Flux Transport into the Heliosphere

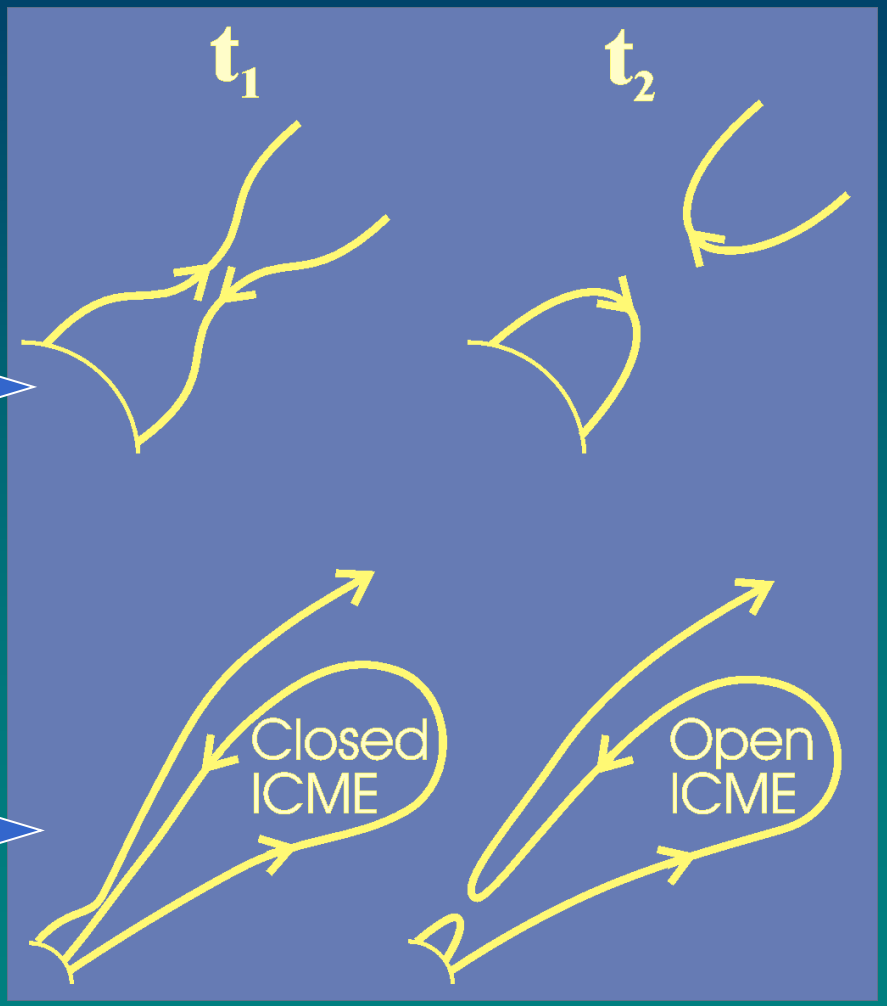
Viewing the heliosphere
with a Fisk-eye lens

Topics

- Transport of closed flux from CMEs
  - Heliospheric magnetic flux budget
    - *Crooker, Gosling, and Kahler* [2002]
- Transport of non-Parker-spiral fields
  - Radial field events
    - *Gosling and Skoug* [2002]
    - *Schwadron* [2002]
  - Fields turned back on themselves
    - *Crooker and Schwadron* [in progress]

Heliospheric Magnetic Flux Budget

- **PROBLEM**: CMEs draw closed fields into the heliosphere and build up magnetic flux, but no build-up is observed
- **PRE-1995 SOLUTION**: Flux reduction by disconnection
- **PROBLEM**: True signatures of disconnection are rare
- **POST-1995 SOLUTION**: ICMEs open through interchange reconnection



Key contributions

- **1975:** Gosling points out problem of magnetic flux build-up from CMEs
- **1989:** McComas et al. document heat flux dropouts (HFDs) in solar wind and interpret them as signatures of disconnection
- **1992:** McComas et al. estimate flux contribution from CMEs to be 4 times larger than decrease from disconnection estimated from HFDs
- **1992:** Lin and Kahler use higher-energy electron data to demonstrate that most HFDs do not signal disconnection
- **1995:** McComas reviews status of problem and considers disconnection as only solution

- **1995:** Gosling et al. propose 3D 3-step CME disconnection process with interchange reconnection as second step
- **1997:** Larson et al. document magnetic cloud with open and disconnected fields and suggest cause is interchange reconnection in CME leg well after lift-off
- **2000:** Shodhan et al. report that magnetic clouds at 1 AU are more open than previously thought, implying they continue to open beyond 1 AU

