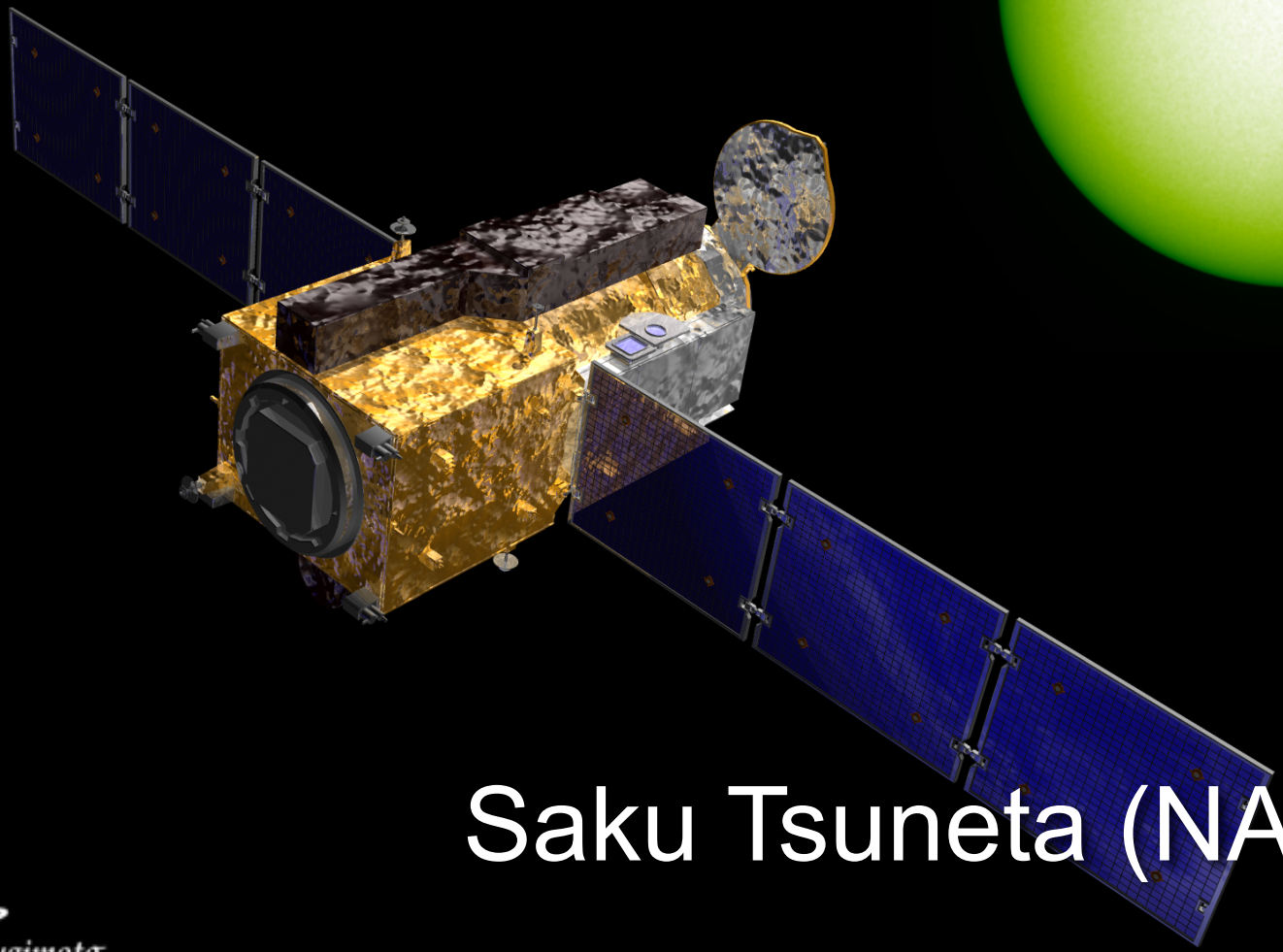
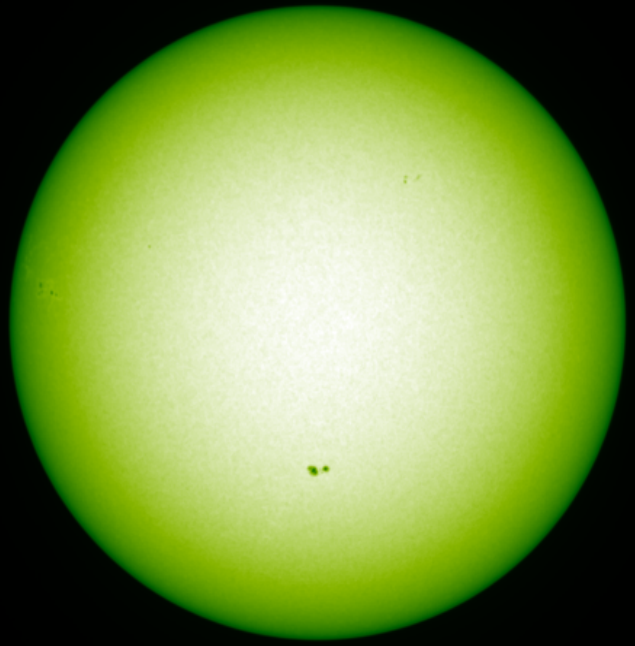
Polar magnetic fields and SOLAR-C

Hinode Observations on polar fields





Saku Tsuneta (NAOJ)

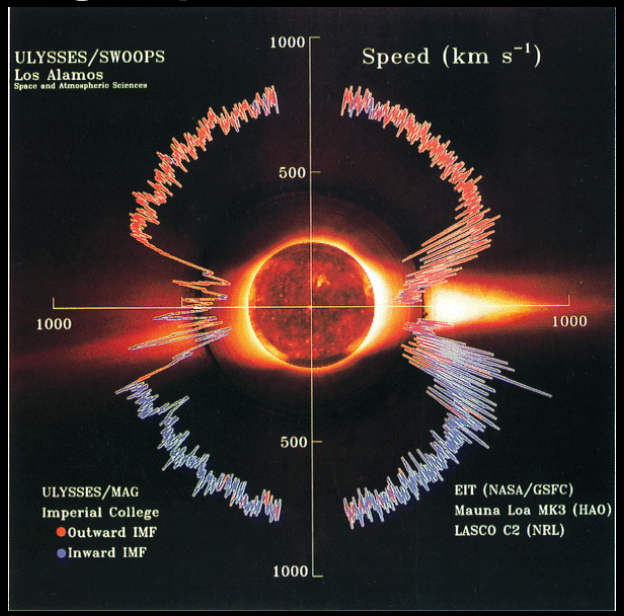
Maki Sugimoto

What is going on in polar region ?

Source of fast solar wind
Location of global poloidal fields
sink of meridional flow

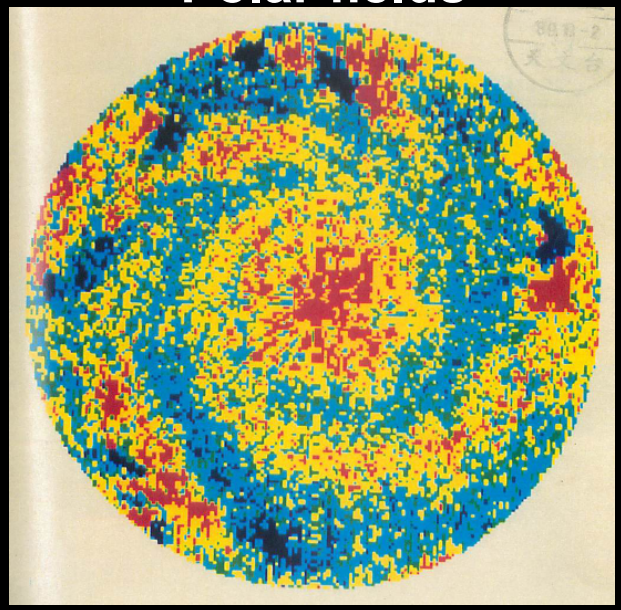
High speed solar wind

Ulysses
(McComas etal 2000)

