年輕星團中變星 GM Cephei 的光學觀測

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摘要

我們在年輕（約四百萬年）的疏散星團Trumpler 37中，針對一顆類似太陽的變星GM Cep進行了光學觀測。這顆恆星是一顆典型金牛座T型星，具有環星盤及活躍的吸積現象。GM Cep可能曾經歷爆發現象，因此我們懷疑它是顆EXor類型的變星。我們在2010至2011年間對GM Cep的長期觀測中，發現GM Cep在R波段經歷了約0.82等的亮度降低，爲期長達39天，以及數個短暫的類似爆發的變亮時期，亮度變化小於1等，時間長度約10天左右。亮度變亮時恆星的顏色變藍，因此可能是由於吸積活動的增加所導致。但在亮度變暗的時期，恆星顏色也變藍；我們另外蒐集了AAVSO和文獻資料，發現這顆恆星的亮度變暗有一約311天的半週期。我們推測變暗的可能原因，是在恆星周圍有一團塵埃擋住了星光。因此我們認爲GM Cep是顆UXor類型的變星，處於環星盤中微粒凝結到微行星形成的過渡階段。

Photometric Observations of the Young Cluster Variable GM Cephei

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Abstract

We present our photometric observations of GM Cep, a solar type variable in the young (~ 4 Myr) open cluster Trumpler 37. The star is known as a classical T Tauri star with a circumstellar disk and active accretion. GM Cep was suspected to undergo an outburst, thus a candidate for an EXor-type variable. In our monitoring campaign observations in 2010–2011, GM Cep experienced a ~ 0.82 mag brightness decrease in the R band continuously for 39 days, and frequent, transient flare-like episodes with the amplitude < 1 mag, each lasting for about 10 days. The brightening was accompanied with a bluer color, presumably arising from increased accretion activity. Interestingly, the star also turned bluer in the fading phase. Combining the AAVSO and literature data, we found a quasi-cyclic period of ~ 311 days for the fading event.

A possible mechanism for the fading could be obscuration by a clump of dust around the star. We proposed that GM Cep therefore should be a UXor-type variable in the transition phase between grain coagulation and planetesimal formation process in the circumstellar disk.

關鍵字 (Keywords)： 變星(variable)、年輕恆星(young stars)、微行星形成 (planetesimal formation)、GM Cephei,、UXor

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1. Introduction

The Young Exoplanet Transit Initiative (YETI) is an international multi-site project which consists of a relay global network of telescopes (Fig. 1) to search for exoplanet transit events in young open clusters (Neuhäuser et al. 2011). During an observing campaign, telescopes at different longitude range are used to monitor a young, nearby star cluster continuously for several days. Since 2009, the YETI has monitored two clusters, Trumpler (Tr) 37 at an age of 4 Myr (Sicilia-Aguilar et al. 2004) and 25 Ori at an age

