Joy's law revisited
by using the new Debrecen tilt angle database

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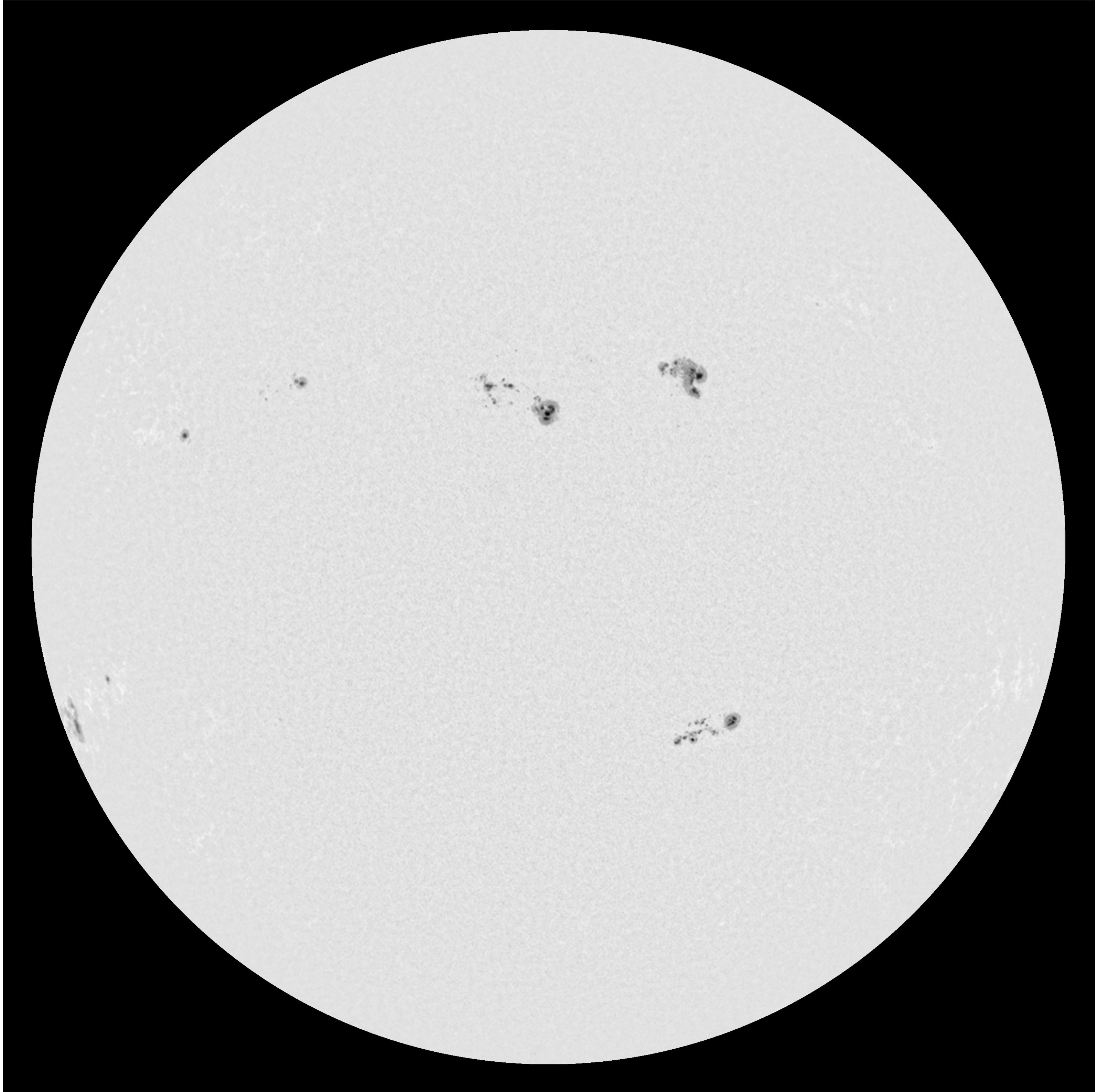
MTA CsFK CsI Heliophysical Observatory, Debrecen, Hungary

Sunspot formation, Nordita, 9-13 March 2015

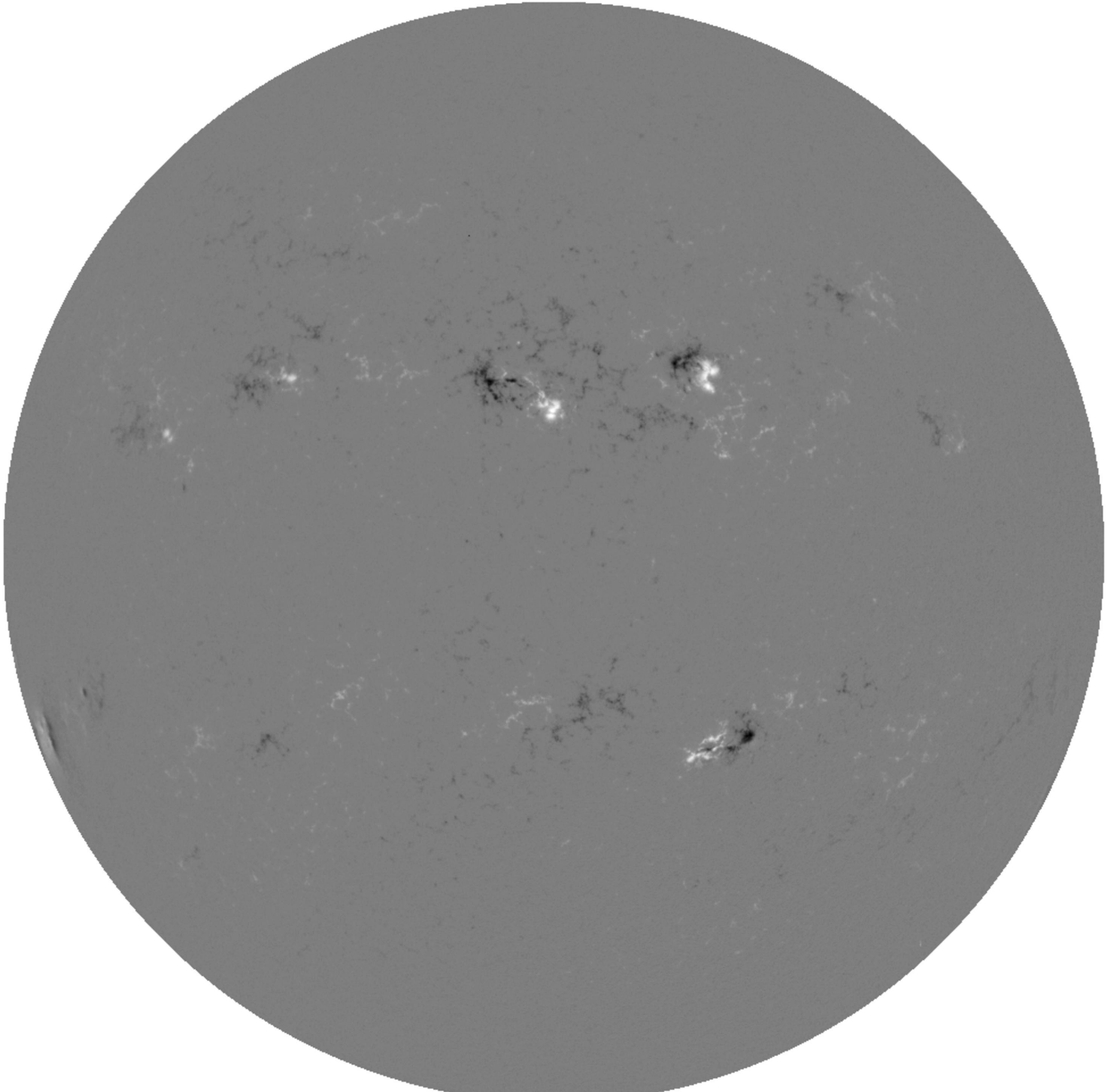
SOHO/MDI

12.05.2000



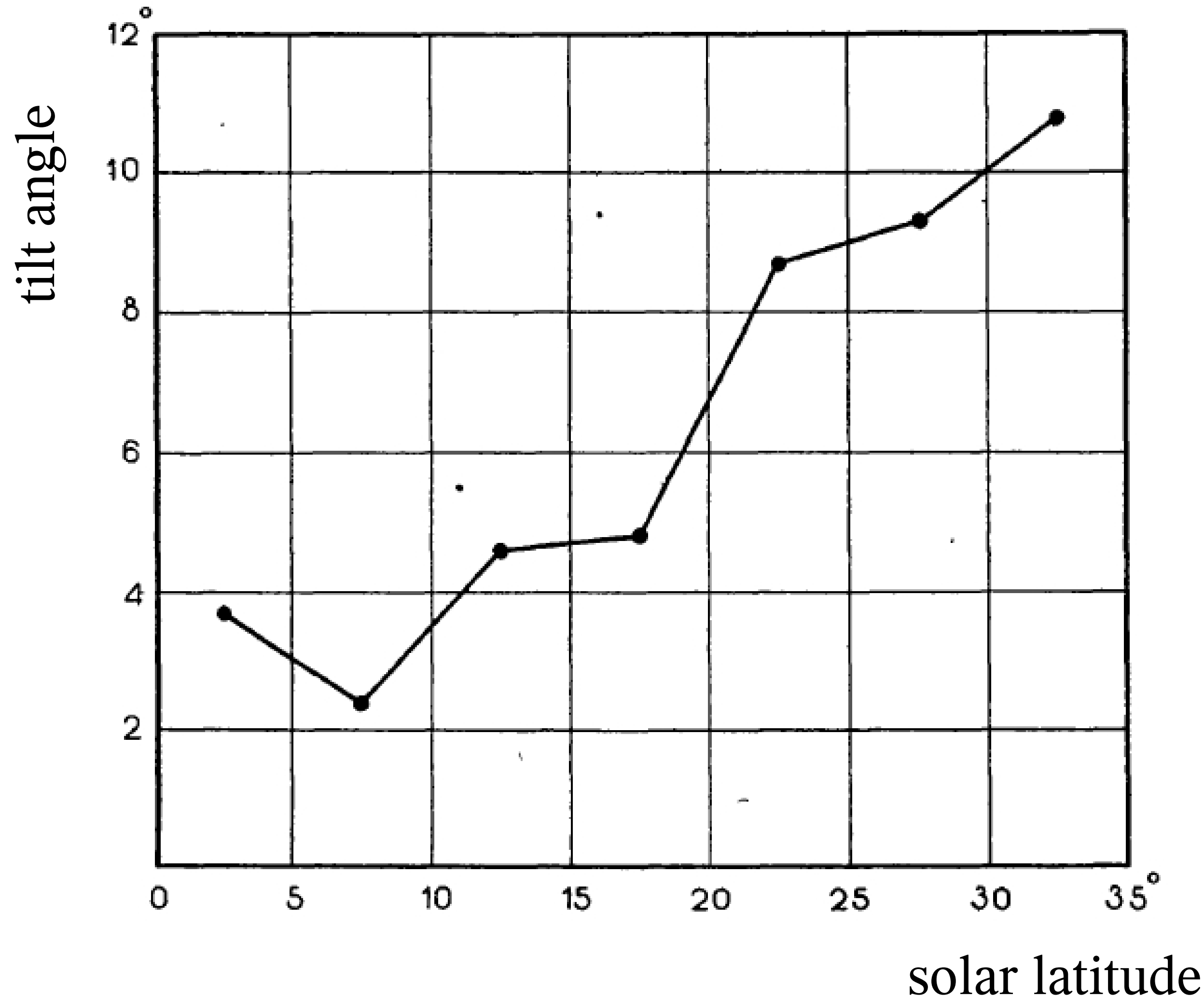
SOHO/MDI

12.05.2000



An almost century old figure about the Joy's law

(Hale, Ellerman, Nicholson, Joy, 1919, *ApJ*, **49**, 153)



Still existing questions about the tilts

What are the reliable data of the tilts?

What is the reliable form of Joy's distribution?

What is the cause of the tilts?
- winding up of the poloidal field?
- Coriolis impact?

What may have impact on the tilts?
- large scale magnetic field?
- flux density at the root?
- emerging flux amount?
- evolutional state?
- large-scale flow pattern?

There are some answers but apparently not the final ones.

Data of active region tilts

Sunspot groups:

Mount Wilson - white light images
Kodaikanal - white light images
Debrecen (see: Győri et al., at the poster session)
- DPD (Debrecen Photoheliographic Data) white light images
- SDD (SOHO/MDI-Debrecen Data) wl images + magnetograms
- HMIDD (SDO/HMI Debrecen Data) wl images + magnetograms

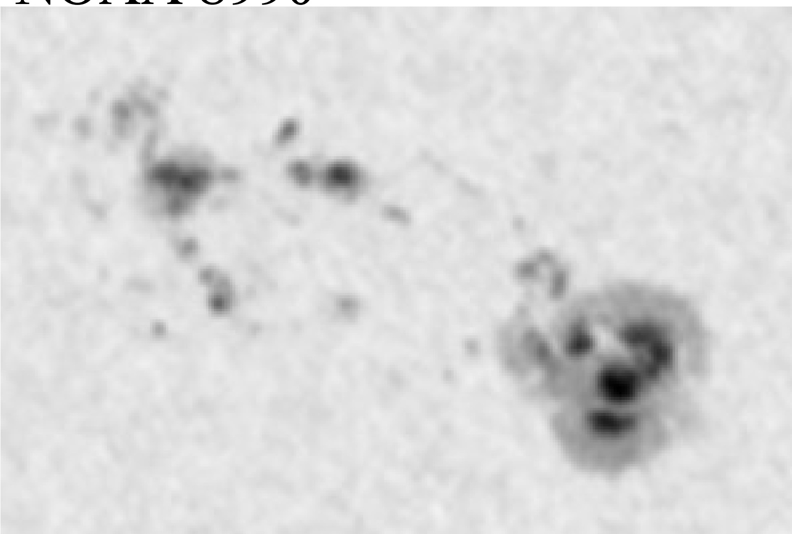
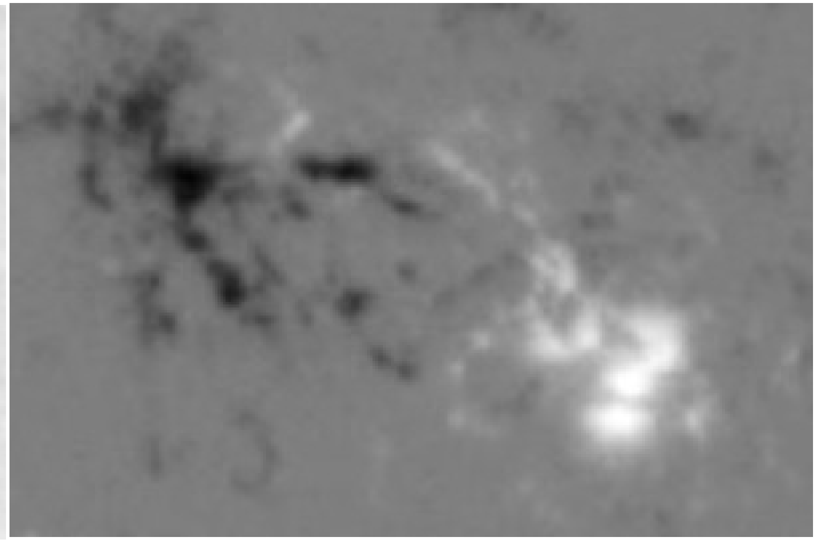
AR magnetic fields - from magnetograms

