Particles Distribution Inside Magnetic Mirrors

Dragoş Constantinescu[1,2]

Summary:

Last reported status

- Model: Assumptions
- Model: Predicted Magnetic field
- Model: Identified Structure

Particles simulation

- Method
- How many particles do we need?
- Preliminary results

1: Institut für Geophysik und Meteorologie, TU Braunschweig, Germany
2: Institute for Space Sciences, Bucharest, Romania

Magnetic mirror structures

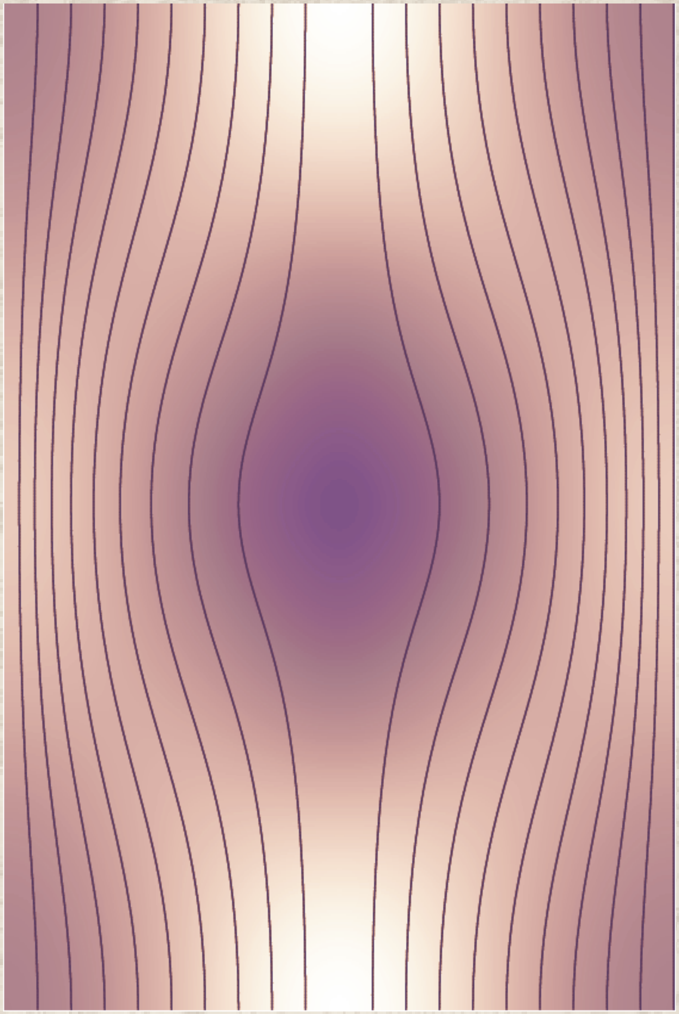
Fundamental plasma instability

Needs temperature anisotropy ($T_\perp > T_\|$) in order to develop

Non propagating (purely imaginary frequency), strongly compressive mode

Magnetic field is anti-correlated with plasma density

Common in Earth magnetosheath but also in other space plasmas



Methods for deriving the geometry

Correlations

- applicable for any "well defined" magnetic structures
- assume linear correlation
- essentially statistical
- works when the correlations between measurements from different spacecraft are large

Model

- less general then correlations method
- assume certain geometry of magnetic mirror structures
- allow the study of each structure separately
- can work even if the measurements from different spacecraft are dissimilar

