Magnetic Flux Ropes from the Sun to 1 AU

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Acknowledgements: V. Yurchyshyn (BBSO), J. Chen

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Model Flux Ropes from the Sun to 1 AU

How well do we reproduce observed dynamics?

- Near sun position, velocity and morphology
- Transit time to 1 AU
- Magnetic cloud size, strength, and orientation

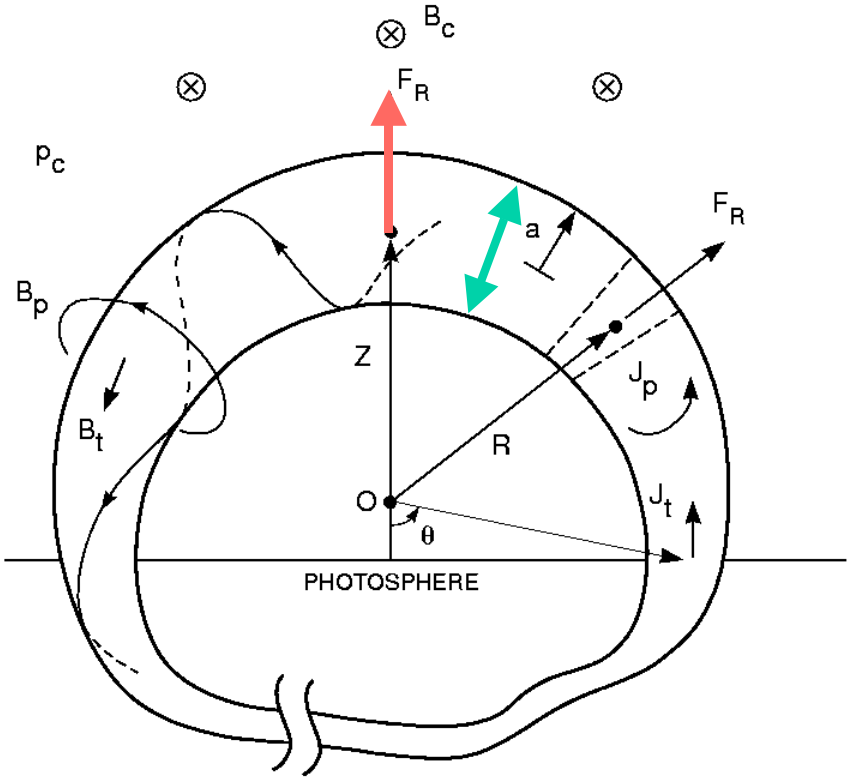
What can we predict?

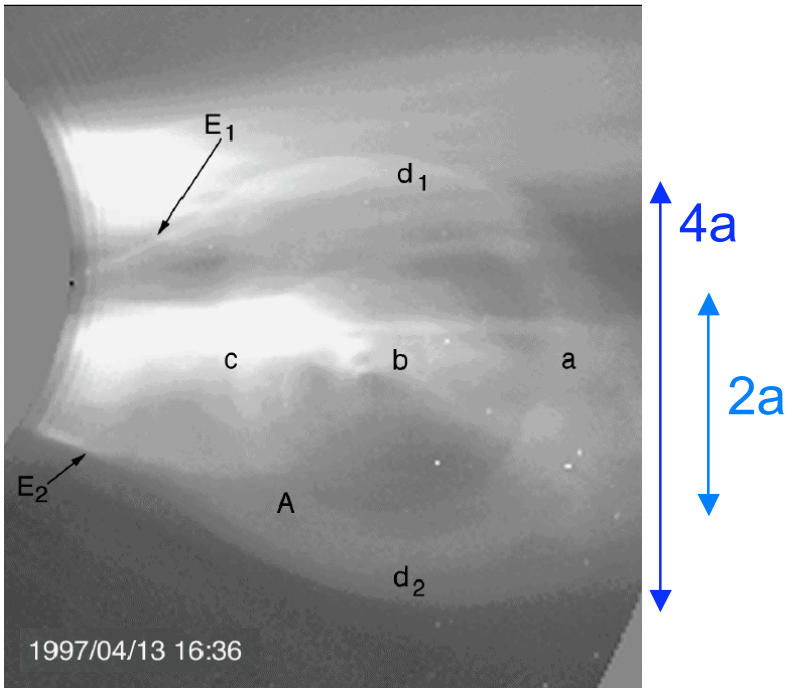
- Ideally: magnetic cloud onset, size, strength and orientation

Flux Rope Model

$$\frac{\partial^2 Z}{\partial t^2} = F[Z, a, \square_t, \square_p(t), \mathrm{SW}]$$

$$\frac{\partial^2 a}{\partial t^2} = G[Z, a, \square_t, \square_p(t), \mathrm{SW}]$$



