Wakes in cold tenous plasmas: nuisance and blessing
… and some other stuff

Anders Eriksson
Swedish Institute of Space Physics
Uppsala

Work with Erik Engwall, Chris Cully, Arne Pedersen, Per-Arne Lindqvist, Yuri Khotyaintsev, Erik Winkler, …

SPINE meeting, ESTEC, Nov 13, 2008

Outline

- S/c and instrumentation
  - Cluster
  - E-field instruments: EFW and EDI
- Polar wind wakes
  - Data signatures
  - Model & simulation
  - Making use of it
- Solar wind wakes
- The s/c potential measurement
- Effects of solar UV variations

Wake, polar wind & method studies

- Eriksson et al., Electric field measurements on Cluster: comparing the double-probe and electron drift techniques. *Ann. Geophysicae, 24*, 275-289 (2006)
- Engwall & Eriksson, Double-probe measurements in cold tenuous space plasma flows. *IEEE Trans. Plasma Sci., 34,* 2071-2077 (2006)
- Engwall et al., Wake formation behind positively charged spacecraft in flowing tenuous plasmas. *Phys. Plasmas, 13*, 062904 (2006)
- Engwall et al., Low-energy (order 10 eV) ion flow in the magnetotail lobes inferred from spacecraft wake observations. *Geophys. Res. Lett.,* 33, L06110 (2006)
- Engwall, *Cold magnetospheric plasma flows: properties and interaction with spacecraft*. Licentiate thesis, Uppsala University, March 2006
- Cully et al., Electrostatic structure around spacecraft in tenuous plasmas. J. *Geophys. Res.,* 112, A09211, 2007.
- Pedersen et al., Electron density estimations derived from spacecraft potential measurements on Cluster in tenuous plasma regions, *J. Geophys. Res., 113*, A07S33 (2008)
- Upcoming papers & PhD thesis by Engwall et al. (2008-2009)

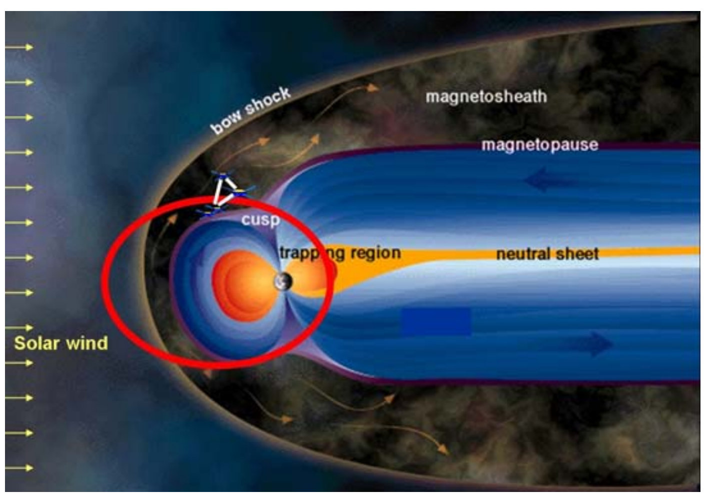
Cluster

ESAs four-spacecraft mission to the magnetosphere

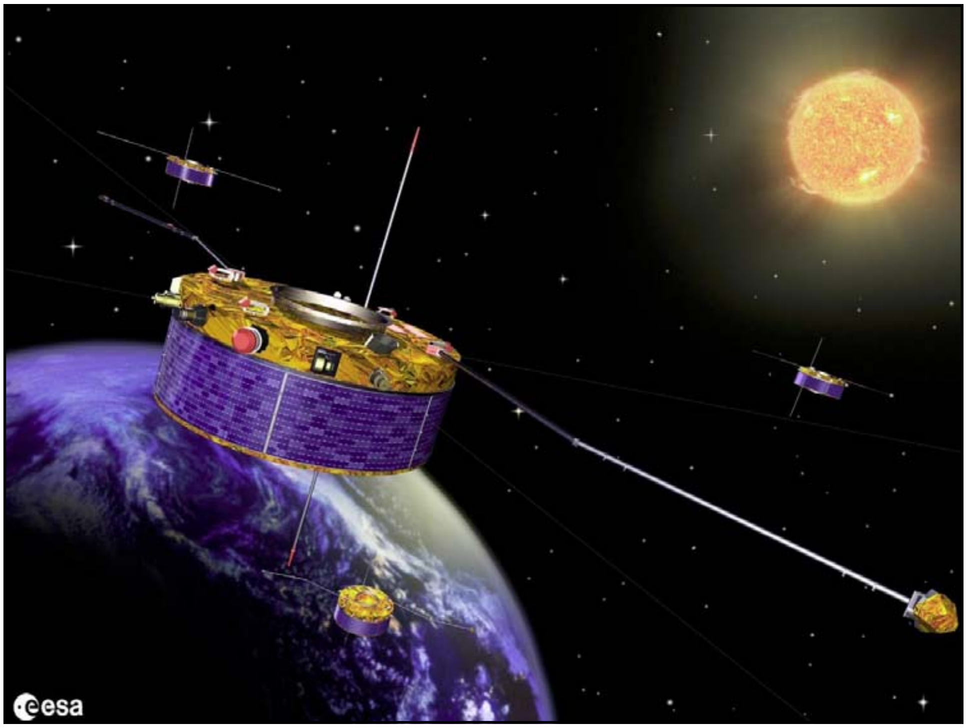
In orbit since 2000, operational since 2001

