Periodicity of 2.53 Hours Present in a Cosmic Time Series?

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Abstract
We present the results of the power spectral analysis of the cosmic ray signal observed at Misato station (34 m.w.e.) for the period from 1975 until 1995. At high frequencies, a narrow significant increase at the period 2.53 hours is seen for the epoch around solar maximum in 1989-90. The periodicity is present in the data from vertical telescope having the highest count rate starting from1985-86 until 1992-93, disappearing in 1994-95 as well as for the years before 1985-86. For 1989-90, the phases of the different direction telescopes indicate the signal is of coherent character, all phases are within 10 degrees. Although the origin of the periodicity is not explained yet, it is stressed the coincidence of the observed periodicity with one of the g-mode oscillations of the Sun. One of the possibilities of the periodicity is due to the atmospheric effects having much stronger influence on muon telescope count rate than on neutron monitors.

1 Introduction:

For the obtaining of both the correct shape (slope) and structural features of the power spectrum density (PSD) of cosmic ray time series, one important problem arises from the presence of the background noise of the instruments. Its presence is especially putting the limit at high frequencies. The correct determination of the PSD slope as a function of solar activity is problematic, since it depends on the selection of upper frequency limit above which the spectra becomes to be flatten due to the noise (if PSD is assumed as a single power-law). The white noise is putting a limit, constant value of $2/n$, where n is the count rate per second, in the whole frequency range. Shifting the upper frequency limit to lower values leads to insufficient number of points upon which the estimates of the PSD slope, or its fractal or correlation dimension, are based.

In general, the PSD obtained from the observed data, if no filtering or other type of processing is done, is describing the superposition of a physical signal and a white noise with random phases. While the first one is assumed to be changed for particles affected at least particularly by the solar activity during its activity cycle (as its variability is changing), the second component is expected to be not influenced strongly by that at high energies if the slight anticorrelation of the flux with the activity is neglected. Since the variability of cosmic ray signal at various scales is generally expected to be larger for solar maxima than for solar minima, the specific features at high frequencies will be less masked by the presence of instrumental noise than during the solar minima epoch.

The best way of eliminating the high frequency noise is to increase the count rate of the measurements. Here we are using the hourly measurements of the Misato underground muon telescope station described in Mori et al. (1975) recorded in the period 1989-1995. The average counting rate is 280000 count per hour for the vertical telescope. Also we are analyzing the signals of the four directional telescopes having lower count rate. In the signal at high frequencies we observe rather stable periodicity at 2.53 hours with the best significance during 1989-1990 and persistent for the whole period from 1985-86 until 1992-93, while no evidence is seen in the data before 1985 and after 1994, if two year intervals are analyzed. No filtering or other type processing is applied on the observed data.

2 Observations:

The power spectrum density, more precisely the periodogram estimating a frequency spectrum for a time series, decomposing the variance of the data into contributions over a range of frequencies is used for the

three periods, each constructed from 16384 hours starting at the beginning of years 1989, 1992, and 1994 respectively. In the present analysis, hourly count rate in unit of percent is used, and the missing data are interpolated by the straight line. The PSD for the years 1992-1993 is plotted in Figure 1. While the most pronounced periodicities at $f > 10^{-5}$ Hz are the diurnal and semidiurnal one in all three signals, in addition to that a tridiurnal one, recently analyzed in detail by Ahluwalia (1998) is seen only during the period near solar maxima. In addition to that another one periodicity at $f > 10^{-4}$ Hz is apparent for two periods, namely 1989-1990 and 1992-1993. It is absent in the signal of 1994-1995.

To determine more exactly this feature, the detailed PSD in linear f scale at high frequencies is examined. The increase in PSD is repeated in the same frequency region for the two epochs mensioned above: 1.096 – 1.098 x 10^{-4} Hz (corresponding to 2.5345 – 2.5298 hours). In the peak value the PSD is by almost two orders larger than the average PDS in the range 0.000106 – 0.000114 Hz for the first epoch. For the second epoch it is by factor 7-8 larger if compared with the average PSD. On the other hand for the period 1994-1995 there is no evidence of the increase of this periodicity above the average level.

