Magnetic Fields at Hale Solar Sector Boundaries

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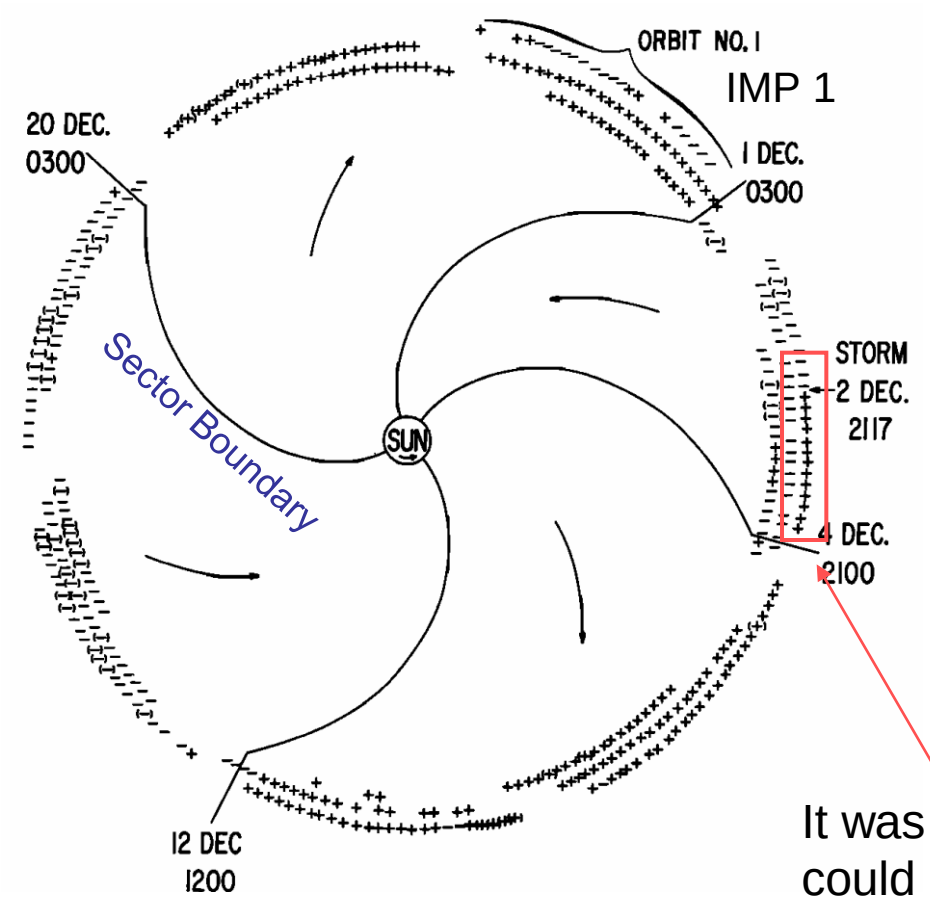
HEPL Stanford University

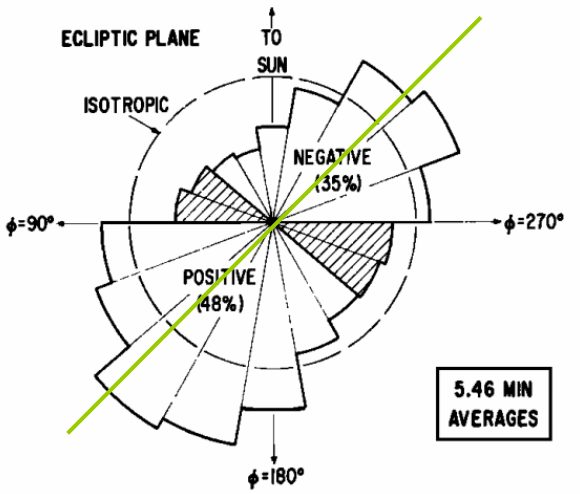
Huntsville Workshop, 25 March 2014

Discovery of Sector Structure

Quasi-Stationary Corotating Structure in the Interplanetary Medium
John M. Wilcox & Norman F. Ness (1965), JGR, 70, 5793.

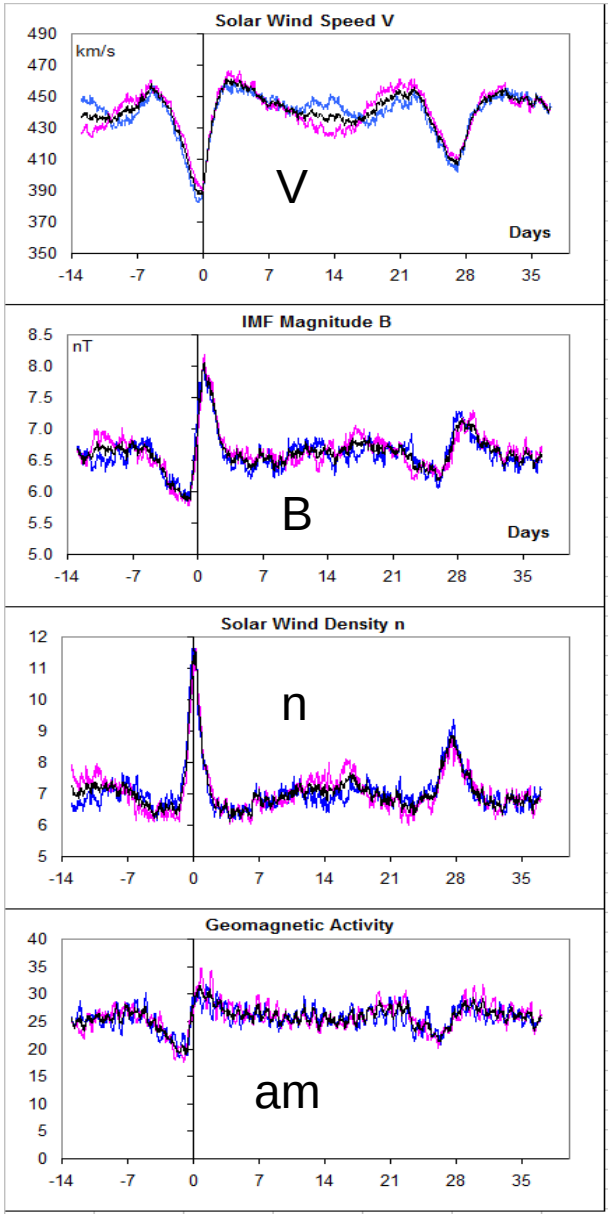


The large-scale structuring of the IMF was a surprise at the time

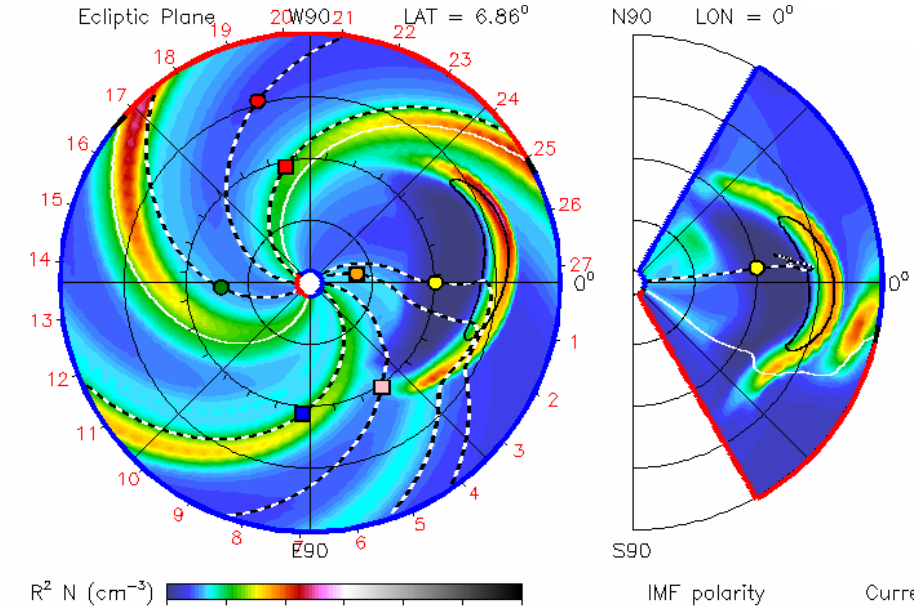


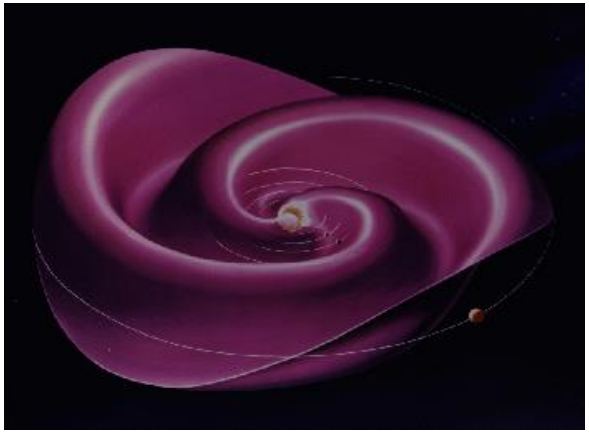
It was also noted that solar storms could briefly disrupt the structure

Organization is Robust
(Recovers from occasional CME)