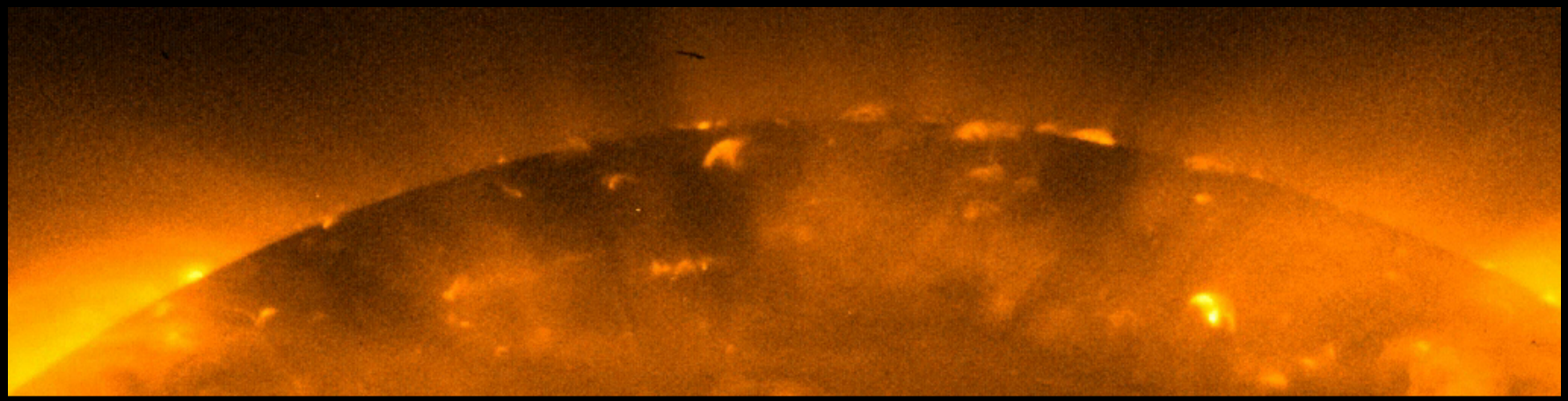


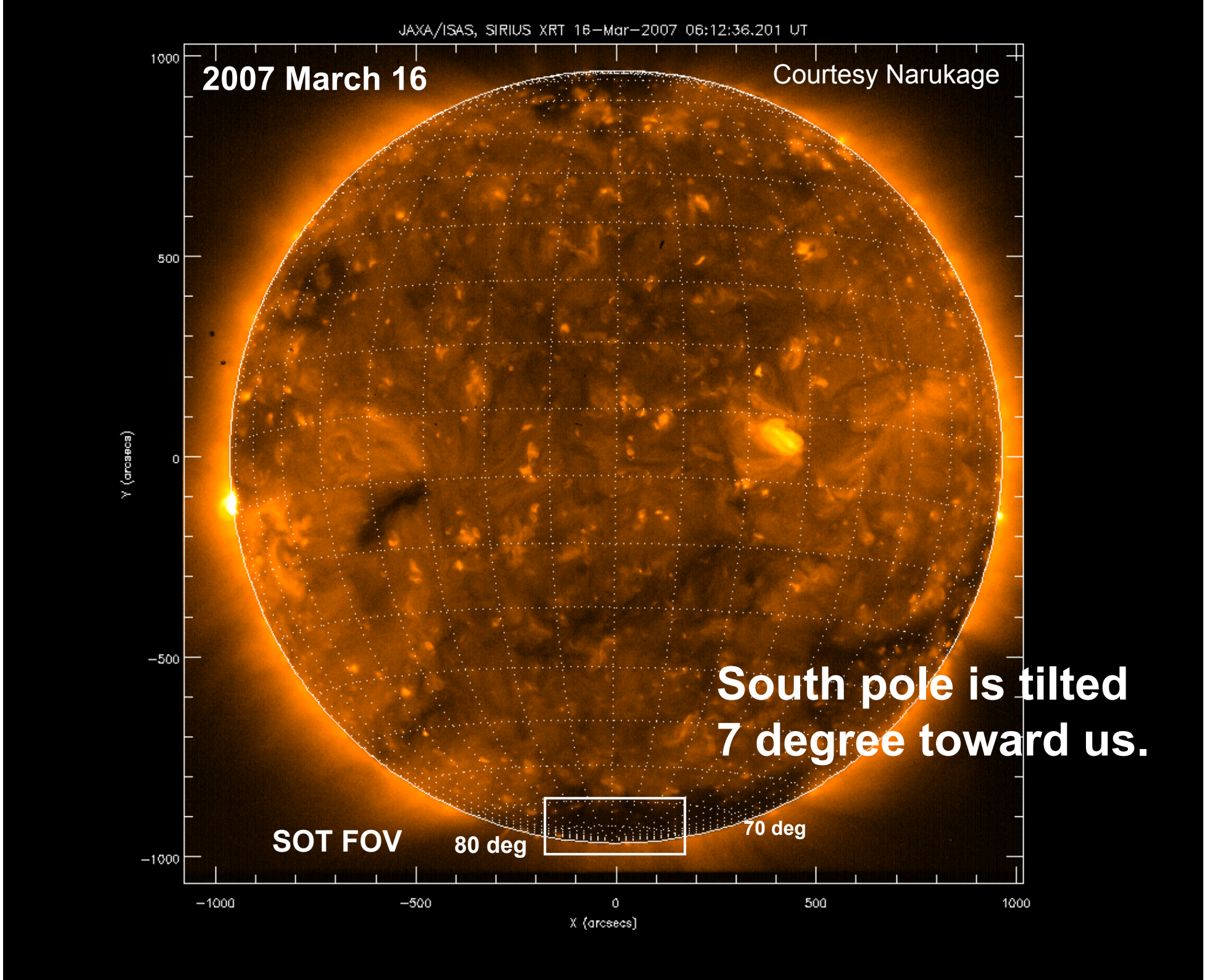
Kitt Peak
(Wang et al)

