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PERIODICITIES IN THE X-RAY EMISSION FROM THE SOLAR CORONA: SPHINX AND SOXS OBSERVATIONS

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Abstract. The structure and evolution of the solar magnetic field is driven by a magnetohydrodynamic dynamo operating in the solar interior, which induces various solar activities that exhibit periodic variations on different timescales. Therefore, probing the periodic nature of emission originating from the solar corona may provide insights of the convection-zone-photosphere-corona coupling processes. We present the study of the mid-range periodicities, between rotation period (∼27 days) and the Schwabe cycle period (∼11 yr), in the solar soft X-ray emission, based on the data obtained by two instruments: SphinX and SOXS in various energy bands.

Key words: soft X-ray - periodicities - solar corona

1. Introduction

Solar observations in different energy bands reveals periodic nature corresponding to various structures, with the periods ranging between as short as few seconds and as long as centuries (Solanki *et al.*, 2004; Usoskin *et al.*, 2004; Hanslmeier *et al.*. 2013; Chowdhury *et al.*, 2013; Zaqarashvili *et al.*, 2015). The most common periodicities are the long-term sunspot cycle (∼11 yrs), and the short-term variations connected to the solar rotation (∼27 days). The range of timescales between these boundaries so called "mid-range" or "intermediate-term" periodicities are observed.

Helioseismic analysis of the solar interior shows periodic changes in the rotation rate near the base of convective zone. The period of those changes is roughly 1.3 years (Howe *et al.*, 2000; Christensen-Dalsgaard, 2002). The differential rotation of the Sun is one of the crucial ingredients of the solar dynamo, which generates the magnetic field observed in the solar outer layers: photosphere, chromosphere and corona. Therefore it is not surprising that 1.3-year periodicity is also observed at the solar surface (Krivova & Solanki, 2002). In this context, investigation of the ∼1.3 year periodicity can help us in understanding solar dynamo and connections between the convective zone and the corona (McIntosh *et al.* 2015).

Other periodicities in solar activity are so called Rieger and near Rieger periods. The periodicity of 154 days was first found by Rieger *et al.* (1984) in the periodicity in the occurrence of γ-ray flares observed by Gamma-Ray Spectrometer (GRS) on-board *Solar Maximum Mission* (*SMM*). Furthermore the analysis of a different indicators of solar magnetic activity confirmed the existence of Rieger-type periods. The periodicity was detected in:

- sunspot areas (Lean & Brueckner, 1989; Lean, 1990; Carbonell & Ballester, 1990; 1992; Oliver *et al.*, 1998; Chowdhury *et al.*, 2009),
- sunspot numbers (Lean & Brueckner, 1989; Lean, 1990; Ballester *et al.*, 1999; Kiliç, 2008; Chowdhury & Dwivedi, 2011),
- solar flare activity (Dennis, 1985; Bai & Sturrock, 1987; Kile & Cliver, 1991; Dimitropoulou *et al.*, 2008),
- full-disk-integrated soft and hard X-ray emission from the solar corona (Chowdhury *et al.*, 2013),
- occurrence of solar coronal type II and IV radio bursts (Verma *et al.*, 1991),
- type III radio burst occurrence (Lobzin *et al.*, 2012),
- microwave flares (Kile & Cliver, 1991),
- proton flares (Bai & Cliver, 1990),
- occurrence rates of solar flare energetic electrons (Dröge *et al.*, 1990),
- 10.7 cm radio flux (Lean & Brueckner, 1989).

The number of different indicators of solar magnetic activity, where the Rieger-type periodicity is present, suggests that it is associated with regions of compact magnetic field structures. Therefore, the periodicity should be connected to the strong magnetic field generation.

Appearance of the Rieger-type periodicity in different indicators of solar magnetic activity may possibly depend on the position in the solar cycle. Periodic changes of a sunspot area is usually observed near the cycle maxima (Lean, 1990; Oliver *et al.*, 1998; Zaqarashvili *et al.*, 2010), additionally the period may vary from 130 to 185 days. Detailed analysis of historical behavior of the 156-day periodicity has shown that the Rieger periodicity of 154 days is not a permanent feature of the solar activity, but that it varies from cycle to cycle (e.g. Akimov & Belkina, 2012; Gurgenashvili *et al.*, 2016).

