L1

Asymmetric Solar Polar Field Reversals

Leif Svalgaard, Stanford Univ.
Yohsuke Kamide, Nagoya Univ.

Stanford, July 27, 2012

Slide 1

L1 Title page, authors Leif Svalgaard, Yohsuke Kamide
Leif, 7/26/2012

L2

（夕刊）　第3種郵便物認可

太陽活動 11年周期に異変？

「下り坂」のはずが依然活発

頻発する大規模フレア 過渡期を示す「両極N」

太陽の黒点付近が突然明るくなり、膨大なエネルギーをはき出すフレアという現象が最近、頻繁に観測されている。約十一年で一巡する太陽活動の周期はどのところを変調気味で、二年間も「ハイ」な状態が続いている。まぶしさの向こうで何が起こっているのか。

今月四日ごろから、相次ぐ大規模フレアで太陽から地球への粒子の流れがふえ、地磁気のあらしが起こった。米コロラド州ボールダーでは、太陽活動の変化を追う専門家会議の最中だった。会場は米海洋大気局（NOAA）の建物。別の階で地磁気などの担当官が予報に追われた。「会議の参加者がどっとつめかけ、最新情報をあさっていた。みんな興奮気味でした」と、居合わせた京都産業大理学部の上出洋介教授。

確かに今の太陽はちょっと変だ。活動の目安になる黒点数は一七〇〇年ごろから、ほぼ十一年周期で上下している。今回は八九年がピークのようにも見えたが、その後も落ち込まず、約二年間上がったままだ。

「そろそろ下り坂か」といろいろ、太陽フレアが頻発し始めた。郵政省通信総合研究所の平磯宇宙環境センターが集めた観測記録では、今月、大きなものだけで約十回も起こっている。

活動の水準を黒点数で見ると、前世紀半ば以降の周期の中で二、三位ぐらい。「さっと立ち上がり、かなりの高さに達し、しかも長く続いているのが今回の特徴」と国立天文台の桜井隆・助教授はいう。

磁気の様子は、太陽が今「過渡期」にあることを物語る。活動が盛んなころ、北を南が追いかける形になっている」と同大学の日江井榮二郎教授。

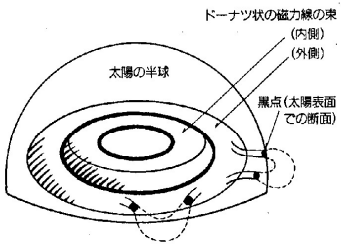
東大理学部の吉村宏和・助教授は、太陽活動の変動のなぞをコンピューターで探っている。太陽の対流層に着目、電気を帯びたガスの大がかりな対流や緯度と深さの違いによる回転のずれなどを考えに入れて、この層にできる磁力線の束の様子を描き出した。

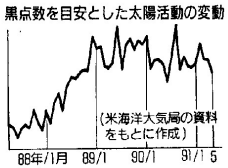
それによると、南北両半球に、ドーナツ状の磁力線の束が水平に一回りしている。ドーナツの内側では、逆向きの磁力線の新しいドーナツが次々に生まれ、古いものは表面近くに押し出される形になる。これが活動期だ。この古い太い束から細い束がはみ出し、太陽表面からとび出す。東の切り口が黒点だ。磁力線のひずみなどでフレアが起こる。

「コンピューターの計算で浮かんだ筋書きを手がかりに、太陽の内側を診断したい。表面振動の様子などを観測することで中身の様子がわかり、活動周期のなぞにも迫れるだろう」と日江井さんは期待している。

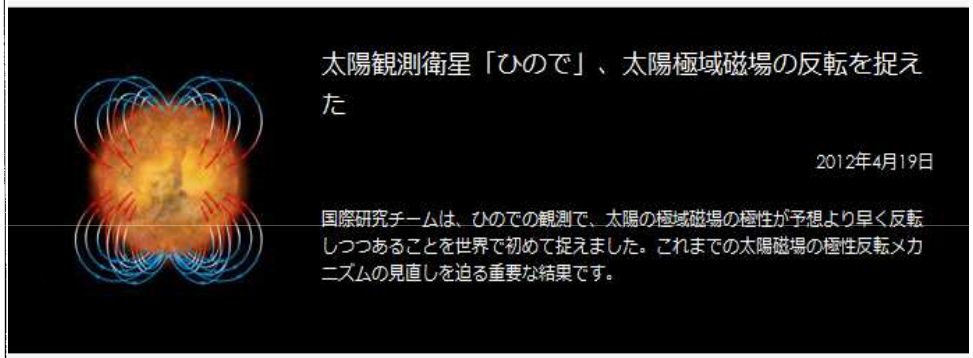
太陽フレア三つの顔

❶上空の爆発で、太陽表面が熱せられ、熱くなったガスの広がりが白く見える❷熱せられたガスが膨張し、上へ立ち上る❸ガスが冷え始め、磁力線に沿ってアーチ状に落ちて行く＝いずれも国立天文台提供。4日、太陽フレア観測鏡がとらえた画像から





Why are we writing/talking about reversals?



国立天文台と理化学研究所の研究者を中心とした国際研究チームは、太陽観測衛星「ひので」に搭載された可視光・磁場望遠鏡により、太陽極域の磁場観測を定期的に行ってきました。このたび、極域磁場の極性が予想より早く反転しつつあることを世界で初めて捉えました。

現在、太陽活動は極小期を過ぎ、やや上昇してきています。太陽の南北両極の極性は、2013年5月に予想される太陽活動極大期にほぼ同時に反転すると予想されていました。ところが、2012年1月の「ひので」による観測で、予想される時期より約1年早く北極磁場がほぼゼロ近くになっていることが発見されました。現在太陽の北極域では、逆極性の磁場が大規模に消滅しつつあり、太陽の北極磁場がまもなく反転すると予想されます。一方、南極は安定しており、極性反転の兆候がほとんどみられていません。これらの研究成果は、これまでの太陽極域磁場の極性反転過程に対する認識に変更を迫る、極めて重要な結果です。

This is why

"just because we have a shiny new satellite, doesn't mean we are seeing 'unprecedented events'" Keegan, 2011

Slide 2

L2 Japanese researchers [Hinode] recently claimed [right panel] that they had observed 'for the first time' a polar field reversal in only one hemisphere, and thus that the Sun is now a quadrupole 'for the first time', and that that meant an overthrow or severe revision of current dynamo theories. The left panel shows a [Japanese] newspaper clipping from 1991 reporting that the two poles had the same polarity for about two years. Perhaps the claim is due simply to unawareness of the literature and observations of the past. In this talk, we set the record straight.

Leif, 7/27/2012

L3

Outline and Roadmap

- Observing the Polar Fields
- Observing [or Inferring] Polar Field Reversals
- Observing Solar Activity
- Determining Activity Asymmetry
- Connecting Hemispheric Asymmetries in Activity and Reversals
- Longer-term Cycles and Asymmetries

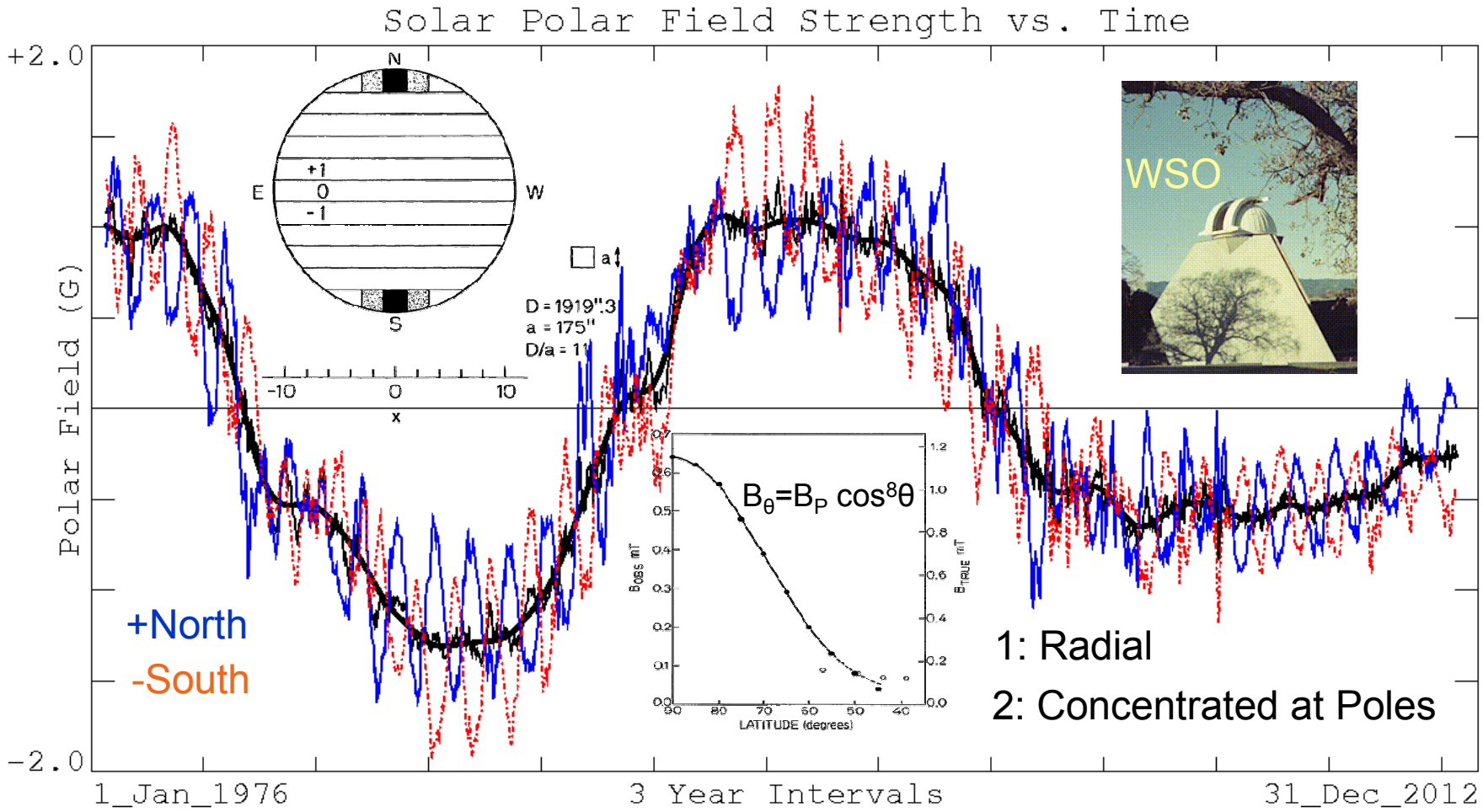
Slide 3

L3 Outline. Direct observations of solar polar magnetic fields and the polar field reversals inferred from those. Observations of hemispheric asymmetries in solar activity: sunspots, sunspot groups, and how to objective determine which hemisphere was the most active. Seeing that the asymmetry in activity simply leads to different times for reversals of the polar fields in the two hemispheres. Possible longer-term periods.

Leif, 7/26/2012

L4

Observing the Polar Flux



Slide 4

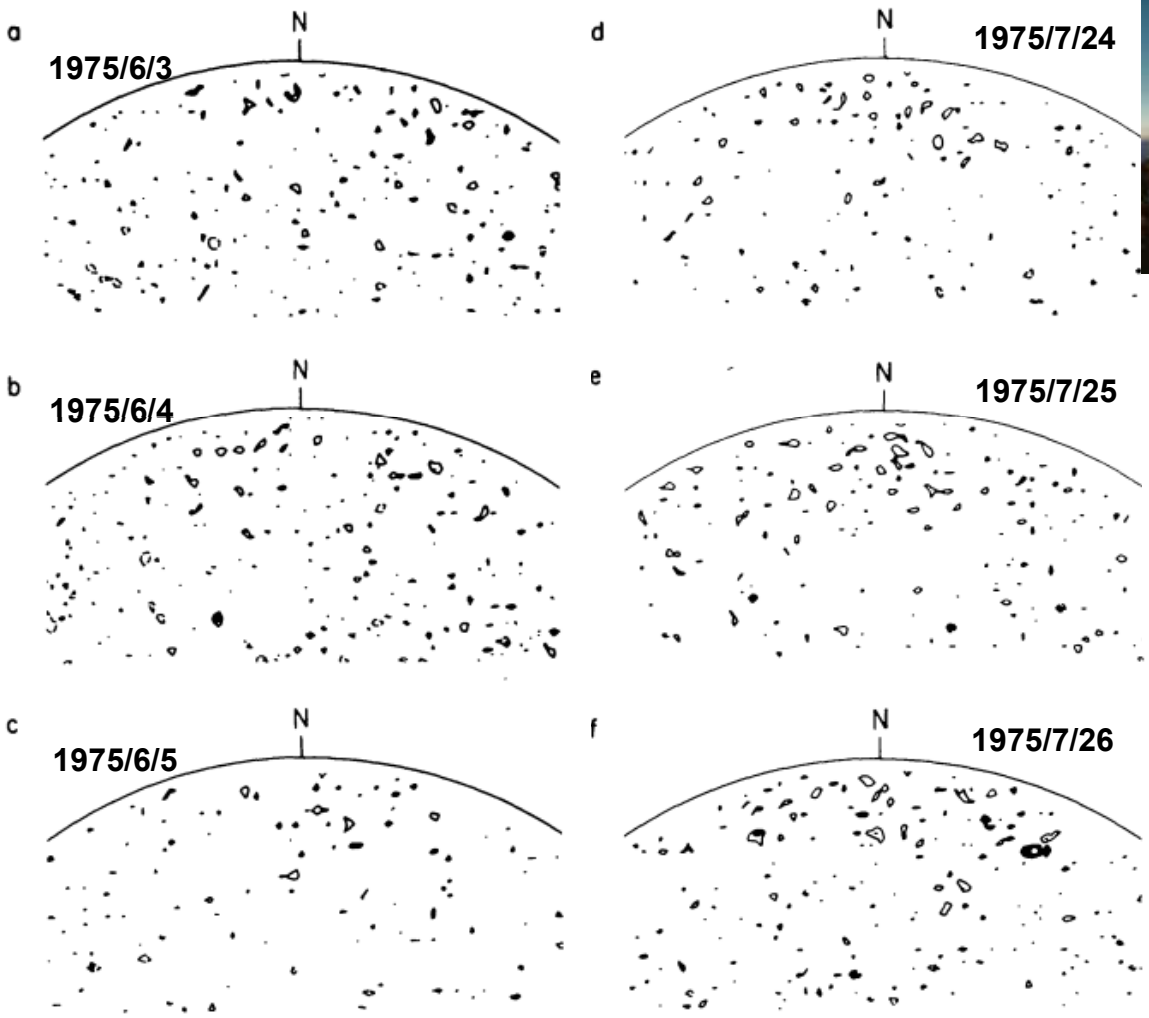
L4 First precision measurements of solar polar fields at Wilcox Solar Observatory [WSO].
Large aperture size [black rectangles show what we call the 'polar field']. The graph shows 30-day averages taken every ten days. We confirmed the strong annual modulation with the heliographic latitude of the Earth, which was already suggested by Babcock. We determined that the field was radial and showed a strong concentration towards the poles [the $\cos 8\theta$ dependence]. This result has been verified several times later with the exponent varying from 7 to ~10. Shows polar field strongest at solar minimum, reversing at solar maximum.

Leif, 7/26/2012

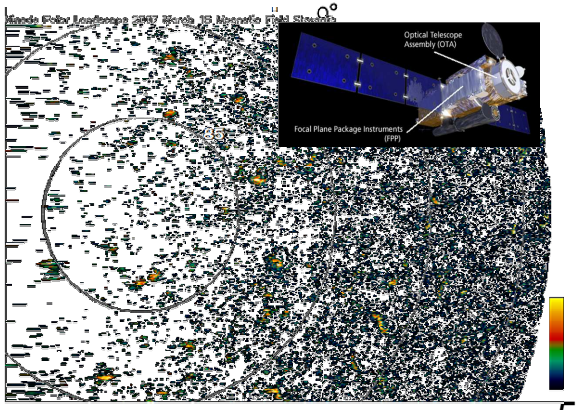
L5

Observing the Polar Fields

Scattered strong elements concentrating at pole



MWO: Stenflo, 1968



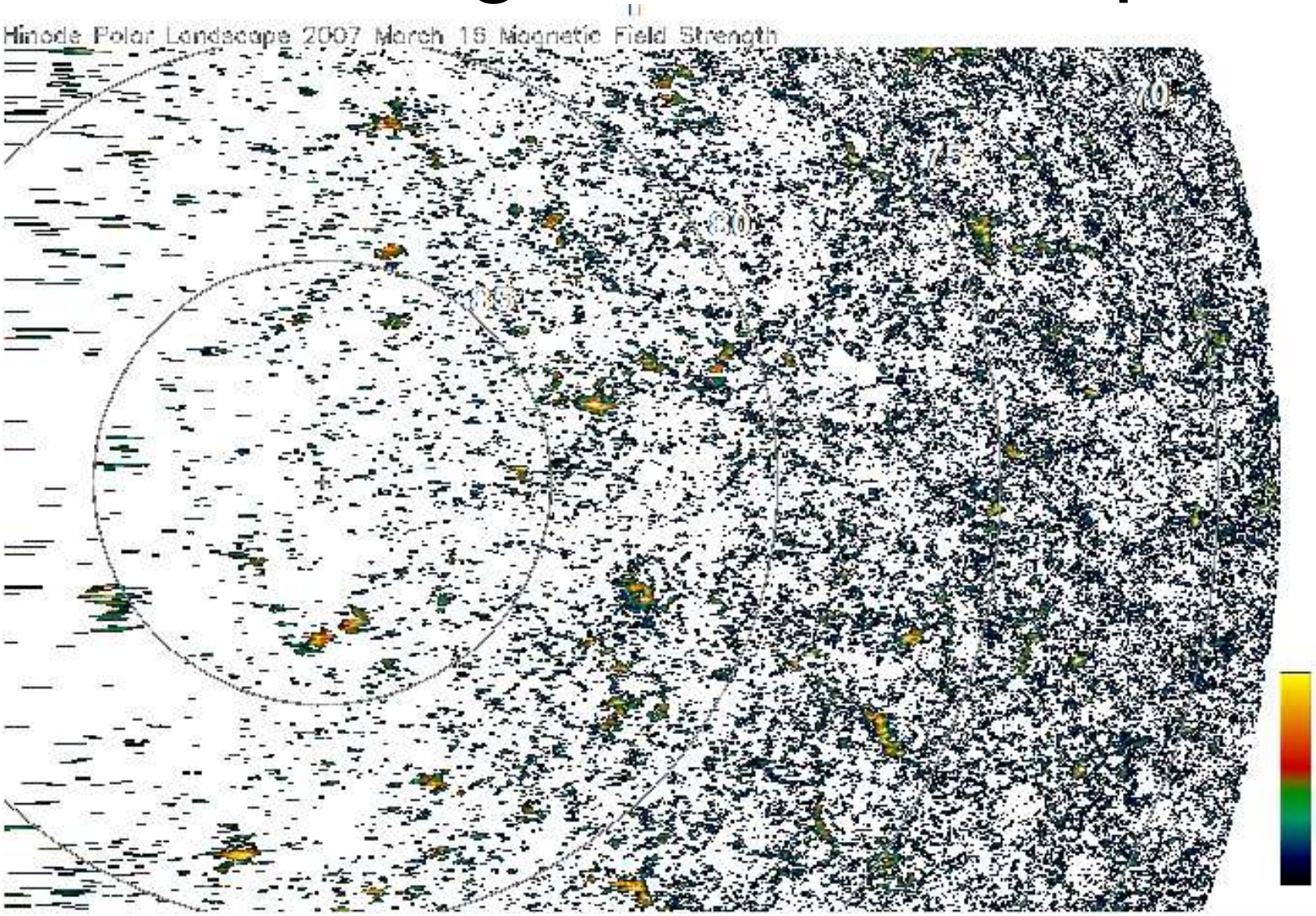
MWO: Howard, R., Solar Physics, 59, 243 (1978)

