Stellar Variability in the Early Evolution Stages

Evgeni H. Semkov
Institute of Astronomy - BAS, Sofia, Bulgaria
evgeni@skyarchive.org

Abstract

A short review on the variability of young stellar objects is presented. The physical mechanisms causing photometric variability are summarized according to the object type. As an example, the results from our photometric and spectral observations in the field of the emission nebula NGC 7129 are presented. Light curves, spectra and deep direct images of two interesting pre-main sequence stars V 350 Cep and V 391 Cep are analyzed. For the variable star V 350 Cep the continued gradual rising of brightness resembling the light curve of V 1515 Cyg - a FU Ori type star, is observed.

Introduction

During the time of formation the young stellar objects (YSO) pass through periods of a gravitational instability and a chromospheric activity. The duration of these periods strongly depends on initial mass of the recent formed star. The massive stars ($M>2M\odot$) evolve quickly and reach the main sequence for less then 10 Myr, while the low mass stars spend more time in the contracting phase above the main sequence. The presence of circumstellar disks, molecular outflows, infalling envelopes, stellar wind and companion stars makes the YSOs vicinities very complicated. In the pre-main sequence (PMS) stage of evolution YSOs show different types of photometric variability.

The study of the T Tauri stars (TTSs) begins with the pioneering work of Joy (1945). The first definition of these objects was made on the basis of its emission-line spectra and connection with nebulosity. The light variability is another general characteristics of the TTSs. A high percentage of discovered emission stars by Ha surveys seems to be variables with amplitudes from some tenths to 3 stellar magnitudes. First Ambartsumian (1947) recognized that the T Tauri variables as very young low mass stars make groups that he named T-associations. The spectroscopic criteria that define the TTSs were summarized by Herbig (1962) as follow: 1) the hydrogen lines and the H and K lines of Ca II are in emission, 2) the fluorescent Fe I emission lines are present, 3) the [S II] emission lines are usually but not always present, 4) strong Li I absorption line if an absorption spectrum can by seen. Later, Bastian et al. (1983) add the criteria for no supergiant or early-type (earlier than late F) photospheric absorption spectrum. Appenzeller & Mundt (1989) assume for the TTSs 10 Myr as an upper age limit and $3M\odot$ as an upper mass limit. These somewhat arbitrary limits are in disagreement because the stars with masses 2-3 M⊙ have reached the main sequence for less than 10 Myr and most of the authors prefer to use 2 M⊙ as a upper mass limit.

Presently, it is generally accepted that the TTSs can be divided in two subgroups: the classical (CTTSs) and the naked or weak-line (WTTSs). The CTTSs differ from the WTTSs with a strong Hα emission line and significant infrared and ultraviolet excesses. Usually, the upper limit of W(Hα)$\leq 5\AA$ is used for defining the WTTS, but some authors prefer to use W(Hα)$\leq 10\AA$ (Apenzeller & Mundt 1989). The classification of TTSs in two subgroups became very important after analyzing of X-ray data obtained in the star forming regions. A number of weak X-ray sources on the TTS's region in the H-R diagram were discovered. The majority of these stars seems to be WTTSs or post TTSs undetected up to now (Martin 1997). CTTSs and WTTSs form a continuum of objects with various degrees of activity and some known CTTSs may go through an inactive phase during which they may look spectroscopically like WTTSs (Bertout & Bouvier 1989).

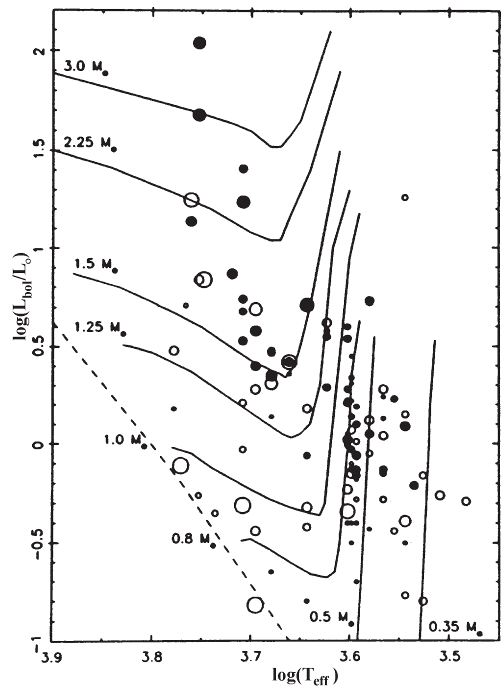

Figure 1: Position of CTTSs (dark circles) and WTTSs (open circles) in the H-R diagram. The zero age main sequence and pre-main sequence evolutionary tracks for various masses are also plotted.

