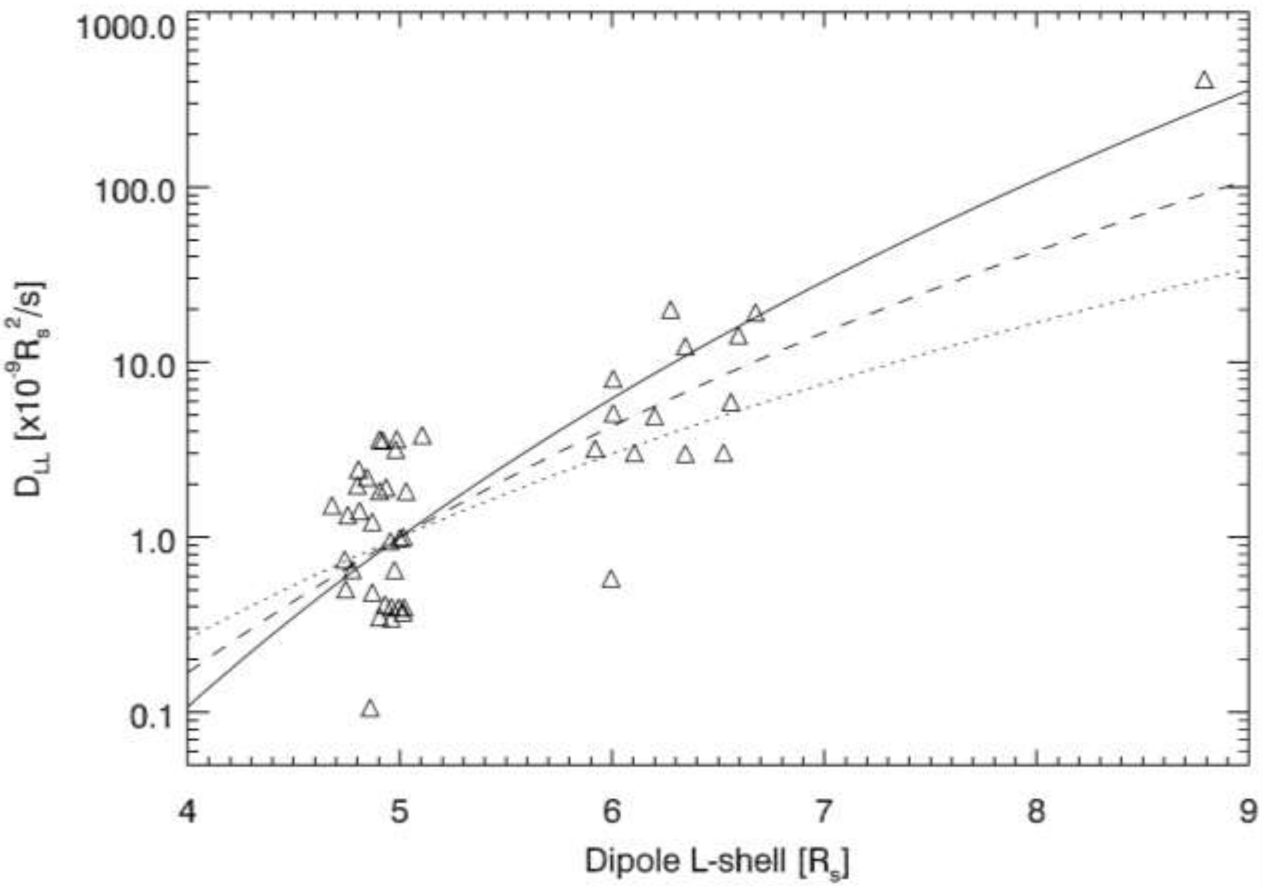
(Van Allen et al., 1980, JGR)

Day 2005/258 06:37 UT

Tethys (28-37 keV)

D_{LL} ~ 1.5 10^{-9} R_s^2/s

Magnetospheric diffusion (II)

