Magnetic Mirror Geometry Using Cluster Data: Case Study

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Preview

Magnetic Mirror Model

- Magnetohydrostatic (Pressure Equilibrium)
- Small perturbations
- Symmetry

Data analyzing

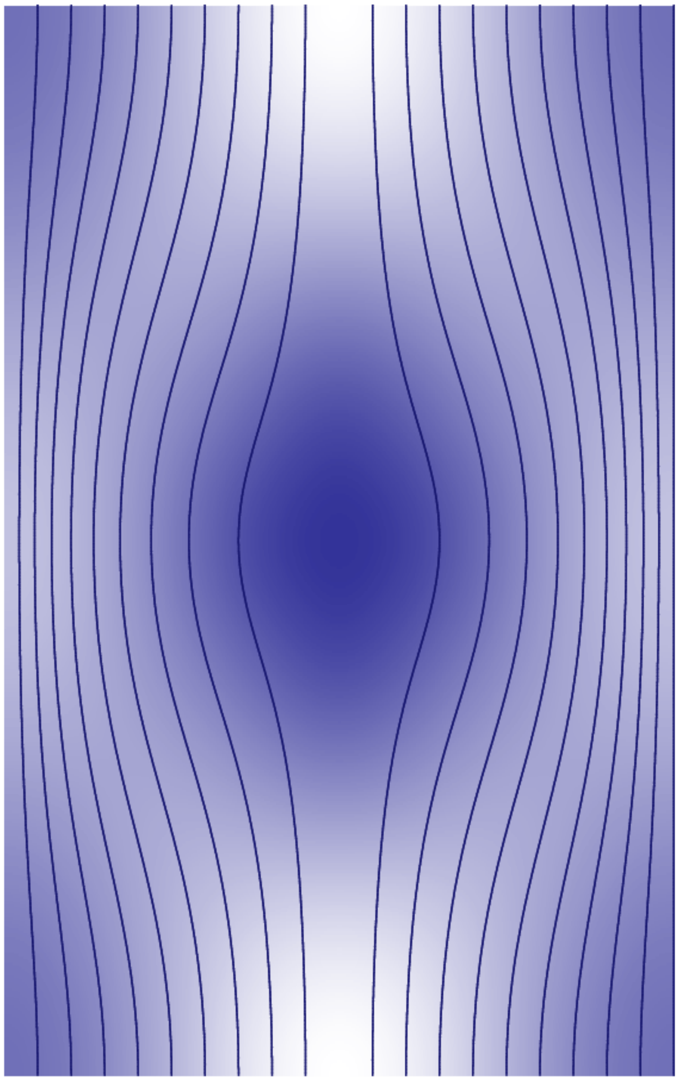
- Fit data from multiple spacecraft
- Comparison with witness spacecraft data

Results

- Full geometry of magnetic mirror structure
  - ▷ *location*
  - ▷ *orientation*
  - ▷ *shape*
  - ▷ *size*

Mirror Structures

- Fundamental plasma instability
- Needs temperature anisotropy ($T_\perp > T_\parallel$) in order to develop
- Non propagating (purely imaginary frequency), strongly compressive mode
- Magnetic field is anticorrelated with plasma density
- Very common in Earth magnetosheath but also in many other space plasmas