Model: Assumptions

Pressure equilibrium

- $\mathcal{P}_{plasma} = \mathcal{P}_{magneticfield}$

Small perturbations

- $\delta B << B$

Time-independent magnetic field

- $\mathbf{B} \neq \mathbf{B}(t)$

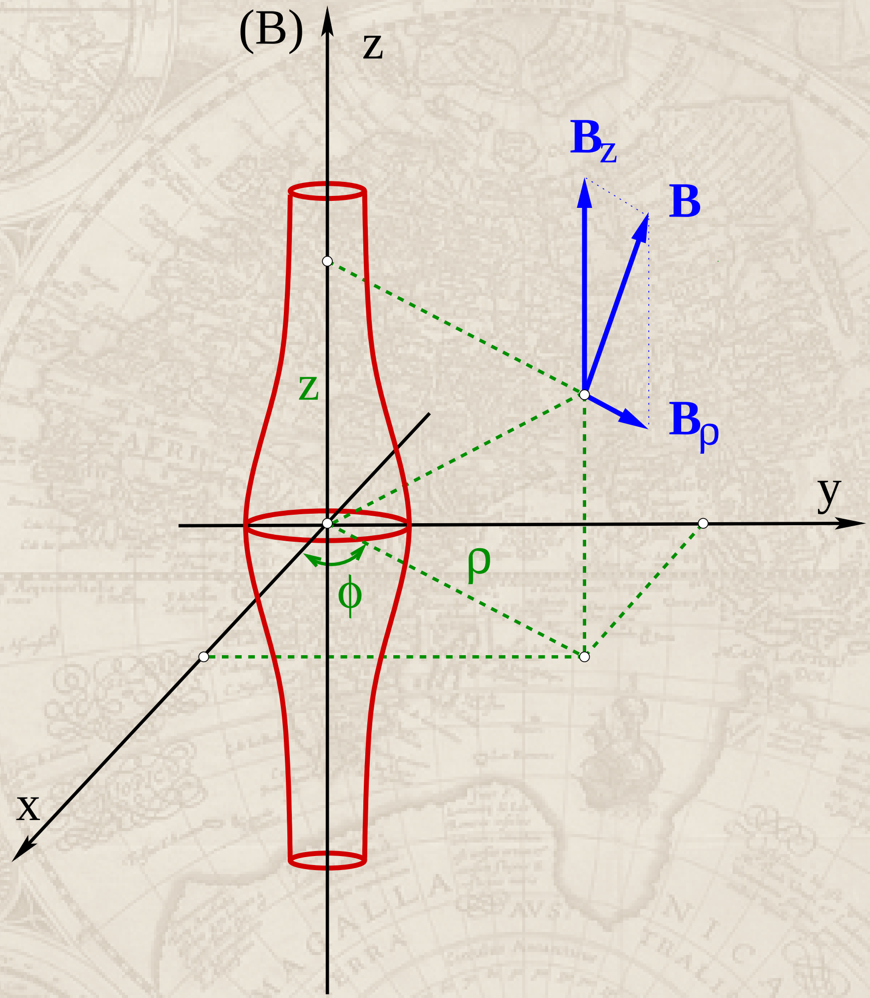
Symmetry around z-axis

- $\mathbf{B} \neq \mathbf{B}(\varphi)$

Periodicity along z-axis

- $\mathbf{B}(\rho, z + 2L) = \mathbf{B}(\rho, z)$

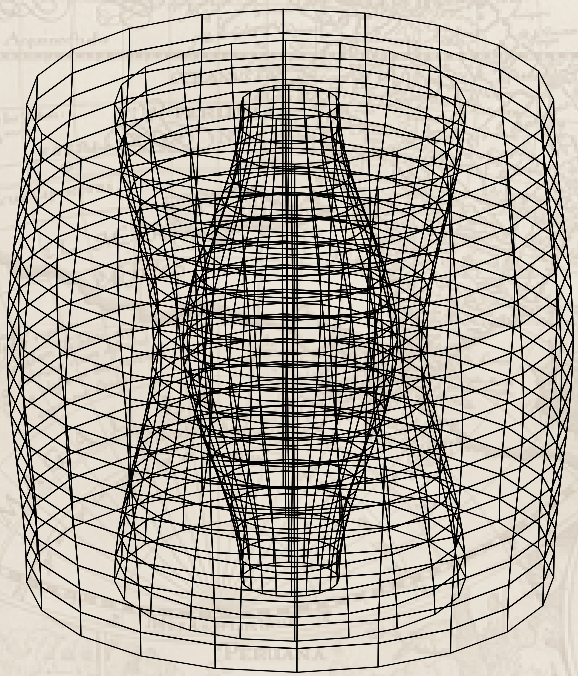
Bi-Maxwellian Distribution



Model: Magnetic field

Magnetic field perturbation:

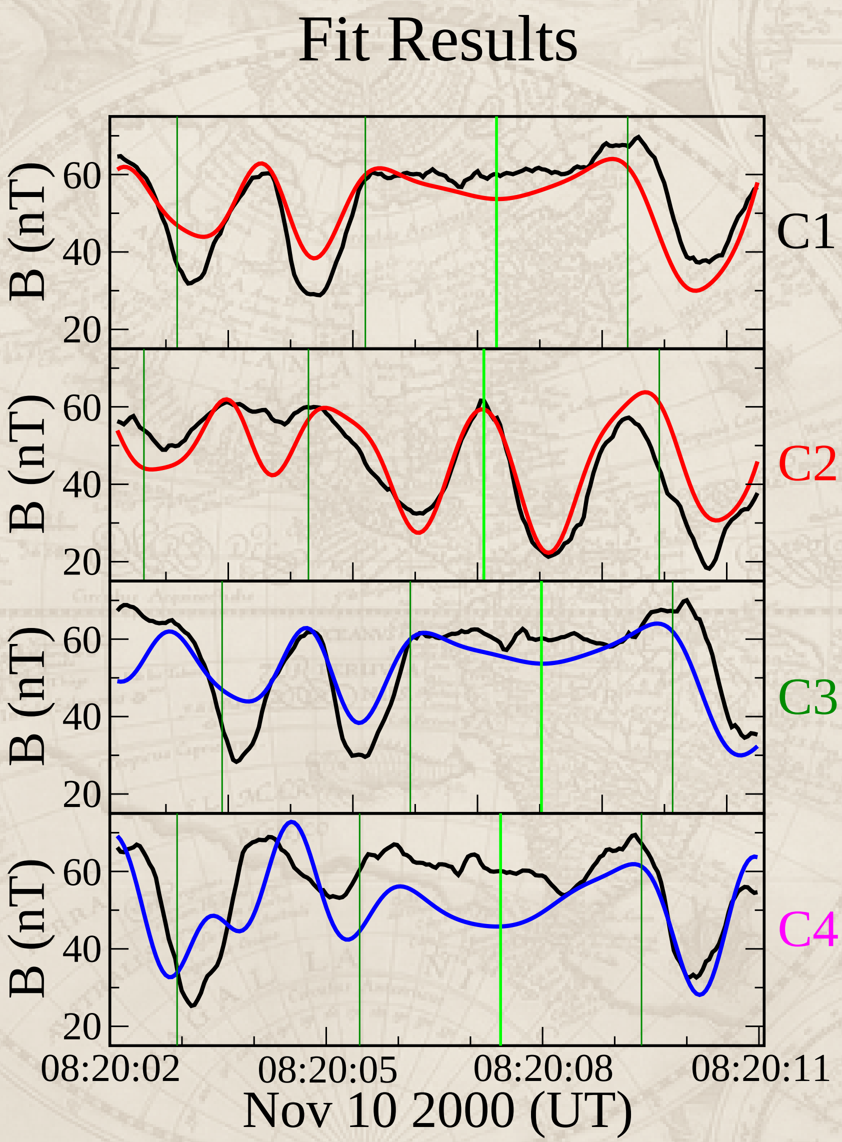
- $$\delta B_\rho(\rho, z) = \frac{2\pi}{\alpha} \sum_{n=1}^{\infty} J_1\left(\frac{n\alpha\rho}{L}\right)\left[a_n \sin\left(\frac{n\pi z}{L}\right) - b_n \cos\left(\frac{n\pi z}{L}\right)\right]$$
- $$\delta B_z(\rho, z) = 2 \sum_{n=1}^{\infty} J_0\left(\frac{n\alpha\rho}{L}\right)\left[a_n \cos\left(\frac{n\pi z}{L}\right) + b_n \sin\left(\frac{n\pi z}{L}\right)\right]$$



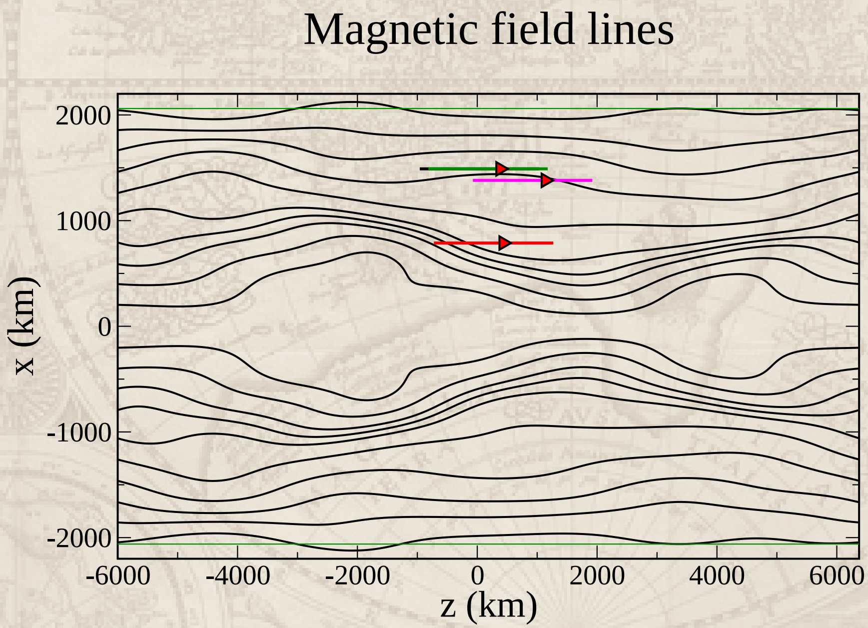
- Multi-layer structure
- Central structure is the classical image of magnetic mirror
- Multiple magnetic field minima belong to one structure
- In real world only inner layers will survive