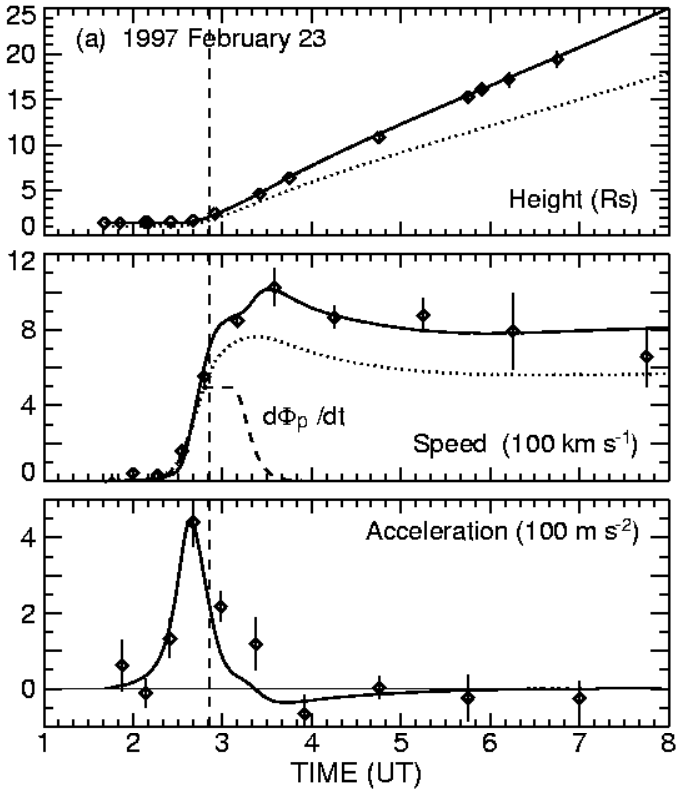


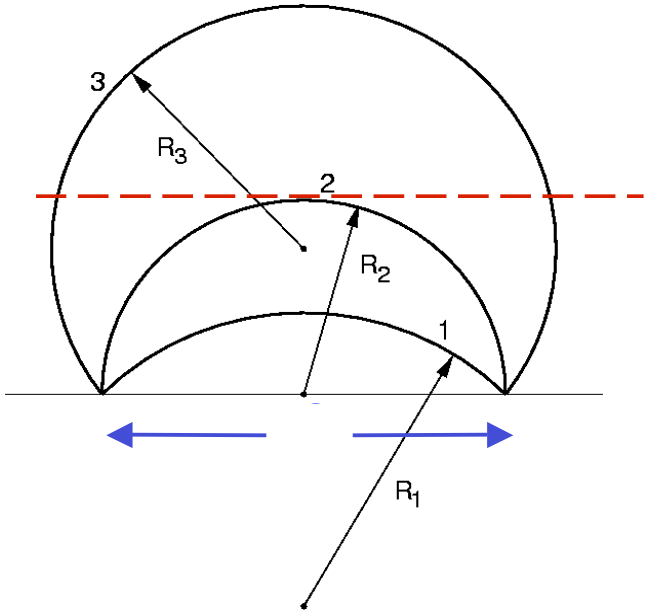
Chen 1996 JGR; Krall et al. 2000 ApJ

Forces near the sun

$$F_{JxB} \sim \Phi_p^2 / R^2$$

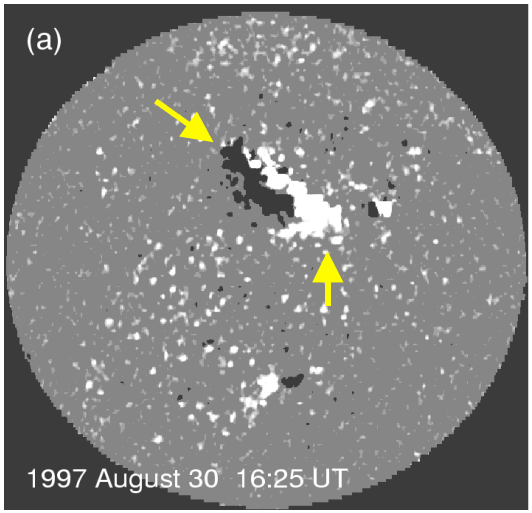
$$F_{B\Phi} \sim I_t B_{\Phi,c}$$

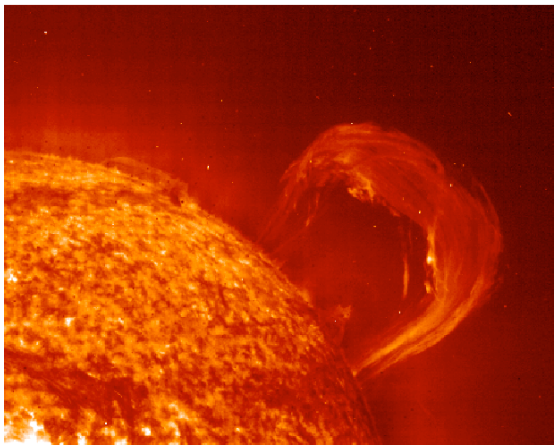


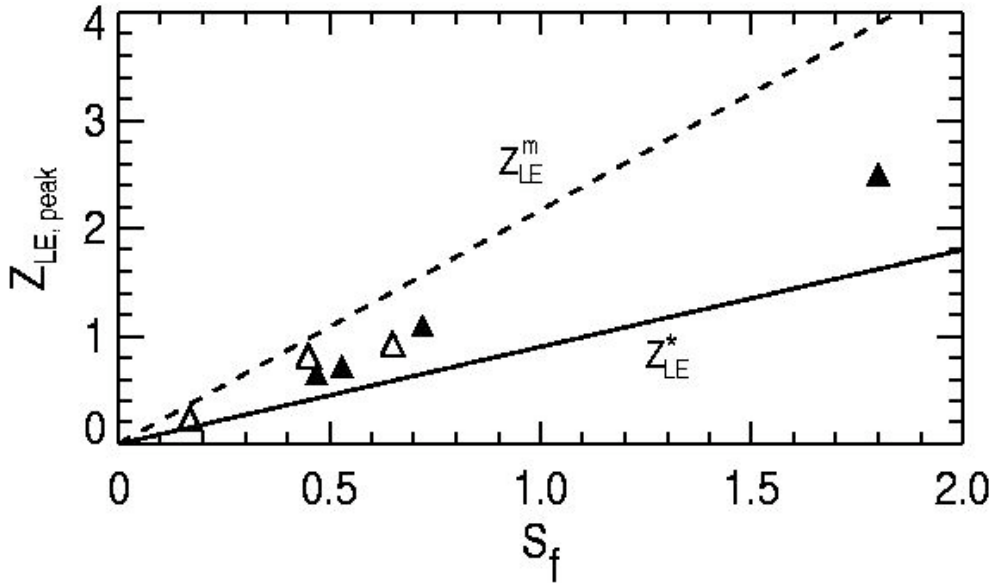


Chen and Krall 2003 JGR

Near-sun acceleration







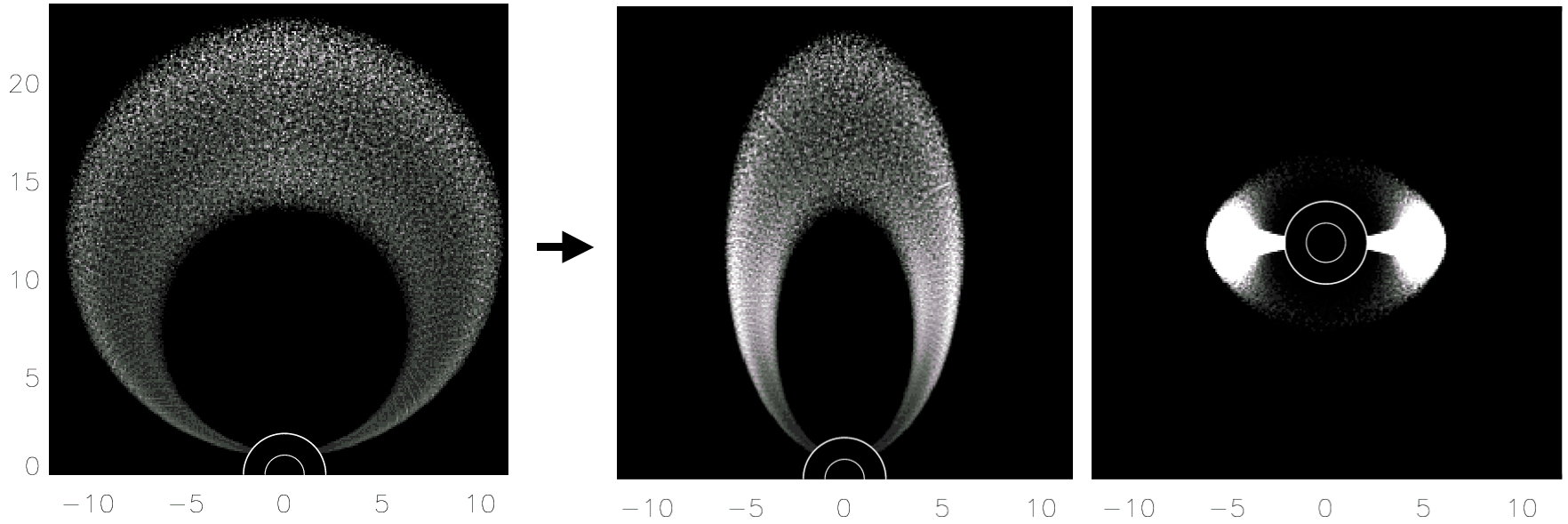
▲ *Sf* determined by neutral line length

