Consistent long-term variation in the hemispheric asymmetry of solar rotation

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Differential rotation and magnetism across the HR diagram
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Rotation of the solar surface

- Latitudinal differential rotation

$$\Omega = \Omega_0 - B\sin^2\varphi$$

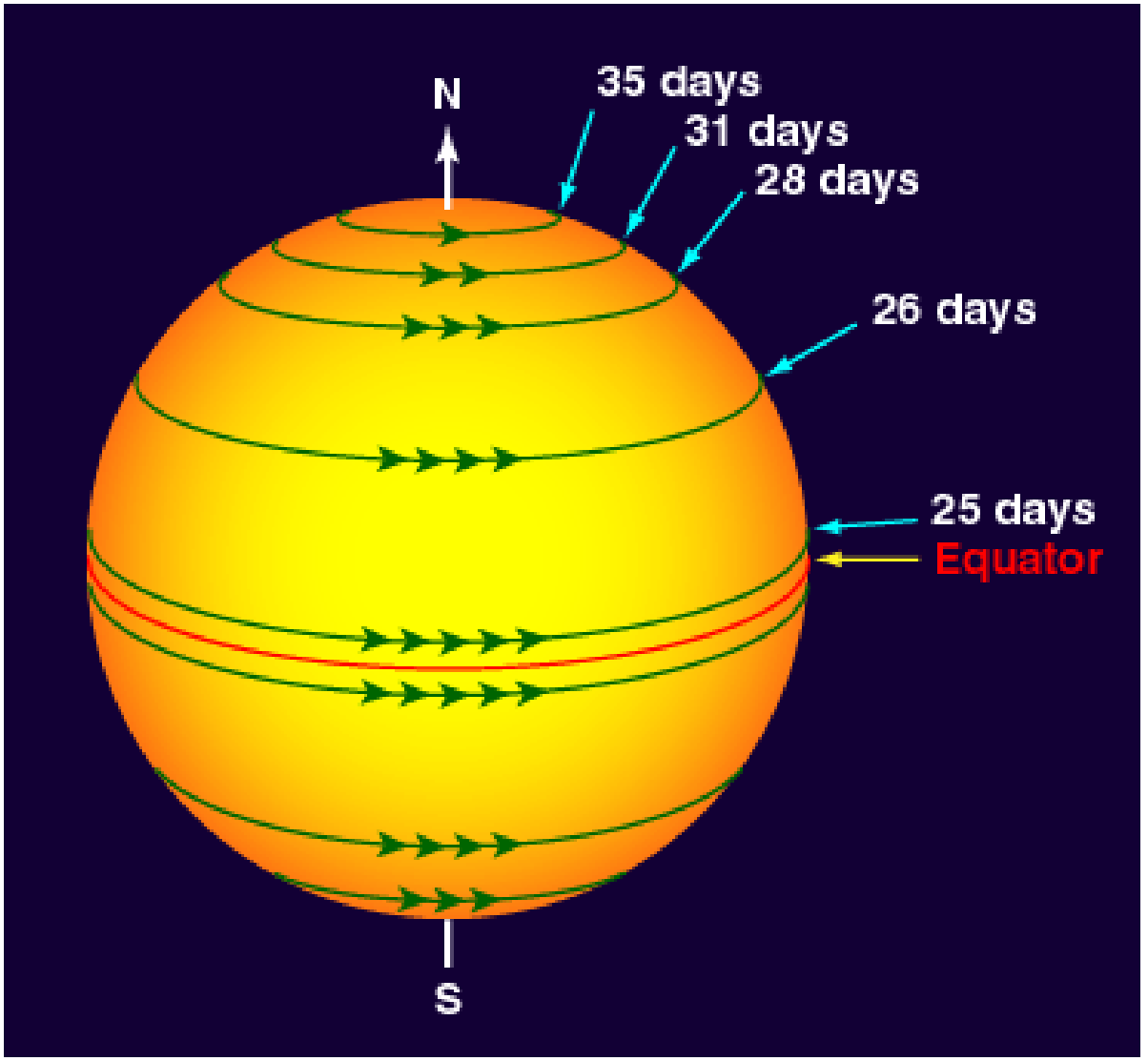
φ Latitude

Ω_0 Velocity of equator

$B = \Omega_0 - \Omega_{pole}$

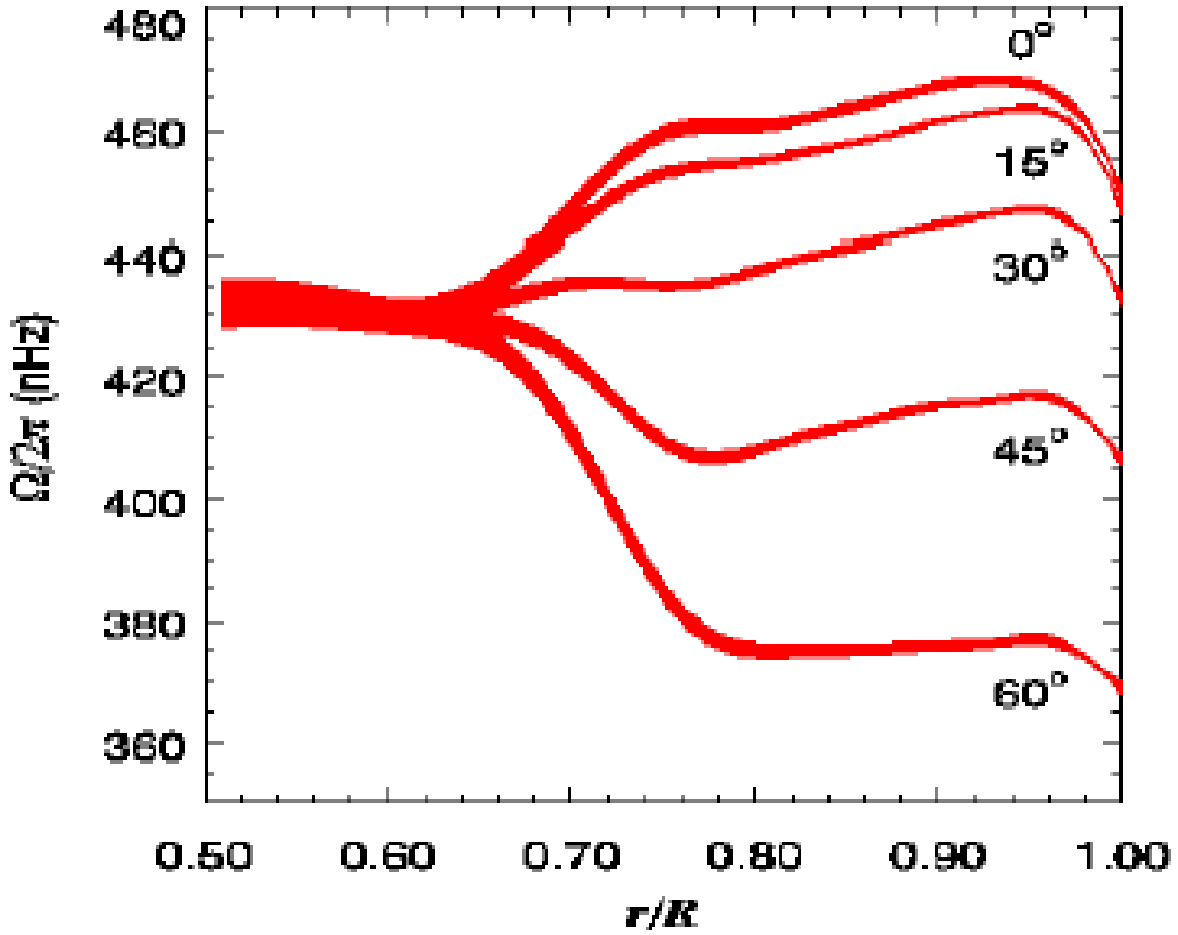
Rotational shear

Ω_0 and B vary with time

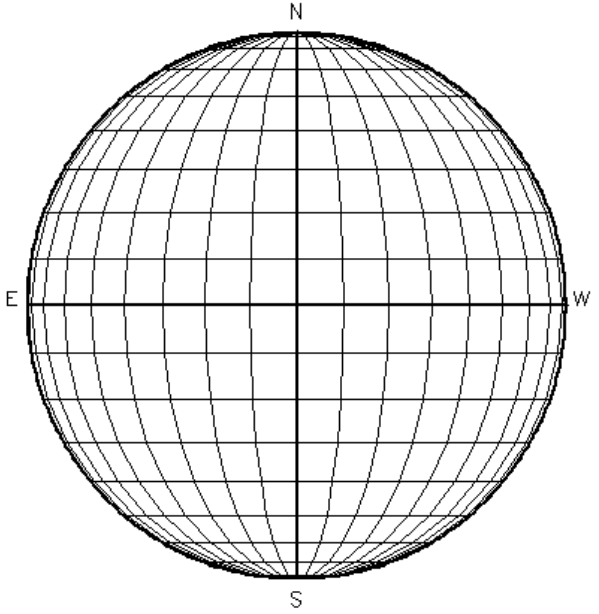


Internal rotation of the Sun

- Radial differential rotation

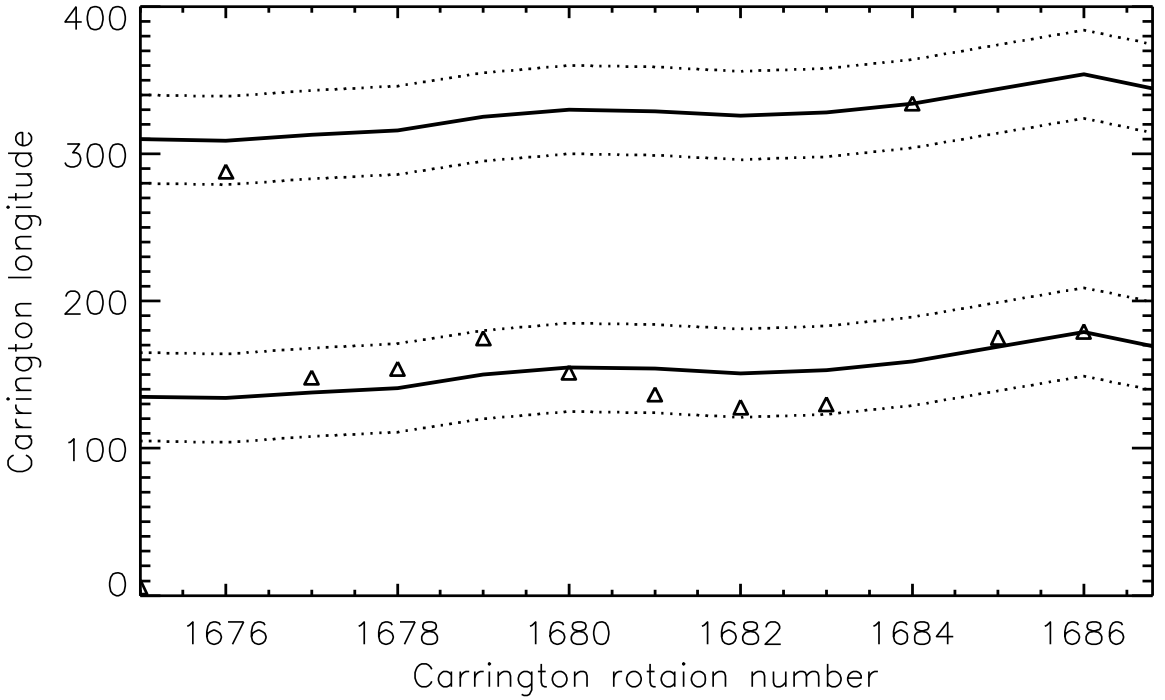


Active longitudes



