1999 CEDAR Workshop
Boulder, Colorado
June 13-18, 1999

Solar-Terrestrial Coupling Processes
Tutorial Lecture I

by Nancy Crooker
Boston University

Solar and Heliospheric Aspects of Solar-Terrestrial Coupling

Tribute to Venki

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UCLA

Professor to all three tutorial speakers
First Joint CEDAR-GEM-SHINE Workshop
"Solar-Terrestrial Coupling Processes"

Solar and Heliospheric Aspects
Nancy Crooker

Solar Wind-Magnetosphere-Ionosphere Coupling
Larry Lyons

Ionosphere /Thermosphere Response
Art Richmond

Solar and Heliospheric Aspects of S-T Coupling

- Geoeffective Disturbances
  - Coronal Mass Ejections
    - » Solar signatures
    - » Interplanetary signatures
    - » Magnetic topology
  - High-Speed Streams
  - High Density
- Application to 1997 cases

Solar Signatures of CMEs

White light

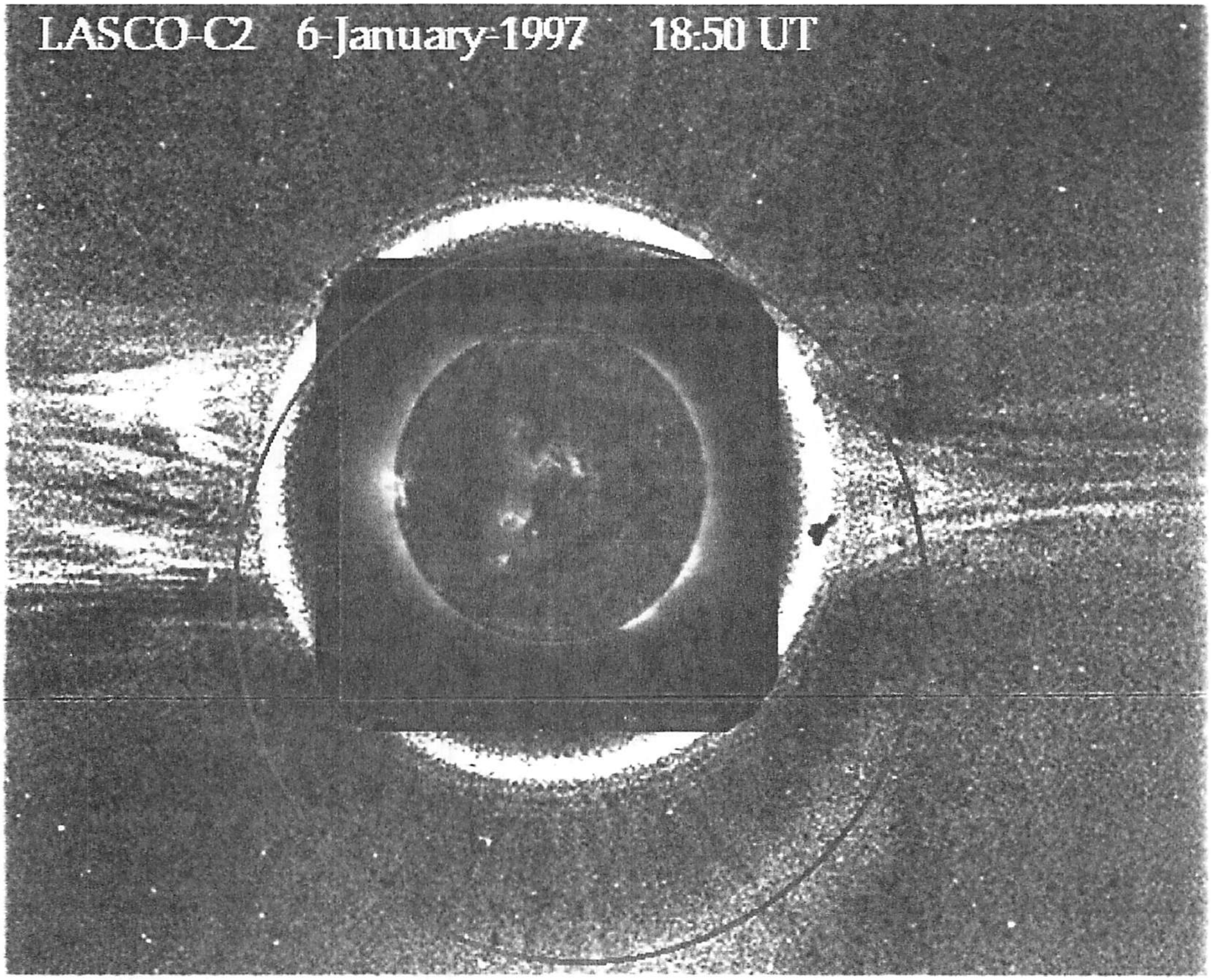
- Halo CMEs

Hα

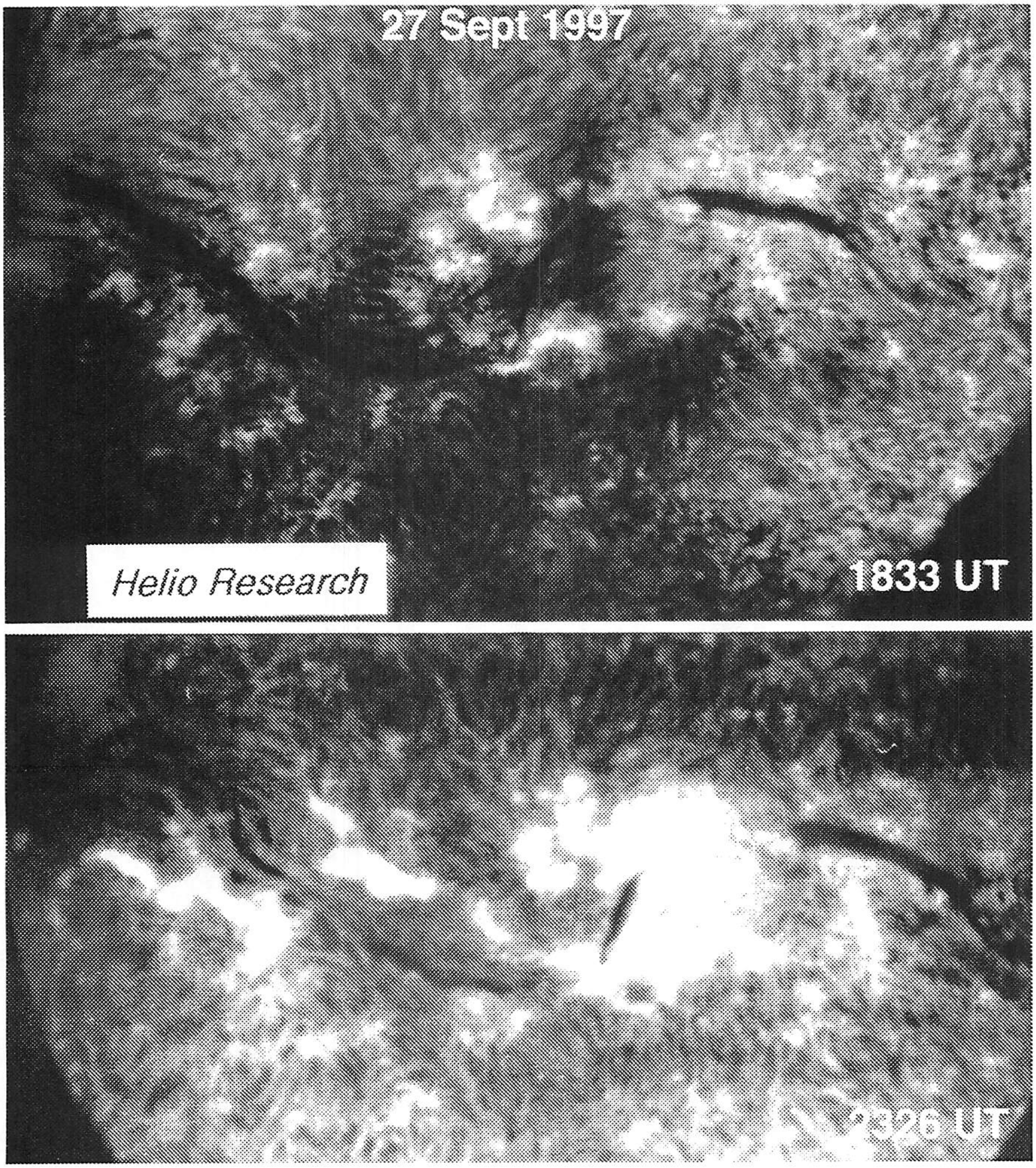
- Filament Eruptions

X-rays, EUV

- Arcade events
- Dimming
- Sigmoids
- EIT (Moreton) waves

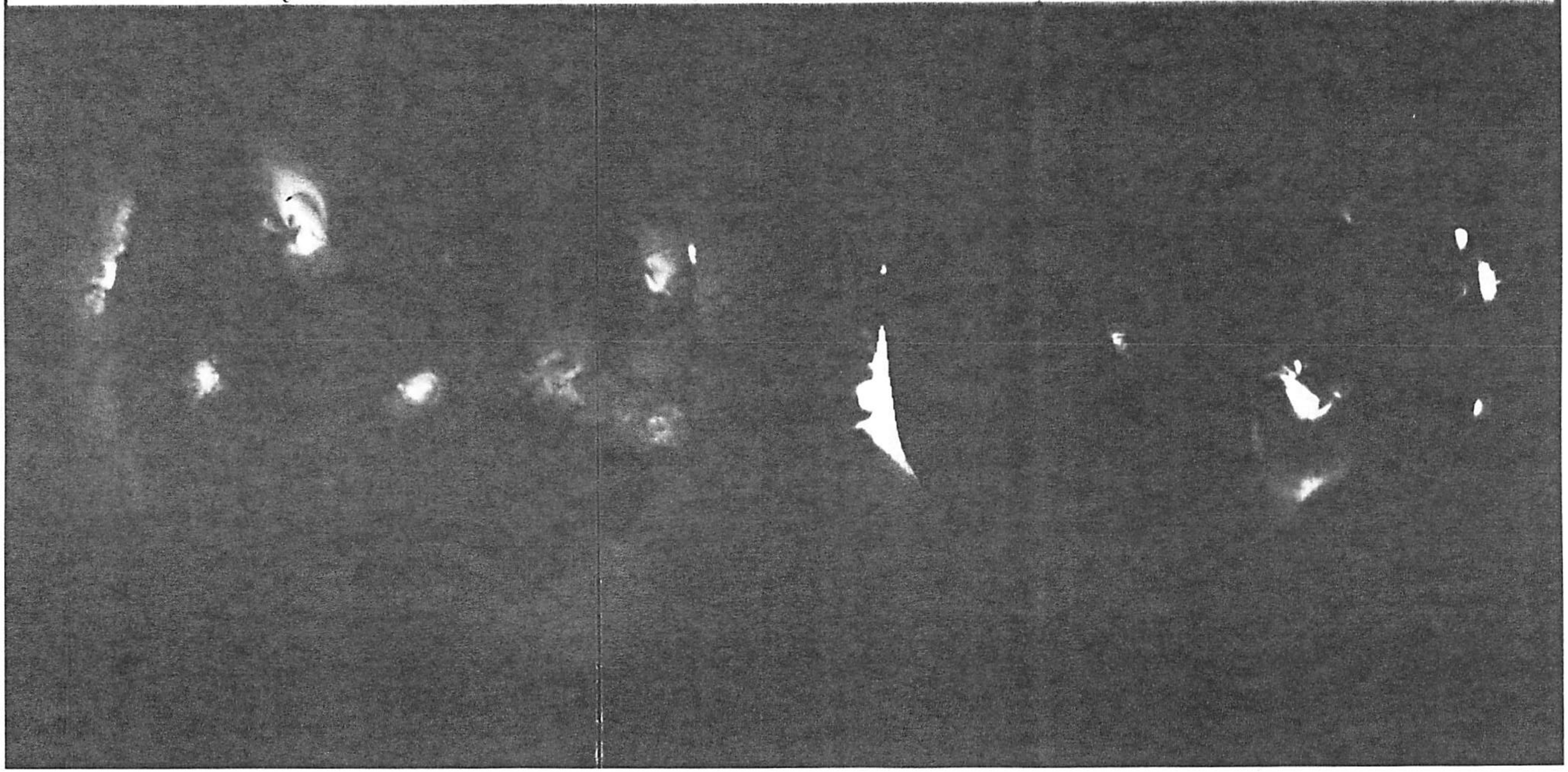

LASCO-C2 6-January-1997 18:50 UT

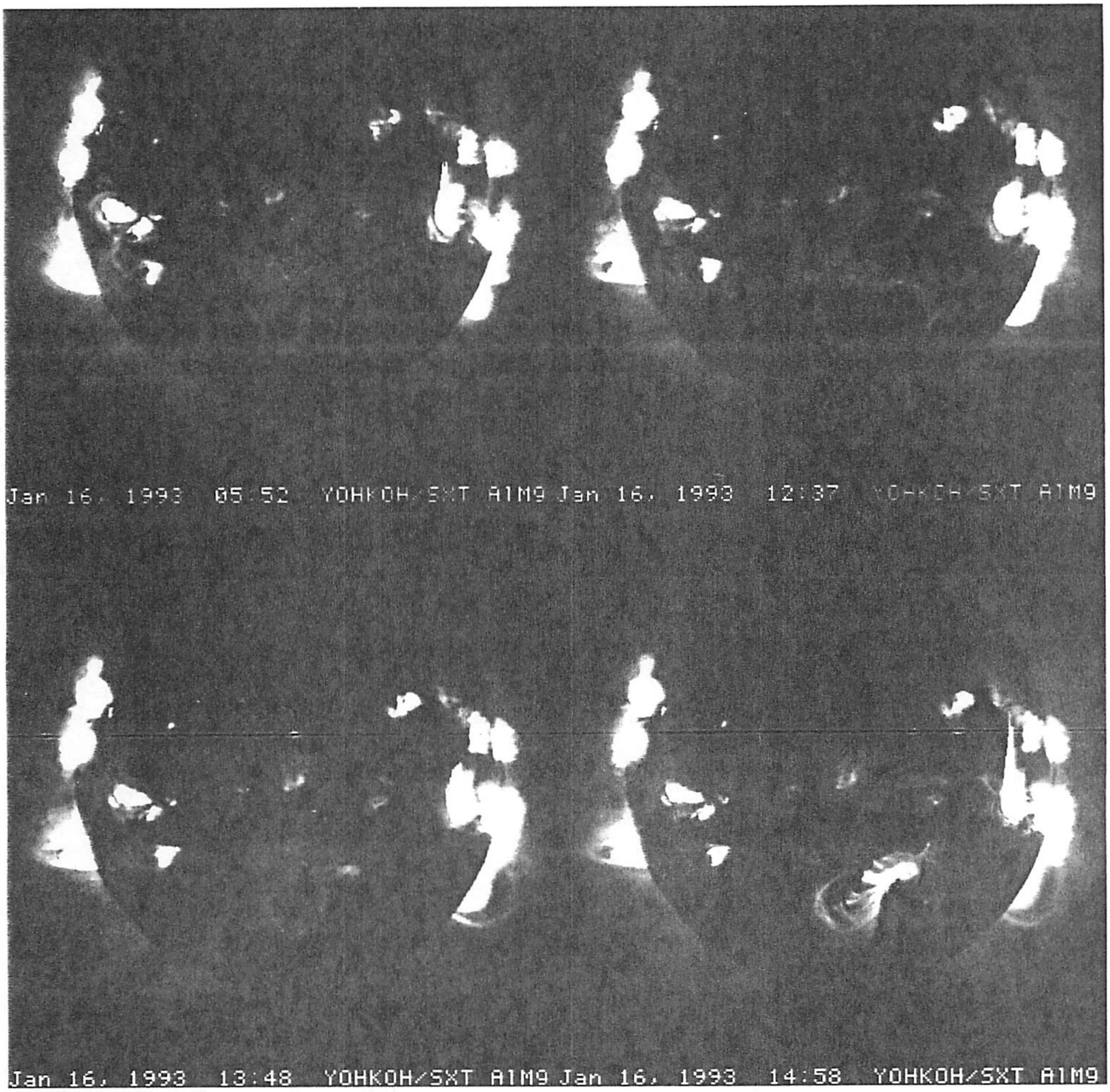

EIT: 1997/04/07 14:35 UT
C2: 1997/04/07 15:52 UT


27 Sept 1997
Helio Research
1833 UT
2326 UT

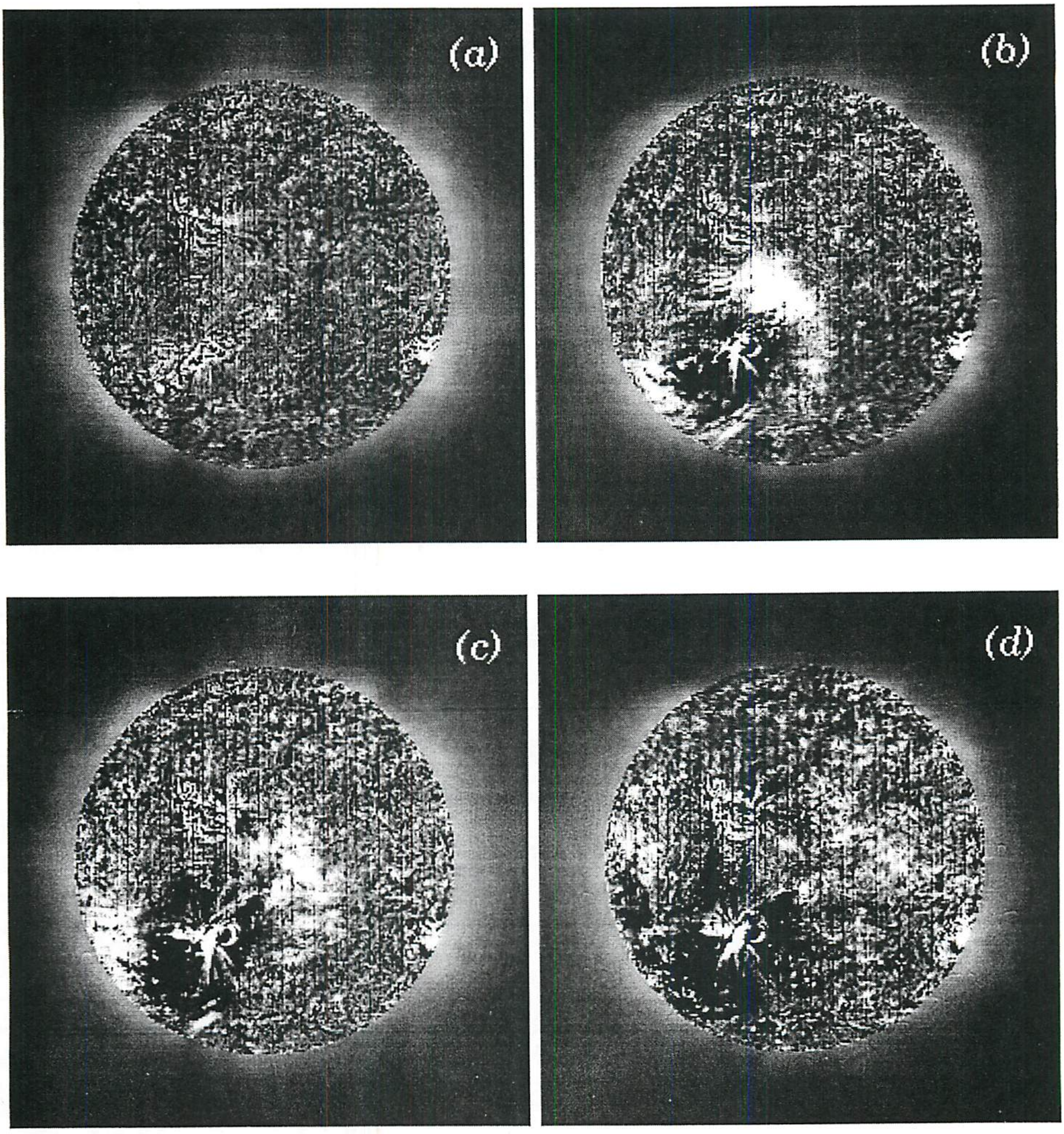
Arcade Examples: polar, diagonal, AR

February 25, 1992 (04:35) January 26, 1992 (19:28)



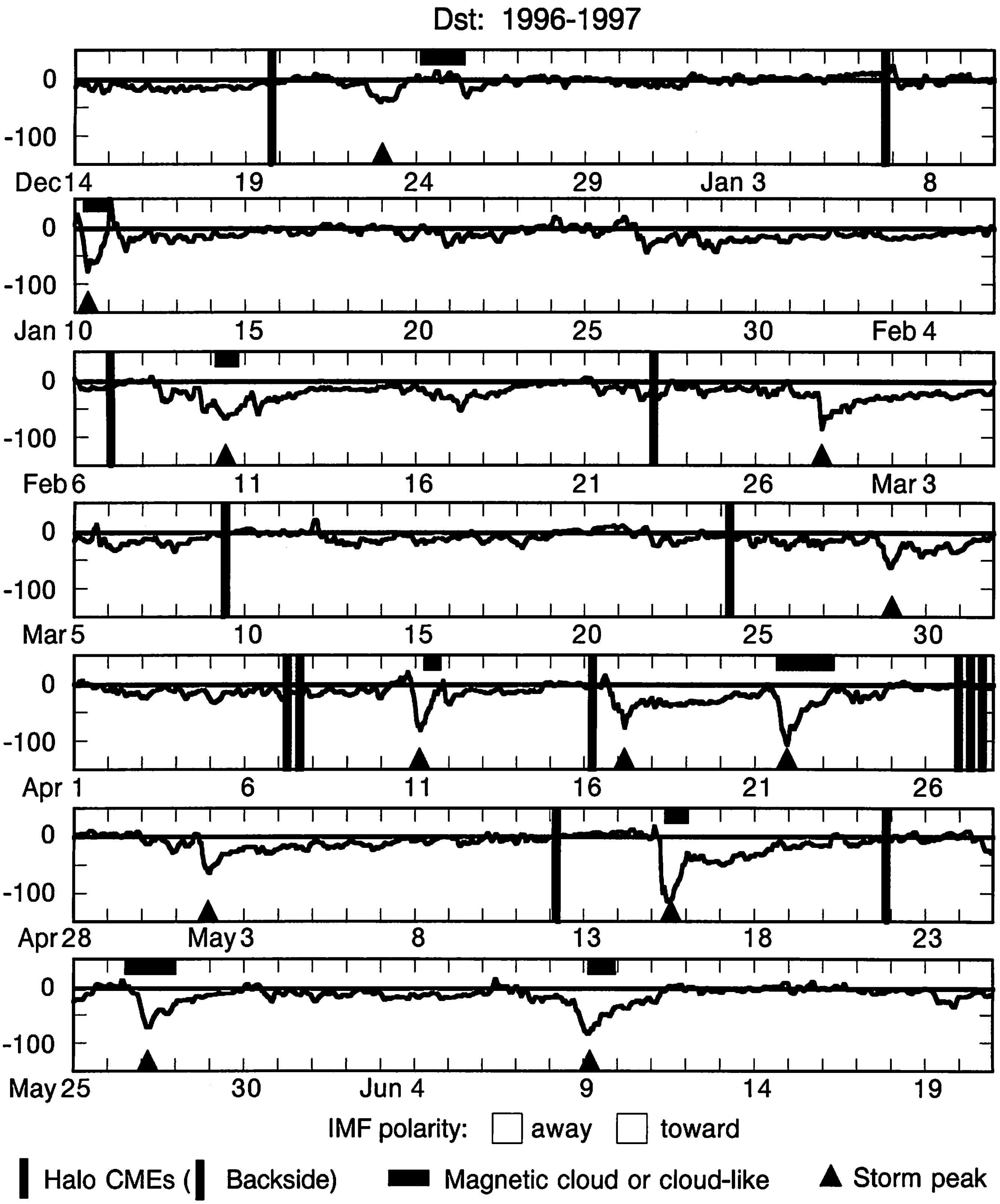

Jan 16, 1993 05:52 YOHKOH/SXT A1M9
Jan 16, 1993 12:37 YOHKOH/SXT A1M9
Jan 16, 1993 13:48 YOHKOH/SXT A1M9
Jan 16, 1993 14:58 YOHKOH/SXT A1M9

