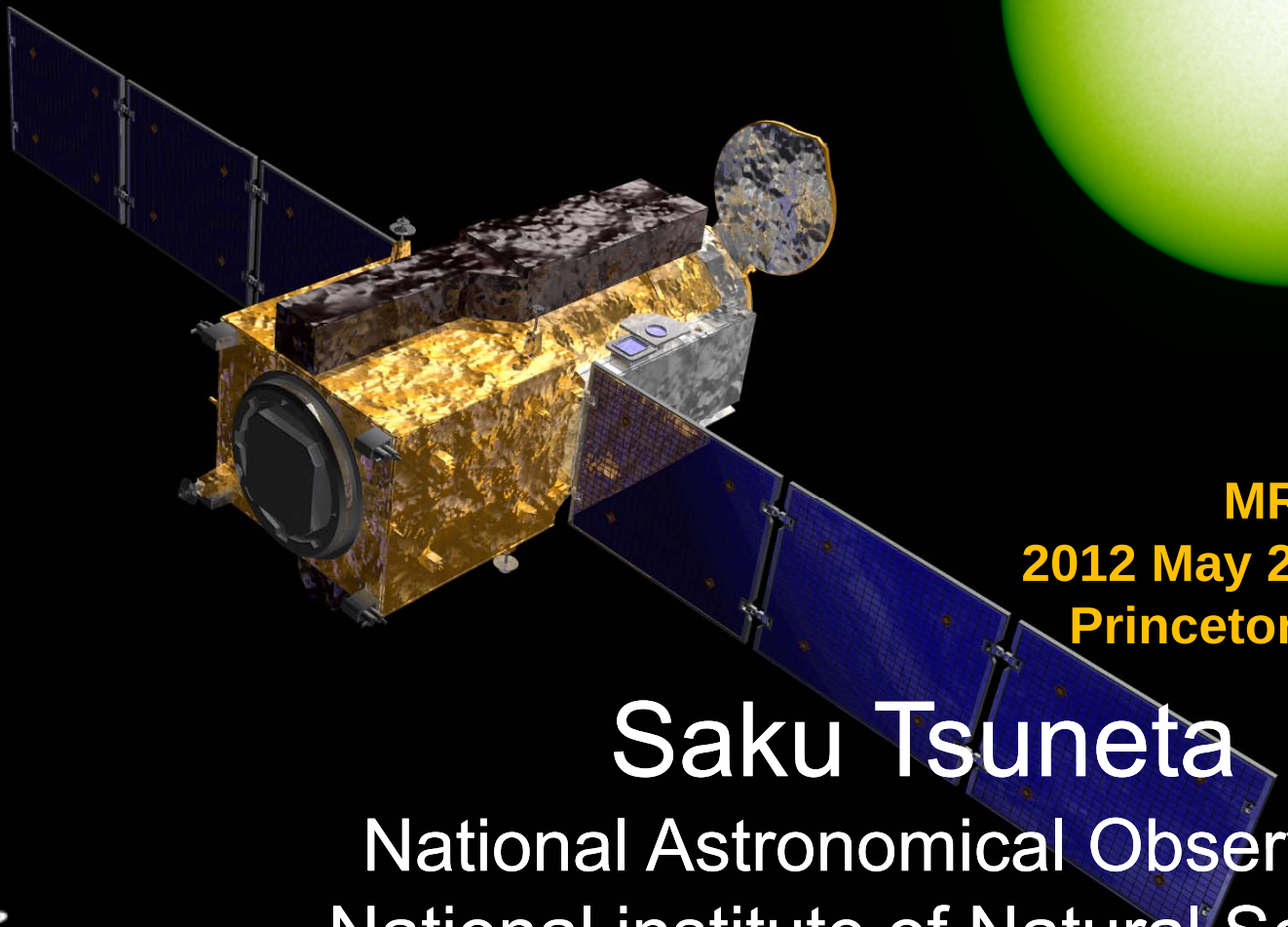
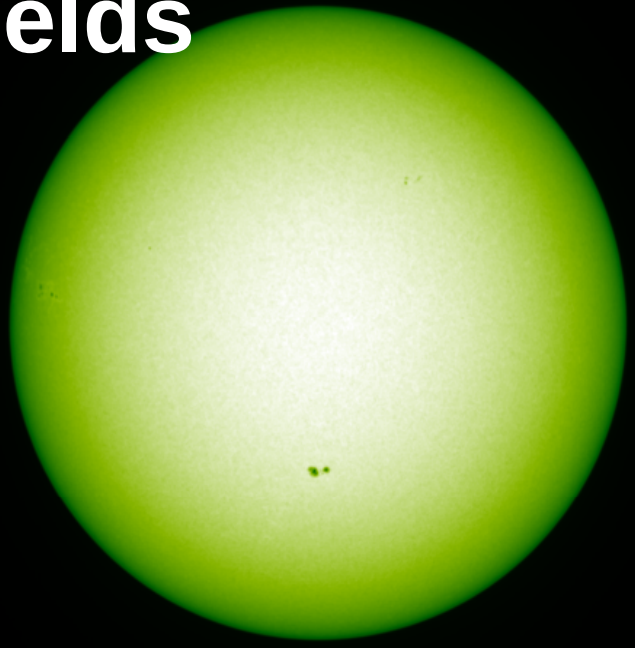
Quadruple solar poloidal fields as observed with *Hinode*

dedicated to Masaaki Yamada



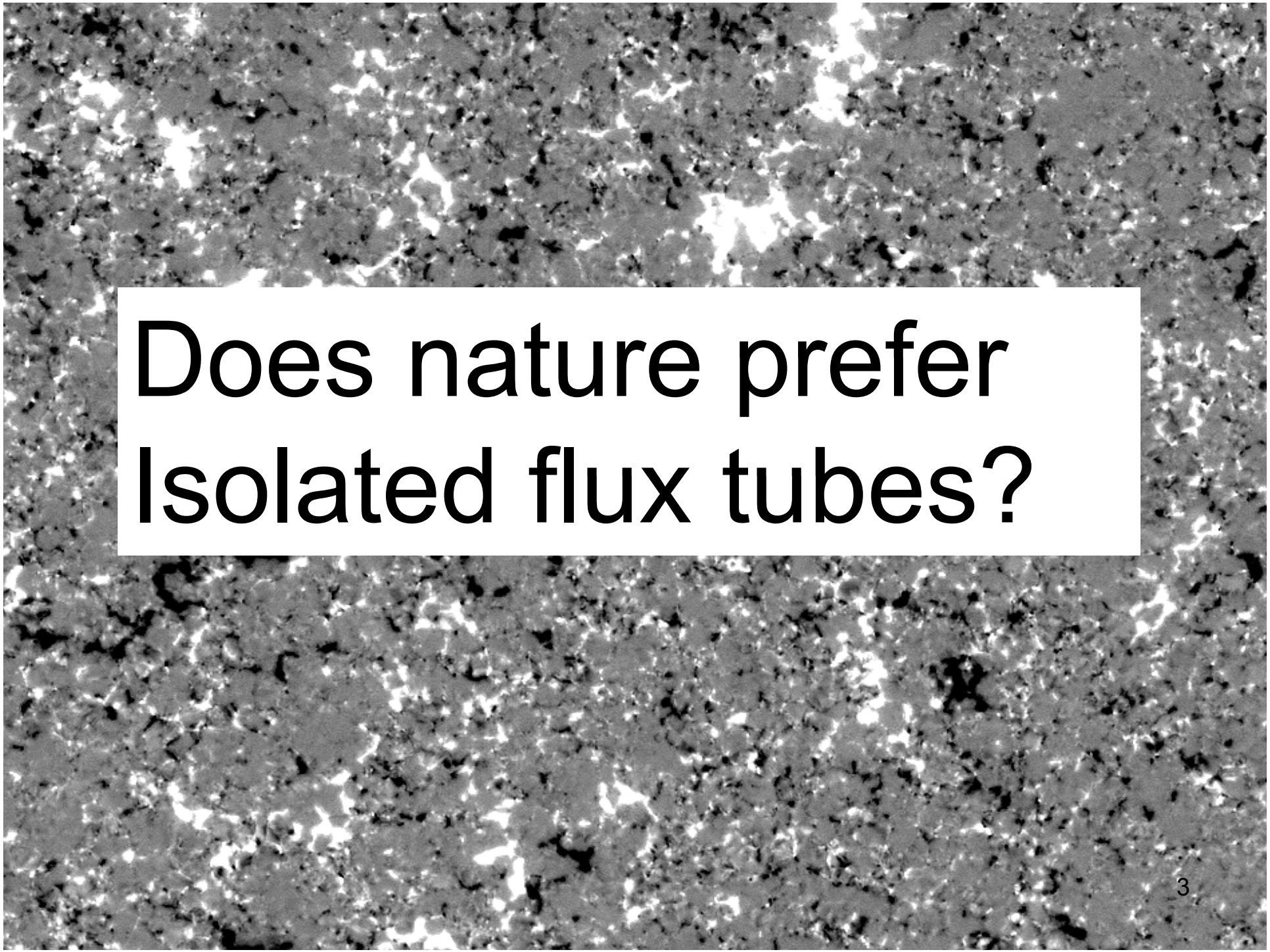


MR2012
2012 May 24 15:30-15:55
Princeton University

Saku Tsuneta
National Astronomical Observatory
National institute of Natural Sciences

Maki Sugimoto

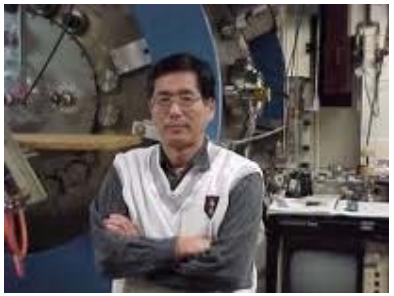
Masaaki Yamada's contribution to astrophysics


Does nature prefer
Isolated flux tubes?

Part1: Initial encounter

- Masaaki Yamada and his collaborators published ***a historical paper*** on magnetic reconnection in laboratory environment in ***1990***. Fortunately, I happened to see the paper. This paper, which was not known then in astrophysical community, fascinated me, and I sent a personal letter to Dr. Yamada, who was obscure to us at that time. In return, I got a friendly letter from Yamada-san, and I dare to say that this is the ***start of the fruitful collaboration between solar physics and laboratory plasma physics***.

Part2: Magnetic reconnection in solar flares



- The interaction resulted in one remarkable achievement; decision of NASA Headquarters to support the construction of the ***Princeton MRX*** experiment.
- In the following year, ***Yohkoh*** was launched. The mission was supposed to solve the ***solar flare*** problem. At that time, magnetic reconnection was mere possibility, and there is a feeling not to accept the concept in solar physics community. It needed certain courage to propose that ***magnetic reconnection do play a role in solar flares*** based on Yohkoh results at that time. But, I was confident partly because of the laboratory experiment.

Part3: Magnetic reconnection in astrophysics

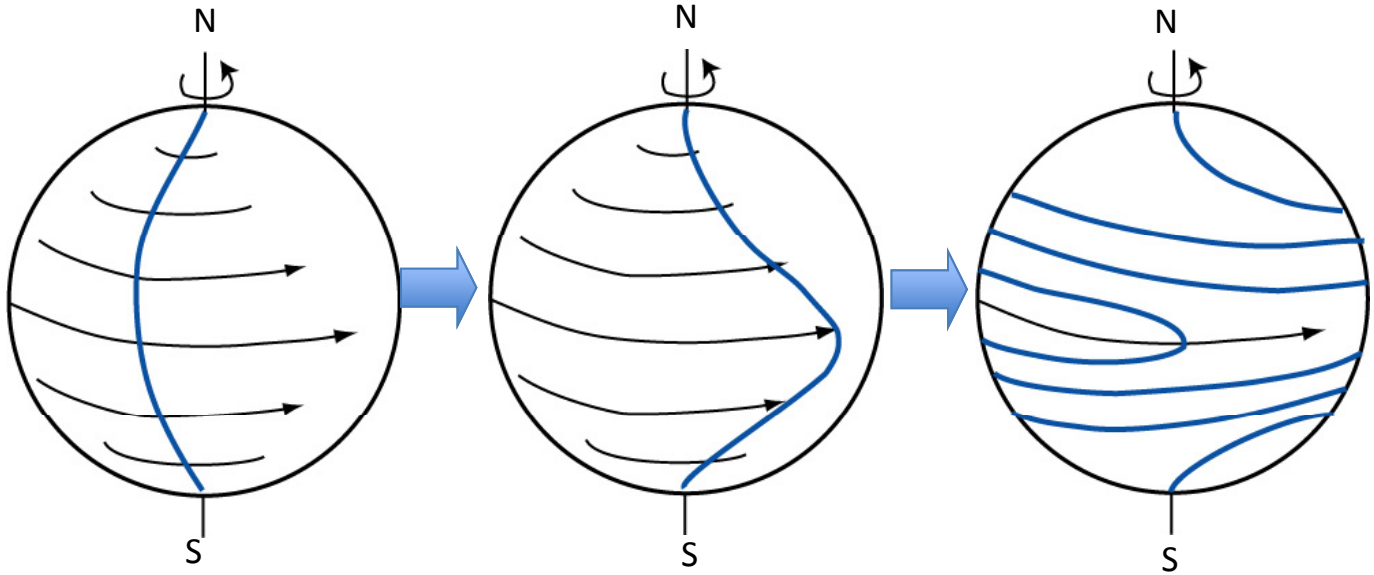
- As the time went on, magnetic reconnection became, by its own and from the point of application to various astrophysical phenomena, one of the ***central topics in plasma astrophysics*** including solar physics.
- I deeply recognize and appreciate the work done by Masaaki and collaborators, especially with regards to astrophysics. Their success is primarily due to Masaaki's wisdom and ability to see 20 years into the future.
- I will here talk about the latest ***Hinode*** observations related to ***solar dynamo*** where magnetic reconnection would play a role to ***commemorate Masaaki's 70th birthday.***

