Photometric variability of the Pre-Main sequence stars

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Abstract. The photometric and spectral studies of the pre-main sequence stars are very important for understanding of the early stages of stellar evolution. Depending of the initial mass the young stars pass through different periods of stellar activity. The most prominent manifestations of this activity are changes in the star brightness with different periods and amplitudes.A short review on photometric variability of young stellar objects is presented in the paper. The physical mechanisms raising the photometric variability were summarized according to the main types of pre-main sequence stars. The importance of photometric and spectral observations of young variable stars with small telescopes is discussed.

Key words: Stars: pre-main sequence, Stars: variables: T Tauri, Herbig Ae/Be, Stars: individual: HBC 722, V350 Cep, V1184 Tau

Фотометрична променливост на звездите преди Главната последователност

Евгени Х. Семков

Фотометричните и спектрални изследвания на звездите преди главната последователност са от голямо значение за изучаването на ранните етапи от звездната еволюция. В зависимост от първоначалната си маса младите звезди преминават през различни периоди на звездна активност. Тази активност се изявява най-често с промени в блясъка на звездите с различни периоди и амплитуди. В статията е представен кратък обзор на фотометричната променливост на младите звезди. Разгледани са физическите механизми предизвикващи фотометричната променливост на звездите преди главната последователност. Значението на фотометричните и спектралните наблюдения на младите, променливи звезди с малки телескопи е разгледано в края на статията.

1 Introduction

Only a few decades ago the idea of continuous star formation in our galaxy was not familiar among the astronomical community. The first hypothesis of starformation assumed that all stars in the stellar systems are formed at the same time. The idea that star formation in our galaxy is a continuous process has been expressed for the first time by Ambartsumian (1954) in the middle of the last century.

According to our present knowledge the stars form in the clouds of interstellar matter as a result of a gravitational contraction. In the early stages of formation the protostars can be observed only in the far infrared, but when accretion phase is nearly complete they become visible in the optical spectral region. During the last periods of star formation, accretion of material onto the star surface continues partially through a circumstellar disc. Then the newly formed stars are located above the Main Sequence and, depending on its initial mass reach the Main Sequence for different periods of time. During this stage of evolution the stars are named pre-main sequence stars (PMS) and their radiation is due only to the gravitational contraction. When the density and temperature at the core of the star reach the appropriate values the reactions of hydrogen burning begins and the young star became a star from the Main Sequence (Fig. 1).

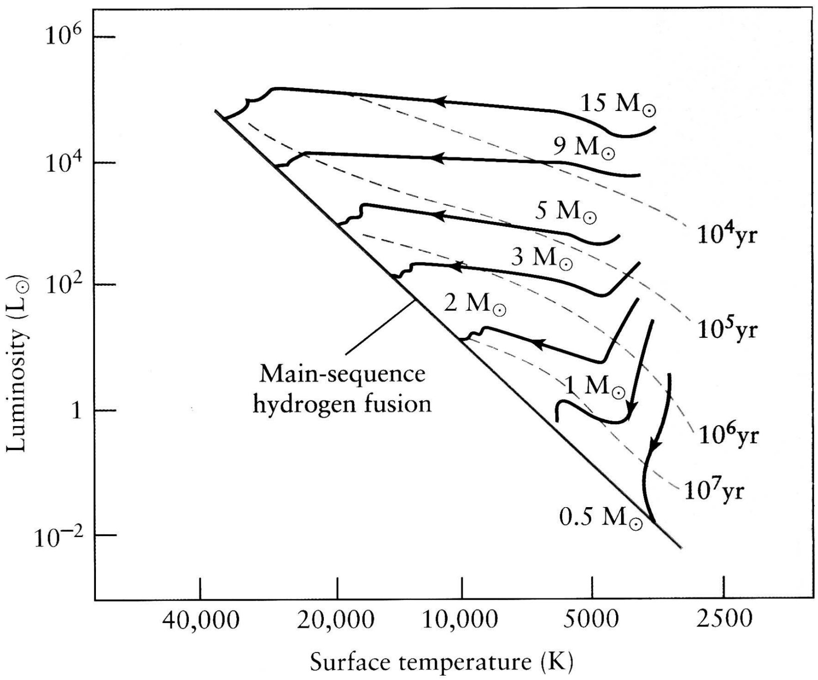

Fig. 1. Evolutionary tracks of the stars with different masses to the Main sequence

2 T Tauri and Herbig Ae/Be stars

Both classes of PMS stars - the low mass ($M < 2M_\odot$) T Tauri (TT) stars and the more massive ($2M_\odot < M < 8M_\odot$) Herbig Ae/Be (HAEBE) stars - show various types of photometric variability. The most spread type of PMS objects are TT stars which study began after 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 strong light variability is another general characteristic of TT stars. First Ambartsumian (1954) recognized

TT stars as very young low-mass stars grouped in stellar systems named T-associations. Ambartsumian demonstrated the gravitational instability of the stellar associations and concluded that associations are very young systems of recently formed stars.

