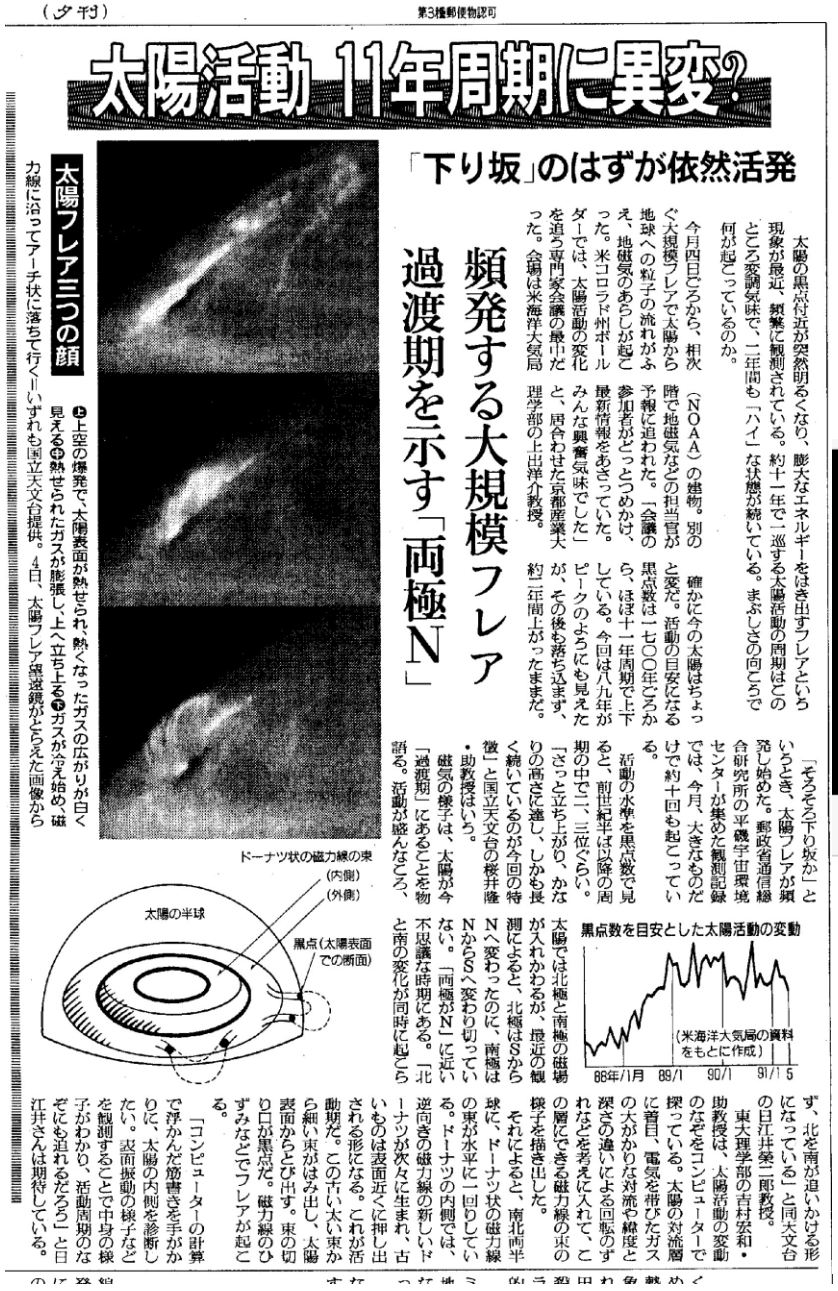
Asymmetric Solar Polar Field Reversals

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

Stanford, July 27, 2012

Why are we writing/talking about reversals?



（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最新情報をあさっていた。

「会議の参加者がどっとつめかけ、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、約三年間上がったままだ。

「そろそろ下り坂か」といったとき、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、前世紀半ばは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」と同大台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。

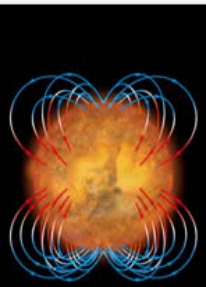
それによると、南北両半球に、ドーナツ状の磁力線の束が水平に一回りしている。ドーナツの内側では、逆向きの磁力線の新しいドーナツが次々に生まれ、古いものは表面近くに押し出される形になる。これが活動期だ。この古い太い束から細い束がはみ出し、太陽表面からとび出す。東の切り口が黒点だ。磁力線のひずみなどでフレアが起こる。

「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。

ドーナツ状の磁力線の束
（内側）
（外側）
太陽の半球
黒点（太陽表面での断面）

黒点数を目安とした太陽活動の変動
（米海洋大気局の資料をもとに作成）
86年/1月　88/1　90/1　91/1　5

太陽フレア三つの顔
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。熱せられたガスが膨張し、上へ立ち上る。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、太陽フレア観測衛星がとらえた画像から



太陽観測衛星「ひので」、太陽極域磁場の反転を捉えた

2012年4月19日

国際研究チームは、ひのでの観測で、太陽の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。これまでの太陽磁場の極性反転メカニズムの見直しを迫る重要な結果です。

いいね！ 893　ツイート 382

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。

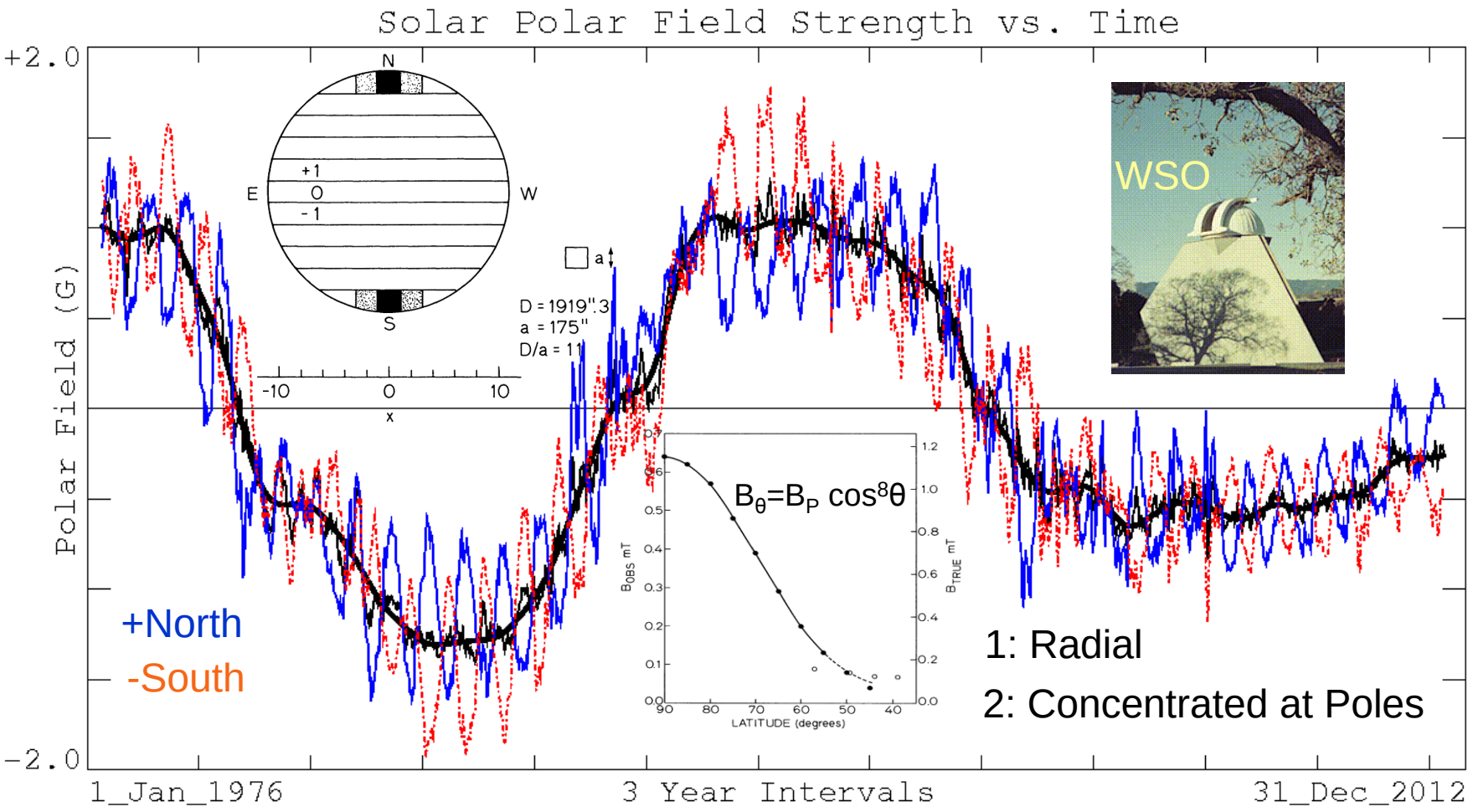
This is why

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

Outline and Roadmap

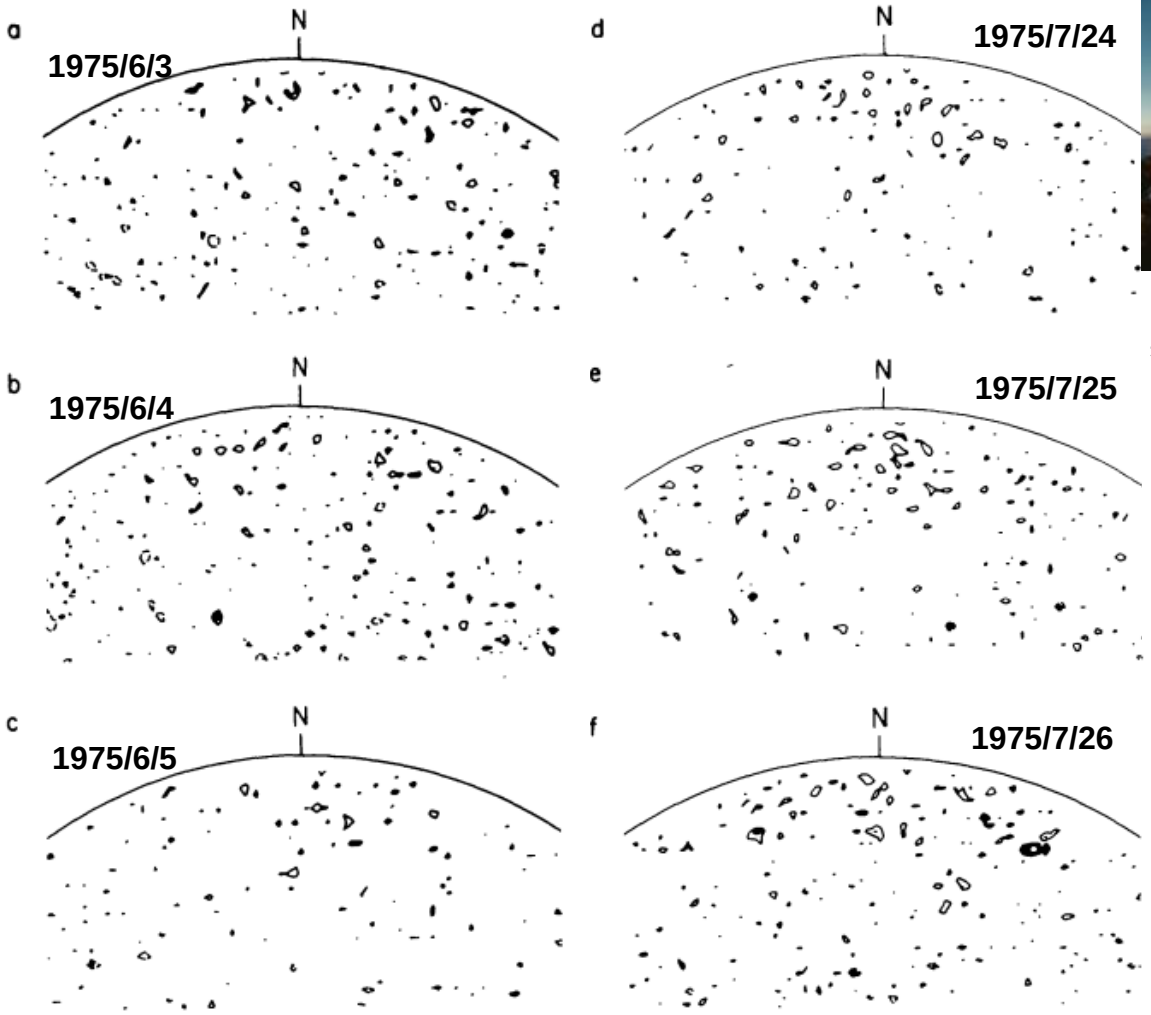
- Observing the Polar Fields
- Observing [or Inferring] Polar Field Reversals
- Observing Solar Activity
- Determining Activity Asymmetry
- Connecting Hemispheric Asymmetries in Activity and Reversals
- Longer-term Cycles and Asymmetries

