Magnetic Cloud model without force-free restriction

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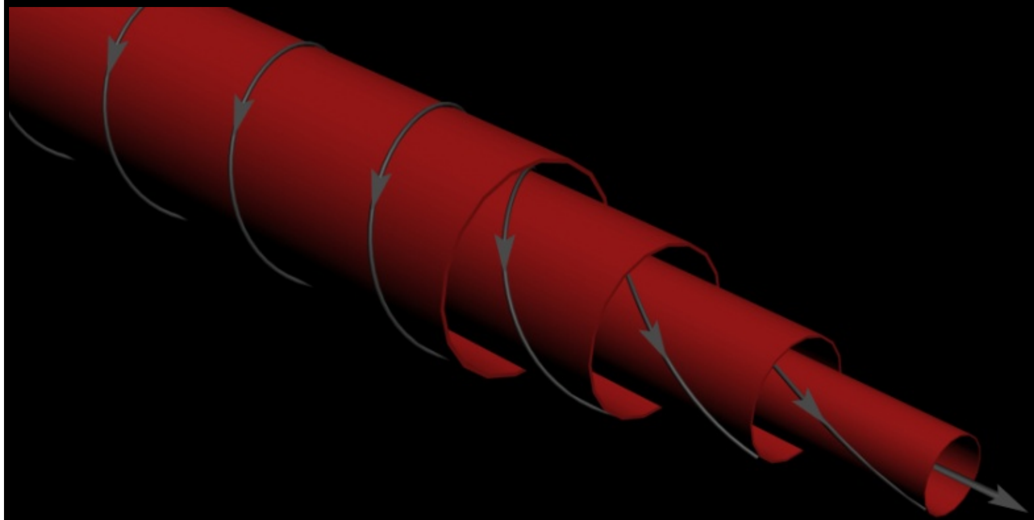
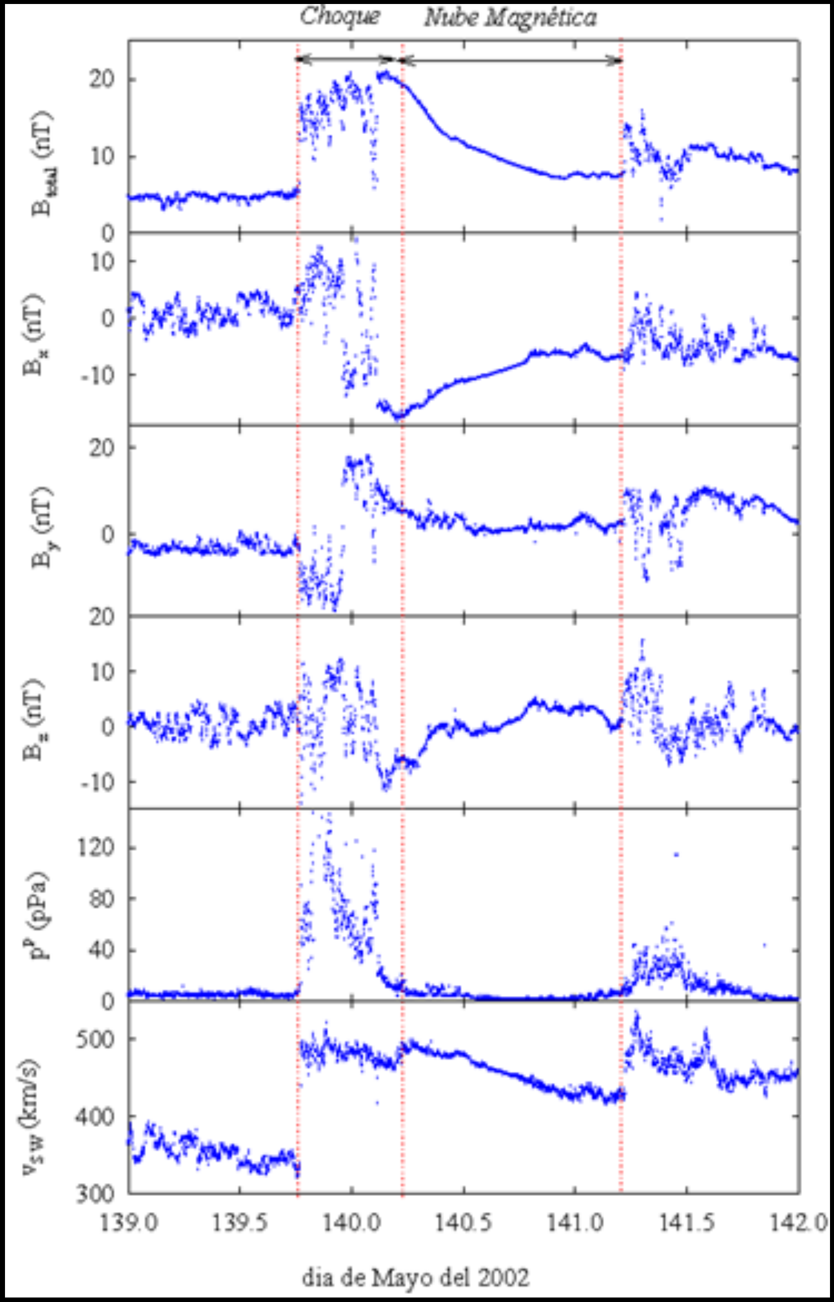
Magnetic clouds

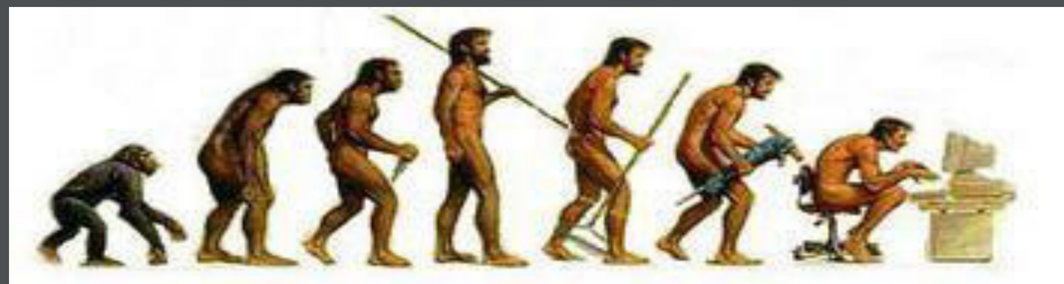
(Burlaga *et al*., 1981)

1) High magnetic field intensity
2) Rotation of magnetic filed vector
3) Low temperature (pressure) protons





Model evolution



* Why FF?

Once upon ..

