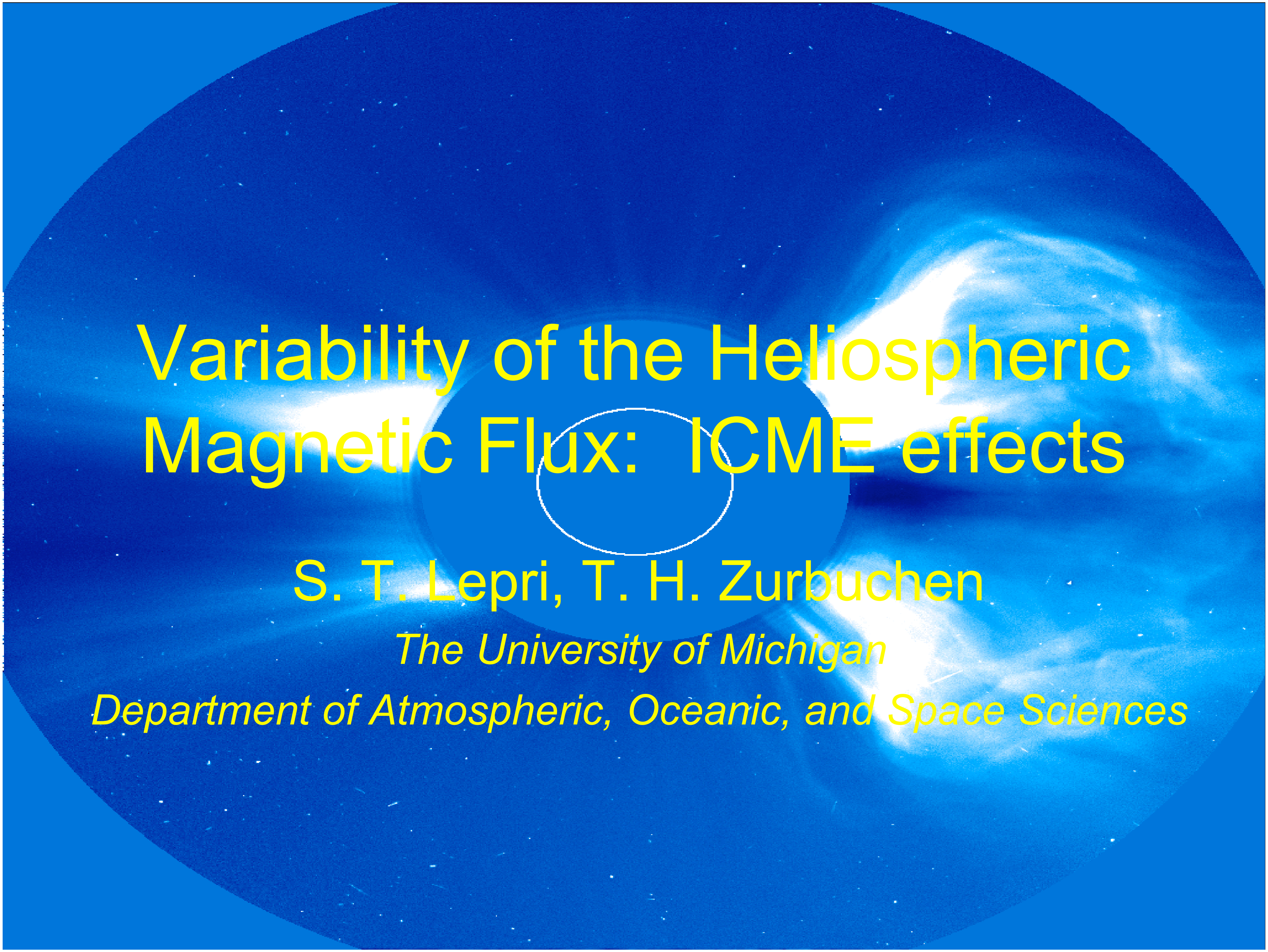

Variability of the Heliospheric Magnetic Flux: ICME effects

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Signatures of ICMEs

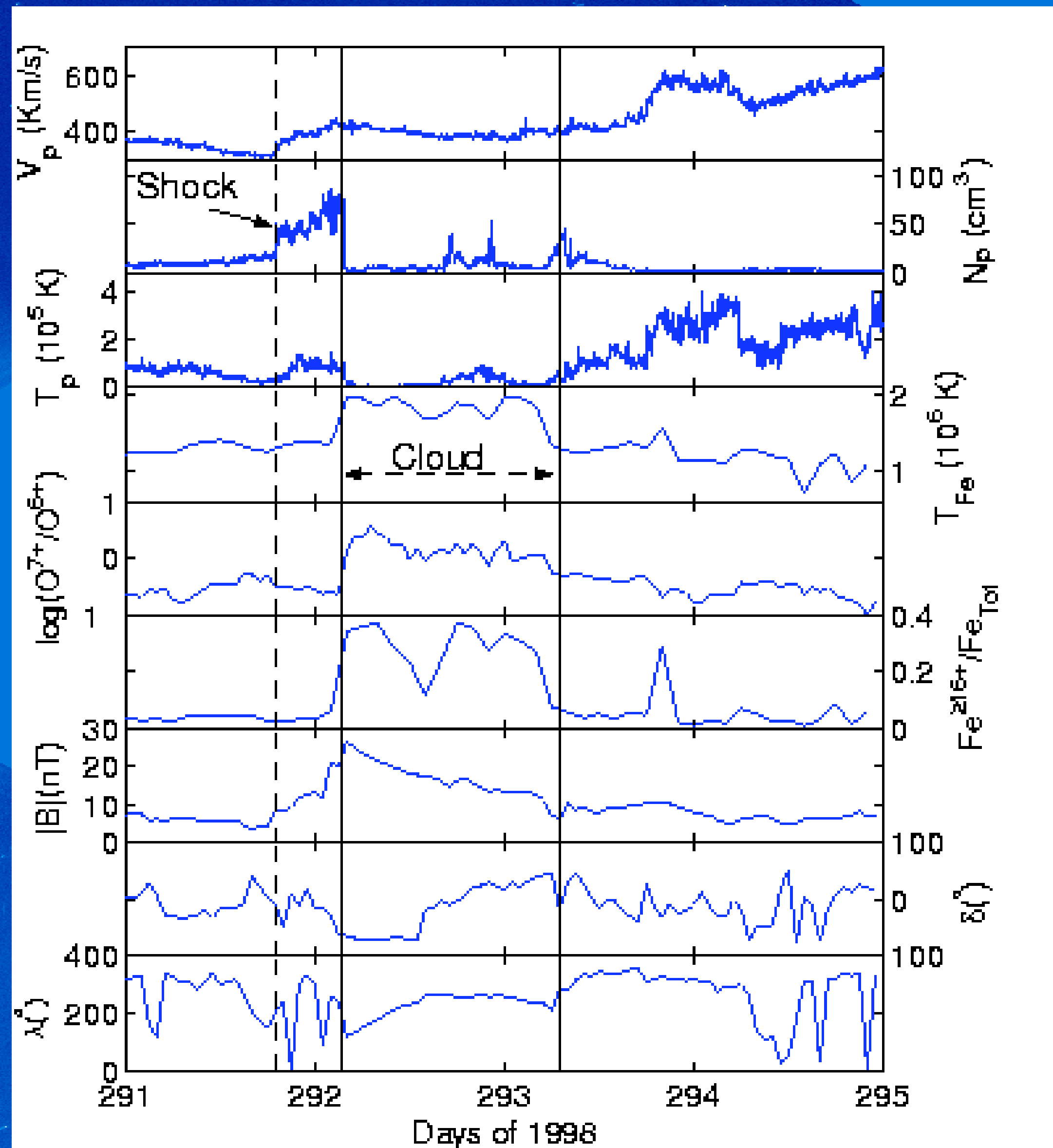
- Interplanetary Coronal Mass Ejections (ICMEs) are the heliospheric counterparts of CMEs.
- Various signatures have been reported for the in-situ identification of ICMEs, but the specific features of individual ICMEs show considerable variation
- Signatures may depend on the observational cut through the ICME
- Some signatures:
  - Counterstreaming (a.k.a. bi-directional) suprathermal electrons
  - Magnetic field signatures
  - Expansion signatures in the proton velocity and density profiles
  - Forbush decreases
  - Proton temperature depressions
  - Compositional signatures including ionic charge states and enhanced helium abundances

Signatures of ICMEs

$\langle Q \rangle_{Fe}$ Freeze in T

O^{7+}/O^{6+}

Fe^{16+}/Fe_{Tot}



Counterstreaming Electrons

- Heat of solar corona much higher than interplanetary space, hence heat flux escapes along field lines into heliosphere.
- Since electrons are more mobile, they carry the majority of the heat flux.
- Counterstreaming electrons come from the suprathermal population of electrons.
- When suprathermal electrons are observed flowing parallel and anti-parallel to the field, this presumably indicates that both foot points are rooted deep in the solar corona as part of a closed field configuration.
- Among the first signatures to be used to identify ICMEs (e.g. Gosling et al., 1987a)