△ *Sf* determined by prominence legs

The flux rope is pre-existing or forms early in the process

Halo CMEs: an elliptically-shaped model flux-rope

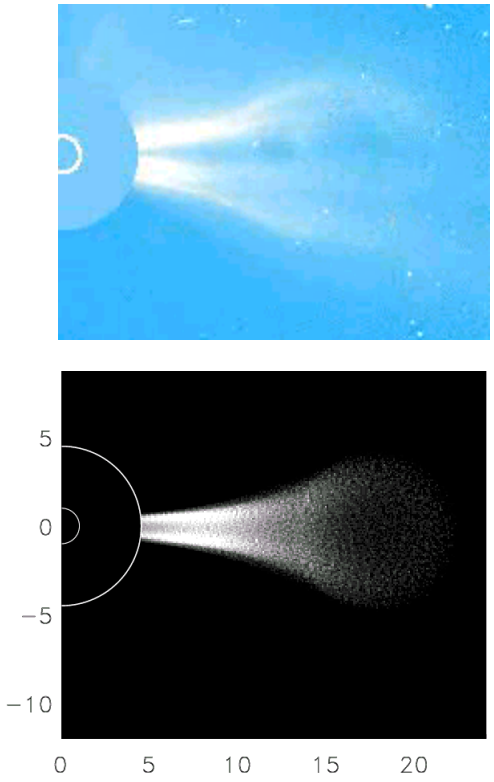
To obtain a flux rope which reproduces CME dynamics and "looks like a CME" from all angles, we use an elliptical flux rope



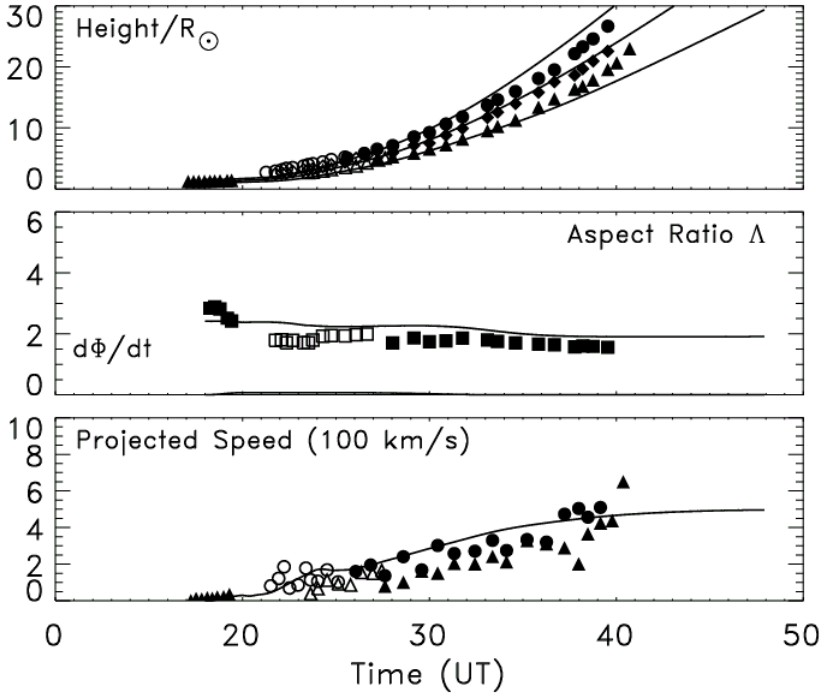
$F_{JxB} \sim \square_p^2 \square^2$ (JxB force is related to the local curvature)

Garren and Chen 1994 Phys. Plasmas

The elliptical flux rope model reproduces CME dynamics as in the circular model (forces and inputs differ somewhat)



LASCO C3 and model
(1997/11/02 12:41 UT)



model/data comparison for 1997/11/01 CME
(data from Krall et al. 2001 ApJ)

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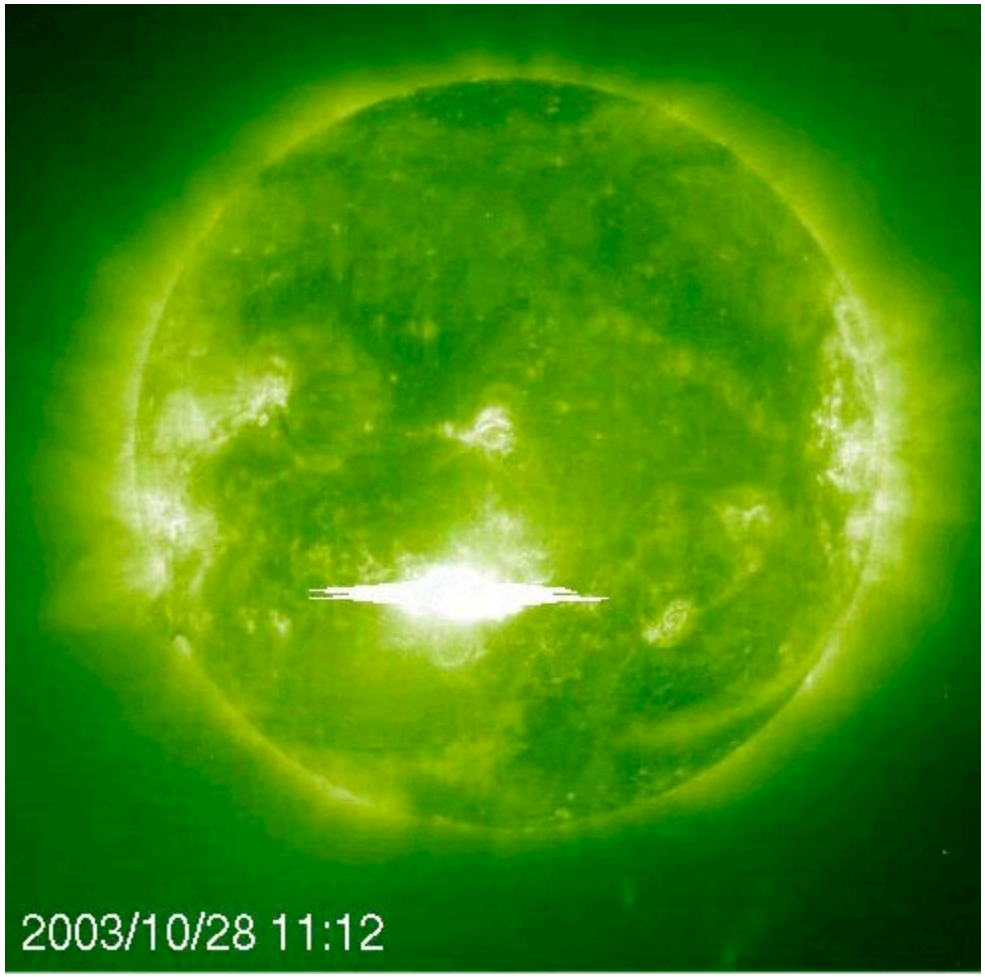