Tsuneta et al. ApJ, 2008

Slide 5

L5 Already the early observations showed non-uniformly scattered polar flux concentrations. Confirmed by the Hinode observations [lower right] which the next slide shows in detail.
Leif, 7/26/2012

Polar Magnetic Landscape



Tsuneta et al. ApJ, 2008

Slide 6

L6 The "Polar Magnetic Landscape" [2007-03-15] observed by Hinode showing about two dozens kilogauss field elements [with the same polarity]. Foreshortening makes it difficult to accurate measuring the field near the pole.
Leif, 7/26/2012

L7

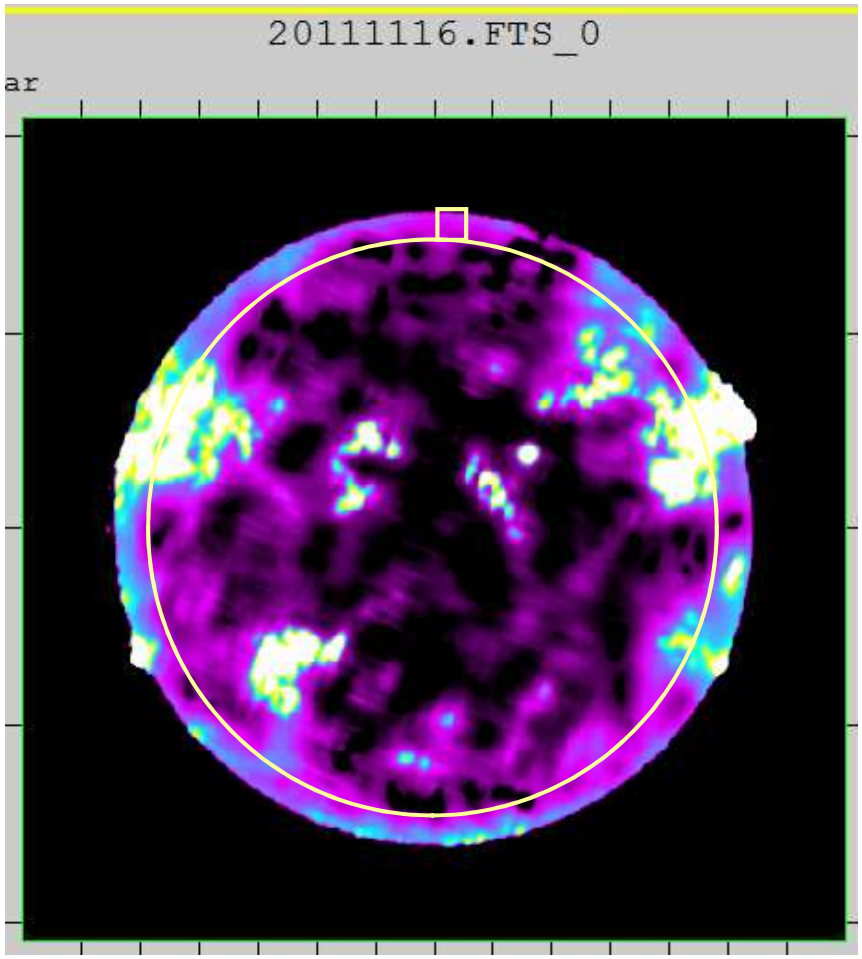
Another View of Polar Fields from the Nobeyama Radioheliograph

Slide 7

L7 The Nobeyama Radioheliograph provides an alternative way of assessing the polar fields as we shall now show.
Leif, 7/26/2012

L8

Image of 17GHz Emission, beam width 10”



ν17 GHz = λ1.76 cm

v_e = B (Tesla) · 28 GHz

17 GHz is 3rd harmonic v_e for 2000 G

1. General Limb brightening
2. Active regions bright

A. Gyro-resonance is thought (?) to result as 3rd harmonic of 2000 G

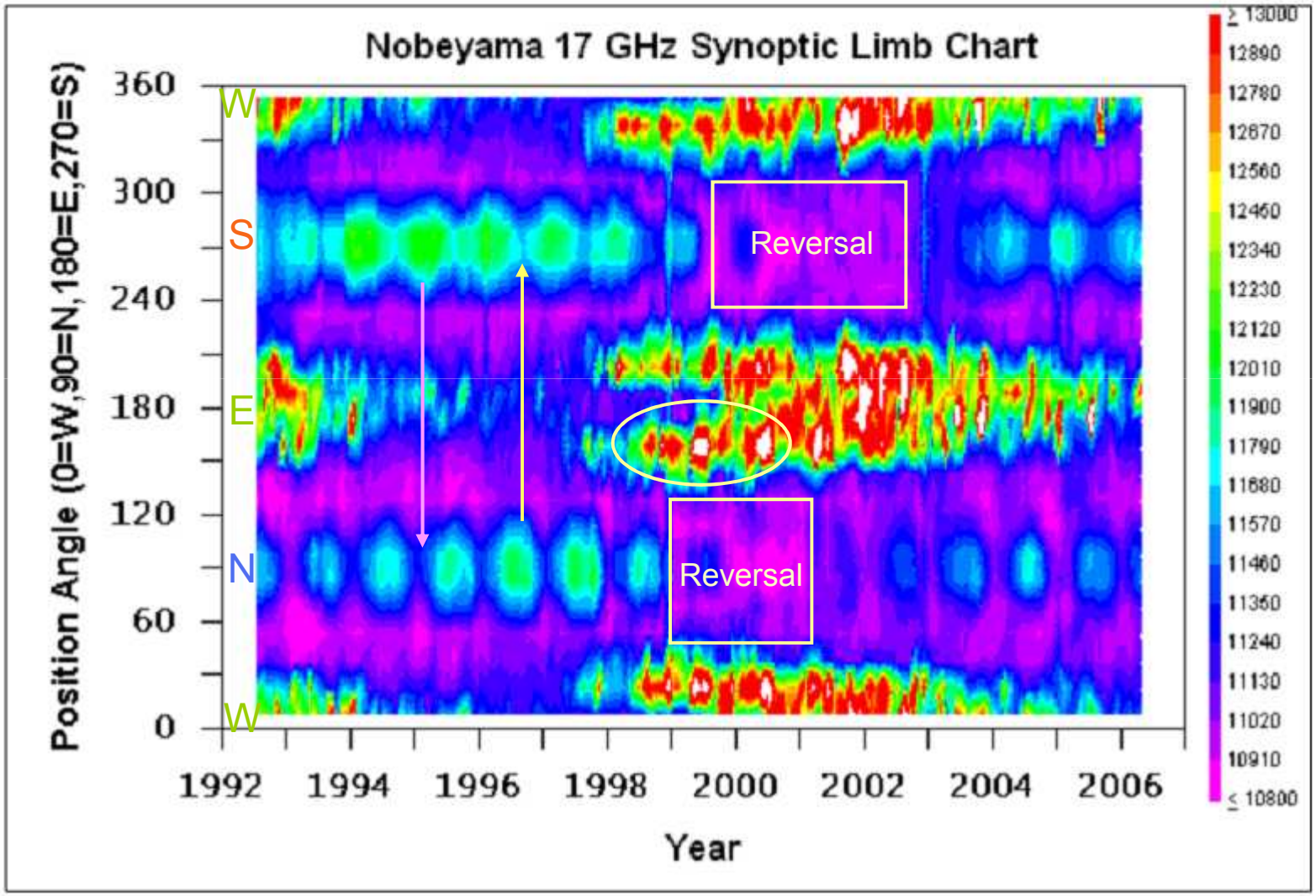
B. Also Bremsstrahlung from hot atmosphere [10,000 – 13,000 K]

Slide 8

L8 Nobeyama observes at 17 GHz [λ1.76 cm]. The data is shown as 'brightness temperature', TB. Active regions are hot and bright and there is general limb brightening [annulus] as expected for an optically thin medium. We can quantify the limb TB by computing the average brightness temperature in a small area [yellow-outlined square] as a function of position angle around the limb.
Leif, 7/26/2012

L9

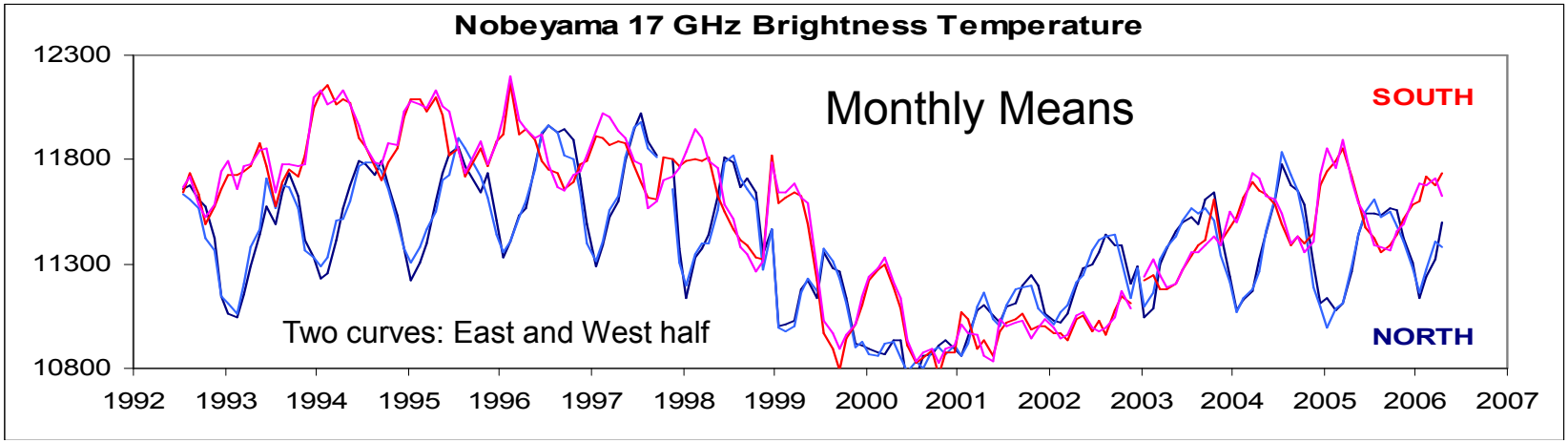
Evolution of Patches over the Cycle

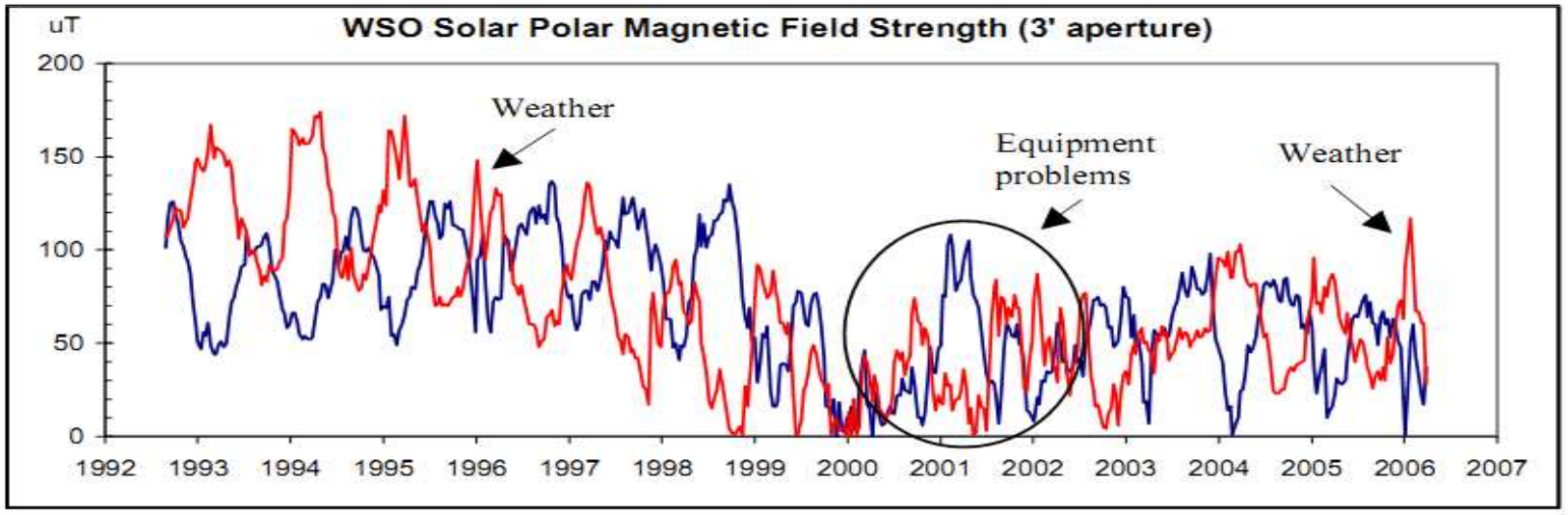


Slide 9

L9 TB as a function of position angle in 1992-2006. The 'butterfly' diagram of solar activity is clearly seen [East limb in the middle]. The poles [N and S] have hot [bright] patches that show a yearly modulation just like the magnetic field. At solar maximum or shortly thereafter [2000-2001] the polar bright patches disappear [as do the magnetic field concentrations] when the poles reverse polarity.
Leif, 7/26/2012

Proxy for Polar Magnetic Field



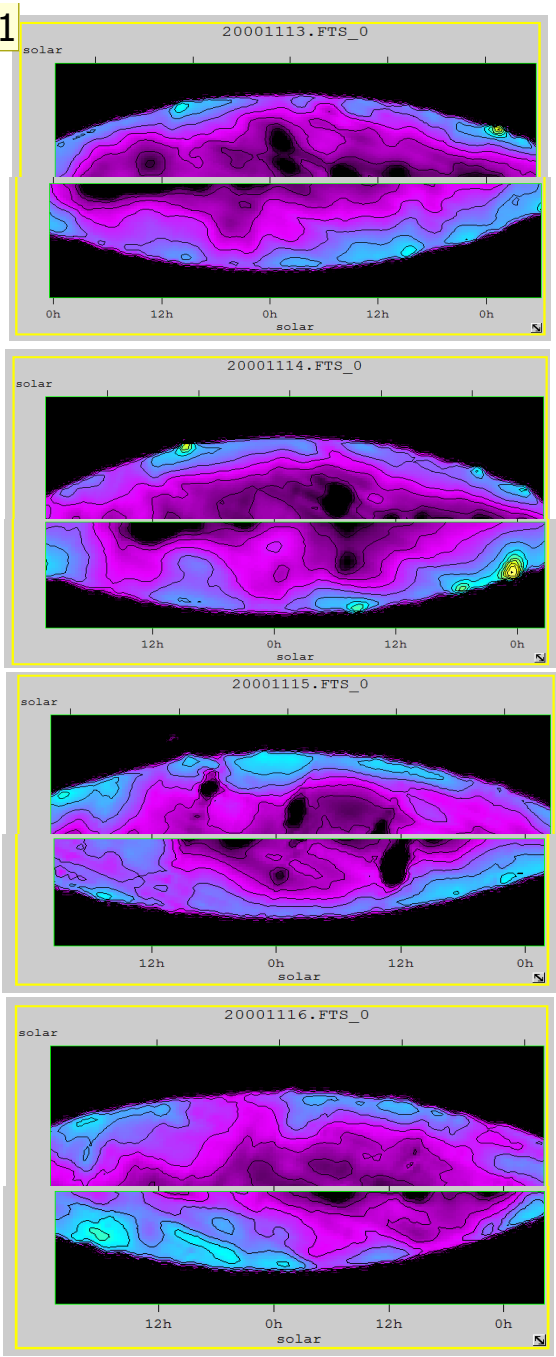


This shows that the brightening is not just general limb brightening, but is concentrated at the pole just as the polar magnetic field (is thus due to the field?)

