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Modeling the Structure of Magnetic Mirrors Using Cluster Data

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Summary

Magnetic mirror structures are common in space plasmas where the temperature is anisotropic, in particular they can be often found in the terrestrial magnetosheath.

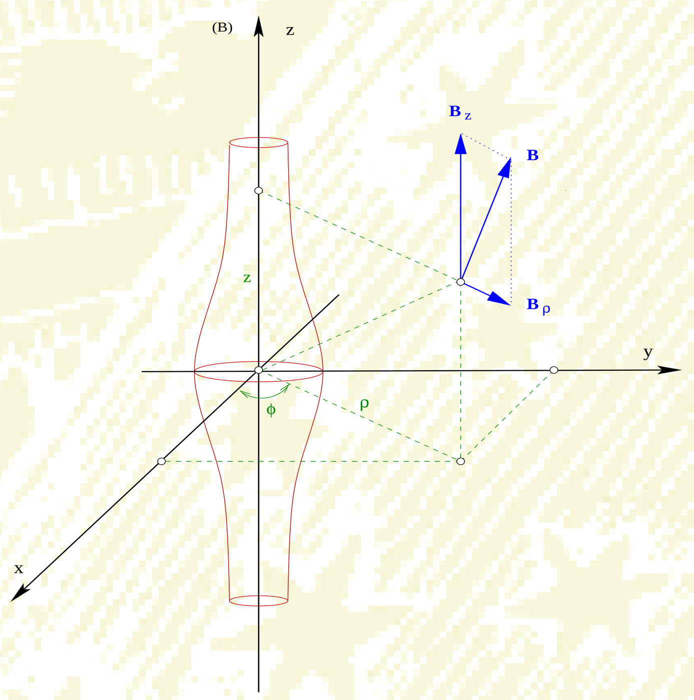
Because of their ability to provide simultaneous measurements from points separated by distances of the order of the magnetic mirror dimensions the four Cluster spacecrafts constitute an adequate tool for the study of the geometrical structure of magnetic mirrors.

Here we present a method for the identification of magnetic mirror structures using Cluster magnetometer observations and a recently developed analytical model for magnetic mirrors.

Model

Assumptions

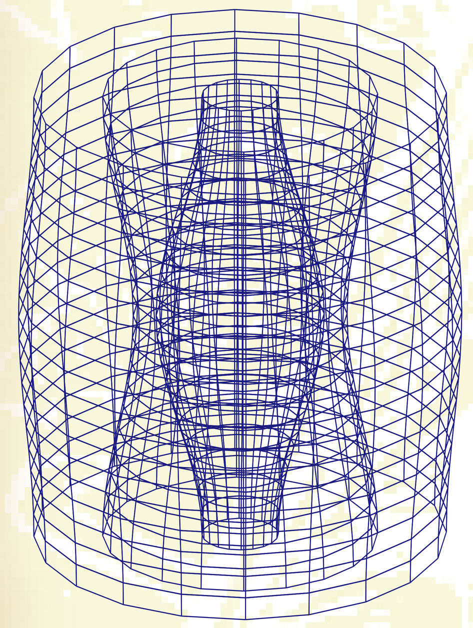
- Small perturbations
- Time-independent magnetic field
- Symmetry around z-axis
- Periodicity along z-axis
- No φ component of the magnetic field
- Magnetohydrostatic equilibrium
- Bi-Maxwellian distribution



Magnetic field perturbations

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

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



The above relations define the model magnetic field components where (ρ,φ,z) are cylindrical coordinates, $2L$ is the period of the perturbation along the average magnetic field, J_k is the k-order cylindrical Bessel function and α is an dimensionless parameter depending on the plasma β parameter and on the anisotropy.

For one Fourier order we can imagine the magnetic mirror being made by coaxial layers wrapping up each other. Each such layer corresponds to a given sign of the first order Bessel function in the expression of the radial component of the perturbation. The central structure represents the classical image of the magnetic bottle.