- circular CS
- cylindrical approximation
- conditions in the radial and axial current densities

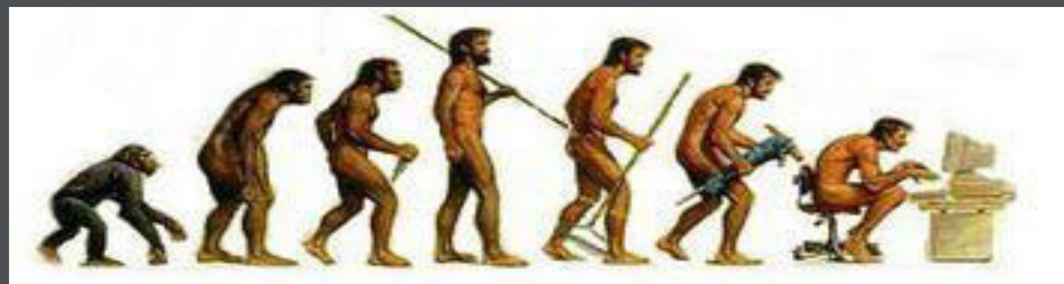
$$\nabla \cdot \mathbf{E} = \frac{1}{\epsilon_0}\rho$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} + \frac{\partial \mathbf{B}}{\partial \mathbf{t}} = 0$$

$$\nabla \times \mathbf{B} - \mu_0\epsilon_0\frac{\partial \mathbf{E}}{\partial \mathbf{t}} = \mu_0 \mathbf{J}$$

Model evolution



2000

Circular Cross Section (CS)
(Hidalgo et al. 2000, Solar Physics)

Once upon ..

Circular CS

$$B_{\varphi}^{MC} = \frac{\mu_0}{2} j_{\psi} r ,$$

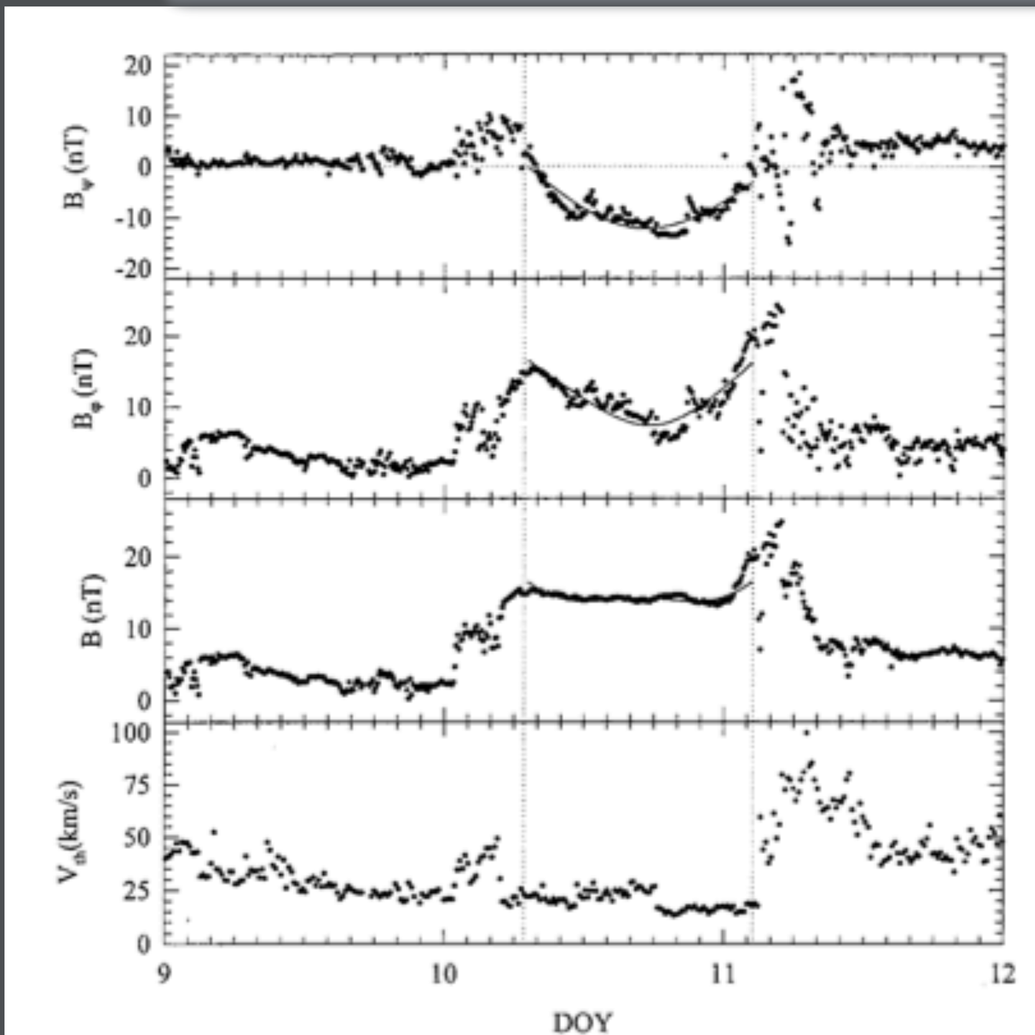
where μ_0 is the vacuum permeability, r t
radius) and j_{ψ} the toroidal component of t
Similarly, we suppose that the toroidal
poloidal component of the current density
symmetric and the poloidal current distribu

$$B_{\psi}^{MC} = \frac{\mu_0}{2} j_{\varphi} \frac{(\rho_0 - r)^2 - (\rho_0 - R)^2}{(\rho_0 - r)}$$

Parameters
-Orientation
- Impact parameter
- Axial/Poloidal current density comp.

Event 1 - MC

Event (Year-month)	Start (Doy-hour)	End (Doy-hour)	V_{sw} (km s^{-1})	R (10^9 m)	j_ψ (10^{-12} C m^{-2} s^{-1})	j_φ (10^{-12} C m^{-2} s^{-1})	θ (deg)	ϕ (deg)	y_0/R	χ^2
97-01	10-07	11-02	438	17.9	1.46	1.17	6	259	0.57	0.029