The physical explanation of the Rieger-type periodicity occurrence is not clear. Several different mechanisms have been proposed to explain the phenomena:

- the 155-day periodicity may be connected to the timescale of the storage and/or the escape of the magnetic fields in the solar convection zone (Ichimoto *et al.*, 1985),
- the periodicity of 155-160 days is just a subharmonic of that fundamental period of an oblique rotator or oscillator with a period of 25.8 days (Bai & Sturrock, 1991),
- the Rieger periodicity can be explained in terms of r-mode oscillations of the solar interior (Wolff, 1992; Sturrock *et al.*, 2013; 2015),
- the periodicity can be related to large-scale equatorially trapped hydrodynamic Rossby-type waves in the solar photosphere (Lou, 2000),
- the observed periodicity could be explained by the unstable harmonics of magnetic Rossby waves in the solar tachocline, which lead to the periodic emergence of magnetic flux at the solar surface due to the magnetic buoyancy (Zaqarashvili *et al.*, 2010; Gurgenashvili *et al.*, 2016).

Models involving magnetic Rossby waves, which depend on the unperturbed magnetic field strength, can explain changes in the Rieger periodicity due to the variation of the mean dynamo magnetic field from cycle to cycle. Therefore the cycle strength can define the value of Rieger-type periodicity.

This means that the Rieger-type period during the individual cycle provides information about the strength of the cycle (Gurgenashvili *et al.*, 2016). In general longer periods ∼181 days indicates weaker cycle, while the shorter ∼154 days indicate a stronger one.

It is interesting to note that 150-160 days is a whole number fraction of a 1.3 year periodicity. Therefore, the relation between the 1.3-year and Rieger-type periods is possible.

Several researchers also reported mid-range periodicities except the Rieger ∼154-day periodicity. In the occurrence rate of major flares Bai (1987) found a ∼50-day periodicity, similar values were found by Kilcik *et al.* (2010) in the solar flare index. Also 70-80 days periods were found in the flare occurrence rate (Bogart & Bai, 1985; Bai & Sturrock, 1991; Lou *et al.*, 2003). Additionally periods ∼95 days and ∼130 days were reported by Lou *et al.* (2003) and Kilcik *et al.* (2010) respectively. Similar mid-range periodicities were found in the solar X-ray flux (Chowdhury *et al.*, 2013).

In this paper, we analyze Rieger-type periodicity in the solar soft X-ray flux observed by two instruments *Solar X-ray Spectrometer* (SOXS) and *Solar photometer in X-rays* (SphinX) during a deep minimum in 2009.

2. The Data and the Data Analysis

In our investigation we employ observations from "the SOXS: *Low Energy Detector* (SLD)". The SOXS instrument (Jain *et al.* 2005) was launched on-board the GSAT-2 Indian spacecraft on May 8, 2003 by the GSLV-D2 rocket and was operational until May 2, 2011. The SLD is comprised of two solid state detectors: the Si and CZT detector, which provide integrated X-ray emission from the Sun with dynamic energy ranges 4-25 and 4-56 keV, respectively. The details of the instrumentation, on-board calibration, and response of the detectors are given by Jain *et al.* (2005, 2006a, 2006b, 2008, 2011). In current study we used the averaged daily flux obtained by Si detector in 2009.

Additionally we used data from the SphinX instrument. Similar to SOXS instrument, it consists of four silicon PIN detectors (for details see Sylwester *et al.*, 2013 and Gburek *et al.*, 2011; 2013). It conducted integrated soft X-ray emission measurements in energy range between 0.8 and 15 keV, which provide the basis for determination of coronal average properties like temperature, emission measure and related thermodynamic characteristics for quiet corona and flares in particular. The SphinX instrument was launched on 30 January 2009 on-board the Russian CORONAS–PHOTON satellite and it was operational until end of November, 2009. For the current study we analyzed recorded soft X-ray light curve and manually removed solar flares from the data. Next, we calculated hourly average of the observed X-ray flux in three energy bins: from 1 to 2 keV, from 2 to 4 keV, and from 4 to 8 keV.