Observing the Polar Flux

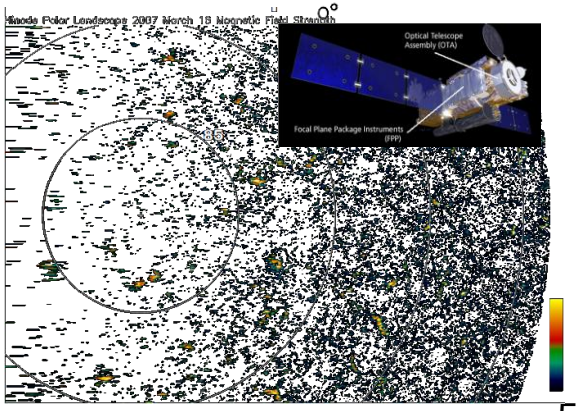


Observing the Polar Fields

Scattered strong elements concentrating at pole



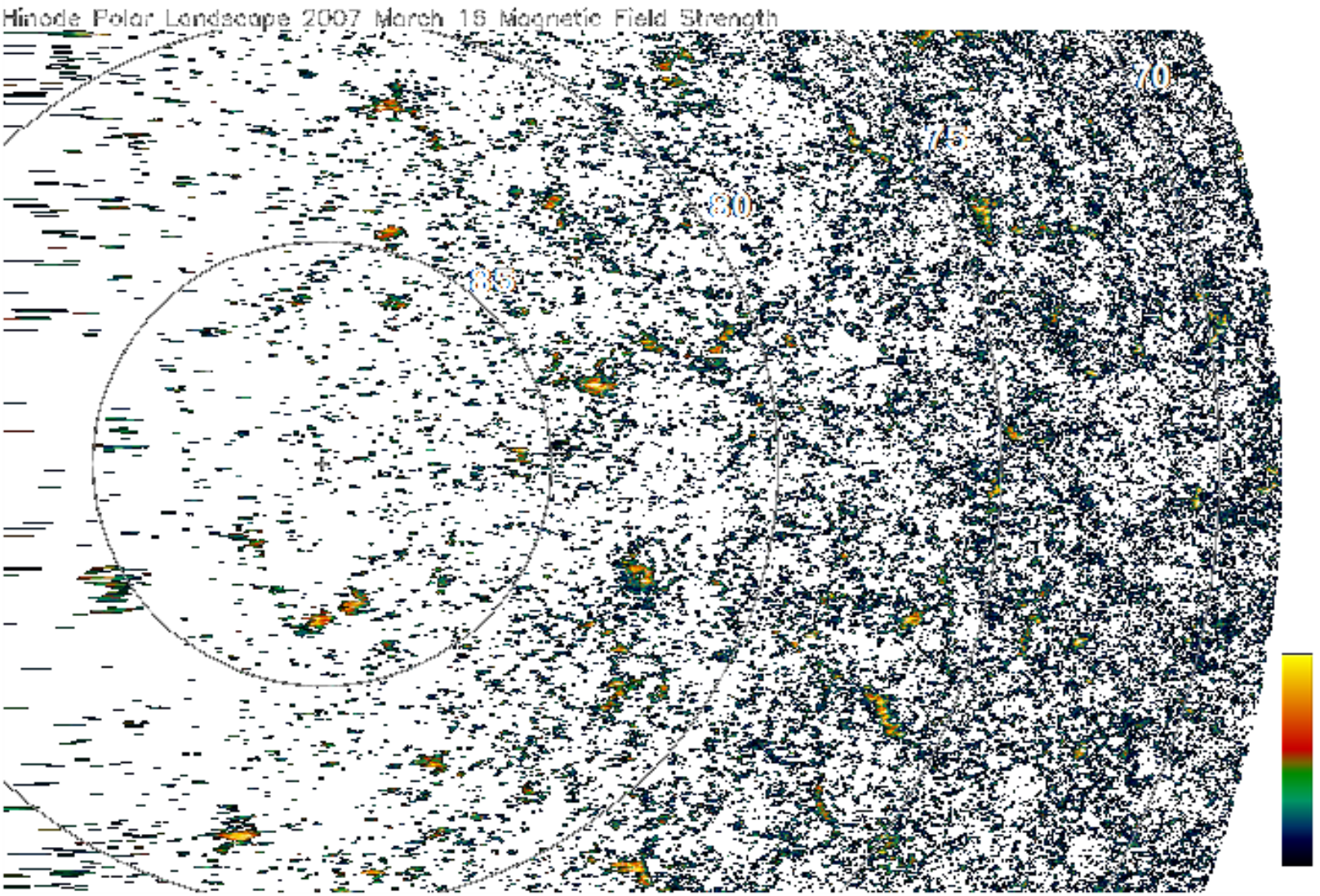
MWO: Stenflo, 1968



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

Tsuneta et al. ApJ, 2008

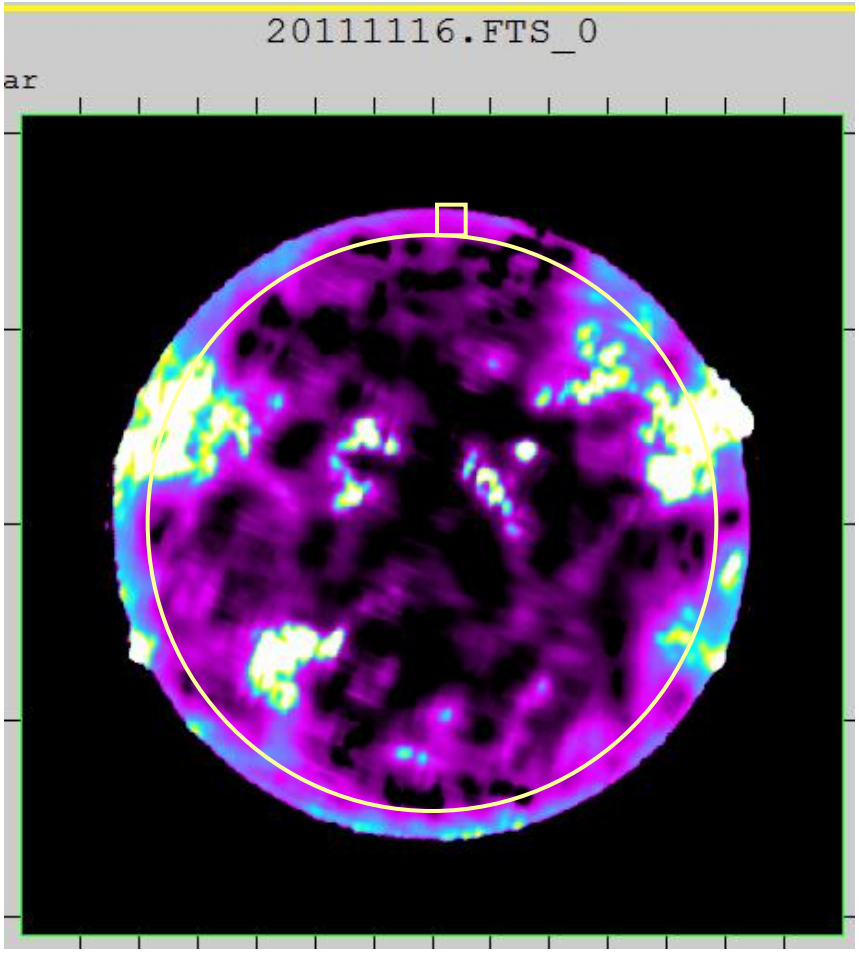
Polar Magnetic Landscape



Tsuneta et al. ApJ, 2008

Another View of Polar Fields from the Nobeyama Radioheliograph

Image of 17GHz Emission, beam width 10”



ν17 GHz = λ1.76 cm

v_e = B (Tesla) · 28 GHz

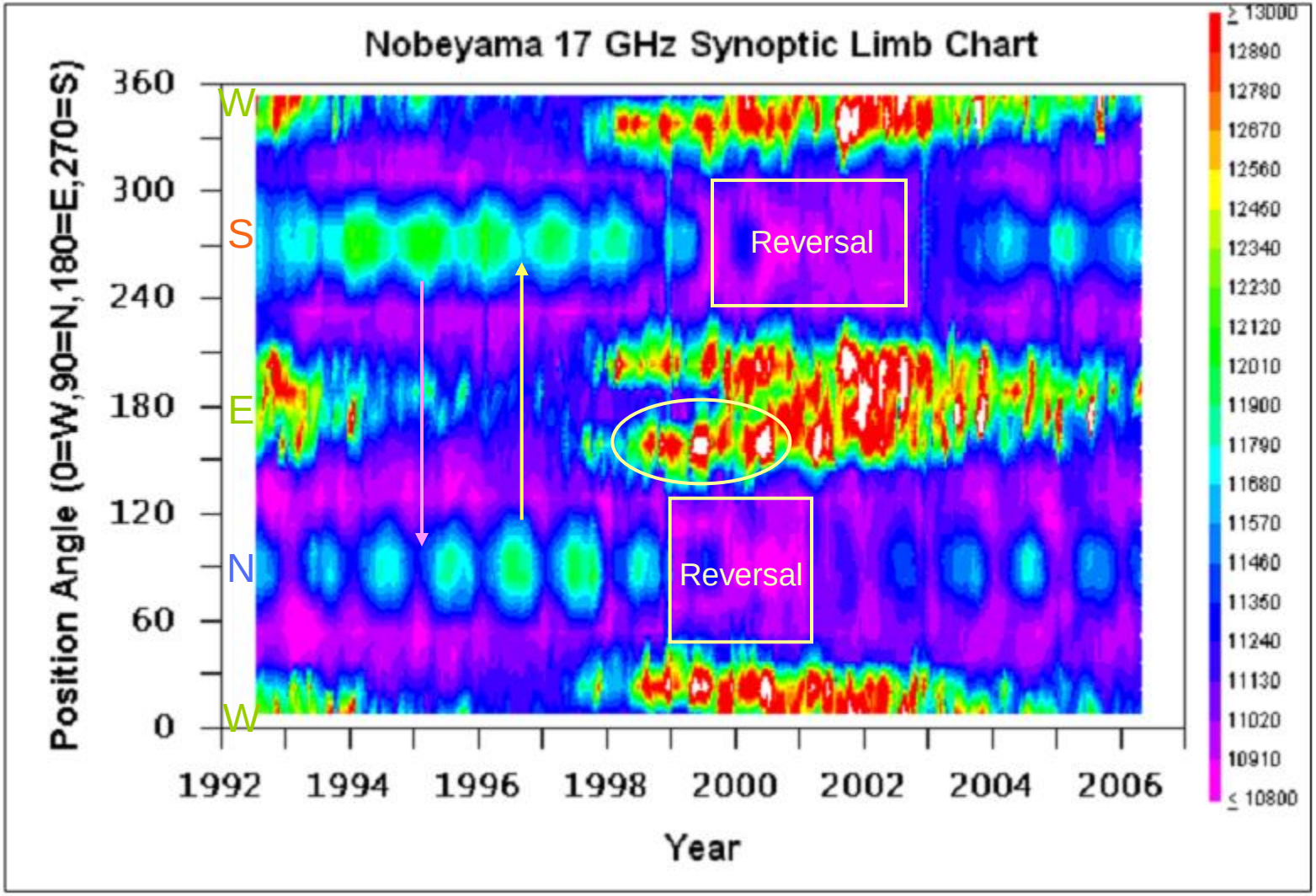
17 GHz is 3rd harmonic v_e for 2000 G

1. General Limb brightening
2. Active regions bright

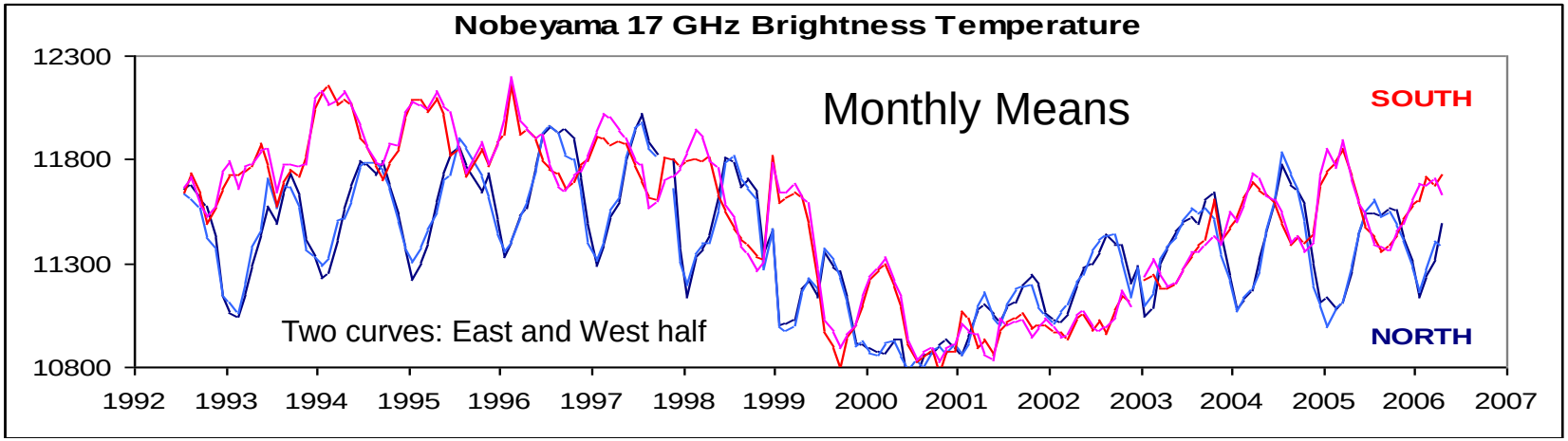
A. Gyro-resonance is thought (?) to result as 3rd harmonic of 2000 G

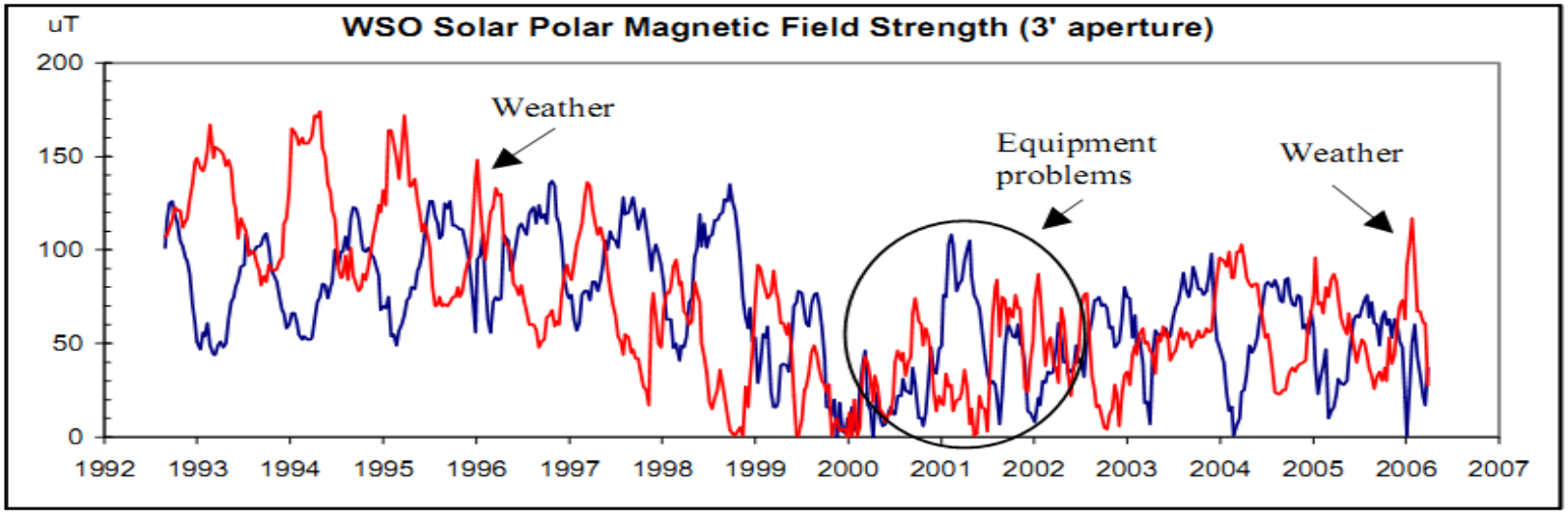
B. Also Bremsstrahlung from hot atmosphere [10,000 – 13,000 K]

Evolution of Patches over the Cycle

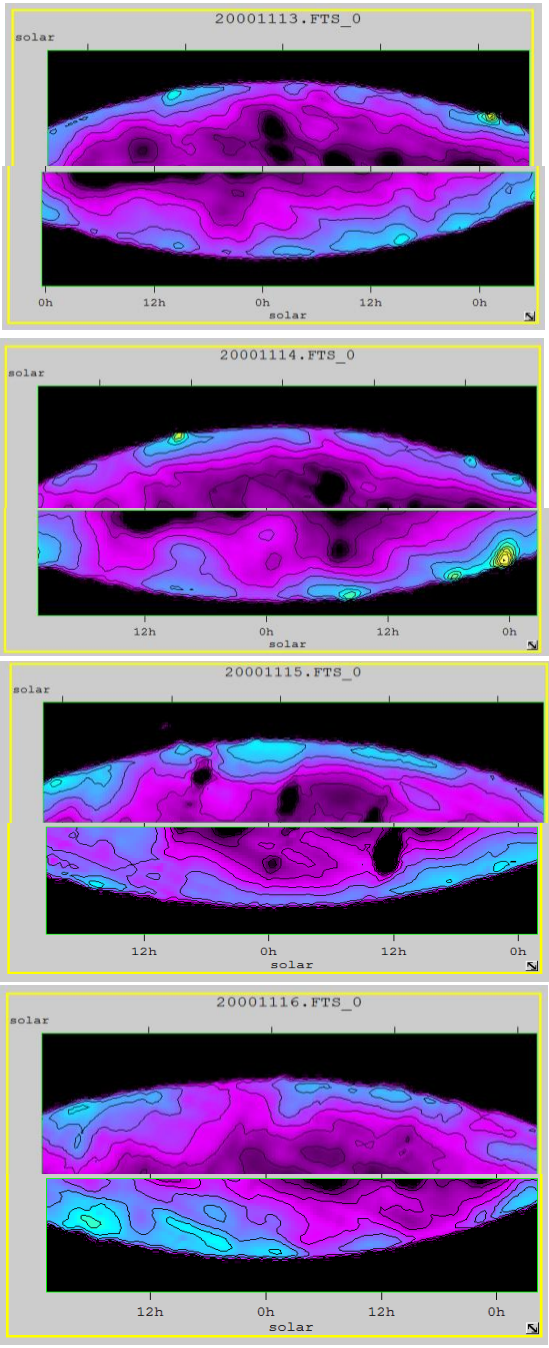


Proxy for Polar Magnetic Field

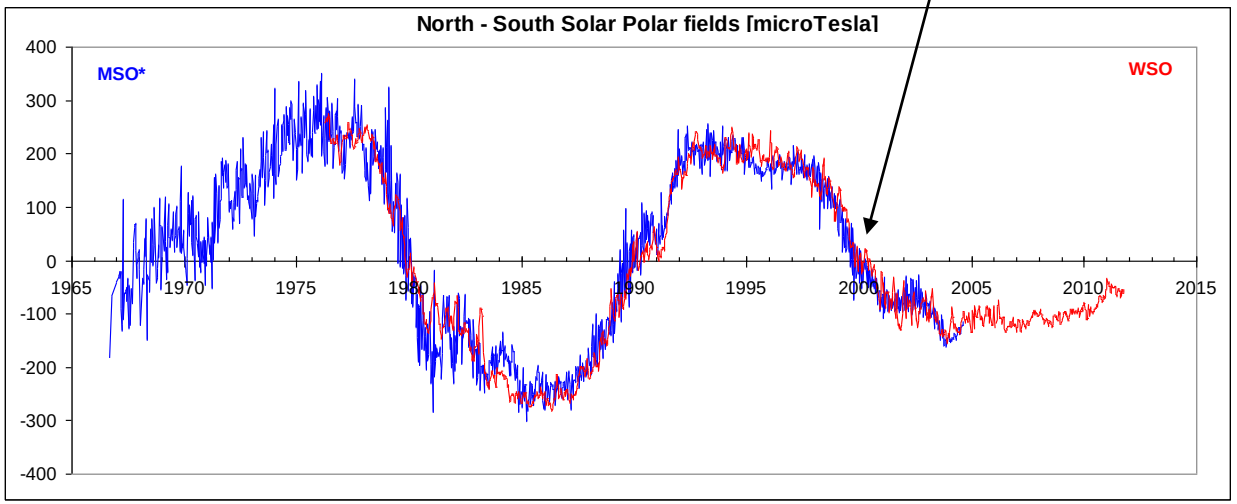




This shows that the brightening is not just general limb brightening, but is concentrated at the pole just as the polar magnetic field (is thus due to the field?)

