Relationship between steepnes of the solar differential rotation and activity

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INTRODUCTION.

Numerical models: an increase in magnetic field - reduction of differential rotation Brun et al., ApJ, 614 (2004), 1073; Lanza, MNRAS, 373 (2006), 819; Lanza, A&A, 471 (2007), 1011

strong magnetic fields **(activity maximum)**

less efficient transport of angular momentum towards the equator

weaker magnetic fields **(activity minimum)**

more efficient transport of angular momentum towards the equator

THEORETICAL INTERPRETATION (ACTIVITY MINIMUM):

a) increased equatorial rotation - **larger differential rotation parameter *A*** (Eq. 2)

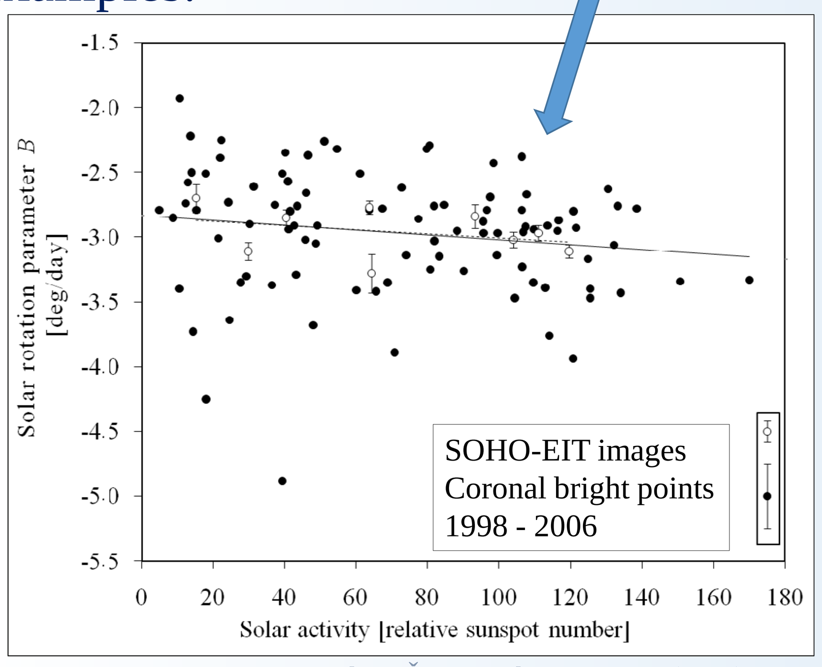
b) more pronounced differential rotation - **larger absolute value of parameter *B*** (Eq. 2)

PUBLISHED EXPERIMENTAL RESULTS

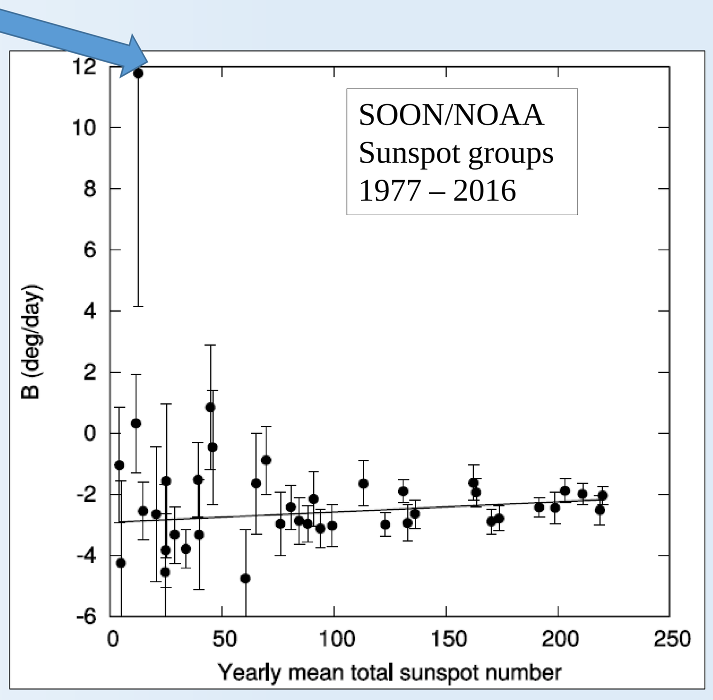
Behaviour of *A* - **in accordance** with the theoretical predictions

Behaviour of *B* - **is not conclusive**

Examples:



R. Jurdana-Šepić et al., A&A, **534** (2011), A17



D. Ruždjak et al., *Sol. Phys.*, **292** (2017), 179

METHODS.