Kosovichev& Stenflo, 2008, *ApJ*, **688**, L115
Li & Ulrich, 2012, *ApJ*, **758**, 115L

Active regions on 12 May 2000 01:41 UT

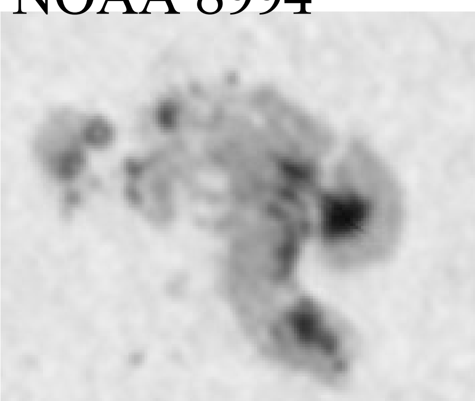
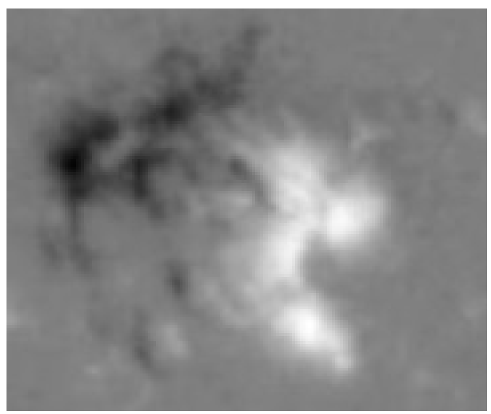
DATA

NOAA 8990

N

NOAA 8994

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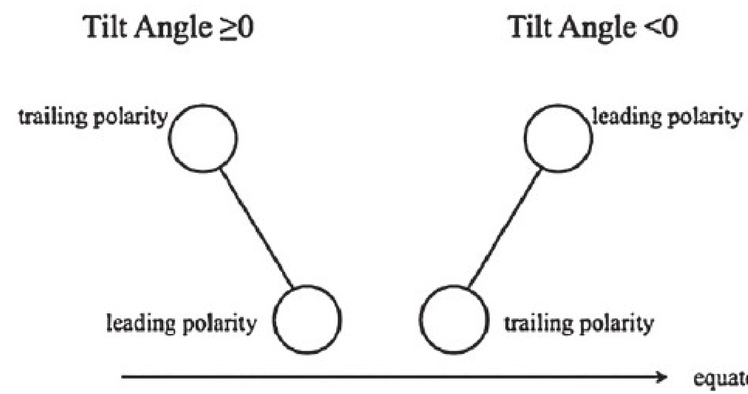
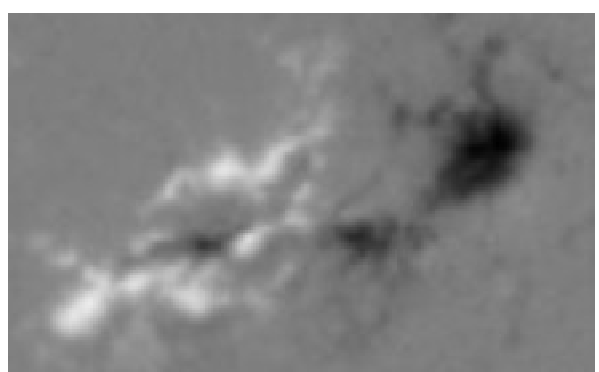


NOAA 8993

S

The most detailed tilt databases belong to the Debrecen catalogues.
Tilt data of the AR NOAA 8990 from the SDD database:

With Howard's method (no magnetic information)

penumbrae					umbrae				
Bf	Bl	Lf	Ll	tilt	Bf	Bl	Lf	Ll	tilt
14.82	12.25	60.74	66.64	**24.04**	14.95	12.21	60.69	66.69	**25.16**

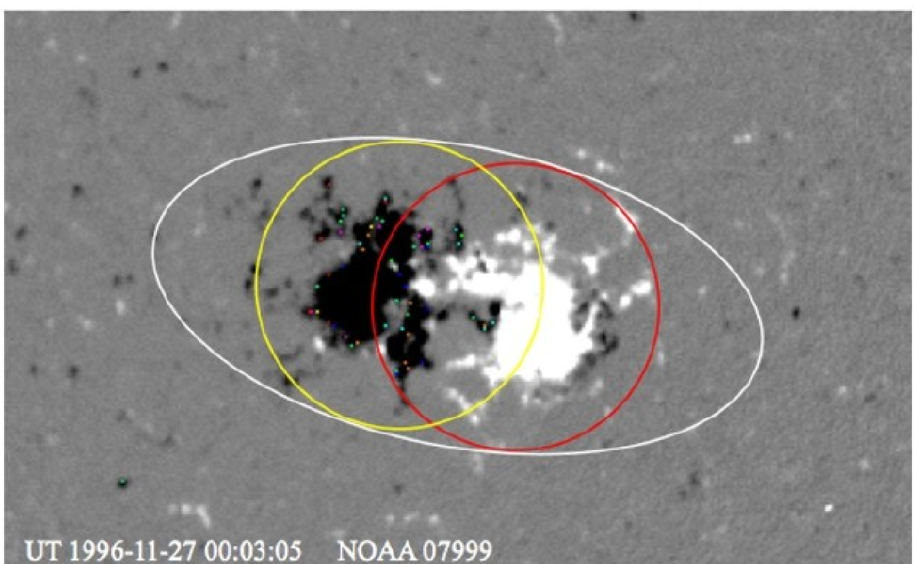
By using magnetic information:

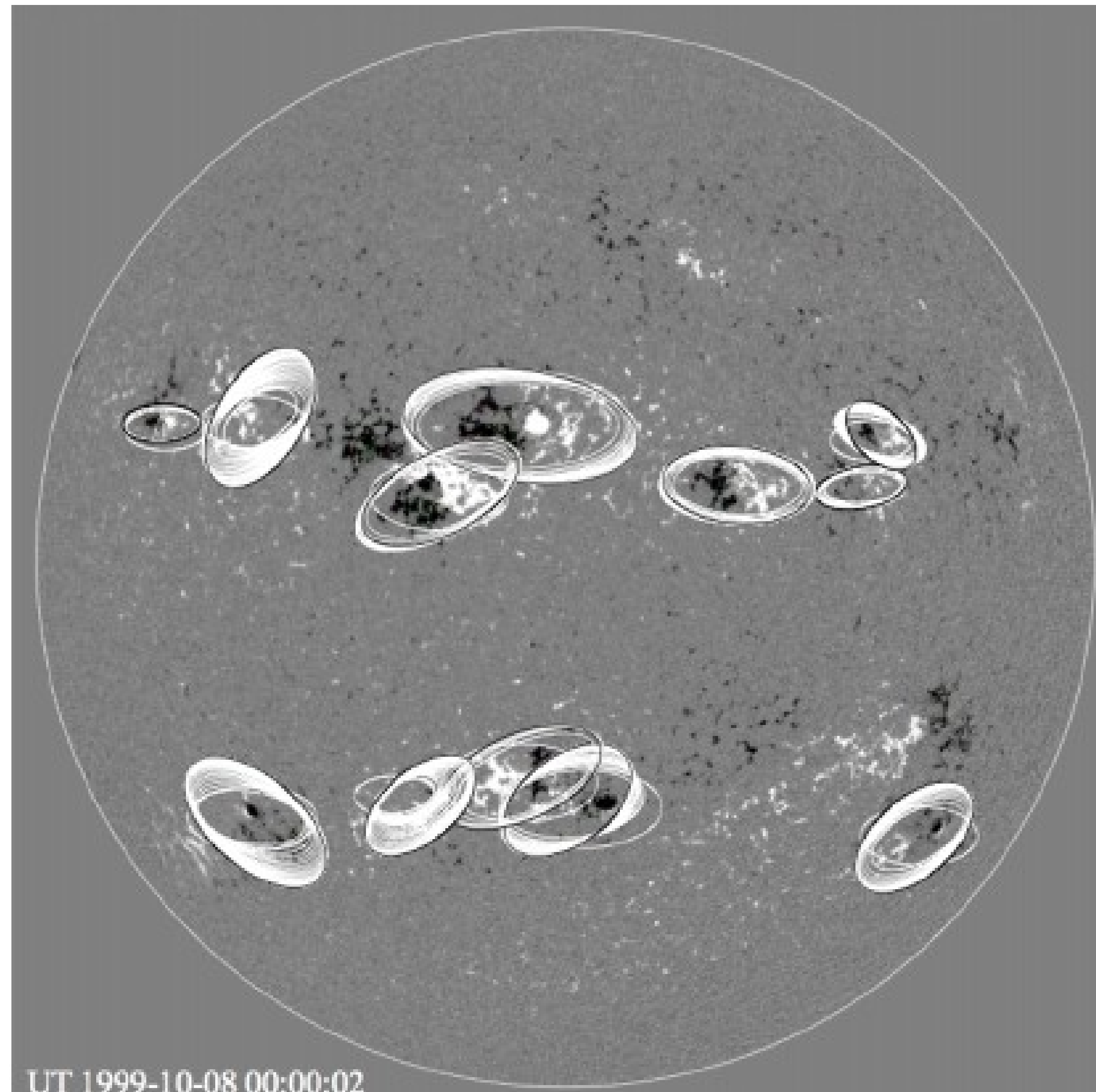
penumbrae					umbrae				
Bf	Bl	Lf	Ll	tilt	Bf	Bl	Lf	Ll	tilt
14.73	12.45	60.55	66.43	**21.76**	14.90	12.34	60.63	66.50	**24.05**

Determination of tilts from magnetograms

Li, J., Ulrich, R.K., 2012, *ApJ*, **758**, 115

The AR axis is represented by the major axis of the fitted ellipse.