7 APRIL 1997 = EIT WAVE



THOMPSON et al., 1997

Dst and Halo CMEs

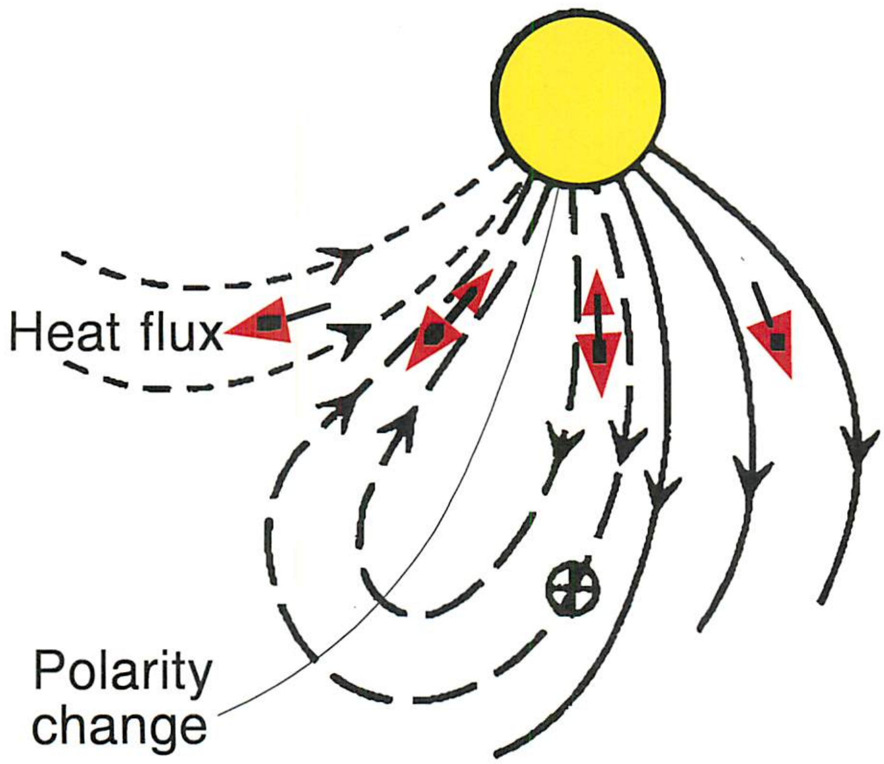


Interplanetary Signatures of CMEs

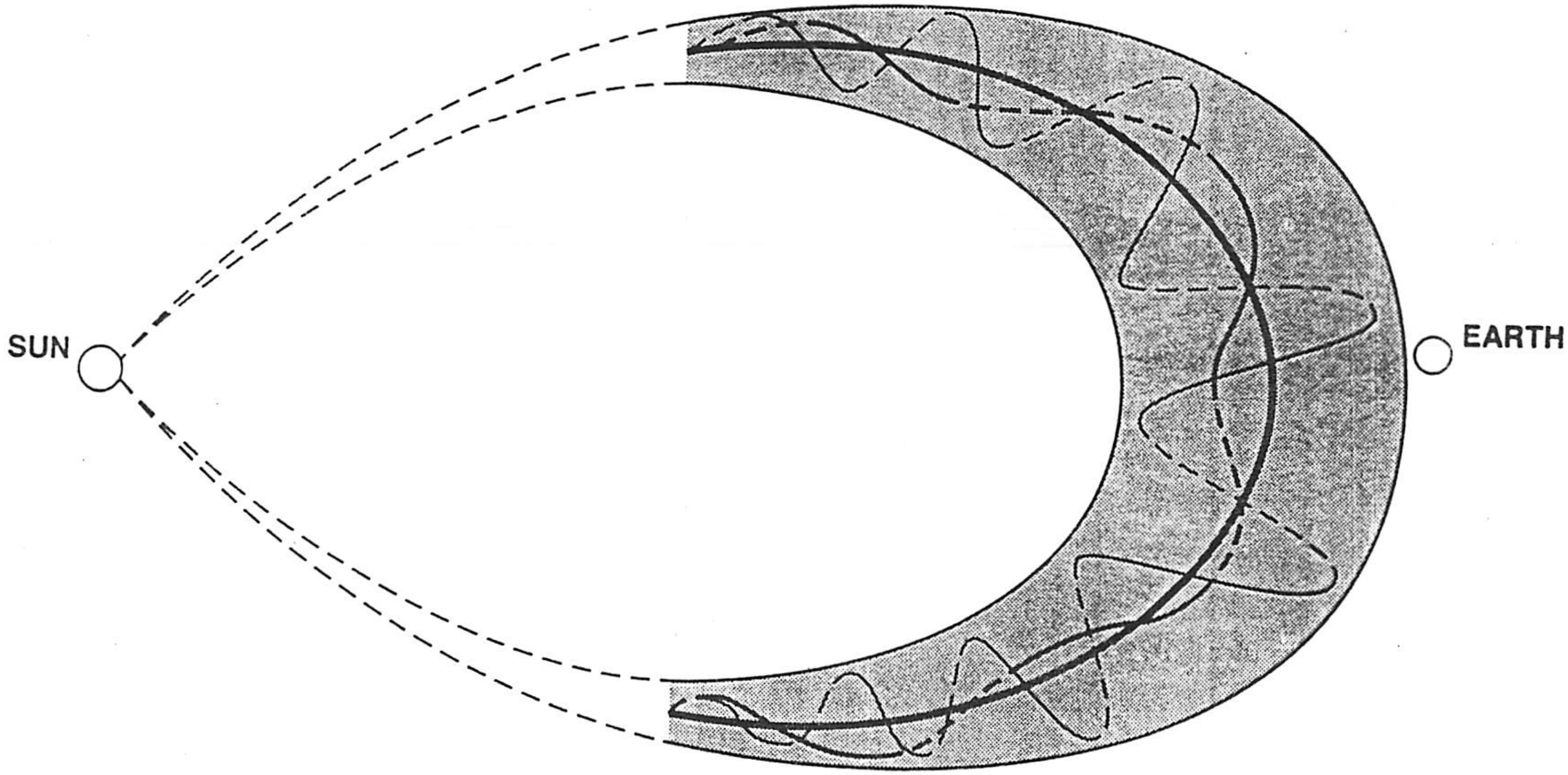
- Widely used
  - Counterstreaming electrons
  - Large-scale magnetic field rotation
  - Low temperature
  - Strong, steady magnetic field
  - Preceding shock (fast CMEs)
- Other
  - Cosmic ray depressions
  - Pronounced temperature anisotropy
  - Composition anomalies
  - Charge state anomalies

Magnetic cloud

Counterstreaming Electrons



- Suprathermal electrons carry heat flux away from Sun
- Counterstreaming indicates closed magnetic topology
- Direction of dominant heat flux indicates magnetic polarity

