



# 27-DAY VARIATION OF THE THREE DIMENSIONAL SOLAR ANISOTROPY OF GALACTIC COSMIC RAY: 1965-2014

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## ABSTRACT

The temporal evaluation of the 27-day variation of the three dimensional (3D) galactic cosmic ray (GCR) anisotropy has been studied for 1965-2014. 3D anisotropy vector was obtained based on the neutron monitors and Nagoya muon telescopes data. We analyze the 27-day variation of the (1) two dimensional (2D) GCR anisotropy in the ecliptic plane, and (2) north-south anisotropy normal to the ecliptic plane. Studying the time line of the 27-day variation of the 2D GCR anisotropy, we confirm that the average amplitude in the minimum epoch of solar activity is polarity dependent, as it is expected from the drift theory. The amplitude in the negative polarity epochs is less as we had

shown before. The feeble 11-year variation connected with solar cycle and strong 22-year pattern connected with solar magnetic cycle is visible in the 27-day variation of the 2D anisotropy for 1965-2014. We show that the 27-day variation of the  $GG$  index (being a measure of the north-south asymmetry) varies in accordance to solar cycle with a period of 11-years, being in good agreement with the 27-day variation of the  $At$  component of the GCR anisotropy calculated by the IZMIRAN group. Detailed analysis are presented for the solar cycles no. 23 and 24.

## LONG TERM CHANGES OF THE 27-DAY VARIATION OF THE GCR ANISOTROPY

We investigate the two dimensional (2D) case of the GCR anisotropy vector being the projection of the vector  $A$  on the ecliptic plane ( $A_r$ ,  $A_f$ ). Using harmonic analysis method we calculated the amplitudes of the 2D 27-day variations of the GCR anisotropy ( $A_{27A}$ ), [Alania et al., 2008] for Climax, DeepRiver, Kiel, Moscow and Oulu NMs for each Sun's rotation period during 1965-2014. Amplitudes  $A_{27A}$  of the 2D GCR anisotropy for individual NMs are compared with the 27-day variation of the GCR anisotropy vector (for 10 GV particles) calculated using Global Spectrographic Method (GSM) by the cosmic ray laboratory of IZMIRAN combining all NMs (<http://helios.izmiran.troitsk.ru/cosray/main.htm>).

The next goal is to study the periodic character of the

north-south component of the GCR anisotropy. It is performed by two different approaches: (1) using  $At$  component obtained by GSM and (2) using  $GG$  index being the measure of the north-south anisotropy [Mori and Nagashima, 1979; Munakata et al., 2014],  $GG = \frac{1}{2}[(49N - 49S) + (49N - 49E)]$ . Subsequently using harmonic analysis method we calculated the amplitudes of the 27-day variations of the  $GG$  index ( $A_{27GG}$ ) and  $At$  component ( $A_{27At}$ ) being the measure of the north-south anisotropy normal to the ecliptic plane. We compare results for the  $GG$  index with analysis of the  $At$  component obtained by GSM. As far the formulation of the north-south anisotropy is based on the drift model, the  $GG$  index being the measure of the north-south asymmetry is highly anticorrelated with  $By$  component of the IMF. As an example Fig. 2

presents daily  $GG$  index,  $By$  component and the sector structure of the IMF in 2008.

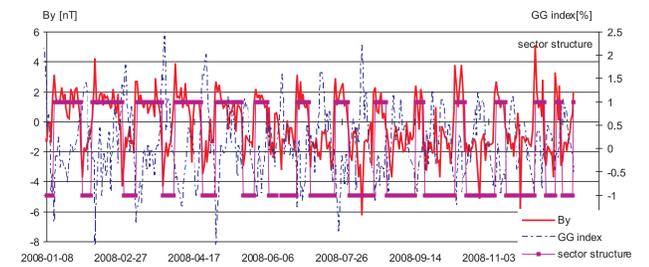


Fig.2. Daily  $GG$  index,  $By$  component and the sector structure of the IMF in 2008.