Carrington longitude increases East 0 → West 360

Ω_c=14.18 deg/day



ALs of X class flares in 1979

Two permanent ALs, 180° apart, were found by many authors, e.g., Usoskin, et al , 2005, A&A, 441, 347; Zhang, et al 2007, A&A, 471, 711

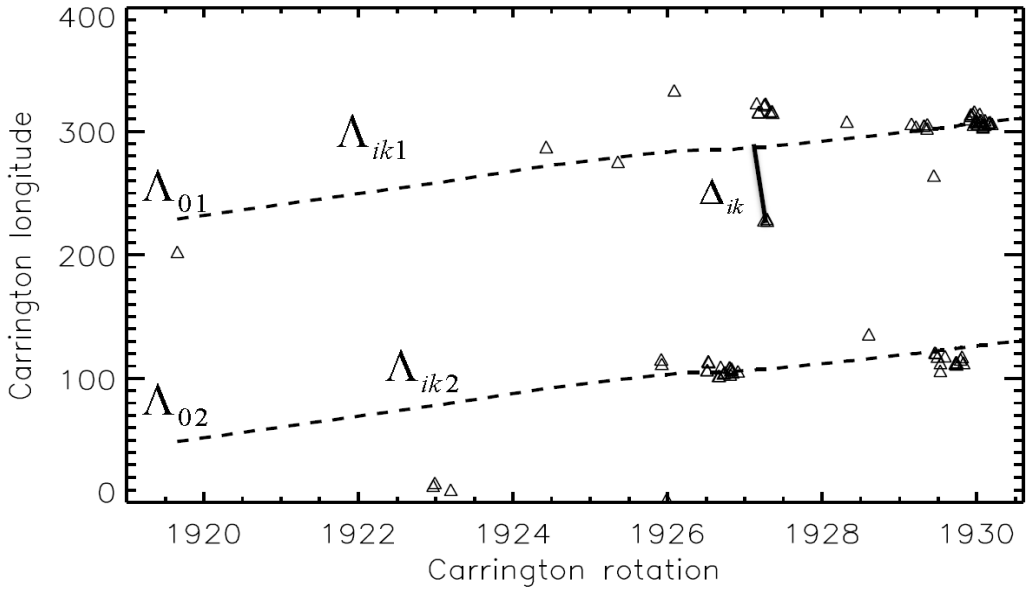
ALs migrate significantly in the Carrington reference frame when the rotation of the Sun deviates much from Ω_c.

