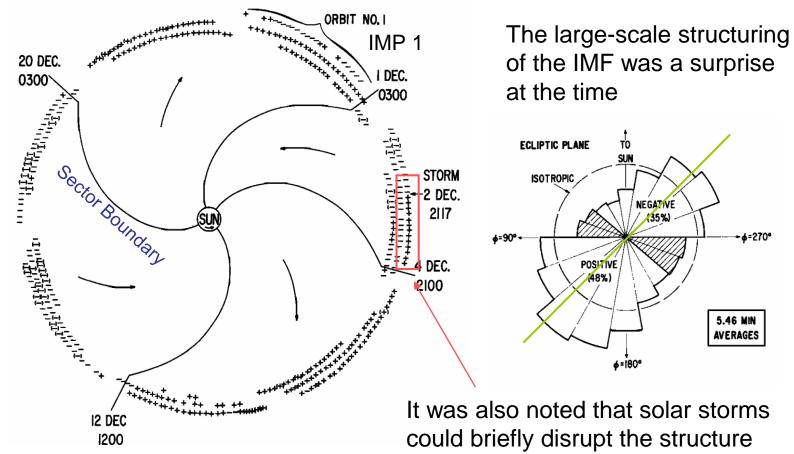


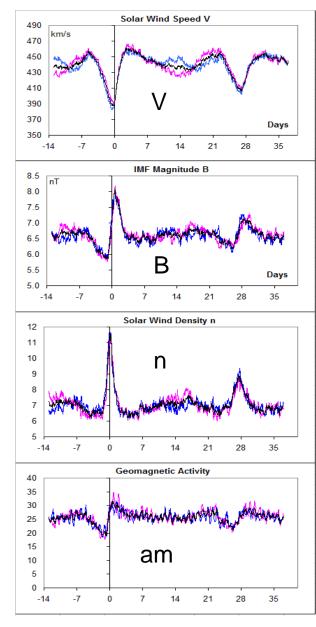
## Magnetic Fields at Hale Solar Sector Boundaries

Leif Svalgaard HEPL Stanford University Huntsville Workshop, 25 March 2014

# **Discovery of Sector Structure**

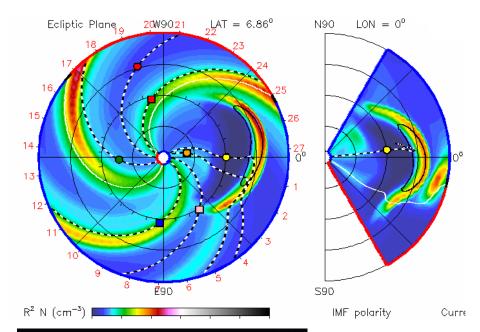
Quasi-Stationary Corotating Structure in the Interplanetary Medium John M. Wilcox & Norman F. Ness (1965), JGR, 70, 5793.





Superposed Epoch ~1000 Boundaries

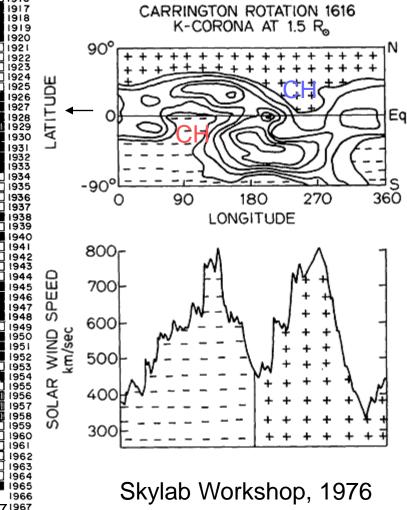
### Organization is Robust (Recovers from occasional CME)





