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Cool spotted binary system IN Vir (HD116544)

I.M. Volkov[1,2], A.S. Kravtsova[2], T. Pribulla[3], J. Budaj[3], Z. Garai[3], Ľ. Hambálek[3], R. Komžík[3] and E. Kundra[3]

[1] *Institute of Astronomy, Russian Academy of Sciences, Pyatnitskaya Str., 48, 109017 Moscow, Russia, (E-mail: hwp@yandex.ru)*

[2] *Sternberg Astronomical Institute, Lomonosov Moscow State University, Universitetskij Ave. 13, 119992 Moscow, Russia*

[3] *Astronomical Institute of the Slovak Academy of Sciences 059 60 Tatranská Lomnica, The Slovak Republic*

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Abstract. High-precision spectral and photometrical observations of the binary IN Vir were carried out during 2015-2018. Basic geometrical and physical parameters were derived. The multicolour photometry made it possible to estimate the orbital inclination of the system, the size and the temperature of the cold spots. Solar like cycles due to chromospheric activity were found. Light Curves (LC)'s form changes with time.

Key words: stars: individual: IN Vir – stars: binaries – methods: observational – techniques: spectroscopy, techniques: photometry

1. Introduction

IN Vir is an X-ray source discovered by EXOSAT (Giommi et al., 1991). The optical variability of the star with the period of 8.15 days was found by Cutispoto et al. (1992). The star was classified as an RS CVn variable with K4 IV + G8 V components. A Doppler-imaging analysis was used to construct a map of spots on the surface of the cooler component (Strassmeier, 1997). The period of the spectral binary from the radial velocity curve was derived as $8^d.22$.

2. Échelle spectroscopy

Medium and high-dispersion spectroscopy of IN Vir was obtained with two spectrographs. At the Stará Lesná observatory observations were performed in the G1 pavilion using a 60 cm, f/12.5 Zeiss Cassegrain telescope equipped with a fiber-fed échelle spectrograph eShel (see Thizy & Cochard, 2011; Pribulla et al., 2015) and having a maximum resolving power of R 11 000. The observations were also performed with a 1.3 m, f/8.36, Nasmyth-Cassegrain telescope, equipped with a fiber-fed échelle spectrograph, at the Skalnaté Pleso observatory.

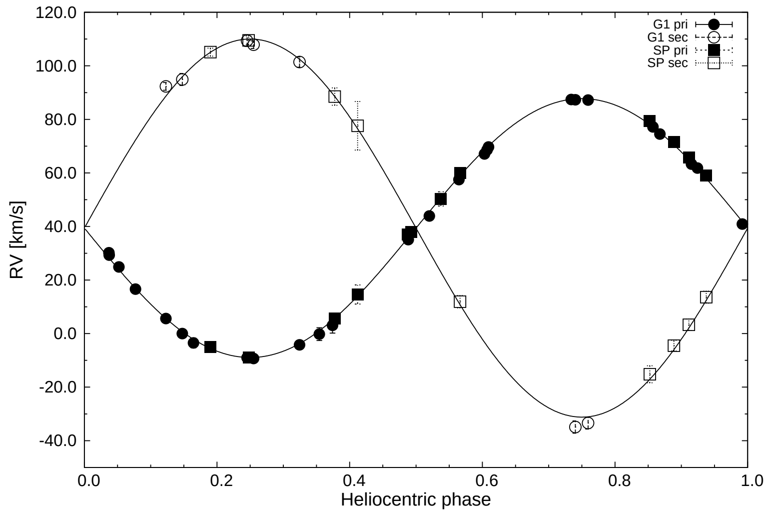

Figure 1. RV measurements of the primary and secondary component of IN Vir

3. CCD photometry

Photometrical observations were made in 100+ nights during 2015-2018 with the Zeiss-600 and Zeiss-1000 telescopes in Simeiz Observatory on Mt. Koshka (Crimea). We used a CCD camera FLI PL09000 with the $BV(RI)c$ filter set mounted at a 1 m reflector and the VersArray512UV camera with $UBVRI(Rc)$ filters at a 60 cm telescope. We've obtained measurements in 100+ nights in four years. We analyzed photometric data using the methods described in our earlier works (see Volkov & Volkova, 2009). All observations were corrected for differential atmospheric extinction.

4. Data Analysis

4.1. Broadening functions and radial velocities

Spectra of IN Vir were analyzed using the broadening-function (hereafter BF), a technique developed by Rucinski (1992). The BFs have been determined in the 4900-5510 Å spectral range (free of hydrogen Balmer lines and telluric lines) for both spectrographs. BFs were extracted using HD185144 (K0V) as the template. The extracted BFs clearly show two components: a fairly-rapidly-rotating primary and a faint slow-rotating secondary. To determine the radial velocities, the BFs were modelled by two limb-darkened rotational profiles (see Pribulla et al., 2015). The orbital period of the eclipsing pair was optimized. A circular orbit was assumed. The resulting best parameters are given in Table 1 and the corresponding fit is plotted in Fig. 1.