Analysis Method

- Least-square fitting method

Assuming one AL in the beginning at Carrington longitude Λ_{01}, its rotation rate follows the differential rotation. It will move to Λ_{ik1} on the *k*th day of the *i*th rotation.
The other AL migrates to

$$\Lambda_{ik2} = \Lambda_{ik1} \pm 180^{\circ}$$



$$\Omega_{\varphi} = \Omega_0 - B\sin^2\varphi$$

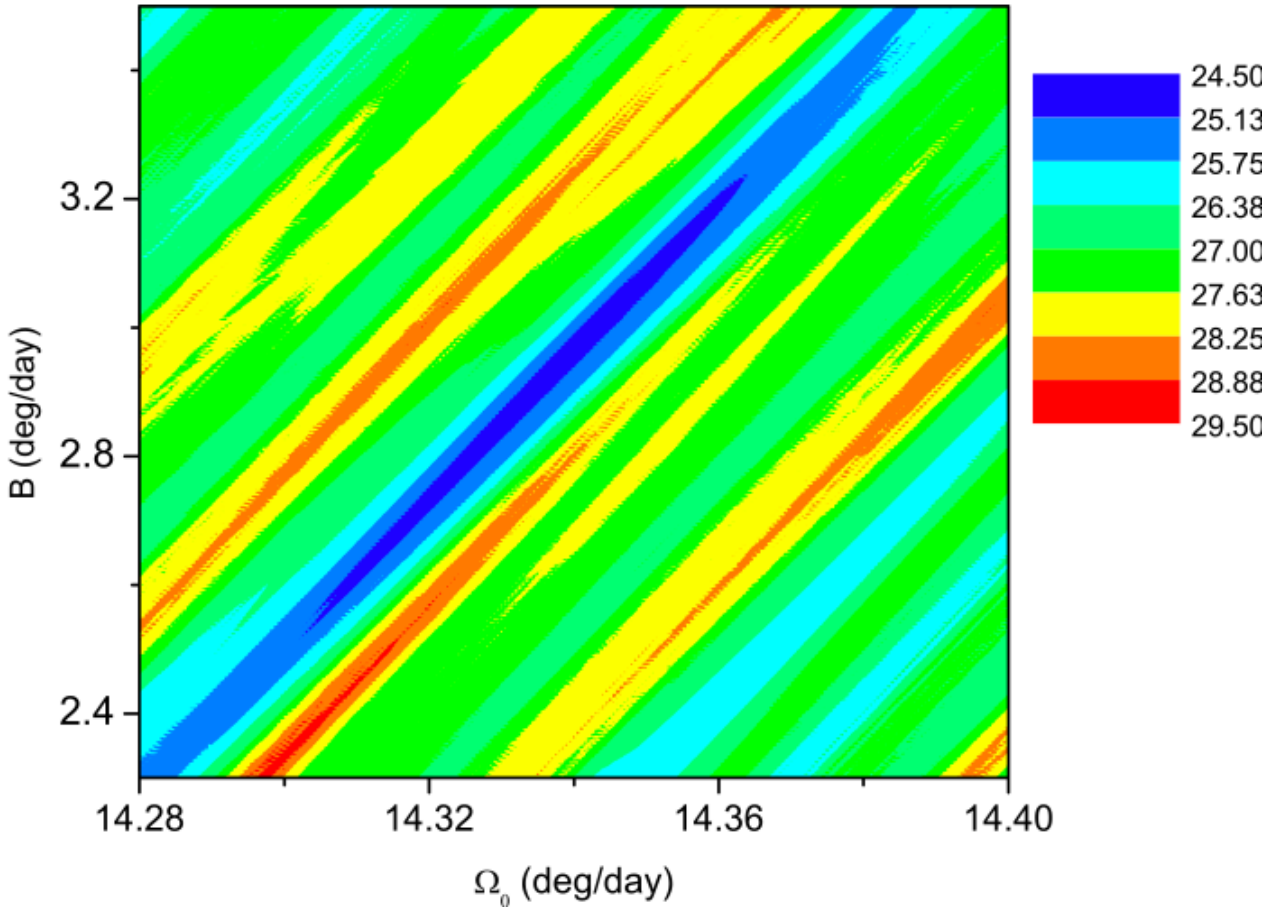
$$\varepsilon(\Lambda_{01}, A, B) = \frac{1}{n}\sum_i\sum_k \Delta_{ik}^2$$ merit function

Search for the optimal values of the parameters

	step
Λ_{01} [0,360] (deg)	1
Ω_0 [13.5, 15.0] (deg/day)	0.001
B [0.0, 5.0] (deg/day)	0.001

Search for optimum values

The best fit values are found at the center of an elongated area of small values of ε, and their errors are given by the horizontal and vertical extent of this area, respectively.