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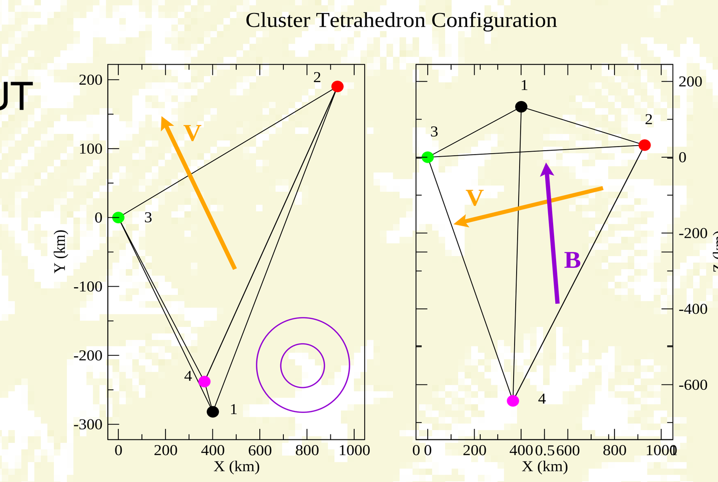
Looking for MM

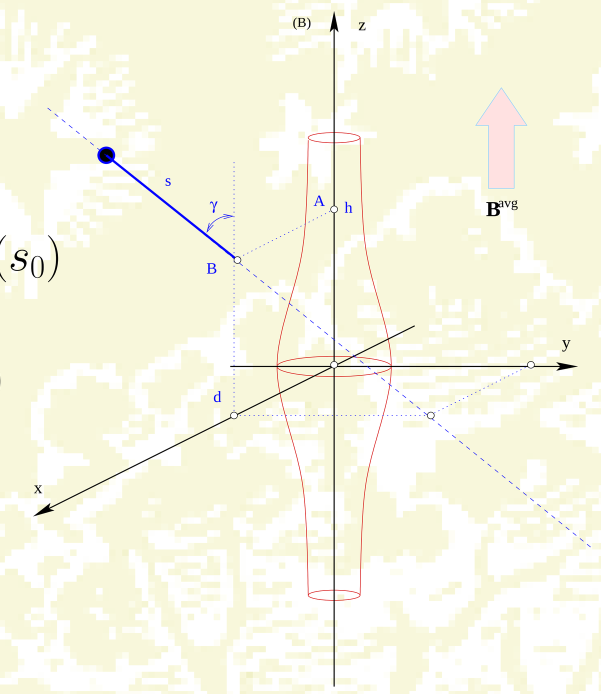
Data and tetrahedron configuration

- 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



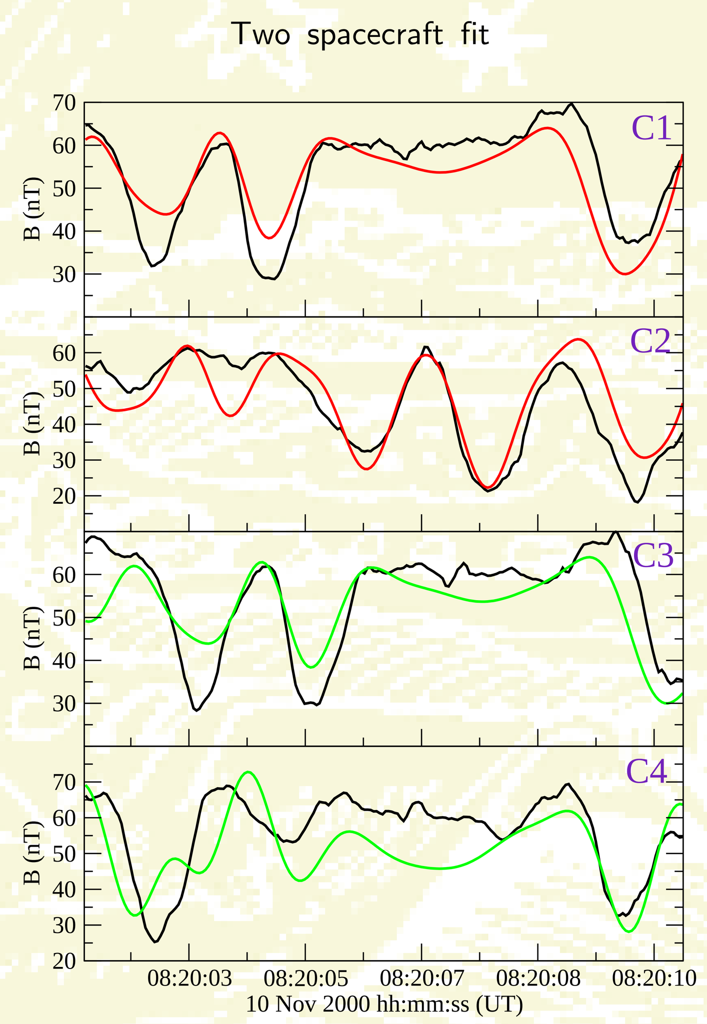
Fit parameters

- (1-3) trajectory coordinates (h,d,γ)
- (4) initial position of the spacecraft on its path (s_0)
- (5) the length of the the magnetic mirror (L)
- (6) the unperturbed magnetic field intensity (B_0)
- (7) the α plasma parameter
- (8-n) the Fourier coefficients a_j and b_j