Polar fields



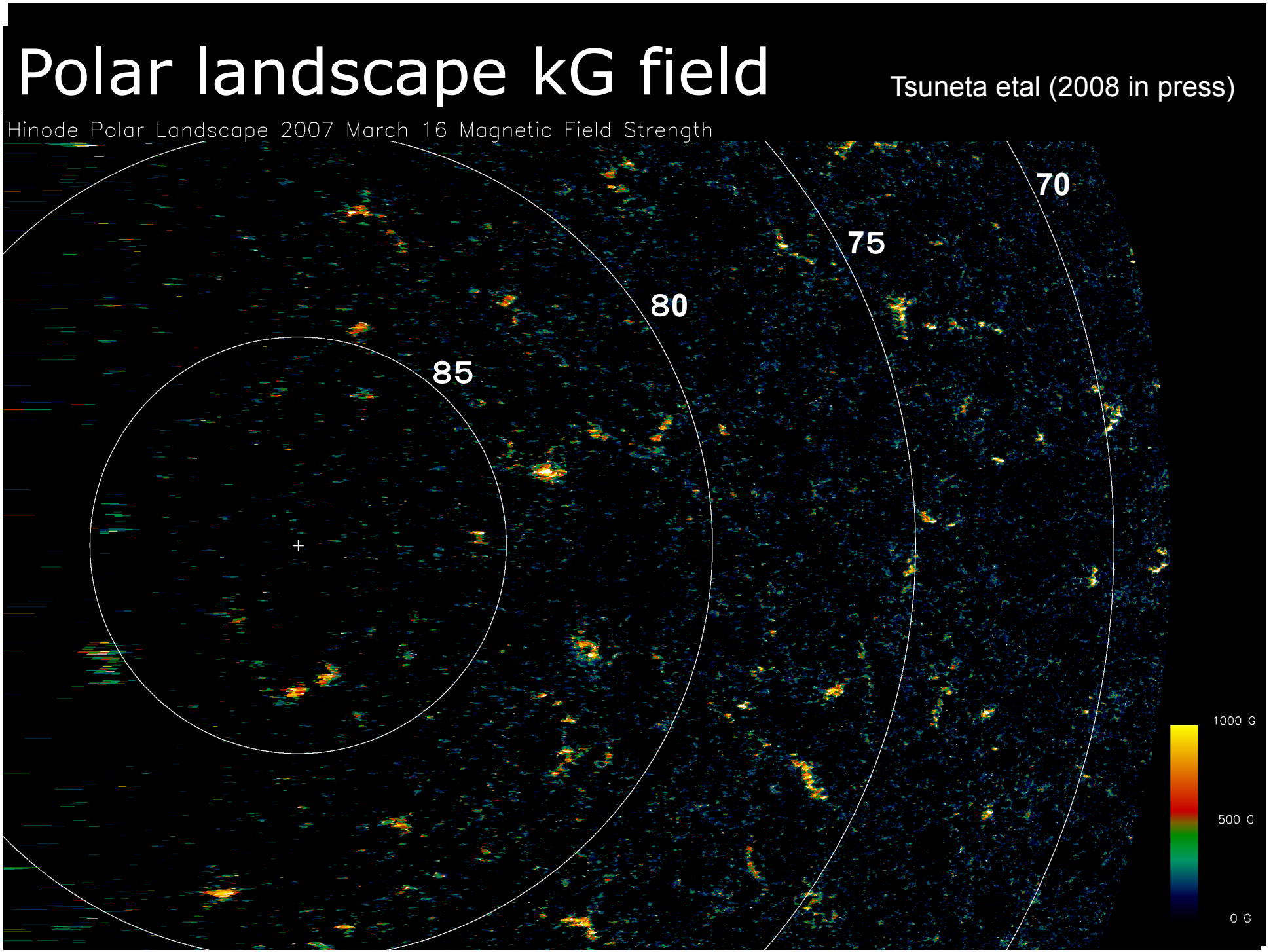
Cirtain etal

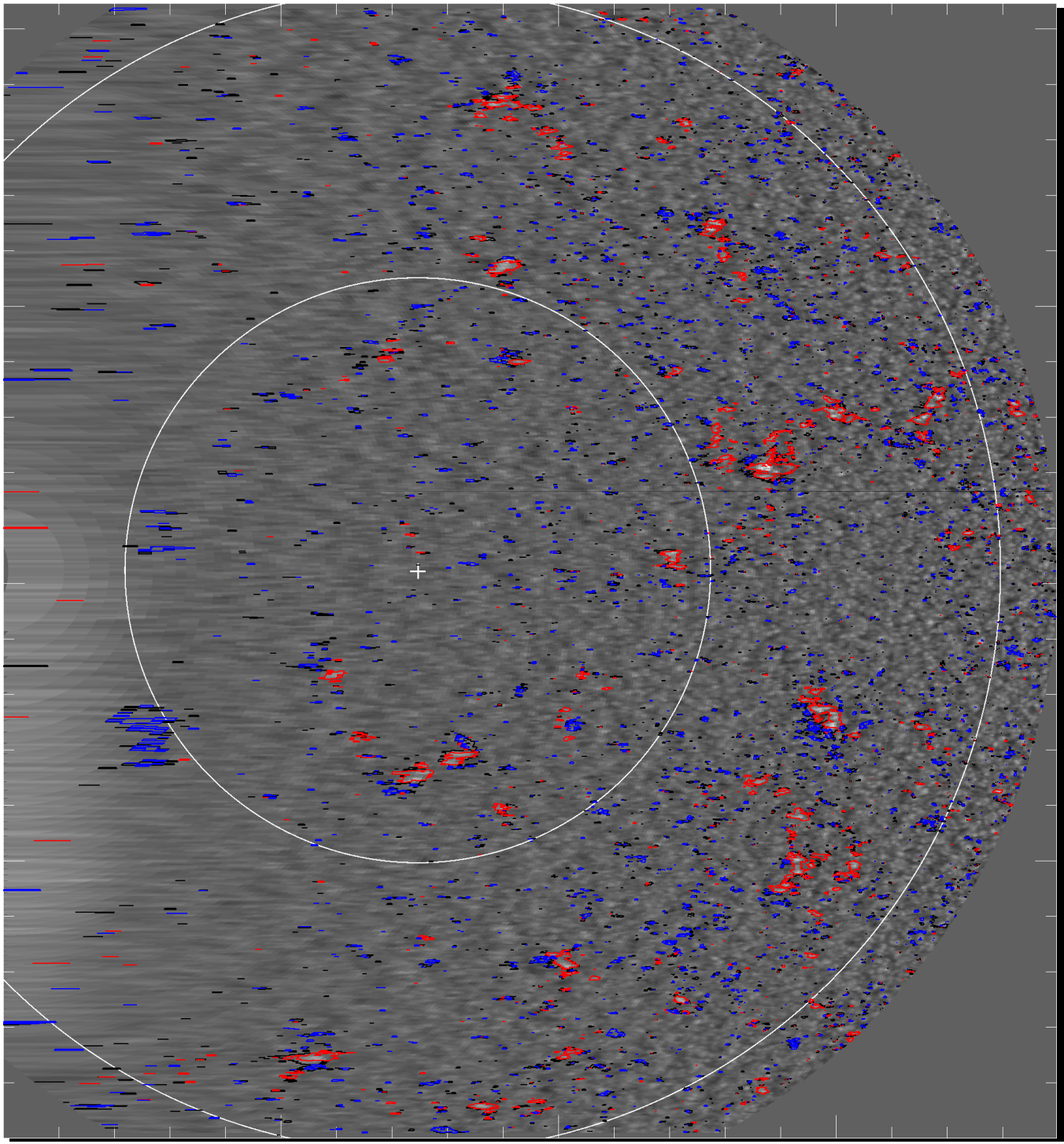



JAXA/ISAS, SIRIUS XRT 16-Mar-2007 06:12:36.201 UT
2007 March 16
Courtesy Narukage
South pole is tilted
7 degree toward us.
SOT FOV
80 deg
70 deg
1000
500
0
−500
−1000
Y (arcsecs)
−1000
−500
0
500
1000
X (arcsecs)

Polar landscape kG field

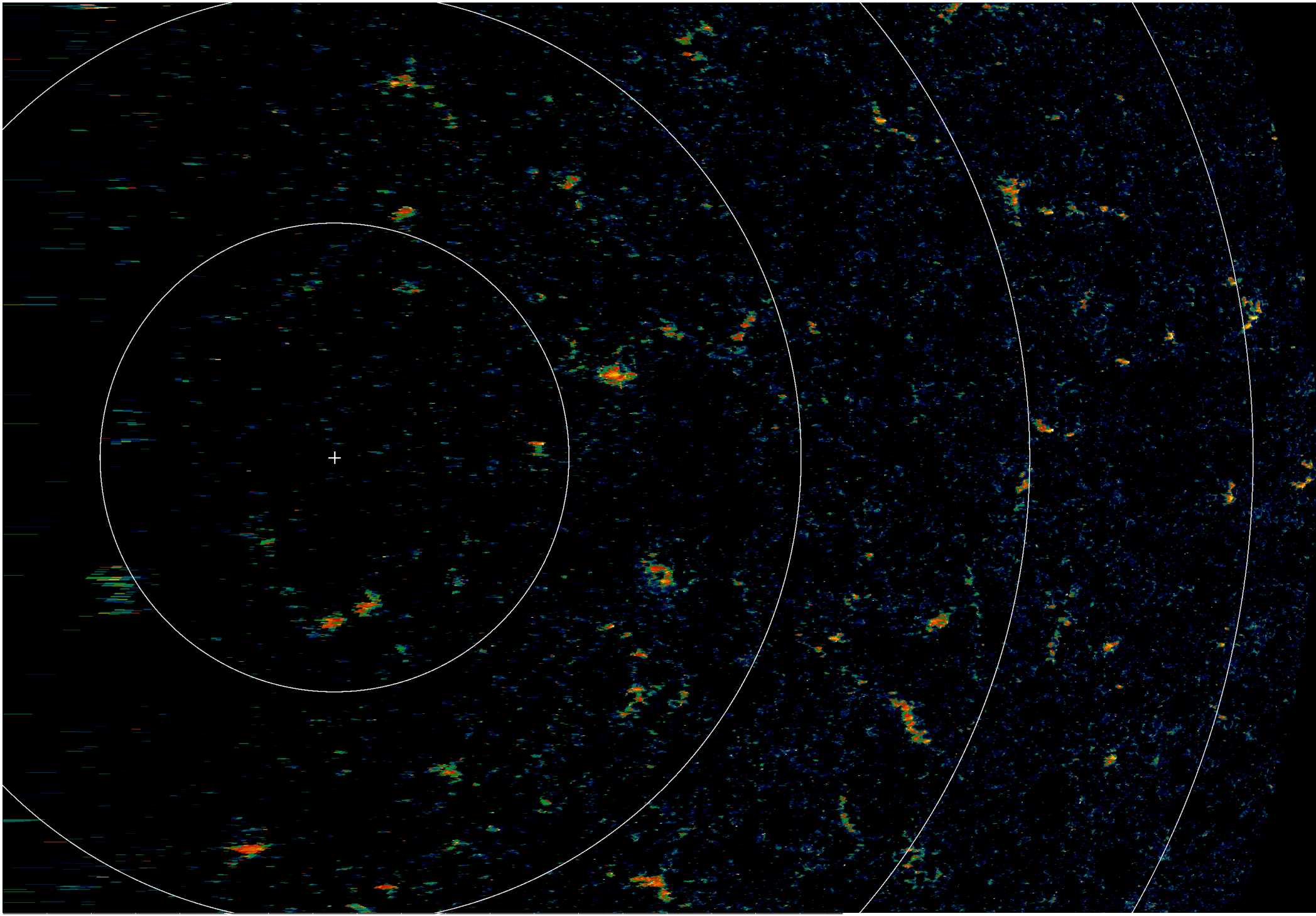
Tsuneta etal (2008 in press)





