Heliospheric flux and ICMEs

Mathew Owens

Center for space physics
Boston University

Overview

1. Background
   – Heliospheric flux catastrophe
   – |B| with solar cycle – explained by ICMEs?
2. How much flux is injected by ICMEs?
   – New flux-rope model of MCs
3. What "disconnection rate" is required to match observations?
   – "Back of the envelope" calculation

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Flux from CMEs

- CMEs involve the eruption of closed magnetic field systems

- At 1 AU BDEs suggest ICMEs are still (partially) closed structures, and thus add to the heliospheric flux budget

- ICMEs must eventually open to avoid the heliospheric "flux catastrophe" (*McComas et al.,* 1992)
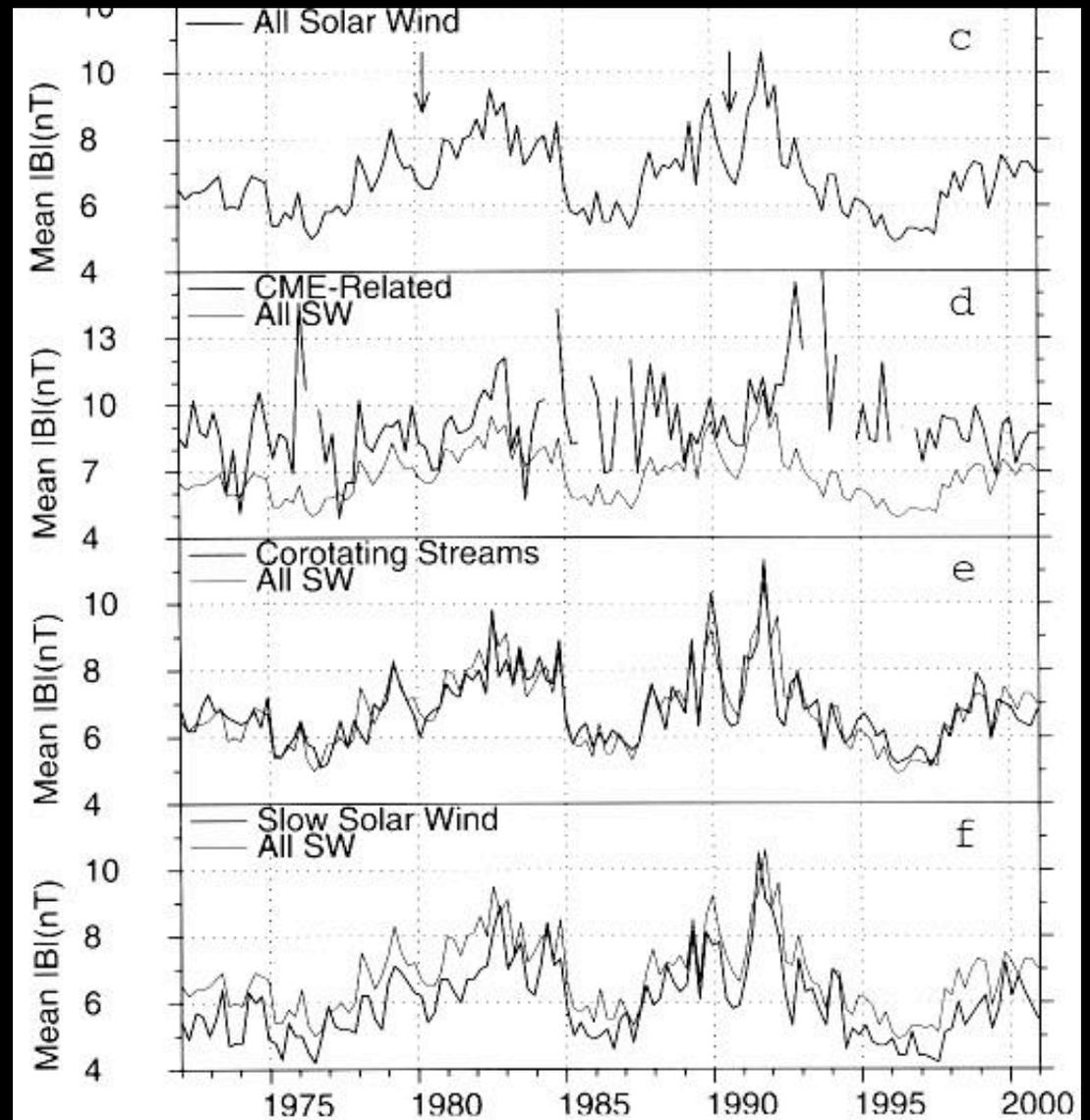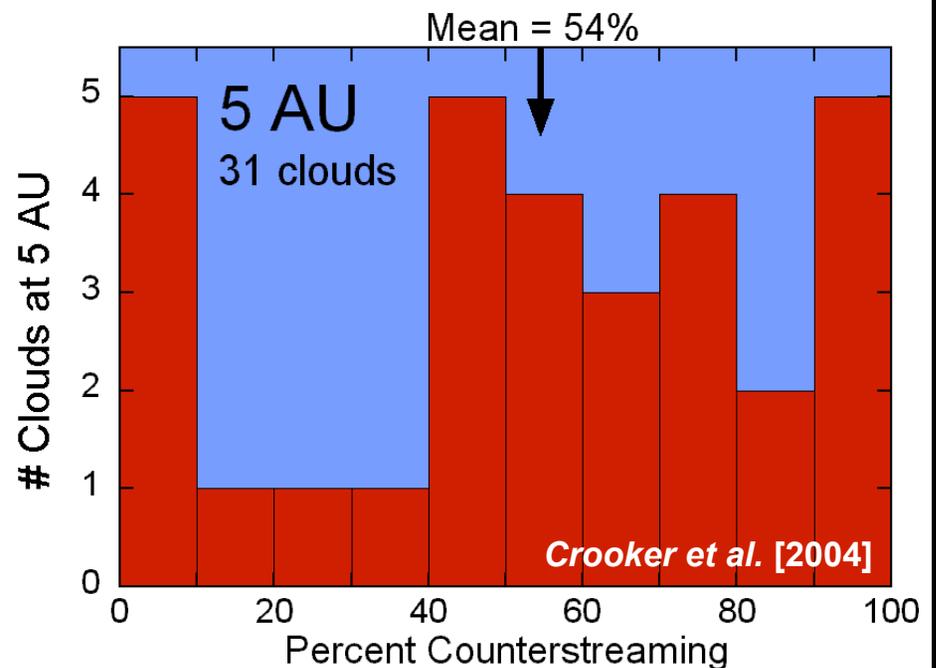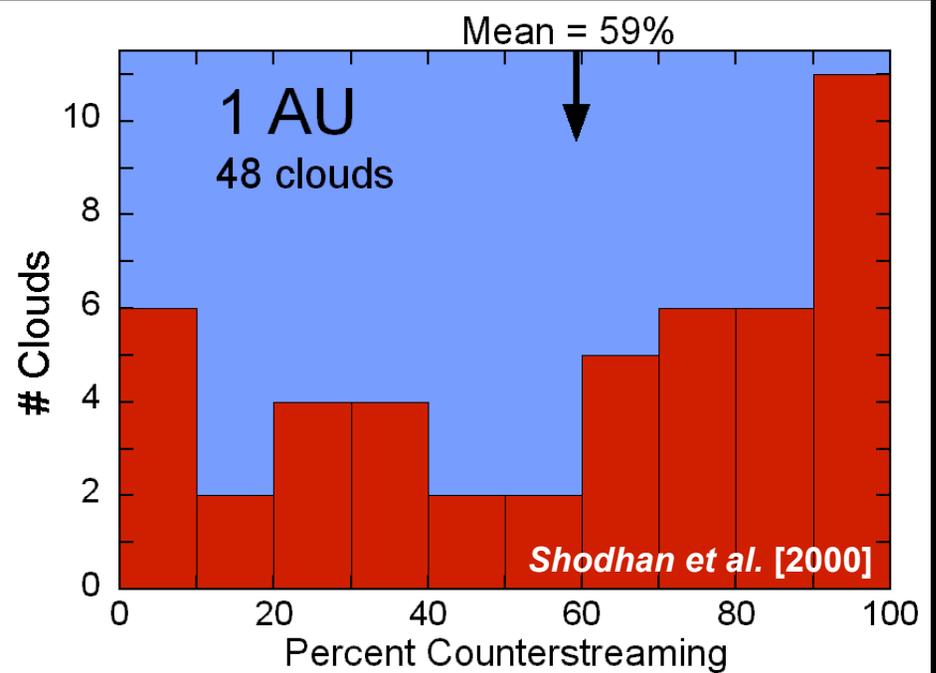
Heliospheric flux variation

