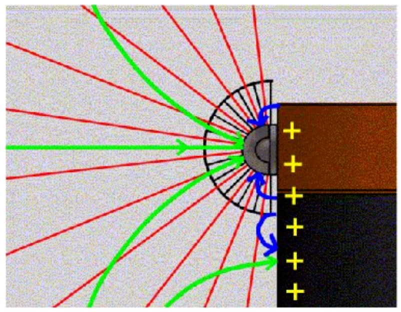
Correcting spacecraft calculated electron moments

Application to CLUSTER/PEACE



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Based on ***Génot & Schwartz, 2004*** and ***Geach et al., 2005*** (Ann. Geophys.)

Measuring the Electron Velocity Distribution: Spacecraft Potential Effects: Data Example

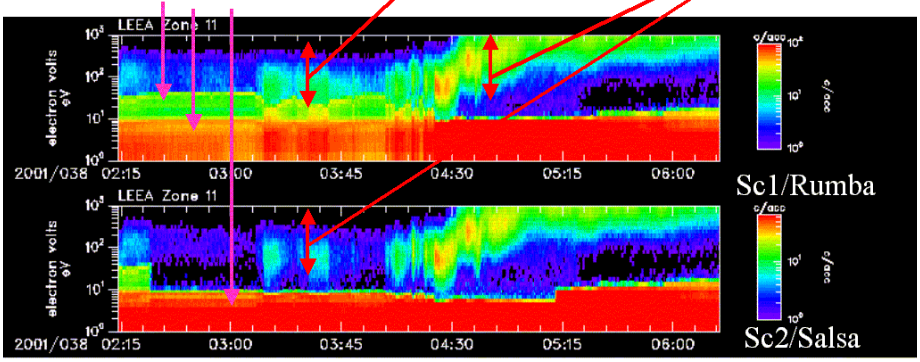
(*from MSSL PEACE website*)

ASPOC reduces the potential and so reduces distortion of f(v).
Compare Sc1 and Sc2 :

HEEA Onboard Moments (energy > 34 eV) will be reliable here

but not here

Spacecraft Electrons



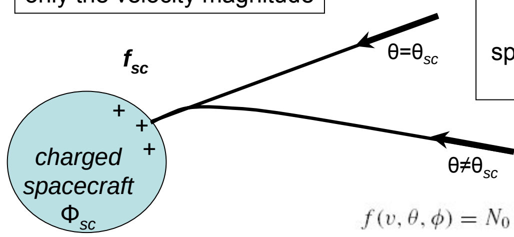
General assumptions

Liouville theorem
along a trajectory in phase space the distribution function remains constant :

$$f_{sc}(v_{sc}, \theta_{sc}, \phi_{sc}) = f(v, \theta, \phi)$$

Scalar approximation :
$\theta=\theta_{sc}$ and $\varphi=\varphi_{sc}$
i.e., the potential affects only the velocity magnitude

In "free space" we assume a thermal equilibrium :
the distribution function *f* is a Maxwellian drifting with the vector velocity V_0 in the spacecraft frame, of temperature T_0 and density N_0.



$$f(v, \theta, \phi) = N_0 \left(\frac{m_e}{2\pi k T_0}\right)^{3/2} \exp\left(-\frac{m_e}{2kT_0}(\boldsymbol{v} - \boldsymbol{V}_0)^2\right)$$

Observed moments N, V_z, … are functions of the "true" free-space moments N_0, V_0, …

$$N = \left(\frac{m_e}{2\pi k T_0}\right)^{1/2} \frac{N_0}{V_0} \int_{v_L}^{v_U} dv \sqrt{v^2 - \mathcal{E}} \left(e^{-\frac{m_e}{2kT_0}(v-V_0)^2} - e^{-\frac{m_e}{2kT_0}(v+V_0)^2}\right)$$