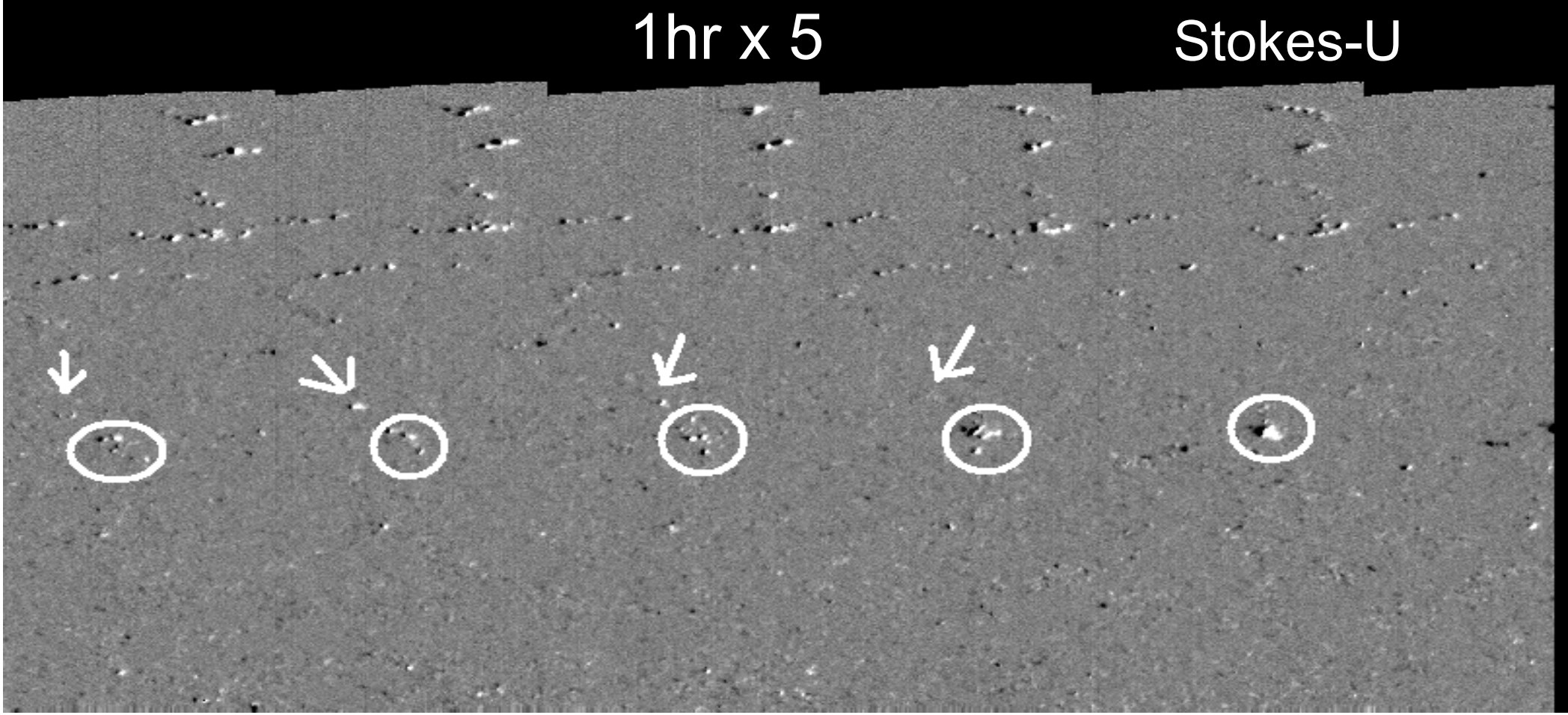
Red : vertical
Blue : horizontal

Polar region consists of same-sign vertical B with horizontal B

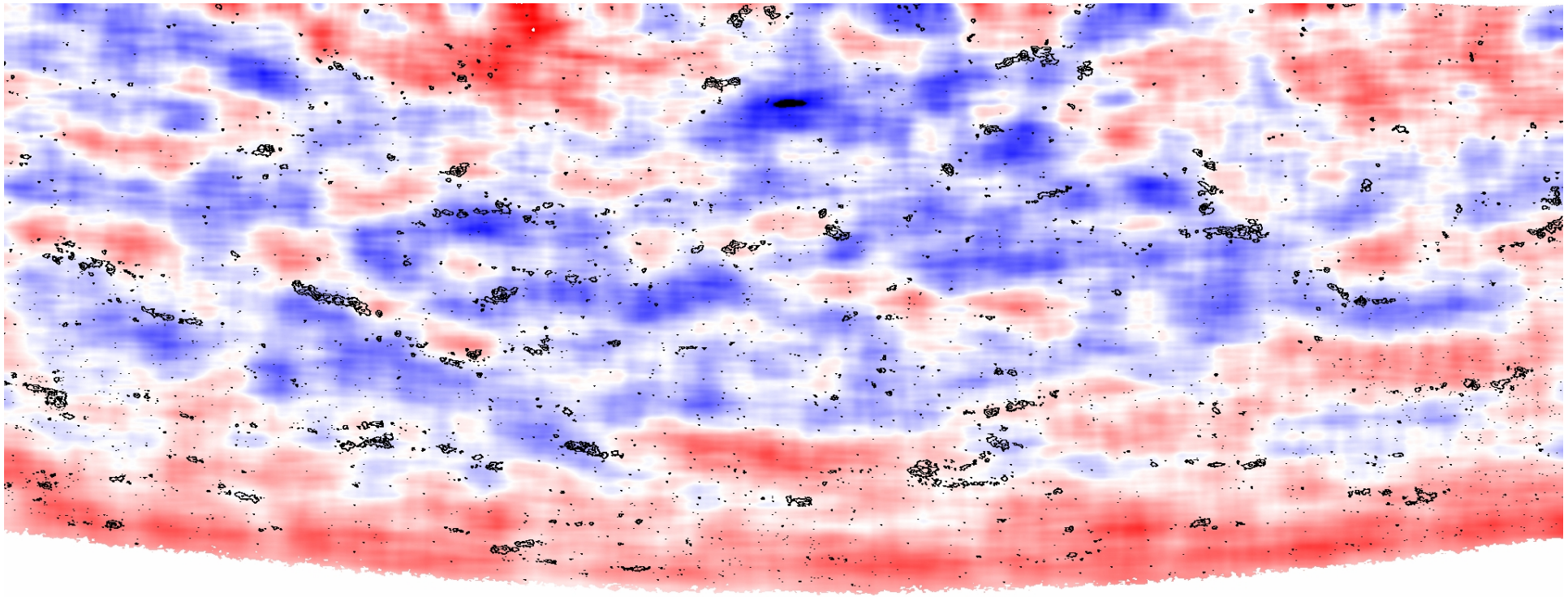


Temporal evolution of kG patches

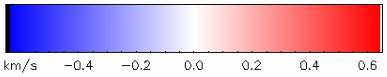
- kG patches have canopy structure
- Life time ～10-20 hours
- Super Equi-partition & unipolar
- Small flux tubes merge to form large patch
- Large patch disintegrates to smaller patches



Velocity map obtained from Stokes-I and kG patches (contour)

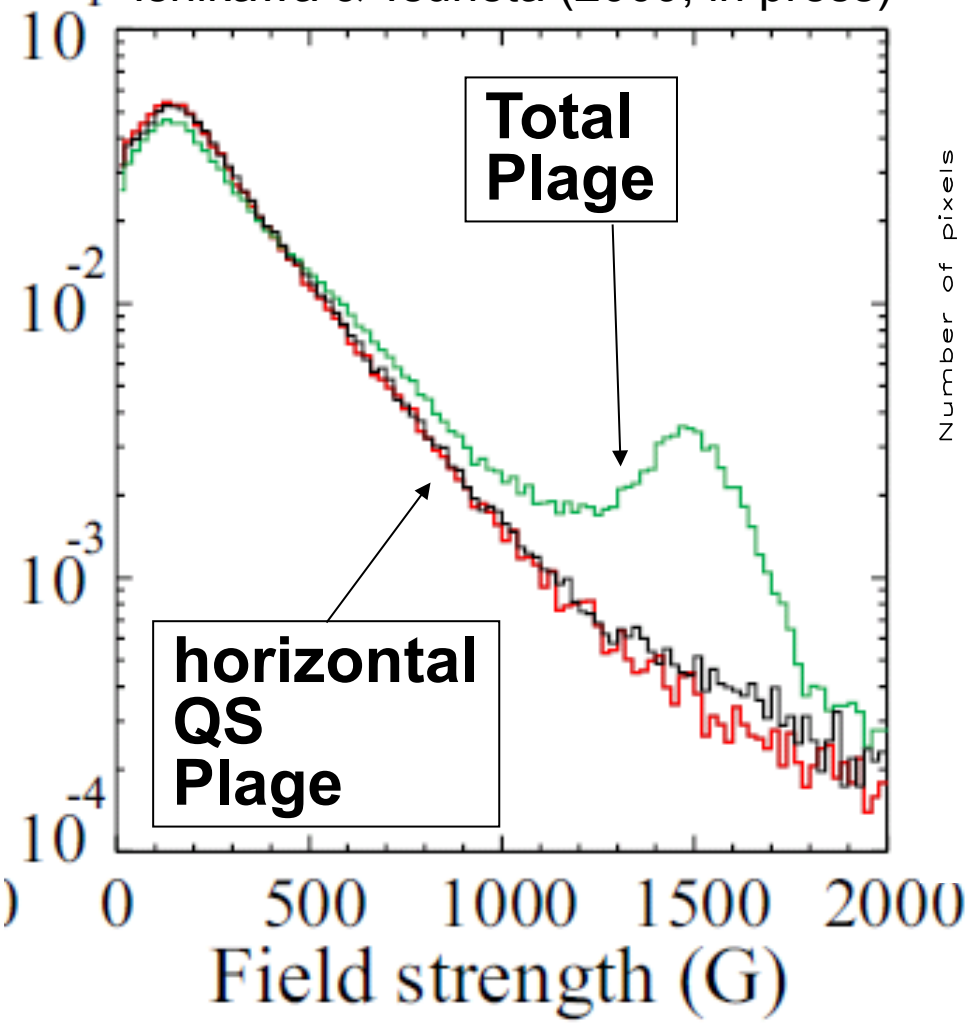


- **Relation between flow-field and magnetic patches are being analyzed.**

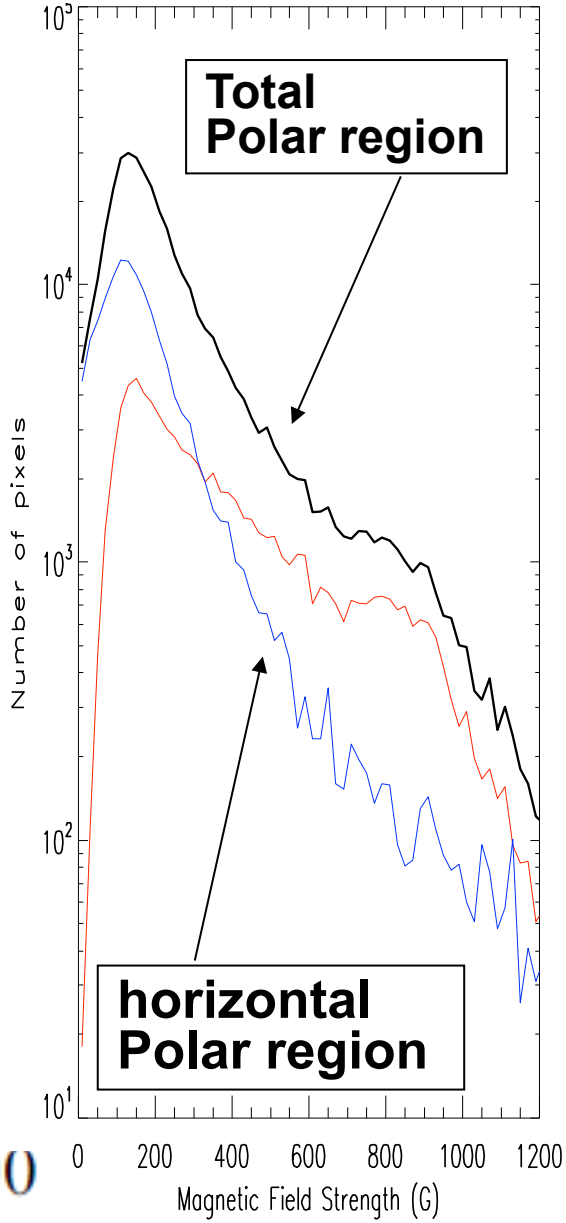


Horizontal field
PDF comparison with Quiet Sun and Plage region

Ishikawa & Tsuneta (2009, in press)