From JASTP Vol 64, Constantinescu, Self-consistent model of mirror structures

Model: Results



- fit on data from C1 and C2
- C3 and C4 are witness spacecraft
- Resulting dimensions:
  - ▷ $L = 6186$ *km*
  - ▷ $R = 2051$ *km*



Particles simulation

Test particles:

- particles do not influence the magnetic field

Quasi-static magnetic field:

- time scale for the magnetic field variations $\gg$ giroperiod

Equation of motion:

- $$m\frac{\partial^2 \mathbf{r}}{\partial t^2} = q\left(\frac{\partial \mathbf{r}}{\partial t} \times \mathbf{B}\right)$$

Integrator:

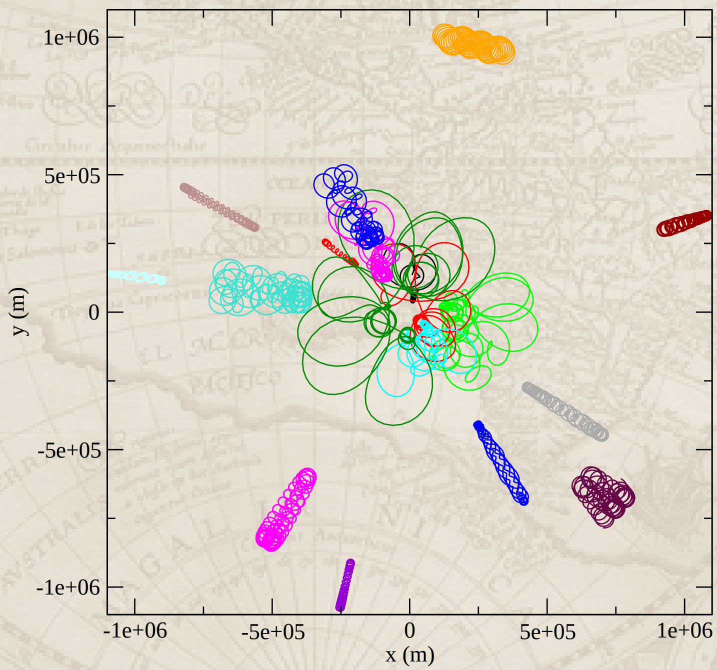
- 5th order Runge-Kutta with adaptive stepsize control

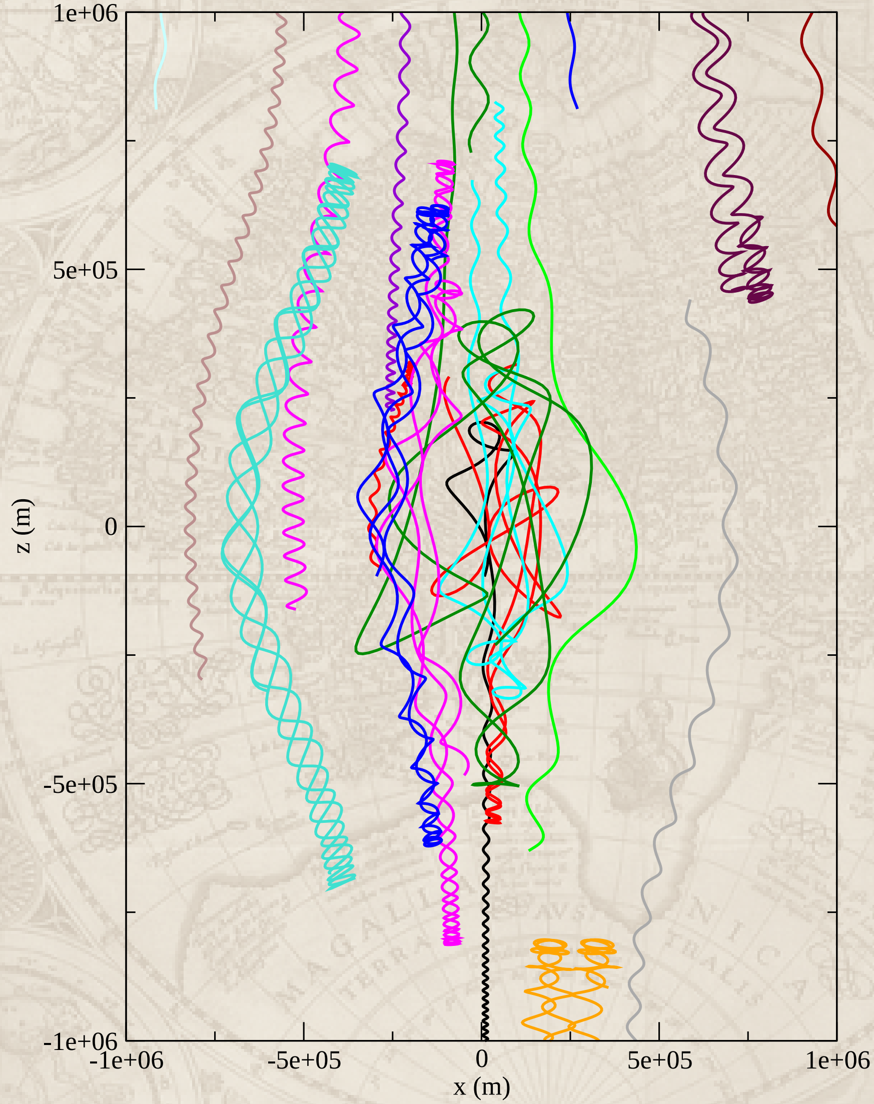
We want to:

- determine the distribution function as a function of position inside the magnetic mirror
- check the bi-Maxwellian distribution assumption
- compare with Cluster CIS data