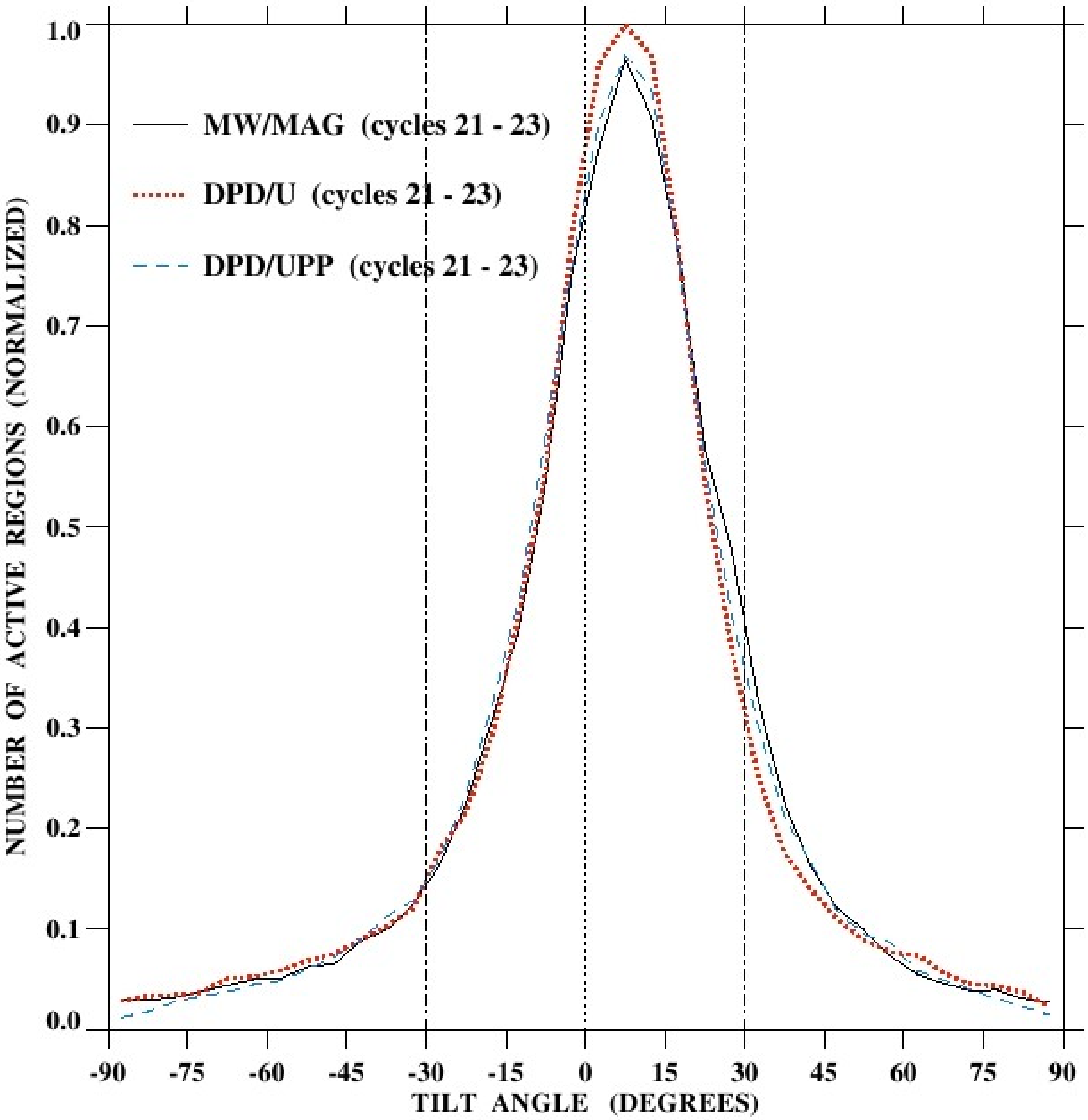


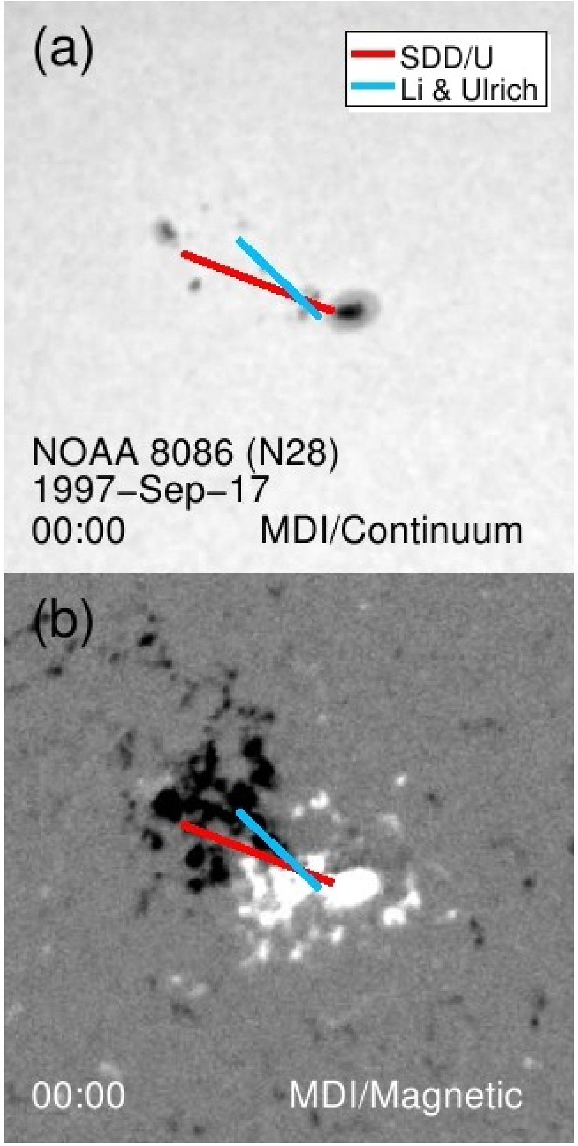


Comparison of sunspot tilts of Debrecen and magnetic field tilts of Mount Wilson

Wang, Y.-M. Colaninno, R.C., Baranyi, T., Li, J., 2015, *ApJ*, **798**, 50W

Larger tilts measured in AR magn.fields than in sunspot positions

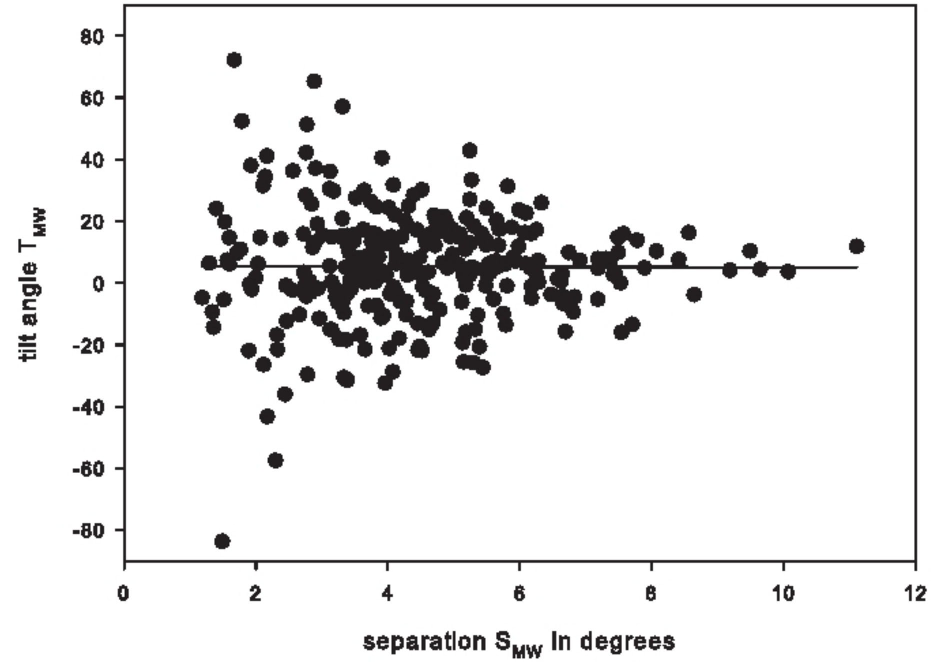




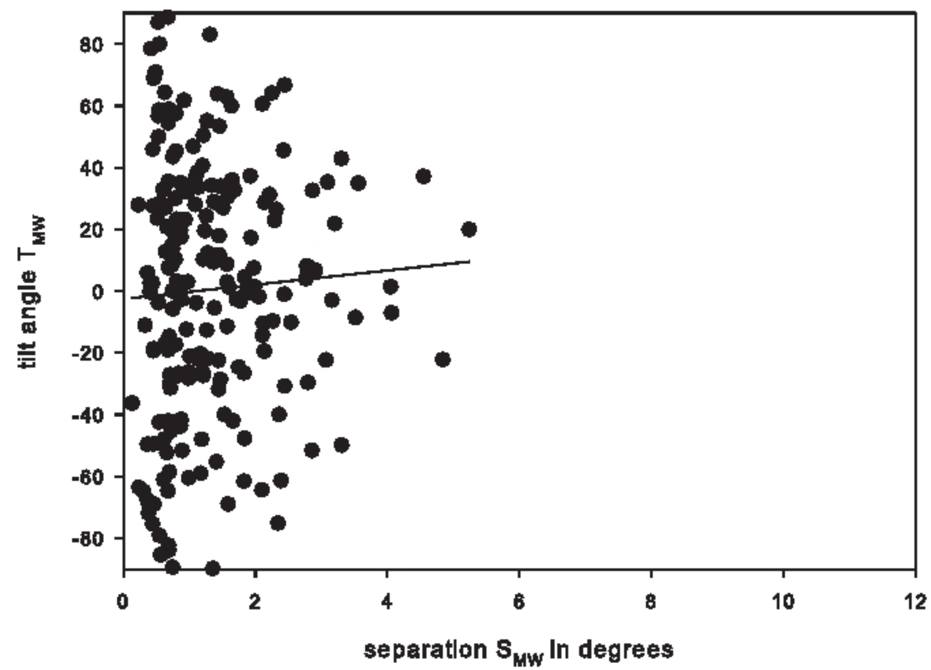
Test of a dataset of original MW data
+ data reduced from MW observations by DPD method
+ MW polarity drawings.
1961-67

DATA

Tilt angle – separation relationship for bipolar groups



Tilt angle – separation relationship for unipolar groups



<u>S<3° cases should be filtered out!</u>

Baranyi, T., 2015, *MNRAS*, **447**, 1857B

Slopes without and with filtering:

Data base	Slope	Slope if $S > 3$
T_{MW}	0.292(±0.019)	0.396(±0.016)
T_{KK}	0.294(±0.027)	0.423(±0.037)
T_{DPDu}	0.327(±0.017)	0.422(±0.016)
T_{SDDu}	0.373(±0.042)	0.423(±0.025)

After filtering:

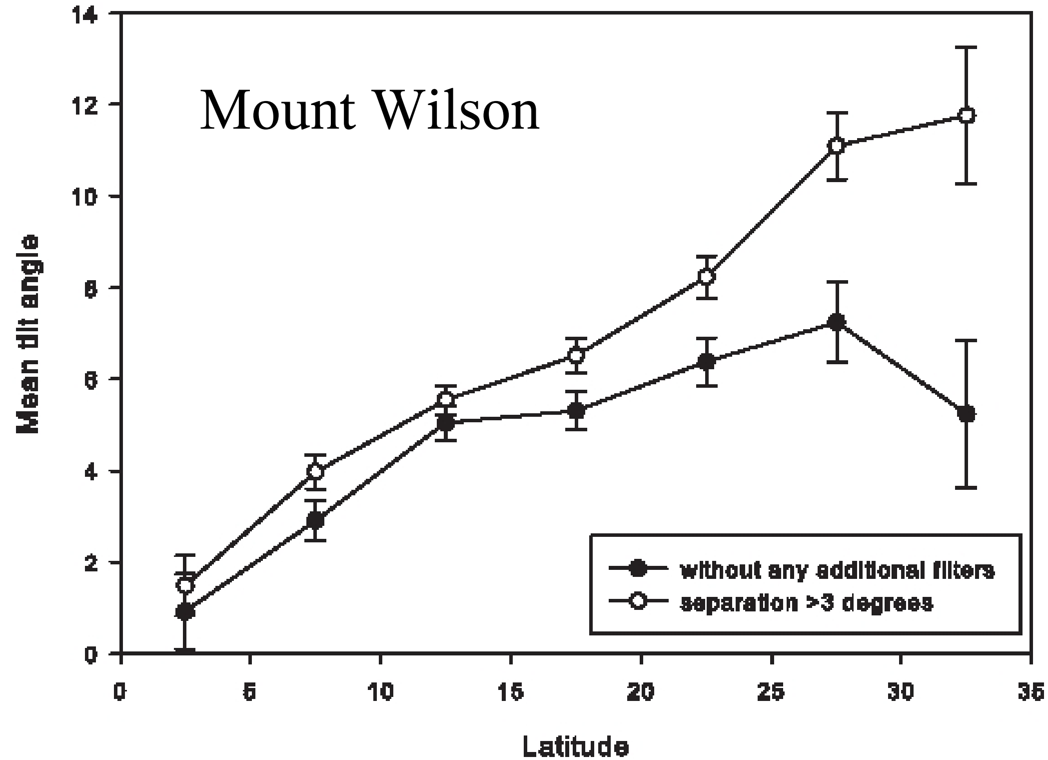
In 1961-67:

$$T_{MWDPD} = 1.02(\pm 0.02) * T_{MW}$$

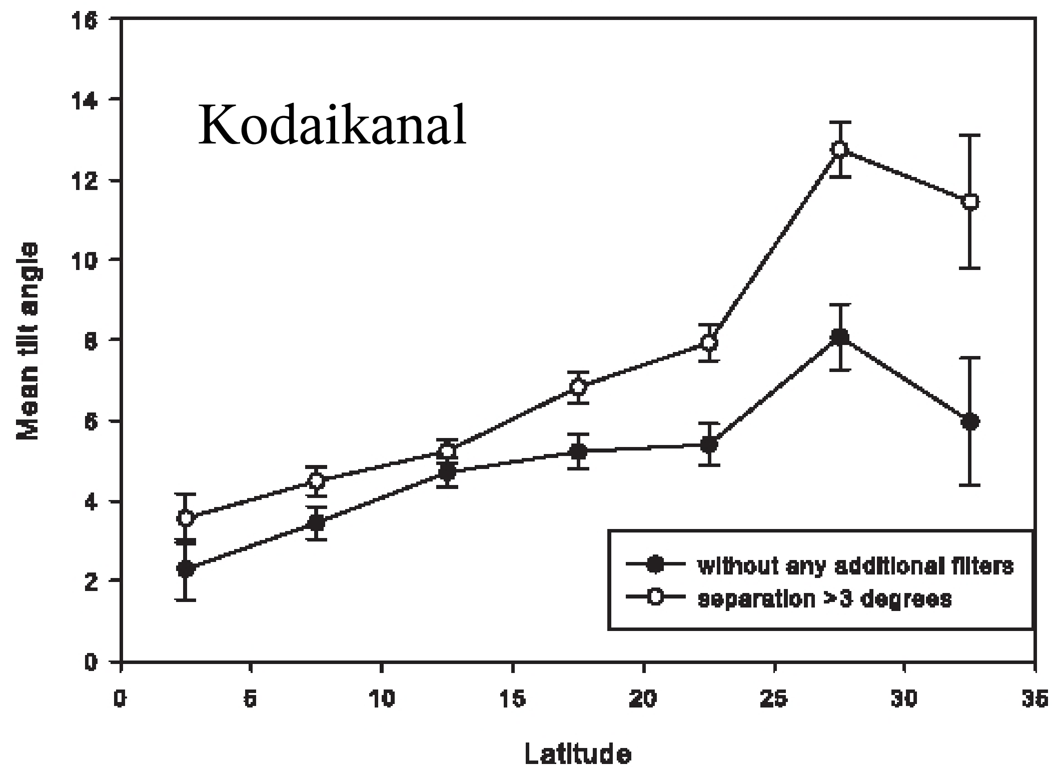
In 1977-85:

$$T_{DPDu} = 1.01(\pm 0.01) * T_{MW}$$

Baranyi, T., 2015, *MNRAS*, **447**, 1857B



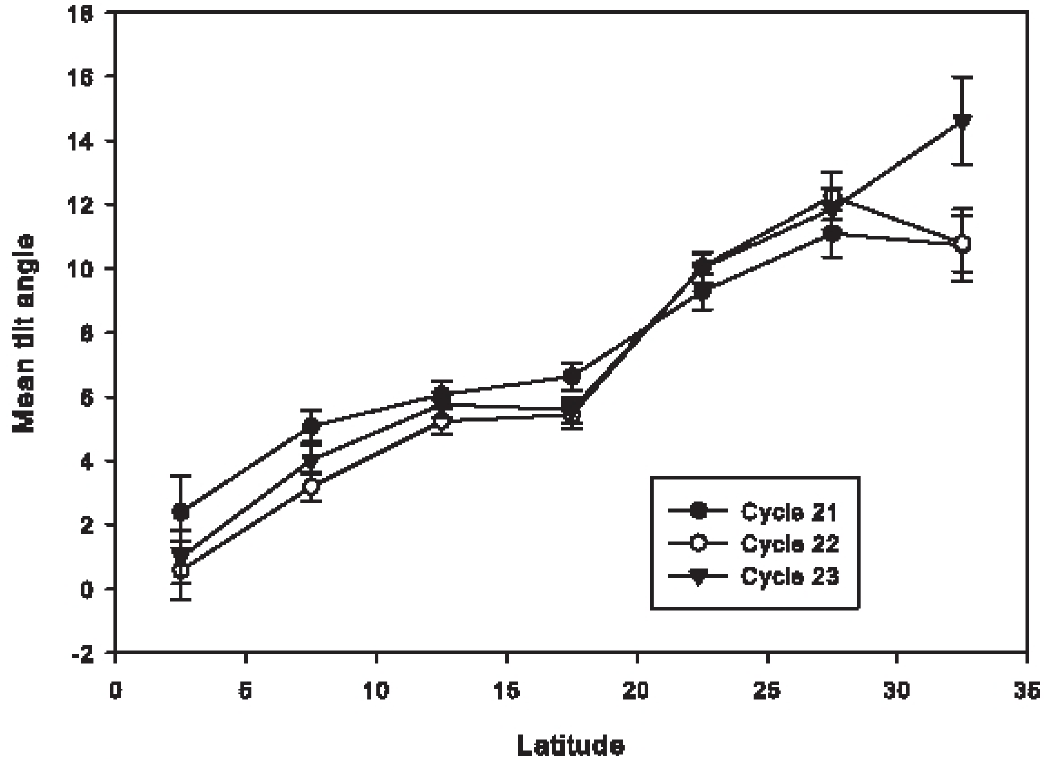
Joy



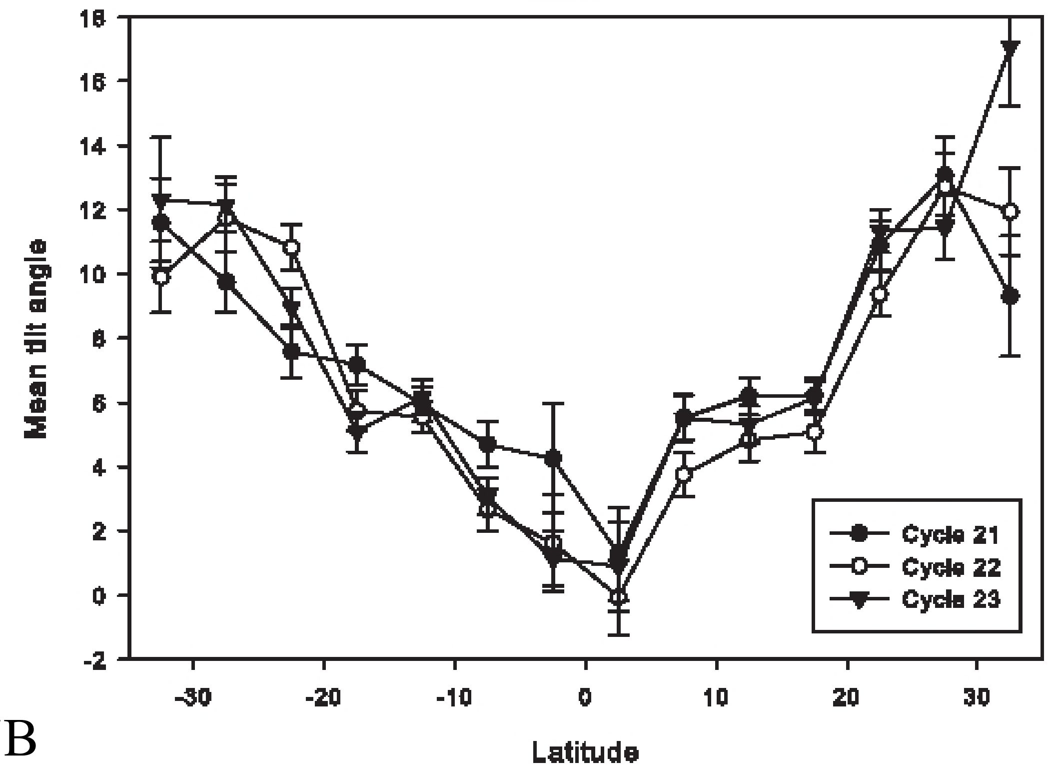
Joy

Distributions of DPD tilts after filtering

cycles 21, 22, 23



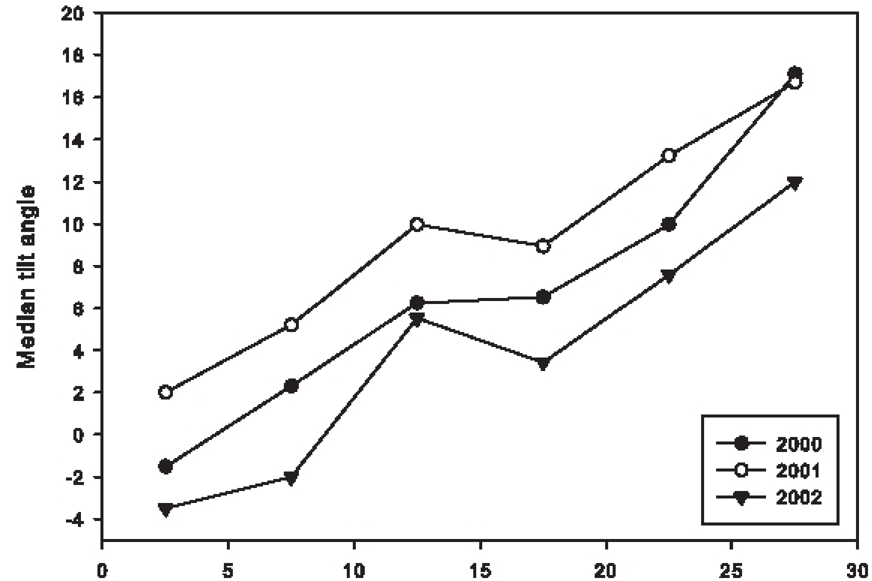
cycles 21, 22, 23
on both hemispheres



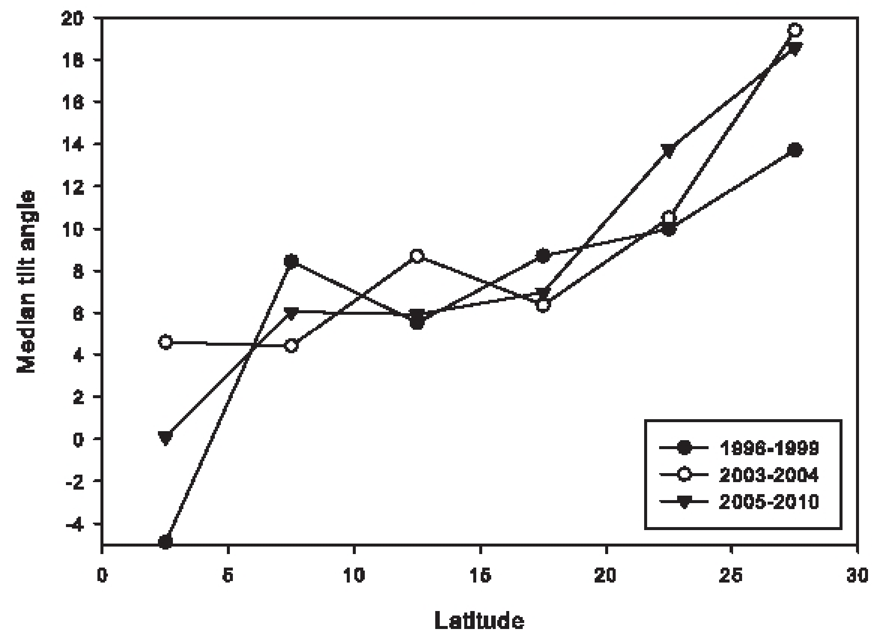
Baranyi, T., 2015, *MNRAS*, **447**, 1857B

Joy diagrams with tilt angles from SDD
(with polarity information)

Years around cycle maximum:



Years before and after maximum:

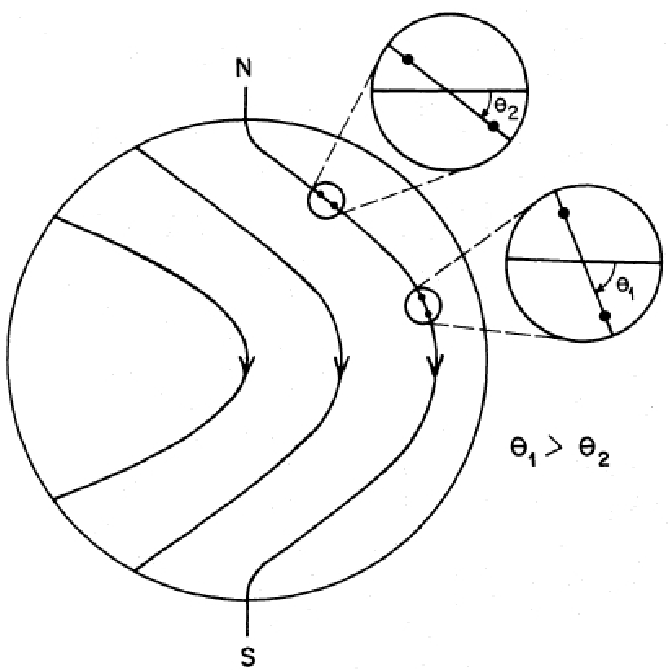


Baranyi, T., 2015, *MNRAS*, **447**, 1857B

Coriolis?

D'Silva & Choudhuri, 1993, *An.Ap*. **272**, 621

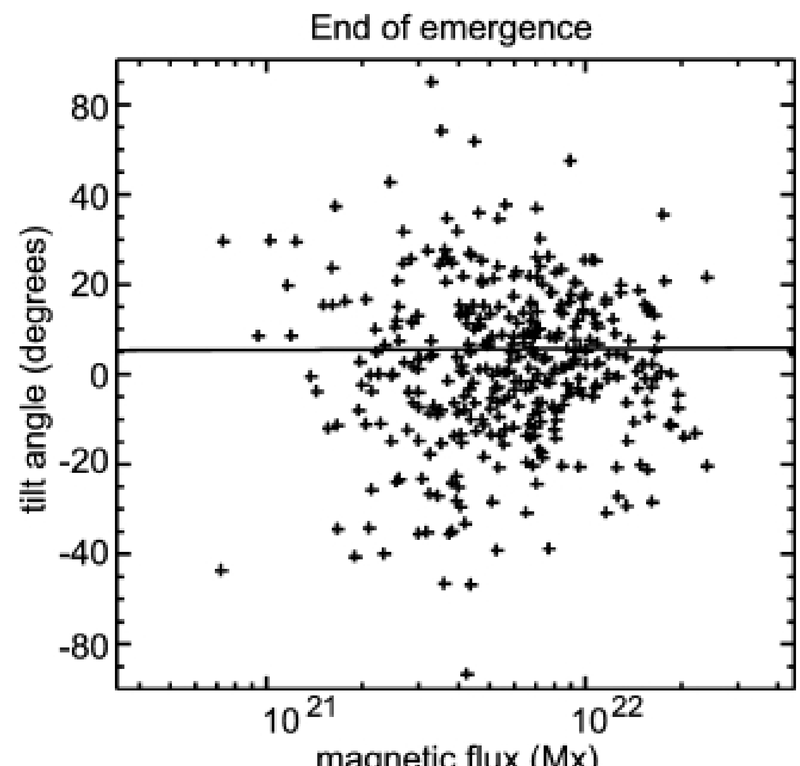
(No such latitude-dependence as expected from wind up:)



Winding up?

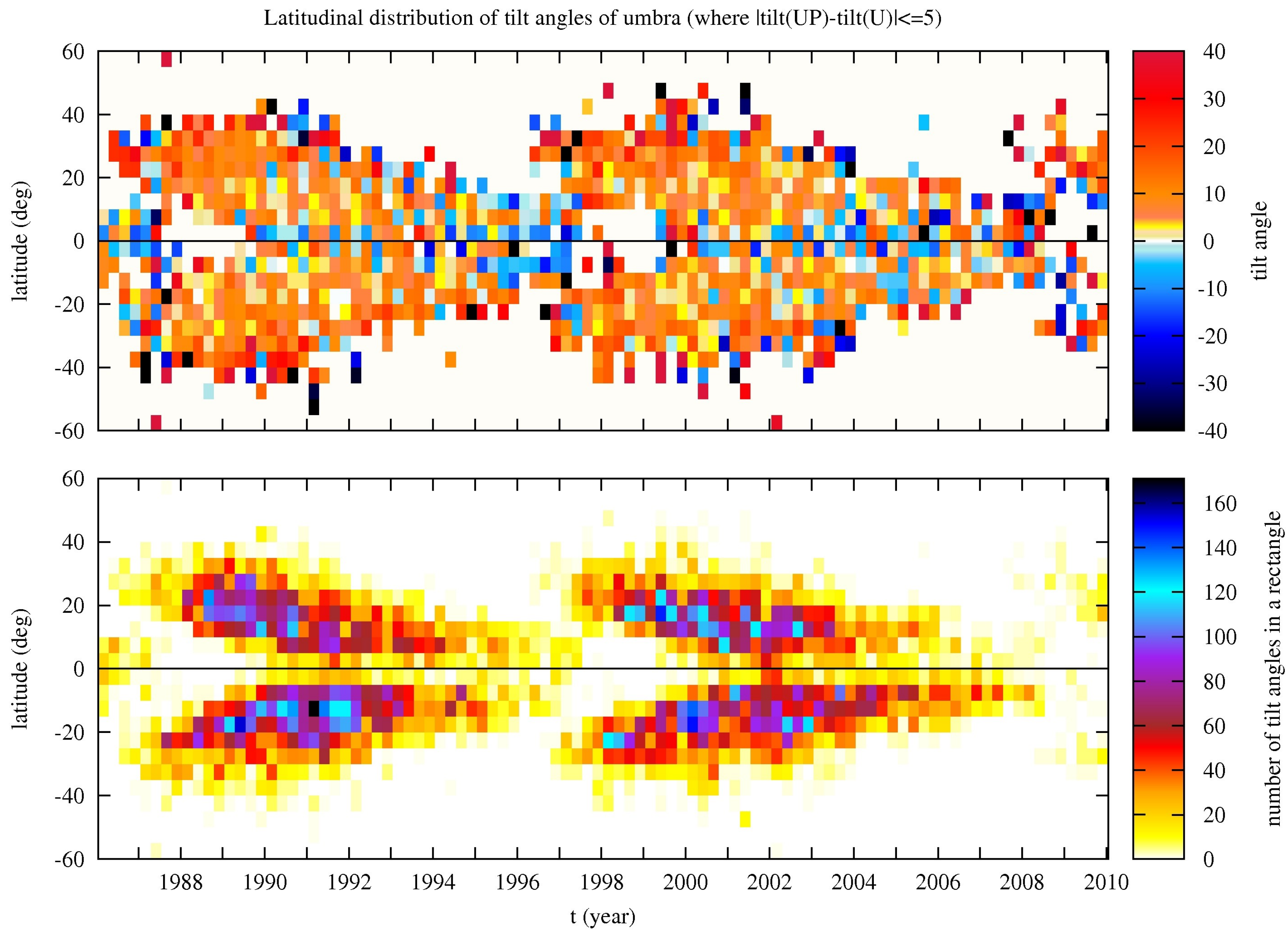
Kosovichev & Stenflo, 2008, *ApJ*, **688**, L115

(No flux-dependence as expected from the Coriolis impact.)



cause

Mean tilt angles in pixels of (3 months x 5°), cycles 22-23

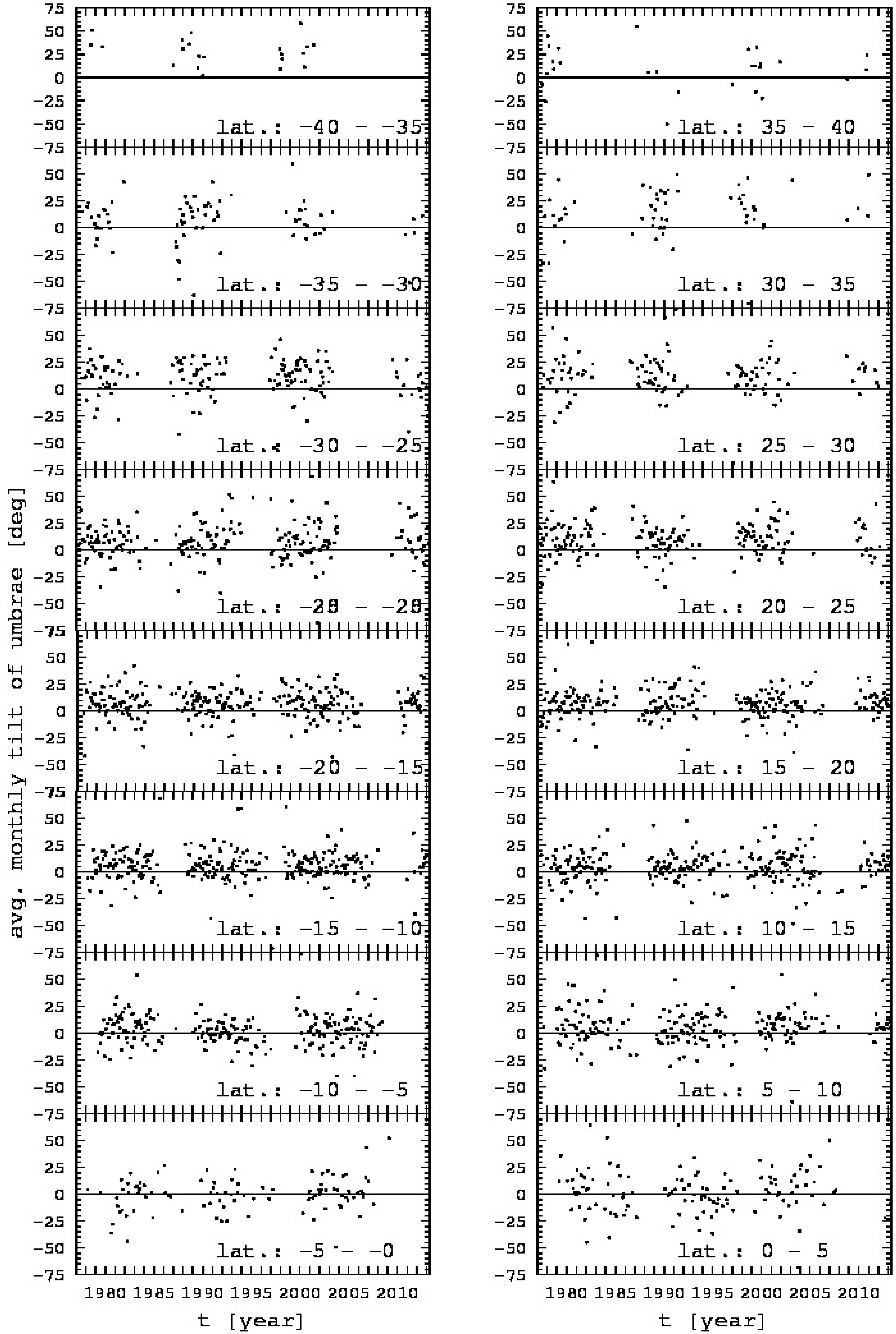


Muraközy, J., Baranyi, T., Ludmány, 2012, *CEAB*, **36**, 1, 1

cause

Monthly mean tilt angles of sunspot groups at their maximum sizes in 5° latitudinal bins in both hemispheres.