Herbig (1960) initiates a new class of YSOs with masses M>3M⊙ still in their pre-main sequence stage of evolution. His selection criteria were: 1) the spectral type A or earlier, with hydrogen emission lines, 2) the star lies in an obscured region, 3) the star illuminates fairly bright nebulosity in its immediate vicinity. This class of extremely young objects is called now Herbig's Ae/Be stars. They can be observed only in the regions of active star formation. The earlier Herbig's Ae/Be stars generally show essentially no variations, but some stars later than A0 are variable and Herbst et al. (1994) use for them the term Early type T Tauri Stars (ETTSs).

A very rare phenomenon in the pre-main sequence star evolution is the FU Orionis (FUOR) outburst. Increase in optical brightness of the order of 3-5 magnitudes, F-G supergiant spectrum with broad blue shifted Balmer lines, strong infrared excess and connection with reflection nebulae are the main characteristics of FUORs (Reipurth 1990). The progenitors of FUORs are red, low-mass, slightly variable stars in the regions of active star formations. Presently it is generally accepted that the FOUR phenomena is a stage from the pre-main-sequence evolution. The statistical estimations in 1 kpc vicinity demonstrate that among all observable TTSs , at least, 10 FUOR outbursts will occur (Herbig 1977).

More 50 years ago George Herbig and Guillermo Haro independently discovered some curious semi-stellar objects in the Orion star forming region. Later such kind of objects called Herbig-Haro (HH) objects, have been found also in another, close to the Sun, star forming regions. The main properties of the HH objects are strong emission line spectra with a very weak continuum, non-stellar nebular shapes, high proper motions and photometric variability in some cases. The first explanations of the nature of these objects presume that they represent the early stages of newly formed TTSs or existence of low luminosity hot stars inside them. The last 20 years the assumption that the HH objects are a product from the TTSs activity , obtained a strong support from the observations. The supersonic shocked jets emanating from young stars produced HH objects where the flow encounters the ambient medium.

1 Main properties of PMSs

The presence of photospheric dark spots and accretion circumstellar disks play s a significant role in explanation of the pre-main sequence star variability. One manifestation of magnetic stellar activity is the formation of dark spots on the surface of the PMS stars. As we know from the analogues sunspots the enhanced magnetic flux partially blocks the convective energy transport under stellar photosphere. The result is formation of low temperature regions called dark or cool spots. According to detailed models in the case of TTSs the dark spots are often large, typically 10% of the stellar surface, the temperature difference is typically 700-1000 K and the life time - from days to a few years (Bouvier & Bertout 1989).

There is some evidence from the observations that suggests the presence of optically thick circumstellar disks around the CTTSs. The presence of a disk and the interaction between disk and star may be responsible for some properties of the CTTSs, as infrared and ultraviolet excesses and stellar wind. In contrast, the WTTSs do not display evidences for accreting circumstellar disks. This important difference between the CTTSs and the WTTSs manifest in different types of photometric variability.

According to Herbst et al. (1994) there are two well established physical mechanisms which must cause photometric variability in TTSs. They are rotation of a star with dark surface spots (Type I) and variations in the veiling continuum or variable accretion from circumstellar disk (Type II).

1.1 WTTSs

The light variability of WTTSs can be generally explained with the model of surface dark spots. The observed periods of variations are from 0.5 to, at least, 18 days with amplitudes up to $0\overset{m}{.}8$ mag in V and $0\overset{m}{.}5$ in I (Herbst et al. 1994). The light curve shape of WTTSs may change in time scales of weeks but the periods can be stable over months or years. The absence of changes in radial velocity and comparatively large periods exclude the hypothesis for pulsation nature of variability. While there is no essentially scatter in the relationships between V and R or I, in U and B sometimes there are evidences for a second source of variability similar to the flares observed in the M dwarfs (Vrba et al. 1993). Indeed, the classical time-resolved flares are very rare phenomena for the WTTSs but micro flares as a result from the strong magnetic activity can change the light curve in U and B.