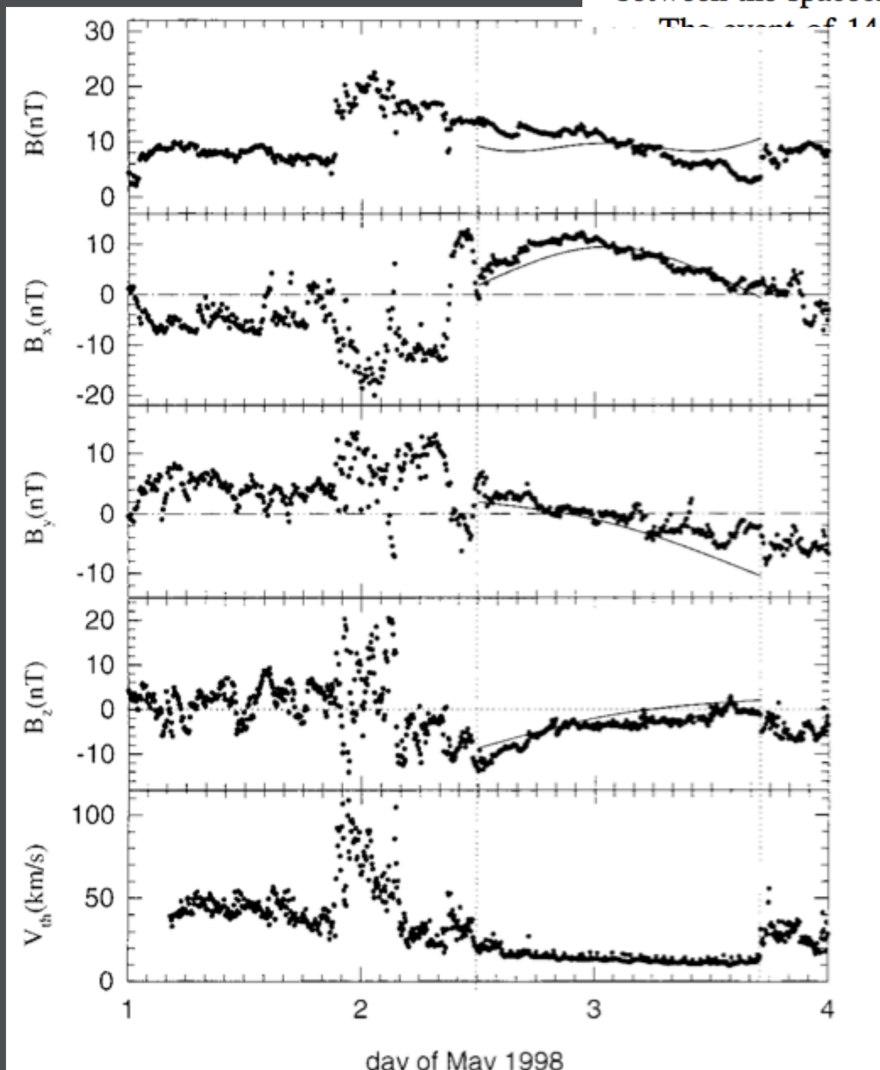


- Crossing the front
- close to the ecliptic plane

(Hidalgo et al. 2000, Solar Physics)

Event 4 – Ejecta?

are consistent with identification of the events as an MC. Fitting the model we find that the axis direction is $\theta = 14°$, $\phi = 14°$ and the minimum approach distance between the spacecraft and the cloud axis is $0.57R$, where R is 0.07 AU.



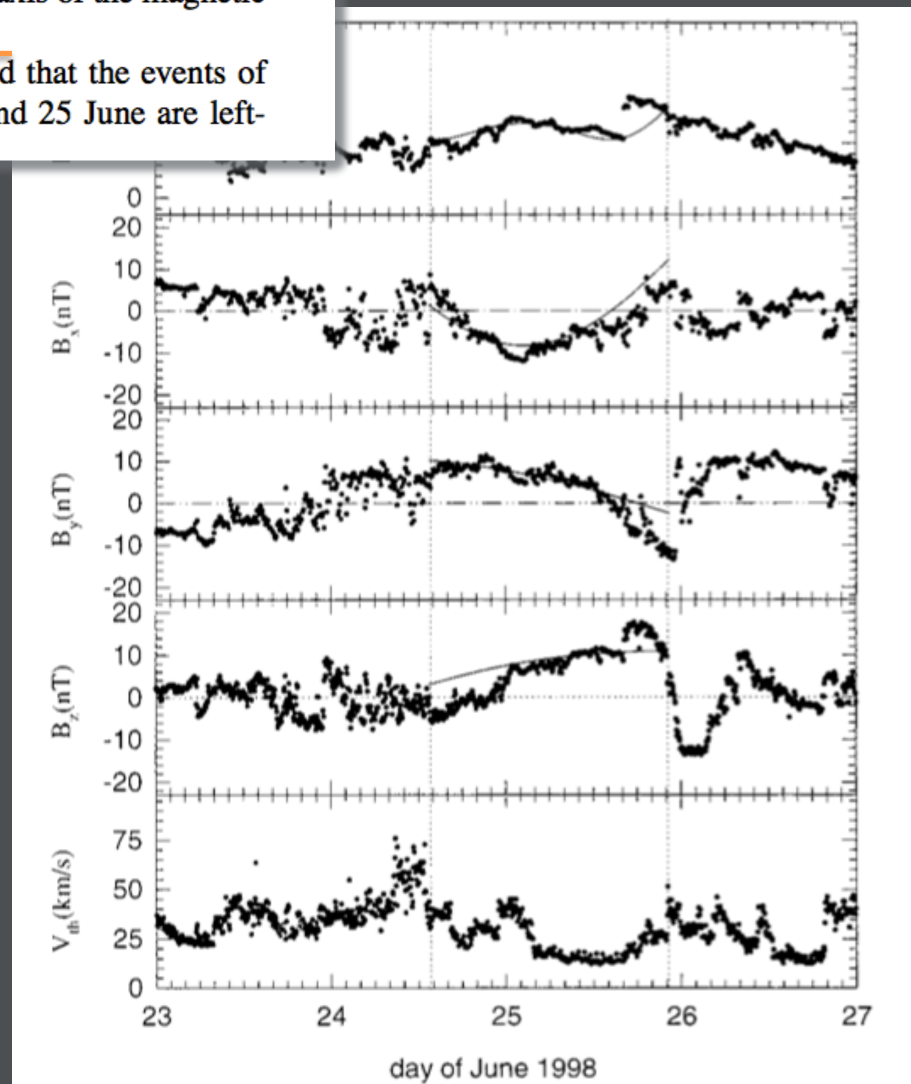
- Crossing the flank
- close to the ecliptic plane

(Cid et al. 2001, Solar Physics)

Event 6 – Ejecta+

June, taking into account where the thermal velocity increases, we fit the model to data from 24 June, 13 h to 25 June, 16 h in order to avoid the internal 'shock-like' feature that appears inside the MC. The axis of the MC is estimated to be in the direction $\theta = -1°$, $\phi = 181°$. The spacecraft was far from the axis of the magnetic cloud, y_0/R being 0.62, where R is estimated to be 0.004 AU.

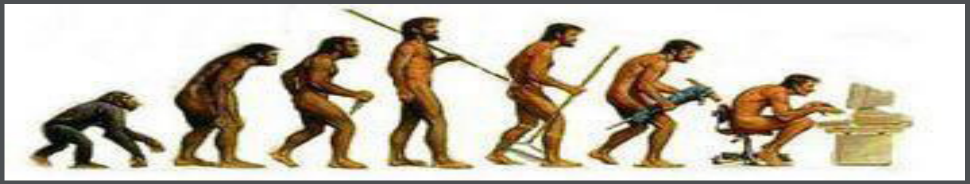
Concerning the helicity of the magnetic field lines, we find that the events of 2 May and 14 June are right-handed and those of 4 March and 25 June are left-handed.



- Crossing the flank
- Close to the ecliptic plane

(Cid et al. 2001, Solar Physics)

Model evolution



Circular CS (improved) + Plasma Pressure
(Hidalgo et al. 2002, JGR)
(Cid et al. 2002, Solar Physics)

2000

2002

Once upon ..

