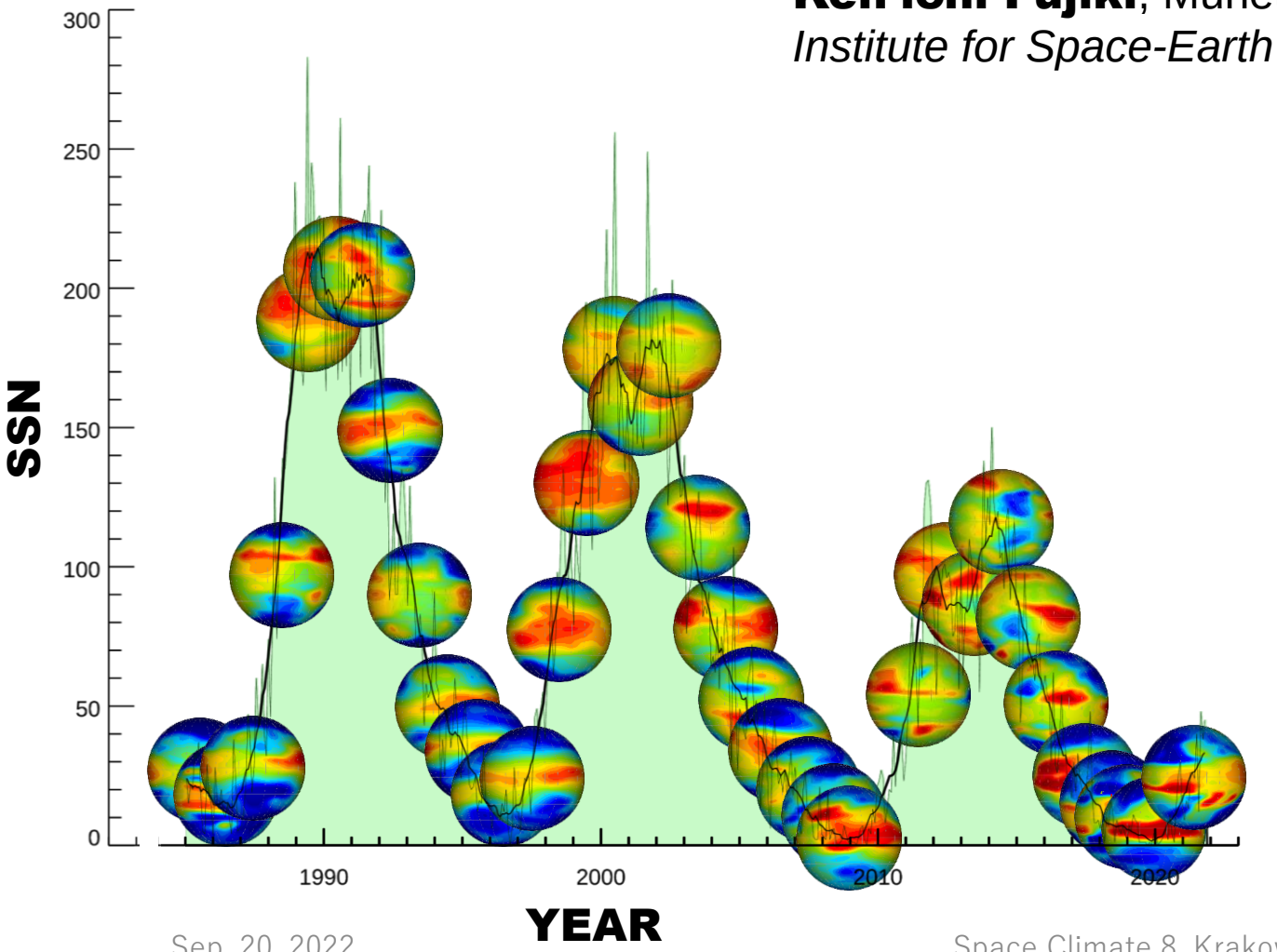
Reconstruction of the global solar wind structure using IPS observation and coronal magnetic field parameters obtained from PFSS extrapolation

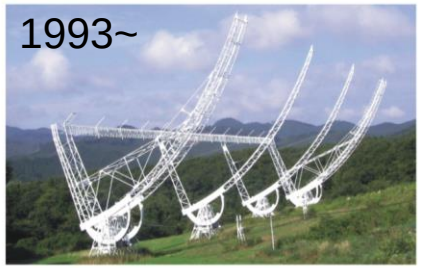
Ken'ichi Fujiki, Munetoshi Tokumaru, and Kazumasa Iwai
Institute for Space-Earth Environmental Research (ISEE), Nagoya University



- Global solar wind structure
  Interplanetary scintillation (IPS)
- Photospheric source distribution
  of the solar wind (IPS&PFSS)

→Try to find a good proxy
Reconstruction of solar wind
Simple is the best!

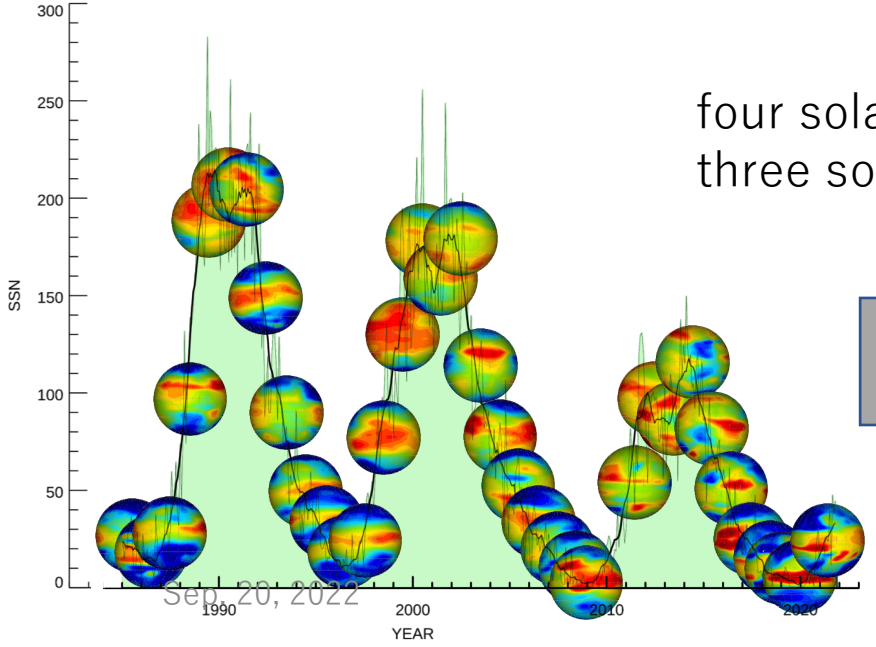
IPS Observation in Japan



1981~2007: old
2008~ : new

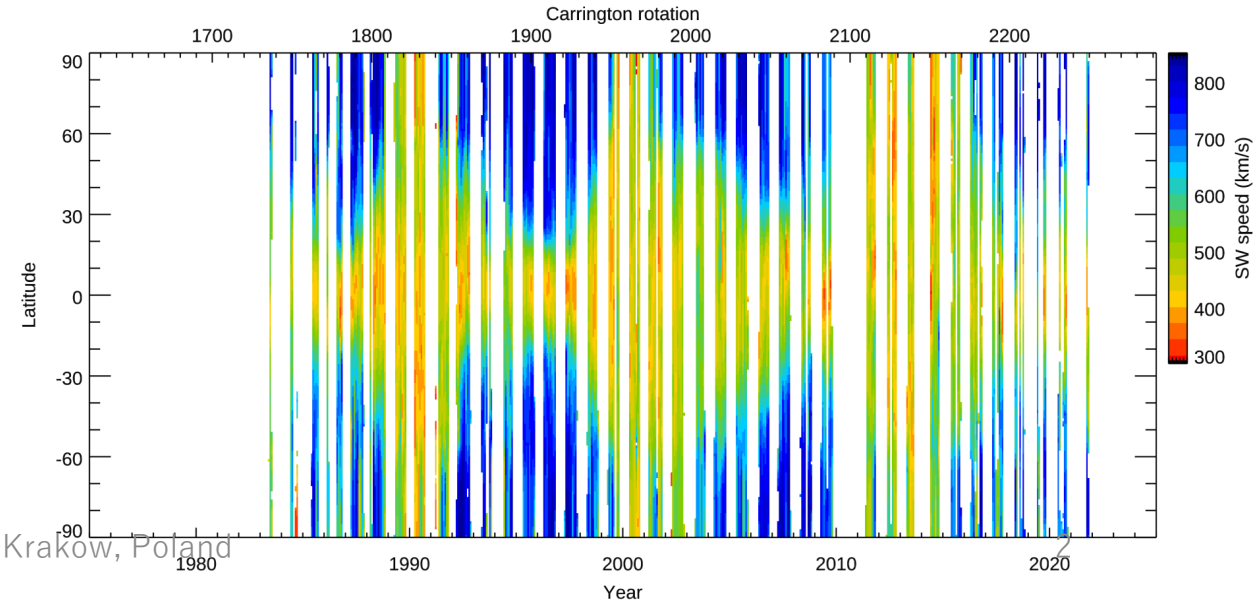
Multi-site UHF (327 MHz) Observation: 1985~