Full orbit coverage since 2002

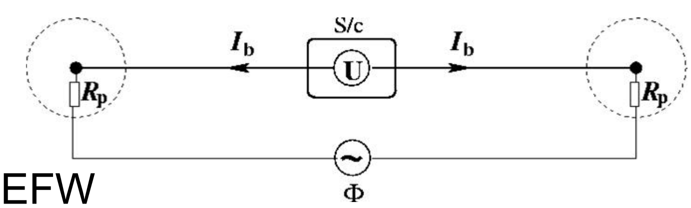
Orbit 4 x 22 RE



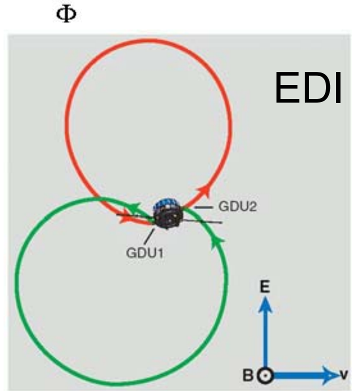
Cluster orbit in spring



Cluster electric field instruments



EFW



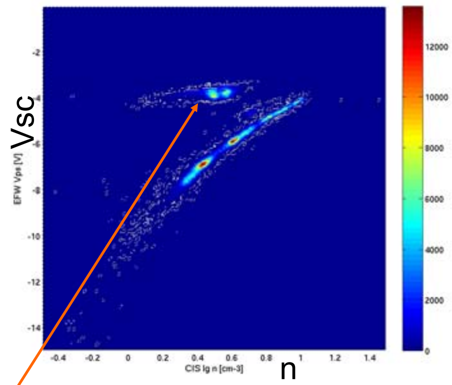
EFW: Potential differences from double probes

EDI: Electron Drift Instrument

Vsc as density proxy

Winkler, student project, 2007

- Currents to spacecraft:
  - $I_e \sim n$: collected plasma e-, scales with density n
  - $I_{ph}(V_{sc})$: photoemission
    - Saturation for $V_{sc} < 0$
    - Decays for $V_{sc} > 0$
  - I_i: negligible ion current
  - Current balance $I_e + I_{ph} = 0$ $\Rightarrow V_{sc} = f(n)$ relation
- V_{sc} a proxy for the density
- Easy to measure down to 10 ms time scale
- Vsc changes when ASPOC ion emitter is on (talk by Klaus Torkar)

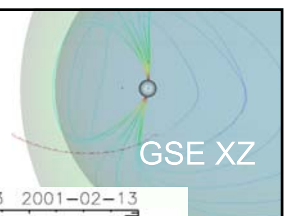


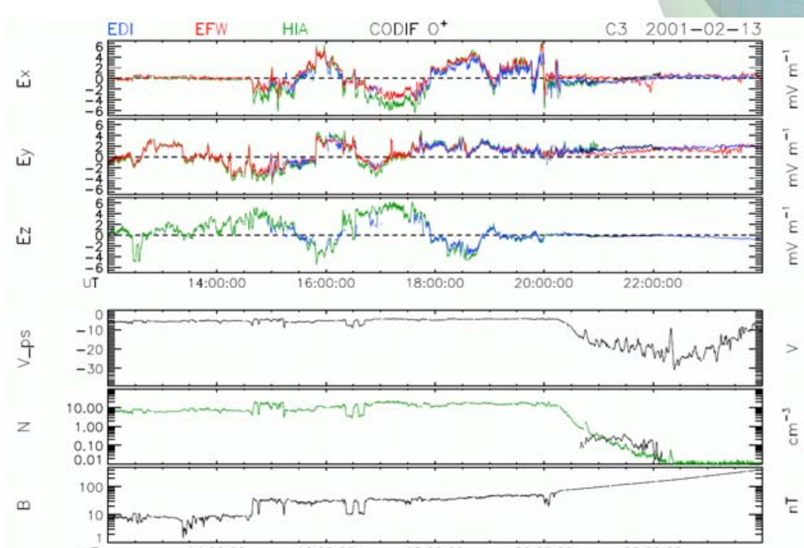
Empirical relation: EFW Vsc vs. plasma density from Cluster CIS ion spectrometer:
1.1 million data points (spins) from Feb-March 2003, 2004 & 2005