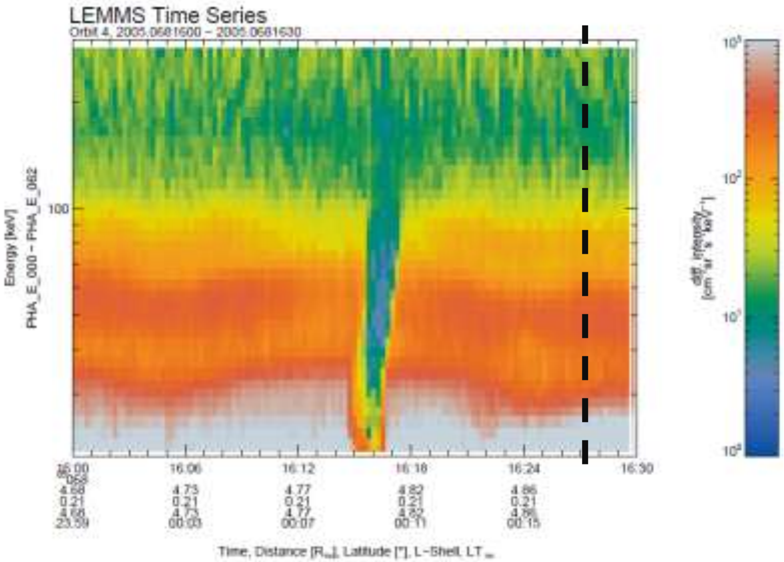


Roussos et al. (2007)