Two procedures for determination of the heliographic positions of sunspot groups:

INTERACTIVE PROCEDURE (1964 - 2008) KSO sunspot drawings

special software *Sungrabber*

Hržina et al., CEAB, 2007, 31, 273

AUTOMATIC PROCEDURE (2009 - 2016) KSO white light images

the algorithm for automatic recognition of sunspot groups - morphological image processing

Watson, F. & Fletcher, L.,2011, in Physics of Sun and Star Spots, eds. D. Prasad Choudhary, & K. G. Strassmeier, IAU Symp., 273, 51

Rotation velocities were calculated by **daily-shift method (DS)**

$$\omega_{syn} = \frac{\Delta CMD}{\Delta t} \quad \text{(Eq. 1)}$$

Angular rotation velocities were converted from synodic to sidereal ones (Brajša, R. et al. 2002, Sol. Phys., 206, 229;, Skokić, I. et al. 2014, Sol. Phys., 289,1471).

The solar differential rotation

$$\omega(b) = A + B\sin^2 b \quad \text{(Eq. 2)}$$

b – heliographic latitude,
A – equatorial rotation velocity,
B – gradient of the differential rotation

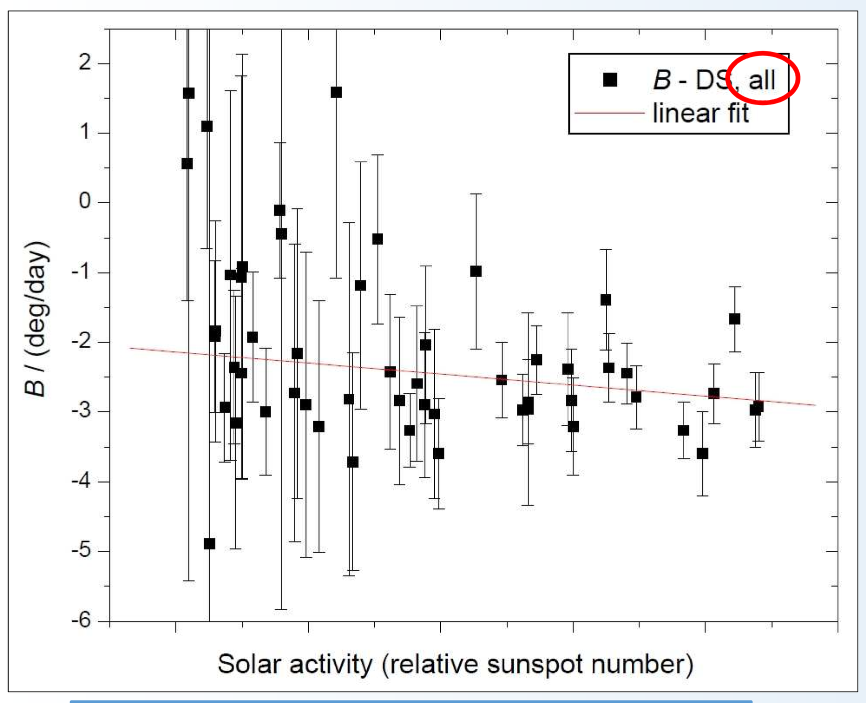
- parameters A and B - calculated for each year in the timespan 1964 – 2016 (solar cycles nos. 20 - 24)
- both solar hemispheres were treated together
- a measure for the solar activity of a given year - the recalibrated yearly mean total sunspot numbers* (Clette et al. 2014, 2015a,b)**

AIM.

- **to gain more insight into these discrepancies** between observations and theoretical predictions
- preliminary results from the Kanzelhöhe Observatory for Solar and Environmental Research (KSO) - sunspot group position data, 1964 – 2016

RESULTS.