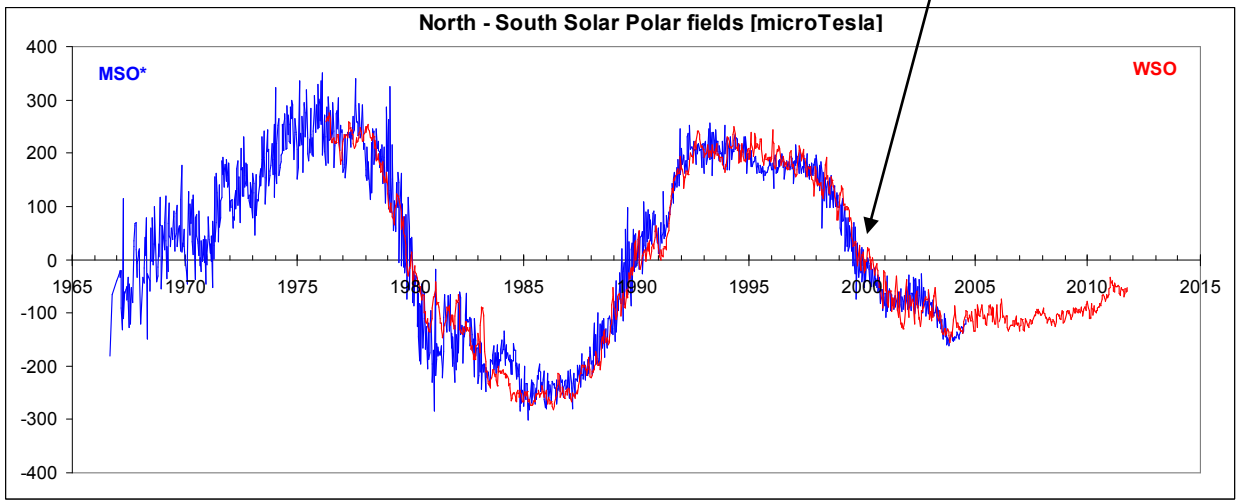
Slide 10

L10 The correlation between 17 GHz brightness temperature and magnitude of the WSO polar fields. South pole shown in red colors, North pole in blue.
Leif, 7/26/2012

L11



No Bright Patches at Solar Maximum, 2000

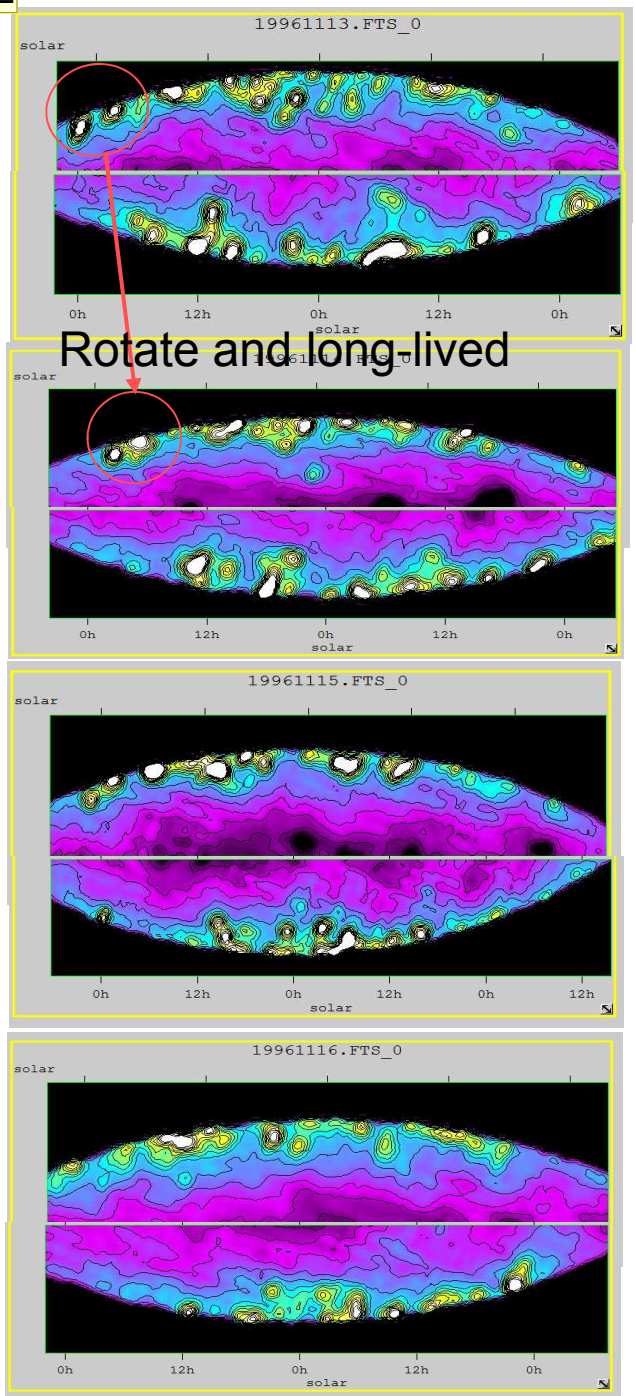


Only a few scatted, weak patches. So no magnetic flux of the kind that makes patches [kG], thus the polar fields are not an equal mixture of opposite polarities. There aren't any.

Slide 11

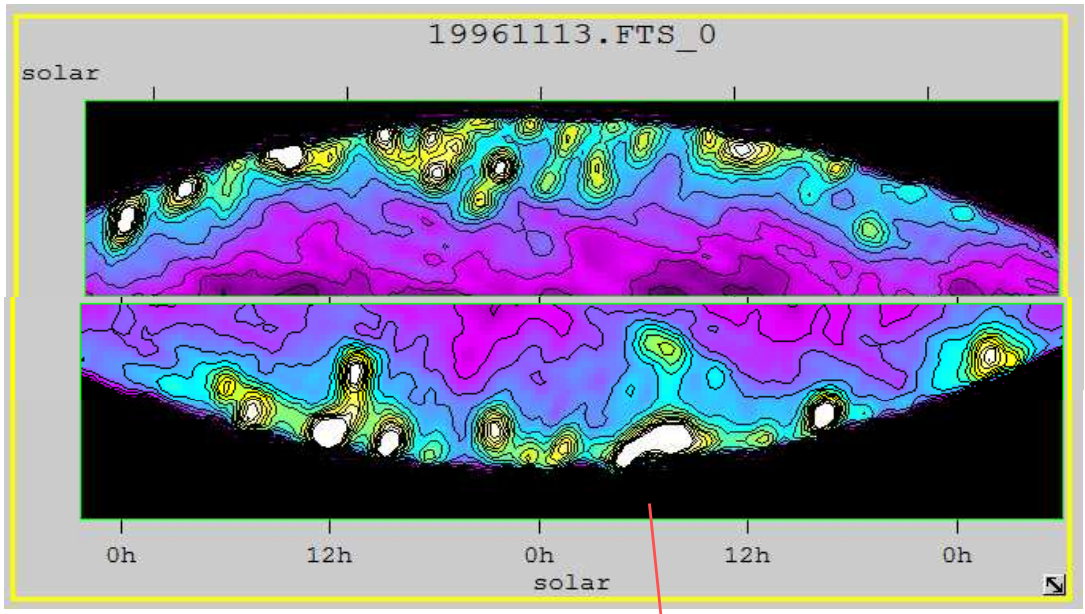
L11 No bright patches at solar maximum. So, no magnetic flux of the kind [kilogauss] that makes patches, thus the polar fields at maximum are not an equal mixture of opposite polarities. There simply aren't any.
Leif, 7/26/2012

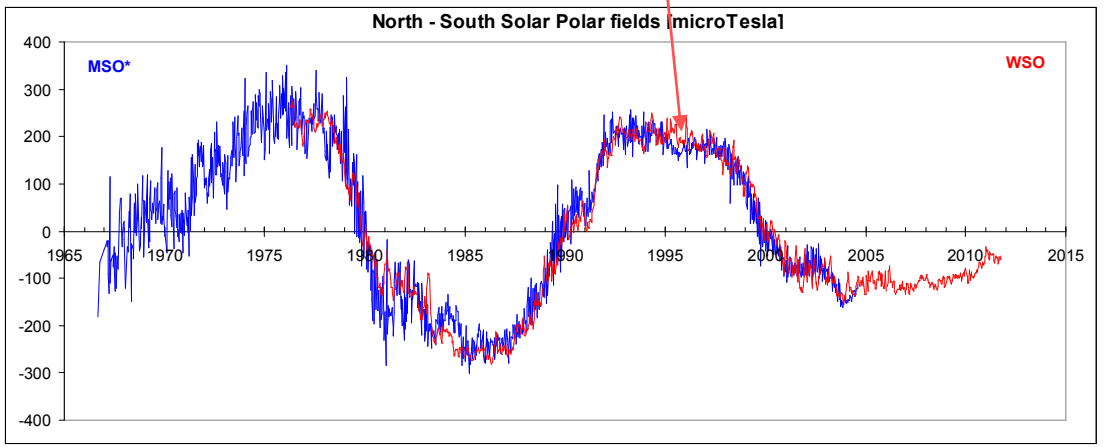
L12



Rotate and long-lived

But at Solar Minimum, Oh Boy!



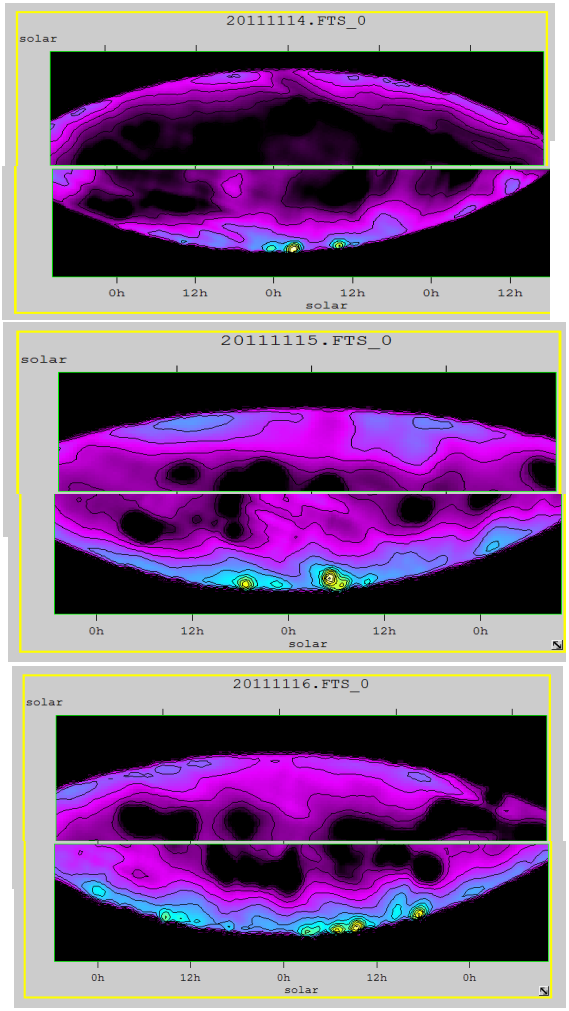


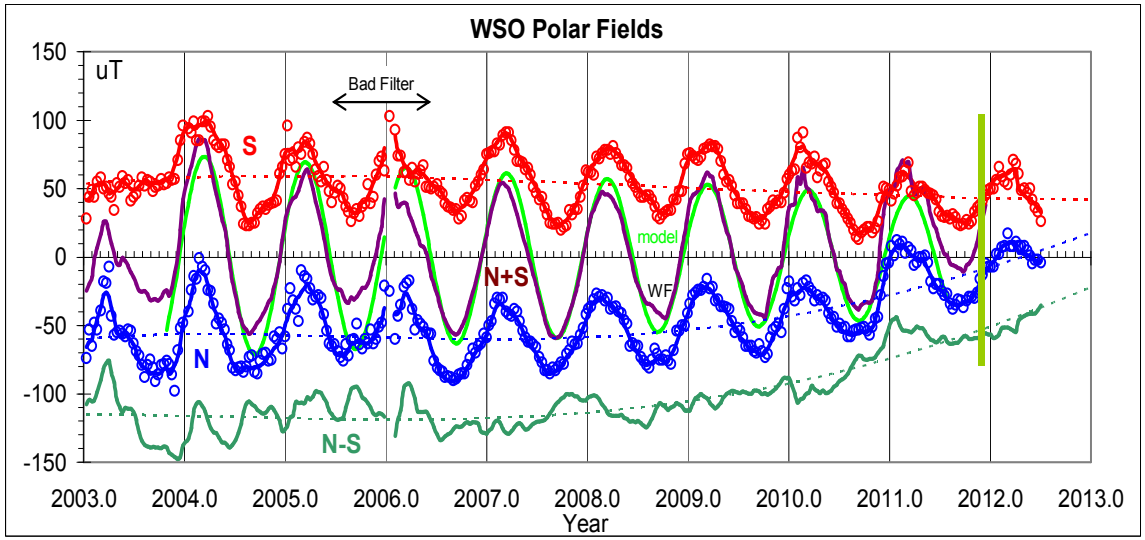
Slide 12

L12 At solar minimum the polar fields are strong and the polar microwave patches are numerous and hot. The patches live long enough to allow determination of solar rotation. The MWO/WSO polar fields are shown at lower right.
Leif, 7/26/2012

Magnetic Flux in the Polar Caps

2011-11-14 to 16





Average flux above 55°; North is now reversing.

Question: At solar maximum, are the polar caps, when reversing field, covered with equal amounts of opposite polarity magnetic fluxes or isn't there any flux?

Answer: There isn't any.

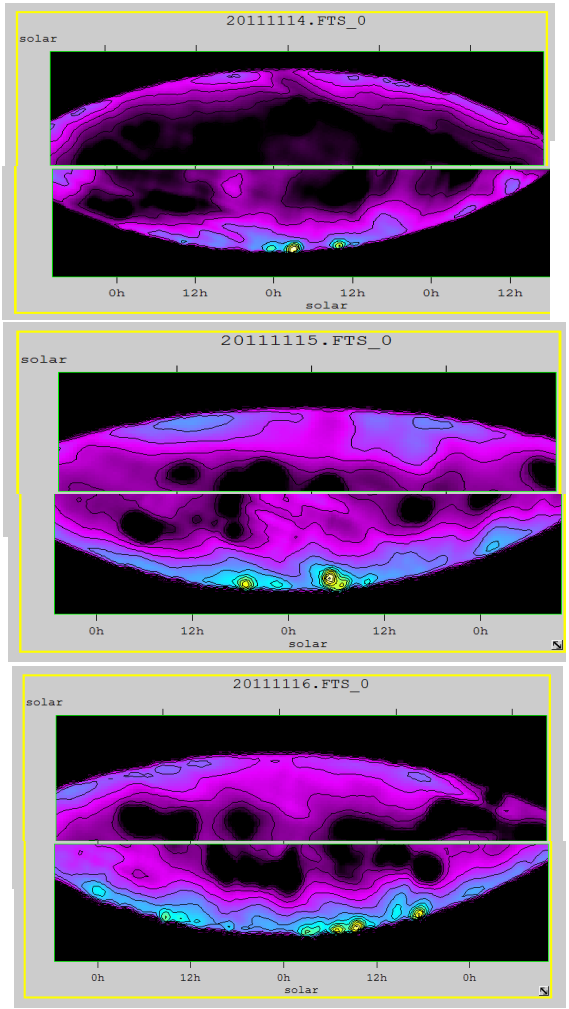
Slide 13

L13 Approaching solar maximum, the patches disappear. There are none left at the North Pole on 2011-11-14 to 16 [left panel]. The magnetic field in the North is also disappearing [at green vertical line on the WSO graph].
Leif, 7/26/2012