$$N V_z = \left(\frac{m_e}{2\pi k T_0}\right)^{1/2} \frac{N_0}{V_0} \int_{v_L}^{v_U} dv \left[(v^2 - \mathcal{E})\left(e^{-\frac{m_e}{2kT_0}(v-V_0)^2} + e^{-\frac{m_e}{2kT_0}(v+V_0)^2}\right) - \frac{v^2 - \mathcal{E}}{v} \frac{kT_0}{m_e V_0}\left(e^{-\frac{m_e}{2kT_0}(v-V_0)^2} - e^{-\frac{m_e}{2kT_0}(v+V_0)^2}\right)\right]$$

with

$$v_{L,U} = \sqrt{v_{l,u}^2 + \mathcal{E}}$$

$$\mathcal{E} = -\frac{2e\Phi_{sc}}{m_e}$$

... and similarly for Px, Py, Pz

This system can be inverted and solved for N_0, V_0, T_0 at each data record

$$\begin{cases} g_1^{(v_l, v_u, \Phi_{sc})}(N_0, V_0, T_0) - N = 0 \\ g_2^{(v_l, v_u, \Phi_{sc})}(N_0, V_0, T_0) - N V_z = 0 \\ g_3^{(v_l, v_u, \Phi_{sc})}(N_0, V_0, T_0) - 3NkT = 0 \end{cases}$$

General behaviour

– For small values of the spacecraft potential, the density is underestimated, but as the potential increase it becomes overestimated (there is a potential value for which the correct density is measured),

– For increasing potential, the overestimation of the velocity magnitude decreases,

– For increasing potential, the overestimation of the temperature slightly increases.

Regional behaviour

– For solar wind conditions, the range of values corresponding to under/over-estimation can be quite large: from 60% underestimation for zero potential it goes up to 75% overestimation in the case where the spacecraft potential and the lower energy cutoff equals. The range spanned by the velocity and temperature is much smaller, however the velocity measure can reach a 75% overestimation for zero potential.

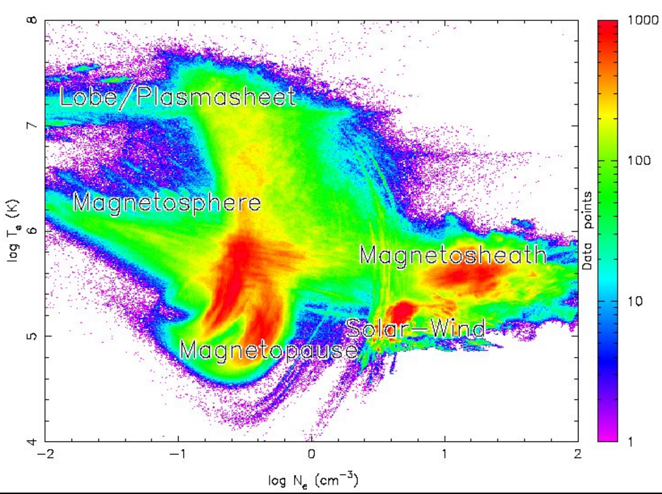
– For magnetospheric plasma conditions, the measured temperature (100 eV) is much larger than the maximum potential value (10 eV) : the estimation ratios do not vary much (less than 6% for the density and temperature ones, whereas the density goes from 3% underestimation to 8% overestimation)

– To a lesser extent, this is also true for the magnetosheath conditions: the temperature remains overestimated by 25% whereas the velocity overestimation varies from 30% to a few %. The density measure is still the most affected by the spacecraft potential and varies from 25% underestimation (for zero potential) to 37% overestimation.