The Study

- As CMEs erupt from the Sun, they carry closed fields embedded within them into interplanetary space.
- These fields must reconnect via interchange reconnection or another mechanism in order to keep the flux in the heliosphere from catastrophically building up (Gosling 1975).
- Studies have indicated that the magnetic fields in ICMEs tend to be at least 50% closed at 1 AU and beyond.
  - At 1AU: ICME fields are on average 59% closed (Shodhan et al., 2000; Crooker et al., 2004).
  - Beyond 3 AU: ICME field lines are on average 55% closed (Crooker et al., 2004).
- These studies indicate that the fields are not opening much between 1 AU and 3 - 5 AU.
- *There is an apparent disconnect between the rate at which ICME fields open and the observed relatively steady magnitude of the heliospheric magnetic flux.*

The Model

- Examine the build up of flux based on a range of reconnections times.
- Assume that heliospheric flux closes off in a way that can be described similar to radioactive decay. The rate depends on the number of closed field lines attached to the Sun. The number of field lines attached to the Sun are part of the open flux, Φ.
- The loss term accounts for reconnection of closed field lines; τ is the characteristic reconnection time

$$d\Phi/dt = - 1/\tau \ \Phi$$

- CMEs drag closed field lines into the heliosphere as they erupt, hence acting as a source term

$$d\Phi/dt = d\Phi_{CME}/dt - 1/\tau \ \Phi$$

Source due to CMEs

Loss due to reconnection

The Model

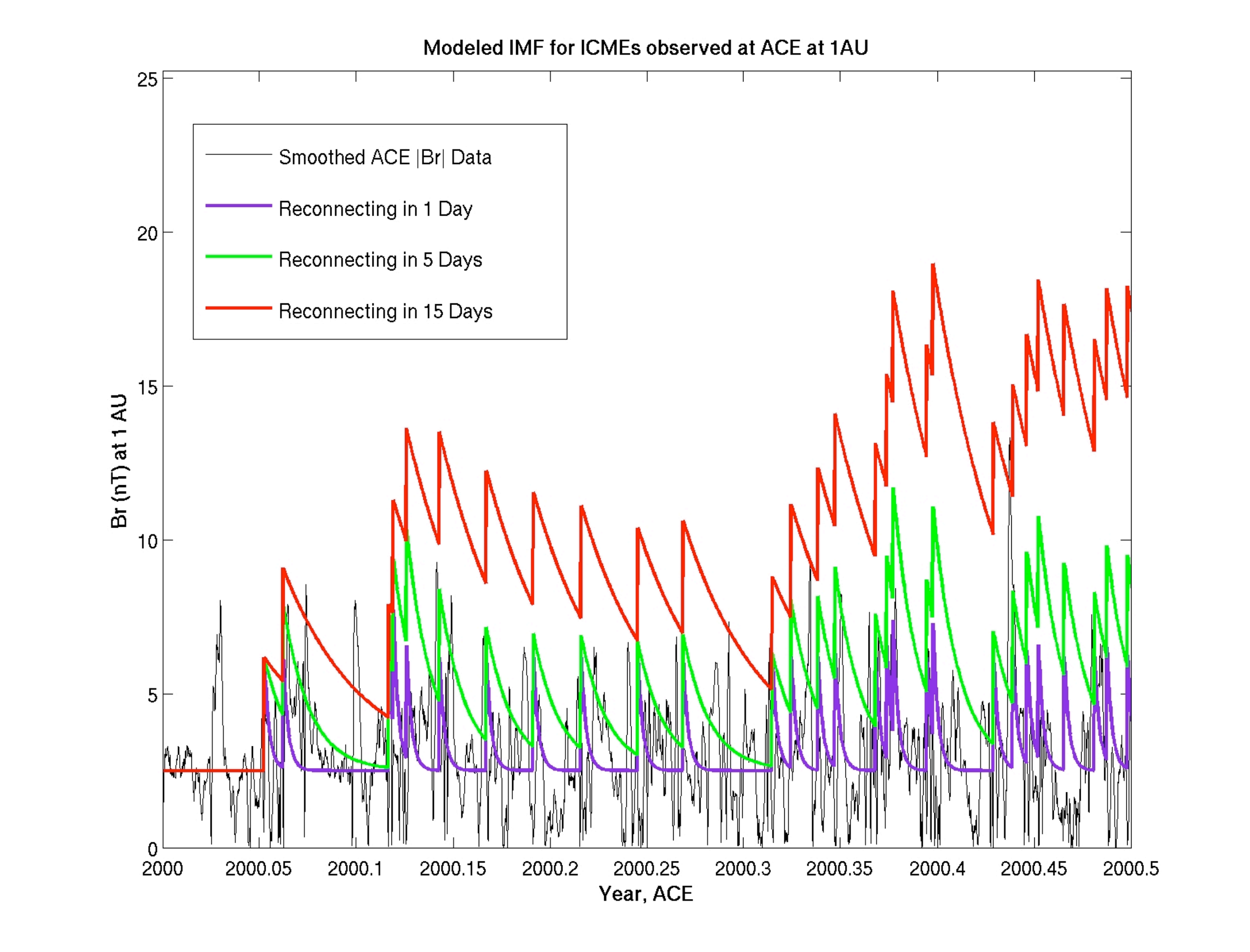
- In the case where there are no CMEs adding to the flux at a certain time, the field decays to its equilibrium value on a time scale τ .
- If a CME occurs, it will add flux that will eventually decay back toward the equilibrium value.
- The balance of the rate at which CME flux is being added vs. the reconnection rate will determine the overall state of the heliospheric flux.
- Observations indicate that the heliospheric flux varies by a factor of two over the solar cycle (Wang and Sheeley 2002, Wang 2004); the additional flux from CMEs does not build up and lead to a “flux catastrophe” (Gosling, 1975)