Tsuneta etal (2008 in press)

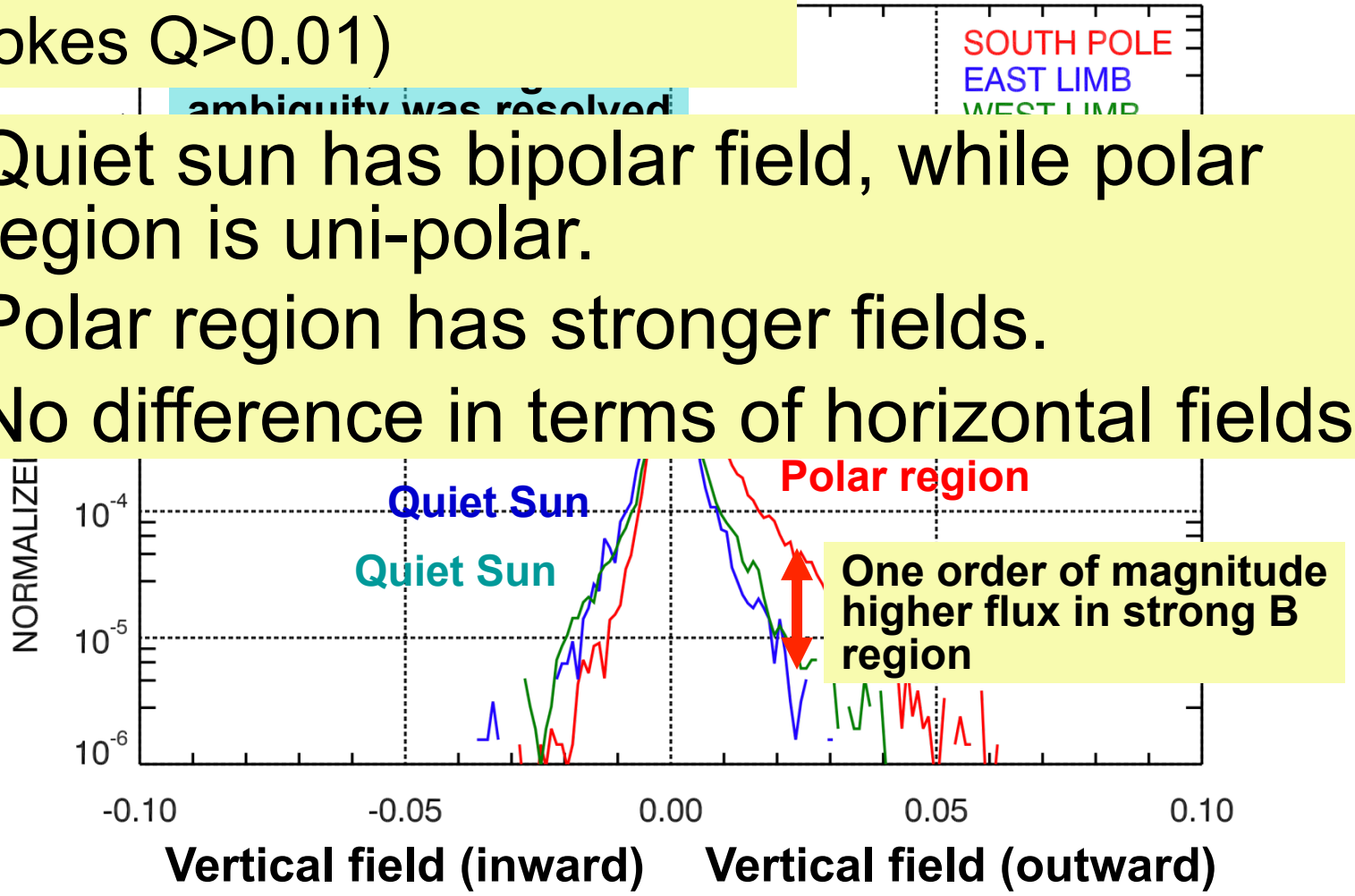


ce between olar region?

Ito & Tsuneta 2008

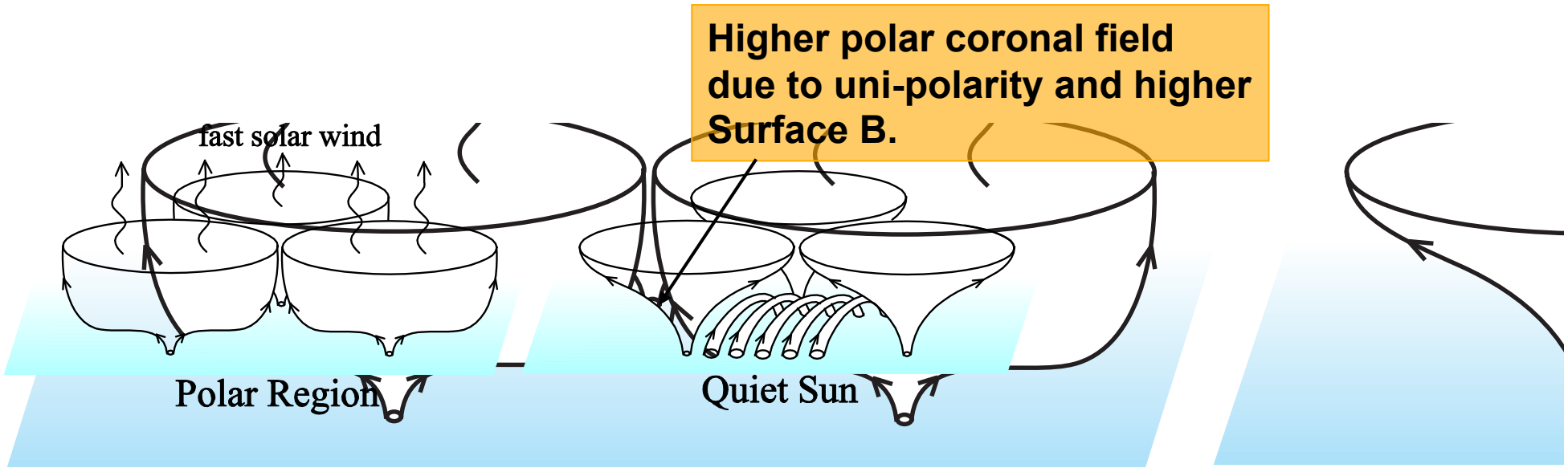
Outward and inward flux
South pole: 96.3% : 3.7%
East limb QS: 50.5% : 49.5%
West limb QS: 64.0% : 36.0%
(Stokes Q>0.01)

ertical field



- Quiet sun has bipolar field, while polar region is uni-polar.
- Polar region has stronger fields.
- No difference in terms of horizontal fields

Inflation of polar flux tubes near photosphere-chromosphere boundary



Polar Region

All the flux tubes are connected to interplanetary space.

Very small fraction of flux tubes is connected to interplanetary space.

Figure Courtesy Joten Okamoto

Summary
Properties of polar fields

- *Vertical* field component
  - PDF with extenstion to super-equipartition (400-500G) field strength seen as kG patch
  - kG patch fanning-out structure
  - Unipolar in contrast to QS
  - Appear from nothing to disappear to nothing
  - 10-15 hour life time
  - North flux same as south flux
- Ubiquitous *horizontal* fields component everywhere as seen in Stokes V
  - PDF similar to those of quiet sun and plage region
  - Local dynamo process (Ishikawa and Tsuneta 2009)

Impact to solar dynamo

- Magnetic flux is transported to the polar regions with meridional flows and supergranular diffusion. Flux transport would be done via an aerodynamic (drag) force against magnetic tension force, and may be more difficult than the case for the mean field case.
- If the flux tubes seen on the surface of the Sun are maintained inside the Sun, they may affect a known difficulty in Ω-mechanism to generate intense toroidal field
  - an amplification factor of 100 that is needed to explain a combination of 1kG poloidal field with 100kG toroidal field may be achievable within a solar cycle.
  - There remains, however, a serious energetic problem.

Do we need polar mission in terms of B-observations?