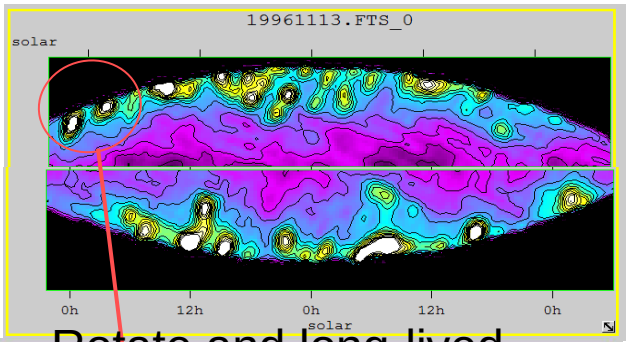


No Bright Patches at Solar Maximum, 2000

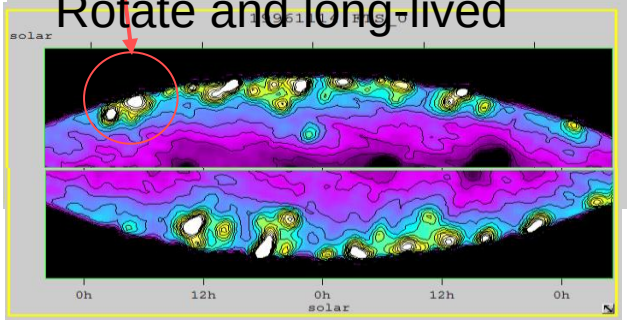


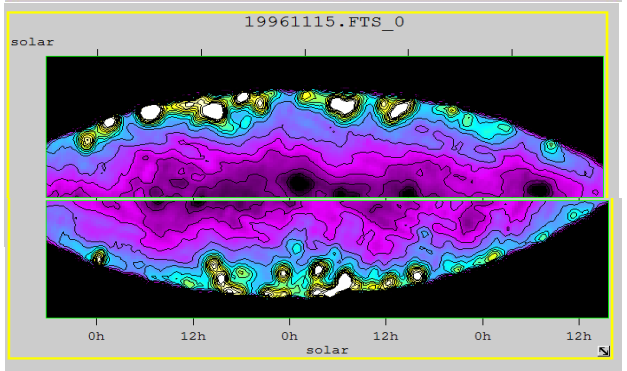
Only a few scatted, weak patches. So no magnetic flux of the kind that makes patches [kG], thus the polar fields are not an equal mixture of opposite polarities. There aren't any.

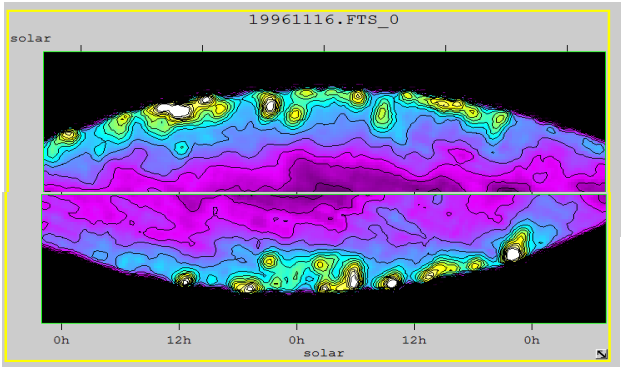
But at Solar Minimum, Oh Boy!

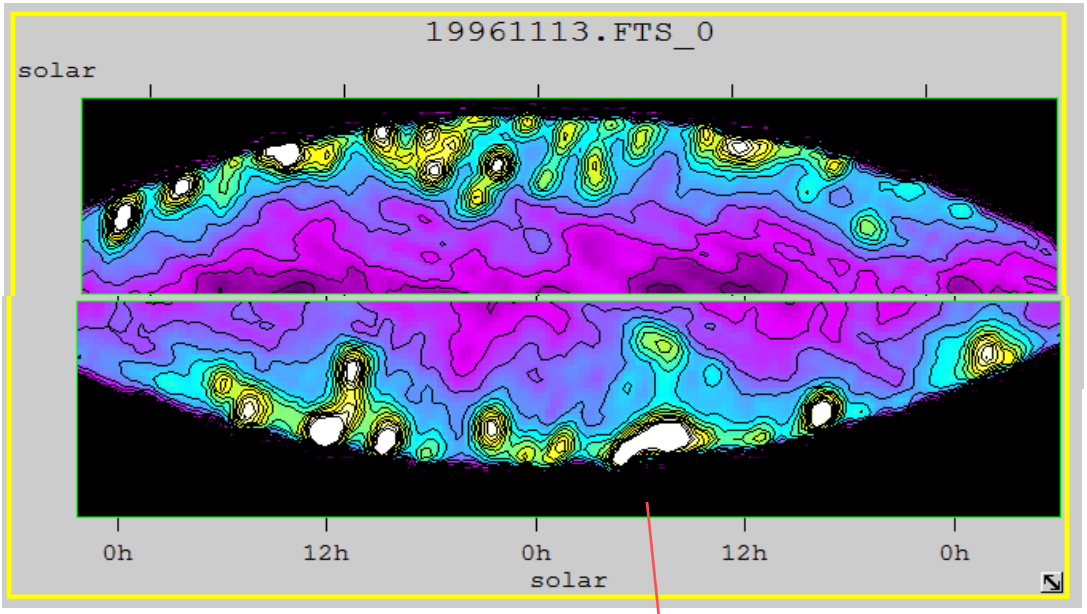


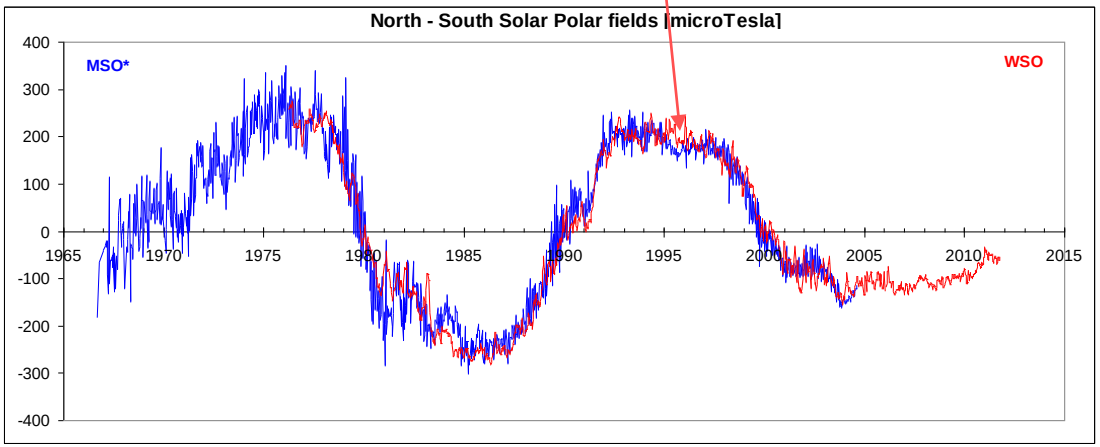
Rotate and long-lived





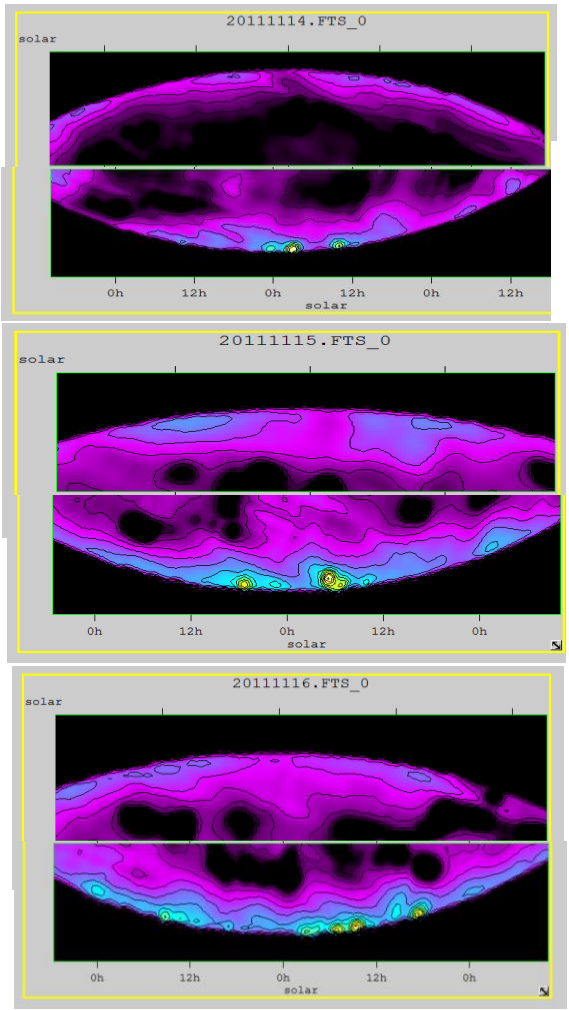


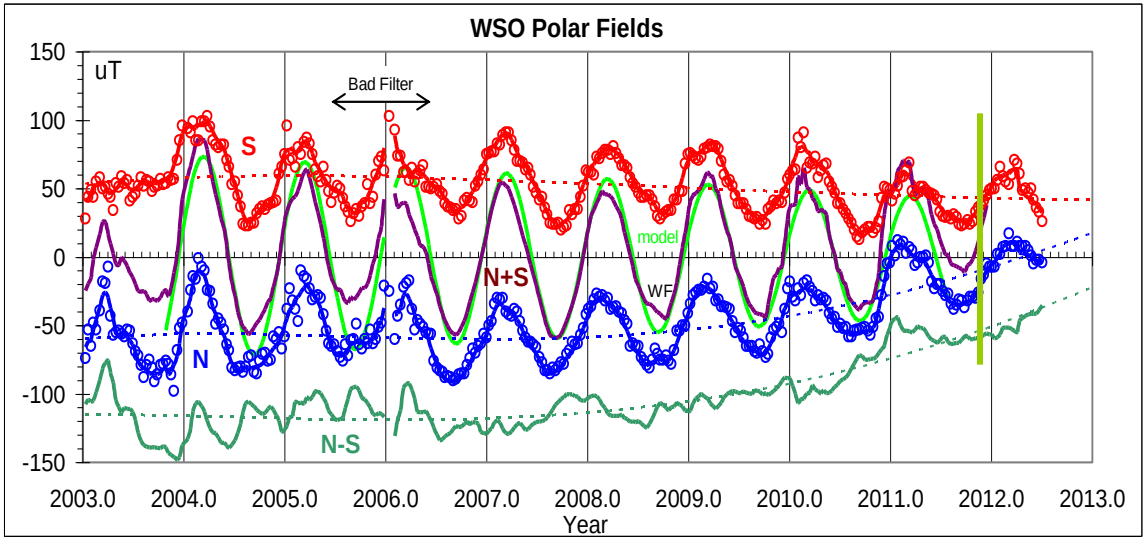




Magnetic Flux in the Polar Caps

2011-11-14 to 16





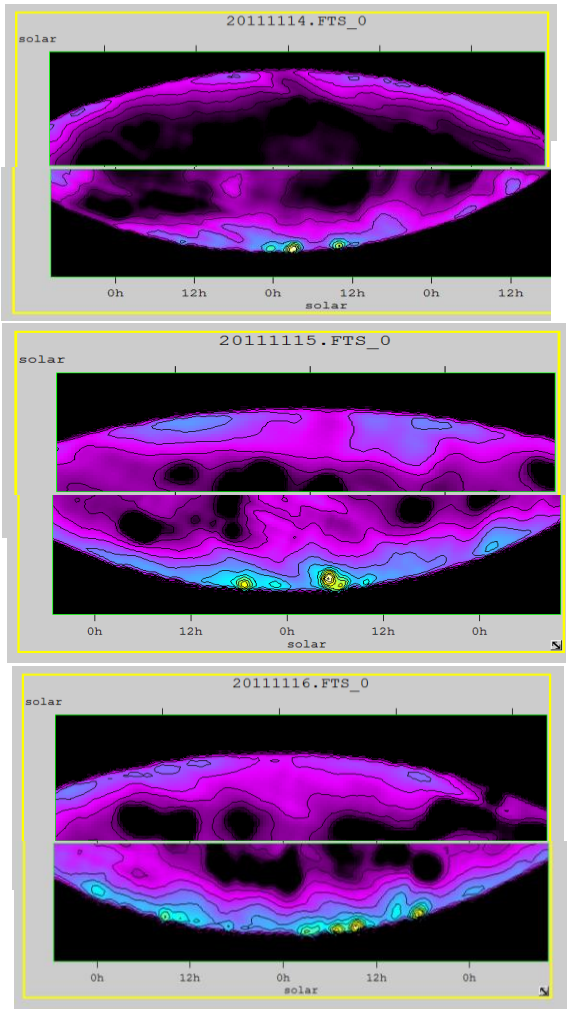
Average flux above 55°; North is now reversing.

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?

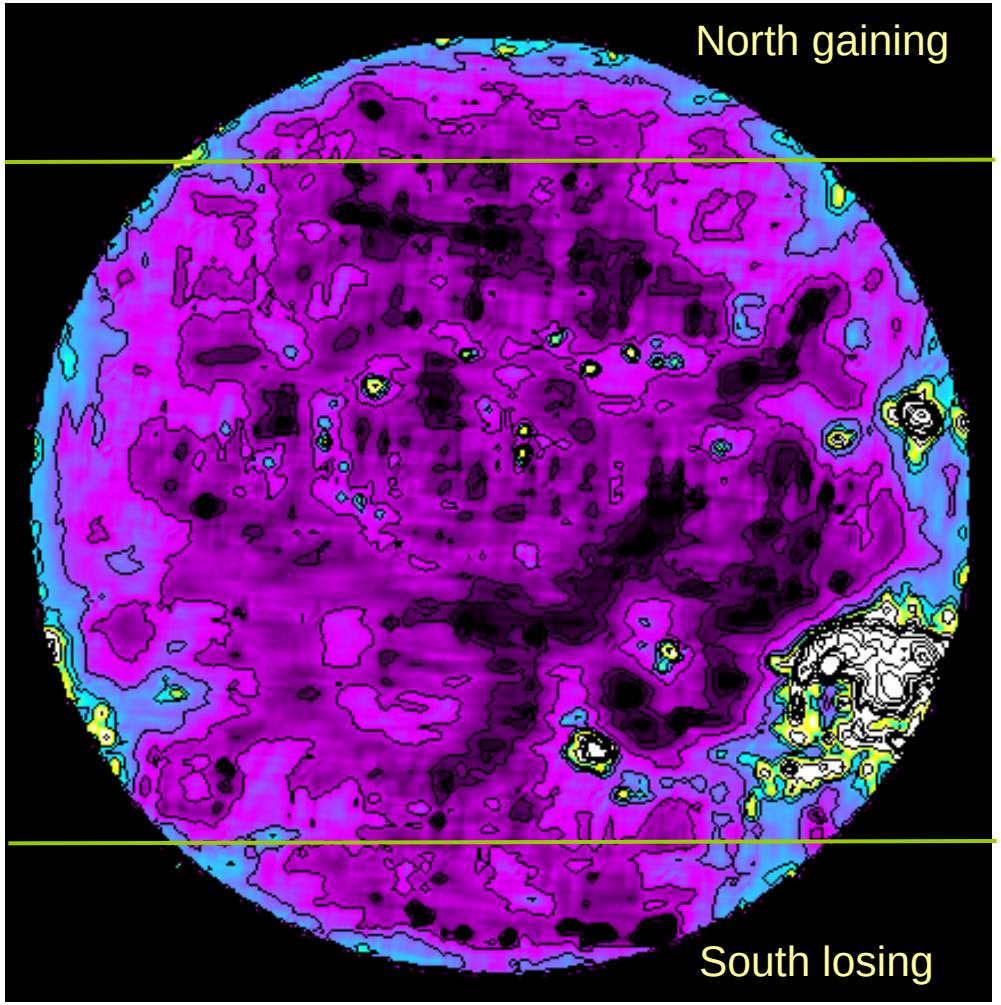
Answer: There isn't any.

