Four Decades of Research on Massive Stars
ASP Conference Series, Vol. 465
Laurent Drissen, Carmelle Robert, Nicole St-Louis, and Anthony F. J. Moffat, eds.

Stellar Parameters of Galactic WC Stars

Andreas Sander and Wolf-Rainer Hamann

Institut für Physik und Astrophysik, Universität Potsdam, Karl-Liebknecht-Str. 24/25, 14476 Potsdam, Germany

Abstract. Since the last large sample of Galactic WC stars had been analyzed in the middle of the 1990s, significant improvements have been achieved in the simulation of stellar-wind spectra. We have (partly re-) analyzed all available Galactic WC stars with the current generation of stellar atmosphere models computed with the Potsdam Wolf-Rayet (PoWR) code. In contrast to previous results, the obtained stellar parameters now show a close correlation with the WC subtype. The stellar temperatures form a sequence from 45 kK (WC9 subtype) to about 120 kK (WC4). For those stars with known distance, we also derived luminosities using flux-calibrated spectra and photometry.

1. Introduction

Wolf-Rayet (WR) stars show spectra that are dominated by broad emission lines. Depending on the presence of nitrogen or carbon emission lines, one can distinguish two major subclasses, the so-called WN stars, showing nitrogen lines, and the WC stars, dominated by the lines of carbon and oxygen. In addition, all WR stars display helium emission lines. While some WN stars also contain a certain amount of hydrogen, WC stars never show hydrogen in their spectra. The broad WR emission lines indicate strong stellar winds and high mass-loss rates. We analyzed a sample of in total 56 WR stars with the Potsdam Wolf-Rayet (PoWR) model atmosphere code, comprising 48 WC, 6 WN/WC and 2 WO stars. For comparison, we included a few known binary systems to find out how the parameters are biased if their composite nature is neglected.

2. WC Star PoWR Models

Although the emission-line spectra of stellar winds are affected by several parameters, Schmutz, Hamann, & Wessolowski (1989) found that their appearance is actually very similar if they agree in their chemical composition, the stellar temperature T_*, and in a certain combination of radius $R_\star$, terminal wind velocity υ_∞, mass-loss rate $\dot{M}$, and clumping contrast D. To reflect this scaling invariance, they introduced the so-called "transformed radius":

$$R_\mathrm{t} = R_* \left[\frac{\upsilon_\infty}{2500\,\mathrm{km\,s^{-1}}} \middle/ \frac{\dot{M}\,\sqrt{D}}{10^{-4}\,\mathrm{M_\odot yr^{-1}}} \right]^{\frac{2}{3}} . \tag{1}$$

The name is in fact misleading. It would be more suggestive to consider R_t^{-3}, which might be called a “normalized emission measure”. R_t^{-3} is proportional to the volume integral of the density squared, divided by the stellar surface. It therefore scales with the emission from recombination lines normalized to the continuum. Therefore different combinations of R_*, υ_∞, and $\dot{M}$ result in approximately the same normalized WR emission-line strengths as long as R_t is kept constant.

To analyze a larger sample of stars in a systematic way, we calculated grids of PoWR models in the log T_*-log R_t plane as WR model spectra are most sensitive to changes in T_* and R_t. The other parameters, namely the chemical composition and the terminal wind velocity, are kept constant within a grid of models. Our standard WC model grid uses a chemical composition with mass fractions of 45% helium, 40% carbon, 5% oxygen, and 0.16% iron group elements. This turned out to be adequate for reproducing the overall spectral appearance of all WC stars excluding WN/WC transition types and WO stars. For the latter an enhanced oxygen abundance (30%) is needed while the helium mass fraction is reduced to 30%. Carbon and iron fractions are the same as for WC.

Note that the current PoWR grid models are not hydrodynamically consistent. Instead, the stellar mass-loss rate is implied by specifying R_t in Equation (1). The luminosity is obtained from fitting the calibrated flux distribution. For stars without a known distance from cluster membership, we employed a subtype magnitude calibration. The terminal velocities are inferred from the line widths (Prinja, Barlow, & Howarth 1990; Niedzielski & Skorzynski 2002).