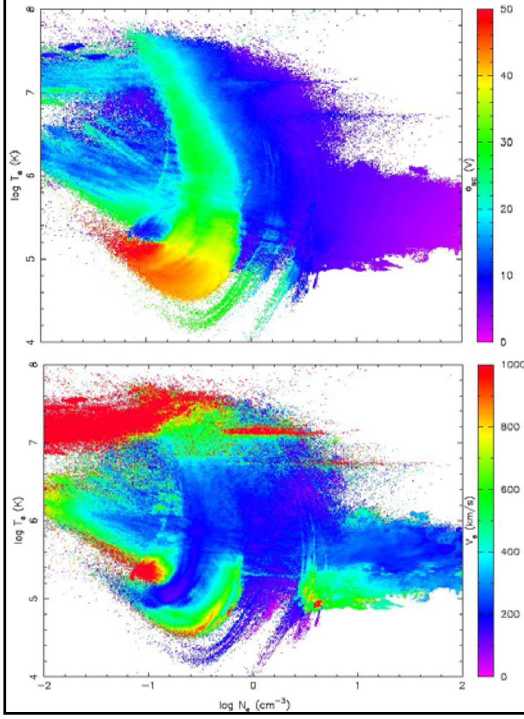
Massive correction of *PEACE* on-board calculated moments

-all 4 *Cluster* spacecraft over the duration of 2002 scientific operations

- in total, approximately 1.5 $\times 10^7$ data points contribute to each map, requiring a total of 11 days of CPU (2.66 GHz, 4 GB RAM) time



1 day
of computation
=
1 month
of corrected data

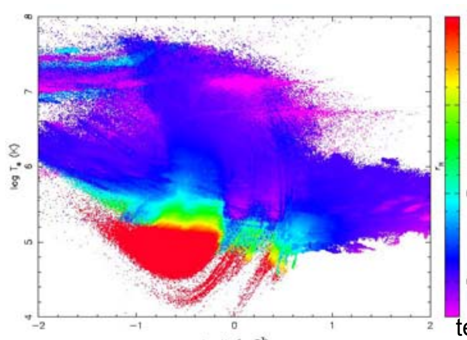


Spacecraft potential

Corrected velocity

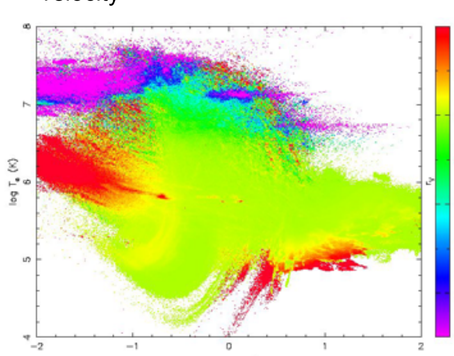
Successful data correction
=
no features of the potential appear in the maps of corrected moments. Indeed, the corrector aims at finding free-space values which are unperturbed by spacecraft effects.

Estimation parameter :
(measured-true)/true
>0 = over-estimation
<0 = under-estimation