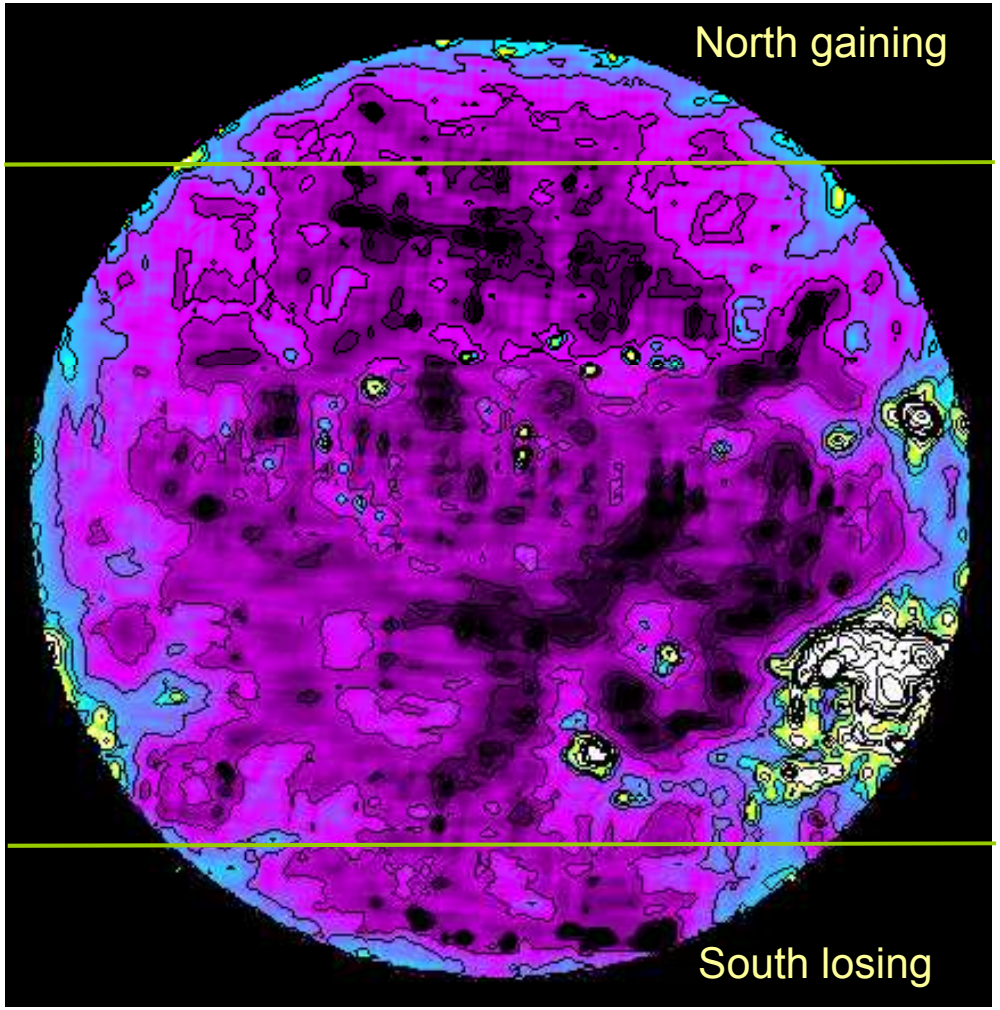
L14

Flux in the Polar Caps Rebuilding

2011-11-14 to 16



2012-07-16



Slide 14

L14 Eight months later [i.e. now], the South Pole has begun to lose its patches, while [new polarity] patches begin to appear in the North.
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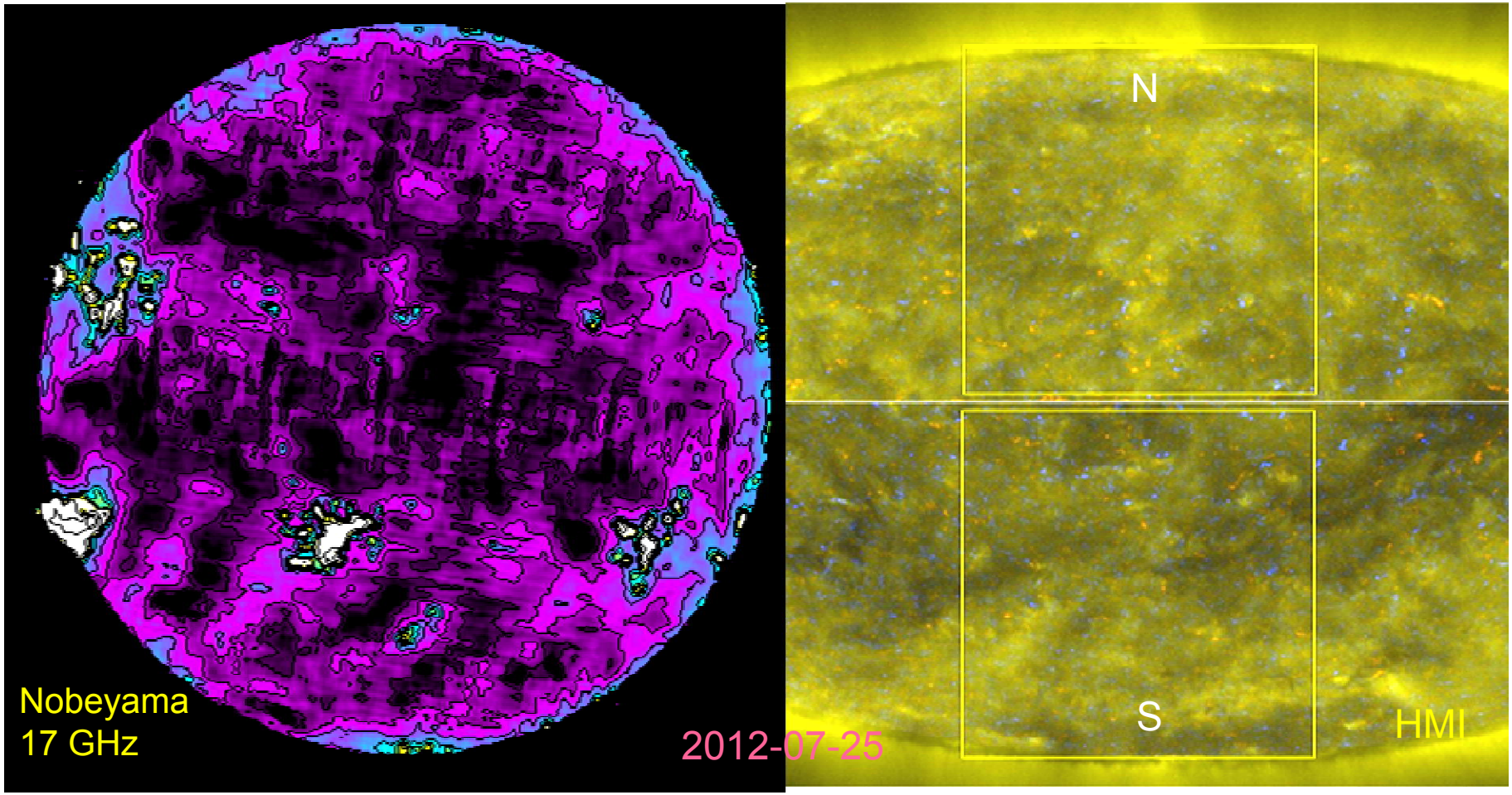
HMI Indicates Both Poles Now Positive

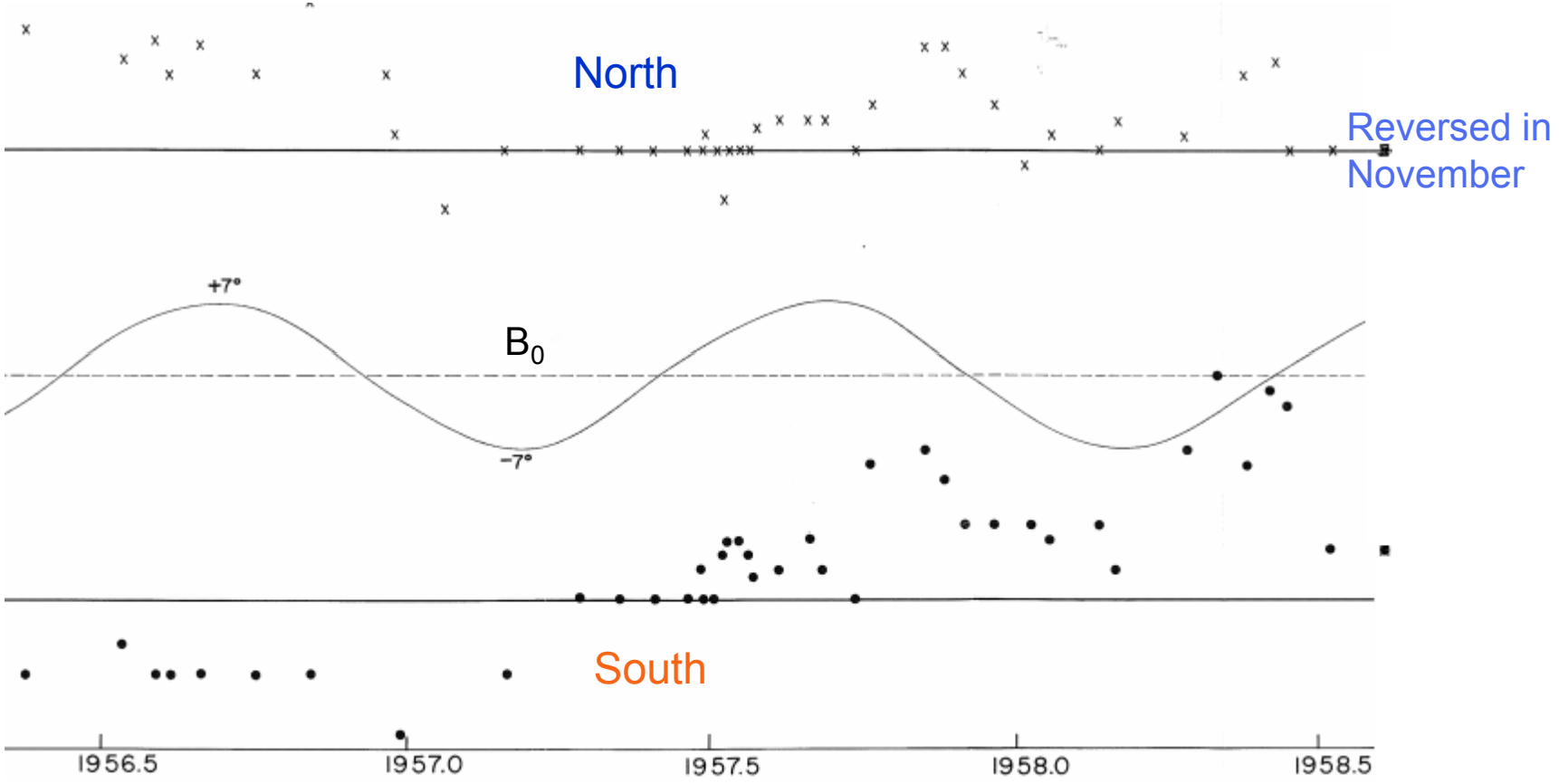


Slide 15

L15 SDO's HMI instrument shows that the dominant polarities in both WSO-size apertures [yellow squares] have become 'orange' [i.e. positive – BTW a poor choice of color scheme, deviating from the long-established convention: blue = positive (out of surface), red = negative (into the surface)]

Leif, 7/26/2012

Babcock's Discovery of Polar Field [Asymmetric] Reversal, 1959



"Signs and average intensities of the sun's polar magnetic field. *Above*, north polar zone; *bottom*, south polar zone; *center*, earth's heliographic latitude"

Slide 16

L16 Babcock discovered in 1959 that the South Pole clearly revered sign in early 1957, but that the North Pole remained positive until November, 1958 [not shown in his Figure]. This was a real surprise and may have been important for his 1961 solar cycle model.
Leif, 7/26/2012

Waldmeier Related the Asymmetric Reversal to Asymmetry in Activity

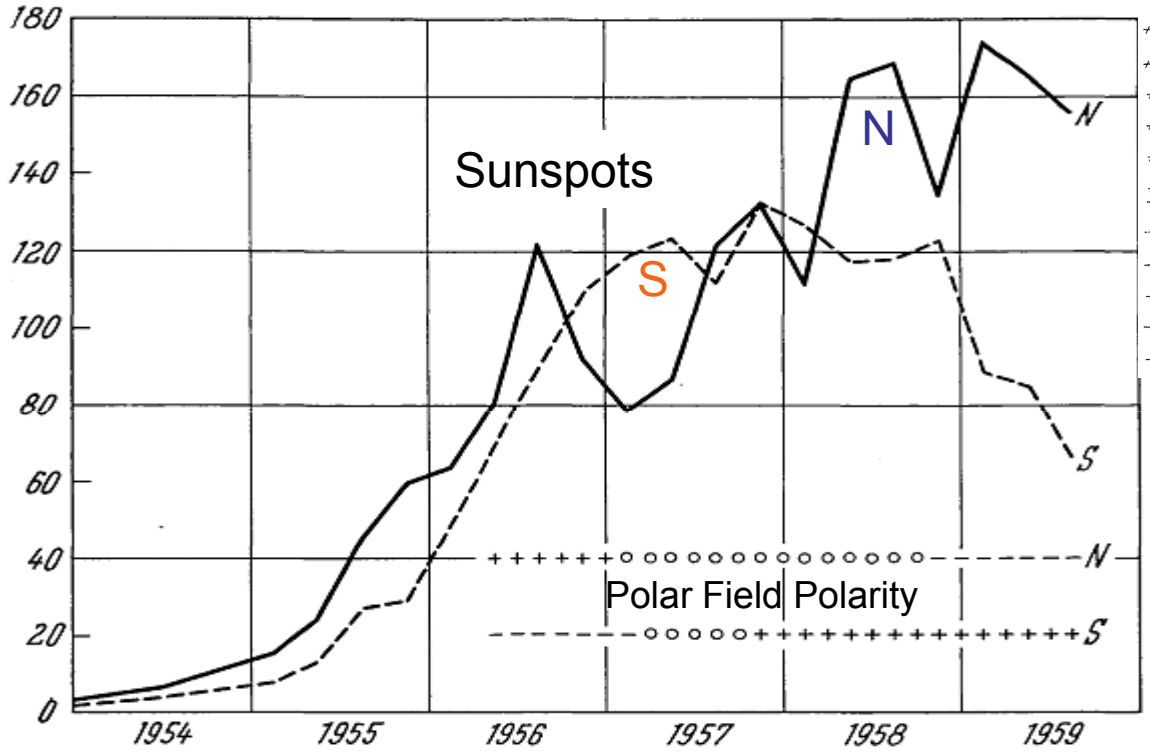
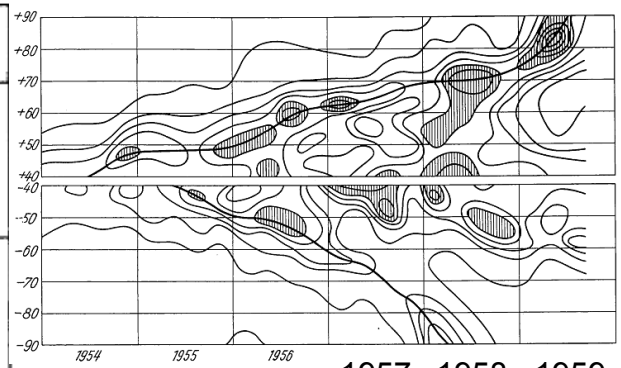


Abb. 1. Verlauf der Fleckentätigkeit und Variation des polaren Magnetfeldes



Occurrence of Prominences:

"Rush to the Poles"

As Waldmeier (21) has pointed out, if the northern and southern hemispheres are considered separately, the sunspot numbers reached a maximum in the south about one year earlier than in the north, and this suggests a physical connection with the earlier reversal of the south polar field. Waldmeier (1960) quoted by Babcock (1963)

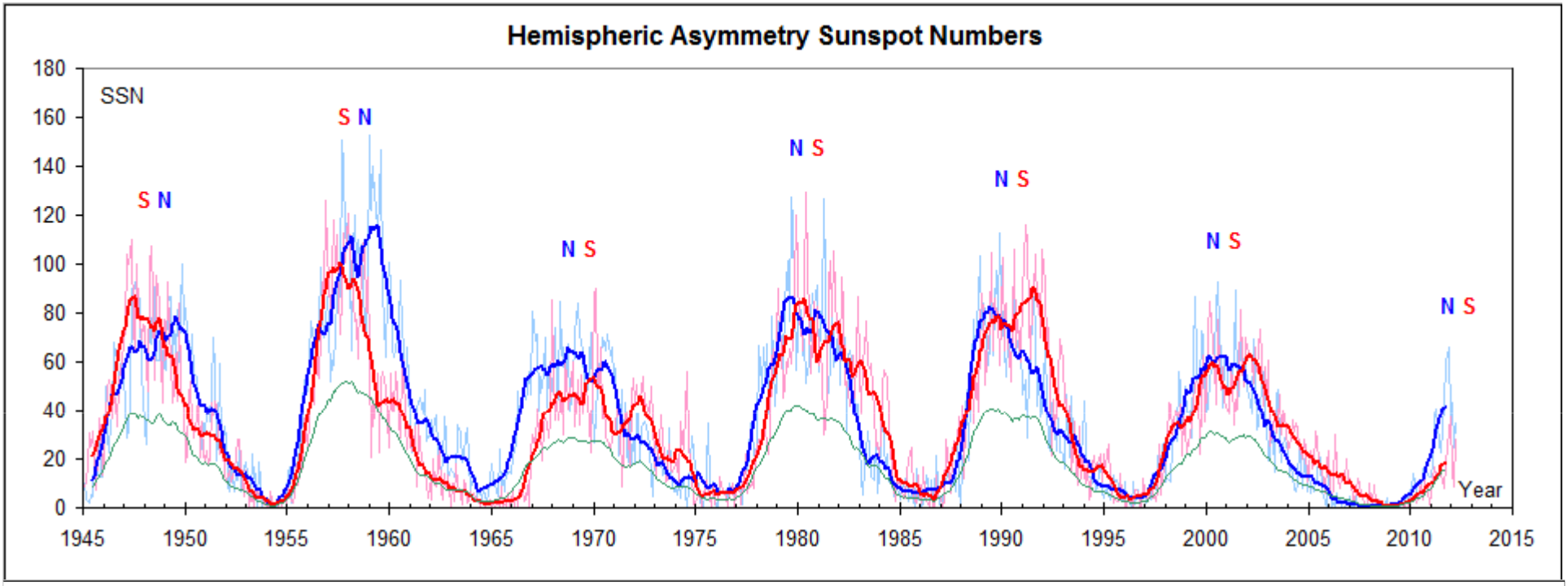
Slide 17

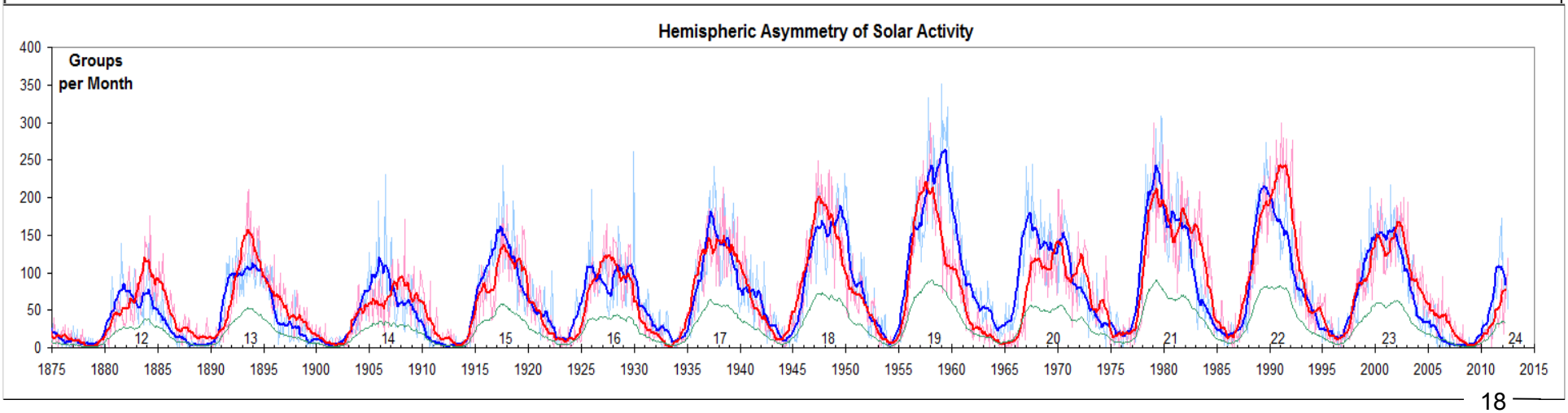
L17 Waldmeier quickly suggested that the different times of reversals [as measured by Babcock] were simply a consequence of a corresponding asymmetry in solar activity. The 'Rush to the Poles' shown by his measurements of occurrence of prominences supported that the polar fields had reversed, as Waldmeier had already suggested that filaments and prominences lie over magnetic neutral lines.