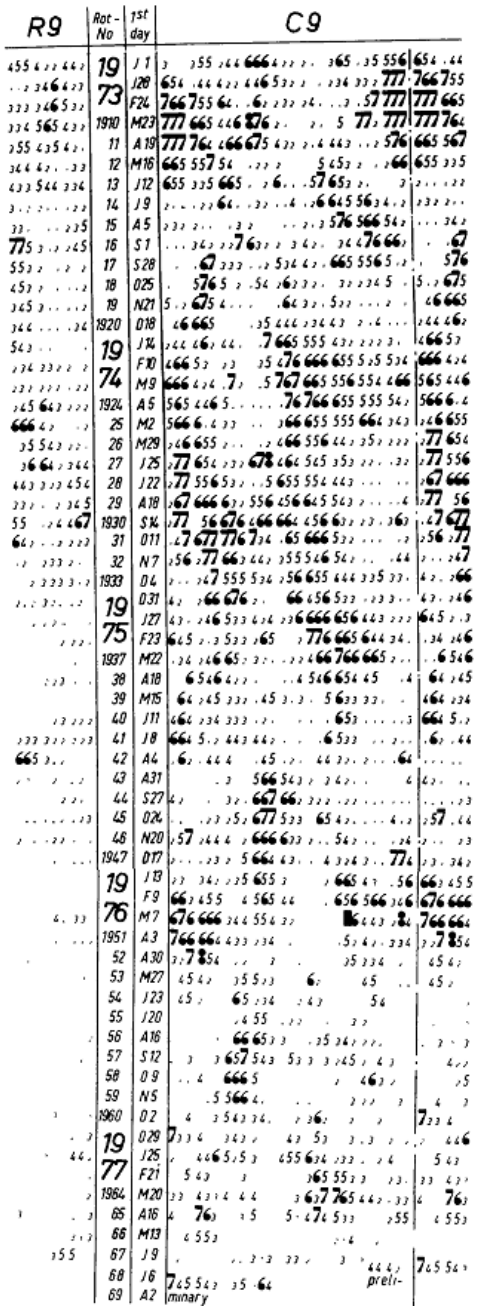
Superposed Epoch ~1000 Boundaries

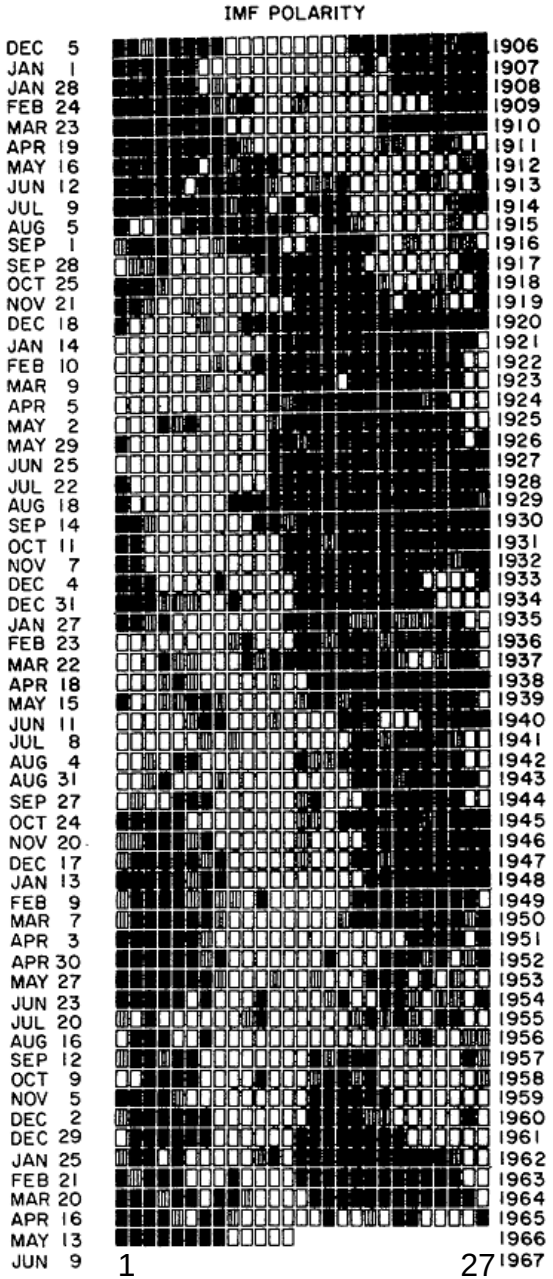




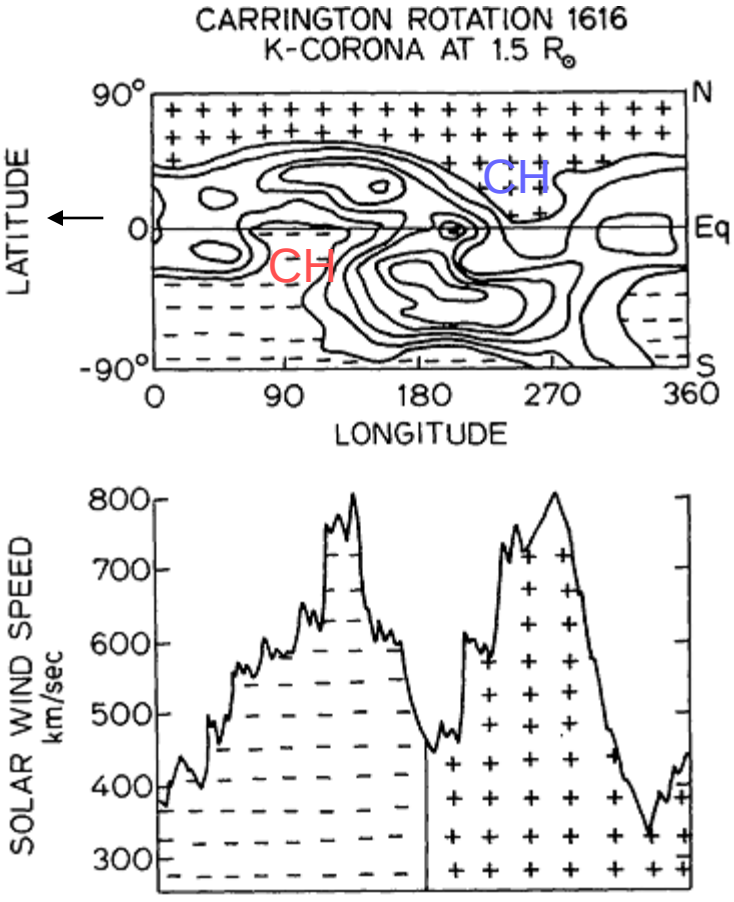
Heliospheric
Current Sheet

Rotation Plots of the Sector Polarity



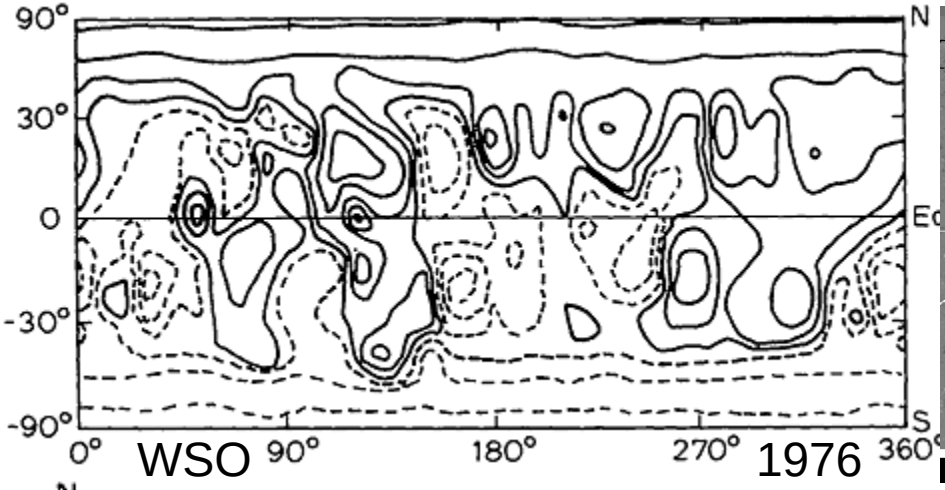


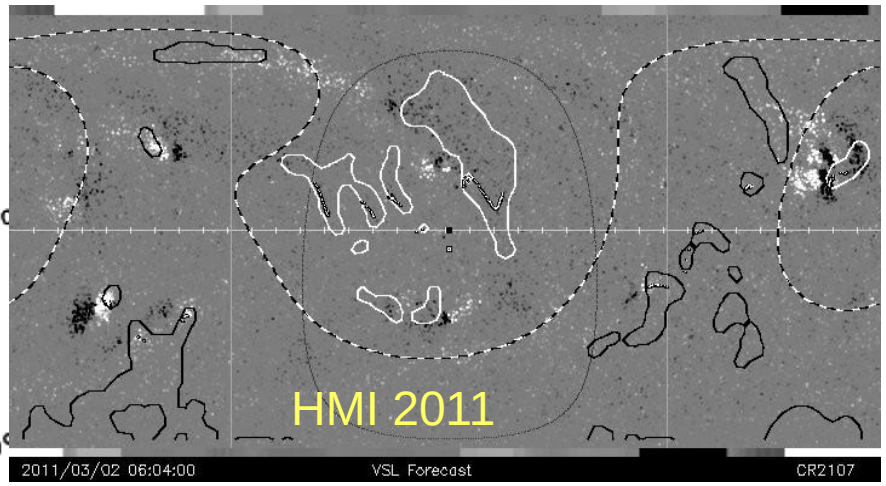
Bartels Rotations

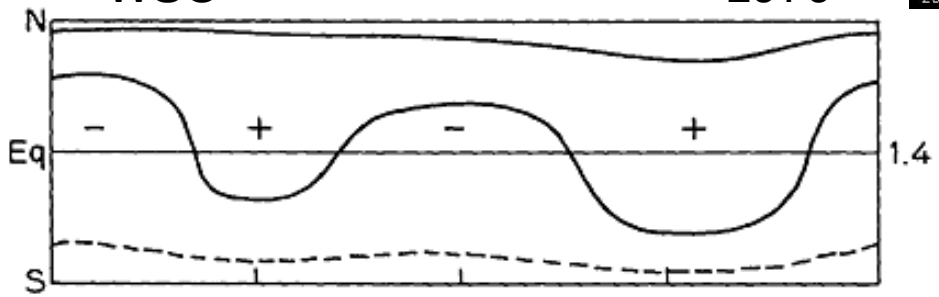


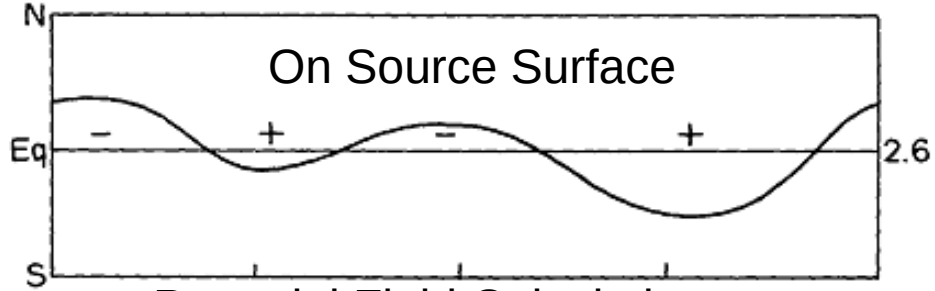
Skylab Workshop, 1976

From the Surface to the Corona

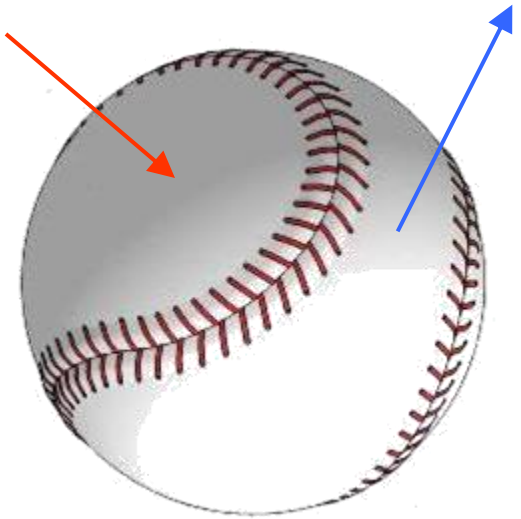








Potential Field Calculation



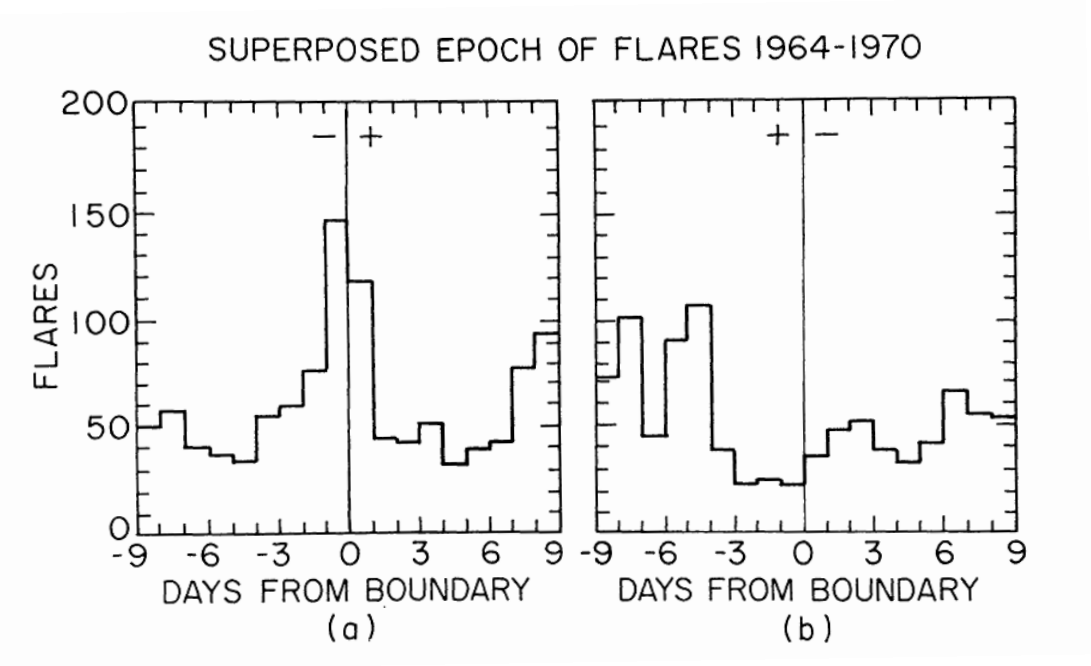
Almost 40 years ago one of our students published this paper in *Solar Physics*