1.2 CTTSs

The light variability of CTTSs can be understood in the terms of a mixed change of long-lived dark spots and short-lived hot spots or zones. The variable hot component produces the well-known veiling phenomenon (masking of the absorption lines) seen in the spectroscopic studies. Typically irregular variations have amplitudes from few tenths of magnitude to $3\overset{m}{.}8$ mag in U, $2\overset{m}{.}6$ mag in V and $1\overset{m}{.}6$ in I (Herbst et al. 1994). The hot spots with temperatures typically 10 000 K covering surface areas of 0.3% or less, are result from variation in mass accretion rate and star rotation. The stellar flares extended to V, R and I, play an essential role in the irregular variability. The CTTSs do not have strictly periodic light curves, although some show periodicity , at least, at some epochs.

1.3 ETTSs

The variability of the ETTSs can not be explained by the rotational modulation of a spotted surface or variable veiling continuum. Their variations are not periodic with amplitudes $0\overset{m}{.}8$ or more and they show little or no evidence of a veiling continuum at any epoch (Herbst et al. 1994). To explain variability of ETTSs two classes of models have been proposed: variable circumstellar extinction and variable surface magnetic activity. The variable circumstellar extinction hypothesis is the most popular model and it is confirmed by the near constancy of the spectrum of these stars as they fade. The irregular light curves of the ETTSs come out from the movement of dust concentrations in the inner regions of the stars. The another hypothesis for variable magnetic activity presumes the heavily spotted stars and that the spots grow and decay in a time scale shorter then the rotation period. It is difficult to explain why such type of variability would not occur on another stars with strong magnetic activity.

1.4 FU Ori type stars

¿From the ten classified as FUORs objects only three (FU Ori, V 1057 Cyg and V 1515 Cyg) have detailed photometric observations during the outburst. The light curves show a rapid rise of about a year or more and slow decline. The observed outburst is explained by increasing accretion caused by thermal instabilities in the circumstellar disk (Hartmann & Kenyon 1996). This model assumes increasing of the accretion rate through the disk by 2-3 orders up to $\sim 10^{-4}$ M$\odot$/yr. For the period of 10-100 years the circumstellar disk adds $\sim 10^{-2}$ M$\odot$ onto the central star and it ejects ~10% of the accreting material in a high velocity stellar wind. The surface temperature of the disk becomes 6000-8000 K and it radiates most of its energy in the optical wavelengths. None of the known FUORs have spectral observations at the time of rising and the moment when the spectrum has changed from absorptional to emission one is unknown now.

2 Young variable objects in the region of NGC 7129

The results of our observations in the field of the emission nebula NGC 7129 present a good example for young stellar variability. The investigations have as an object the photometric and spectral observations of variable stars in a wide field around the centre of the emission nebula and discoveries of new young variable objects. The observations suggest that NGC 7129 is a region of active star formation, the stars of different masses are formed in the dark cloud surrounding the small bright nebula. A large number of Herbig-Haro objects, collimated jet, H_2O masers, reflection and cometary nebula, variable TTSs and Herbig's Ae/Be stars are observed in the field of NGC 7129.

Our observations were carried out in the National Astronomical Observatory Rozhen (Bulgaria) and in the Astronomical Observatory Skinakas (Crete, Greece). Photographic observations with the 50/70 cm Rozhen Schmidt telescope and CCD spectral and photometric observations with the 2m RCC telescope in Rozhen and the 1.3 m telescope in Skinakas were made.

2.1 V350 Cep

The variability of V 350 Cep was discovered by Gyulbudaghian & Sarkissian (1977) comparing their photographic observations in NGC 7129 with the Palomar Observatory Sky Survey charts. They found the star brighter in 1977 with more than 4^m in B light in comparison with the brightness in 1954, while the increase beginning and the light curve are unknown. The following photometric observations of V 350 Cep demonstrated changes of brightness, which are typical for CTTSs with amplitude of about $1\overset{m}{.}5$ in B-light. The spectral investigations of V 350 Cep show the presence of hydrogen and metals emission lines with variable intensity (Magakian et al. 1999). Using all known observations we composed the light curves in B/pg- and V-band of V 350 Cep (Fig. 2).

