Sunspot group tilt angles and the strength of solar cycles

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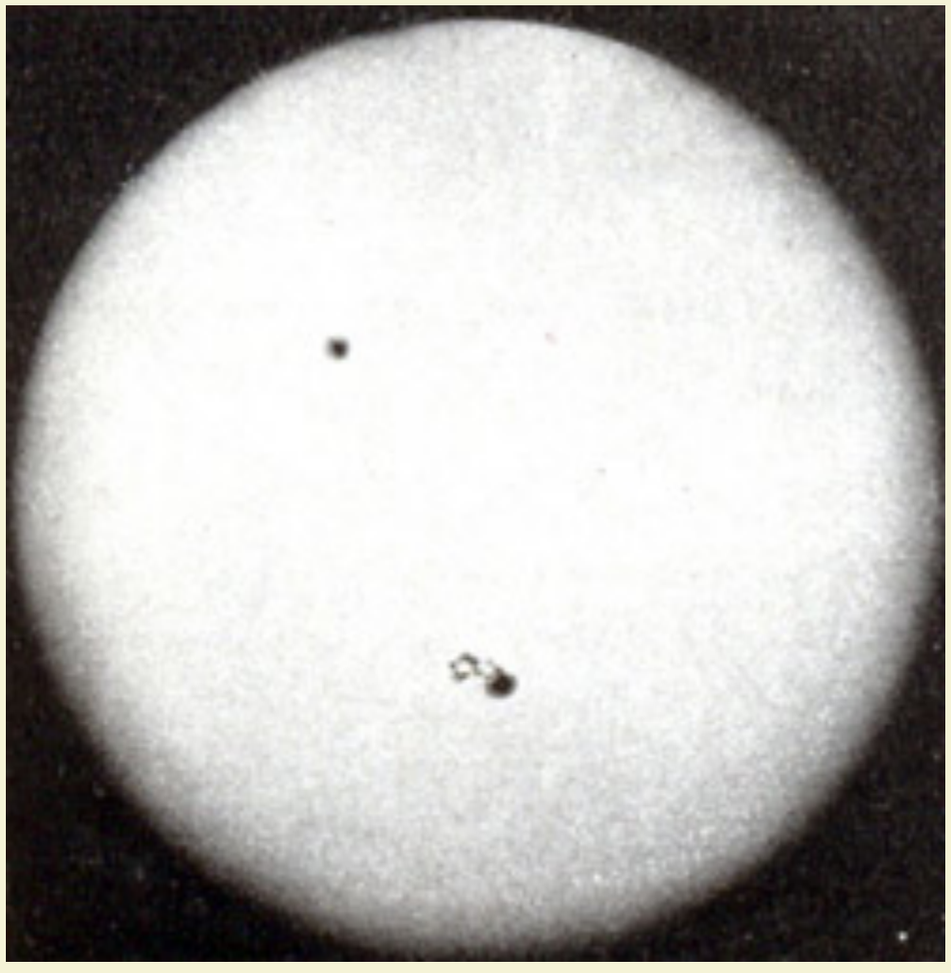
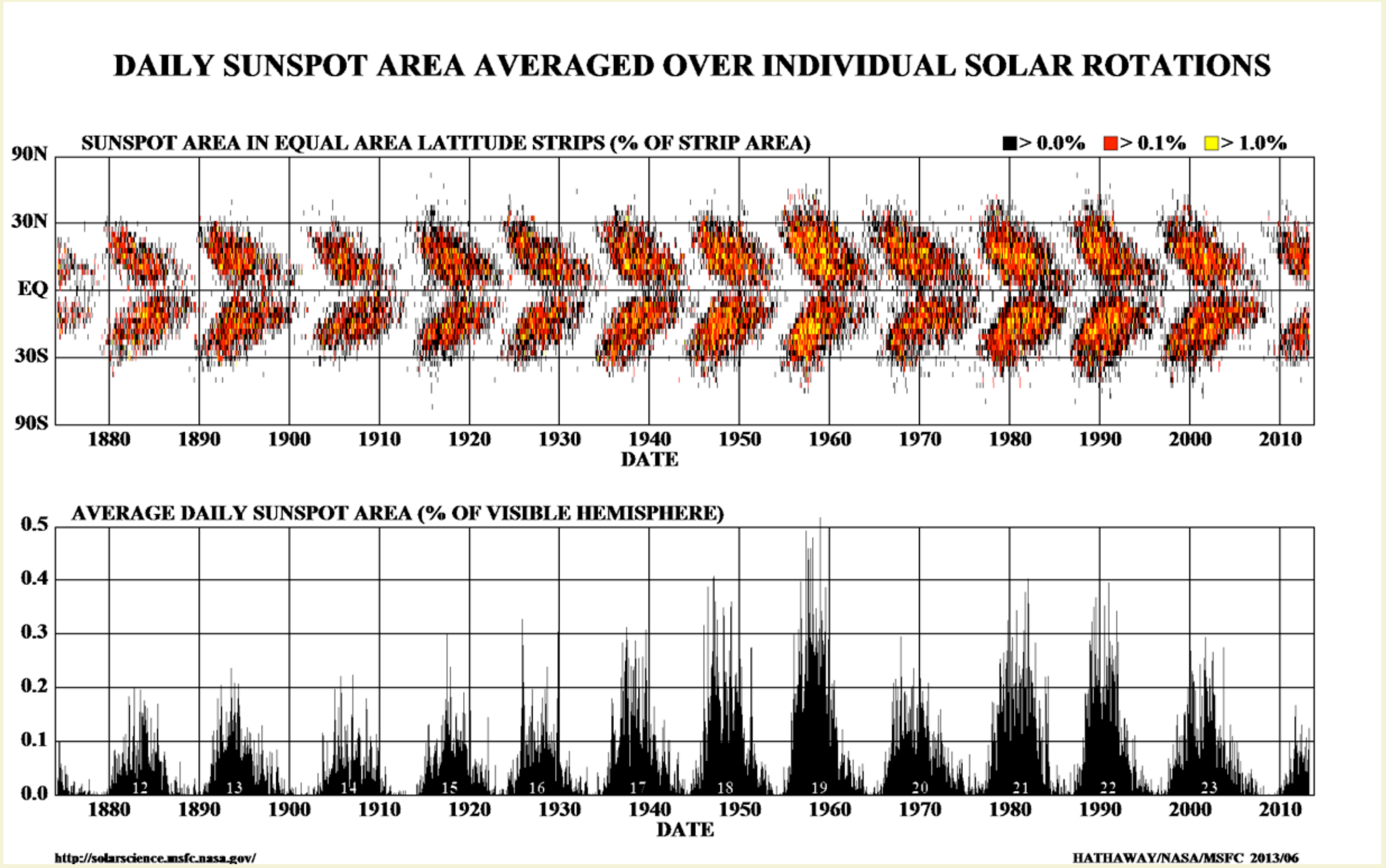
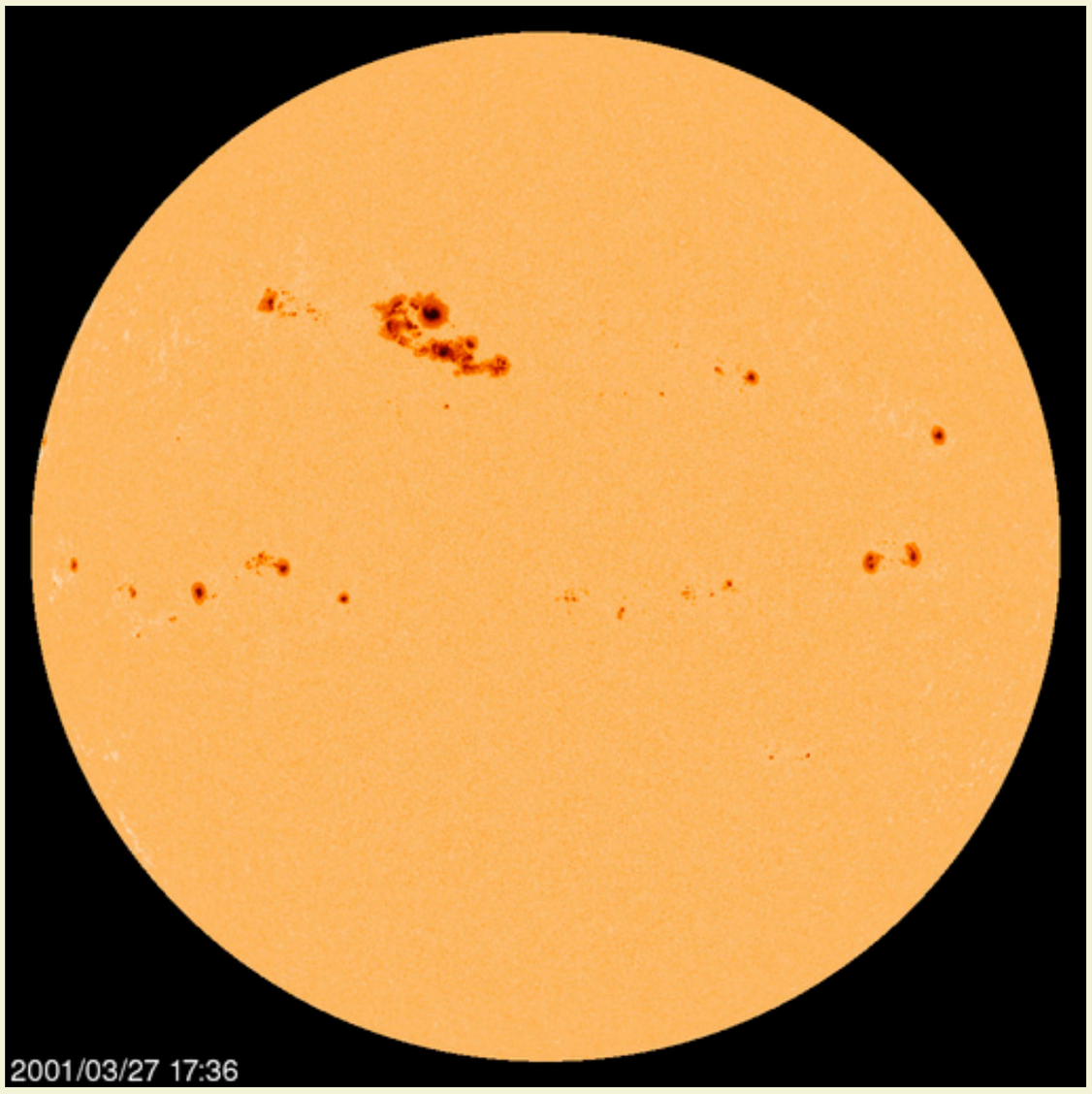