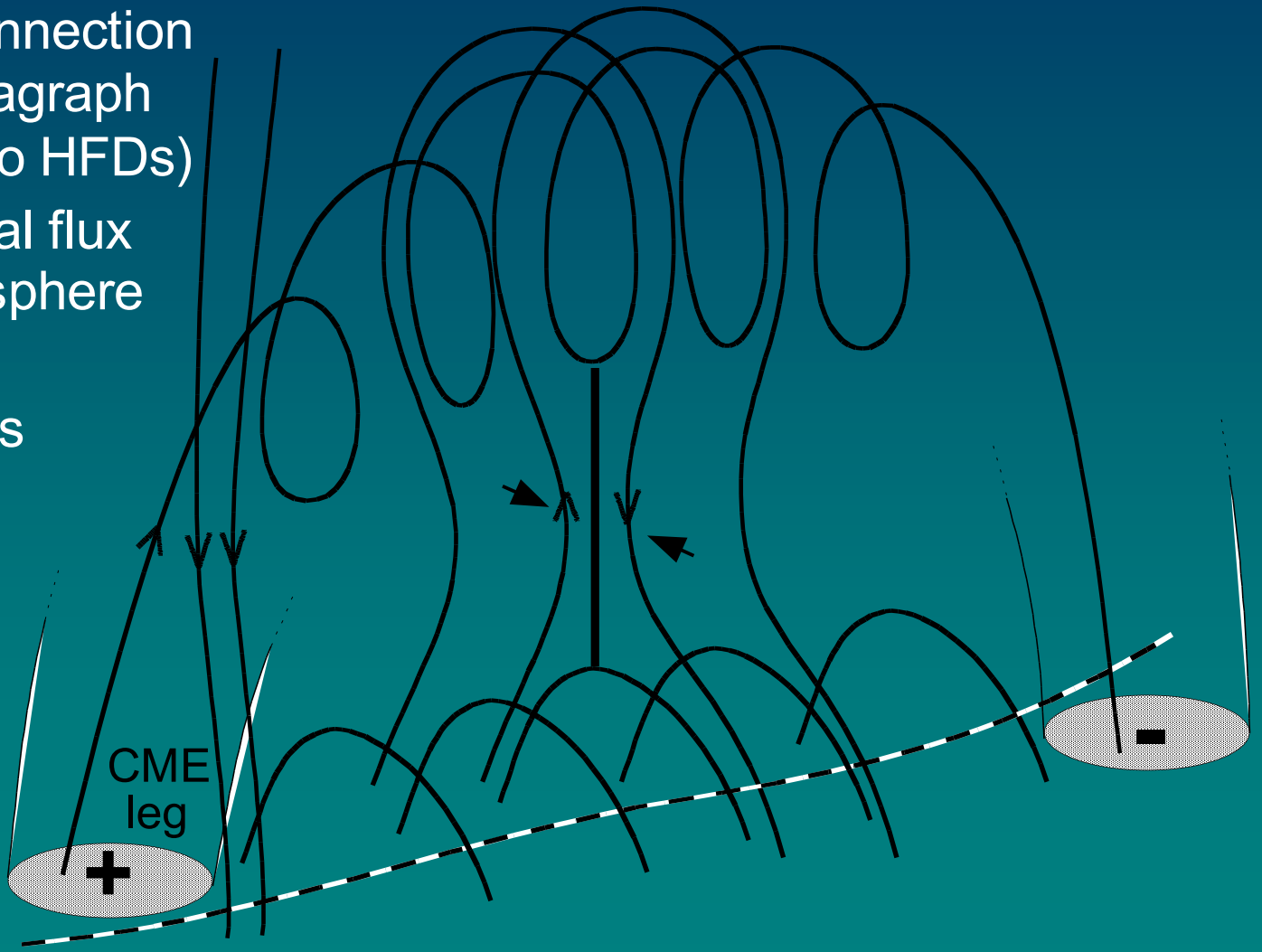
Gosling, Birn, and Hesse [1995]

- Analogy to magnetospheric model [*Hesse and Birn*, 1991]
- Explains how coherent flux rope can have open, closed, and disconnected fields through remote reconnection at the Sun
- Step b removes flux without disconnection

PARTIAL DISCONNECTION **INTERCHANGE RECONNECTION**

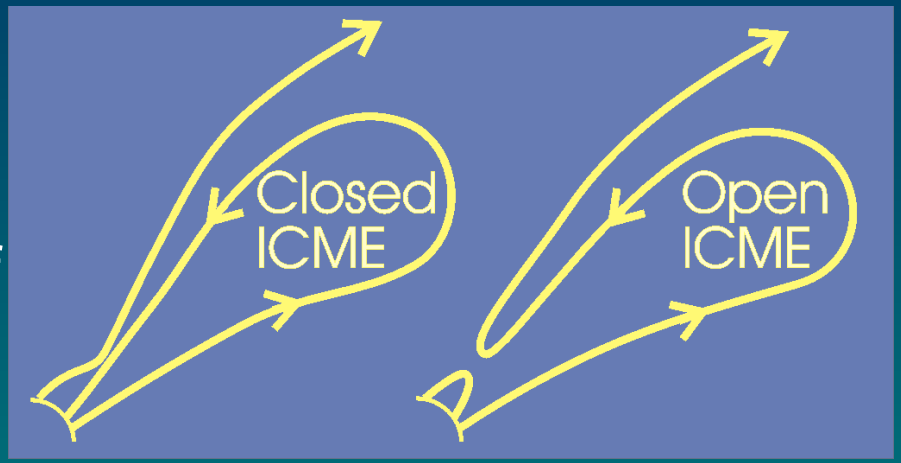
Partial Disconnection

- Source of “disconnection events” in coronagraph observations (w/o HFDs)
- Reduces potential flux addition to heliosphere by large factor
- Leaves CME legs attached to Sun
- Lasts for ~1 day after CME lift-off
- Interchange reconnection continues in legs

