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Near-infrared monitoring and modeling of V1647 Ori in its ongoing 2008–2012 outburst phase

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Abstract   We present results of the Mt Abu *JHK* photometric and HI Brackett γ line monitoring of the eruptive young stellar object V1647 Orionis (McNeil's Object) during its ongoing outburst phase in 2008–2012. We discuss *JHK* color patterns and extinction during the outburst and compare them with those from the previous outburst phase in 2004–2005 and in the intervening quiescent period that lasted about 2 yr. Commencing from early 2012, the object has shown a slow fading out in all the bands. We report brightness variations in the nearby Herbig-Haro object HH22 that are possibly associated with those in V1647 Ori. We also present modeling of the spectral energy distributions of V1647 Ori during both its recent outburst and its quiescent phase. The physical parameters of the protostar and its circumstellar environment obtained from the modeling indicate marked differences between the two phases.

Key words: stars: pre-main sequence — stars: formation — (stars:) circumstellar matter — stars: individual (V1647 Ori)

1 INTRODUCTION

It is believed that most low-mass pre-main-sequence (PMS) stars undergo a recurring active stage during which they show enhanced brightness or an 'outburst' lasting for a few years to a decade or longer (e.g., Stahler & Palla 2004 and references therein). Among the various mechanisms proposed (see Hartmann & Kenyon 1996), by which the rate of accreted mass substantially increases over a period of time causing the outburst, are the thermal instability in accretion disks (Bell et al. 1995), evolution from envelope accretion to disk magnetospheric accretion (Hartmann & Kenyon 1985), and gravitational or tidal triggering by the passage of a putative binary companion (Bonnell & Bastien 1992). Depending upon the duration of the outburst, PMS stars are sub-classified as FUors (prototype being FU Orionis) that last for over a decade or longer and EXors (prototype EX Lupis) that occur over shorter periods of about two years (Herbig 1977). V1647 Ori (IRAS 05436–0007), first discovered by McNeil et al. (2004) and since called McNeil's object, showed an outburst akin to EXors, yet it seemed to be distinctive (e.g., Ojha et al. 2006; Aspin et al. 2008; Aspin & Reipurth 2009 and the references therein). While the duration of its outburst was similar to EXors, its spectral characteristics seemed to be so different from EXors that it may as well be a new class of object in itself (Kun 2008). However, in recent times the star showed a second outburst (currently ongoing) starting from mid-2008 (for a comprehensive study, see Aspin 2011 and references therein).

Reporting post-2008 outburst behavior, Aspin (2011) concluded that the object remained "in an elevated photometric state" till early 2011. It was also concluded that McNeil's nebular morphology remained unchanged in its two recent outbursts. Furthermore, a large discrepancy in the accretion rates derived from Hα and Brγ emission line fluxes was reported. Using high resolution spectroscopy, Brittain et al. (2010) showed that the accretion rates derived from Brγ emission were similar during the two outbursts (though varying) and a factor of ~ 16 higher than the smallest accretion rate during the quiescent phase. These studies showed that the current (ongoing) outburst was basically different from the earlier one and this deserves further investigation. Clearly, therefore, continued monitoring of the object is necessary to detect possible changes in its behavior post-2011.

In this work, we present a substantial volume of *JHK* photometric and some *K* band spectroscopic observations made from Mt Abu during 2008–2012. We discuss their possible implications on the nature of V1647 Ori, in comparison with the previous outburst and quiescent phases. Further, we attempt to model the spectral energy distribution (SED) using an online modeling tool developed by Robitaille et al. (2007) and compare the physical parameters including accretion rates of both disk and envelope for V1647 Ori during the two epochs (viz. quiescence and outburst). Section 2 gives the details of our observations and Section 3 presents the results and discussion, including SED modeling results. Section 4 gives important conclusions.

2 NEAR-INFRARED PHOTOMETRIC AND SPECTROSCOPIC OBSERVATIONS

JHK photometric observations were made using the Near Infrared Camera & Multi-object Spectrograph (NICMOS) (256×256 HgCdTe array) and the Near Infrared Camera & Spectrograph (NICS) (HAWAII-1 1k×1k HgCdTe array), both mounted at the Cassegrain focus of the 1.2 m infrared telescope of the Physical Research Laboratory's (PRL's) Mt Abu Observatory.

The data consist of more than 40 sets of *JHK* observations during the period 2004–2012, a majority of which were made during the period 2008–2012. A part of the photometric data obtained between 2004–2005 appeared in Ojha et al. (2006). Single frame integration times were 40–60 s/20–30 s for *J*, 20–40 s/10–20 s for *H* and 2 s/10–15 s for *K* band with the NICMOS/NICS cameras. Several such frames were taken amounting to total integration times of 120–720 s for NICMOS and 120–400 s for NICS. A sufficient number of dithered frames were obtained for effective background subtraction and flat fielding. The seeing during the observations was typically $1.7'' - 2.5''$. Photometric flux calibration was done by observing a standard star in the AS 13 region (Hunt et al. 1998).