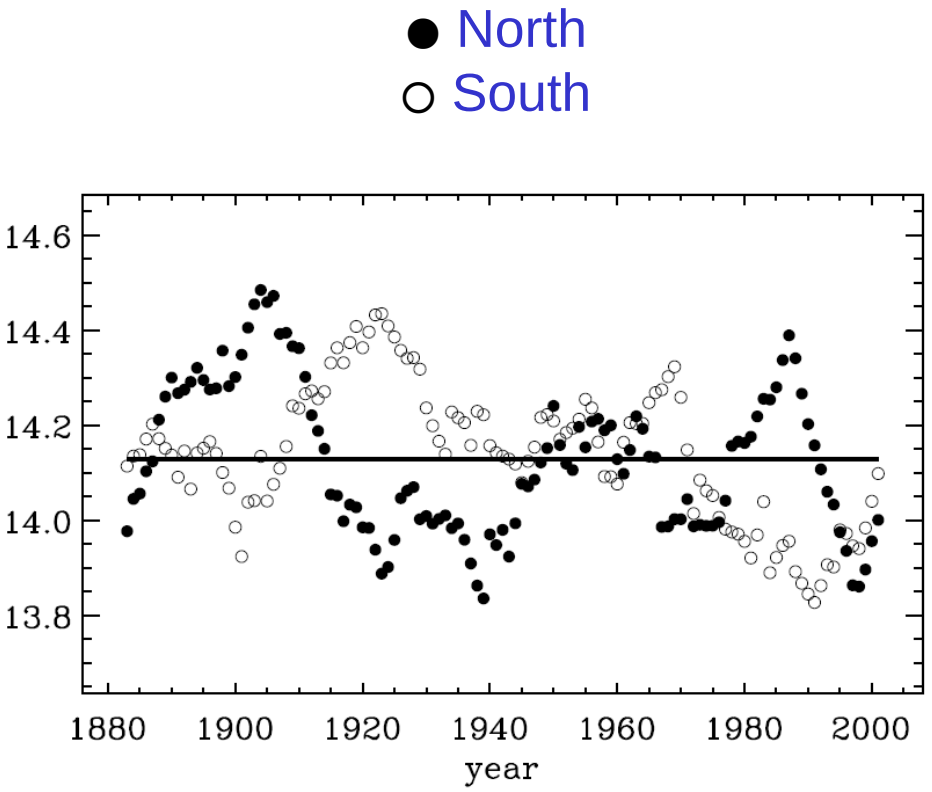


Rotation of sunspot groups

The rotation of sunspot groups in the northern and southern hemispheres at the reference latitude 17° .

The rotation rates vary around the mean by up to (3-4)%.

The two hemispheres show an anti-correlation and both have an 80-90-year quasi-periodicity.



Using 3yr running and 1yr step forward fit interval

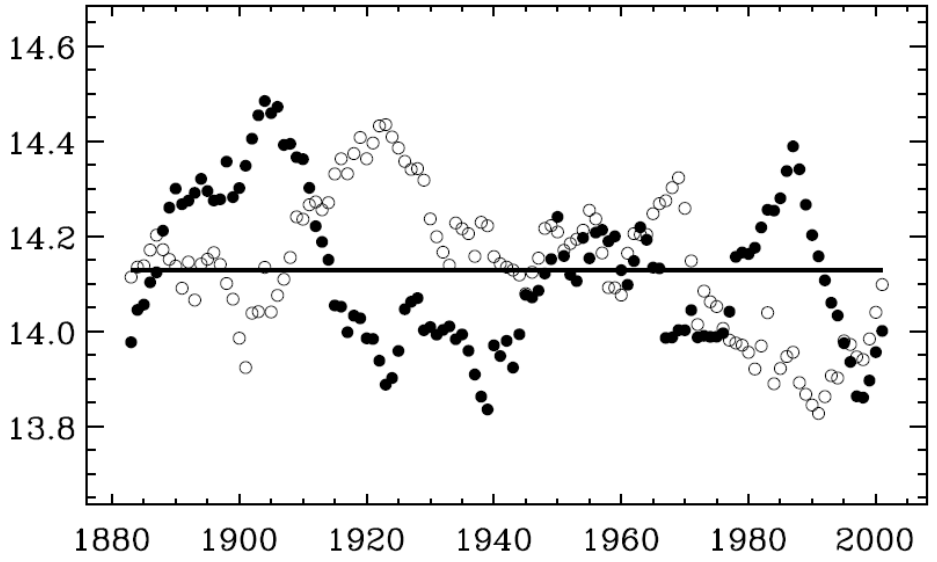
(Zhang et al. A&A 552, A84)

N-S asymmetry in the rotation of sunspot groups

North-south (N-S) asymmetry:

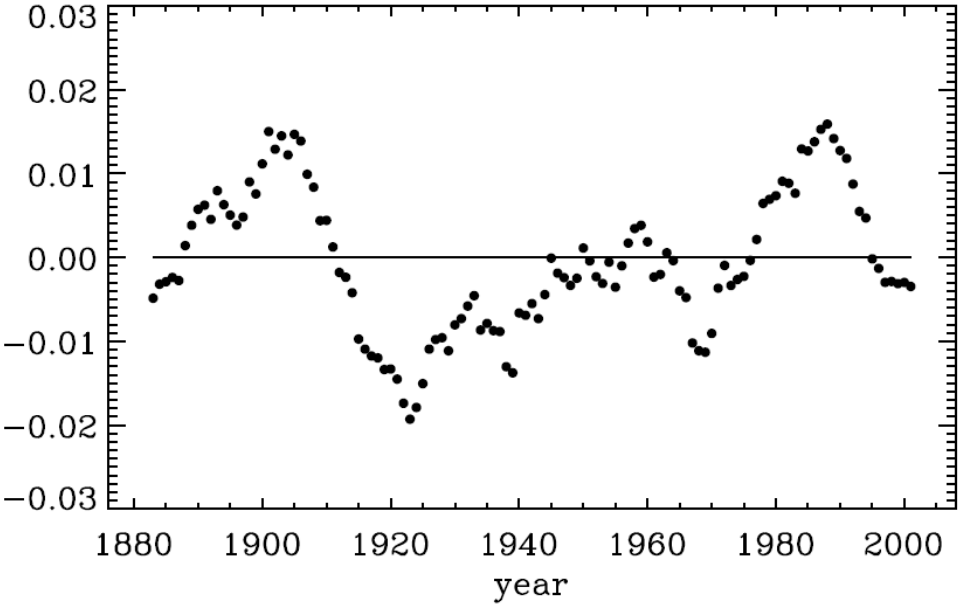
$(N - S)/(N + S)$

Rotation
● North
○ South



The N-S asymmetry also shows a 80-90-year periodicity.

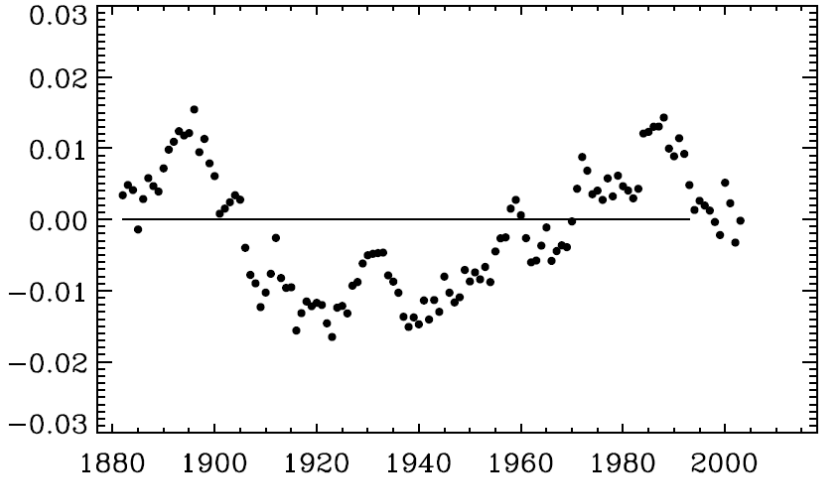
N-S asymmetry of solar rotation (deg/day)



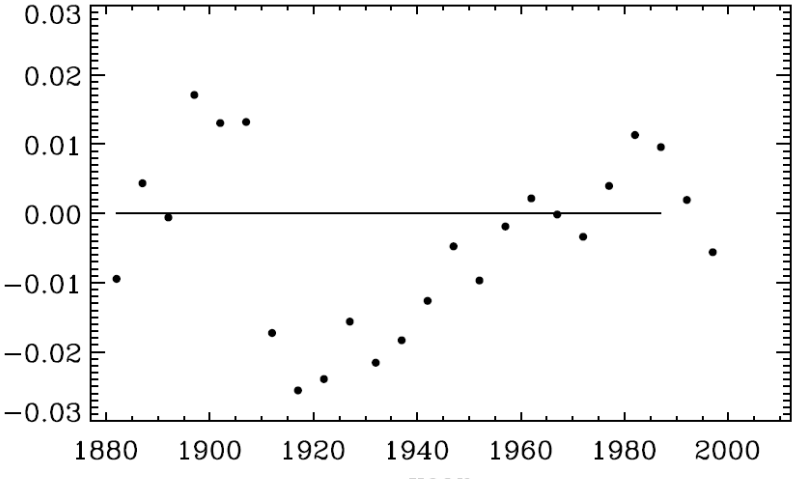
(Zhang et al. A&A 552, A84)