3 Discussion and Summary:

The large and constant position of the PSD increase was checked in the data. We do not know about the possible instrumental effect which could produce such types of oscillations with constant periodicity observed for several years. The decrease of the signal at the marked periodicity with decrease of solar activity does not imply automatically this feature is correlated with solar activity itself. Comparing the low frequency parts of the signals for the two periods, namely 1989-1990 and that at 1994-1995, their absolute values are by factor 4-5 lower in the second one. Although we do not know the exact shape of the physical signal corresponding to the contribution of different frequencies at the high frequency edge, we assume similar behavior as for the low frequency regions.

PSD MISATO 92-93

Figure 1: The power spectrum density of Misato muon time series for 16384 hour period starting from the first hour of 1992. The increase in PSD due to 2.53 hrs periodicity is seen at $f = 1.096 - 1.098$ x 10^{-4} Hz.

Thus, the subsequent decrease and diminishing of the peak at 2.53 hours periodicity during the decrease of solar activity can be caused just by increasing the ratio of noise to signal which is most pronounced close to the high frequency edge. Using this as a working hypothesis there is no unambiguous reason to rule out that a constant periodic feature at 2.53 hours in the signal was present for the whole period.

However checking the older data from Misato station we found the periodicity significant also during the period of 1985-1986, 1987-1988, but no signature in the data from years 1975-1976, 1979-1980, and 1983-1984. Thus it is probable that the marked periodicity is present clearer in the cosmic ray time series measured during the solar cycle 22 than in the cycle 21.
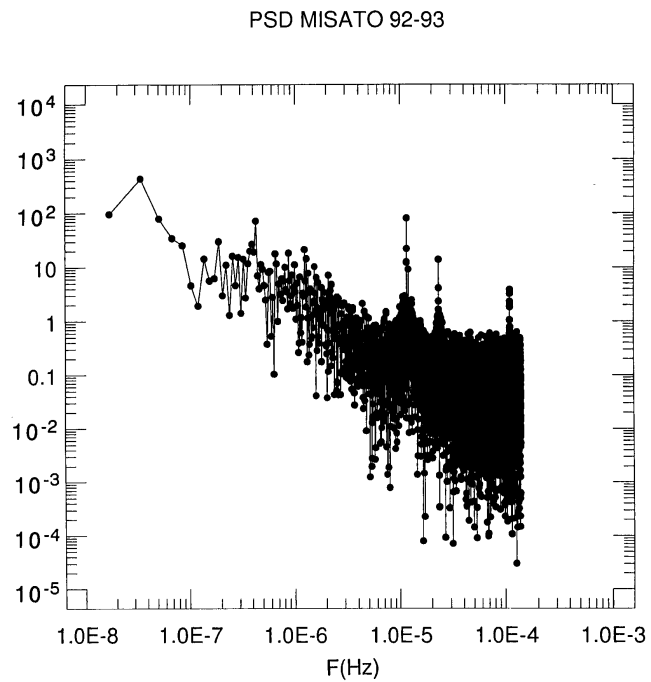
Using special method for identification of discrete periodicity in the data, Thomson et al. (1995) reported about the presence of many periodic components in the fluxes of charged energetic particles in the region 1 to 140 μHz corresponding to gravity mode oscillations (g) of the Sun. The authors suggested that super granulation motions are not completely random, but partially effect of many g modes. Using the prediction that magnetic flux frozen in the supergranulation is responsible for the observed transverse magnetic field in the polar region of Sun (Jokipii and Kota, 1989), it was suggested that periodic components in the interplanetary magnetic field would cause the periodic modulation of the charged particle flux.

It is interesting to note that in paper (Bahcall and Kumar, 1993) among the list of typical low order solar g-modes (Table 1 of the paper) there is a mode n=5, l=1 at the period 2.53 hours or 109.9 μHz, the very close to the observed periodicity in CR time series presented here. This mode is characterized (along with another one at higher frequency, thus if present in the CR data more masked by the background noise) by the largest energy.

However, it is not straightforward to deduce unambiguous conclusion from the coincidence of the two periodicities. The energetic particles pronouncing in interplanetary space similarities in their spectra with solar g- and/or p-mode oscillations (Thomson et al., 1995) refers to lower energies than those to which Misato underground muon telescope is sensitive and for those the scales corresponding to the supergranula-tions are small in comparison with their gyroradii and thus the simple assumption of scattering on IMF inhomogenities of that size are not probable. However the clear and stable periodicity at 2.53 hours is found in the data and its clarification requires analysis of more CR data sets with high count rate as well as theoretical considerations of the effect.