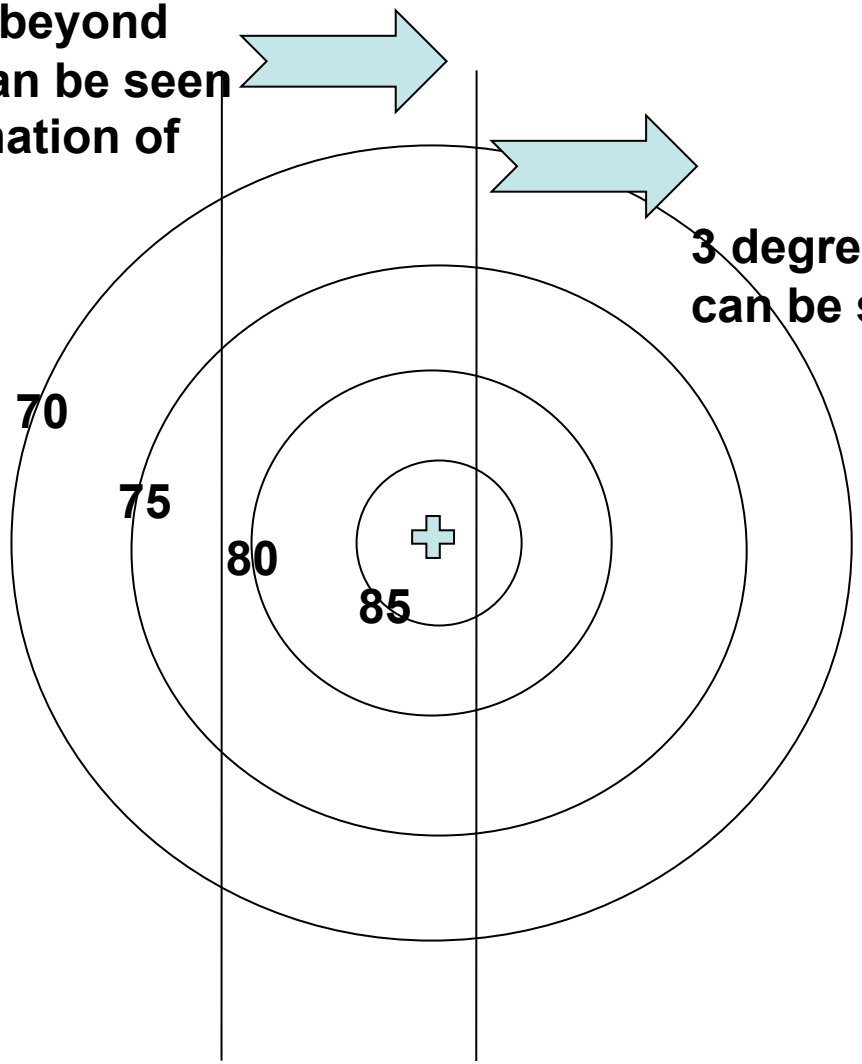
- What is the difference between QS and polar region? Further analysis on Hinode is needed.
- We need Stokes-polarimeter for precise measurement for magnetic fields. High quality ME maps are available upto latitude of 87 degree, if the sun is 7 degree tilted toward us.
- If orbital inclination is 15 degree, we can see 12 degree beyond the pole.
- We should resolve THMFs. Its relationship with global dynamo is totally unknown. (Is 1 arcsec magnetograph for polar region interesting enough when we are familiar with Hinode images?

How far we can see?

12 degree beyond the pole can be seen from inclination of 15 degree.

Polar axis is tilted 7 degree toward us.

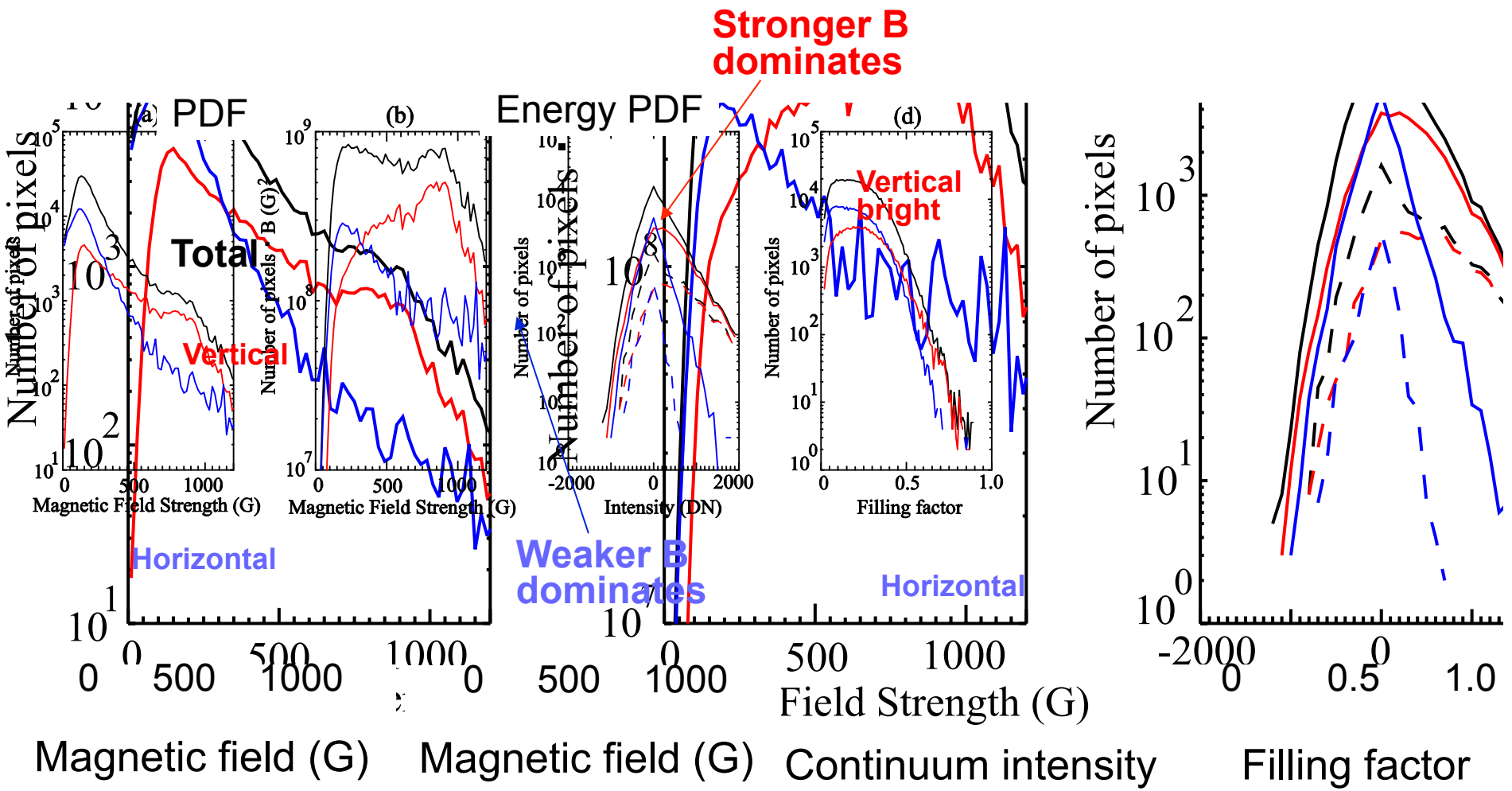
3 degree from the pole can be seen with Hinode



A proposal

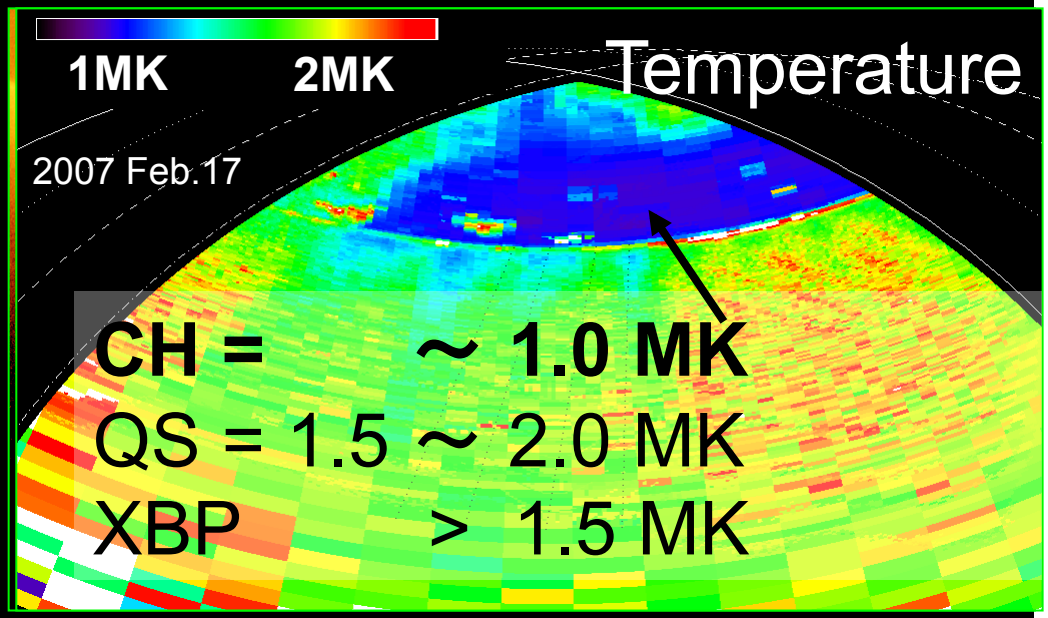
- Put B-satellite into plan-A orbit, but with low inclination of 10-20 degree.
- B-satellite is high-resolution mission.
- In addition to the B-satellite, we should have high-inclination A-satellite via inter-agency collaboration. Inclination angle should be optimized by considering science drivers and resources.