Assumptions

Small perturbations

- ▷ $\delta B << B$

Time-independent magnetic field

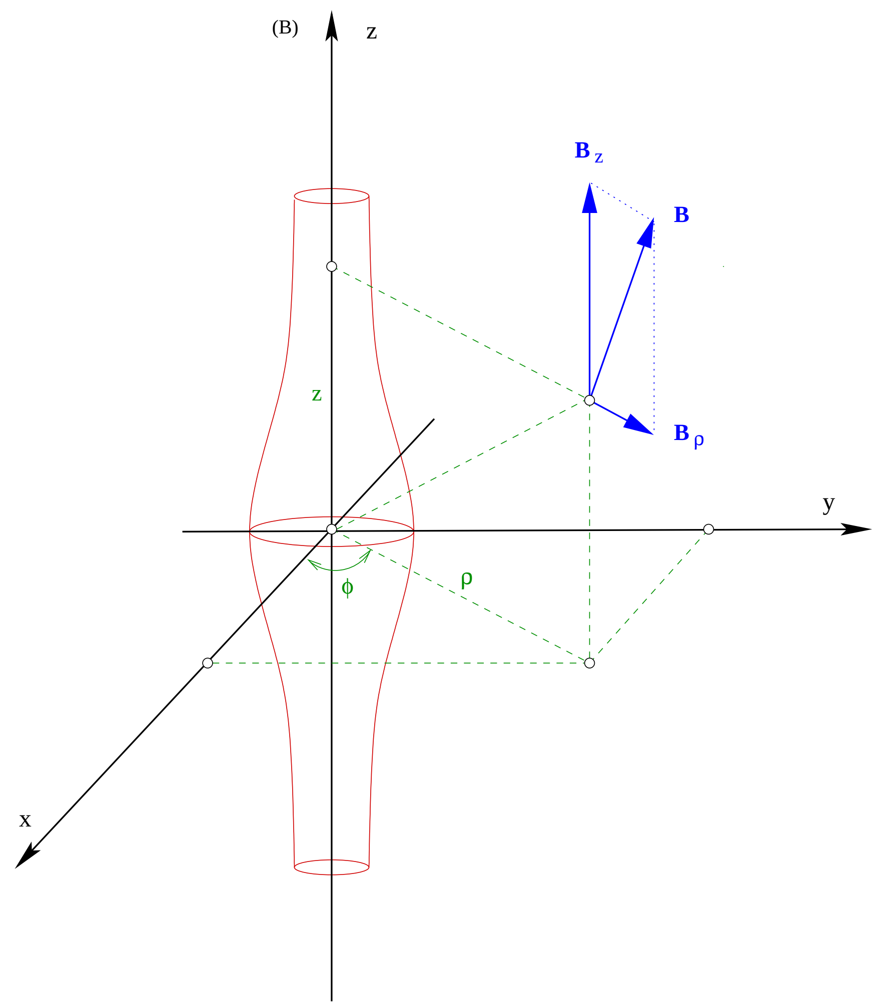
- ▷ $B \neq B(t)$

Symmetry around z-axis

- ▷ $B \neq B(\varphi)$

Periodicity along z-axis

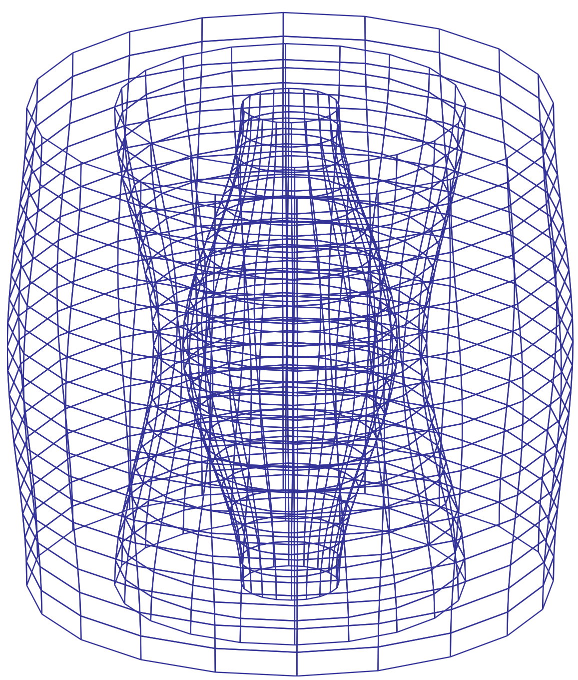
- ▷ $B(\rho, z + 2L) = B(\rho, z)$



Model magnetic field

Magnetic field perturbation:

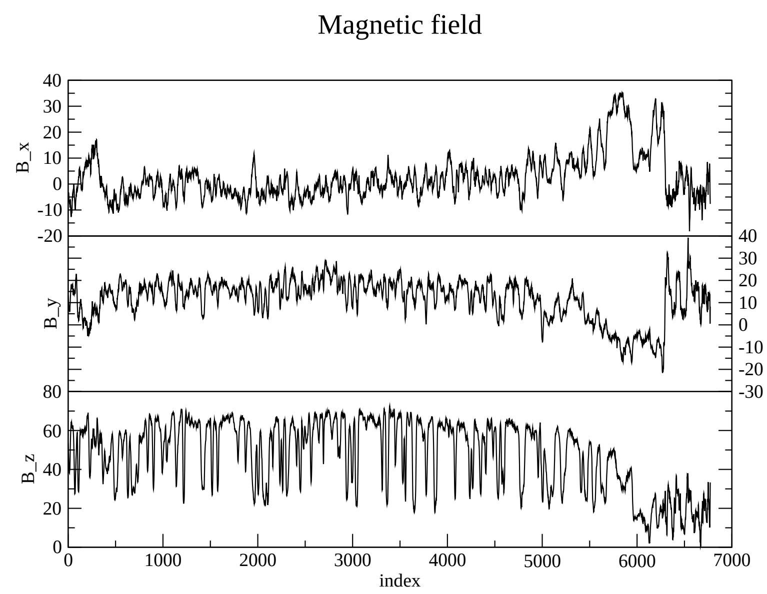
- $$\delta B_\rho(\rho, z) = \frac{2\pi}{\alpha} \sum_{n=1}^{\infty} J_1\left(\frac{n\alpha\rho}{L}\right)\left[a_n \sin\left(\frac{n\pi z}{L}\right) - b_n \cos\left(\frac{n\pi z}{L}\right)\right]$$
- $$\delta B_z(\rho, z) = 2\sum_{n=1}^{\infty} J_0\left(\frac{n\alpha\rho}{L}\right)\left[a_n \cos\left(\frac{n\pi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

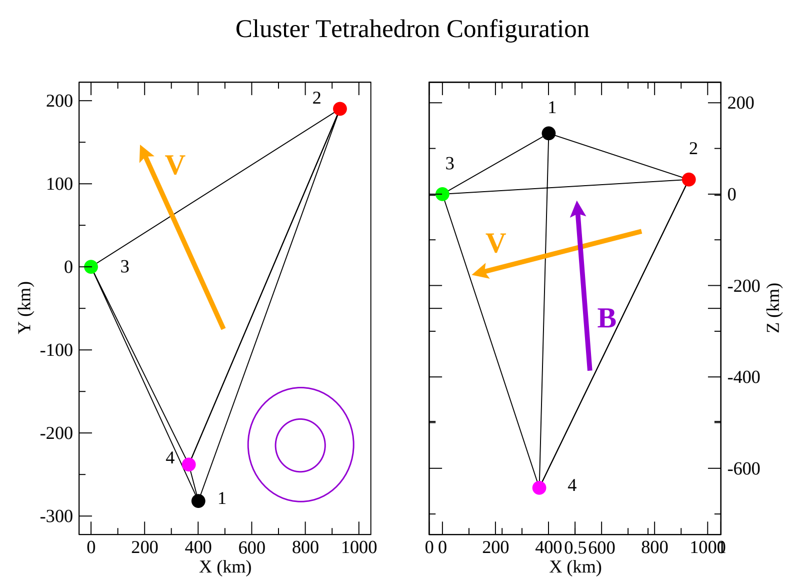


For one Fourier order we can imagine the magnetic mirror being made by coaxial layers wrapping up each other. Each such layer corresponds to a given sign of the first order Bessel function in the expression of the radial component of the perturbation. The central structure represents the classical image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