Cycles 21-24

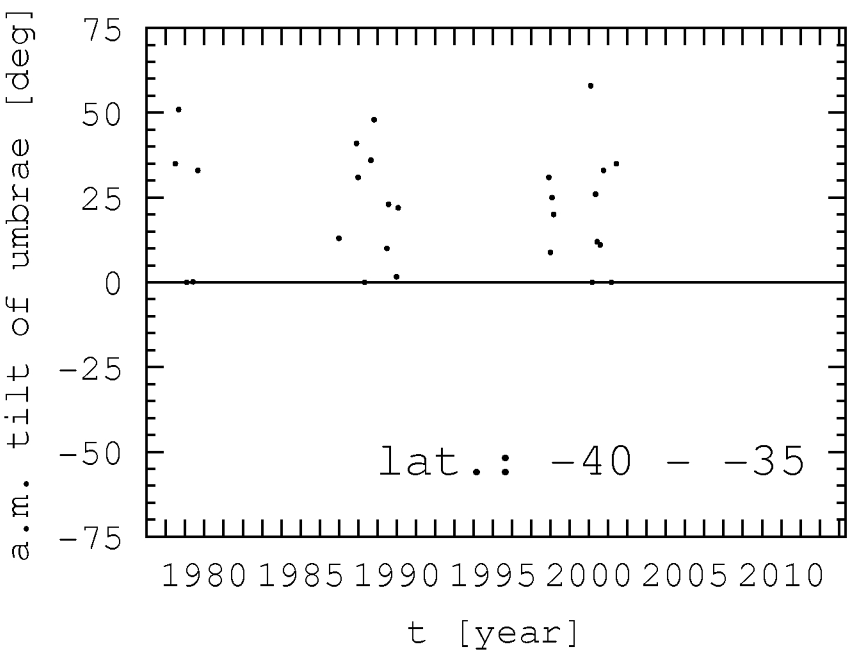


Muraközy, J. thesis 2014

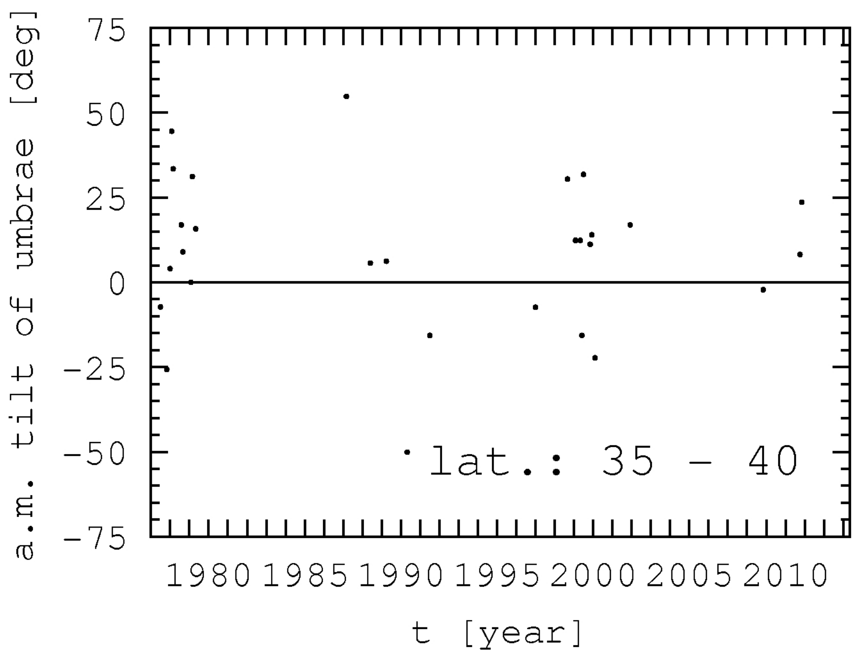
cause

Monthly mean tilt angles of sunspot groups at their maximum sizes in 5° latitudinal bins
Cycles 21-24

South



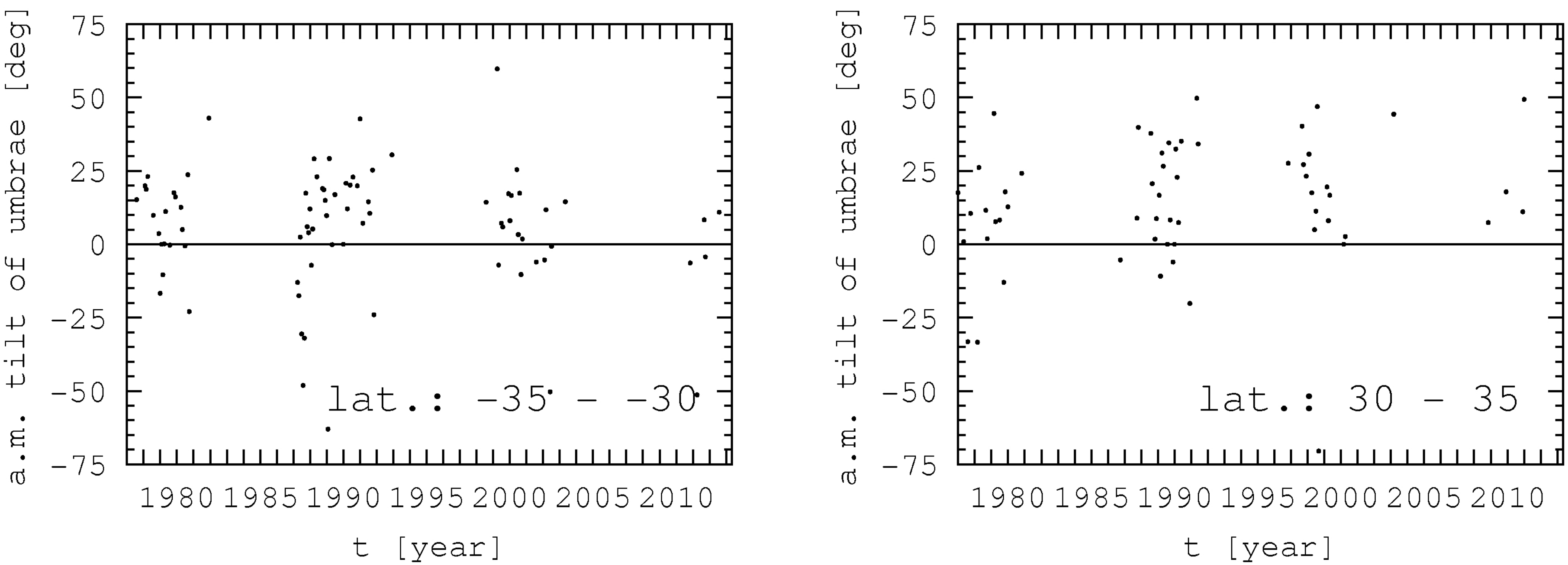
North



Muraközy, J.
thesis 2014

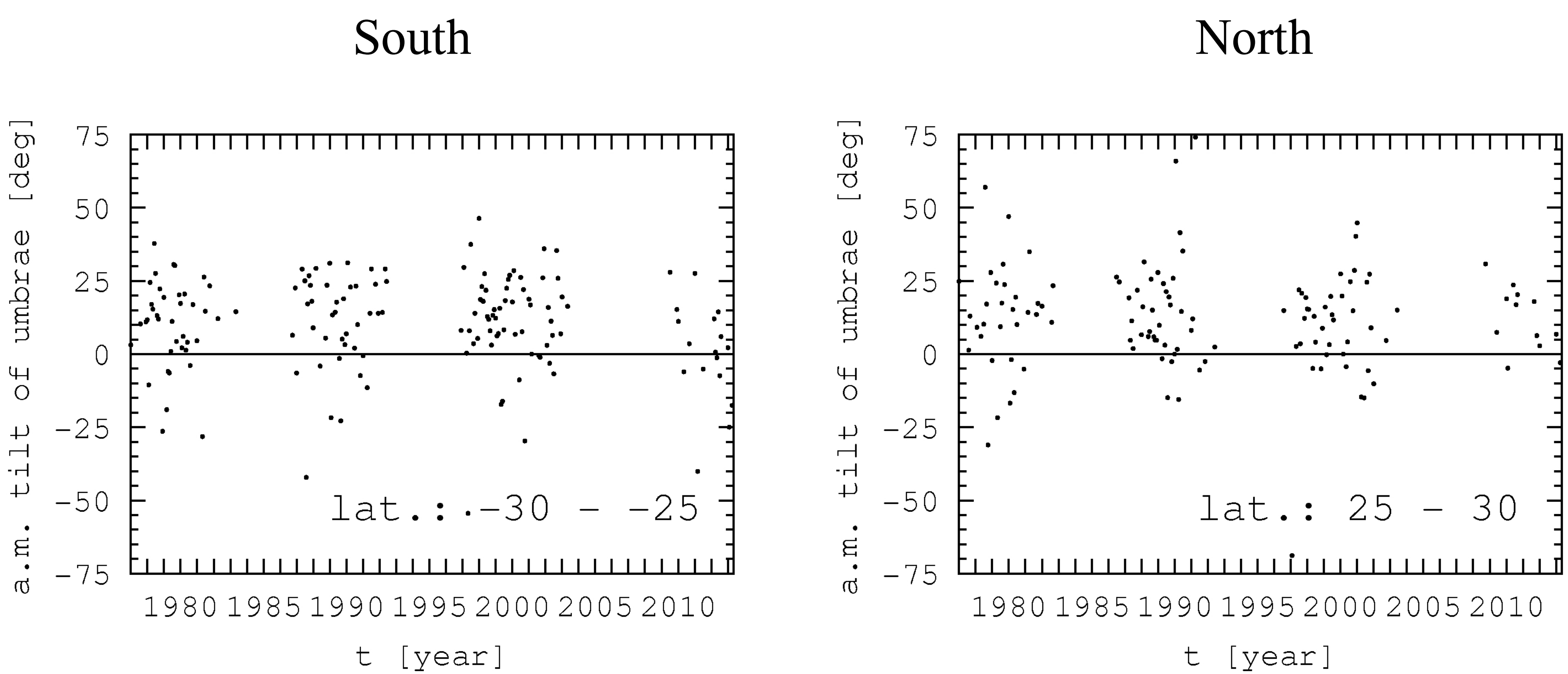
Monthly mean tilt angles of sunspot groups at their maximum sizes in 5° latitudinal bins
Cycles 21-24

South North



Muraközy, J.
thesis 2014

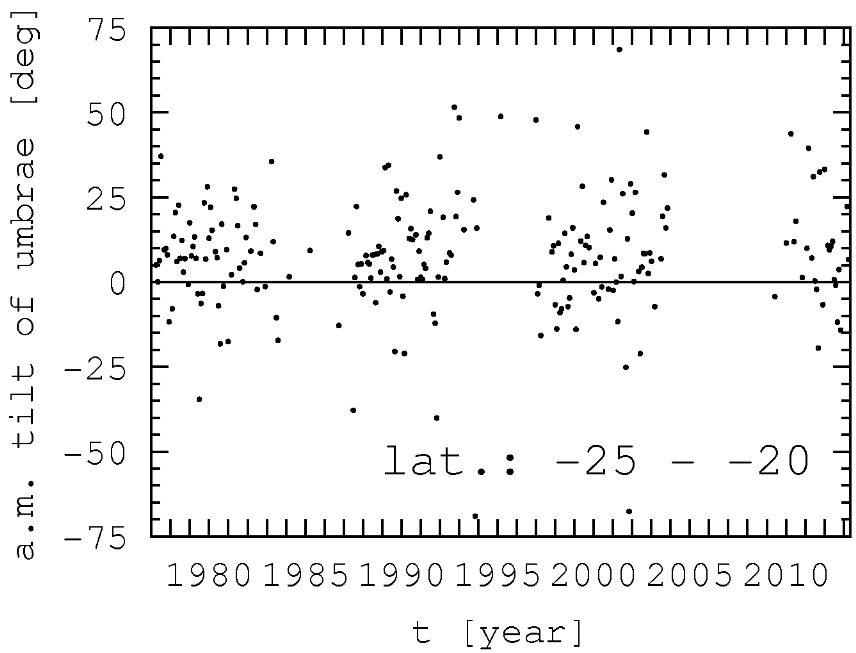
Monthly mean tilt angles of sunspot groups at their maximum sizes in 5° latitudinal bins
Cycles 21-24



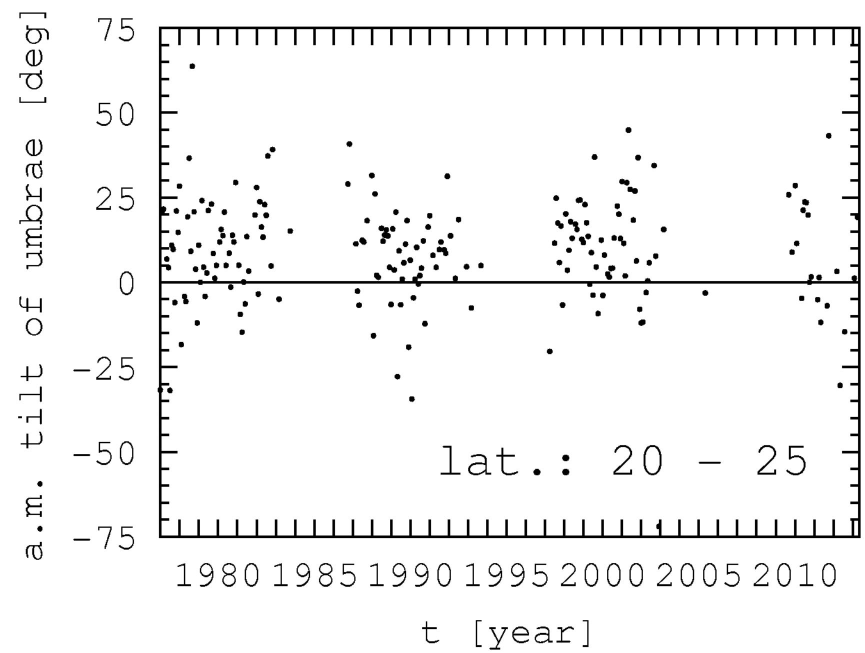
Muraközy, J.
thesis 2014

Monthly mean tilt angles of sunspot groups at their maximum sizes in 5° latitudinal bins
Cycles 21-24

