Detection of high-frequency variability in chromospherically active stars

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Abstract

We have carried out high-speed photometry of three chromospherically active stars, BD +15 3364, II Peg, and SAO 52355 with the Zeiss 2-m telescope, as well as low-resolution spectroscopy of SAO 52355 with the Zeiss-600 telescopes at Peak Terskol. BD +15 3364 is known as chromospherically active star of the spectral type G0. II Peg is the RS CVn binary. It has a spectral type K2IV-Ve. SAO 52355 is a field star of the spectral type K0 III. The X-ray observations taken by Ginga and ROSAT indicate in II Peg and SAO 52355 coronae plasma temperatures as high as 10^7 K. These two stars are supposed to have high-powered chromospheres. Photometric observations of all three stars show high-frequency variations in brightness in the UBV bands at subsecond range. Intensity variations are found peaked at frequency around about 0.5 Hz, spanning the range up to 1.5 Hz for BD +15 3364, II Peg, and up to about 35 Hz for SAO 52355. The relative power of fluctuations reaches (10^{-3.7} – 10^{-4.2}) in the UBV bands. Spectroscopic monitoring of SAO 52355 showed variations of emission in the Balmer lines and in the CaII H, K lines at time intervals ranging from seconds to minutes. From the power spectrum data one can find that variations in the intensities of the CaII H, K and Hγ lines are 3.2% and 1.5%, respectively. This allows us to assert the existence of intense microflaring activity in these stars.

keywords stars: late-type – stars: chromospheres – methods: observational – techniques: photometric

1 Introduction

In this paper we present a set of high time-resolution observations of some chromospherically active stars and their reference stars in the UBV bands acquired in August 2011 at the Peak Terskol. Here we discuss photometric observations of three stars: BD +15 3364, II Peg, and SAO 52355. BD +15 3364 is known as chromospherically young, kinematically old star [5], spectral type G0, magnitudes in Johnson V = 8.66, B = 9.27. II Peg is the RS CVn binary. According to the GCVS its photometric magnitude spanning the range V:(7.18 - 7.78), period of variation: 6.7026 days, Spectral type: K2IV-Ve. The X-ray observations taken by Ginga indicate coronae plasma temperatures as high as 10^7 K [6]. SAO 52355 is a field star, spectral type: K0 III, Johnson magnitude V: 9.86, Johnson B-V color, computed from the Tycho catalog B-V: 1.33.

We found on these three stars photometric evidence of chromospheric activity, as this will be shown below. It is found that chromospherically active stars show strong Hydrogen and Ca II emission lines as well as high X-ray luminosity. As mentioned by [1], the high X-ray flux from chromospherically active stars detected by space observatories could be explained by assuming that the heating of its corona results from a large number of small flares. It is well-known that the solar corona is heated by the two most favored agents involving magnetic fields, namely MHD waves and transients, such as flares, micro- and nanoflares (see [3] and references
It is expected that when two oppositely-directed magnetic fields come closer, the current density of the contained plasma increases considerably, so that even a small resistivity is quite sufficient to convert magnetic energy of plasma to thermal energy via magnetic reconnection. The reconnect heating by foot-point motions was proposed first by Parker [4]. Reconnection is associated with direct magnetic field dissipations. A forest of closed magnetic loops has foot points ankered in photospheric regions. The mechanical energy flux is generated by foot point motions. These motions increase the energy stored in the entwined magnetic field. This system can return to a minimum energy configuration only after a reconnection (or a cascade of reconnections). It is thought that these small and frequent reconnection events give rise to the microflare heating [2].

Our primary goal is to present clear evidence of intense microflaring activity in stars of such a type, using a high-speed photometer that can operate in three bands (UBV) with sampling frequencies up to 100 Hz. In the subsequent sections we describe the observation, then the analysis technique applied and the main results.

2 Observations

The observational data for program stars and their references stars were obtained over 3 nights in August 2011. We used the 2-m Ritchey-Chretien telescope at Peak Terskol (North Caucasus, 3100 m a.s.l.) with a high-speed two-channel UBVR photometer [9]. The integration time was 0.01 and 0.1 s. Hence, our instrumentation allows to detect signals with frequencies up to 50 Hz.

A new promising approach based on the theory of count statistics allowed us to detect activity in some chromospherically active stars and late-type giants on short time-scales. The actual value of variability caused by atmospheric scintillation was determined from measurements of a reference star. The intrinsic activity of the star was found as a difference between the observed relative power and that of the atmospheric scintillations.

The SAO 52355 spectra were observed with the grating spectrograph on the Zeiss-600 telescope at Peak Terskol on May 30-31, 2010. A blazed transmission grating is included in the converging beam in the Zeiss-600 filter wheel. The observations were acquired with a SpectraVideoTM Camera, Pixel Vision, Inc. 2. The grating spectrograph observations cover the wavelength range from \(\approx 3700\) Å to 9000 Å and a time interval of 1600 seconds. The exposure time was 8 seconds. The wavelength scale after calibration is accurate to about 30 Å. The grating spectrum has a resolution of \(R \approx 100\) at 4800 Å.