#### Heliospheric Current Sheet

Rotation Plots of
the Sector Polarity



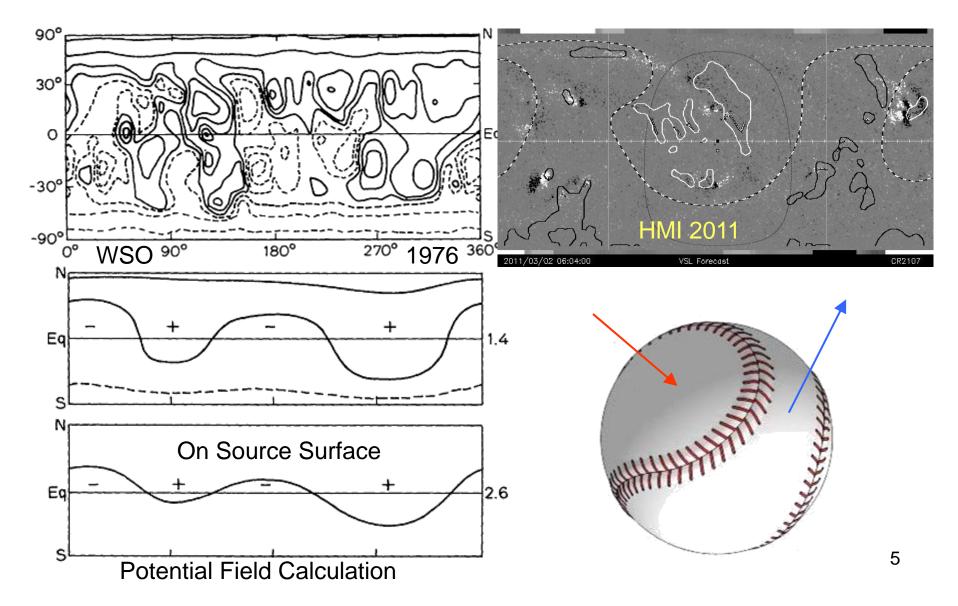
Skylab Workshop, 1976

	IMF POLARITY	
DEC 5		1906
JAN I JAN 28		1907
FEB 24		1909
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APR 19 MAY 16		1911
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AUG 5 SEP I		1916
SEP 28		1917
OCT 25 NOV 21		1918
DEC 18		1920
JAN 14		1921
FEB 10 MAR 9		1922
APR 5		1924
MAY 2		1925
MAY 29 JUN 25		1927
JUL 22		1928
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NOV 7		1932
DEC 4 DEC 31		1934
JAN 27		1935
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NOV 20		194
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APR 30		195
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JUN 23 JUL 20		195
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SEP 12 OCT 9		195
NOV 5		1959
DEC 2 DEC 29		1960
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**Bartels Rotations** 

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### From the Surface to the Corona



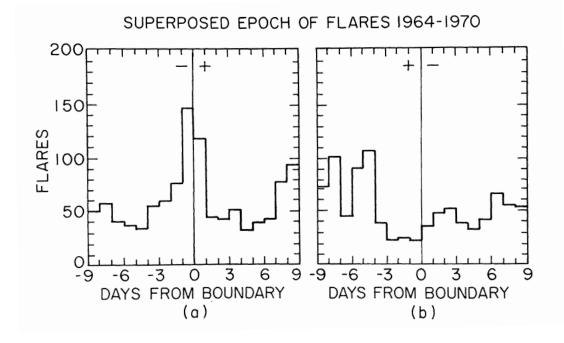
# Almost 40 years ago one of our students published this paper in Solar Physics