Test particle orbits

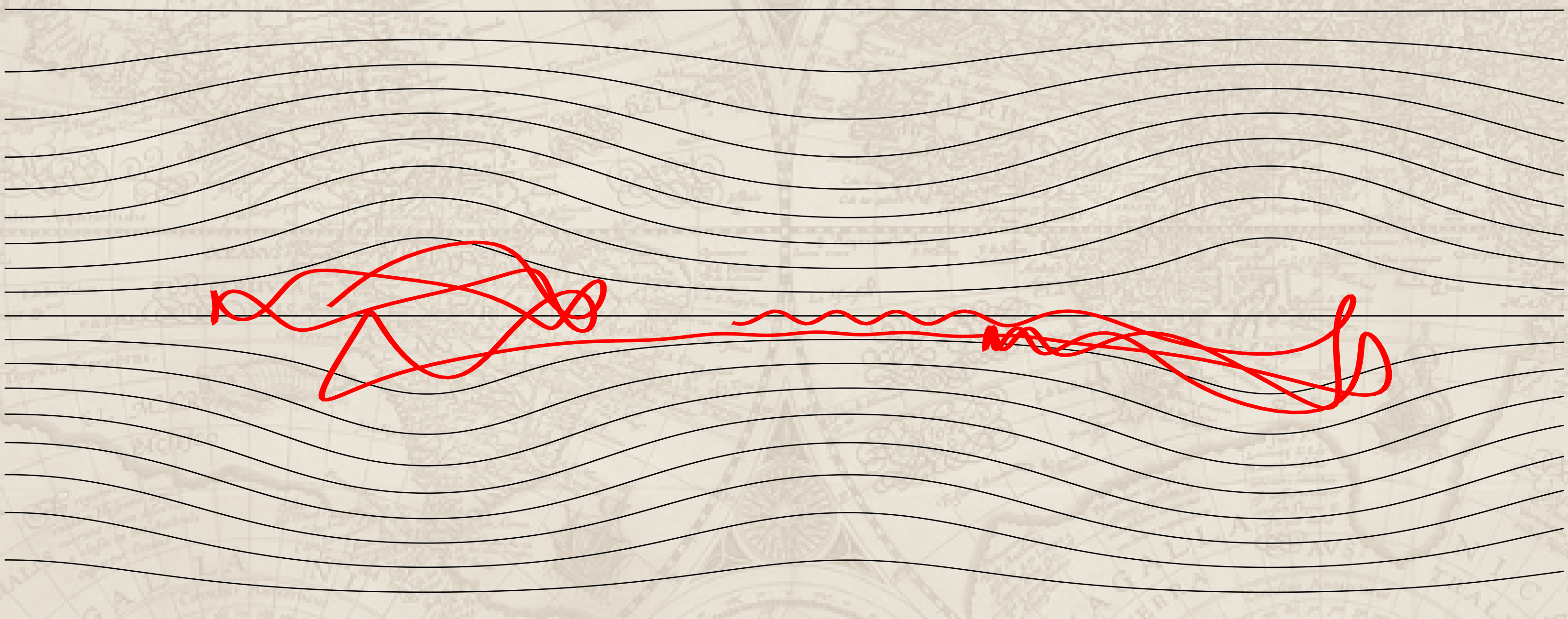
- Trapped particles
- Escaping particles
- Drift around z axis



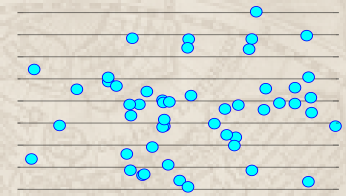
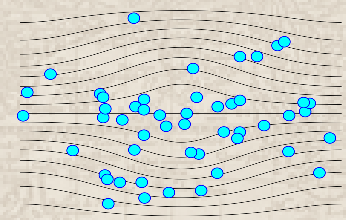
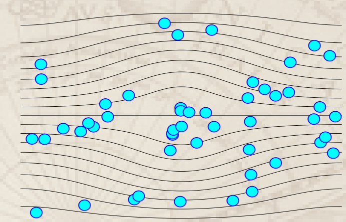


Trapped or not?

