THE REMARKABLE HERBIG AE STAR V351 ORI

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ABSTRACT. The photometric behaviour of the Herbig Ae star V351 Ori was investigated combining data from the literature with new photometry. It is shown that this object changed from a Herbig Ae star with strong photometric variations, due to extinction by circumstellar dust clouds, to that of an almost non-variable star. Such a behaviour is not unique; it has been found also in the star BN Ori. This suggests that such transitions as well as the opposite must occur quite often during the evolution of these intermediate mass stars towards the main-sequence. A provisional model to explain V351 Ori's behaviour, in which it is assumed that a temporarily strong accretion of matter onto the star took place, is proposed.

1. INTRODUCTION

V351 Ori = HD 38238 is an irregular variable Hα-emission line star, located in the direction of the Lynds 1630 dark cloud region. Although V351 Ori fulfills all primary criteria for membership of the Herbig Ae/Be stellar group (A or B-type emission-line star with infrared excess, located in a plausible region of recent star formation), as well as many secondary ones (large brightness variations, spectral signatures of mass accretion), it was only first recognized by Koval'chuk (1985) and by Zajtseva (1986) to belong to this special class of intermediate-mass pre-main sequence objects. As a consequence of this late discovery, the star was not well studied and a more careful analysis of all available photometric and spectroscopic data of this object was in place, the results of which are presented in this paper.

2. PHOTOMETRIC BEHAVIOUR

During the last seven years, V351 Ori was monitored by the ESO "Long Term Photometry of Variables"-group, using the Strömgren Automatic Telescope at La Silla, Chile. The new y data are, together with visual photometry of V351 Ori collected from literature, plotted in Fig. 1. Colour-magnitude diagrams with these data are shown in Fig. 2. When we examine the lightcurve in Fig. 1, we notice that V351 Ori has changed its photometric behaviour drastically over the period of 14 years covered by this diagram. In the period before JD 2446000 the star shows large brightness variations. When we look at the colour-magnitude diagrams in the Johnson $UBVRI$ system over this period (Fig. 2b), we notice that for $V < 10^{\rm m}\!.0$ there seems to be a linear relation between the V magnitude and the colour-indices, in which the colours

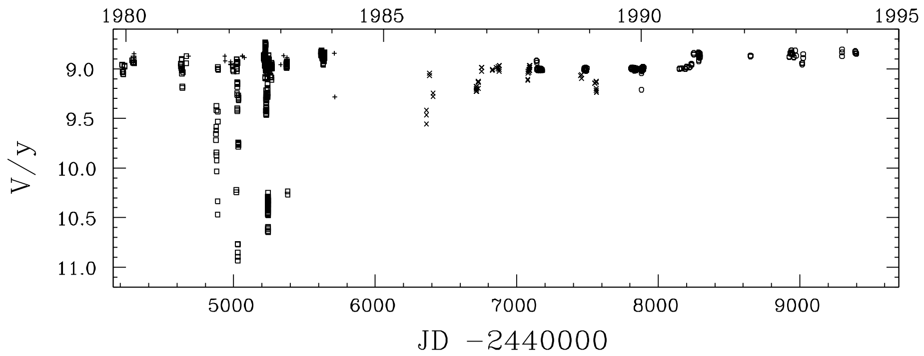

Figure 1. Lightcurve of V351 Ori. Squares represent data of Koval'chuk (1985), plus signs those of Kilkenny et al. (1985), crosses those of Chkhikvadze (1990) and open circles are data of the LTPV group.