Circular CS

ccs/+plasma

$$B_{\varphi}^{\mathrm{MC}} = \frac{\mu_0}{2} j_{\psi} r,$$

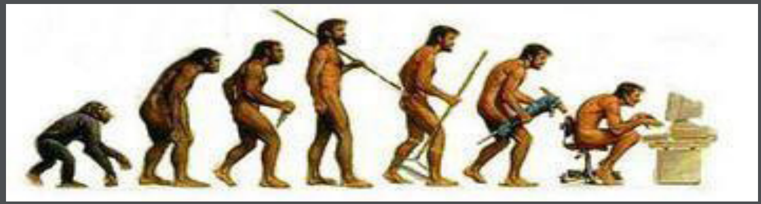
$$B_{\psi}^{\mathrm{MC}} = \frac{\mu_0}{2} \alpha \left(R^2 - r^2\right),$$

$$P = \frac{\mu_0}{4} \left[\frac{-\alpha^2}{2} r^4 + \left(\alpha^2 R^2 - j_{\psi}^2\right) r^2 \right] + P_0,$$

jxB=grad(P)

Parameters
-Orientation
- Impact parameter
- Axial/Poloidal current density comp.
- Plasma pressure

Model evolution

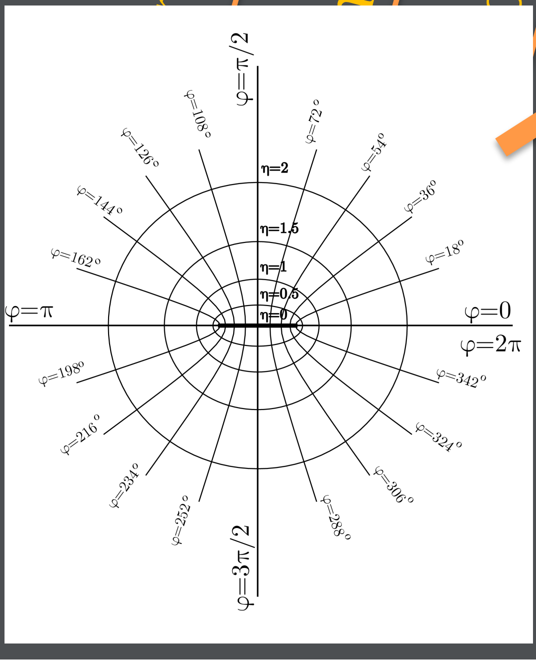


2000 2002 2002

Elliptical cross-section
(Hidalgo et al. 2002, JGR)

Elliptic Cylindrical Coordinates:

$$x_{MC} = a \cosh\eta \cos\varphi$$
$$y_{MC} = y$$
$$z_{MC} = a \sinh\eta \sin\varphi$$



- Elliptical CS
- cylindrical approximation
- conditions in the radial and axial current densities

$$B_y = B_y^0 + \mu_0 j_r r SE(\cos\varphi, 1/\cosh\eta)\cosh\eta$$

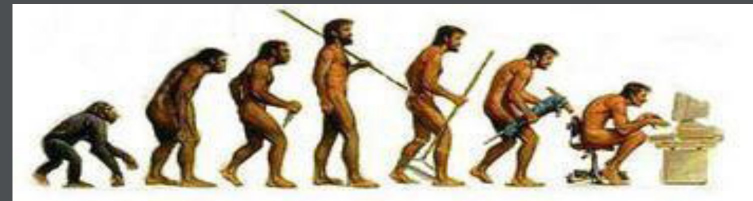
$$B_\varphi = -\frac{\mu_0 j_y^0 r \cosh\eta}{[\cosh^2\eta - \cos^2\varphi]^{\frac{1}{2}}}$$

$$j_r = costant$$

$$j_y = \frac{\sinh\eta}{[\cosh^2\eta - \cos^2\varphi]} j_y^0$$

$$j_\varphi = \frac{\sinh\eta \; SF(\cos\varphi, 1/\cosh\eta)}{[\cosh^2\eta - \cos^2\varphi]^{\frac{1}{2}}} j_r$$

Model evolution



2000

2002

2002

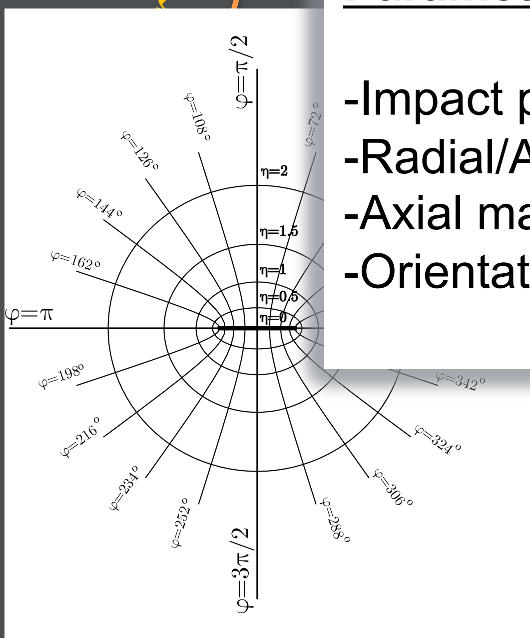
Elliptical cross-section
(Hidalgo et al. 2002, JGR)

Or

Elliptic Cylindrical Coordinates:

$$x_{MC} = a\cosh\eta\cos\varphi$$
$$y_{MC} = y$$
$$z_{MC} = a\sinh \ldots$$

- Elliptical CS
- cylindrical approximation
- conditions in the radial and axial
...es



Parameters

- -Impact parameter: 1
- -Radial/Axial current densities:2
- -Axial magnetic field
- -Orientation: 2->3 parameters