#### THE RELATIONSHIP BETWEEN SOLAR FLARES AND SOLAR SECTOR BOUNDARIES

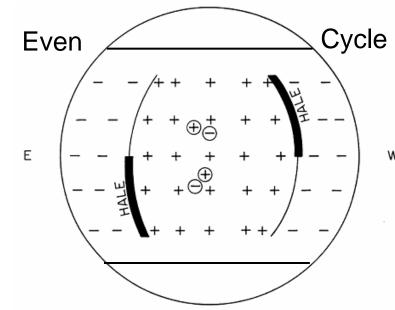
PHIL H. DITTMER

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

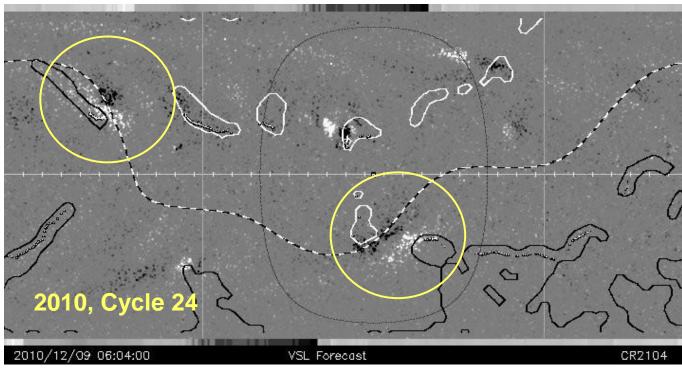
(Received 25 October; in revised form 2 December, 1974)



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."

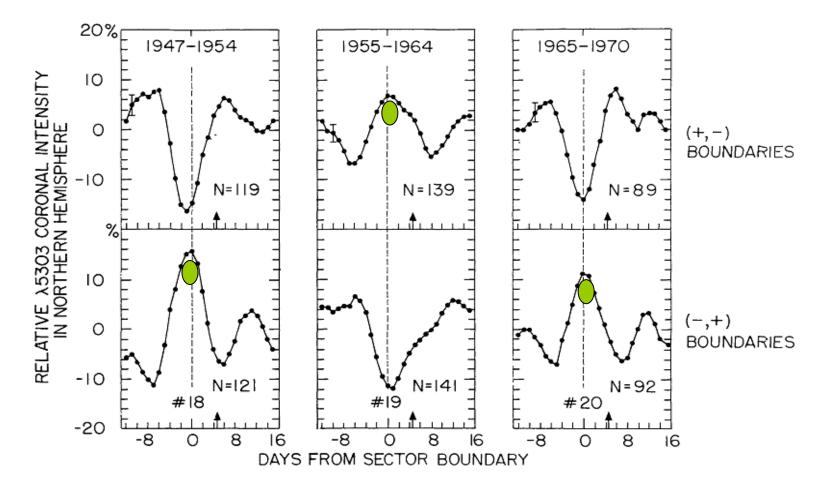


### The 'Hale' Boundary Concept. Svalgaard & Wilcox, 1976



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

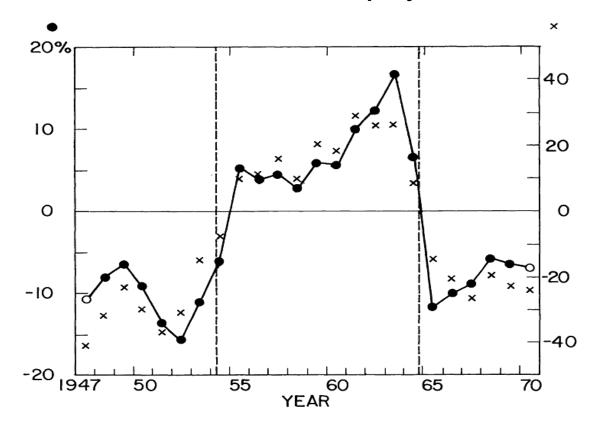
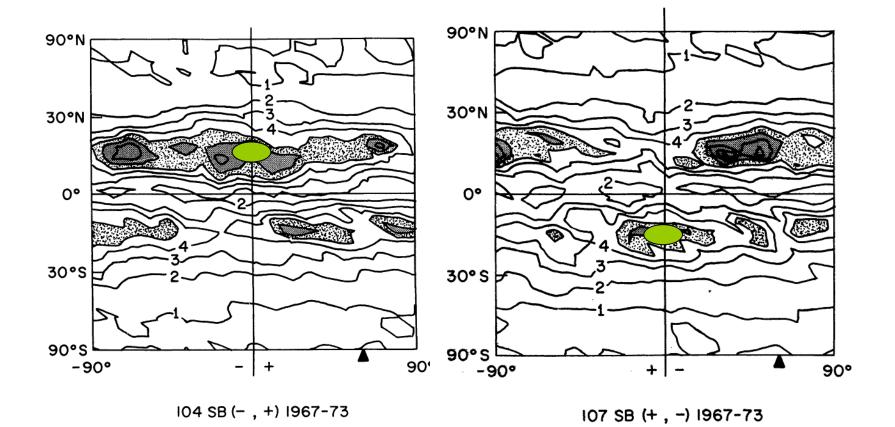