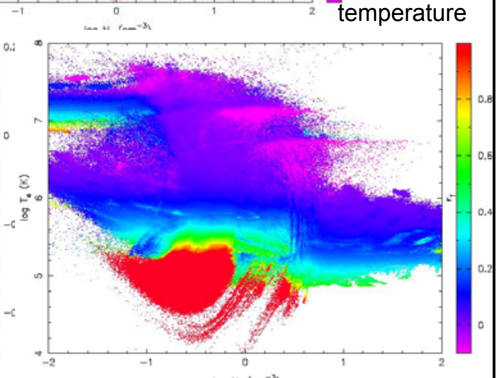


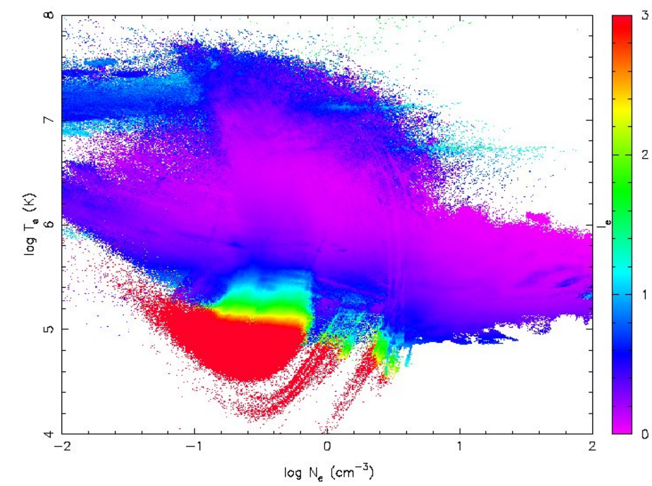
density

velocity



temperature





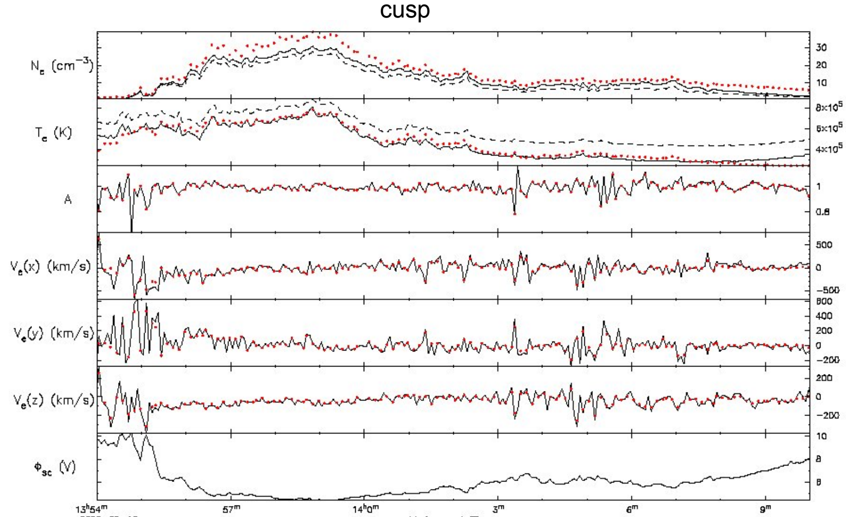
-For 10^6<T<10^7 K, the overall correction is generally less than 20% for all densities

-For T<10^6 K and N → 0 cm-3, the moments become severely affected and the overall correction required rapidly exceeds 300% : this is dominated by the over-estimation of the density and temperature moments, the velocity being not so badly affected in this region

Cluster 1
Moment comparison

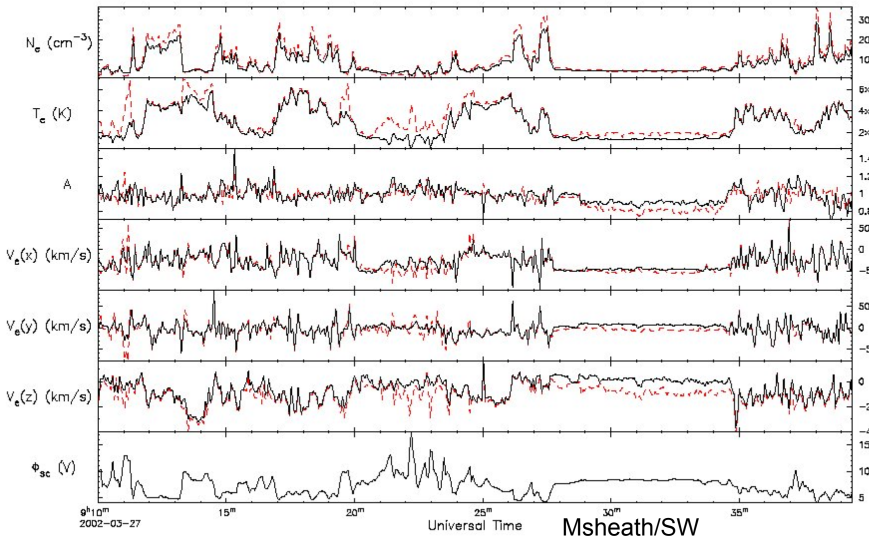
- (dotted) ground 3d moments
- corrected moments
- (dashed) un-corrected on-board moments