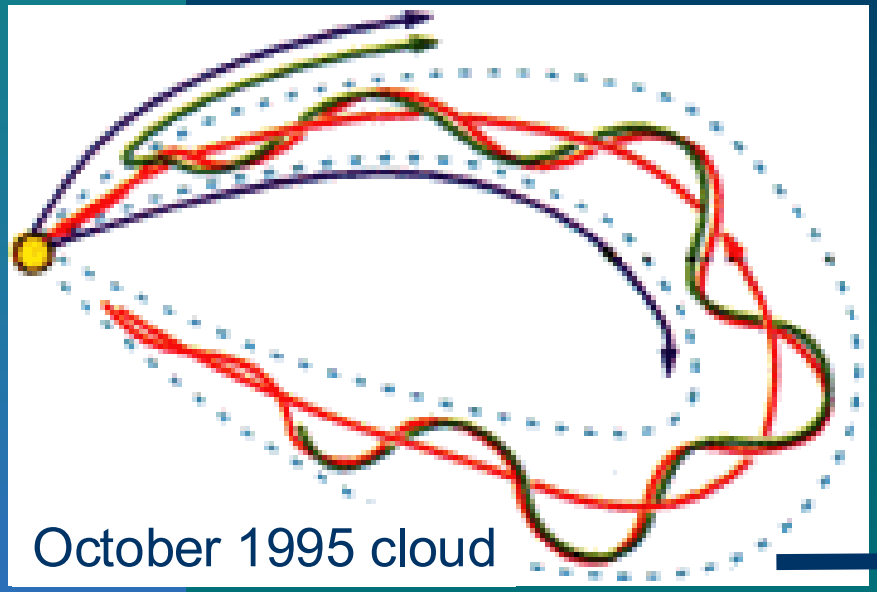


Interchange reconnection

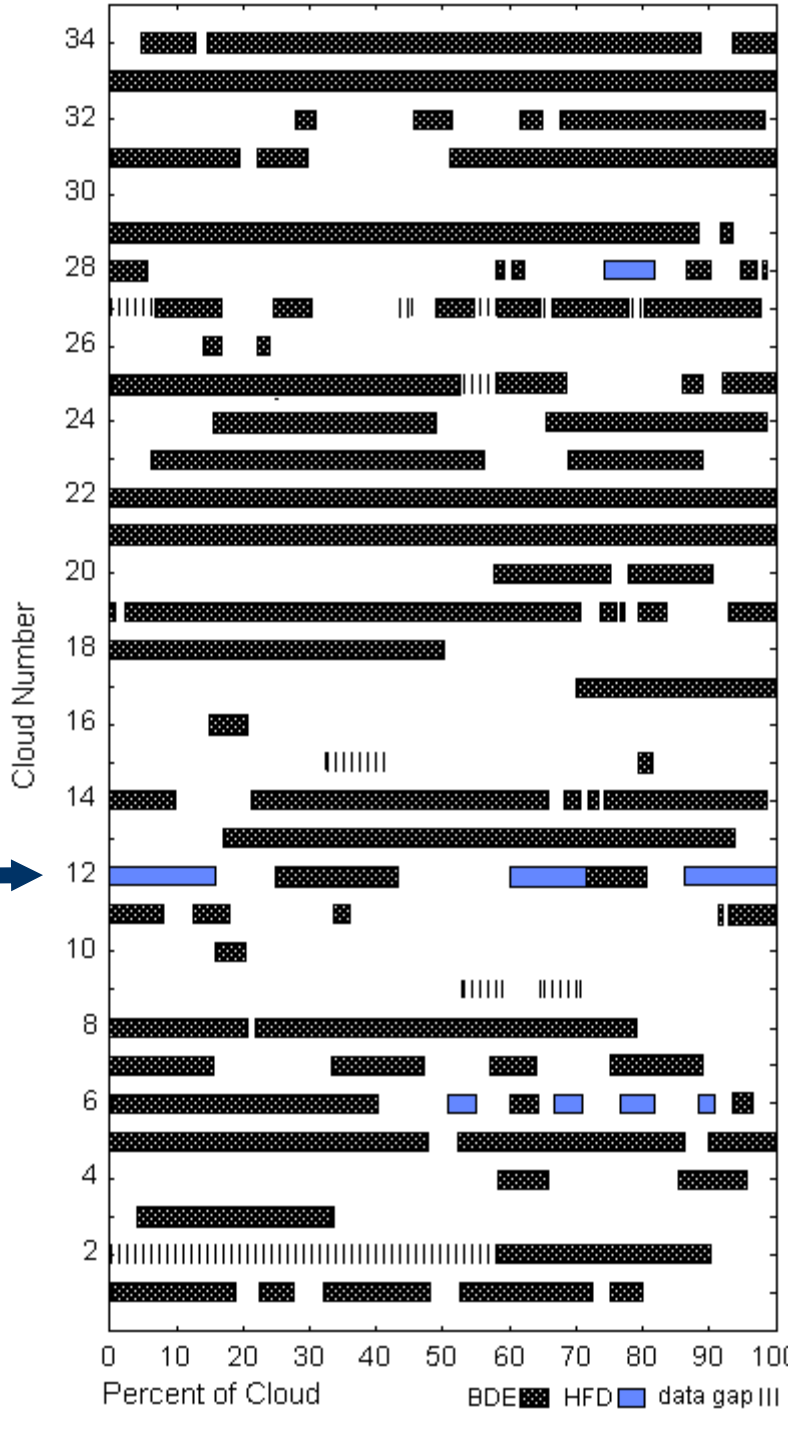
- Name for “reconnection between an open and a closed field line”
- Effects an interchange of closed loops
- In the case of ICMEs
  - a heliospheric loop is interchanged for a coronal loop
  - field lines extending into the heliosphere are reduced from three to one without disconnection
- Effects footpoint exchange proposed by *Wang et al.* to explain, e.g., the release of material at the tips of helmet streamers
- Effects footpoint motion in Fisk model