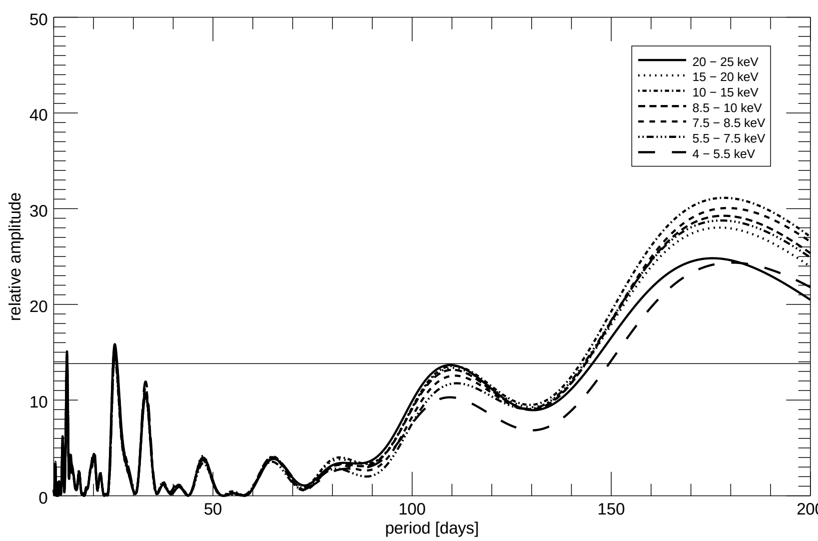

Figure 1: Lomb-Scargle periodogram of total solar X-ray flux measured in seven different energy bins by the Si SOXS detector in 2009. The horizontal solid line represents 99% confidence level.

The periodicities in the daily (in case of SOXS data) and hourly (in case of SphinX data) variation of coronal X-ray emission were analyzed using the Lomb–Scargle method by calculating the Scargle normalized periodograms (Lomb, 1976; Scargle, 1982).

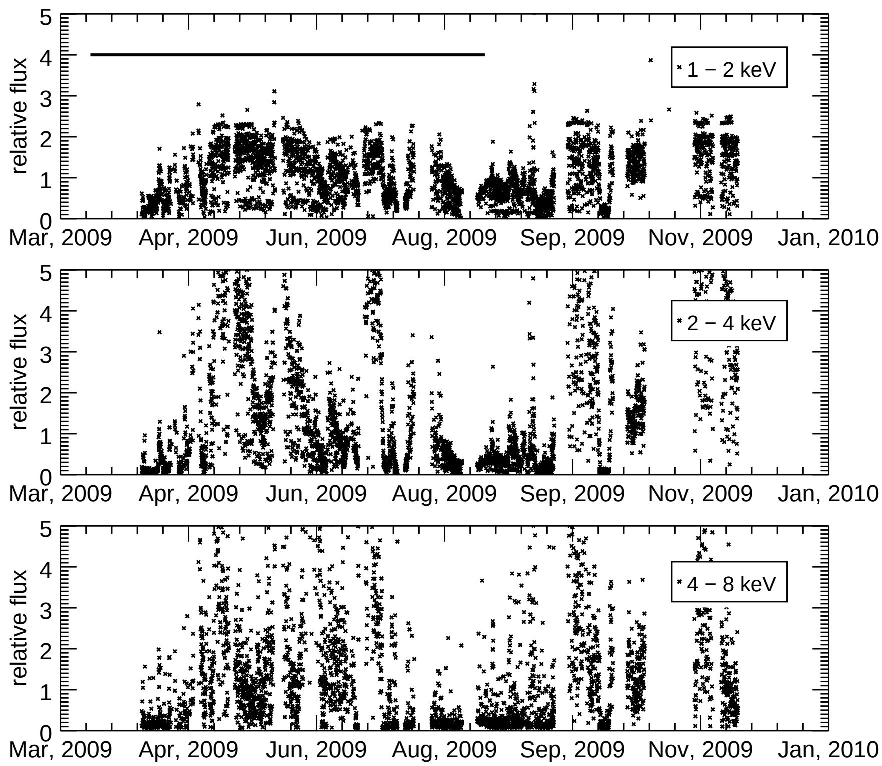

Figure 2: Hourly averages of soft X-ray flux after removing flare contribution observed by SphinX instrument in three energy bins: from 1 to 2 keV (top), from 2 to 4 keV (middle) and from 4 to 8 keV (bottom). Horizonlal line in the top panel represents length of Rieger period – 154 days.

