Wolf-Rayet Stars
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Improving distances to Galactic Wolf-Rayet stars

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Before GAIA improves the HIPPARCOS survey, direct determination of the distance via parallax is only possible for γ Vel, but the analysis of the cluster or association to which WR stars are associated can give distances with a 50% to a 10% accuracy. The list of Galactic clusters, associations and clusters/association candidates has grown significantly in the last decade with the numerous deep, high resolution surveys of the Milky Way. In this work, we revisit the fundamental parameters of known clusters with WR stars, and we present the search for new ones. All our work is based on the catalogs from the VVV (from the VISTA telescope) and the UKIDS (from the UKIRT telescope) near infrared surveys. Finally, the relations between the fundamental parameters of clusters with WR stars are explored.

1 The distance to WR stars

The absolute magnitude of Wolf-Rayet (WR) stars can be estimated to be between $M_v = -3$ mag for earlier subtypes and $M_v = -6$ mag for late ones, or $M_v = -7$ mag for WNH stars. But for accurate determination of the luminosity (and the mass) of WR stars, a precise determination to their distance and extinction is necessary. To this date, the distance to 204 WR stars is fairly well known (Rosslowe & Crowther 2015). A total of 160 of these distances were deduced from the membership of the star to a cluster or an association (the rest are estimates from photometry). However, the distance to more than 2/3 of the ∼640 currently known WR stars is still undetermined. In a near future, the GAIA spacecraft will fix that problem for any stars brighter than $V = 15$ mag, but this still covers a small fraction of all WR stars. In the meantime, new public surveys already deliver good quality near-infrared (NIR) photometry allowing detailed study of the Galactic clusters and association. We count as many as ∼6000 clustery objects (confirmed and candidates combined) in our Galaxy (e.g. Dutra et al. 2002; Dias et al. 2002; Bica et al. 2004; Borissova et al. 2011, 2014), and many of them hang close to the coordinates of known WR stars.

2 WR stars in the public surveys UKIDSS and VVV

The UKIRT Infrared Deed Sky Survey (UKIDSS) was performed by the instrument WFCAM on the UK Infrared Telescope (UKIRT) in Hawai'i. It covers both high and low Galactic latitudes in JHK to $K = 18.3$ mag (Lawrence et al. 2007; Lucas et al. 2008). The Vista Variable in the Vía Láctea (VVV) survey is done with the NIR camera VIRCAM on the ESO 4-m Visible and Infrared Survey Telescope for Astronomy (VISTA) in Chile. It is scanning the bulge and the adjacent section of the disk (Minniti et al. 2010; Saito et al. 2012; Hempel et al. 2014). Both surveys have already observed the area around 95% of the currently known WR stars (see Figure 1). They therefore allow the deepest and the best resolved NIR photometric analysis of the regions near young star forming regions were WR stars are found.

2.1 Study of known clusters with WR stars

The first step is to verify our method on previously studied clusters with WR stars (see Figure 2). We have based this analysis on the aperture photometry delivered by the Cambridge Astronomy Survey Unit (CASU), or on point spread function fitting photometry performed by the SkZ pipeline (Mauro et al. 2013) in the most crowded regions. To determine the clusters fundamental parameters, we follow the methodology described in Chené et al. (2012). We obtain results comparable to what is present in the literature. Also, we can confirm that Hogg 15, debated birth place of the star WR 47 (Piatti et al. 2002; Kook et al. 2010), has an age of ∼10 Myr. However, we cannot add more on the possible membership of WR 47 to the cluster. Finally, we take advantage of this uniform set of data to compare the clusters' parameters and search for possible correlations. Using the Kendall's τrank method, we find the following correlations :

- *Number of WR stars and reddening*: This correlation could be biased by the large number of WR stars in the clusters near the Galactic center, such as the Galactic Center cluster, Arches and the Quintuplet.