Flux in the Polar Caps Rebuilding

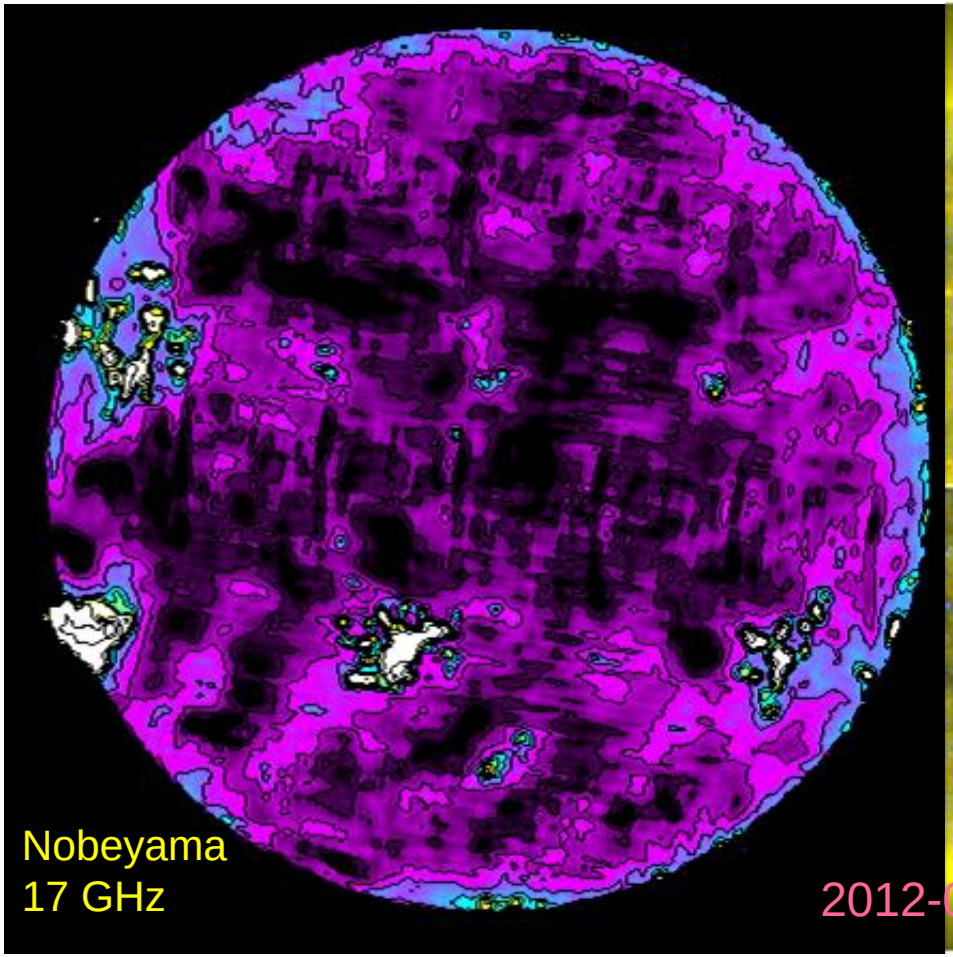
2011-11-14 to 16

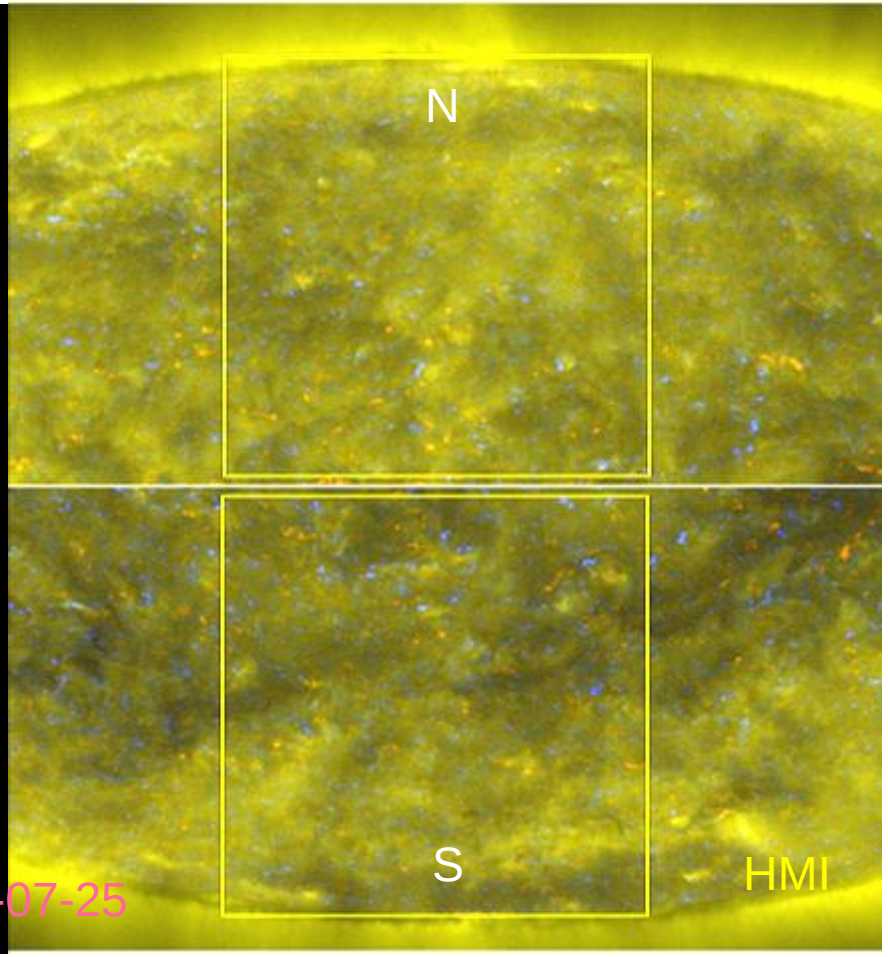


2012-07-16



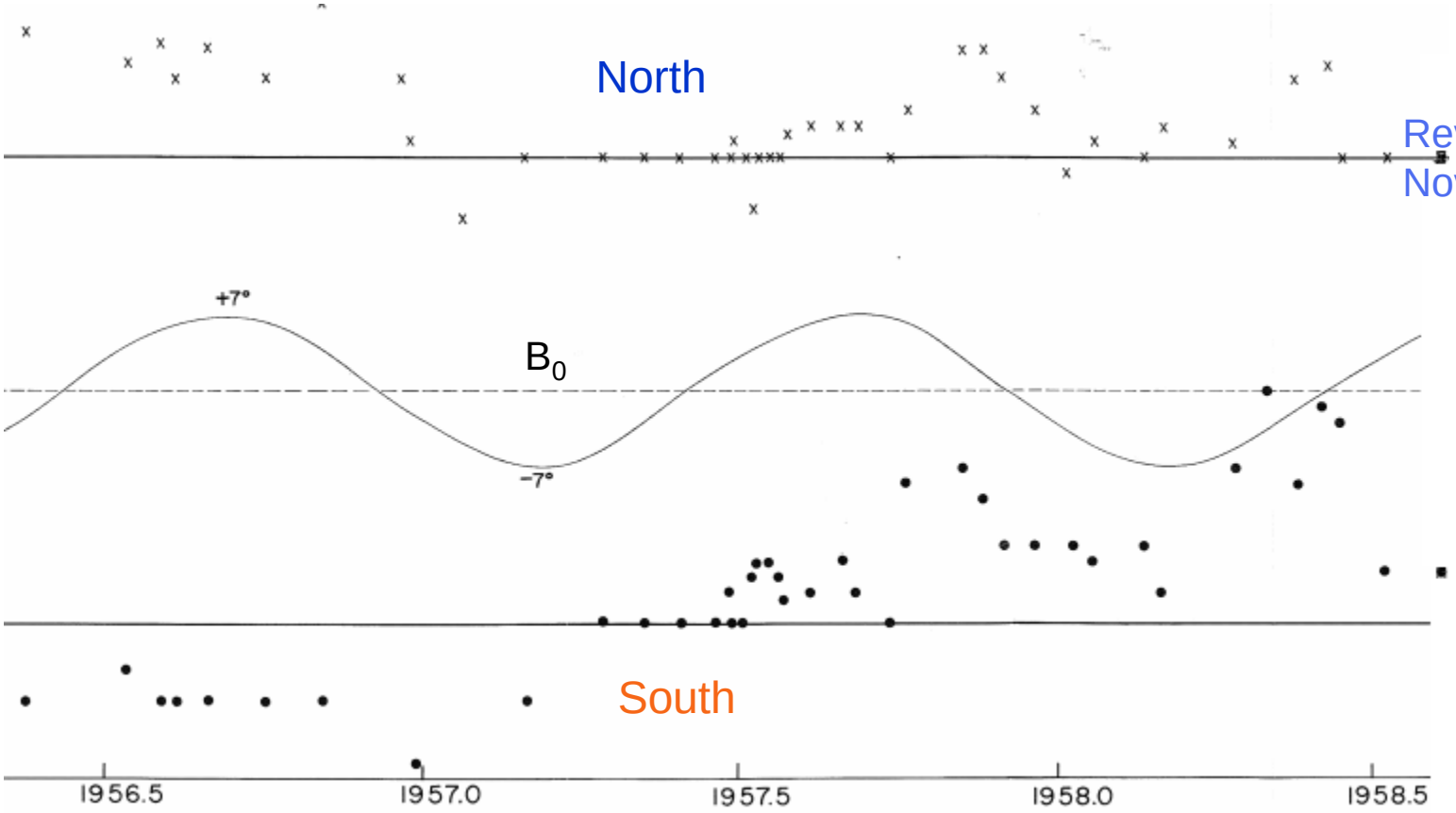
HMI Indicates Both Poles Now Positive





2012-07-25

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"

Waldmeier Related the Asymmetric Reversal to Asymmetry in Activity

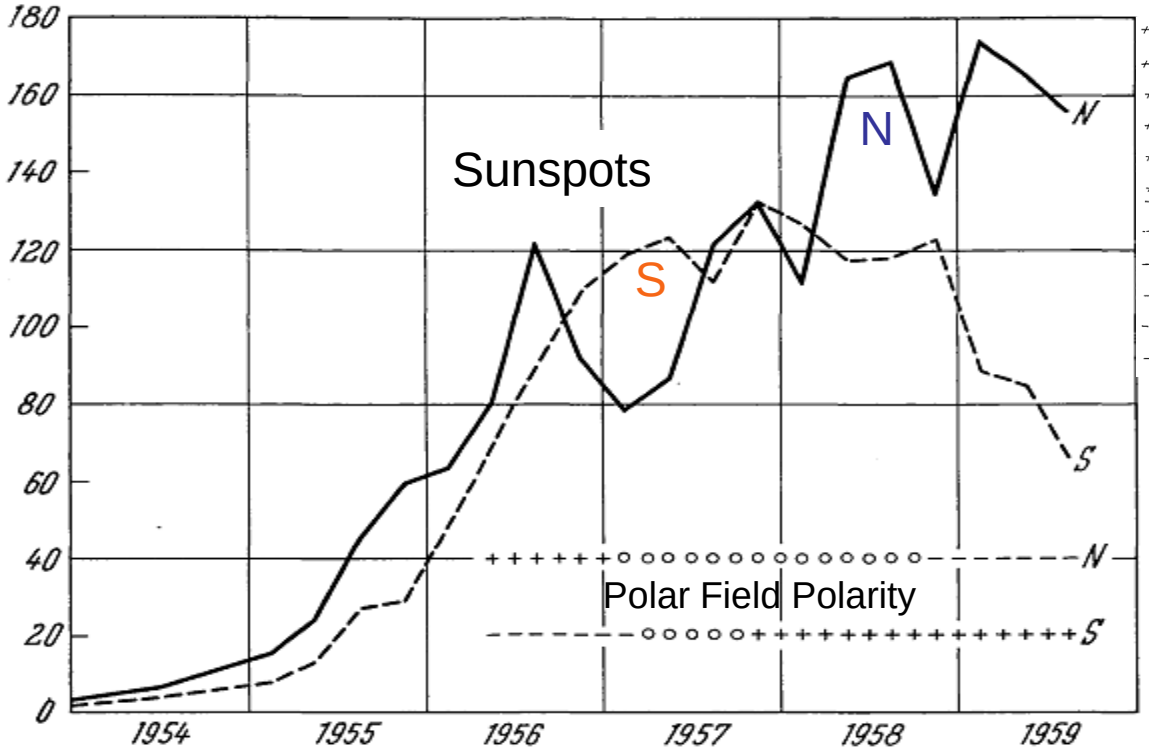
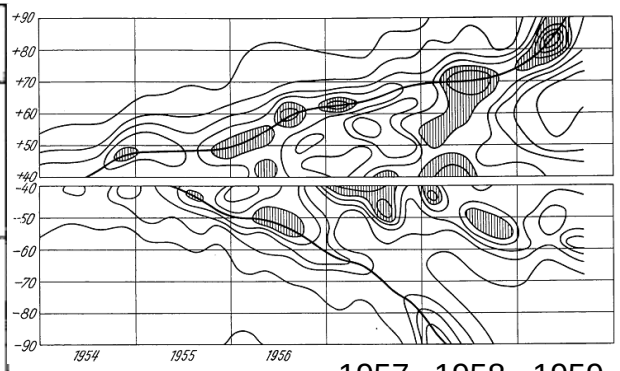