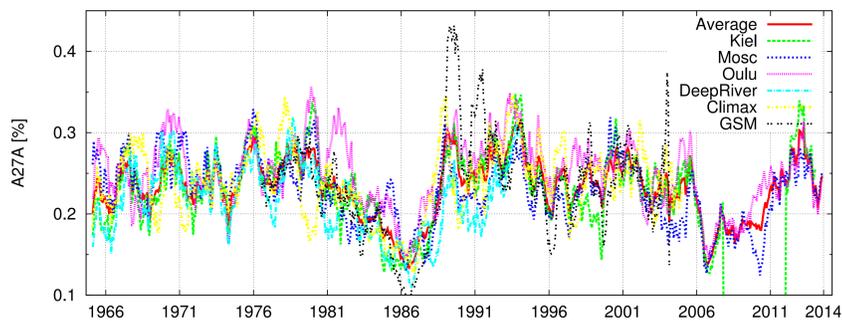


Fig.1. Time line of the amplitudes of the 27-day variation of the 2D GCR anisotropy ( $A_{27A}$ ), smoothed over 13 Sun's rotations, for Climax, DeepRiver, Kiel, Moscow and Oulu individual NMs and for all combining NMs by GSM method for 1965-2014.

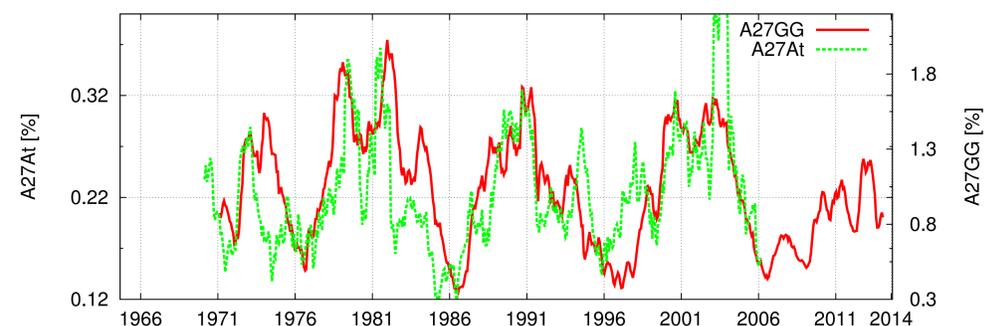


Fig.3. Temporal changes of the smoothed over 13 Sun's rotations amplitudes of the 27-day variation of the  $GG$  index ( $A_{27GG}$ , solid line) and  $At$  component of the 3D anisotropy ( $A_{27At}$ , dashed line).  $A_{27GG}$  is presented for 1970-2014,  $A_{27At}$  - for 1970-2006.

## 27-DAY VARIATIONS IN THE SOLAR CYCLES NO. 23 AND 24

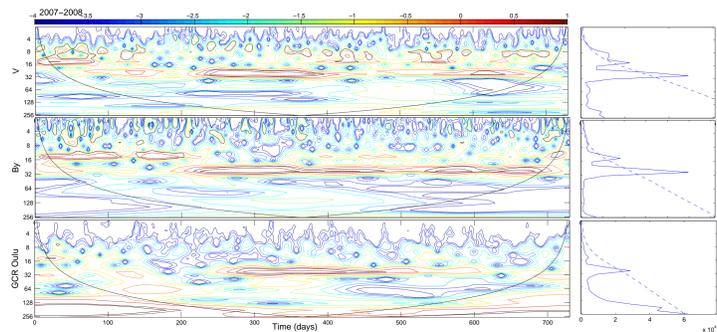


Fig.4. Wavelet analysis of the daily solar wind velocity  $V$  (a),  $By$  component of the IMF (b), GCR intensity for Oulu NM (c) for 2007-2008.