Data reduction was done using the Image Reduction and Analysis Facility (IRAF) software. The dark-subtracted and background-subtracted images were co-added to obtain the final image in each band. The photometric magnitudes of V1647 Ori were then found using the task APPHOT in IRAF. The magnitude of extended sources such as HH22 was also estimated using a larger sampling aperture (usually four times the FWHM of a star image). The integrated magnitude of the nebula surrounding V1647 Ori was estimated from the images after the star was subtracted using a $40''$ aperture. *K* band spectroscopic observations were made using the NICMOS array at a spectral solution of ~ 1000. The integration time for the spectra was 60 s per frame. Spectral reduction was done using standard spectroscopic tasks in IRAF. For sky background subtraction, a set of at least two spectra was taken with the object dithered to two different positions along the slit. The sky-subtracted spectra were then co-added resulting in a total exposure time of 480 s. The atmospheric OH vibration-rotation lines were used for wavelength calibration. The spectra of V1647 Ori were then ratioed with that of a spectroscopic standard star of AOV type, observed at a similar airmass, to remove the telluric absorption features. Prior to ratioing, the HI absorption lines from the standard star spectra were removed by interpolation. The ratioed spectra were then multiplied by a blackbody curve at the effective temperature of the standard star to yield the final spectra. The observed *K* band photometric flux of V1647 Ori was used for flux calibration of the spectra.

3 RESULTS AND DISCUSSION

3.1 Photometry

Table 1 gives the *JHK* magnitudes and colors for all the dates of our observations. The photometric errors are typically 0.02 to 0.05 magnitudes. For the ongoing 2008 outburst period (observations from Nov 2008 till Nov 2012), the average magnitude with standard deviation (σ) for 29 data sets are: 10.85 (0.17); 9.02 (0.18); 7.60 (0.24) for the *J*, *H* and *K* bands respectively. Occasional deviations of more than 3σ due to variability of the object were noticed in all the three bands. For the 2004 outburst period (observations from Mar 2004 till Dec 2004) the averages for seven data sets are 11.01 (0.16); 9.06 (0.17); 7.73 (0.15) for the *J*, *H* and *K* bands respectively; the deviations are within 2σ. For the quiescent phase during 2006–2007 (observations from Dec 2005 till Dec 2006), the averages for eight data sets are 14.2 (0.18); 11.61 (0.14); 9.89 (0.18) for the *J*, *H* and *K* bands respectively; occasional deviations seen are within 2σ. Thus the ongoing outburst shows higher amplitude fluctuations in brightness than the 2004–2005 outburst, especially in the *K* band (more than 0.5 mag). The light curves in the *J*, *H* and *K* bands are shown in Figure 1 covering the period between 2004–2012. For comparison, a few data points from other published work are also shown (from McGehee et al. 2004; Ojha et al. 2006; Acosta-Pulido et al. 2007 and Aspin 2011). It may be mentioned here that Acosta-Pulido et al. (2007) reported a 56 day periodic component in their optical light curves in the visible bands. Our *JHK* data do not clearly show this component.

Trend of decline of Outburst phase since early 2012: In comparison with its behavior till 2011 (e.g. Venkat & Anandarao 2011), the object seems to show a steady decline in the brightness beginning from Feb-Mar 2012 (cf. Semkov & Peneva 2012; Ninan et al. 2012) with an approximate rate of 0.16, 0.06 and 0.18 mag per year in the *JHK* bands respectively (see Fig. 1). It is necessary to confirm this declining trend by continued monitoring. The slow decline compared to the one noticed in the 2004 outburst is reminiscent of a typical FUor light curve, but it is premature to conclude that
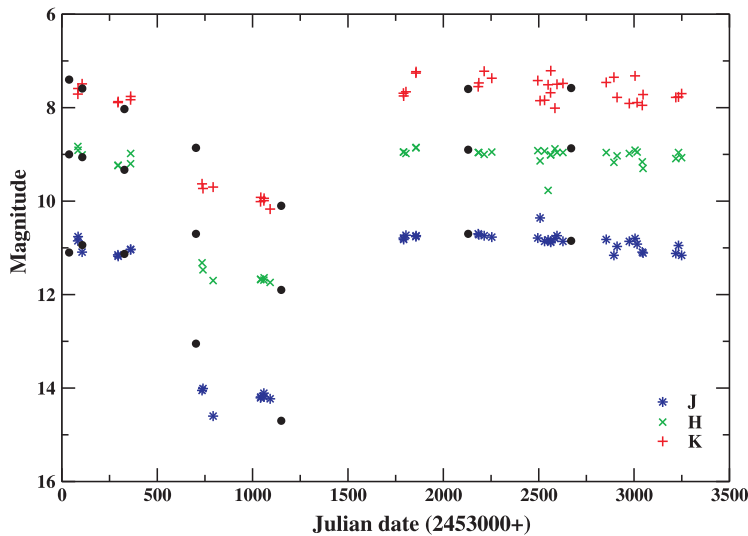