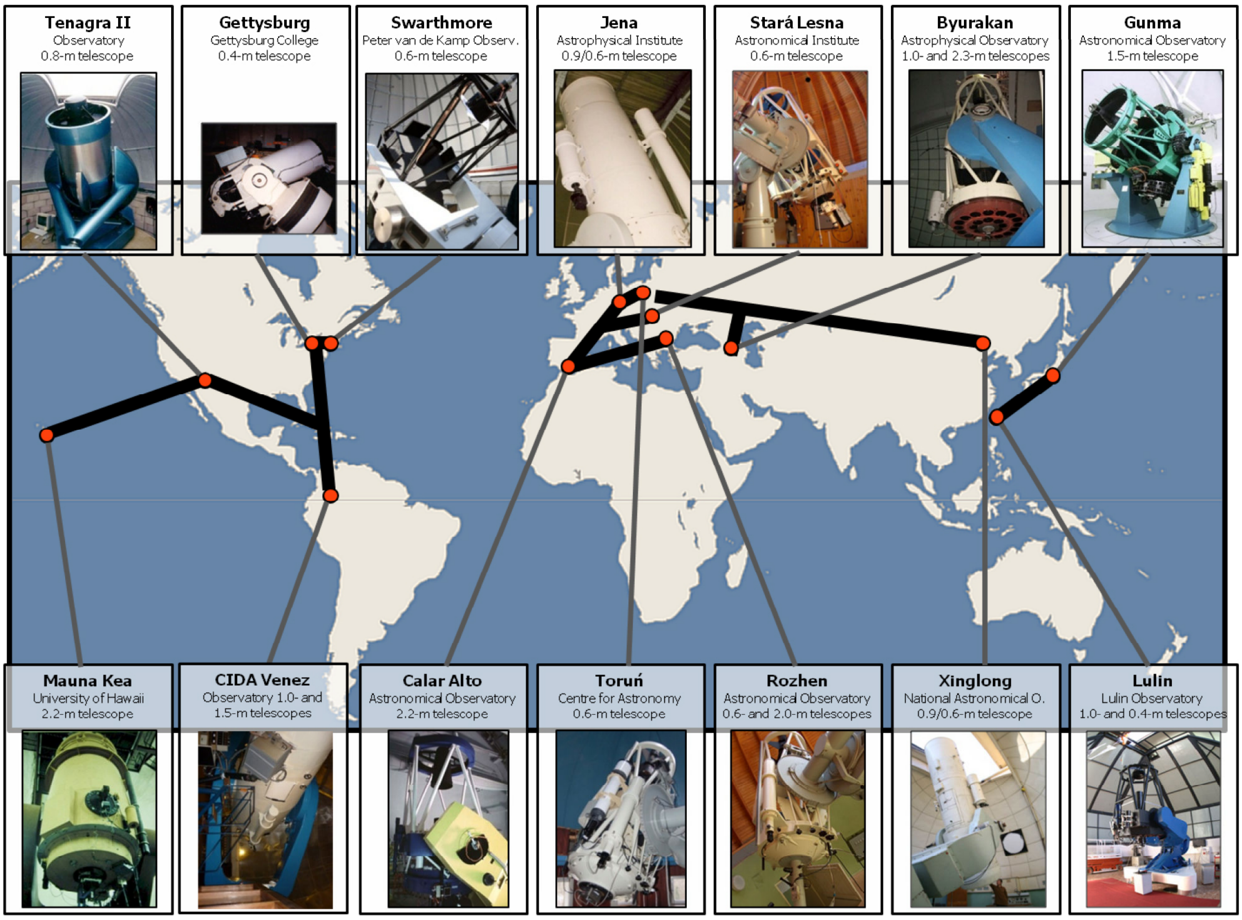

Fig. 1: The YETI network of telescopes.

of 10 Myr (Briceño et al. 2007). While the primary goal of the YETI campaigns is to search for possible youngest exoplanets, the intensive monitoring produces data sets also valuable for young stellar variability study, which might be relevant to planet formation (Bouvier et al. 2003).

The open cluster Tr 37, at a heliodistance of 900 pc (Contreras et al. 2002), is part of the Cepheus OB2 association. Young stars are believed to evolve from Class II disk bearing Classical T Tauri Stars (CTTSs) to Class III diskless Weak-lined T Tauri Stars (WTTSs) in 1 Myr to 10 Myr, when disk dissipation and planet formation are taking place. With a disk frequency of ~ 39% (Mercer et al. 2009), Tr 37 hence serves as a good target to search for and to characterize exoplanets in formation or early evolutionary stages (Neuhäuser et al. 2011). Most pre-main sequences stars show irregular photometric variability. Herbst et al. (1994) classified the variability into three categories. Type I variation is a periodic modulation caused by the rotation of a star with cool spots. Type II variation is caused by unsteady accretion or the rotation of hot spots on the star surface. Stars with Type III variation, also called UXors, with UX Ori being the prototype, are hypothesized to suffer variable obscuration by circumstellar dust. GM Cep (RA = 21 38 17.3, Dec = +57 31 23, J2000) is a solar type variable in Tr 37. It has a possible spectral type of G7 to K0, with an estimated mass of 2.1 $M_{\odot}$ and radius 3–6 $R_{\odot}$ (Sicilia-Aguilar et al. 2008). The youth of GM Cep is exemplified by its emission-line spectra, prominent IR excess (Sicilia-Aguilar et al. 2008), and as a Chandra X-ray source (Mercer et al. 2009), all characteristics of CTTSs. It has a circumstellar disk (Mercer et al. 2009), with an accretion rate up to 10^{-6} $M_{\odot}$ yr^{-1}, which is 2–3 orders higher than the median value of the TTSs in Tr 37 (Sicilia-Aguilar et al. 2006). It is also one of the fastest rotators in the cluster, with v sin$i$ ~ 43.2 km s^{-1} (Sicilia-Aguilar et al. 2008).