South



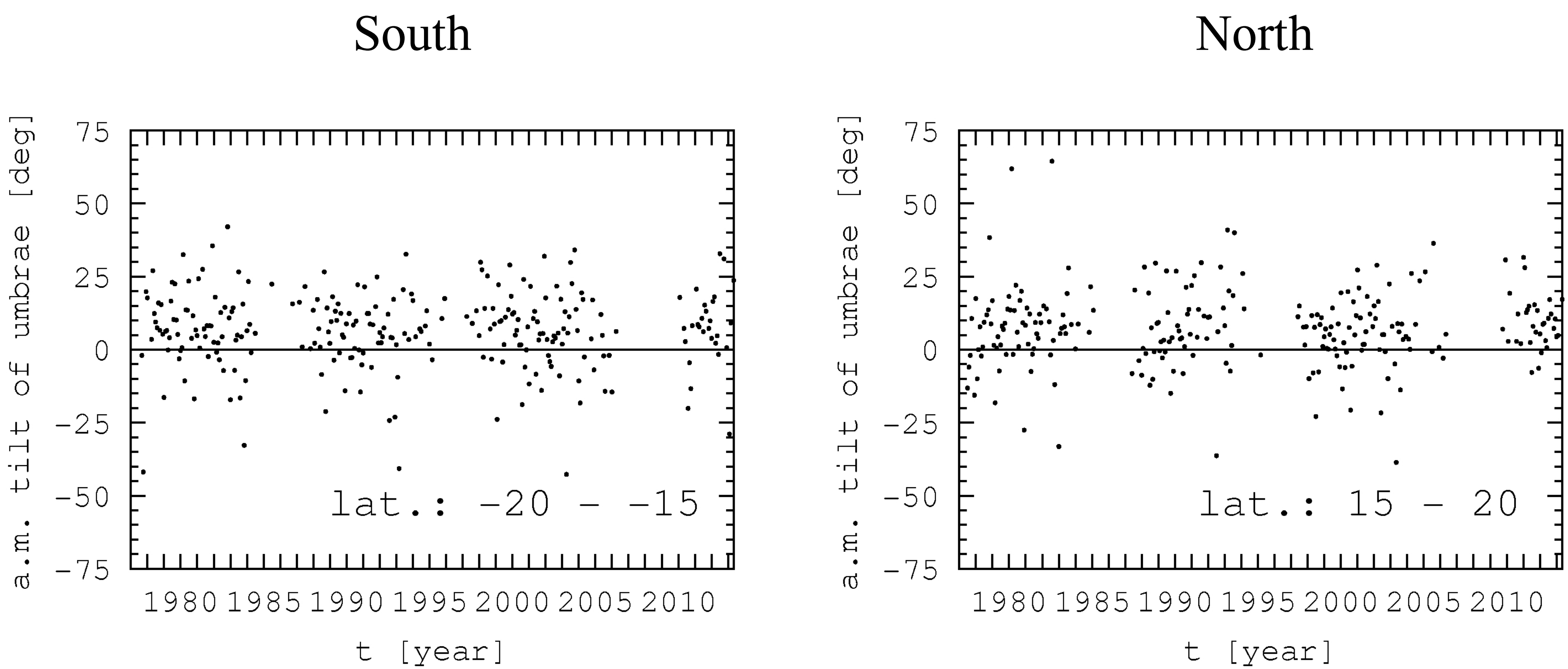
North



Muraközy, J.
thesis 2014

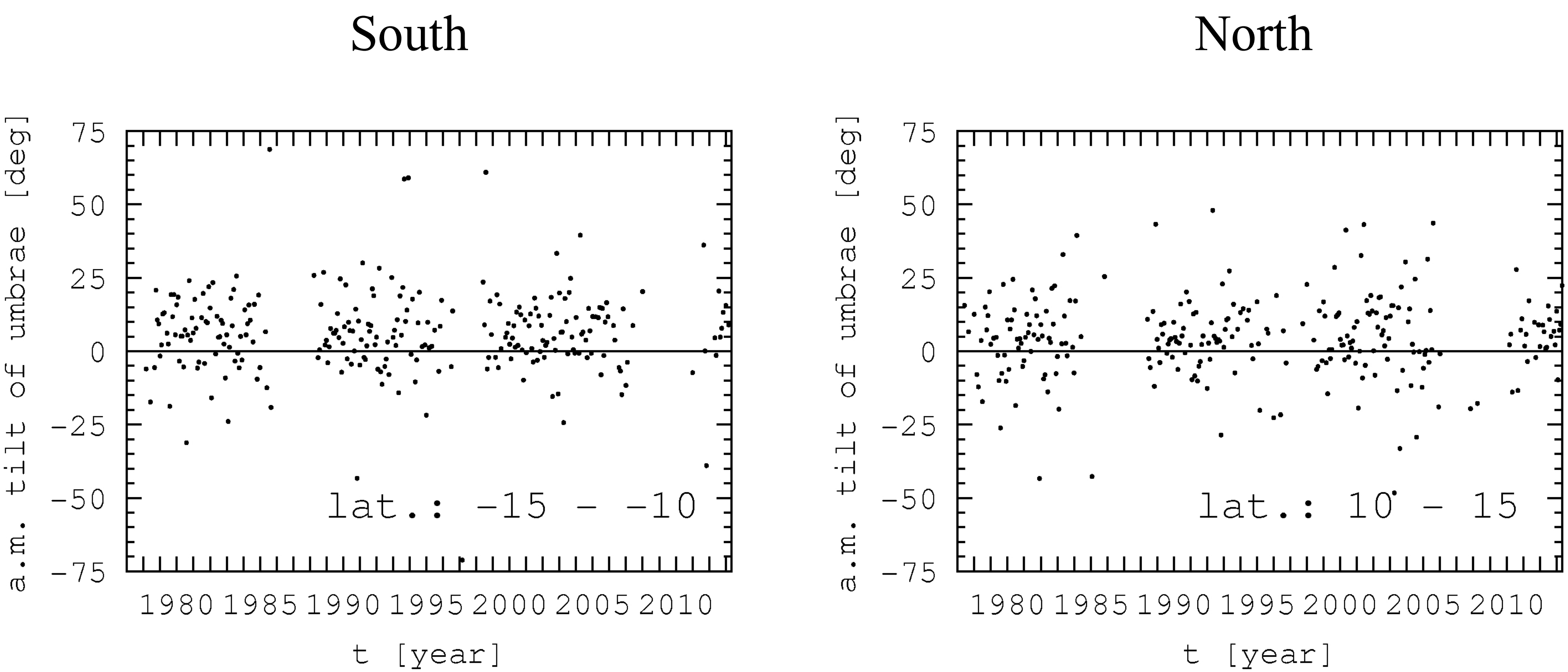
cause

Monthly mean tilt angles of sunspot groups at their maximum sizes in 5° latitudinal bins
Cycles 21-24



Muraközy, J.
thesis 2014

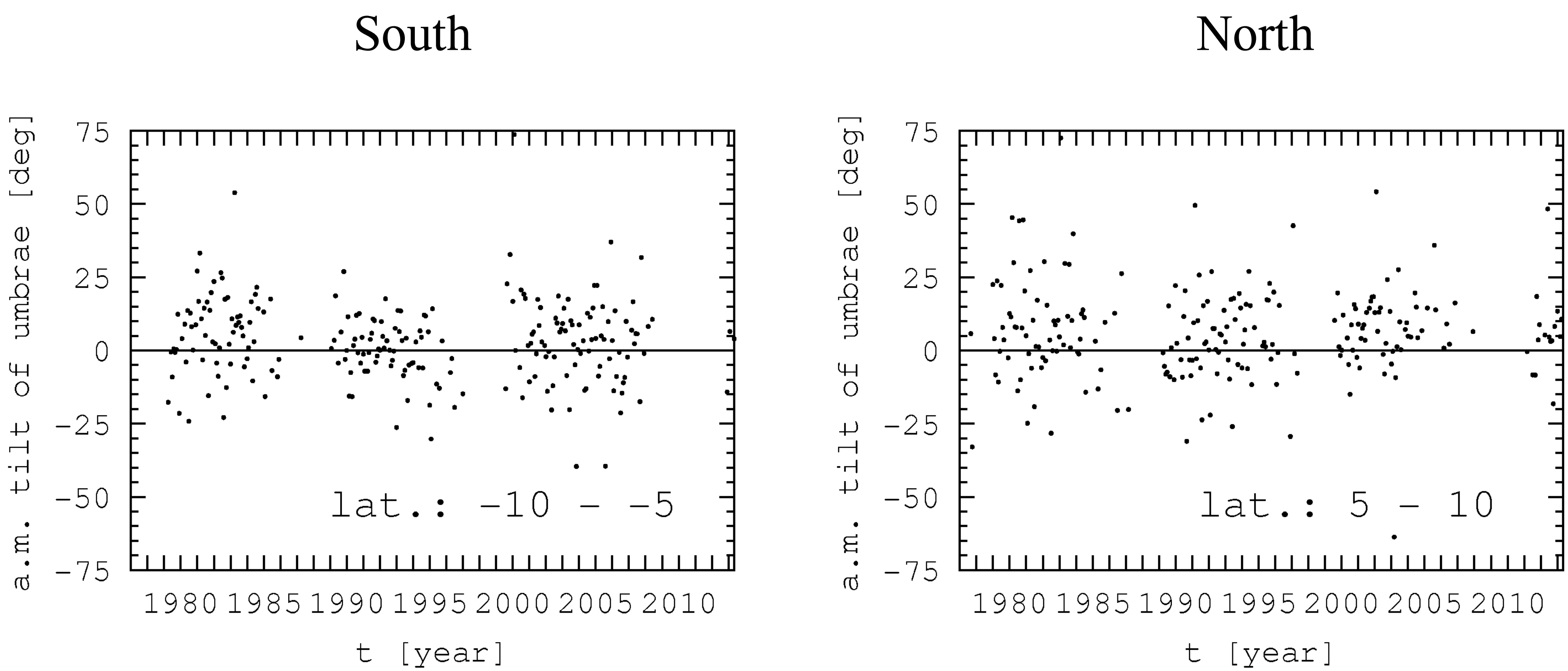
Monthly mean tilt angles of sunspot groups at their maximum sizes in 5° latitudinal bins
Cycles 21-24



Muraközy, J.
thesis 2014

cause

Monthly mean tilt angles of sunspot groups at their maximum sizes in 5° latitudinal bins
Cycles 21-24

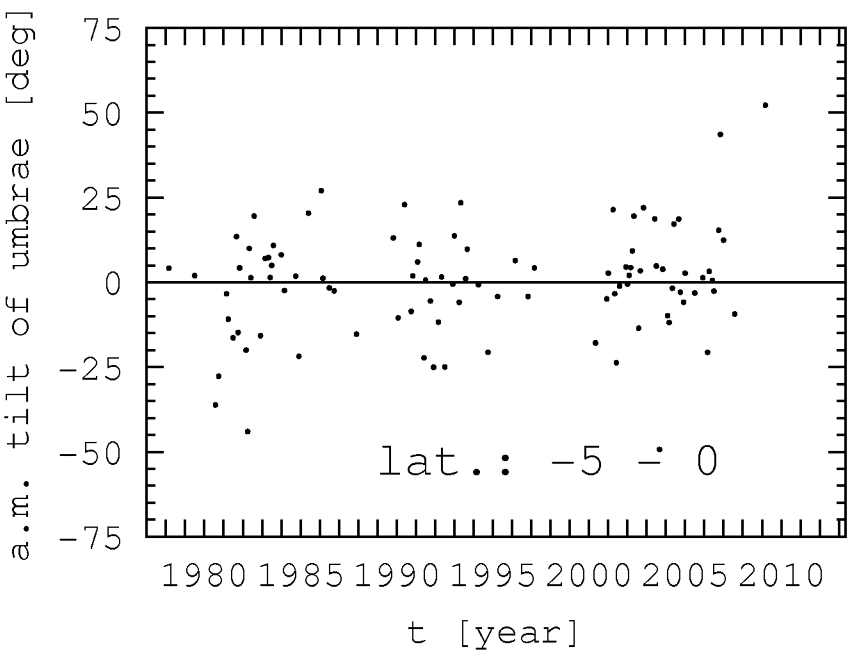


Muraközy, J.
thesis 2014

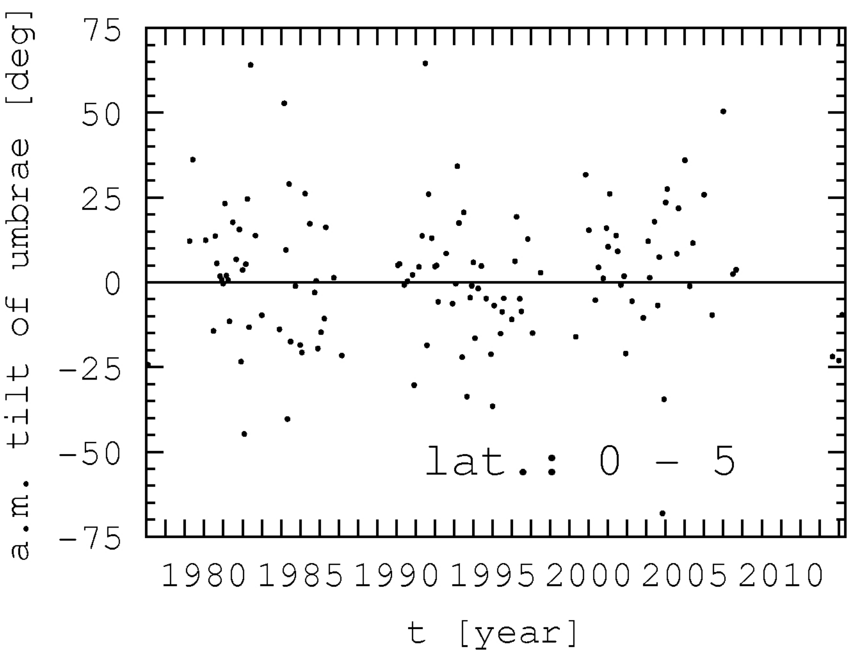
cause

Monthly mean tilt angles of sunspot groups at their maximum sizes in 5° latitudinal bins
Cycles 21-24

South



North



Muraközy, J.
thesis 2014

What may have impact on the tilts?

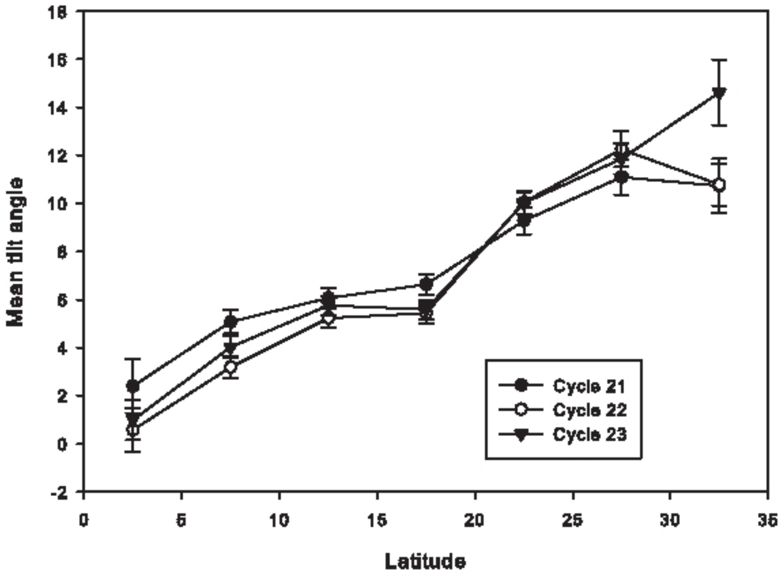
large scale magnetic field?

