Rotation Period - X-ray Activity Relations Based on ASAS and ROSAT Data

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Abstract. We announce provisional results of an ongoing search for periodic variability of optical counterparts of ROSAT X-ray sources, based on the ASAS photometric data. We present the collective rotation period - X-ray activity relation for all detected variables found so far (more than 3500) and also for spotted stars of different spectroscopic types and classes, selected based on the data available in the SIMBAD database and in other literature sources. The known period-activity relations for different types of stars are confirmed with our sample, substantially more numerous than used in earlier studies.

1. Introduction

Rotation is one of the most important parameters governing stellar magnetic activity. Activity level can be measured by the ratio of coronal X-ray flux to the stellar bolometric flux. Active stars with detectable X-ray emission are often photometrically variable due to a presence of nonuniformly distributed dark spots. Rotation periods can thus be obtained from the brightness modulation.

2. Analysis

Using the ASAS photometric data (see http://www.astrouw.edu.pl/asas/) we analyzed variability of stars close to X-ray sources identified by the ROSAT All Sky Survey (RASS). We searched for optical ASAS counterparts within a circle with a radius of 30" centered on an X-ray source (approximately two ASAS pixels). Preliminary period search was performed using the AOV algorithm (Schwarzenberg-Czerny 1989) for 10300 stars, related to RBSC (ROSAT Bright Source Catalog, Voges et al. (1999)) sources and for 12000 stars with declination north of $+29^o$, related to sources in the ROSAT All-Sky Survey Faint Source Catalogue (RASS-FSC). Details of the used method are given in Kiraga (2012) (K12) and Kiraga & Stępień (2013) (KS13). So far, we identified 3600 periodic variables. Their light curves were inspected visually to confirm variability and to assign a preliminary variability type (e.g. a spotted rotator, eclipsing binary or pulsating star). Our sample includes several distinct classes of stars which should be analyzed separately. The presently analyzed sample of stars is based essentially on variables listed in K12, because very few data can be found in the SIMBAD database for stars listed in KS13 and those related to sources from RASS-FSC. The sample consists of optical counterparts to RBSC sources located south of declination $+29^o$ for which ASAS photometry in the V and I color bands exists. Here we present a preliminary analysis of these stars.

3. Rotation period – X ray activity diagrams

The logarithm of X-ray to bolometric flux ratio, R_X, *versus* logarithm of variability period expressed in days for all 3626 stars is presented in Fig. 1a. This set of stars includes 2800 spotted rotators, 790 eclipsing stars, a few more exotic variables (e. g. noneclipsing nova) and the rest with uncertain classification. A general tendency of decreasing activity level with increasing variability period is visible, although it is masked by a large spread of R_X at a given period, resulting from a heterogeneity of considered stars. The shape of the period-activity relation is better visible when we restrict our attention to stars classified as spotted rotators (Fig. 1b). The spread in R_X is substantially decreased, particularly for periods shorter than 1 d when a large number of W UMa-type stars present in our total sample has been removed. Cool contact binaries show systematically lower X-ray activity levels than single stars with the same rotation periods (Stępień, Schmitt & Voges 2001). The period-activity relation for spotted rotators shows three characterictic parts: for periods longer than about 4 d activity decreases with the increasing rotation period, for periods between 4-0.4 d the activity is constant at the saturation level, and for periods shorter than 0.4 d we observe *decrease* of activity with a decreasing period. This is called supersaturation effect (Randich et al. 1996). We disregard two very active stars with periods around 0.15 d; one of them is a nova and the data for the other one are very uncertain.