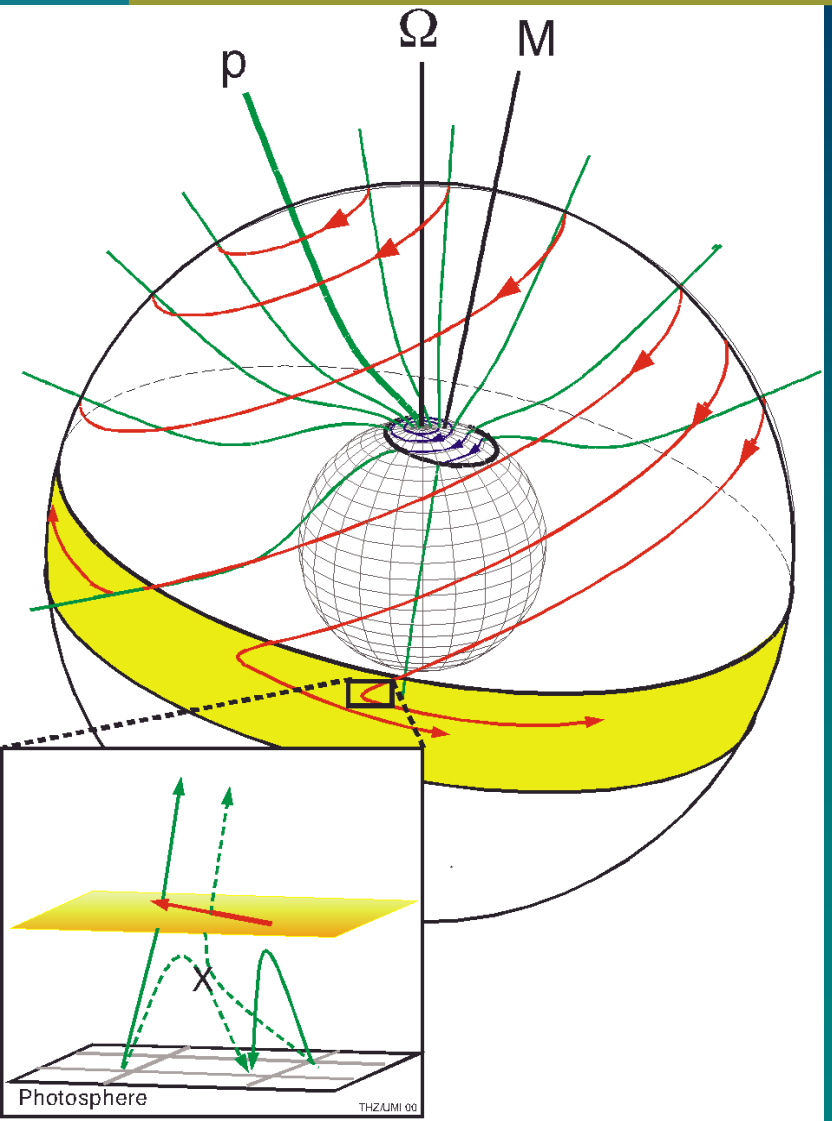
Interchange reconnection in magnetic clouds



- Larson et al. [1997] propose that it continues in legs well after CME lift-off
- Shodhan et al. [2000] imply it is ongoing at 1 AU



