CIRCUMSTELLAR DUST SHELLS AROUND WN10-11 and WC8-10 STARS: AN EVOLUTIONARY SEQUENCE?*

K.A. van der Hucht
Space Research Laboratory, Utrecht, The Netherlands
P.M. Williams
The Royal Observatory Edinburgh, UK and
United Kingdom Infrared Telescope Unit, Hilo, Hawaii, USA
P.S. Thé
Astronomical Institute 'Anton Pannekoek', Amsterdam,
The Netherlands

ABSTRACT

In a recent IR photometric survey of late-type WC and WN stars, it was discovered that not only most WC8-10 stars have circumstellar dust shells, but that two extreme late-type WN stars also have strong IR excesses from circumstellar dust. The latter shells appear to have significantly different density distributions. In this paper the possibility of an evolutionary sequence is suggested.

INTRODUCTION

Late-type WC stars are known to differ from other Wolf-Rayet subtypes in the sense that they exhibit strong thermal infrared excesses emitted by heated dust particles. The circumstellar (CS) dust shell radii are typically of the order of 100 AU (Allen et al., 1981). At similar radii FeIII UV absorption lines were observed (Van der Hucht et al., 1982), indicating gas in the shells as well. Since the dust shells are located well within the stellar wind spheres, they must be continuously replenished.

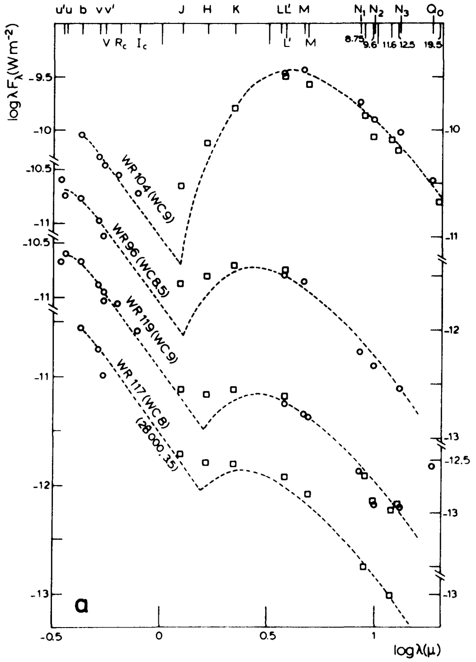
In order to investigate individual dust shells around different WR stars, the authors conducted an IR photometric survey of most of the 24 WC8-9 stars in the 6th WR catalog (Van der Hucht et al., 1981, henceforth HCLS). Recently, some of these stars have been reclassified by Massey and Conti (1983) to extreme late-type WC subclasses. They also classified the faint star WR122 as WN10, which represents a natural extrapolation of the WN sequence. Following this trend, Lundström and Stenholm (1983a) classified the faint star LSS4005 (Stephenson and Sanduleak, 1971) as WN11. However, on the basis of their line identification study, they argue that perhaps both WR122 and LSS4005 are possible pre-WN stars. We observed also these two objects in the IR.

OBSERVATIONS

The observations were conducted in June 1982 and March 1983 with the ESO 1 m and 3.6 m telescopes (J-Q) and in June 1982 and July 1983 with UKIRT (J-[19.5]).

A. Maeder and A. Renzini (eds.), Observational Tests of the Stellar Evolution Theory, 273–277.

https://doi.org/10.1017/S0074180900031016 Published online by Cambridge University Press



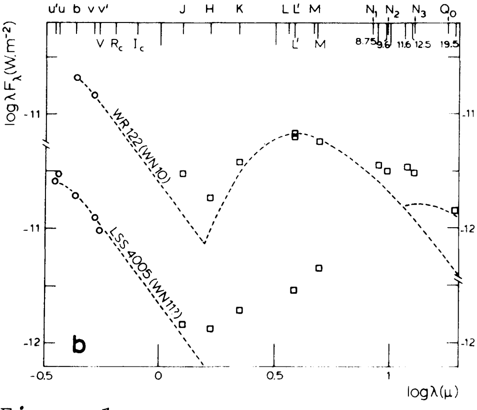


Figure 1a.
Dereddened energy distributions of WC8-9 stars. O : observed from ESO. □ : observed from UKIRT. Optical data points fit with model atmosphere flux from Kurucz (1979).
Figure 1b.
Dereddened energy distributions of WN10-11 stars. Same format as Fig. 1a.