THE RELATIONSHIP BETWEEN SOLAR FLARES AND SOLAR SECTOR BOUNDARIES

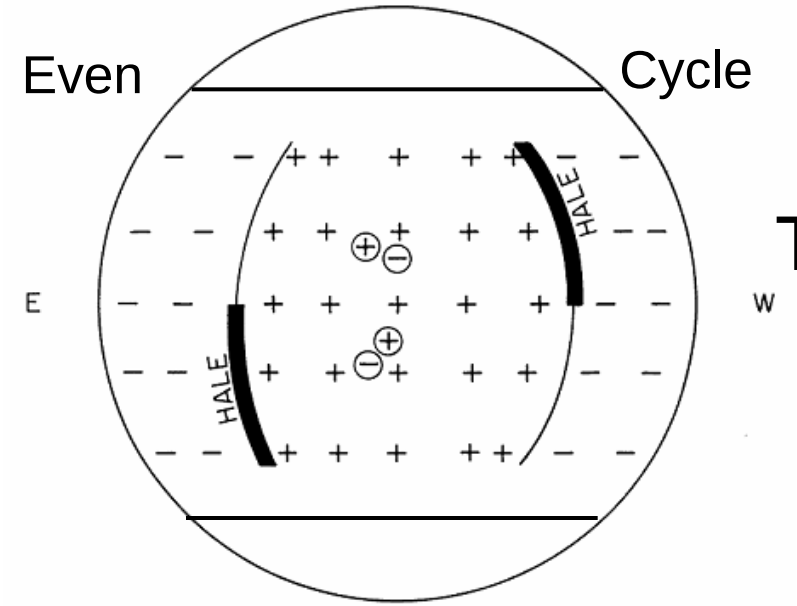
PHIL H. DITTMER

Institute for Plasma Research, Stanford University, Stanford, Calif. 94305, U.S.A.

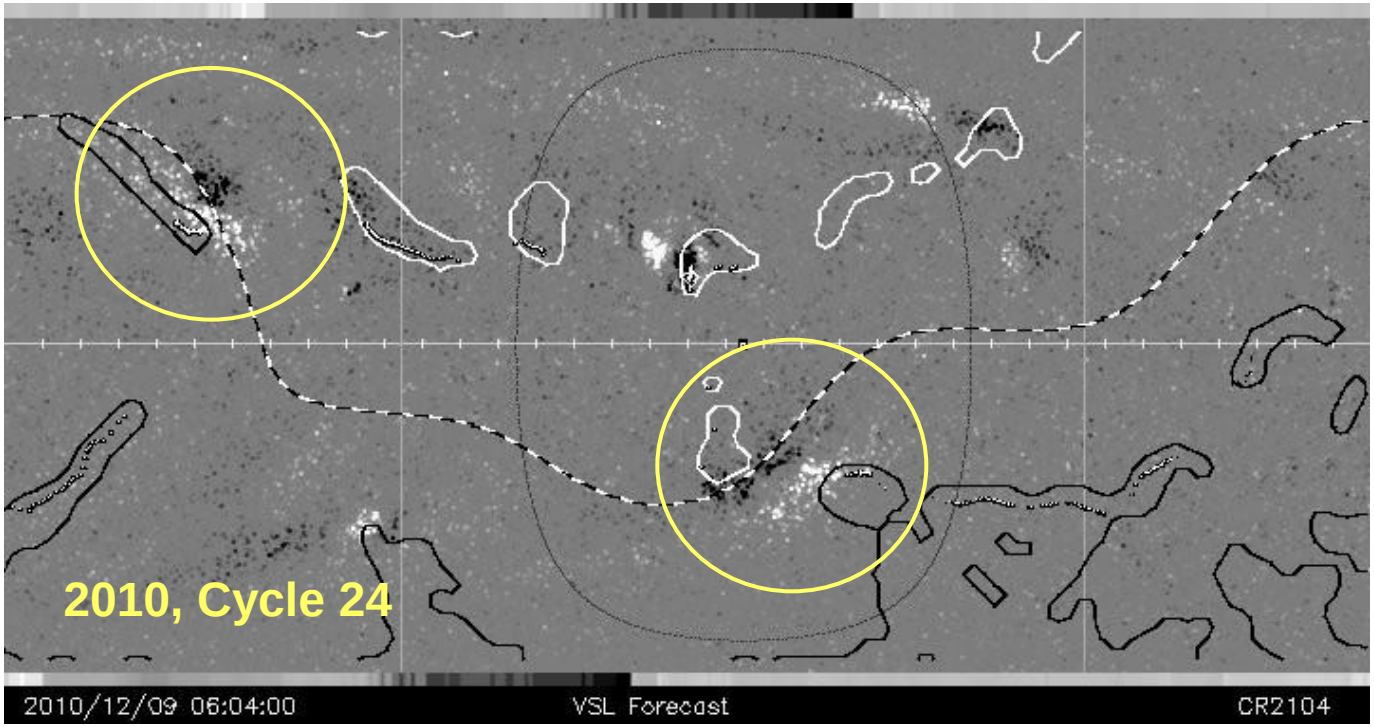
(Received 25 October; in revised form 2 December, 1974)



Dittmer concluded: "Although obscured by the lack of a reversal in the south, the pattern that emerges is one of flares preferring to occur near sector boundaries whose polarity agrees with that of bipolar active regions as given by the Hale polarity law."

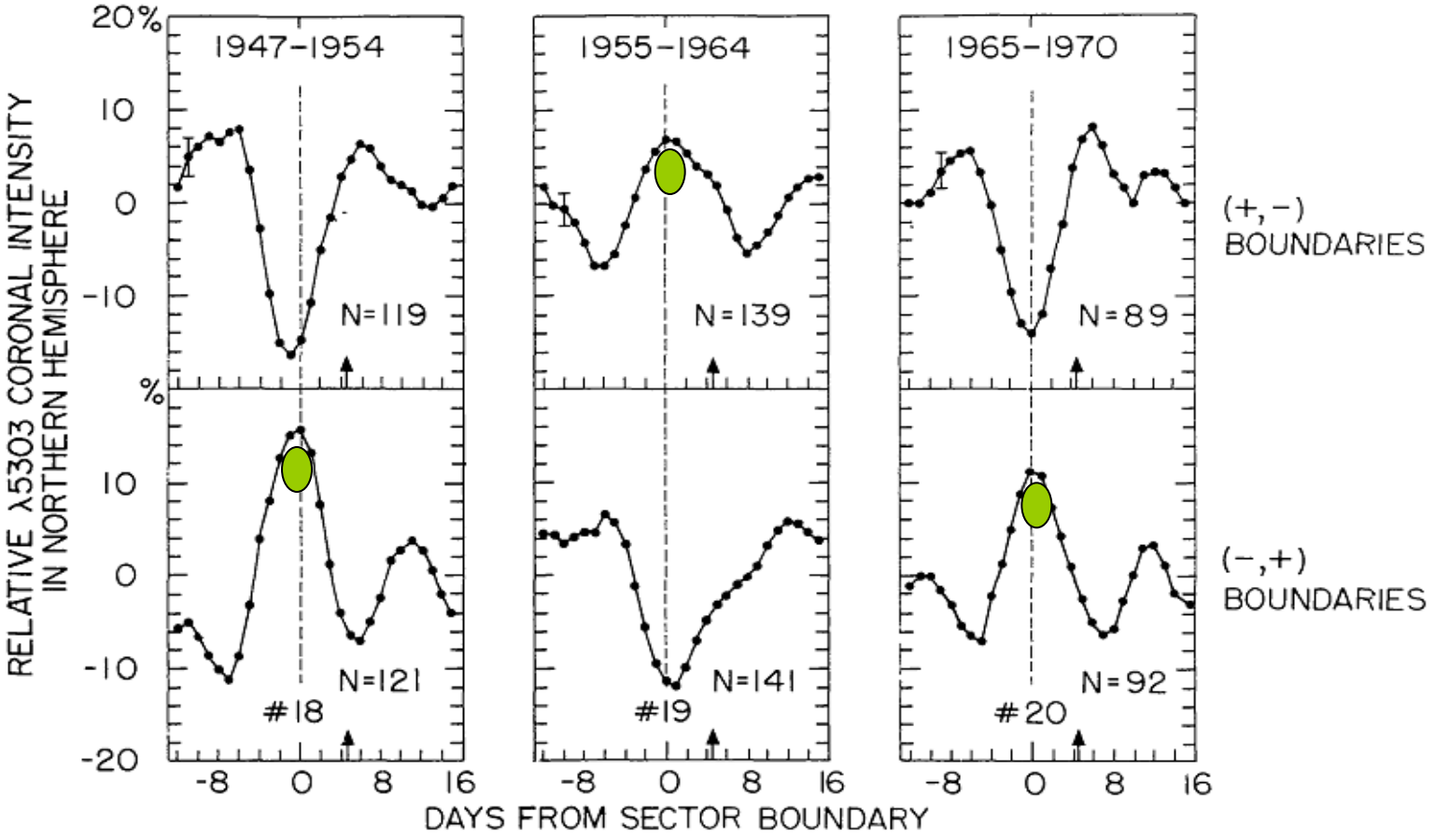


The ‘Hale’ Boundary Concept. Svalgaard & Wilcox, 1976



A Hale Boundary is that *portion* of a sector boundary that is located in the solar hemisphere in which the change of magnetic polarity across the sector boundary is the same as the change of magnetic polarity from a preceding spot to a following spot.

We would predict from Dittmer's finding that the Green Corona would have a Maximum at the Hale Boundary, and found precisely that:



It was brighter over Hale boundaries and darker over non-Hale boundaries.