Fig. 4. Top: Relative coronal brightness above a (+,-) boundary in the northern hemisphere as a function of time from 1947 to 1970. During cycle number 19 (1954–1964) this portion of the boundary was a Hale boundary and had maximum coronal brightness, while at other times it was a non-Hale boundary and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

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



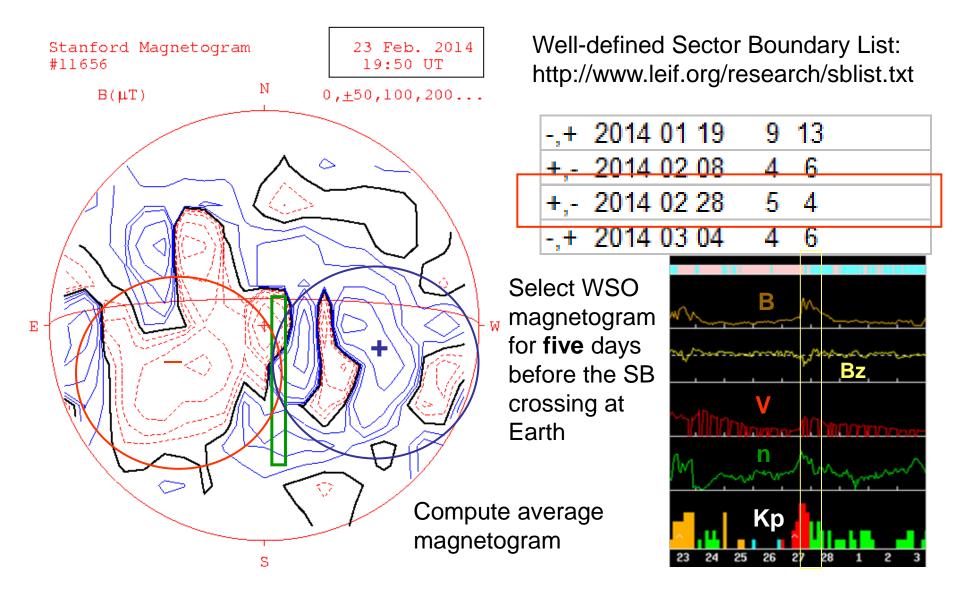
Magnitude of the field measured at Mt. Wilson