IRF

Cluster EFW/EDI agree...

Eriksson et al., *Ann. Geophys.*, 2006

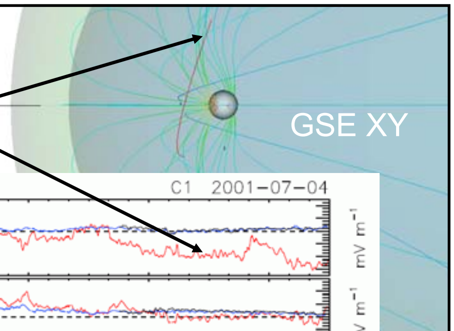


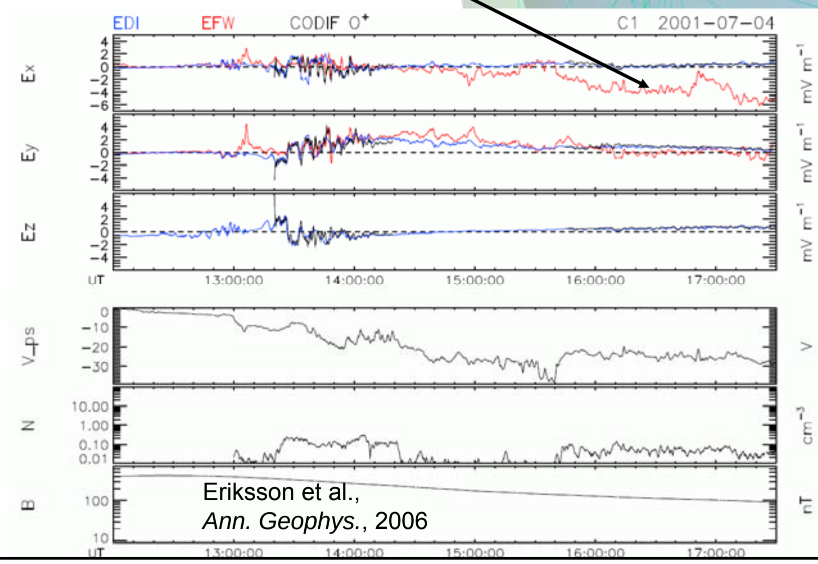


IRF

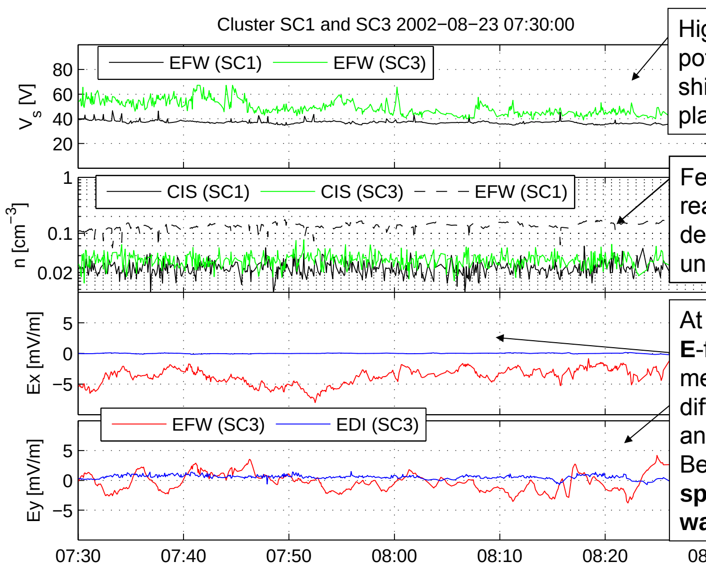
...and disagree

Violent disagreement in polar cap/tail lobes





Problems when ion flow is hidden



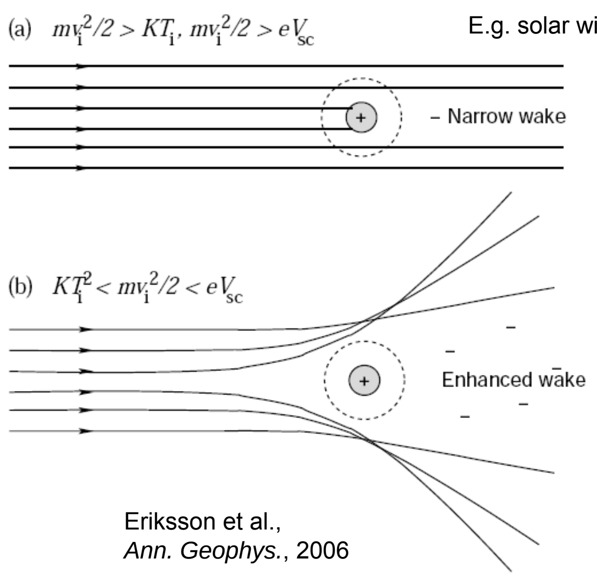
High s/c potential will shield out the plasma ions.

Few ions will thus reach CIS and the density is underestimated

At the same time **E**-field measurements differ from EDI and EFW. Why? Because of **spacecraft wake.**