White-light full disc image of the Sun taken on July 30, 1906 at Mount Wilson Observatory

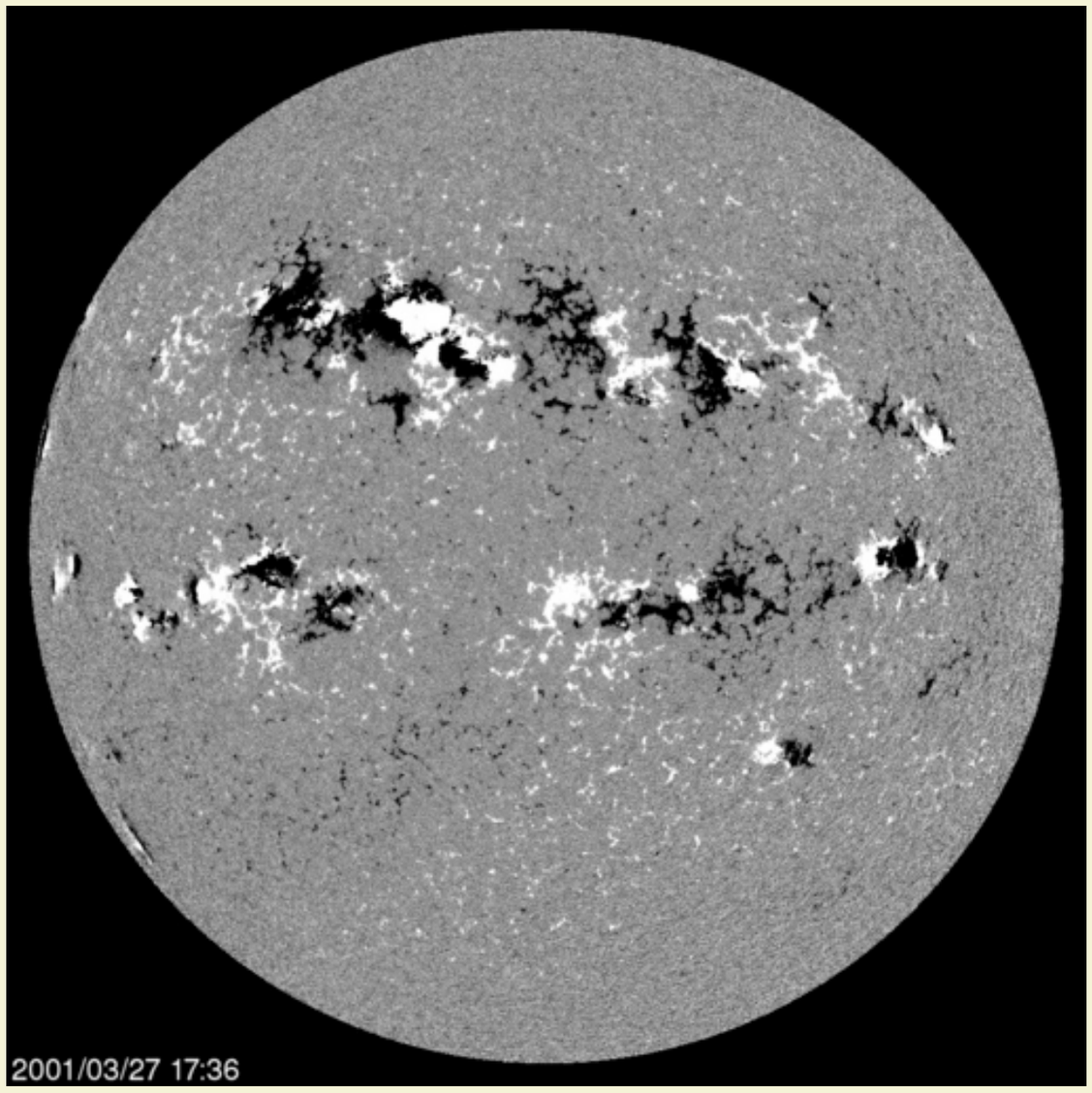
The sunspot cycle



Tilt angle of bipolar regions

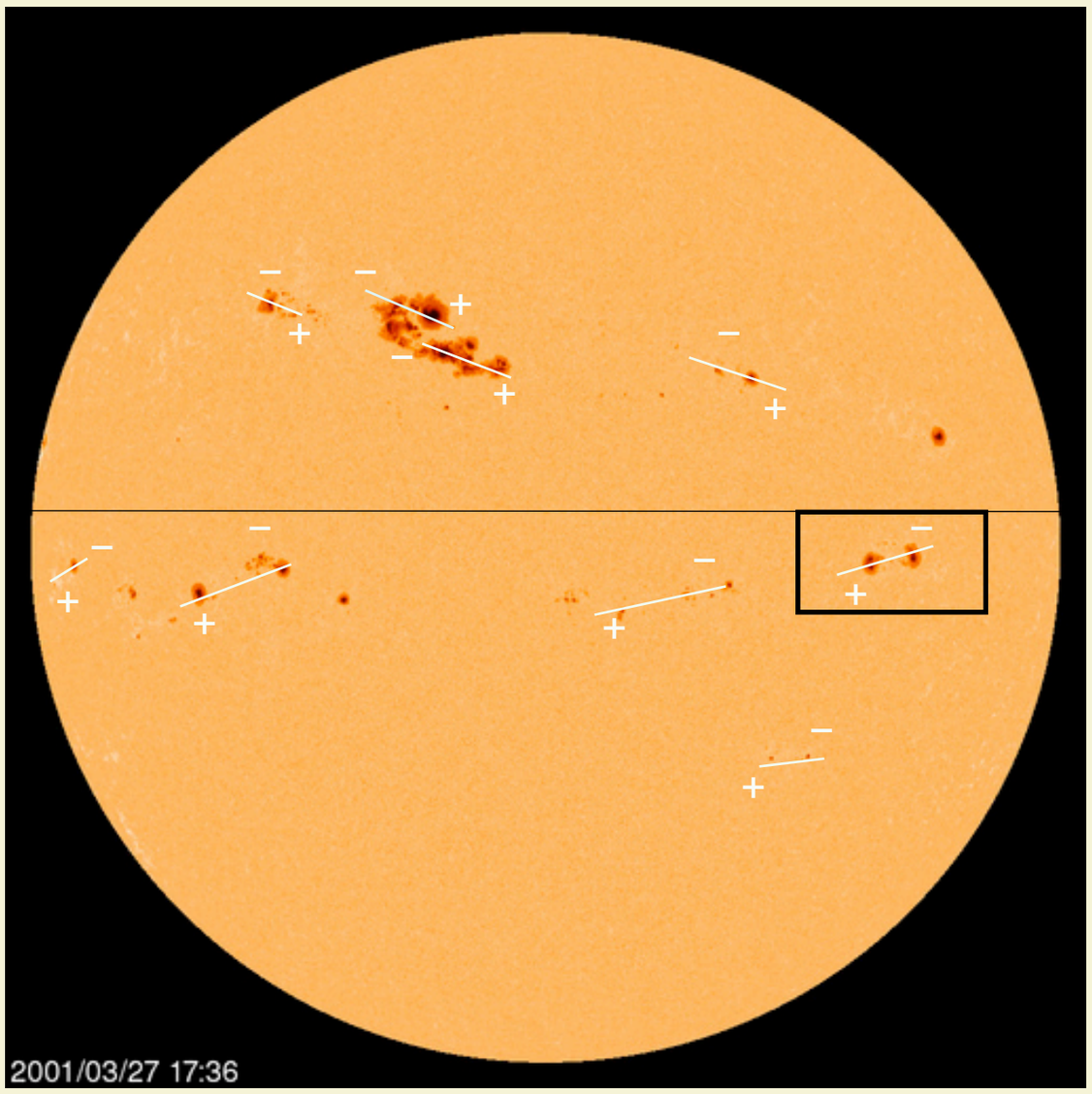


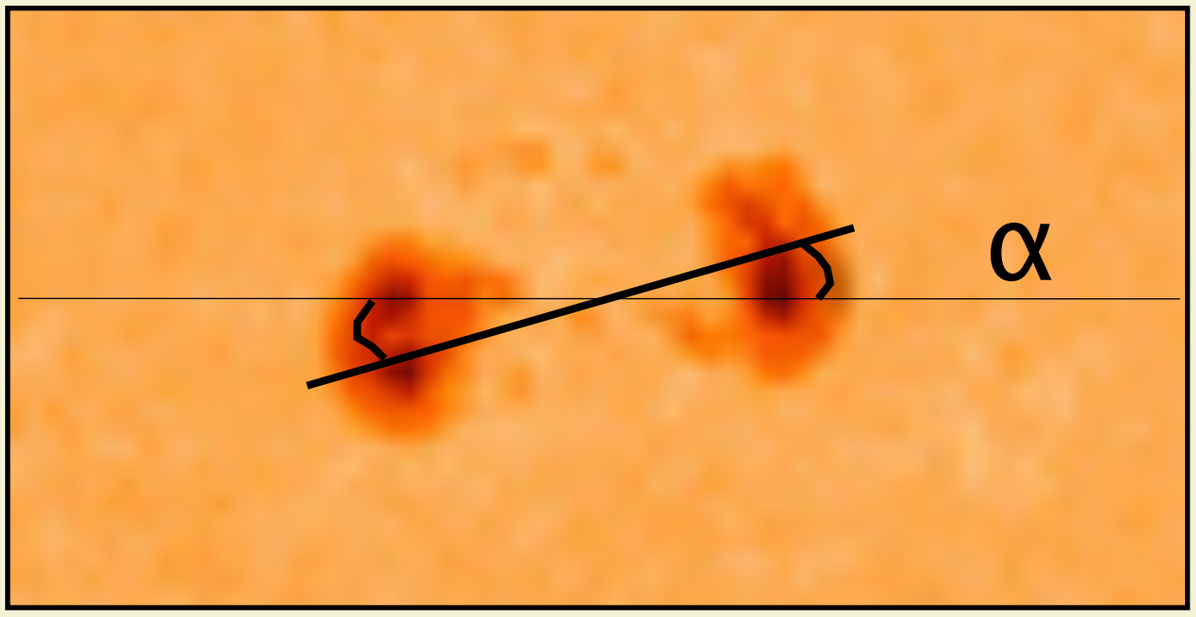
MDI continuum



MDI magnetogram

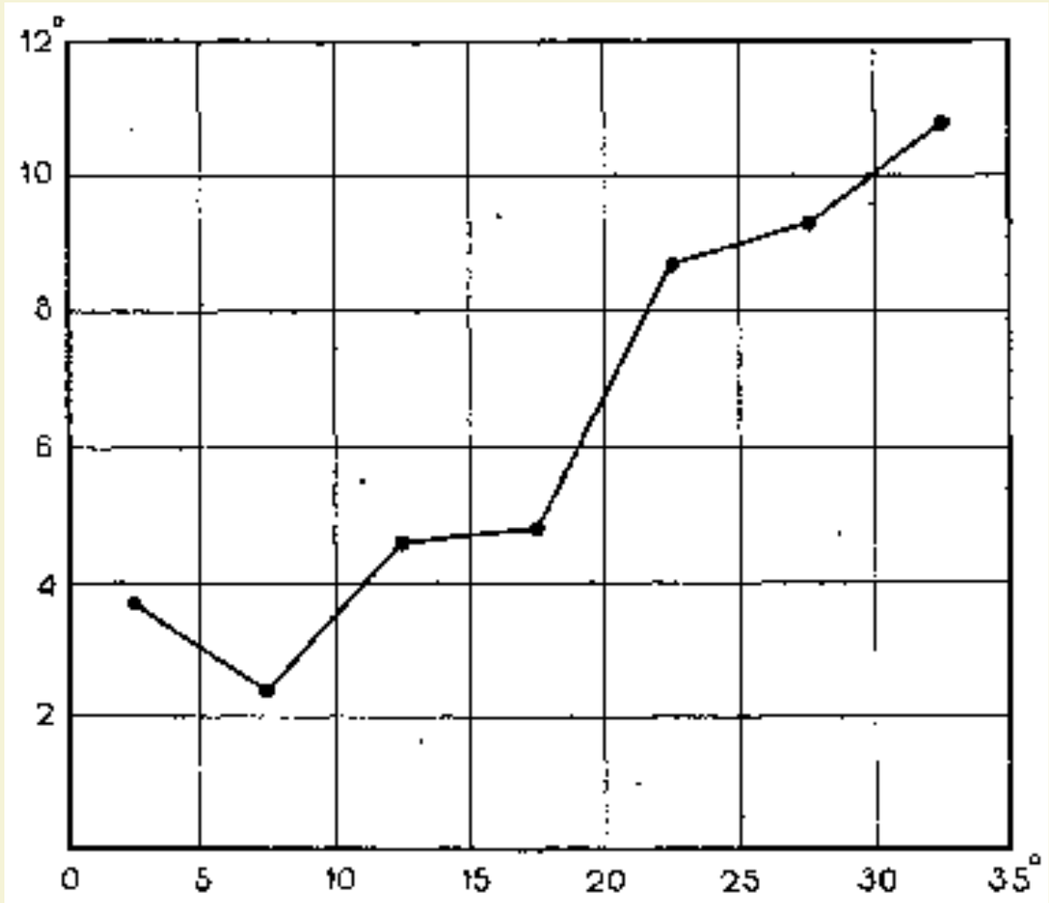
Tilt angle of bipolar regions





Joy's law

α (deg)



λ (deg)

FIG. 5.—Summary of a statistical study of the sun-spot drawings of Carrington and Spörer showing the variation with latitude (abscissae) in the preferential inclination (ordinates) of the axis of bipolar sun-spot groups. In low latitudes the axes are nearly parallel to the sun's equator, but with increasing latitude the mean inclination increases to a maximum of about 11°.