- Solar cycle variation in |B|
- *Richardson et al. [2002]*
  - Only s/w in corotating streams carries solar cycle variation of |B|
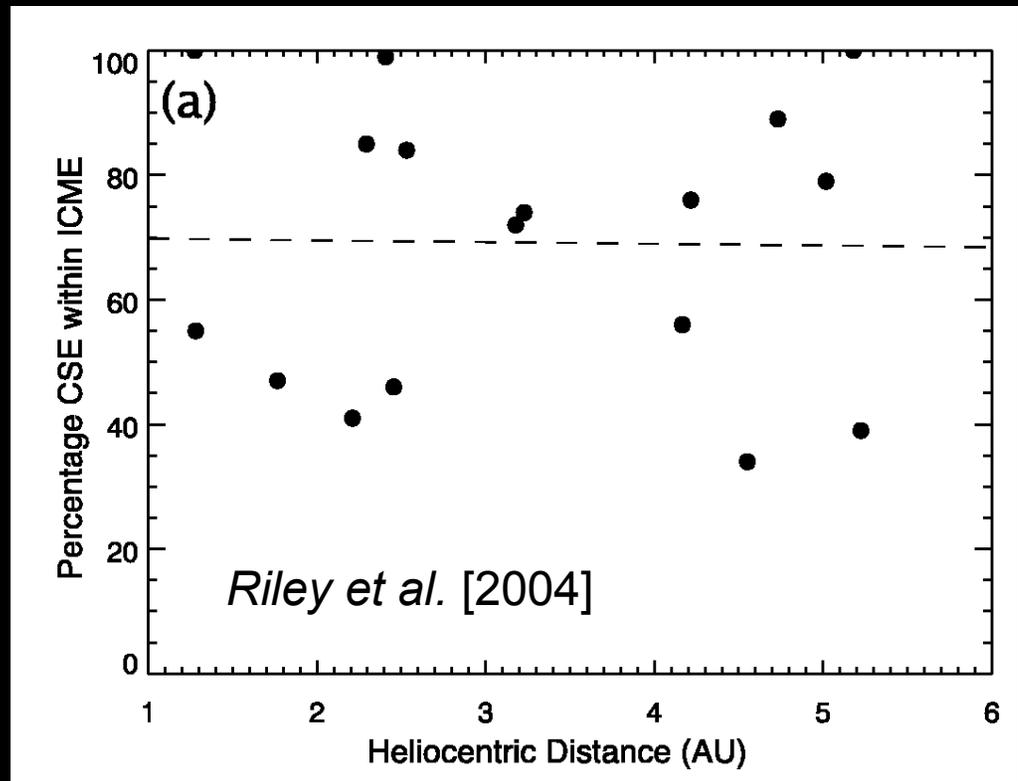 - S/W in **recognisable** ICMEs has different variation
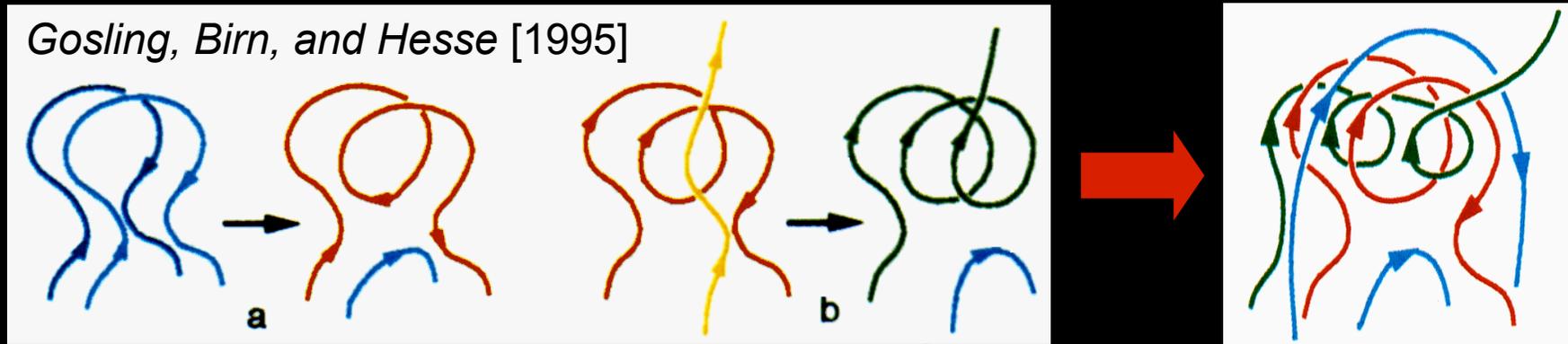
How closed are ICMEs?