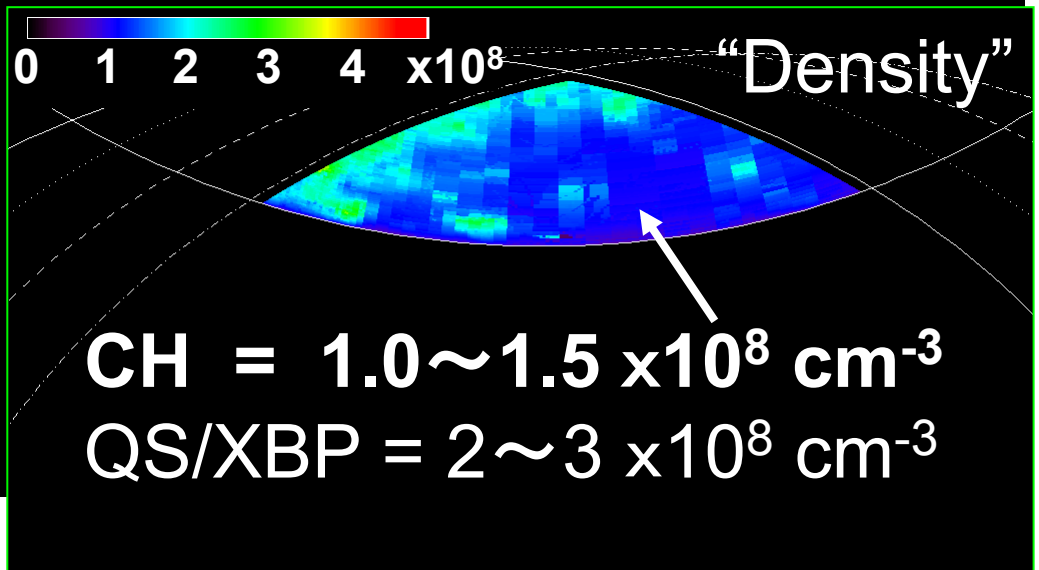
Probability Distribution Function of polar field



Low pressure coronal hole is sustained by higher magnetic pressure of coronal hole

- CH pressure is a factor of 2 (T-diff.) x 3 (n-diff.) = 6 smaller than that of surrounding quiet Sun.
- This must be balanced by stronger CH magnetic field.



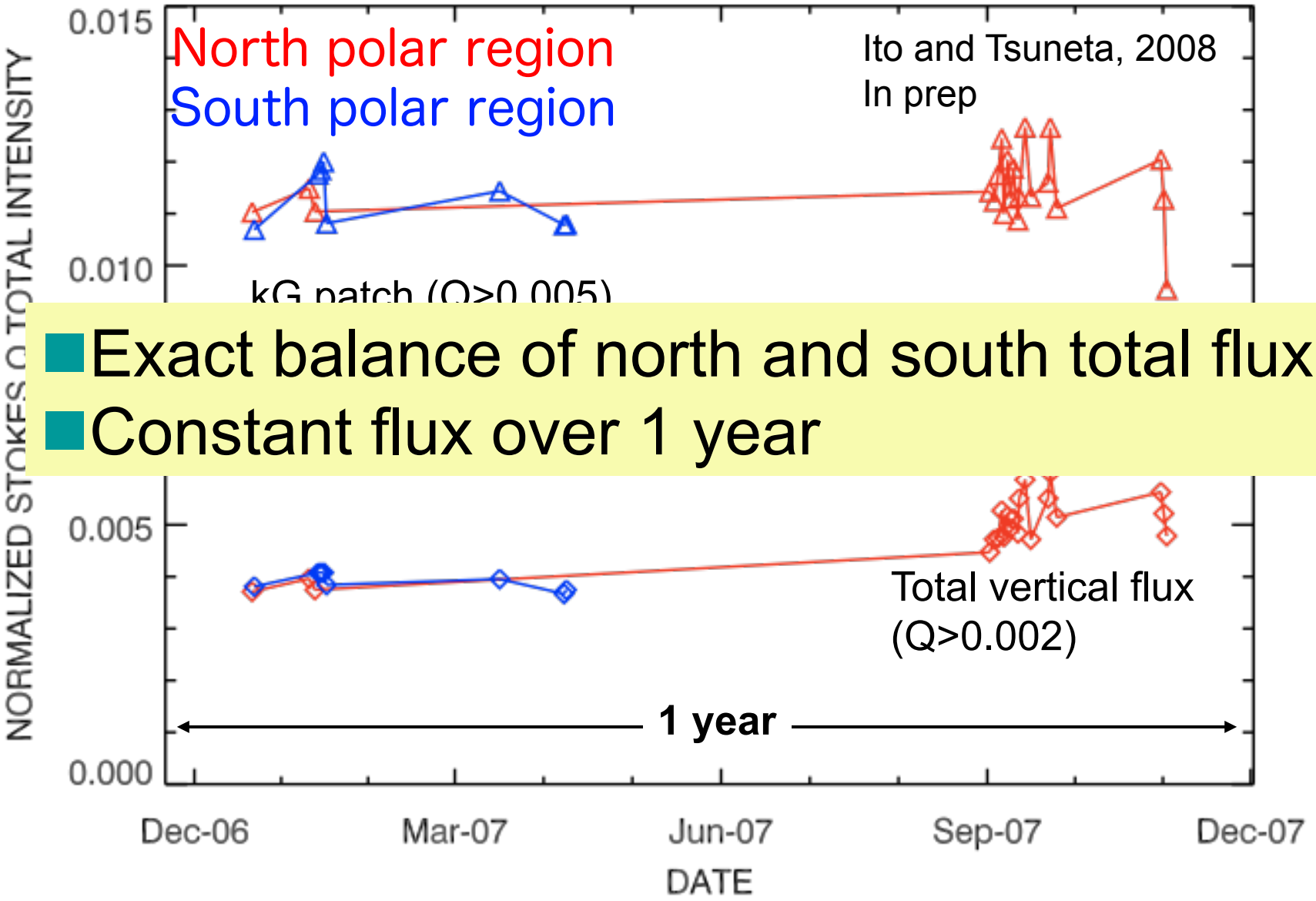


Kano et al (2008)

Total and average magnetic flux

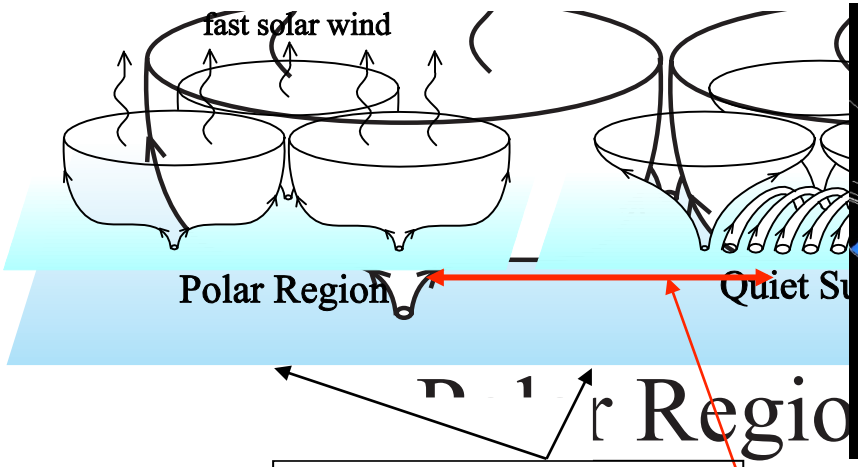
- Magnetic filling factor: **$0.05 < f < 0.35$**
- Total magnetic flux in a pixel
  - *B x f x pixel size with foreshortening correction*
- Total magnetic flux in SOT FOV
  - vertical flux **$2.2\text{-}9.9 \times 10^{21}$ Mx**
  - horizontal flux **$0.4\text{-}2.0 \times 10^{22}$ Mx**
- *Horizontal flux factor of 2 larger*
- Average vertical flux 10.0 G
- Total vertical magnetic flux for > 70 degree
  - **$0.6\text{-}2.5 \times 10^{22}$ Mx**
- Ulysses observations
  - **2×10^{22} Mx** (above 35 degree)

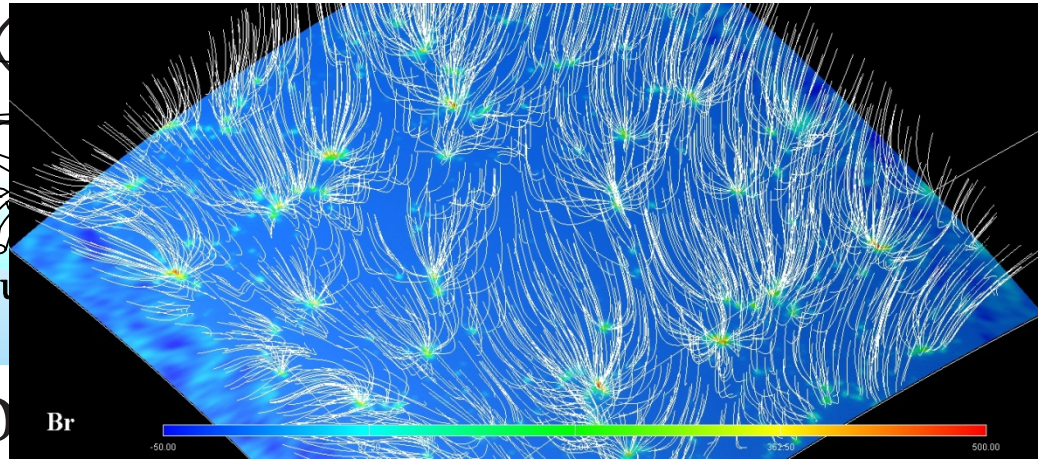
Variation of total polar flux over one year