cusp



Cluster 1
Moment comparison

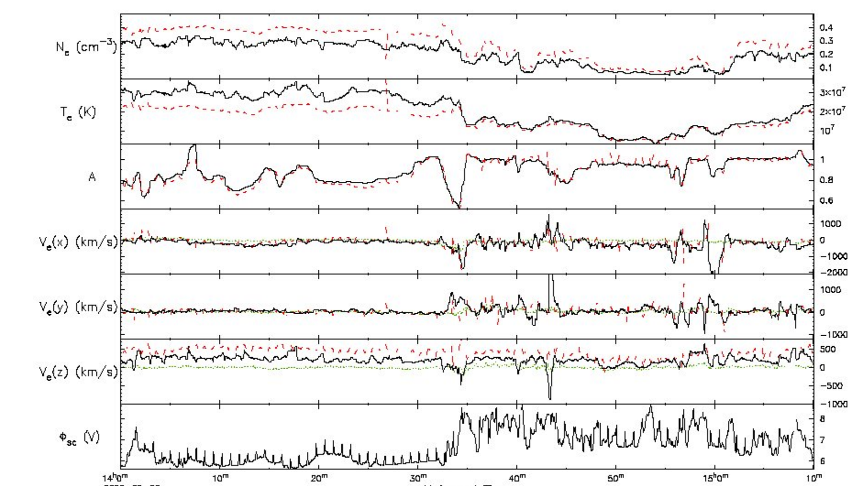
- (dashed) ground 3d moments
- corrected moments



Msheath/SW

Cluster 3
Moment comparison

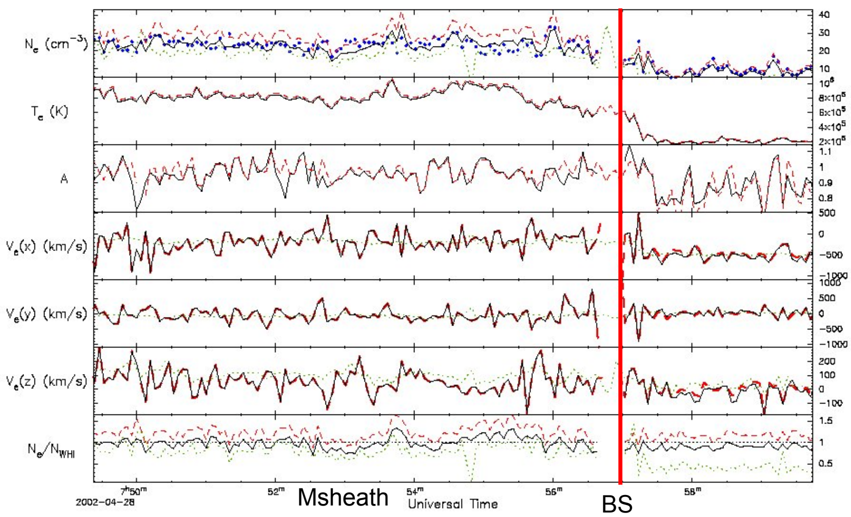
- (dashed) ground 3d moments
- corrected moments smoothed with a 30-second wide boxcar
- (dotted) *CIS (HIA)* velocity



plasmasheet

Cluster 1
Moment comparison

- (dashed) ground 3d moments
- corrected moments
- (dotted) *WHISPER* density
- (dotted) *CIS* data



Conclusions

- Quick, reliable method
- Can be applied to plasma moments when the spacecraft potential is known
- Yields brand new corrected data sets with a coverage as good as the on-board moment one (3D distribution are obtained with a lower telemetry rate)
- Yields a very good estimate of the temperature anisotropy $T_{\perp}/T_{//}$ (assuming the potential does not affect it)

Perspectives ...

- Improvements may be envisaged *but* at significant high cost :
  - More realistic geometry
  - Magnetic field
- Full PIC simulations could help
- A comparison between the scalar and the planar approximation with a full computation of electron trajectory in spherical geometry has been performed :
  - preprint by V. Génot, A. Hilgers, & S. Schwartz “Analytical computation of electron trajectories around a charged spherical spacecraft : implication for moment calculation”