Importance of polar fields to predict future solar activity

Cause
Weak polar field

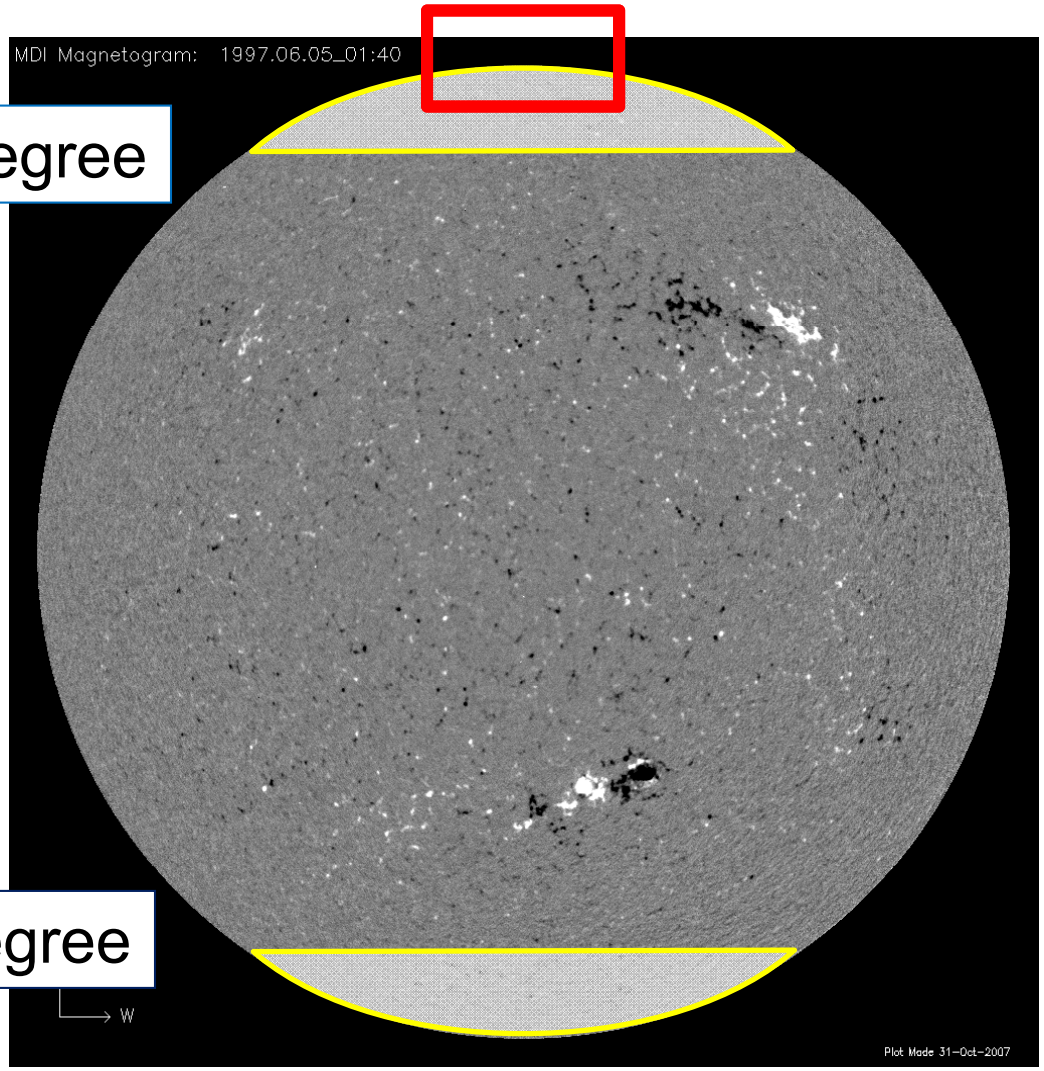
130 rotations in 11 year

Result
Less number of sunspots



$\nabla\Omega$-dynamo

Polar observations from ground

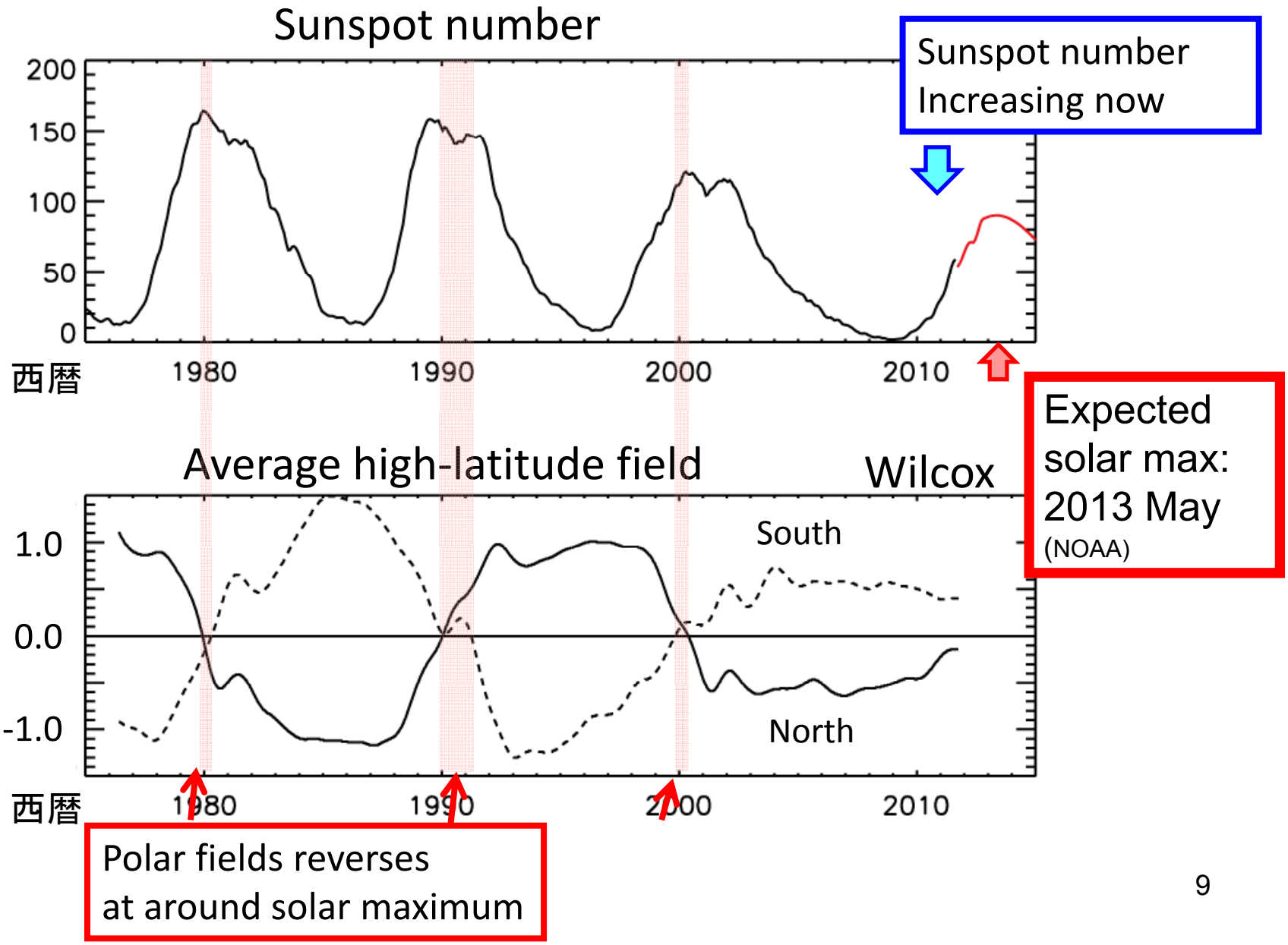


W : plus
B : minus

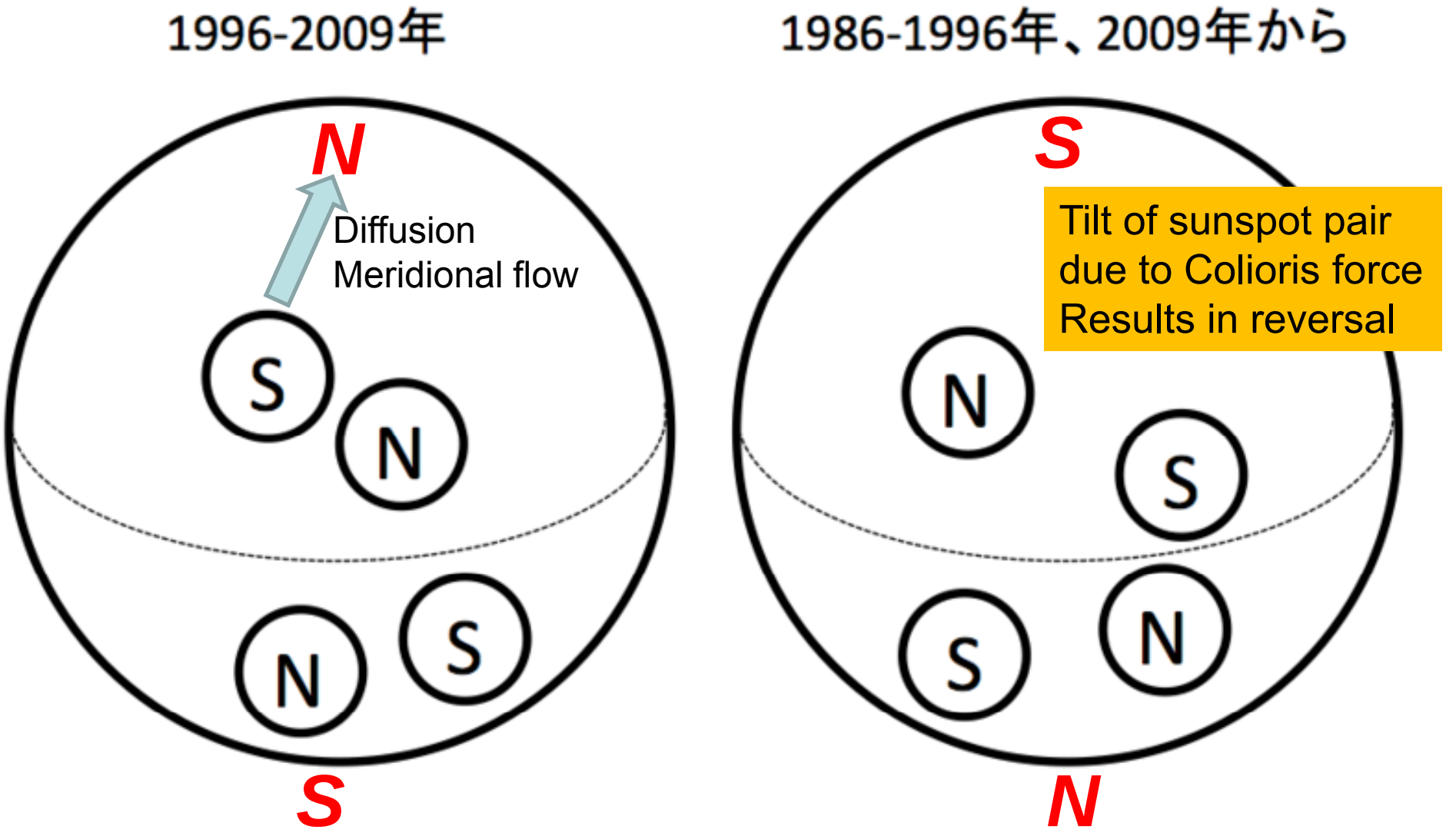
SOHO

Polar field= single pixel observations above latitude of 55 degree.

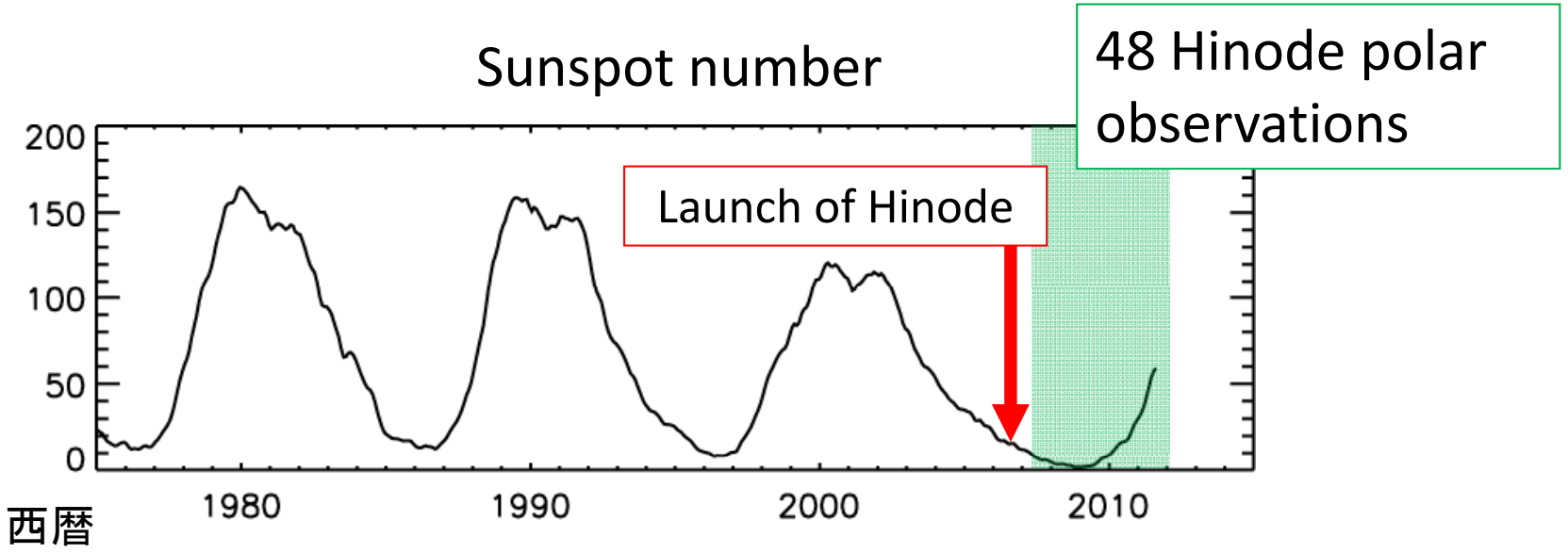
Reversal of high-latitude (>55 deg) field