Wake behind positive s/c

E.g. solar wind (poster 15)

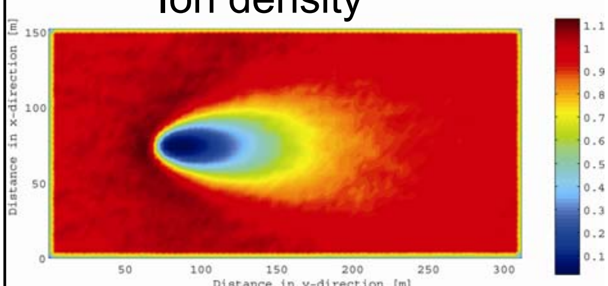


E.g. polar wind

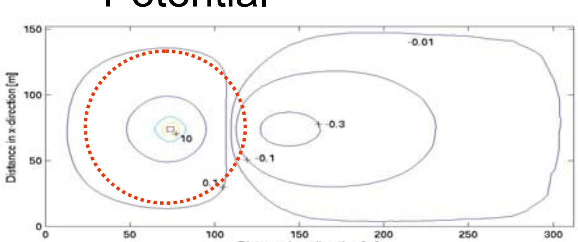
Eriksson et al.,
Ann. Geophys., 2006

Simulations verify concept...

Ion density



Potential



Simulations using PicUp3D

Condition for enhanced wake formation:

$$KT_i < \frac{mv_i^2}{2} < eV_s$$

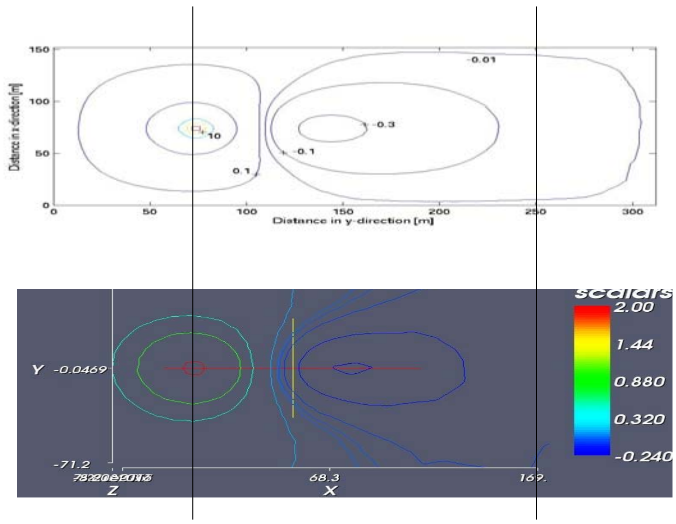
The negatively charged wake behind the spacecraft will be seen by EFW (probe-to-probe separation 88 m) but not by EDI.