ICME opening as part of global circulation in Fisk model

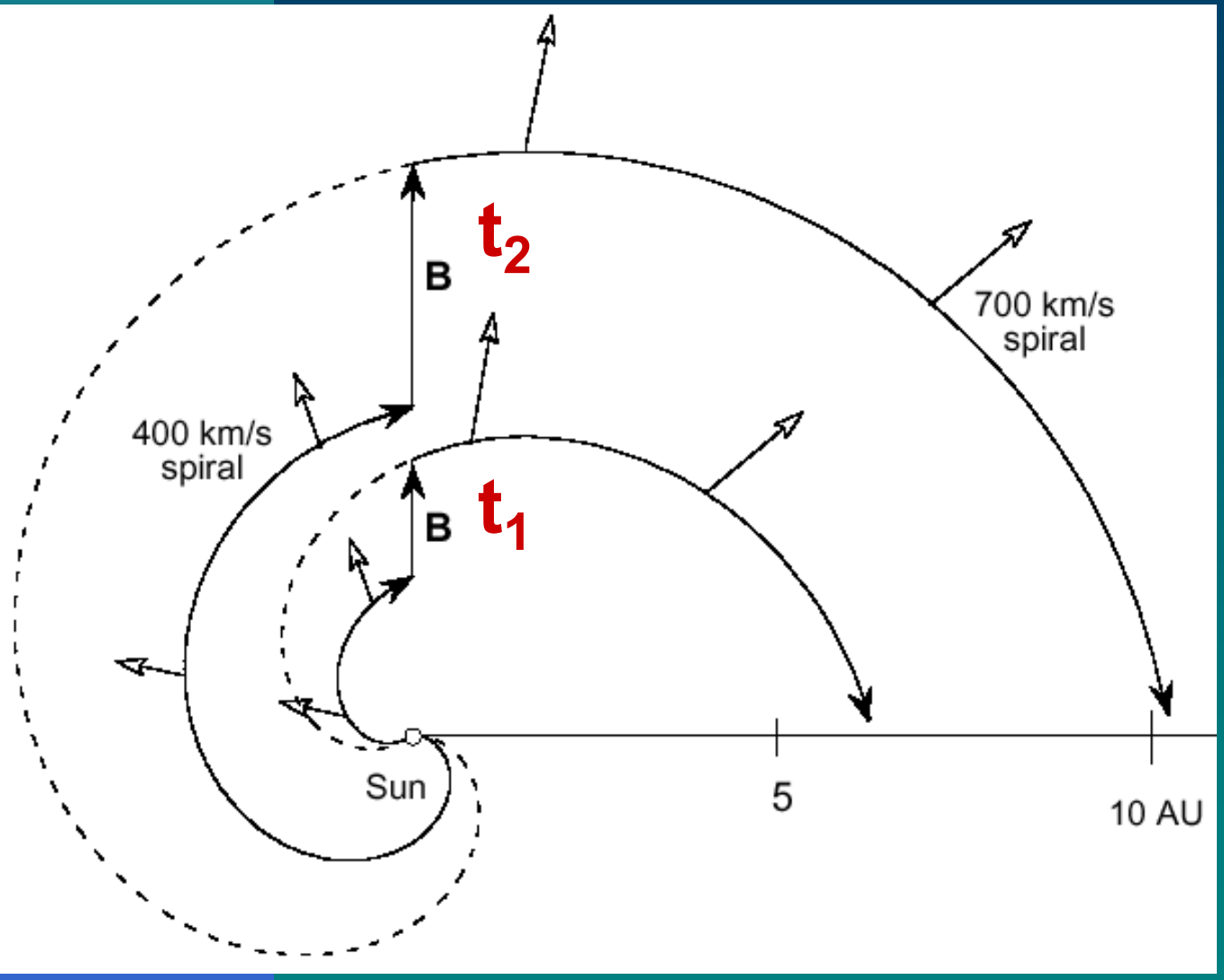


- *Fisk, Zurbuchen, and Schwadron* [1999] propose closure of global circulation cells in streamer belt via interchange reconnection
- *Crooker, Gosling, and Kahler* [2002] suggest ICME opening is part of same process
- *Reinard et al.* [2002?] model ICME opening in terms of Fisk circulation and show
  - agreement with dependence of openness on ICME size found by *Shodhan et al.* [2002]
  - possible disagreement with prediction that ICMEs should be more open beyond 1 AU

Transport of non-Parker-spiral fields

- Radial fields and fields turned back on themselves are common solar wind events
- Fisk model offers a global context for understanding these events
- Interchange reconnection may play a significant role

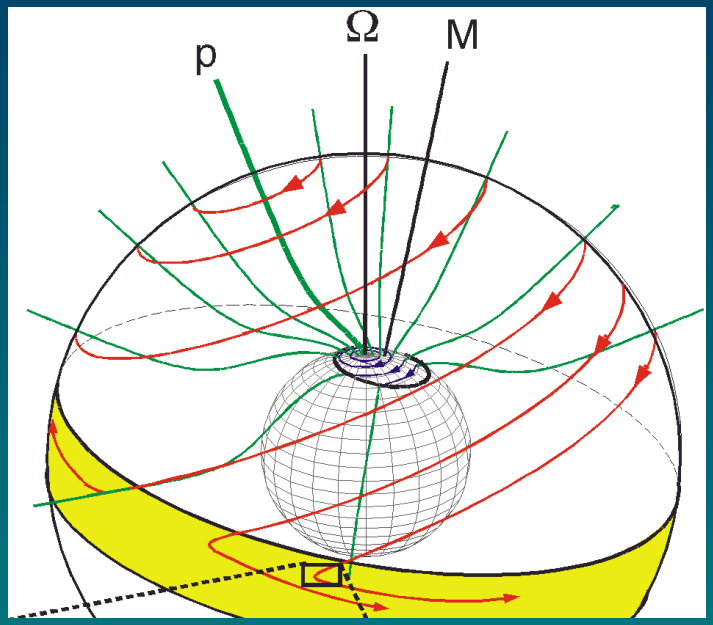
Radial field events: *Gosling and Skoug*