Data and tetrahedron configuration

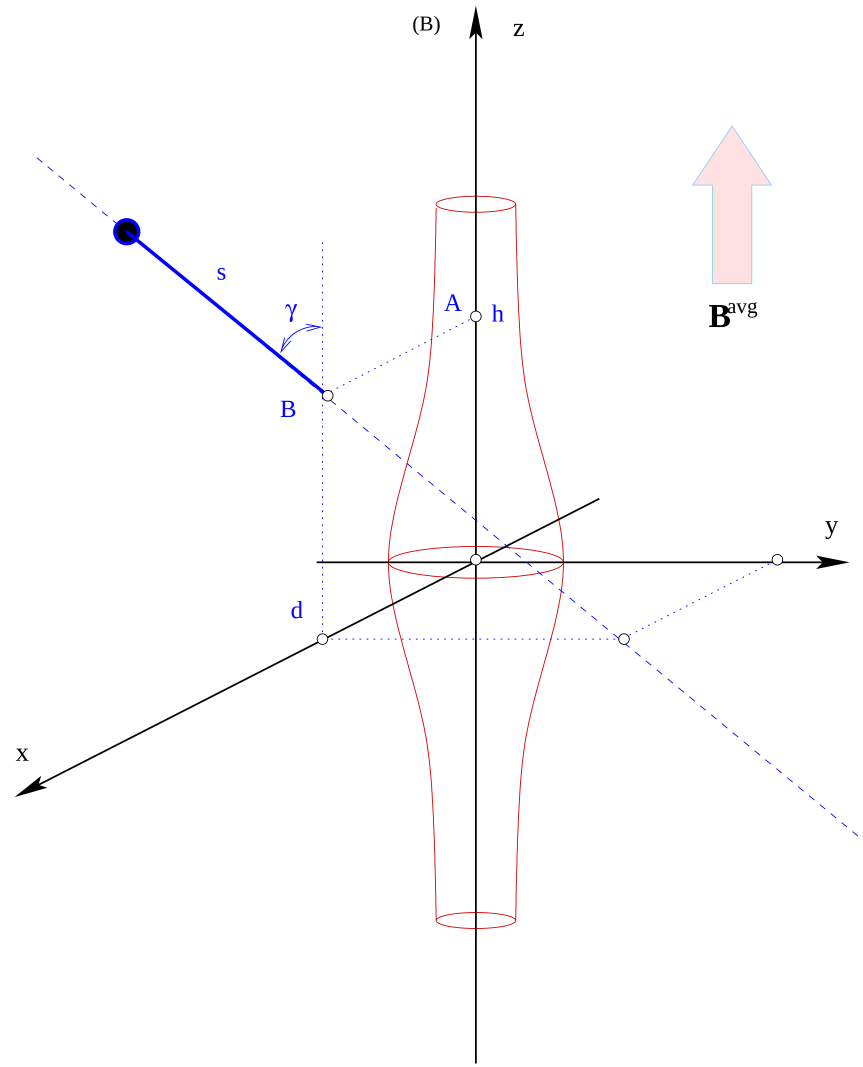
- Date: Nov. 10 2000, 08:20:00 - 80:25:00 UT
- Data resolution: High (22 vec/sec)
- Location: Dusk side magnetosheath
- Plasma flow: 815 km/s , C1 -> C3
- Magnetic field almost:
  - ▷ *aligned with Z_{GSE} axis*
  - ▷ *orthogonal to plasma flow*





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 MM (L)
- (6) the unperturbed magnetic field intensity (B_0)
- (7) the α plasma parameter
- (8-n) the Fourier coefficients a_j and b_j