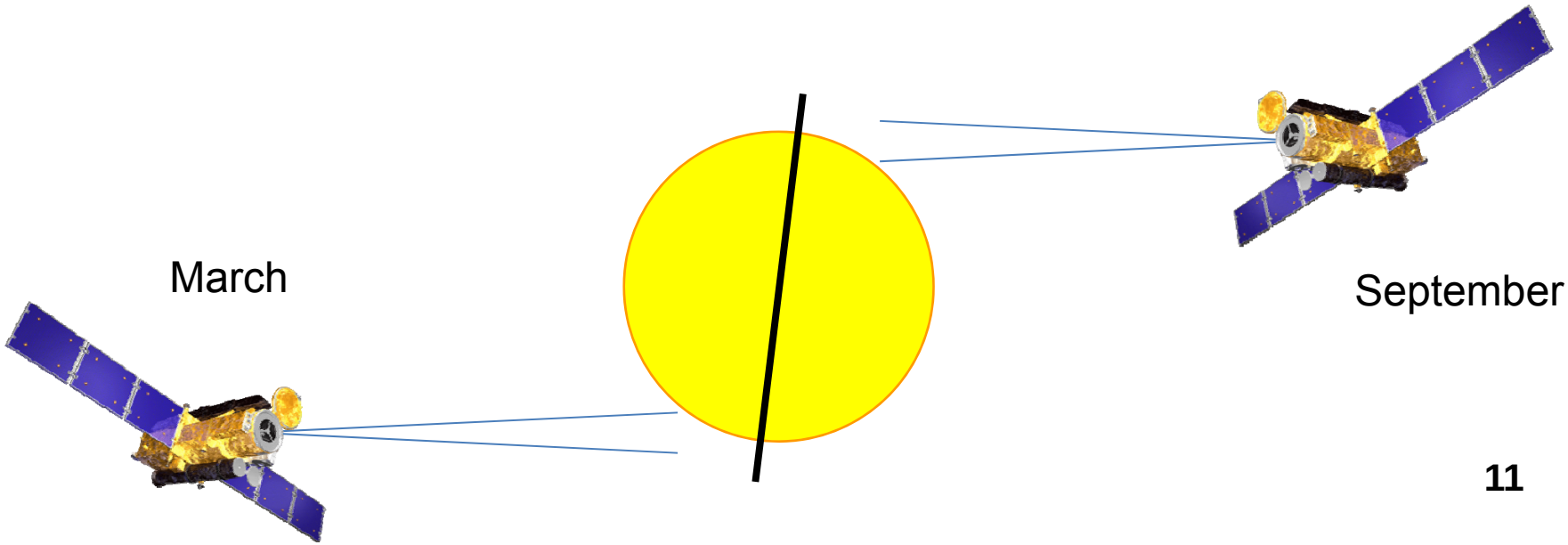


Joy's law and reversal of poloidal field

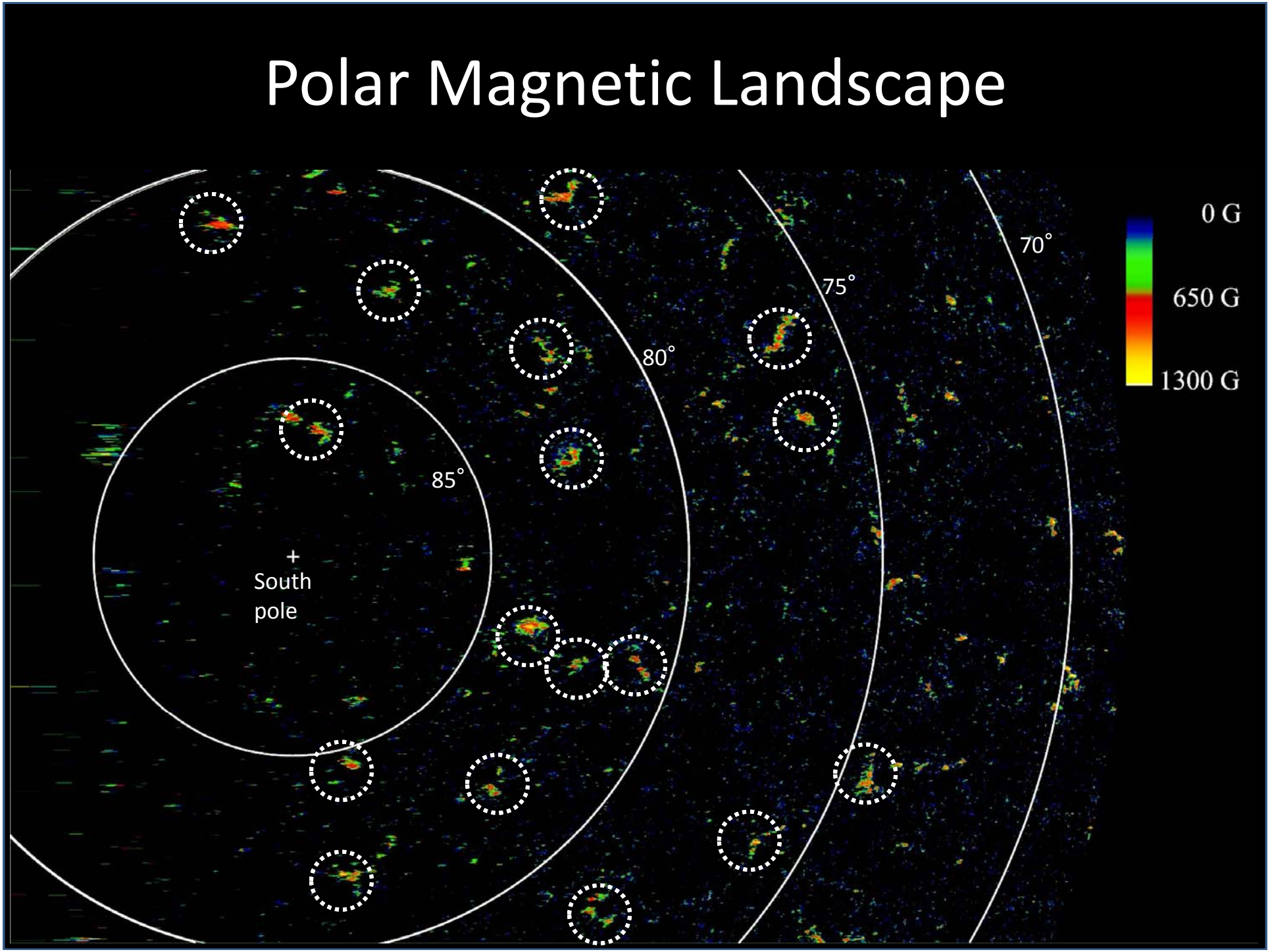


Hinode observations of polar regions





Polar Magnetic Landscape

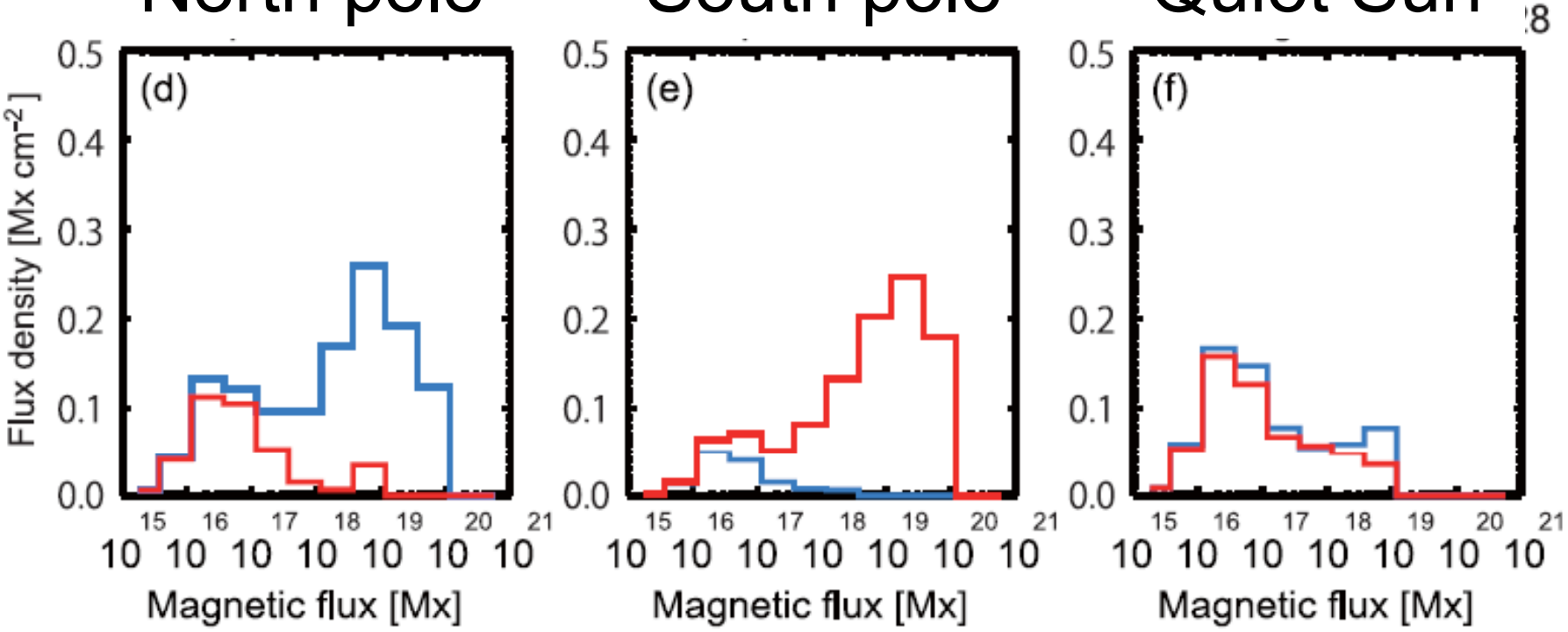


Magnetic flux v.s. flux density

North pole

South pole

Quiet Sun



Minus dominant

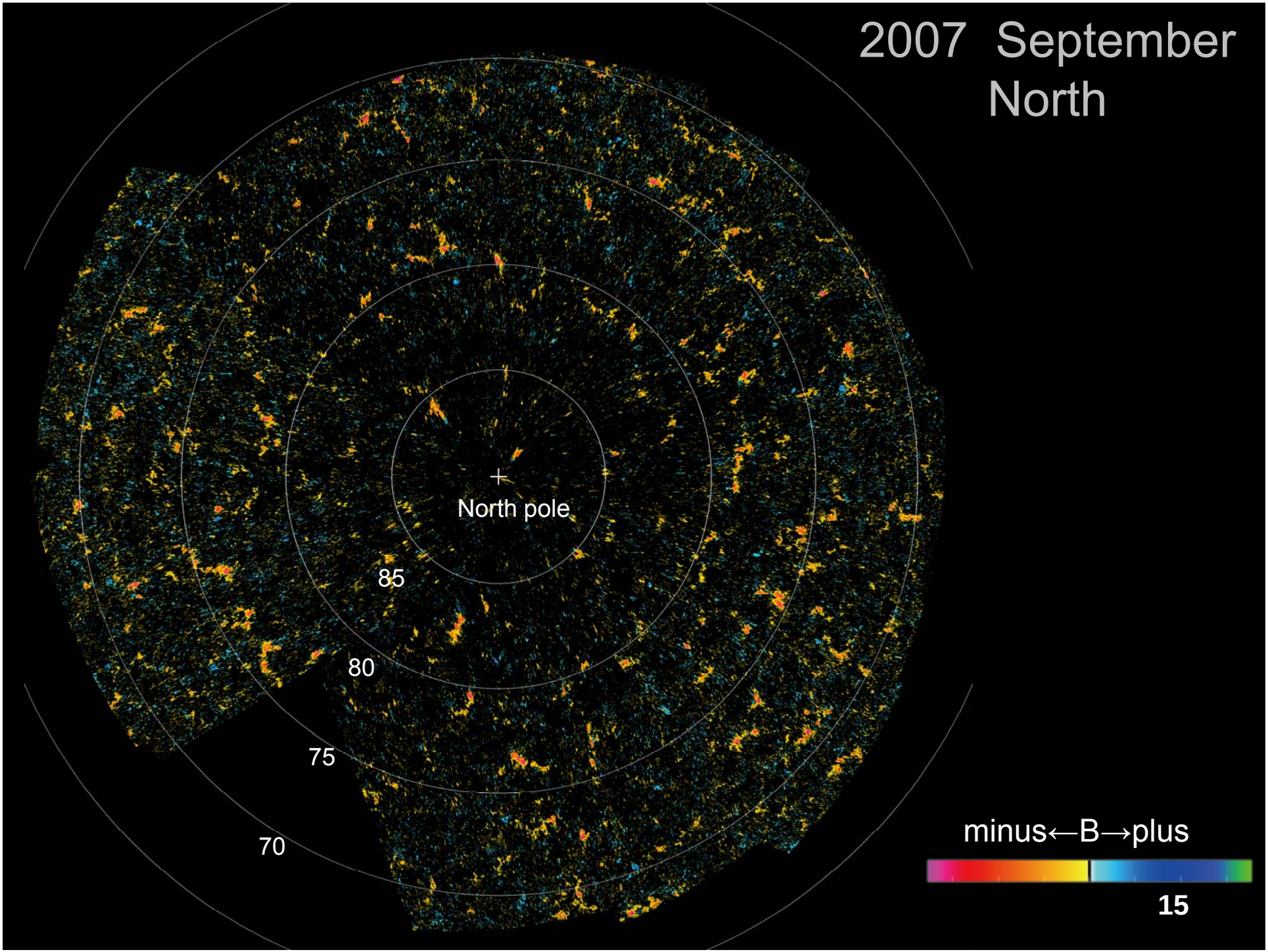
Plus dominant

Balanced

Shiota+ ApJ in press

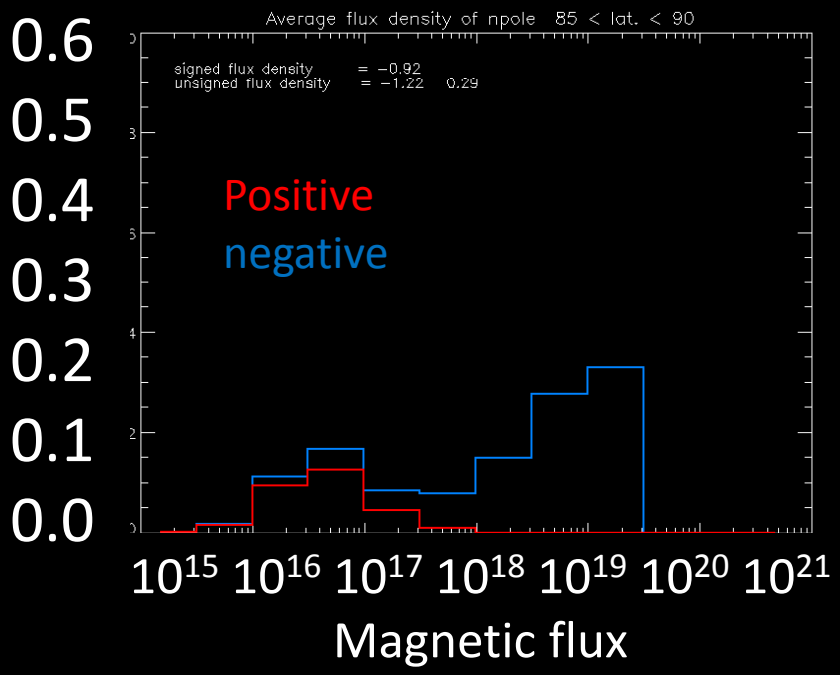
Paradigm change of poloidal fields

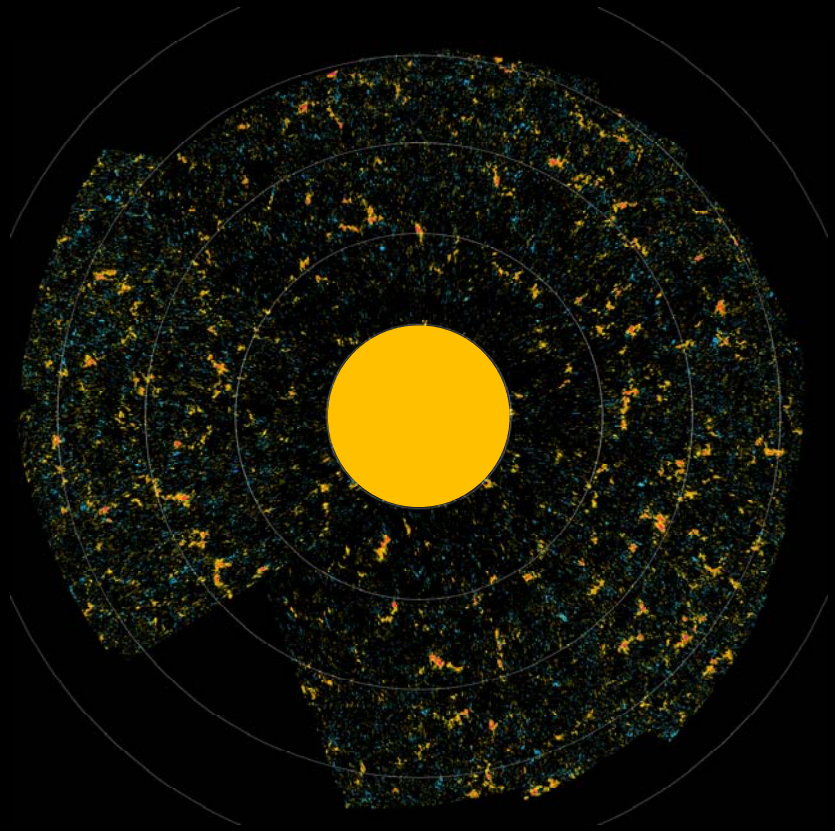
- Polar regions have scattered kG-patches instead of weak extended fields.
- Large kG-patches have size comparable to small sunspots (pores) in terms of magnetic flux and size
- KG-patches with>10(18) Mx have the same polarity, and determine the global polarity.
- Small patches (<10(16) Mx) are of bipolar nature with same amount of plus and minus magnetic fluxes.


