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THE R-BAND OBSERVATIONS AND COMPARISON WITH RESULTS IN THE V-BAND OF FI Sge

L. Keir[1], S. Udovichenko[2]

[1] Department of Physics and Astronomy, Odesa I. I. Mechnikov National University, Ukraine, *partneroae@gmail.com*

[2] Research Institute "Astronomical Observatory", Odesa I. I. Mechnikov National University, Ukraine, *s.udovichenko@onu.edu.ua*

ABSTRACT. We present the result of the processing of our observations of the FI Sge, the pulsating RR Lyrae type variable with the Blazhko effect in the R-band. The data were obtained during 36 nights in 2018 as well as during 13 nights in 2021. We used the period and initial epoch obtained from our observations in V-band. We confirmed the presence of the Blazhko effect, the bi-cyclicity effect, and also the effect of discrete displacement of the light curves along the phase curve detected firstly in the V-band. We detect some differences in the dynamic of the light curve variability in different photometrical bands, possibly related to the Blazhko effect.

Keywords: stars: variables: RR Lyr: individual: FI Sge.

АНОТАЦІЯ. Нами викладені результати обробки спостережень у фільтрі R пульсуючої змінної зорі типу RR Ліри з ефектом Блажко FI Sge за 36 ночей у 2018 році та 13 ночей у 2021 році. Ми використовували період та початкову епоху для цієї зорі, які були вже визначені за спостереженнями у V фільтрі. Наші спостереження у фільтрі R підтверджують наявність у FI Sge двох періодів модуляції амплітуди всередині циклу Блажко, виявлених за спостереженнями у фільтрі V раніше. Аналіз зміщень кривих блиску вздовж фазової кривої за 2021 рік у фільтрі R призводить до висновку, що значення величини дискретного зміщення для зорі FI Sge потрібно змінити з 0,043 фази подвійного періоду (0,50500*2 дні) на кратне їй значення 0,01075. Нові спостереження 2021 року у фільтрі R дозволяють припустити, що час зміни напрямку зміщень кривих блиску вздовж фазової кривої становить півтора року, а приблизний період цих змін становить три роки. Порівняння кривих блиску у фільтрі R та фільтрі V показує, що існує деяке запізнення часу моментів зміщень у фільтрі V по відношенню до фільтру R. Його значення не менше ніж 12 діб. Зміна показника кольору (V–R) вказує на ймовірне підвищення температури зорі, або в момент зміщення кривої блиску, або відразу після цього.

Спостереження у фільтрі R підтверджують наявність у зорі FI Sge ефекту Блажко, ефекту бі-циклічності та ефекту зміщення моментів максимумів до початкової епохи вздовж фазової кривої.

Ключові слова: зорі: змінні: RR Lyr: індивідуальні: FI Sge.

1. Introduction

FI Sge is a pulsating variable star of the RR Lyrae type with the Blazhko effect. In the GCVS (Samus et al., 2017) this star ($RA_{2000.0} = 20^h13^m16.2^s$, $Dec_{2000.0} = +17°30'37''$) is described as RRab type variable, Sp=A2, the magnitude variations are in the range from 13.2^m to 14.3^m, $JDmax = (2428333.441 + 0.5047545E)^d$, and period of the Blazhko effect $P(BL) = 22.4^d$. It is a little studied variable star. Hoffmeister (1936), based on observations from the Sonneberg Observatory, noted the star as a variable. In 2017, Mainz (2017) observed FI Sge over 5 nights. She studied the information from the literature in detail. Using her observational data, Mainz determined the FI Sge period to be P=0.50477d. This value is different from that given in the GCVS. Maintz studied the (O–C) values for the maxima of the light curves based on data from Richter (1961), Wils et al., (2006), Agerer and Hubscher (2002). She suggested that the period of variability changed after J.D. 2452000. She also noted that the phase curves constructed from NSVS and ASAS data differ in amplitude and phase. For NSVS data, the shift of the position of the maxima on the phase curve from the initial epoch was equal to 0.15 of the period of variability. Mainz did not discover the Blazhko effect. Skarka and Cagas (2017) also observed FI Sge in August, September and October 2017. Observations were made without a filter over 14 nights. They analyzed their data and determined the Blazhko effect period to be 22.4 days.

Thus, FI Sge is an RR Lyrae star that has the Blazhko effect. In addition to the Blazhko effect, the

star has a bicyclicity effect. The star also demonstrates the effect of shifting light curves along the phase curve. All these effects introduce changes in our final picture of its brightness fluctuations. Our task was to separate these changes and determine the contribution of each of them.