- Magnetic clouds at 1 AU are ~ 50% open

- Clouds at 5 AU ~ as closed as those at 1 AU

- Results imply
  - ~50% of fields open during CME liftoff
  - Fields must open over very long timescales

Mean = 59%

1 AU
48 clouds

Shodhan et al. [2000]

Clouds (y-axis)
Percent Counterstreaming (x-axis)

Mean = 54%

5 AU
31 clouds

Crooker et al. [2004]

Clouds at 5 AU (y-axis)
Percent Counterstreaming (x-axis)

CISM
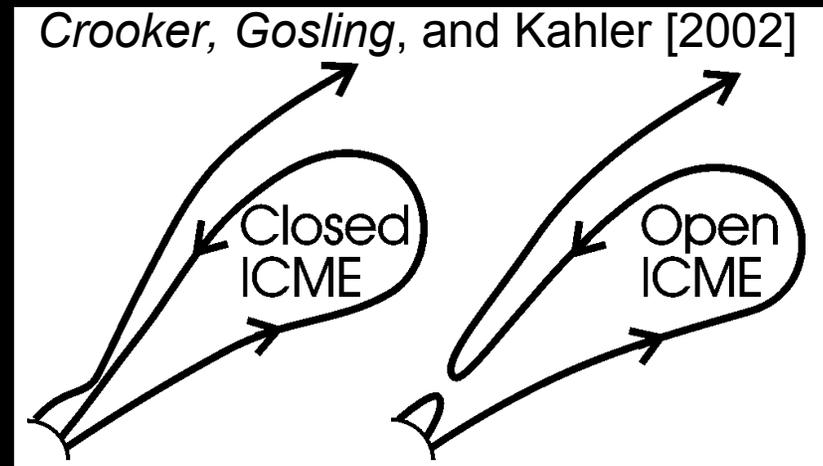CENTER FOR INTEGRATED SPACE WEATHER MODELLING

Rate of ICME opening

- Variation of closed nature of ICMEs with distance
  - No discernable trend
- Rate of opening below detection threshold
- Sampling same ICME at difference times
  - Closed fields increase? (*Skoug et al.*, 2000)
- Sensitive to spacecraft trajectory through ICME?

Riley et al. [2004]

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Gosling, Birn, and Hesse [1995]

- At CME liftoff
  - a. Partial disconnection (closed-closed) creates flux rope coil
  - b. Interchange reconnection (closed-open) opens coil
- In the following months to years
  - Interchange reconnection at Sun opens remaining field lines
- Meanwhile closed fields in legs of ICMEs far out in heliosphere may
  - no longer exhibit counterstreaming
  - be counted as open fields
  - cause solar cycle rise in |B|

Crooker, Gosling, and Kahler [2002]

Closed ICME

Open ICME

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# What is the typical flux injected by a single CME?