Station	T_{sys} [K]	A_e[m²]	ΔS_{min} [Jy]
Toyokawa	146	1970	0.2
Fuji	151	1500	0.28
Sugadaira	229	1120	0.58
Kiso	221	1409	0.43



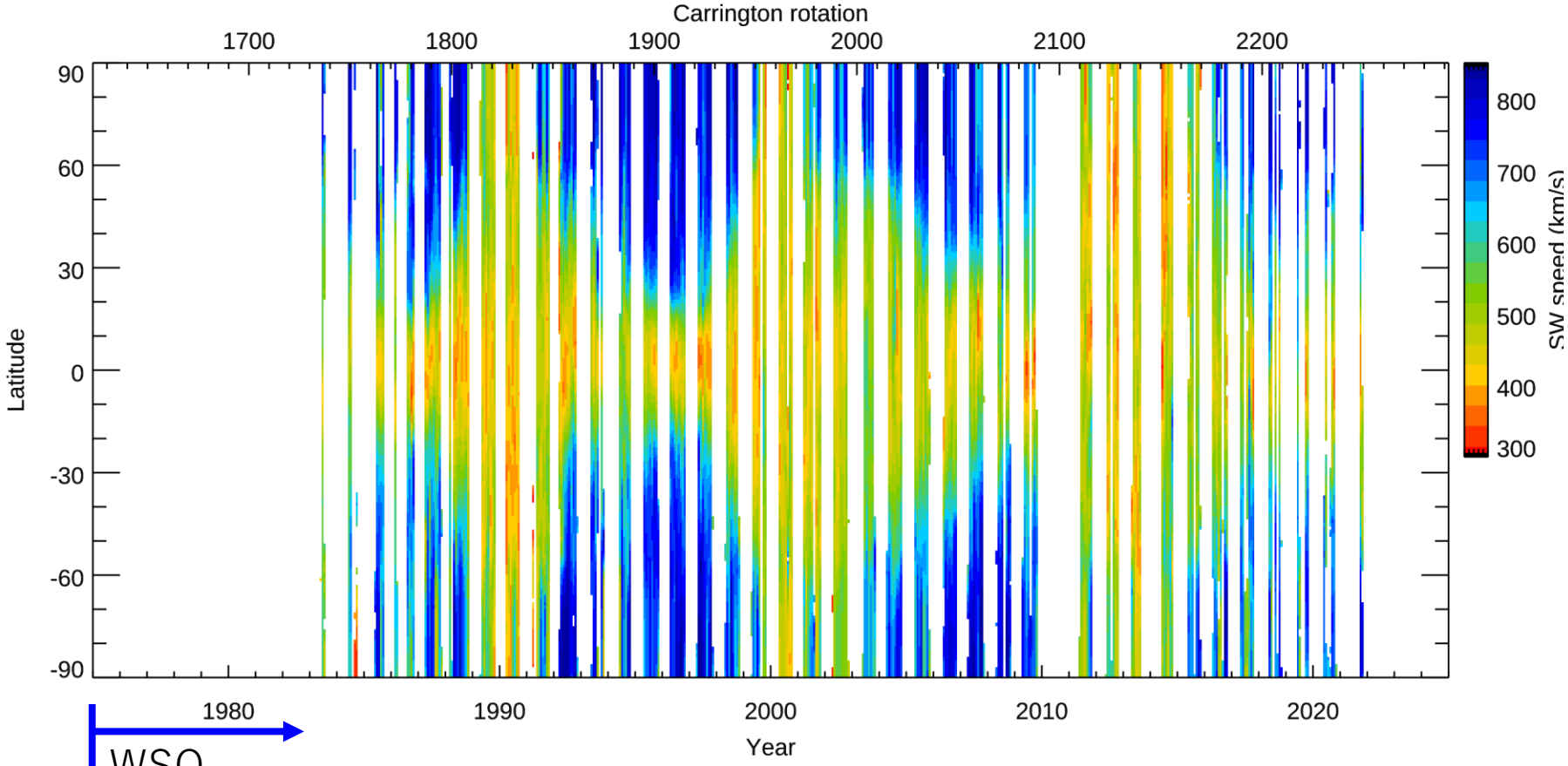
four solar minima
three solar maxima

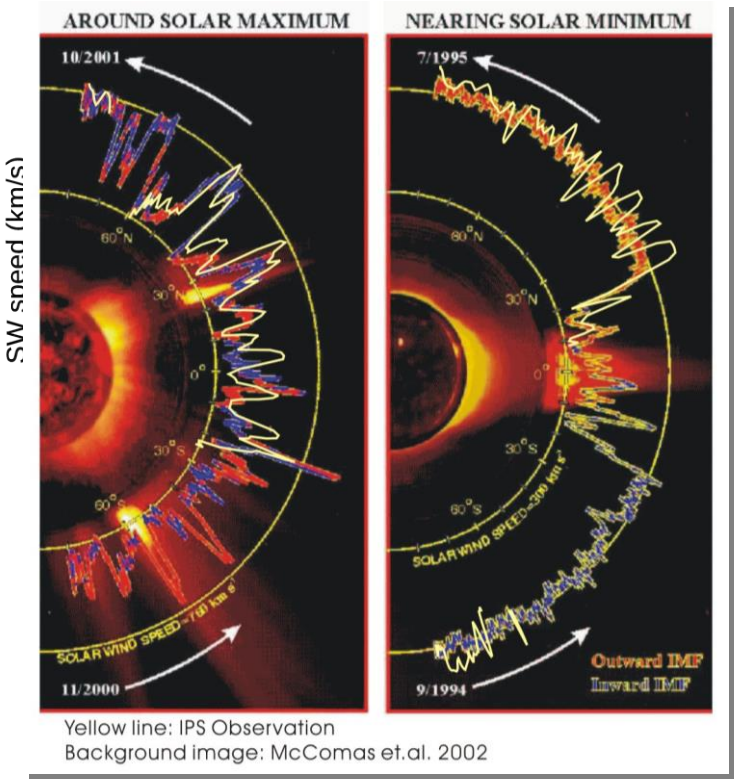
Longitudinal average



Global Solar Wind Structure

- Period: 1984 – (except winter)
- Observation range: 0.2-1.0 AU
- Velocity distribution: mapped on 2.5 Rs by tomographic analysis
- Bimodal structure: low-speed & high-speed solar winds