Fig. 1 V1647 Ori: Light Curves in the *J*, *H* and *K* bands from Mt Abu observations during 2004–2012 covering the two outbursts with the $\sim$ 2-yr quiescence in between. The asterisks represent the *J* band, crosses represent the *H* band and pluses represent the *K* band. Observations made elsewhere are shown in black filled circles (see text for references).

Table 1 V1647 Ori: *JHK* Photometric Magnitudes and Colors, and A_V (in mag) during 2004–2012

Date	JD	J	H	K	J–H	H–K	A_V
2004Mar20	2453084.5	10.85	8.83	7.71	2.02	1.12	11.76
2004Mar21	2453085.5	10.76	8.91	7.59	1.85	1.32	7.81
2004Apr11	2453106.5	11.09	9.01	7.49	2.08	1.52	9.38
2004Oct16	2453294.5	11.15	9.24	7.89	1.91	1.35	8.40
2004Oct17	2453295.5	11.18	9.23	7.87	1.95	1.36	8.87
2004Dec21	2453360.5	11.04	9.20	7.83	1.84	1.37	7.27
2004Dec22	2453361.5	11.03	8.98	7.76	2.05	1.22	11.37
2005Dec31	2453735.5	14.05	11.32	9.63	2.73	1.69	17.01
2006Jan05	2453740.5	14.01	11.47	9.73	2.54	1.74	13.98
2006Feb27	2453793.5	14.60	11.70	9.70	2.90	2.00	16.87
2006Nov03	2454042.5	14.21	11.67	10.01	2.54	1.66	14.62
2006Nov04	2454043.5	14.19	11.68	9.92	2.51	1.76	13.41
2006Nov20	2454059.5	14.11	11.69	9.99	2.42	1.70	12.64
2006Nov21	2454060.5	14.19	11.64	9.94	2.55	1.70	14.44
2006Dec23	2454092.5	14.23	11.74	10.17	2.49	1.57	14.65
2008Nov21	2454791.5	10.79	8.95	7.69	1.84	1.26	8.15
2008Nov22	2454792.5	10.82	8.95	7.75	1.87	1.20	9.05
2008Dec04	2454804.5	10.73	8.98	7.66	1.75	1.32	6.42
2009Jan25	2454856.5	10.76	8.86	7.26	1.90	1.60	6.25
2009Jan26	2454857.5	10.74	8.85	7.23	1.89	1.62	5.95
2009Dec18	2455183.5	10.70	8.96	7.55	1.74	1.41	5.56
2009Dec21	2455186.5	10.72	8.96	7.47	1.76	1.49	5.20
2010Jan18	2455214.5	10.74	9.00	7.22	1.74	1.78	—
2010Feb27	2455254.5	10.77	8.95	7.37	1.82	1.58	5.31
2010Oct26	2455495.5	10.79	8.92	7.42	1.87	1.50	6.64
2010Nov07	2455507.5	10.36	9.14	7.85	1.22	1.29	—
2010Dec01	2455531.5	10.86	8.93	7.84	1.93	1.09	10.76
2010Dec19	2455549.5	10.83	9.77	7.51	1.06	2.26	—
2011Jan01	2455562.5	10.86	9.01	7.68	1.85	1.33	7.73
2011Jan02	2455563.5	10.88	9.01	7.21	1.87	1.80	—
2011Jan24	2455585.5	10.80	8.88	8.01	1.92	0.87	—
2011Feb04	2455596.5	10.74	8.96	7.50	1.78	1.46	5.72
2011Mar07	2455627.5	10.86	8.96	7.48	1.90	1.48	7.21
2011Oct20	2455854.5	10.82	8.96	7.46	1.86	1.50	6.50
2011Nov29	2455894.5	11.16	9.17	7.35	1.99	1.82	—
2011Dec16	2455911.5	10.97	9.03	7.78	1.94	1.25	9.61
2012Feb18	2455975.5	10.86	8.98	7.91	1.88	1.07	10.23
2012Mar19	2456005.5	10.80	8.91	7.32	1.89	1.59	6.19
2012Mar30	2456016.5	10.92	8.95	7.89	1.97	1.06	11.55
2012Apr26	2456043.5	11.09	9.16	7.95	1.93	1.21	9.80
2012Apr30	2456047.5	11.11	9.30	7.72	1.81	1.58	5.17
2012Oct19	2456219.5	11.12	9.09	7.78	2.03	1.31	10.38
2012Nov02	2456233.5	10.95	8.96	7.77	1.99	1.19	10.79
2012Nov18	2456249.5	11.16	9.07	7.70	2.09	1.37	10.72

it is an FUor; as there have been spectroscopic indications to the contrary. In fact it could be a class in itself which shows characteristic features of both FUors and EXors (see Kun 2008).