- Exact balance of north and south total flux
- Constant flux over 1 year

What is the implication of the kG polar field for acceleration of fast solar wind





Fast solar wind comes from here

Polar field extrapolation (potential) using polar SP data embedded in MDI data (Shiota, Ito, Tsuneta, 2009)

Flares and jets

reconnection

Horizontal field

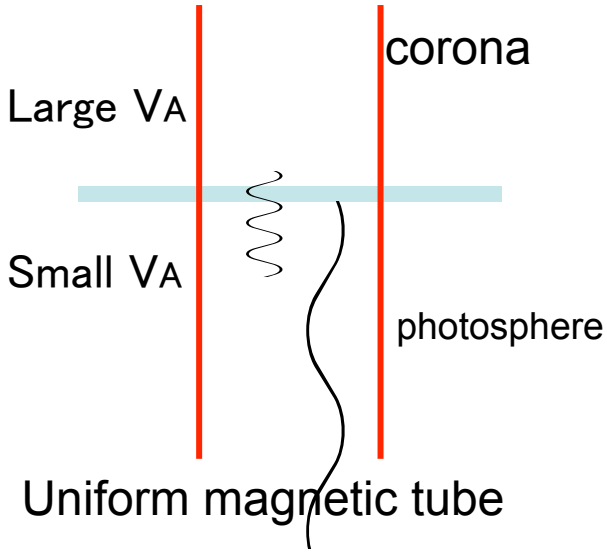
A factor of 345 inflation of the flux tubes near photosphere-choromosphere-corona boundary

Figure Courtesy Joten Okamoto

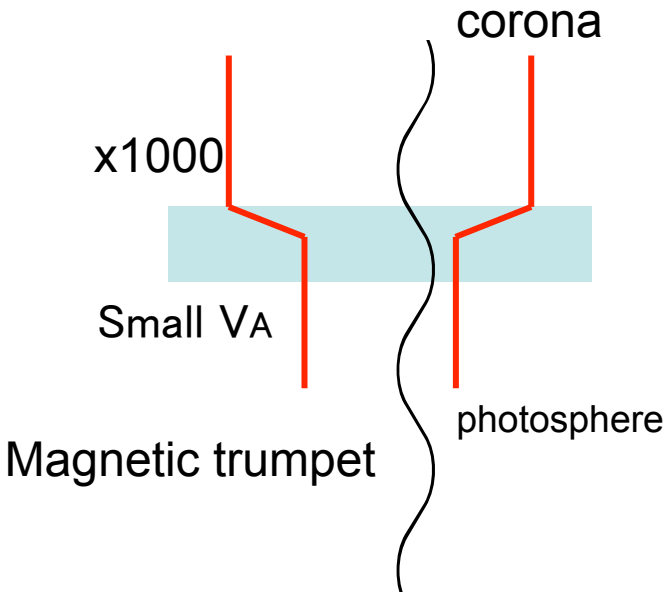
Fanning-out kG patch Chimney for Alfven waves

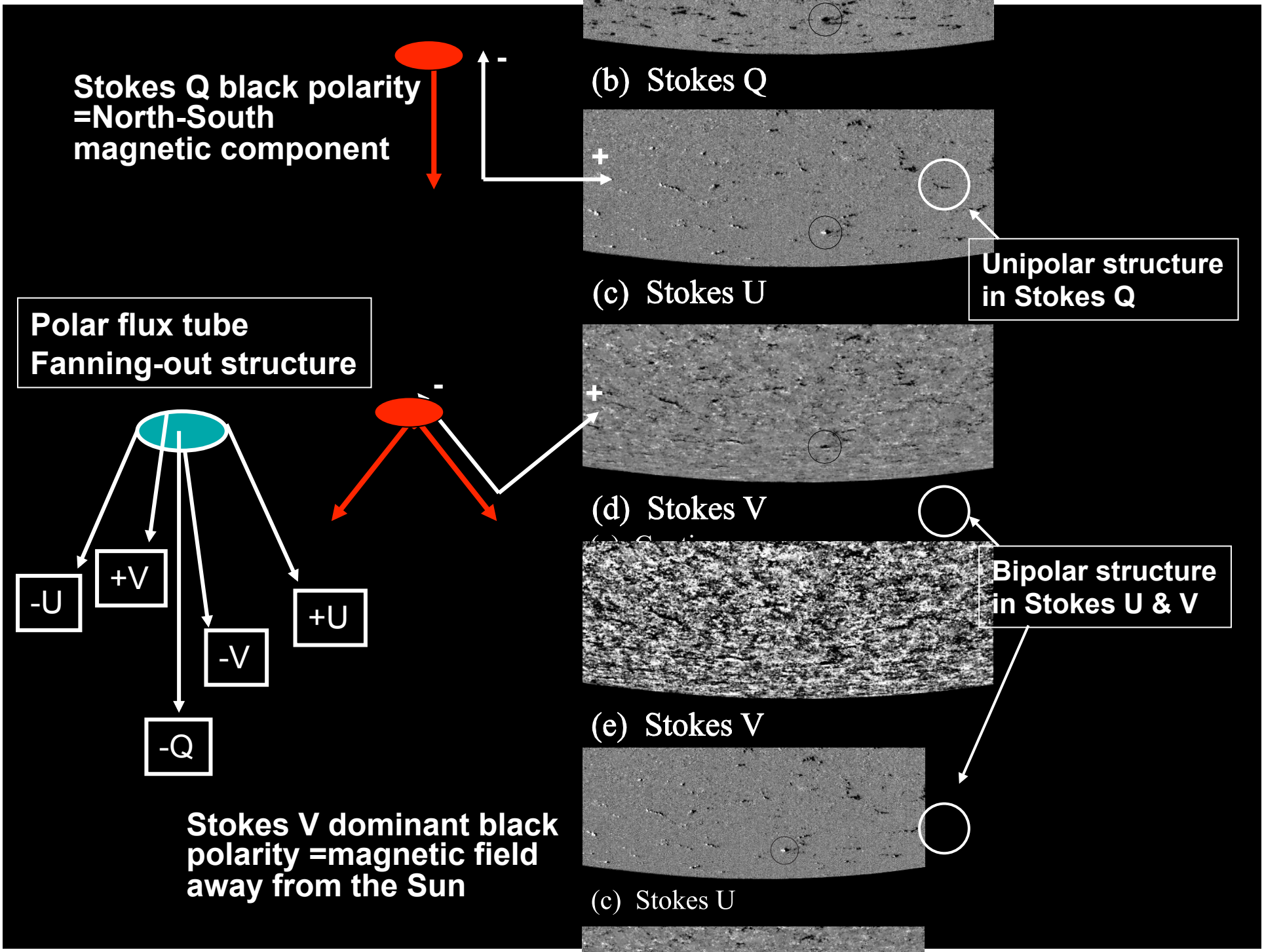
- ***Uniform magnetic field***: Aflven wave reflection in the photosphere-corona boundary

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



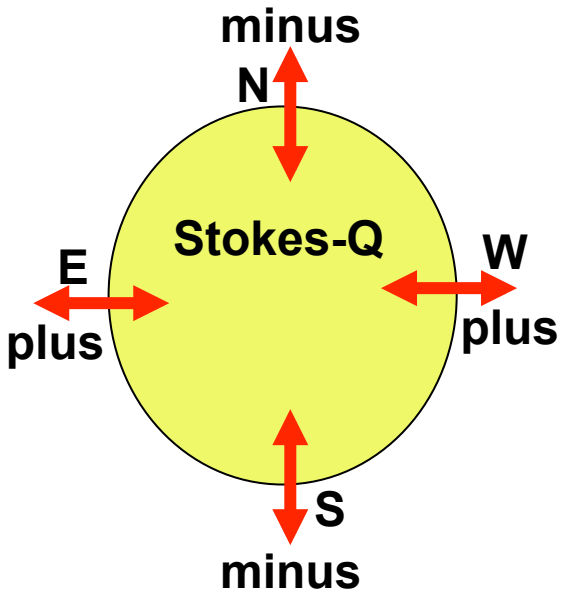
- ***Fanning-out flux tube***: serves as chimney for Alfven waves
  - more Alfven wave flux that accelerates fast solar wind is transmitted to the corona due to the fanning-out structure.




Stokes Q black polarity
=North-South
magnetic component
-
+
(b) Stokes Q
(c) Stokes U
Unipolar structure
in Stokes Q
Polar flux tube
Fanning-out structure
-U
+V
-V
+U
-Q
(d) Stokes V
Bipolar structure
in Stokes U & V
(e) Stokes V
(c) Stokes U
Stokes V dominant black
polarity =magnetic field
away from the Sun

Milne-Eddington least-squares fit

- To minimize the influence of noise, fitting is performed for pixels whose *Q, U or V signals are larger than 5 sigma.*
  - 10.5% of the area meets the criteria.
- Formation layer at 80 degree latitude is approx. 100 km above the nominal height.
- *ME works fine for the extreme limb!*
- Parameters
  - vector magnetic field (strength, inclination angle, and azimuth angle), the line of sight velocity, two parameters describing the source function, the line-to-continuum absorption coefficient ratio, Doppler width, damping parameter, stray light factor(filling factor)


minus
N
Stokes-Q
E
plus
W
plus
S
minus