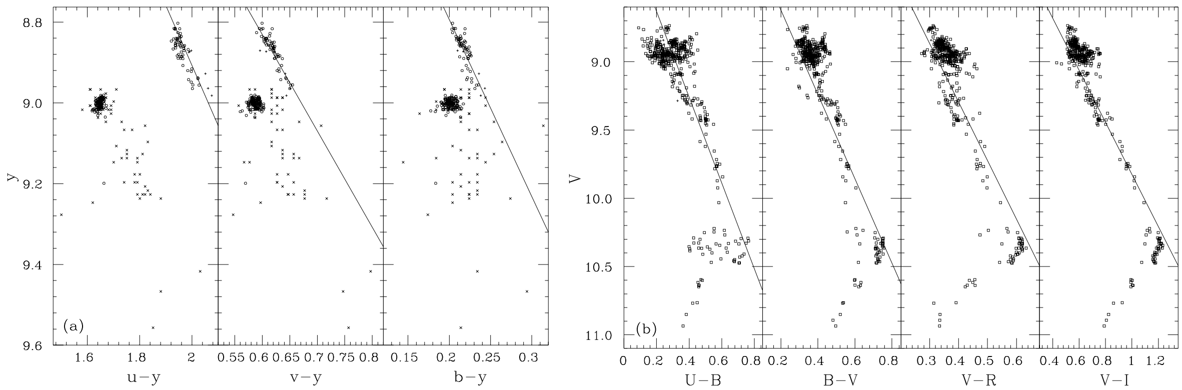

Figure 2. (a) Colour-magnitude diagrams of V351 Ori in the Strömgren *uvby* system. (b) Colour-magnitude diagrams of V351 Ori in the Johnson *UBVRI* system. Plot symbols have the same meaning as in Fig. 1. The solid lines indicate the interstellar reddening direction.

become redder as V increases. The slope of this relation is compatible with that of the normal (i.e. $R_V = A_V/E(B-V) = 3.1$) interstellar extinction law. This suggests that these variations are caused by variable amounts of extinction of the starlight.

As the stellar brightness decreases even further, we see the blueing effect; with increasing V, the colours now become bluer. Such an effect can be explained by assuming the presence of a dust envelope around V351 Ori. The radii of the particles in this envelope are small enough to scatter the blue photons of the stellar radiation, producing a faint blue emission. The complete colour-magnitude diagram in Fig. 2b can now be explained by assuming the passing by of obscuring dust clouds, revolving around the star. Due to extinction by the particles in the cloud, the light from the star becomes fainter and redder. Below some brightness level, the scattered blue light from the dust envelope dominates, and produces the observed blueing effect.

If we only look at the first part of the light curve in Fig. 1 and the colour-magnitude diagrams in Fig. 2b, we would come to the conclusion that the photometric behaviour of V351 Ori is like that of a typical Herbig Ae star with large photometric variations, such as UX Ori. However, in Fig. 1 we can see that *V351 Ori changed its photometric behaviour from that of a Herbig Ae star showing large photometric variations to that of a nearly constant one.* This process seems to have started around JD 2446000. Before

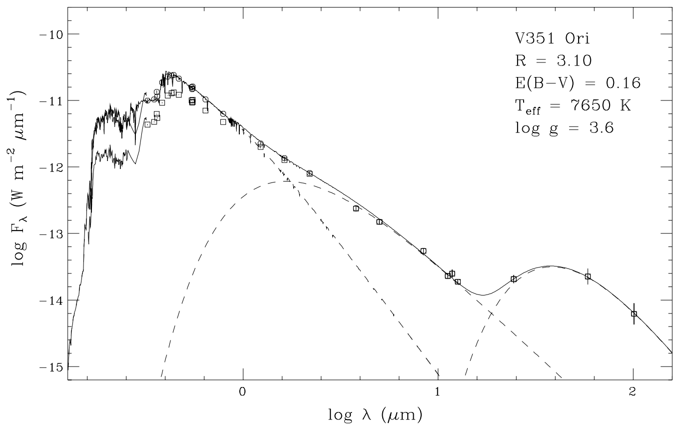

Figure 3. Observed (squares) and extinction-corrected (circles) SEDs for V351 Ori. Also shown are the Kurucz model (left dashed line), the disk model (middle dashed line) and the Planckian (right dashed line) fitted to the infrared excess and the total model (solid line), fitted to the extinction-free SED.

this date, the star showed large ($> 2^{\mathrm{m}}$) variations in y with a maximum brightness of $\approx 8\overset{\mathrm{m}}{.}8$ in this passband. Between JD 2446000 and JD 2448200, V351 Ori only varied by several tenths of a magnitude in y, and the star's maximum visual brightness dims by $0\overset{\mathrm{m}}{.}16$ to $y \approx 9\overset{\mathrm{m}}{.}0$. Between JD 2448200 and JD 2448250, the maximum brightness of V351 Ori rapidly increases to $y \approx 8\overset{\mathrm{m}}{.}84$, equal to its level before JD 2446000. After JD 2448250, the variations in brightness nearly vanished.