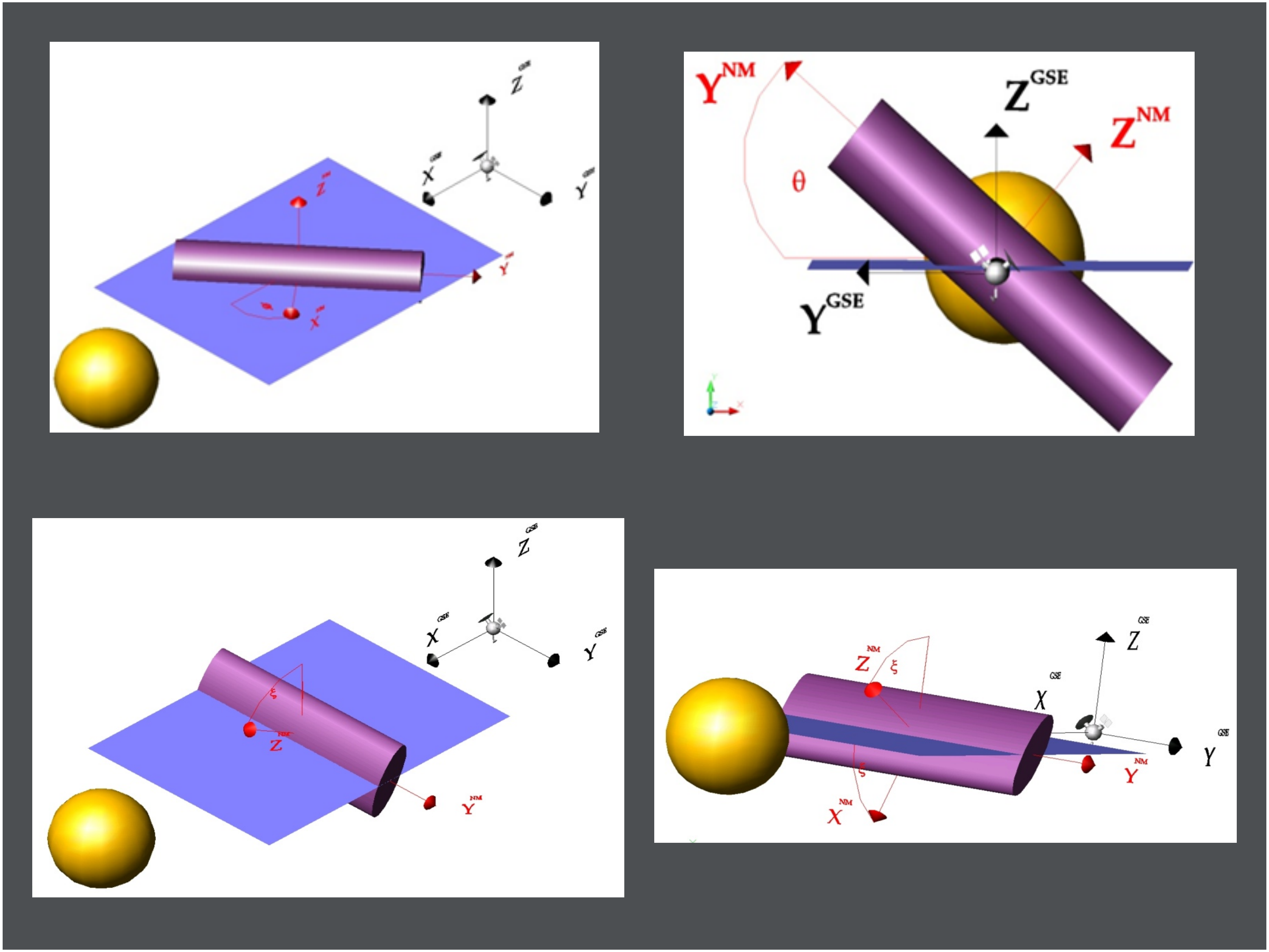
$\ldots sh\,\eta)cosh\,\eta$

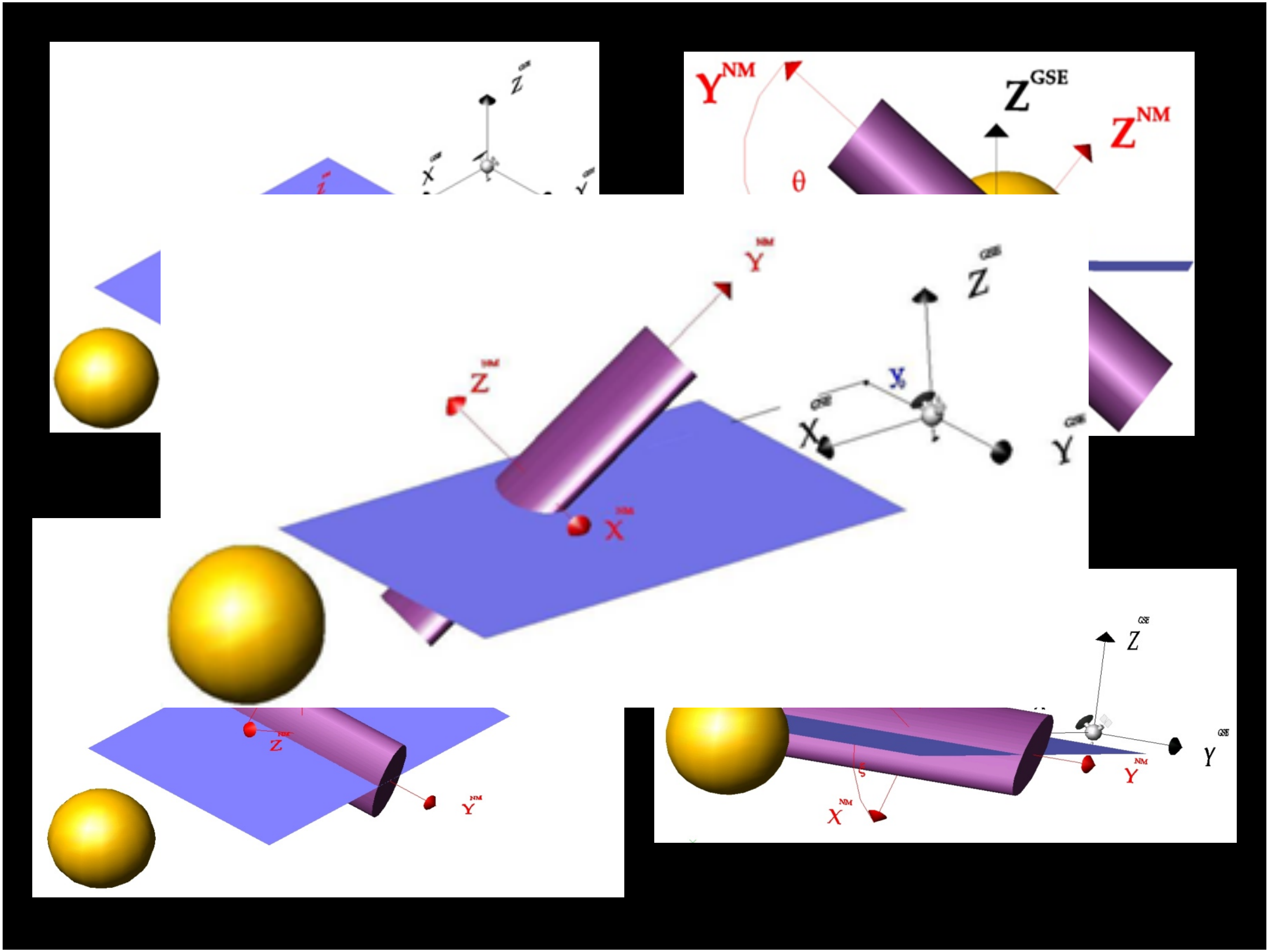
$\ldots \varphi]^{\frac{1}{2}}$

$$j_r = costant$$

$$j_y = \frac{sinh\eta}{[cosh^2\eta - cos^2\varphi]} j_y^0$$

$$j_\varphi = \frac{sinh\eta\ SF(cos\varphi, 1/cosh\eta)}{[cosh^2\eta - cos^2\varphi]^{\frac{1}{2}}} j_r$$


