The activity in the isolated T Tauri binary V4046 Sagittarii

M. V. Mekkaden
Indian Institute of Astrophysics
Bangalore - 560034, India
mvm@iiap.ernet.in

Abstract

New photometric, spectroscopic and polarimetric observations of the T Tauri binary V4046 Sgr are presented. An analysis of the observations obtained over several seasons enabled us to determine the photometric period, and hence the rotation period of the binary. The variations could be caused by cool spots since the light curves show less scatter and no sudden brightenings as noticed in other classical T Tauri stars. Though the Hα emission strength in V4046 Sgr is comparable to that in other classical T Tauri stars, it has very little near and far infrared emissions. The Hα emission may be arising from the circumbinary environment as indicated by a possible periodic trend in its strength. The polarimetric observations show the highly variable nature of the linear polarization and its position angle. This phenomenon is probably due to the changes in the geometry of the circumstellar material as well as the illumination by the star.

1. Introduction

The light variability of V4046 Sgr (HDE 319139) was discovered by Busko & Torres (1978) who found the star to show BY Draconis-type light variability with a period of 1.70 days. They also detected U band flares and $U - B$ colour excess in the star. V4046 Sgr was found to display strong Hα emission in its spectrum by Merril & Burwell (1950).

The double-lined spectroscopic nature of V4046 Sgr was discovered by Byrne (1985). His photometry gave only a slight indication of periodic light variability with an amplitude of 0.02 mag in V. However the observations indicated a large scatter in $U - B$ colour. The radial velocity measurements obtained by him, though not of high accuracy, gave an orbital period of 2.45 days. From the overall behaviour of V4046 Sgr he concluded that it belongs to the Post T Tauri group.

De la Reza et al. (1986) carried out photometric, spectroscopic and CORAVEL radial velocity studies of V4046 Sgr. Their observations showed that V4046 Sgr is a typical classical T Tauri star (CTTS). The radial velocity measurements gave an orbital period of 2.4213 days and $V \sin i = 13\ kms^{-1}$ for the brighter component. Their CORAVEL observations showed that the ratio of cross correlation dips of the two components is nearly 0.5, and hence the secondary is fainter by about 0.7 mag. They classified the secondary to be of spectral type K7. They further identified V4046 Sgr as an IRAS source (IRAS, 1985) and found that the flux at IRAS bands are similar to those of other CTTS.

V4046 Sgr is not associated with any star forming regions like the CTTS TW Hya (Mekkaden 1998). The nearest dark cloud to V4046 Sgr is at a projected distance of 1° and de la Reza (1986) suggested that the star might have been formed in a tiny cloud that has since dispersed.

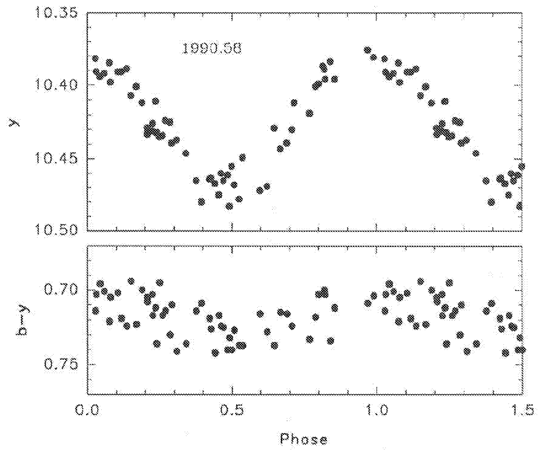

Fig. 1.— Plots of y and $b - y$ of V4046 Sgr.

V4046 Sgr was included in the present study mainly to investigate the nature of variability in light, Hα emission and Li I absorption strengths, and linear polarization.

2. Observations

Photometric observations were done over four seasons: May 1988, June 1988, August 1989 and July 1990. $UBVRI$ observations were carried out during May 1988 and by observations during the remaining seasons using the 50 cm telescope of European Southern Observatory, (ESO) La Silla. Spectroscopic observations were obtained during March-April 1993 with the 102 cm telescope of the Vainu Bappu Observatory (VBO), Kavalur. The spectrograph set up gave a resolution of 1.38 Å/pixel. The linear polarization measurements were made with the 236 cm telescope of VBO.