Studies

1. Refilling of microsignatures
2. Displacement of microsignatures

Types of displacements

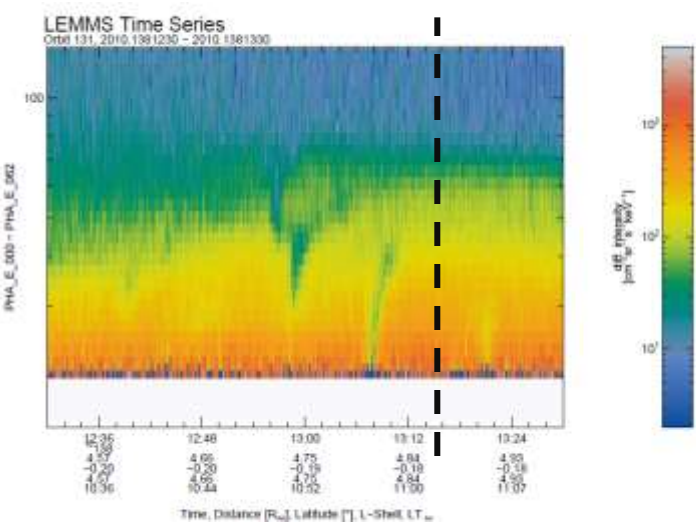


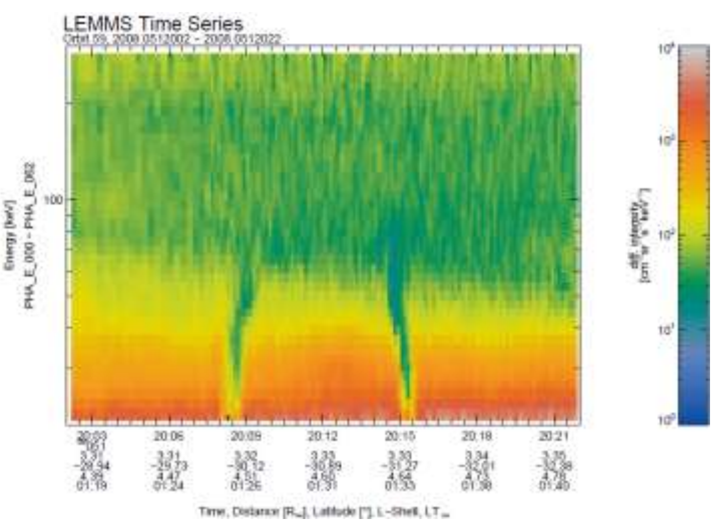
(A) ORGANIZED

(B) COMPLEX

<u>Displacement origin:</u>

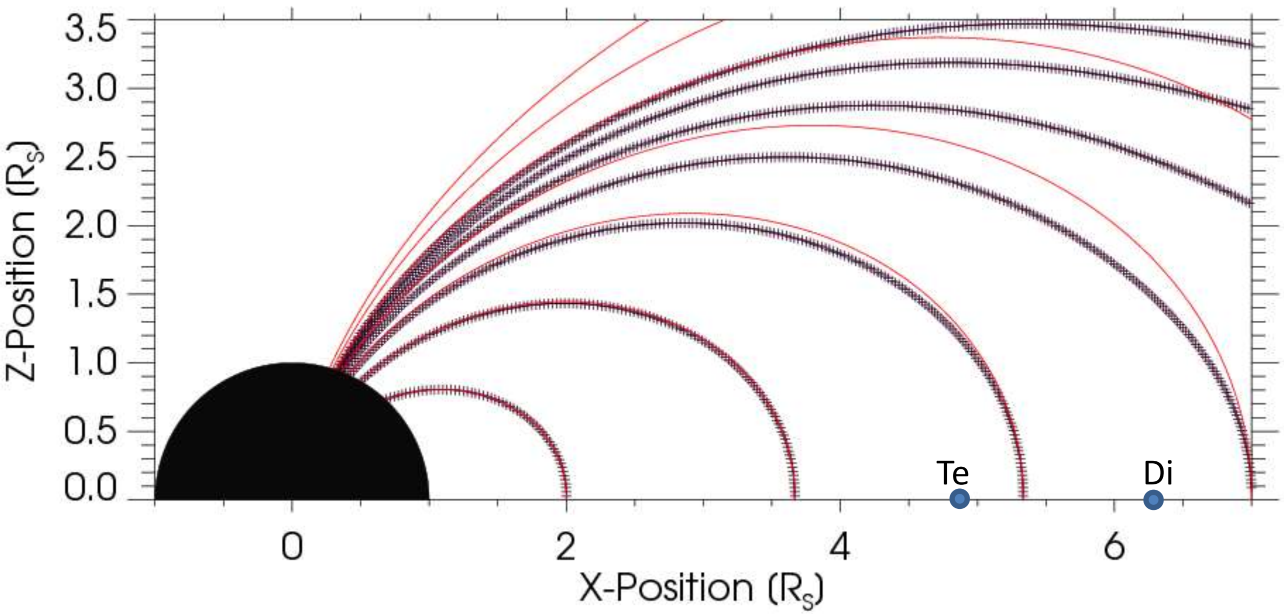
- Dipole assumption insufficient
- Magnetospheric electric fields





Magnetic field models (I)

Insufficient mapping of equatorial microsignature location when using a dipole?

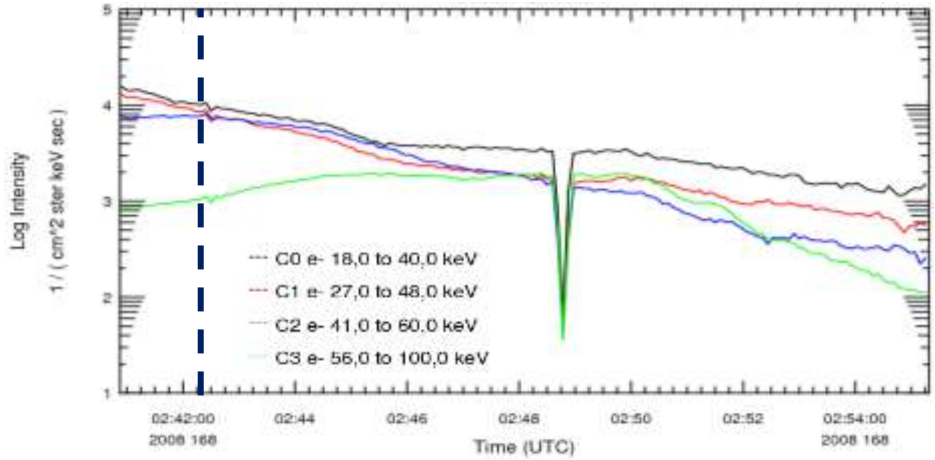


Model field lines based on: Giampieri and Dougherty (2005)