Weighted least-squares fits of yearly values of solar differential rotation parameter *B* vs. relative sunspot number as the indicator of the solar activity:



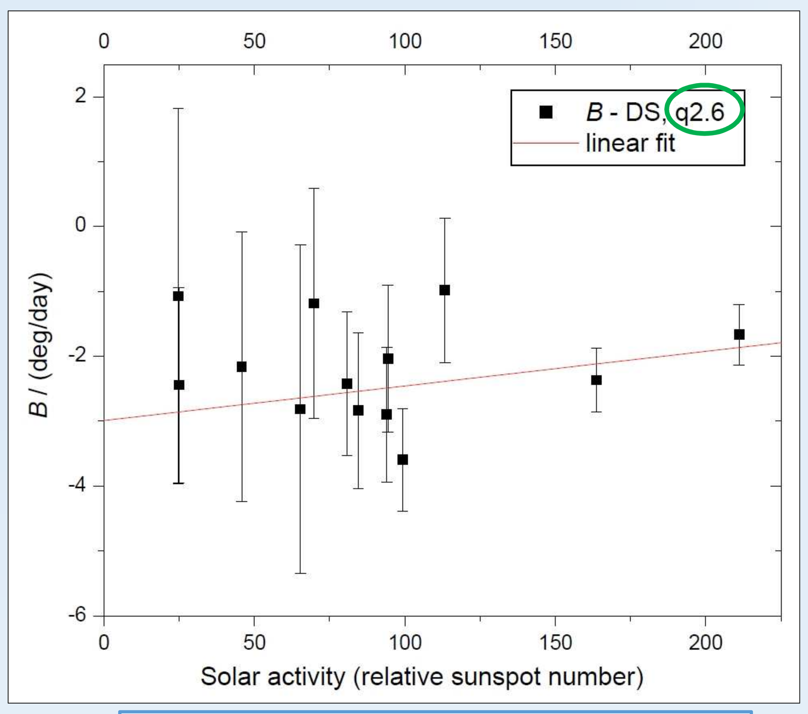
- **NOT in accordance with theoretical assumptions**

Table 1 - Statistics

Quality	Slope *B*	*N*	*r*	*P*
ALL	-0.0012 ± 0.0019	40	-0.1053	0.5179
q3.0	-0.0013 ± 0.0019	36	-0.1188	0.4902
q2.9	-0.0013 ± 0.0019	35	-0.1104	0.5279
q2.8	0.0002 ± 0.0022	28	0.0154	0.9379
q2.7	-0.0005 ± 0.0024	21	-0.0488	0.8335
q2.6	0.0053 ± 0.0033	13	0.4430	0.1295

Slope *B* – slope of the linear fit; *N* – number of years/dots; *r* – correlation coefficient; *P* – corresponding *p*-value

After applying quality filter according to Figure 11 (W. Pötzi et al. Sol Phys (2016) 291, 3103)