We selected 1930 spotted rotators from K12 with known $V-I$ color index, then we divided them into four color intervals and plot their R_X as a function of $\log(P)$ in four separate panels in Fig. 2. The ranges of $V-I$ in the four panels roughly correspond to the following spectral types: $V-I > 2.5$ corresponds to spectral types later than M3, $2.5 \leq V-I \leq 1.8$ corresponds to spectral types M1-M3, $1.8 \leq V-I \leq 0.95$ to K2-M1 and $0.95 \leq V-I \leq 0.4$ to F2-K2. In addition, we marked stars with a known luminosity class by different colors: red means giants, green - subgiants and blue - dwarfs. Stars shown with black symbols have unknown luminosity class. No giants are present on the upper left panel (Fig. 2a) and only one appears on the upper right panel (Fig. 2b). This is a K3IIIe RS CVn type star, very likely strongly reddened due to interstellar extinction because it is situated close to the galactic plane. Fig. 2c with K-type stars contains the highest number of identified variables. All three luminosity classes are abundantly represented. They all show the same pattern of period-activity dependence, with saturation at short periods and a steep decrease of activity for longer periods. However, the relation for subgiants is systematically

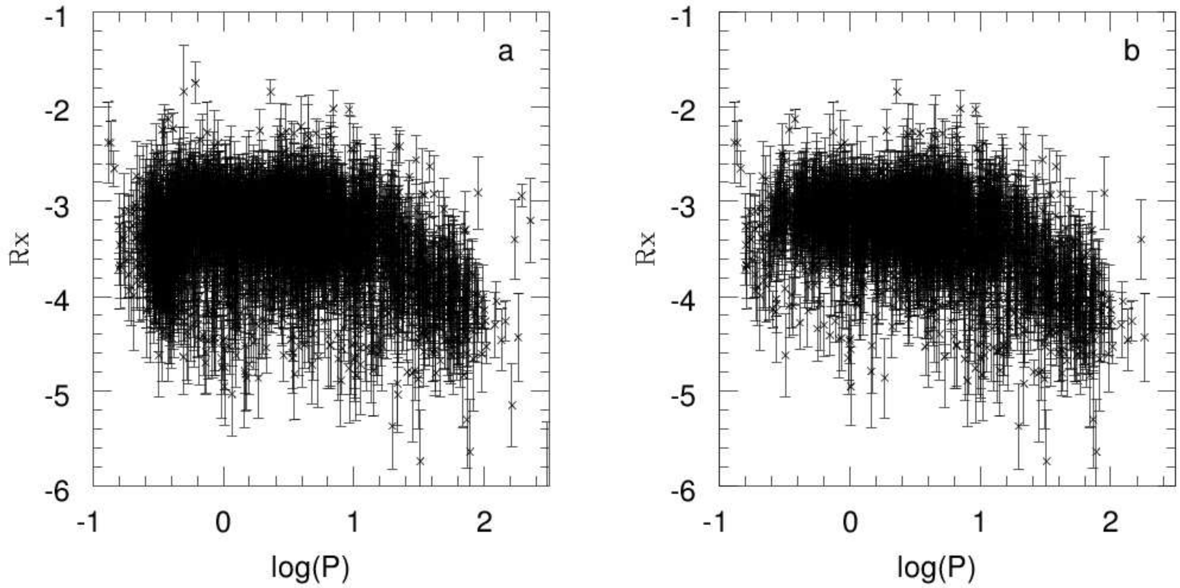

Figure .1: The X-ray to bolometric flux ratio versus variability period given in logarithmic scale for all variable stars from our list (a) and for stars preliminarily classified as spotted rotators (b).

shifted towards longer periods, compared to dwarfs, and the relation for giants is shifted even more. Very scattered relation between period and activity is visible in Fig. 2d.

Heliocentric parallaxes are known for 288 rotationally variable stars from our K12 sample. We plot them in the color-magnitude diagram (Fig. 3a). For some of these stars a strength of the lithium line at 670.4 nm has been determined (we took data mostly from Torres et al. (2006)). It is used as a measure of stellar age; young cool stars have strong lithium line and the line weakens with time. We marked stars with the known equivalent width (EW) of the lithium line by different colors: red indicates EW above 25 pm, green describes EW between 5-25 pm and blue means EW below 5 pm. Black symbols refer to stars with unknown EW. We see that all late K-type stars above the main sequence (MS) are young objects of T Tauri-type. Several young stars have already reached MS although it is mostly populated by older stars. Some of subgiants and giants, seen at the upper part of Fig. 3a, still show moderately strong lithium line. These are most likely stars with high enough masses in which lithium is not destroyed during their MS life. Fig. 3a confirms the absence of active M-type giants, which is also visible in Figs. 2a-2b. They do not possess hot coronae (see review of Güdel (2004))