Abb. 1. Verlauf der Fleckentätigkeit und Variation des polaren Magnetfeldes



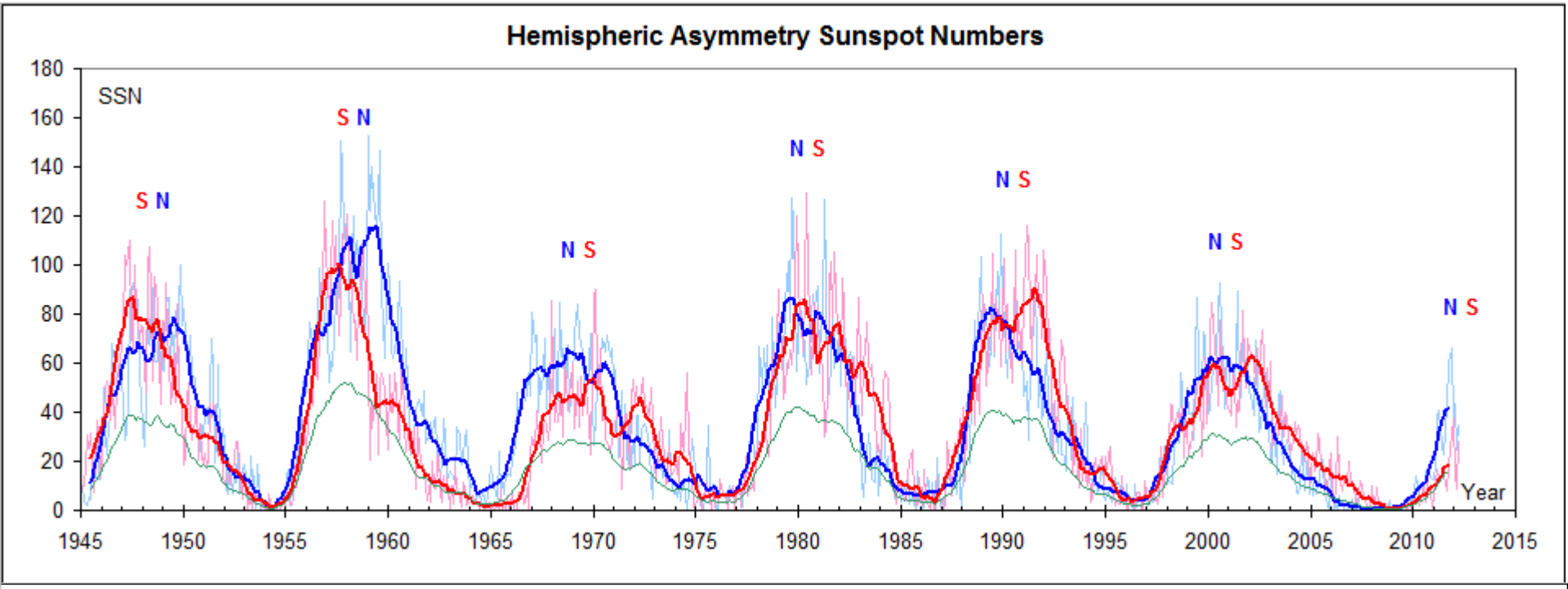
1957 1958 1959

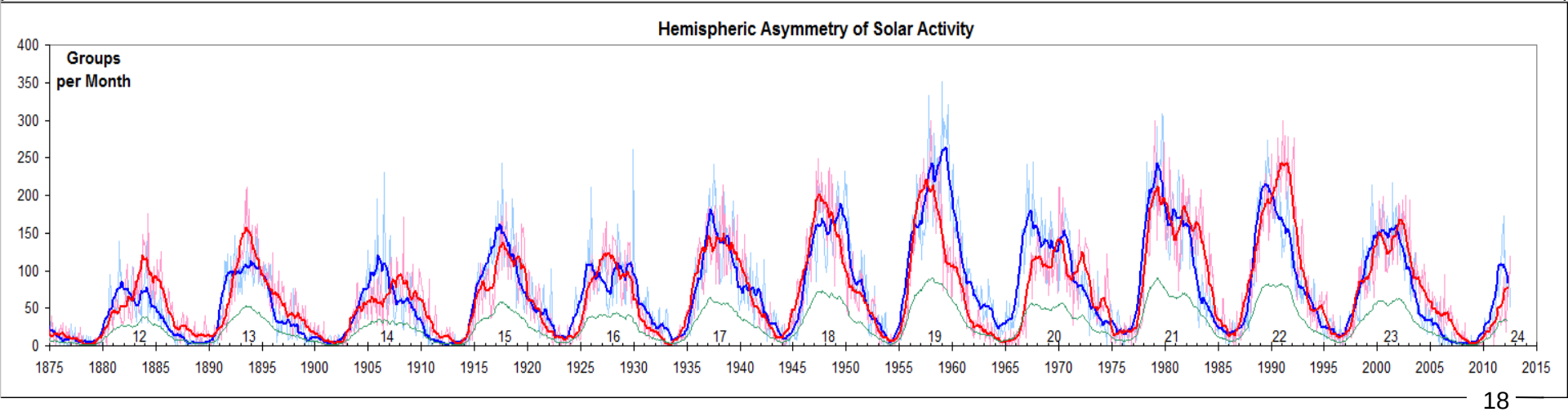
Occurrence of Prominences:

"Rush to the Poles"

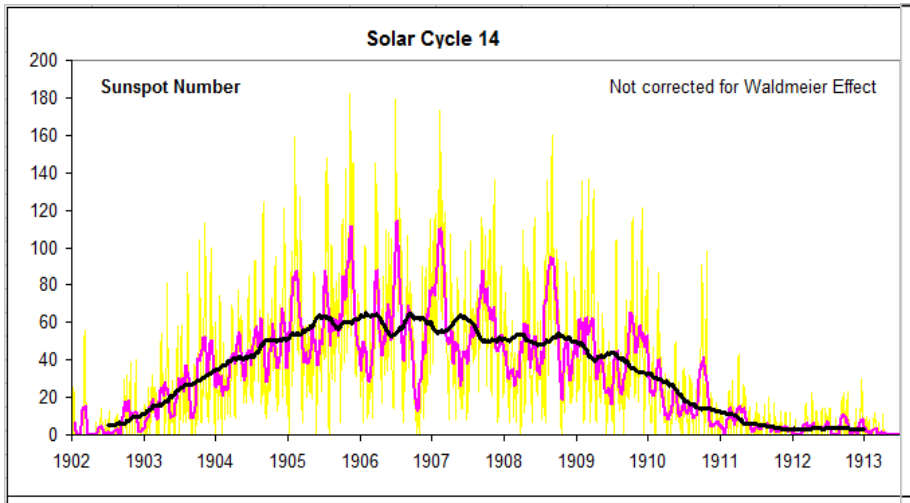
As Waldmeier (21) has pointed out, if the northern and southern hemispheres are considered separately, the sunspot numbers reached a maximum in the south about one year earlier than in the north, and this suggests a physical connection with the earlier reversal of the south polar field. Waldmeier (1960)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

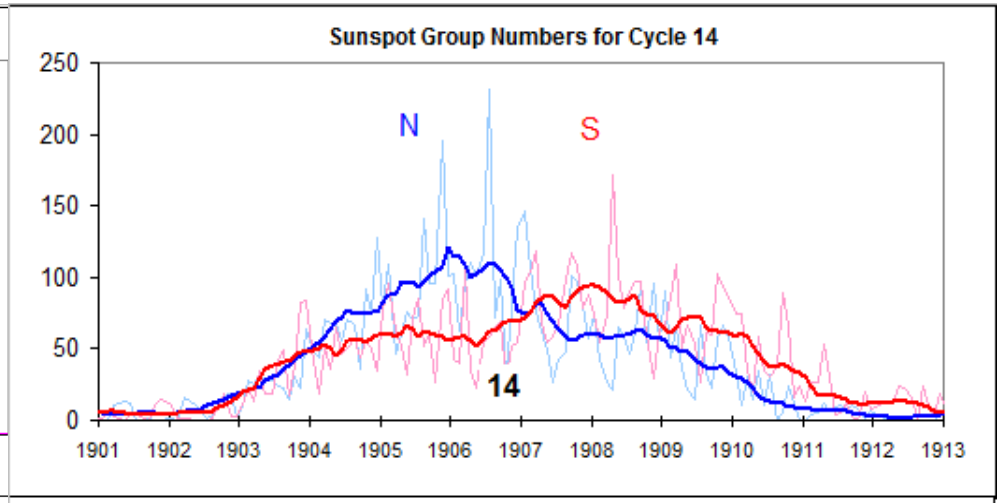
Asymmetric Solar Activity

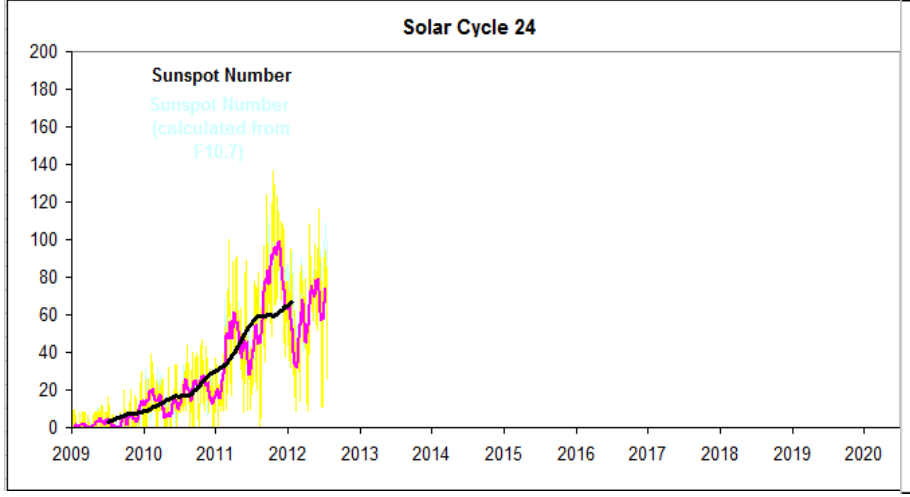


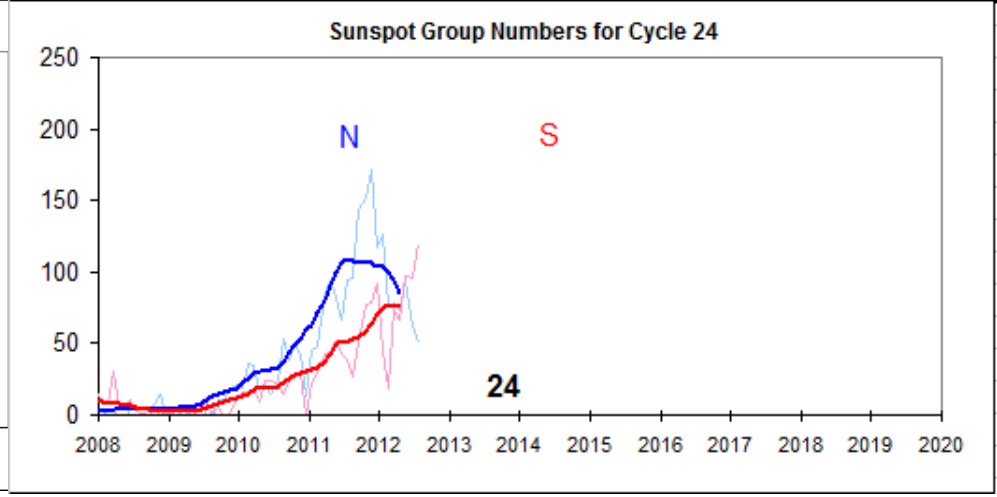


Comparing Cycles 14 and 24

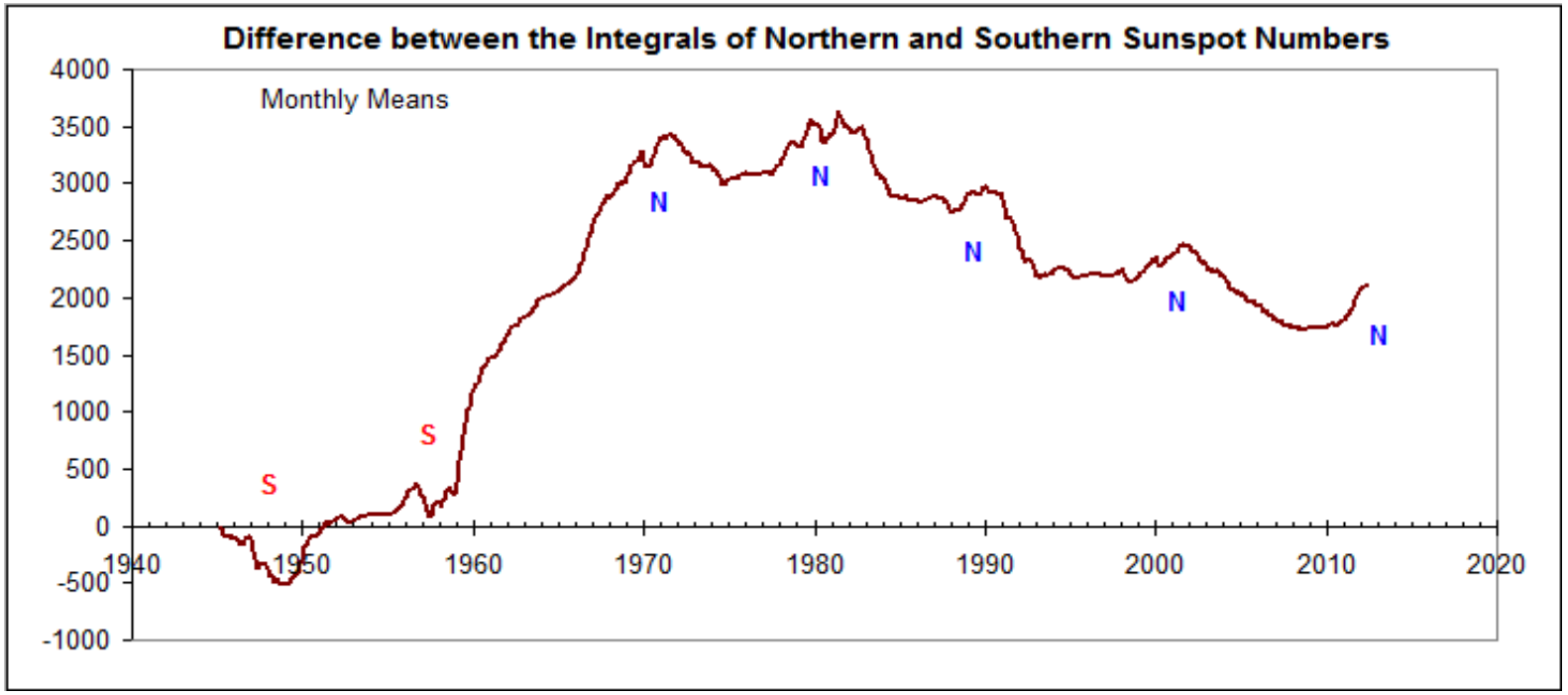








Quantifying the Asymmetry

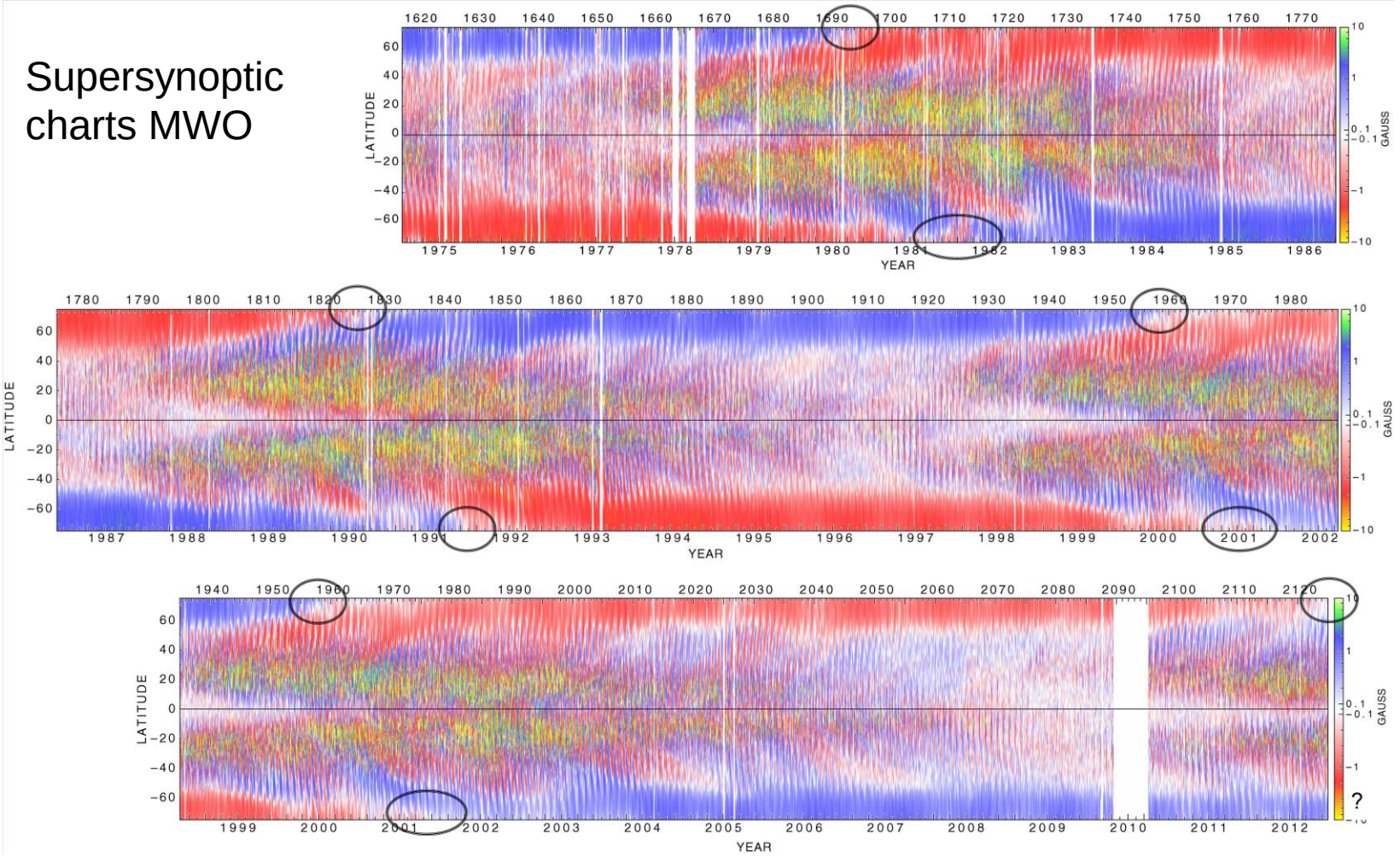


$$D(t) = \int_{x=1945}^{t} SSN_{North}(x)\,dx - \int_{x=1945}^{t} SSN_{South}(x)\,dx$$