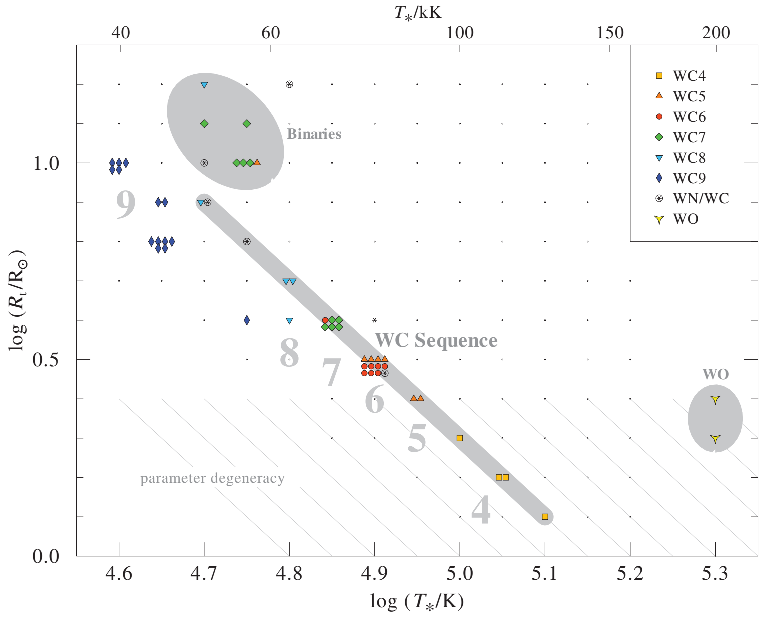

Figure 1. Results of the WC analyses in the log T_*-log R_t plane. The WC4 to WC9 subtypes form a clear sequence while binary systems that have been treated as single stars appear in a different area. The two WO2 stars WR 102 and WR 142 do not simply continue the WC sequence at earlier subtypes, but turn out to be significantly hotter.

3. Results

We assigned the best-fitting model from our WC grid (or special grids in case of a WN/WC or a WO star) to each star in our sample. The results are displayed in Figure 1 showing the positions of the stars in the model grid. Figure 2 plots the obtained mass-loss rates vs. the stellar luminosities. The different WC subtypes are indicated by different symbols and colors. It turns out that there is a clear subtype sequence in the $\log T$-$\log R_t$ plane revealing a temperature sequence correlating with subtype from the cool WC9 to the hot WC4 stars.

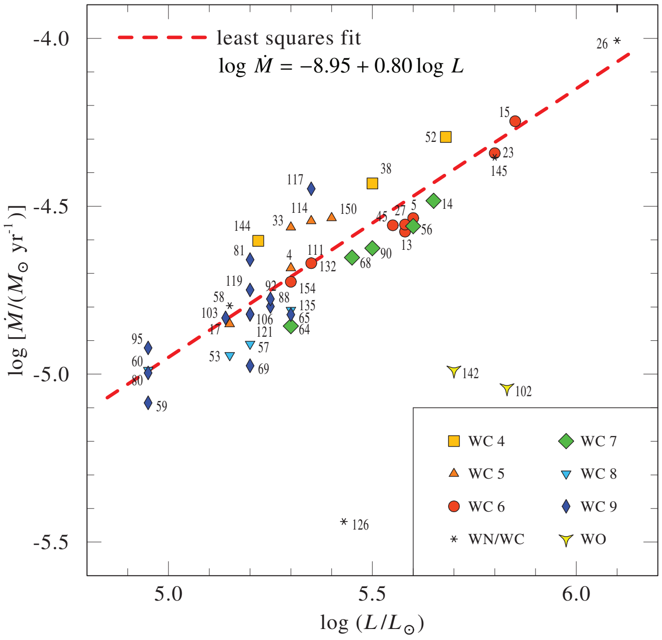

Figure 2. The obtained mass-loss rates show a strong correlation with the stellar luminosity. The least square fit is marked by the dashed line.

Most of the stars in Figure 1 are on or at least close to this sequence, although there is a slight offset from the slope for the WC9 stars. The two groups apart are the WO stars, where we analyzed the two Galactic WO2 stars WR 102 and WR 142 which turned out to be much hotter than the WC4 stars, and the binary systems that have been analyzed as single stars for comparison. Due to the so called "diluted emission lines" such binary systems would end up at lower temperatures and lower transformed radii if accidentally treated as single stars. As no single WC star turned out to be in this parameter range so far, we might be able to use this as a binary indication if future WC stars that are thought to be single appear in this parameter range. The evolutionary situation of the single stars is discussed in Sander & Hamann (these proceedings).

References

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