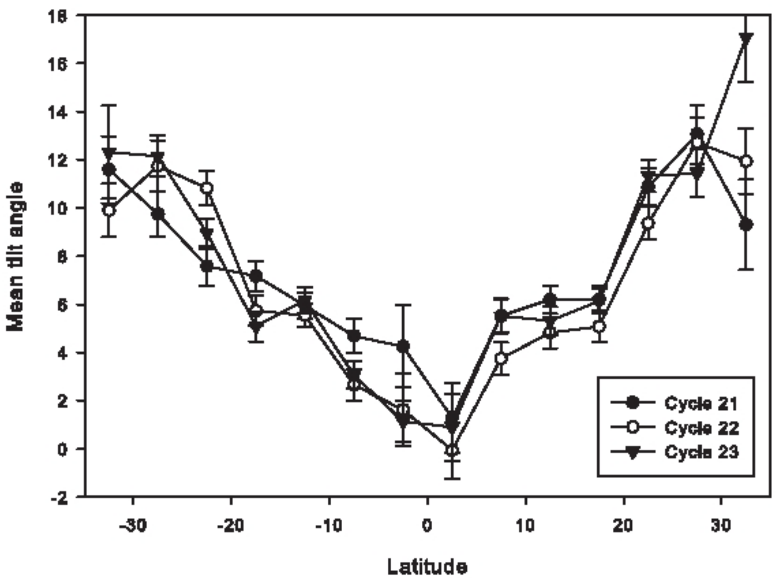
flux density at the root?

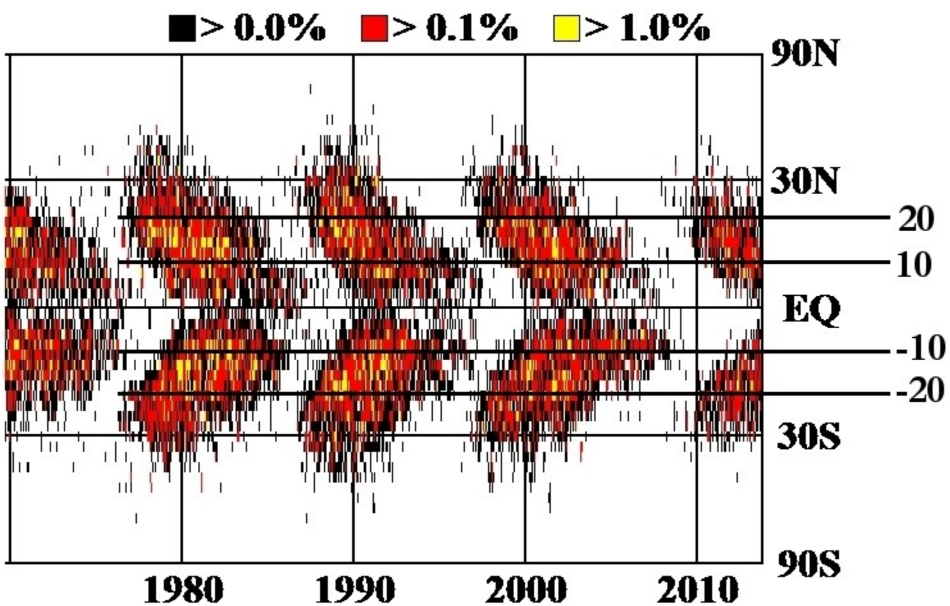
Baranyi, T., 2015, *MNRAS*, **447**, 1857B :

Fan, Y., Fisher, G.H., McClymont, A.N., 1994, *ApJ*, **436**, 907 :

$$\alpha \propto \sin\,\theta_{\rm em} B_0^{-5/4} \Phi^{1/4}$$







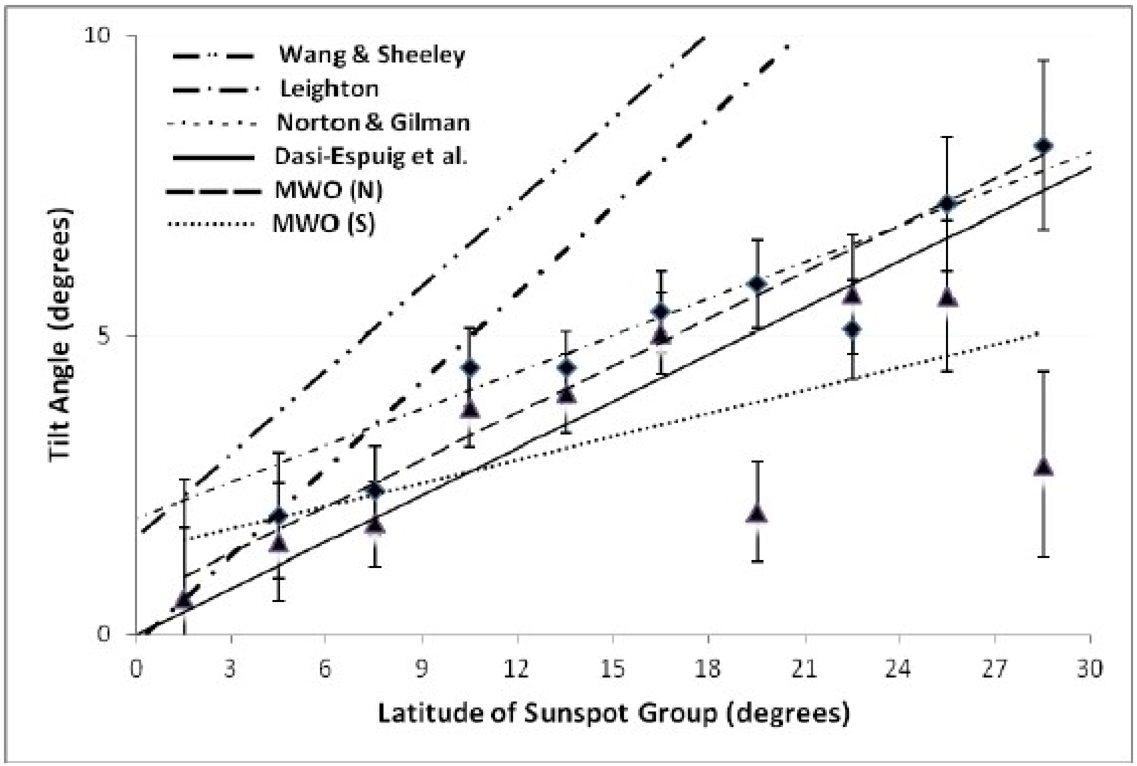
What may have impact on the tilts?

impact

large scale magnetic field?

flux density at the root?

Mc Clintock, B.H., Norton, A.A.: 2013, *SPh*, **287**, 215



$$\sin\gamma = 0.48\sin\theta + 0.03$$ Wang & Sheeley 1991

$$\sin\gamma = 0.5\sin\theta$$ Leighton, 1969

$$\gamma = 0.2\theta + 2.0$$ Norton & Gilman, 2005

$$\gamma = (0.26 \pm 0.05)\theta$$ Dasi-Espuig et al. 2010

$$\gamma_N = 0.26\theta + 0.58 \ \ (\text{or } \sin\gamma_N = 0.271\sin\theta + 0.010)$$

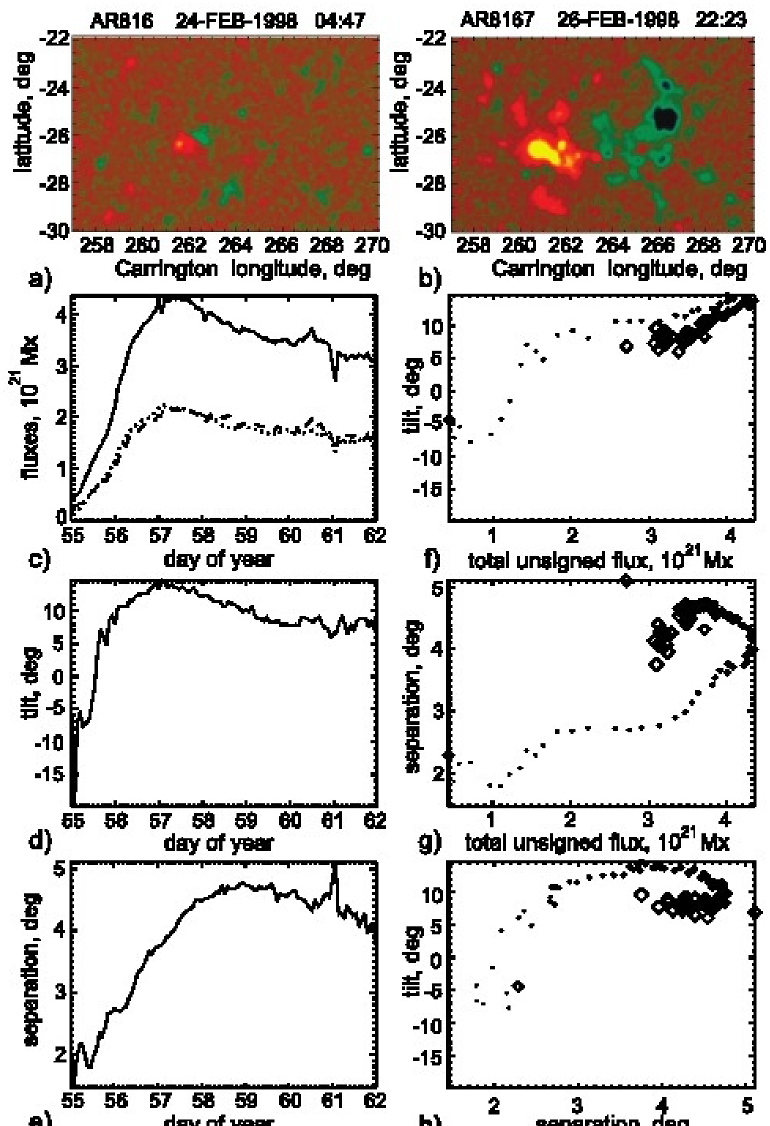
$$\gamma_S = 0.13\theta + 1.38 \ \ (\text{or } \sin\gamma_S = 0.425\sin\theta + 0.024)$$

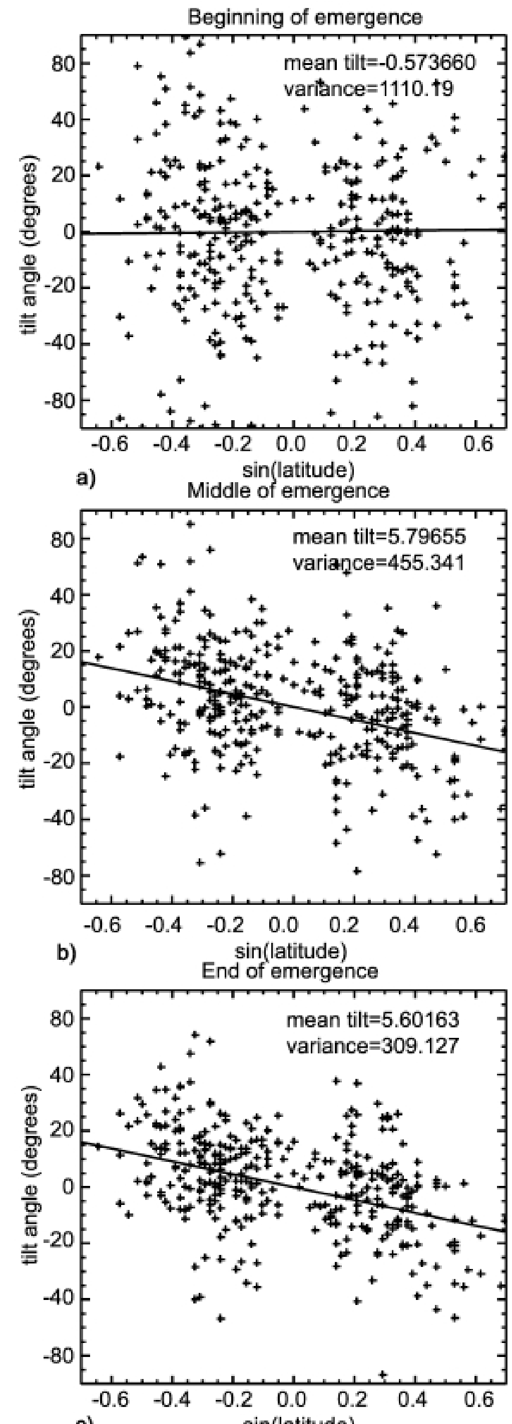
Mc Clintock & Norton, 2013

What may have impact on the tilts?
evolutional state?

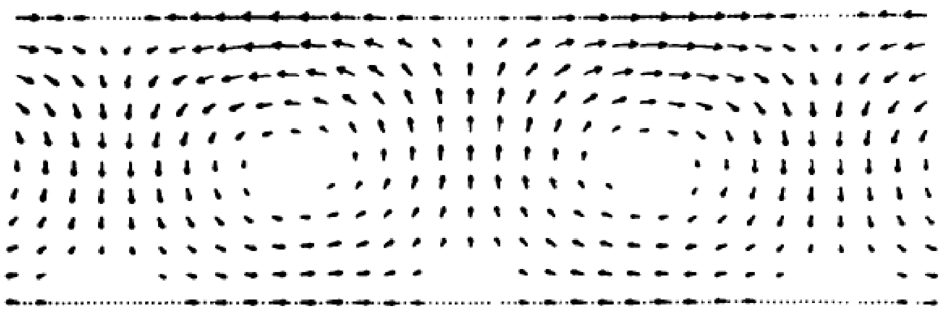
impact

Kosovichev & Stenflo, 2008, *ApJ*, **688**, L115

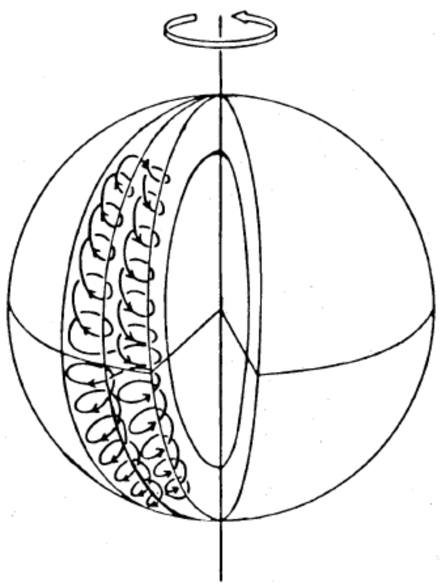




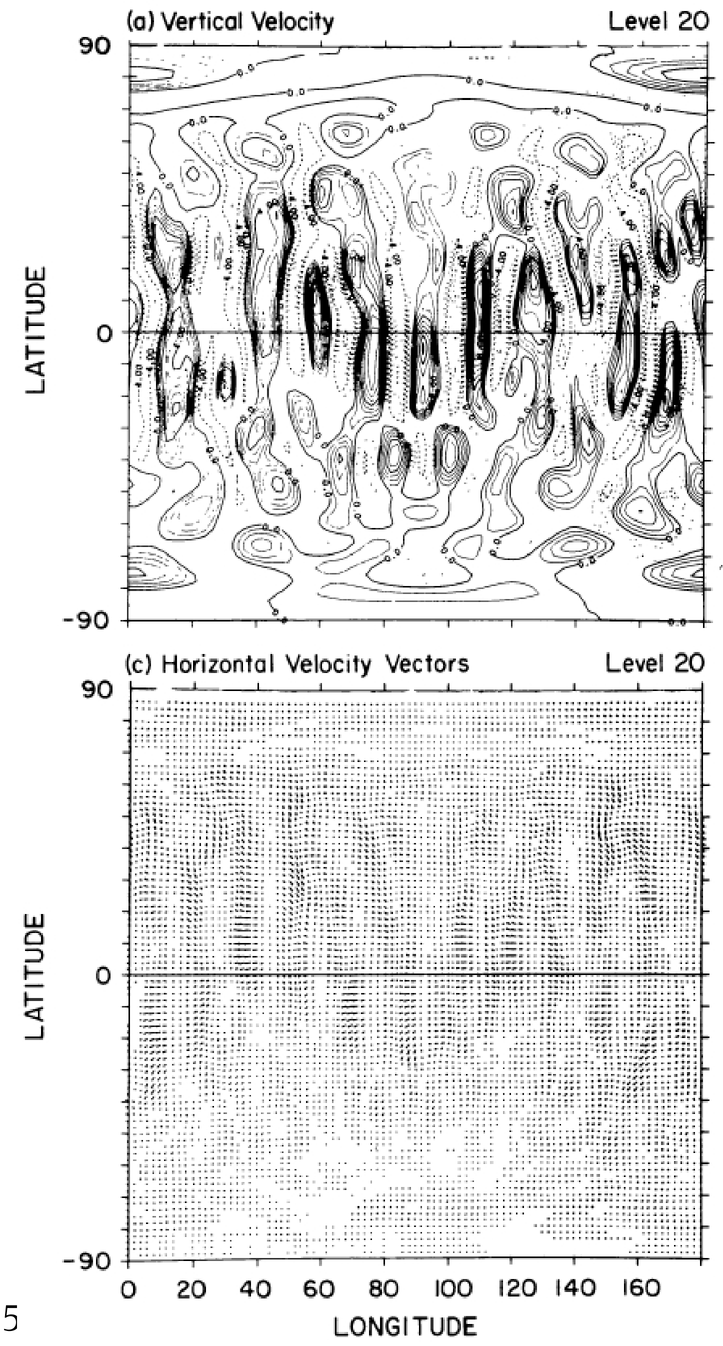
What may have impact on the tilts?
large-scale flow pattern?