3 Detection and estimation of high-frequency variability

A high-frequency variability is present, for example, in all dwarf novae in all stages of activity and other cataclysmic variables [7] in a form of random brightness fluctuations, with a continuous distribution in the corresponding frequency domain. The frequency distribution gives some indication about the geometrical extent of the variable source, namely there is either a point-like source or an extended, optically thick one. In view of random nature of variability, there is some difficulty in detection of any intrinsic low-amplitude fluctuations close to the noise level. A new promising tool for solving the problem relies on the theory of count statistics. The intrinsic activity can be detected using the factorial moments [8]

\[
\left\langle \frac{n!}{(n-k)!} \right\rangle = \langle (n(n-1)\ldots(n-k+1) \rangle = n[k]
\]  

(1)
where \( n \) is the count rate, the angle brackets denote time averaging. It is convenient to use the normalized factorial moments

\[
h_{[k]} = \frac{n[k]}{\langle n \rangle^k}
\]

(2)

In the case of a Poisson statistics it can be shown that, for any \( k \), \( h_{[k]} \equiv 1 \). Hence, any significant deviation of \( h_{[k]} \) from one may signal the presence of variability. Attempting to detect activity on shortest time-scales, we applied this relatively straightforward approach. The expression for the factorial moment of the second order

\[
\varepsilon = \frac{\sigma^2 - \langle n \rangle}{\langle n \rangle^2} = h_{[2]} - 1
\]

(3)

specifies the relative power of fluctuations \( \varepsilon \) in the frequency range \( \Delta f = \frac{1}{2\Delta t} - \frac{1}{m\Delta t} \), where \( \Delta t \) is the sampling time, \( m \) the length of the data segment, \( \langle n \rangle \) and \( \sigma^2 \) are the sample mean count rate and the variance, respectively. Choosing appropriate values of \( m \) and \( \Delta t \), one can calculate the power spectrum of fluctuations by averaging \( \varepsilon \) over time. In our case, we adopt \( m = 5 \). The standard deviation for \( h_{[2]} \), as shown in [10] is defined by the relation

\[
\text{std}(h_{[2]}) \approx \frac{1}{\langle n \rangle} \sqrt{\frac{1}{N}}
\]

(4)

The actual value of \( \varepsilon \) caused by atmospheric scintillation can be determined from measurements of a reference star. The difference in \( \varepsilon \) between the observed relative power of the star and that of the atmospheric scintillations is taken to be the intrinsic \( \varepsilon \) spectrum of star.

4 Results and discussion

4.1 SAO 52355

In photometry of bright stars scintillation noise is usually a dominant error source. The intensity of scintillations is log-normally distributed. Hence, for weak scintillations in bright stars the standard errors are identical, if expressed in the stellar-magnitude or relative power scales. It is important to use a nearby comparison star to evaluate the scintillation component of the covariance in Eqn. (3) and exclude the atmospheric effect.

Fig. 1 shows for SAO 52355 and the comparison star the powers of variation and standard errors in the B band. The estimated scintillation powers do not depend on stellar magnitudes and agree within the limits of experimental errors up to 5 Hz. It is interesting to note that situation outside of the (5 - 35) Hz range significantly differs due to intrinsic activity of SAO 52355 in the B band.

Fig. 2 shows the difference in \( \varepsilon \) between the observed relative power of the variable star and that of the atmospheric scintillations taken from the \( \varepsilon \) - spectrum of a reference star. Thus, Fig. 2 indicates the presence of intrinsic activity in the range \((\sim 5 - 35) \text{ Hz}\) in SAO 52355. The power excess reaches \( \sim 7.8 \cdot 10^{-5} \) of the total power in the B band. The rms amplitude caused by intrinsic activity in the B band is about of 0.009 mag. The power of fluctuations at frequencies below 5 Hz is impossible to evaluate due to large estimation errors.

Fig. 3 indicates the presence of intrinsic activity in the range \((\sim 0.5 - 35) \text{ Hz}\) in SAO 52355 for an integration time of 0.1 s. The power excess reaches \( \sim 6.8 \cdot 10^{-5} \) of the total power in the U band.

Fig. 4 shows the relative power of intrinsic fluctuations in the range \((\sim 0.5 - 35) \text{ Hz}\) in SAO 52355 for an integration time of 0.01 s. The power excess reaches
2.2 \cdot 10^{-4} of the total power in the V band and corresponds to the rms amplitude of about 0.015 mag. Thus, a new approach based on the theory of count statistics allowed us to detect activity of SAO 52355 on short time-scales. The actual value of variability caused by atmospheric scintillation was determined from measurements of a reference star. The intrinsic activity of the star was found as a difference between the observed relative power and that of the atmospheric scintillations.

