On quasi-periodicities in cosmic rays and their relationship to those in solar, interplanetary and geomagnetic activity

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***Abstract*. Extended data sets of neutron monitor and muon telescope measurements available until now are reviewed for occurrence of the quasiperiodicities shorter than 11 years. Special attention is paid to those shorter than 27 days. The higher harmonics of that periodicity are computed for different primary energies of cosmic rays and compared with those observed in the solar activity, solar wind speed, components of the interplanetary magnetic field and geomagnetic activity. The third harmonics, namely T∼9 days is discussed for the first time in connection with the coronal holes. The occurre of higher harmonics in cosmic ray time profile checked for different epochs and found to be pres up to the 7th one. Comparison with earlier results the subject is done and possible mechanisms beh these variabilities are discussed.**

***Keywords*: Cosmic rays, neutron monitors, qu periodic variations**

I. INTRODUCTION

Cosmic ray (CR) variability observed from the gro is affected by complex of mechanisms forming primary CR flux at different energies in the heliosph within the Earth magnetosphere and in atmosphere Earth (review e.g. in [1]). The diurnal variation v the fixed frequency is studied for long time (one of first papers is [2]) and remains the subject of resea in connection with IMF configurations in heliosph (out of recent papers e.g. [3-5]). On the other side "high frequency variations" is that of ∼ 27 day per (discussed since long time ago, e.g. in [12]). Its dep dence on solar magnetic field polarity, on IMF and so wind characteristics at different energies of prima is discussed e.g. in [6, 15]. Second harmonics in in planetary and geomagnetic characteristics is studied detail e.g. in [13]. The power spectrum in the freque region between those two is rather complicated, affec by various transitional effects in the heliosphere and magnetosphere. Here we illustrate the power spectra of cosmic ray time series at T<27 days from long time measurements by neutron monitors and muon telescope and discuss the indications of higher harmonics of ∼27 day quasi-periodicity with those of solar, interplanetary and geomagnetic activity.

II. COSMIC RAY POWER SPECTRA

Probably the longest continual data sets from measurements by neutron monitors are those from Climax (medium geomagnetic cut-off), Huancayo/Haleakala (high geomagnetic cut-off). Nagoya muon telescope measurements covers the extended time interval of measurements at higher primary energies. Figure 1 shows the complicated structure of the power spectra of the three long time series.

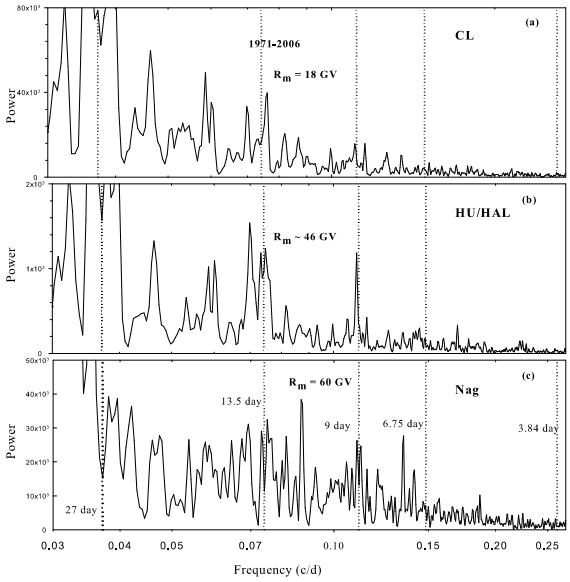

Fig. 1: Power spectrum of daily averages of the two neutron monitors as well as of the muon telescope. Local peaks are marked in days.

Rather complicated structure with several local maxima is apparent. Out of the maxima below 27 days the almost identical and clear seems to be at about 9 days, the third harmonic of the ∼27 day periodicity.

The region around the different higher harmonics of ∼27 day period was checked in detail in comparison of the two data sets at lower geomagnetic cut-offs, namely Oulu, Kiel and at Lomnicky stit with similar cut-off to Climax. Figure 2 is illustrating that.

