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*Letter to the Editor*

# A second dust episode of the Wolf-Rayet system WR 19: another long-period WC+O colliding-wind binary*

**P.M. Veen**[1], **K.A. van der Hucht**[2], **P.M. Williams**[3], **R.M. Catchpole**[4], **M.F.J. Duijsens**[2], **I.S. Glass**[5], **and D.Y.A. Setia Gunawan**[2,6]

[1] Leiden Observatory, P.O. Box 9513, 2300 RA Leiden, The Netherlands (e-mail: veen@strw.leidenuniv.nl)
[2] Space Research Organization Netherlands, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands (e-mail: K.A.van.der.Hucht@sron.nl)
[3] Royal Observatory, Blackford Hill, Edingburgh EH9 3HJ, Scotland, UK (e-mail: pmw@roe.ac.uk)
[4] Royal Greenwich Observatory, Madingley Road, Cambridge CB3 OEZ, UK (e-mail: catchpol@ast.cam.ac.uk)
[5] South African Astronomical Observatory, P.O. Box 9, Observatory 7935, South Africa (e-mail: isg@saao.ac.za)
[6] Kapteyn Astronomical Institute, P.O. Box 800, 9700 AV Groningen, The Netherlands (e-mail: diah@astro.rug.nl)

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**Abstract.** We present observations of WR 19 showing an infrared excess due to newly created dust similar to an event observed in 1988. We suggest that these episodes of dust-formation are periodic ($P \sim 10$yr) and related to the binary nature of the object, comparable to the colliding-wind binary WR 140. In support of this thesis we identified absorption lines from a companion of spectral type O9.5-9.7. We propose monitoring the object to determine orbital parameters, non-thermal radio emission and the accurate shape of the infrared light-curve.

**Key words:** stars: Wolf-Rayet – stars: individual: WR 19, HD 96620 – binaries: general – infrared: stars

## 1. Introduction

For many late-type carbon-rich Wolf-Rayet (WCL) stars the infrared free-free wind emission is dominated by circumstellar heated dust. In a survey of galactic WC8–9 stars Williams, van der Hucht & Thé (1987) modelled the IR excesses as emission from dust shells. These dust shells are being replenished continuously as the dust is carried away by the stellar wind. Since the dust around WR stars was first discovered by Allen, Harvey & Swings (1972), the question of how to form the dust in such a hostile environment is pressing. The temperature in a homogeneous, smooth stellar wind is much too high to expect dust particles to condense. Recently, Cherchneff (1997) described this problem in chemical detail. Apparently, inhomogeneity, maybe post-shock super-cooling as inferred for R Coronae Borealis stars (Woitke et al. 1996ab) and possible shielding overcome this problem. Indeed, a link between the WC and RCrB stars is provided by observations of some dust-making WCL stars (Crowther 1997; Veen et al. 1998).

The phenomenon of *episodic* dust-formation near WR stars is even more intriguing. A sample of seven WC stars has shown at least one episodic infrared excess due to temporary dust formation (Williams 1997). The prototype, WR 140 (WC7+O4-5), has shown three dust-formation episodes, with a period of $P = 7.94$ yr. These occur near periastron passage, when the stellar winds collide most strongly (Williams et al. 1990a). Several other members of the group showed evidence confirming the binary origin of the phenomenon.

Smith (1968) was first to recognize LS 3, listed as WR 19 by van der Hucht et al. (1981), as a WR star. In their 1988 IR observations, Williams et al. (1990b) happened to catch the fading of a dust *shell*. We would prefer to indicate the dust as a *cloud*, since the geometry is not well determined (see also modelling of WR 125 by Williams et al. 1994). Now, ten years later, we observed a second IR outburst (Sect. 2). In Sect. 3 we present spectral lines from a companion. Depending on the classification scheme the WR star is either of spectral type WC4 (Smith, Shara & Moffat 1990a) or WC5 (Crowther, De Marco & Barlow 1998). Either way, it is the only star, so far, earlier than WC7 showing dust formation.