We have computed the visual extinction A_V from the colors [*J–H*] and [*H–K*] for both epochs, using the formula for T Tauri stars derived from Meyer et al. (1997) and the extinction model of Bessell & Brett (1988),

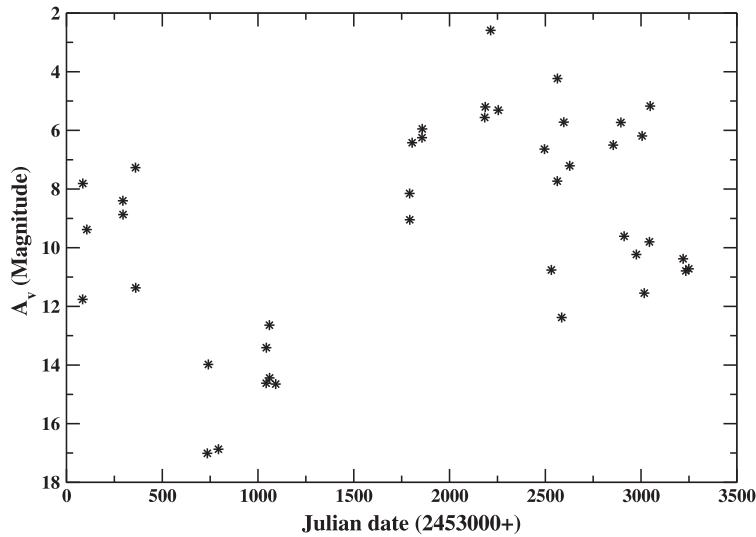$$A_V = 13.83 \times [J - H] - 8.02 \times [H - K] - 7.19. \tag{1}$$

Fig. 2 V1647 Ori: Time variation of A_V from Mt Abu observations during 2004–2012 comprising two outbursts flanking the quiescent epoch (with larger extinction).

The computed A_V values are listed in Table 1. For comparison, the A_V corresponding to the 2MASS epoch (quiescent on 1998 October 7) is 13.3. The time evolution of A_V is shown in Figure 2. We find that there is ~ 6 mag difference in A_V between the two phases, with the outburst phase having a lower extinction. This can be attributed to the excess mass accreted by the envelope (from the environment) during the quiescent phase in comparison with the outburst phase during which the disk accretion (from the envelope) is expected to dominate (e.g. Aspin et al. 2008 and Aspin 2011).

A *JHK* color-color diagram constructed from Mt Abu data during 2004–2012 is shown in Figure 3. The A_V values computed using Equation (1) are in reasonable agreement (within 1 – 2 mag) with those obtained by de-reddening the *JHK* colors to the T Tauri locus in the color-color diagram. The color-color diagram demonstrates the variable nature of the source in the ongoing 2008 outburst phase in comparison with the 2004 outburst. The region occupied by the latest outburst (asterisks in Fig. 3) extends horizontally (i.e. with [*J–H*] ~ 1.7–2.0) beyond the T Tauri region; quite in contrast with the 2004 outburst phase (open circles). This tendency during the ongoing outburst indicates the presence of cold dust in the envelope/disk of the star compared to the 2004 outburst. Also, we found at least two occasions (in 2010 November 7 & 2010 December 19) in which the colors showed extreme values, as indicated by the magenta asterisks in Figure 3 around [*J–H*] ~ 1.0–1.2, with [*H–K*] at 1.3 and 2.3. On another occasion (2011 January 24) the colors indicate a position to the left of the T Tauri region. The A_V could not be calculated for these cases falling well beyond the T Tauri regime (shown as dashes in Table 1). We suspect that such extreme fluctuations may have short duration (a few days) and be attributable to variation in circumstellar dust temperature.