Z^{GSE}
X^{GSE}
Y^{GSE}
Y^{NM}
Z^{NM}
θ
ξ
X^{NM}

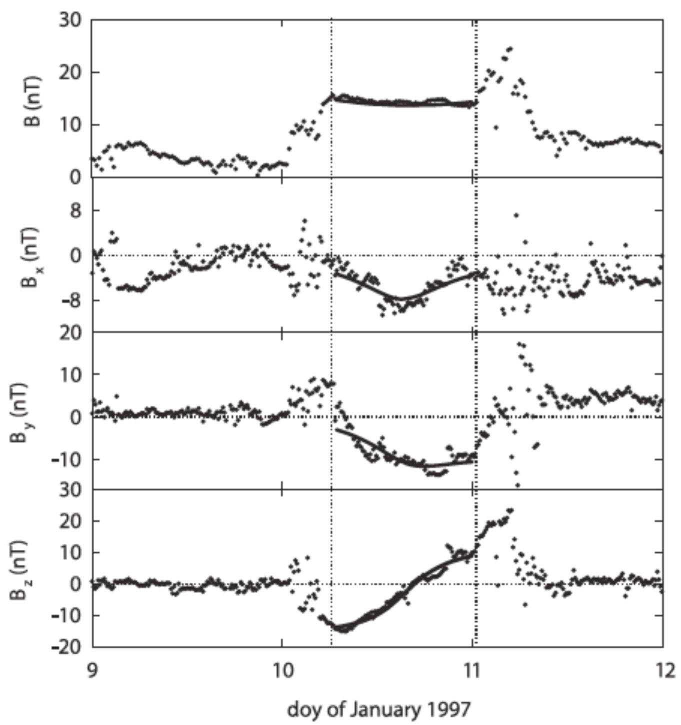


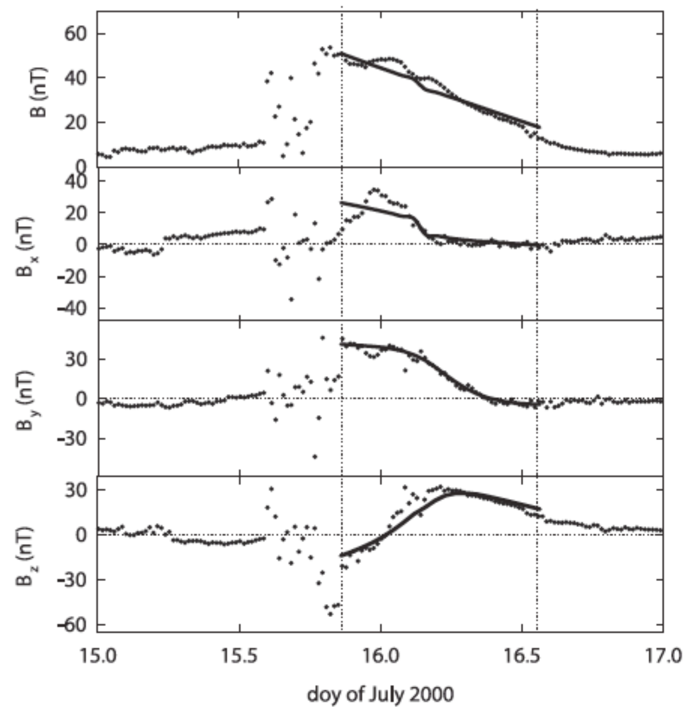
Y NM
Z GSE
Z NM
θ
X NM
X GSE
Y GSE
Z
Y
X

4. Comments and Discussions

[20] We ... analyz
the topolog ... they ar

Event 19 – MC





Event 1 – MC

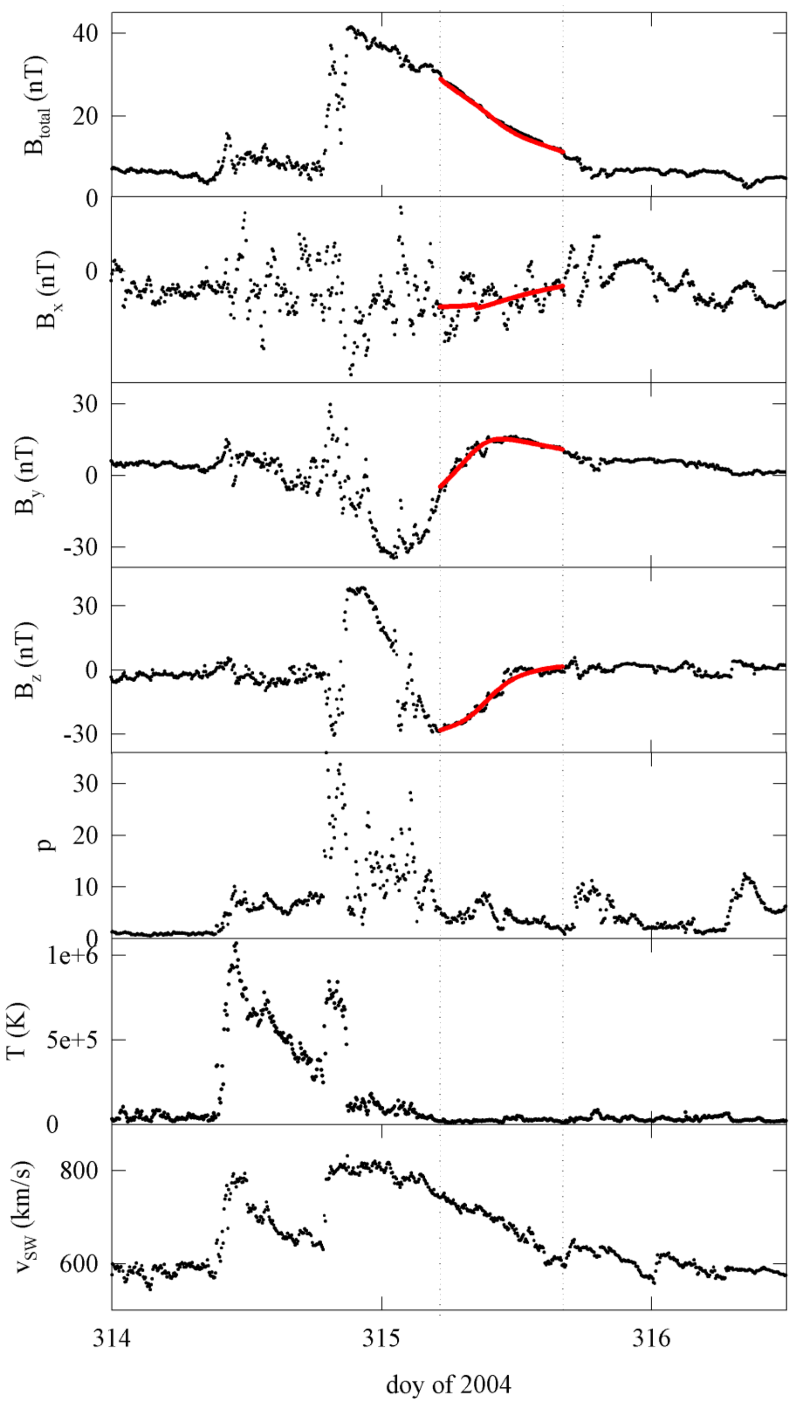
Fi... e cartesian GSE-
co... h January of 1997
fr... start and end time

Table 1. Parameters Obtained for Every MC from the Fitting of the Model to the Experimental Data

Event Yy-mm	j_r (10^{-12}Cm^{-2}s^{-1})	j_y^0 (10^{-12}Cm^{-2}s^{-1})	θ (deg)	ϕ (deg)	ζ (deg)	η	B_y^0 (nT)	y_0 (AU)
97 Jan	0.003	−0.09	12	134	75	12.8	−3	0.018
97 Sep	0.020	−0.03	6	190	322	0.7	7	0.001
98 Oct	0.0001	−0.30	−2	−160	132	9.7	6.7	0.030
00 Jul	0.35	0.13	−11	171	63	2.5	−12	0.050

These parameters are the radial, j_r, and axial, j_y^0, components of the current density, the attitude (latitude, θ, and longitude, ϕ) of the cloud axis, the

(Hidalgo et al. 2002, JGR)



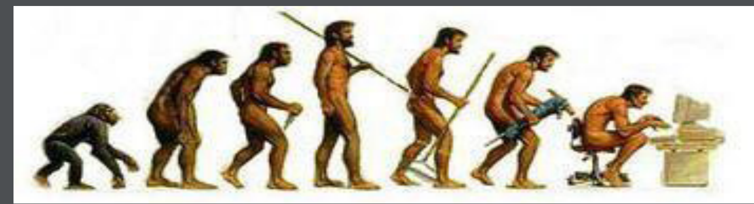
More general case

Cross-section distortion

+

Expansion

Model evolution



Elliptical cross-section +
Local expansion
(Hidalgo 2003, JGR)

Once upon ..