- Typical dimming "foot-point" fluxes
  - E.g. May 12th 1997 (*Webb et al*, 2001) : $1\text{x}10^{21}$ Mx
- How much flux is seen at 1 AU?
  - Estimates made using force-free models
  - E.g. May 12th 1997 (*Webb et al*, 2001) : $7\text{x}10^{20}$ Mx
- Problems:
  - Axis orientation errors – MC thickness: f (cos [$_{YGSE}$])
  - Axial field strength (i.e. estimate of closest approach)
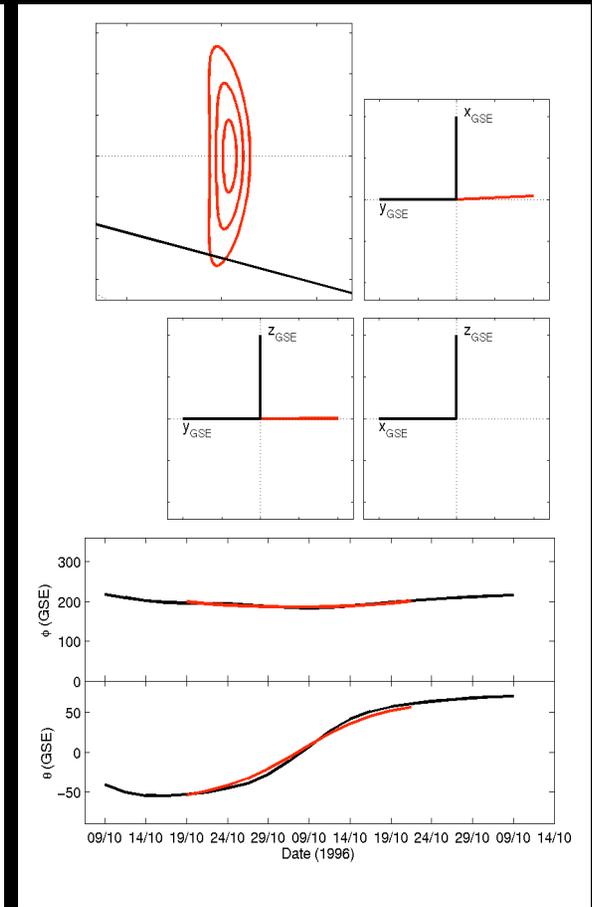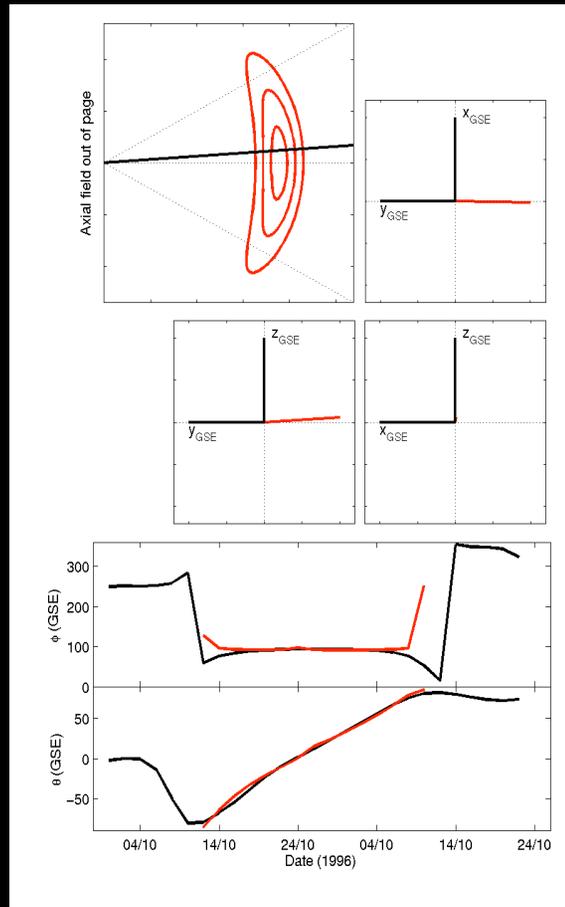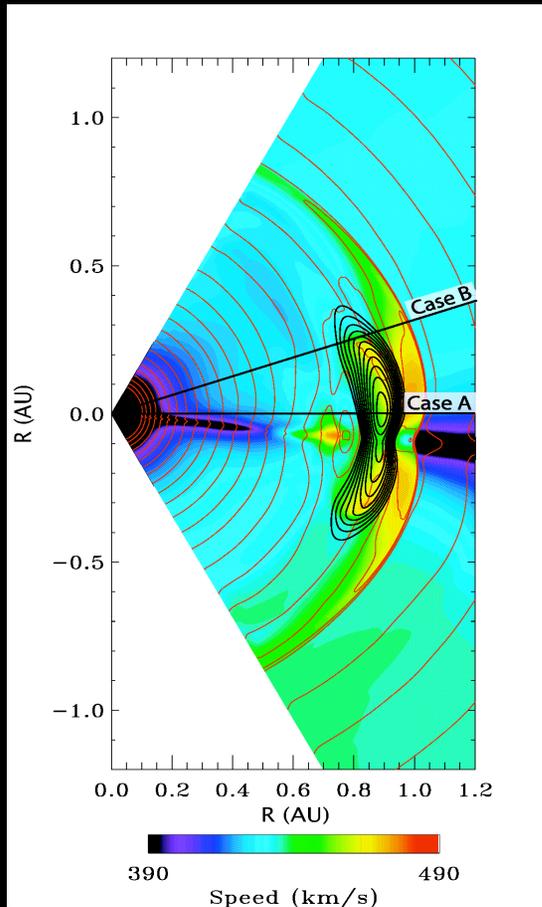 - **Cross-sectional shape/extent**

