The N-S-asymmetry of the different magneto-morphological types active regions in the 23rd and 24th solar cycles

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The SOHO/MDI & EIT, SDO/HMI & AIA data (http://jsoc.stanford.edu); websites www.helioviewer.org, www.solarmonitor.org; the Debrecen Photoheliographic Data (http://fenyi.solarobs.csfk.mta.hu/DPD); the catalog Magneto-morphological classification (MMC) of active regions (ARs) of CrAO (https://sun.crao.ru/databases/catalog-mmc-ars); and the Royal Observatory, Greenwich – USAF/NOAA Sunspot Data (https://solarscience.msfc.nasa.gov/greenwch.shtml) were used to study N-S-asymmetry of ARs in solar cycles (SC) 23 and 24.

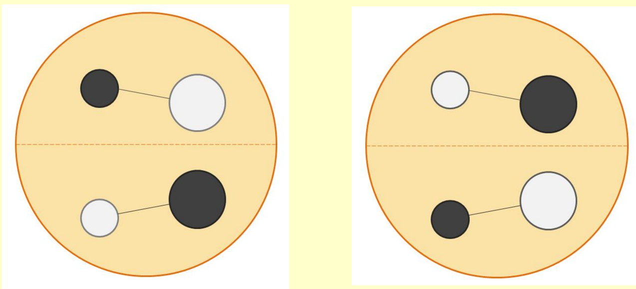
According to the empirical rules for sunspot groups [1,2], magnetic-cycle models [3,4], the mean-field dynamo theory [5], properties of ARs [6], and MMC of ARs CrAO [7–9], 2046 ARs of the SC 23 and 1507 ARs of the SC 24 (from 1996 to 2018) were divided into three categories: A-type – regular bipolar ARs; B-type – irregular bipolar (multipolar) ARs, violating either Hale polarity law or Joy's law or having the leading spot less than the main following spot; U-type – unipolar spots (that were not considered in the following study).

Magneto-morphological classes of ARs

Regular ARs

are bipolar groups that follow classical empirical rules for sunspot groups

A



Odd SCs — Even SCs

Fig. 1. Regular ARs

- **Hale's polarity law:** leading spots of ARs have a negative (positive) polarity in the N-(S-) hemispheres [1];
- **Joy's law:** a leading (westward) spot is usually located closer to the equator than the following one; the average tilt becomes steeper with increasing latitude and its value does not exceed 20° [1,10];
- **Prevalence of a leading sunspot:** an area of the leading spot usually exceeds an area of the main following spot (ratio 3:1) [2,6].

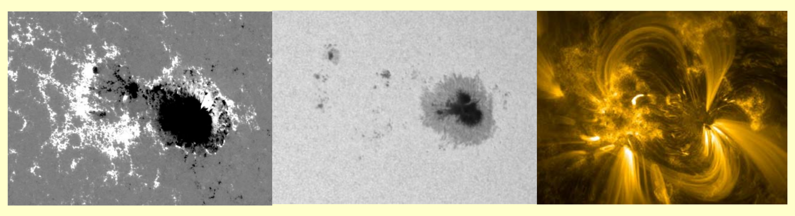


Fig. 2. Regular AR 12529; **SC 24, N-hemisphere** (SDO magnetogram, continuum, Fe IX/X 171 Å)

Irregular ARs are bipolar (multipolar) groups that violate at least one classical empiric rule