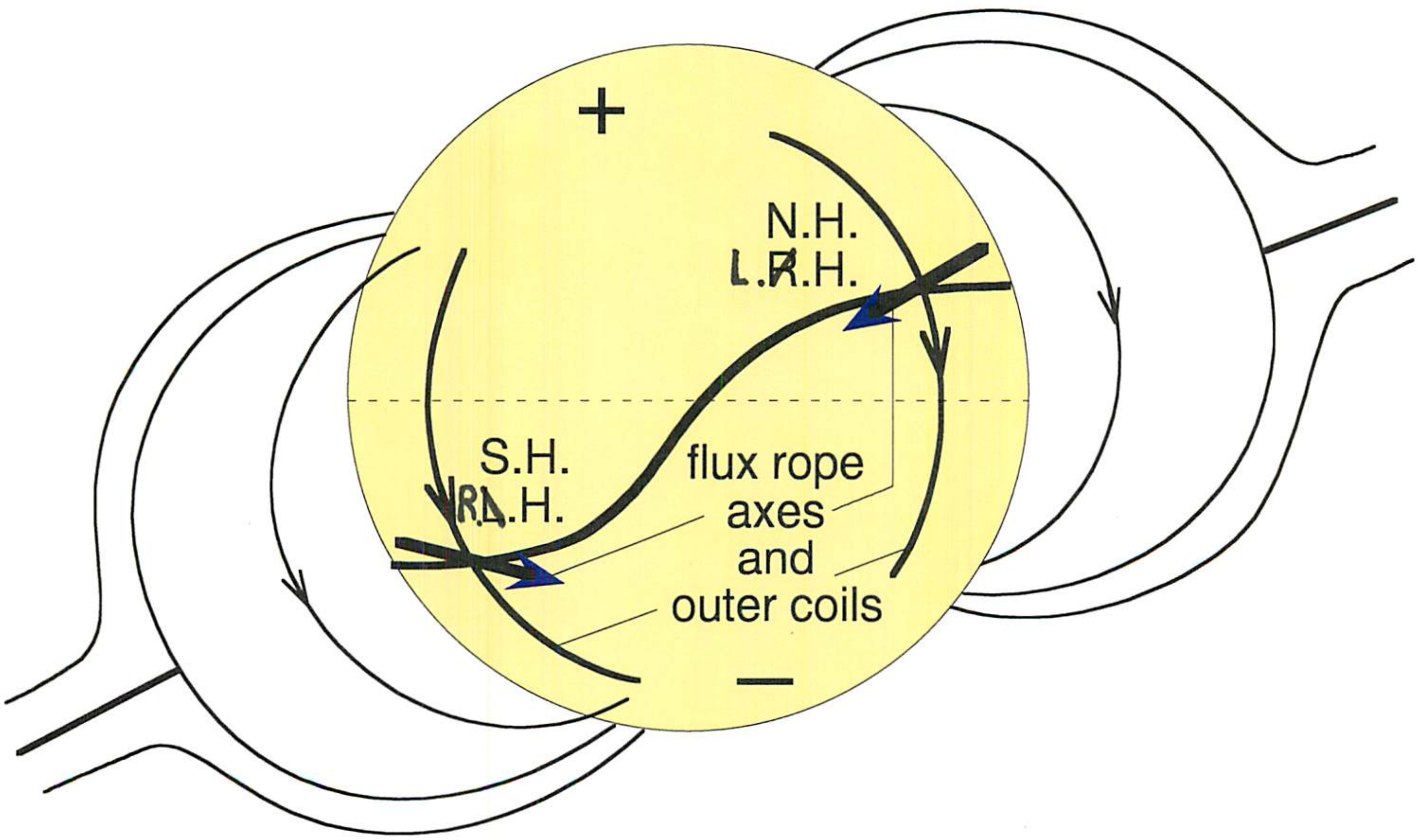


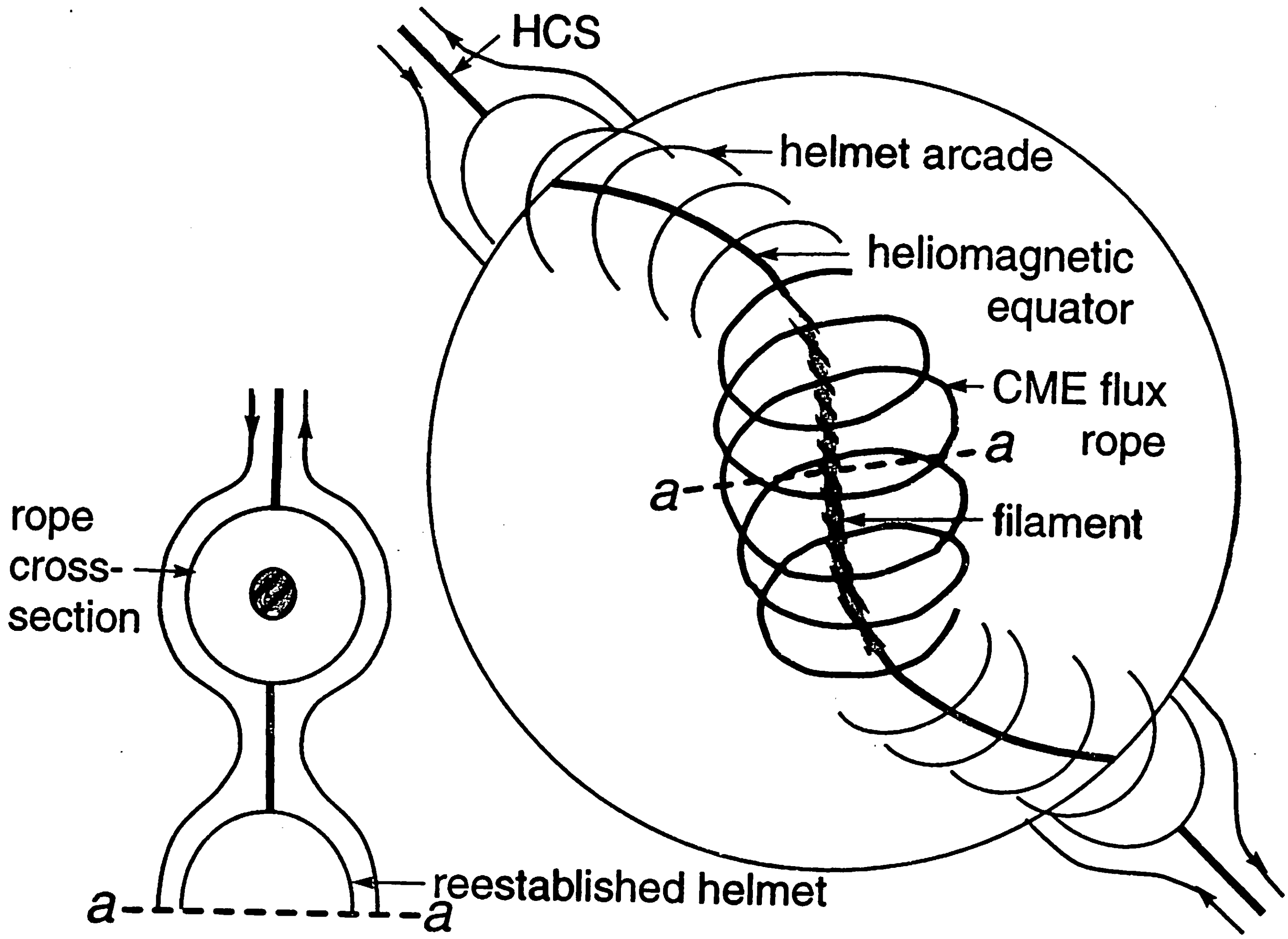
Ecliptic Plane

Lepping et al. [1993]

Solar Field Imprint on CMEs

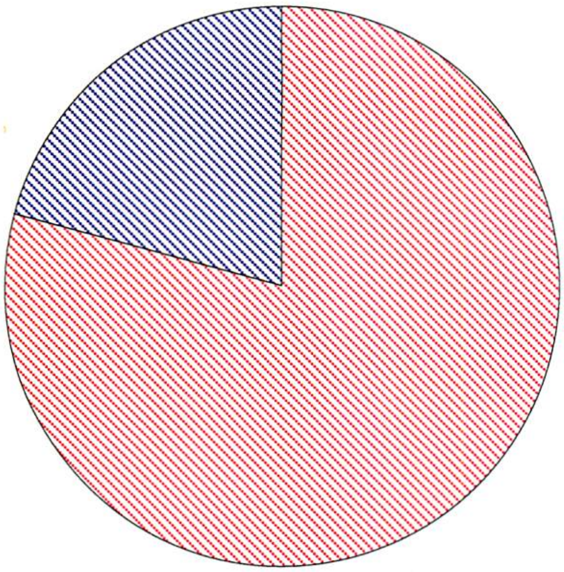
- CMEs arise from helmet streamer belt
- Solar dipole controls leading field
- Neutral line/filament controls axis orientation
- Solar hemisphere controls chirality
- CMEs blend into sector structure




HCS
helmet arcade
heliomagnetic
equator
CME flux
rope
filament
a
a
rope
cross-
section
reestablished helmet
a
a

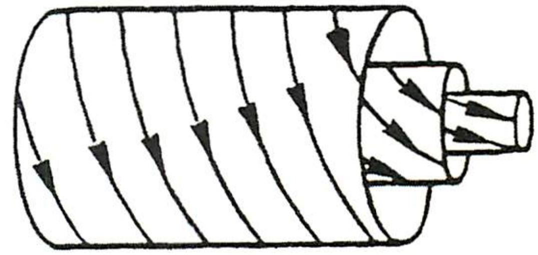
Cloud type depends on solar cycle

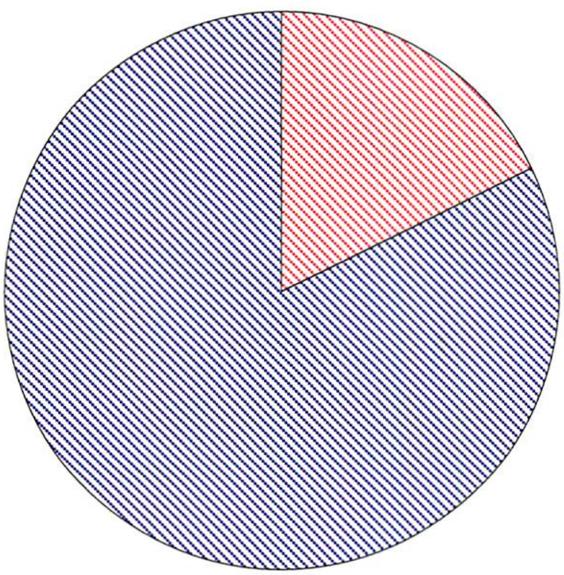
Cloud type: South-North / North-South



1974-1981

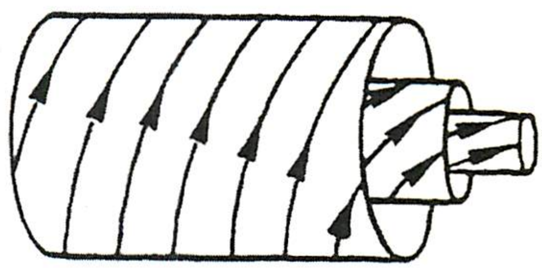
cycle 20_{max} -21_{max}





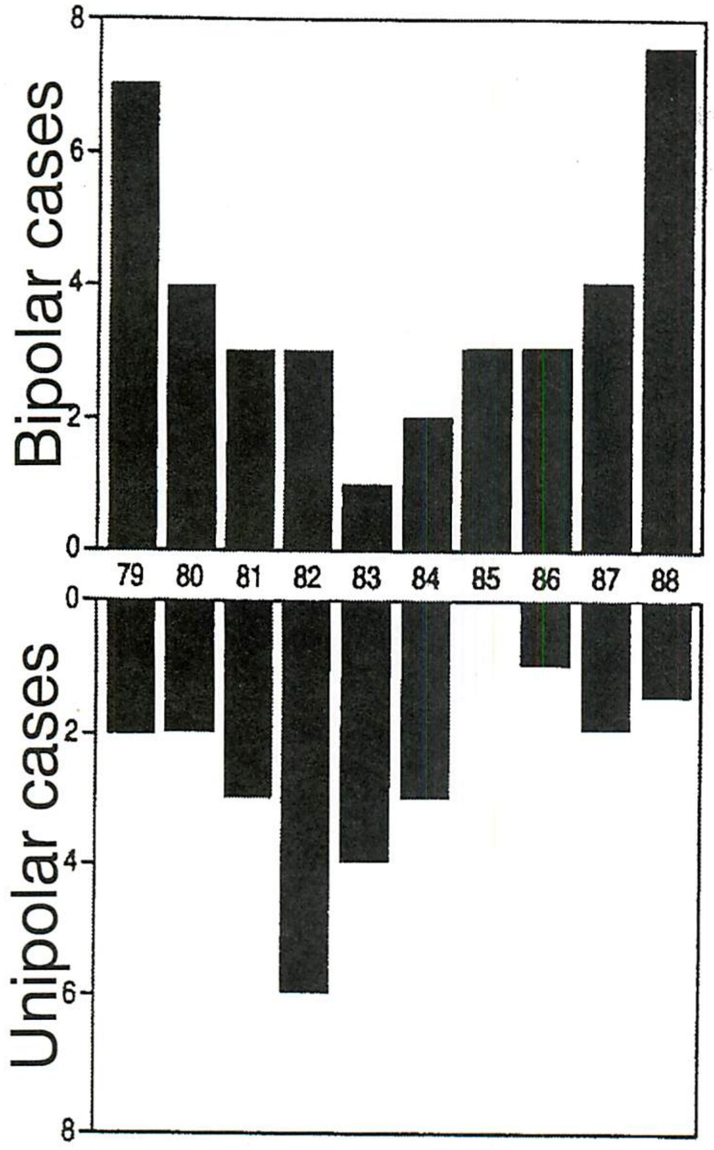
1982-1991

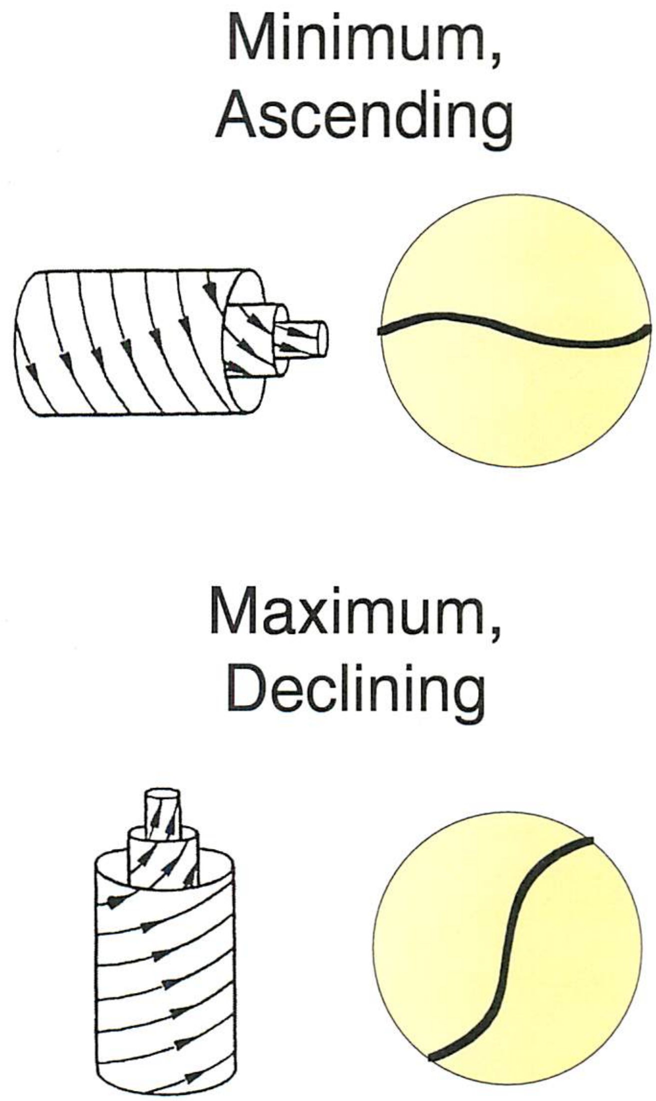
cycle 21_{max} -22_{max}



Bothmer and Rust [1997]