Succesfull tracing can help set constrains on field model inputs:

- Current sheet boundaries/dimensions
- Plasma/energetic particle parameters of ring current
- Solar wind parameters, magnetopause distance

Magnetic field models (II)



Example:

- *DOY 2008-168/ 40 deg latitude*
- *2 deg downstream of Dione*
- *Inwards displaced assuming a dipole*

Succesfull tracing with:

a) Current sheet model + magnetopause scaling laws by Bunce et al. (2006), (MP at 21.3Rs) + current sheet thickness of 2.4-2.5 Rs

b) K. Khurana‘s model (AGU, 2006) for SW dynamic pressure that corresponds to a MP distance of 21.5 Rs

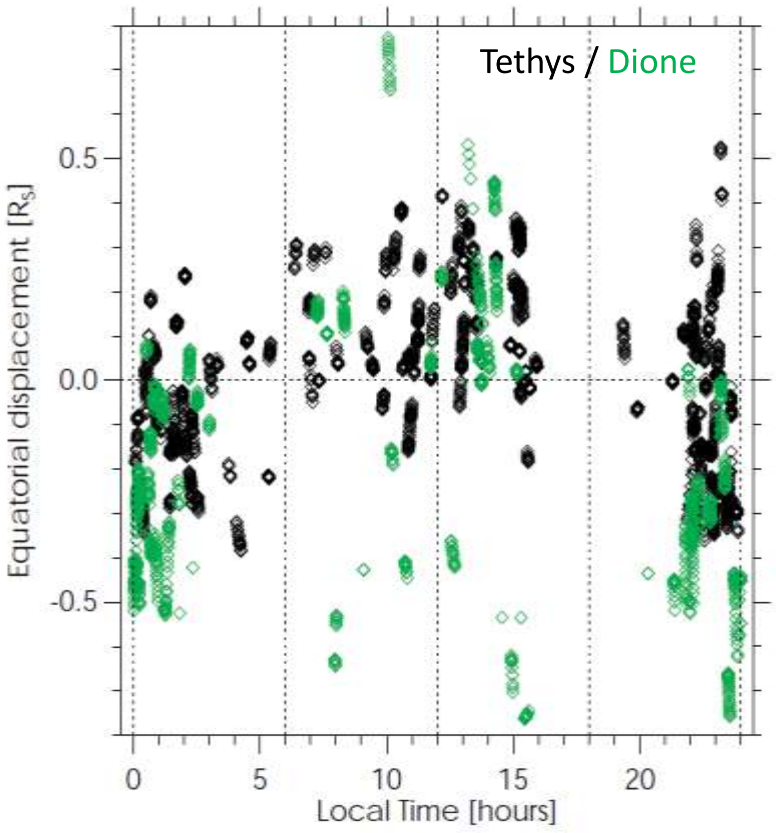
Results not always consistent from different magnetic field models

Magnetic field models (III)

1. Only part of the solution
2. Displacements visible also at equatorial latitudes
3. Current sheet perturbation explains only inward displacements
4. Drift shell spliting weak (10-15% difference would be required between day/night |B| at constant radial distance & latitude)
5. Energy dependent displacements, complex displacement profiles cannot be explained