- *How can we reconcile the absence of the “flux catastrophe” and the observed degree of closed field lines observed in ICMEs using CSEs?*

Local vs. Global Behavior of Magnetic Flux

- Start by examining the local case, set an observer at 1 AU.
- Use Cane and Richardson [2003] list for CME boundaries.
- Start from an equilibrium value for the field and calculate the changes in the field in time as ICMEs occur and the field decays according to a prescribed reconnection time.
- How does reconnection time affect the open flux through time?
- Which reconnection time best reproduces the data observed by ACE at 1 AU?

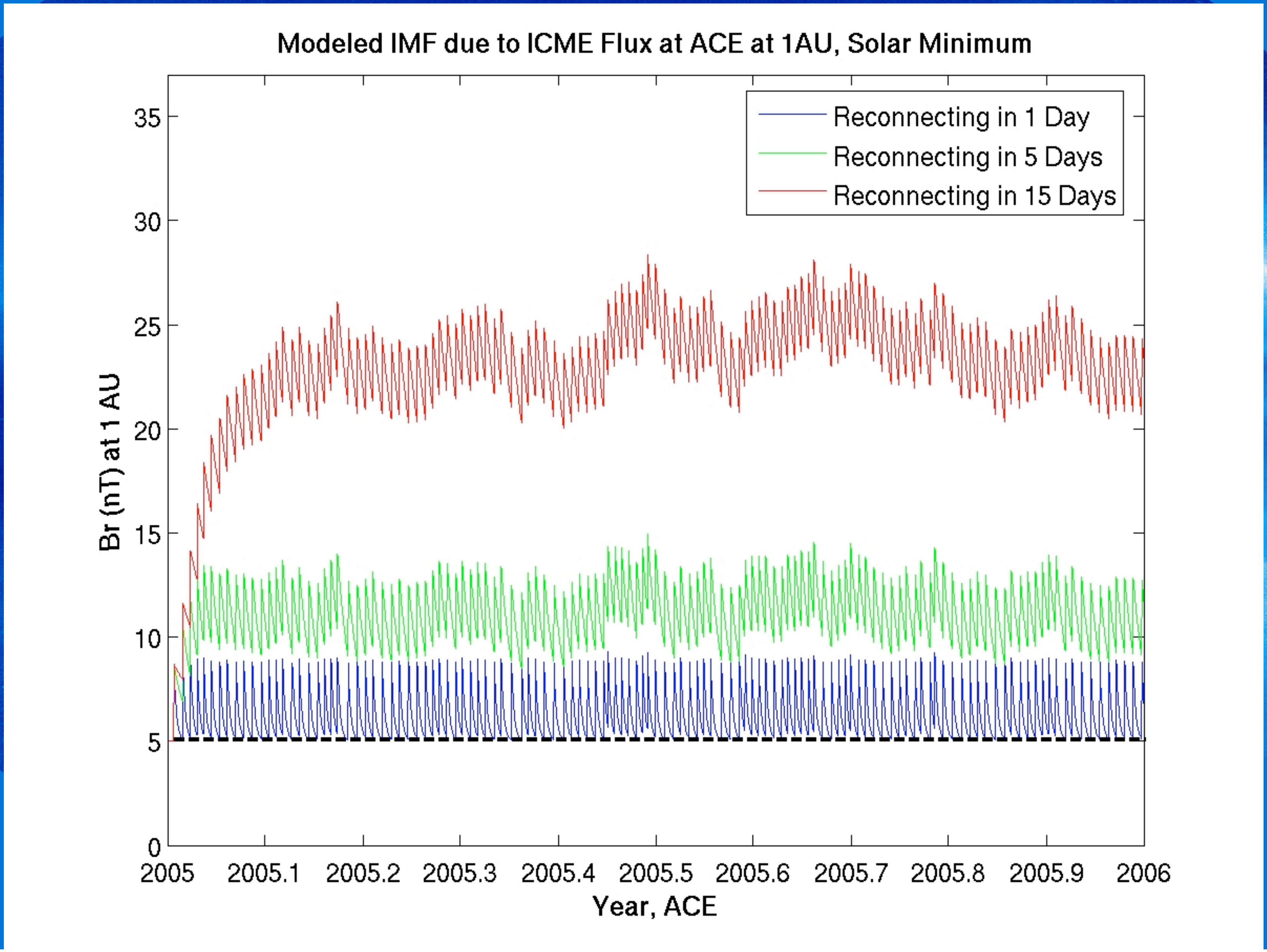
Local Results



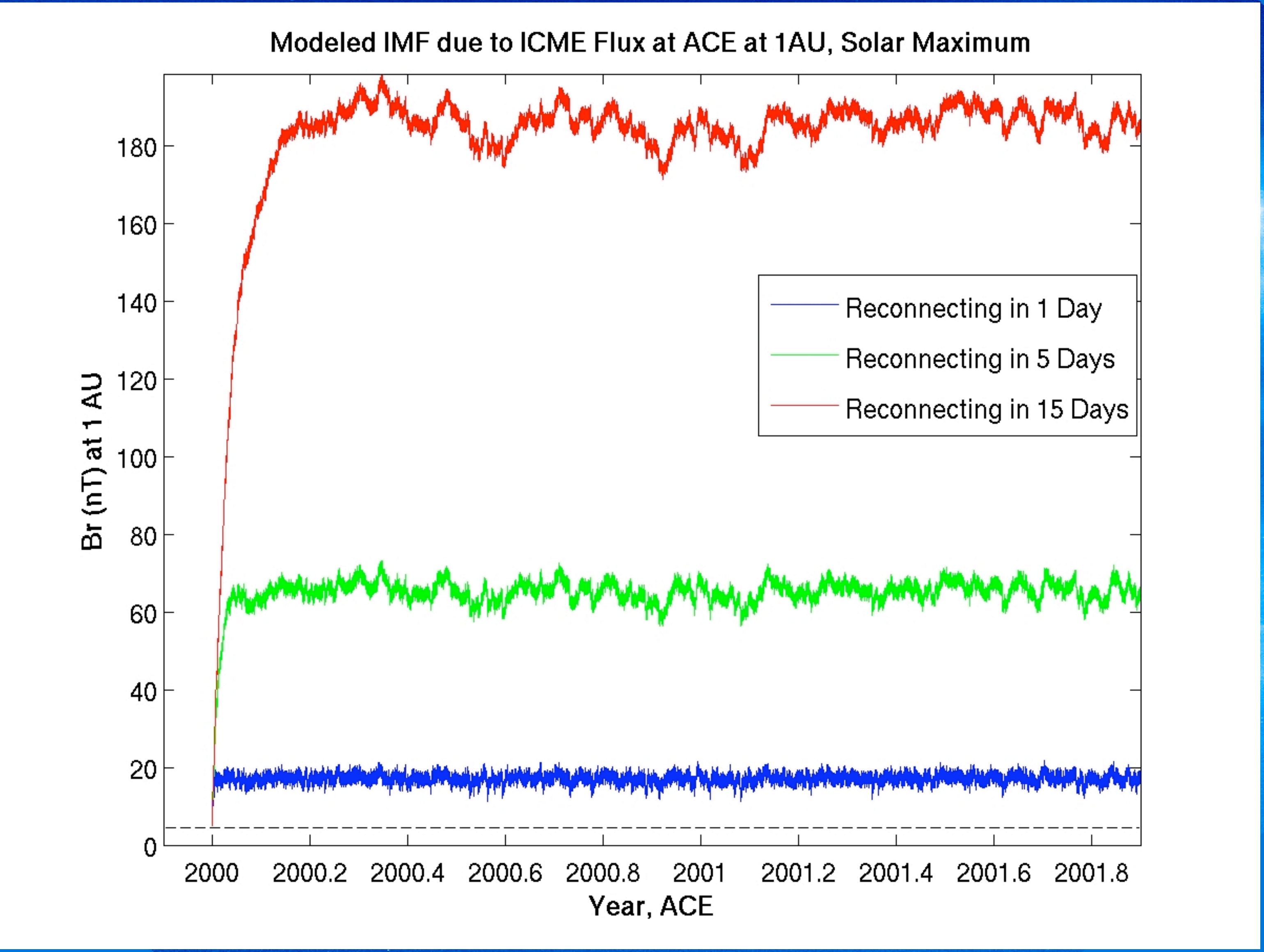
Global Case

- For solar minimum, assume there are ~ 0.3 CMEs/day.
- For solar maximum, assume there are ~ 3 - 4 CMEs/day
- Create a model “list” of the CMEs that occur in the whole heliosphere for time period in question.
- Starting at the beginning of the year, set CME start times according to a Poisson time distribution with a mean of 3 days between CMEs for solar minimum and 0.3 days for solar maximum.
- Survey of CR03 list CMEs shows that CME frequency vs. duration behaves as a normal distribution. Use the normal distribution to randomly select model CME duration.
- The result is an unbiased global model CME list that closely resembles the observed frequency and duration of CMEs.