- First reported by *Neugebauer et al.* [1997] and *Jones et al.* [1998]
- *Gosling and Skoug* [2002] propose sudden decrease in speed in given flux tube as cause
- Essence of effect illustrated in diagram at two different times

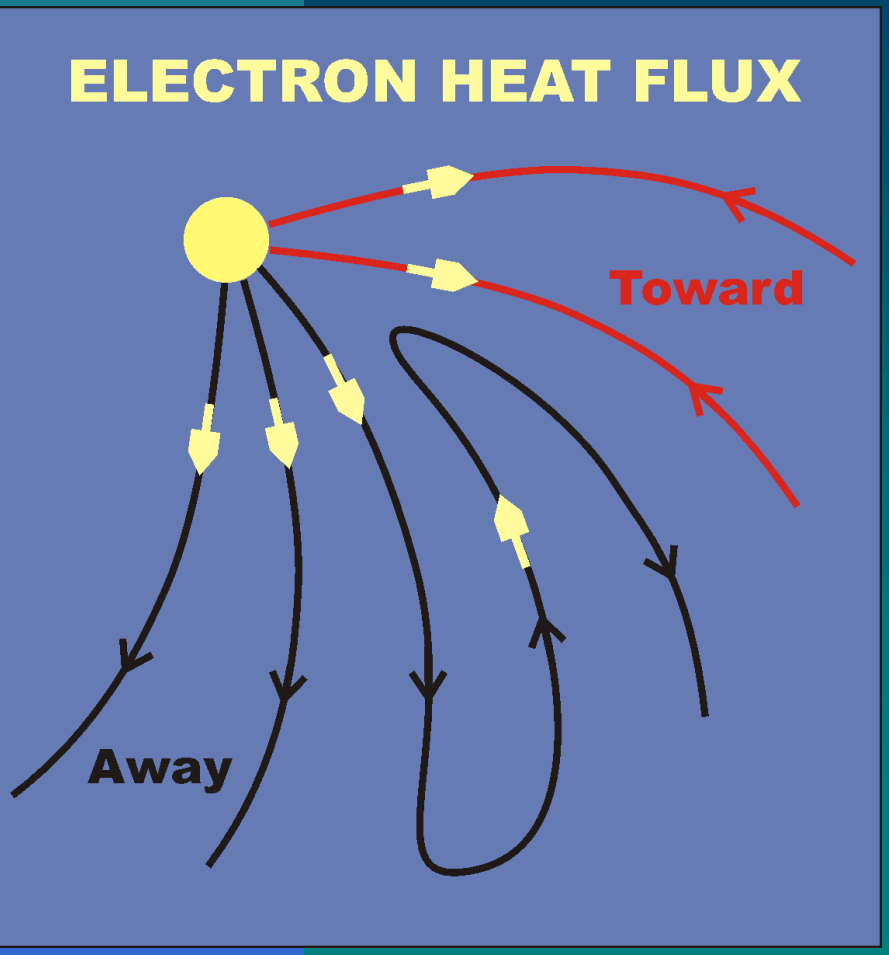
Radial field events: *Schwadron*

- *Schwadron* [2002] independently offers same explanation—sudden speed decrease—in context of Fisk model
- Combines with additional Fisk effect—counter-solar-rotation footpoint circulation



- Provides analytical formula for orientation of non-Parker-spiral segment as function of radial speed change and longitudinal circulation speed
- Formula predicts fields turned back on themselves