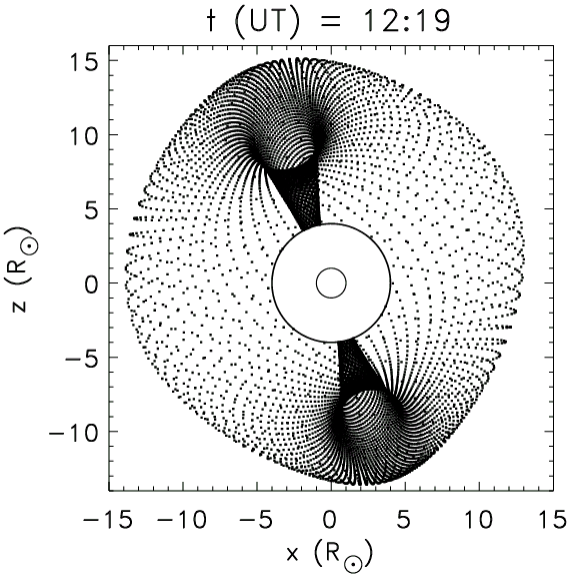

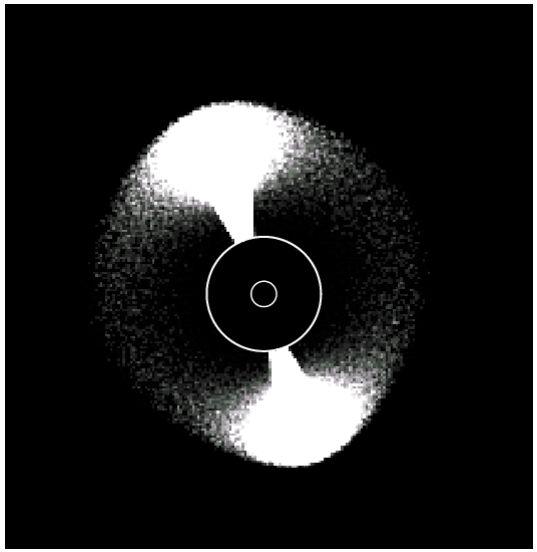

EIT image, scatter-plot of outer flux surface, synthetic coronagraph

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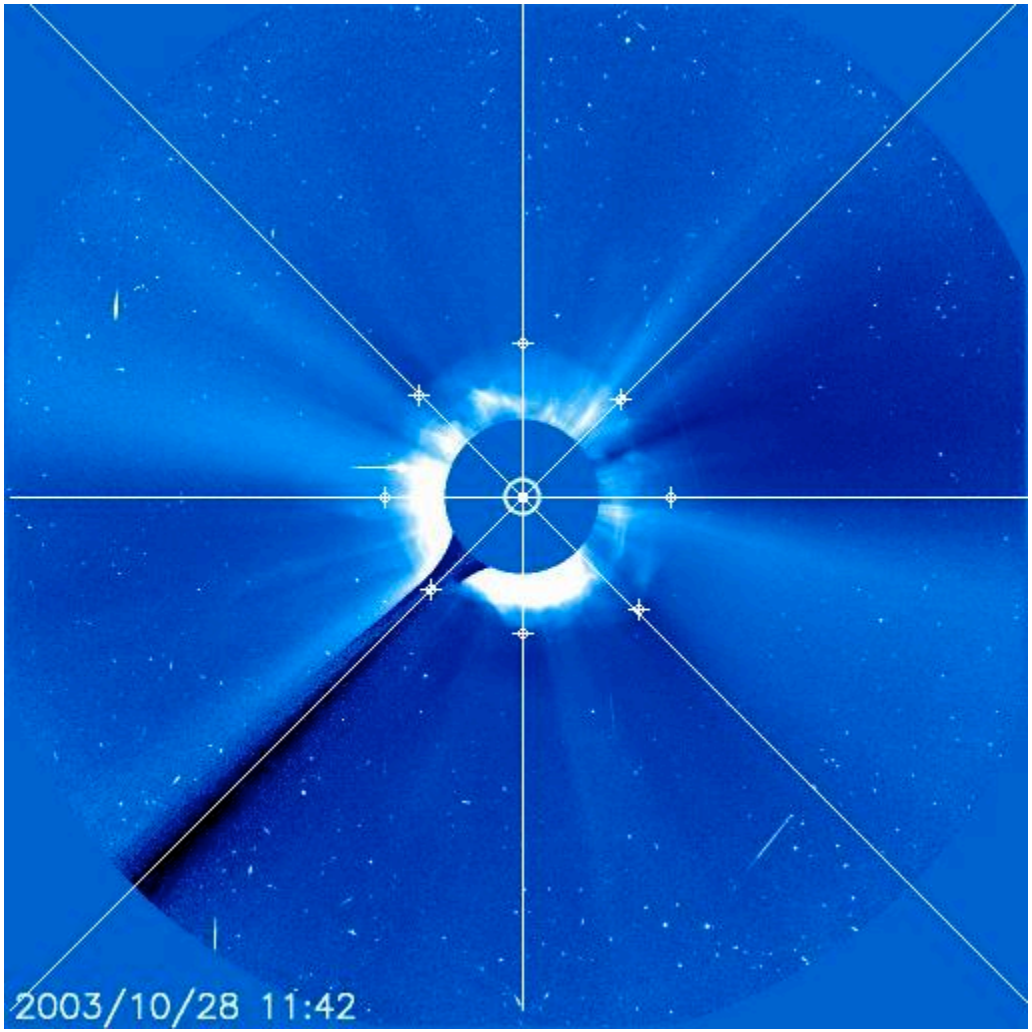

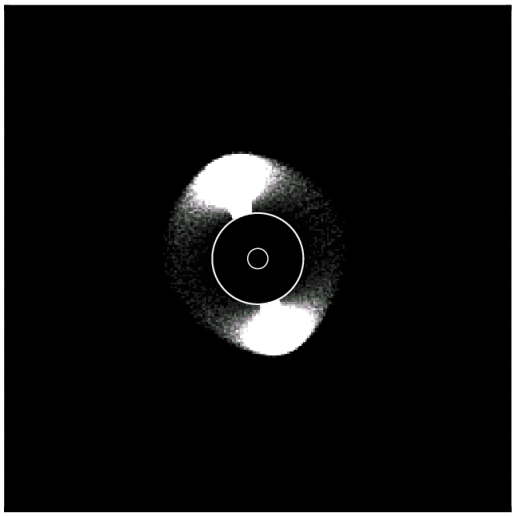

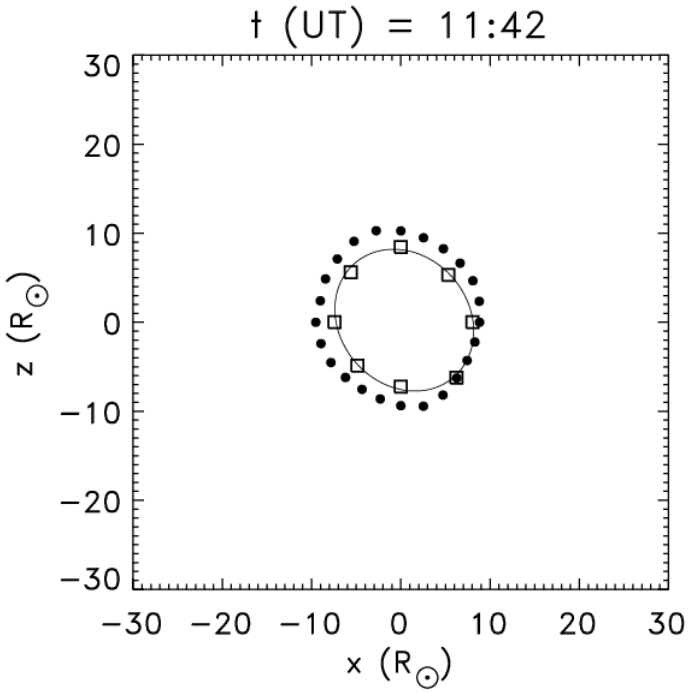

Measurements by Vasyl Yurchyshyn (BBSO)