Leif, 7/27/2012

L18

Asymmetric Solar Activity



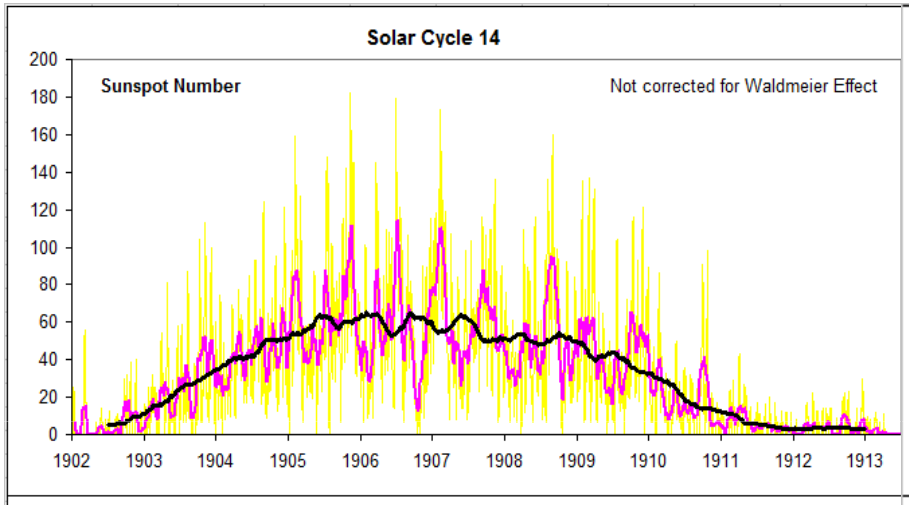


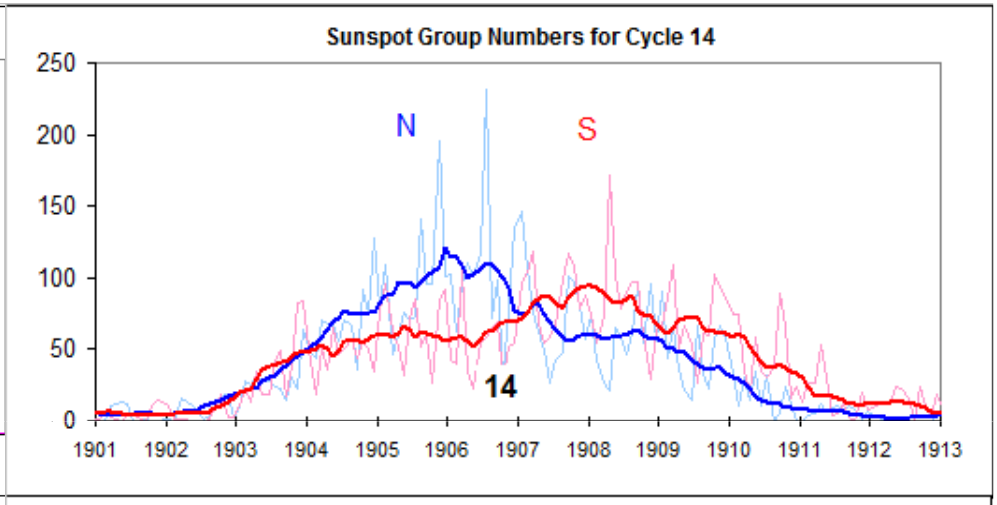
Slide 18

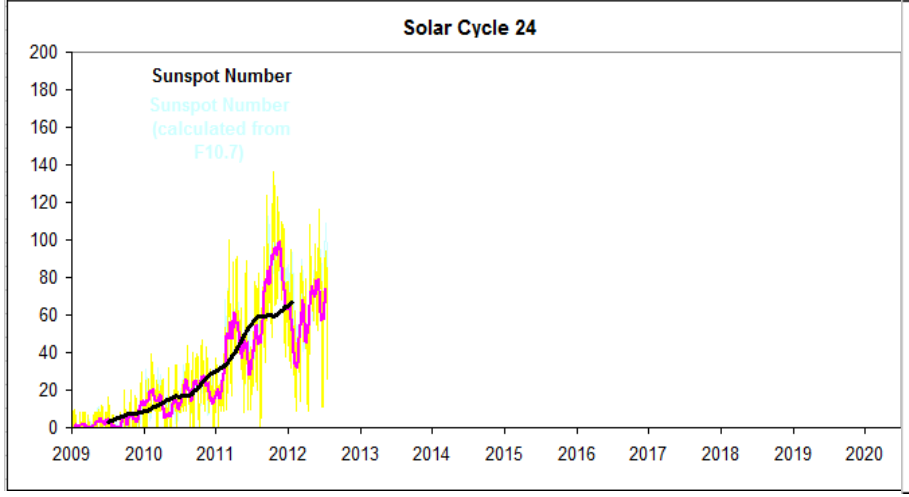
L18 Upper panel: Monthly sunspot numbers separately for Northern Hemisphere [blue] and Southern Hemisphere [red]. Heavy lines are running one-year averages. The thin green line is the total smoothed sunspot number, scaled down by a factor of five. The letters N and S denote which hemisphere was most active around solar maximum. Lower Panel: Same, except using the number of active regions per month [sunspot groups] from the Greenwich [and later] catalog. The regions are counted once per day.
Leif, 7/26/2012

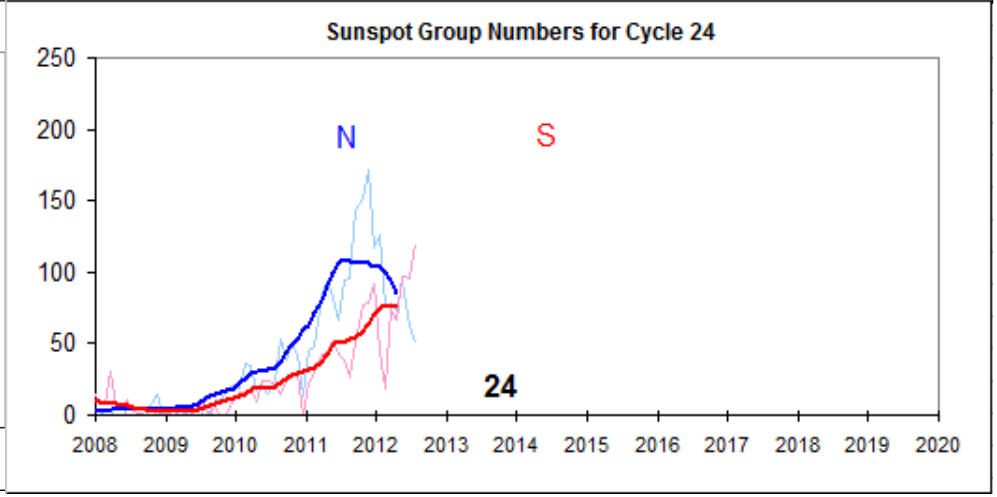
L19

Comparing Cycles 14 and 24





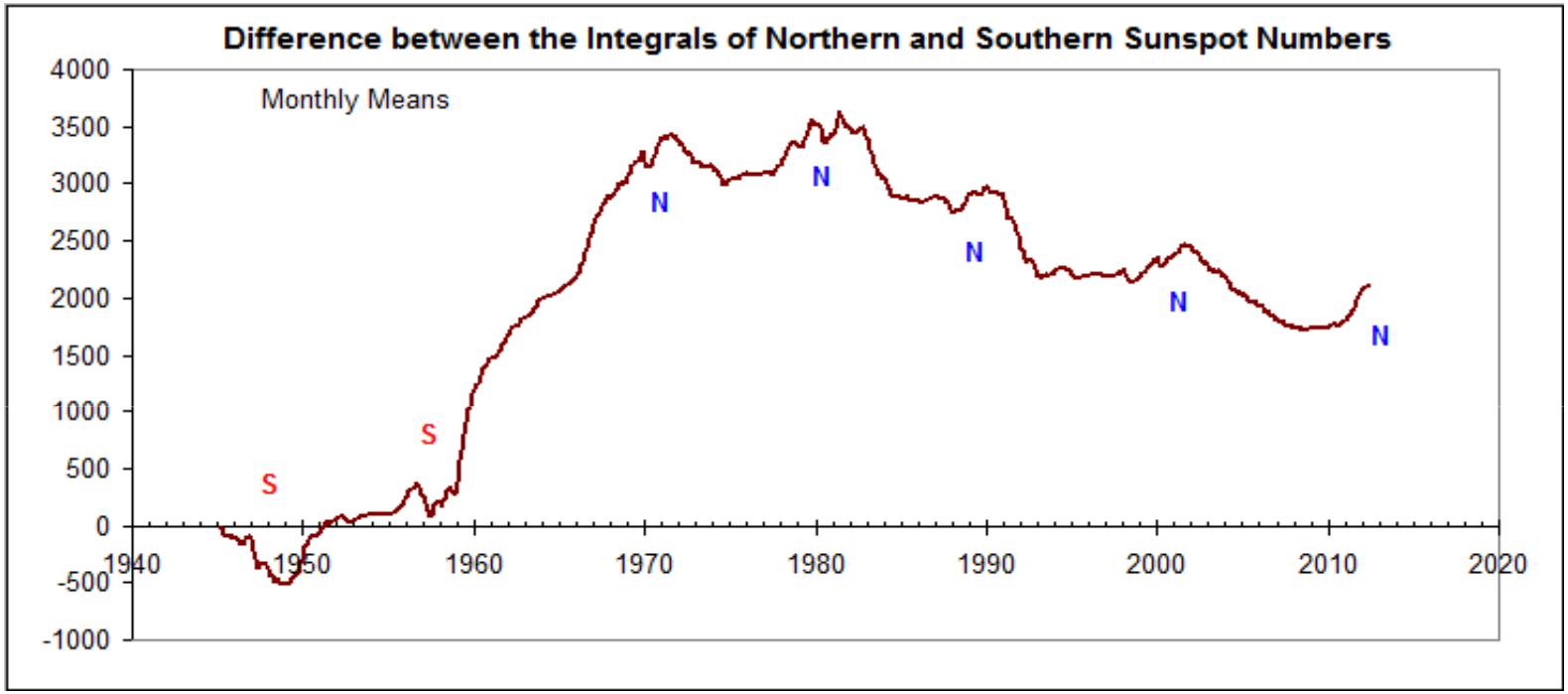




Slide 19

L19 Solar cycle 24 is beginning to look like cycle 14 [as 23 also looked like 13]. Left panel shows daily whole-disk sunspot numbers [yellow], 27-running mean [red], and 1-yr running mean [black]. Weak cycles seem to have those wild swings. Right panel compares the two cycles separately for each hemisphere [North = blue, South = red] determined from the total number of sunspot groups per month.
Leif, 7/27/2012

Quantifying the Asymmetry



$$D(t) = \int_{x=1945}^{t} SSN_{North}(x)\,dx - \int_{x=1945}^{t} SSN_{South}(x)\,dx$$

The integral of activity is a convenient determining factor, as it is the total amount of flux migrating to the poles that matters.

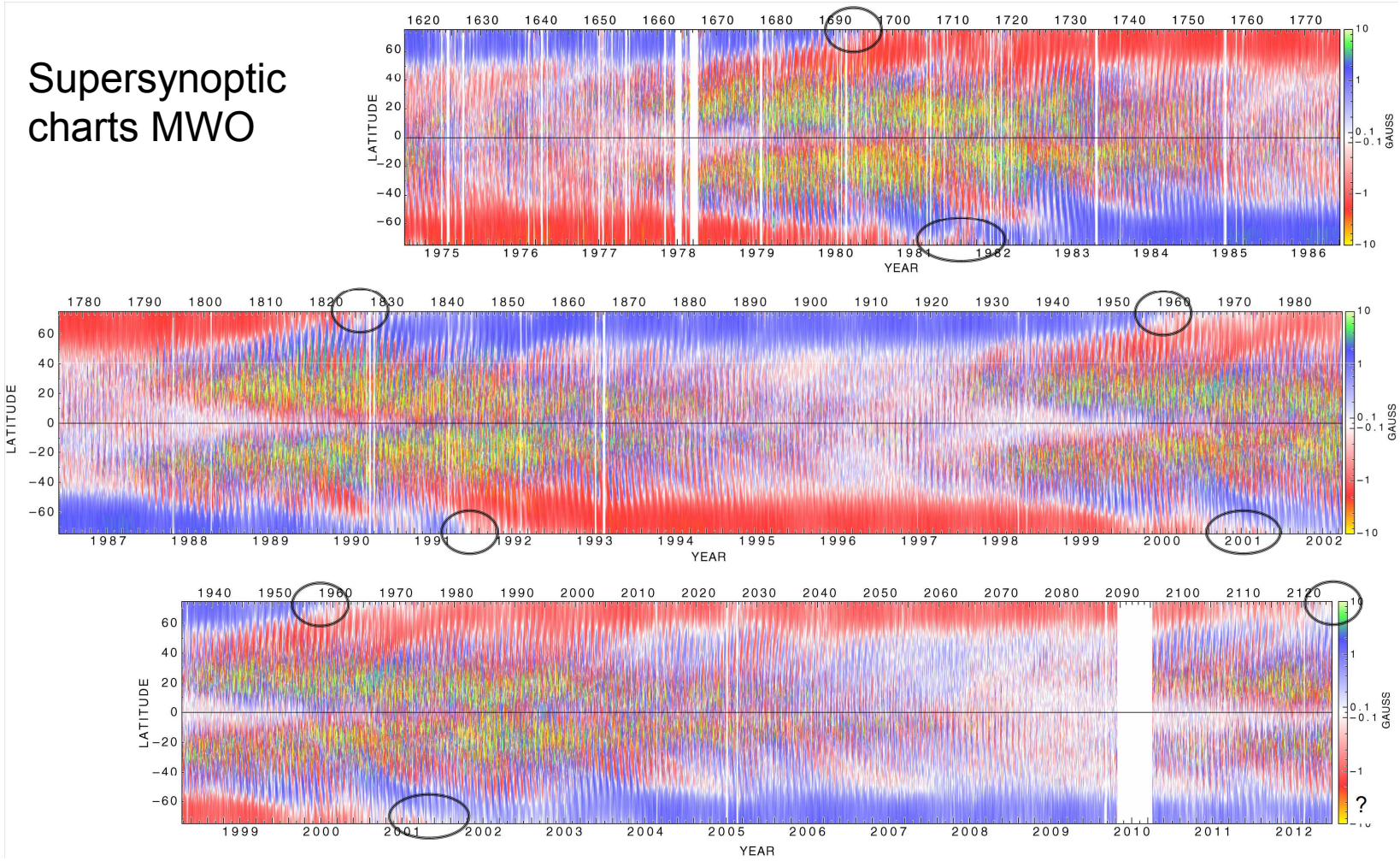
Slide 20

L20 To determine which hemisphere supplies most magnetic flux around solar maximum we integrate the sunspot number in each hemisphere from 1945 on. The difference between the North and South integrals will have a dip if the South supplied most flux and a bump if the North did.

Leif, 7/26/2012

Observed Polar Field Reversals

Supersynoptic charts MWO



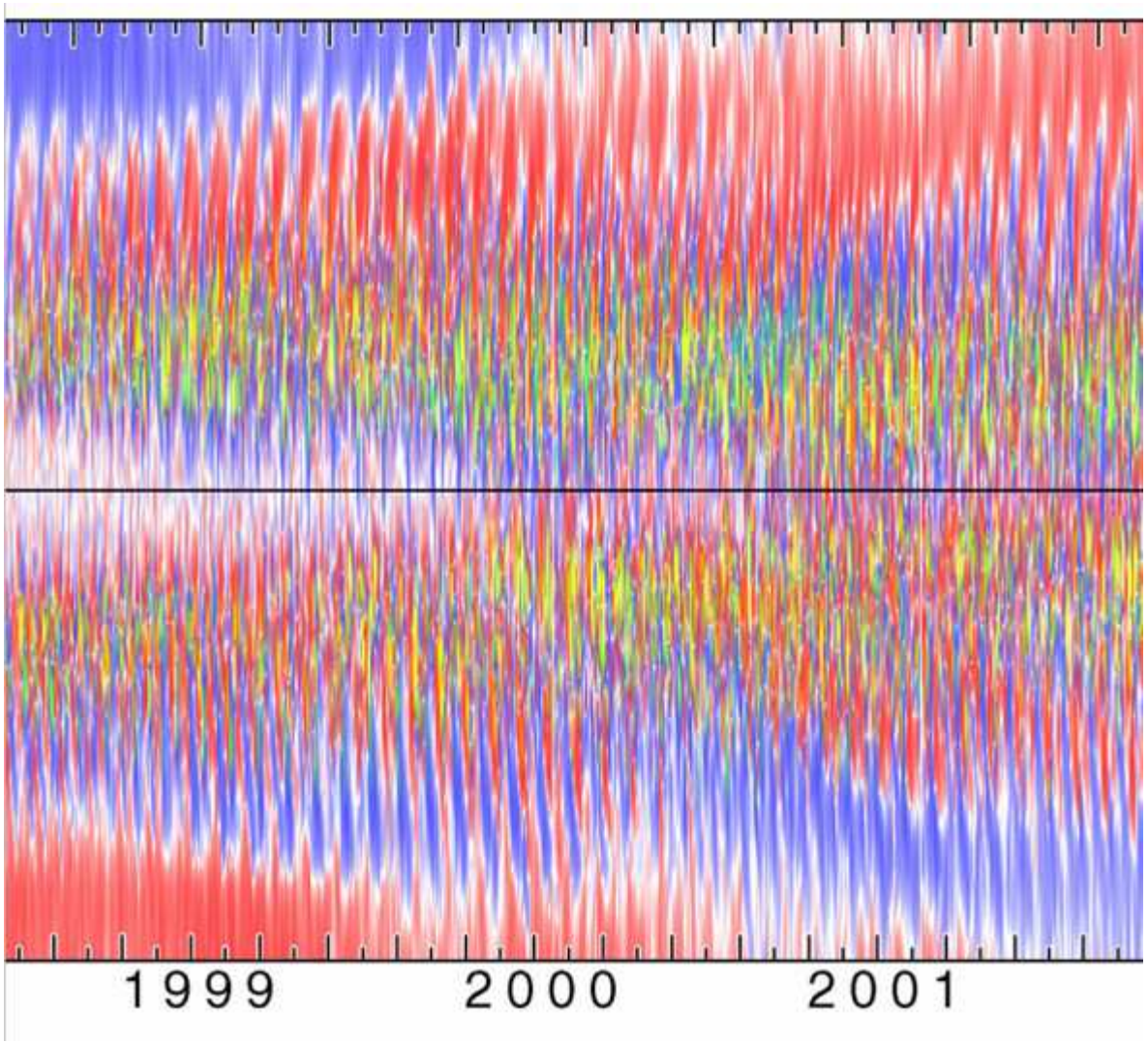
MWO: Roger Ulrich, 2012

Slide 21

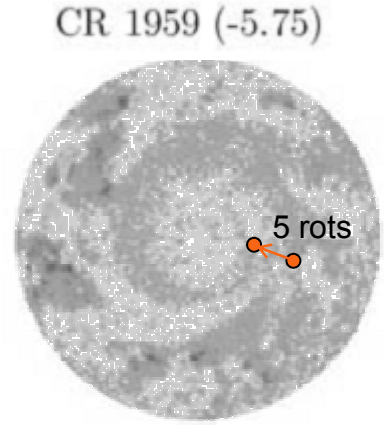
L21 On the Supersynoptic charts from Mount Wilson [MWO] the polar field reversals are clearly seen [marked with ovals]. A supersynoptic chart is a series of normal synoptic charts strongly compressed in time and time-reversed. Carrington rotations are denoted on the top of each strip. Negative polarity [towards the surface] is read, positive is blue. Note the half-dozen surges of flux that are involved in reversing a pole.