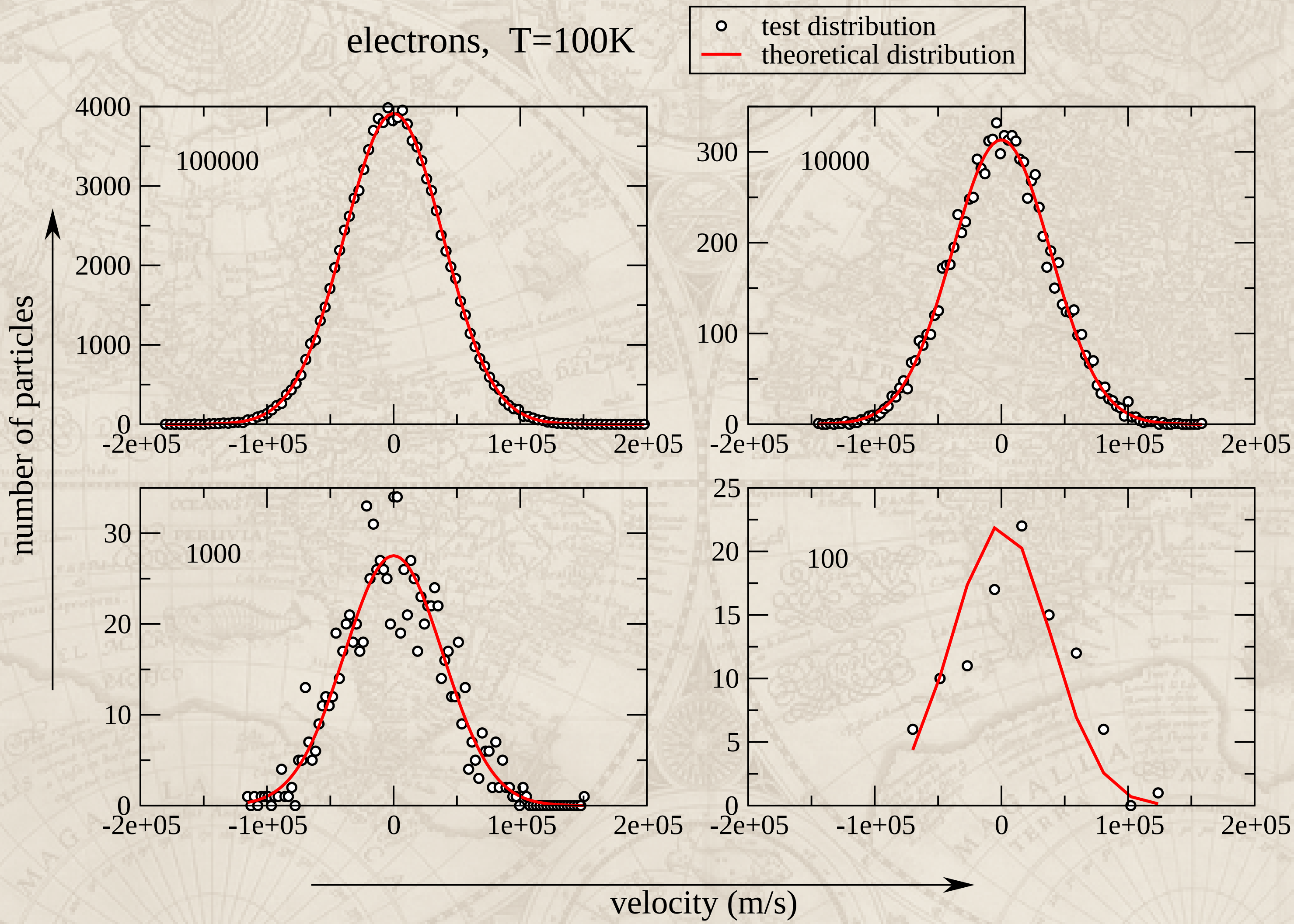
Used criterion: v_z change sign



Simulation steps

t_i	distribution function: bi-Maxwellian	magnetic field: uniform	
	$\int$ equation of motion	$\Downarrow$	$\mathbf{B} = \mathbf{B}(t)$
t_1	distribution function: local bi-Maxwellian (?)	magnetic field: magnetic mirror	
	$\int$ equation of motion	$\Downarrow$	$\mathbf{B} = constant$
t_f	distribution function: local bi-Maxwellian (??)	magnetic field: magnetic mirror	

How many?...


electrons, T=100K
test distribution
theoretical distribution
number of particles
velocity (m/s)
100000
10000
1000
100
4000
3000
2000
1000
0
300
200
100
30
20
10
25
15
5
-2e+05
-1e+05
1e+05
2e+05

Simulation parameters

Input

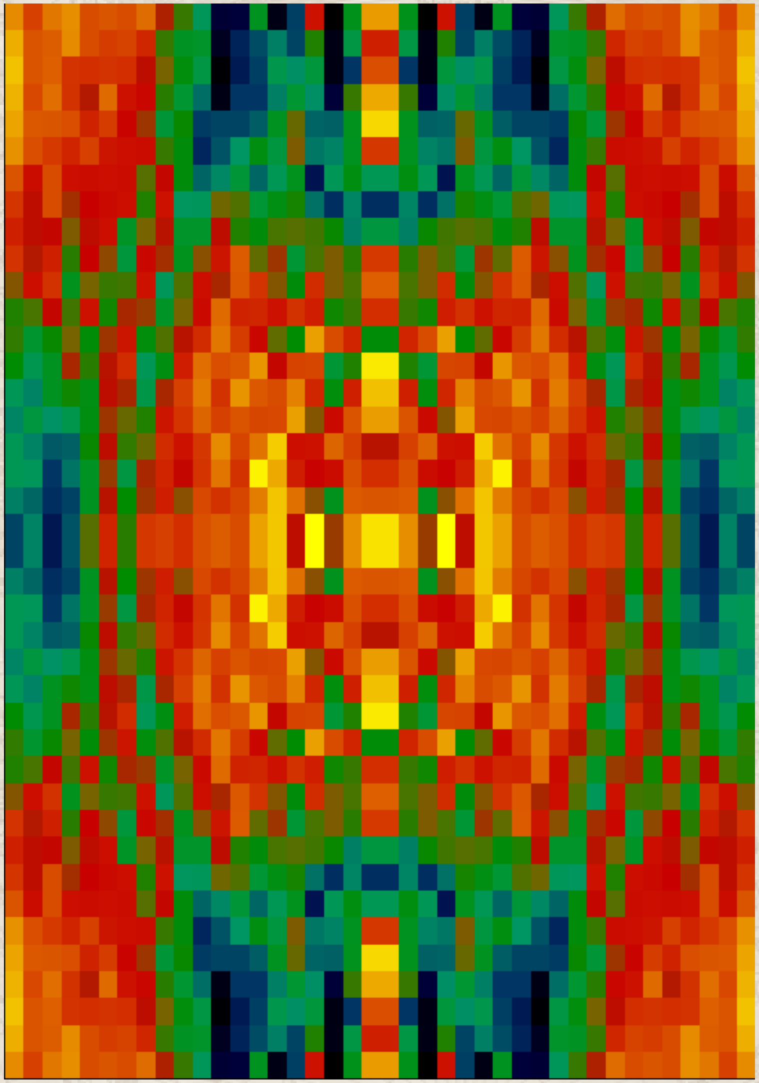
- Number of particles: 10000
- Grid ρ, z: 20x20 => average of 25 particles/cell
- Orthogonal temperature: 10 mil K
- Parallel temperature: 5 mil K
- Simulation time: 30 giroperiods
- magnetic field change time: 15 giroperiods

Output

- Trapped particles: 6032
- Escaping particles: 3968
- Energy conservation: 0.99

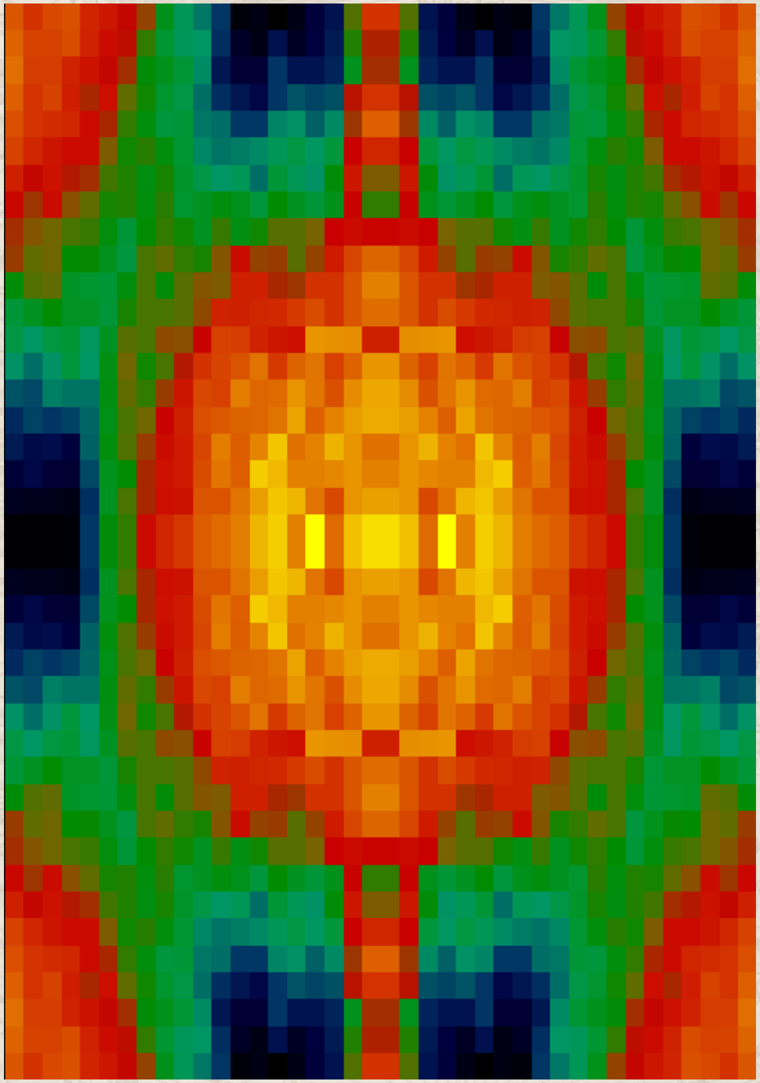
Preliminary results: Density of particles