- **in accordance with theoretical assumptions**

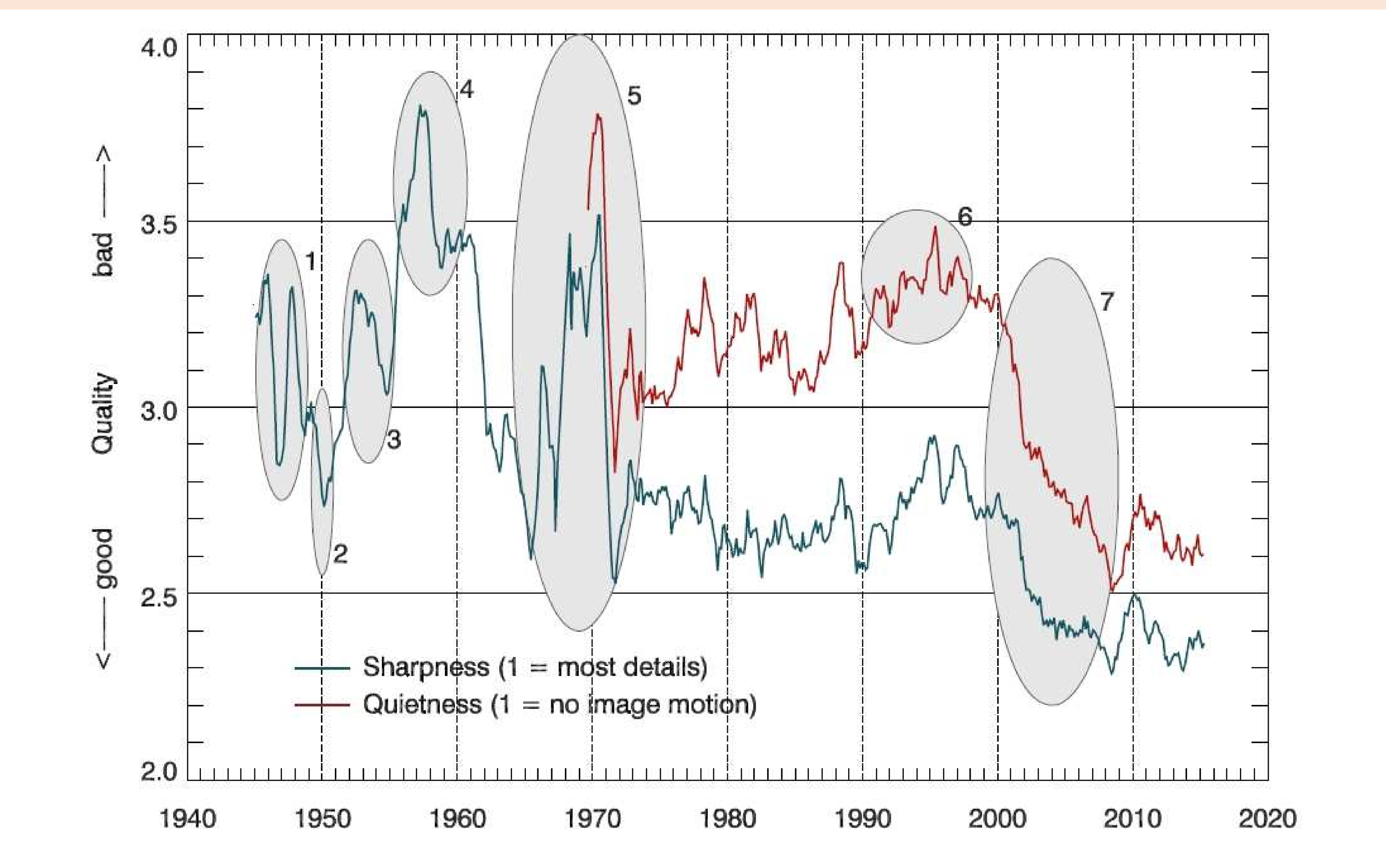


Figure 11 Yearly running mean of sharpness and quietness values of the past seven decades; the quietness is almost proportional to the sharpness. The ellipses indicate the times of major changes in the observational conditions.

W. Pötzi et al. Sol Phys (2016) 291, 3103

Yearly image quality at KSO (1945 – 2015): the change in seeing conditions over the past seven decades of observations

The quality defined through the **sharpness:**

1 (good) - the granulation is clearly visible and even details inside the umbra can be observed,

3 (bad) - the granulation pattern is no longer recognizable.

CONCLUSIONS.

Standard errors of parameters *A* and *B* (both hemispheres together):

Whole period (1964 – 2016) or cycle periods

A: 0.01 - 0.03 deg/day

B: 0.10 - 0.30 deg/day

Annual values

A: 0.04 - 0.30 deg/day

B: 0.40 - 3.00 deg/day

considerably higher values

Standard error for *B* is 10 times higher than the one for *A* – sometimes *B* shows correlation sometimes anticorrelation with solar activity.

Calculation of the slope of linear fit is sensitive on image quality and standard error of individual values of *B*. So, it is necessary to use:

- weigthed least-squares fits,
- image quality filters.

Result for quality filter q2.6 shows insignificant positive correlation, but the highest value of correlation coefficient (*r* = 0.44) and the most acceptable p-value (0.13). This indicates a medium correlation and consistency with theoretical assumptions.

ACKNOWLEDGEMENTS.

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* The version 2.0 of the data series provided by SILSO World Data Center (2015), Royal Observatory of Belgium, Brussels

** Clette, F. et al., 2015a, IAU General Assembly, 22, 2249591
Clette, F. et al., 2014, Space Sci. Rev., 186, 35
Clette, F. et al., 2015b, Revisiting the Sunspot Number, ed. A. Balogh, H. Hudson, K. Petrovay, & R. Von Steiger, 35