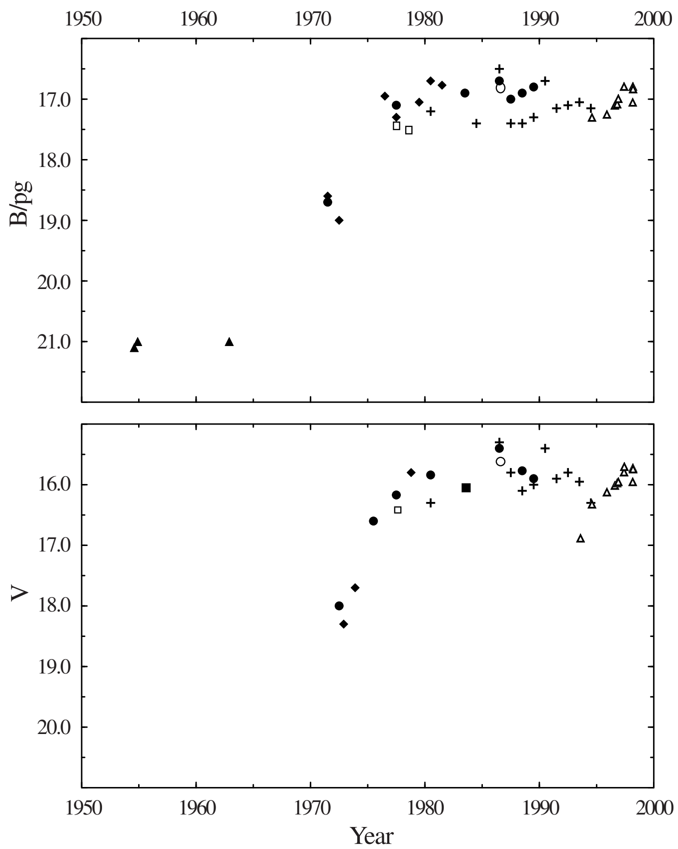

Figure 2: B/pg- and V-band light curves of V 350 Cep

The gradual increase of brightness of V 350 Cep resembles the FUOR type star V 1515 Cyg light curve (Hartmann & Kenyon 1996). It is impossible to define a moment of rising of V 350 Cep because of the absence of deep photometric observations in the period 1962-1970. The period of fast increase of brightness finishing about 1978 is followed by a period of slow increase lasting up to now. Therefore, the star keeps its maximum brightness more than 25 years. The observed outburst with an amplitude of order of 5^m, the location of the star in the region of active star formation NGC 7129 and its connection with a reflection nebulosity (Fig. 3) are characteristics which classify V 350 Cep as a FUOR type object. On the other hand the strong emission line spectrum (Fig. 4), the low luminosity ($M_v \sim 4^m$) and the observed ultraviolet excess are properties typical for CTTSs.

A similar increase of brightness was observed in some CTTSs such as DR Tau (Chavarria-K. 1979). In contrast with DR Tau the color indices U-B and B-V of V 350 Cep remain comparatively constant during the observed outburst. Another unique property of V 350 Cep is the relatively small brightness changes on the time scale of days (Fig. 5). Interpretation of this fact may be in the

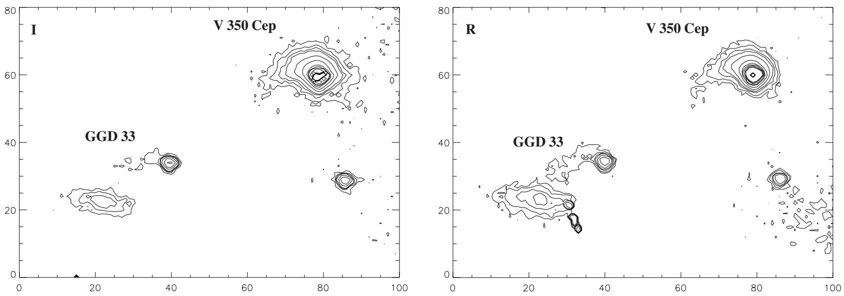

Figure 3: I and R isocontour plots of V 350 Cep and the near HH object GGD 33. The frames were obtained with the 1.3 m telescope in Skinakas. The contours are arbitrary and have been chosen to enhance the main features of the objects