2007 September
North
North pole
85
80
75
70
minus←B→plus
15

2007 North polar region
85 < Latitude < 90

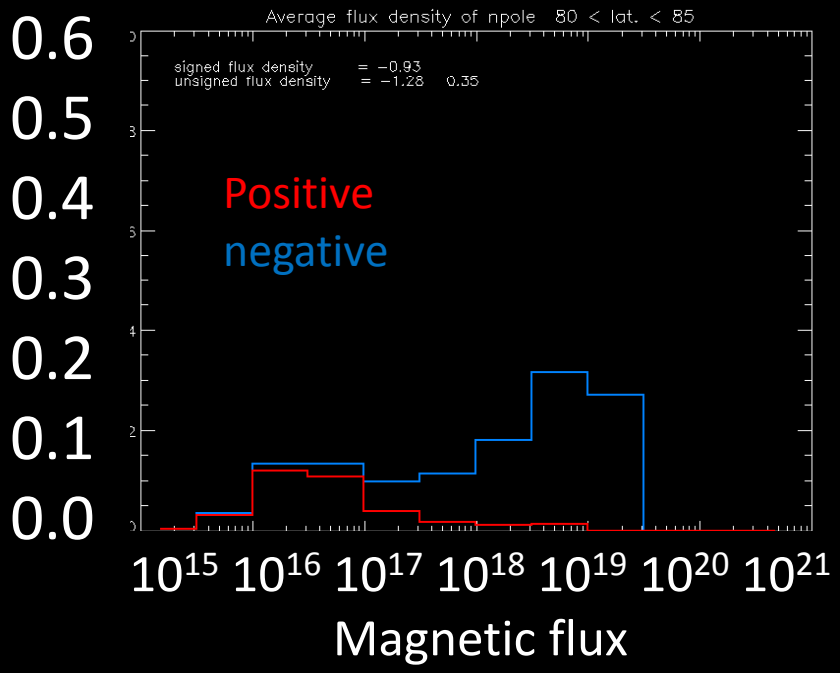
Signed flux density =-0.92

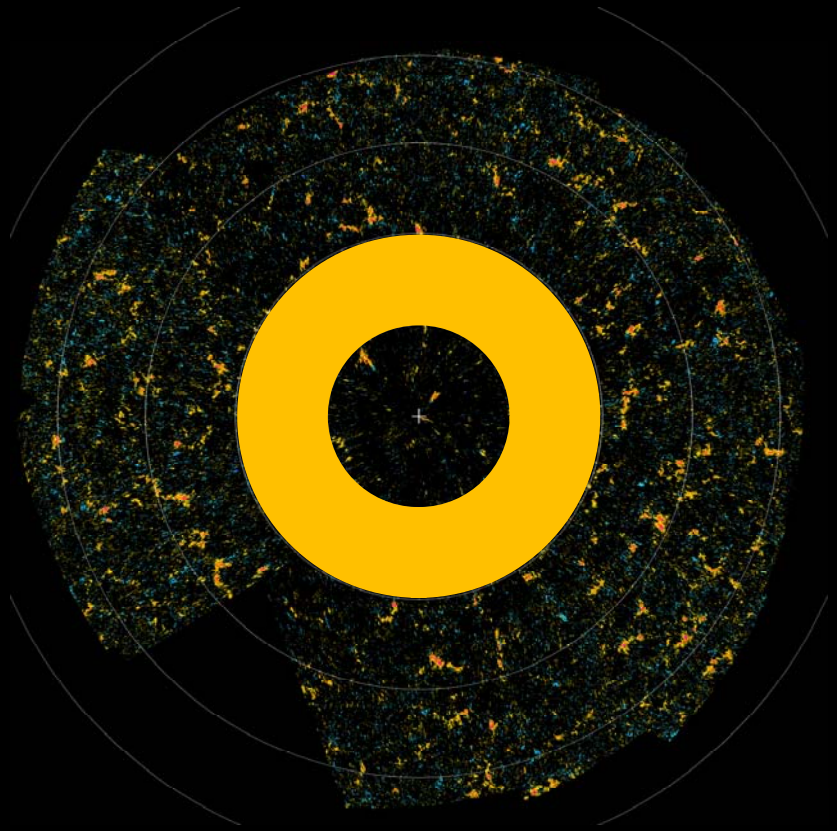




2007 North polar region
80 < Latitude < 85

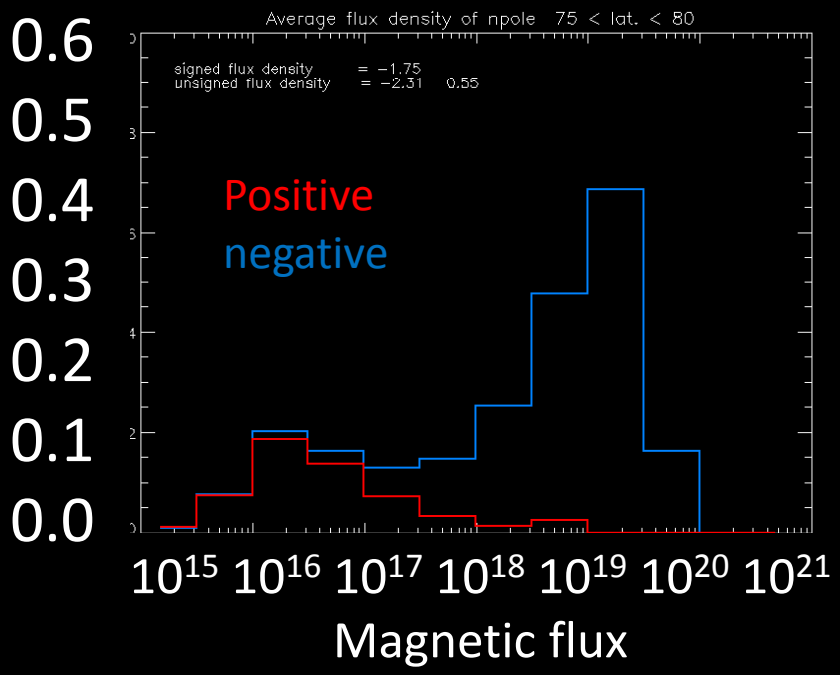
Signed flux density =-0.93

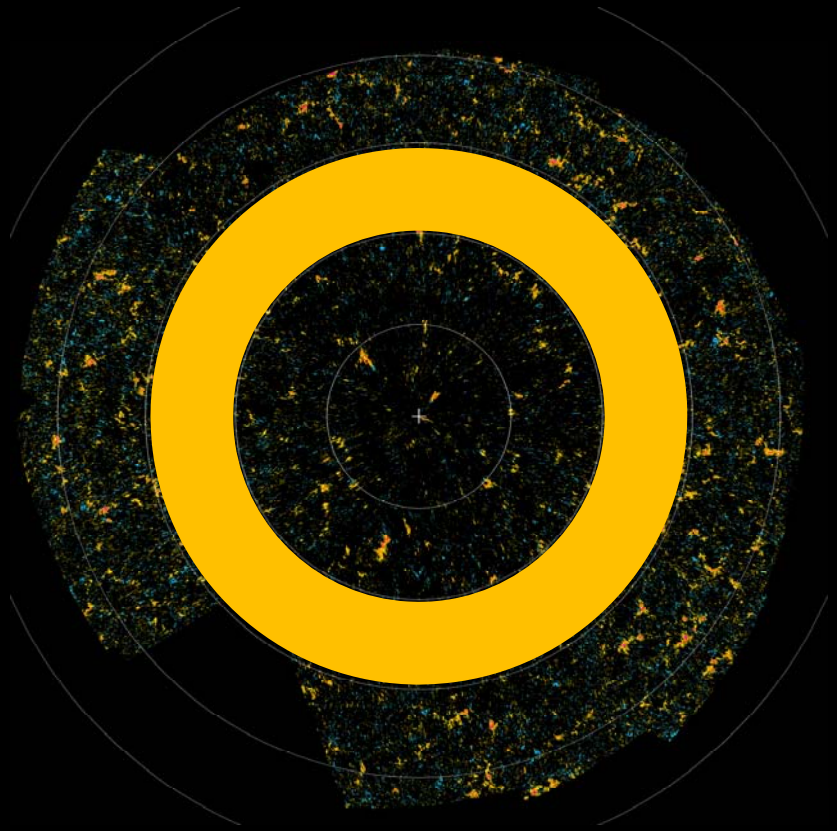




2007 North polar region
75 < Latitude < 80

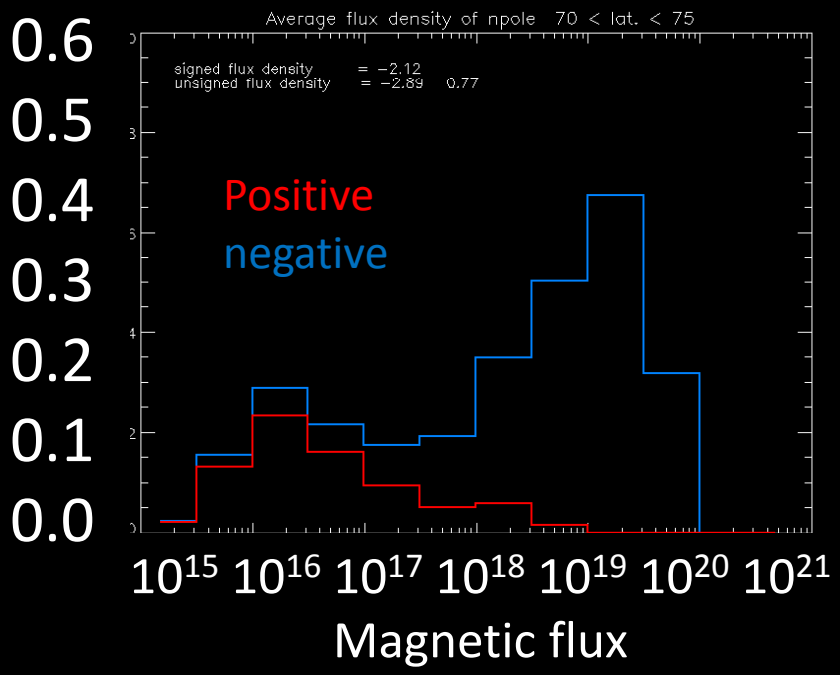
Signed flux density =-1.75

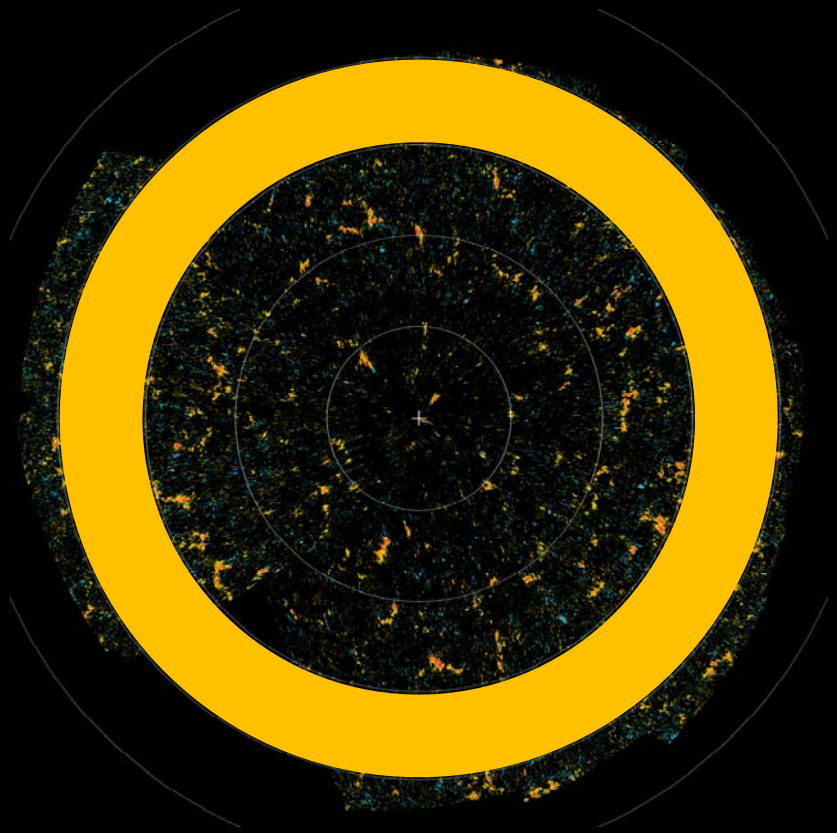




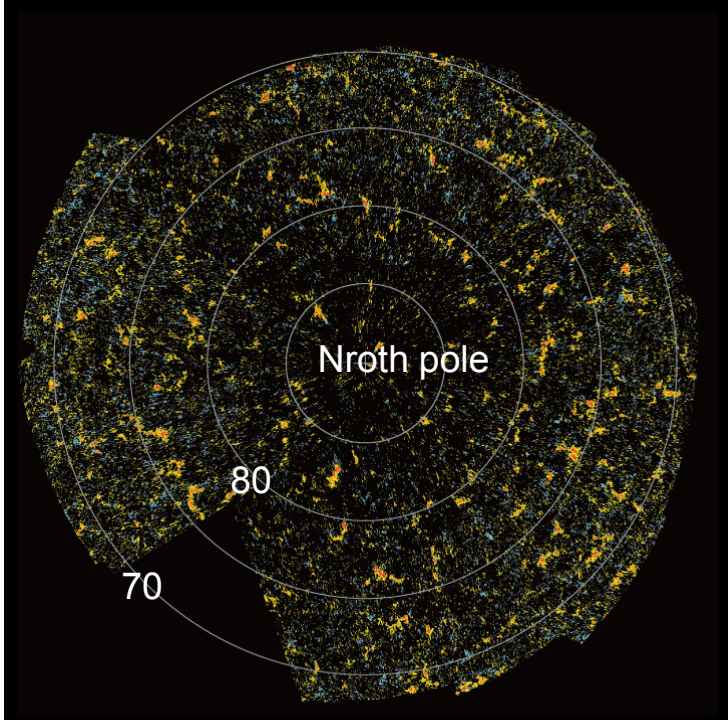
2007 North polar region
70 < Latitude < 75