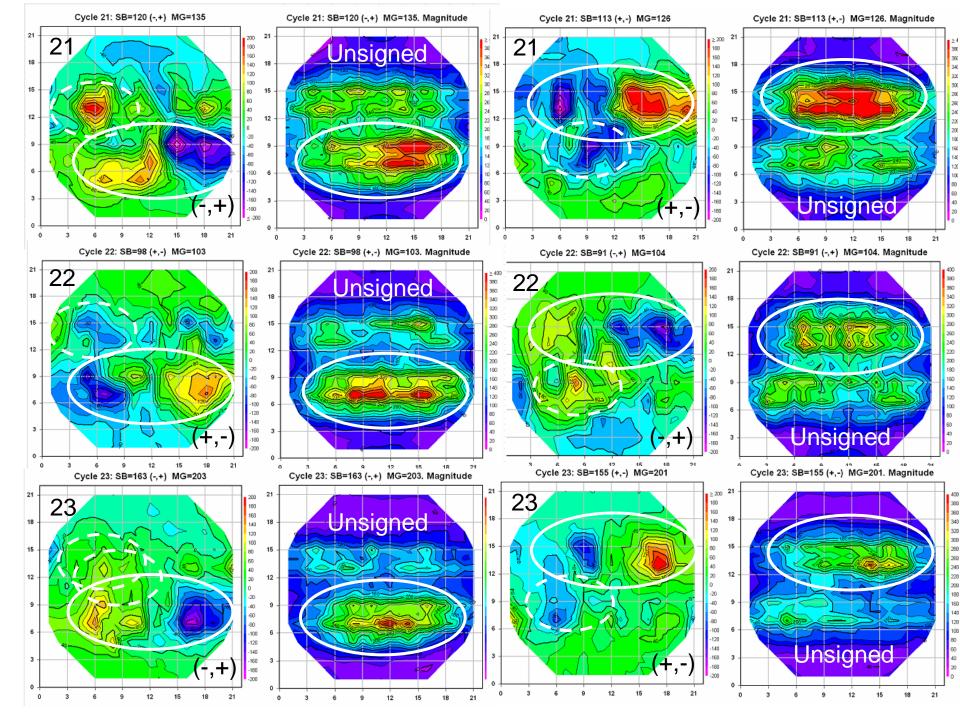
## And then this line of inquiry died



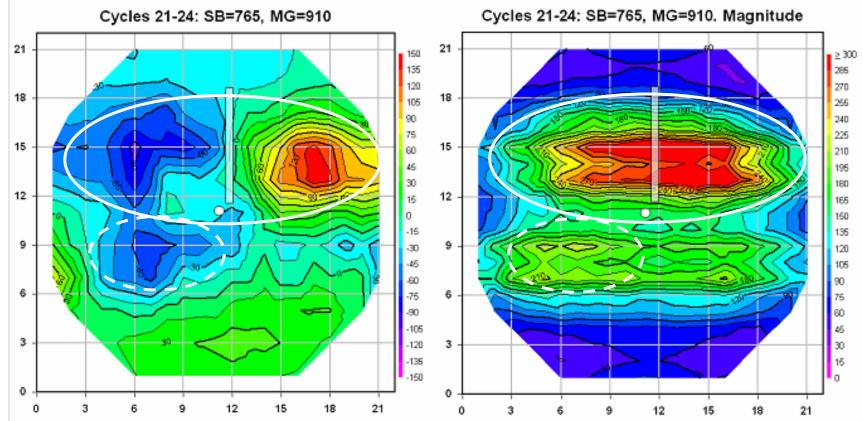
Until I revisited the problem a couple of years ago, prompted by a discussion over lunch with Hugh Hudson