Blazhko modulation changes the shape of the light curve. Here, modulation of the amplitude of the light curve leads to the phase modulation. When light maximum increases, the period becomes longer. Accordingly, when light maximum decreases, the period becomes shorter. As a result, light maximum is slightly shifted in phase (0.1 cycle). Negative phase shifts always occur for fainter maxima, positive phase shifts for brighter maxima.

The next effect is the bi-cyclical effect. This is a conditional name, since there is no established name. The effect was described in 2010 by Smolek (2016). It consists in the fact that for some stars of the RR Lyrae type with the Blazhko effect, neighboring pulsation cycles differ significantly in amplitude. The modulation of the maxima also differs for these cycles. We consider these cycles to be distinct and construct a phase curve using a double period. This technique allows you to separate cycles with different types of pulsation activity on the phase curve. This method is described in more detail in Keir (2023).

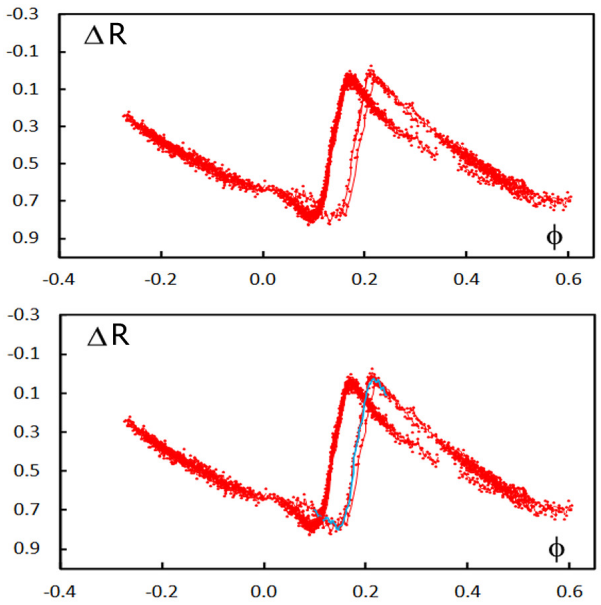

Figure 1: Observations FI Sge 2018 in the upper figure. The phase curve is plotted with a period of 0.50500*2 days. In the bottom figure, the light curve of October 10, 2018 (blue) is shifted to the right by one discrete shift (0.0430 phase value).

2. Observations

Our observations were carried out at the AZT-3 telescope in the Astronomical Observatory Odesa National University, located at the observational station N583 in Mayaki village. The AZT-3 telescope has a primary mirror diameter of 480 mm and a focal length of the Newton optical scheme F = 2024 mm, the exposure time was 90 sec. The images were registered with CCD Sony ICX429ALL (≈600x800 pixels) with the Peltier cooling, in the V, R photometric system. The registration complex was developed and installed by Udovichenko (2012).

The photometry of the original frames was made with Muniwin software (Motl, 2009). The comparison star was UCAC4-538-127214 ($J_{2000.0}$: RA : $20^h13^m14.876^s$ Dec : $+17°33'39.95''$, $V = 13.36^m$), and the control star was UCAC4-538-127074 ($J_{2000.0}$: RA : $20^h12^m59.405^s$, Dec : $+17°33'49.42''$, $V = 13.73^m$). We determined the Julian Date with the correction to the barycenter of the Solar and instrumental magnitudes for the variable star (V), comparison star (C), and control star (K) for each frame.

Fig. 1 shows observations in the R filter of the star FI Sge in 2018. They confirm the effect of shifting light curves along the phase curve to the initial epoch, discovered from observations in the V filter. The distance between the October maxima and the July maxima corresponds to one discrete shift (0.043 phases of the double period). This is confirmed in the bottom picture. The divergence of the maxima in phase in July is not a consequence of the Blazhko effect, since the higher maxima (July 12, 13) are located to the left of the weaker maximum (July 6). We consider only a small discrepancy in the light curves in each individual set of observations to be a manifestation of the Blazhko effect. This slight discrepancy is also proof that we have correctly determined the period of variability. We did not obtain maxima for the adjacent pulsation cycle in these observations. However, the descending part of the light curve on the left is flatter than in the cycle on the right. This means that the maximum of the left cycle will be fainter than the maximum of the right one. The difference in the amplitudes of the maxima of two neighboring cycles confirms the bicyclicity effect in this star. The amplitudes and moments of the maxima were determined by polynomials up to the seventh degree using the MCV program, which was created by Andronov and Baklanov(2004). Analysis of the amplitudes of the maxima in October 2018 shows that, as in the V filter, there is a statistically significant division of maxima on those whose numbers of cycles are multiples and those whose numbers of cycles are not a multiple of four. This means that within the Blazhko period there are at least two independent periods of oscillation.