Hale et al. (1919)

Babcock-Leighton dynamo

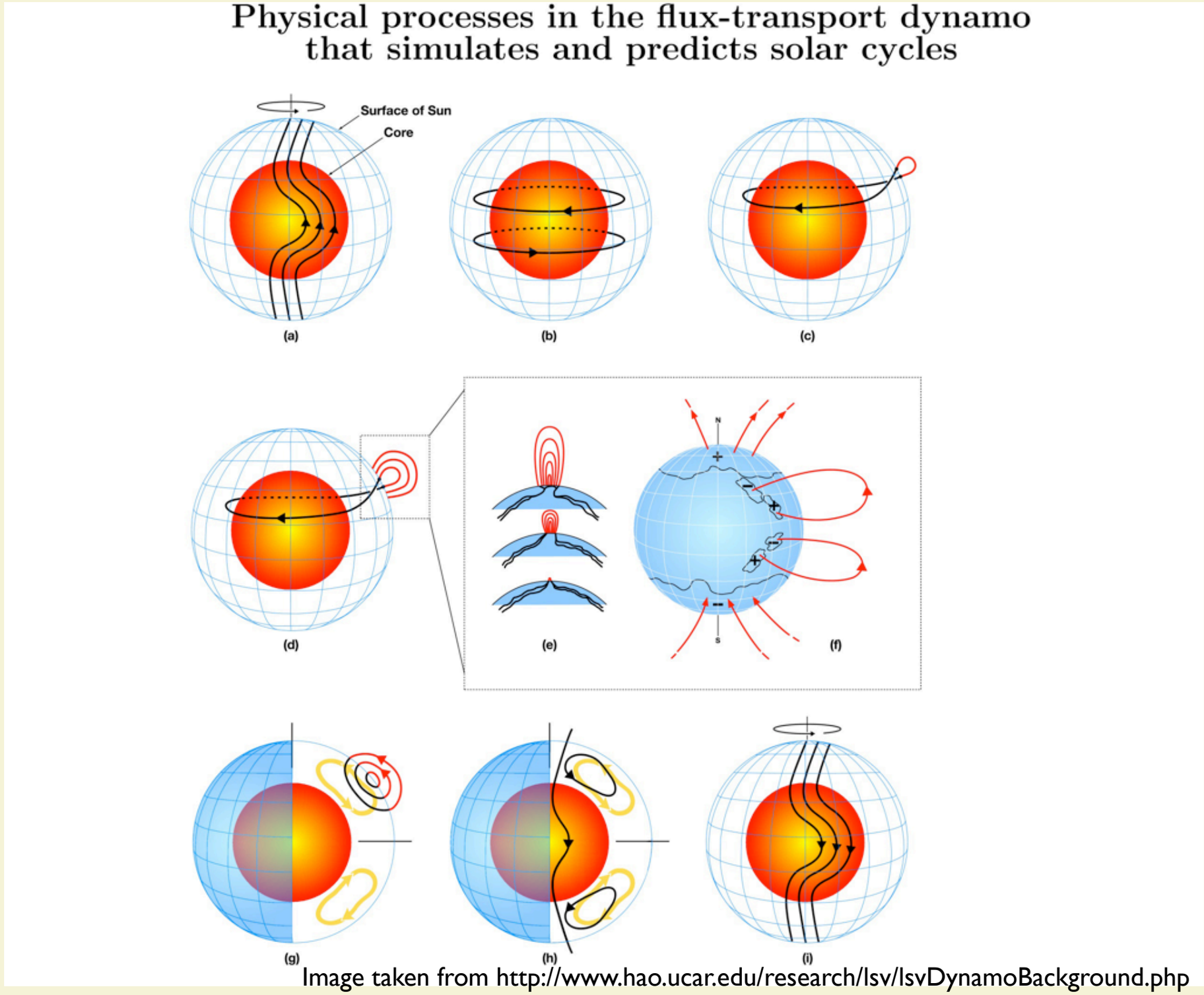


Image taken from http://www.hao.ucar.edu/research/lsv/lsvDynamoBackground.php

Tilt angle data

Digitised white-light images from two observatories:

- Kodaikanal Observatory: 1906 — 1987

(Sivaraman et al. 1993)

- Mount Wilson Observatory: 1917 — 1985

(Howard et al. 1984, Howard 1991)

7 solar cycles

Data available from: ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_REGIONS

Tilt angle data

- Individual spots:

- Positions and areas are measured

- Group identification method (Howard et al. 1984):

- Box 3x5 deg^2 centered at each individual spot.

- Every spot within the box is considered to be part of the same group.

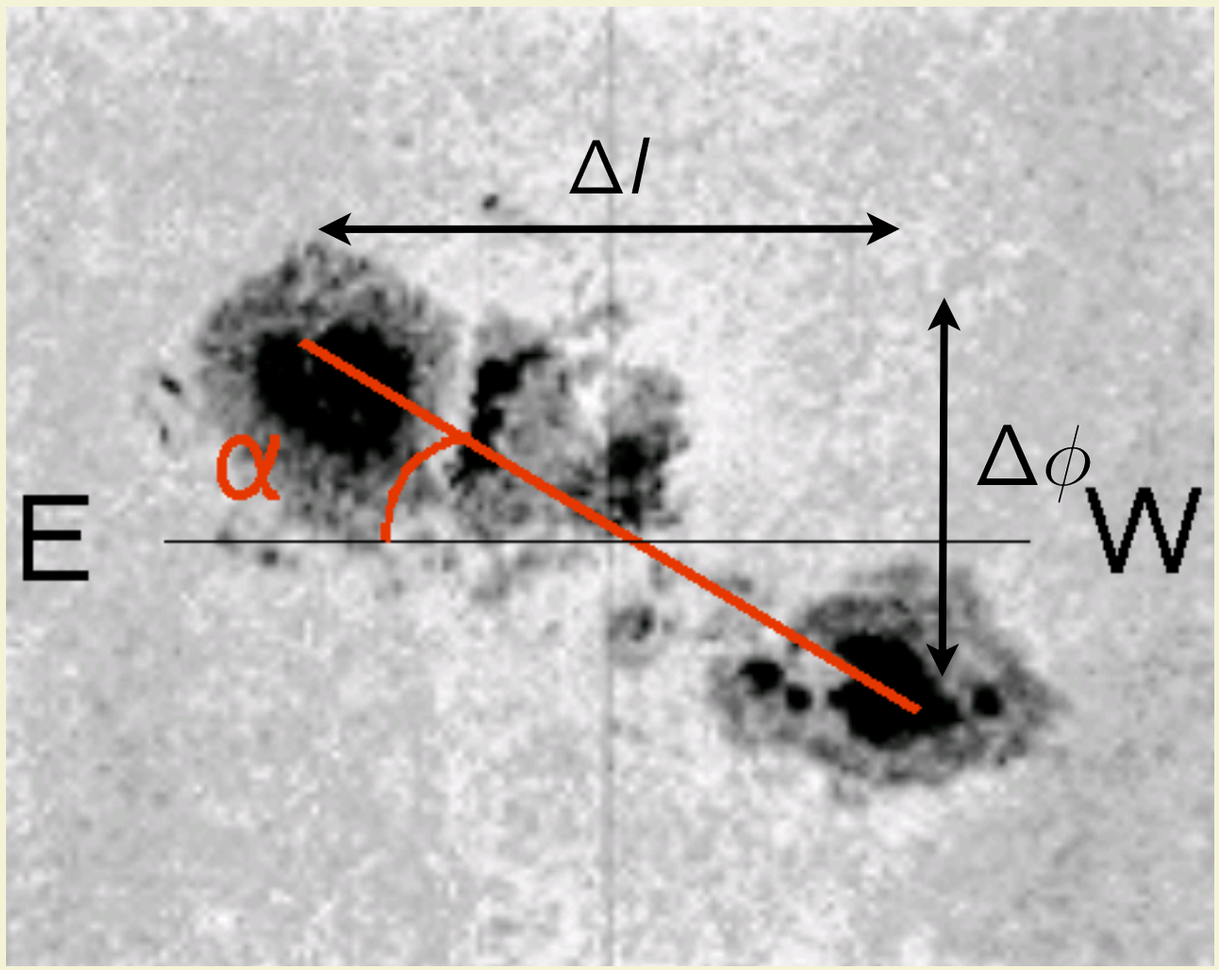
* No polarity information!