- Trapped and escaping particles
- Density roughly anti-correlated with magnetic field intensity
- Specific regions where anti-correlation is brocken



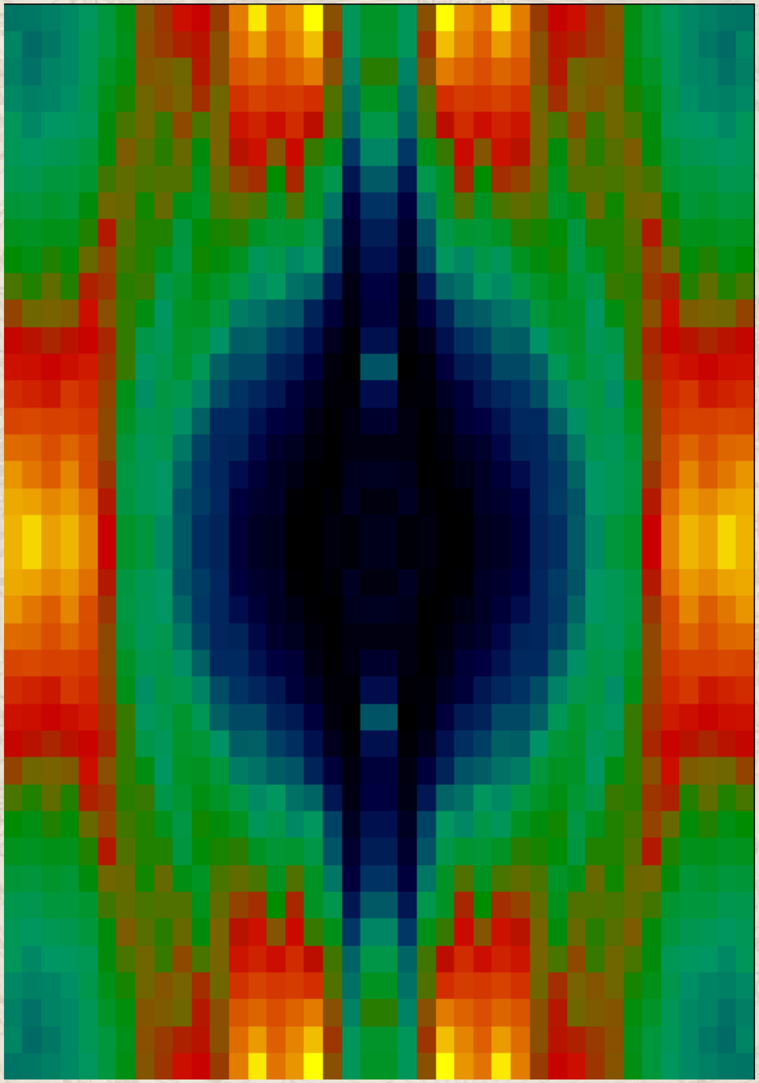
PR: Trapped particles density

- Much better anti-correlation
- Still at the necks the density is high
- Is this because of the "quasi-trapped" particles?



PR: Escaping particles density

- Density roughly correlated with magnetic field intensity
- There is a region where magnetic field intensity is constant along magnetic fild lines. Most particles there are escaping.
- Why correlation?
  - ▷ low parralel velocity
  - ▷ closer field lines



Conclusions

A case study has been performed

- multi-spacecraft measurements have been used
- full geometry have been determined

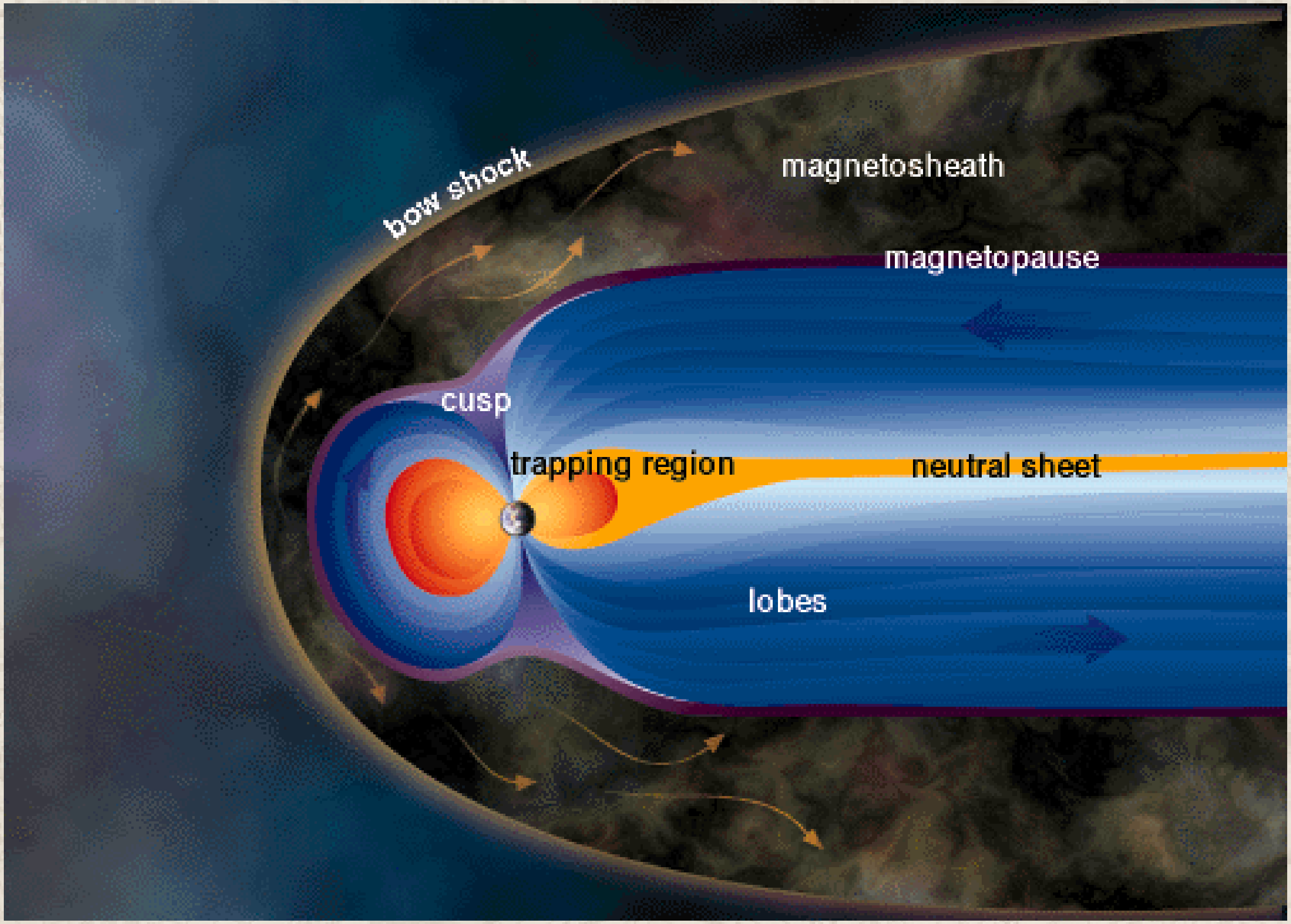
Preliminary results from particles simulation have been obtained