N-S asymmetry of rotation using 4 more fit intervals

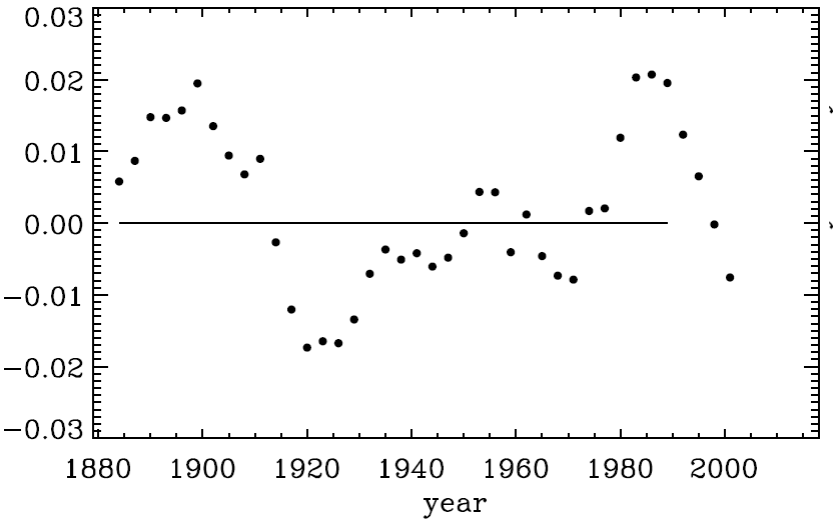
1yr



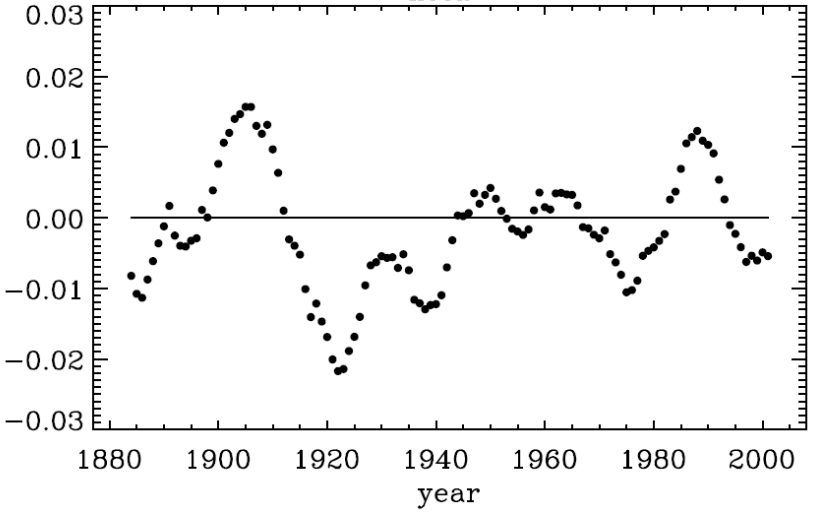
5yr



3yr



5yr running



(Zhang et al. A&A 552, A84)

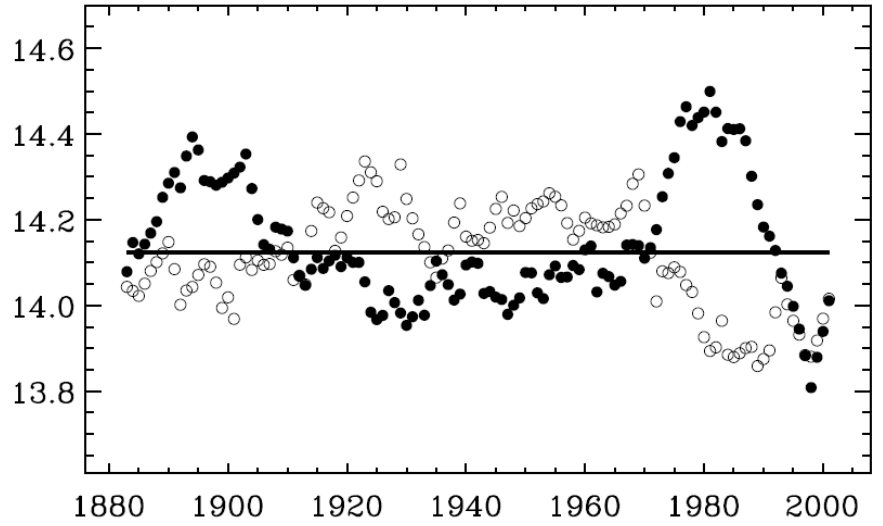
Results from using weighting method

Using sunspot area as weight in the merit function when searching for best fit parameters.