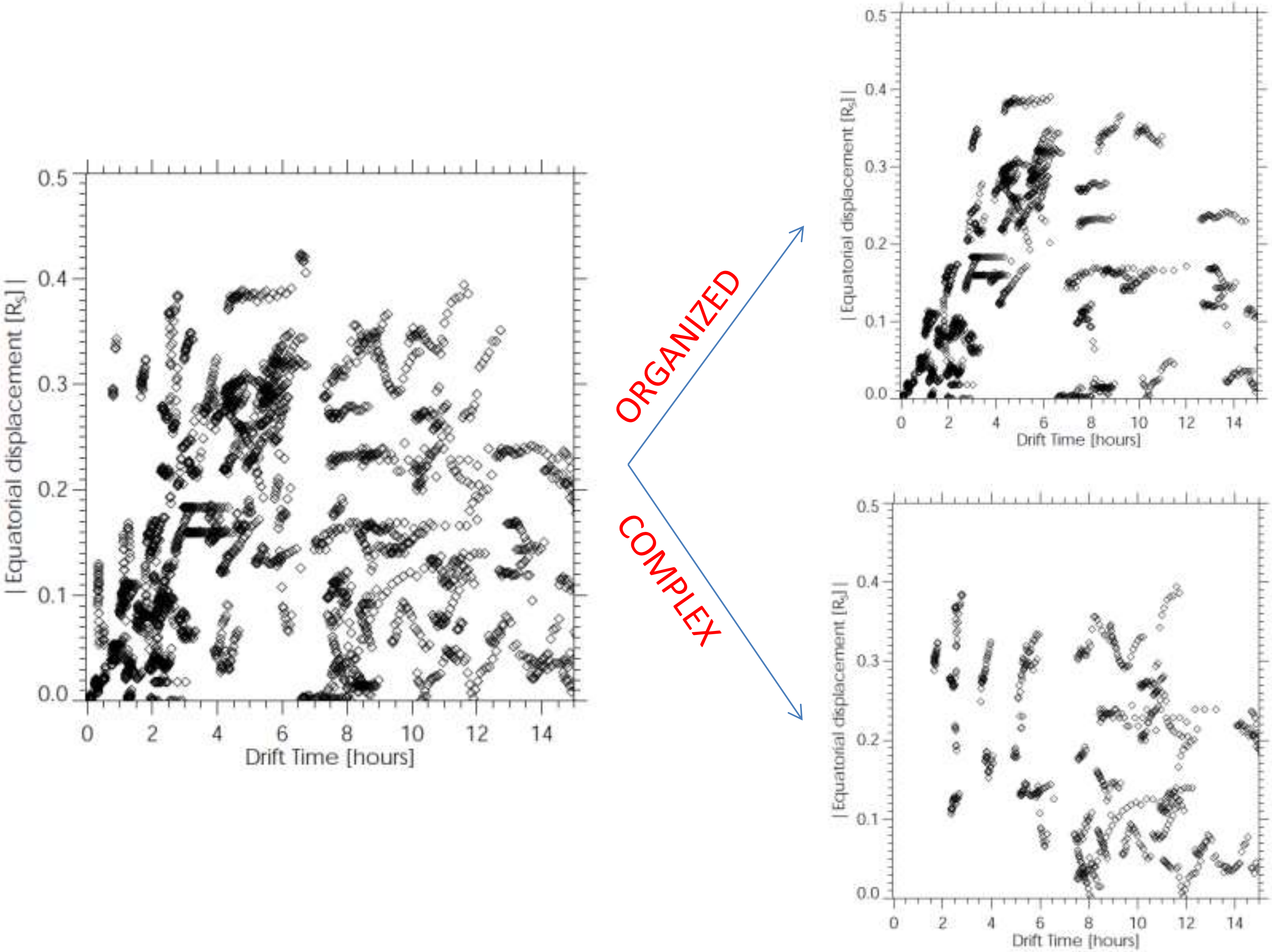
→ Magnetospheric electric fields necessary

Electric Fields (I)



1. Displacement calculation corrected for current sheet perturbation
2. On average:
   - outward at noon
   - inward at midnight
   - smaller amplitudes at dawn-dusk
3. Consistent with a noon-midnight electric field

Electric Fields (II)