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

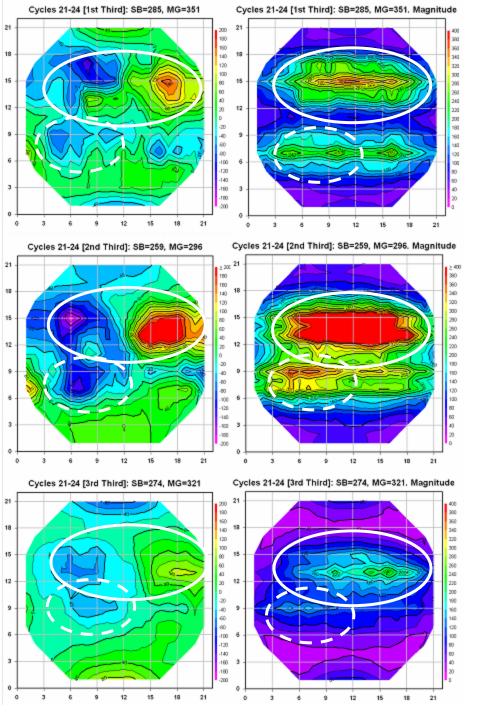




# Average Magnetogram for Nominal (+,-) Hale Boundary in the North



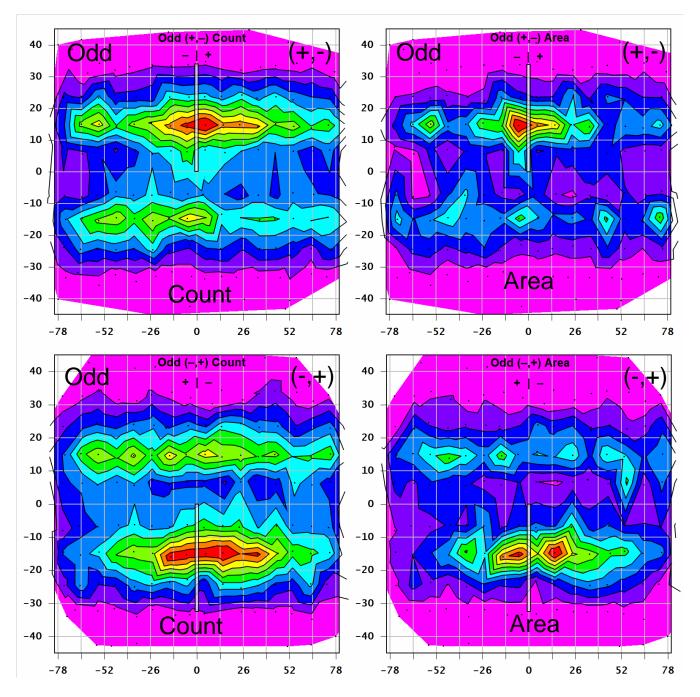
The average magnetogram for a *nominal* (+,-) Hale boundary in the northern hemisphere. 910 magnetograms superposed on 765 sector boundaries for WSO observations 1976-2010. Some Data has been mirrored and signreversed as per Hale Polarity Law.



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

#### 1<sup>st</sup> Third

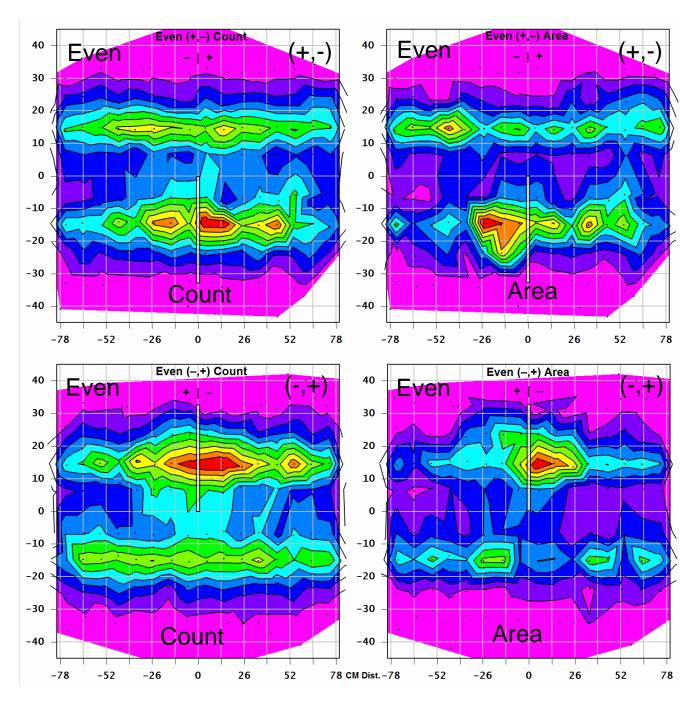
2<sup>nd</sup> Third, Magnetic Field strongest at Maximum