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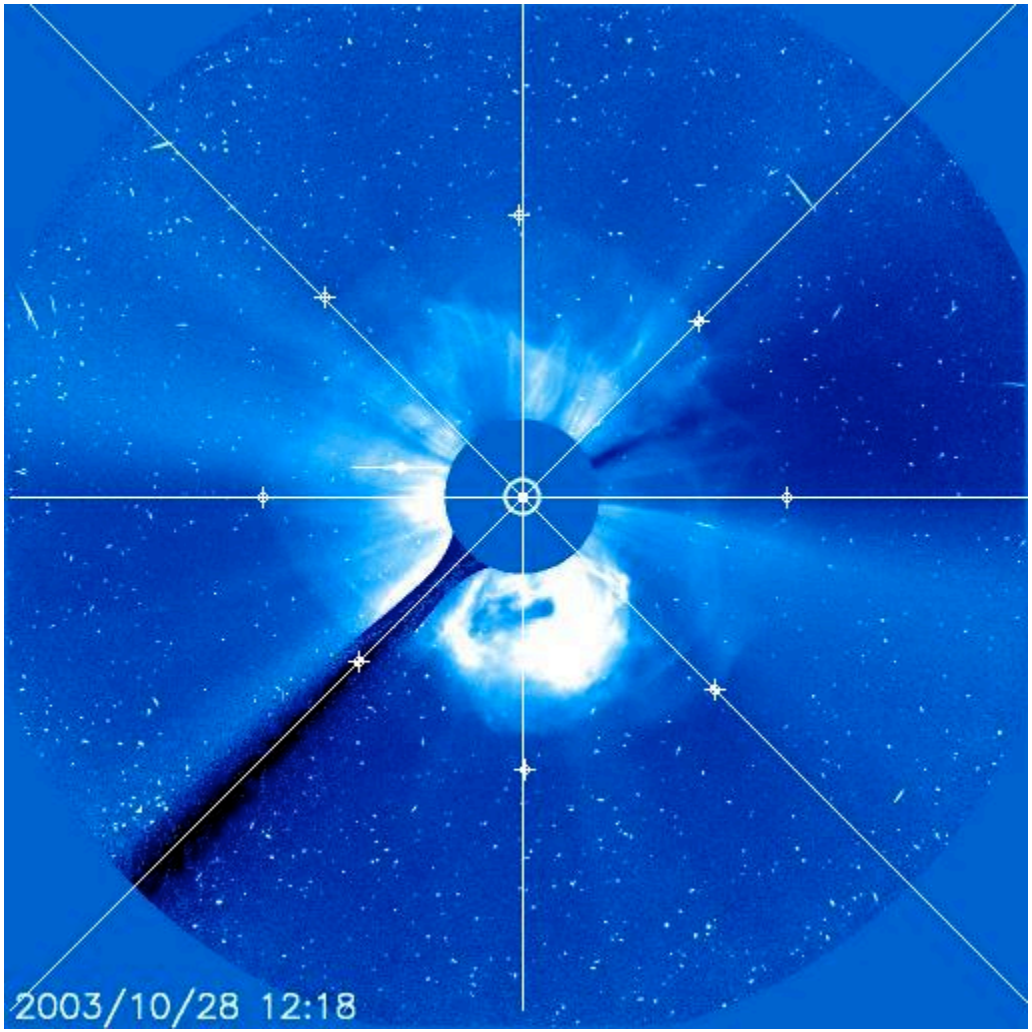

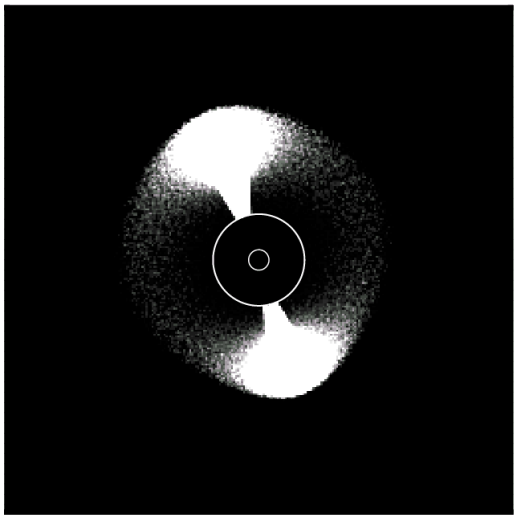

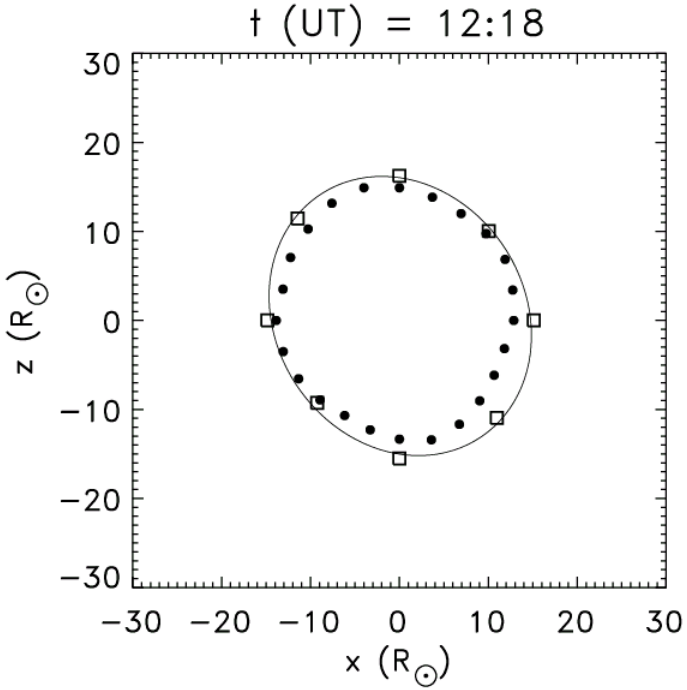

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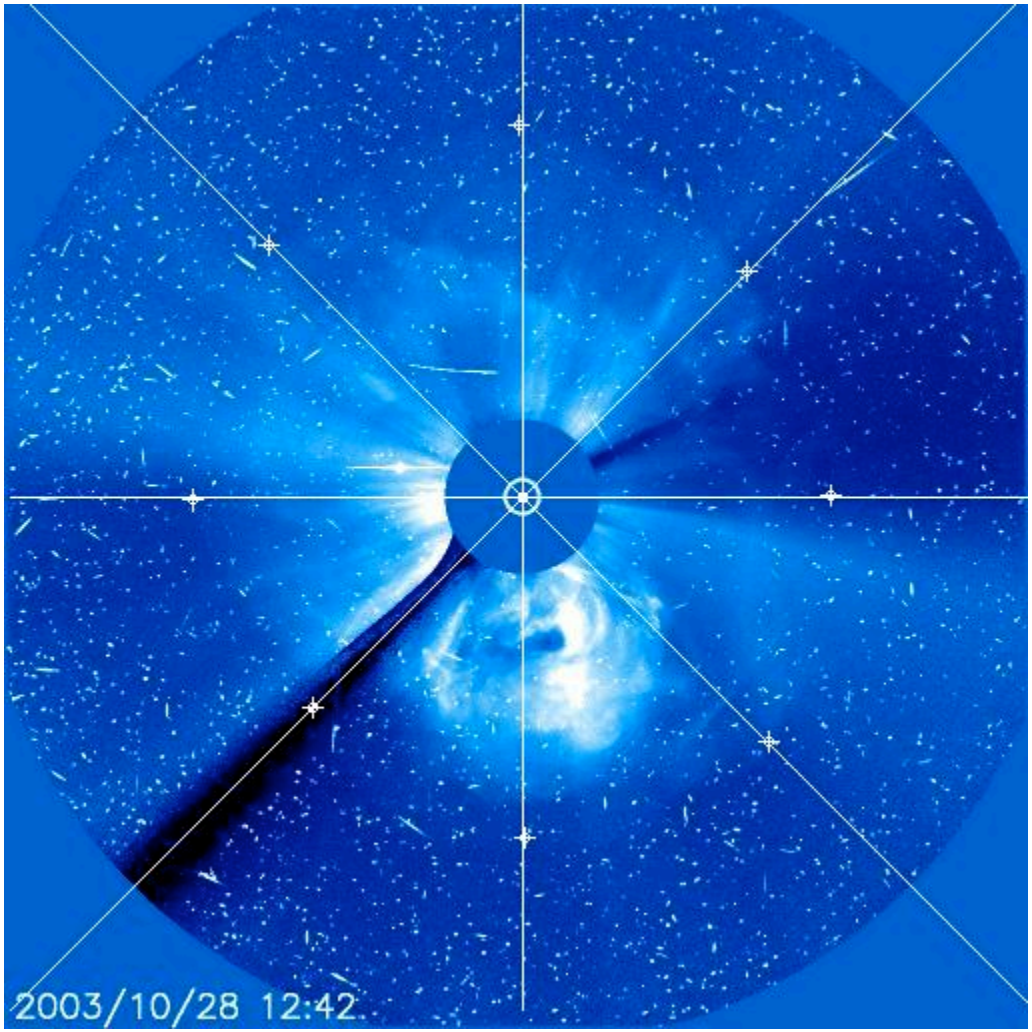