The Coronal Excess Brightness over Hale Boundaries switches abruptly at solar minimum

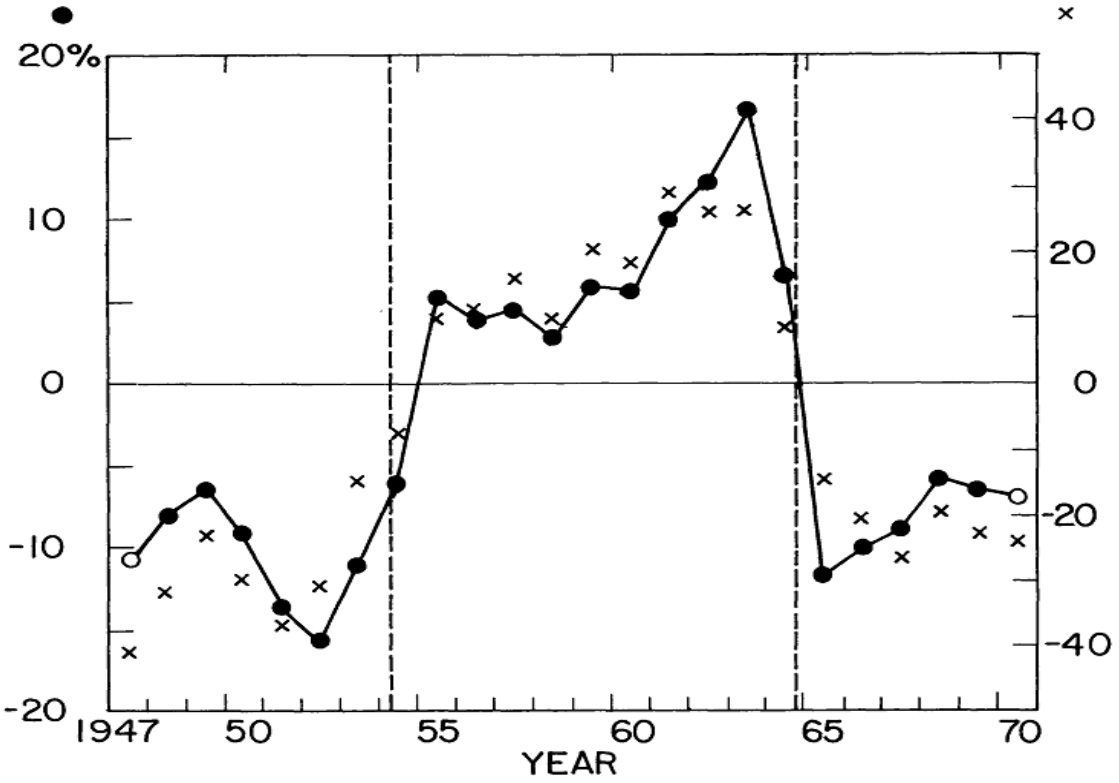
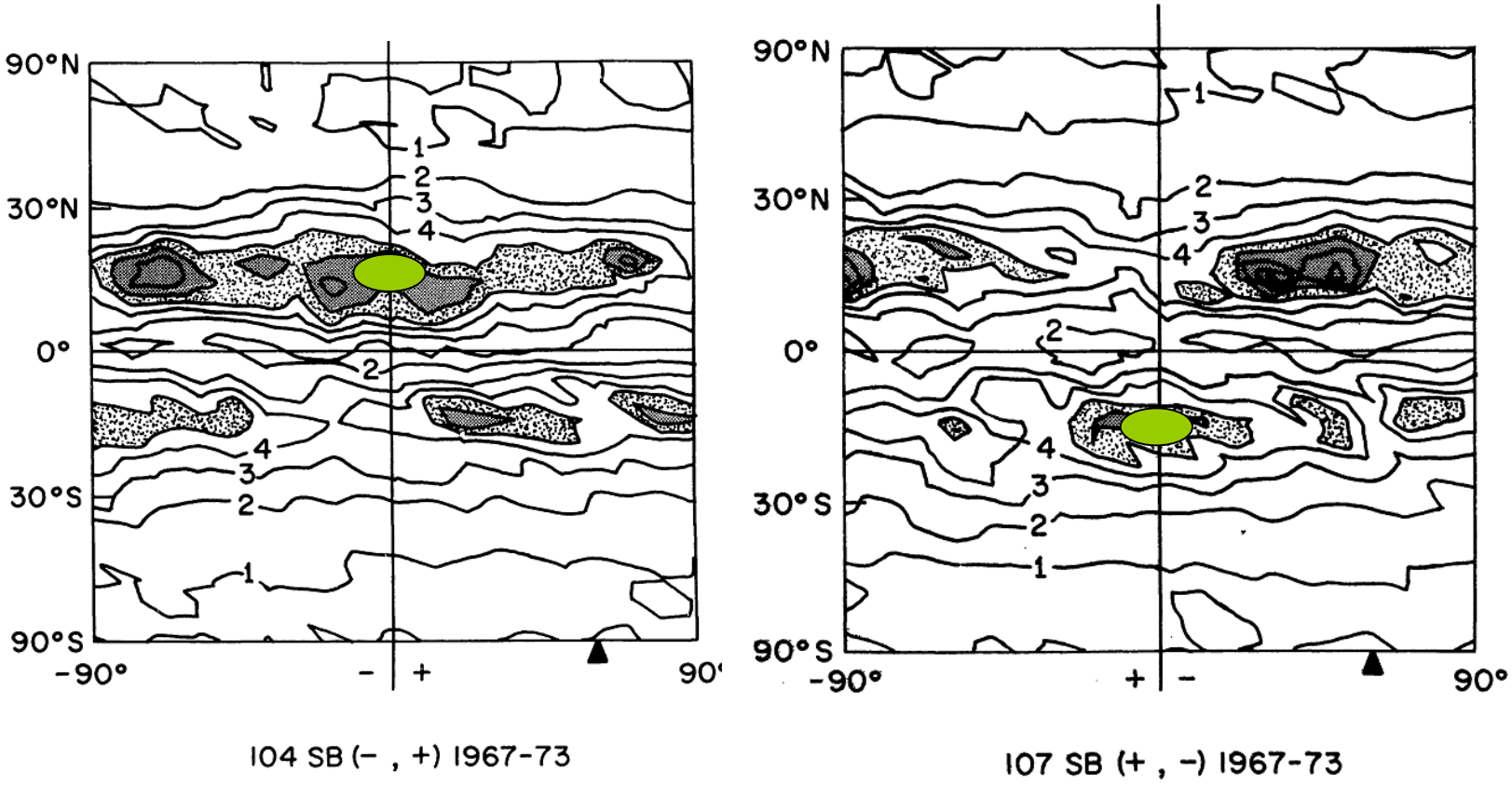


Fig. 4. *Top:* Relative coronal brightness above a (+,−) boundary in the northern hemisphere as a function of time from 1947 to 1970. During cycle number 19 (1954–1964) this portion of the boundary was a Hale boundary and had maximum coronal brightness, while at other times it was a non-Hale boundary and had minimum coronal brightness.

The Photospheric Magnetic Field [MWO] is at a maximum at the Hale Boundary

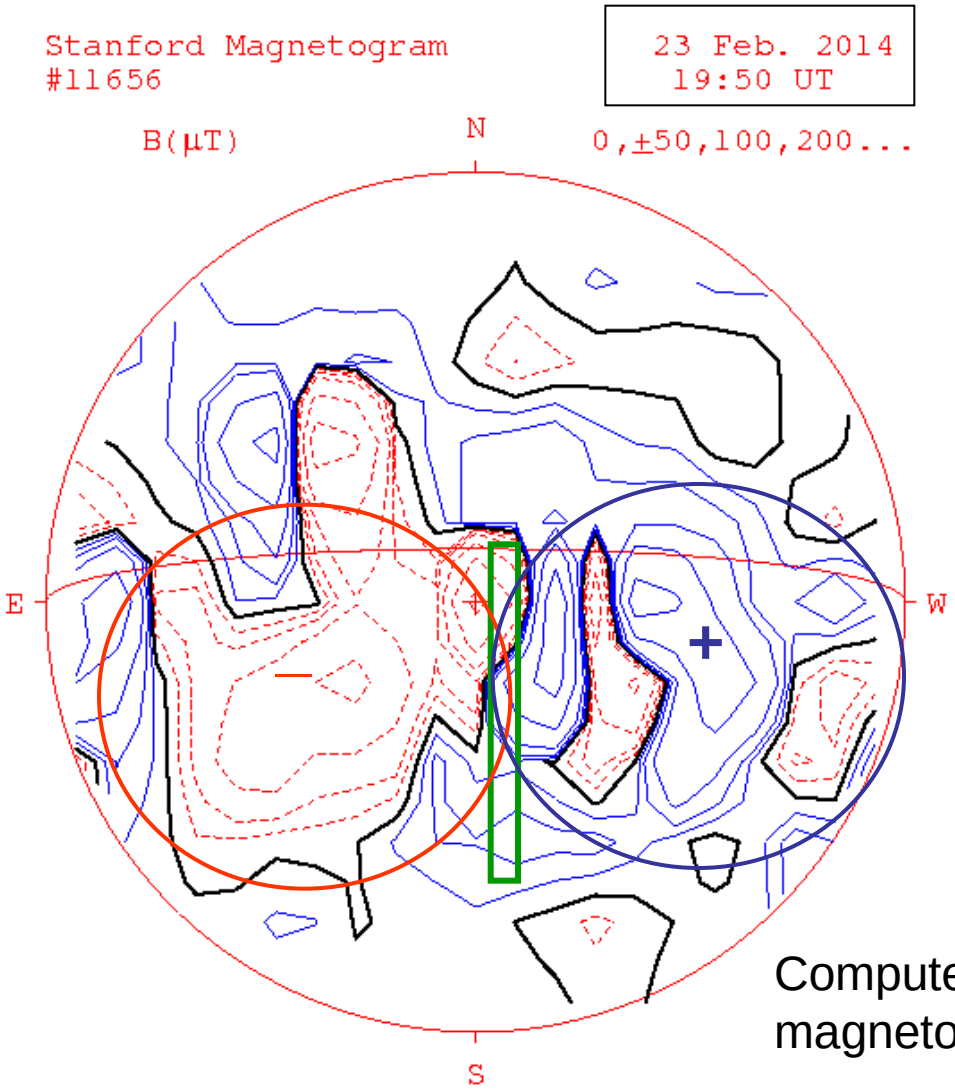


Magnitude of the field measured at Mt. Wilson

And then this line of inquiry died

Until I revisited the problem a couple of years ago, prompted by a discussion over lunch with Hugh Hudson

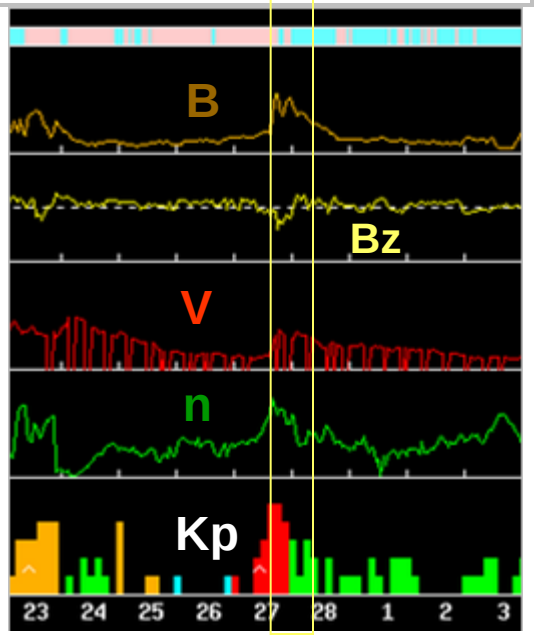
Perform Superposed Epoch Analysis of Photospheric Field with Sector Boundary Passages as Key Times



