New windows on massive stars: asteroseismology, interferometry, and spectropolarimetry
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Westerlund 1 is a Galactic Treasure Chest: The Wolf-Rayet Stars

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Abstract. The Westerlund 1 Galactic cluster hosts an eclectic mix of coeval massive stars. At a modest distance of $4-5$ kpc, it offers a unique opportunity to study the resolved stellar content of a young (~ 5 Myr) high mass ($5 \cdot 10^4\,M_\odot$) star cluster. With the aim of testing single-star evolutionary predictions, and revealing any signatures of binary evolution, we discuss on-going analyses of NTT/SOFI near-IR spectroscopy of Wolf-Rayet stars in Westerlund 1. We find that late WN stars are H-poor compared to their counterparts in the Milky Way field, and nearly all are less luminous than predicted by single-star Geneva isochrones at the age of Westerlund 1.

Keywords. stars: early-type, mass loss, Wolf-Rayet - infrared: stars - galaxies: star clusters

1. Introduction

Westerlund 1 (Wd1) is amongst the most massive young clusters in the Galaxy. We witness this coeval collection of stars at an interesting epoch, as Clark *et al.* (2005) have identified a plethora of post-main sequence massive stars, indicating an age of 5 ± 1 Myr and a main sequence turn-off at approximately $30-35\,M_\odot$ (O 7V).

A high fraction of dust producing WC stars and coincidental hard X-ray sources amongst the observed Wolf-Rayet (WR) stars suggests a binary fraction approaching unity (Crowther *et al.* 2006). Indeed, Schneider *et al.* (2014) predict that after only a few Myr, the majority of a cluster's most luminous stars are the products of binary interaction. Here we report on preliminary tailored spectral analyses of 15 WR stars in Wd1 from Crowther *et al.* (2006), and discuss how derived parameters compare to single-star and binary evolutionary models.

2. Data & Analysis Method

We obtained NTT/SOFI spectra of 23 WR stars in Wd1 using IJ and HK grisms (R$\sim$1000), identified by differential narrow-band imaging (Crowther *et al.* 2006).

We have carried out spectral modelling of 15 of these WR stars (neglecting very late WN9-10 or dusty WC) – 2 of which are shown in Fig 1 – using the CMFGEN model atmosphere code (Hillier & Miller 1998) to derive effective temperatures, luminosities, abundances, mass-loss rates and wind velocities.

We constrain luminosities and extinction simultaneously, by requiring model spectral energy distributions to match a combination multi-band photometry and flux calibrated spectra, as shown in Fig. 2.

3. Results

Most WR stars are less luminous than single-star Geneva isochrones covering the expected age of Westerlund 1; older ages are precluded by the presence of high-mass main sequence stars. Late WN stars are generally H-poor compared to their field Milky

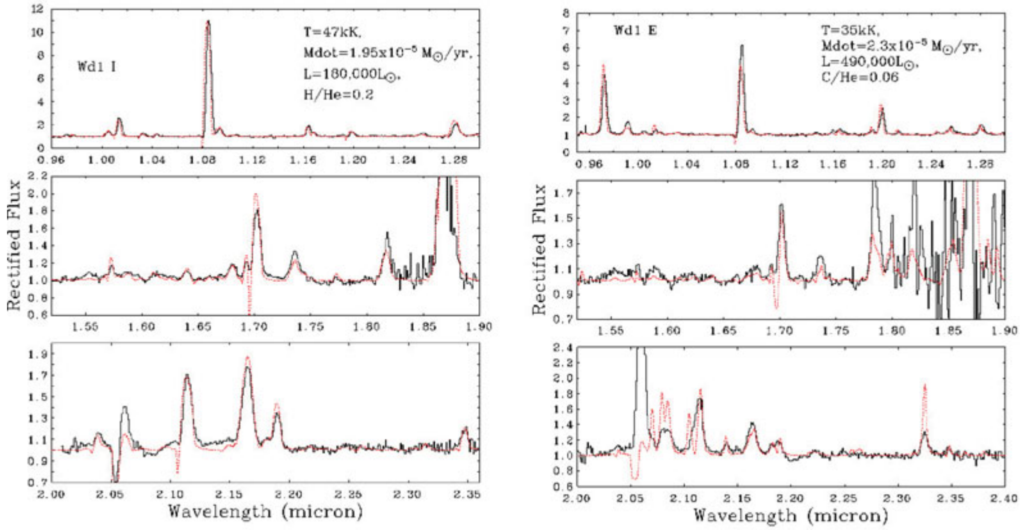

Figure 1. *Left.* NTT/SOFI spectrum (solid) and corresponding CMFGEN model (dotted) for Wd1-I (WN8). *Right* As left for Wd1-E (WC9). CMFGEN parameters are displayed in the upper panels.

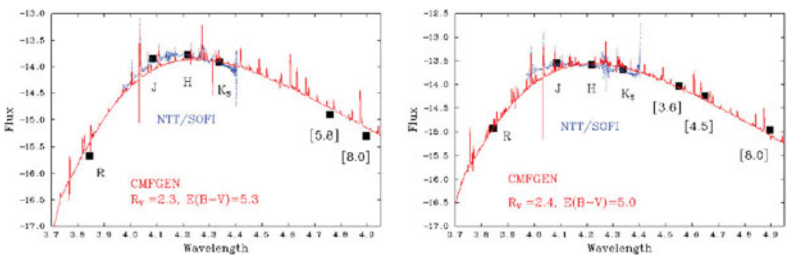

Figure 2. *Left* SED of Wd1-I, with flux calibrated NTT/SOFI spectra and multiband photometry (R:VLT/FORS2, JHK:SOFI, [5.8]-[8.0]:GLIMPSE). *Right* As left for Wd1-E. Model spectra are reddened using a Howarth (1983) extinctin law.

way counterparts. Low luminosity and H deficiency amongst the WN stars is consistent with outcomes of binary evolution (e.g. Eldridge *et al.* 2008). Preliminary mass-loss rates of the H-free early WN stars are systematically lower than those adopted by stellar models for their luminosities. Overall, The WR stars in Westerlund 1 analysed to date display properties that are inconsistent with the current generation of single-star models (Ekström *et al.* 2012). Analysis of the dust producing WC stars is forthcoming.

References

Clark, J. S., Negueruela, I., Crowther, P. A., & Goodwin, S. P. 2005, *A&A* 434, 949

Crowther, P. A., Hadfield, L. J., Clark, J. S., Negueruela, I., & Vacca, W. D. 2006, *MNRAS* 372, 1407

Ekström, S., Georgy, C., Eggenberger, P., *et al.* 2012, *A&A* 537, A146

Eldridge, J. J., Izzard, R. G., & Tout, C. A. 2008, *MNRAS* 384, 1109

Hillier, D. J. & Miller, D. L. 1998, *ApJ* 496, 407

Howarth, I. D. 1983, *MNRAS* 203, 301

Schneider, F. R. N., Izzard, R. G., de Mink, S. E., *et al.* 2014, *ApJ* 780, 117

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