3. Light variations

All the photometric observations were made differentially with respect to SAO 209861 and the magnitudes in various bands thus obtained were converted to the corresponding standard systems. No systematic investigation of the light variability of V4046 Sgr exists in the literature; the reported periods of light variability range from 1.8 to 2.45 days. The extensive data obtained during August 1990 was analyzed using a period finding technique resulting in a period of 2.445 days which satisfied the data. Since this period is very close to the orbital period, the active component is rotating nearly synchronously with the orbital motion. Using this period the Julian days of observation were converted to photometric phases with the following ephemeris:

$$JD(Hel.) = 2447296.805 + 2.^{d}4457E,$$

where the initial epoch corresponds to the first observation during the season May 1988. $UBVRI$ observations of May 1988 showed that the amplitude of light variation is very low, of the order of 0.06 mag. The $B-V$, $V-R$ and $V-I$ colours tend to be redder as the star becomes fainter. The $U-B$ colour shows a large scatter, far exceeding the observational error. The light curve obtained after one month (June 1988) had a slightly different shape and amplitude. The maximum brightness also increased from 10.40 mag to 10.36 mag. The data obtained during August 1989 showed a large scatter and only a slight indication of rotational modulation. The observations of August 1990 is plotted in Fig.1. The light curve showed a quasi-sinusoidal shape with little scatter; the variation in $b-y$ colour was in phase with the light curve. The amplitude of the light curve was around 0.10 mag, which is the largest amplitude observed so far in V4046 Sgr. The minimum scatter indicates that the surface brightness inhomogeneity on the primary that caused the light variation remained in the same location with out much change through out the observing run of approximately 4.5 rotation periods duration and the inhomogeneity was caused by cool spots. Vrba et al. (1993) have shown that both the periodic and irregular light variations of the CTTS can be understood in terms of a changing mix of cool and hot spots on their surfaces. This could be the case in V4046 Sgr also since we observe light curves with very low amplitudes and large scatter at some epochs caused, probably, by hot spots and quasi-sinusoidal light curves with little scatter at other epochs due to cool spots.

The secondary component of V4046 Sgr is fainter than the primary by 0.7 mag if its spectral type is K7. So the light contribution to the total light variation by the secondary may be negligible. Usually, the CTTS show large amplitude (> 0.2 mag) variations. V4046 Sgr is probably viewed at a low inclination (i <40°) and this could be the reason why only very low amplitude light variations are observed.

4. Hα and Li I lines

Hα and Li I 6708 Å spectra of V4046 Sgr were obtained during March-April 1993 overlapping with the polarimetric observations described in the next section. Figure 2 shows the plots of Hα emission equivalent widths (EEW) and Li I absorption EWs against the photometric phase. The Hα EEW was found to vary from 39 to 80 Å and showed a trend of periodicity. Byrne (1985) and de la Reza (1986) also reported the periodic variations of Hα EEW. Byrne (1985) suggested that the modulation of Hα emission is caused either due to the orbital motion, or due to an inhomogeneously distributed Hα emitting region. However, from the far infrared and sub-millimetre and millimetre observations there is convincing evidence that V4046 Sgr has an active accretion disk which could be circumbinary as suggested by Mathieu (1994).

The Hα emission is supposed to be formed in the boundary layer, the interface between the relatively slowly rotating star and the inner disk rotating at Keplerian velocities. It is probable that the orbital motion produces the periodicity in Hα emission. The nature of the accretion disk and hence also the Hα emitting region is quite complex in V4046 Sgr. A conclusive inference can be made only by a high resolution Hα study over a few rotation periods. The EW of Li I absorption line does not show any appreciable variation with the photometric phase; its value is found to be 0.54±0.05Å, similar to that usually found in CTTS.

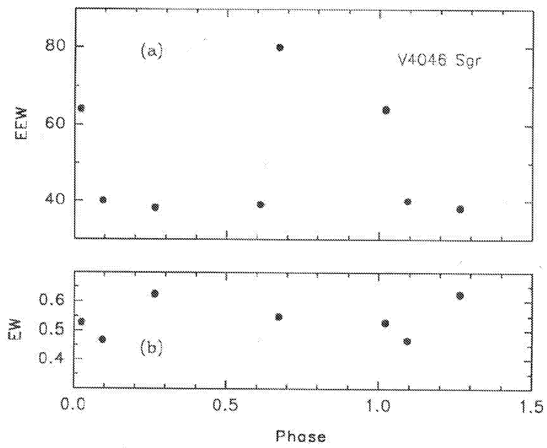

Fig. 2.— Plots of (a) Hα EEW and (b) Li I EW.

5. Linear polarization

V4046 Sgr was observed in BVR bands on 18 May 1991 and 15 March 1992 for the detection of possible variation in linear polarization. Since these observations indicated polarization variation, polarimetry was done on three nights during March 1993 to look for short time-scale variations. Figure 3 shows the plots of P% and θ° observed during 18 May 1991, 15 March 1992 and 13 March 1993 against the corresponding inverse of the effective wavelength of observation. From Fig.3 it is seen that V4046 Sgr shows large variations in P% and θ°. During 15 March 1992 and 13 March 1993 P% was quite large and showed a steeper wavelength dependence when compared to that on 18 May 1991. The range in P% is the highest in B band. The values of θ° observed during 18 May 1991 and 15 March 1992 are almost the same while those observed on 13 March 1993 show a change of about 90°.