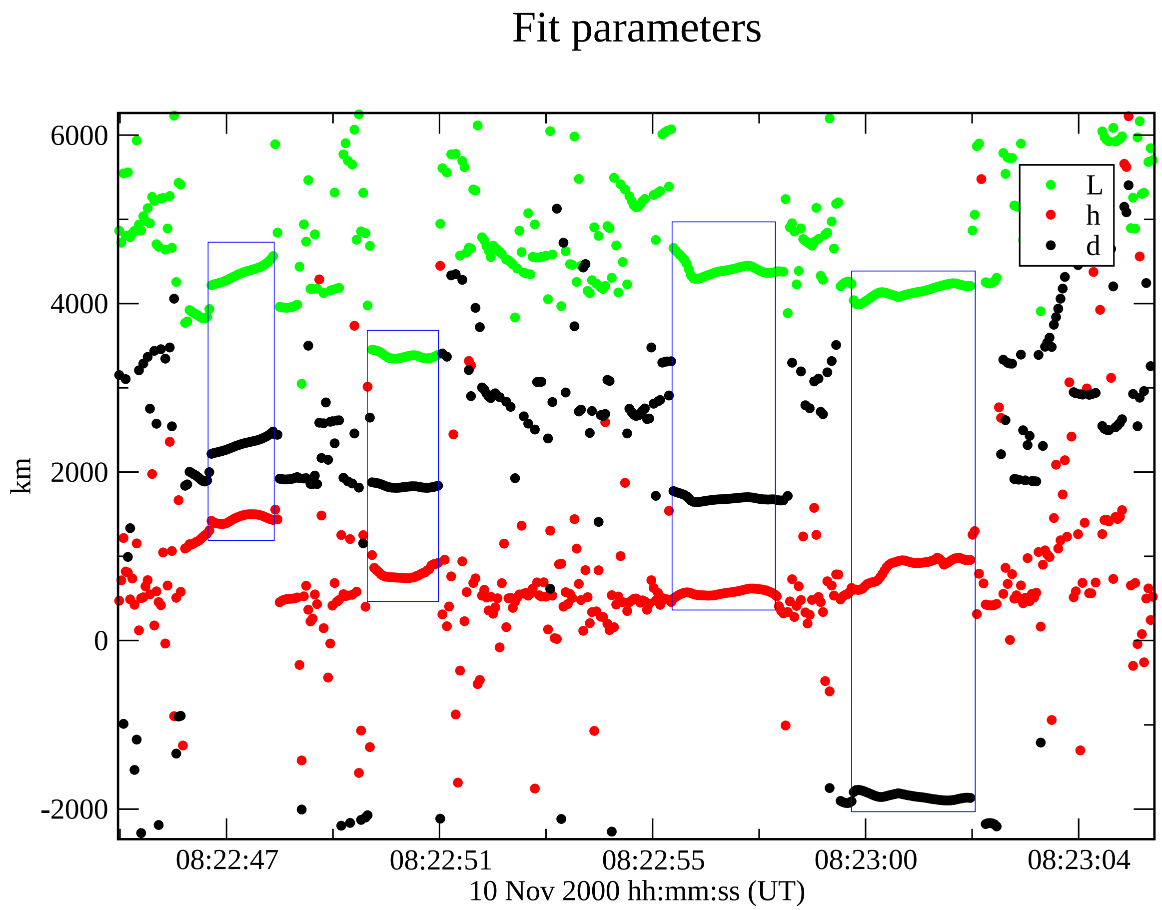
Scan procedure

- Simultaneous fit using $n \leq 4$ spacecraft for data interval $[i, i+k]$
- Compute model field for the other (witness) spacecraft using parameters found from fit
- Compare model field with data
- Decide starting guess parameters for the next interval
- Return to the first step for interval $[i+1, i+k+1]$

