DUST FORMATION IN, AND THE STRUCTURE OF WOLF-RAYET STELLAR WINDS

K.A. van der Hucht, SRON Space Research Utrecht
P.M. Williams, Royal Observatory Edinburgh
P.S. Thé, Astronomical Institute "Anton Pannekoek"

ABSTRACT. An infrared photometric survey of all 40 known galactic WC7-10 stars shows that around most of them hot amorphous carbon is condensing continuously at distances of about 8500 $R_\odot$, well within the ionized stellar winds around these stars. Typical dust production rates are of the order of 10^{-7} $M_\odot$/yr.

1. INTRODUCTION

Evolved massive stars in their Wolf-Rayet phase are a particularly appropriate subject for this Symposium on Circumstellar Matter, because this is all we can see of the WR stars! UV and optical continua arise in the lower regions of the dense steller winds, IR and radio continua are formed in the outer regions, while X-rays are apparently observed where winds of binaries collide.

IR photometric observations of WR stars since the early 1970's have shown two kinds of IR excesses: free-free radiation caused by dense stellar winds ($\dot{M}_{WN} \approx 1\text{-}12 \times 10^{-5}$ $M_\odot$/yr, $\dot{M}_{WC} \approx 2.5\text{-}15 \times 10^{-5}$ $M_\odot$/yr, van der Hucht et al., 1986) and thermal emission by hot ($T \approx 1000$ K) circumstellar dust. This dust radiation is observed from the latest subtypes of the WC sequence only and known for some cases since the work of Allen et al. (1972). In order to study origin, composition and mass of this hot circumstellar dust around WR stars, we carried out an IR ($JHKLMN_1N_2N_3Q_0$) photometric survey at ESO and UKIRT since 1982 of all the 40 known galactic WC7-10 stars (van der Hucht et al., 1981, and updates), supplemented with IRAS data.

2. WC STAR DUST

We find hot dust around 5 of the 10 known WC8 stars, around 15 of the 17 known WC9 stars and around the one and only known WC10 star. In addition, episodic presence of hot dust is found around 2 of the 12 known WC7 stars: the WC7+a star WR137 = HD192641 (Williams et al., 1985) and the WC7+O4 system WR140 = HD193793, recently recognized as a spectroscopic binary (P = 7.9 yr, Williams et al., 1987b; this Symposium). Typical energy distributions can be found in van der Hucht et al. (1985). Heated dust emission from two very late WN stars was

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reported by van der Hucht et al. (1984): the WN10 star WR122 and the suspected WN11 star LSS4005. High resolution spectroscopy of the latter shows that it is better classified as Ofpe/WN9 or B[e] (van der Hucht et al., 1987).

The hot dust shells around WC stars can be characterized by the following aspects: (a) the IR energy distributions are featureless, except for the interstellar 9.7μ absorption feature, for which we find a relation $A_V/\tau_{9.7}$ = 19.8±1.7; (b) the dust shells are optically thin in most cases; and (c) the dust is being formed continuously at a fixed distance from the star *within the ionized stellar wind*. The fact that the IR energy distributions are featureless rules out dielectric grains, and the $1/\lambda$ emissivity found for the episodic dust producer WR140 (Williams et al., 1987) points to amorphous carbon. Table 1 gives some typical WC dust shell parameters. The dust production by the 10 late WC stars within 3 kpc from the Sun amounts to $6\text{x}10^{-7}$ $M_\odot$/yr, or, projected on the galactic plane, $1.4\text{x}10^{18}$ g/kpc^2.s.

Van der Hucht et al. (1986) argue that WC7-10 stars have mass loss rates 2 to 3 times greater than the WC4-6 stars and that, because of their lower terminal wind velocities, WC7-10 stars consequently have 4 to 7 times larger stellar wind densities. The late WC subtypes apparently provide the proper circumstances for dust to form: at those radii where the radiation temperature for the dust grains is about 1000 to 1500 K, the gas density in the ionized carbon-rich (25 % by number, Prantzos et al., 1986) WC stellar wind is sufficiently high to allow dust formation. WC stars hotter than WC7 apparently have winds of insufficient density at radii where dust could survive in the stellar radiation fields. This gas density limit above which dust can form is $4.3\text{x}10^{-18}$ g/cm^3, i.e. $n = 3.4\text{x}10^5$ cm^{-3}.

Table 1. WC dust shell parameters

average values	WC8 (5)	WC9 (15)	WC10 (1)
L_{IR}/L_*	.02	.10	.59
T (K)	1550	1350	1330
R ($R_\odot$)	7300	8900	6600
ρ (g/cm^3)	5.8E-21	3.4E-20	5.7E-18
ρ/ρ_{gas}	0.0008	0.008	
M_d ($M_\odot$)	3.1E-8	2.9E-6	1.0E-5
$\dot{M}$ ($M_\odot$/yr)	5.4E-8	3.7E-7	2.5E-5

Particulars of this study are published in Astronomy and Astrophysics (Williams et al., 1987a).

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