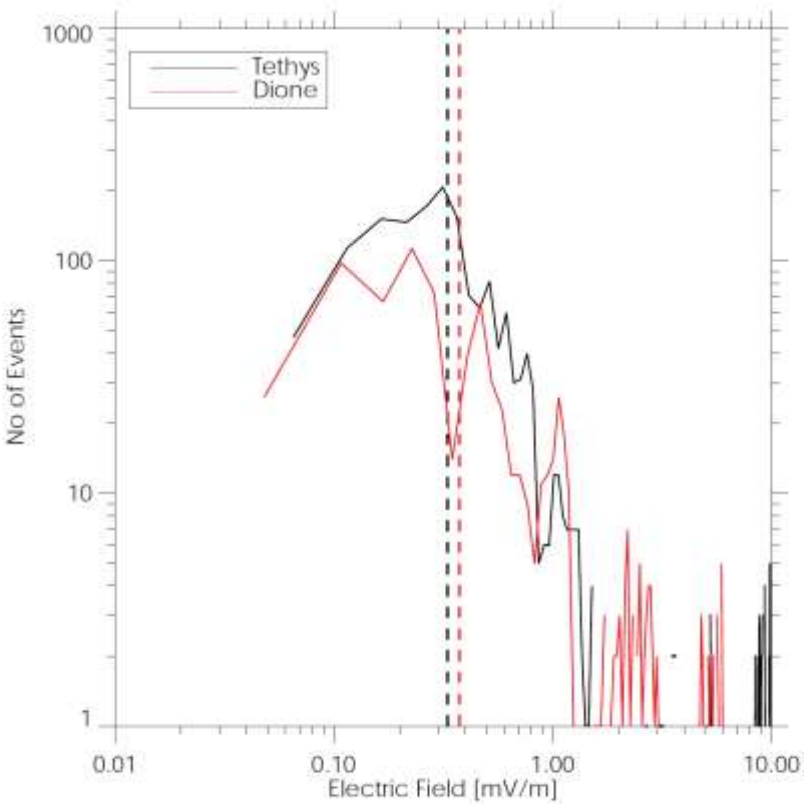


Electric Fields (III)
(noon to midnight electric field)

Various methods for electric field estimation, eg:

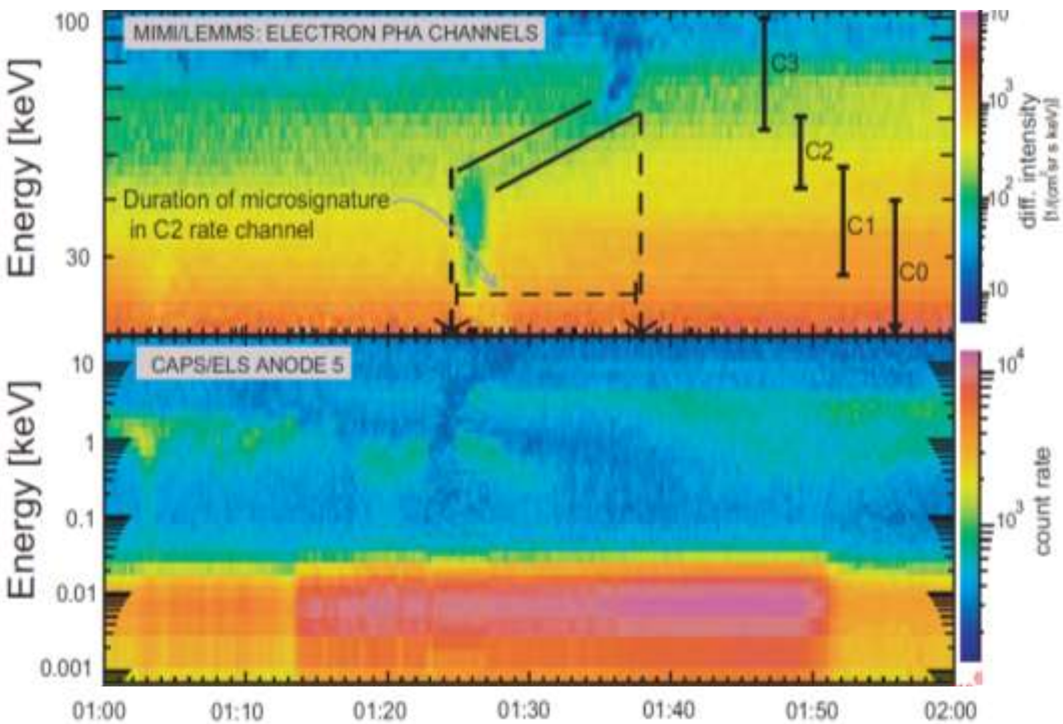
$$\Phi = \frac{\alpha\,\Omega\,B_O R_S^2}{L} - \frac{mc^2}{|q|}\left[\left(\frac{2\mu B_m}{mc^2}+1\right)^{\frac{1}{2}} - 1\right] - E_o L R_s cos\vartheta,\ \ (\theta = 0, \text{LT 12h})$$