Data available at: ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_REGIONS

Tilt angle data

Tilt angle measurements

(Howard et al. 1984, Sivaraman et al. 1993)



$$tan\alpha = \frac{\Delta\phi}{\Delta l \cos\phi}$$

ϕ : latitude

l : longitude

Data available from: ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_REGIONS

Cycle-to-cycle analysis

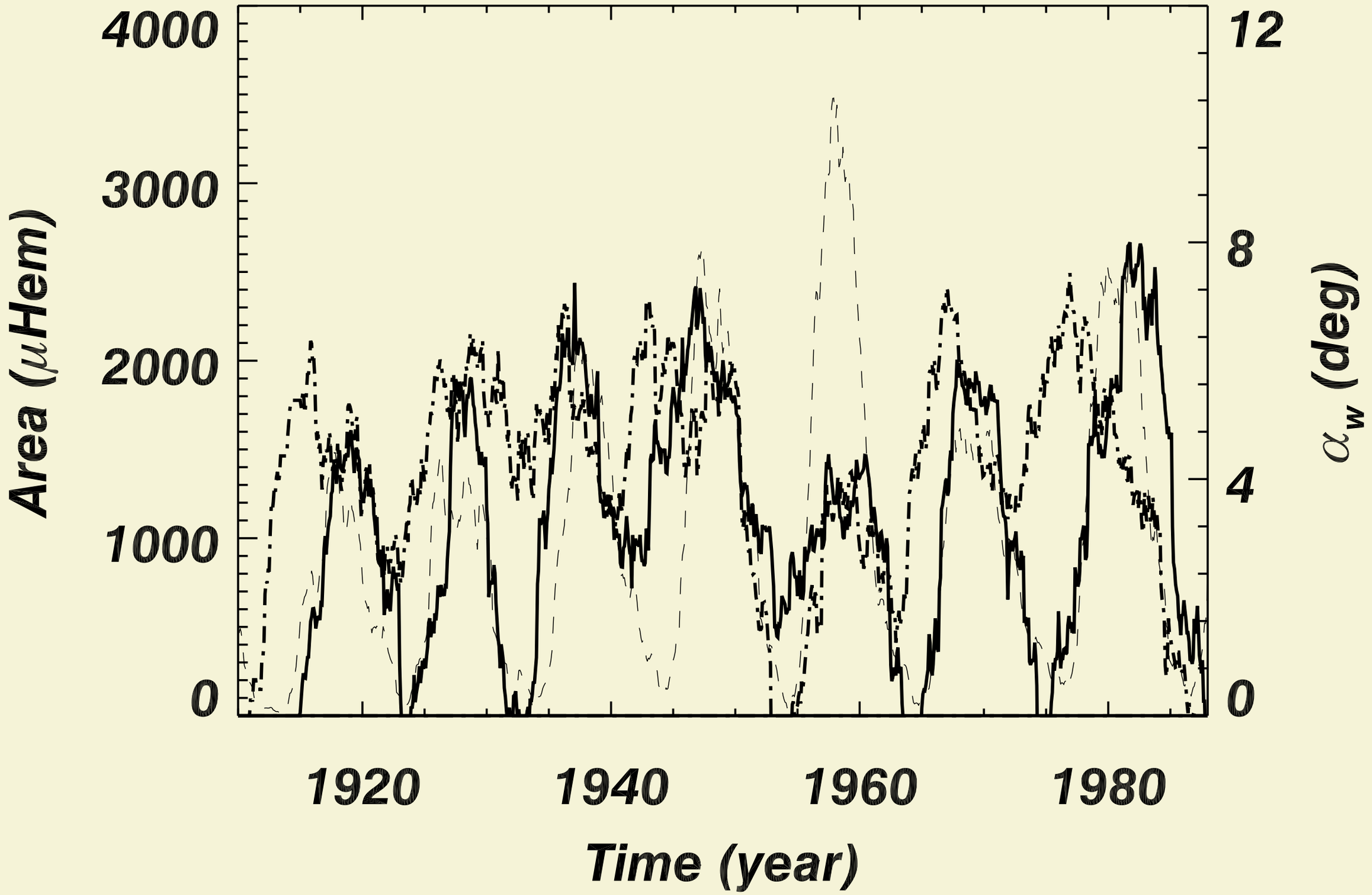
- Pre-selection of the *tilt angle* data:
  - distance between polarities < 16 deg
  - number of spots in leading or following > 0
  - position of portions are not all 0 deg

- α_w : *area-weighted mean tilt*

- α_w/λ_w : *area-weighted mean tilt normalised by mean latitud*e, measure of Joy's law (Hale et al. 1919)

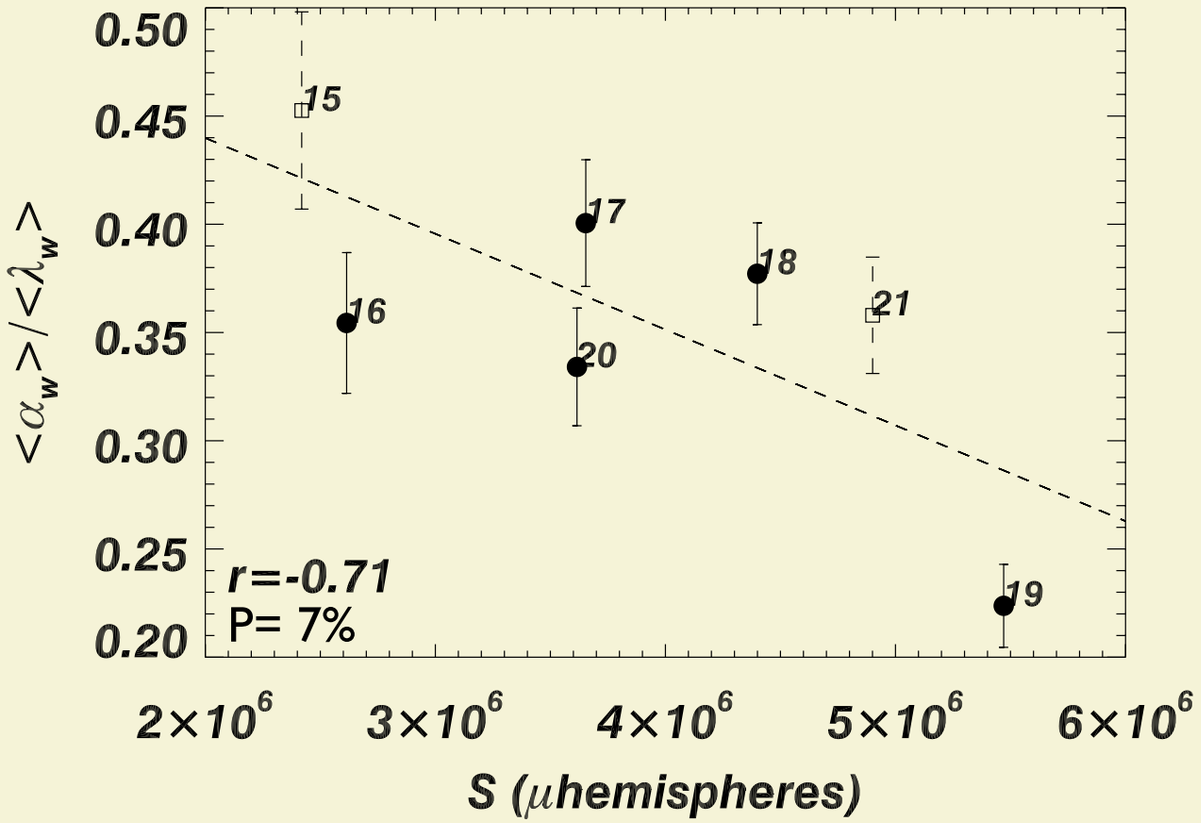
- *S*: sum of the area of all groups in a cycle (Balmaceda et al. 2009)