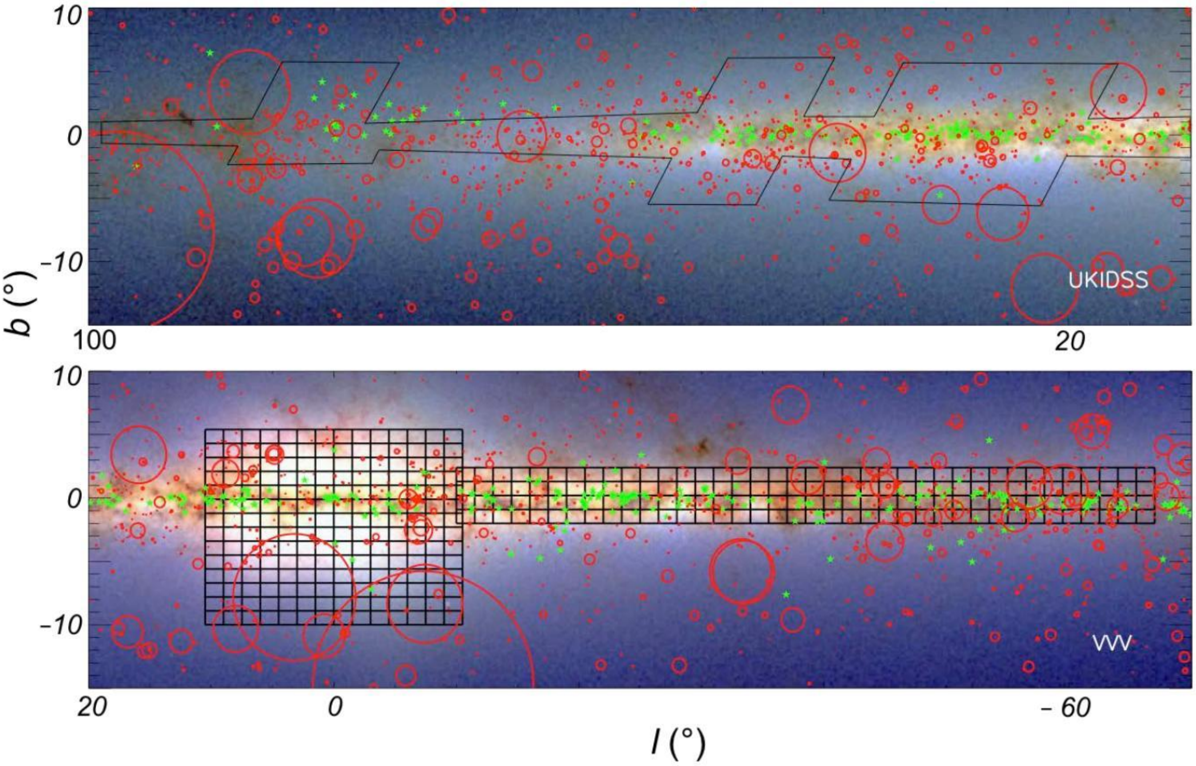

Fig. 1: Area covered by both the UKIDSS and VVV surveys in the Milky Way. The green stars mark the position of known WR stars, and the red circles are cluster and association candidates. The size of the circles correspond to the radii of the clusters/associations.

- *Number of WR stars and the mass of the most massive star in the cluster*: This could be an interesting correlation, but we would prefer to get more clusters for this analysis before making any statement.

- *Total cluster mass and the mass of the most massive star in the cluster*: This is essentially what Weidner et al. (2010, 2014) have already presented.

- *Age and the mass of the most massive star in the cluster*: This could be a simple effect of stellar evolution, causing the older clusters to show less massive stars. An inflexion point in the correlation is seen at around 4 Myr.

- *Total cluster mass and the number of WR stars*: Could be a selection effect, since traditionally, the search for WR stars was done in the most massive clusters. Also, not all the WR stars in the clusters might have been found.

- *Age and total cluster mass*: Could we see here the effect of clusters' evolution? With the data in hand, we would see the mass of the clusters decreasing passed 4 Myr.

2.2 Finding new clusters with WR stars

We take three approaches to find new clusters with WR stars. The first is to **analyse clusters and cluster candidates near known WR stars** (see again Figure 1). We have found nearly a dozen clusters candidates filling this condition and that are not known to have WR stars, but none of them seem to be young enough (some are as old as 100 Myr) and/or to show clear signs of association (older/lower mass population or small radius). The second is to **search for WR stars in young clusters**. We have currently found 7 new clusters with WR stars (Chené et al. 2013, 2015). Interestingly, none of them have a total mass higher than a couple 1000 $M_\odot$. These clusters are currently studied in depth to determine the evolution of massive stars (Hervé in prep.), similarly to what was already presented in Martins et al. (2007, 2008, 2012); Crowther & Bohannan (1997); Crowther & Walborn (2011) for other clusters. Finally, we **search for clusters and associations near WR stars.** But this task is the most challenging and time consuming. Also, we always run the risk that the WR star is the brightest star in the cluster, and the second brightest is fainter by many magnitudes, rending the analysis of the cluster impossible, even with photometry going as deep as $K = 18\,\mathrm{mag}$.