B

Violation of **Hale's polarity law (HN)**

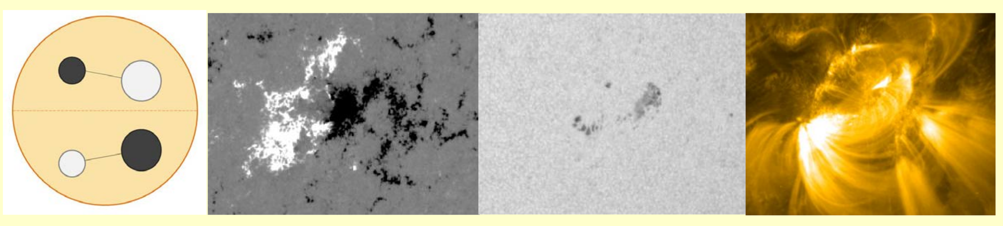


Fig. 3. AR 12401; **SC 24, S-hemisphere**

Violation of **Joy's law (JN)**

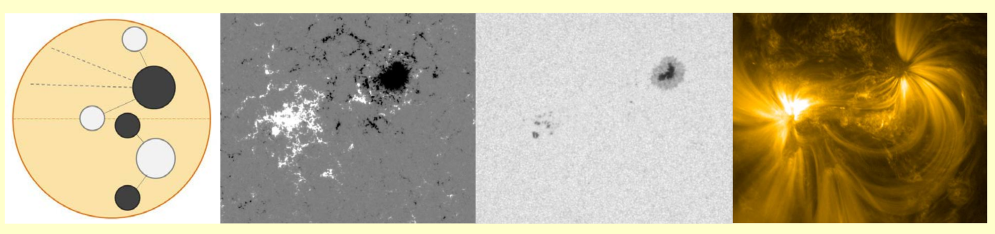


Fig. 4. AR 12135; **SC 24, N-hemisphere**

Violation of **leading sunspot prevalence rule (LN)**

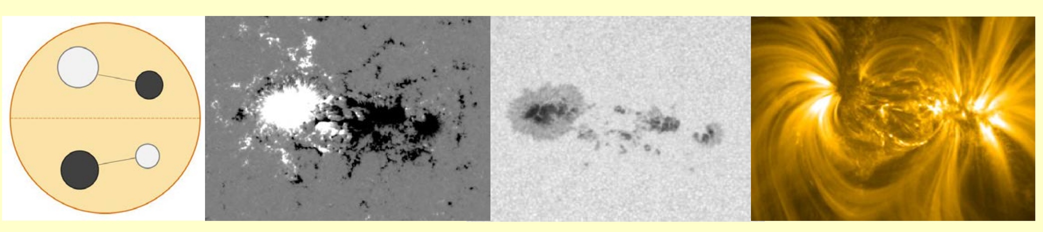


Fig. 5. AR 11946; **SC 24; N-hemisphere**

Violation of **bipolar structure (multipolar ARs)**

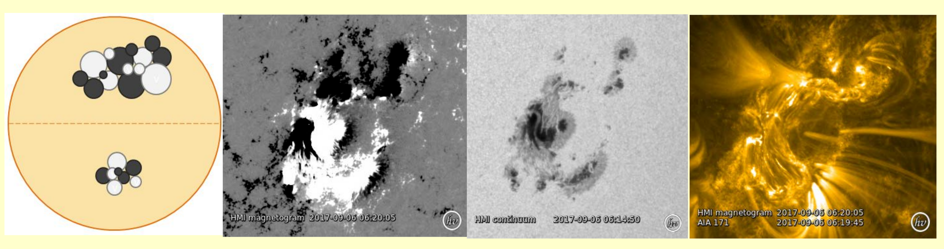


Fig. 6. AR 11946; **SC 24; S-hemisphere**

Statistics

Regular ARs make up about 50%; irregular ARs – about 25% of all sunspot groups in SCs 23 [11] and 24 [7].

The existence of **regular ARs** is **consistent with** classical **magnetic cycle models** [3,4] and the mean-field dynamo theory [5]. Quite a large number of irregular groups require an explanation.