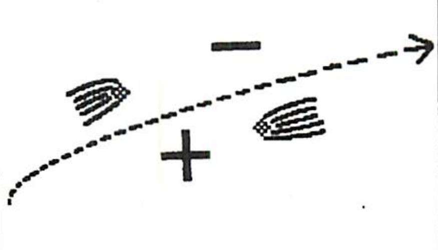
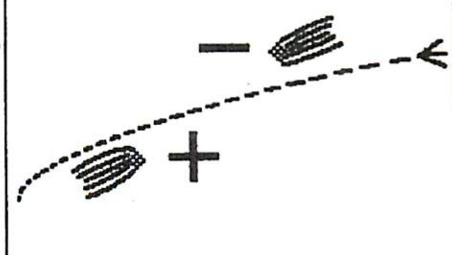
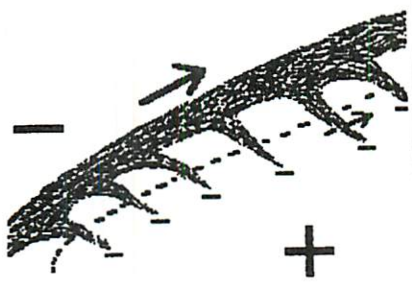
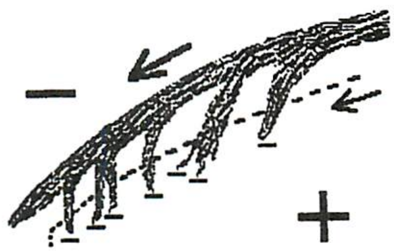
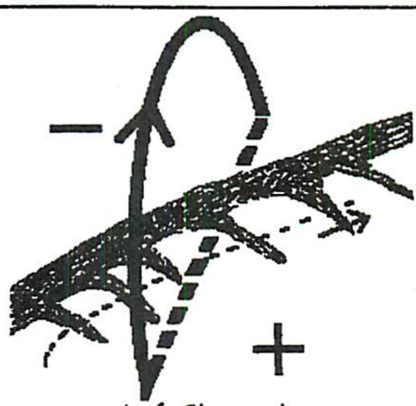
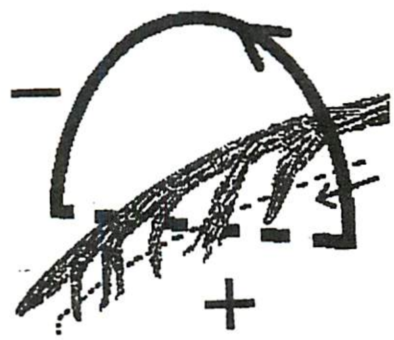
Axis orientation depends on solar cycle





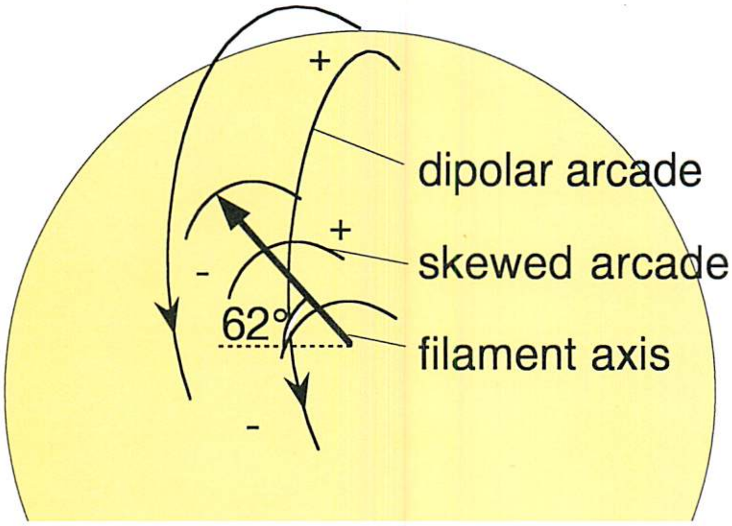
Mulligan et al. [1998]

Filament Topology

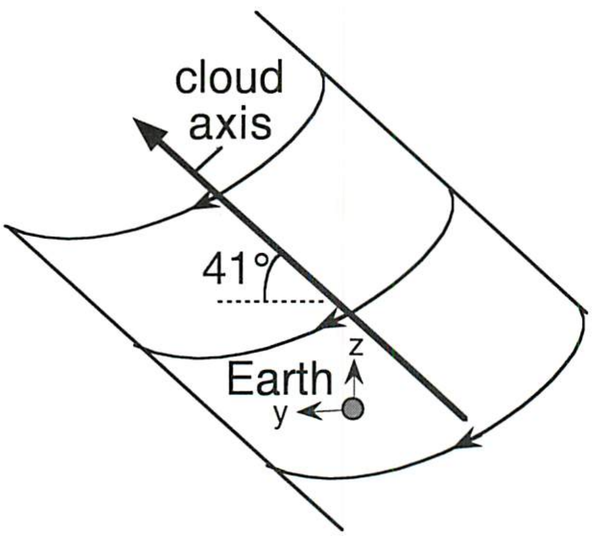
Feature	Chirality	
Filament Channels Small Scale	 Dextral	 Sinistral
Filaments Medium Scale	 Right Bearing	 Left Bearing
Coronal X-Ray Arcades Large Scale	 Left-Skewed	 Right-Skewed
	Dominant in Northern Hemisphere	Dominant in Southern Hemisphere

Martin and McAllister [1998]

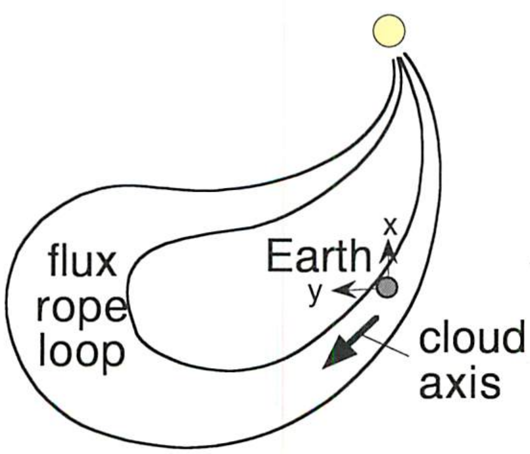
Real-time Prediction



- 27 Sep 97 filament eruption



- 1 Oct 97 cloud at Earth



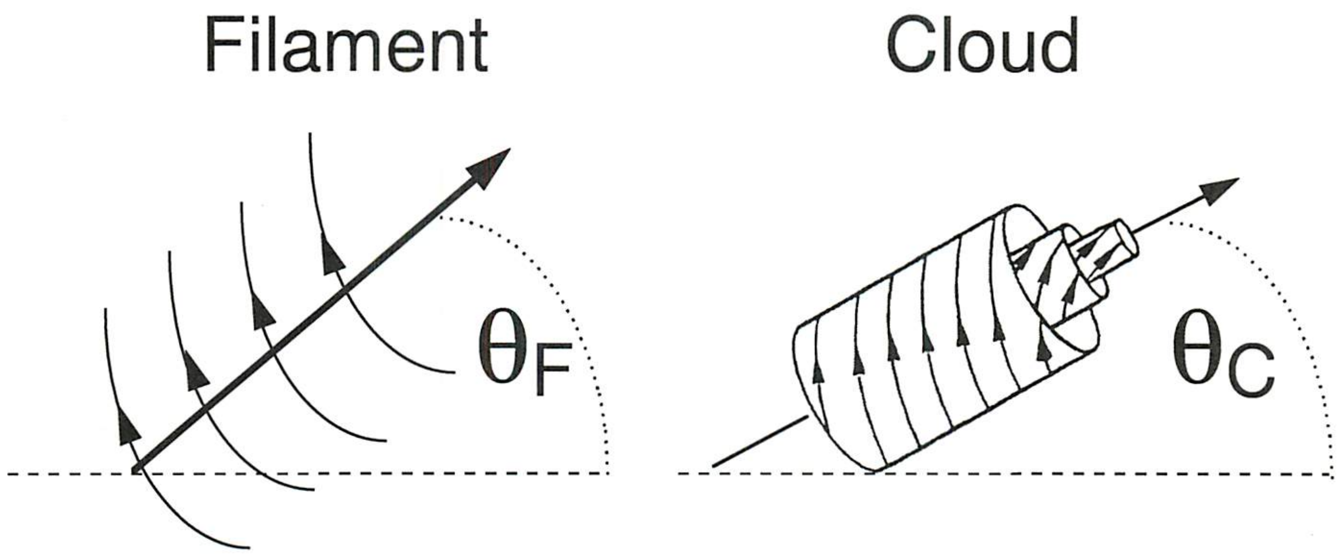
- top view

McAllister et al. [1999]

Mixed Results

- Predicted
  - Cloud occurrence
  - Cloud helicity
  - Cloud axis orientation
  - Storm occurrence
- Not predicted
  - No B-south encountered in cloud
  - B-south in sheath