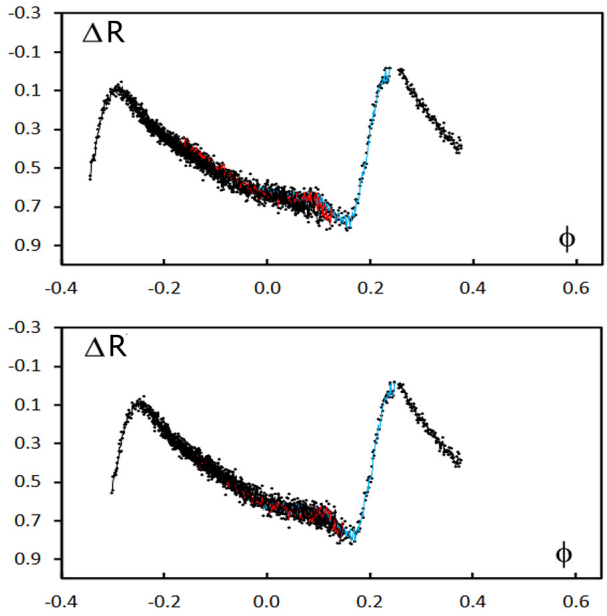

Figure 2: Observations of FI Sge 2021 (the upper figure). In the bottom figure, the light curve of 01 August (blue) is shifted to the right by 0.01075 phases. The light curves for August 14 and 15 (red) are shifted to the right by 1/2 discrete shift. All later light curves are shifted to the right by the amount of one discrete shift (0.0430 phase).

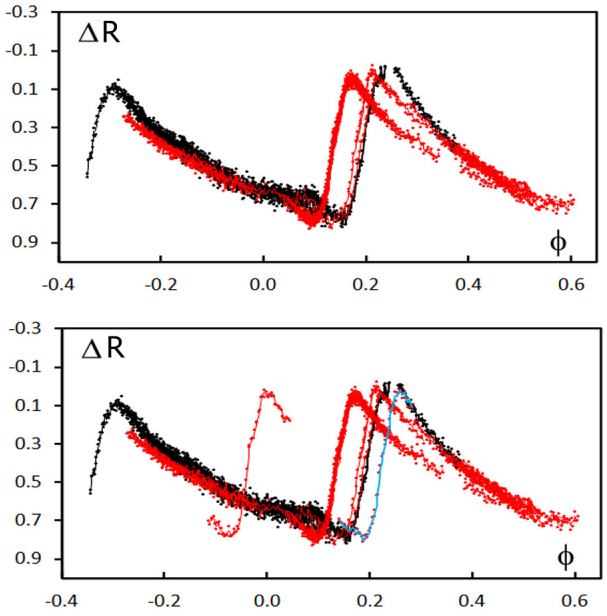

Figure 3: Observations of FI Sge 2018 (red) and 2021 (black) in the upper figure. The light curve for October 10, 2018 (blue) is shifted by two discrete shifts to the right (bottom figure).

There were fewer observations in 2021 than in 2018. We can see that in Figure 2 above. In the bottom graph of Fig. 2 we have combined all the light curves into one common phase curve. To do this, we shifted the light curve on August 1 to the right of the initial epoch by 0.01075 phase of the double period. This value is equal to the discrete shift (0.043 double period phase) divided by four. The light curves of August 14 and 15 are shifted to the right of the initial epoch by the same amount. All other light curves on August 26,28,30,31, September 2,3, October 29,30 and November 3 are shifted to the right from the initial epoch by one discrete shift (0.043 phases of the double period). In this way we combined them with earlier light curves. The figure shows that in this phase curve the period between maxima is exactly equal to the period of variability. We made fractional shifts from the discrete one for the first time, since there was no need for such shifts for V-filter observations, or so we thought. But, as we noted above, the light curve of July 6, 2018, falls out of the general picture of discrete shifts. However, if we shift it to the left toward the initial epoch by 0.01075 from the double period phase, it fits well with the light curves of July 12 and 13, 2018. Thus, in 2021 we observe discrete shifts of the light curves toward the initial epoch. In their meaning and direction, they are similar to the shift of the light curves in 2018.

3. Analysis of observations

The overall phase curve for all light curves is shown in Fig. 3 in the top graph. Here we see that the arrangement of the light curves of 2021 follows the light curves of 2018 with a slight shift in time. So the light curve of August 1, 2021 falls on the light curve of July 6, 2018. The bottom graph shows that the light curve of October 10, 2018, shifted by two discrete shifts to the right, complements the light curve of July 17, 2021, and the light curves of June 2018. To check, we shifted the light curve of October 9, 2018 to the left by four discrete shifts. As evident in Figure 3, the peak of light maximum coincides with zero phase..