Figure 3b presents the period-activity relation for a subsample of stars from Fig. 3a with $V-I$ between 0.9-1.4. Blue symbols indicate stars with $M_{bol} < 2$ (mostly giants), magenta, stars with M_{bol} between 2 and 4 (mostly subgiants and T Tauri stars) and black symbols, stars with $M_{bol} > 4$ (mostly MS). Regions occupied by symbols with different colors show an overlap but the tendency shown in Fig. 2c is now even better visible.

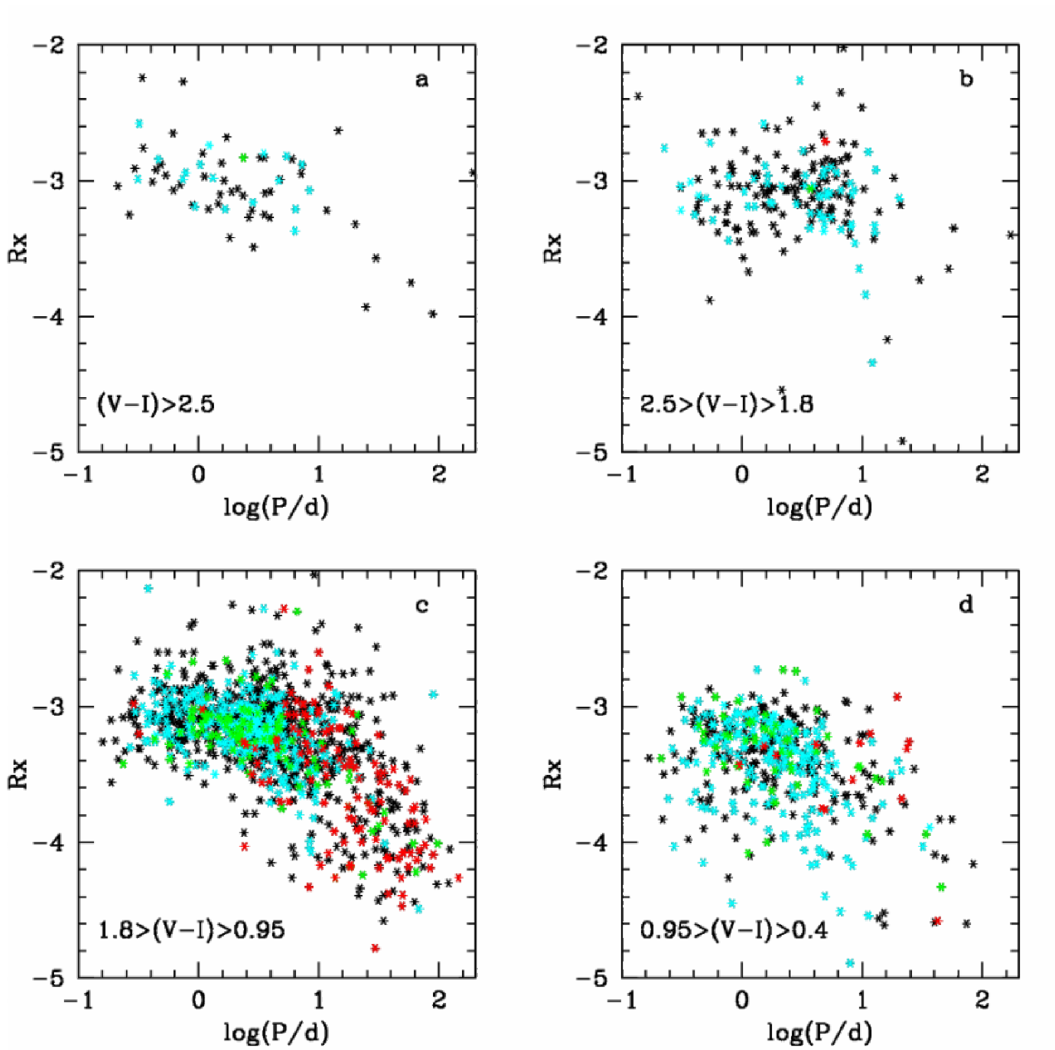

Figure .2: Log of X-ray to bolometric flux ratio is given as a function of $\log(P)$ for stars in our sample in four $V - I$ colour intervals. Red symbols denote giants, green – subgiants, blue – dwarfs and black – unknown luminosity class