Statistical Results

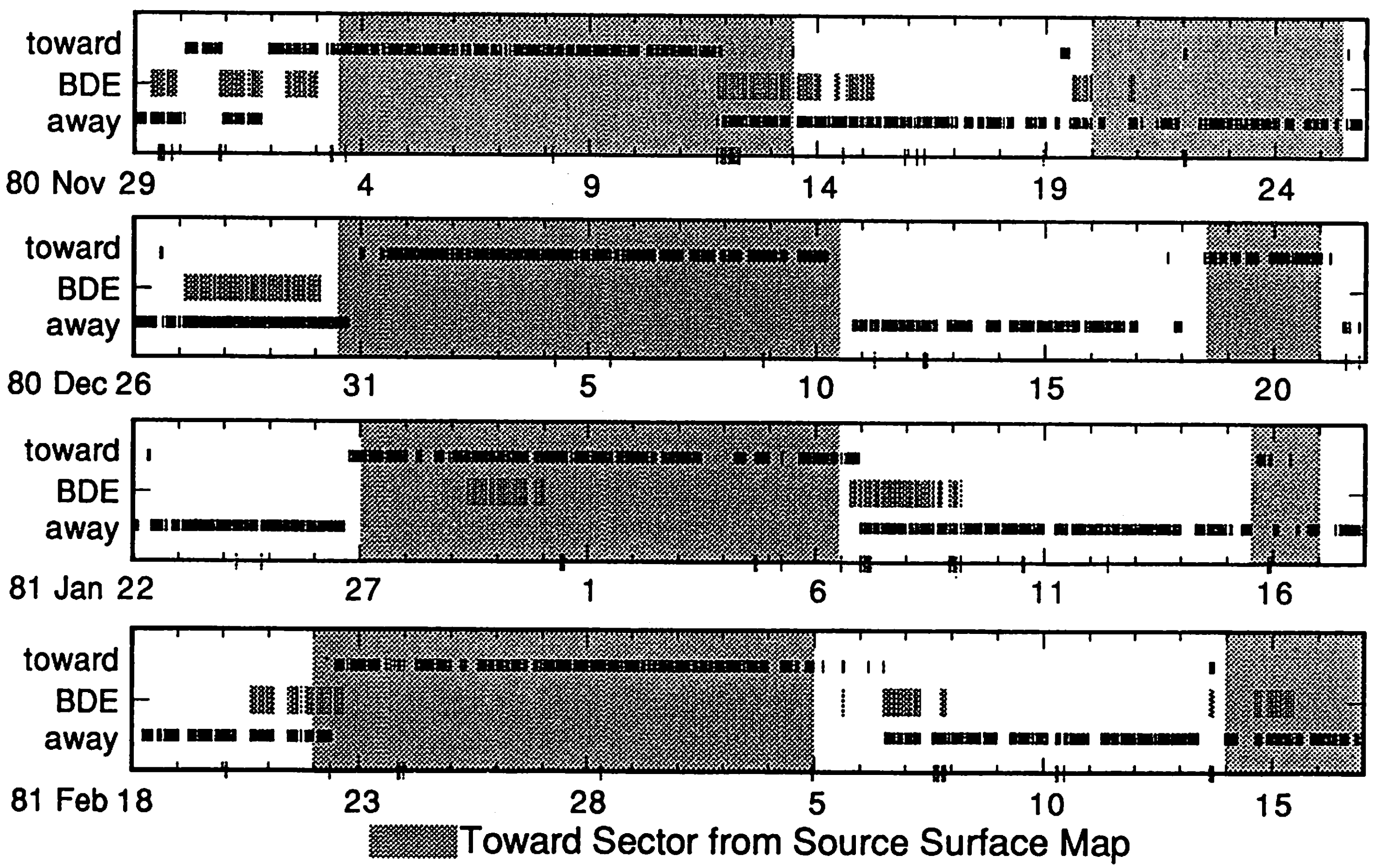


- $\theta_C = -1.4 + 0.7\,\theta_F \quad \pm 18^\circ$
- max B-south $\propto$ θ_C $\pm 5^\circ$
- Δt B-south $\propto$ θ_C $\pm 5^\circ$

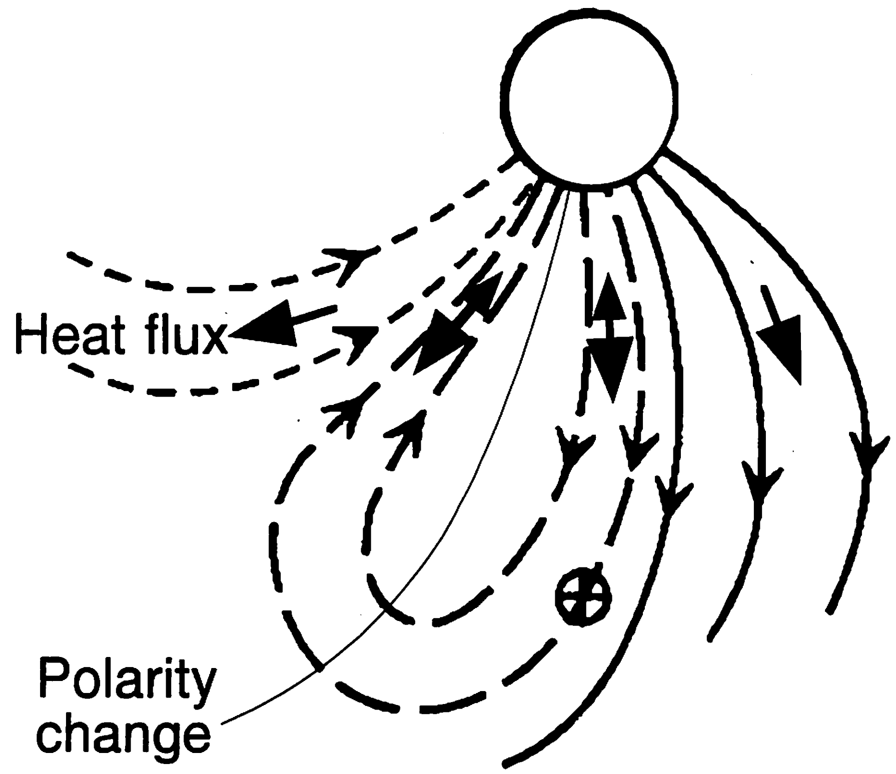
Zhao and Hoeksema [1997, 1998]

Sector Polarity from Heat Flux Data

BDEs mark CMEs. Most CMEs carry polarity of sector in which they are embedded and thus do not disrupt sector structure.

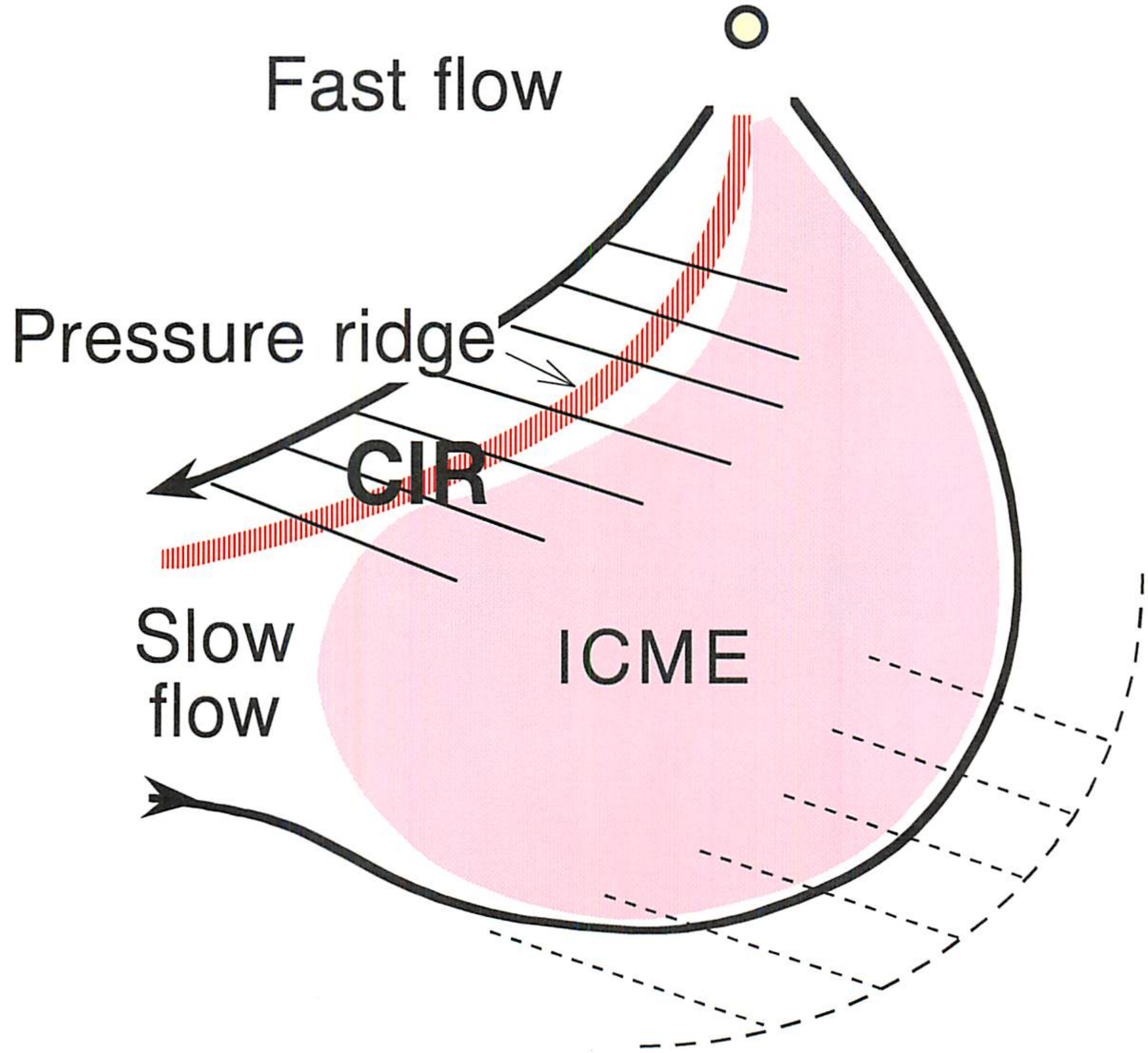


Counterstreaming Electrons



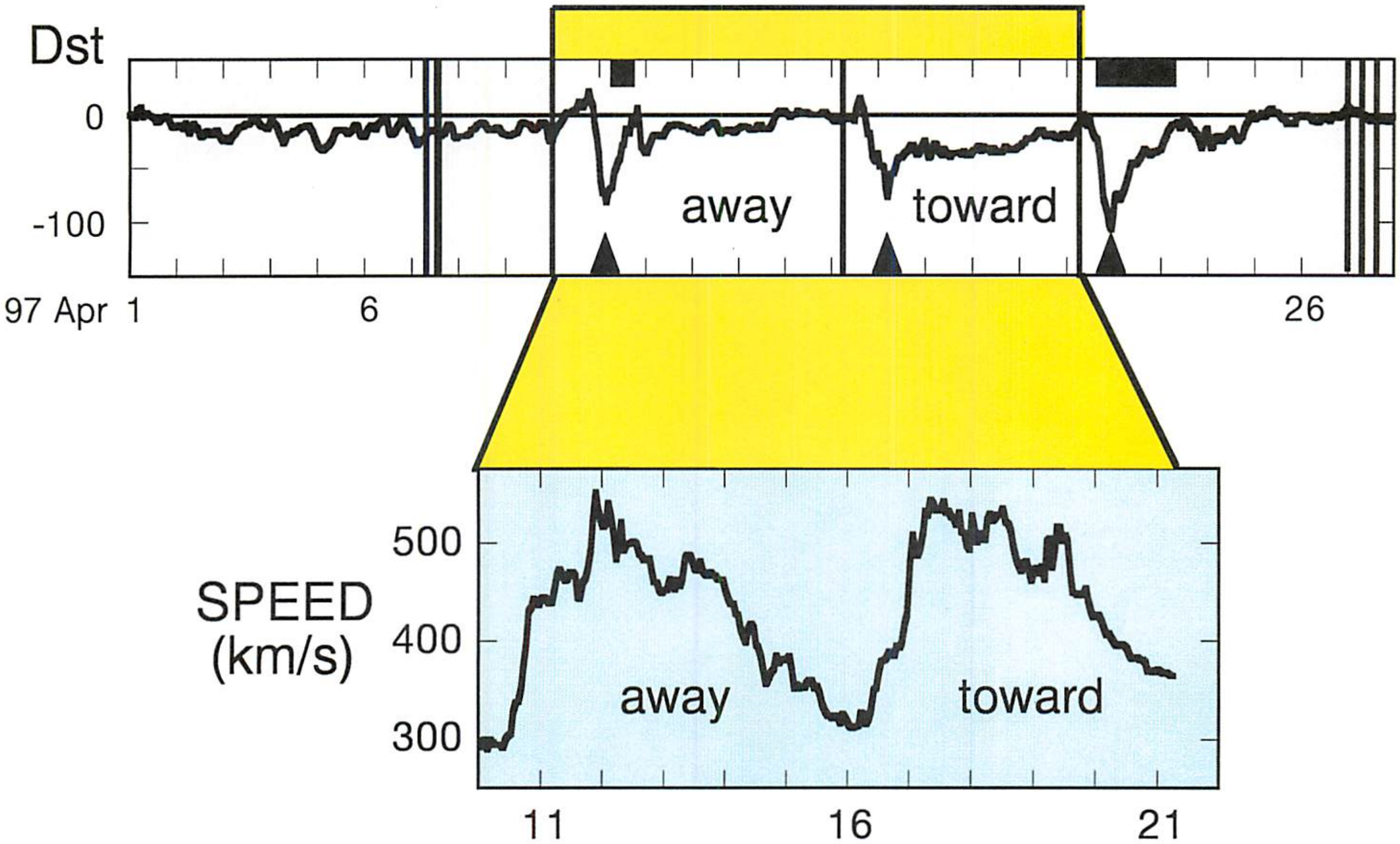
- Suprathermal electrons carry heat flux away from Sun
- Counterstreaming indicates closed magnetic topology
- Direction of dominant heat flux indicates magnetic polarity