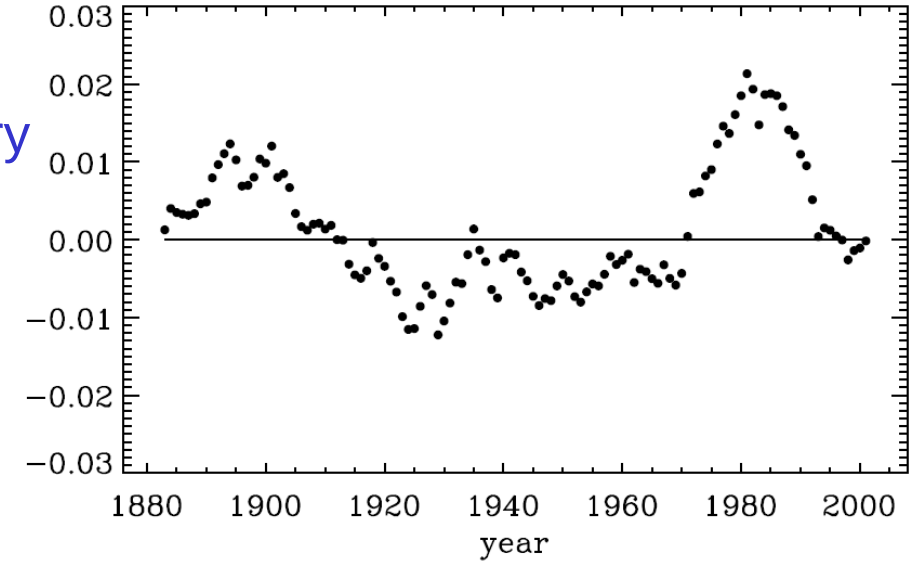
$$\varepsilon(\Lambda_{01}, A, B) = \frac{1}{n}\sum_i \sum_k W_{ik}\Delta_{ik}^2$$

The weighting method also leads to an anti-correlation between the two hemispheres.

Rotation
● North
○ South



N-S asymmetry of rotation (deg/day)

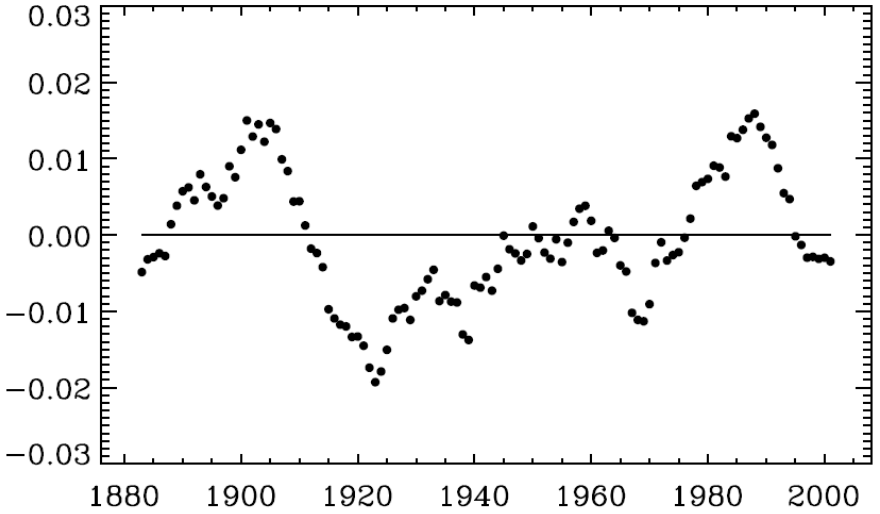


(Zhang et al. A&A 552, A84)

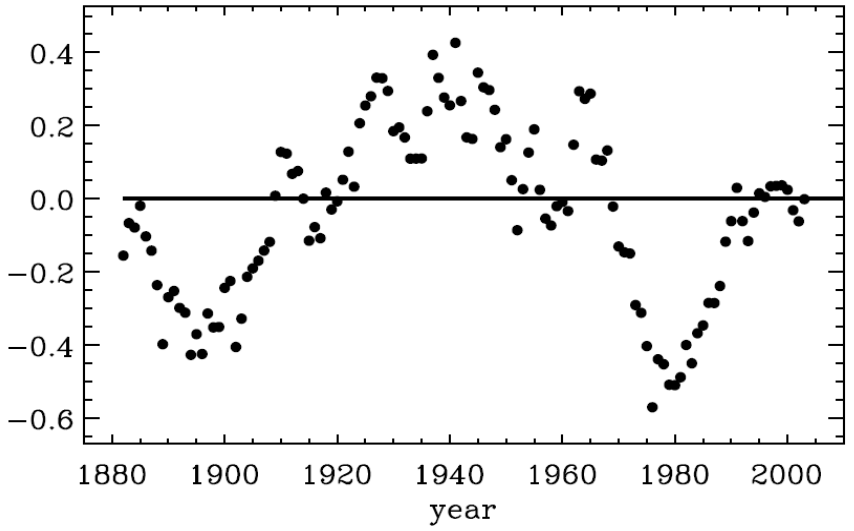
Relationship of N-S asymmetry of rotation and sunspot area

the N-S asymmetry of large sunspots shows a clear anti-correlation with the N-S asymmetry of solar surface rotation.
Large sunspots rotate more slowly than small sunspots.

N-S asymmetry of rotation (deg/day)



N-S asymmetry of sunspot area above 2000 μhem



(Zhang et al. A&A 552, A84)

Conclusions

All the results give strong evidence for the anti-correlation of the rotation of the two solar hemispheres.

The found long term oscillation of solar rotation suggests that a systematic interchange of angular momentum takes place between the two hemispheres at the period of about 80-90 years.