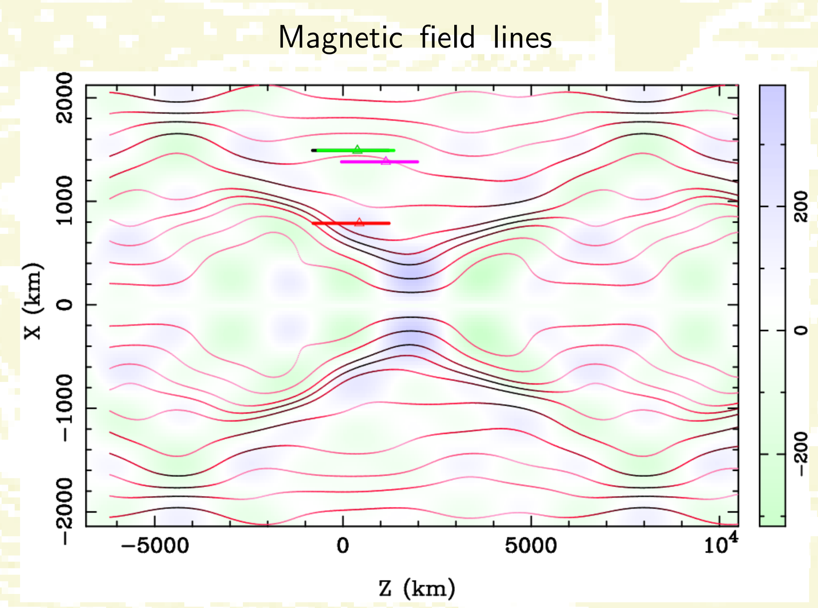


Multi-spacecraft fit

We fit the magnetic field intensity by minimizing the χ^2 function between the measured data and the model magnetic field for $n \leq 4$ (C1 and C2 in the example below). With the parameters found we calculate the model magnetic field at the location of the remaining spacecraft (C3 and C4 in the example below)



- $h = 383$ km
- $d = 1490$ km
- $\gamma = 74^o$
- $L = 6186$ km
- $B = 52.23$ nT
- $\alpha = 11.56$
- $R = 2051$ km
- $C_1 = 0.812$
- $C_2 = 0.829$
- $C_3 = 0.776$
- $C_4 = 0.640$