Leif, 7/26/2012

Poleward Migration of Flux



Flux of **both** polarities move towards the pole. There is little evidence for significant amount of flux crossing the equator



Durrant & Wilson, 2003

Slide 22

L22 As an aside [but important, I think], the charts clearly show that both polarities migrate towards no poles, with very little crossing the equator. Seen from the pole the migrating flux patterns make two spirals, one of each polarity, if plotted in the fixed Carrington longitude system. In a system rotating with the plasma, the migration is simply polewards.
Leif, 7/26/2012

This is no News, of Course

B.1 Polar Crown Filaments and the Polar Magnetic Field, K. TOPKA and R. L. MOORE, Caltech, BBSO, and B. J. LABONTE and R. HOWARD, Mt. Wilson Obs., Carnegie Institution of Washington. We report on the results of a follow up study to the recent results of Howard and LaBonte (submitted to Solar Physics) concerning the evolution of solar photospheric magnetic fields

....

conclude that the observed behavior of polar crown filaments during the solar activity cycle supports the results of Howard and LaBonte in that the solar polar magnetic field arises from discrete injections of field from active region latitudes and that there exists in the sun a meridional flow. We further conclude that magnetic field of both polarities must be migrating poleward, but that the following polarity dominates slightly.

SPD Meeting, 1980, BAAS, 12, 893, B1

Slide 23

L23 This is, of course, no news. From AAS meeting in Taos NM, 1980. Both polarities must be migrating polewards. Also, note the finding that "the solar polar magnetic field arises from discrete injections of field from active region latitudes"

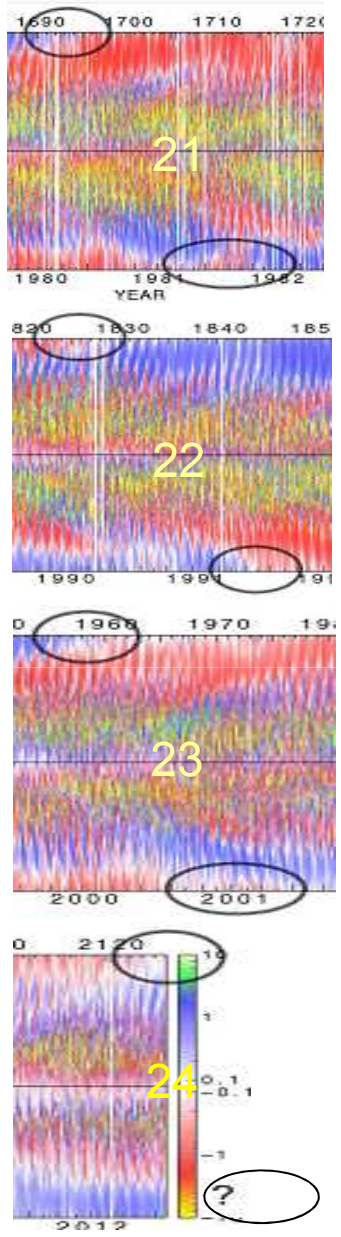
Leif, 7/26/2012

Neither are the Reversals due to Migrating of Fields

Large-Scale Patterns of the Solar Magnetic Field. V. BUMBA, *Astronomical Institute of the Czechoslovak Academy of Sciences*, ROBERT HOWARD, *Mount Wilson and Palomar Observatories*, AND SARA F. SMITH, *Lockheed Solar Observatory*.

Astronomical Journal, Vol. 69, p. 535 (1964)

The main direction of motion of the migrating fields is eastward and poleward. The following polarity in each hemisphere usually predominates in the poleward drift of fields. The polar magnetic field measurements record this quantized migration of fields (Undoubtedly, as has already been pointed out, this drift of following polarities was responsible for the reversal in polarity observed in the polar fields during the last maximum.)

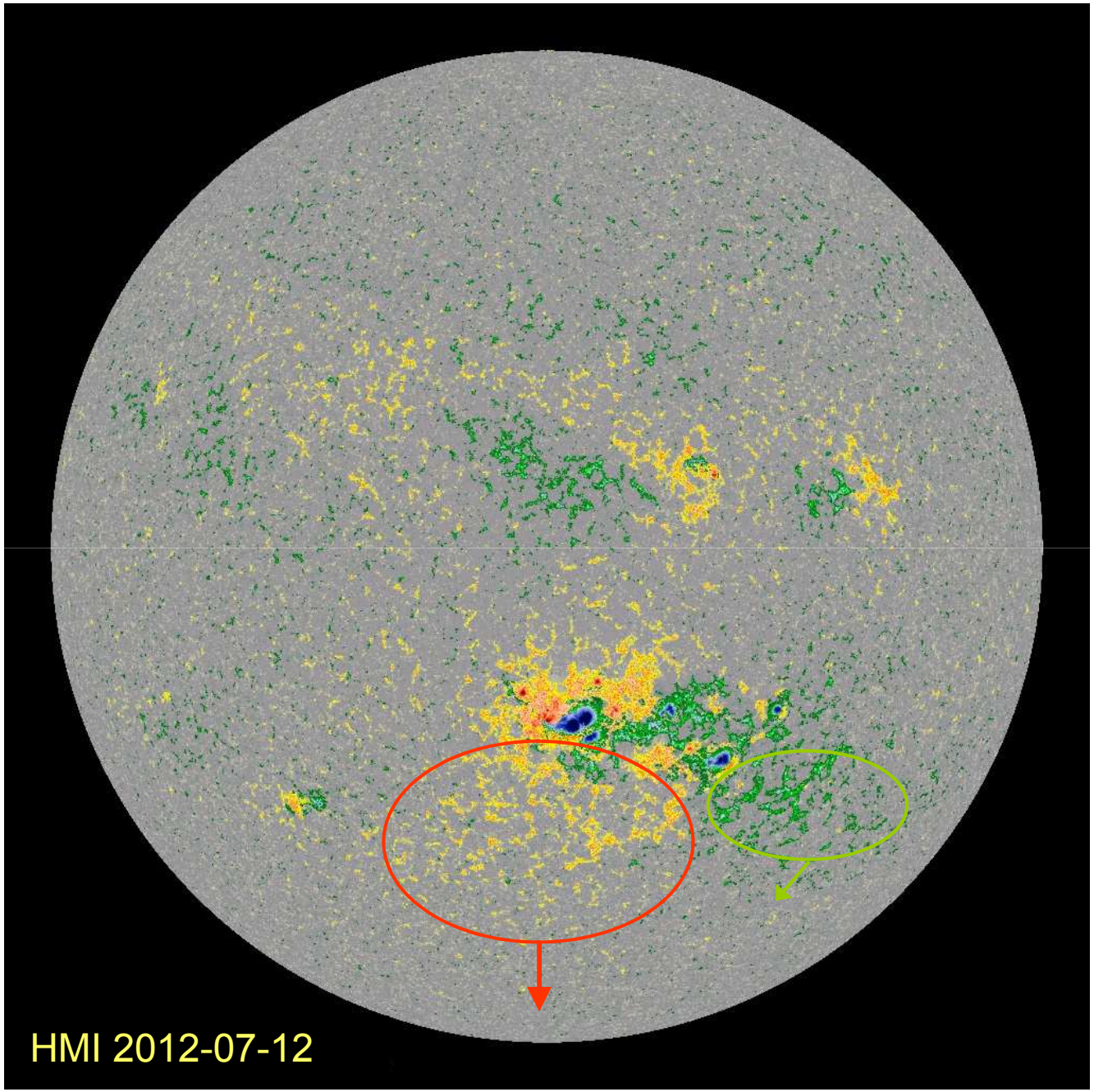


Slide 24

L24 All of this was clear already in 1964…

Leif, 7/26/2012

L25



"This just in:"

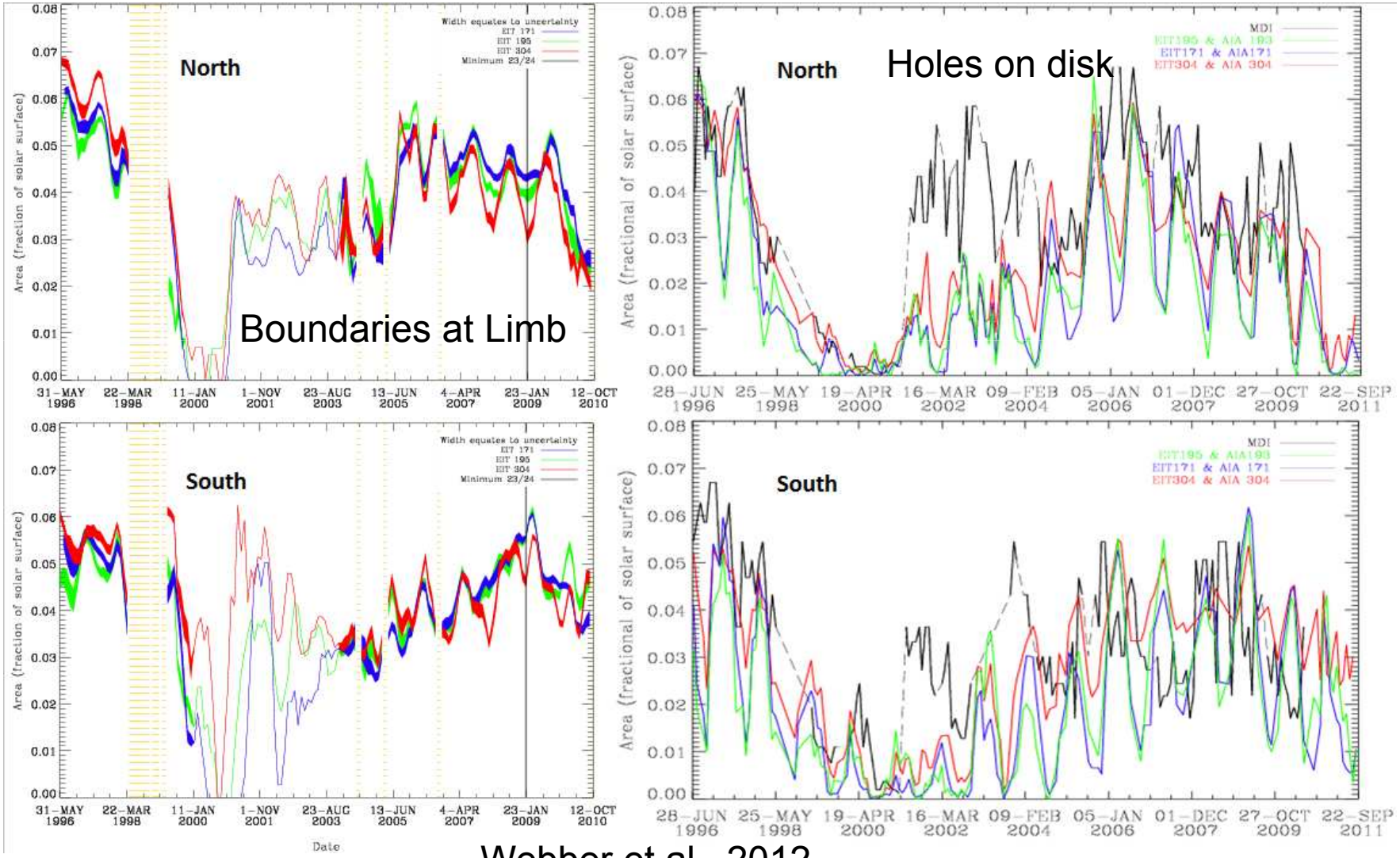
Large (-) Flux Injection Heading for the South Pole

Todd Hoeksema, 2012: "It wouldn't surprise me if this is the region that eventually moves poleward to reverse the stalled southern pole"

Slide 25

L25 A large UMR with negative polarity [red oval] is moving polewards. Note also the positive 'ghost' UMR [green oval to the right of the red] that may eat away some of the negative flux, but one can hope that enough survives to reverse the South Pole.
Leif, 7/26/2012

Polar Coronal Holes also Show When Reversals Happen



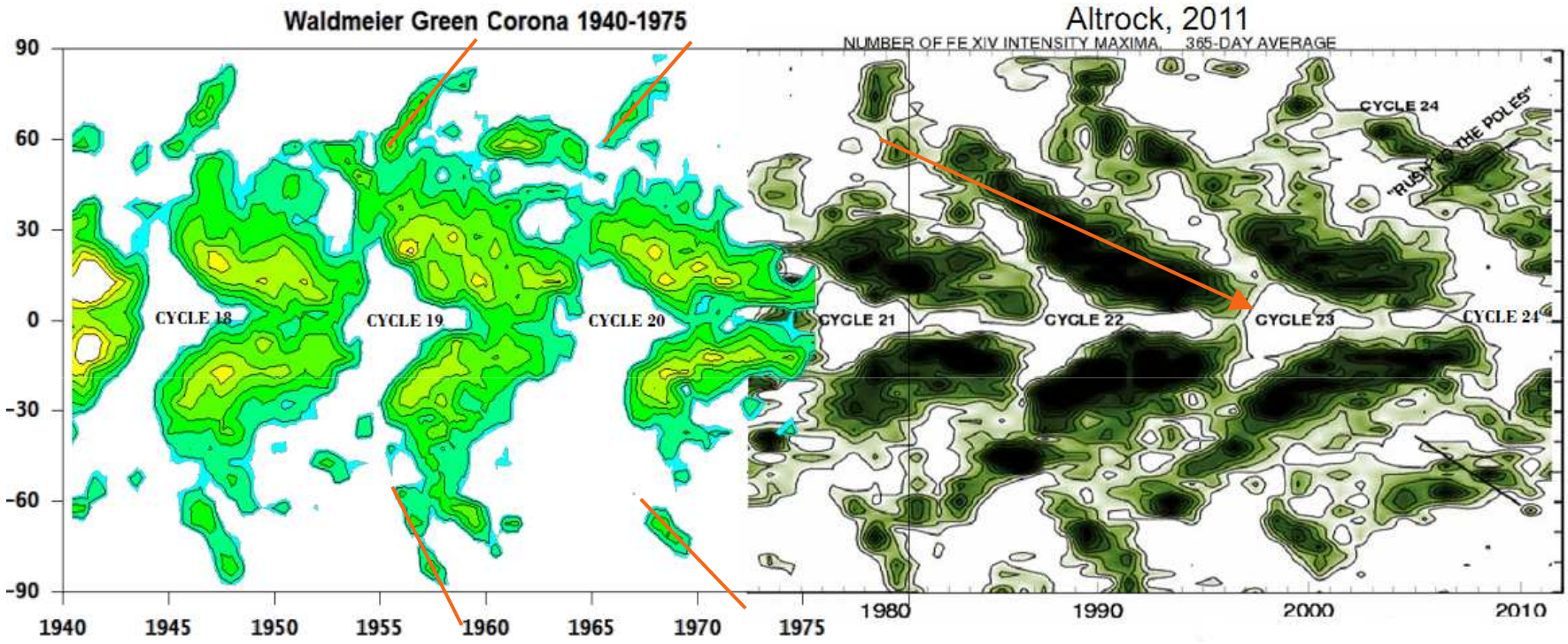
Webber et al., 2012

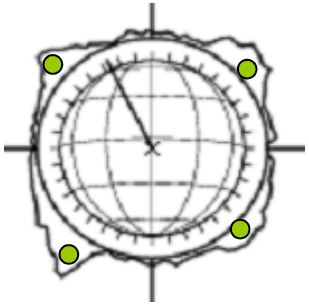
Slide 26

L26 The polar fields are found in Polar Coronal Holes [with field lines open into the solar wind]. During a polar field reversal, the holes also disappear, giving us a proxy for the time of polar field reversal. Here are shown two different ways of observing the disappearance of coronal holes during the reversal. One can observe the boundary of the holes at the limb [left panel] or on the disk [right panel]. The limb data go back to the 1940s.