3.2 Spectroscopic Variations

As may be seen in Figure 4, *K* band spectra taken at different times during the outburst phase show variability in hydrogen Brγ, indicating variable disk accretion rates. The Brγ line shows a fluctuating trend that does not seem to be associated with photometric fluctuations (cf. Hα line reported by Walter et al. 2004 and Aspin & Reipurth 2009). Quanz et al. (2007) reported molecular line
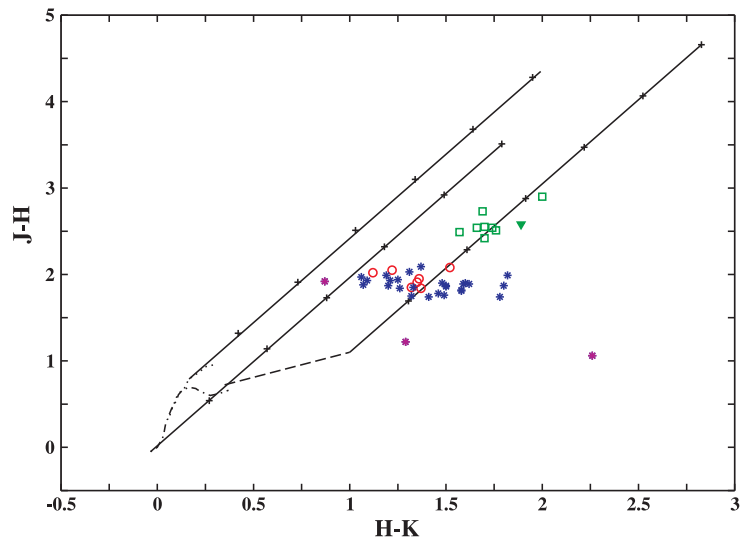
Fig. 3 V1647 Ori: Color-color diagram from Mt Abu observations. The 2MASS value is marked as an inverted *triangle* (corresponding to 1998 October 7). The *asterisks* correspond to the ongoing outburst period 2008–2012; while the *circles* correspond to the outburst period of 2004–2005. The *squares* are for the quiescent epoch of 2006–2007. The three "stray" magenta asterisks, with two appearing around $J - H \sim 1.0$ and the one appearing around $H - K \sim 0.8$, correspond to extremities in photometric magnitudes observed in our monitoring. See text for discussion. The *dot-dashed* curve represents the unreddened main-sequence stars; the *dotted* curve shows the unreddened giant stars. The black slanting parallel lines indicate the extinction vectors for $A_V = 30$ mag (the extinction law from Bessell & Brett 1988 was adopted). The pluses along the extinction vector correspond to an extinction interval of $A_V = 5$ mag. The T Tauri stars fall on the black dashed straight line, adopted from Meyer et al. (1997).

variability in the mid-IR region during the 2004 outburst. It may be noted that the width at zero-intensity and the ratio of peak to continuum intensity in Mt. Abu profiles are in reasonable agreement with those of Brittain et al. (2010) for the year 2009, in spite of the large differences in the resolving power employed and signal-to-noise values between the two observations. The accretion luminosities and disk accretion rates derived from the dereddened Brγ line fluxes from our spectra (following the procedure described by Muzerolle et al. 1998) range from 20–60 $L_\odot$ and 1.0×10^{-6} to 3.0×10^{-6} $M_\odot$ yr^{-1} respectively, which are comparable with those reported by Brittain et al. (2010).

3.3 Variations in HH22 and the Nebula around V1647 Ori

Figure 5 shows a *JHK* color composite image of V1647 Ori and its associated nebula taken from Mt Abu on 2011 February 04 using NICS. Superposed on the image are the contours of isomagnitudes in the *H* band. The curved tail at the top left part of the nebular object is usually attributed to the ongoing accretion (cf. Reipurth & Aspin 2004). HH22 (knot A in Eisloffel & Mundt 1997), seen nearly to the north of V1647 Ori (see Fig. 5), is a Herbig-Haro type object (for the mid-IR counterpart, see Muzerolle et al. 2005). It happens to be located very close to V1647 Ori (30″ of separation at an assumed distance of 0.40 kpc) and its originating source has not yet been identified. It could possibly be a reflection nebulosity powered by V1647 Ori (see Briceño et al. 2004 and Aspin et al. 2008).
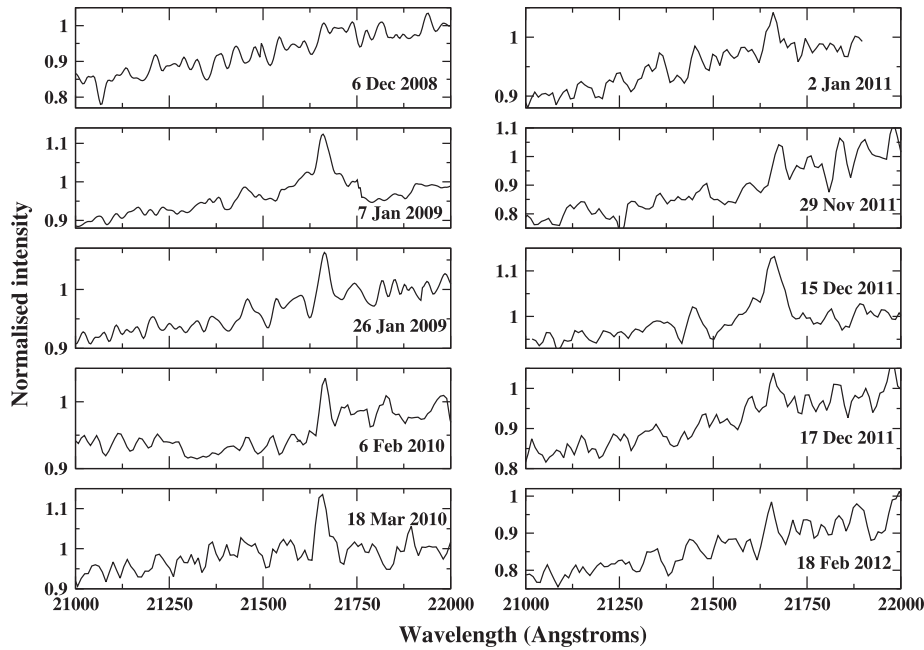
Fig. 4 V1647 Ori: Brγ line (at 2.16 μm) in the *K* band observed on a few occasions at Mt Abu. Variability is evident.