High-speed streams compress



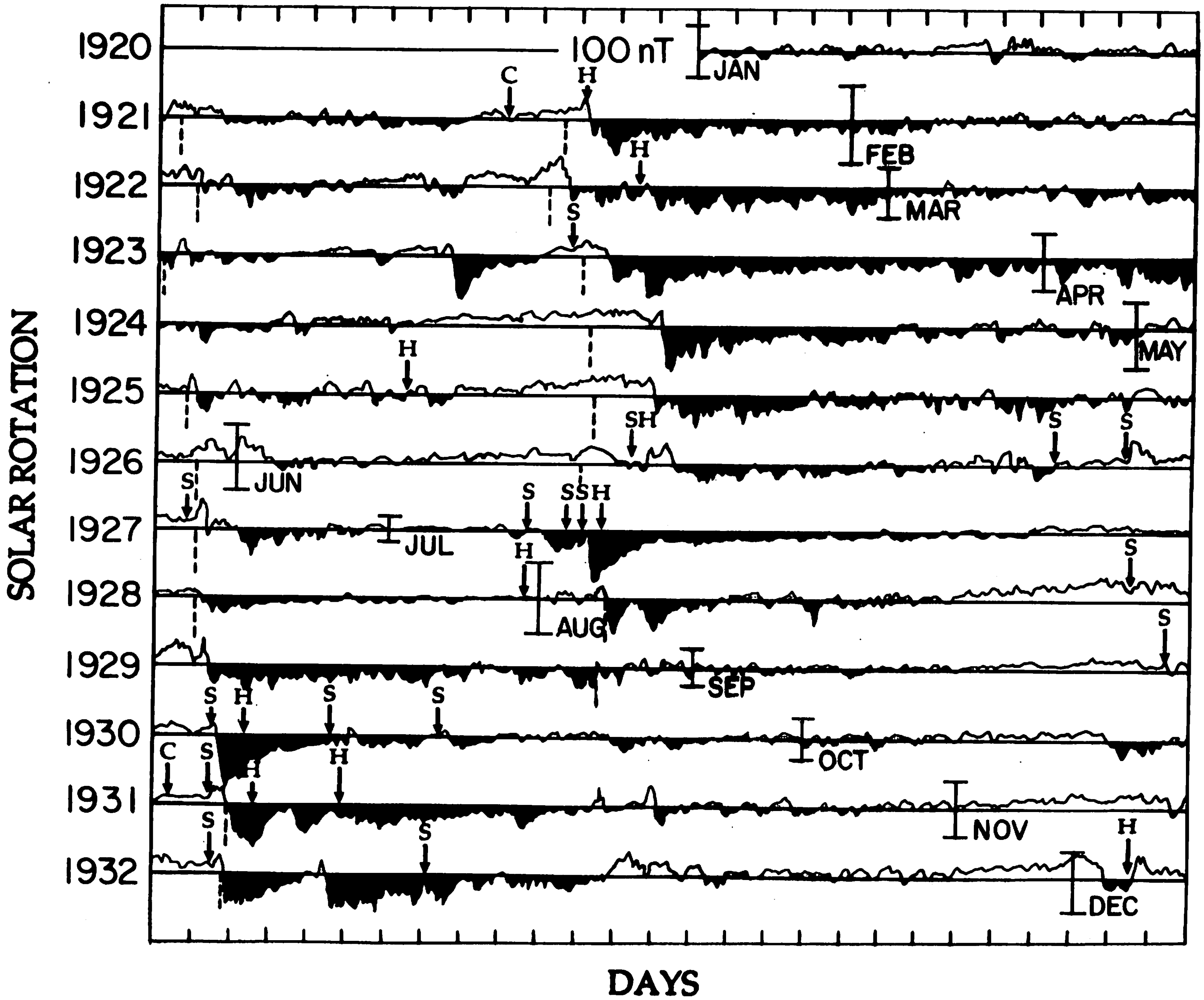
- Fast flow runs into slow flow and creates corotating interaction region (CIR)
- Strengthens any B-south
- Increases density
- Compresses trailing edge of passing CME

Magnetic Polarity Effect in High-Speed Streams



- Toward fields in spring (NH) favorable for Russell-McPherron effect
- Enhance B-south in Alfvenic fluctuations found in high-speed flow
- Causes sustained activity in stream with toward polarity

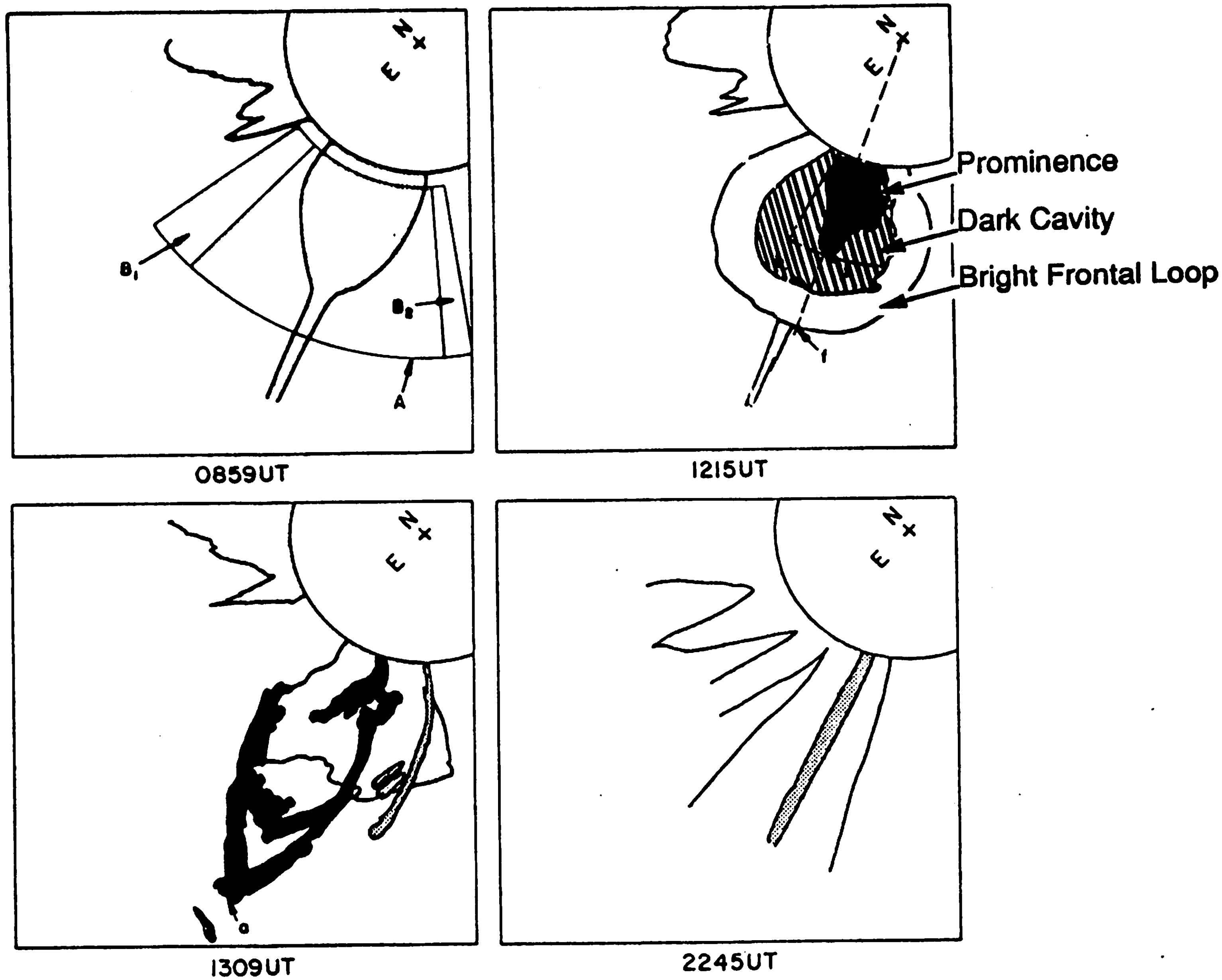
Dst, 1974



SOLAR ROTATION
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
100 nT
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
C
H
S
SH
SSH
DAYS

High Density

- Density in CMEs is usually low at 1 AU, owing to expansion.
- Density leading and trailing CMEs is usually high, owing to both solar source and interplanetary compression.
- Dst responds to density rise in 3 ways:
  - ♦ Through dynamic pressure rise
    - » (1) Strengthens magnetopause currents, which increase Dst.
    - » (2) Correlates with Dst decrease [*Murayama*, 1980; *Fenrich and Luhmann*, 1998].
  - New! ♦ Directly, with delayed response
    - » (3) Increases ring current density when B is southward, with 4-5 hour delay [*Smith, Thomsen*, *Borovsky , and Collier, Spring AGU Meeting*].
- High density most geoeffective when B-south is in sheath or CIR.