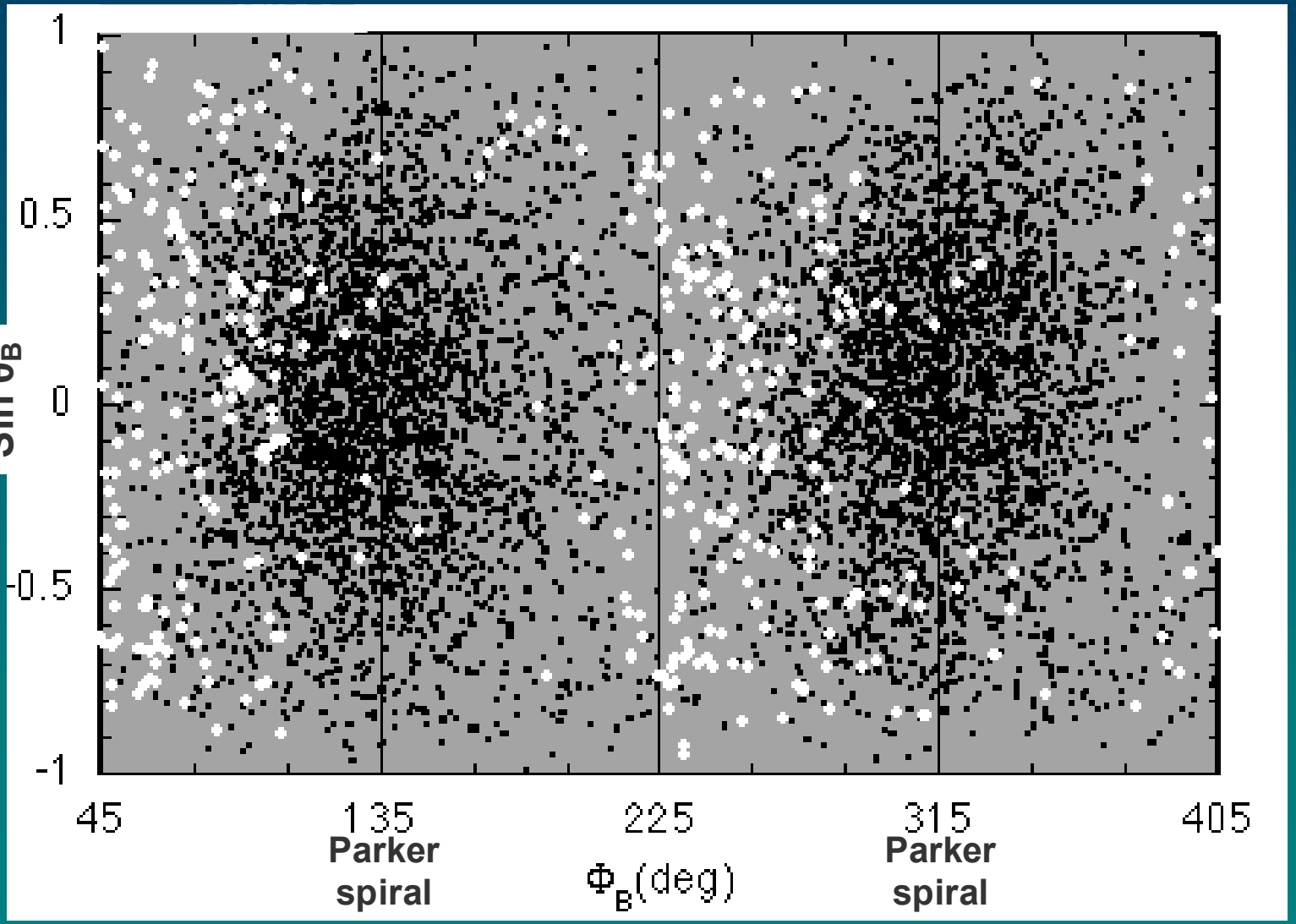
Fields turned back on themselves



- Easy to identify in electron data [*Kahler and Lin*, 1994, 1995]
- Direction of electron heat flux relative to field gives correct solar polarity
- Disagreement between local and solar polarity (sunward heat flux) signifies field turned back on itself
- Constitute 7% of ecliptic data [*Kahler, Crooker, Gosling*, 1998]
- Tend to hover near ortho-Parker-spiral direction

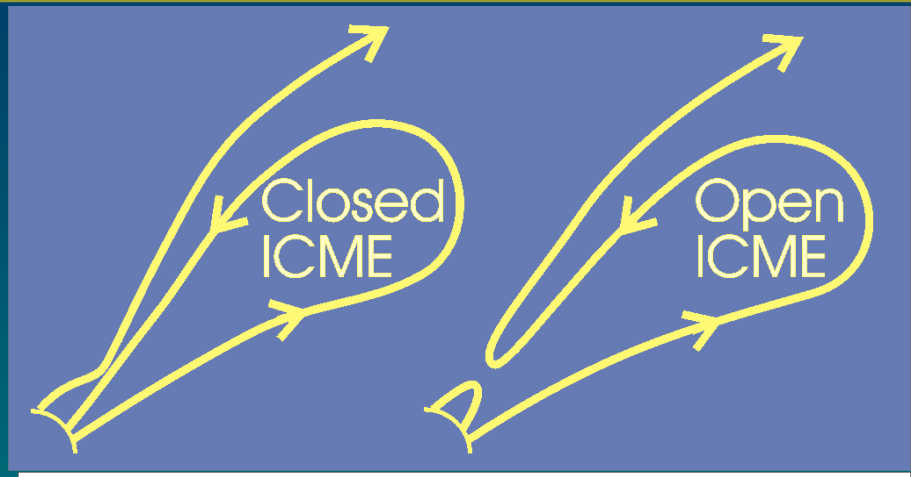
Non-Parker spiral orientations of fields turned back on themselves (white dots)

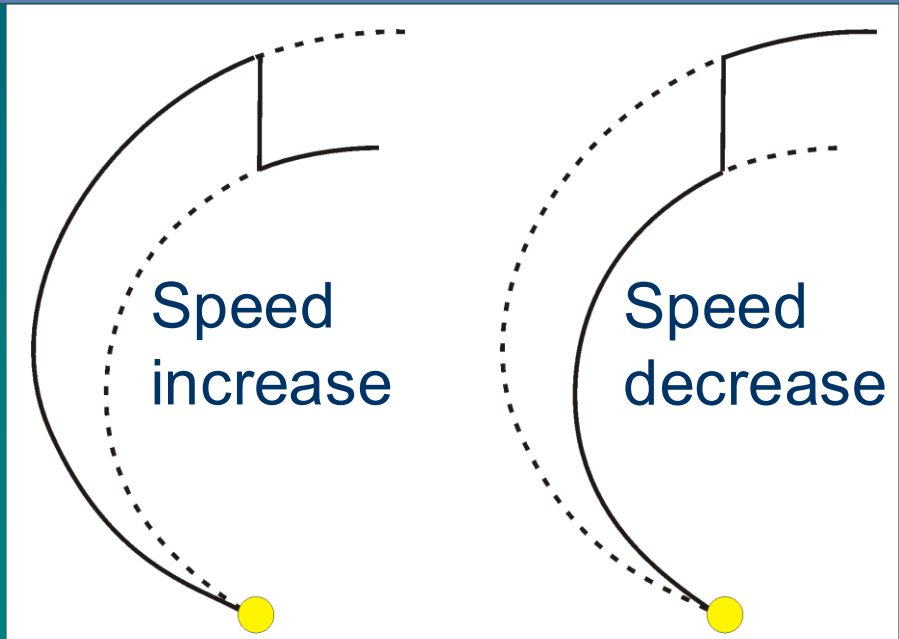
- 1980 ISEE 3 magnetic field data
- White points have heat flux in sunward Parker hemi-sphere
- From *Kahler, Crooker, and Gosling* [1998]