3. STELLAR PARAMETERS

Using newly obtained low-resolution spectra, we determined V351 Ori to be an A6 or A7 weak emission-line star, well in agreement with the spectral type of A7 III given by Zajtseva (1986). From new high-resolution ($R = 55,000$) spectra of V351 Ori in the Hα and Na I D lines, we notice that the Hα emission has a very strong reversed P Cygni profile, indicating accretion of matter towards the star. Indications for the presence of a disk-like structure around V351 Ori come from the presence of a weak and broad component in the sodium lines.

The extinction-free spectral energy distribution (SED) of V351 Ori, employing only data taken near maximum brightness, was analyzed by comparing it with a Kurucz (1991) model with $T_{eff} = 7650$ K and $\log g = 3.6$, corresponding to the spectral type of A7 III. The photometry used in the construction of this SED were taken from literature and were all obtained in the period when the star still showed strong photometric variations. The resulting SED of V351 Ori is shown in Fig. 3.

As can be seen from this plot, the quality of the fit to the Kurucz model is very good in the ultraviolet and the optical wavelength ranges, with a large amount of excess radiation in the infrared. The fact that the SED in the near infrared can be approximated by a straight line indicates the presence of an extended disk or dust shell around the star, whereas the strong bump in the far-infrared suggests the presence of an additional cooler component. We modelled this SED using a simple parametrized disk model, with $T \propto r^{-0.9}$, similar to the ones by Beckwith et al. (1990). An additional Planckian component with a temperature of 78 ± 4 K represents the dust shell. These two models are also shown in Fig. 3.

4. DISCUSSION AND CONCLUSIONS

We have shown that V351 Ori changed from a Herbig Ae star with strong photometric variations to a almost non-variable one. Such a change had previously only been observed in the Herbig Ae star BN Ori around 1947 (Shevchenko et al. 1996). A first conclusion that can be drawn from the fact that we have actually been able to observe such transitions in the relatively short period these stars have been observed systematically, is that *such transitions from Herbig Ae stars with strong photometric variations to almost non-variable ones must occur quite often during the evolution of such stars towards the main-sequence.* This also implies that the reverse process must occur frequently.

Since before JD 2446000 the photometric variations of V351 Ori were caused by dust clouds orbiting the star, it seems that around this date some event started which either destroyed the dust in these clouds, or moved the dust clouds from our line of sight. This event continued until JD 2448200, after which the star rapidly became nearly constant in brightness. So far, we can only speculate about the cause of this event. It could be that it is correlated with a temporarily strong accretion of dust onto the star. Such an event will be accompanied by shock-fronts which create an extremely hot gaseous disk near the equatorial plane close to the star. This hot optically thick gaseous disk blocked part of the visual and blue light of the star, causing a visual brightness decrease of about $0^{\mathrm{m}}_{.}2$. At the same time, this hot object radiates ultraviolet energy superposed on that of the central star. This is causing the increase of the ultraviolet brightness of the star. When the accretion of dust stops, the visual and blue stellar light regain its maximum brightness, whereas the ultraviolet contribution of the hot disk disappears, and the ultraviolet brightness drops.

Since all infrared observations of V351 Ori were made during the period in which the star still showed photometric variations, it is very important to obtain new infrared photometry of this object. If the dust clouds close to the star have indeed accreted onto the central star, we should expect to see a clear decrease of the infrared excess of the star. Further optical monitoring of V351 Ori remains necessary to see whether the dust clouds start to re-occur, in which case the star will become variable once more.

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