2000

2002

2002

2003

r CS

na pressure

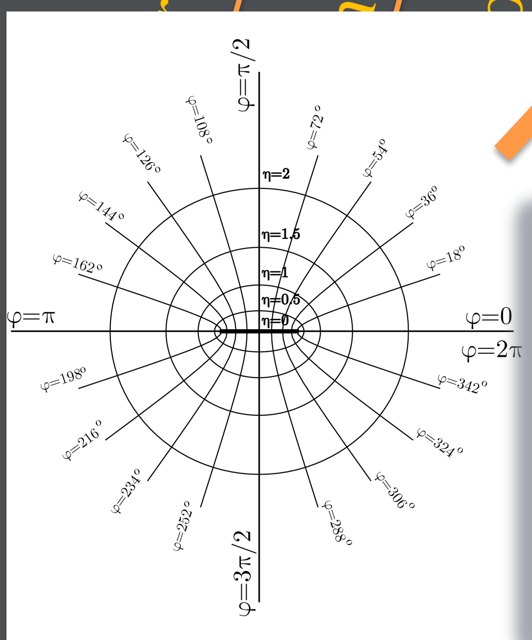
ortion

ansion

temporal conditions in the radial and axial current densities

$$B_y = B_y^0 + \mu_0 j_r r S E(\cos\varphi, 1/\cosh\eta)\cosh\eta$$

$$B_\varphi = -\frac{\mu_0 j_y^0 r \cosh\eta}{[\cosh^2\eta - \cos^2\varphi]^{\frac{1}{2}}}$$



$$j_y^0 = \lambda(t_0 - t)$$

s it is deduced from
ne dependence in the p
sity, we need to assume
also suppose a linear

$$j_\eta = \alpha(t_0 - t)$$

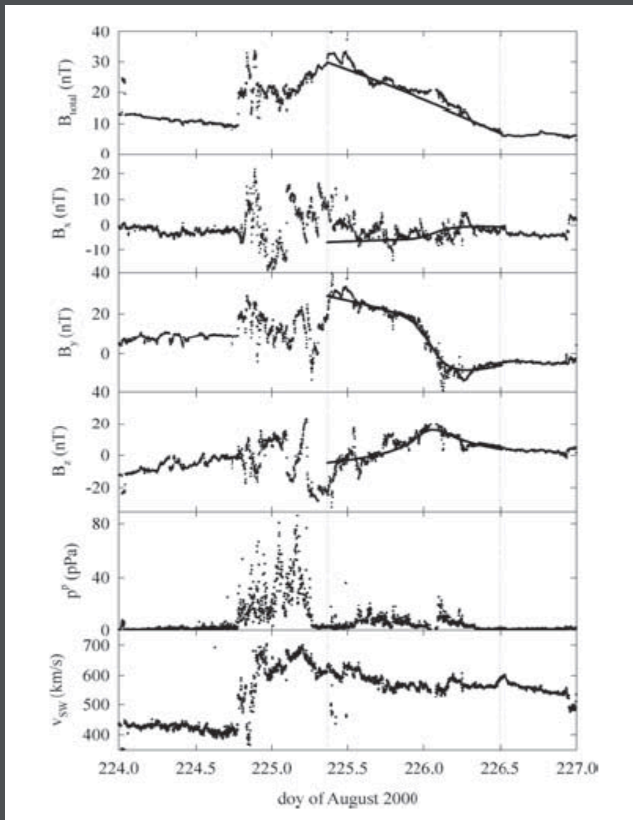
e time behavior for j_φ.

$$j_r = costant$$

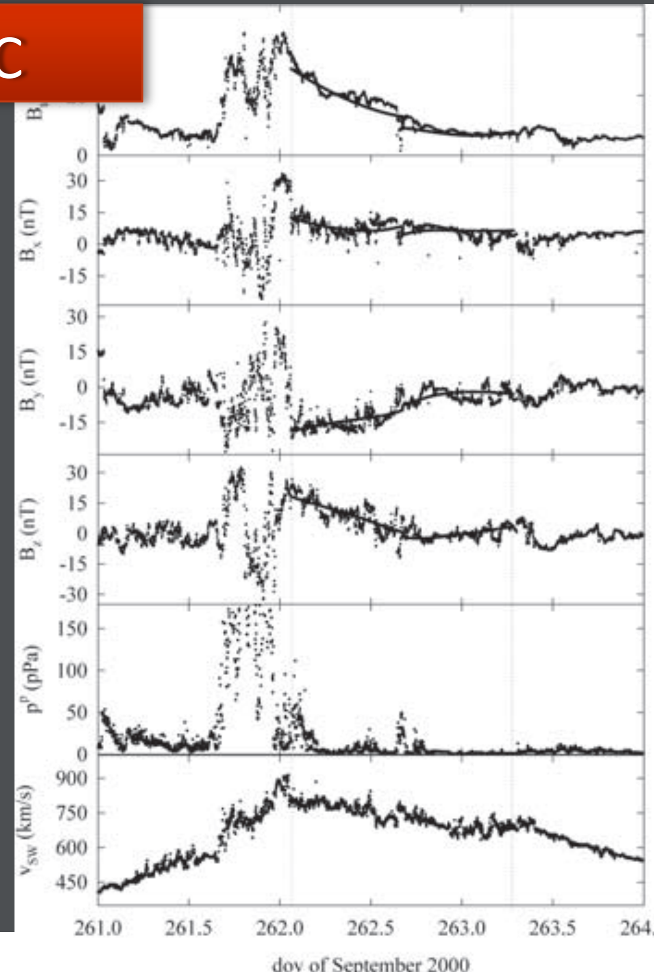
$$j_y = \frac{\sinh\eta}{[\cosh^2\eta - \cos^2\varphi]} j_y^0$$

$$j_\varphi = \frac{\sinh\eta \; SF(\cos\varphi, 1/\cosh\eta)}{[\cosh^2\eta - \cos^2\varphi]^{\frac{1}{2}}} j_r$$