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

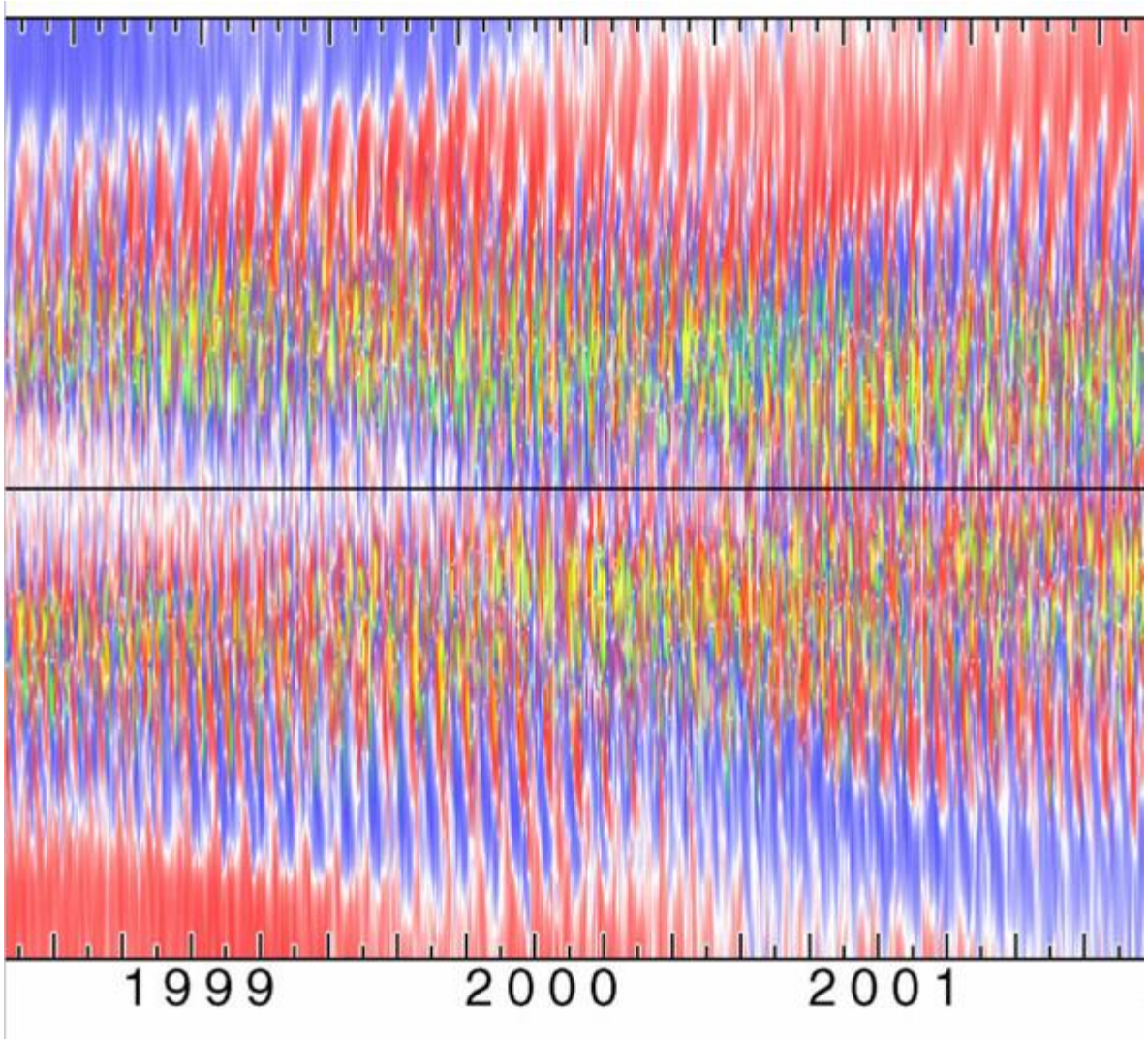
Observed Polar Field Reversals

Supersynoptic charts MWO

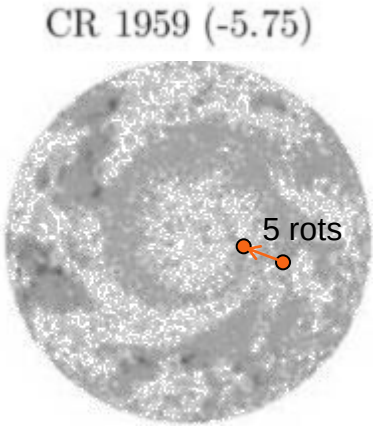


MWO: Roger Ulrich, 2012

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

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.

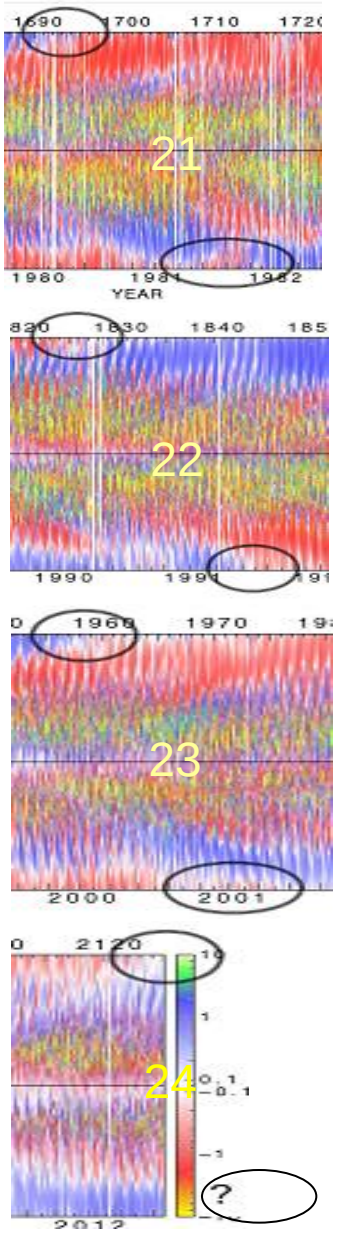
SPD Meeting, 1980, BAAS, 12, 893, B1

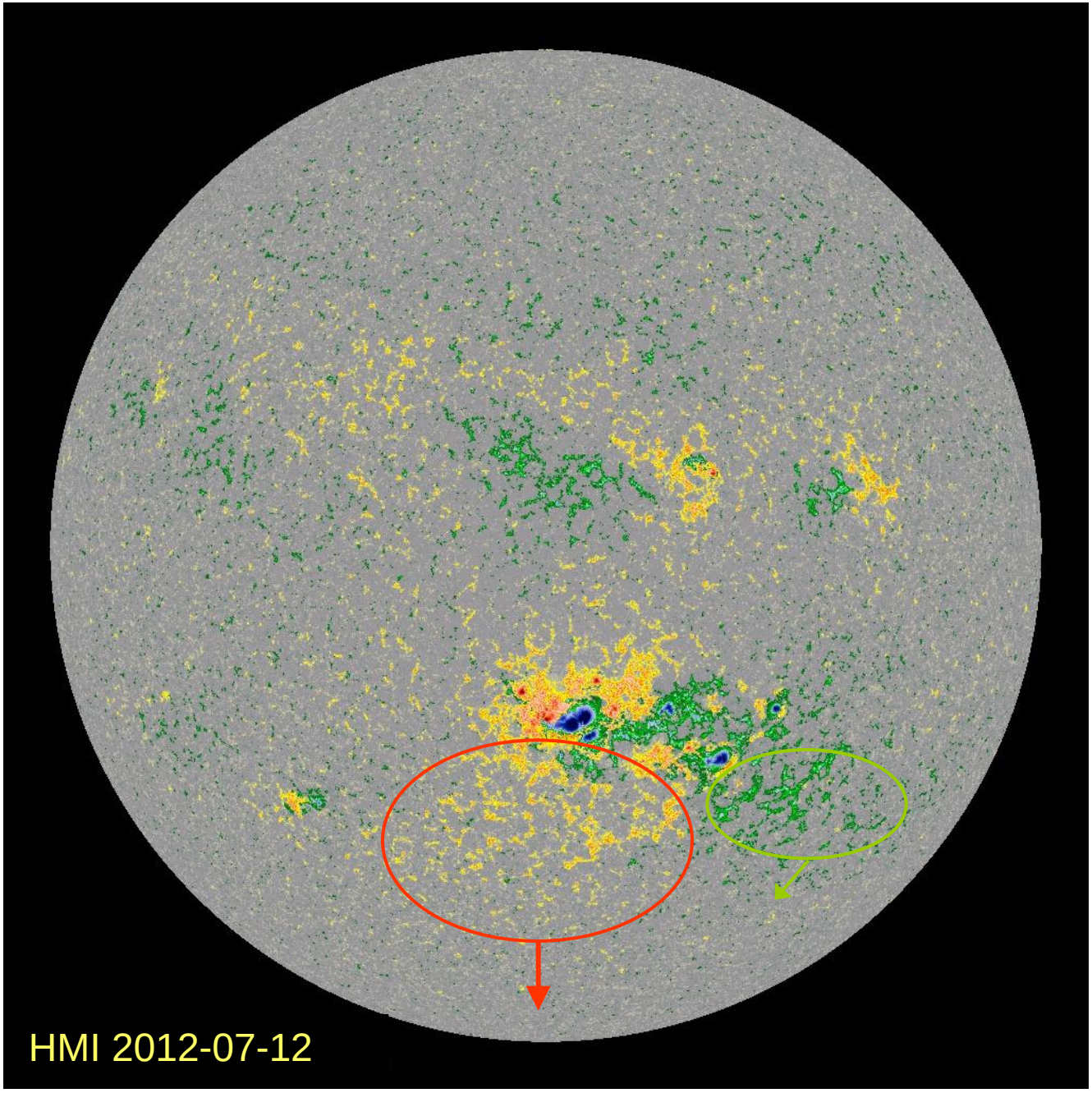
Neither are the Reversals due to Migrating of Fields

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.)



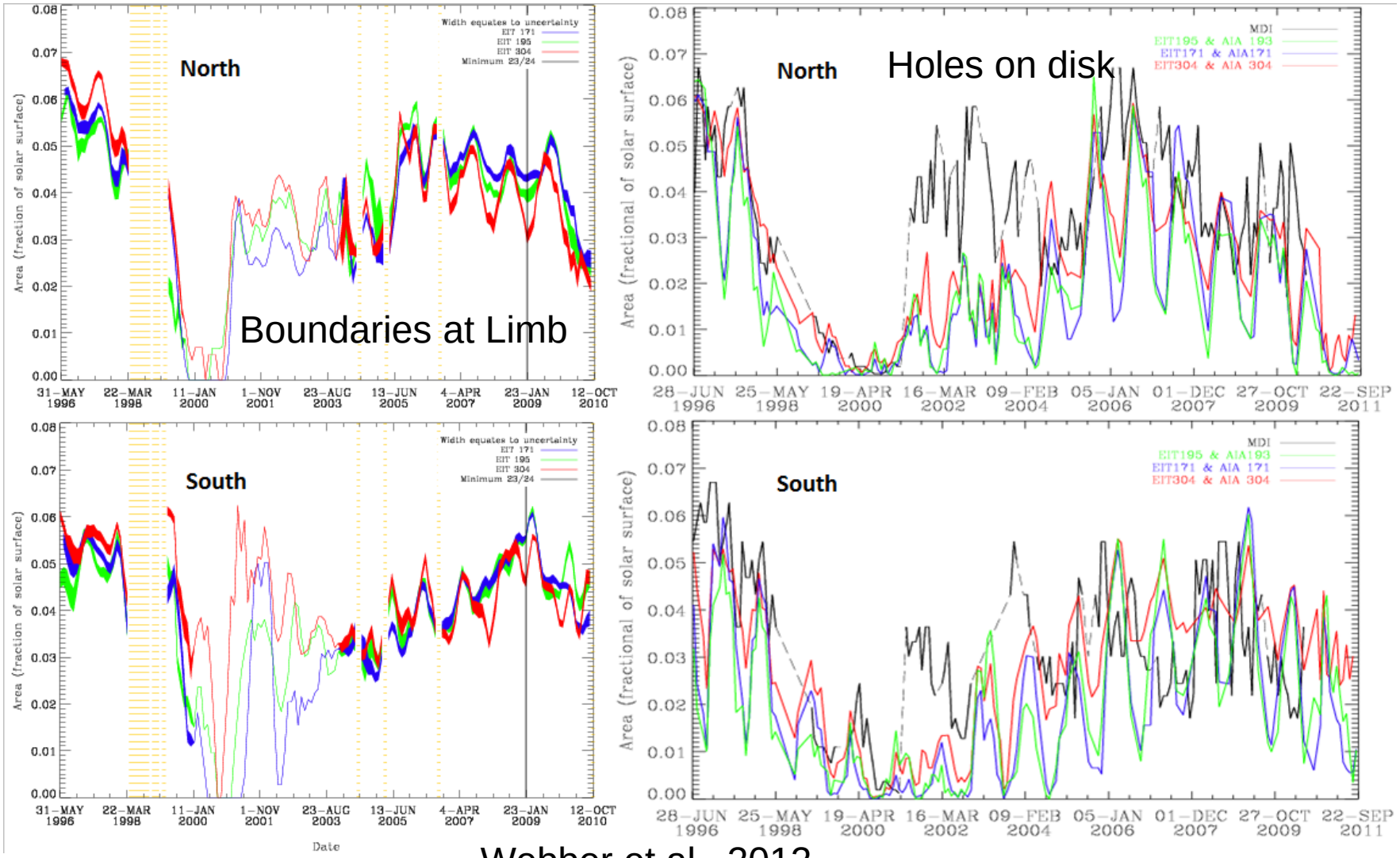


"This just in:"

Large (-) Flux Injection Heading for the South Pole

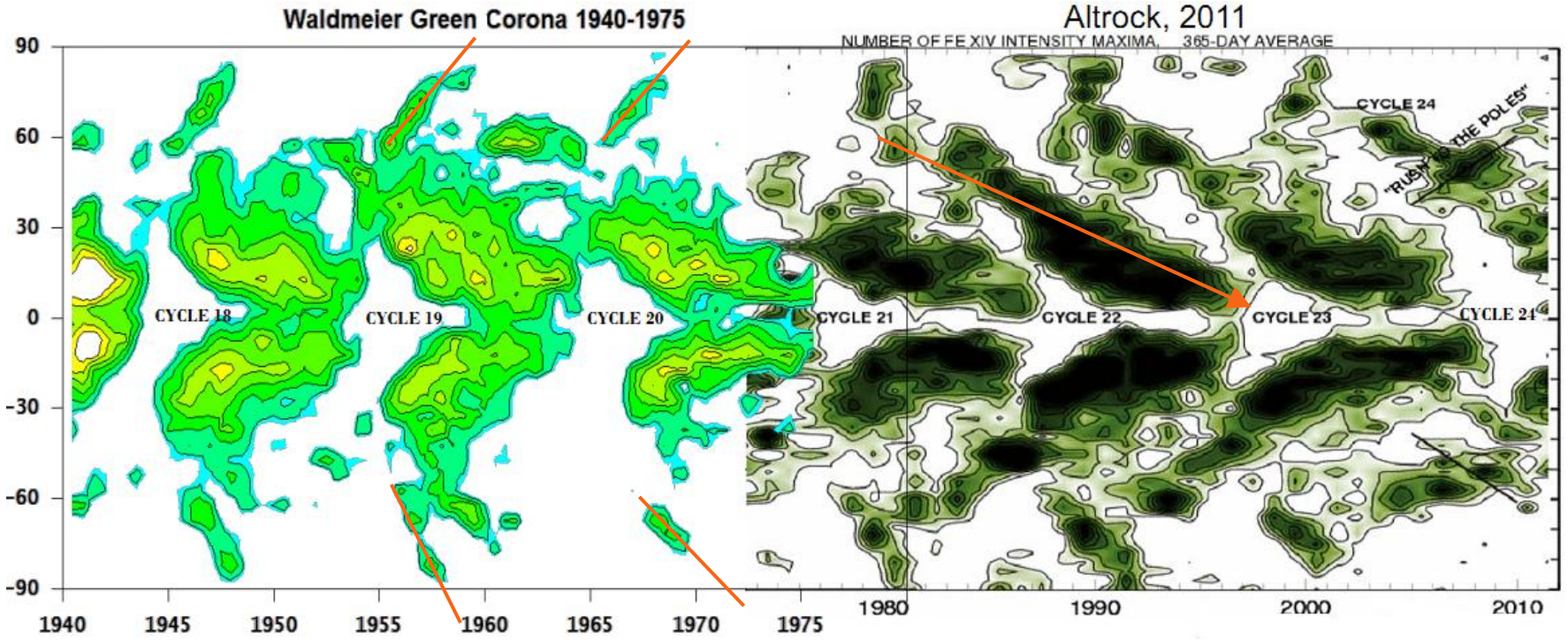
Todd Hoeksema, 2012: "It wouldn't surprise me if this is the region that eventually moves poleward to reverse the stalled southern pole"