Glatzmaier, G.
1985, *ApJ*, **291**, 300



Gilman & Miller
1986, *ApJ*, **61**, 585

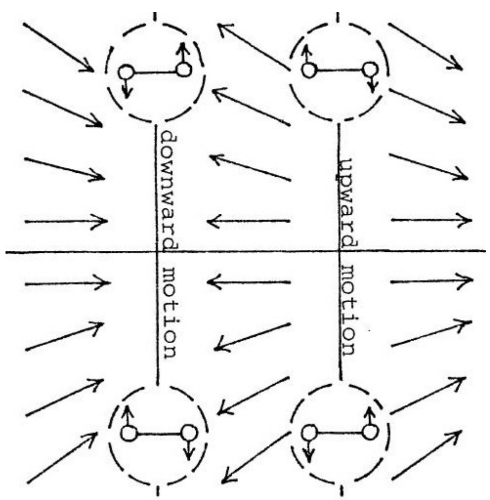


impact

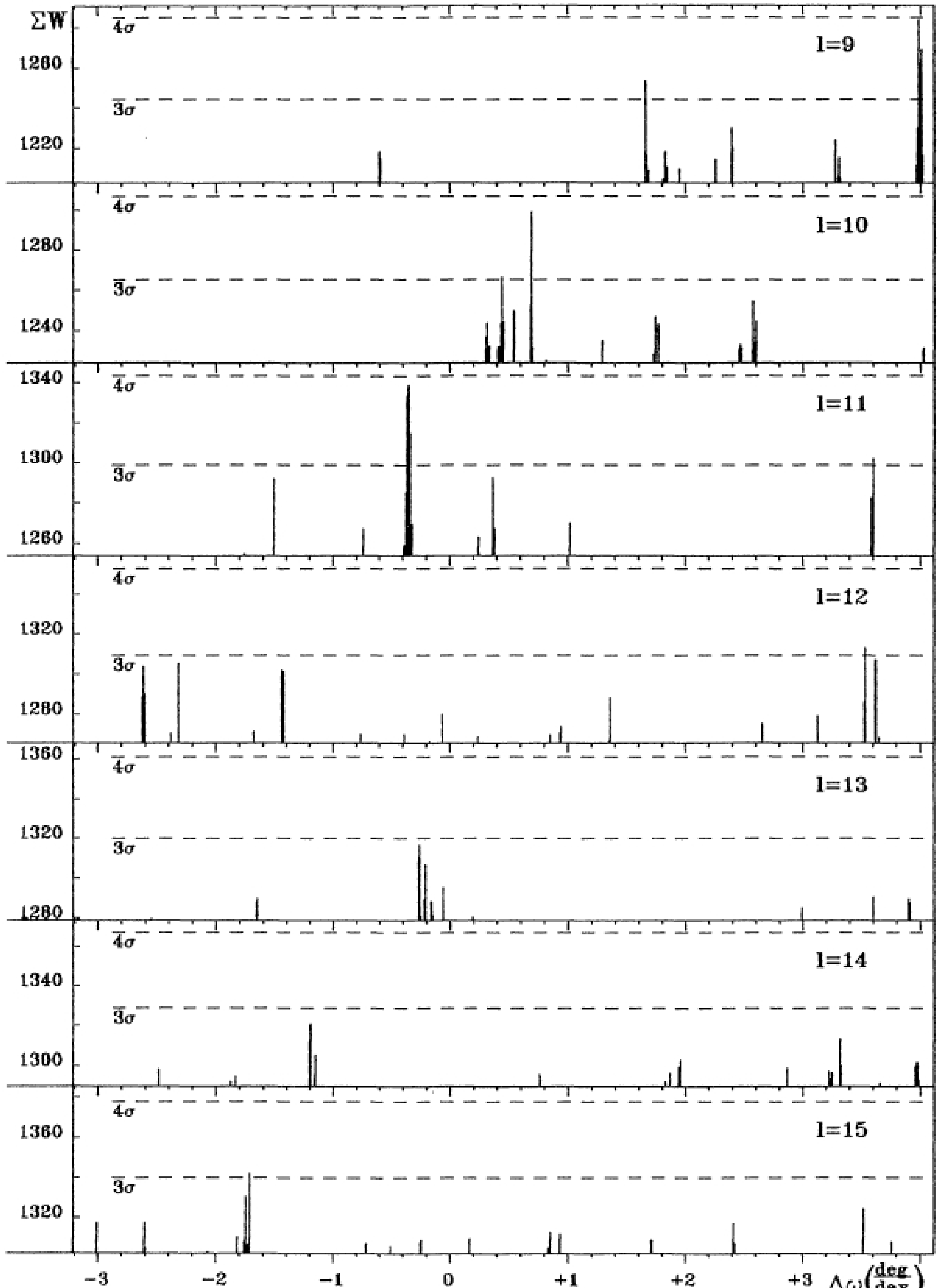
A possible signature: alternating tilts in converging/diverging sectors

Baranyi & Ludmány 1992, *SPh*, , **139**, 247

$$W = \frac{\sum \alpha_i (A_i)^{1/2}}{10}$$



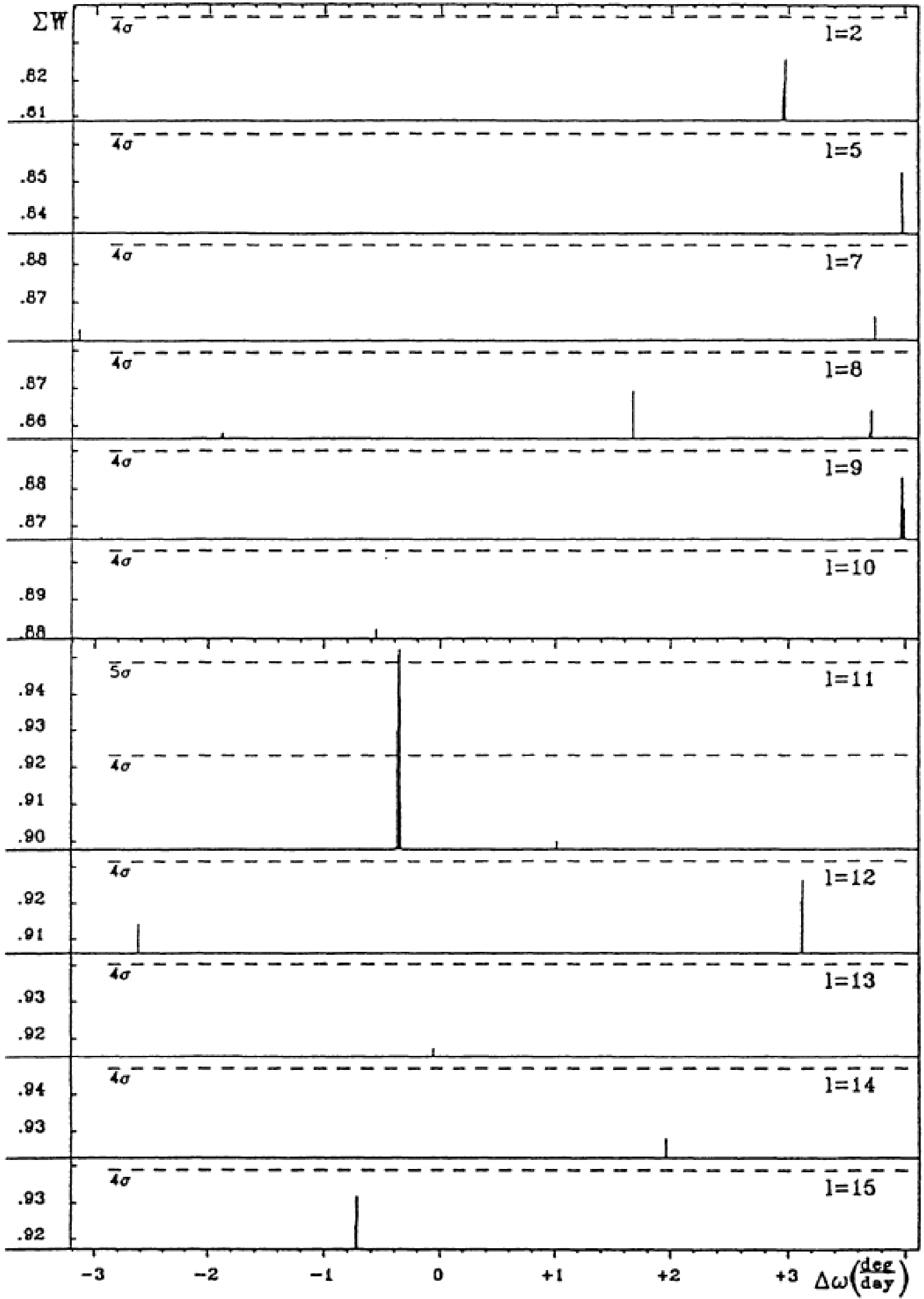
$\Delta\omega = -(0.38\text{–}0.33)$ deg day^{-1}



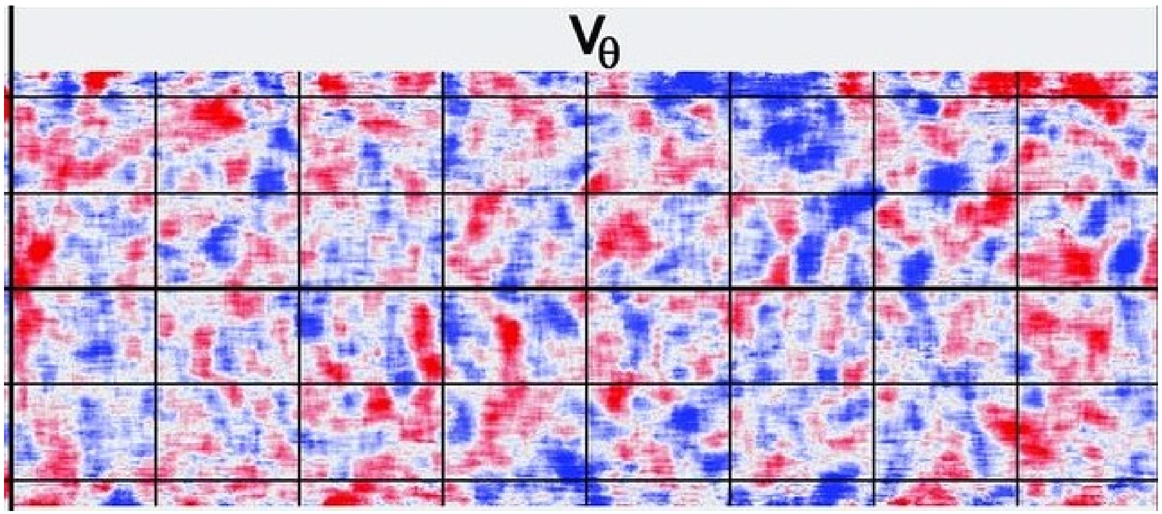
impact

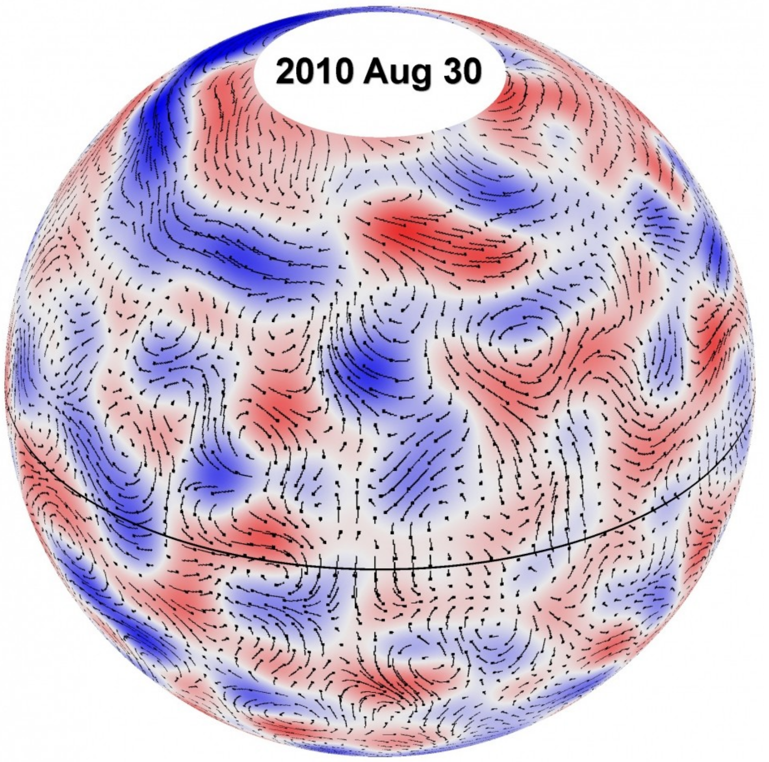
Baranyi & Ludmány
1993, *ASPC* , **40**, 81

$$W = \Sigma\, \alpha_i (A_i)^{0.5}$$



Hathaway, D.H. Upton, L., Colegrove, O.
Science, 2013, **342**, 1217





SUMMARY

What are the reliable tilt angle data?

- for data without magnetic information: L-F separation should be larger than 3°
- for data with magnetic information: appendices of SDD and HMIDD

What is the reliable form of Joy's distribution?

It contains a plateau at about 10° - 20°

What is the cause of the tilts?

The Coriolis impact seems to be dominant.

What may have additional impact on the tilts?

- large scale magnetic field,   it is the cause of the plateau.
- emerging flux amount, its impact is very weak, if any.
- evolutional state,   the tilt angle should be considered at the time of the maximum
- large-scale flow pattern - a possible modifying effect

This work has received funding from the European Community's Seventh Framework Programme (FP7/2012-2015) under grant agreement No. 284461 (eHEROES).

The authors acknowledge the significant contribution of Norbert Nagy to the compilation and presentation of the tilt angle databases

Thank you for your attention