It may be expected therefore that the outburst from V1647 Ori could cause the nebulosity to show a corresponding brightening. The light travel time from the young stellar object (YSO) to HH22 is ∼ 70 d. We analyzed images in the *JHK* bands obtained from Mt Abu to see if HH22 shows any variability in its brightness.

Figure 6 shows the integrated *K* magnitude of HH22 with time along with magnitudes of V1647 Ori. The plot indicates a possible correspondence between HH22 (knot A) and the outburst activity, as well as indication of a trigger from even short term fluctuations in V1647 Ori. We also noticed fluctuations in the brightness of the nebula around V1647 Ori, which typically follow those of V1647 Ori itself. Similar fluctuations were also noticed in the *J* and *H* bands.

3.4 Modeling of the Spectral Energy Distribution

Modeling the SED of V1647 Ori was done for three sets of data taken during: (i) the outburst phase 2004–2005; (ii) the quiescent phase 2006–2007 and (iii) the second (ongoing) outburst phase 2008–2012. For each of these three phases, the mean values of Mt Abu *JHK* magnitudes were considered. To the *JHK* data we added the visible, mid-infrared, far infrared and mm-wave data during quiescent and outburst epochs taken from Andrews et al. (2004) and Aspin et al. (2008). The SEDs given in Aspin et al. (2008) for the outburst and quiescent phases show that the fluxes of the PMS star in sub-mm and mm regions did not change more than 10% between the two phases. It is in the visible and infrared that a substantial change had taken place. The near-infrared region occurs right at the position of turn-over in the SED and hence is quite important. It was assumed that the small photometric variations, if present in the mid-infrared and far-infrared, are not significant in each phase. We used an online tool developed by Robitaille et al. (2007) for SED modeling. Using this tool, several authors have successfully modeled T Tauri stars and massive protostars with masses up
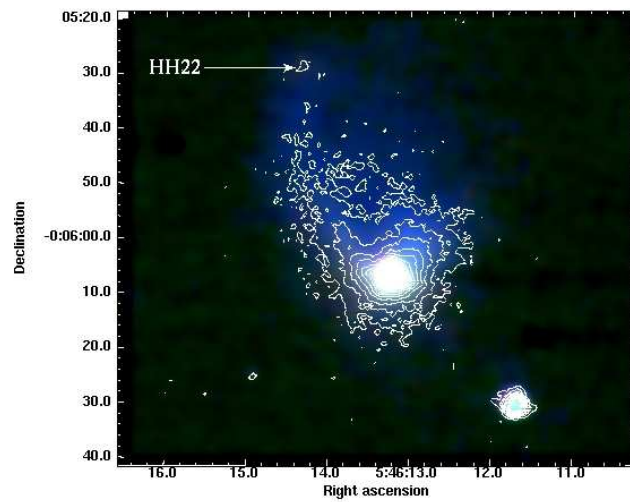
Fig. 5 Color composite image of V1647 Ori and the surrounding McNeil's nebula in the J(blue), H(green) and K(red) bands taken at Mt Abu using NICS on 2011 February 4; HH22 is seen nearly north of V1647 Ori. The H band contours (in white) are shown superposed on the image: the outermost contour is 20 mag arcsec^{-2} with each contour brightening by 2 mag arcsec^{-2} inwards.
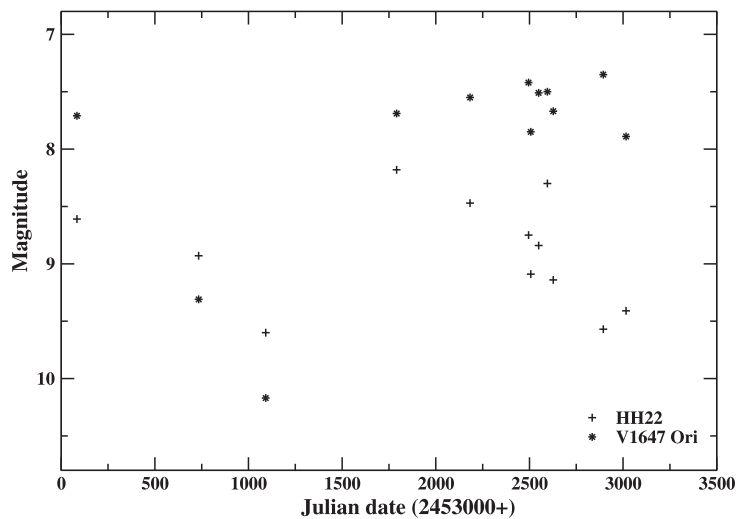