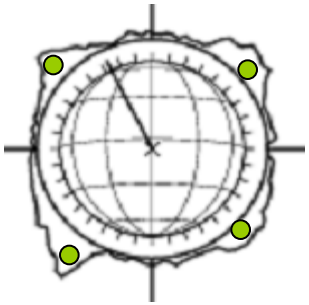
Polar Coronal Holes also Show When Reversals Happen



Webber et al., 2012

And the ‘Rush to the Pole’ of Coronal Emissions

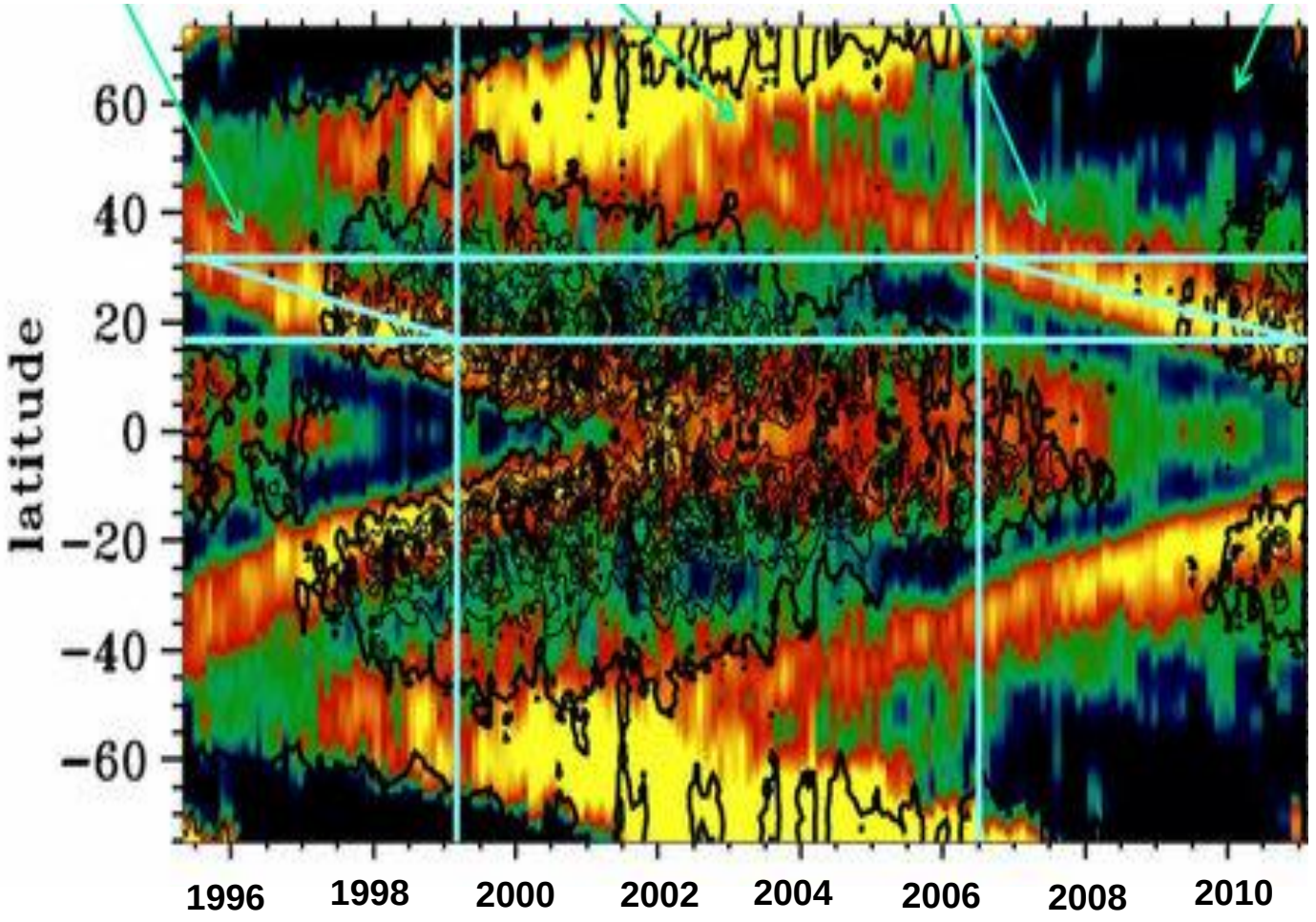




Measurements of the location of ‘peaks’ of Fe XIV coronal emission at 503 nm (the ‘Green Line Corona’) over 7 solar cycles. The plots show the probability of observing a ‘peak’ at a given latitude as a function of time.

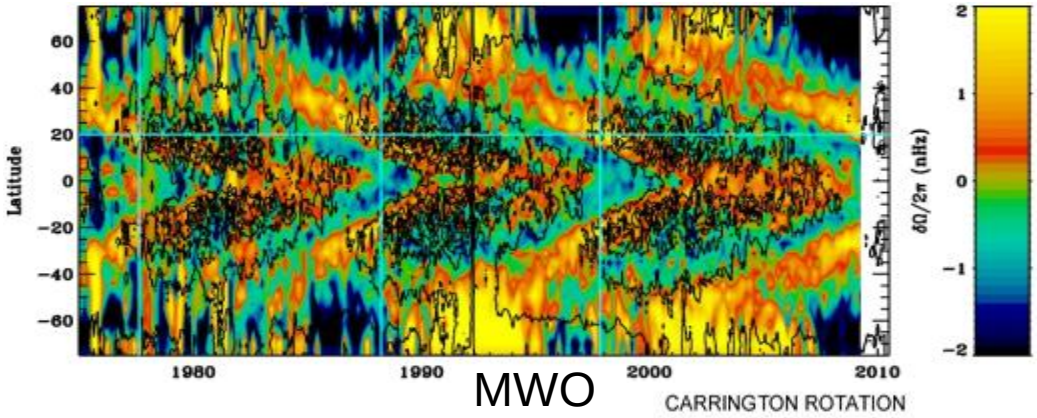
Is there an ‘extended’ cycle of 17 years?

Torsional Oscillation Seems to Support an Extended Cycle



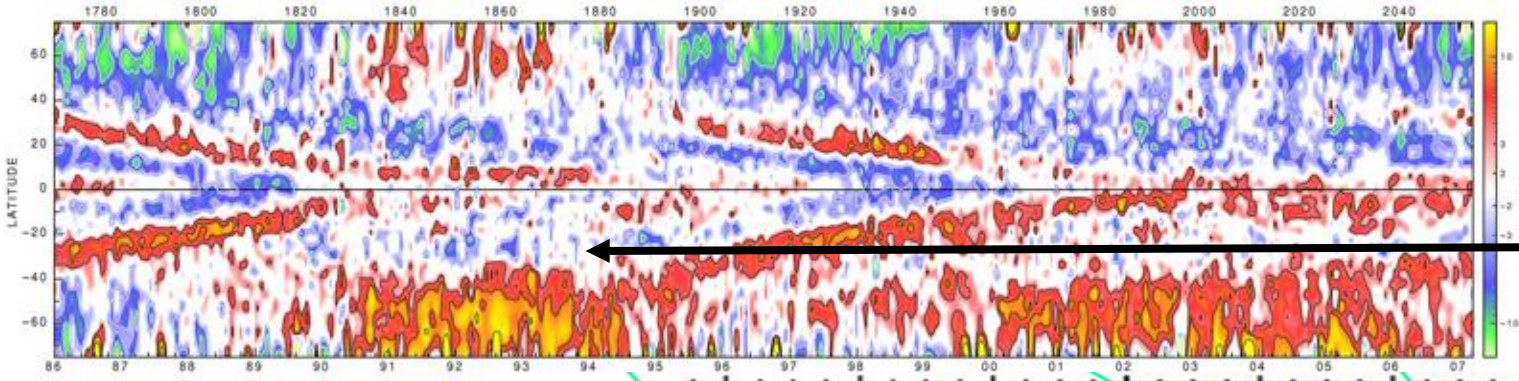
Torsional Oscillation and Extended Solar Cycle ?

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



MWO

CARRINGTON ROTATION

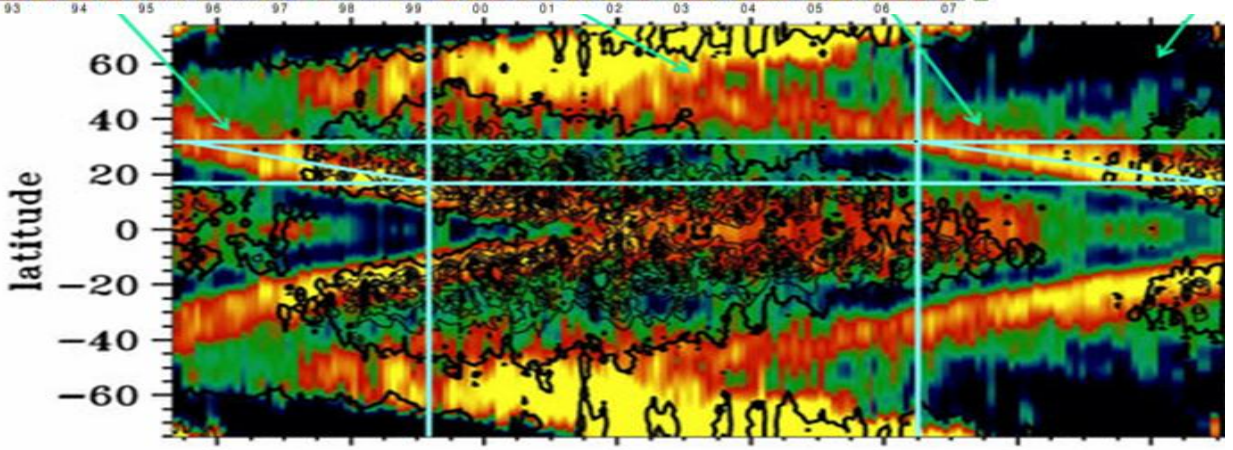


MWO

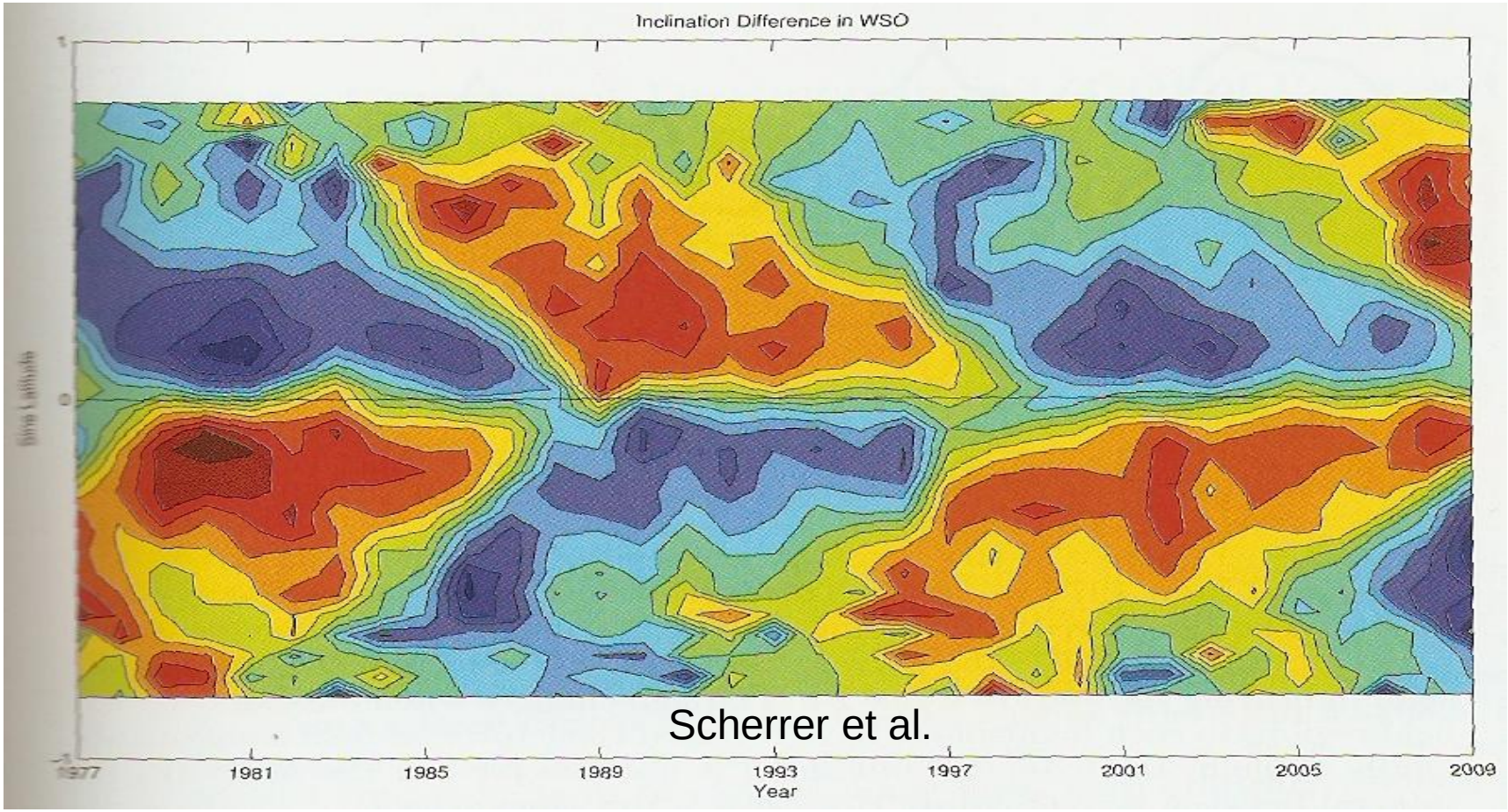
15 yrs

MDI, GONG

Frank Hill



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

Extended cycle is controversial [perhaps]

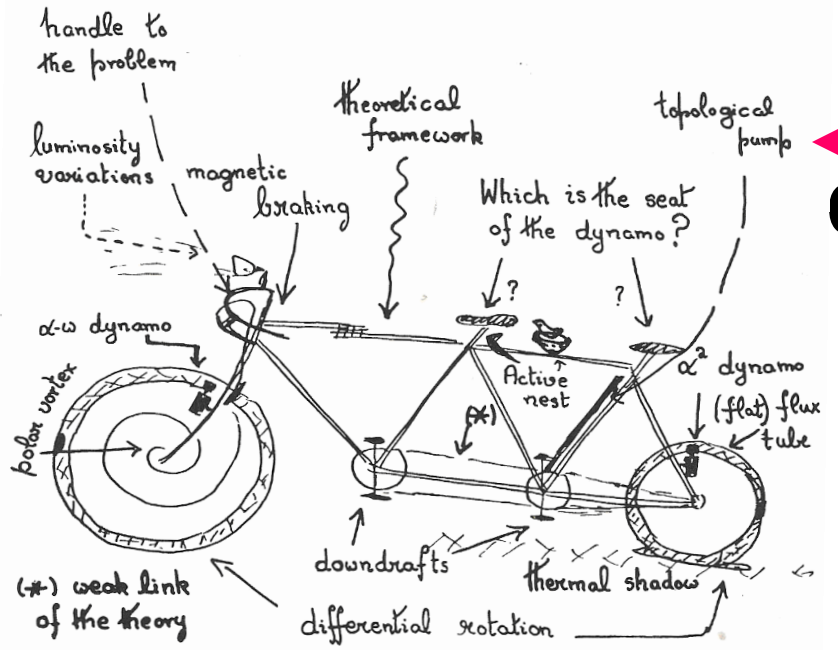
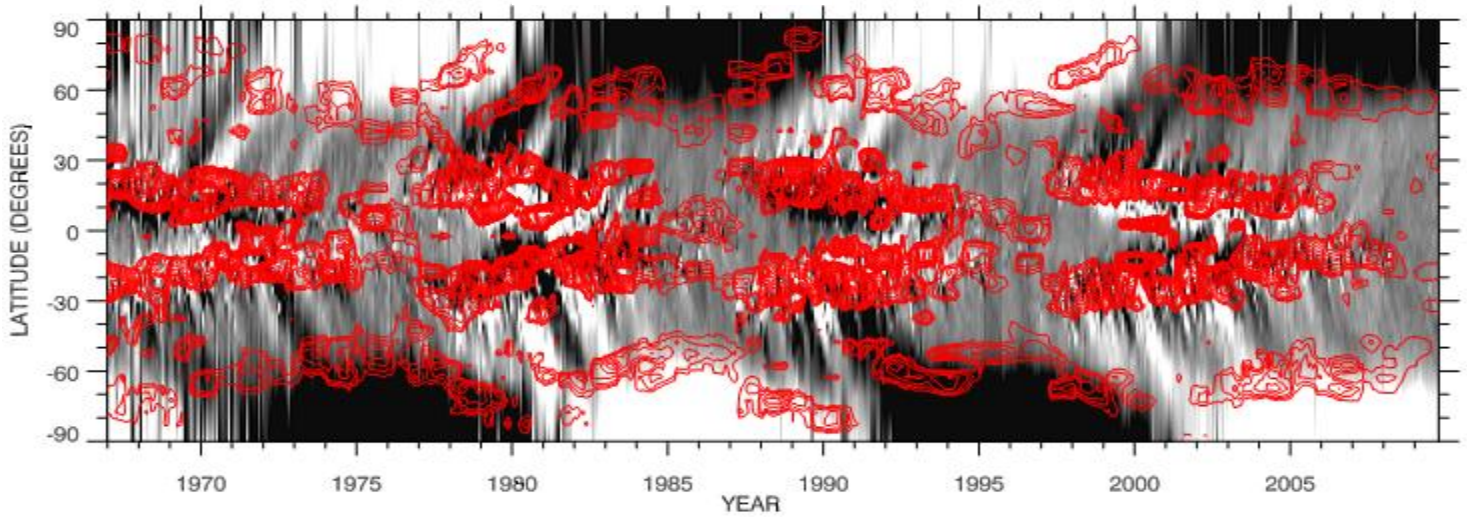