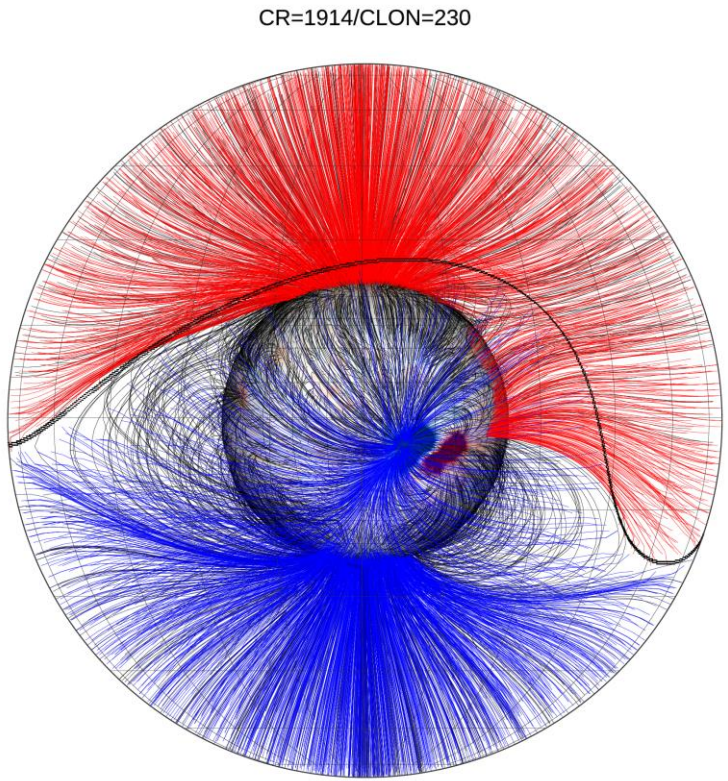


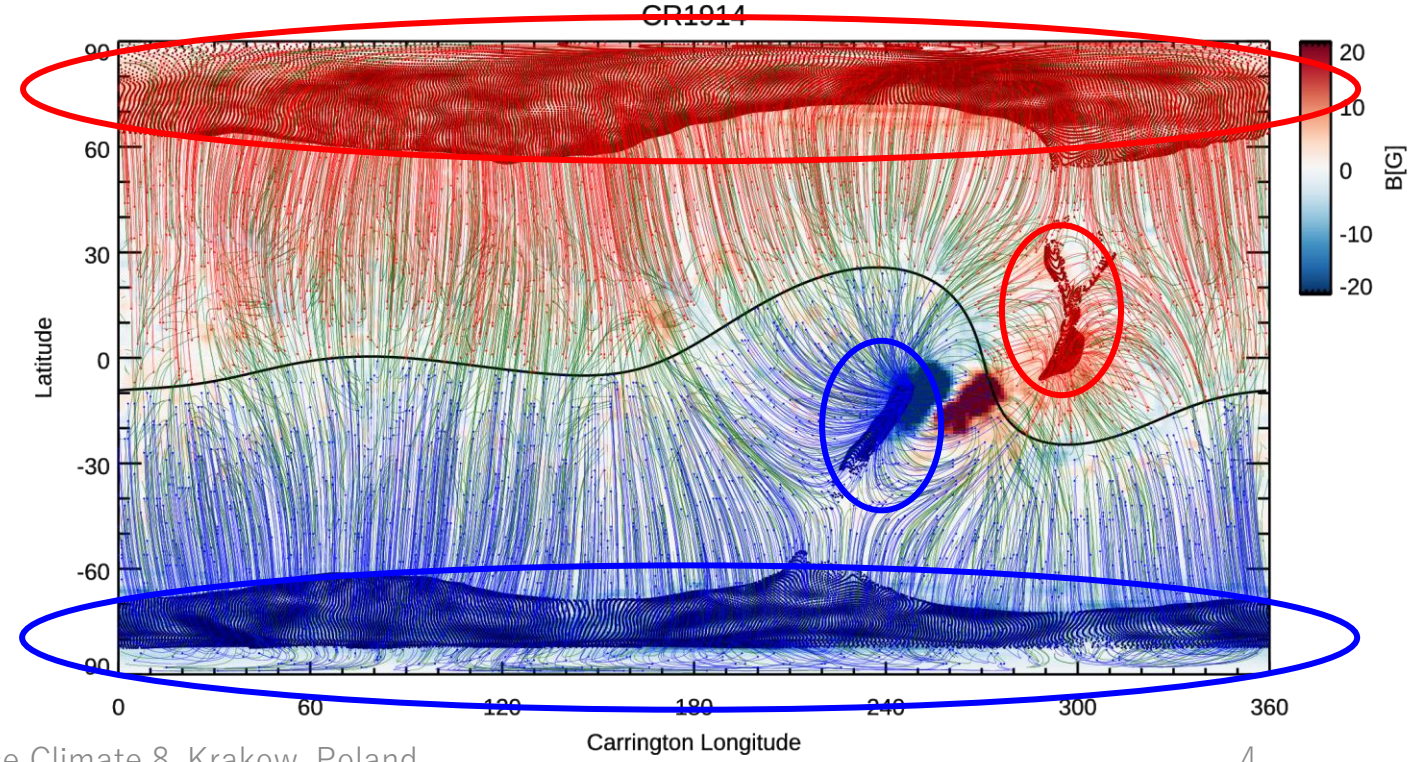
Yellow line: IPS Observation
Background image: McComas et.al. 2002

Coronal Holes ~ A Source of the Solar Wind

Coronal holes (CHs):

- Dark features in the solar corona (X ray, EUV)
- Magnetically open to the heliosphere
- Source of the solar wind





Coronal Holes Estimated From PFSS Analysis

Peroid: 1975- (CR1625-)

Data:

- CR1625-CR1856 : KPNSO
- CR1857-CR2250 : ADAPT

PFSS Analysis:

- 90th order of spherical harmonics

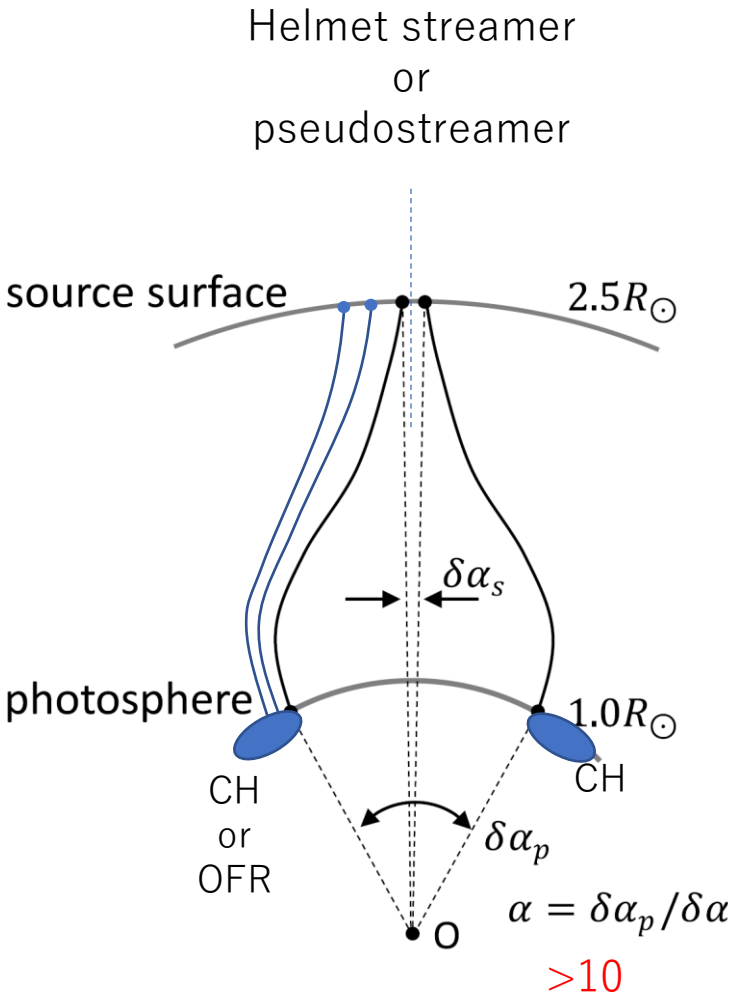
CH definition

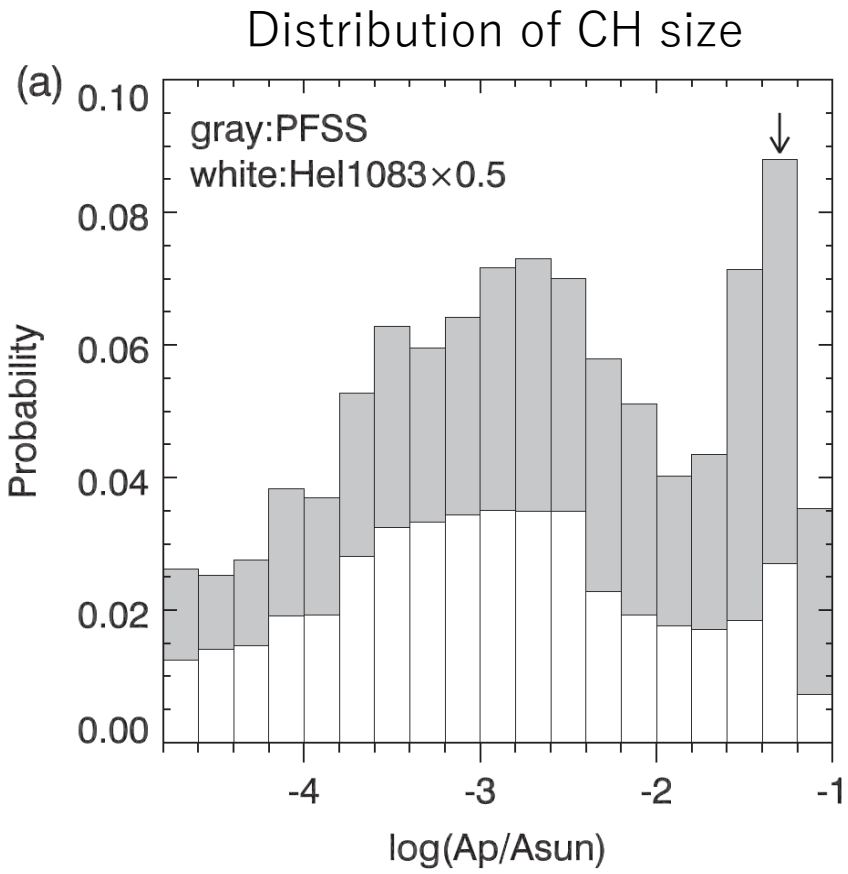
- Separation angle of footpoints

$$\alpha \equiv \frac{\delta\alpha_p}{\delta\alpha_s} > 10$$

CH Labeling:

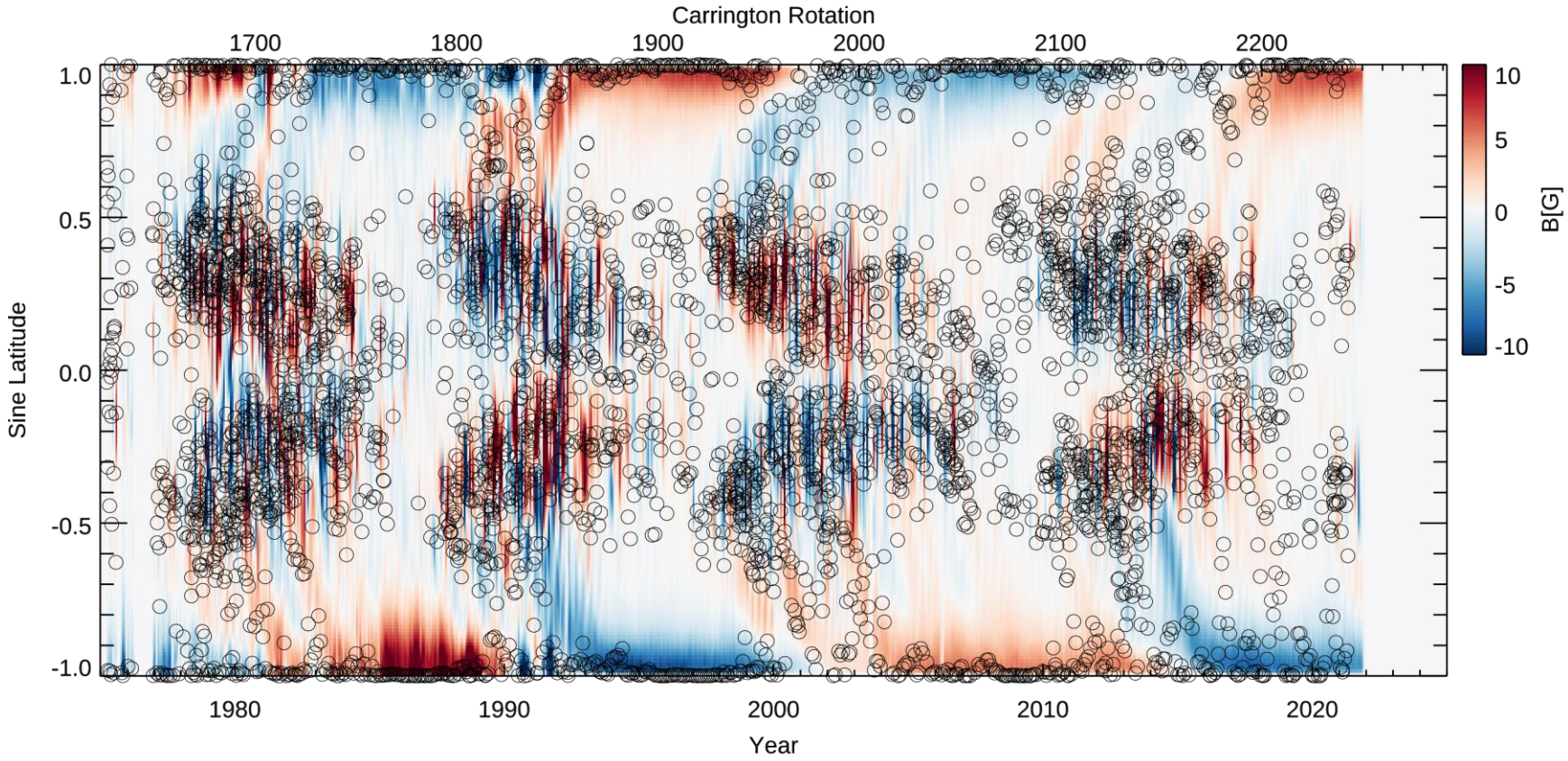
- Position (centroid), lon. & lat.
- Magnetic field strength, B
- Size, A
- Flux expansion rate, f
- Solar wind speed, V (if available)