Cycle-to-cycle analysis

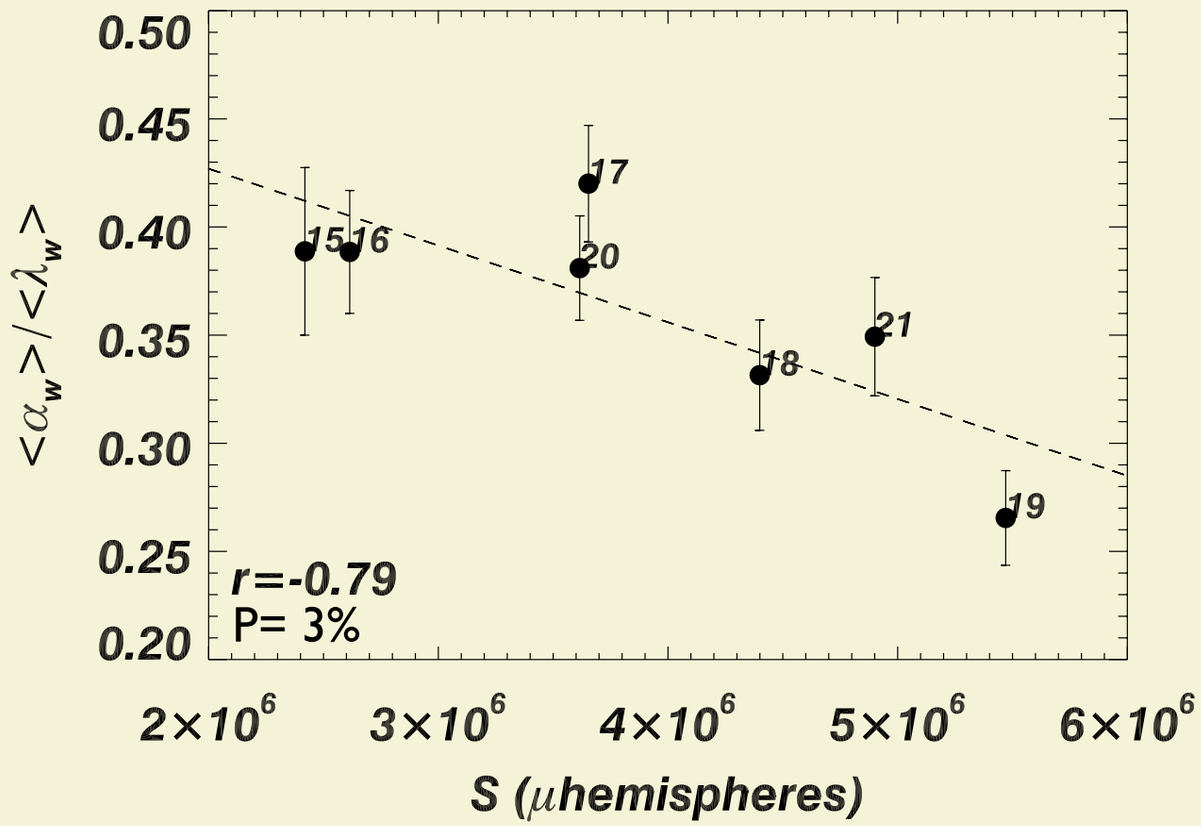


Joy's law and cycle strength

Mount Wilson



Kodaikanal



Cycles 15 and 21 incomplete!

Joy's law and cycle strength

- Surface flows converging towards activity belts reduce tilt (Jiang et al. 2010, Cameron and Schüssler 2012).

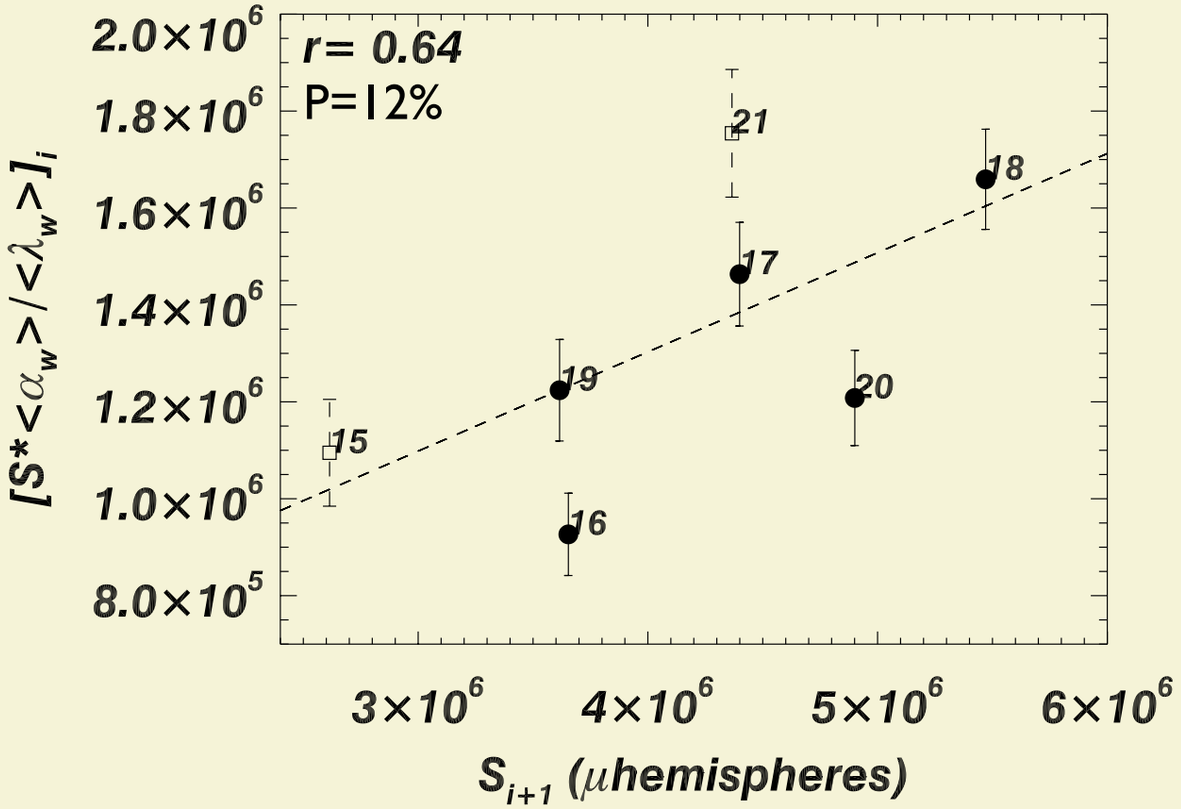
- Inflows have been observed (e.g. Gizon and Rempel 2008, Svanda et al. 2008, Gizon 2004, Gonzalez Hernandez et al. 2010).

- Inflows result due to cooling in the presence of faculae (Gizon and Rempel 2008), thus, stronger with higher activity.

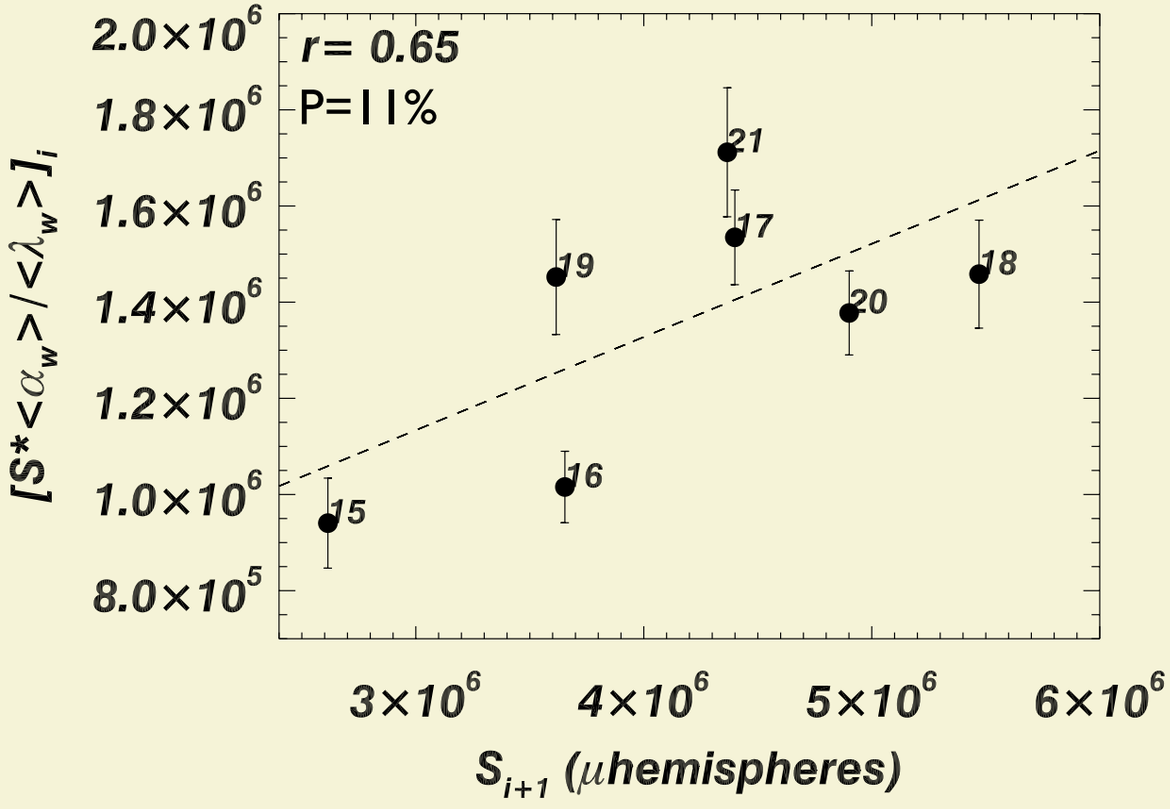
- Surface flux transport model with inflows provides saturation mechanism to cycle strength (Jiang et al. 2010, Cameron and Schüssler 2012).