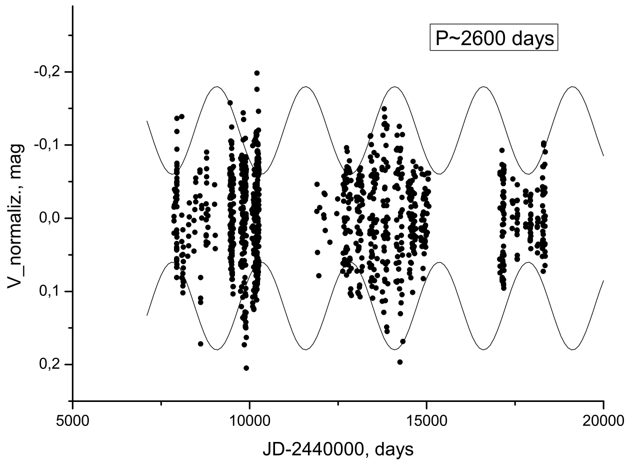

Figure 2. Long-term variability of IN Vir in V. Envelopes show solar-like activity cycles. The mean stellar magnitude is set equal to 0 for each year.

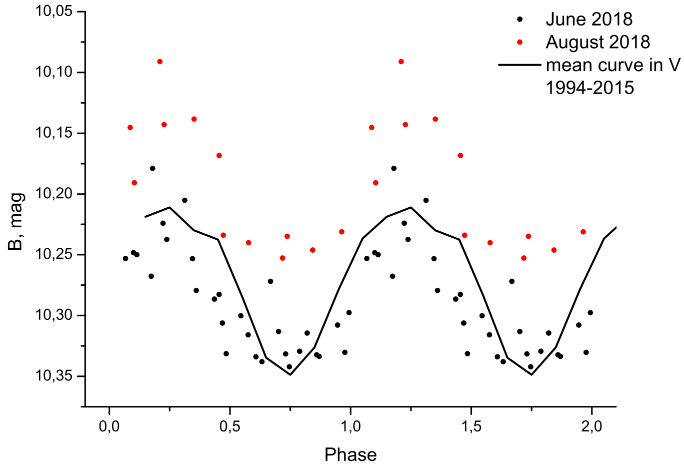

Figure 3. The B - LC during June to August 2018. It demonstrates a nearly flat bottom and narrow peak in maximum. Mean V - LC in 1994-2015 is also presented.

4.2. Photometric variability

We've determined the spectral class of IN Vir as K2 using our $UBVRI$ observations and Popper (1980) calibration. The value of interstellar extinction is nearly zero. We used Hipparcos, ASAS Pojmanski (2002), and Strassmeier (1997) data in combination with our V-observations. A general picture of the variability in V is presented in Fig. 2. The amplitude of the variability changes with time and resembles the chromospheric activity of the Sun. The approximate period of this activity is about 7 years.

Table 1. Spectroscopic elements of the primary and secondary components of IN Vir.

Parameter	Value	σ
P [d]	8.18977	0.00014
T_0 [HJD]	2 457 929.565	0.005
V_0 [km s^{-1}]	+39.38	0.15
K_1 [km s^{-1}]	48.35	0.21
K_2 [km s^{-1}]	70.6	0.6
q	0.685	0.007
$m_1 \sin^3 i$ [M$_\odot$]	0.848	0.016
$m_2 \sin^3 i$ [M$_\odot$]	0.581	0.007
$v_{1rot} \sin i_1$ [km s^{-1}]	24.6	0.5
$v_{2rot} \sin i_1$ [km s^{-1}]	≤ 8	
i [°]	55 - 68	
$r_1 \sin i$ [R$_\odot$]	4.1	0.2
$r_2 \sin i$ [R$_\odot$]	1.6	0.2

From 1994 to 2015, the photometric period, average brightness and the form of LC (not amplitude) remained unchanged. One can suppose a stable configuration of cold spots for 20 years. The photometric period of 8.1321 days during these years did not coincide with the orbital period. This probably indicates that the double system is not fully synchronized. The behavior of variability has changed in the last 2.5 years. At the present time we observe the active period with rapid changes in mean brightness (see Fig. 3).

Comparing the LCs in different bands and taking into account that there are no eclipses in the system, we derived the orbital inclination of the binary to be $55 - 68°$. Further we found that the spectrum of cold spots during the stable configuration corresponds to K5 and the spots occupy 24% of the surface.

5. Conclusions

Using high-precision spectral and photometric observations we have determined the reliable parameters of the binary system IN Vir: masses, velocities, sizes, temperatures of the components, parameters of the orbit. The period of photometric variability is non-equal to the orbital one. The solar-like chromospheric activity of the K2 IV component is found. The star demonstrates long, till 20 years, intervals of a relatively stable configuration of the spots, and active periods with rapid changes on its surface.

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