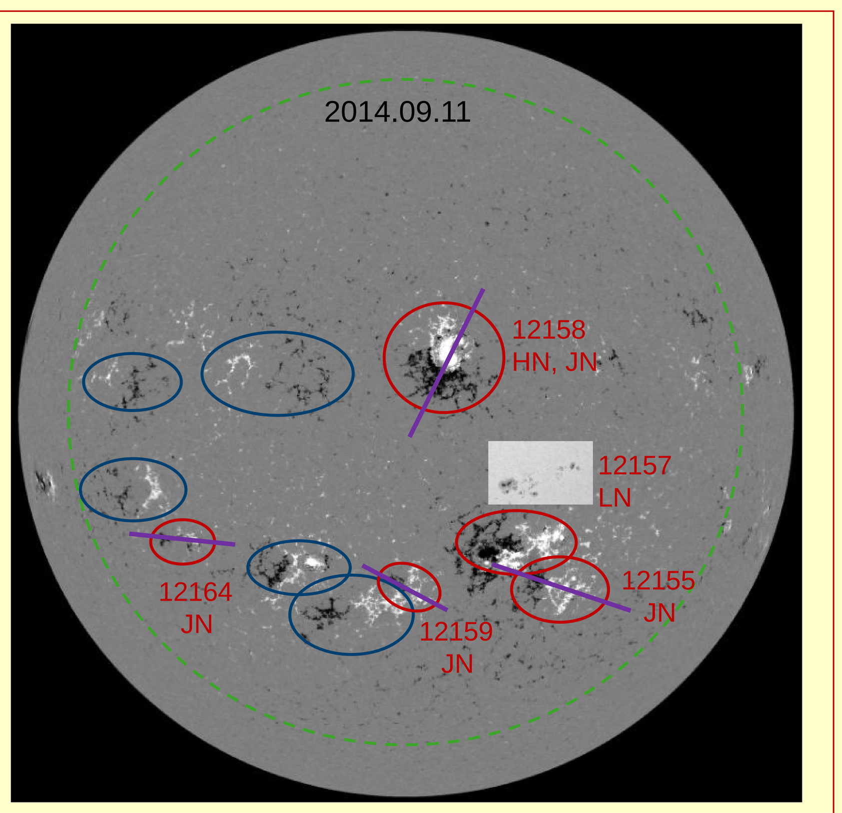
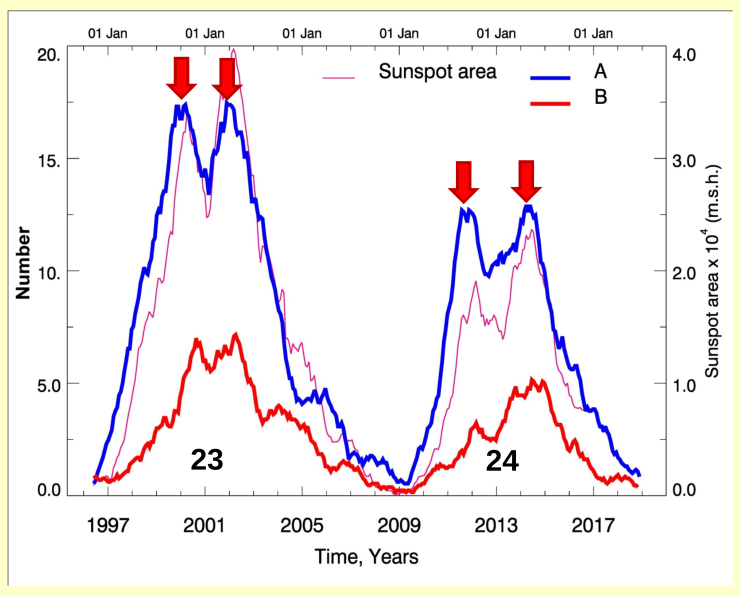


Fig. 7. HMI full-disk magnetogram with different type-ARs; **SC 24**

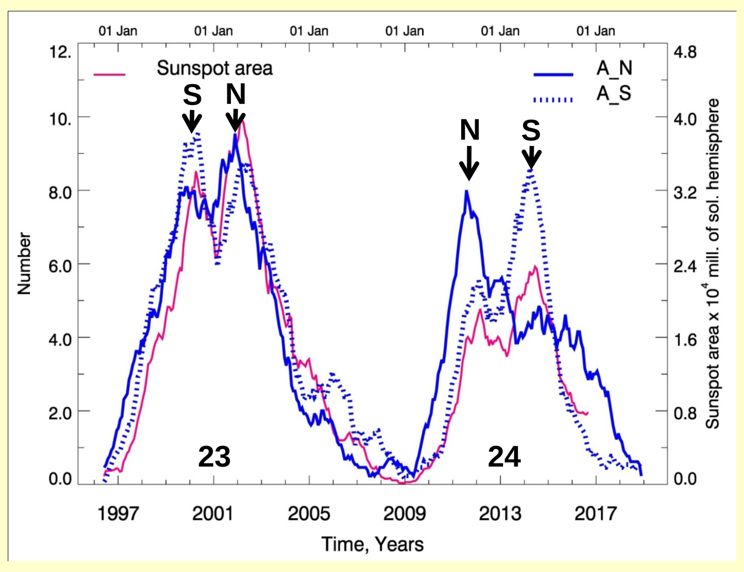
Cyclic variations of regular/irregular ARs



✓The contribution of the number of **regular** ARs during the cycle **is 2-5 times greater** than that of the irregular groups.
✓The **two-maximum pattern** in number of regular ARs **is similar** for both cycles.
✓The **irregular groups** are observed mainly in the **second maximum**.

Fig. 8. Total number of regular (A) and irregular (B) ARs per solar rotation; total area of sunspots (pink line) shows the cycle progress. The data are smoothed per 13 rotations.