III. ∼9 DAY PERIODICITY

For the comparison of the CR PSD in the regions of higher harmonics of ∼27 d quasi-periodicity, the spectra of various characteristics of solar, interplanetary and

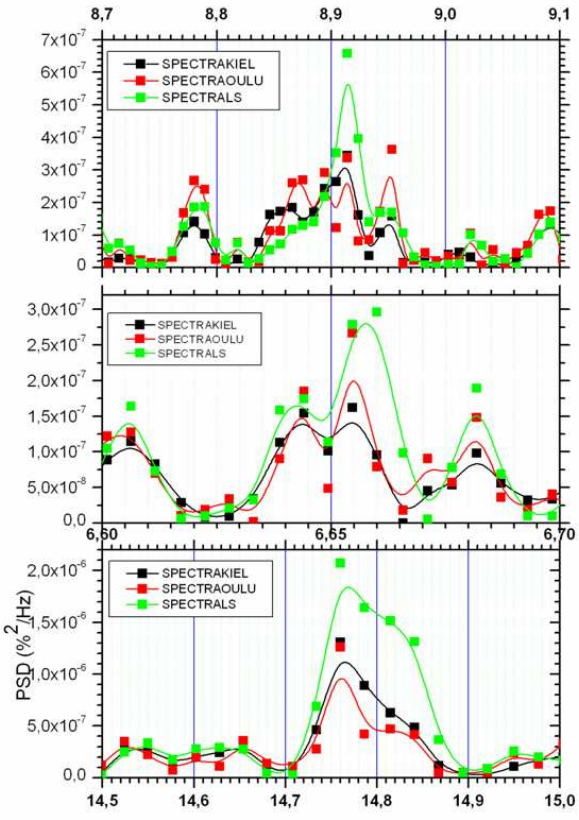

Fig. 2: Fragments of the power spectrum density (by FFT method with Welch window) in the vicinity of three higher harmonics of the $\sim$ 27 day quasi-periodicity at three neutron monitors for the interval day 182 of 1982 until end of 2007. The structure of PSD is rather complicated and the intervals with maxima pronounced at all three NMs are plotted. Similarity of the shape of PSD (by B-spline approximation) is apparent. The most pronounced maxima (as well as variability) is seen in most cases for Lomnicky stit. This may be caused by high count rate and thus relatively high statistical accurracy.

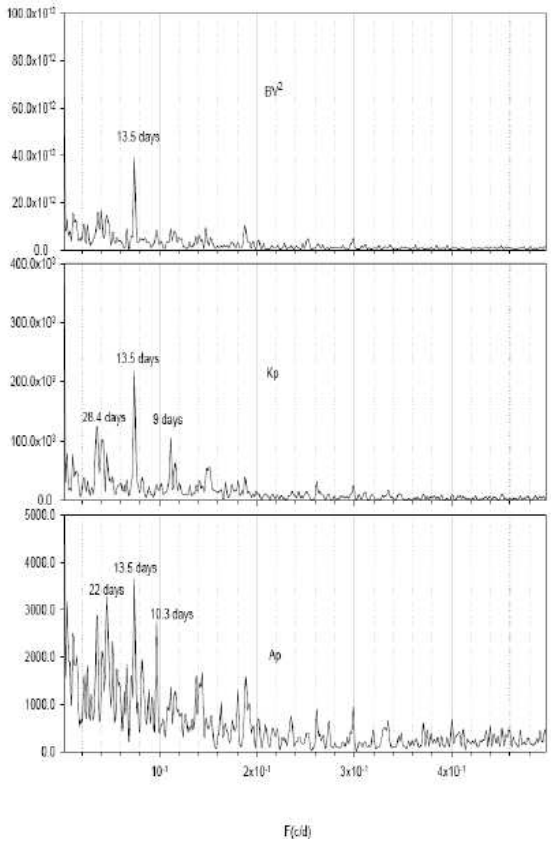

Fig. 3: Lomb-Scargle periodogram of product $B.v^2$, Kp and Ap.

geomagnetic activity were computed using data from [7]. For B.v^2 and for Kp the second harmonic $\sim$13.5 days is clearly pronounced. In addidition to that in Kp there is also enhanced $\sim$9 day periodicity. It is seen in Figure 3.