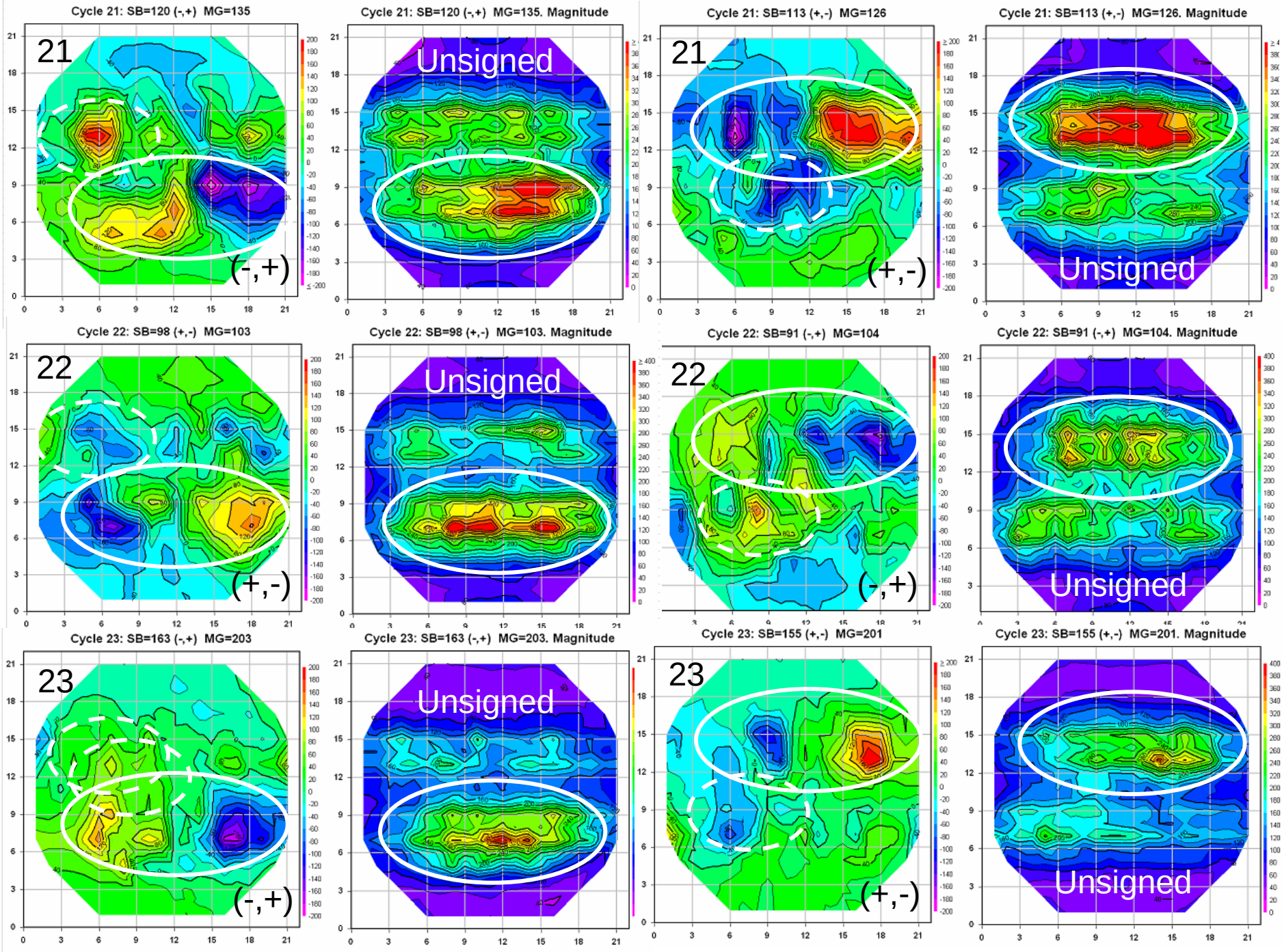
Well-defined Sector Boundary List:
http://www.leif.org/research/sblist.txt

-,+	2014 01 19	9	13
+,-	2014 02 08	4	6
+,-	2014 02 28	5	4
-,+	2014 03 04	4	6

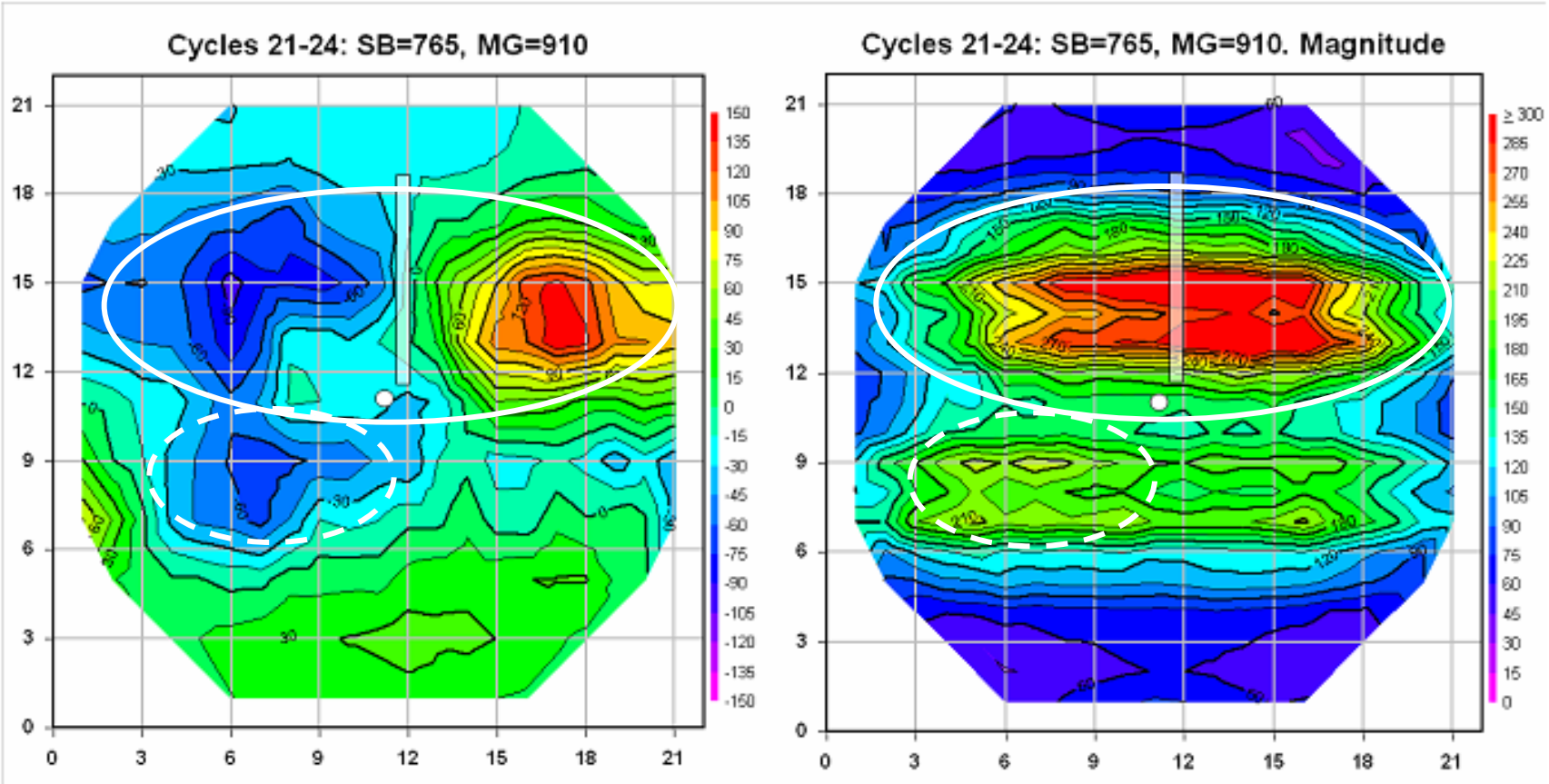
Select WSO magnetogram for **five** days before the SB crossing at Earth



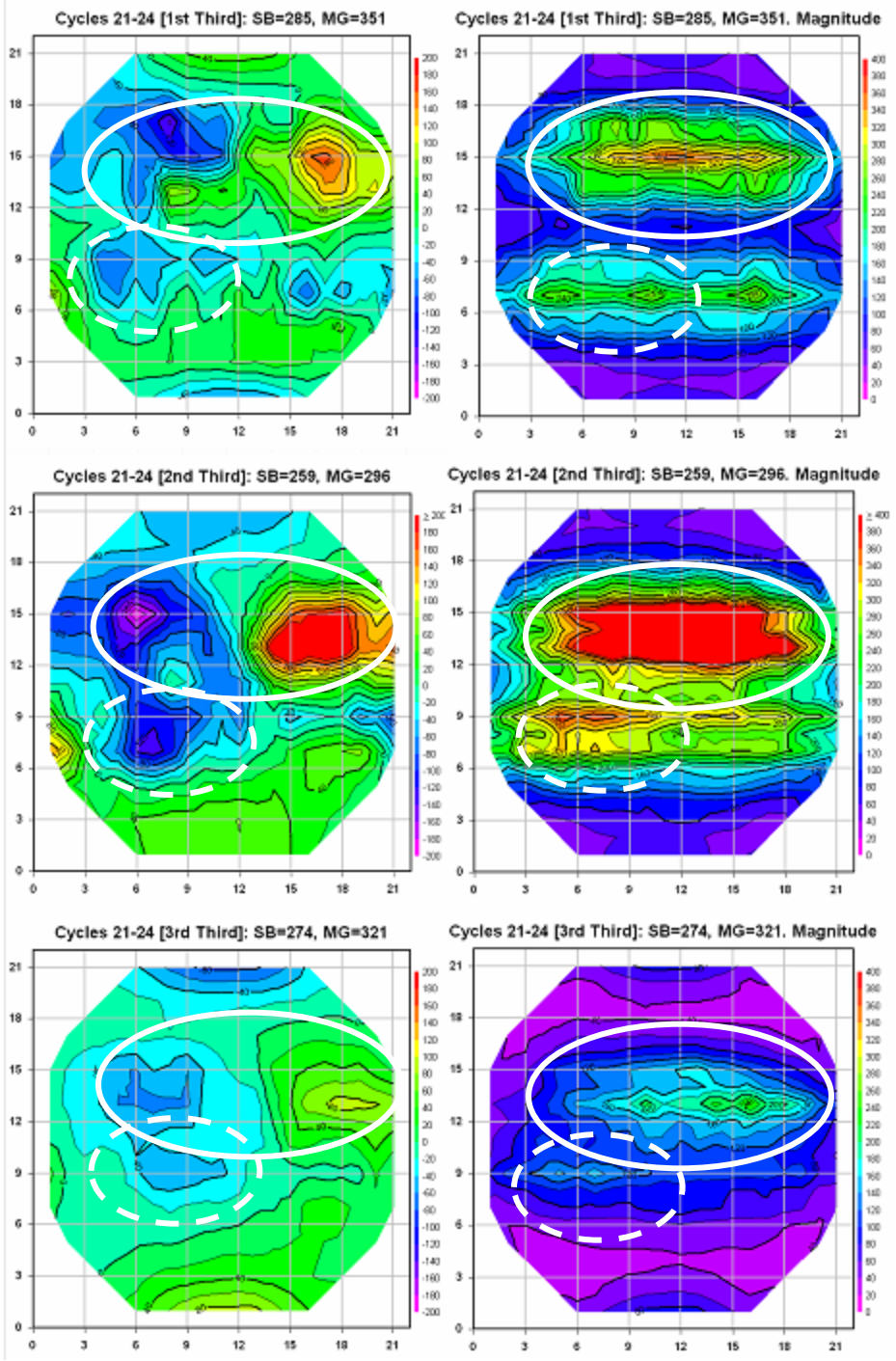
Compute average magnetogram


Cycle 21: SB=120 (-,+) MG=135
21
(-,+)
Cycle 21: SB=120 (-,+) MG=135. Magnitude
Unsigned
Cycle 21: SB=113 (+,-) MG=126
21
(+,-)
Cycle 21: SB=113 (+,-) MG=126. Magnitude
Unsigned
Cycle 22: SB=98 (+,-) MG=103
22
(+,-)
Cycle 22: SB=98 (+,-) MG=103. Magnitude
Unsigned
Cycle 22: SB=91 (-,+) MG=104
22
(-,+)
Cycle 22: SB=91 (-,+) MG=104. Magnitude
Unsigned
Cycle 23: SB=163 (-,+) MG=203
23
(-,+)
Cycle 23: SB=163 (-,+) MG=203. Magnitude
Unsigned
Cycle 23: SB=155 (+,-) MG=201
23
(+,-)
Cycle 23: SB=155 (+,-) MG=201. Magnitude
Unsigned

Average Magnetogram for Nominal (+,-) Hale Boundary in the North



The average magnetogram for a *nominal* (+,-) Hale boundary in the northern hemisphere. 910 magnetograms superposed on 765 sector boundaries for WSO observations 1976-2010. Some Data has been mirrored and sign-reversed as per Hale Polarity Law.