4. Conclusions

Using ASAS and ROSAT data we have identified a large number of stars with known rotational periods and the activity level. However, a more accurate analysis needs a careful classification of the variables and additional data, like a spectral type, spectral class, distance etc., because the period-activity relations are different for different types of stars (single *versus* binary, young *versus* old, early spectral type *versus* late, or evolved *versus* unevolved). We are in the course of collecting such data from all available sources. Unfortunately, no useful data exist for a large fraction of identified variables. New, systematic observations of all bright stars are urgently needed.

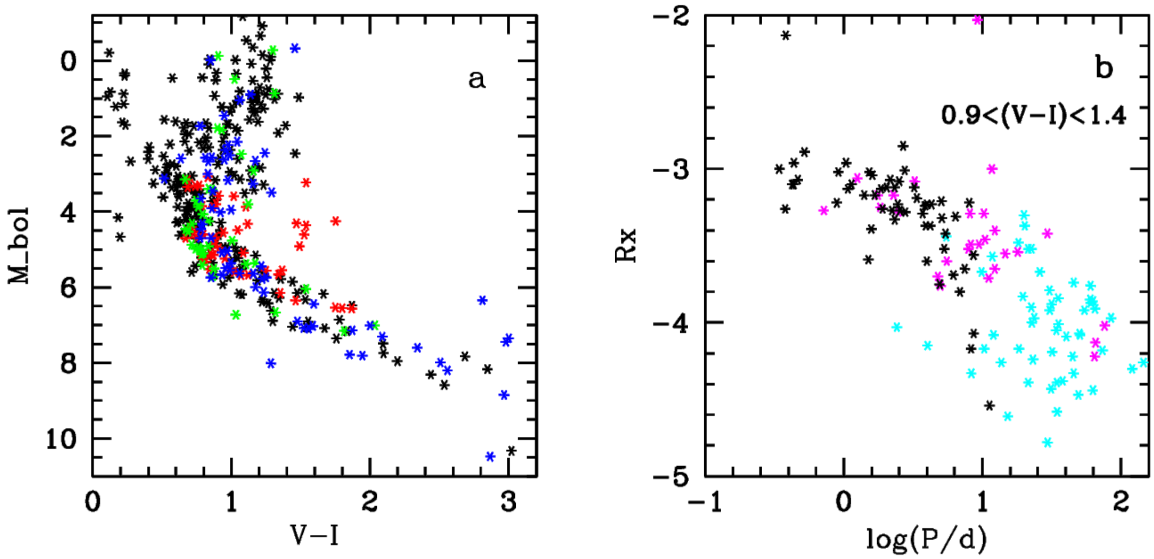

Figure .3: (a) The colour - magnitude diagram for stars with known parallaxes. Those with known EW of the lithium line are marked with different colors: red denotes stars with EW> 25 pm, green – EW between 5-25 pm, blue – EW < 5 pm and black – unknown EW. (b) The period-activity diagram for stars with known parallaxes and $V - I$ in the range 0.9-1.4. Blue symbols denote giants, magenta – subgiants and T Tauri stars and black – dwarfs

Nevertheless, the preliminary analysis of the already existing sample confirms the period-activity relations for different types of stars obtained based on a less numerous data. More quantitative results will be presented in the near future. We also confirm earlier results about the absence of hot coronae in M-type giants. Our data indicate that all coronally active M-type stars are dwarfs.

Acknowledgements. This research was partly supported by the National Science Centre under the grant DEC-2011/03/B/ST9/03299

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