Thermal emission by heated dust was found for most of the objects, even among some of the WC8 stars. A detailed account of all the observational results will be published elsewhere (Williams, van der Hucht, and Thé, in preparation).

The observations are corrected for extinction using Van de Hulst curve no. 15. Visual extinction values are based on $(b-v)_o = -0.42$ for all WC8-10 stars, $(b-v)_o = -0.33$ for the WN10-11 stars, and narrow-band bv photometry from HCLS, with improvements by Lundström and Stenholm (1983b). Additional data points are from Lundström and Stenholm (1979) and VRI fluxes are from one of us (PST). Extinction free energy distributions for a sample of our program stars are presented in Figure 1a,b.

THE 9.7 μm SILICATE ABSORPTION FEATURE

With the available narrow-band filters around 9.7 μm we observed silicate absorption in many of our program stars. We define a silicate index S.I. as:

$$\text{S.I. (ESO filters)} = N_2 - 0.5\,N_1 - 0.5\,N_3 \quad \text{and}$$
$$\text{S.I. (UKIRT filters)} = [9.6] - 0.5[8.7] - 0.5[12.5].$$

In Figure 2 we present A_V vs. S.I.. Recently Roche and Aitken (1983) observed a few late-type WC stars. From their 8-13 μm grating spectra they show that the silicate absorption feature at 9.7 μm is correlated with the visual extinction by $A_V = 18.5\ \tau_{9.7}$. With our definition of S.I. this means $A_V = 27(\text{S.I.})$. This line is marked in Figure 2. One star, having indices measured on both systems, WR119, shows more silicate absorption than expected. This extra silicate absorption can not come from the CS shell responsible for the general emission (otherwise we would see a silicate emission feature), but could originate in a much cooler shell, at least 10.000 times further away from the WC star than the carbon shell. The star with the most negative index, WR121, may also be variable and deserves further study.

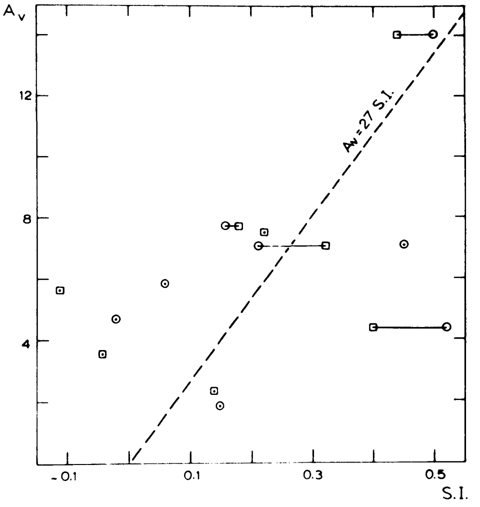


Figure 2.

Visual extinction A_v vs. silicate index S.I. for WC8-10 stars.
○ : observed from ESO;
□ : observed from UKIRT.
Connected data points refer to the same star.

CIRCUMSTELLAR DUST SHELLS

The energy distributions in Figure 1a are close to black bodies having temperatures ranging from 950 K for WR104 to 1500 K for WR117. We do not believe the shells to be optically thick, because we observe much less IR flux than this predicts. The smoothness of the energy distributions is compatible with carbon as the grain material. We have constructed model shells wherein the grain density falls of as $\rho \sim r^{-2}$ from an inner radius determined in the fitting process. The dust temperatures are given by thermal equilibrium on the grains. Our models fit the WC8-9 star observations better than the black bodies, and yield dust shell masses ranging from 5×10^{-9} $M_\odot$ for WR117 to 10^{-6} $M_\odot$ for WR104, and shell inner radii ranging from 1300 R_* for WR119 to 2200 R_* for WR104. Attempts to fit shells having density distributions differing from $\rho \sim r^{-2}$ were not successful, confirming that the grains are replenished in the stellar wind.

The energy distributions of the WN10-11 stars WR122 and LSS4005 are shown in Figure 1b. It is obvious that also for these stars the IR excess is caused by thermal emission by heated dust. That of WR122 might even be explained in terms of two CS dust shells, one comparable to those around the WC8-10 stars and the second much cooler ($T_C \approx 280$ K), more distant and more massive. Alternatively, the observations are compatible with a CS shell wherein the density is constant or increases slightly with radius. This is obviously quite different from the late-type WC dust envelopes. The JHKLM data for LSS4005 are not sufficient for modelling, but they do show that the star is surrounded by an substantial amount of heated dust. It is remarkable, that, except for the possible multiplicity of their dust shells, these two late-type WN stars have a characteristic in common with the late-type WC stars, namely CS dust. Thus, the low-ionization end of both the WN sequence and the WC sequence are characterized by CS dust shells.