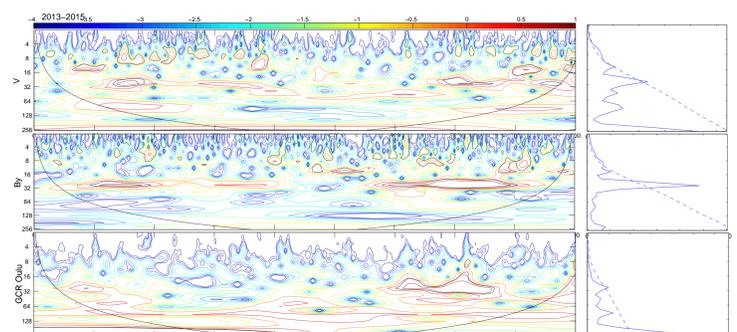


Fig.6. Wavelet analysis of the daily solar wind velocity  $V$  (a),  $By$  component of the IMF (b), GCR intensity for Oulu NM (c) for 2013-2015.

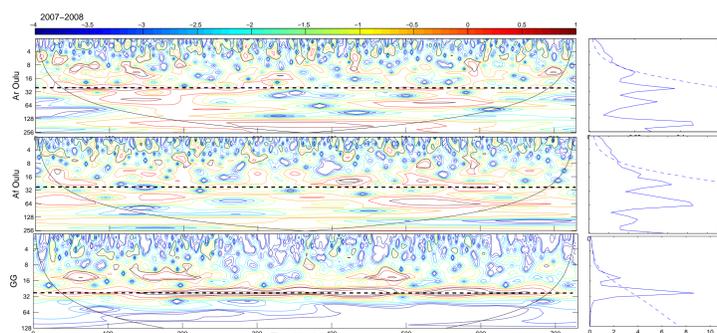


Fig.5. Wavelet analysis of the  $A_r$  (a) and  $A_f$  (b) components of the 2D GCR anisotropy and daily  $GG$  index (c) for 2007-2008. Dashed line designates the period of 27 days.

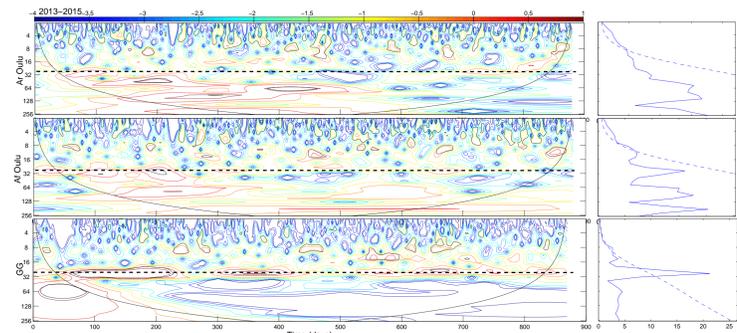


Fig.7. Wavelet analysis of the  $A_r$  (a) and  $A_f$  (b) components of the 2D GCR anisotropy and daily  $GG$  index (c) for 2013-2015. Dashed line designates the period of 27 days.

## CONCLUSIONS

1. The time line of the 27-day variation of the 2D GCR anisotropy confirm that the average amplitude in the minimum epoch of solar activity is polarity dependent, as it is expected from the drift theory. The amplitude in the negative polarity epochs is less as we had shown before. The feeble 11-year variation connected with solar cycle and strong 22-year pattern connected with solar magnetic cycle is visible in the 27-day variation of the 2D anisotropy for 1965-2014.
2. We show that the 27-day variation of the  $GG$  index varies in accordance to solar cycle with a period of 11-years and is almost independent of solar magnetic polarity, being in good correlation with the 27-day variation of the  $At$  component of the GCR anisotropy calculated using the GSM method.
3. We study recurrent variations in 3D GCR anisotropy connected with corotating structures observed in the heliosphere in the Solar Cycles no. 23 and 24. 2D GCR anisotropy generally does not show evident 27-day variation, but in some periods weak recurrent character is visible. This is connected with large dispersion of daily  $A_r$  and  $A_f$  components of the 2D GCR anisotropy. Using wavelet time-frequency method we reveal clear 27-day waves in the  $GG$  index, being the measure of the north-south anisotropy, for almost whole analyzed period.