Early observations of GM Cep by the YETI in 2009 suggested a possible EXor-type outburst. Previous studies on the light variability have been controversial. Sicilia-Aguilar et al. (2008) collected photometric data of GM Cep from 1952 to 2007 in the literature, supplemented by their own intensive multi-wavelength observations. They suggested that GM Cep is an EXor-type variable with an unstable disk and variable accretion rate. On the other hand, Xiao et al. (2010) measured archival plates taken at Sonneberg and Harvard observatories between 1895 and 1993, and concluded the variability in the long-term light curve to be dominated by dips (possibly from extinction) superposed on quiescence states, instead of outbursts caused by accretion flares. Here we present our multi-band optical observations of GM Cep, and discuss the possible mechanism underlying its variability.

2. Observations and Data Reduction

The data presented here includes 200 time epochs obtained from 20 Jun, 2010 to 21 July, 2011. Our optical observations in the *BVR*c bands were carried out with the 1.0 m and 0.4 m telescopes at the Lulin Observatory (120.5E, 23.3N) in Taiwan and the 0.81 m telescope at the Tenagra Observatory (110.5W, 31.3N) in Arizona, USA.

The Lulin One-meter Telescope (LOT) was equipped with a Princeton Instruments model 1300B (PI-1300B) camera, with a back-illuminated EEV CCD36-40 chip of 1340 x 1300 pixels. Each 20 μm pixel corresponds to a plate scale of 0.51" per pixel, yielding a field of view of 11' x 11'. For the YETI campaign, a 0.55 x focal reducer was used to enlarge the field. The 0.4 m SLT telescope at the Lulin Observatory was equipped with an Apogee Alta U9000 front-illuminated CCD camera with a Kodak KAF-9000 sensor. With 3056 x 3056 pixels, each of 12 μm on a side, the field of view is 37' x 37'. Between 26 August to 22 November in 2010, another camera was used instead. It was a back-illuminated Apogee Alta U42 with E2V CCD42-40, which has 2048 x 2048 13.5 μm pixels, giving a field of view of 28' x 28'. The 0.81 m Tenagra II telescope at the Tenagra Observatory was equipped with a back-illuminated SITe SI003 AP8p CCD, with 1024 x 1024 24 μm pixels. The field of view of the Tenagra II images is 15' x 15'. All the photometry images were reduced following standard routines to correct the bias, dark and flat field. In addition, some data were taken with the 90/60 cm telescope of the University Observatory Jena (11.5E, 50.9N). For imaging, the telescope works in the Schmidt mode, with an effective diameter of 0.6 m. It was equipped with E2V CCD42-10 (STK), with 2048 x 2048 13.5 μm pixels. The images were subtracted by overscan and dark, then divided by the master flat.