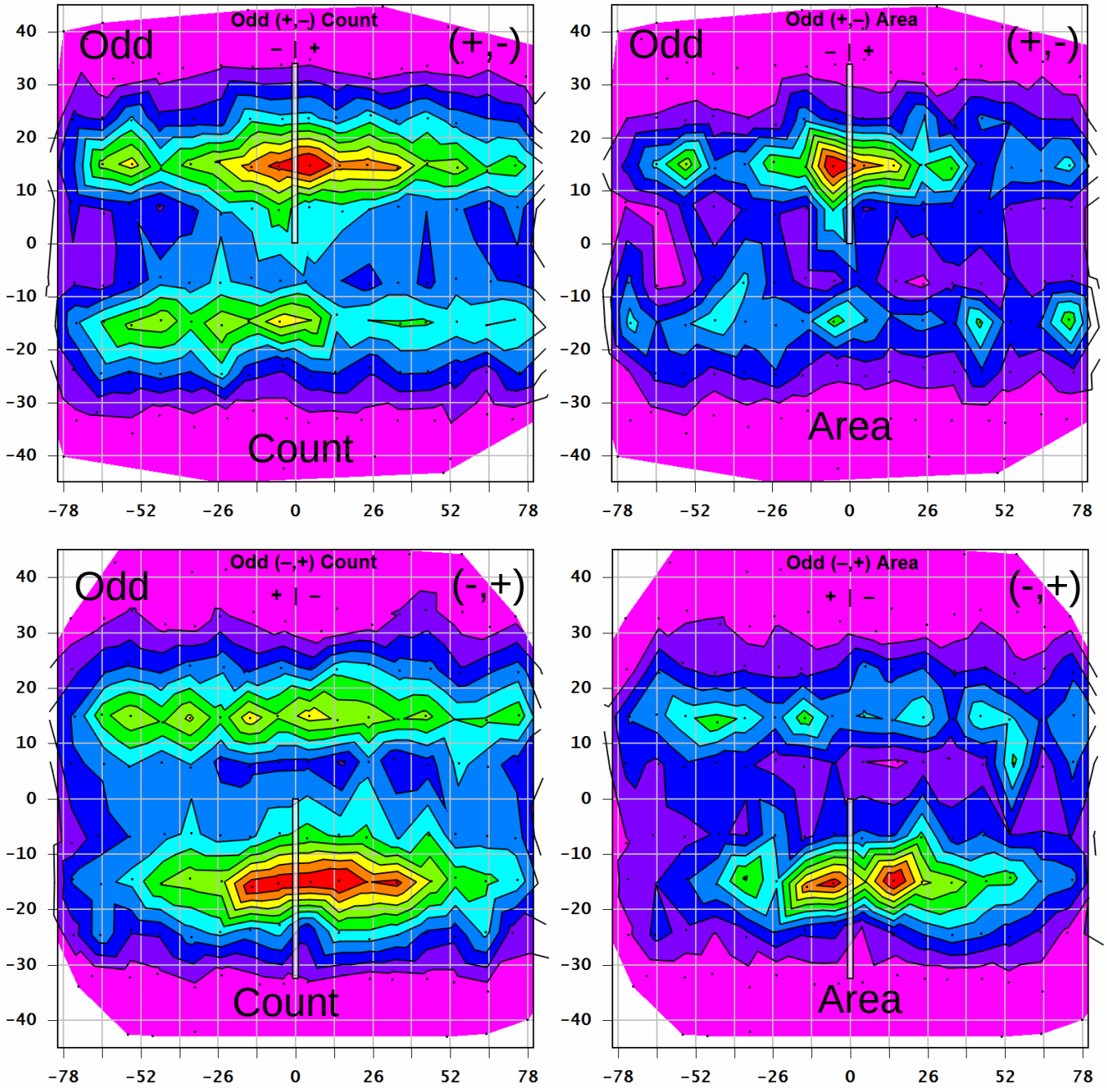


Variation of Nominal (+,-) Northern Hale Boundary Magnetogram Through the Solar Cycle (21-24)

1st Third

2nd Third, Magnetic Field strongest at Maximum

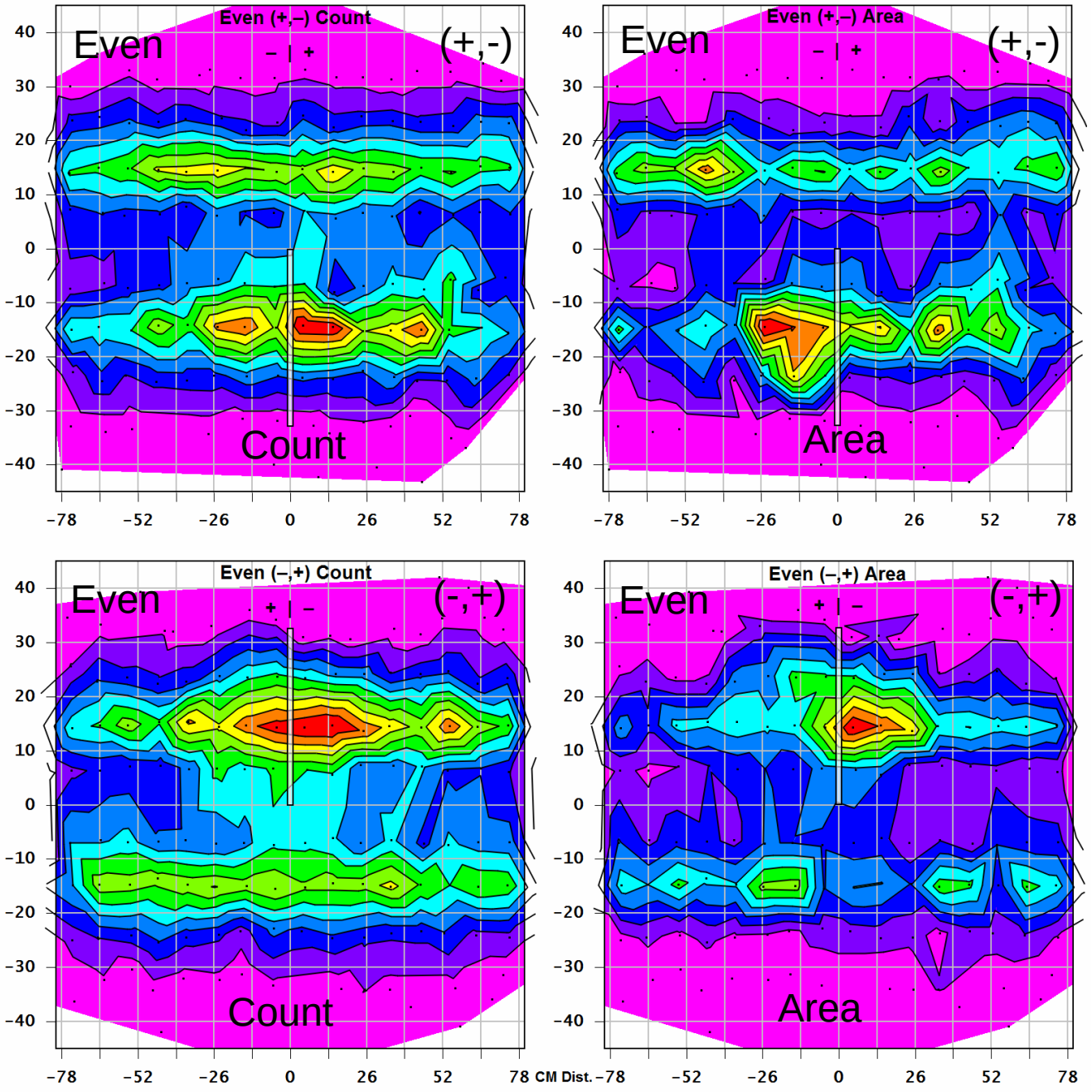
3rd Third



As we have sector boundaries back to 1926 we can superpose the Greenwich Active Region data (kept up-to-date by David Hathaway).

Left panel is for the number of regions and the right panel is for their areas.

This slide is for **odd** cycles



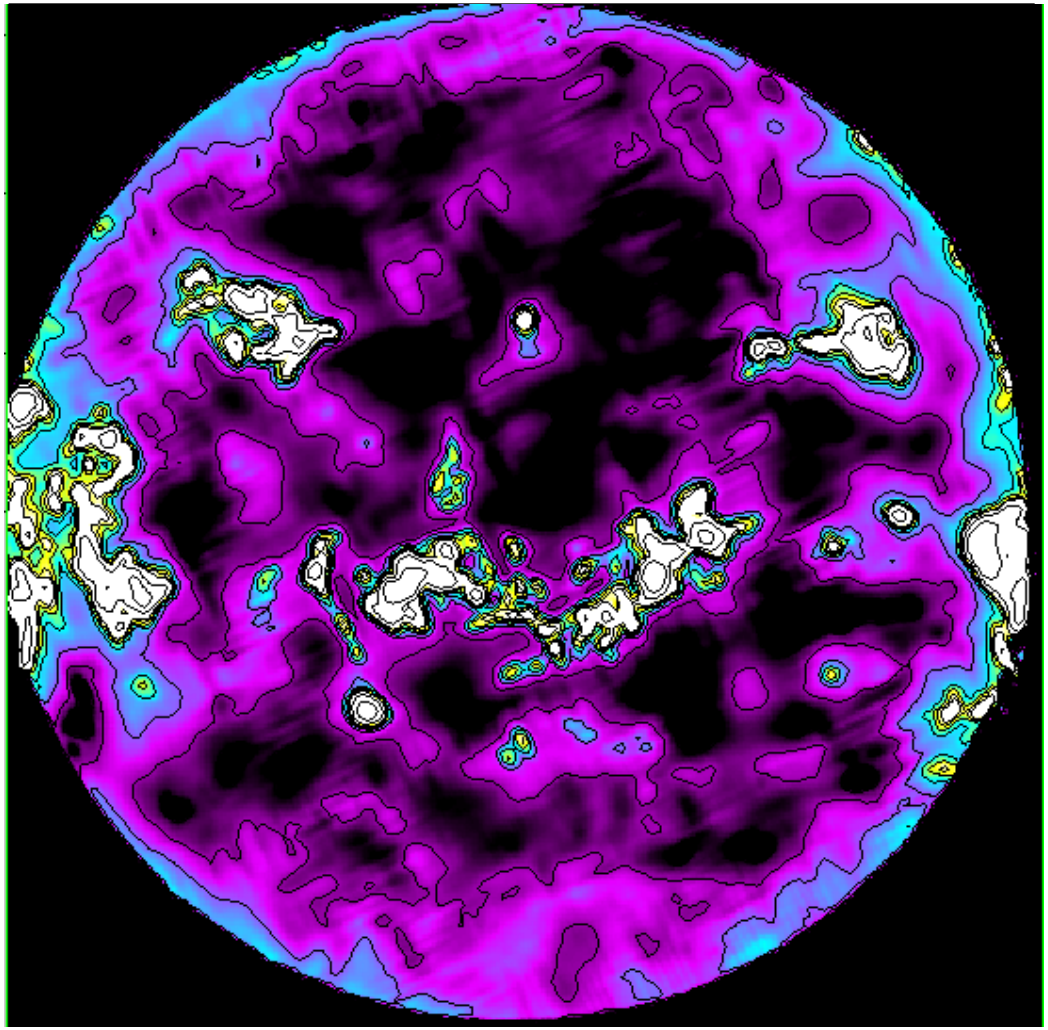
As we have sector boundaries back to 1926 we can superpose the Greenwich Active Region data (kept up-to-date by David Hathaway).