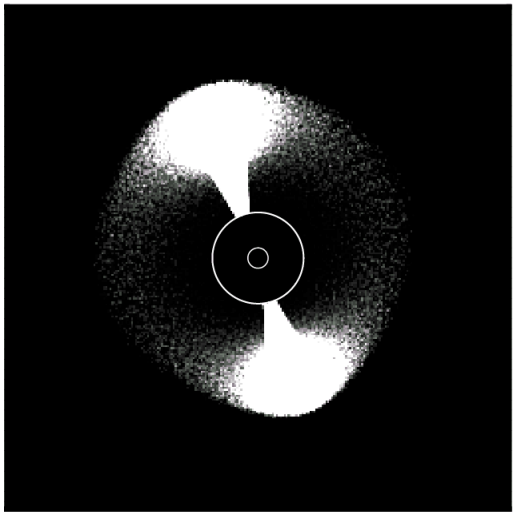

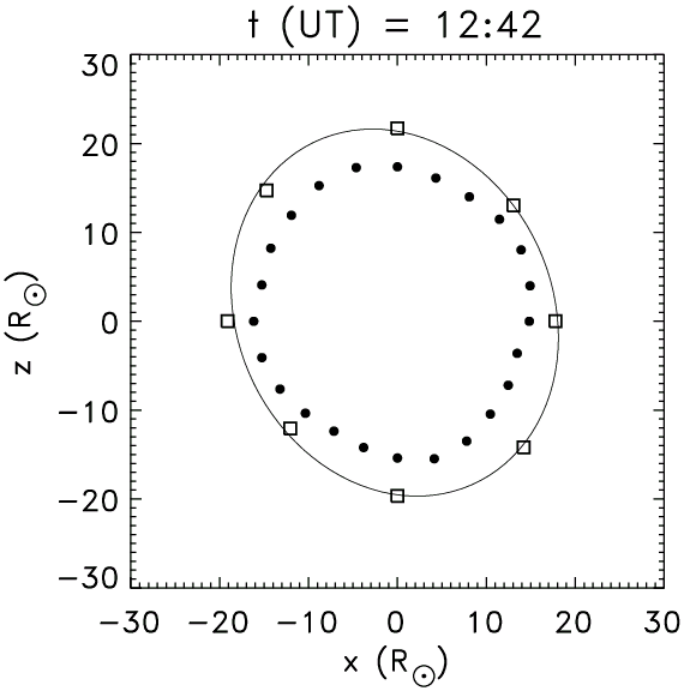

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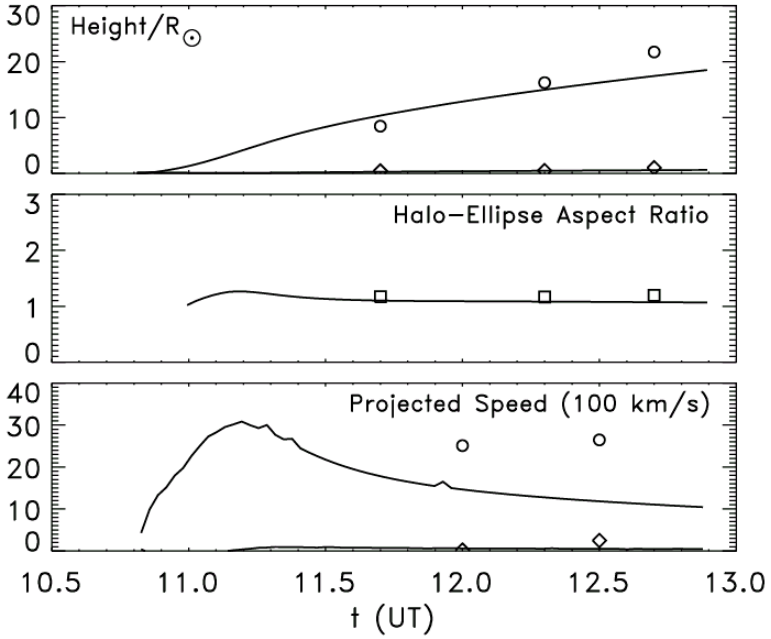
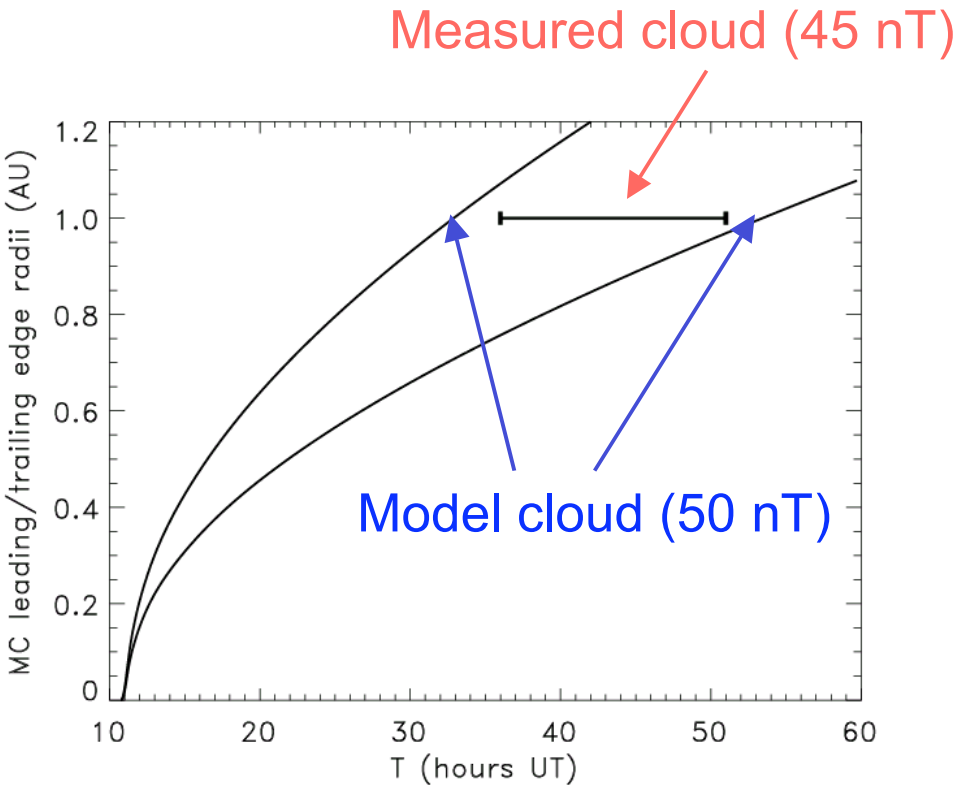