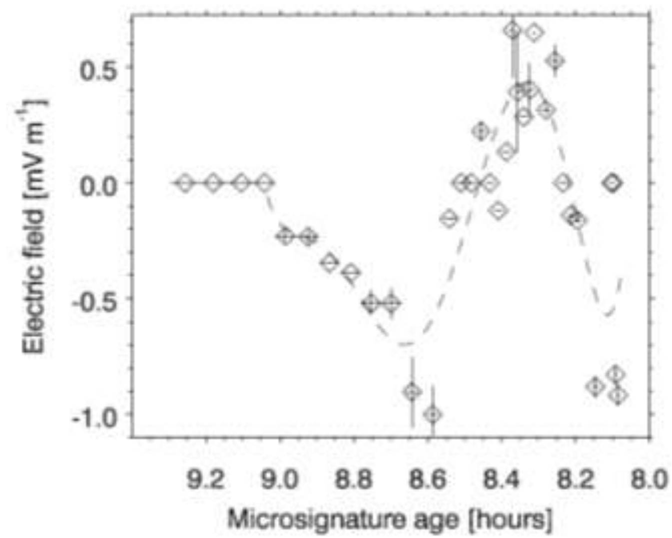
$\Phi =$ const. at microsignature observation & formation point



- Range: 0.1 – 1.0 mV/m
- Method not applicable for small displacements
- Other methods being tested currently
- Pointing of E-field can also be set as free parameter

Electric Fields (IV)
(magnetospheric dynamics)