The strength of the next cycle

Mount Wilson



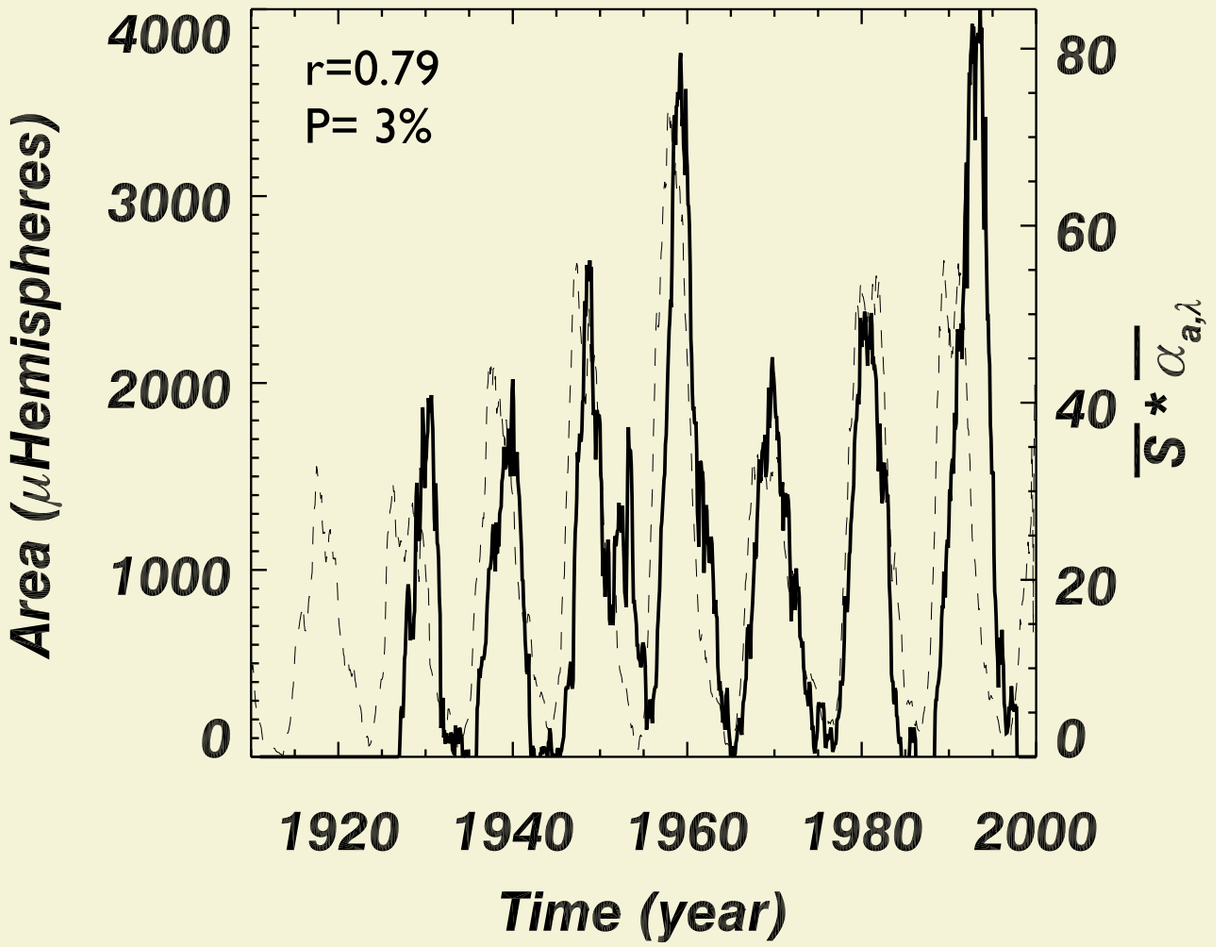
Kodaikanal



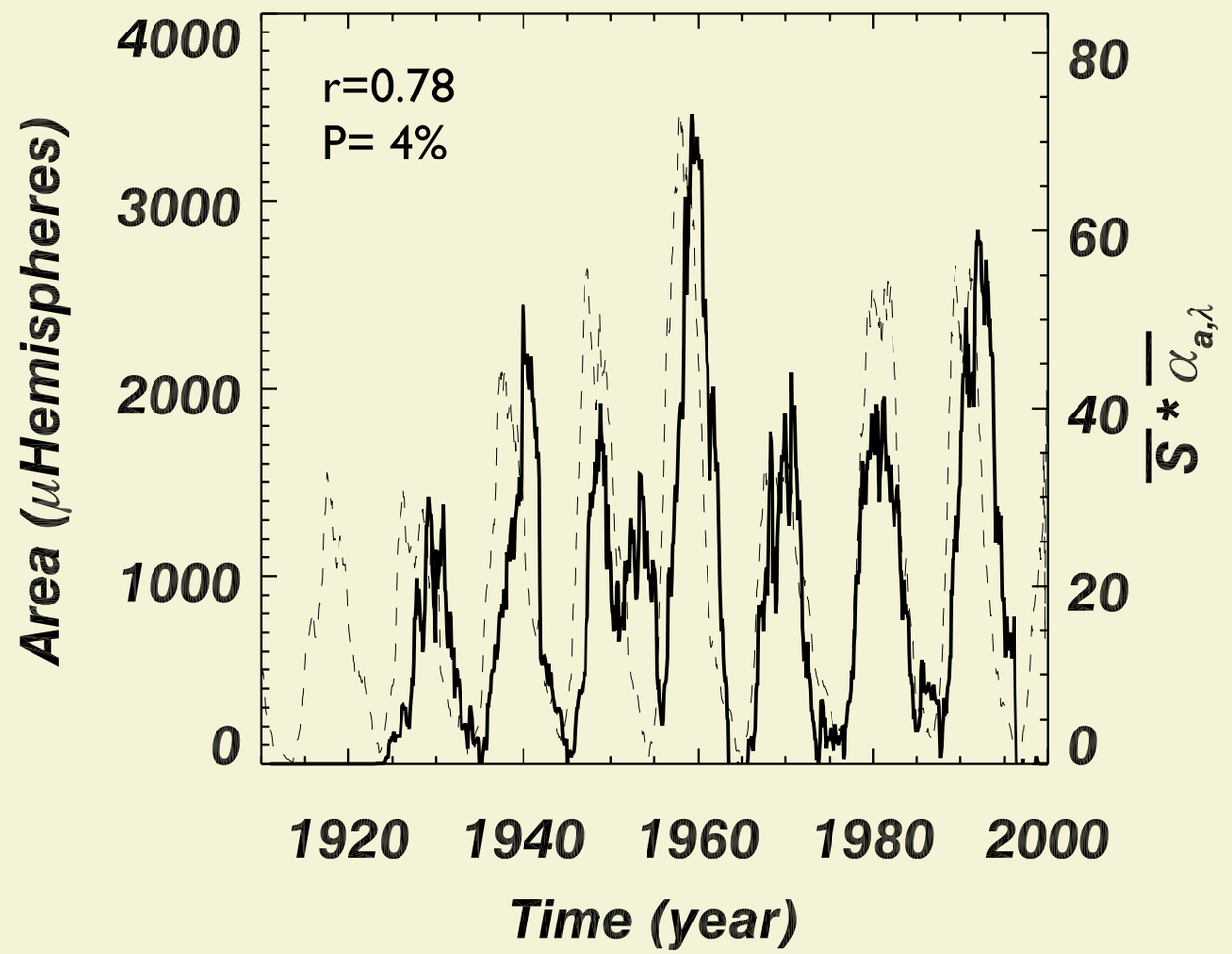
Cycles 15 and 21 incomplete!