Fig. 8.8 A diagram of the *Xtended Cycle* constructed at a party held during the Sunspot meeting of the Solar Cycle Workshop in 1991. The author disclaims any responsibility but understands that Jean-Paul Zahn is liable for the drawing,

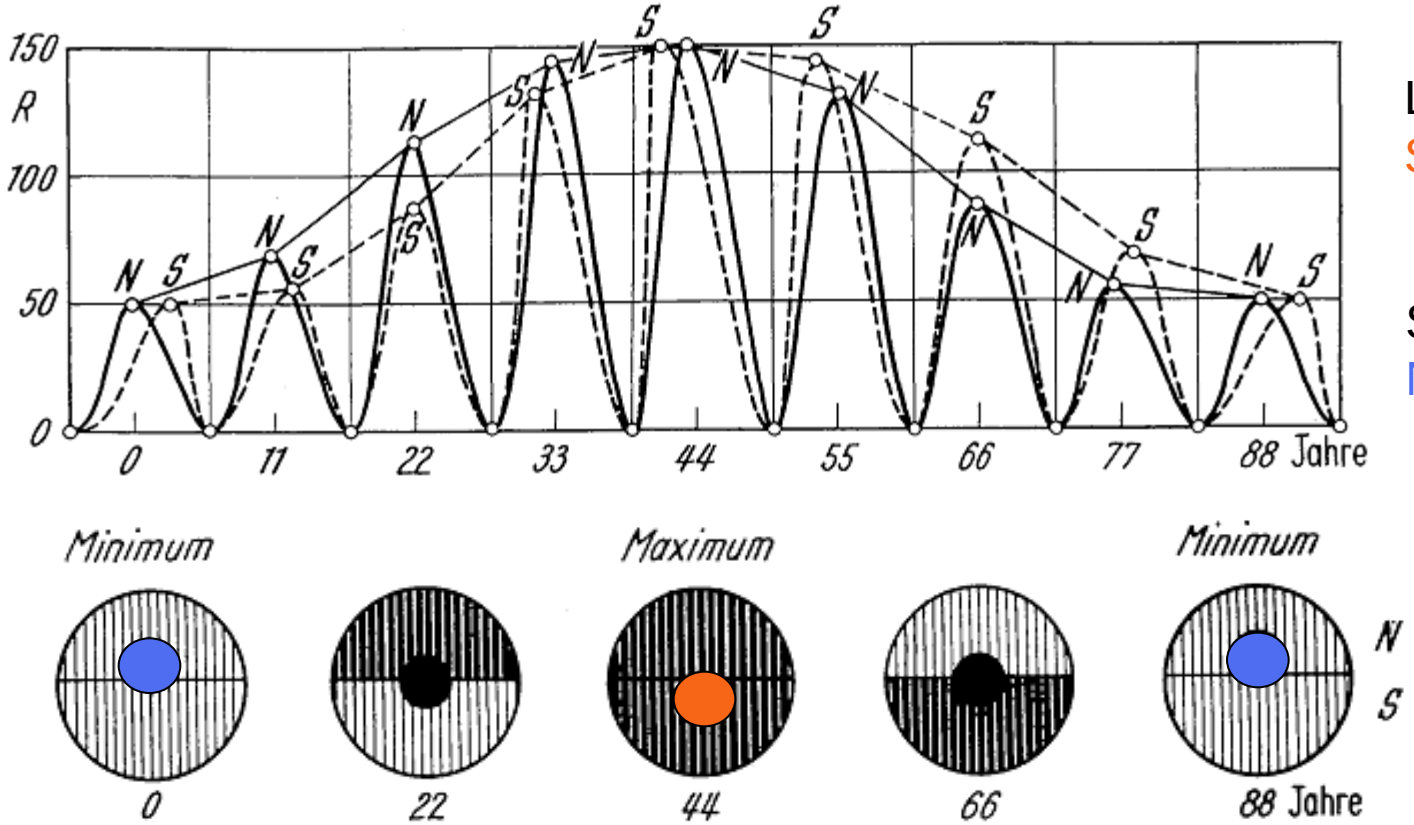
Our 'Understanding' of the Extended Cycle

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)

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

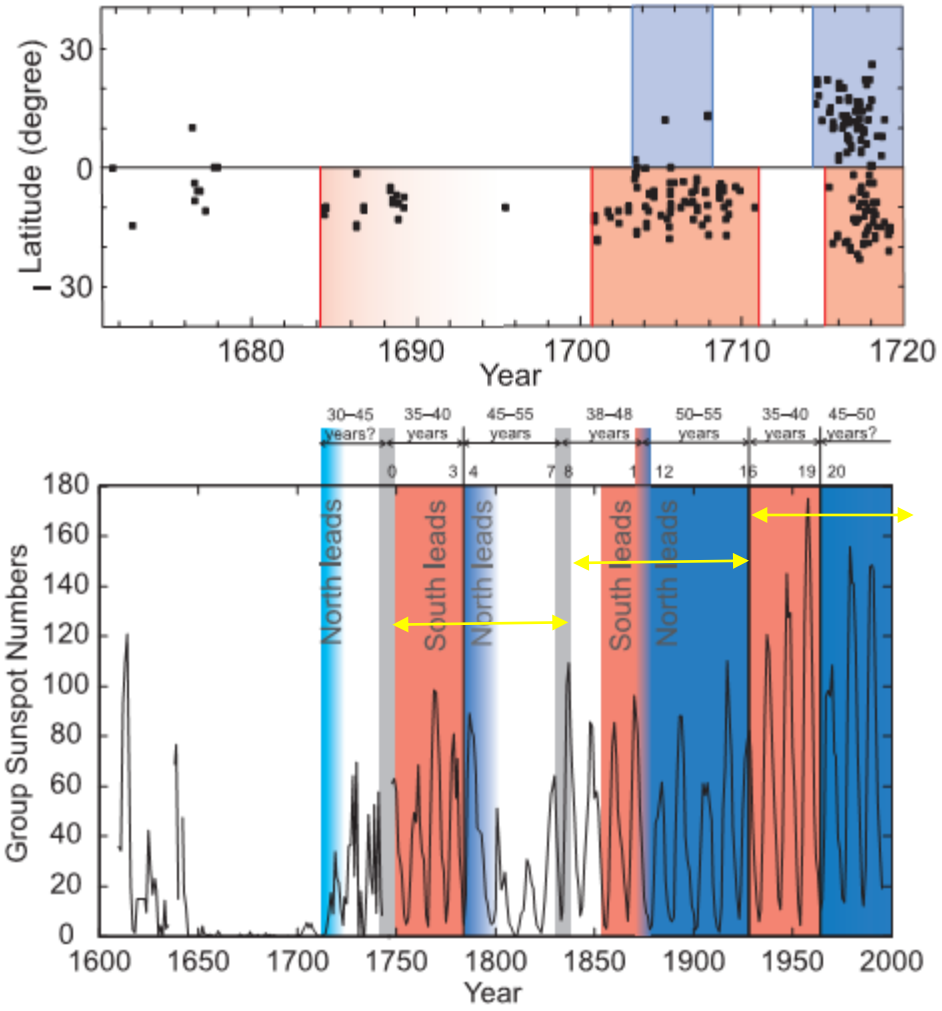


Large cycles:
S leading

Small cycles:
N leading

Waldmeier, 1957

70-100 Year ‘Gleissberg Cycle’ in Solar Activity Asymmetry?



Zolotova et al., 2010

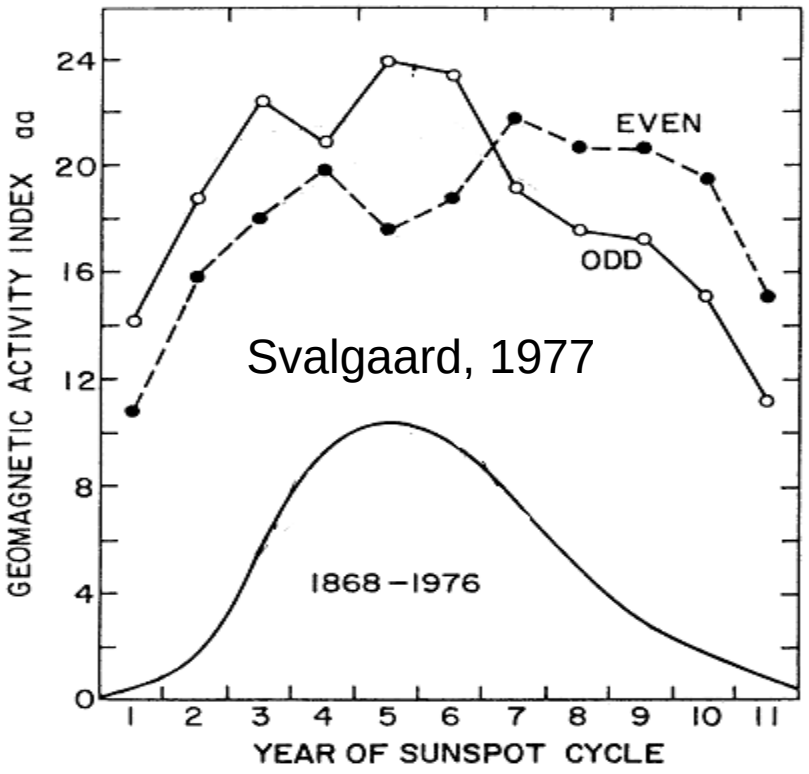
Extreme Asymmetry during the Maunder Minimum…

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…

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

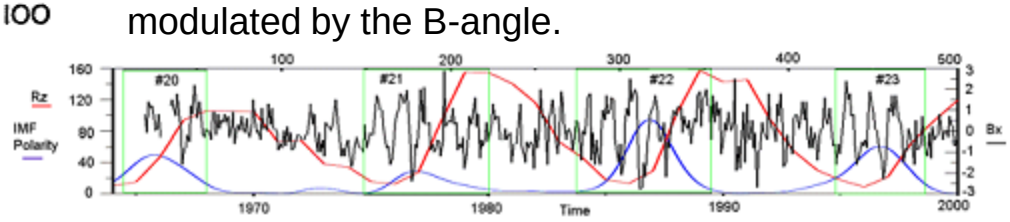


Svalgaard, 1977

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

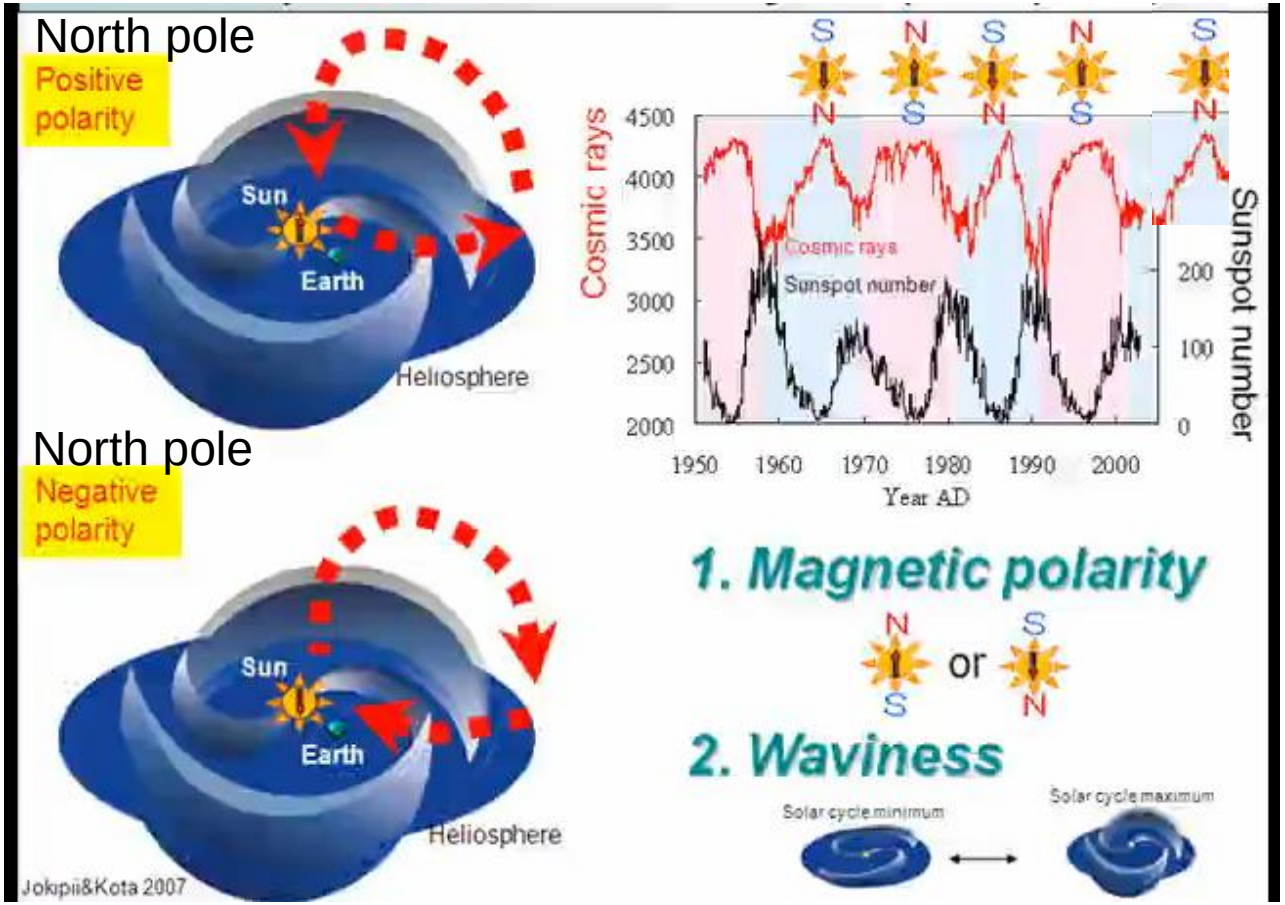
In any case, our result over a 45-year interval is probably the most direct evidence for a continuing change of the predominant polarity of the large-scale solar-magnetic field with a period equal to the sunspot magnetic cycle, i.e., ~20 years during this century. Wilcox & Scherrer, 1972

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

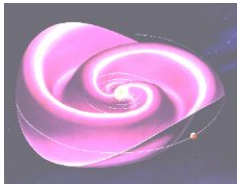


This effect combined with the Russell-McPherron effect [geomagnetic activity enhanced by the Southward Component of the HMF] predicts a 22-year cycle in geomagnetic activity synchronized with polar field reversals, as observed (now for 1840s-Present).

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.

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