## 2. A new dust episode

Table 1 lists the near-infrared photometry since the end of the first dust-formation episode (for the log of earlier observations we refer to Wiliams et al. 1990b). The measurements from 1991 to 1993 were obtained at the 1.0, 2.2 and 3.6 m telescopes at ESO using classical IR-photometers. Later we used both the 2-D IRAC1 and IRAC2 cameras attached to the ESO 2.2 m telescope. The $JHK$ images were dithered around the array; chopping and nodding was applied to the 3.8$\mu$m $L'$ and $M$ images. The observations from SAAO were performed by two of us

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*Send offprint requests to*: P.M. Veen

[*] Based on observations collected at the European Southern Observatory (ESO), La Silla, Chile and the South African Astronomical Observatory (SAAO)

**Table 1.** Near infrared photometry of WR 19. A colon indicates an uncertain value. The last column lists the observatory (E = ESO and S = SAAO) and instrument (P = photometer, I1 = IRAC1, I2 = IRAC2)

| Date | $J$ | $H$ | $K$ | $L'$ | $L$ | $M$ | O |
|---|---|---|---|---|---|---|---|
| 1991.16 | 9.80 | 9.16 | 8.56 | 8.2 | | | EP |
| 1991.25 | 9.70 | 9.09 | 8.49 | 8.16 | | 7.9 | EP |
| 1992.06 | 9.77 | 9.16 | 8.55 | 8.26 | | 7.8 | EP |
| 1993.17 | 9.79 | 9.16 | 8.55 | 8.19 | | | EP |
| 1993.34 | 9.76 | 9.16 | 8.55 | 8.16 | | 7.6 | EP |
| 1995.28 | 9.93 | 9.11 | 8.49 | | | | EI1 |
| 1995.43 | 9.80 | 9.14 | 8.54 | | 8.30 | | SP |
| 1995.46 | 9.76 | 9.11 | 8.55 | | 8.31 | | SP |
| 1996.30 | 9.74 | 9.15 | 8.52 | | | | EI2 |
| 1996.31 | | | | 8.25: | | | EI1 |
| 1998.21 | 9.83 | 9.27 | 8.26 | 6.22 | | 5.5 | EI1 |
| 1998.37 | 9.75 | 9.07 | 8.27 | 6.47 | 6.83 | 5.7 | SP |

**Table 2.** Newly determined IR photometry of HD 96620. For $UBVRI$ magnitudes see Wizinowich & Garrison (1982).

| standard star | $J$ | $H$ | $K$ |
|---|---|---|---|
| HD 96620 (A0V) | 7.31 | 7.31 | 7.30 |

(RMC and ISG) using the IR photometer at the 1.9 m Radcliffe telescope and included the $L$ band (3.6$\mu$m). All observations using a photometer were done with small aperture ($d < 15''$) so as to prevent any light contribution from the nearby star at $\sim 11''$. The observations were obtained in the framework of the long-term infrared WR monitoring project maintained by two of us (KAvdH & PMW).

Last March, during the final run of the IRAC-1 instrument, we observed a second brightening of about $2^{\rm m}$ in $L'$, even more in $M$, and $0\overset{\rm m}{.}26$ in K of WR 19. Those $JHK$ observations were obtained using HD 96620 (A0V) as a standard star. However, it appeared that the magnitudes as presented by van der Bliek et al. (1996) and Catalano & Leone (1994) represent HD 96**2**20. We used the "real" HD 96620 during three nights and determined the mean $JHK$ magnitudes of this calibrator (Table 2). The subsequent observations were obtained at SAAO with HR 4023 as standard star and confirmed this second episode.

The light curves in $K$ and $L'$ are shown in Fig. 1. The brightness in $L'$ faded after April 1988 in about two years at a rate of $1\overset{\rm m}{.}2$ yr$^{-1}$ and our observations of the latest eruption suggest fading at a comparable rate. The fading depends on the cooling of the dust as it flows outward with the wind velocity. Since the fading of WR 140 ($0\overset{\rm m}{.}8$ yr$^{-1}$, Williams et al. 1990a) is slower with a $v_\infty = 2900$ km s$^{-1}$ (Eenens & Williams 1994), we estimate the terminal velocity of WR 19 to be $v_\infty \geq 3000$ km s$^{-1}$. There is no other wind velocity measure available for WR 19, while Eenens & Williams (1994) find for the WC4 star WR 143 a terminal wind velocity of $v_\infty = 2750$ km s$^{-1}$.