HYPOTHESIS

The observations presented above show that not just WC8-10 stars have CS dust, but also the recently classified WN10-11 stars. Dust formation is likely to occur in regions of relatively high density, perhaps caused by a drop in the stellar wind velocity (van der Hucht et al., 1982). All WN and WC stars appear to have, at least within a factor 2, the same high value for their mass loss rates: $2.8 \times 10^{-5}\ M_\odot$ /yr (Abbott, 1982). We expect WC stars to evolve from WN stars. Let us assume that stellar wind parameters for low-ionization WC stars are not different from those of low-ionization WN stars. Before these stars were in the WR phase, e.g. during their post-RSG phase (Maeder, 1982), their stellar wind parameters and mass loss rate may have been quite different. Notably the mass loss rate will have been smaller, initially. Wind parameter variations during the pre-WN phase, could very well have caused high density regions and subsequent CS dust formation, pertaining from the WN phase into the WC phase. On the basis of this argumentation we would like to hypothesize that WC8-10 stars with CS dust have evolved from WN10-11 stars like WR122 and LSS4005. A supporting factor is, that their galactocentric distances (5.9 and 3.5 kpc respectively Hidayat et al., 1984) are within the sphere where the late-type WC stars are found ($r \lesssim 9$ kpc, viz., van der Hucht, 1982, Fig. 3). Because of their small number the WN10-11 lifetime may be about 10x shorter than the WC8-10 lifetime.

ACKNOWLEDGEMENT

We would like to thank Dr. Chris Impey for timely observations of LSS4005, and Pieter Mulder (SRL) for conducting part of the ESO observations.

LITERATURE

Abbott, D.C.: 1982, Astrophys. J. 263, 723.
Allen, D.A., Barton, J.R., and Wallace, P.T.: 1981, Monthly Notices Roy. Astron. Soc. 196, 797.
Hidayat, B., van der Hucht, K.A., Supelli, K.R., and Admiranto, A.G.: 1984, to be submitted to Astron. Astrophys.
van der Hucht, K.A.: 1982, in: S. D'Odorico, D. Baade and K. Kjär (eds), The Most Massive Stars, Proc. ESO Workshop, Garching, 23-25 Nov. 1981, p. 157.
van der Hucht, K.A., Conti, P.S., Lundström, I., and Stenholm, B.: 1981, Space Science Reviews 28, 227.
van der Hucht, K.A., Conti, P.S., and Willis, A.J.: 1982, in: C. de Loore & A.J. Willis (eds), Wolf-Rayet Stars, Observations, Physics, Evolution, Proc. IAU Symp. No. 99 (Dordrecht, Reidel), p. 277.
Kurucz, R.L.: 1979, Astrophys. J. Suppl. 40, 1.
Lundström, I., and Stenholm, B.: 1979, Astron. Astrophys. Suppl. 35, 303.
Lundström, I., and Stenholm, B.: 1983a, in: Proc. Nordic Astronomical Meeting, Oslo, August 15-17, 1983.
Lundström, I., and Stenholm, B.: 1983b, in preparation.
Maeder, A.: 1982, Astron. Astrophys. 105, 149.

Massey, P., and Conti, P.S.: 1983, Publ. Astron. Soc. Pacific 95, 440.
Roche, P.F., and Aitken, D.: 1983, Monthly Notices Roy. Astron. Soc., in press.
Stephenson, C.B., and Sanduleak, N.: 1971, Publ. Warner and Swasey Observatory 1, No. 1.

* Based on observations collected at the European Southern Observatory (La Silla, Chile) and at the United Kingdom Infrared Telescope (Mauna Kea, Hawaii, USA).

DISCUSSION

de Loore: Are these circumstellar dust shells also observed around Of-stars? The presence or absence could be an important clue for the investigation of the mass loss mechanism in Wolf-Rayet stars.

van der Hucht: To my knowledge nothing about CS dust shells around Of-stars has been published. Maybe the search for this has not been deep enough.

https://doi.org/10.1017/S0074180900031016 Published online by Cambridge University Press