Presently, it is generally accepted that TT stars can be separated into two subgroups: the classical TT (CTT) stars and the weak-line TT (WTT) stars. The CTT stars differ from the WTT stars in a strong Hα emission line and significant infrared and ultraviolet excesses (Fig. 2). The classification of TT stars 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 lie on the TT stat's region in the H-R diagram were discovered. Majority of these stars seem to be WTT or post TT stars undetected up to now (Martin 1997). CTT and WTT stars form a continuum of objects with various degrees of activity and some known CTT stars may go through an inactive phase during which they may look spectroscopically like WTT stars (Bouvier & Bertout 1989).

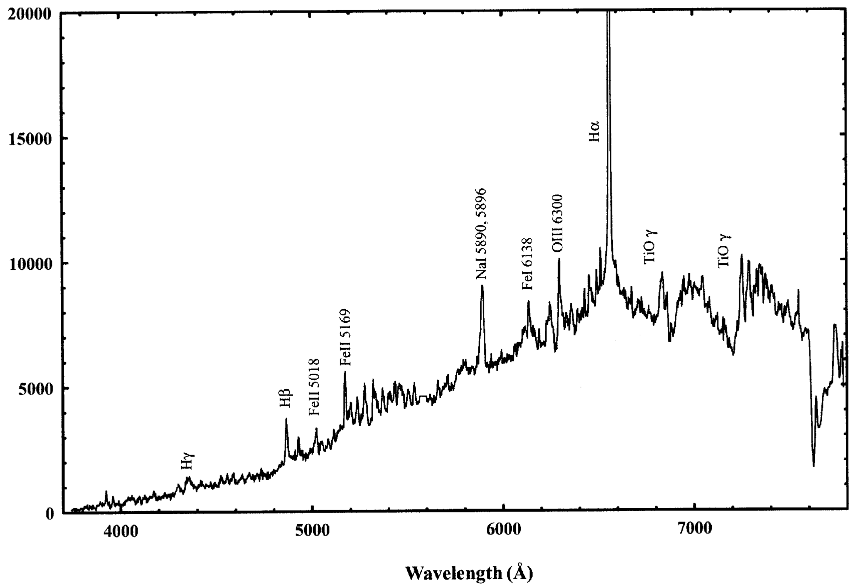

Fig. 2. Optical spectrum of V350 Cep showing the typical of CTT stars broad and intensive emission lines.

The presence of photospheric dark spots and accreting circumstellar disks play a significant role in explanation of the PMS stars variability. One manifestation of magnetic stellar activity is the formation of dark spots on the surface of young 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 TT stars the dark spots are often large, typically 10-20% of the stellar surface, the temperature difference is typically 700-1000 K and the live time of spots is from days to a few years (Bouvier & Bertout 1989).

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

Main characteristics of HAEBE stars are broad emission lines in the optical spectra, rapid irregular photometric variability and infrared excess (The et al. 1994). Many of them are connected with reflection nebulae and dark clouds. Approximately 25% from HAEBE stars show strong photometric variability with sudden quasi-Algol drops of brightness (Natta et al. 1997). During the deep minima of brightness an increase of polarization and specific color variability are observed. The prototype of this group of PMS objects named UXors is the HAEBE star UX Ori. The wide spread explanation of its variability is a variable obscuration from orbiting circumstellar clumps of dust or edge-on circumstellar disk (Grinin et al. 1991).

3 Main types of photometric variability of PMS stars

Because of the wide variety of the photometric variability observed in young stars, their classification is very difficult. Sometimes, the same object can show two or even three types of changes in brightness due to different reasons. The most complete classification of the observed variability of PMS stars is made in the papers of Herbst et al. (1994, 2007).