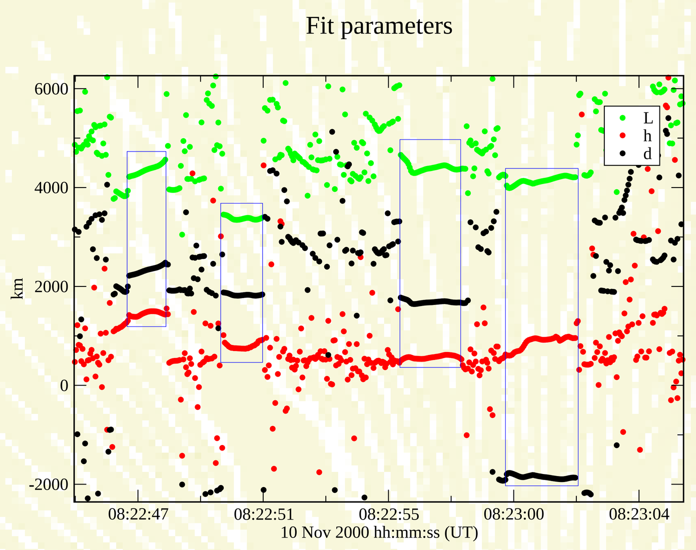


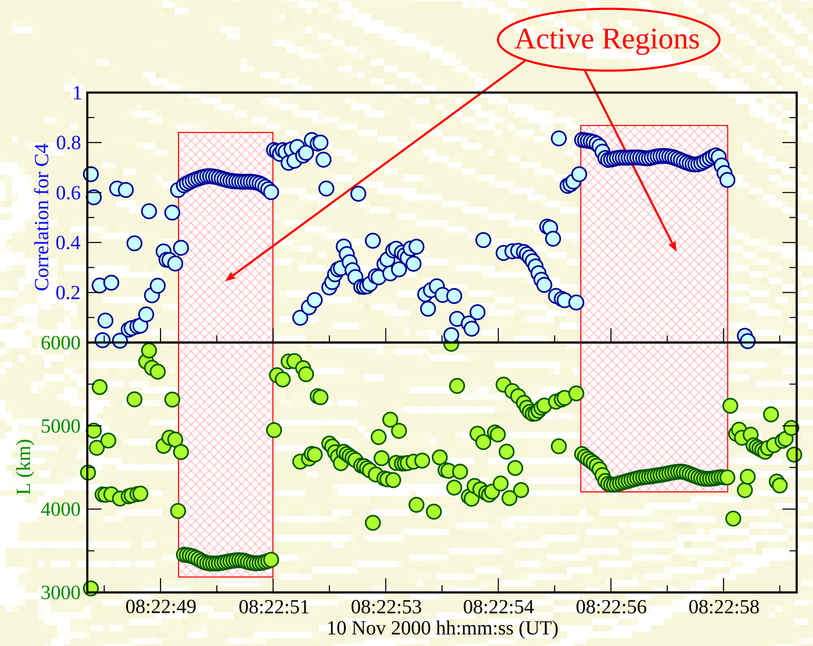
The right side figure represents the magnetic field lines derived from the model using the resulting fit parameters. In the background we plotted the electric current density in nA/m^2. The straight lines are the projections of the spacecraft trajectories.

Data Scanning

We scan the magnetic field data using multi-spacecraft fits for 200 datapoints (about 9 s, or 7000 km) overlapping intervals. If the fit of the previous interval was satisfying the set of parameters is used as starting guess for the next interval, otherwise default values are used.

In the left figure we have plotted the L, h and d fit parameters resulting from scanning a 30 s data interval using overlapping intervals. The fits are performed using C1 and C2 data. Each region where the fit parameters are grouping close to each other at relative constant values represents a possible MM. In this interval we can identify four such possible mirror structures (blue boxes)





The correlation between the data from the spacecraft not involved in the fit and the magnetic field predicted by the model at the location of these spacecraft decides if a mirror structure (as defined by the model) had been found. In the right side figure we show an example where good correlation has been found for two intervals with stable parameters from fits.

By scanning the data we are able to find "mirror active intervals" where consecutive fits give stable parameters and the correlation between the data from spacecraft not participating in the fit and the model magnetic field is good, and non active intervals where the fit parameters are scattered and/or the correlation for spacecraft not participating in the fit is poor.

Conclusions

- We have developed an analytical model which describes the properties and geometry of the magnetic mirrors
- We were able to identify mirror active intervals where the magnetic field is consistent with our model separated by non-active intervals
- We have demonstrated the possibility of deriving the shape and parameters of the magnetic mirrors using multi spacecraft data
- Further investigation is necessary
  - *include particle data*
  - *perform the fit for ρ and z components instead of the module of the magnetic field*
  - *perform particle simulations for model magnetic field configurations*
  - *look at the distribution function*
  - *improve or develop a nonlinear model*
  - *...*

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