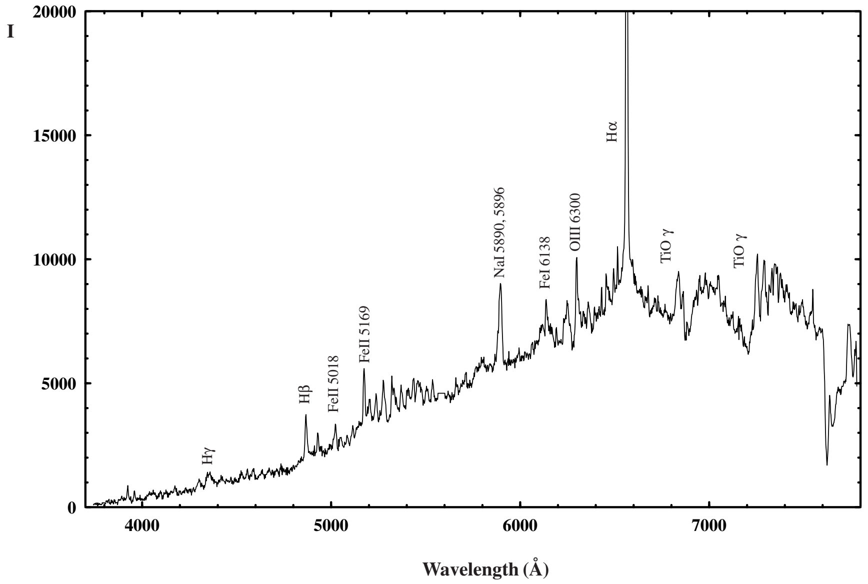

Figure 4: Long-slit grism spectrum of V 350 Cep obtained with the 1.3 m telescope in Skinakas

absence of large cool and hot spots on V 350 Cep. Alves et al. (1997) find a variable object in the Bok globule CB34 having in generally the same photometric and spectroscopic properties as V 350 Cep. They propose two possibilities to explain variability of this object: 1) extreme accretion episode (an edge-on FUOR) and 2) variability by extinction due to motions of circumstellar material surrounding CB34V. Such mechanisms can be used to explain the variability of V 350 Cep but the second one is less possible because the observed large outburst of order of $5\overset{\mathrm{m}}{.}0$ (in the case of CB34V the observed outburst is $3\overset{\mathrm{m}}{.}5$).

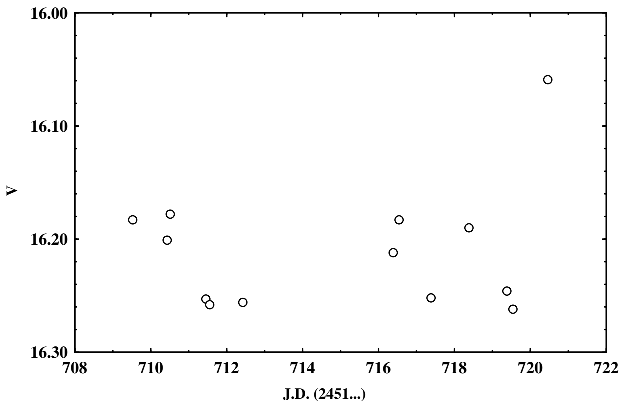

Figure 5: V-band light curve of V 350 Cep in the period 13-24 June 2000

2.2 V391 Cep

V 391 Cep is located in the dark clouds, at about 40' from the center of the bright emission nebula NGC 7129. The identification chart and the coordinates of this object can be found in Semkov (1993). Our spectral observations of V 391 Cep exhibit strong emission line spectrum. The most intensive are the Balmer emission lines Hα and Hβ. The light curve of V 391 Cep in B-light for the period of our observations 1987 - 1999 shows essential changes of the brightness from $14\overset{\mathrm{m}}{.}9$ to $16\overset{\mathrm{m}}{.}6$ (Fig. 6). Having in mind the presence of intensive emission spectrum and comparatively quick irregular variations we suggest that V 391 Cep is a CTTS. Fig. 6 shows that the amplitude of variability was changed from $1\overset{\mathrm{m}}{.}7$ in 1989 to $0\overset{\mathrm{m}}{.}5$ in 1999. This fact can be explained by changes in magnetic activity and the presence of large cool and hot spots on the stellar surface. The existence of T Tauri variable star in this place suggest s that the star formation takes place in a more extensive region in the dark clouds surrounding the bright nebula.