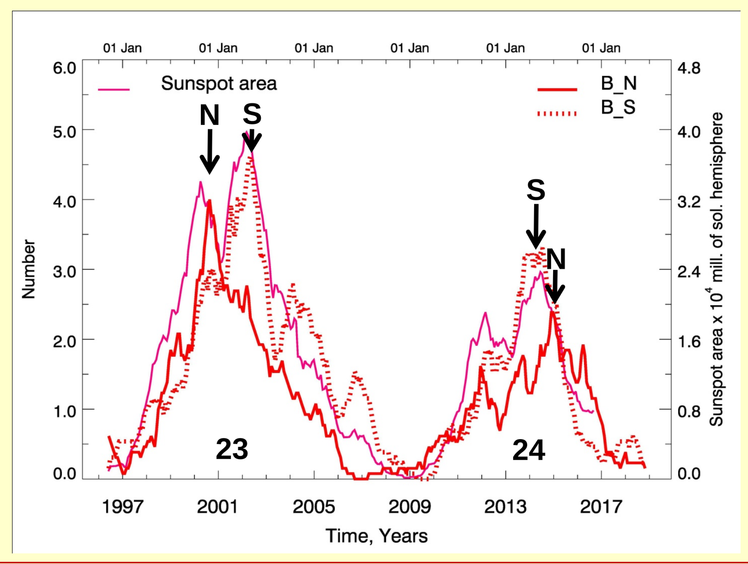
N-S-asymmetry of regular ARs



✓In each of the hemispheres, **the peaks** in the two maxima of each cycle **are different**.
✓In the **SC 24**, **the difference** between the peaks is **greater**.
✓**The sequence** of the peaks is **different**:
SC 23 **S → N**
SC 24 **N → S**

Fig. 9. Total number of regular ARs in the N- (solid line) and S-hemispheres (dashed line) and the total sunspot area.

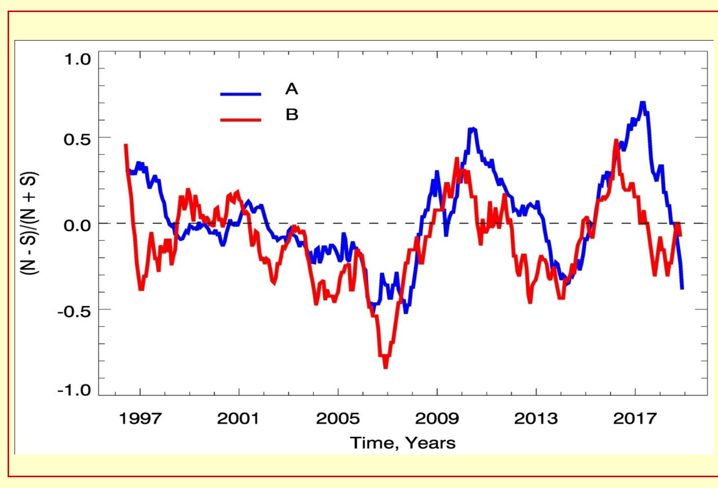
N-S-asymmetry of irregular ARs



✓In **SC 23**, the observed **order of the peaks** (relative to the regular groups) **is reversed**:
regular ARs **S → N**
irregular ARs **N → S**
✓In **SC 24**, the expected **order is broken**:
regular ARs **N → S**
irregular ARs **S → !S!**

Fig. 10. Total number of irregular ARs in the N- (solid line) and S-hemispheres (dashed line) and the total sunspot area.

Normalized asymmetry index



✓In **SC 23**, the regular and irregular ARs prevail in different hemispheres; then all the activity moves to the S-hemisphere.
✓In **SC 24**, there are repeated transitions of activity from hemisphere to hemisphere for ARs of both MMC classes.

Fig. 11. Asymmetry index for regular (A) and irregular (B) ARs.

Conclusions

*1. **The increase in the number of irregular ARs during the second maximum** of the cycle (Fig. 8) may be due to the **loss of regularity** (weakening) of the **toroidal magnetic field** with cycle progress, which might lead to the manifestation of **other mechanisms** besides the global dynamo (for instance, **the fluctuation dynamo**).*

*2. The **two maxima** of the SC **are formed** in the N-and S-hemispheres **due to ARs of different MMC classes**; **the order of extremes** for regular and irregular groups in the studied SCs **is different** (Figs. 9, 10).*

*3. **The increase** in the number of **irregular ARs in the S-hemisphere** (Fig. 10) might be the result of an **additional weakening of the toroidal field** due to the interaction of dipole and quadrupole components (their mutual orientation provides strengthening/weakening of the total field). Such a weakening might also **enhance the contribution of the fluctuation dynamo** in their interplay with the global dynamo.*

*4. **The predominance of the number of regular or irregular ARs** in one or the other hemisphere during the SC (Fig. 11) might occur due to the **changing of mutual orientation of the dipole and quadrupole components** of the magnetic field more often than once per cycle (the periods of the components can be different [12]).*

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The classification of ARs by AZh was supported by the RSF (Project 18-12-00131). VA thanks the MSHE of RF (Research 0831-2019-0006). The work of AKh was supported by the basic financial program of the FSR II.16. AKh thanks the support of the RFBRs grant 19-52-45002.

The catalog Magneto-morphological classification of ARs
http://sun.crao.ru/databases/catalog-mmc-ars