Like ten years ago, we may have just missed the IR maximum again. To determine the recurrence time and thereby the

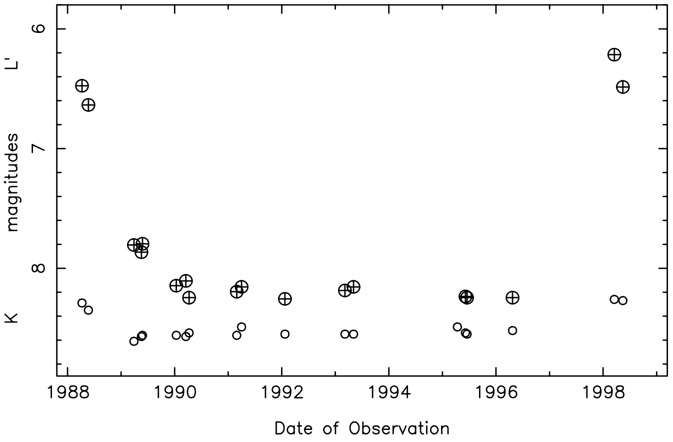

**Fig. 1.** $L'(\oplus)$ and $K(\circ)$ photometry of WR 19, $H$ is barely affected and $J$ not at all. This demonstrates that the variability, indicating the occurence of dust formation, is observable primarily beyond $2.2\mu$m, as confirmed by the $M$ band (see Table 1).

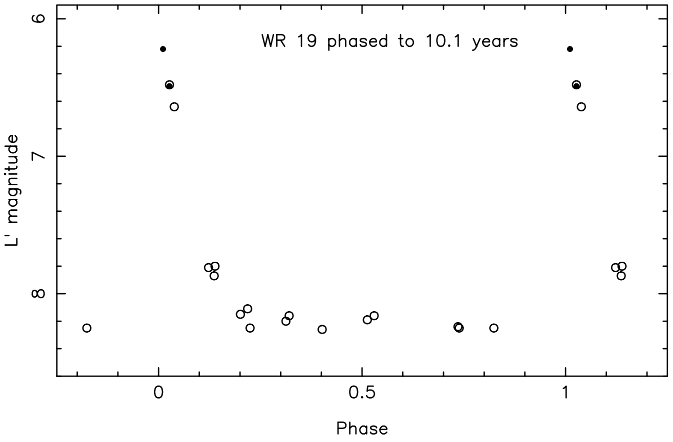

**Fig. 2.** The observed $L'$ magnitudes of WR 19 are phased with a period of 10.1 yr. For the lightcurves in quiescence, we estimated $L'$ from the 1995 $L$ magnitudes ($L - L' = 0.06$).

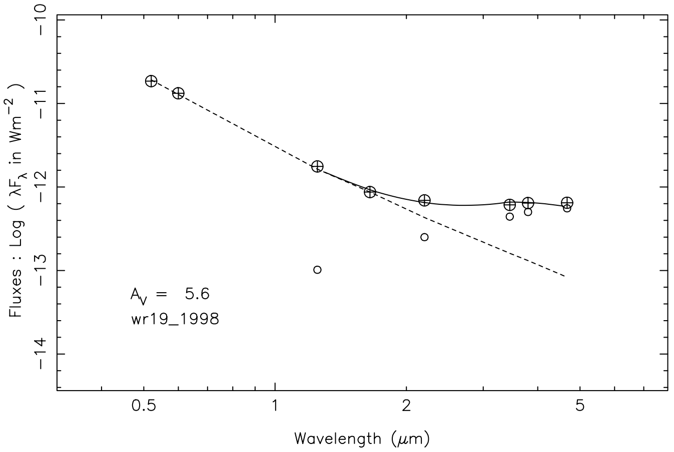

**Fig. 3.** Comparison of spectral energy distributions from de-reddened observed magnitudes ($\oplus$), stellar wind from the pre-eruption data (broken line), the differences between the 1998 May magnitudes and the wind (o) and model dust cloud + wind (solid line).