The light variability of WTT stars can be generally explained with the model of surface dark spots. The most common reason for photometric variability is the rotation of the star with asymmetric distribution of cool spots. The typical amplitudes in brightness vary in the range 0.03-0.3 mag (V), with extreme values up to 0.8 mag. The observed periods of variations are in a wide range, from 0.5 to 18 days (Herbst et al. 2007). The shape of the light curve may change in timescales of weeks but the periods can be stable over months or years. Stars are redden as they fade and there is no essentially scatter in the relationships between V and R and between V and I.

The light variability of CTT stars can be understood in terms of a changing mix of long-lived dark spots and short-lived hot spots or zones (Bouvier et al. 1995). The variability is irregular, caused by highly variable accretion from the circumstellar disk onto the stellar surface. The variable hot component produces the well-known veiling phenomenon (masking of the absorption lines) seen in spectroscopic studies. Typically irregular variations have amplitudes from few tenths of magnitude to $3^{\mathrm{m}}\!.8$ mag in U, $2^{\mathrm{m}}\!.6$ mag in V and $1^{\mathrm{m}}\!.6$ in I (Herbst et al. 1994). The accretion rate is variable in time and the accretion zones are certainly not uniformly distributed over the stellar surface. Some times the variability can be periodic due to long lived hot spots. This periodicity typically persists for only a couple of rotation cycles.

The UXor type of variability is seen in HAEBE and some CTT stars from F-G spectral types. The typical amplitudes are of the order of 2-3 mag (V), and time scales are longer compared to the irregular variations of CTT stars. During the deep minima the stars often get bluer when fainter (Fig. 3). This effect of color reversal (or co-called "blueing") was described in many studies (Bibo & The (1990), Grinin et al. (1994)). According to the model of dust clumps obscuration the observed color reversal is caused by the scattered light from the small dust grains. Normally the star becomes redder when its light is covered by dust clouds on the line of sight. But when the obscuration rises sufficiently the part of the scattered light in the total observed light become significant and the star color gets bluer.

The stellar flares from UV Ceti type are typical for WTT stars and low-mass red dwarfs in the young open clusters and associations. The flares are predominately seen in the U and B bands and continued from several minutes to 1-2 hours (Mirzoian 1990). The flares are characterized by a rapid increase in brightness and subsequent slower decline. Occasionally such flares are observed and on late type CTT stars.

Some PMS stars show a large amplitude increase in brightness (outbursts). They can be separated into two main types, named after their respective prototypes: FU Orionis (FUor; Ambartsumian 1971) and EX Lupi (EXor; Herbig 1989). Both type of stars seem related to low-mass PMS objects (TT stars) with massive circumstellar disks, and their outbursts are generally attributed to infall to the central star of material from a circumstellar disk (Hartmann & Kenyon 1985).

FUor are defined as a class by Herbig (1977) after the discovering of two new objects from this type - V1057 Cyg and V1515 Cyg. The main characteristics of FUors are an increase in optical brightness of about 4-5 mag, a F-G supergiant spectrum with broad blue-shifted Balmer lines, strong infrared excess, connection with reflection nebulae, and location in star-forming regions (Reipurth 1990, Clarke et al. 2005). Typical spectroscopic properties of FUors include a gradual change in the spectrum from earlier to later spectral type from the blue to the infrared, a strong Li I (λ 6707) line, P Cygni profiles of Hα and Na I (λ 5890/5896) lines, and the presence of CO bands in the near infrared spectra (Herbig 1977, Bastian & Mundt 1985). The light curves of FUors show a rapid rise and relatively slow decline in brightness and the outburst lasting several decades (Peneva et al. 2010). The cause of increased accretion from $\sim 10^{-7} M_{\odot}$/yr to $\sim 10^{-4} M_{\odot}$/yr appears to be thermal or gravitational instability in the circumstellar disk (Hartmann & Kenyon 1996). For the period of $\sim$ 100 years the circumstellar disk adds $\sim 10^{-2}$ M$\odot$ onto the central star and it ejects $\sim$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.

EXor objects shows frequent, irregular and relatively brief (a few months to a few years) outburst of several magnitudes amplitude $\Delta V \approx$3-5). During such events, the cool spectrum of the quiescence is veiled, and strong emission