Leif, 7/26/2012

And the ‘Rush to the Pole’ of Coronal Emissions





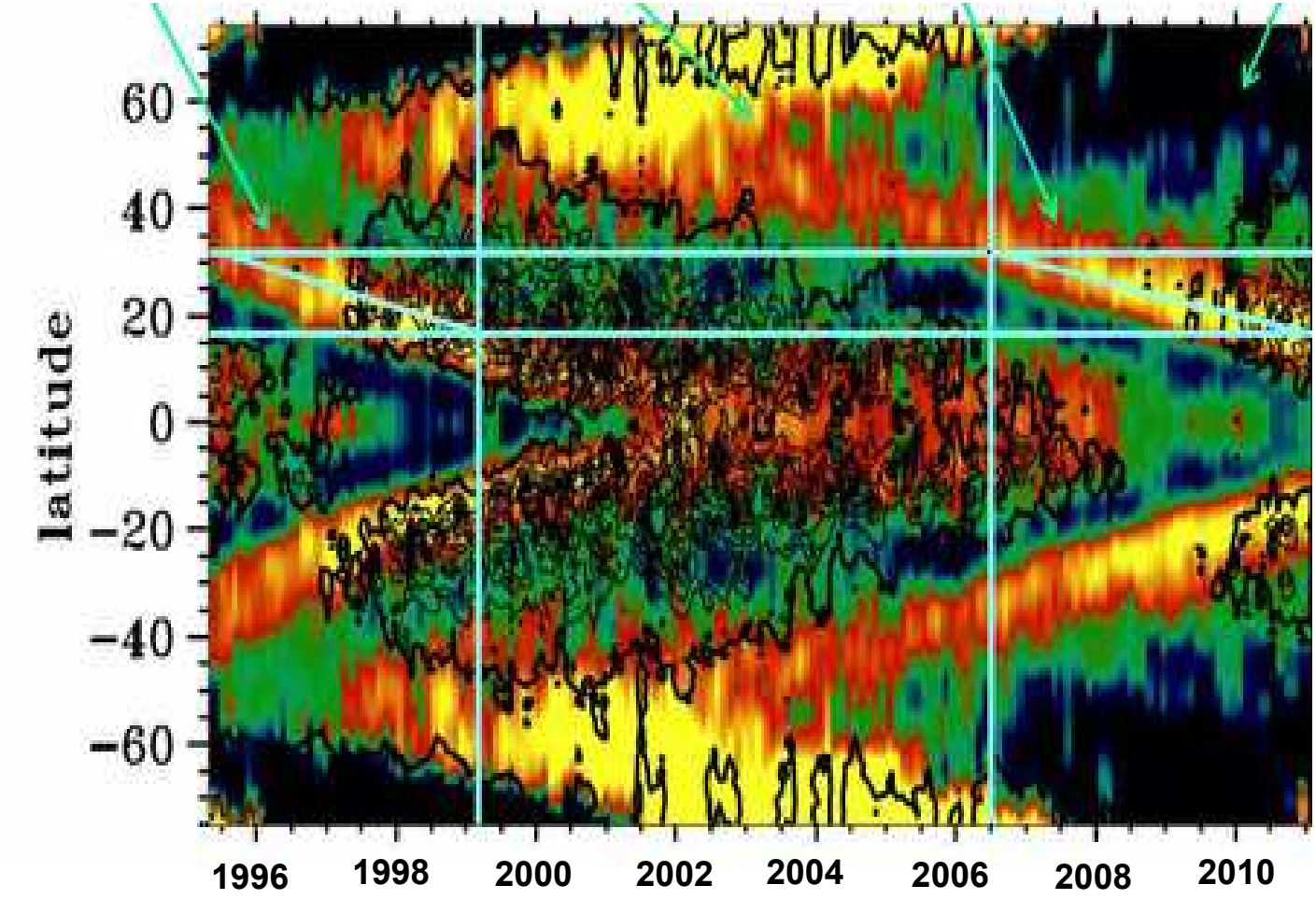
Measurements of the location of ‘peaks’ of Fe XIV coronal emission at 503 nm (the ‘Green Line Corona’) over 7 solar cycles. The plots show the probability of observing a ‘peak’ at a given latitude as a function of time.

Is there an ‘extended’ cycle of 17 years?

Slide 27

L27 The distribution in latitude over time of 'peaks' of strong coronal Green Line emission by Waldmeier and Altrock. The 'Rush to the Pole' is evident. There is some indication that the emission maxima follow and 'extended cycle' of 15-17 years, thus beginning their equatorward progression several years before the visible sunspots appear.
Leif, 7/26/2012

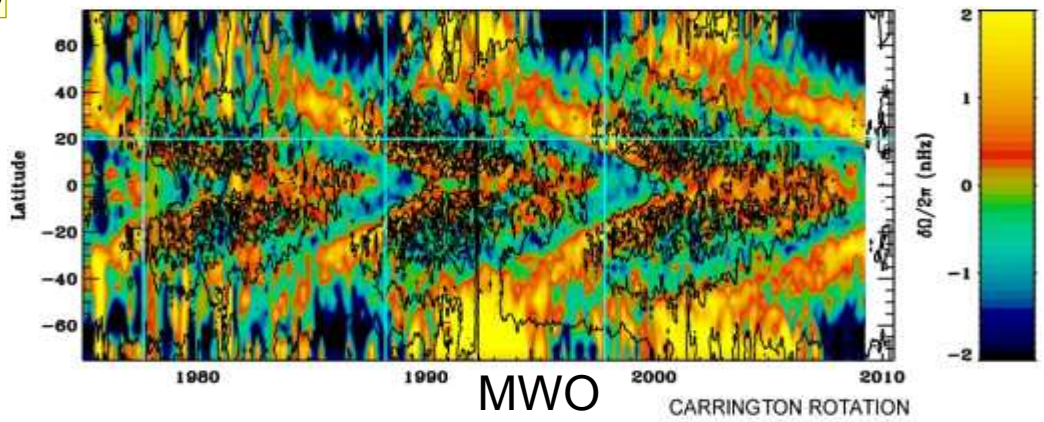
Torsional Oscillation Seems to Support an Extended Cycle



Slide 28

L28 The ‘Torsional Oscillation’ [dreadful name], TO, also suggests that ‘something’ starts well before the visible cycle.
Leif, 7/27/2012

L29

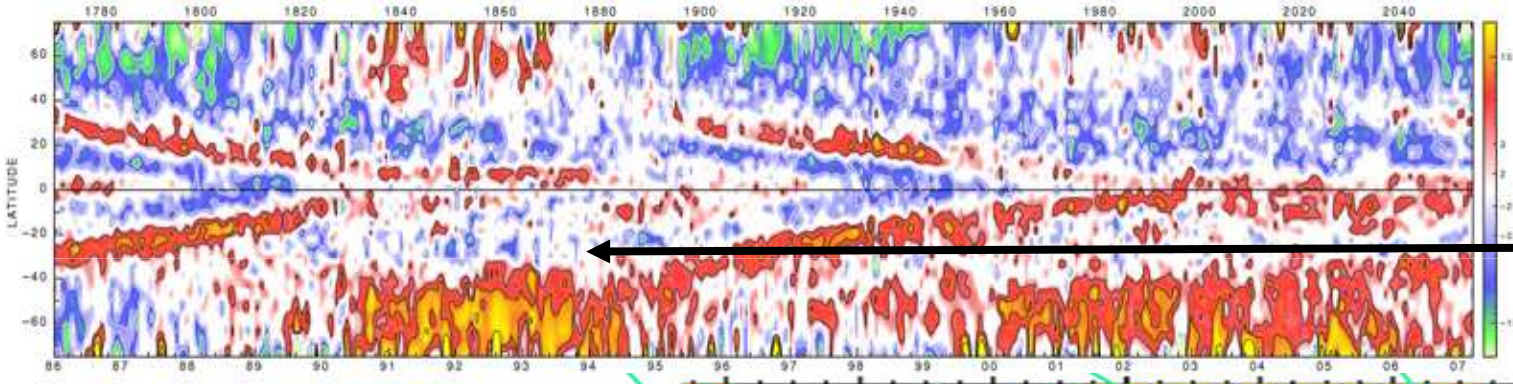


MWO

CARRINGTON ROTATION

Torsional Oscillation and Extended Solar Cycle ?

TO begins about three years before visible sunspots of the new cycle

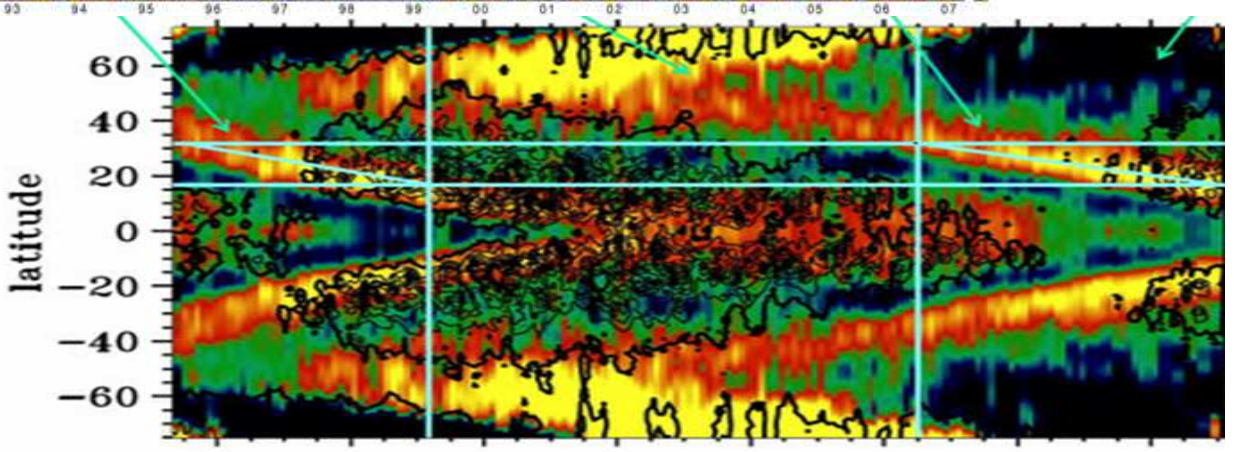


MWO

15 yrs

MDI, GONG

Frank Hill

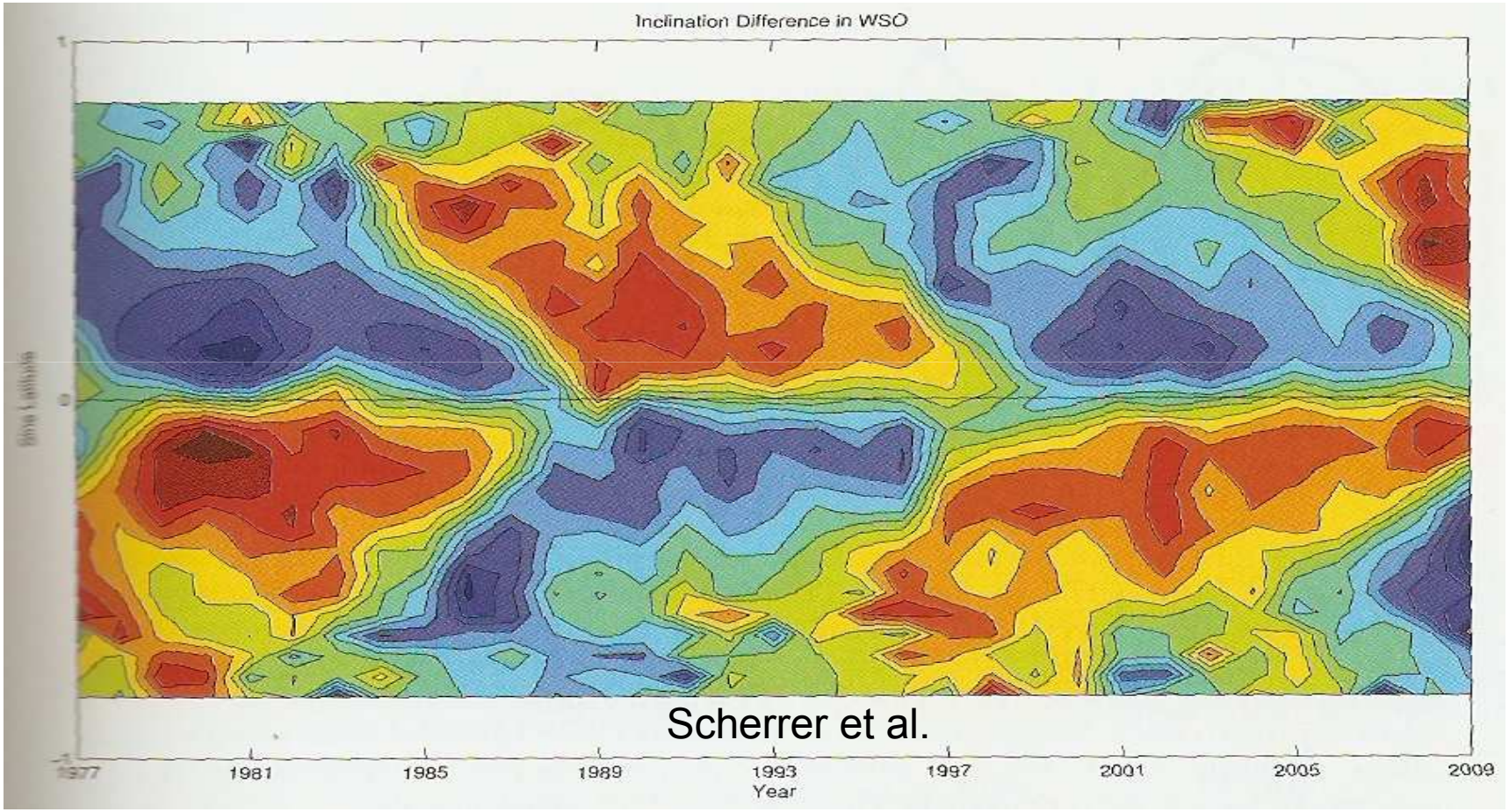


Slide 29

L29 Some other compilations of TO data [Frank Hill, Roger Ulrich]. The MWO map is marred by an asymmetry in rotational speed between the hemispheres: the northern rotates a bit faster. In the extraction of the TO, the same rotation was assumed for both hemispheres. The poleward branch is mysterious.

Leif, 7/26/2012

The angle between B and Br seems to show an ‘extended cycle’



Scherrer et al.

I would rather think of this as a ‘toroidal field’ instead of an inclination angle

Slide 30

L30 There is a large-scale toroidal magnetic field [discovered by Duvall, Svalgaard & Scherrer back in 1978] in the sense that the magnetic field in the Eastern Hemisphere does not balance that in the Western. This effect also suggests something starts well before the new cycle shows its spots.

Leif, 7/26/2012

Extended cycle is controversial [perhaps]

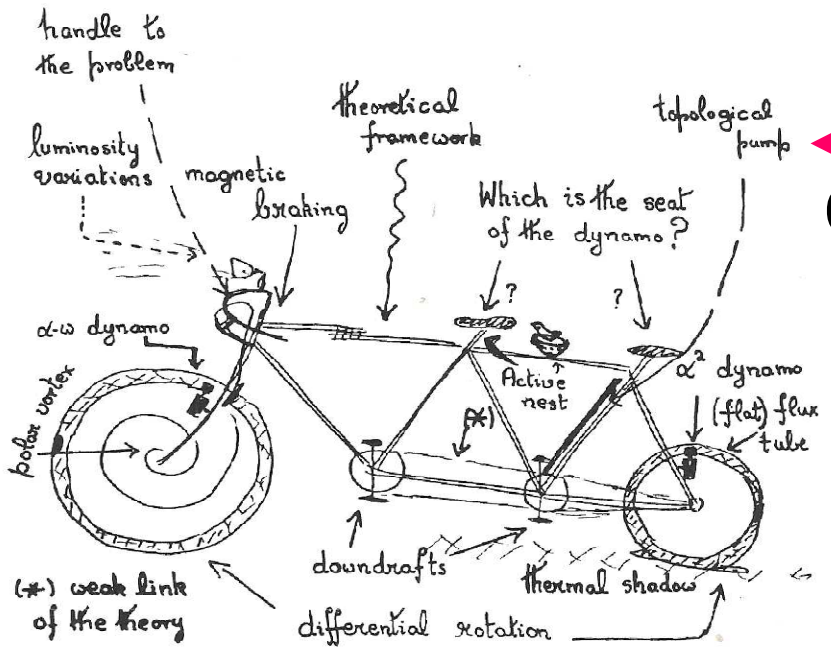
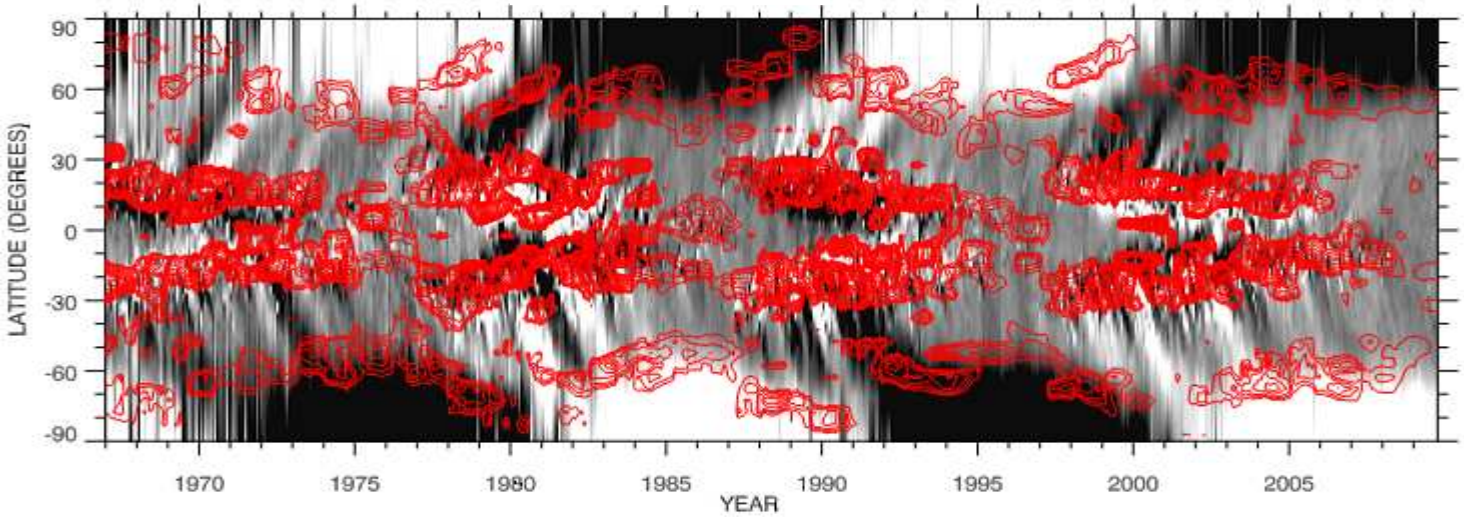