N
E
B_1
B_2
A
0859UT
Prominence
Dark Cavity
Bright Frontal Loop
f
1215UT
a
1309UT
2245UT

Selected Case Studies

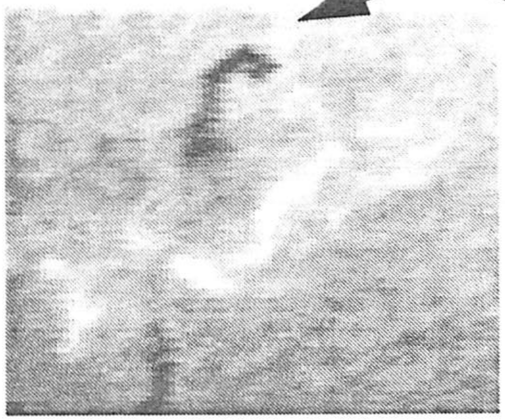
- **January 6-11, 1997**
  Unremarkable solar signatures
  - Halo CME
  - Obscure filament eruption
    - » predicted B-south duration, 14 hrs, observed, 13 hrs
    - » predicted B-south max, -13 nT; observed, -15 nT
  - Minor arcade event

  Clear interplanetary signatures
  - Leading B-south in magnetic cloud, as predicted
  - B-north in high-density filament/CIR
  - No sustained activity from following stream
- **April 7-12, 1997**
  Excellent solar signatures
  - Halo CME
  - Filament eruption
  - EIT wave
  - Sigmoid, dimming, arcade

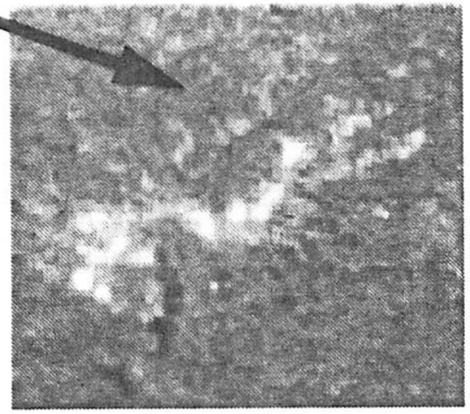
  Complex interplanetary signatures
  - Multiple ejecta
  - Cloud-like feature, no field rotation within
  - B-south in high-density plasma
  - No sustained activity from following stream

Probable Cause of 10 Jan 97 Geomagnetic Storm

Loop Vanished on 06 Jan



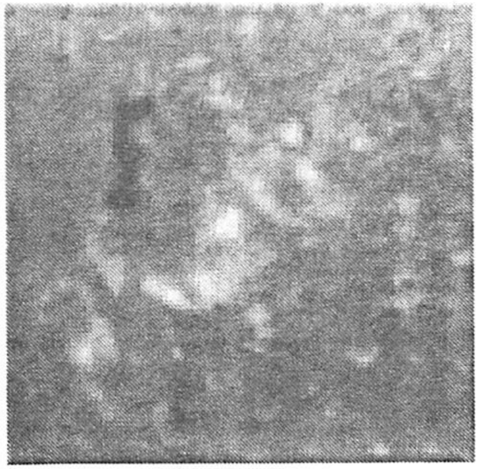
05 Jan



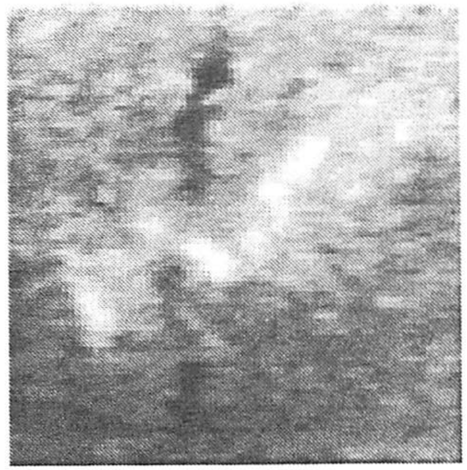
06 Jan

07 Jan

02 Jan



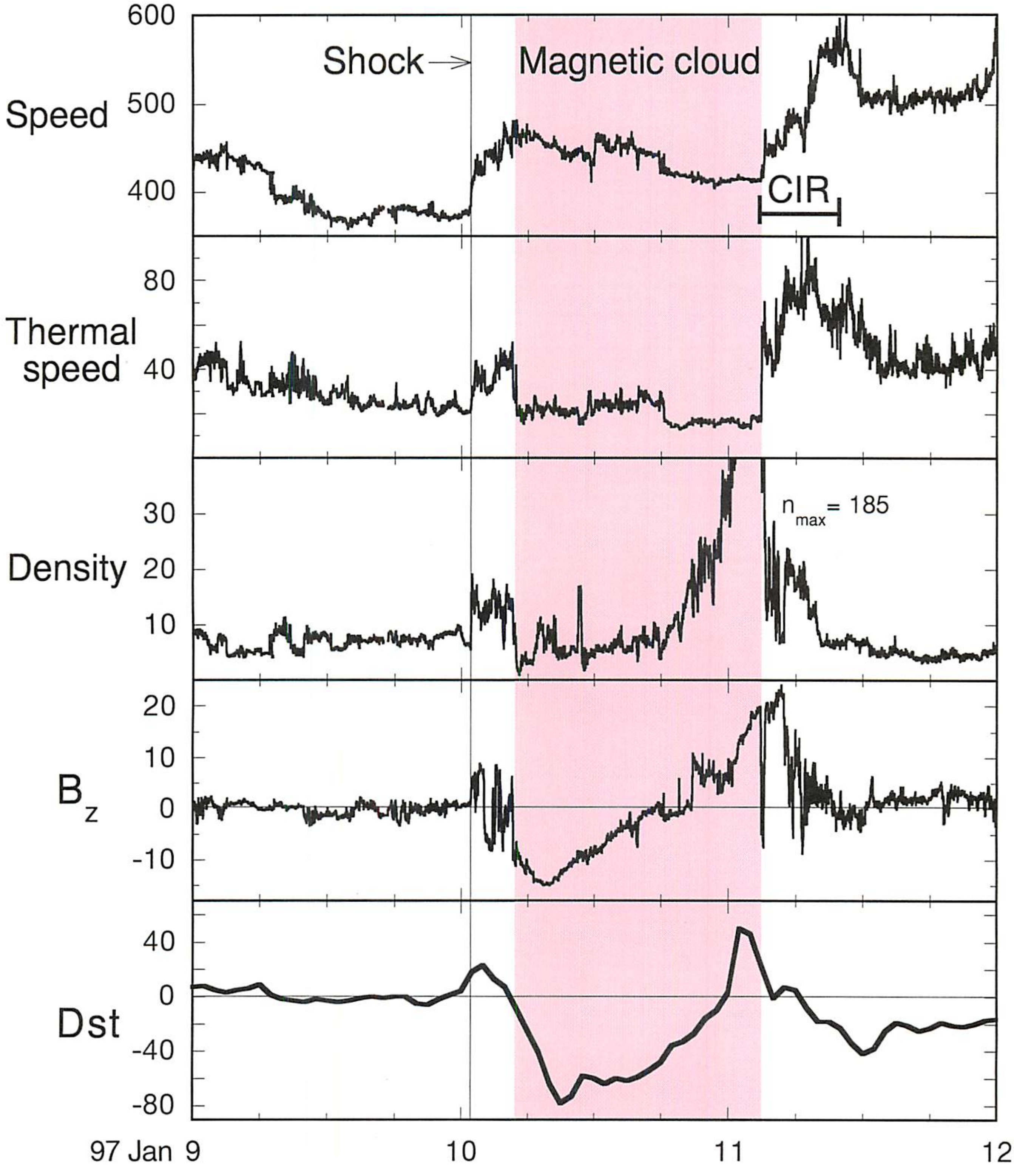
03 Jan



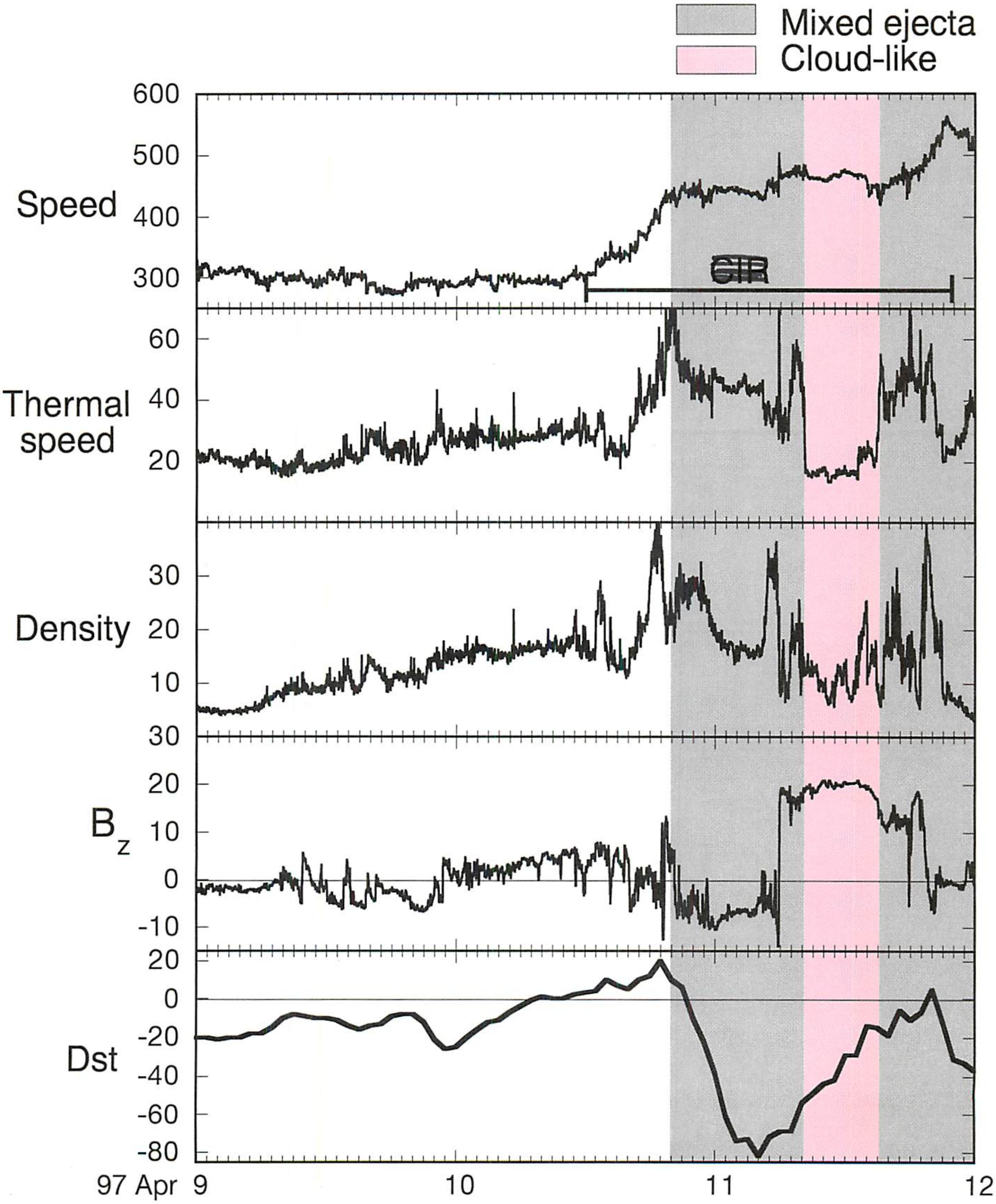
04 Jan

H-α Images From Sac Peak, SOON, & Pic du Midi

January 9-11, 1997



April 9-11, 1997



What does *NOT* make structures geoeffective?

- CMEs are *NOT* geoeffective because they are massive.
- High-speed streams are *NOT* geoeffective if their magnetic polarity is unfavorable for the Russell-McPherron effect.
- High density is *NOT* geoeffective if the IMF points northward.

What makes structures geoeffective?

KEY WORDS: southward IMF, compression

- CMEs are geoeffective because
  - They usually contain southward IMF.
  - If fast, they compress southward IMF and density structures.
  - They create southward IMF by distorting the ambient field.
  - They bring high-density structures.
- High-speed streams are geoeffective because
  - They compress southward IMF and density structures in CIRs/CMEs.
  - The Russell-McPherron effect enhances southward IMF in the Alfvenic fluctuations in streams if the polarity is favorable.
  - The solar wind electric field is proportional to speed.
- High density during southward IMF is geoeffective because
  - It increases ring current density.