New flux-rope model of MCs

See poster
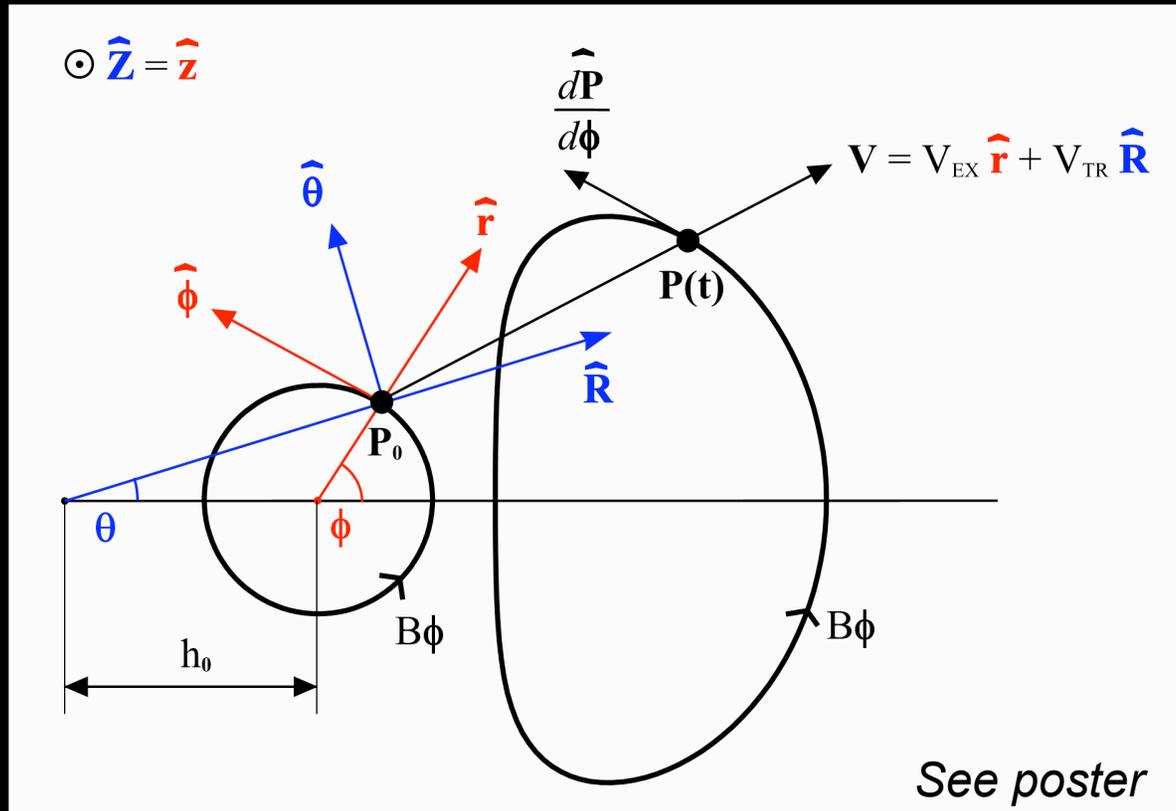
Model validation

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Flux estimates using new model

- Estimate for May 12th 1997:

  1×10^{21} Mx

  - However, can vary from force-free model by ~ 10