- most of the necessary numerical code has been written
- density distribution is consistent with the magnetic field configuration

To do list

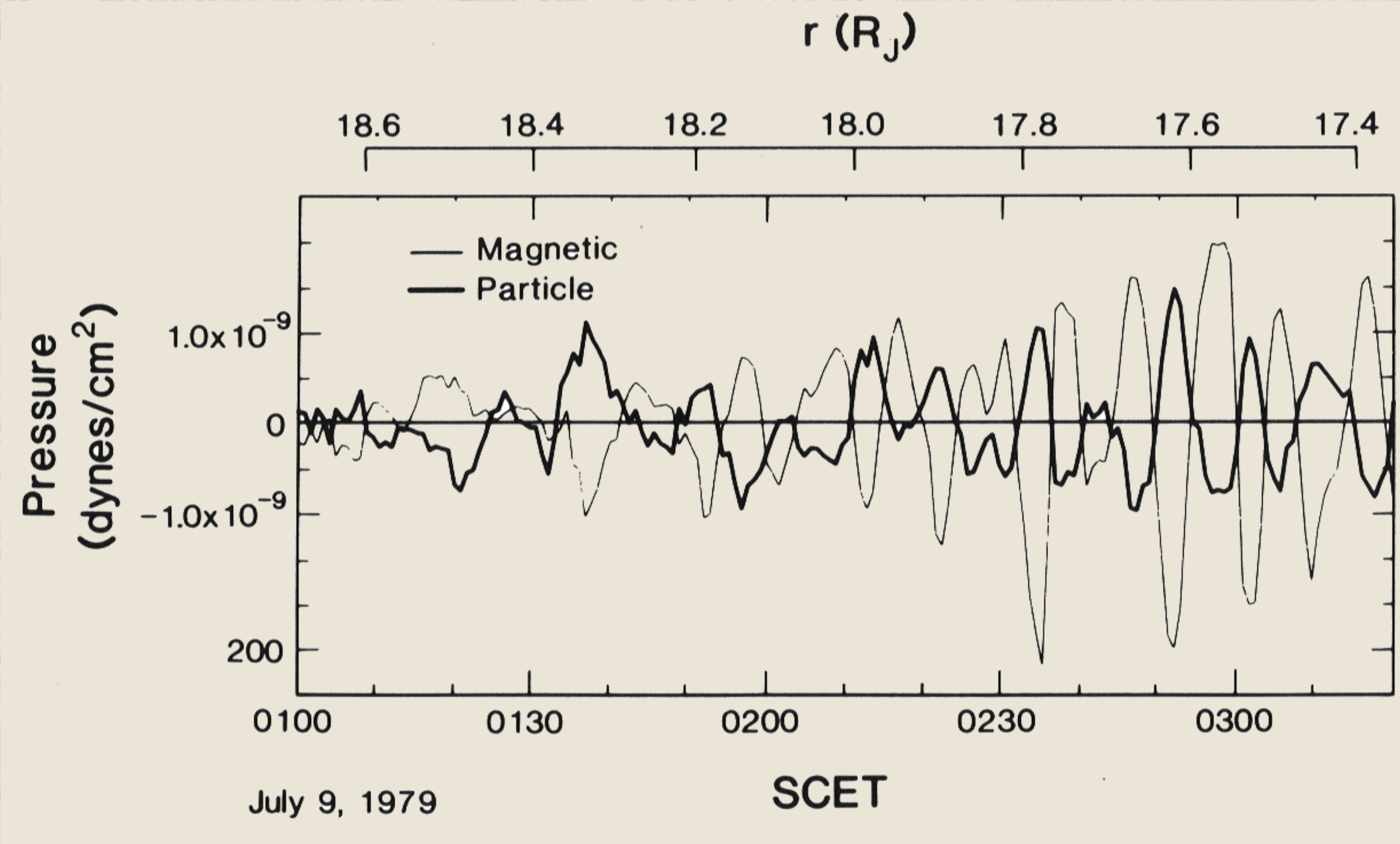
- increase number of particles in the simulation in order to improve statistics
- find the distribution function as function of position
- find the temperature, anisotropy, flow velocity as function of position
- compare the results with Cluster CIS data

A1. The Earth magnetosphere



Courtesy of Windows to the Universe, http://www.windows.ucar.edu

A2. Magnetic mirrors in spacecraft data



Khurana, K. K and M.G Kivelson 1989, Ultralow frequency MHD waves in Jupiter's middle magnetosphere, J. Geophys. Res. 94:5241

A3. Magnetic field data

- Date: Nov. 10 2000,
  08:20:00 - 80:25:00 UT

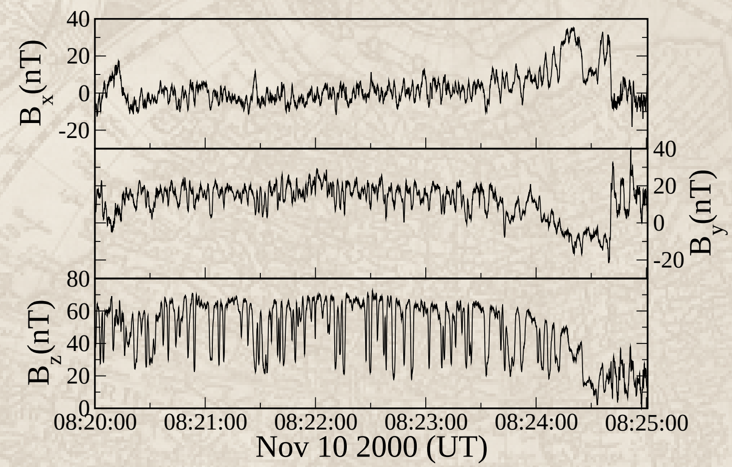
- Data resolution: High (22 vec/sec)