Aperture photometry was performed on GM Cep by comparison with the seven reference stars within 30 of GM Cep used in Xiao et al. (2010). These comparison stars have comparable brightness as that of GM Cep. In each image we measured the FWHM of GM Cep and the comparison stars, then 3x, 5x, and 7x the largest FWHM among them were used for the aperture radius, inner sky radius, and outer sky radius, respectively. A linear regression between the instrument magnitudes and calibrated magnitudes of the comparison stars was utilized to compute the brightness of GM Cep. Images with inferior sky conditions were excluded in the analysis. In addition to our own observations, visual observations from the American Association of Variable Star Observers (AAVSO) from 2006 onwards were collected as well.

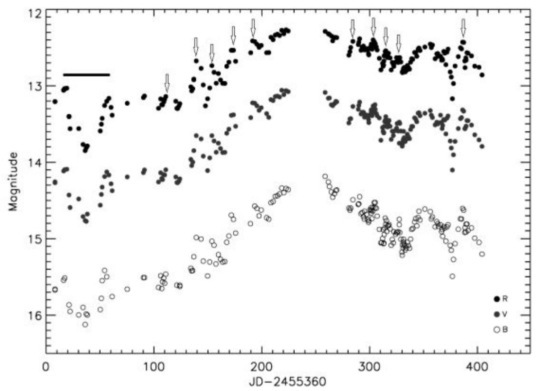

Fig. 2: The light curves of GM Cep in the *B* (open circles), *V* (gray circles), and *R* (filled circles) bands from our observations.

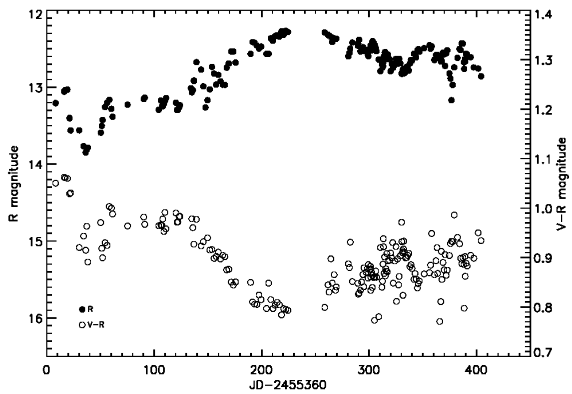

Fig. 3: The *R* band light curve (filled circles) and *V-R* color curve of GM Cep from our observations.

3. Analysis

The light curves of GM Cep in the *B*, *V*, and *R* bands are depicted in Fig. 2. Typical errors are smaller than the symbol sizes so are not shown (0.005 mag in R, 0.007 mag in V, and 0.015 mag in B in average). The variations in different bands follow well with each other, and abruptive fluctuations are obvious. Several days after our monitoring campaign started in 2010, GM Cep experienced a 0.82 mag fading in the *R* band lasting for about 39 days (indicated by a bar in Fig. 2). The corresponding amplitude drop in the *V* band is smaller, about 0.68 mag. One also sees transient flaring-like episodes with amplitude less than 1 mag, each lasting for about 10 days (indicated by arrows in Fig. 2). The nature of the variability is better diagnosed with color variations. Our data in the *B* band suffered large photometric errors, so the *R* band light curve and the *V-R* color curve are presented in Fig. 3. Typical errors are smaller than the symbol sizes so are not shown. One sees that the color in general turned bluer as the star became brighter. However, during the fading episode, GM Cep also had a bluer color.

We extended the time baseline of the light curve by including the data from the literature (Sicilia-Aguilar et al. 2008) and from the AAVSO archive. A quasi-cyclic fading period of 310-320 days was discernible by eye inspection (Fig. 4). The NStED (NASA/IPAC/NExScI Star and Exoplanet Database) Periodogram Service was utilized to search for periodic signals with the Lomb-Scargle algorithm, after removing the long-term trend in the light curve. The first-ranked period is 311 days.