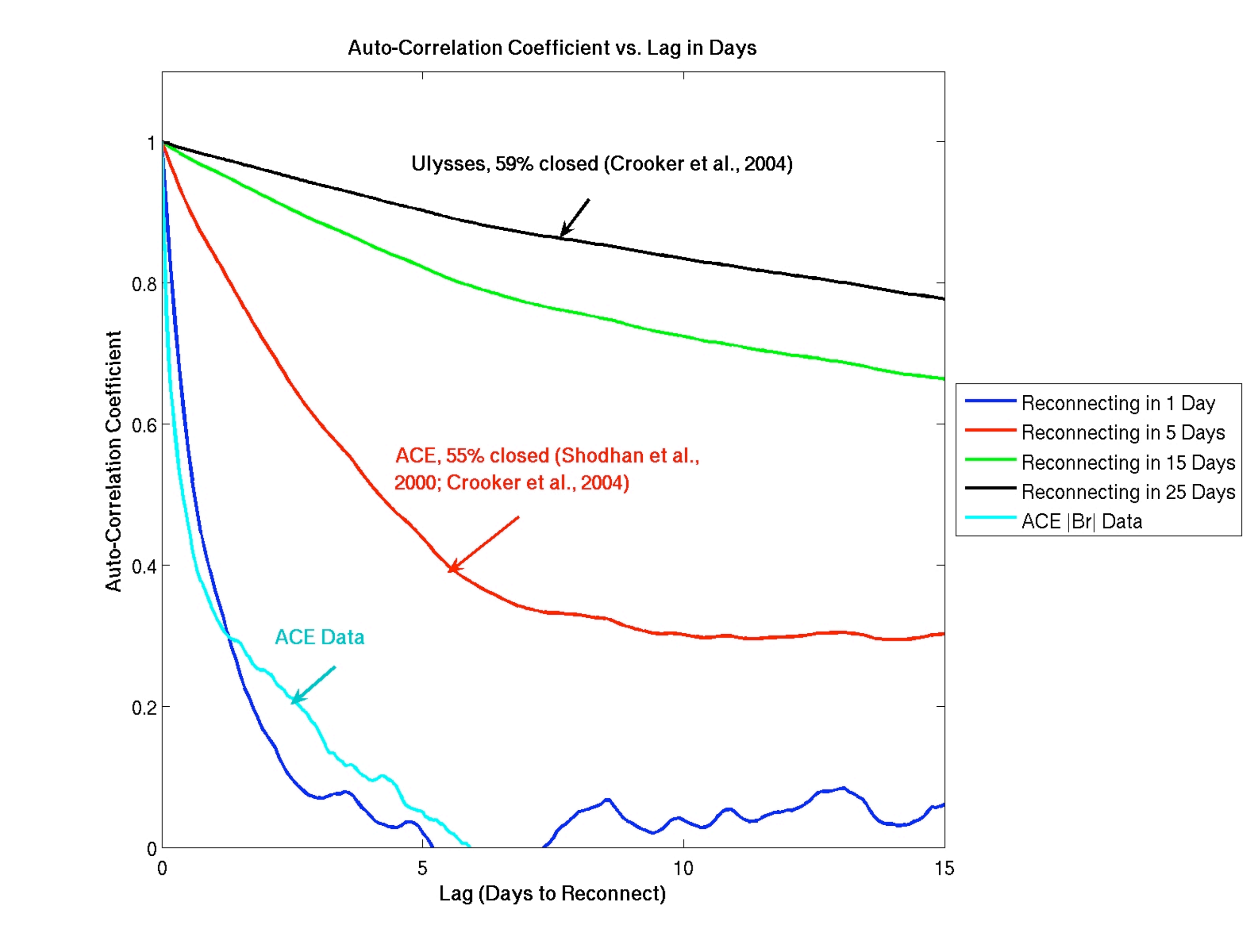
Global Results--Solar Minimum



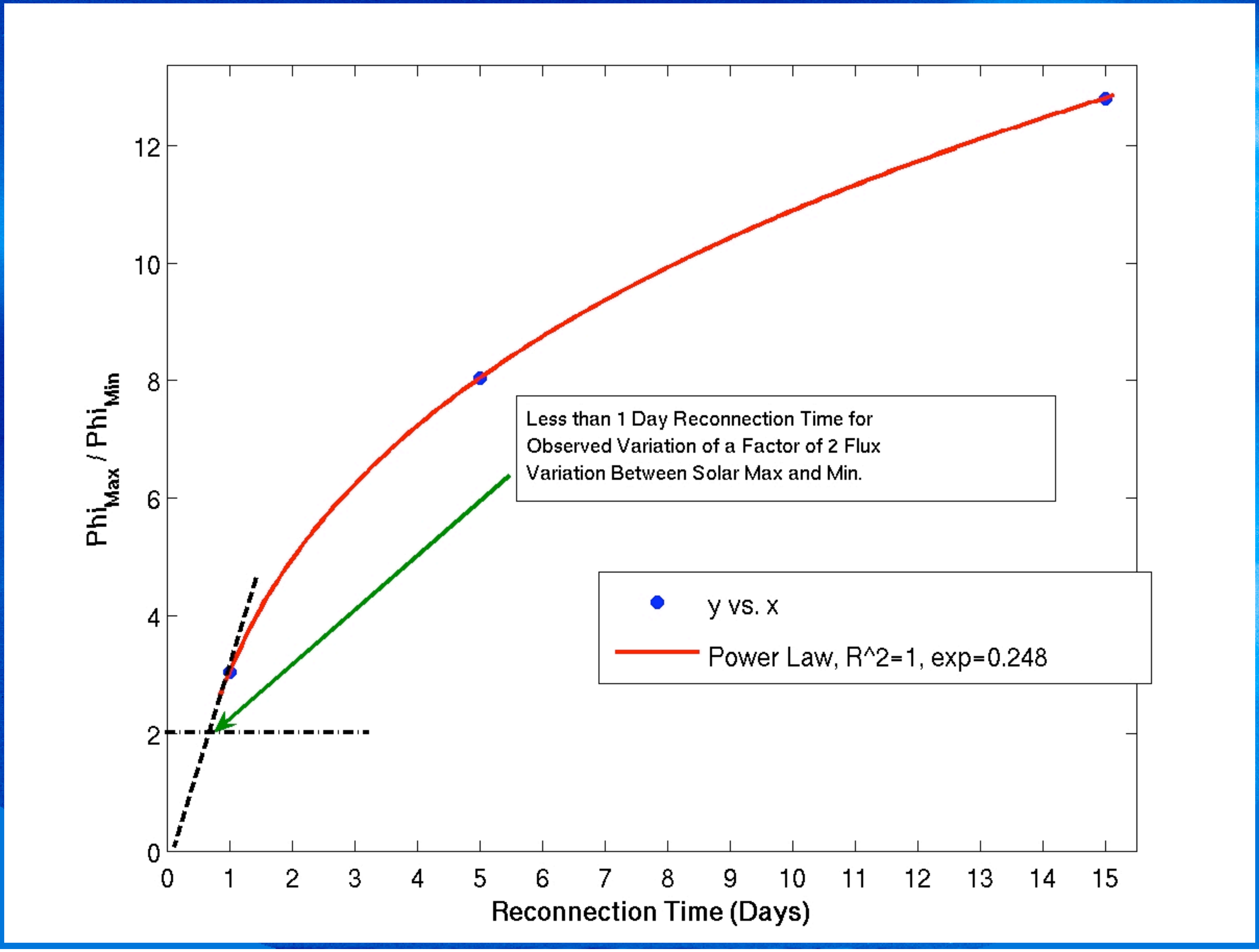
Global Results--Solar Maximum



Auto-Correlation for Time-Scale of Change

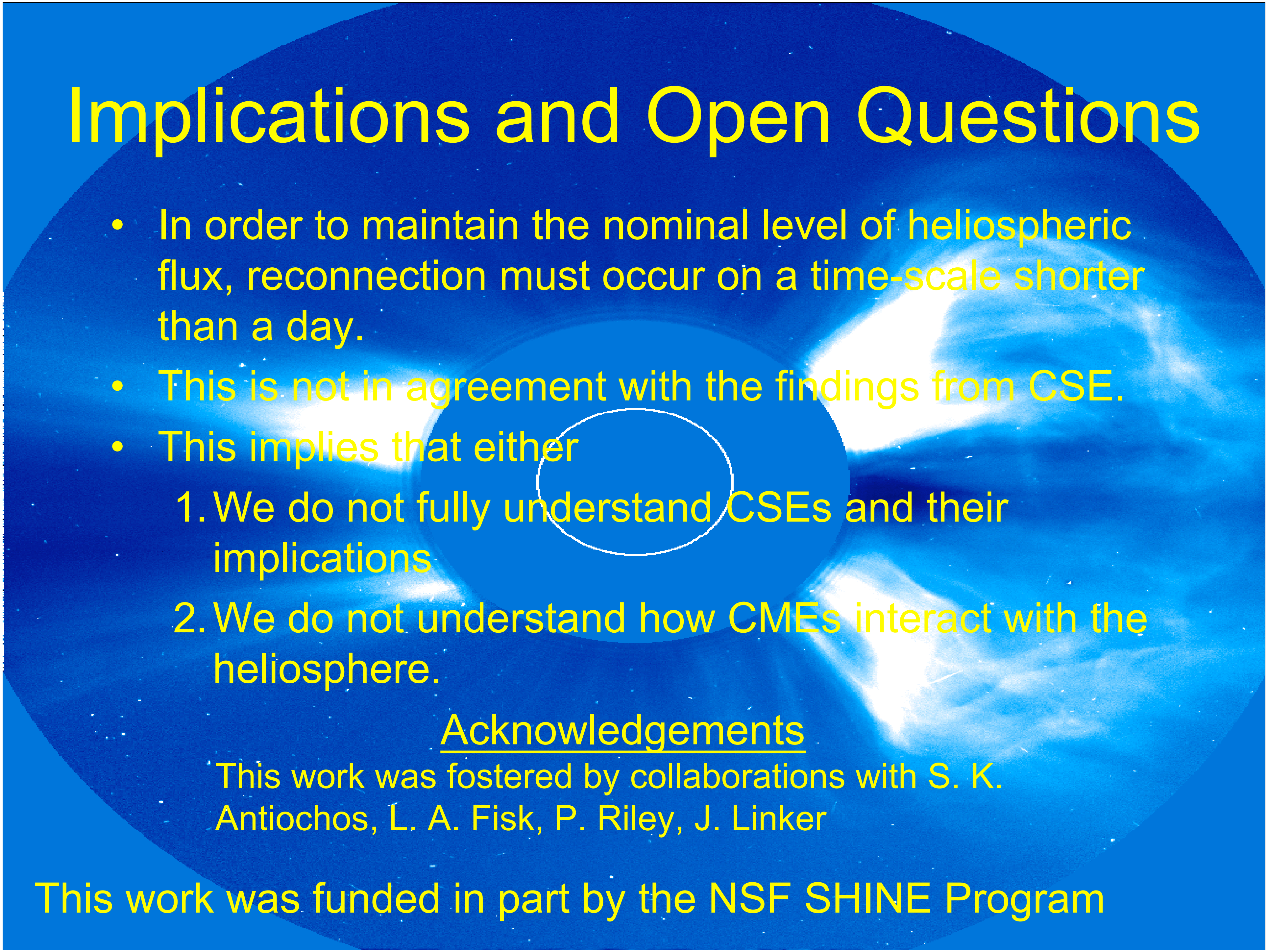


Deriving the Behavior for Observed Flux Variations



Summary of Findings

- The reconnection times implied from the ACE (5 days) and the Ulysses (25 days) CSE findings would lead to a noticeable accumulation of flux in the heliosphere
- During solar minimum, a reconnection time of 1 day would be sufficient to return the flux levels to their equilibrium value without a buildup.
- During solar maximum, even a 1 day reconnection time results in a catastrophic build up.
- Reconnection times on the order of hours are needed to prevent a build up of flux during solar maximum.



Implications and Open Questions

- In order to maintain the nominal level of heliospheric flux, reconnection must occur on a time-scale shorter than a day.
- This is not in agreement with the findings from CSE.
- This implies that either
  1. We do not fully understand CSEs and their implications
  2. We do not understand how CMEs interact with the heliosphere.

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