Periodicities in the soft X-ray emission from the solar corona during descending phase of cycle 23

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We have studied the time series of full disk integrated soft X-ray emission from the solar corona during January 2004 to December 2008, covering the entire descending phase of solar cycle 23 from a global point of view. We employ the daily X-ray index (DXI) derived from 1s cadence X-ray observations from the Si detector of "Solar X-ray Spectrometer (SOXS)" mission in four different energy bands ranging between $6-25$ KeV. The daily time series is subjected to power spectrum analysis after appropriate correction for noise. Lomb-Scargle periodogram technique has shown prominent periods of $\sim$ 13.5 days, $\sim$ 27 days, and near Rieger period of $\sim$ 181 days and $\sim$ 1.24 years in all energy bands. Further to this, other periods like $\sim$ 31, $\sim$ 48, $\sim$ 57, $\sim$ 76, $\sim$ 96, $\sim$ 130, $\sim$ 227 and $\sim$ 303 days are also detected in different energy bands. We discuss our results in the light of previous observations and existing numerical models.

1 Introduction

Solar activity as a whole is known to exhibit a wide range of periodicities on different time scales ranging from minutes to centuries. As long-term periodicity, the Sun exhibits the $\sim$ 11yr sunspot cycle (Schwabe cycle) and for short-term variations, the near 27 day periodicity is the most prominent. The former is related to the polarity reversal of solar magnetic field and the latter reflects the modulation imposed on the solar flux at the Earth by solar rotation. The regime between these extremes of time-scales (between 27 day and 11 year) is called the "mid-range" or "intermediate-term" periodicities. Studies of short and mid-term variations in solar activity and their solar-cycle dependence may help to achieve a better understanding of the basic processes of solar activity cycle, dynamics and mechanisms of generation of the solar magnetic field and for predicting the level of solar activity [2, 11, 12], and hence the variation in space weather. The helioseismic probing of the solar interior using SOHO/MDI data has shown that the rotation rate of the Sun near the base of its convective zone changes with a period of roughly 1.3 years [7]. The 1.3yr periodicity has also been detected in variations of the interplanetary magnetic field and geomagnetic activity [13, 14] in the variation of photospheric magnetic flux [11] and in the solar wind speed [16]. In this context, investigation of $\sim$ 1.3yr periodicity in the solar corona would strengthen or weaken the case for associated changes in the layers harbouring the dynamo as well as may enable to understand any connection between convective zone and the corona.

The structure and evolution of the solar magnetic field is believed to be produced by a magneto-hydro-dynamic (MHD) dynamo operating inside the Suns convection zone [4], which induces various solar activities that exhibit periodic variations on different time scales. We consider that any fluctuation in the dynamo process will manifest itself most clearly in relatively freshly emerged flux [12], whose signatures could be visible in the solar corona when viewed in the X-ray waveband. The X-ray intensity of the solar corona, however, varies as a function of emerging flux, sunspots, and flares etc, which are changing over 11-year sunspot cycle. The X-ray corona refers to different plasma temperature and density for different solar features, observed in different X-ray energy bands [8]. In this investigation, for this purpose, we exploit the "Solar X-ray Spectrometer (SOXS)" data [9, 10] for the period of January 2004 to December 2008, declining phase of sunspot cycle 23.

2 The Data

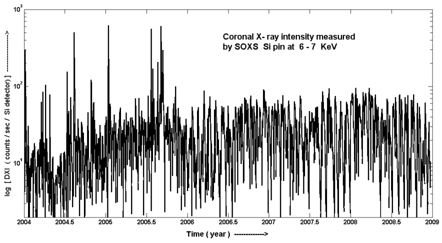
We employ the observations from the "Solar X-ray Spectrometer (SOXS): Low Energy Detector (SLD)" mission for current investigation (http://www.prl.res.in/ soxs-data/).