Fujiki et al., 2016

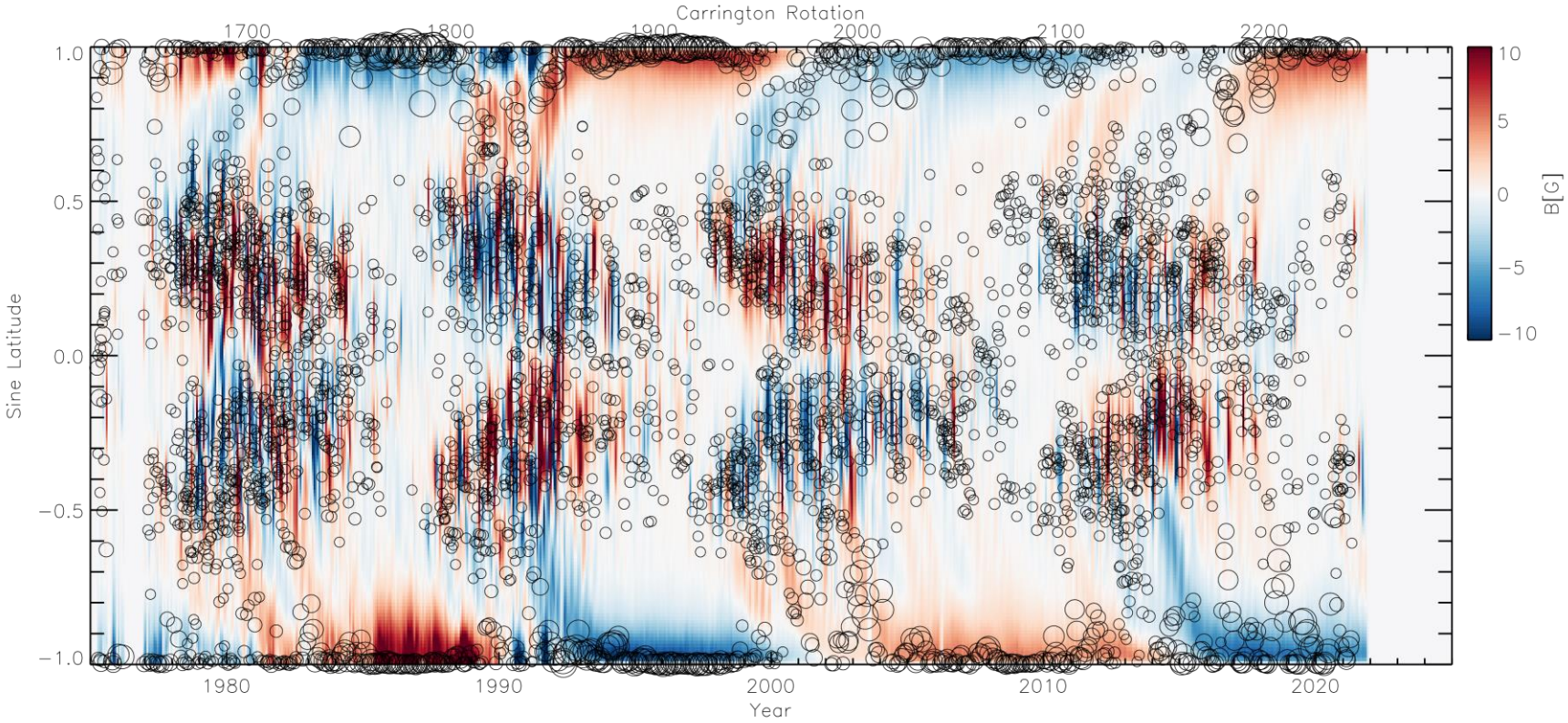
Coronal Hole Distribution



Coronal holes are distributed on …

- magnetic butterfly pattern
- meridional flow
- both poles

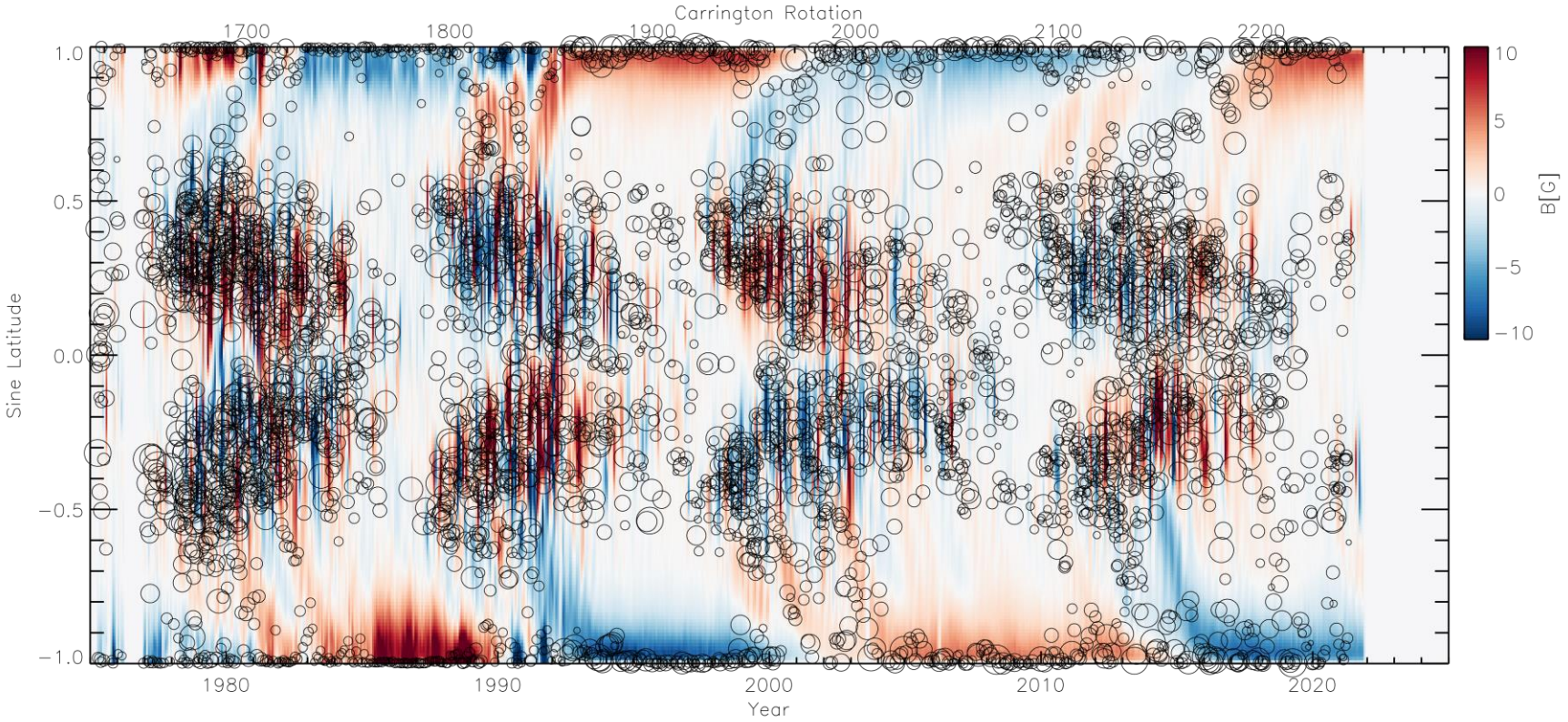
Coronal Holes and their Size



Coronal holes are distributed on …

- magnetic butterfly pattern (small CH) → decay of active regions
- meridional flow (polar CH extension, middle size)
- both poles (polar CH, large size)

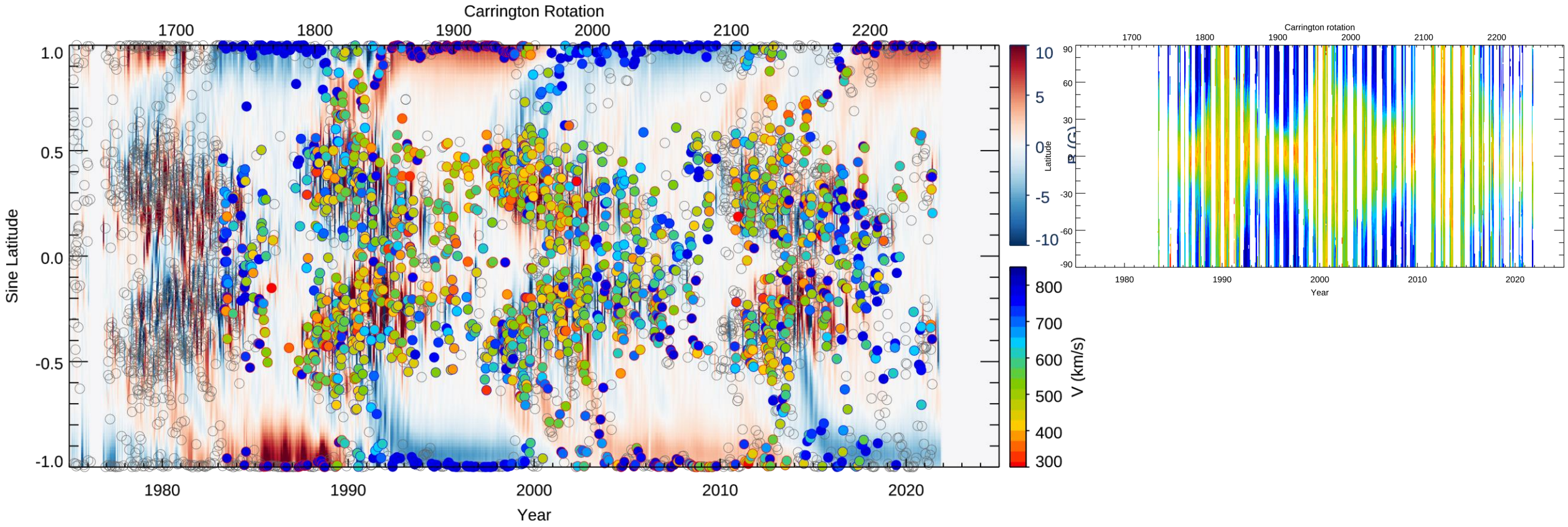
Coronal Holes and their Flux Expansion Rate



Coronal holes are distributed on …

- magnetic butterfly pattern (small CH, large f)
- meridional flow (polar CH extension, middle size, intermediate f)
- both poles (polar CH, large size, small f)