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



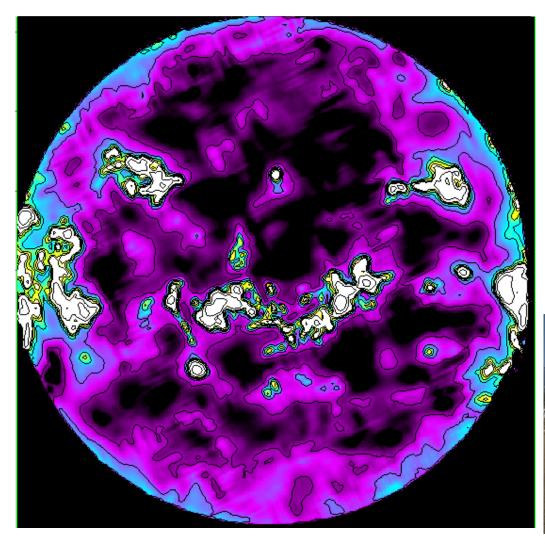
As we have sector boundaries back to 1926 we can superpose the Greenwich Active Region data (kept up-to-date by David Hathaway).

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 17

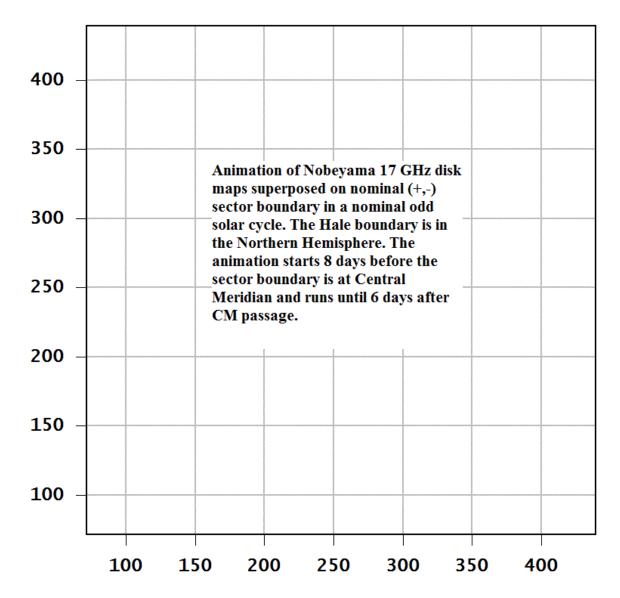
### Animation of a 17 GHz Hale Boundary



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.