Event 23 – MC



Event 24 – MC



Event 32 – MC

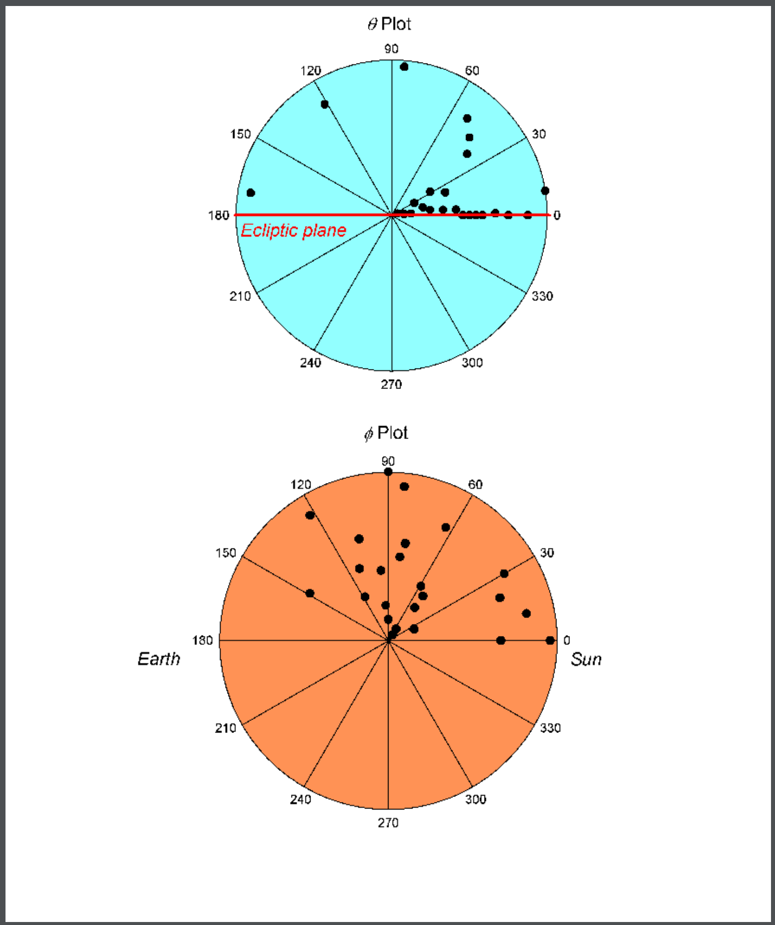
Table 1. Parameters Obtained for Every MC Analyzed[a]

Event (Year/Month/Day)	α, 10^{-19} C m^{-2} s^{-2}	λ, 10^{-19} C m^{-2} s^{-2}	θ, deg	φ^b, deg	ζ, deg	η	t_0/t_{sat}^{out}	B_y^0, nT	y_0, AU
000812	1.16	−0.28	175	191	161	0.011	1.294	−1.4	0.33
000918	0.52	3.5×10^{-4}	−151	336	48	0.0002	1.015	−8.22	0.12
001028	0.01	1.809	161	37	87	0.174	1.693	−7.00	0.164
010320	0.25	0.276	−14	321	50	0.032	9.072	−8.68	0.024
010321	6.061	−13.35	2	38	42	0.607	2.541	9.77	0.106
010401	15.81	−147.35	−164	223	74	0.118	3.167	7.14	0.035
010402	0.375	2.4×10^{-4}	−120	127	31	0.0001	2.232	25.9	0.151
010411	16.35	−1.24	−42	128	34	0.129	6.335	11.1	0.04

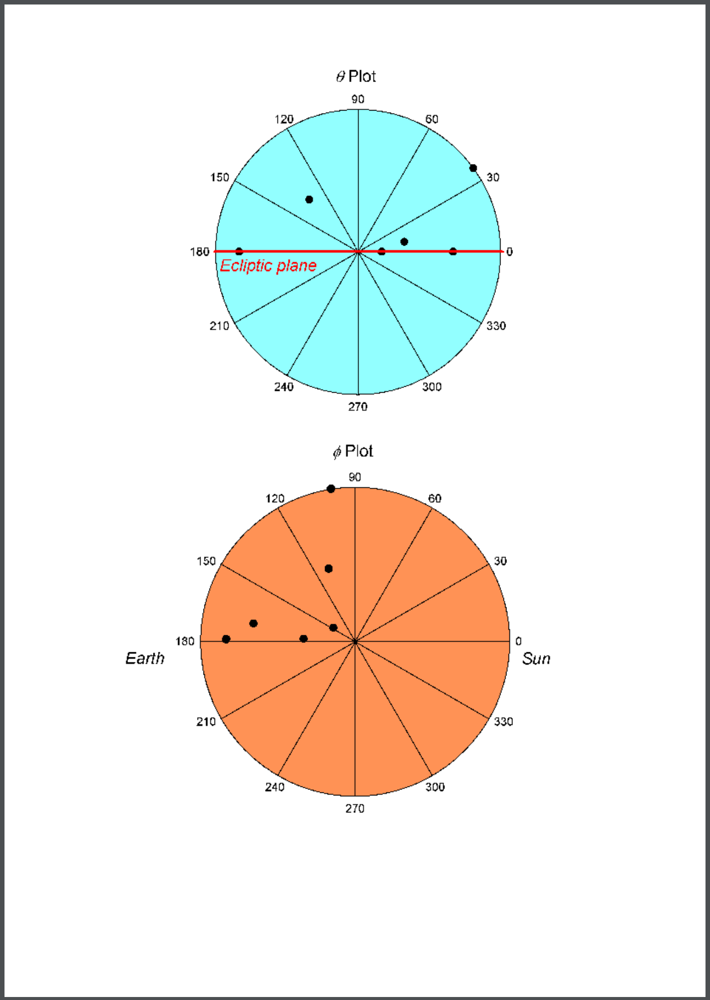
[a]Parameters are as follows: normal, α, and axial, λ, factors of the plasma current density; the attitude (latitude, θ, and longitude, φ) of the cloud axis; the orientation of the cross section of the cloud, ζ; the parameter associated with the

(Hidalgo 2003, JGR

Fitting MCs



Fitting Ejs

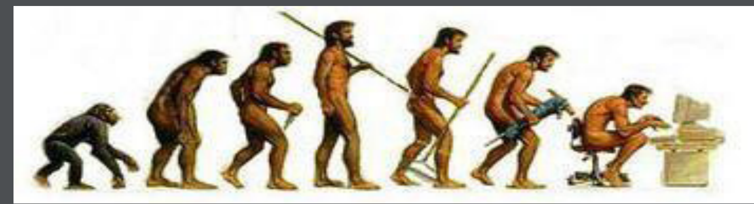


Summary

-Ej -> s/c crossing flank
-MC-> s/c crossing the flank

- the improvement of this non force-free model means adding new aspect of the understanding of the CME/ICME.

Model evolution



Once upon ..

2000 — Circular CS

2002 — ccs+ plasma pressure

2002 — distortion

2003 — Distortion +expansion

Now … what?

- Connexion with the source
- Interactions with magnetospheres
- Propagation in the interplanetary medium
- Expansion from the source up 1 AU
- Plasma behaviour – plasma pressure tensor, total current density analysis ..
- - Global analysis of the structure with the inclusion of the cross section distortion and expansion.