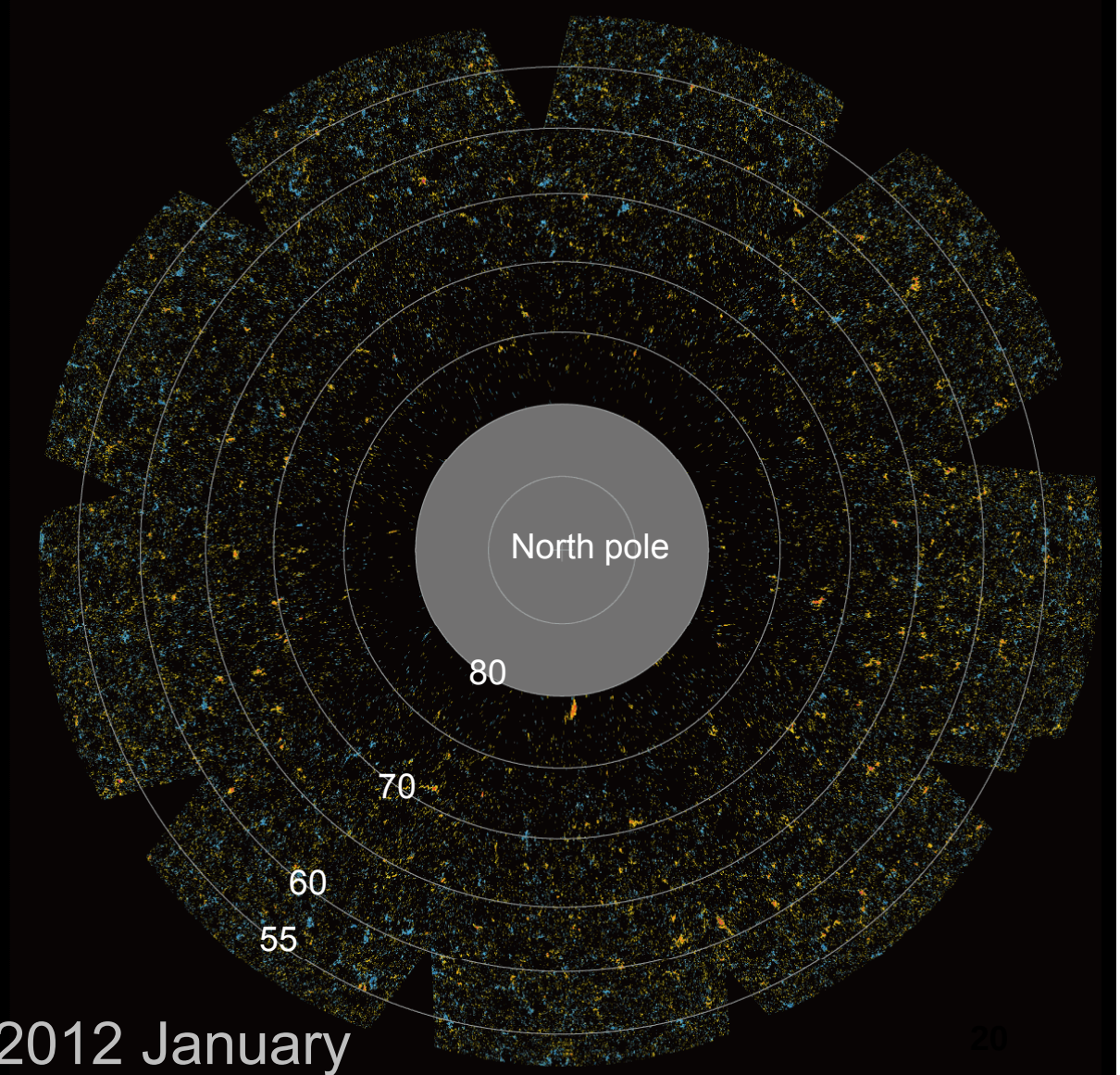
Signed flux density =-2.12





Comparison of 2007 and 2012



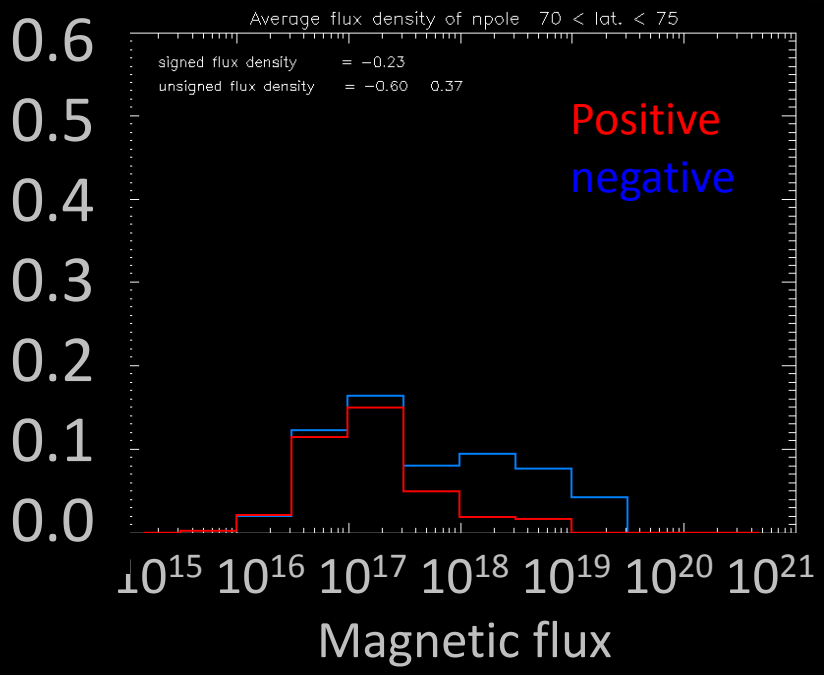


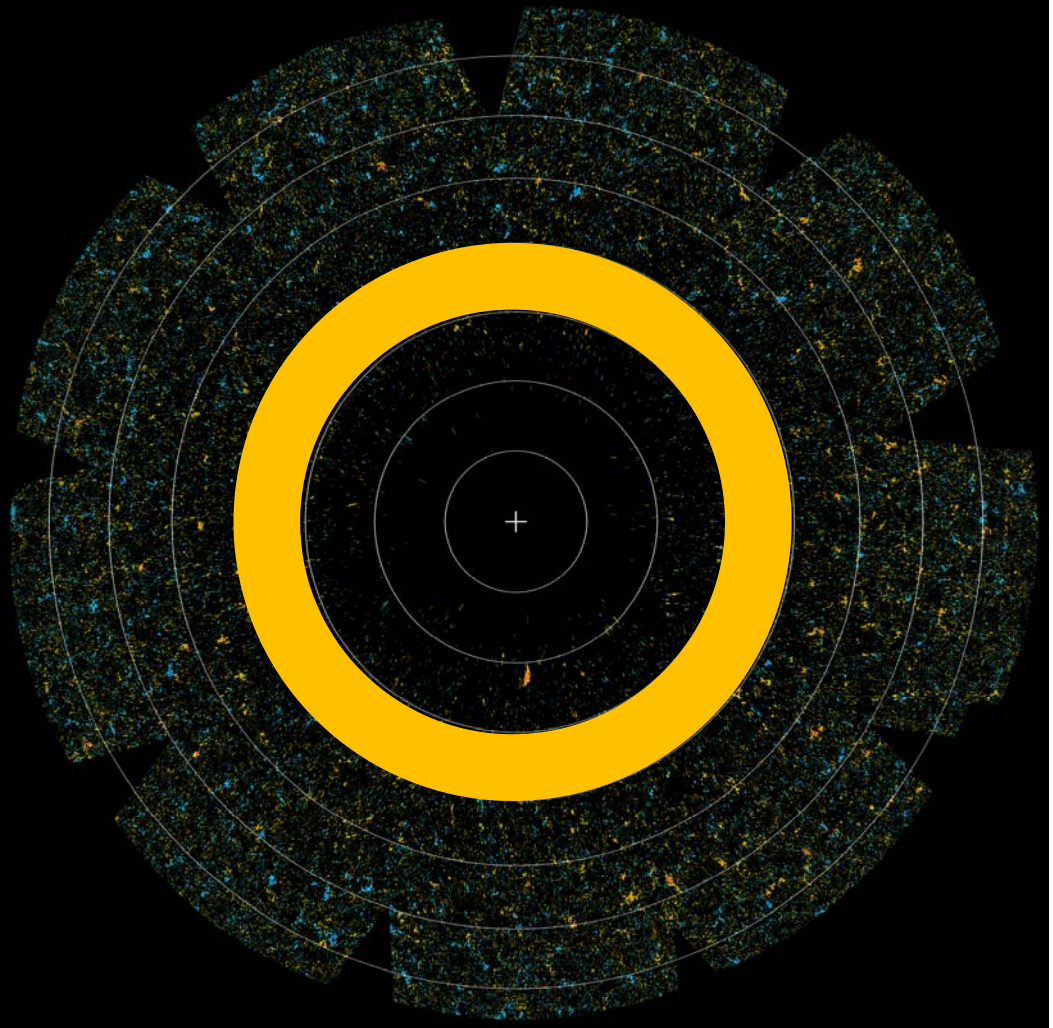
2007 September

2012 January

2012 North polar region
60 < Latitude < 65

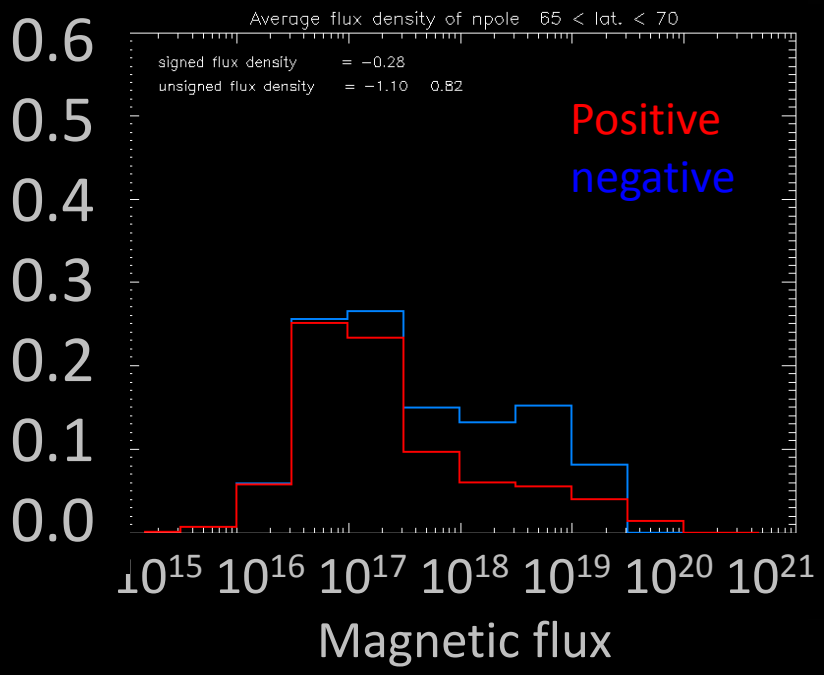
Signed flux density =-0.23

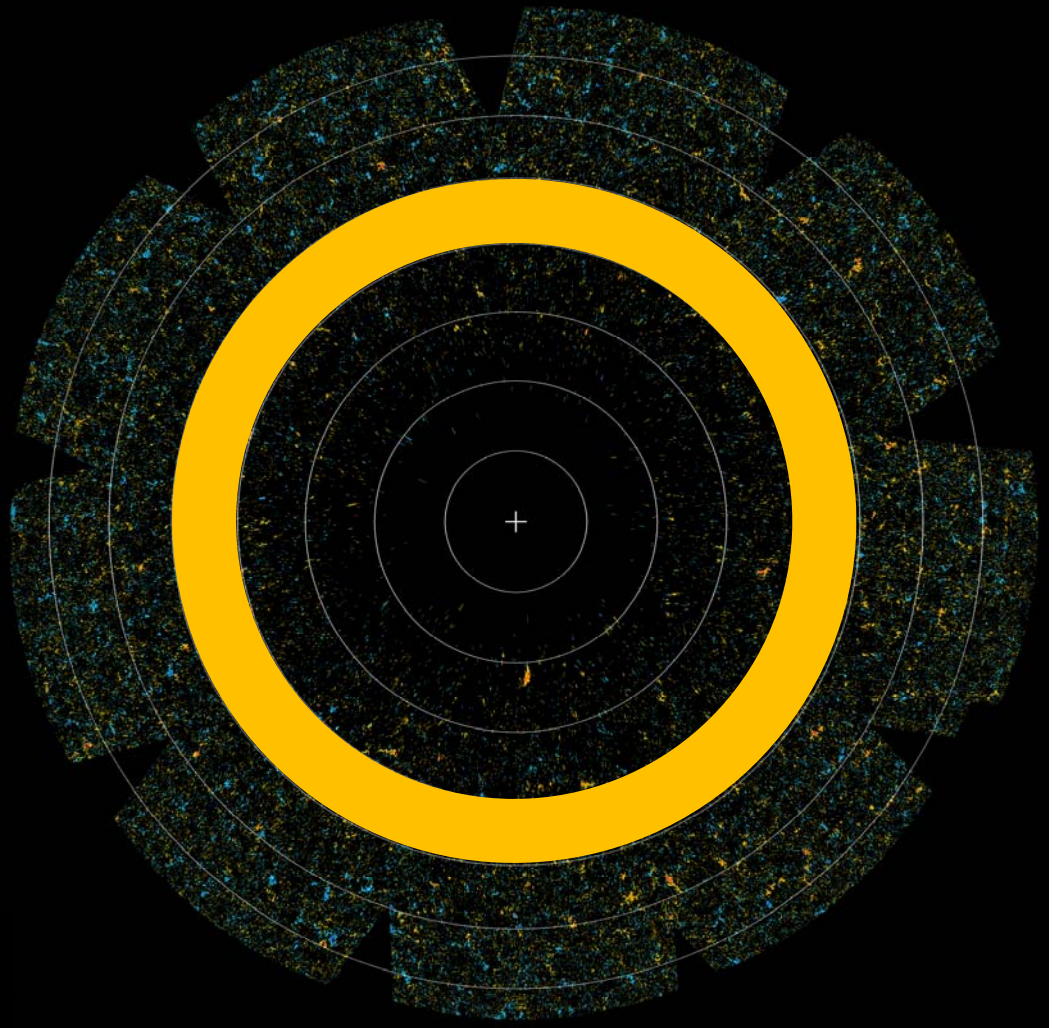




2012 North polar region
65 < Latitude < 70

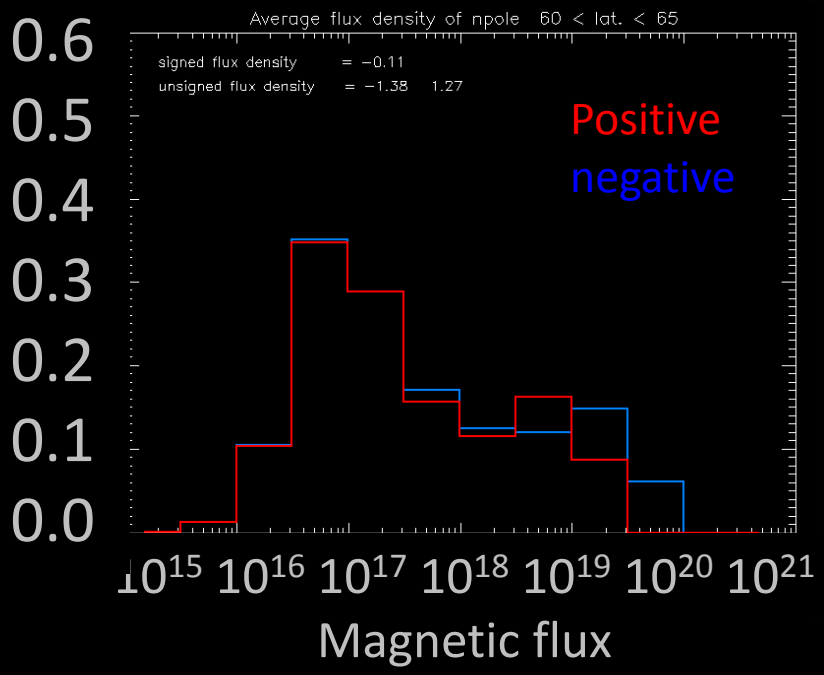
Signed flux density =-0.28