Figure 2: The sine of difference in phases (δφ) for three different pairs of telescopes (vertical – north, north – south, east – south). Close to the 2.53 hrs periodicity, the difference is much smaller and it is within 10 degrees.

The periodicity found here is clearly apparent, for the period of years 1989-1990, not only for vertical telescope with highest count rate, but also for all four directions sampled by the installation of muon telescope in Misato.

The solar 160 minute periodicity is reported in a series of papers on the oscillation of solar surface (Kotov et al., 1997, and references therein, Rybak, Antolova personal communication, 1998). However such oscillations may be observed also in studying other objects, e.g. in radiation of active galaxies. The periodicity found here, 151.8 min, although close to that reported by Kotov et al., is well out of the confidence limit reported for 160 min periodicity.

The atmospheric origin of the periodicity observed in Misato cosmic ray time series can not excluded. There are no, to our knowledge, reports of the presence of 2.53 hr period in the signals of neutron monitor time series, although at some installations their count rate is higher than that at Misato underground
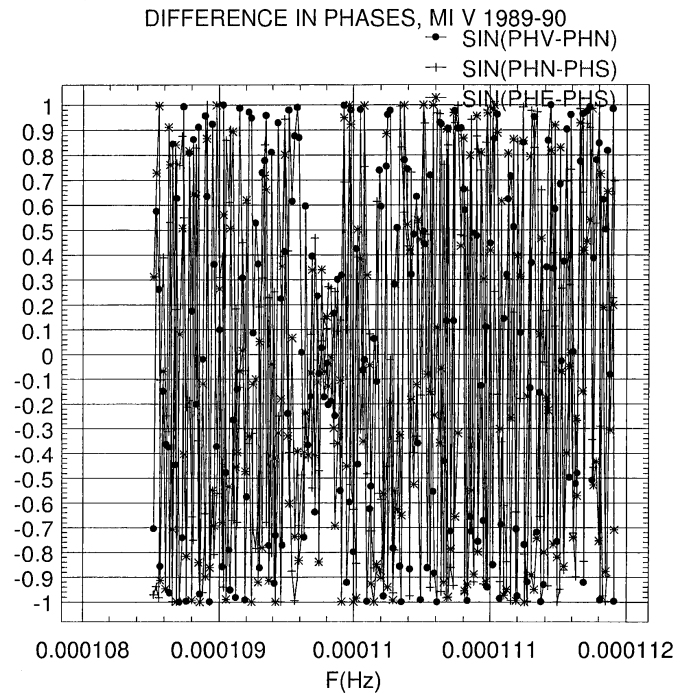
telescope. If the periodicity is caused by the oscillations of atmospheric parameters (pressure and/or temperature profile above the detector), less effect should be expected as a response on neutron monitors than at muons, due to the fact that on neutron monitors there is practically no effects connected with the variation of the air density, while for muons it is (Dorman, 1974). The reason is that while in the process of neutron population formation presumably stable particles (nucleons) take part, the response of muon detectors is depending on the unstable particles.

Checking the phases in the time series 1989-90 for vertical, north, south, east and west directional telescope of Misato respectively, it is apparent almost coherent character of the 2.53 hr periodicity. Figure 2 is showing the differences in phases (sin ($\delta\phi$), the sine of difference in the phases for three different pairs of telescopes). While outside the marked periodicity the difference is ranging large intervals, close to the 2.53 hrs the difference is much smaller and it is within 10 degrees at the peak. This characteristic suggests coherent character of the variability observed simultaneously from all directions of the telescope. This can be the indication of atmospheric effect or a global pulsation of the unknown character pronounced in the cosmic ray data. This effect is worth to be studied more extensively on more data sets and for different periods at the installations with high count rate. The oscillations of local character (atmospheric) can be excluded only with the use of another set of muon telescope data of comparable statistical accuracy (geometric factor). If the result will be confirmed at another data set, the most important question will be examining the phase coherency of the oscillations.

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