

# Heated dust around the LMC Wolf-Rayet system HD 36402 (BAT99-38)

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**Abstract:** Infrared photometry of the probable triple WC4 (+O?) +O8I: system HD 36402 (BAT99-38) in the LMC shows emission characteristic of heated dust. Although HD 36402 is close to two luminous YSOs, it is possible to distinguish its emission at wavelengths less than 10 microns. Simple modelling indicates a dust temperature near 800 K and mass of about  $1.5 \times 10^{-7} M_{\odot}$  amorphous carbon grains. The dust emission appears to be variable. It is apparent that Wolf Rayet dust formation occurs also in metal-poor environments.

## 1 Introduction

Infrared observations show the wide prevalence of dust formation by evolved stars of different types: red supergiants, AGB stars, Novae, LBVs, RCB stars – and some Population I Wolf-Rayet stars. Infrared photometric histories, some spanning decades, show properties ranging from persistent dust formation at apparently constant rates (e.g. WR 104 = Ve2-45) to brief episodes of dust formation at regular intervals (e.g. WR 140 = HD 193793, P = 7.94 y.), and these two stars are considered to be the prototypes of persistent and episodic dust makers respectively. A handful of systems show intermediate behaviour, forming dust persistently, but at a variable rate (e.g. WR 98a = IRAS 17380-3031). The persistent dust makers are nearly all WC9 stars and show a strong preference for the metal-rich region of our Galaxy, generally towards the Galactic Centre, while the smaller number of episodic dust makers have spectral types ranging from WC4 to WC8 and a less concentrated galactic distribution – but all of them are located within the Solar circle.

In the lower metallicity environments of the Magellanic Clouds, the fraction WR/O stars and distribution of WR spectral subtypes are very different from those in our Galaxy. In particular, there are no WC stars in the LMC having spectral subtypes ‘later’ than WC4. To date, the LMC WC4 stars have not been systematically observed for evidence of dust formation, but comparison of their data in the DENIS (Epchtein et al. 1999) and 2MASS (Skrutskie et al. 2006) surveys suggested that HD 36402 (BAT99-38, Brey 31) varied in  $K$  with an amplitude greater than that in  $J$  and could be a dust maker. This was supported by data in the IRSF Magellanic Clouds survey (Kato et al. 2007). The *SPITZER* SAGE photometry of massive stars in the LMC (Bonanos et al. 2009) allows us to examine the spectral energy distributions (SEDs) of LMC WC4 stars at longer wavelengths, and demonstrates that HD 36402 is indeed a dust-making WR star. Bonanos et al. tentatively identified HD 36402 with a 70- and 160- $\mu$ m source but this has to be tested for confusion given the large beam sizes (18 and 40 arcsec respectively) at these wavelengths.

## 2 Infrared Photometry of HD 36402 from Surveys

Photometry and dates of observation of HD 36402 extracted from the DENIS, 2MASS and IRSF LMC surveys are collected in Table 1 and plotted in Fig. 1. These appear to be the only published near-IR photometry of HD 36402 but the star is most likely to have been observed in other studies. Hopefully, more photometry will become available, but the present data are sufficient to show that HD 36402 is variable in the near infrared. The amplitude in  $K_s$  is significantly greater than the uncertainties,  $\sigma K_s$ . It is also greater than that in  $J$ , arguing against a photospheric origin for the variation and suggesting variable emission by hot dust. Given that the data come from three different instruments, a  $K_s$ -band image of the field was searched for close companions which might introduce spurious variability through confusion. The closest is that marked ‘a’ in Fig. 2, 7'' west of HD 36402. This has 2MASS  $K_s = 14.76$ , which is  $\sim 4$  mag. fainter than the WR star and so not a significant contaminant to its near-IR photometry.

Table 1: Near-infrared photometry of HD 36402

Survey	Date	$J$	$H$	$K_s$	$\sigma K_s$
DENIS strip 4963	1996.92	11.63		10.55	0.02
2MASS all-sky	2000.08	11.76	11.62	10.97	0.02
2MASS 6X PSWDB	2000.98	11.73	11.47	10.82	0.02
2MASS 6X PSWDB	2001.09	11.69	11.46	10.73	0.02
IRSF LMC0525-6720A	2002.88	11.80	11.71	11.22	0.01