- *Lynch et al.* [2005] survey of 132 MCs using **force free model**:

  $<\_> \sim 6 \times 10^{20}$ Mx

  Spread over 3 orders of magnitude

- Fitting to **limited number** of MCs with **new model**:

  $<\_> \sim 10^{21}$ Mx
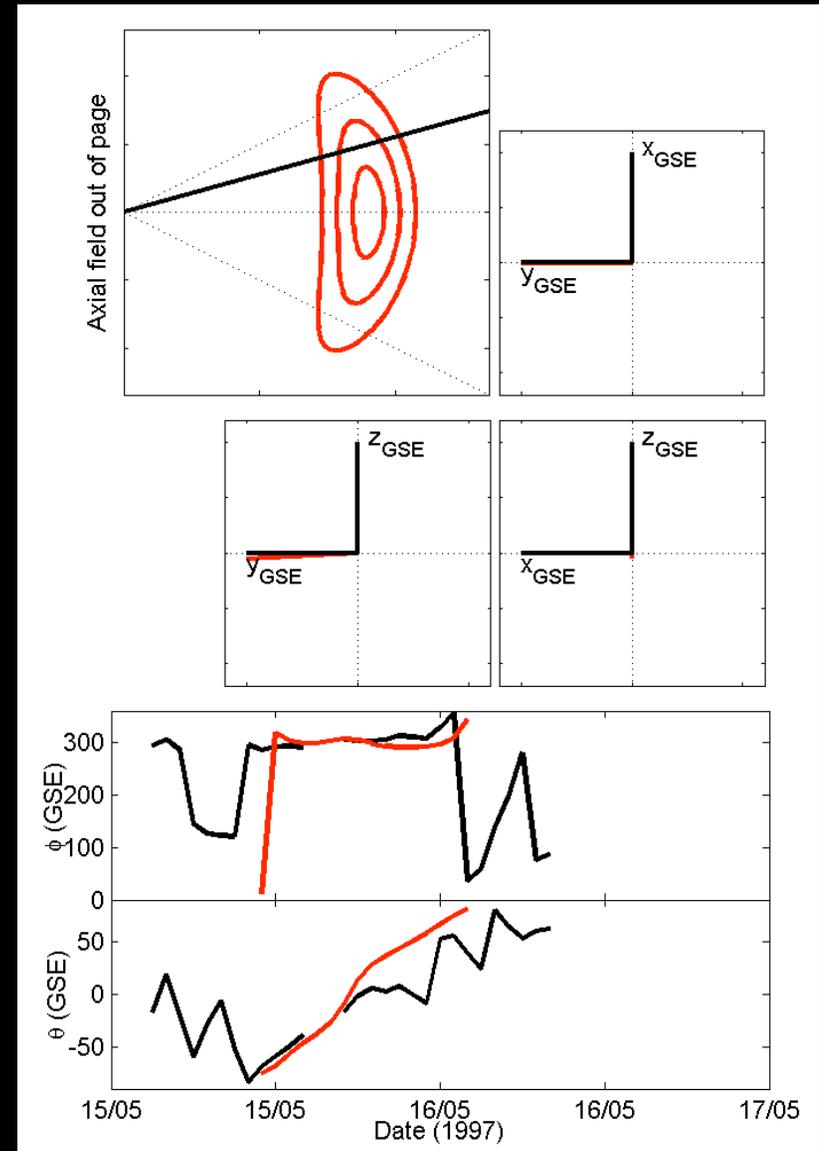
Back of the envelope calculation