Fig. 8.8 A diagram of the *Xtended Cycle* constructed at a party held during the Sunspot meeting of the Solar Cycle Workshop in 1991. The author disclaims any responsibility but understands that Jean-Paul Zahn is liable for the drawing,

Our 'Understanding' of the Extended Cycle

Robbrecht et al. ApJ, 2010:
"We conclude that the so-called extended cycle in coronal emission is a manifestation not of early new-cycle activity, but of poleward concentration of old-cycle trailing-polarity flux by meridional flow"



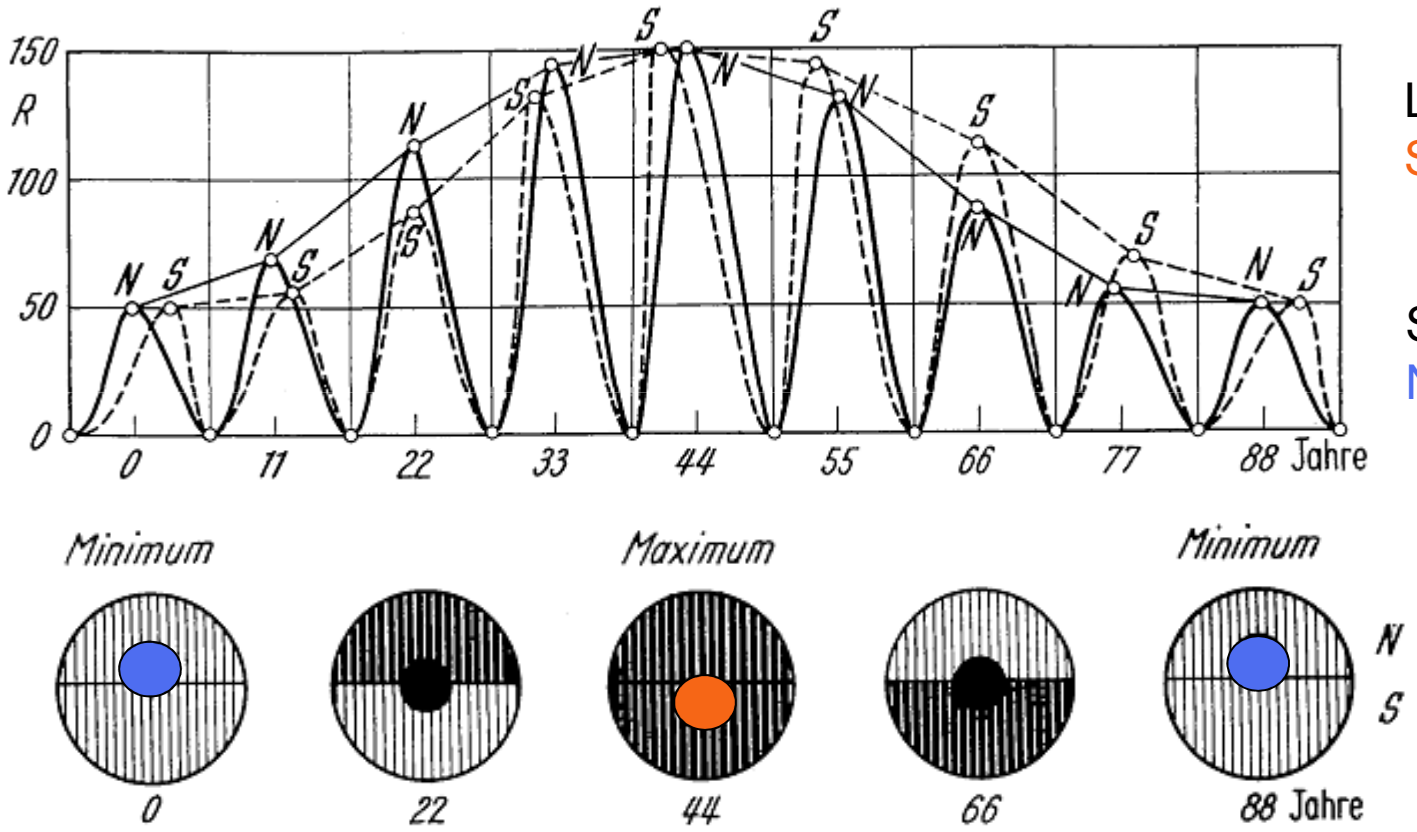
The red contours computed from PFSS coronal field (MWO)

Slide 31

L31 The concept of an ‘extended cycle’ has been challenged by Robbrecht et al. who has a different interpretation of the data [although their ‘data’ is from calculated potential field models]. In any event, “the data may be weak, but the theory is weaker”. The extended cycle and how it may relate to the TO are not understood. The cartoon has some suggestive terms. Our theoretical understanding is not much better than the cartoon.

Leif, 7/26/2012

The Danger of Generalizing from too Short Time Series to Long Cycles



Large cycles:
S leading

Small cycles:
N leading

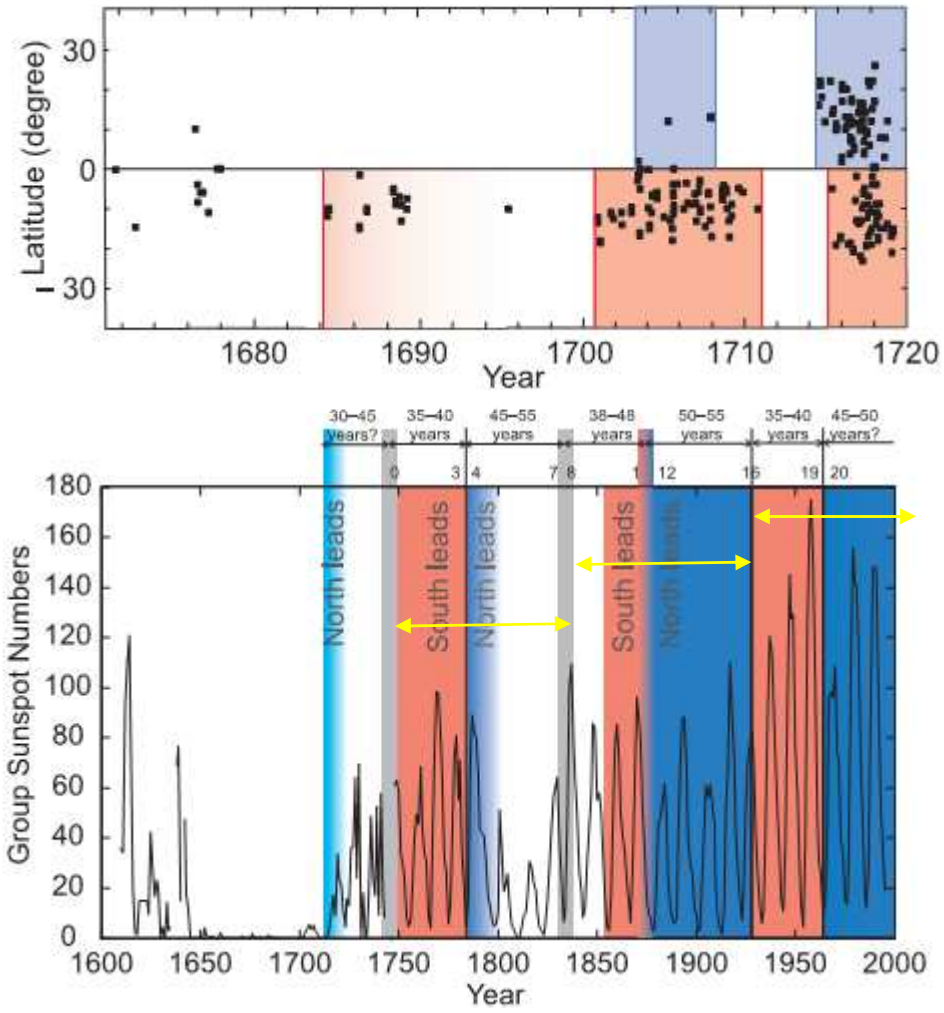
Waldmeier, 1957

Slide 32

L32 Before the polar field reversal was even discovered, Waldmeier studied the N-S asymmetry using sunspot and sunspot group observations back to the 1870s and thought he could see a pattern [as shown] consisting of three to four cycles of one polarity leading, followed by three to four cycles of the opposite polarity leading. From modern data, it is not clear if the pattern is synchronized with the 90-100 yr Gleissberg cycle as he suggested.

Leif, 7/26/2012

70-100 Year 'Gleissberg Cycle' in Solar Activity Asymmetry?



Zolotova et al., 2010

Extreme Asymmetry during the Maunder Minimum…

There are various dynamo theoretical 'explanations' of N-S asymmetry. E.g. Pipin, 1999. I can't judge these…

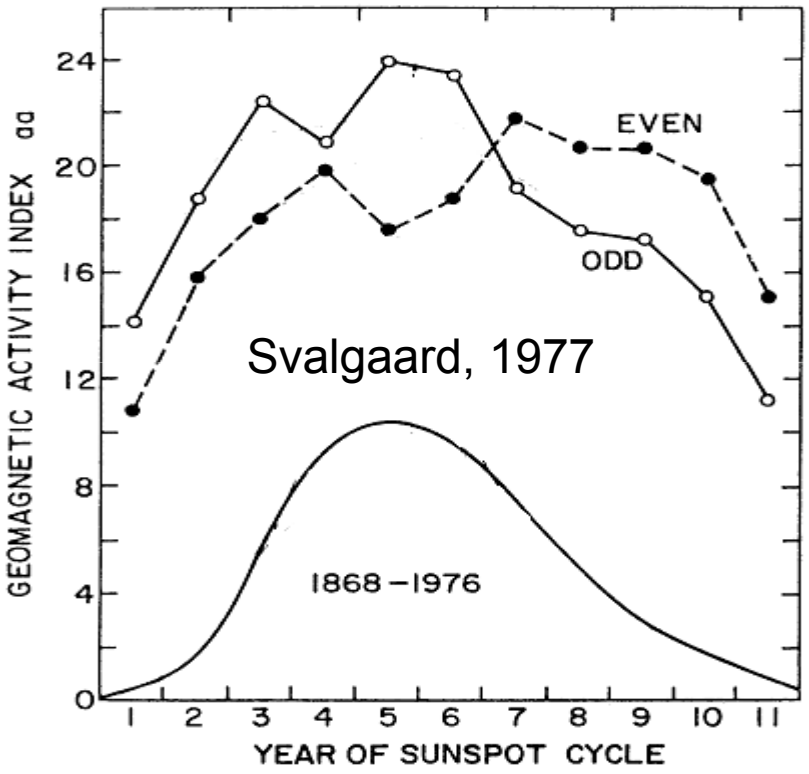
Is this a 'regular' cycle or just over-interpretation of noisy data [like Waldmeier's]?

'Prediction' from this: South will lead in cycle 25 or 26 and beyond. We shall see…

Slide 33

L33 Other people also report a possible Gleissberg cycle or at least a repeating pattern. If this pattern holds we might expect some cycles in the near future where the South leads instead of the North [which has been leading the past several cycles].
Leif, 7/26/2012

How do we Know that the Poles Reversed Regularly before 1957?



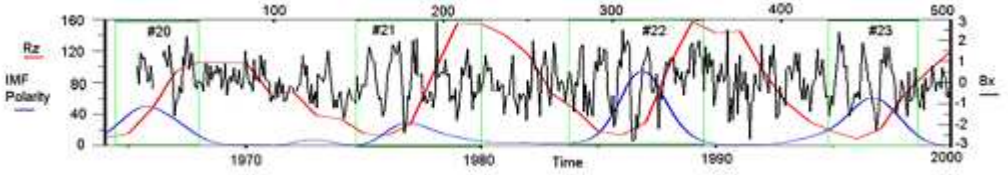
Svalgaard, 1977

"Thus, during last eight solar cycles magnetic field reversals have taken place each 11 year period". S-M effect. Vokhmyanin & Ponyavin, 2012

In any case, our result over a 45-year interval is probably the most direct evidence for a continuing change of the predominant polarity of the large-scale solar-magnetic field with a period equal to the sunspot magnetic cycle, i.e., ~20 years during this century. Wilcox & Scherrer, 1972

The predominant polarity = polar field polarity (Rosenberg-Coleman effect) annually modulated by the B-angle.

100



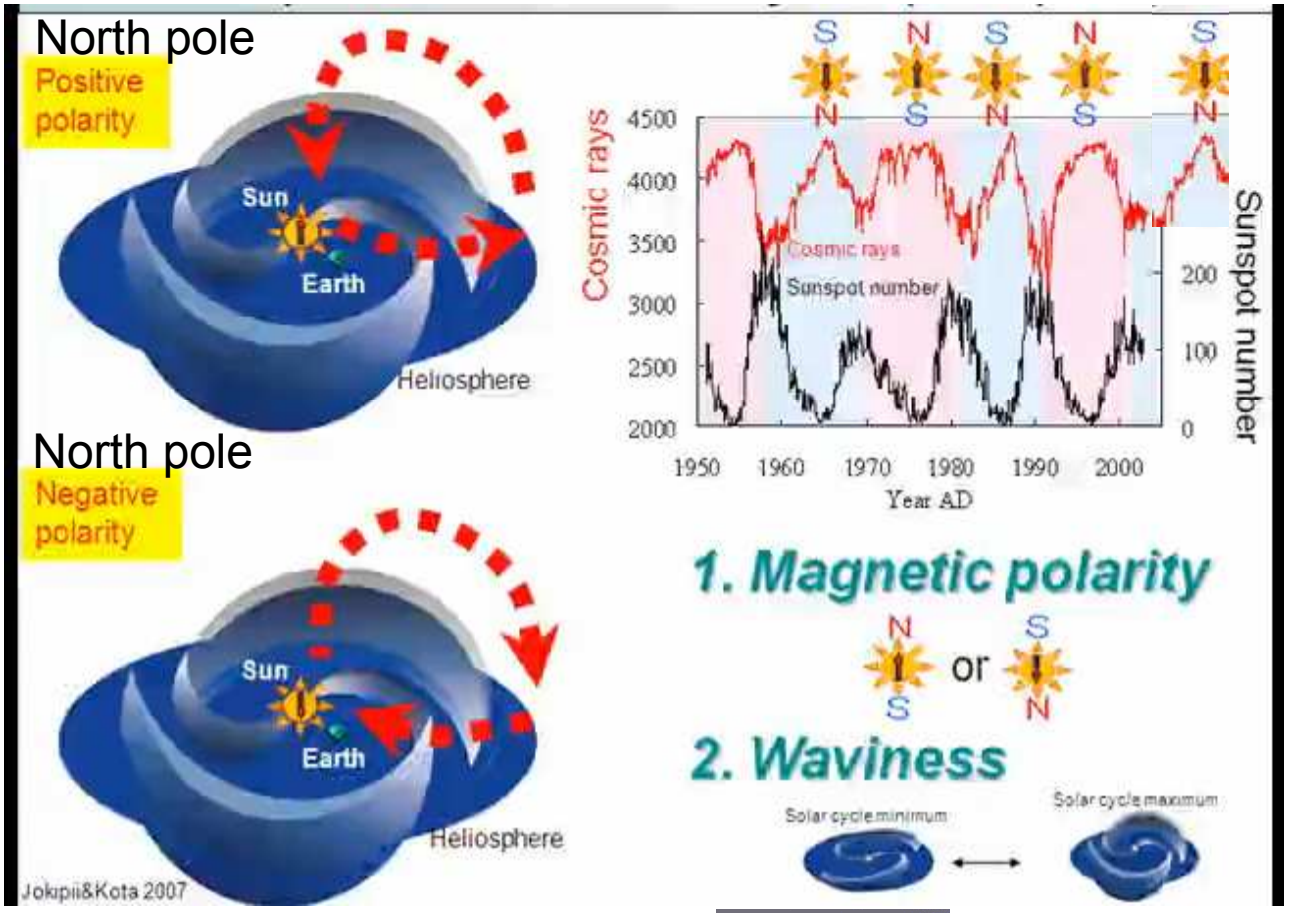
This effect combined with the Russell-McPherron effect [geomagnetic activity enhanced by the Southward Component of the HMF] predicts a 22-year cycle in geomagnetic activity synchronized with polar field reversals, as observed (now for 1840s-Present).

Slide 34

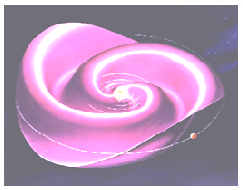
L34 Having data about N-S asymmetry in activity which we relate to corresponding asymmetries in polar field reversals, we may ask: "how to we know that the polar fields actually reverse near the maximum of every cycle" before the actual observations began? A 22-year cycle in geomagnetic activity [from maximum to maximum] related to the 'dominant' polarity of the HMF observed at Earth [as we move above and below the solar equator in the course of a year] has been traced back to the 1840s, so we know that reversals occurred 'as they should' back to then.

Leif, 7/26/2012

Cosmic Ray Modulation Depends on the Sign of Solar Pole Polarity



Miyahara, 2011



Wilcox & Svalgaard, 1976

The shape of the modulation curve [alternating 'peaks' and 'flat tops'] shows the polar field signs.

Ice cores contain a long record of 10Be atoms produced by cosmic rays. The record can be inverted to yield the cosmic ray intensity. The technique is not *yet* good enough to show peaks and flats, but might with time be refined to allow this.

Slide 35

L35 The cosmic ray modulation by solar activity bears a signature of the polarity of the polar fields. The explanation is too long to give here [a topic for another talk, perhaps]. Ice cores hold a many millennium-long record of Beryllium 10 produced by cosmic ray spallation of Nitrogen and Oxygen in the Earth's atmosphere [globally the annual production is 2 ounces!]. In principle [and with future refinement of the data acquisition] we should be able to determine polar field reversals using 10Be. The data is not quite good enough yet.
Leif, 7/26/2012

Conclusions and Speculation

- In every cycle since the polar fields were first observed, the reversals have been at different times, and simply following the prevailing activity asymmetry
- Polar fields have reversed in every cycle since at least the 1840s
- Asymmetric activity may be organized on longer time scales [i.e. not random]
- The Extended Cycle and the TO and how they relate to polar field reversals are Enigmas

The End

Slide 36

L36 Conclusions and Speculations speak for themselves.
Leif, 7/26/2012