3 Analysis techniques

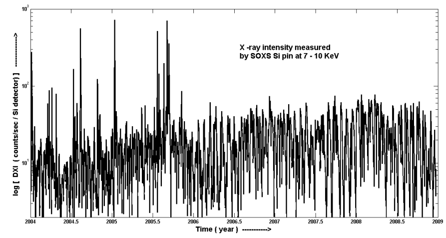
The daily variation of coronal X-ray emission recorded as DXI data sets was analyzed by the LombScargle method by calculating the Scargle normalized periodogram $P_N(\omega)$ [17].

4 Results

During 2004 to 2006, we find ~four sharp peaks in both soft X-rays in consistence to [3] who reported a high flare activity in the early descending phase of cycle 23. The application of Lomb-Scargle periodogram technique on the time series of (DXI) observed by Si detector in $6-7$, $7-10$, $10-20$ and $4-25$ KeV, energy bands reveals several short and intermediate term periodicities of the X-ray corona. The Si detectors explicitly show the most prominent periods of ~ 27 days related to prominent solar rotation, $13-14$ days related to 1800 oppositely directed active longitudes [6] or hotspots [1], and Rieger type period of ~ 181 days proposed to be related to the change in the rotation rate of the Sun near the base of its convective zone [12]. We report the 1.24-year period detected for the first time in the X-ray emission form the solar corona in wide energy band during the declining phase of sunspot cycle 23. We further propose that variation in the solar rotation below techocline due to tensional oscillations [5] manifests to up flowing magnetic flux to corona with variety of periods to cause the solar activity as seen by us in the various X-ray energy bands. Further, we have observed significant power at ~ 31 days periodicity in all energy bands, which, however, becomes stronger with increasing energy. Perhaps this may be related to solar activity at higher latitudes.



(a)



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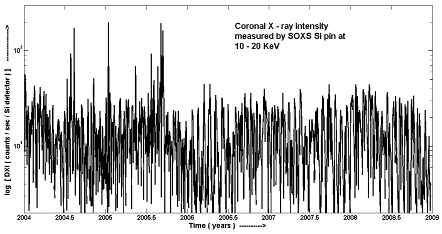

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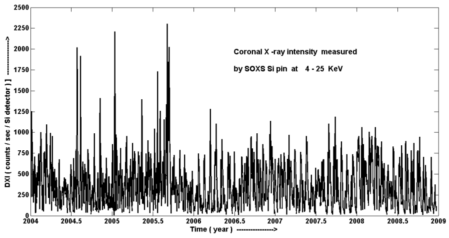

(d)

Figure 1: Time series of daily X-ray index (DXI) in (a) $6-7$, (b) $7-10$, (c) $10-20$ and (d) $4-25keV$ bands of SOXS Si detector for the period from 1 January 2004 to 31 December 2008.