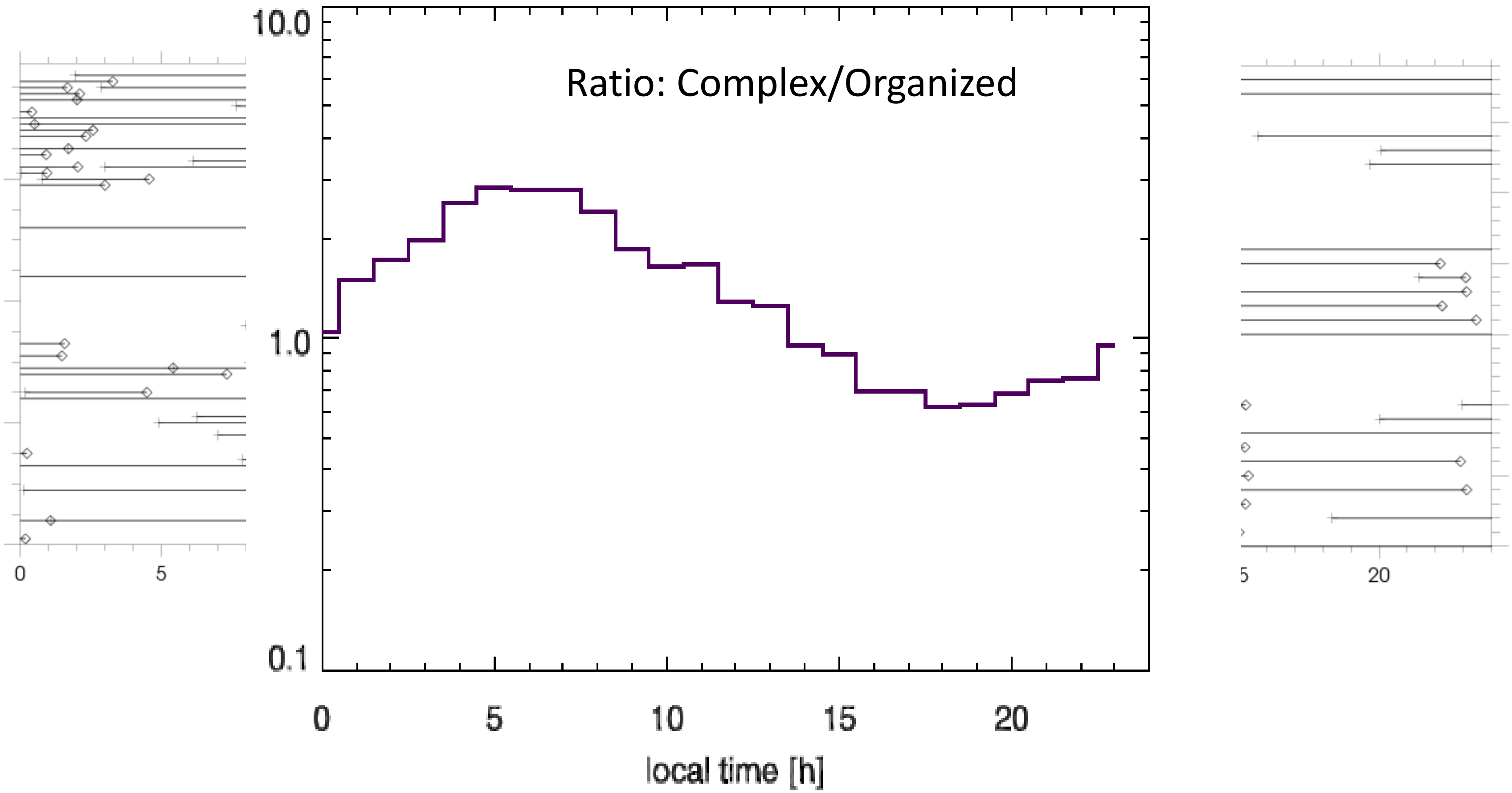




Roussos et al., (2010)

- Complex displacement profiles are indicative of local dynamics
- Microsignature age energy dispersion + energy dispersion in displacement → radial velocities/azimuthal electric fields in these dynamic regions

Electric Fields (IV) (magnetospheric dynamics)



Complex profiles relevant to injections ? (Chen and Hill 2008; Mueller et al. 2010)

Additional/future applications

- Plasma composition/charged states (Selesnick and Cohen, 2009)
- Bimodal diffusion (Selesnick and Cohen, 1993)
- Energetic particle sources (Paranicas et al. 1997)
- Backwards tracing of microsignatures with models for electric/magnetic fields
- Organization as a function of SKR longitude at Saturn
- Combined injection/microsignature studies
- Applications to Jovian magnetosphere
- Multi-instrument studies
- Interdisciplinary science (detection/characterization of ring arcs etc.)
- +++

Moon interaction signatures give us the capability to indirectly perform ´´multi-point´´ observations in the magnetospheres of outer planets.

Instrumentation

- Energetic particle detector

    1. Lowest energy: Where magnetic drifts start to be important (time dispersion effects of microsignatures become visible)
    2. Upper energy: Gradient/curvature drifts cancel corotation (displacements at these energies sensitive to weak electric fields)
    3. Time resolution: Seconds (most microsignatures last 1-2 minutes at a given energy range)
    4. Energy resolution: dE/E~0.1, 10 energy channels at least (time/energy dispersion effects of microsignatures become visible)
    5. Pitch angle coverage: Spinning sensors probably not sufficient (difficult to cover all pitch angles in 1-2 minutes)