Fields turned back on themselves

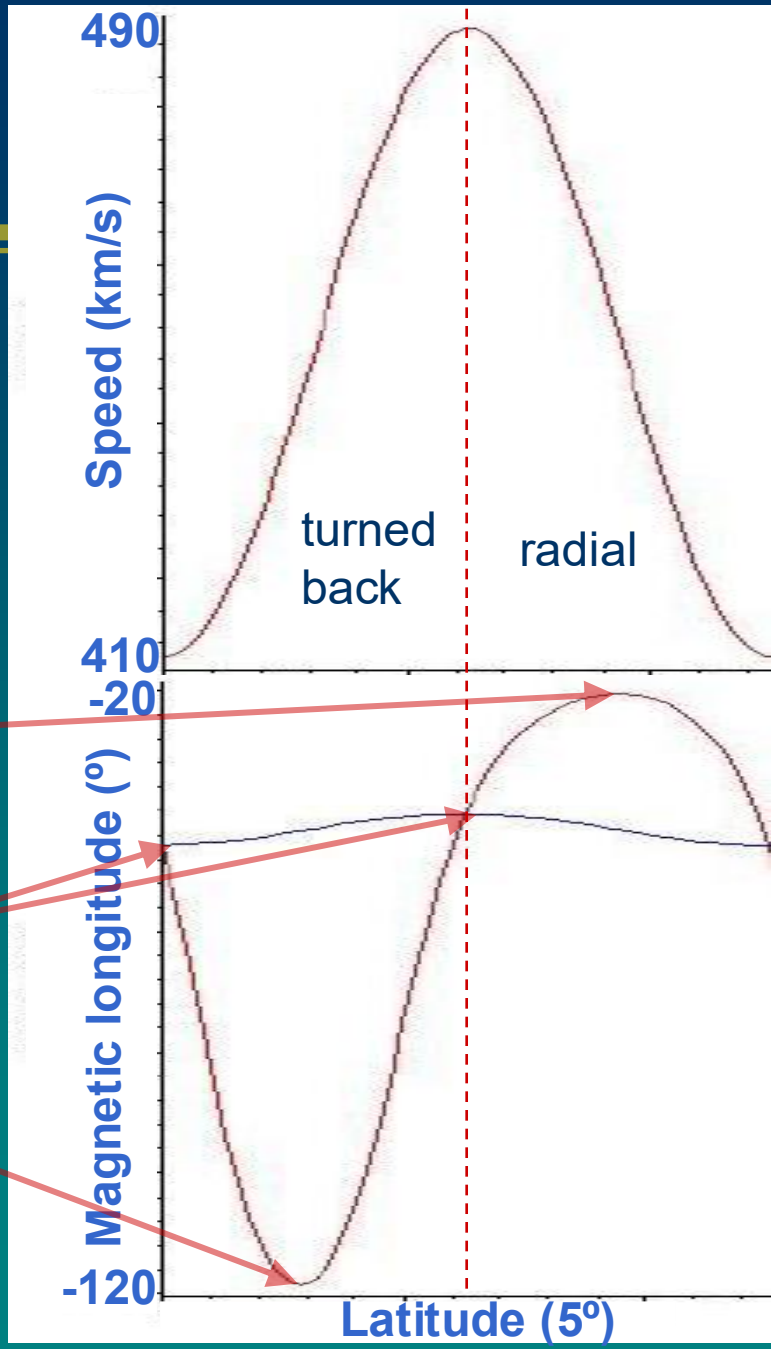
- Possible causes
  - Interchange reconnection in ICMEs
  - Sudden increase rather than decrease in speed along flux tube (latitudinal motion required)





Schwadron's results in terms of Fisk model

- Calculated change in longitude angle of field (bottom) in response to changing plasma speed along field line (top)
- When speed decreases, field veers toward radial.
- When speed gradient is zero, field lies at Parker spiral angle (blue curve).
- When speed increases, field begins to turn back on itself.



Concluding Remarks

- Regarding helicity
  - ?
- Regarding the Fisk model
  - Although controversial, it is providing the community with a new way of viewing a remarkably wide range of heliospheric phenomena
  - The issue of heat flux dropouts needs to be revisited both theoretically and observationally