Fig. 6 Time variations of V1647 Ori in the K band seen against those in HH22. The asterisks correspond to V1647 Ori and pluses represent HH22. For HH22 the magnitudes are made brighter by subtracting five to facilitate a closer comparison.

to 25 $M_\odot$ (e.g. Kumar Dewangan & Anandarao 2010). The online tool selects the best-fit solutions from 20 000 models (each with 10 different angles of inclination for the accretion disk, making a total of 200 000 models). The input parameters include, apart from a minimum of three data points in SED and their corresponding errors, a range of distances to the object and the visual extinction. The output parameters include stellar mass, temperature, radius, age and total luminosity; as well as
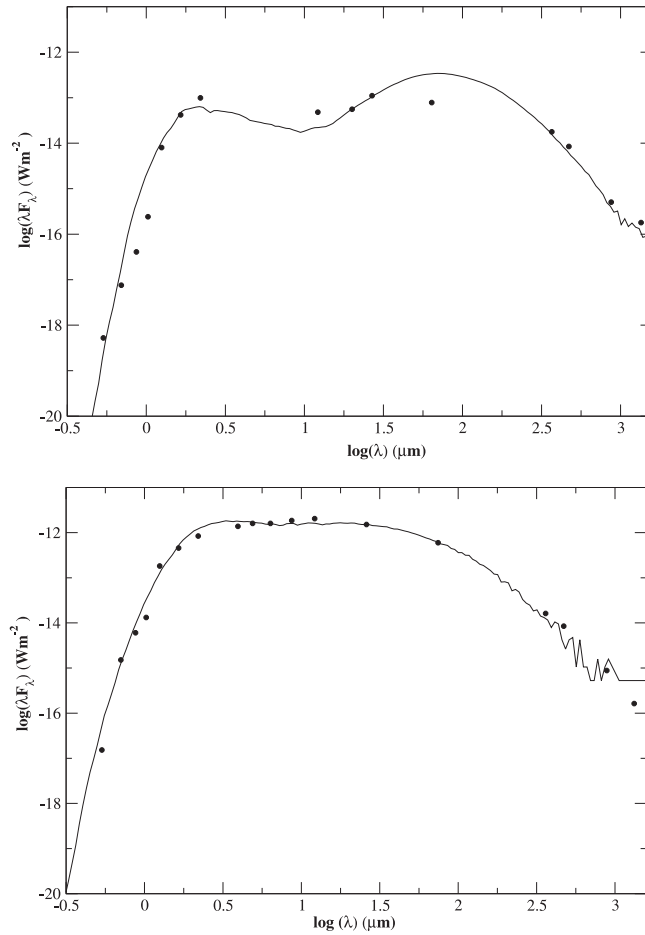
Fig. 7 SED models for V1647 Ori during (a) its quiescent phase (2006–2007) and (b) its outburst phase (2008–2012). The filled circles represent data points. The full dark curves show the best fits (see text for details).

disk inclination angle, masses of the disk and envelope and rates of accretion. In order to minimize the degeneracy of solutions, only those solutions that satisfy the criterion

$$(\chi^2 - \chi^2_{\text{best}}) \leq 3 \tag{2}$$

are chosen with χ^2 considered per data point (see Robitaille et al. 2006). Furthermore, in order to avoid 'over-interpretation' of SEDs, we provided a small range of visual extinction values (from the JHK photometry) for each phase, to account for the inherent uncertainties in their determination. In the present case, a distance of 0.40 kpc is adopted (from Anthony-Twarog 1982). The best fit models are displayed in Figure 7 along with the observed data (shown in filled circles) for the quiescent phase of 2006–2007 and the ongoing outburst phase of 2008–2012.