Engwall et al.,
Phys. Plasmas, 2006

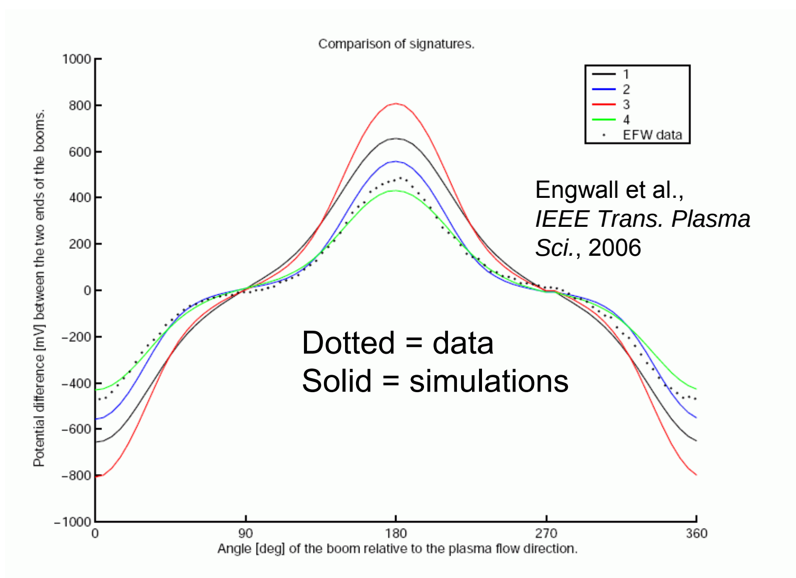
...agree between PicUp3D and SPIS...

Prakash, student project, 2007

Potential



... and reproduce wake spin signature.



Engwall et al., *IEEE Trans. Plasma Sci.*, 2006

Dotted = data
Solid = simulations

Simple model relates wake to flow

- Possible to invert to get parallel flow speed if wake is known
- EFW-EDI comparison gives wake...
- ... so we can now observe ions invisible to particle instruments!

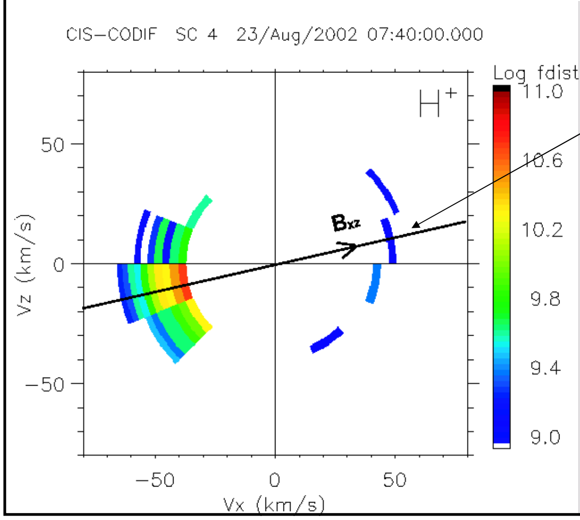
Engwall et al., *Geophys. Res. Lett.*, 2006

$$\mathbf{E}^{\mathrm{w}} = g\mathbf{u}_{\perp} + g u_{\parallel}\frac{\mathbf{B}}{B}$$

$$\begin{cases} g = \dfrac{(\mathbf{B}\times\mathbf{E}^{\mathrm{w}})_z}{E_z^{\mathrm{EDI}}} = \dfrac{B_x E_y^{\mathrm{w}} - B_y E_x^{\mathrm{w}}}{E_z^{\mathrm{EDI}}} \\ u_{\parallel} = \dfrac{B}{g B_c}\left(E_c^{\mathrm{w}} - g u_{\perp,c}\right) \end{cases}$$

Validation: rare case of fast flow

ASPOC ion emitter reduces potential to +7 V, making “energetic” tail of H+ ions visible!

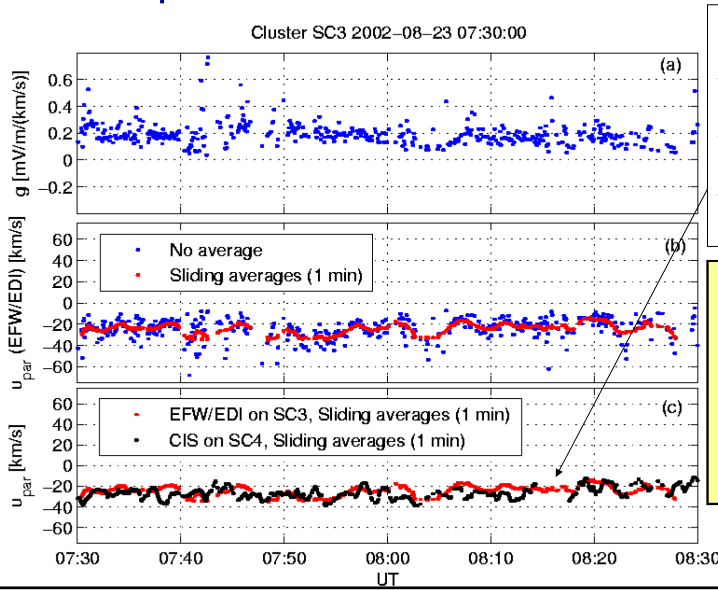


Flow aligned with B, which is expected for outflows in the polar wind.