- Location: Dusk side magnetosheath

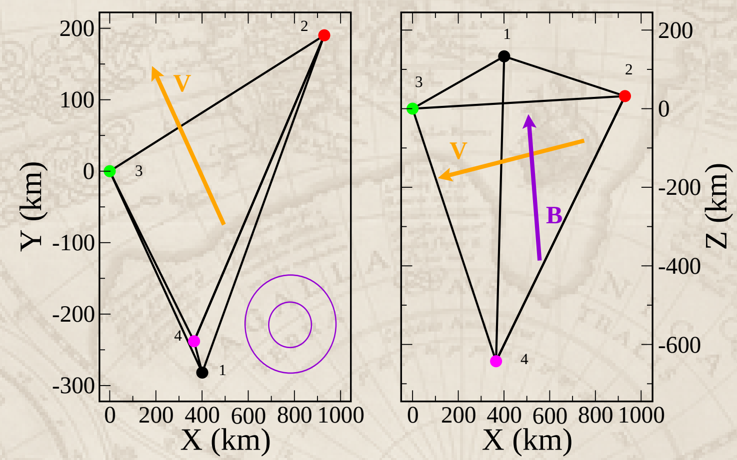
- Plasma flow: 815 km/s , C1 -> C3

- Magnetic field almost:
  - ▷ *aligned with Z_{GSE} axis*
  - ▷ *orthogonal to plasma flow*

Cluster 1 measured magnetic field



Cluster Tetrahedron Configuration



A4. Generating the distribution

we have

- uniform distributed random numbers $s \in (0, 1)$

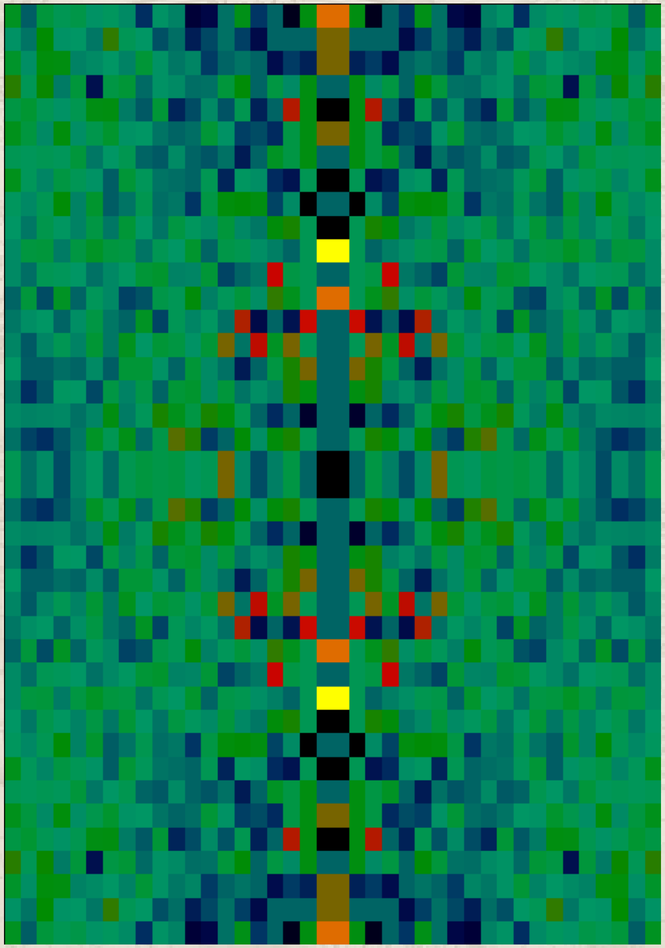
we need

- function $v($random sequence$(s))=$ sequence with probability $f(v)$
- $$f(v) = \left(\frac{m}{2\pi K_B T}\right)^{1/2} exp\left\{-\frac{m(v-u)^2}{2K_B T}\right\}$$

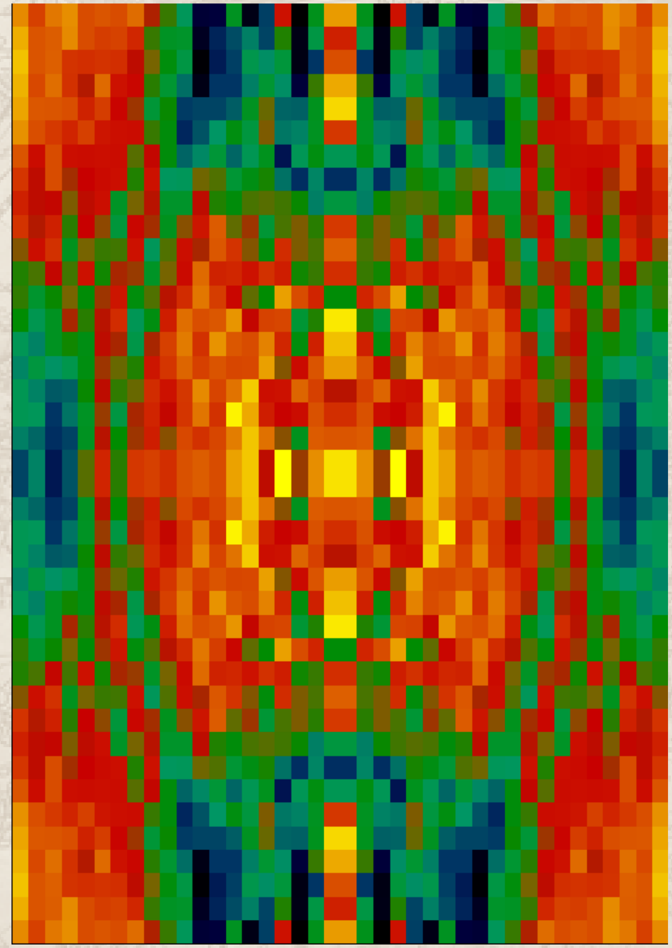
how to find it

- relation between probabilities: $ds = f(v(s))dv$
- $$v(s) = u + \left(\frac{2K_B T}{m}\right)^{1/2} erf^{-1}(1-2s)$$

A5. Effect of time averaging



Without time averaging



With time averaging