- $\Phi_H = \Phi_{CH} + \Phi_{CME}$

- Closed flux from a single CME:

$$\varphi = \varphi_0(1\text{-}D_0) - D(t)$$

- Assume: $\dfrac{d\varphi}{dt} \propto \varphi$ i.e. $\varphi = \varphi_0\,(1\text{-}D_0)\,e^{-\lambda t}$

- Sum over all CMEs: $\displaystyle \Phi_{CME} = \sum_{n=1}^{\infty} \varphi_n = \sum_{n=1}^{\infty} \varphi_{0n}(1-D_{0n})\exp[-\lambda_n t_n]$

- "Average" ICME: $\displaystyle \Phi_{CME} = \overline{\varphi_0}\left(1-\overline{D_0}\right)\sum_{n=1}^{\infty}\exp[-\lambda n / f]$

Back of the envelope calculation

- Solar min/max:

$$\Phi_H(MIN) = \pi(1AU)^2 \mid B_{MIN} \mid \cos(45^0) = \Phi_{CH}(MIN) + \overline{\varphi_0}\left(1 - \overline{D_0}\right)\sum_{n=1}^{\infty} \exp[-\lambda n / f_{MIN}]$$

$$\Phi_H(MAX) = \pi(1AU)^2 \mid B_{MAX} \mid \cos(45^0) = \Phi_{CH}(MAX) + \overline{\varphi_0}\left(1 - \overline{D_0}\right)\sum_{n=1}^{\infty} \exp[-\lambda n / f_{MAX}]$$

- Assume $_{CH}$(MIN) = $_{CH}$(MAX) (i.e. all variation in heliospheric flux is from CMEs):

$$\frac{\pi(1AU)^2 (\mid B_{MAX} \mid - \mid B_{MIN} \mid)\cos(45^0)}{\overline{\varphi_0}\left(1 - \overline{D_0}\right)} = \frac{1}{2}\left(Coth\left[\frac{\lambda}{2f_{MAX}}\right] - Coth\left[\frac{\lambda}{2f_{MIN}}\right]\right)$$

Estimate for disconnection rate

- Using:
  - $|B|_{MAX} = 9nT$ $|B|_{MIN} = 5nT$
  - $f_{MAX} = 3$ per day $f_{MIN} = 1/3$ per day
  - $D_0 = 0.4$ $\_0 = 10^{21} Mx$ ($10^{20} Mx$)
- $\_ = 0.7 \times 10^{-7}$ s^{-1}; i.e. $\_\_$ **~ 12 days** (120 days)
  - If $V_{CME} \sim 400$ km/s, this translates to ~ 4 AU
- Too quick?

Lots of assumptions

- Heliospheric flux inferred from single point measurement

- All ICMEs are magnetic clouds
  - Selection effect: Fitted MCs contain more flux?
    - $\_0 \sim 10^{20}$ Mx gives correct value for $\_$ **~ 120 days**

- ICMEs can be represented by average values

- Observed ICME rates at min/max

- Observed rate of opening – limited dataset
  - Need more multi-point observations of ICMEs

Conclusions

- Flux contained in an MC can be significantly higher than force-free model estimates
  - However $< \Phi_0 >$ is probably over estimated
- Simple model of heliospheric flux, along with best parameter estimates, gives too fast a rate for ICME opening
  - Lots of room for maneuver
- Many assumptions and approximations made in making this estimate