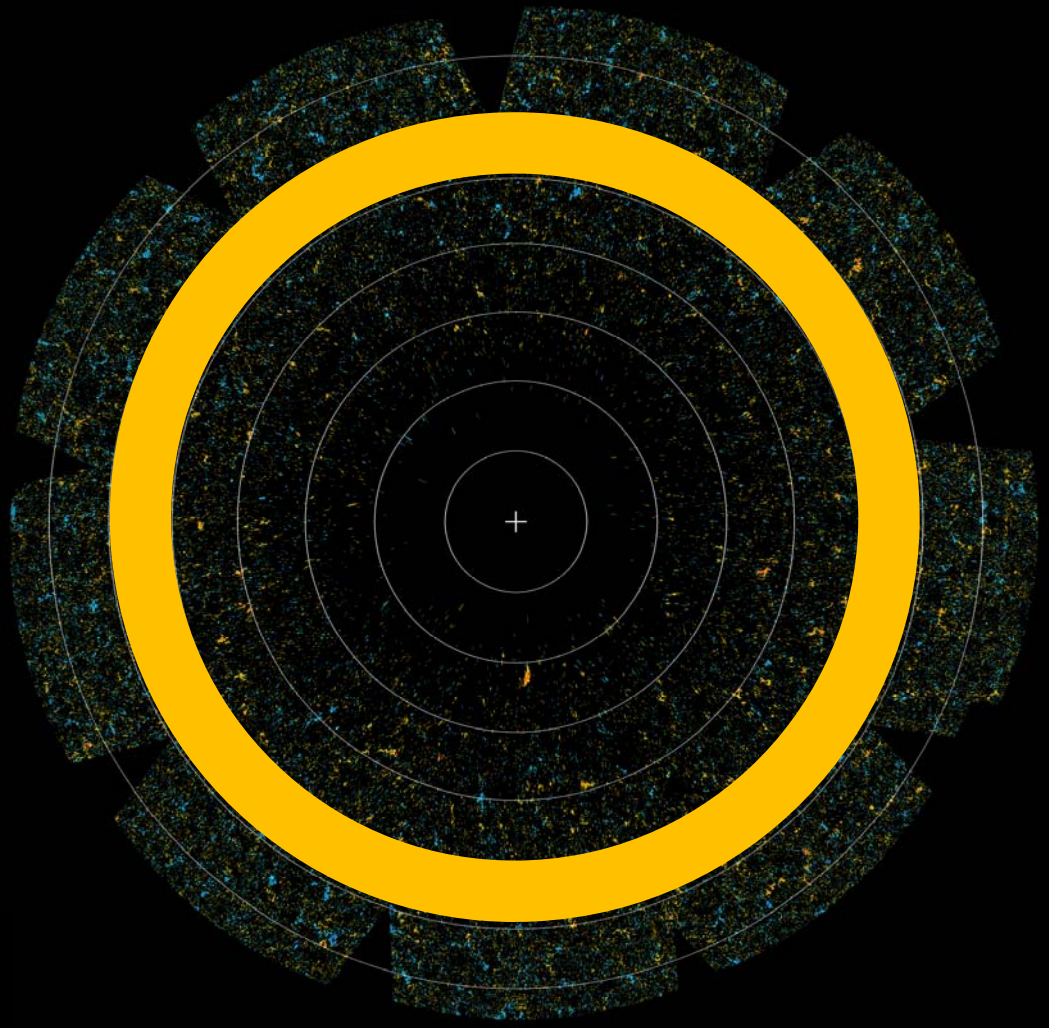




2012 North polar region
60 < Latitude < 65

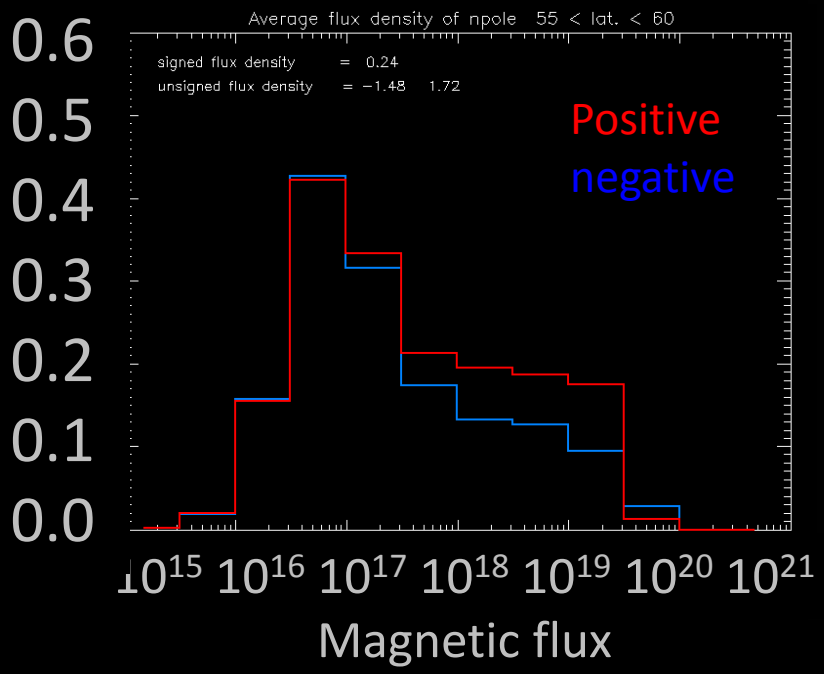
Signed flux density =-0.11

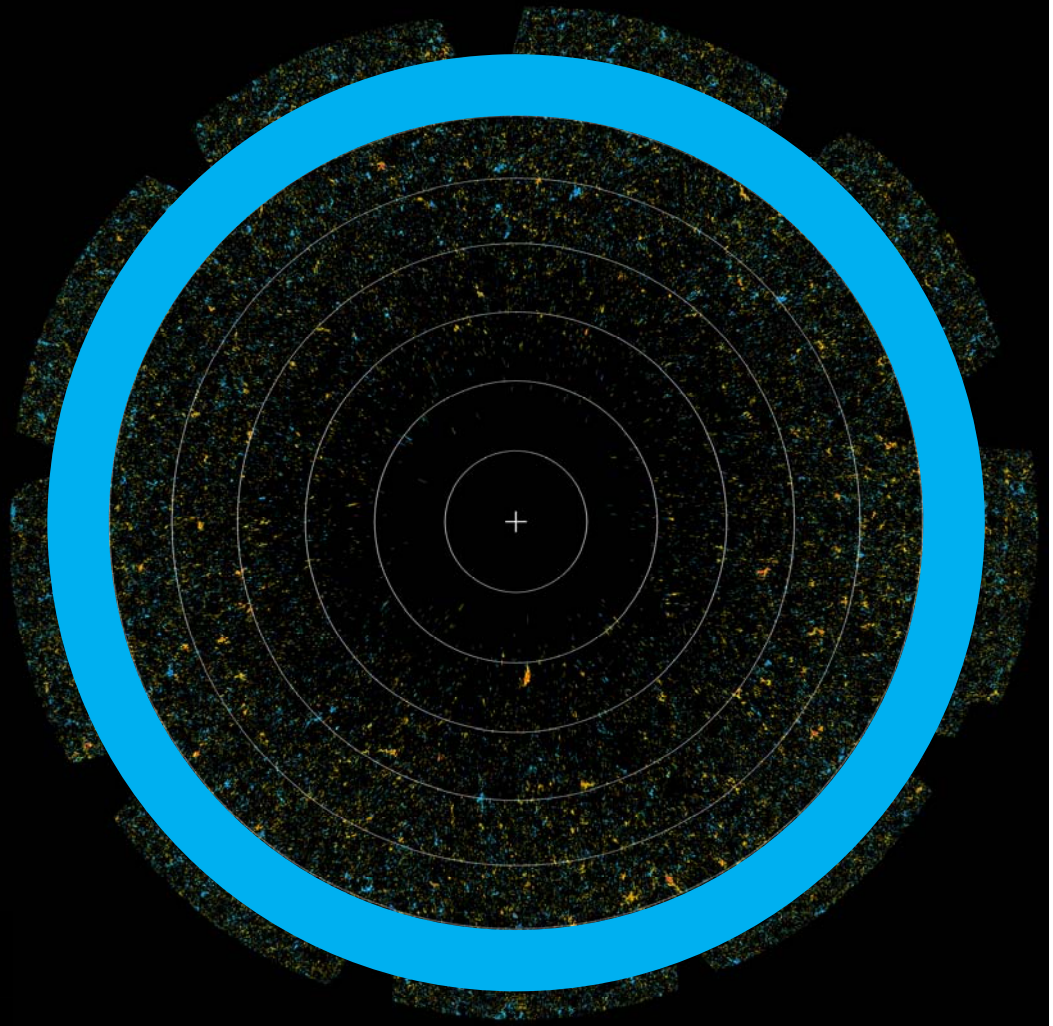




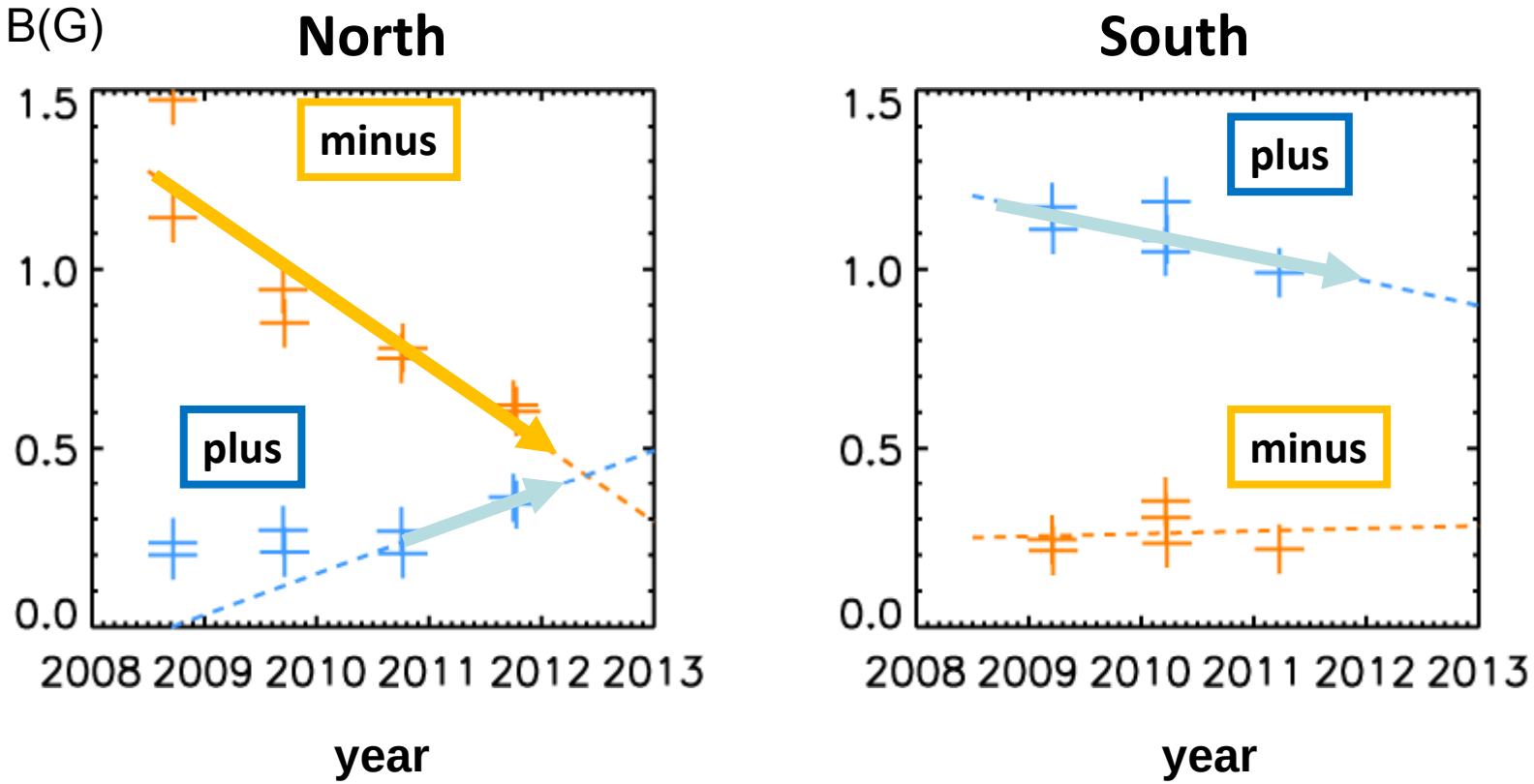
2012 North polar region
55 < Latitude < 60

Signed flux density =0.24





North pole about to reverse

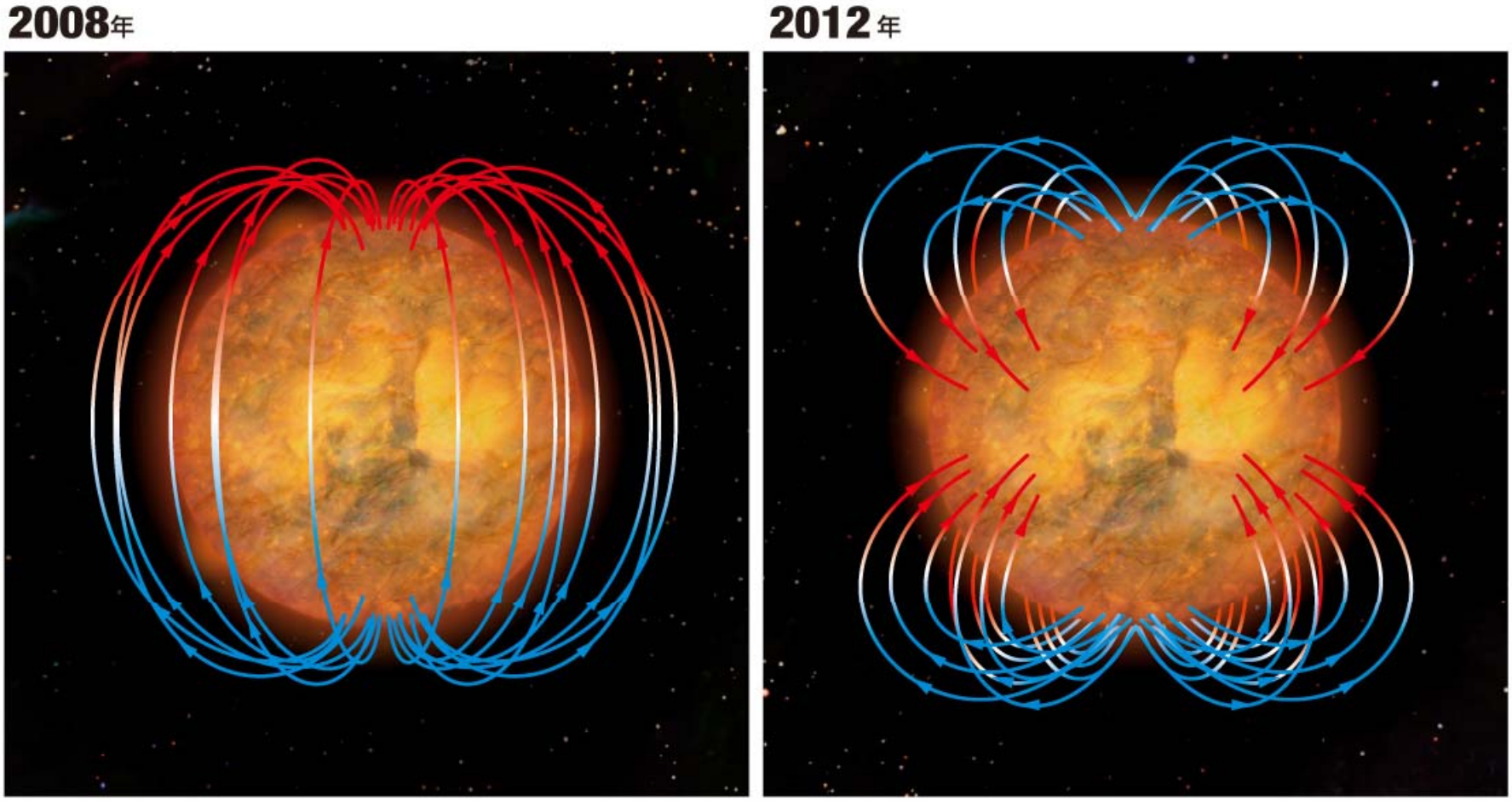


- Majority patches in north disappearing
- Crosses zero point in 2012 May
- South pole stable