The $\sim$9 day recurrence of fast streams in the solar wind was recently reported, specifically during 2005, due to solar coronal holes distributed roughly 120^o apart in longitude [8]. This periodicity modulates the geomagnetic activity and even atmospheric parameters . The coronal holes affects the energy status of the thermosphere via the variability of solar wind. Paper [9] indicates that 9 day periodicity is observed also in the infrared emission.

For the time interval analyzed in Figure 2 the Lomb-Scargle periodogram with the Ap, solar wind velocity and total component of IMF give clearly significant periodicity $\sim$9 days (Fig.4).

IV. Summary and concluding remarks

El-Borie and Al-Thoyiab showed the indication of the $\sim$9 day periodicity in CR [10] and reported that all higher harmonics of $\sim$27 day periodicities are stronger pronounced during solar maxima. Here we indicate the existence of the second, third and fourth quasi-periodicity of the solar rotaion period at lower energies of primaries and we describe the similarity of details in the spectra around them at the three stations differing by cut-off rigidity and altitude. The $\sim$9 day periodicity being important for solar-terrestrial relations, is present in cosmic ray flux via its modulation related to quasi-periodic character of solar wind velocity connected with coronal holes in three dimensions. Similar period is reported also from muon measurements (figure 3 in [14]). The authors of [11] show the complicated structure of differential rotation of solar disc which is observed from chromospheric line emissions. This indicates that beside the basic period around $\sim$27 days there are signals at 32-35 days corresponding to the rotation rate at very high latitudes. Cosmic ray modulation is affected also by high latitude structure of IMF. Thus it is understandable that the fine structure of $\sim$9 day period observed in ecliptical plane (solar wind, IMF measured), is not corresponding exactly to the fine structure of

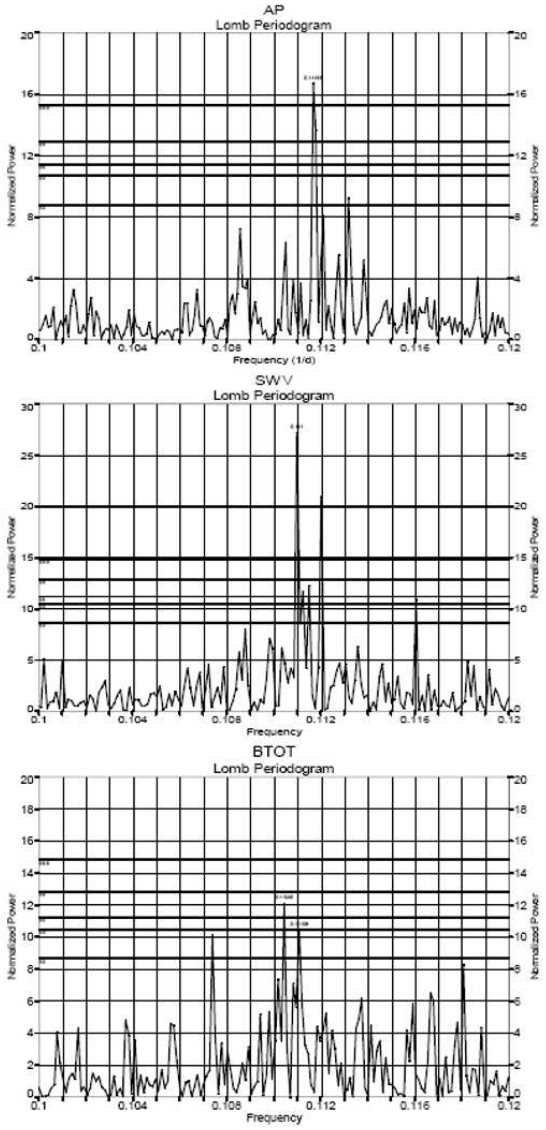

Fig. 4: Normalized power spectrum density of ap, solar wind velocity and of IMF magnitude in the time window 8 - 10 days. The significance lines are for 50; 90; 95; 99 and 99.9%. The most significant periodicities are 8.95 day (ap); 9.01 (sw velocity) and 9.05 as well as 9.00 (IMF B_{tot}).

cosmic ray measured. On the other hand the similarity of the spectral shape of power spectra of cosmic ray time series in the periodicity range $\sim$9 - $\sim$15 days is important for better understanding the cosmic ray modulation. More joint studies with solar physicists are needed in that subject in future.

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