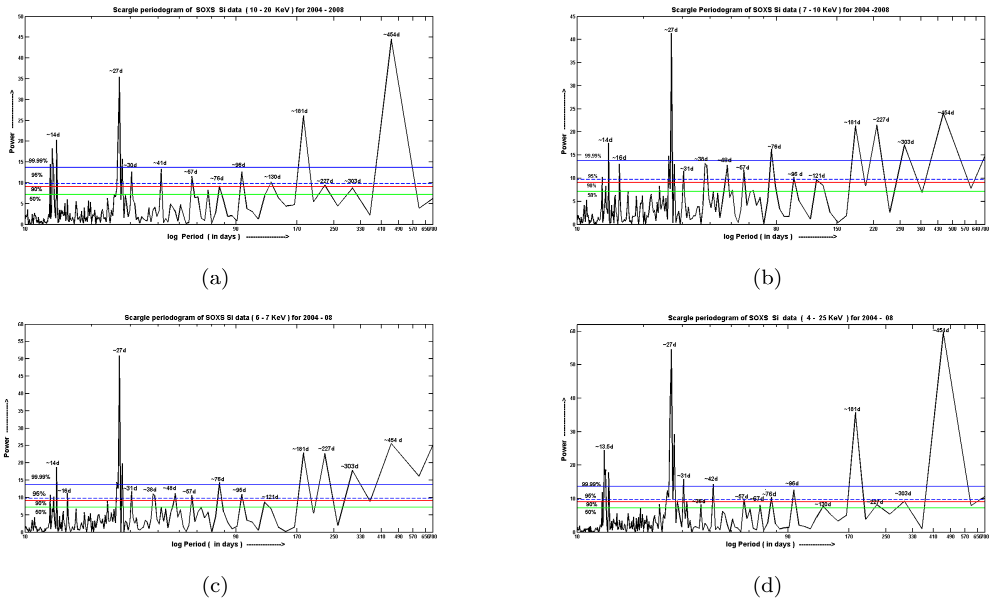

Figure 2: Lomb - Scargle periodogram of the DXI data from the Si detector for 2004 - 2008. (a) $10-20keV$, (b) $7-10keV$, (c) $6-7keV$, (d) $4-25keV$.

5 Discussions and Conclusion

The results presented in section 4 refer to the first investigation of short and intermediate-term oscillations revealing the occurrence rate in the daily X- Ray index (DXI) that obtained from 1s cadence observations made by the Si detectors of the SOXS mission from 1 January 2004 to 31 December 2008 covering the descending phase of solar cycle 23. However, the detection of 1.24 year periodicity in the X-ray corona suggests coupling of this outermost layer with the rotation of the innermost core. It is generally suggested that the $1.24-1.3$ year periodicity is associated with variation in equatorial speed of the rotation in the convective zone, which is in anti-phase with an oscillation in the corresponding speed of rotation of the core, on the other side of the tachocline. However, our current discovery of 1.24-yr periodicity from solar coronal X-ray emission suggests that variation in equatorial speed of the solar rotation beneath convective zone and perhaps at the core level is also manifested in the coronal plasma, and suggests exploring the physical processes that couple the core to corona.

The other prominent periodicities seen in our dataset are ~ 13.5 and 27 days. The 13.5 days periodicity is a result of $180°$ oppositively directed longitudes as many scientists have also shown earlier. On the other hand, 27 day periodicity refers to the solar rotation, which is most prominent due to all the active centers or exciters hotspot are very close to the equator particularly during the declining phase of the solar cycle. Our results endorse earlier conclusion of [15] that this periodicity arises because active regions and their magnetic field are better organized and are long lived during the maximum and declining portion of the solar cycle than its rising portion. Our discovery of 31 days periodicity though not prominent but observed in all the energy bands suggests that many sunspot regions did not approach close to equator during declining phase of cycle 23. This indicates that the length of the declining phase of cycle 23 should be longer which is in agreement to sunspot observations that report decay phase to be ~ 8 years.

The present investigation reveals the prominent existence of a near 26 day periodicity (with 13.5 day period as sub harmonic) and a similar kind of period has been reported in the photospheric magnetic-field evolution. This is important because it represents a link among the sub-photospheric magnetic field evolution, coronal activity, and the loss of magnetic flux through coronal X-ray emission. In conclusion, after studying the periodic behavior of coronal X-ray emission data during descending phase of cycle 23, we have detected a number of short and inter-mediate term oscillations which are consistent with several other studies during cycle 23. In particular, we found that the group of peaks ranges from $26 - 41$ day period may be due to a single quasi-periodic process that is shifting in frequency through the cycle. It is possible that, this intermittent behavior may be due to a random process of magnetic flux emergence through the photosphere. We assume that magnetic Rossby type waves are responsible for this short and mid-term periods.

The present investigation suggests a scenario of emergence and escape of magnetic flux from the solar convection zone to the interplanetary medium through the photosphere and corona. Therefore we may conclude that X-ray emission from the corona is one of the most important solar parameters crucial to probe the Sun Earth coupling and terrestrial climate. However, more observations and theoretical investigations on the dynamics of the solar interior, corona, flare producing active regions and mechanism of the Rossby type waves within solar atmosphere may shed new light on the origin of these short and intermediate-term periodicities.Along with it we should be careful about the gravitational lensing effect by the planets as they revolve with a constant orbital period around the Sun.

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