For the data in the V filter, we were unable to estimate the period of change in the direction of displacements movements. A long break in observations from 2014 to 2017 prevented this. New observations in the R filter for 2021 help reconcile this uncertainty. The direction of displacement changes every year and a half. That is, every three years the direction of movement of the displacements is repeated. This agrees well with observations in both filters.

Next, we looked at whether there was a difference in the dynamics of the shifts of the light curves in the R

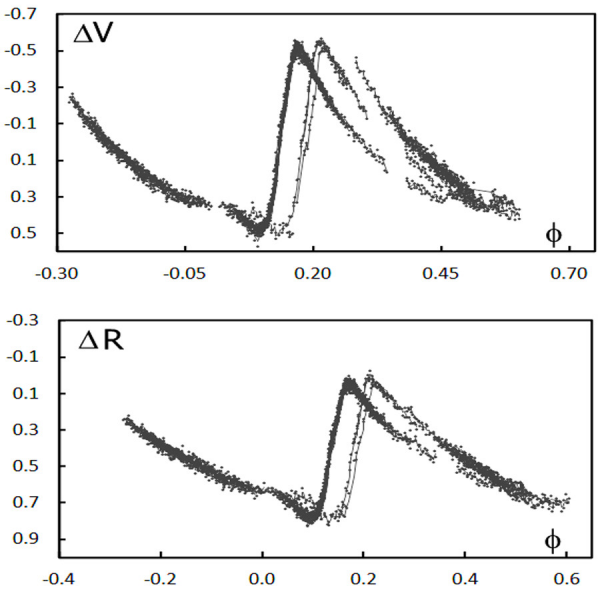

Figure 4: 2018 FI Sge observations in the V(upper) and R(bottom) filters.

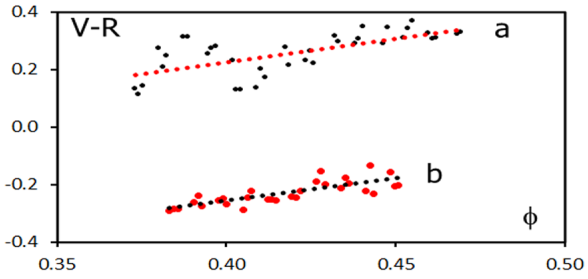

Figure 5: Value of the V–R color index on June 21, 2018 (a), and on June 23, 2018 (b).

filter and the V filter. In Fig. 4, the observations for 2018 in the V filter are shown at the top, and the observations in the R filter are below. As we can see, the shift of the light curves, which in the filter V occurred approximately on June 22, in the R filter it could occur no later than June 10. It was not possible to establish a more precise date. The lag of the shifts in the light curves in the V filter from the shifts in the R filter is at least 12 days. The given time interval is typical for changes associated with the Blazhko cycle. We can assume that the shifts of the light curves themselves along the phase curve are associated with the mechanism of the Blazhko effect.

We calculated the color index (V–R) for all data. It is believed to better reflect changes of the star's temperature. This figure varies greatly depending on what part of the light curve we are observing. The value (V–R) behaves in a mirror manner with respect to changes in the light curve. We show in Fig. 5 the value of (V–R) before the shift in the light curves on June 21, 2018 (top), and immediately after the shift for the date June 23, 2018 (bottom). As we can see from the figure, the index (V–R) has dropped significantly. We infer that the surfase temperature of the star increased during or immediately after the light curve shift.

4. Conclusions

Our observations of the star FI Sge in the R filter confirm the presence of a bicyclicity effect and an effect of shifting the moments of maxima along the phase curve in this star.

Observations in the R filter also confirm the presence of at least two periods of amplitude modulation within the Blazhko cycle, detected from observations in the V filter.

An analysis of the shifts in light curves for 2021 in the R filter leads to the conclusion that the value of the discrete shift for the star FI Sge needs to be changed from 0.0430 double period phase to a multiple of it 0.01075.

New observations from 2021 in the R filter suggest that the time of change in the direction of the light curves shifts is one and a half years, and the approximate period of these changes is three years.

A comparison of the light curves in the R filter and the V filter indicates that there is some delay in the time of the displacements in the V filter relative to the R filter. This delay is at least 12 days.

A change in the color index (V–R) indicates a likely increase in the temperature of the star, either at the moment the light curve shifts, or immediately after this shift.

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