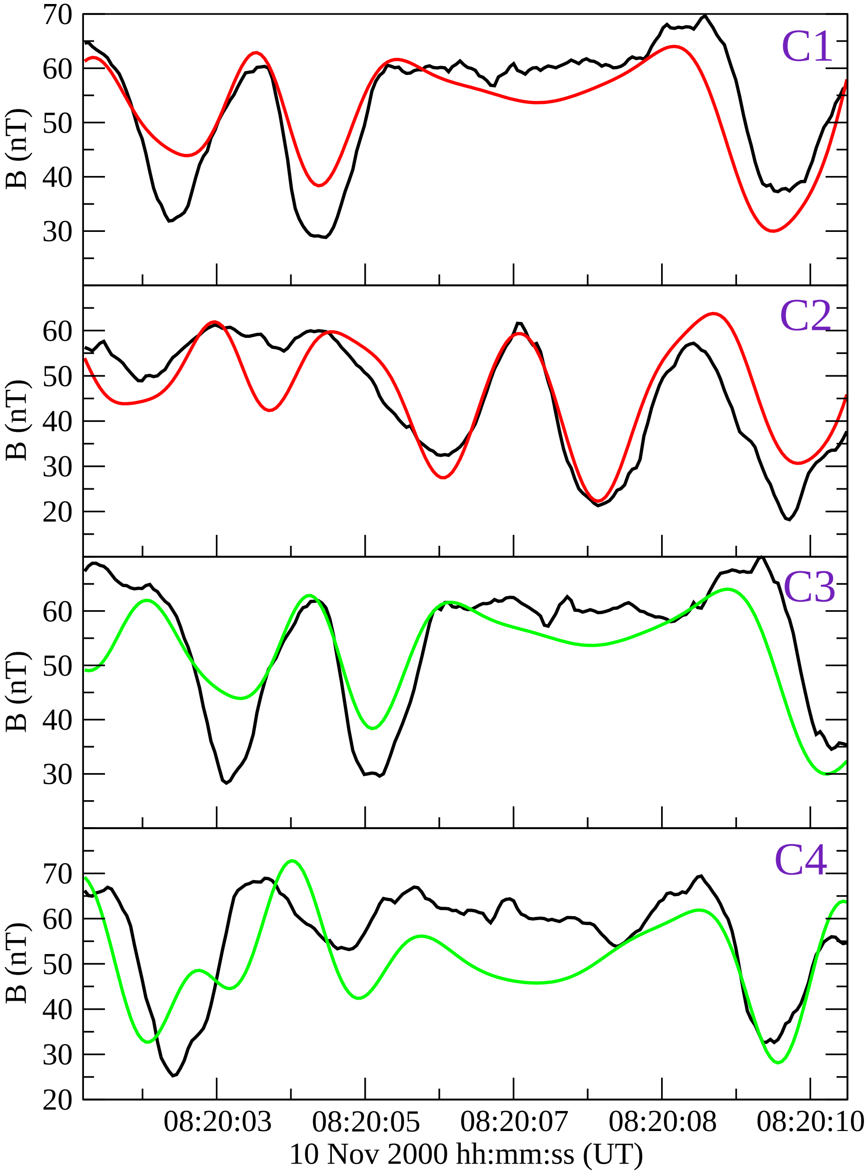
Scan example

We scan the magnetic field data using multi-spacecraft fits for 200 data-points (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.

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)



Identified structure



We fit the magnetic field intensity by minimizing the χ^2 function between the measured data (black) and the model magnetic field for C1 and C2. With the parameters found we calculate the model magnetic field at the location of the witness spacecraft (C3 and C4). The resulting parameters are:

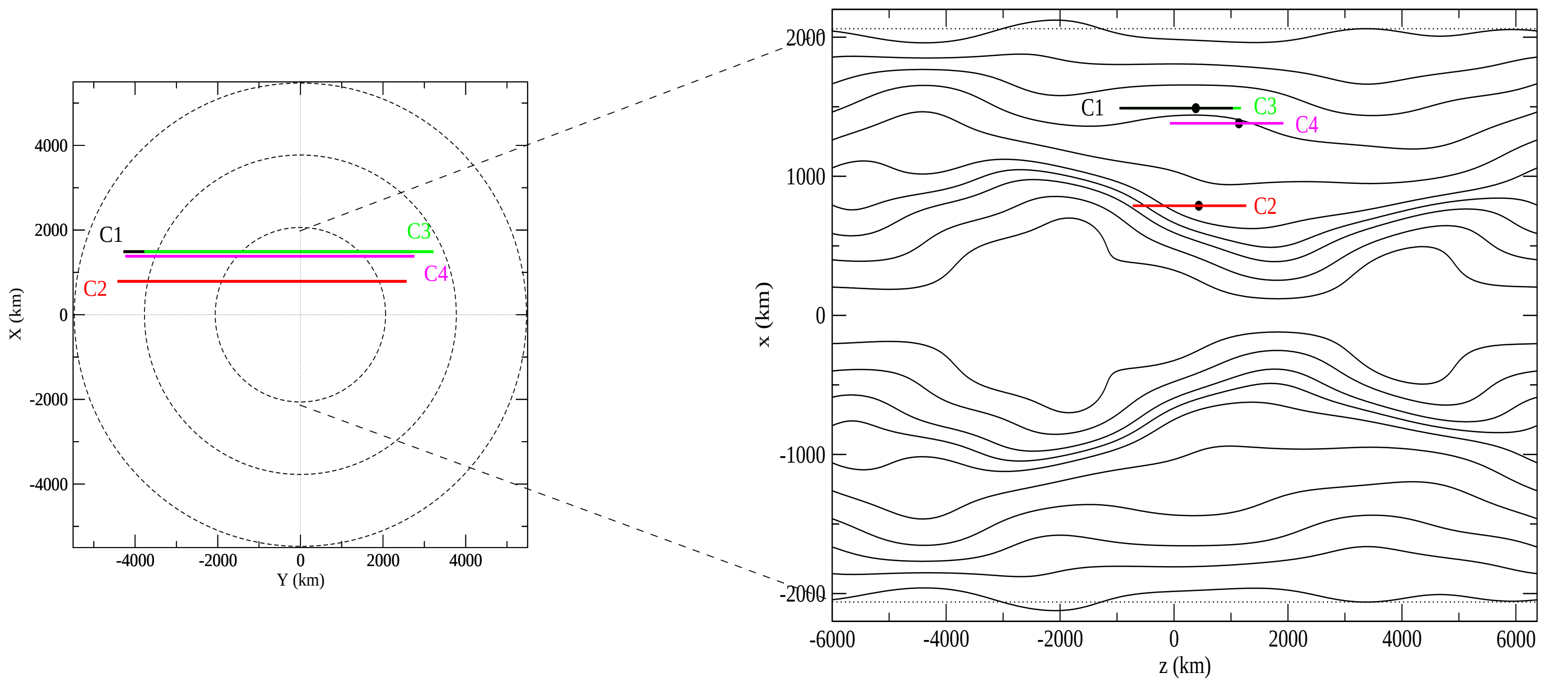
- ▷ h = 383 km
- ▷ d = 1490 km
- ▷ γ = 74^o
- ▷ L = 6186 km
- ▷ B = 52.23 nT
- ▷ α = 11.56

- ▷ R = 2051 km
- ▷ Cor_1 = 0.812
- ▷ Cor_2 = 0.829
- ▷ Cor_3 = 0.776
- ▷ Cor_4 = 0.640

Reconstructed structure

With the parameters obtained from the fit we can calculate the magnetic field for several layers around the symmetry axis.

In the figures below the straight colored lines represent the projections of the spacecraft trajectories. Left side picture is a view along the symmetry axis, the circles are the boundaries between layers. Right side picture represents the magnetic field lines in the (x, z) plane.



Conclusions

- We have an analytical model which describes the geometry of MM.
- By scanning the magnetic field data using multi-spacecraft fits 'possible' magnetic mirror structures are identified.
- Depending on the quality of the fit and on the comparison with witness spacecraft the 'possible' magnetic mirror structure is validated (or not).
- Once a mirror structure is found we can specify its location, orientation, shape and dimension.
- Further investigation is necessary.
  - ▷ *perform statistical study.*
  - ▷ *include particle data.*
  - ▷ *perform particle simulations for model magnetic field configurations.*
  - ▷ *look at the distribution function.*
  - ▷ *develop a nonlinear model.*
  - ▷ *...*