Table 2 lists the mean values and standard deviations of physical parameters derived from the models for the two epochs. The model parameters for the outburst phase 2004–2005 match quite well with those of the ongoing outburst phase of 2008–2012. In the quiescent phase one can notice the stellar parameters similar to those of a T Tauri star. But the outburst parameters mimic more

Table 2 Model Parameters for V1647 Ori in its Quiescent (2006–2007) and Outburst (2008–2012) Phases

Physical Parameter	Quiescent Phase	Outburst Phase
Stellar Age (yr)	$4.8 \pm 2.5 (\times 10^4)$	$6.3 \pm 3.1 (\times 10^5)$
Star Mass ($M_\odot$)	0.34 ± 0.15	4.44 ± 0.34
Star Temperature (K)	3360 ± 170	7560 ± 1590
Star Radius ($R_\odot$)	4.01 ± 0.12	7.08 ± 2.28
Total Luminosity ($L_\odot$)	1.85 ± 0.24	156.5 ± 28.0
Envelope Mass ($M_\odot$)	1.51 ± 0.02	$1.40 \pm 3.79 (\times 10^{-4})$
Envelope Accretion Rate ($M_\odot \, \mathrm{yr}^{-1}$)	$5.3 \pm 0.1 (\times 10^{-5})$	$3.7 \pm 0.0 (\times 10^{-6})$
Disk Mass ($M_\odot$)	$6.8 \pm 8.00 (\times 10^{-5})$	$6.9 \pm 1.8 (\times 10^{-2})$
Disk Accretion Rate ($M_\odot \, \mathrm{yr}^{-1}$)	$5.5 \pm 3.3 (\times 10^{-9})$	$2.2 \pm 1.6 (\times 10^{-7})$

of an intermediate mass star rather than a low mass PMS star. In the outburst phase the disk mass and accretion rate are substantially enhanced when compared to the quiescent phase. The envelope accretion rate decreases by more than an order of magnitude in the outburst phase compared to the quiescence, but envelope mass decreases by several orders of magnitude. This may be due to the enhanced luminosity in the outburst phase which could prevent mass accretion from the envelope. In the quiescent phase, the envelope emission dominates in the mid-infrared and longer wavelength region, while in the outburst phase the disk emission contributes substantially in the region beyond 1 μm.

It may be noted that the disk accretion rate for the outburst phase given in Table 2 matches well with those reported by Briceño et al. (2004), Aspin et al. (2008), Brittain et al. (2010) and Aspin (2011). However, the disk accretion rates in the quiescent phase derived from Brγ/Paβ emission lines by Aspin et al. (2008) are much higher than the value derived from the model reported here. While this could be due to uncertainties in the SED model or emission line method, the important point to be noted is that the disk accretion rate during the outburst phase is much larger than that in the quiescent period. The total luminosity obtained here (which includes contributions from the star and its disk and envelope) matches well with those derived by Ábrahám et al. (2004) and Aspin et al. (2008) from the SEDs of the pre-outburst phase. The total outburst luminosity during the 2003 outburst as derived by Briceño et al. (2004) from the SED is 219 $L_\odot$ which agrees well with that obtained from our model for the current ongoing outburst. Earlier, using a simpler model, Muzerolle et al. (2005) interpreted the *Spitzer* IRAC/MIPS (photometric bands between 3.5–70 μm) data for the pre- and post-outburst phases. Their results are qualitatively similar to ours.

4 CONCLUSIONS

The important conclusions of this work are:

(1) Monitoring of V1647 Ori in the *JHK* bands has shown that the object has been undergoing episodes of variation in mass accretion as indicated by small but significant variations in its *JHK* fluxes. This conclusion is also supported by its spectral variations in near-infrared;

(2) Starting from early 2012, the object has seemed to show a slow fading out with a rate of ∼ 0.06–0.18 mag per year. This may indicate that V1647 Ori is an intermediate type object falling between FUors and EXors, having characteristic features of both the prototypes;

(3) The *JHK* color-color diagram indicates several occasions in the current, ongoing outburst in which the star displays positions beyond the T Tauri region, indicating the presence of colder dust compared to its 2004 outburst phase;

(4) The Herbig-Haro object HH22, whose as yet unidentified energizing YSO is situated at about 30″ from V1647 Ori, seems to show light fluctuations corresponding to those of the latter, thereby confirming that it is a reflection nebulosity triggered by the YSO;

(5) The spectral energy distributions of V1647 Ori modeled for the epochs of quiescence and outburst, show that the disk mass and accretion rate in the outburst phase are significantly greater than those in the quiescent stage, but the envelope mass and accretion rates are much lower.

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