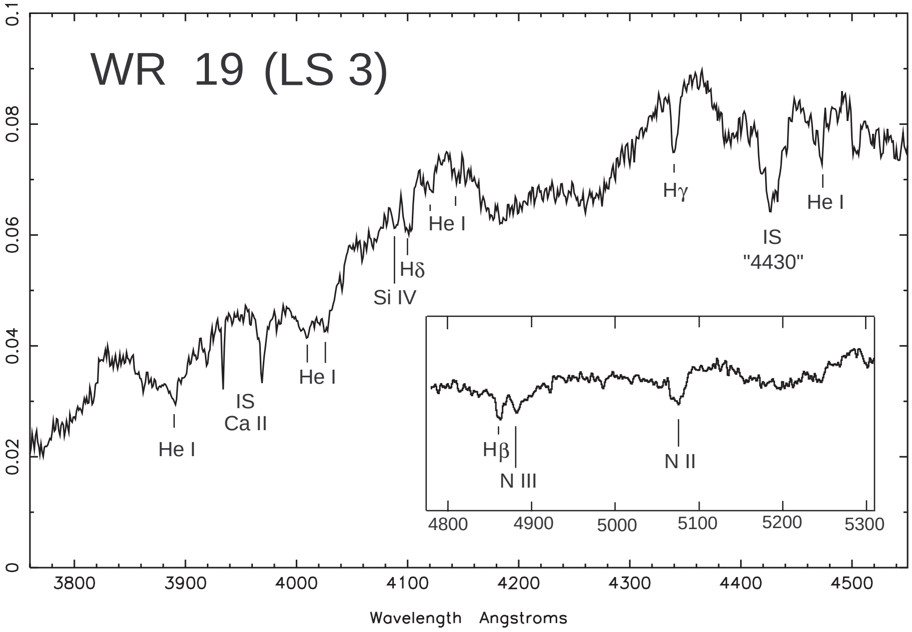

**Fig. 4.** Uncalibrated spectra of WR 19 for which identified absorption lines are listed below (between brackets multiplet numbers from Moore 1959, 1993):

| $\lambda_{\rm obs}$ | $\lambda_{\rm id}$ (Å) |
|---|---|
| 3770 | 3770.4 N III (11), 3770.6 H11? |
| 3862 | 3860.6 S III (5), 3862.6 Si II |
| 3888–91 | 3889 He I, 3889 H$\zeta$ |
| 3920 | 3919.0, 3920.7 C II (4) |
| 3934 | 3933.7 Ca IIH IS |
| 3965 | 3964 He I in wing Ca II |
| 3969 | 3968.5 Ca IIK IS |
| 3970 | 3970.1 H$\epsilon$ in red wing Ca II |
| 4009 | 4009 He I |
| 4026 | 4026 He I, He II? |
| 4069 | 4068-72 C III(16) |
| 4089 | 4089 Si IV(1) |
| 4097–04 | 4101 H$\delta$, 4097,4103 N III (1) |
| 4116–21 | 4116 Si IV (1) 4121 He I |
| 4144 | 4144 He I |
| 4340 | 4340 H$\gamma$ |
| 4387 | 4388 He I in broad feature |
| 4428 | 4428 Diffuse Interstellar Band |
| 4471 | 4471.5 He I |
| 4862 | 4861 H$\beta$, 4859-67 N III(9) |
| 4882 | 4882-4 N III(9) |
| 5074 | 5074 N II (10) |

possible binary period, we folded the observations in $L'$. The resulting light-curve is shown in Fig. 2 with $P = 10.1$ yr.

Fig, 3 presents the energy distribution of WR 19 based on the May 1998 infrared data and the $vr$ magnitudes given by Smith, Shara & Moffat (1990b). The luminosity of the dust is only 0.2% of the total stellar energy output. Therefore, the periodic dust is optically thin in the ultraviolet, where it absorbs the same fraction. By applying the model as described by Williams, van der Hucht & Thé (1987) (see also the case of WR 125 Williams et al. 1992, 1994), the temperature of the amorphous dust grains is determined to be 757 K. The fit results in a dust-mass of 1.2 $10^{-8}$ $M_\odot$, assuming a distance of 2.7 kpc (see Sect. 3).

## 3. Optical spectroscopy

Already before this second dust episode of WR 19, the binary-induced dust formation of WR 140 inspired a search for spectral lines of companions of dust-producing WR stars (Williams & van der Hucht 1996). Observations were obtained at the 1.9 m telescope at SAAO in May–June 1995. The spectra had a resolution of 1.2 Å and were recorded with the intensified Reticon (RPCS) detector system. The grating was set as to place the strong $\lambda$4650 Å emission feature at the end of the array, where the sensitivity was much lower, to avoid overloading the intensifier and get the best signal-to-noise ratio in the continuum to identify possible lines from a companion.