Summary of Hinode observations

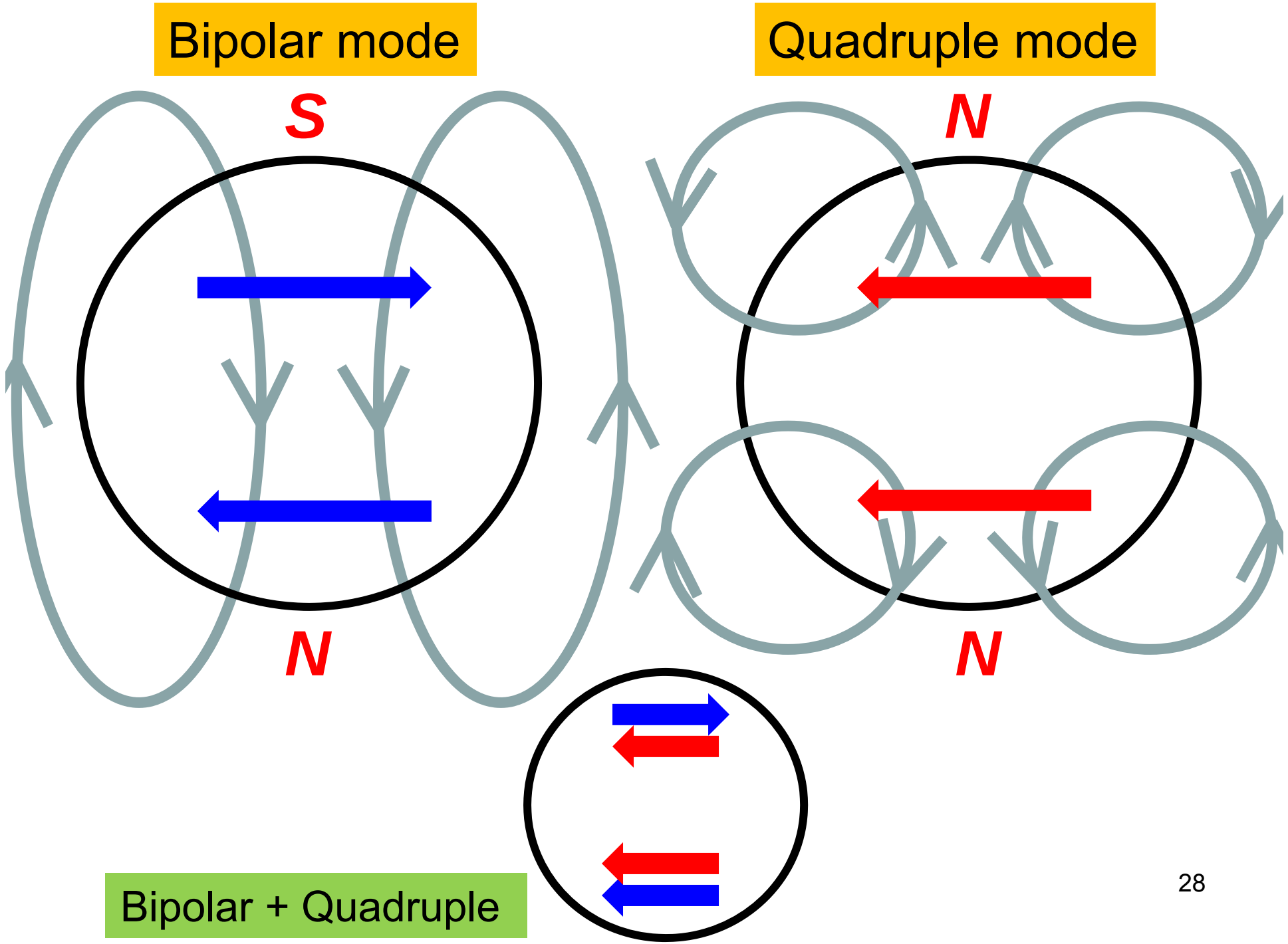
	Current understanding	**Hinode result**
Polar magnetic fields	Extended weak fields (lower energy state)	Sunspot-like kG patches (higher energy state)
Polar field reversal	Reverses at around solar max. (***2013 May***)	North reverses at around ***2012 May*** South stable
Poloidal fields	Bipolar	Quadruple

Quadruple poloidal fields

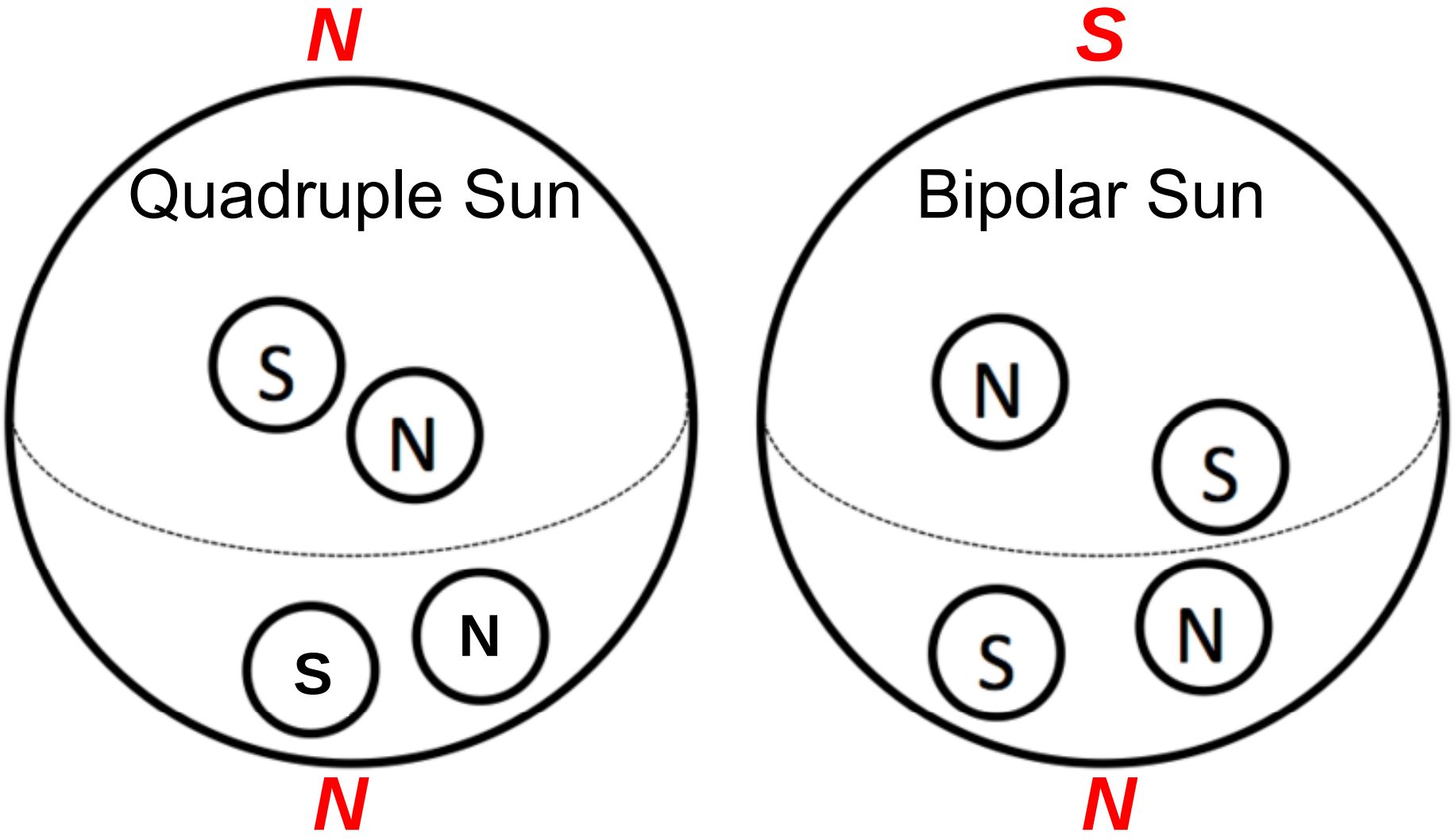


Bipolar

Quadruple

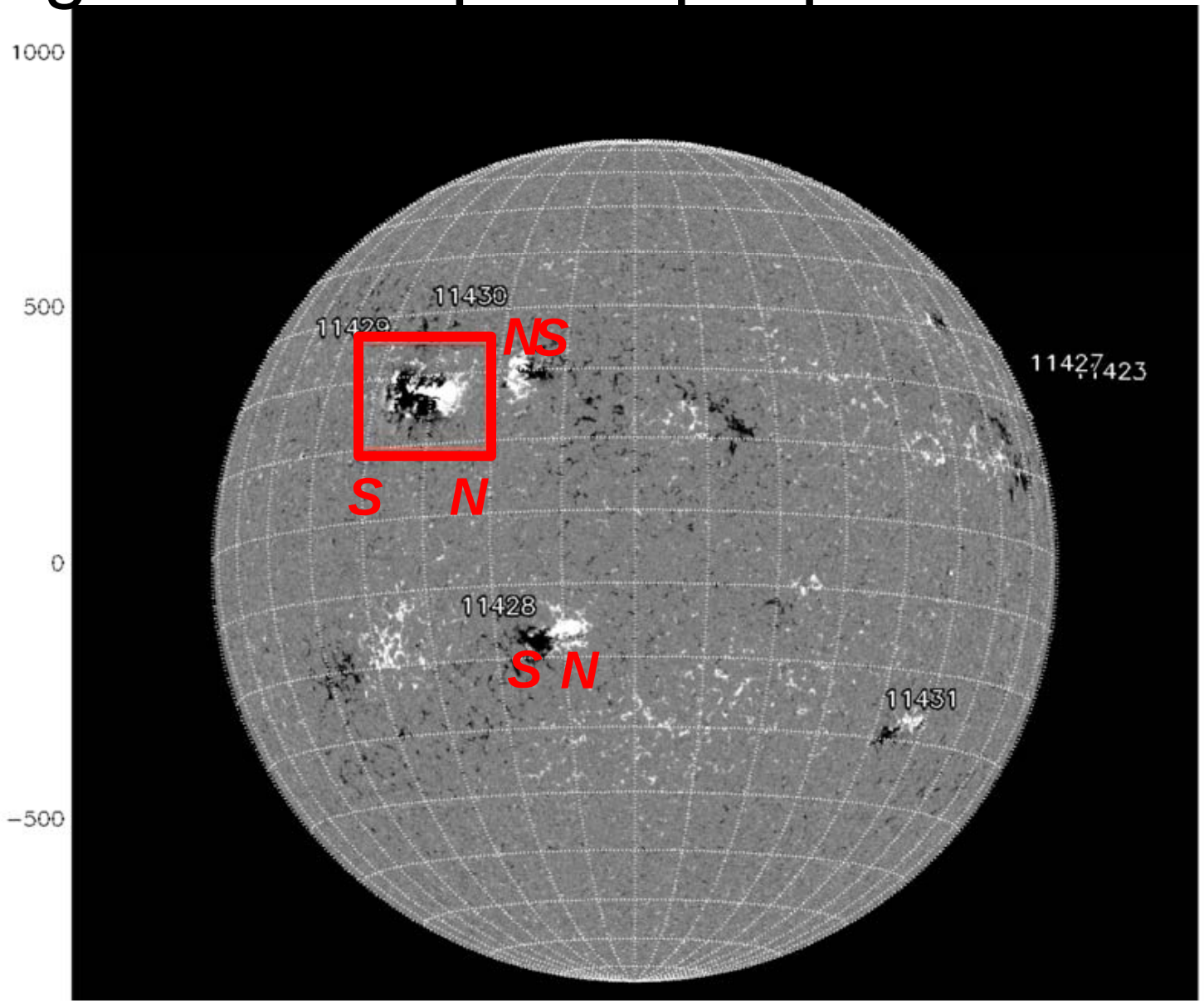

Bipolar mode
Quadruple mode
S
N
N
N
Bipolar + Quadruple

Anti-Joy's law due to quadruple poloidal field



Anti-Joy's law AR#11429

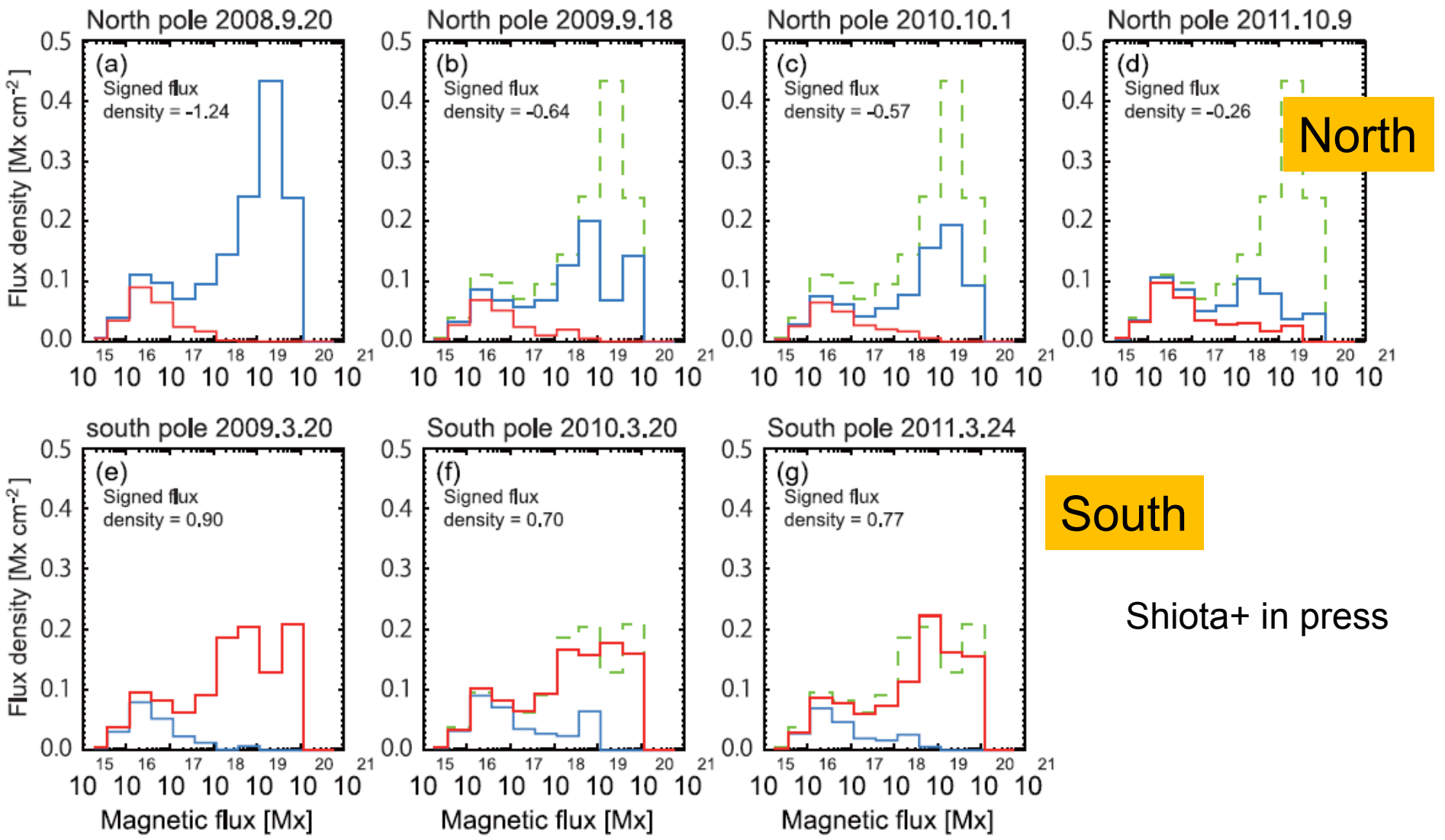
signature of quadruple poloidal field?