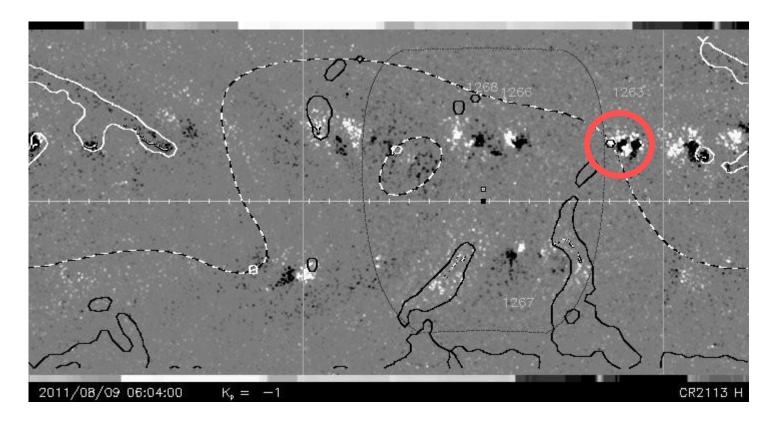


### Animation of a 17 GHz Hale Boundary



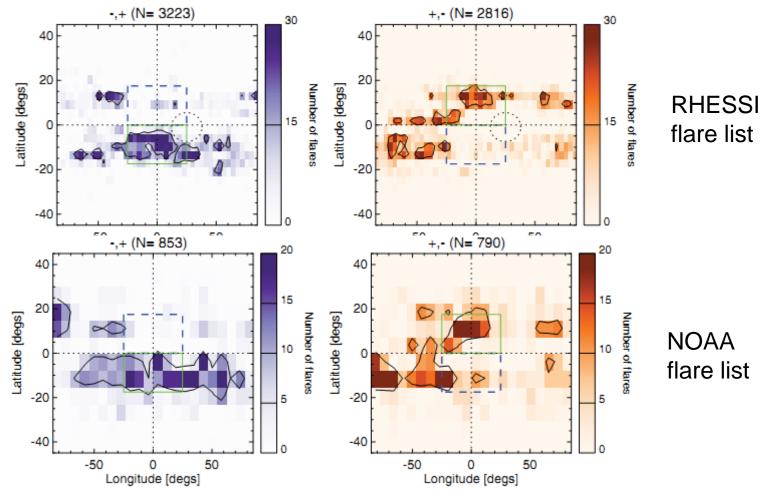
Animation of Nobeyama 17 GHz disk maps superposed on nominal (+,-) sector boundaries in a nominal odd solar cycle. The Hale boundary is in the Northern Hemisphere. The animation starts 8 days before the sector boundary is at Central Meridian [a bright hexagon will flash] and runs until 6 days after CM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

### Recent X7 Flare on Hale Boundary



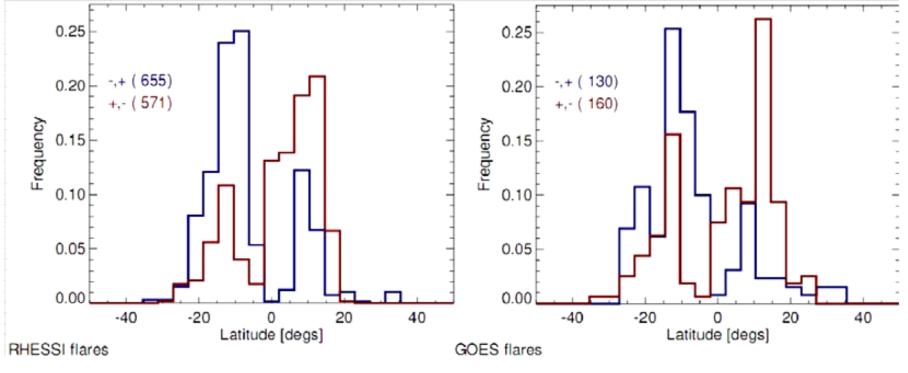
Is the magnetic field already 'stressed' when emerging if on a Hale Boundary? McClymont & Fisher (1989) make this case generally: the emerging flux adds already stressed magnetic fields directly to the lower solar atmosphere, storing the non-potential energy needed for flaring. 20

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



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

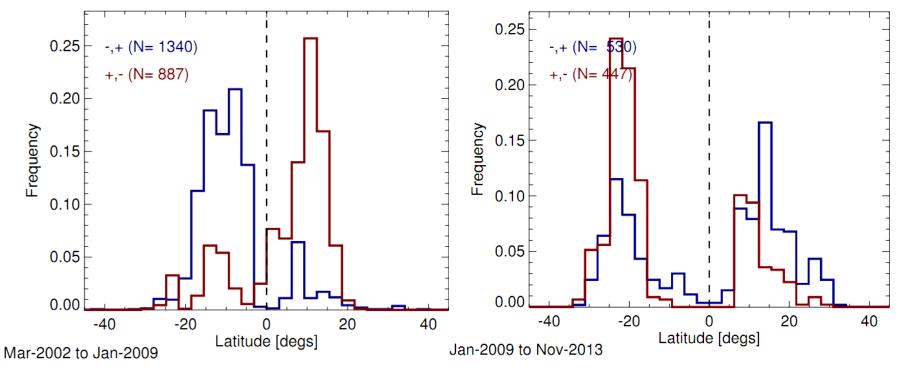
# Alternatively we can plot the latitude distribution of Flare Occurrence:



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

### 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 shortterm predictions of space weather.