The velocity of the H^+ is possible to measure due to low s/c potential. (The lowest velocities are missing due to the instrument low-energy cutoff.)

Engwall et al., *Geophys. Res. Lett.*, 2006

Comparing flow velocities from particle and electric field data



The derived velocity from the wake (**red**) shows good agreement with the corrected velocity for H^+ from CODIF (**black**).

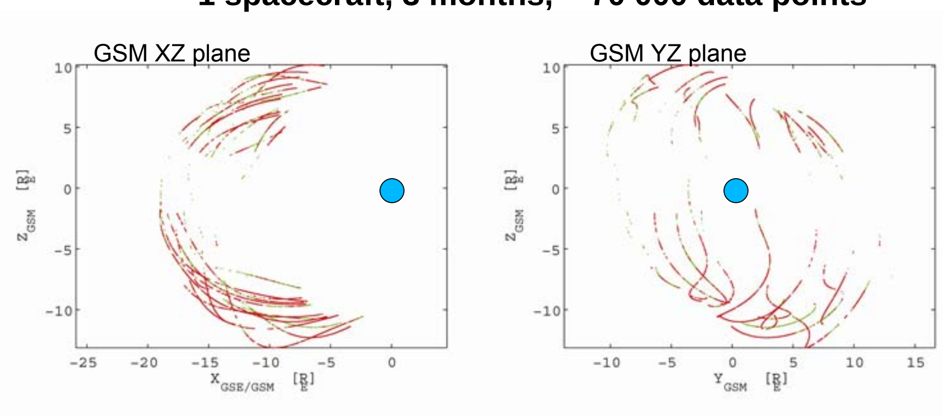
Thus, the wake method to derive flow velocity of cold plasma **works** and can be used in regions where ions are inaccessible to particle detectors.

Engwall et al., *Geophys. Res. Lett.*, 2006

Initial statistics (1/3)

Engwall, licentiate thesis, 2006

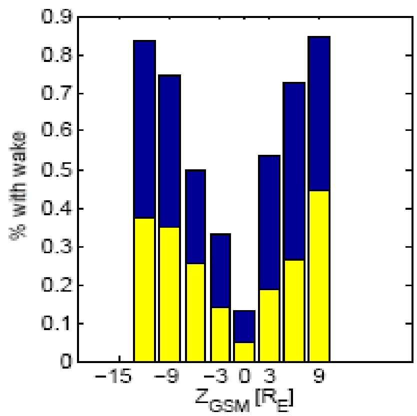
1 spacecraft, 3 months, ~ 70 000 data points



Wake model applied to EFW and EDI data SC3 data for summer 2003
Red: Cold ions detected
Green: No cold ions
Polar wind ion flow normally fills the tail lobes

Initial statistics (2/4)

Engwall, licentiate thesis, 2006

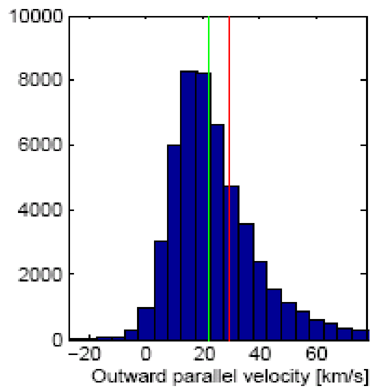


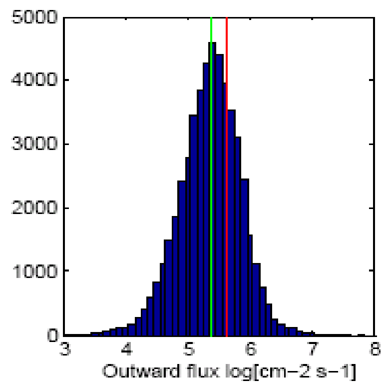
Fraction of spacecraft spins where wakes detected with criteria:

- EFW-EDI > 2 mV/m (**blue**)
- u_{par} > 25 km/s (yellow)

Few wakes detected in plasma sheet

Initial statistics (3/4)



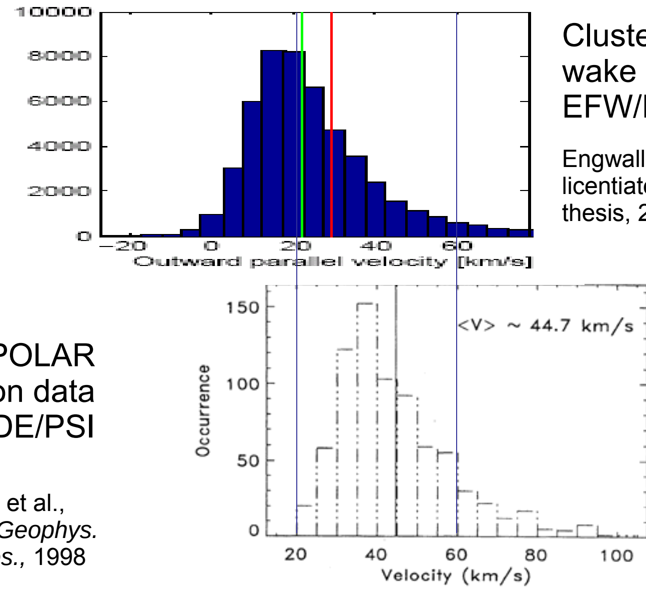


Red line = mean
Green line = median

Engwall, licentiate thesis, 2006

Corresponds to ionospheric mass loss of the order of 1 kg/s.

Initial statistics (4/4)



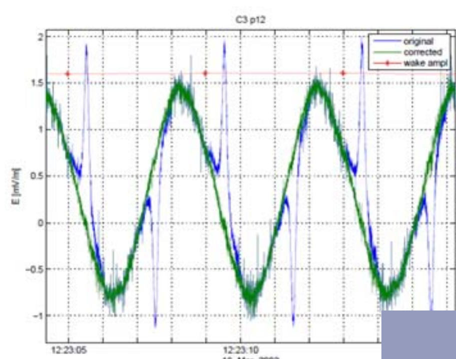
Cluster wake data EFW/EDI

Engwall, licentiate thesis, 2006

POLAR ion data TIDE/PSI

Su et al., *J. Geophys. Res.*, 1998

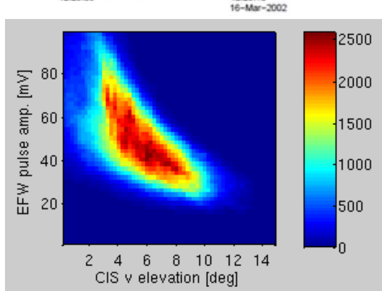
Solar wind wakes

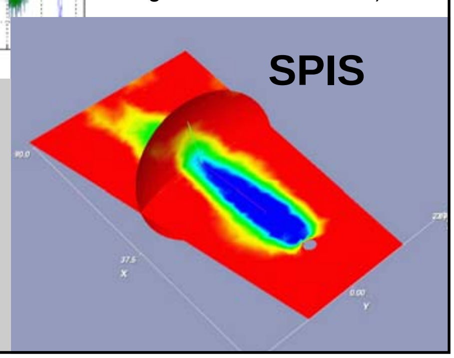


Narrow wake behind spacecraft

$eV_{sc} << mv^2/2$

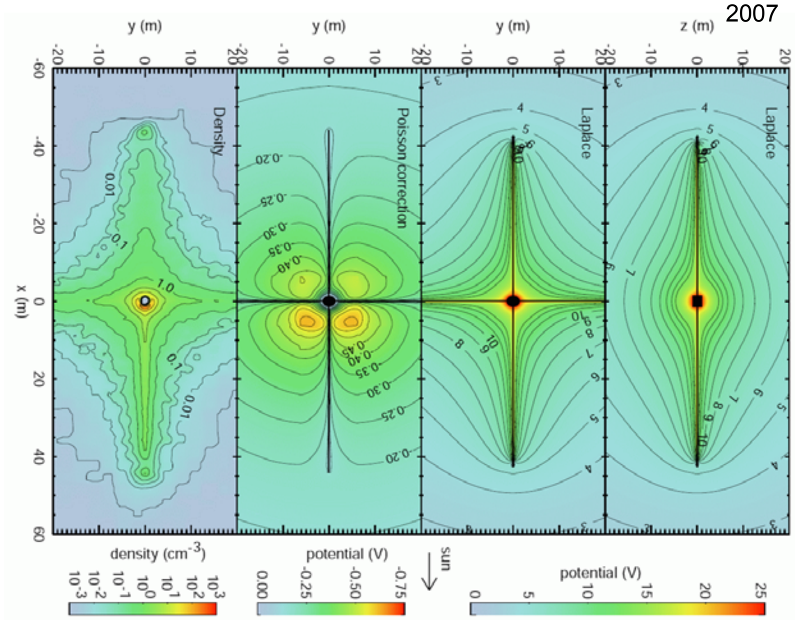
($KTi < mv^2/2 < eV_{sc}$ gave enhanced wake)