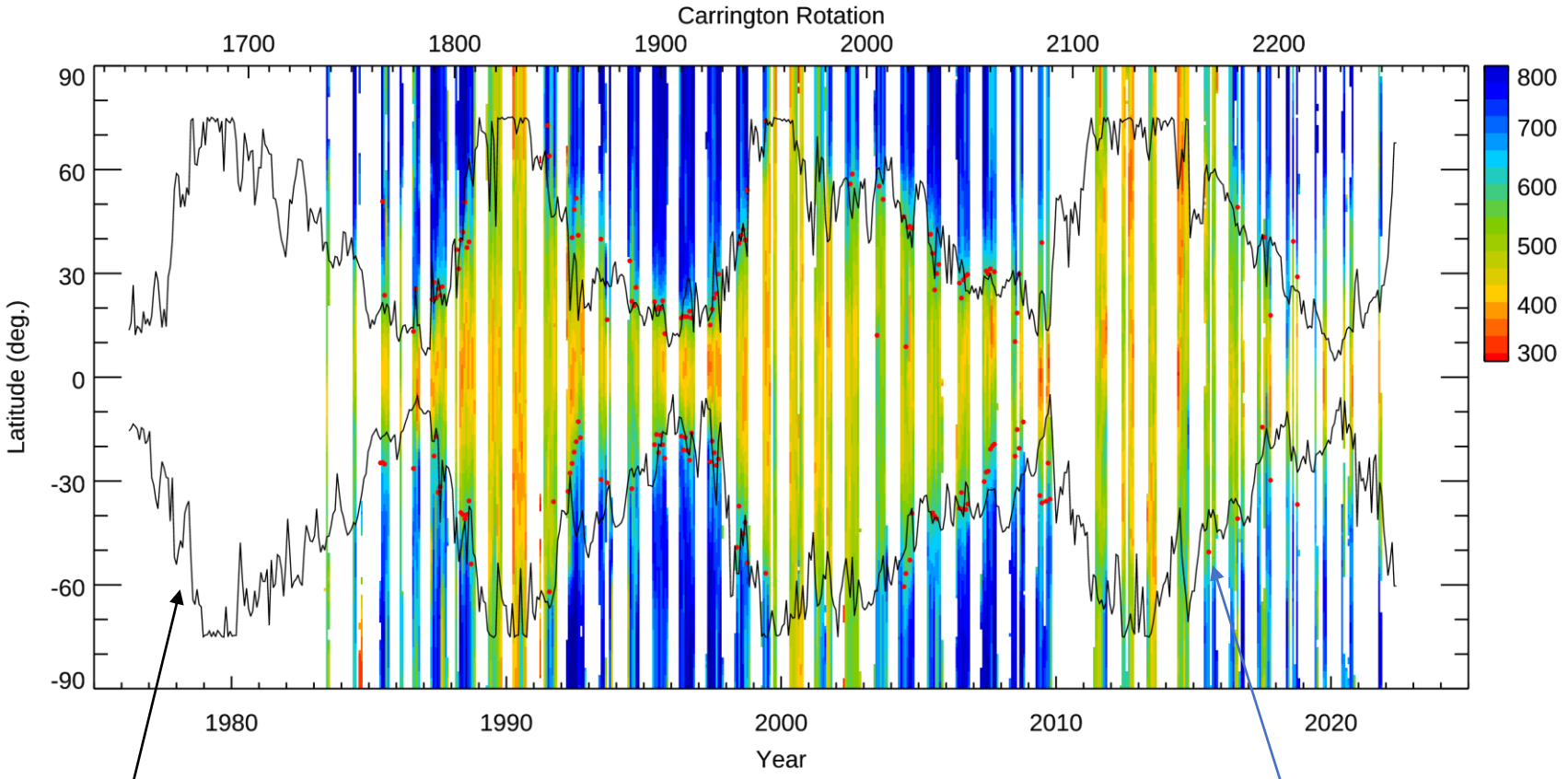
Coronal Hole Distribution and Solar Wind Speed

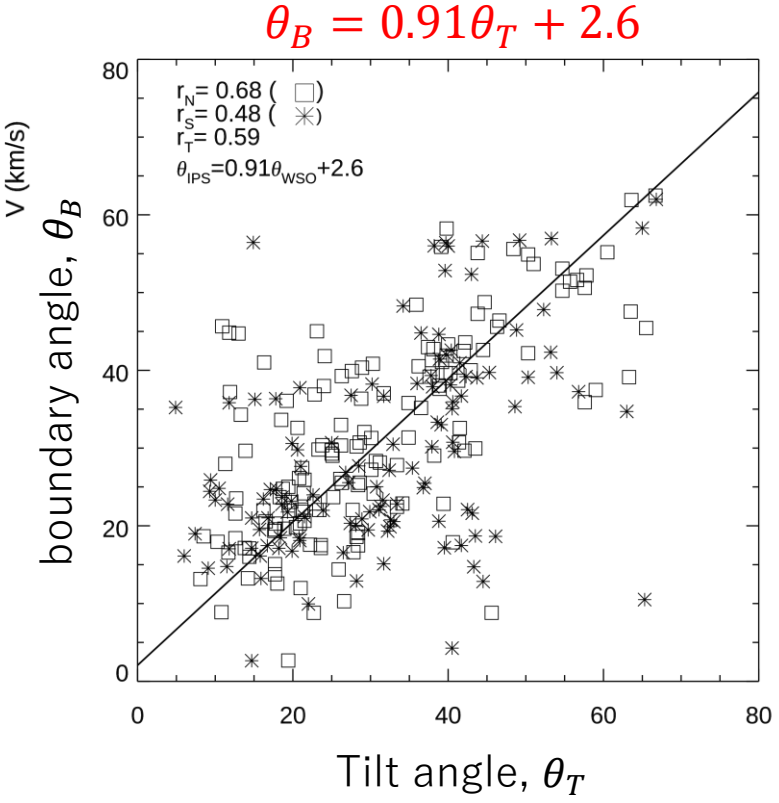


Solar wind sources are distributed on …

- magnetic butterfly pattern (small CH, large f) → mostly low-speed solar wind
- meridional flow (polar CH extension, middle size, intermediate f) → mid-, high-speed solar wind
- both poles (polar CH, large size, small f)→ high-speed solar wind
- Width of low-speed solar wind region reflects the butterfly pattern of the source distribution.

How is the Solar Wind Structure Determined?



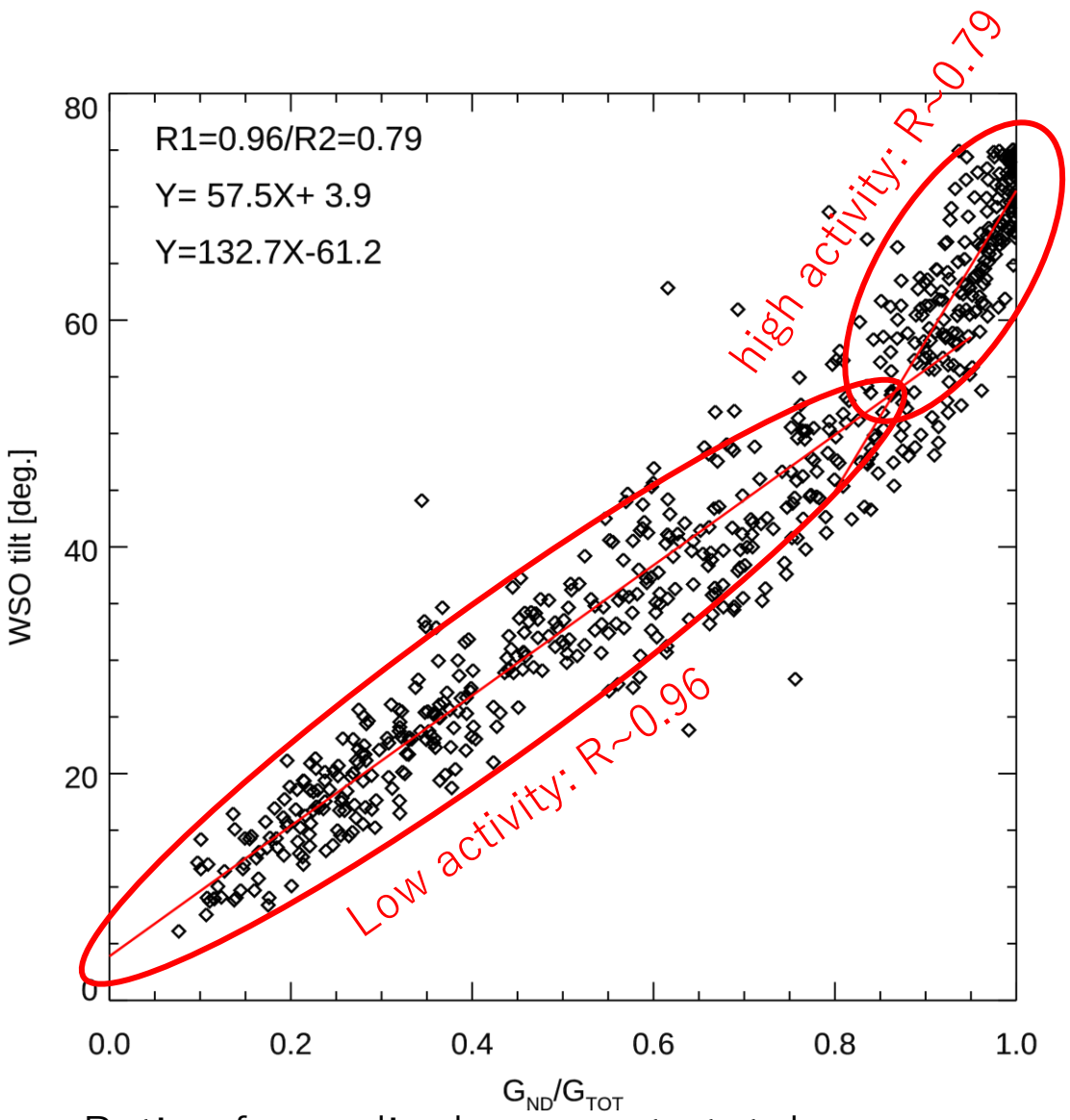


Tilt angle of Heliospheric Current Sheet (WSO)