3. Rieger-type Periodicity during 2009

The Lomb-Scargle periodograms of the daily X-ray flux obtained by SOXS Si detector in seven different energy bins are shown in Figure 1. Periodograms reveals three periodicities above 99% confidence level line, especially broad peak at ∼180 days, this period is consistent with longer Rieger period of the following cycle 24 (Gurgenashvili *et al.*, 2016). Other two peaks at ∼14 and ∼26 days are reflection of the solar rotation. The periodograms were made based on the available daily observations of average solar X-ray flux, therefore the highest contribution to the data represents solar flares. This implies that the observed periods are most likely linked to the occurrence rate of the flares.

In order to examine periodicities in the coronal X-ray emission not affected by the solar flares occurrence rate, we analyzed the SphinX soft X-ray light curve after removing the contribution from solar flares. Figure 2 shows hourly averages of the flux observed by SphinX with flares filtered in three energy bins: 1-2, 2-4 and 4-8 keV. Despite short observational window of the instrument i.e. only ~250 days, the 150-180 days Rieger-type period is clearly seen as shown by the horizontal line in the top panel of Figure 2.

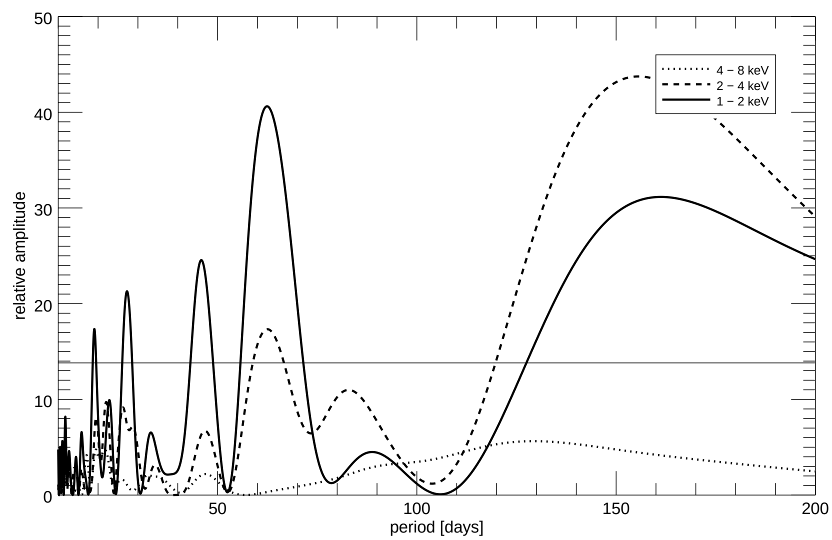

Figure 3: Lomb-Scargle periodogram of total solar X-ray flux measured in three different energy bins by the SphinX instrument. The horizontal solid line represents 99% confidence level.

The application of Lomb-Scargle periodogram technique to the SphinX data (Figure 3) reveals several short- and intermediate-term periodicities in the soft X-ray emission of solar corona in the energies between 1 and 2 keV, and between 2 and 4 keV. The broad peak at 150-180 days is consistent with Rieger-type periodicity. Two shorter periods: ~61 days seen in energies from 1 to 4 keV and ~45 days seen from 1 to 2 keV are similar to periods reported by Ataç & Özgüç (2006) and Chowdhury *et al.* (2013) in the solar flare occurrence rate and coronal X-ray flux during cycle 23. Shortest periods ∼14 and ∼27 days are connected to the solar rotation.

4. Summary

This paper presents the results of the period analysis of the solar soft X-ray flux observed during deep minimum between cycle 23 and 24. The spectral analysis of averaged total X-ray flux reveals the presence of Rieger-type period, which is usually observed near the maximum of a cycle. This suggest that the period is present during the whole cycle. Also, reported period is longer then Rieger-type period in preceding 23rd cycle, but similar to the periodicity found during 24th cycle.

Additionally we have detected two intermediate-term periodicities: ∼45 and ∼61 days, witch is in a good agreement with other studies addressing the periodic behavior of coronal X-ray emission during cycles 23 and 24.

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