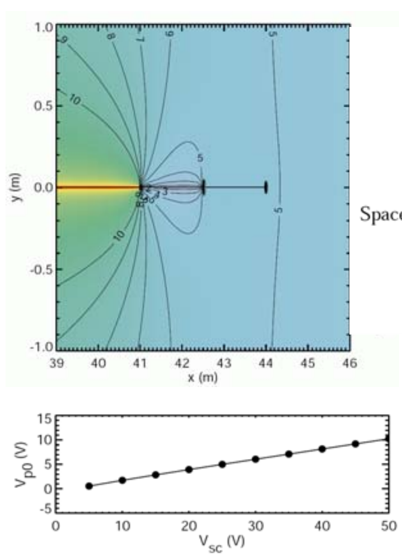
S/c potential simulations

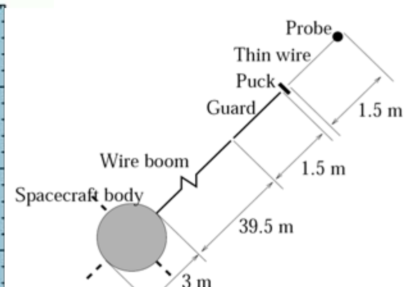
Cully et al.,
J. Geophys. Res.,
2007



S/c potential simulations

Cully et al.,
J. Geophys. Res.,
in press, 2007





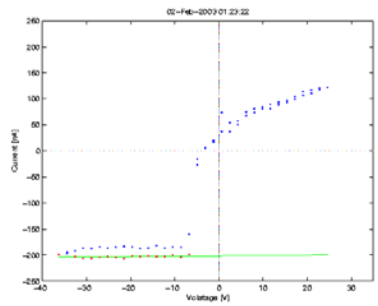
Previously:
Vsc = -Vps + 0.7 V

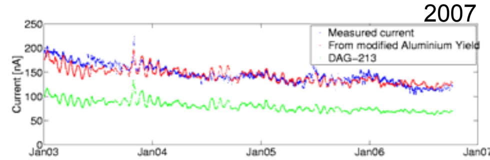
New result:
Vsc = -1.23 Vps + 0.7 V

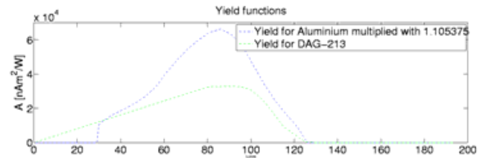
Actual factor depends on geometry

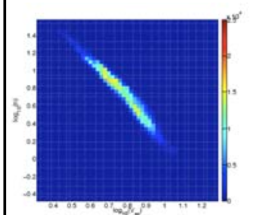
Density-Vsc relation and UV flux

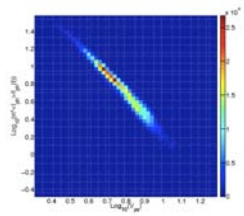
Winkler, student project, 2007











Cluster photoemission measured in bihourly bias sweeps

Can be used for calibrating the density-Vsc relation, decreases spread

Conclusions

- Cluster gives excellent opportunities for wake studies
  - EFW can see wake, EDI cannot: combine!
- Polar wind wake observations give outflow speed and flux
  - Hard to get at for particle detectors even with ASPOC/PSI
  - Perpendicular velocity from EDI
  - Parallel velocity from wake (EFW-EDI)
  - Flux from nv, n from Vsc
- Electrostatic probes see part of potential
  - Vsc = -k Vps + m
  - n(Vps) still all right
- Longer booms can alleviate s/c wake s/c, but boom wake
- Much modelling remains for full understanding of E-field measurements
- Solar UV flux has direct impact on Vsc
- Correcting density from Vps by F10.7 helps