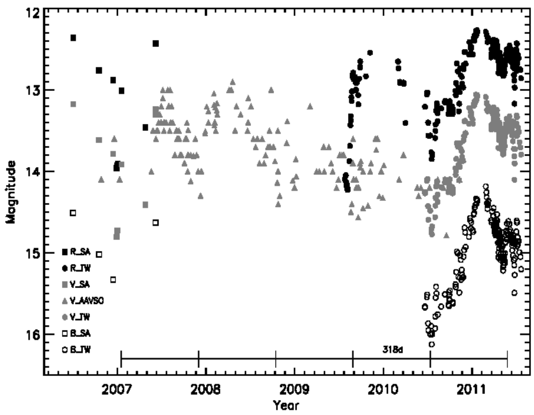

Fig. 4: The long term light curves of GM Cep in the *B* (open symbols), *V* (gray symbols) and *R* (filled symbols) bands. The data are from Sicilia-Aguilar et al (2008) (squares), AAVSO (triangles), and our own observations (circles).

4. Discussions

The sporadic brightening episodes accompanied with a blue color can be accounted for byan enhanced accretion activity. Since the fading due to time variation of mass accretion provides a red color, the fading we observed—a duration of 39 d with a blue color, and a period of 311 d—is puzzling. A possible mechanism could be due to obscuration by a clump of dust around the star, i.e., as suggested for UXor-type variables (Herbst et al. 1994). We therefore suggest GM Cep to be an UXor, rather than an EXor (Sicilia-Aguilar et al. 2008).

Assuming the clump is in Keplerian motion, and given the stellar mass of 2.1 $M_{\odot}$ and an orbital period of P = 311 d, we derive the orbital distance of $a \sim 1.16$ AU. From the duration of the fading episode t, we have

$$\frac{t}{P} = \frac{2R_C}{2\pi a} \quad (1)$$

where t = 39 days, $R_C \sim 0.47$ AU is the radius of the clump. The clump has a size of about 100 $R_\odot$.

Furthermore, the amount of fading allows us to estimate the amount of obscuring dust along the line of sight, i.e., $A_\lambda = 1.086\ N_d \sigma_d\ Q_{ext}$, where N_d is the column density of the dust grains, σ_d is the geometric cross section of a grain, and Q_{ext} is the dimensionless extinction efficiency factor. For particle sizes comparable to the wavelength, $Q_{ext} \sim 1$. We assume the obscuration is attributed mostly to dust grains with an average radius of ~ 0.1 μm (e.g., Honda et al. 2006; Juhász et al. 2010). Given the observed A_V = 0.68 mag, the column density of dust then is $N_d = 2.0 \times 10^7$ cm^{-2}, which leads to a volume density of $n_d = N_d/2R_C = 1.4 \times 10^{-6}$ cm^{-3}.

Since the clump is quite close to the star (a = 1.16 AU), we assume the composition of the dust clump is mostly silicates, having an average density of ρ = 3.5 g cm^{-3}. Therefore we derive the mass of the clump to be

$$M_d = \frac{4}{3}\pi R^3 n_d m_d = 2.269 \times 10^{18} kg \qquad (2)$$

which is about that of an asteroid.

About a dozen UXors have been known thus far. Some show cyclic variability, with periods ranging from 8.2 days (Bouvier et al. 2003) to 11.2 years (Grinin et al. 1998). We propose that GM Cep belongs to this category of objects experiencing highly variable circumstellar extinction. The mass we derived for the clump is only for the dust, and we have no evidence, even with a sufficient amount of associated gas, if the clump is on the verge of gravitational instability. Apparently a relatively small amount of dust mass along the line of sight to the circumstellar disk could cause the obscuration event we detected in our light curve. The intervening material does not need to shape like a clump, as long as the material is not evenly distributed azimuthally, e.g., a warped or arm-spiraled disk. Such inhomogeneity in the young stellar disk might signpost the continuing process of planet formation. Further characterization of the ununiform disk of GM Cep, e.g., by polarization, reoccurrence of the bluing phenomenon in the fading epoch, infrared spectroscopy and submillimeter imaging in and out of the obscuration phase would shed more light on our hypothesis.

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