Figure 4 is a plot of P% in V band and the corresponding θ° against the Julian day of observation. The figure shows the highly variable nature of the P% and θ° in V4046 Sgr. Sudden variations in P% and θ° were also observed within a few days. Hence from this behaviour we can conclude that the geometry of the circumstellar material as well as the illuminating source changes in V4046 Sgr.

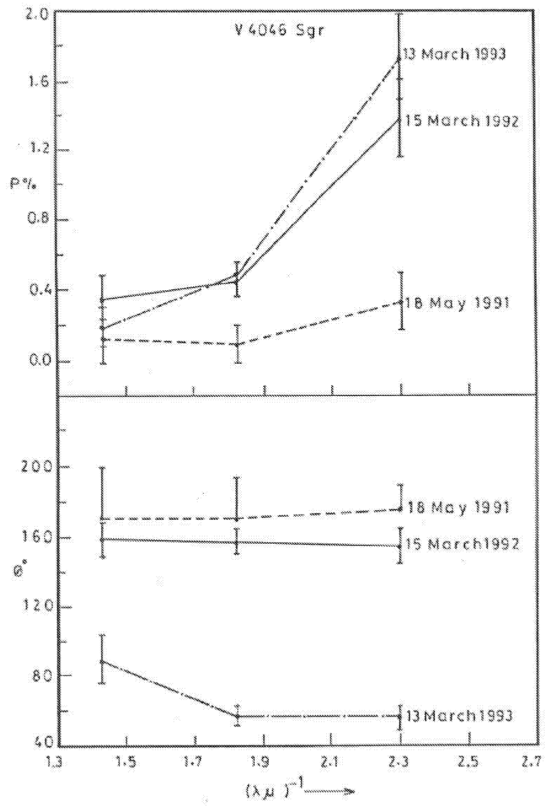

Fig. 3.— Plot of linear polarization and position angle against the corresponding inverse of the effective wavelength.

6. Conclusions

The analysis of the photometric observations of V4046 Sgr obtained over several seasons shows periodic light variations enabling us to derive the rotation period. In CTT stars the strong Hα emissions are supposed to be originating from the boundary layer between the accretion disc and the star. The interpretation of the light variation observed in V4046 Sgr is rather complicated due to its binary nature. Though the Hα emission strength is comparable to that of other CTT stars the star has negligible near and far infra-red excesses. We could say that V4046 Sgr is a peculiar CTT star in the sense that it shows more regular, small amplitude light variations but with strong Hα emission. The light variations could be due to the presence of a changing combination of cool and hot spots on the surface of the primary. The Hα emission may be arising from the circumbinary environment and so we observe some sort of a periodicity. However, it is too early to speculate the nature of spots in this star. Extensive, simultaneous multi-band photometric and high resolution spectroscopic studies are essential to arrive at definite conclusions on the nature of activity in V4046 Sgr.

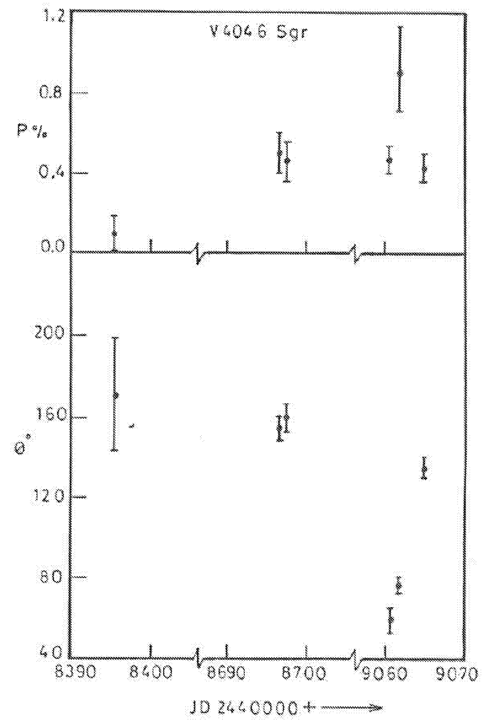

Fig. 4.— Plot time dependence of linear polarization and position angle.

7. Acknowledgements

I am thankful to ESO for the generous allotment of observation time. I am grateful to Dr.D.Sinachopoulos for obtaining part of the photometric data.

REFERENCES

Busko I.C., Torres C.A.O. 1978, A&A 64, 153

Byrne P.B. 1985, Irish Astron.J 17,3

de la Reza et al. 1986, in New Insights in Astrophysics ESA Sp-263, 107

IRAS 1985, IRAS Point Source Catalogue, eds. Beichman et al. JPL

Mathieu D.R. 1994, ARA&A 32

Mekkaden M.V. 1998, A&A 340, 135

Merril P.W., Burwell C.G. 1950, ApJ 112, 72

Vrba F.J., et al. 1993, AJ 106, 1608