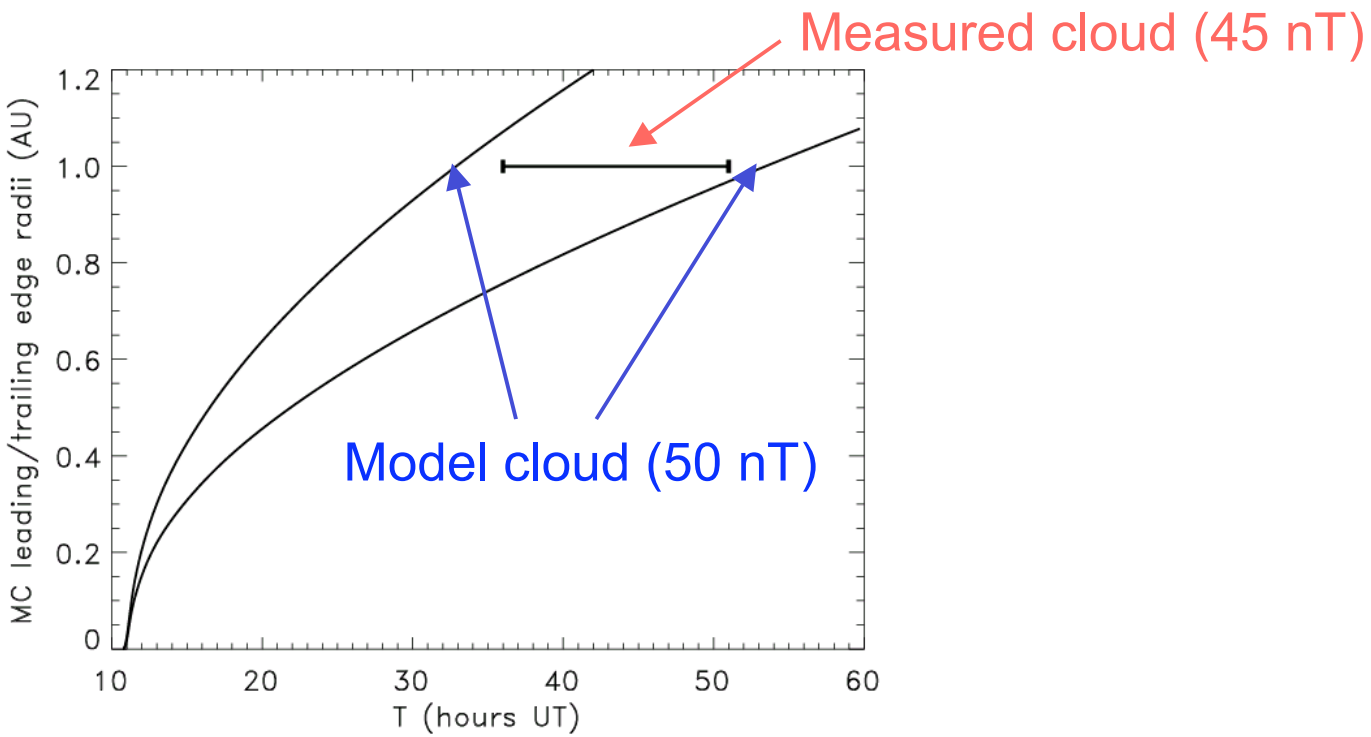
Near-sun dynamics



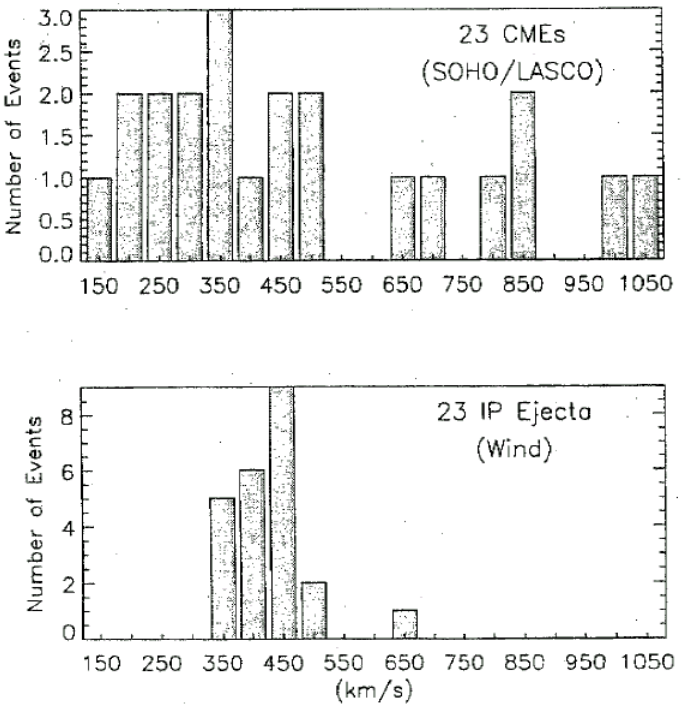
Transit to 1AU

Forces in interplanetary space

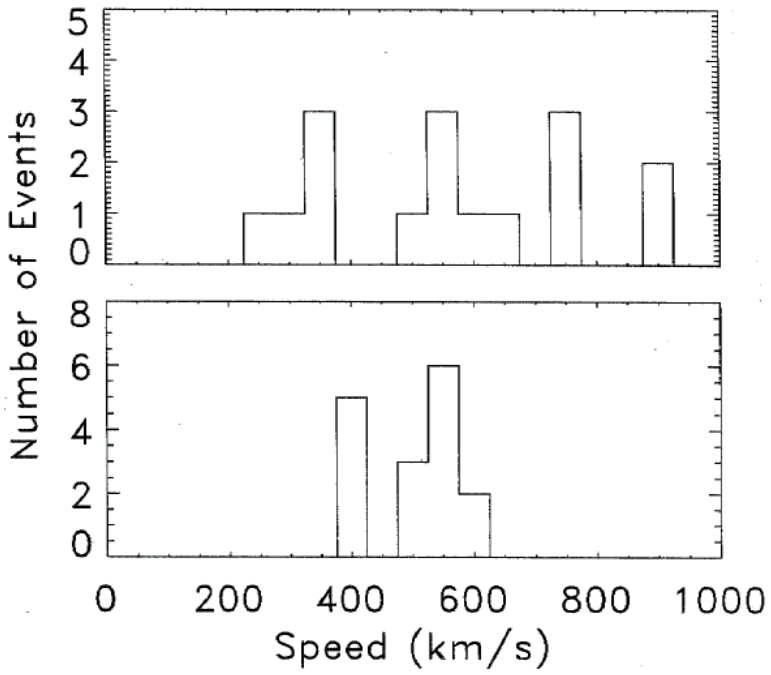
$$F_{JxB} \sim \square_p^2 / R^2 \qquad F_{drag} \sim c_D a(\mathrm{v}_Z \square \mathrm{v}_{SW})^2$$