Left panel is for the number of regions and the right panel is for their areas.

This slide is for **even** cycles

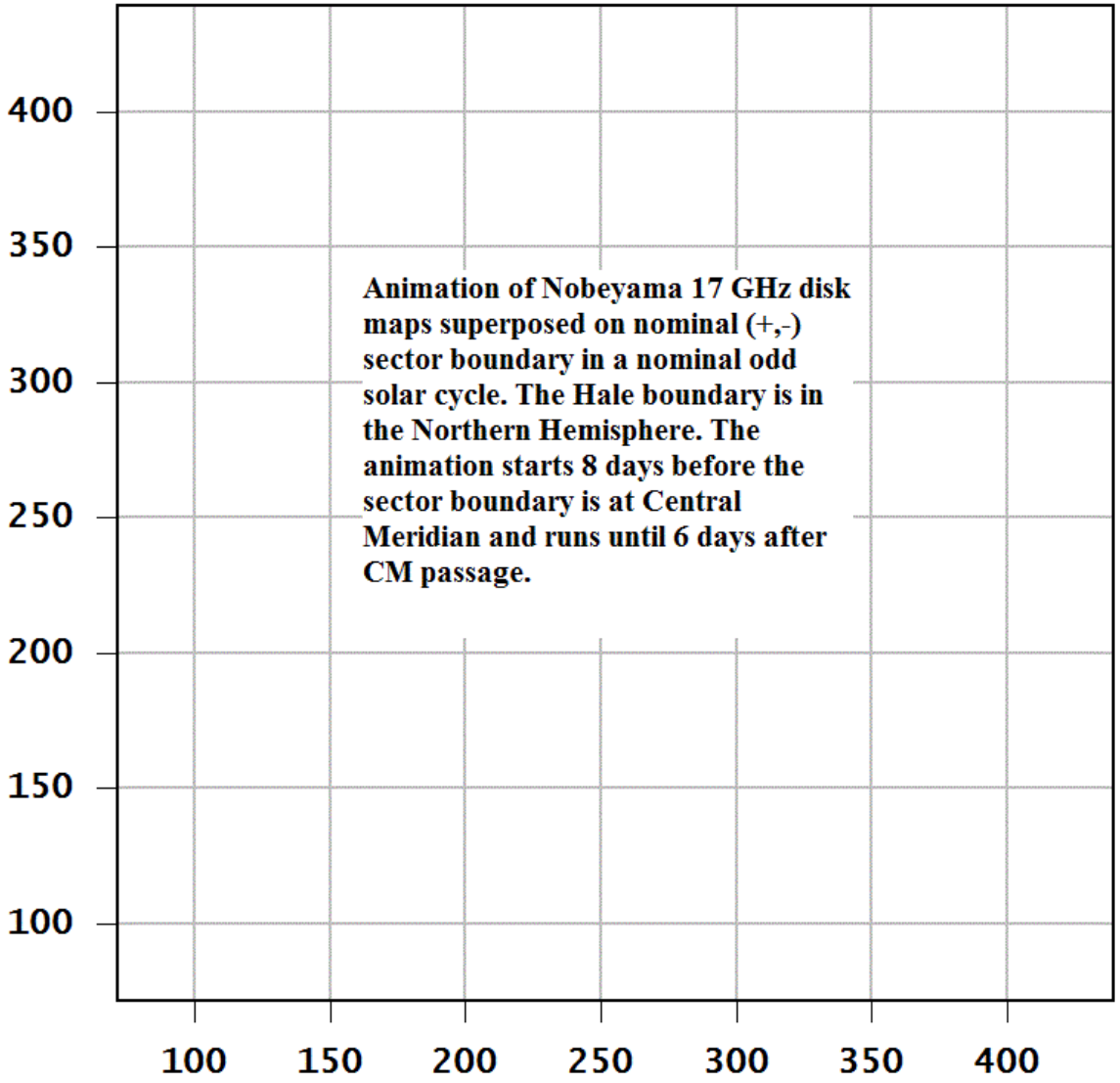
We see the now familiar pattern

Animation of a 17 GHz Hale Boundary



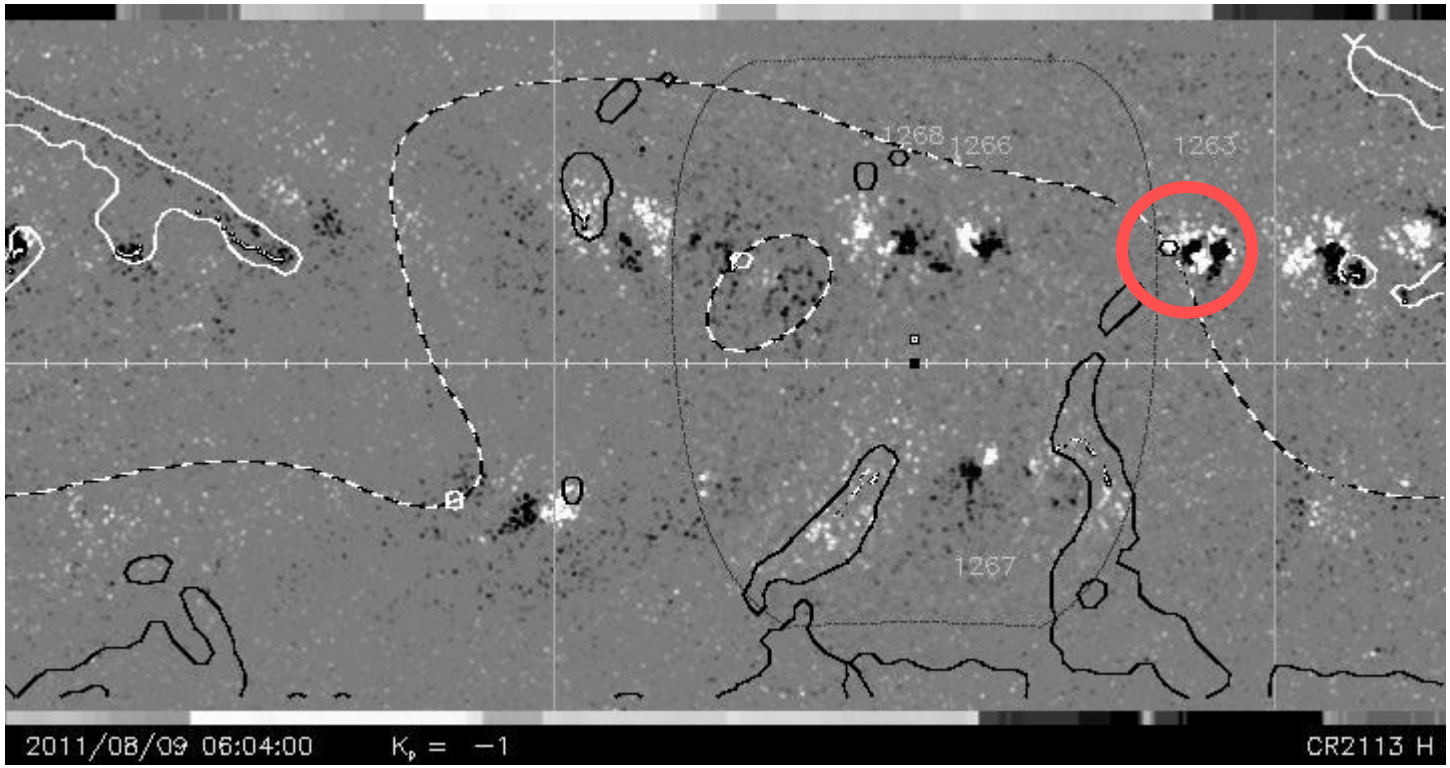
Animation of Nobeyama 17 GHz disk maps superposed on nominal (+,-) sector boundaries in a nominal odd solar cycle. The Hale boundary is in the Northern Hemisphere.

Animation of a 17 GHz Hale Boundary



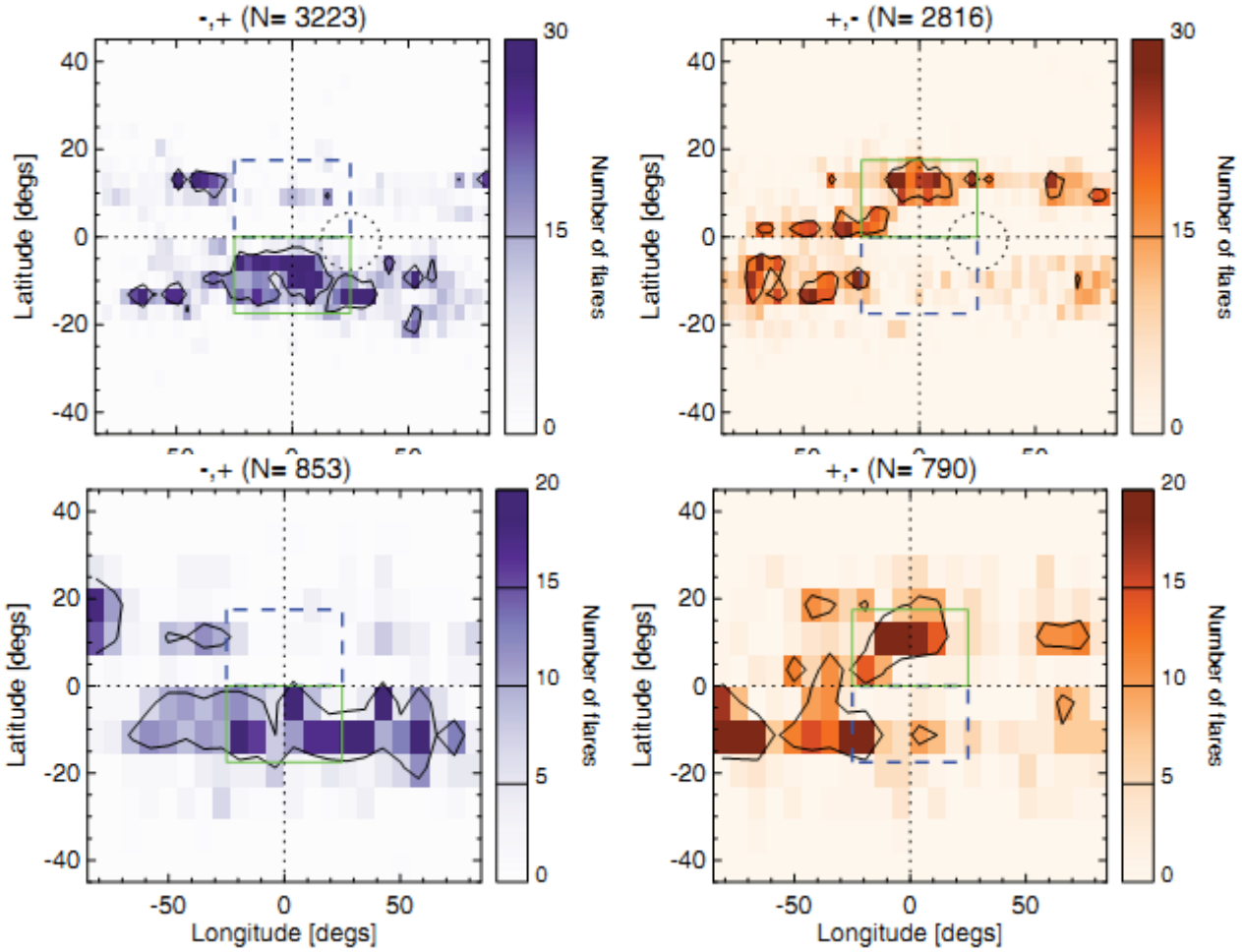
Animation of Nobeyama 17 GHz disk maps superposed on nominal (+,-) sector boundaries in a nominal odd solar cycle. The Hale boundary is in the Northern Hemisphere. The animation starts 8 days before the sector boundary is at Central Meridian [a bright hexagon will flash] and runs until 6 days after CM passage

Recent X7 Flare on Hale Boundary



Is the magnetic field already ‘stressed’ when emerging if on a Hale Boundary? McClymont & Fisher (1989) make this case generally: the emerging flux adds already stressed magnetic fields directly to the lower solar atmosphere, storing the non-potential energy needed for flaring.