Summary

- The north pole is changing polarity earlier without enough sunspots, causing doubts on the current flux transport dynamo.
- The sun now would have quadruple structure.
- The same anomaly (longer sunspot period and the asymmetry) appears to take place around Maunder and Dalton minimums.

Clustering PDF of vertical fields

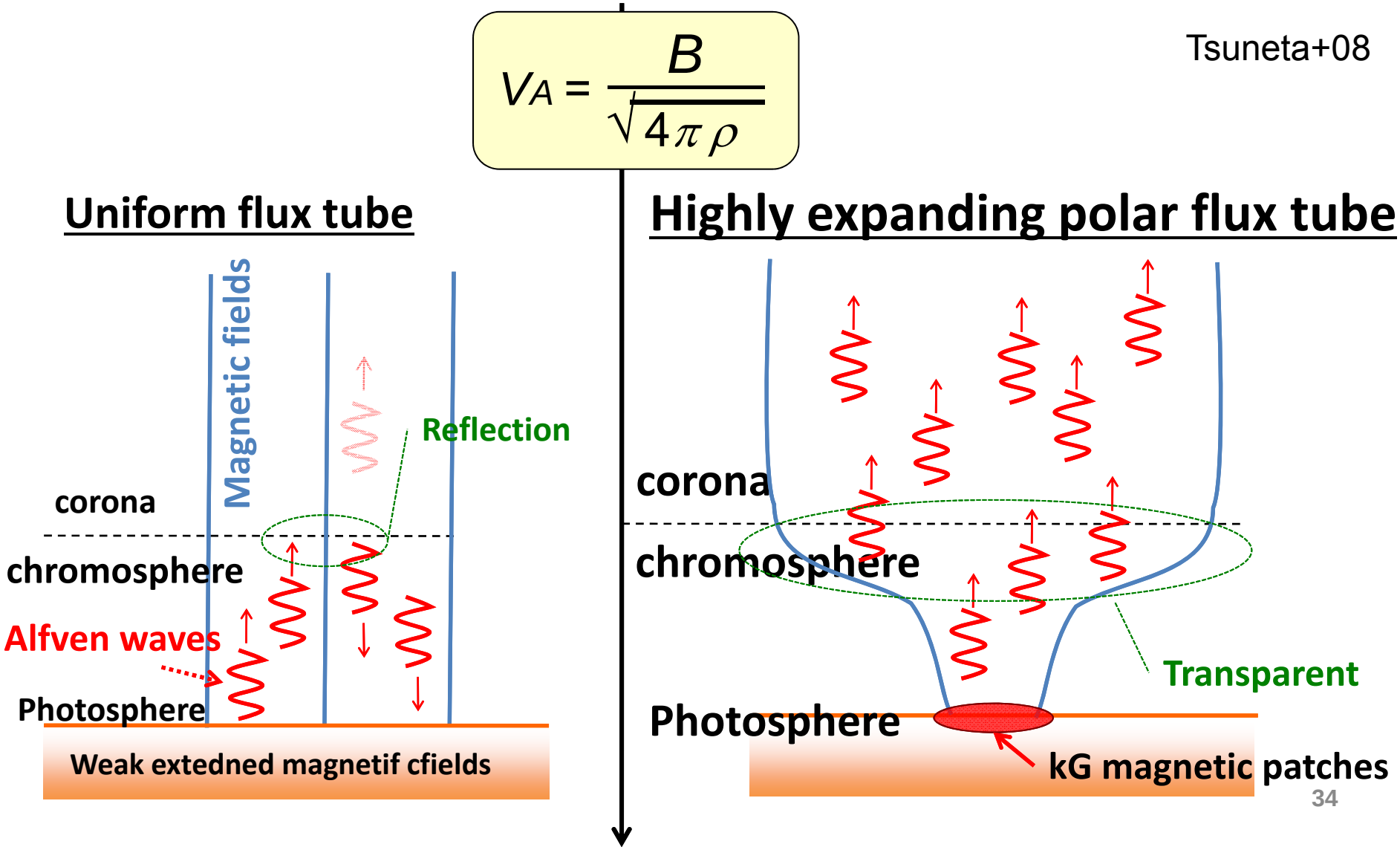


Shiota+ in press

Polar kG patches for Alfvenic Chimney to accelerate fast solar wind

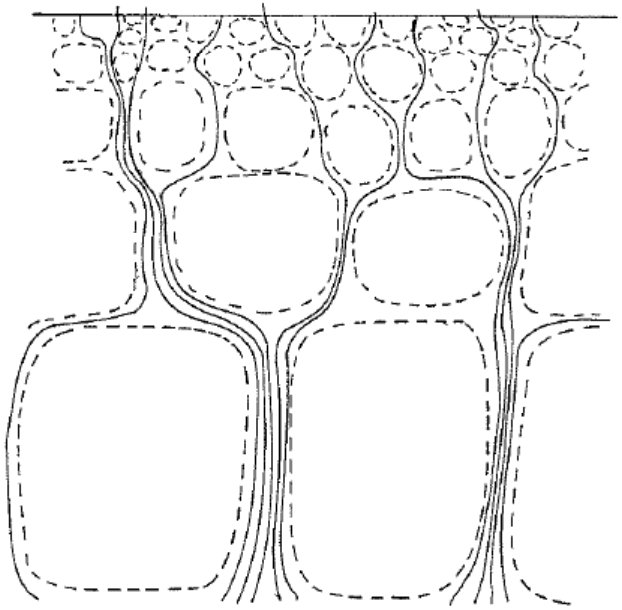
$$V_A = \frac{B}{\sqrt{4\pi\rho}}$$

Tsuneta+08



kG-patches and 100kG toroidal fields in tachocline

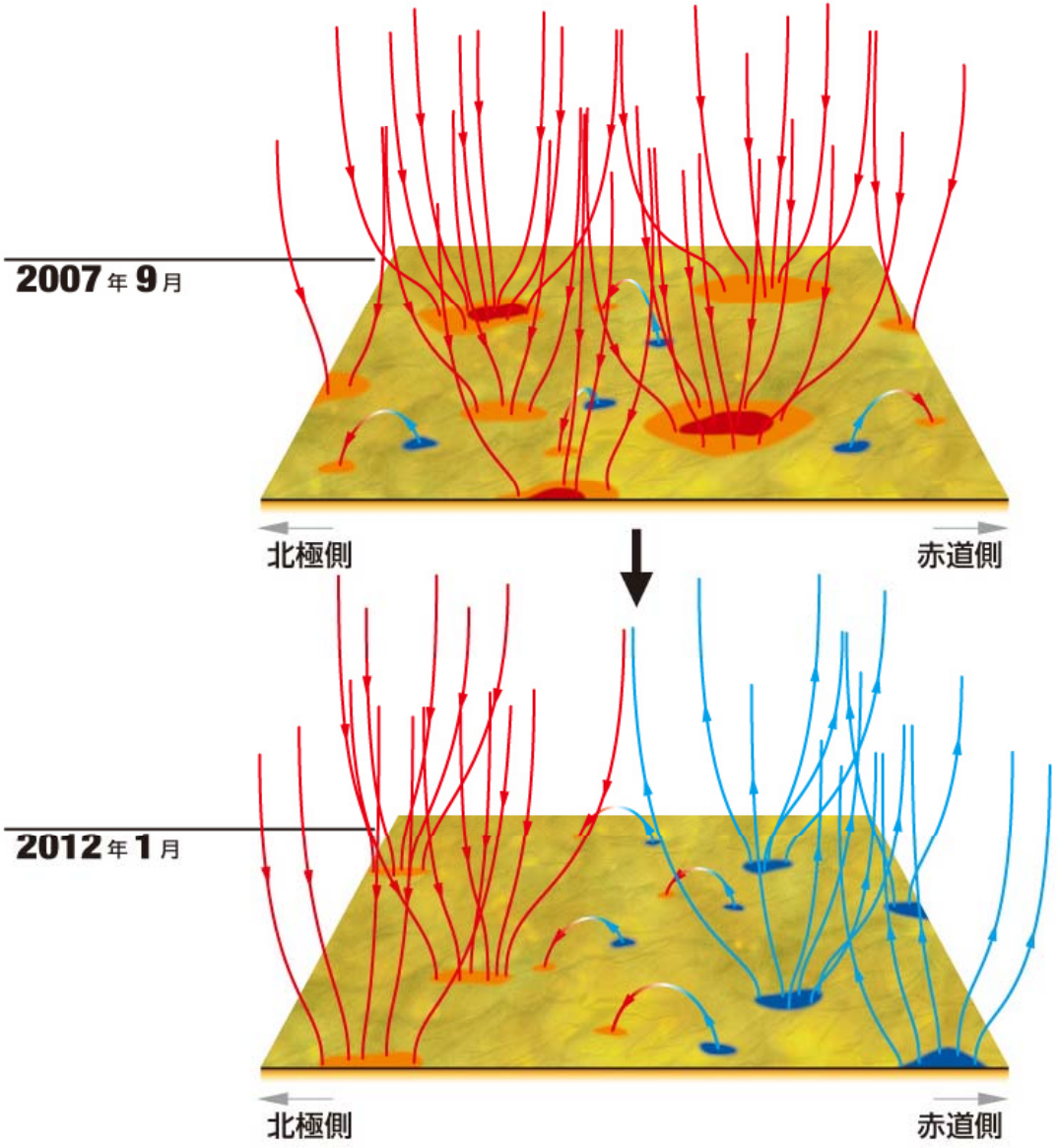
- Theory and observations indicate that toroidal fields at the bottom of convection zone has 50-100kG field strengths.
- It has not been clear why such strong fields are created.
- Bp=800G can be amplified to Bt=100kG with 130 rotations in 11 years.



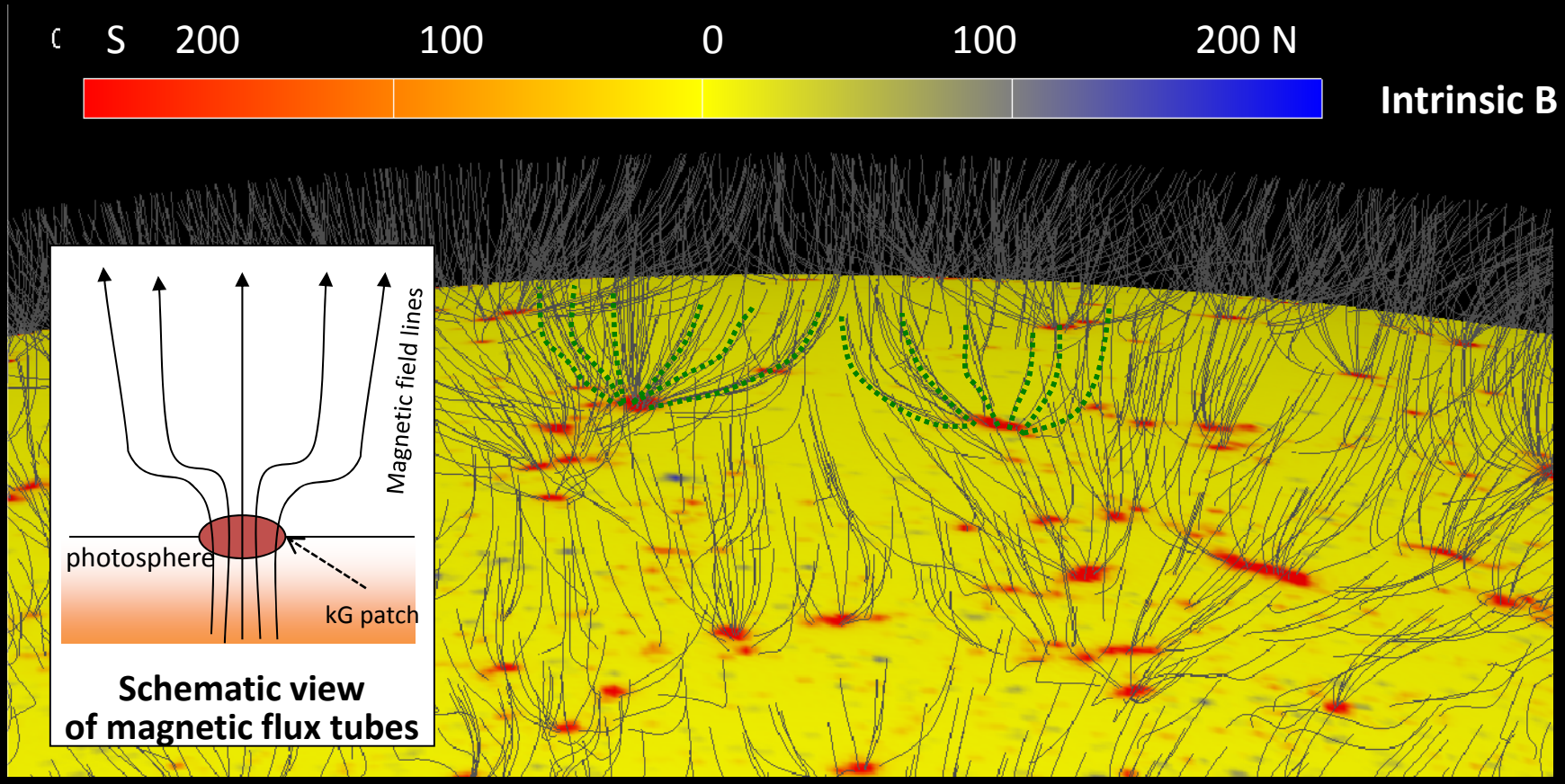
From Choudhuri02

$$\frac{B(r_0,t)}{\rho(r_0,t)} = \frac{B_0}{\rho_0}\nabla_0 r \Rightarrow \frac{M(t)}{M_0} = 1 + \left(\frac{\Delta\omega}{\omega} n(\text{rotations})\right)^2$$

Flux transport via meridional flow and turbulent diffusion



Rapidly expanding field lines from kG patches



Shiota et al.