We found that the intensity from a variable source on SAO 52355 is peaked at frequency around about 0.4 Hz, spanning the range up to 35 Hz. The relative power of fluctuations reaches $(6.8 - 22) \cdot 10^{-5}$ in the UBV bands. It appears that the observed variability patterns in SAO 52355 can be related to an ensemble of microflares with a duration ranging from tenths to a few of seconds. The energy output of the ensemble-average microflares can be estimated roughly as $E \approx 4 \cdot 10^{-4}$ of the stellar luminosity. The observations produced by satellite ROSAT had shown high X-ray luminosity of SAO 52355 that points to presence of a high-temperature, $T > 10^7$ K plasma, suggestive of intense flaring activity.

On May 30-31, 2010, we obtained 200 low-resolution grating spectrograms of SAO 52355. For SAO 52355 we used GSC 3226 640 as the reference star, Johnson V magnitude: 10.69. Data inferred from the Tycho catalog: BT magnitude $11.018 \pm 0.032$, VT magnitude $10.726 \pm 0.036$. Johnson B-V color, computed from BT and VT: 0.270.

Computed averaged spectra of SAO 52355 and its reference star GSC 3226 640 acquired with the Zeiss-600 telescope are shown in Fig 5. In Fig 6. the relative power of variations in grating spectra of SAO 52355 and its reference star GSC 3226 640 are shown. Note the "smooth" spectral energy distribution in the power spectra of the reference star and the "emission" features at wavelengths of the Balmer lines and the CaII H, K lines, as well as at a wavelength of the Balmer jump $\lambda 3700 - 3800 \text{Å}$ in SAO 52355. From the power spectrum data one can find that variations in the intensities of the CaII H, K and $H_{\gamma}$ lines are 3.2% and 1.5%, respectively.

The emission features that identify the hydrogen lines and the CaII H, K lines, prove chromospheric activity of a star. Thus, the spectral observations provide an additional argument in favor of the chromospheric activity of the giant SAO 52355.

### 4.2 II Peg

Further we illustrate the high-frequency activity of II Peg as resulted from observations at the 2-m telescope at Peak Terskol in August 2011 with a high-speed photometer. The light curves of II Peg and its comparison star do not suggest obviously that these stars are active in the subsecond range (Fig. 7). Fig. 8 indicates, nevertheless, the presence of intrinsic activity in the range ($\sim 0.4 - 1.5$) Hz in II Peg for an integration time of 0.1 s. The power excess reaches $\sim 8.8 \cdot 10^{-6}$ of the total power in the U band and corresponds to the rms amplitude of about 0.003 mag. Variability in the V band is not detected above $\sim 5 \cdot 10^{-7}$ in almost all frequencies (Fig 9).

### 4.3 BD +15 3364

Fig. 10 indicates as well the presence of intrinsic activity in BD +153364 in the frequency range ($\sim 0.4 - 1.5$) Hz. That follows from high-speed observations with an integration time of 0.1 s at the 2-m telescope in the B band.

### 5 Conclusion

Photometric monitoring of three chromospherically active stars, BD +15 3364, II Peg, and SAO 52355, reveal high-frequency variations in the UBV bands at sub-second range. Intensity variations are found peaked at frequency around about 0.5
Hz, spanning the range up to 1.5 Hz for BD +15 3364, II Peg, and up to about 35 Hz for SAO 52355. The relative power of fluctuations reaches $10^{-3.7} - 10^{-4.2}$ in the UBV bands. Spectroscopic monitoring of SAO 52355 showed variations of intensity in the Balmer lines and in the CaII H, K lines at time intervals ranging from seconds to minutes. From the power spectrum data one can find that variations in the intensities of the CaII H, K and $H\gamma$ lines are 3.2% and 1.5%, respectively. Satellite surveys at X-ray indicate high temperature coronae plasma in many chromospherically active stars. High-frequency changes, which were found in BD +15 3364, II Peg, and SAO 52355, suggests the existence of intense microflaring activity in these stars.

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Figure 1: The relative power density of variations of noise in the B band for SAO 52355 (denoted by squares) and the comparison star (denoted by circles) obtained with the 2 m telescope at Peak Terskol on Aug 28, 2011. The 1-sigma error borders are shown for both stars.

Figure 2: The relative power density of variations in the B band for SAO 52355 due to intrinsic activity. The 1-sigma error borders are shown.
Figure 3: The relative power density of intrinsic variations in the U band for SAO 52355. The 1-sigma error borders are shown.

Figure 4: The relative power density of intrinsic variations in the V band for SAO 52355. The 1-sigma error borders are shown.
Figure 5: The averaged raw count rate grating spectra of SAO 52355 (squares) and its reference star GSC 3226 640 (thin curve).

Figure 6: The relative power of variations in grating spectra of SAO 52355 (circles) and its reference star GSC 3226 640 (solid curve). 1 sigma error bars are shown.
Figure 7: The light curves of II Peg and a comparison star in the U band with the sampling time of 0.5 sec.

Figure 8: The relative power density of intrinsic variations in the U band for II Peg. The 1-sigma error borders are shown.
Figure 9: The relative power density of intrinsic variations in the V band for II Peg. The 1-sigma error borders are shown.

Figure 10: The relative power density of intrinsic variations in the B band for BD+15 3364. The 1-sigma error borders are shown.