Iain Hannah Plotted the position of all RHESSI (down to A-class) Flares occurring within ±24h of a Hale Boundary being at Central Meridian

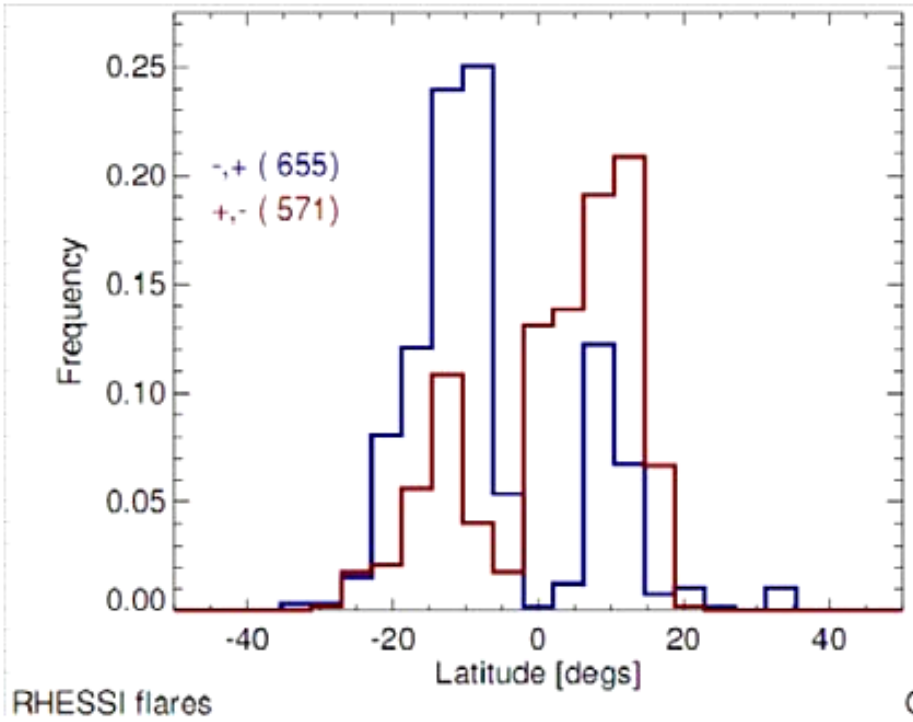


RHESSI flare list

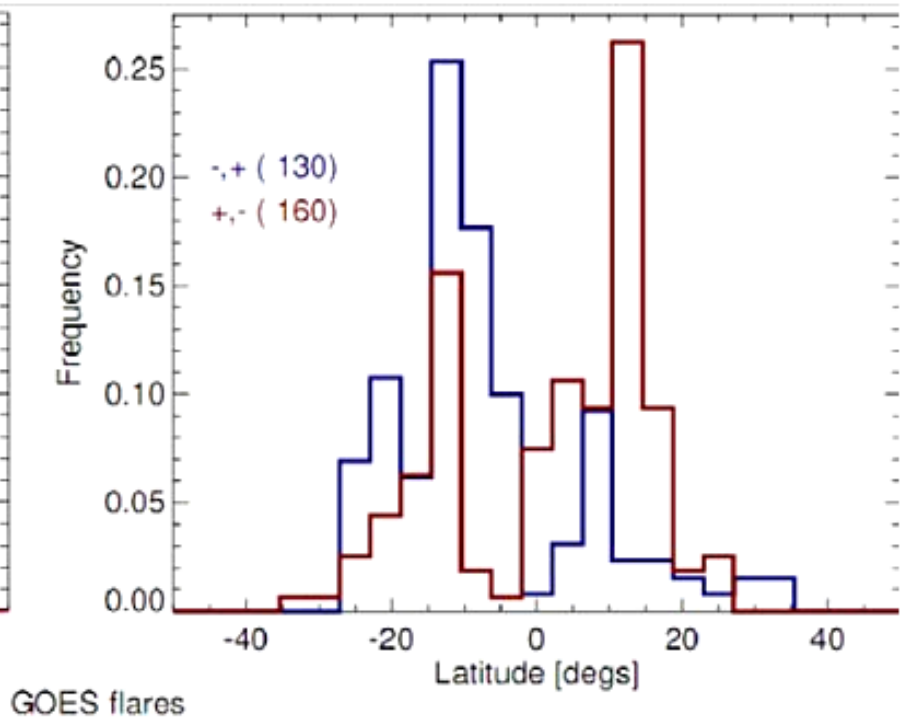
NOAA flare list

And for the larger (>B1) GOES/NOAA Flares as well

Alternatively we can plot the latitude distribution of Flare Occurrence:

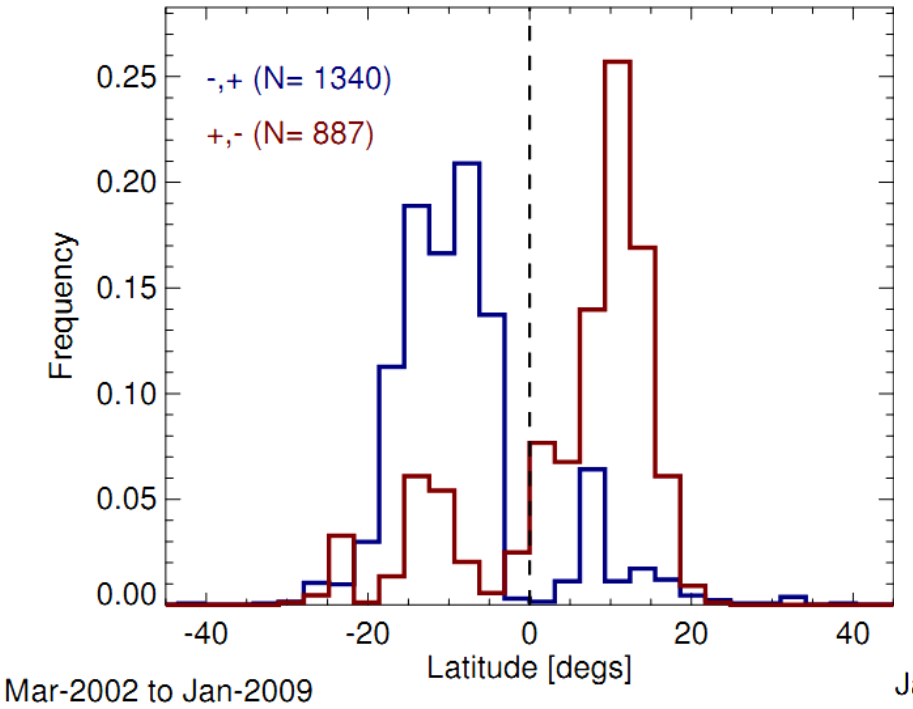


Cycle 23, 2002-2008

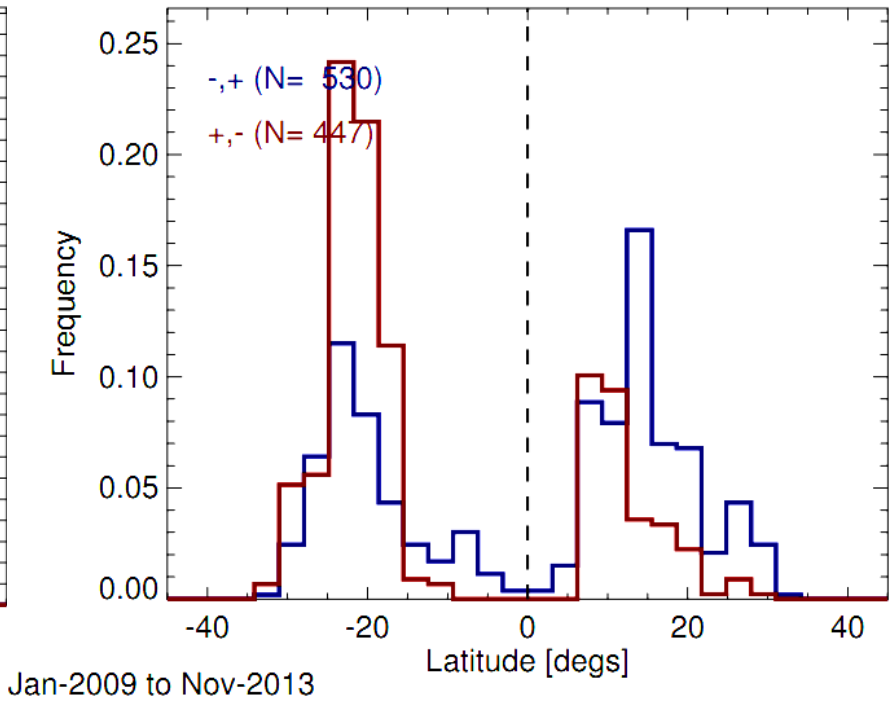


Cycle 23, 1996-2008

Width the Advent of Cycle 24 the Distribution should ‘Reverse’, and it did:



RHESSI, Cycle 23



RHESSI, Cycle 24

Conclusions I

- The findings of Dittmer, Antonucci, Obridko, Wilcox, and Svalgaard are fully confirmed: Flares occur preferentially at Hale Sector Boundaries
- The corona has maximal brightness over a Hale Sector Boundary
- The magnetic field is strongest at Hale Sector Boundaries
- More and stronger Active Regions occur at Hale Sector Boundaries
- The findings have potential value for prediction of flare occurrence

Conclusions II

- The warps of the Heliospheric Sector Structure originates preferentially from magnetic fields in **one** Hemisphere separated by a Hale Boundary where the polarity change matches that of bipolar active regions
- There is a high degree of coherence in the organization of solar magnetic activity on large scales, which presumably links the sector structure to the deep interior of the Sun, reflecting a similar property in the creation of solar magnetism or its propagation to the surface
- The solar sector structure is organized and long-lived, and flaring also has the same degree of spatial and temporal structure

Thank you

Abstract

Interplanetary 'Sector Boundaries' separating opposite magnetic field polarities can be traced back to the photospheric magnetic field. The portion of such a boundary that separates magnetic fields with the same change in polarities as that between the leading and trailing parts of active regions is called a Hale Boundary and is found to be the site of high magnetic field strengths, high occurrence of solar flares, enhanced radio microwave emission, and maximum brightness of the corona. As sector boundaries are very long-lived [years or more], Hale Boundaries must be similarly organized on long timescales, suggesting long-lived internal magnetic structures or cells with excess free energy, i.e. be already stressed by internal processes to harbor that energy released in flares and CMEs. This has obvious implications for short-term predictions of space weather.