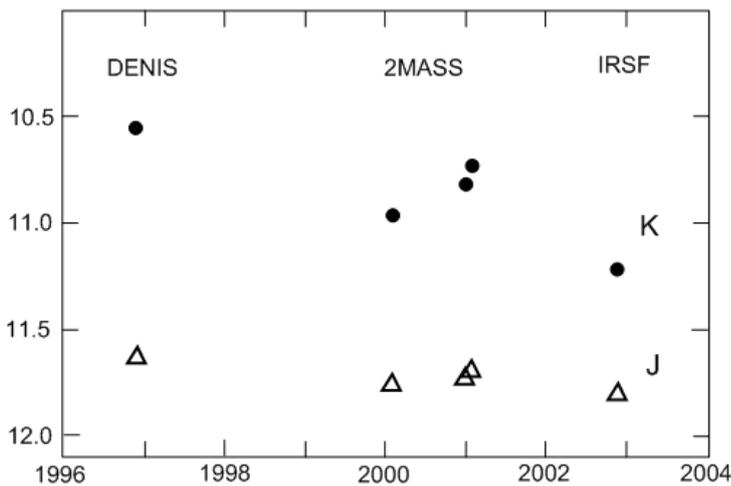


Figure 1:  $J$  ( $\Delta$ ) and  $K_s$  ( $\bullet$ ) magnitudes of HD 36402 from the DENIS, 2MASS and IRSF surveys.

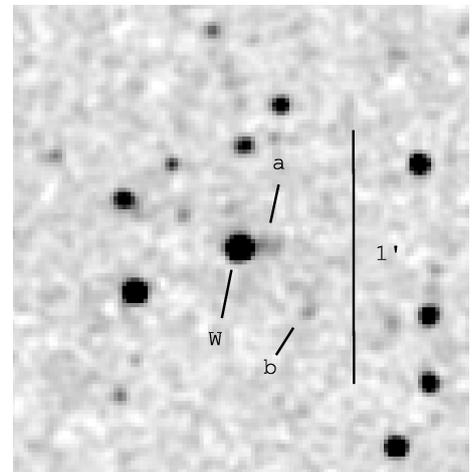


Figure 2: 2MASS  $K_s$ -band image (N top, E left) of the field of HD 36402 (‘W’); see text for ‘a’, ‘b’.

The *SPITZER* SAGE LMC catalogue gives multi-colour photometry, including *SPITZER* IRAC (3.6–8.0- $\mu\text{m}$ ) and MIPS (24- $\mu\text{m}$ ) data, for 17 WC4 stars. Of these, HD 36402 has the most convincing evidence for a Planckian spectrum, peaking near 3.6  $\mu\text{m}$ , similar to those of dust-making Galactic WC stars (e.g. Williams, van der Hucht & Thé 1987, hereafter WHT). The photometry of HD 36402 was de-reddened using  $E_{b-v} = 0.09$  (Smith, Shara & Moffat 1990) and the SED fitted by a simple stellar wind plus isothermal, optically thin, dust shell model following WHT. The dust was assumed to have the emissivity law of amorphous carbon. The fit gave  $T_d \simeq 800$  K and  $M_d \simeq 1.5 \times 10^{-7} M_\odot$ , adopting

a distance of 50 kpc to the LMC. It is illustrated in Fig. 3. The dust temperature is somewhat lower than those ( $\sim 1100$  K) found for persistent dust makers but may result from the sensitivity of  $T_d$  to  $K_s$ -[3.6] and the fact that the  $JHKs$  and IRAC 3.6–8.0- $\mu\text{m}$  data are not contemporaneous.

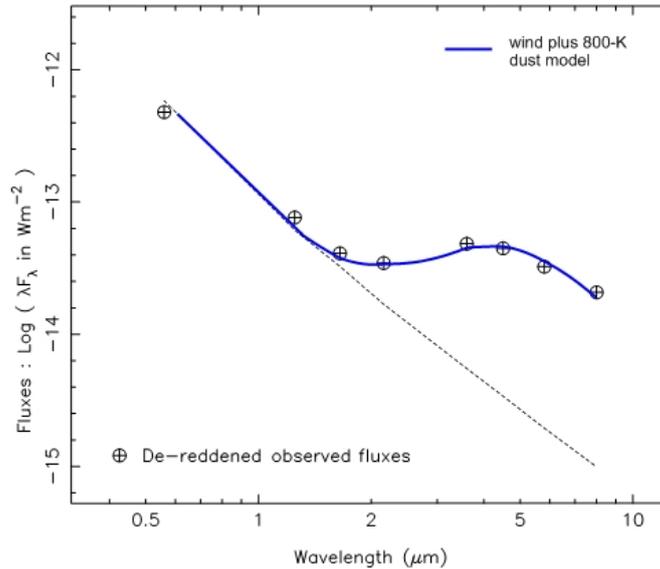


Figure 3: De-reddened optical to 8- $\mu\text{m}$  fluxes of HD 36402 compared with those of a model (solid line) comprising a stellar wind (broken line) fitted to the  $v$  and  $J$  data plus emission from an isothermal dust shell.