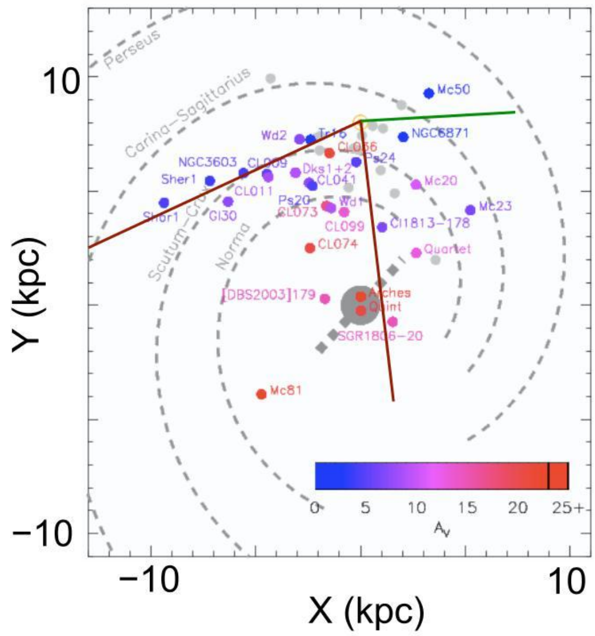

Fig. 2: Positions of the clusters with WR stars in the Milky Way. The model of the Milky Way spiral arms is from Vallée (2008, 2015). The color of the points represents the extinction in the line of sight of the cluster (from blue to red to represent 0 to 25+ mag of extinction). The UKIDSS and VVV surveys cover the area between the left red line and the green line (to the right). The red line in between marks the end of VVV, but UKIDSS overlaps about 20° in the inner part.

3 Conclusions

This is a brief presentation of the past, current and future efforts on the study of clusters and associations with WR stars. We aim to improve our preliminary studies of the correlation between the different fundamental parameters of the clusters in a forthcoming paper. Please, stay tuned for more …

References

Bica, E., Ortolani, S., Momany, Y., Dutra, C. M., & Barbuy, B. 2004, MNRAS, 352, 226
Borissova, J., Bonatto, C., Kurtev, R., et al. 2011, A&A, 532, A131
Borissova, J., Chené, A.-N., Ramírez Alegría, S., et al. 2014, A&A, 569, A24
Chené, A.-N., Borissova, J., Bonatto, C., et al. 2013, A&A, 549, A98
Chené, A.-N., Borissova, J., Clarke, J. R. A., et al. 2012, A&A, 545, A54
Crowther, P. A. & Bohannan, B. 1997, A&A, 317, 532
Crowther, P. A. & Walborn, N. R. 2011, MNRAS, 416, 1311
Dias, W. S., Alessi, B. S., Moitinho, A., & Lépine, J. R. D. 2002, A&A, 389, 871
Dutra, C. M., Santiago, B. X., & Bica, E. 2002, A&A, 381, 219
Hempel, M., Minniti, D., Dékány, I., et al. 2014, The Messenger, 155, 29
Kook, S.-H., Sung, H., & Bessell, M. S. 2010, Journal of Korean Astronomical Society, 43, 141
Lawrence, A., Warren, S. J., Almaini, O., et al. 2007, MNRAS, 379, 1599
Lucas, P. W., Hoare, M. G., Longmore, A., et al. 2008, MNRAS, 391, 136
Martins, F., Genzel, R., Hillier, D. J., et al. 2007, A&A, 468, 233
Martins, F., Hillier, D. J., Paumard, T., et al. 2008, A&A, 478, 219
Martins, F., Mahy, L., Hillier, D. J., & Rauw, G. 2012, A&A, 538, A39
Mauro, F., Moni Bidin, C., Chené, A.-N., et al. 2013, Rev. Mexicana Astron. Astrofis., 49, 189
Minniti, D., Lucas, P. W., Emerson, J. P., et al. 2010, New A, 15, 433
Piatti, A. E., Bica, E., Santos, Jr., J. F. C., & Clariá, J. J. 2002, A&A, 387, 108
Rosslowe, C. K. & Crowther, P. A. 2015, MNRAS, 447, 2322
Saito, R. K., Hempel, M., Minniti, D., et al. 2012, A&A, 537, A107
Vallée, J. P. 2008, AJ, 135, 1301
Vallée, J. P. 2015, MNRAS, 450, 4277
Weidner, C., Kroupa, P., & Bonnell, I. A. D. 2010, MNRAS, 401, 275
Weidner, C., Kroupa, P., & Pflamm-Altenburg, J. 2014, MNRAS, 441, 3348

John Eldridge: Have you thought of comparing your cluster & WR stars to the Galactic supernova remnant cataloque?

André-Nicolas Chené: Not yet, but it is a good idea. It is a work in progress, and we can always increase the list of areas to study. If someone wants to help, they are welcome.

Phil Massey: I gave the example yesterday of the uncertain distance to NGC 3603. I think we improved on that but we had to get a lot of spectra to do so. How accurate do you expect the distances to be to your clusters?

André-Nicolas Chené: This depends on at what stage our analysis of a given cluster is. When we only have photometry (from the public surveys), the uncertainty can be quite high. But with 2–3 spectra from member stars we can get to ± 1 kpc. Obviously, if we get the chance to observe 10s of members with spectroscopy, it would bring the uncertainty down quite a bit.

Alexandre Roman-Lopez: Have you found any correlation between the cluster candidate morphology and the WR content?

André-Nicolas Chené: I could not find time to look for that yet. We have limited our work to single, simple values for now, but we should move on eventually and try more complex analyses, including morphology.