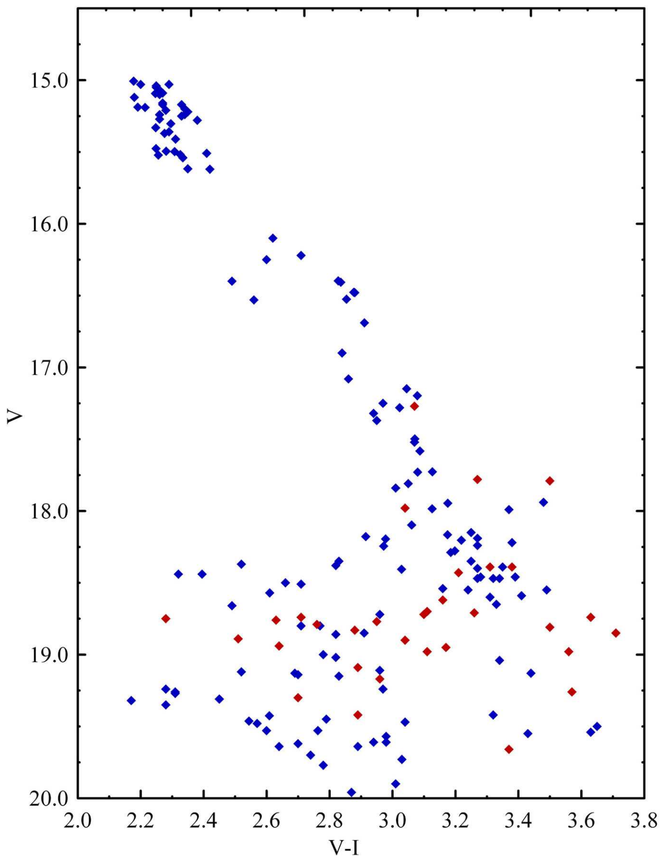

Fig. 3. A color reversal observed on the $V/V-I$ diagram of the UXor star V1184 Tau. The blue diamonds are from Semkov et al. (2008) and the red diamonds from Grinin et al. (2009)

lines from single ionized metals are observed together with appearance of reversed P-Cyg absorption components (Herbig 2007; Aspin et al. 2010).

4 Observations of PMS Stars with small telescopes

To study the nature of PMS stars it is very important to collect more data from observations. There are a number of objects important for photometric studies that can be observed with relatively small telescopes. Many active young stars are located in the stellar clusters and associations at close distance to the Sun. Some of them are relatively bright ($V \sim$ 10-15 mag.) and with high amplitude changes in brightness easily detectable with small

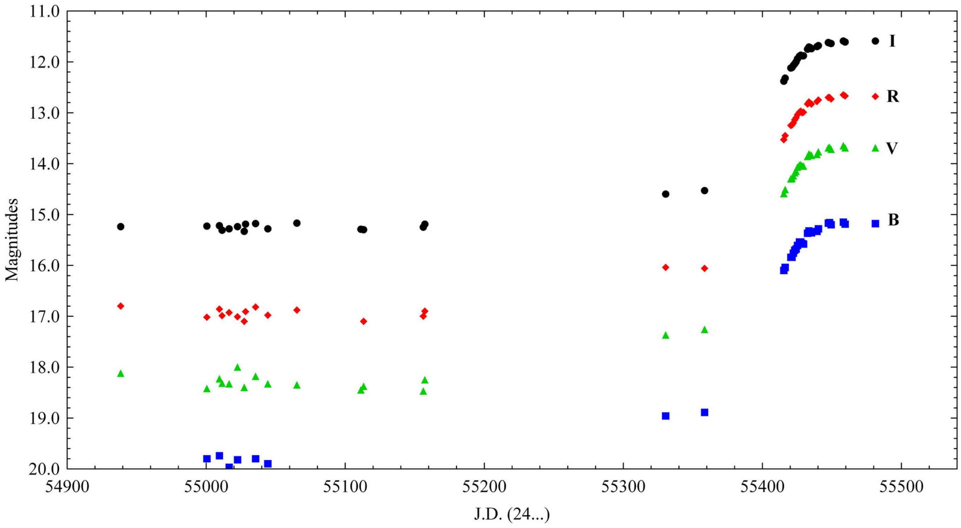

Fig. 4. *BVRI* light curves of the FUor object HBC 722 in the period Apr. 2009 – Oct. 2010 (Semkov et al. 2010).

telescopes. On the other hand, it is very important to carry out a regular photometric monitoring of the regions of star formation. Most of the small telescopes have relatively large field of view and this makes them very effective for such kind of monitoring. Using this type of photometric observations it is possible to study the long-term variability of PMS stars, and to discover new variable objects interesting for further investigations (Semkov et al. 2010). We hope that the study of PMS stars will be interesting for the young astronomers in Bulgaria.

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Fig. 5. Ljubomir Iliev, Tabyu Bonev, Nevena Markova and Orlin Stanchev in the Conference