Modeling the drag force

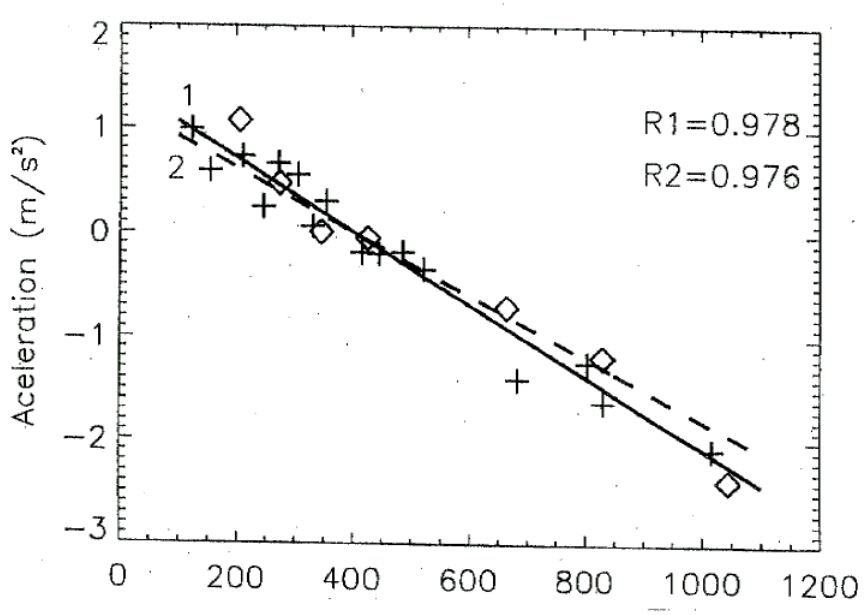


(Gopalswamy et al. 2000 GRL)

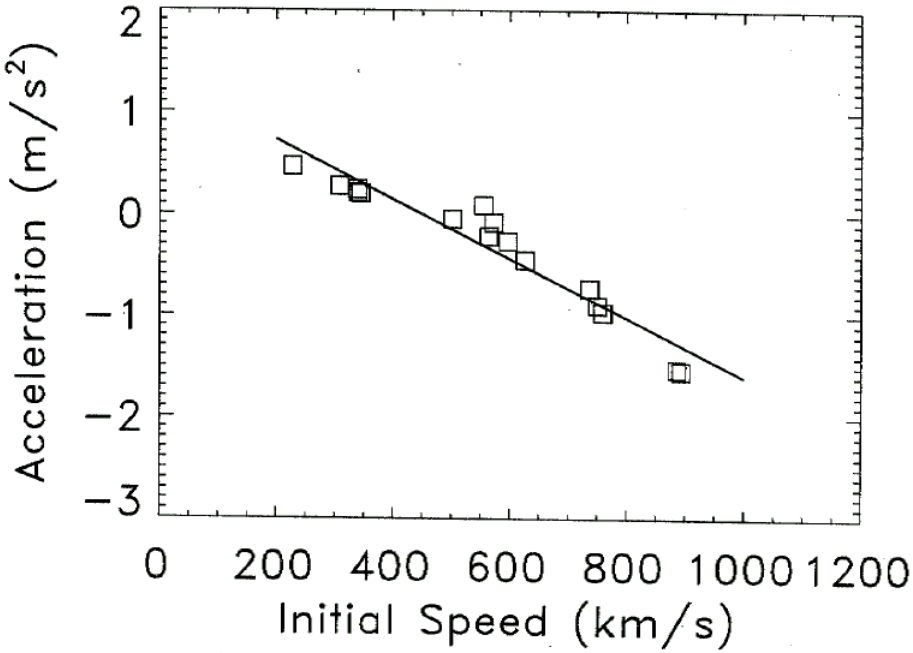


Model results

Modeling the drag force



(Gopalswamy et al. 2000 GRL)



Model results

The drag force works well to first order

Issues...

- Model flux rope is either too slow near the sun or too fast in the interplanetary medium

- Need to better determine $F_{drag} \sim c_D a(\mathrm{v}_Z - \mathrm{v}_{SW})^2$

Drag force

- Background field near the source not known (routine field extrapolations?): $F_{B\perp} \sim I_t B_{\perp,c}$

- Flux rope density and CME/filament masses not known (routine mass measurements?)

Data

- Limits and parameters for “flux injection” not known

Physics

Model Flux Ropes from the Sun to 1 AU

How well do we reproduce observed dynamics?

- Near sun position, velocity and morphology
- Transit time to 1 AU
- Magnetic cloud size, and strength

What can we predict?

- General magnetic cloud parameters
- We need an updated drag force model (and more events)

End

Flux Rope Model

$$M\frac{\partial^2 Z}{\partial t^2} = \frac{I_t^2}{c^2 R}\left[\ln\left(\frac{8R}{a}\right) - 1 + \frac{\ell_i}{2}\right.$$

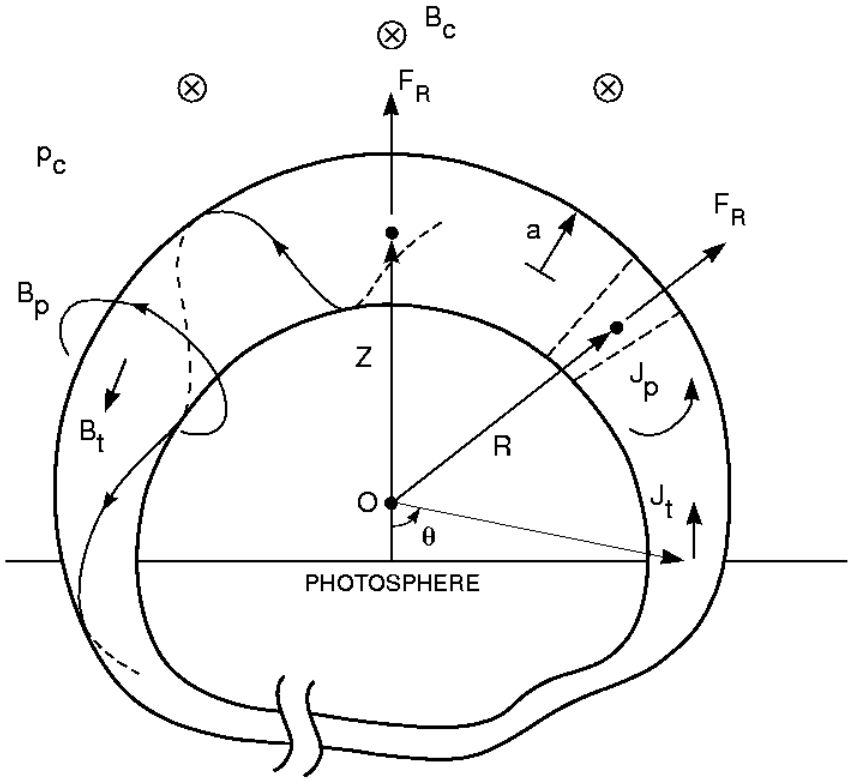
$$- \frac{1}{2}\frac{\overline{B}_t^2}{B_p^2} - \frac{2R}{a}\frac{B_{\perp,c}}{B_p}$$

$$\left. + \frac{1}{2}\ell_p\right]$$

$$- [M_p + \pi a^2(\rho_i - \rho_c)]g(z)$$

$$- c_D n_c m_p a(v_Z - v_c)|v_Z - v_c|$$

$$\frac{\partial^2 a}{\partial t^2} = \frac{I_t^2}{Mc^2 a}\left(\frac{B_t^2}{B_p^2} - 1 + \ell_p\right)$$



Chen, J. 1996, JGR, 101, 27499
Krall J., et al. 2000, ApJ, 539, 964