Shown in Fig. 4 is a blue spectrum of WR 19 composed from observations in three nights and, as an insert, a green spectrum. The undulations in the spectrum are broad C IV and He II emission lines; for a full, lower resolution spectrum, see Torres & Massey (1987). It is evident that the interstellar Ca II H and Ca II K lines and diffuse 4430Å band are conspicuous for this heavily reddened star. Also conspicuous are absorption lines at the positions of the H$\beta$, H$\gamma$ and H$\delta$ Balmer lines. These give us confidence in identifying H$\epsilon$ in the red wing of the Ca II H line and H$\zeta$ as a contributor to the 3890 Å absorption feature. The He I spectrum is well represented, but there is some uncertainty about the presence of He II. Identifications of the absorption lines are given in the figure caption.

The absorption lines are much narrower than the emission lines and are unlikely to be formed in the wind of the early-type WC star, indicating formation in a companion. From the presence of Si IV and, possibly, He II, the companion appears to have a spectral type in the range O9 – B1, which we narrow to O9.5 – O9.7 on account of the weakness of the He II lines. The possible presence of multiplet no. 1 lines of N III adjacent to H$\delta$ invites a comparison with the ON9.7Iab star HD 123008 (Walborn & Fitzpatrick 1990), suggesting N-enhancement of the companion by the Wolf-Rayet star during its earlier WN phase.

The equivalent widths of the $\lambda 4650$Å blend (not shown) and H$\gamma$ indicate (WC$-$O) $\approx 0\overset{\mathrm{m}}{.}2$, less than the $\Delta \mathrm{m}_v = 0\overset{\mathrm{m}}{.}8$ derived by Smith, Shara & Moffat (1990a). In part, this difference may be due to the O star being bluer than the WC star. If the absolute magnitude of the WC4 star is $-3\overset{\mathrm{m}}{.}0$ (van der Hucht et al. 1988), that of the O9.5–9.7 star would be $\sim\ -3\overset{\mathrm{m}}{.}2$. This is a low luminosity for a late-type O star (cf. Underhill & Doazan 1982), suggesting that the companion is on the main sequence.

The distance to the object was determined as 2.34 kpc by van der Hucht et al. (1988), assuming the star to be single. Taking into account the presence of the O-type companion, we estimate the absolute magnitude of the system as $M_v = -3\overset{\mathrm{m}}{.}9$, implying a distance of 2.7 kpc. This result agrees better with the range (2.93–3.90 kpc) derived by Smith, Shara & Moffat (1990b) from their line-flux method, which is independent of a companion. This larger distance explains why Leitherer, Chapman & Koribalski (1997) found only upper limits for the radio fluxes at 3 and 6 cm. We scale their upper limit to the mass-loss rate to $\dot{M} < 10^{-4}\mathrm{M}_\odot\mathrm{yr}^{-1}$ using the $v_\infty$ as estimated in Sect. 2.

## 4. Discussion

Ten years after we observed (the tail of) an episodic IR excess of the early-type WC star WR 19, we observed a new dust-formation episode. In addition, we found spectral absorption lines from a probable companion, confirming results by Niemela & de Castro (unpublished poster at Brussels Workshop 1994). We classified the companion as O9.5-9.7 and $0\overset{\mathrm{m}}{.}2$ brighter. Bearing in mind the model for the archetype periodic dust producer WR 140 (Williams et al. 1990), we conclude that WR 19 is most probably an eccentric WCE+O9.5–9.7 binary, with a period of 10 yr, where during periastron passage somewhere in the colliding wind region heated amorphous dust grains are being produced. Note that for WR 19 the dust IR excess is visible for only 30% of the time (in $L'$; only $\sim$10% in $K$), so that there may be more undiscovered sources of this kind.

In the coming decade infrared monitoring should be continued to confirm the suggested periodicity and define the next rise to a maximum accurately. Furthermore, high signal-to-noise spectra are needed to measure radial-velocity variation and obtain orbital parameters. However, depending on inclination angle, radial-velocity variations may be small, while an eccentric system can still show an IR outburst near periastron. Future observations should address also the radio-emission, to look for non-thermal radiation originating in the wind-wind collision region.

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