Bonanos et al. (2009) tentatively identified HD 36402 with a 70- and 160- $\mu\text{m}$  source, and suggested that its infrared excess might come from its associated ring nebula embedded in N51D (Dopita et al. 1994). The environs of HD 36402 are certainly complex. Chu et al. (2005) discovered two YSOs close to the WR star. One of them, their YSO-2, corresponding to ‘a’ in Fig. 2, is only  $7''$  from the WR star. The SED of YSO-2 formed from *SPITZER* data in Chu et al. and  $JHKs$  magnitudes from 2MASS is compared with that of the WR star in Fig. 4. At 8  $\mu\text{m}$ , YSO-2 is 1.7 mag. fainter than the WR star. At this wavelength, the IRAC beam is smaller than  $2''$  FWHM (Fazio et al. 2004), so we consider YSO-2 well separated from HD 36402 in the IRAC data too. At 8  $\mu\text{m}$ , YSO-1 (‘b’ in Fig. 2) is almost as bright as the WR star (Fig. 4), but is much further ( $22''$ ) away so the IRAC data can define the SED of HD 36402 in the mid-IR without fear of confusion.

At longer wavelengths, YSO-1 is even brighter (Fig. 4 and Chu et al.), and its fluxes at 70 and 160  $\mu\text{m}$  given by Chu et al. are close to those tentatively ascribed to the WR star by Bonanos et al. Given the larger beam sizes ( $18''$  and  $40''$  respectively) at these wavelengths, HD 36402 cannot be resolved from the YSOs and it is better to ascribe the long-wavelength emission to YSO-1 instead of the WR star. Similarly, we do not expect the *IRAS* or *MSX* observations to resolve the WR star from YSO-2.

A more recent observation is the *AKARI* IRC (Ishihara et al. 2010) photometry, which observed HD 36402 between 2006 May and 2007 August in the 9- $\mu\text{m}$  band, giving  $S_{19W} = 6.90$  ( $97.9 \pm 6.8$  mJy). The larger beam ( $5''.5$  at 9  $\mu\text{m}$ ) could include some flux from YSO-2, which is rising in this wavelength region. From the IRAC and MIPS data, we estimate its flux to be 13.5 mJy at 9  $\mu\text{m}$ , while extrapolation of the HD 36402 SED suggests its 9- $\mu\text{m}$  flux would be about 43 mJy (cf. 48 mJy at 8  $\mu\text{m}$ ), three times brighter than YSO-2. Hence, the apparent two-fold brightening of HD 36402 at 9  $\mu\text{m}$  between the IRAC observations in mid-2005 and the IRC observation 1–2 years later cannot be an artefact of confusion with YSO-2 but must result from changes in the WR dust cloud.

### 3 Conclusion: a WR dust maker in the LMC

Evidently, HD 36402 is a dust maker like those in the Galaxy. Moffat et al. (1990) deduced that it is a triple system: a 3-day binary and more distant O supergiant companion. The inner binary separation is probably too small for the O star wind to accelerate to its terminal value, and the colliding wind effects probably arise between it and the third component. The outer orbit deserves study and relation to the pattern of dust formation, which itself requires characterisation from further observations – some of which may already exist.

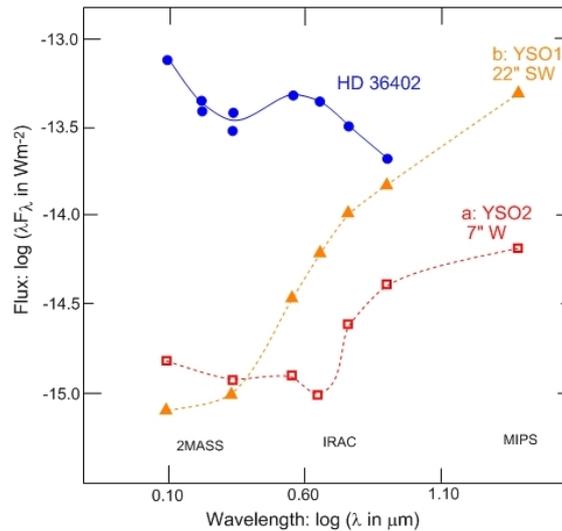


Figure 4: Spectral energy distributions of HD 36402 and the nearby YSOs discovered by Chu et al.

### Acknowledgements

The author is grateful to the Institute for Astronomy for hospitality and continued access to facilities of the Royal Observatory, Edinburgh. This research has made use of the NASA / IPAC Infrared Science Archive, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration; the Vizier database, operated by the CDS, Strasbourg, and the DARTS archive developed and maintained by C-SODA at ISAS/JAXA.

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