The CCD observations with a broad band filters show that a small cometary nebula exists around V 391 Cep. The comparison of the observations in different periods shows the irregular variation of its brightness. While in August 1993 the integral magnitude of the nebula was R = $15\overset{\mathrm{m}}{.}3$, in November 1995 it decreased to R = $17\overset{\mathrm{m}}{.}5$, and in November 1996 increased again to R = $15\overset{\mathrm{m}}{.}9$. This cometary nebula was not seen neither on the Palomar Observatory Sky Survey Prints, nor on our photographic plates. The comparison of the two frames in Fig. 7 displays the existence of a compact infrared object to the East from the star, which is clearly seen in the I frame. The object is also seen in the R frame but in the V and B frames is under the limit of our observations. The distance between the star and the infrared object is 3" and it is constant for the whole period of observations. The preliminary photometry leads to colour index R-I = $1\overset{\mathrm{m}}{.}3$ for this object. On the other hand it has a shape, similar for a star, but without diffusion structure typical for the jets and the Herbig-Haro objects . It

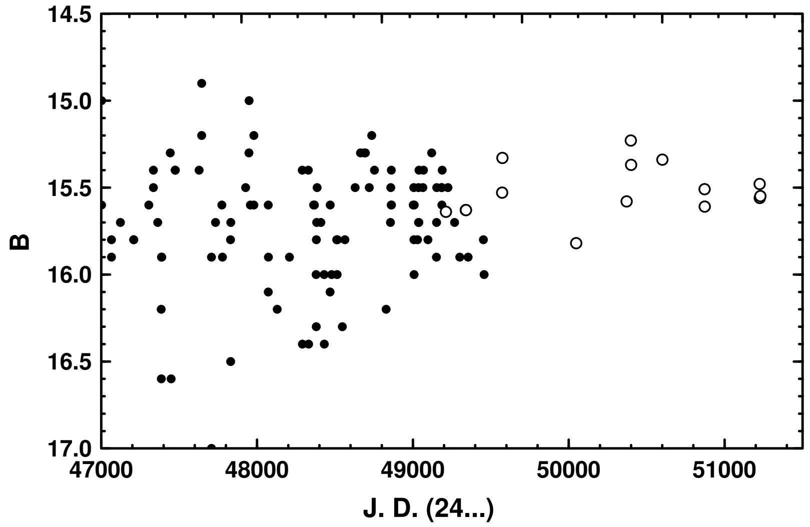

Figure 6: Light curve of V 391 Cep in B-light for the period 1987-1999. The filled circles denote photographic observations with the 50/70 cm Schmidt telescope, open circles - CCD observations with the 2 m RCC telescope in Rozhen

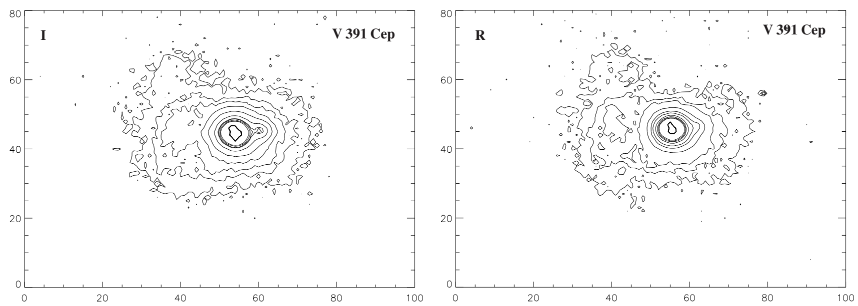

Figure 7: I and R isocontour plots of V 391 Cep. The frames were obtained with the 1.3 m telescope in Skinakas. The contours are arbitrary and have been chosen to enhance the main features of the object

is more likely that this infrared object is a cool star in the first stages of star formation and together with V 391 Cep they form a couple of PMSs.

Conclusions

The results presented in this paper suggest that the investigations of the YSO s are a perspective field of the modern astronomy. The photometric observations of the TTSs can be made with relatively small telescopes. The light curve estimations in time scale from days to years give a sizable information about the physical process in the YSO evolution. The spectral observations are much complicated and need large telescopes and modern spectral equipment but they are very important in some cases as the FUOR type variables. I think that this field of astronomy is very perspective for future cooperation of astronomers from the Balkan countries.

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