●: V=600 km/s

- Mean velocity along HCS tile angle is about 600 km/s. → boundary of bimodal structure
- HCS tilt angle is a good proxy of the boundary latitude between high-speed and low-speed solar wind except during solar maxima when the latitudinal bimodal structure is lost.
- The bimodal boundary latitude: $\theta_B = 0.91\theta_T + 2.6$

HCS Tilt angle and Spherical Harmonics



Ratio of non-dipole power to total power

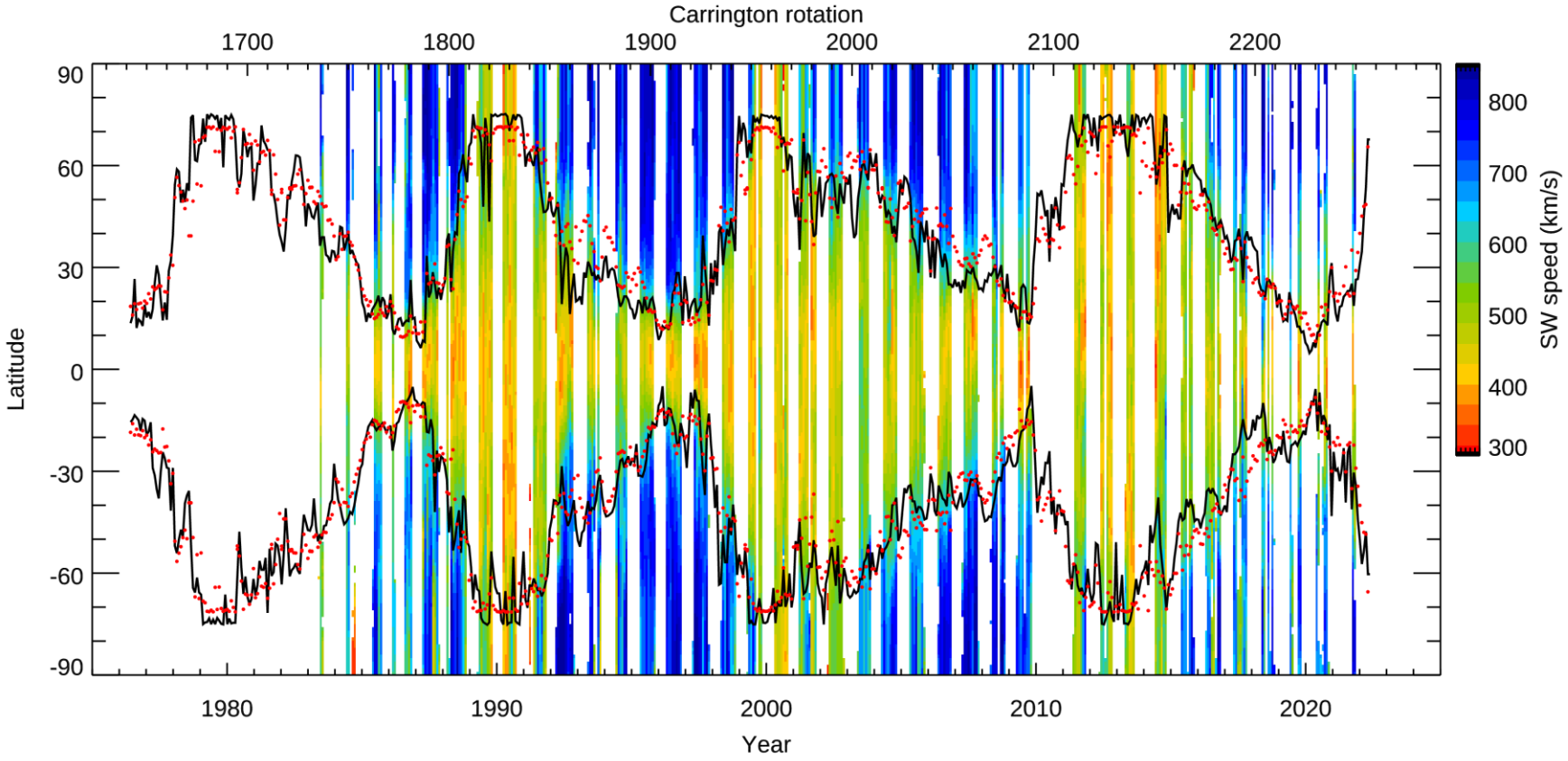
- Correlation Coefficient: 0.96/0.79
- Can be used for tilt angle estimation

$$G_l^2 = \sum_{m=0}^{l} \left(g_{lm}^2 + h_{lm}^2\right)$$

$$G_{total}^2 = \sum_{l=1}^{\mathbf{2}} G_l^2 \qquad \text{Total power}$$

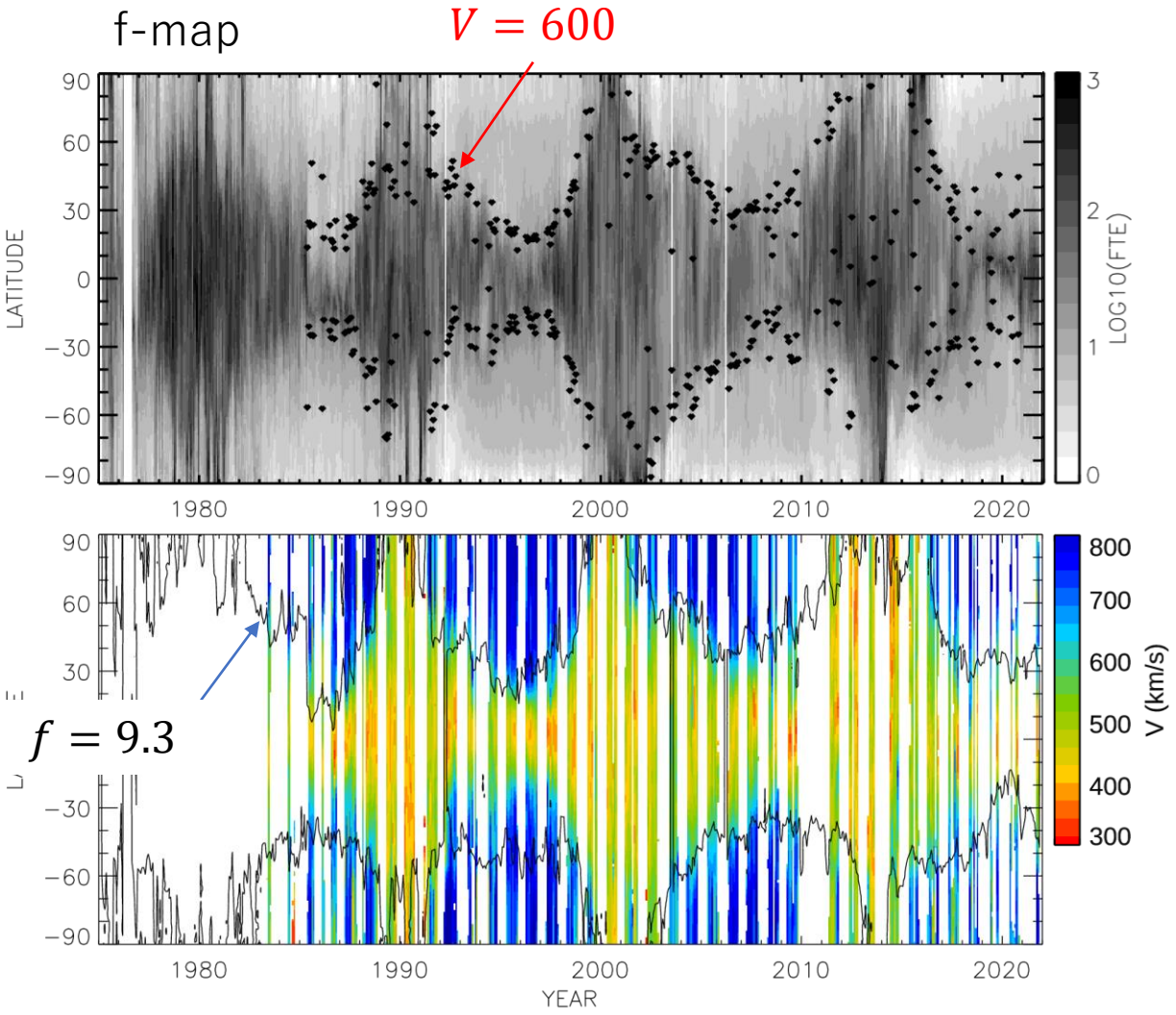
$$G_{ND}^2 = G_{total}^2 - g_{10}^2 \qquad \text{Non-dipole power}$$