The amplitude of the next cycle

Mount Wilson



Kodaikanal



$$\bar{\alpha}_{a,\lambda} = \frac{\sum A_j \alpha_j e^{-\left|\frac{\lambda}{\lambda_0}\right|}}{\sum A_j}$$

The amplitude of the next cycle

- Including the cycle-to-cycle variation of the tilt angles in their SFTM shows no need of an extra radial diffusive term to reproduce polarity reversals (Cameron et al. 2010, Jiang et al. 2013).

- Positive correlation between observed polar flux and tilt angles (Muñoz-Jaramillo et al. 2013).

Conclusions

• Used two data sets of sunspot group tilt angles covering 7 solar cycles (15 to 21): Mount Wilson and Kodaikanal observatories.

• Main results are:

- Anti-correlation between α_w/λ_w and the S of the ***same*** cycle.

- Correlation between the $S\alpha_w/\lambda_w$ and the S of ***next*** cycle.

Outlook

- Debrecen Heliophysical Observatory: 1977 — 2013

(Győri, Baranyi, Ludmány, 2011)

last 3 solar cycles

- Extend the MW and KK data sets (in collaboration with T. Baranyi):

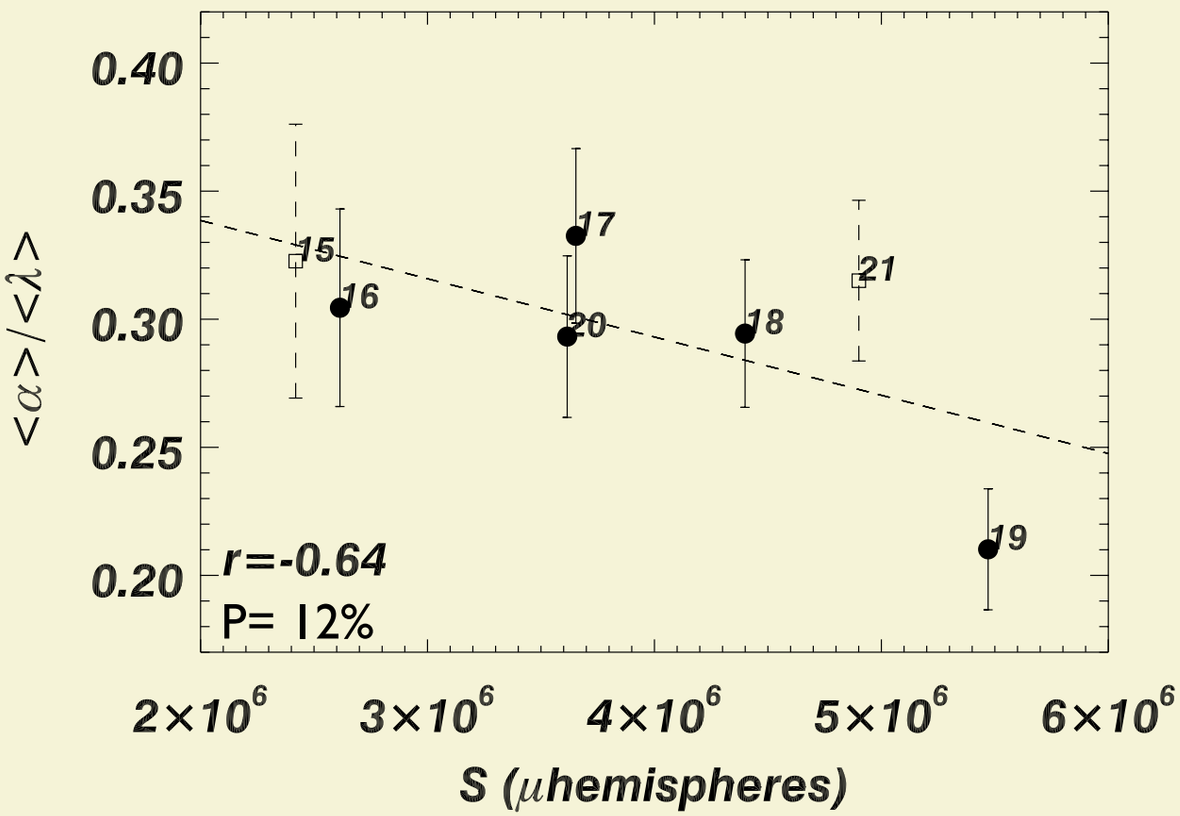
- Group identification
- Group areas

Data available at: http://fenyi.solarobs.unideb.hu/DPD/index.html

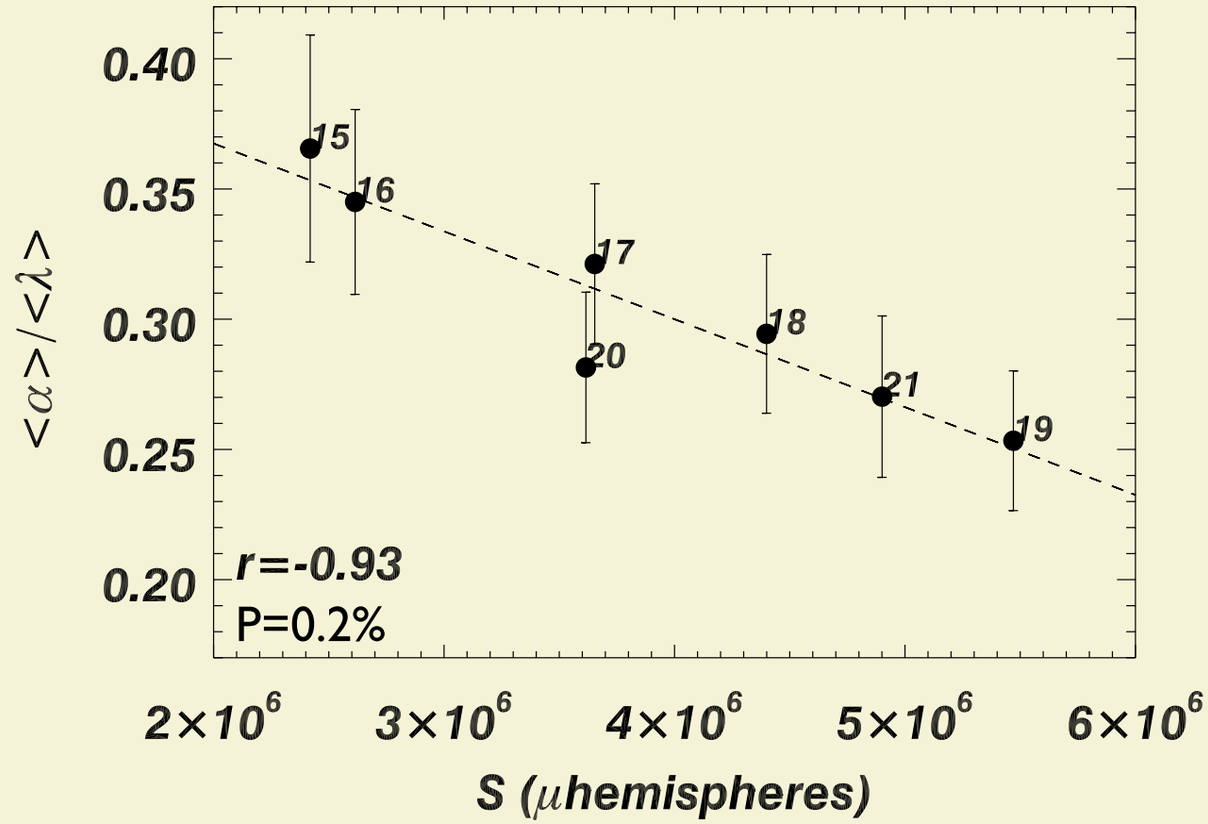
Thank you!

Joy's law and cycle strength

Mount Wilson



Kodaikanal



Cycles 15 and 21 incomplete!