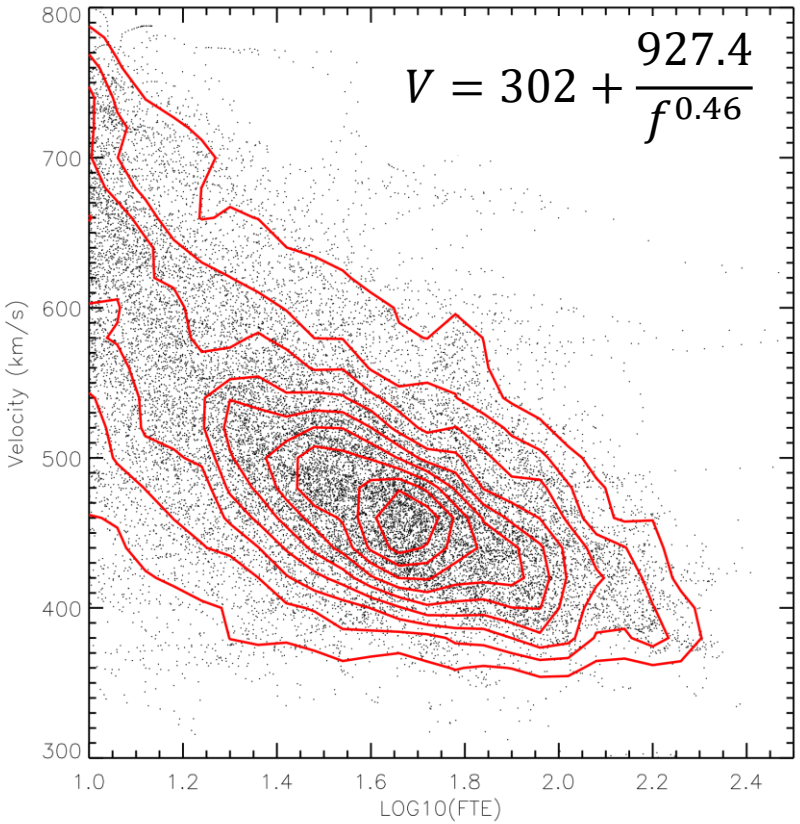
Tilt angle, Spherical Harmonics and Solar Wind



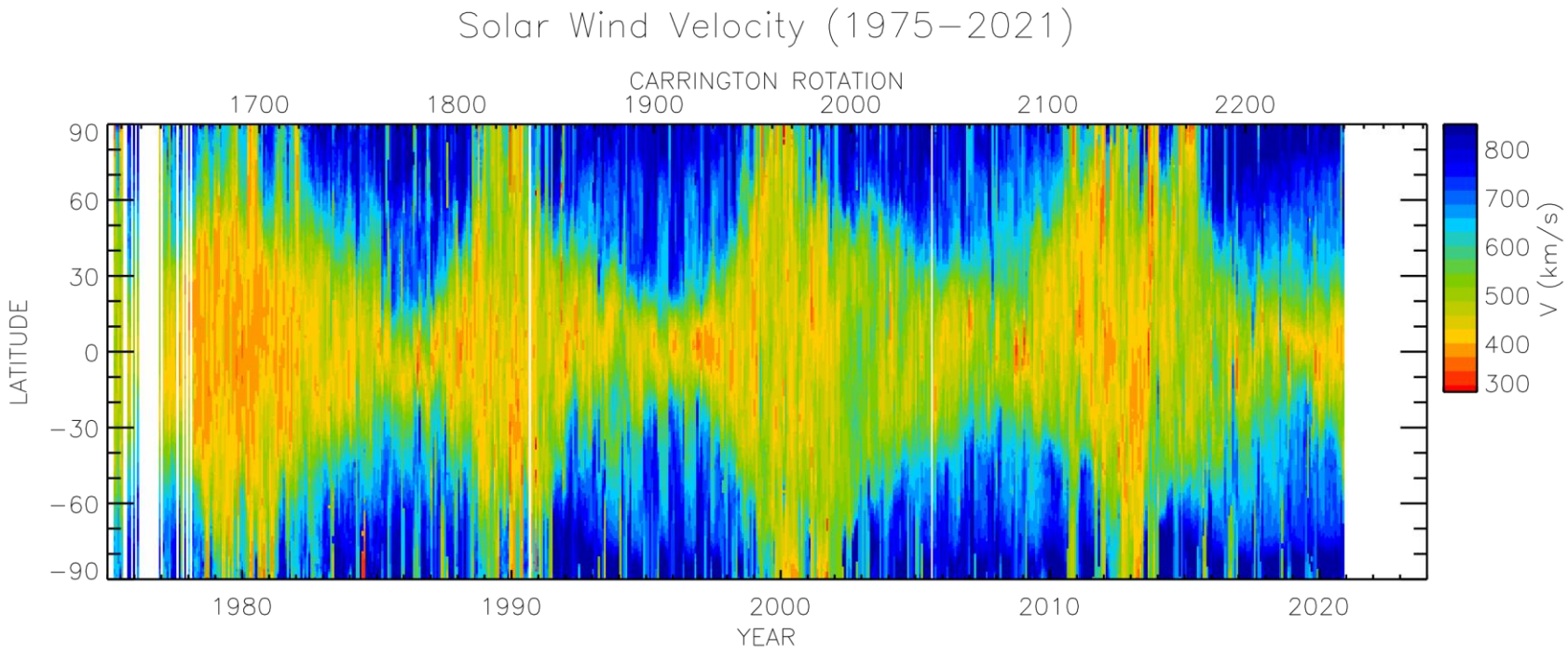
- Ratio of the powers of non-dipole to total of spherical hermonics up to 2nd order predicts solar wind bimodal boundary as well as HCS tilt angle.
- We can obtain the solar wind bimodal boundary latitudes by estimating the non-dipole contribution of the spherical harmonics to the total power.
- However, the velocity structure in low-speed wind should be obtained by another method.

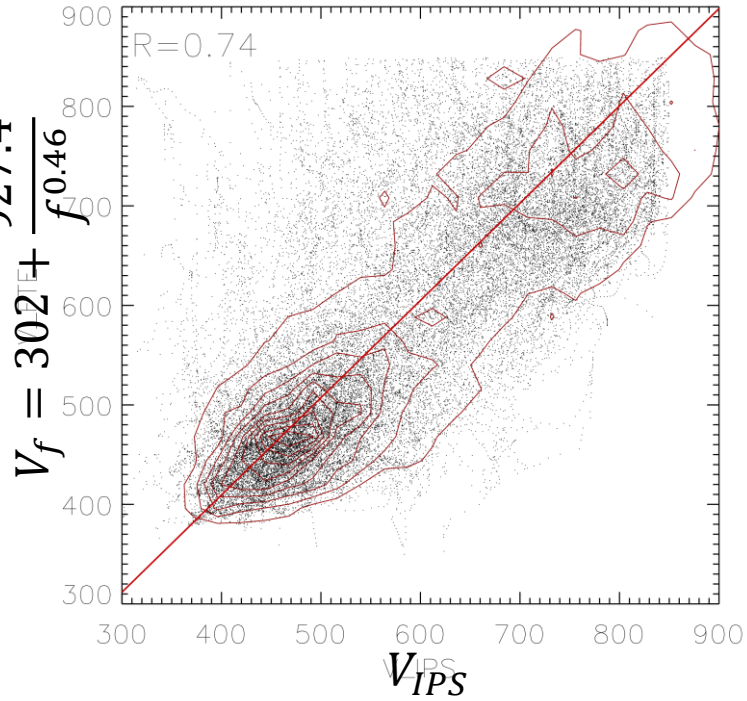
Latitudinal Structure of f and V





Reconstructed Solar Wind Structure





Correlation between V_{IPS} and $V_f = 302 + \frac{927.4}{f^{0.46}}$ is R~0.74.

Latitude structure derived from f shows less sharp boundary. → Need more improvements

Summary

- IPS observation tells us the long-term variation of the solar wind structure from 1985.
- Sources of the solar wind distribute on the magnetic butterfly, meridional flow, and both poles.
- HCS tilt angle and powers of spherical harmonics coefficients are good proxies of the bimodal boundary latitude.
- Flux expansion rate can be used for an estimation of velocity structure in the solar wind (R~0.74). However, the boundary of the bimodal solar wind seems to be less-sharp.