Wolf-Rayet Phenomena in Massive Stars and Starburst Galaxies
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The IVth Catalogue of LMC Wolf-Rayet stars

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Abstract. A number of 134 WR stars is currently known in the Large Magellanic Cloud. A summary of the content and format of the new, Fourth, LMC Wolf-Rayet Catalogue is presented.

1. Introduction

The *Third LMC Wolf-Rayet Catalogue* (Breysacher 1981) contained 100 stars. Since then, additional WR stars have been discovered in the LMC field either as the result of new systematic searches of deep objective-prism plates or by serendipity. Others were detected or resolved in compact clusters/H II regions. The recognition of the genuine or borderline WR nature of some already known stars also contributed to the growth of the LMC WR population. There are now 134 WR stars identified in the LMC. The fact that neither a complete set of finding charts nor accurate equatorial coordinates exist for these objects, has been an incentive for the preparation of an updated *Fourth Catalogue* of WR stars in the LMC.

2. Earlier catalogues

The first systematic search for WR stars in the LMC was carried out by Westerlund & Rodgers (1959) who identified 50 stars on objective-prism plates obtained with the 50cm Schmidt telescope, at the Uppsala Southern Station of the *Mount Stromlo Observatory*.

Later on, Westerlund & Smith (1964) repeated the survey of the same field of about 100 square degrees and published a list of 58 WR stars. In this *First Catalogue* the stars were roughly classified *C* (carbon-type), *N* (nitrogen-type) or *W+O* (binaries); the more accurate spectral types previously assigned to 15 of them by Feast, Thackeray & Wesselink (1960) being, however, also given.

Sanduleak (1969), in his catalogue of 1272 proven or probable LMC member stars, denoted as "WR" 14 objects not listed by Westerlund & Smith (1964).

On plates obtained with the *ESO* 40cm objective-prism astrograph (GPO) — primarily secured for radial velocity measurements — Fehrenbach, Duflot & Acker (1976) recognized all the stars identified by Westerlund & Smith, con-

firmed 12 of the 14 Sanduleak WR candidates and discovered 6 new WR stars. This *Second Catalogue* included 76 WR stars.

Walborn (1977) added a new member to the LMC WR population, and Melnick (1978) increased to 83 the number of known WR stars in the LMC with the detection of 6 additional WR in the core of 30 Doradus.

Finally, Azzopardi & Breysacher (1979, 1980), as a result of a new systematic search for WR stars in the LMC with the *ESO* 40cm GPO, identified 17 new WR stars. The *Third Catalogue* of LMC WR stars published by Breysacher (1981) provided spectral types for all the 100 WR stars then known in this galaxy.

3. Spectral classification

In the classification scheme adopted by the IAU Commission 29 (Beals 1938) only the subtypes WN5 to WN8 and WC6 to WC8 were considered. Subsequent spectroscopic studies of WR stars have led to a refinement of the WR classification: the WN and WC sequences now extend from WN1 to WN11 and WC4 to WC11, respectively.

In order to distinguish, in the WC sequence, those of the WR stars which exhibit unusually strong oxygen lines, Barlow & Hummer (1982) introduced a third sequence called WO, divided into four subtypes: WO1 to WO4.

In the LMC, there are stars for which neither an Of- nor a WN-type unambiguously accounts for the observed spectral features. A fourth generic category designated as "Of/WN" allows to separate these objects from the *classical* WN stars. The spectral type Ofpe/WN9, interpreted as an extension to later types of the WN sequence, was originally assigned by Bohannan & Walborn (1989) to ten LMC stars. Most of them have now been re-classified WN10 or WN11 by Crowther & Smith (1997). A few other LMC stars classified O3If*/WN6-A also enter the Of/WN category.

The advent of linear detectors has facilitated the quantification of the WR classification system, allowing the determination of objective spectral types for:

- WN2-8 stars (Smith, Shara & Moffat 1996)
- WN9-11 stars (Smith, Crowther & Prinja 1994)
- WC4-9 stars (Smith, Shara & Moffat 1990)
- WO1-5 stars (Kingsburgh, Barlow & Storey 1995)
- WC4-11 and WO1-4 (Crowther, De Marco & Barlow 1998)

The spectral types adopted in the *Fourth Catalogue* originate primarily from such quantitative studies; the most recent works being given preference. The three-dimensional scheme for WN stars introduced by Smith, Shara & Moffat (1996) is largely used.

In the classification of WR stars, the question of companions still remains a delicate issue. Although the only secure method to establish the binary nature of a WR star is to search for radial velocity variations and/or eclipses, two other criteria, namely "small ratio of emission-line to continuum intensities" and "presence of absorption lines" are sometimes used as well. Binarity deduced from the use of these criteria only is doubtful.

Although the LMC is a system seen nearly "face on", and not much extended in depth, it is risky as well, to conclude that a WR star is a binary exclu-

sively on the basis of its high luminosity, in view of the absolute-magnitude distribution obtained for the single WN- and WC-type stars in the LMC (Breysacher 1986).

4. The Fourth Catalogue of LMC WR stars

The catalogue contains 134 objects; each of them has been, at least once, assigned a WR type. Accurate equatorial coordinates, photometric data, spectral classification, binary status, correlation with OB associations and H II regions are provided, as well as the miscellaneous designations of the stars.

Spectrograms of LMC WR stars representative of the WNE, WNL and WCE subclasses are shown. In the "Notes on individual stars" the most important results published over the last decade are summarized. A uniform set of finding charts is presented.

The catalogue includes a list of 134 bibliographical references.

4.1. Astrometric measurements

For 87% of the stars listed in the catalogue, the right ascension and declination were determined from 15 direct B plates (IIIa-J emulsion; scale: 50 arcsec/mm) obtained with the *ESO* 40 cm GPO, at La Silla. An average of 30 reference stars per plate, selected from the PPM catalogue available in STARCAT, was used.

For 9% of the stars, located in crowded regions and therefore difficult to measure on the photographic plates, the positions were determined on CCD images (He II 4686 interference filter; scale: $0\farcs26$/pixel) secured with the direct camera attached to the *ESO*/MPI 2.2m telescope, at La Silla. The equatorial coordinates of these stars were calculated by linear interpolation using as secondary standards nearby stars measured on the astrographic plates.

For the remaining 4% of the stars - six members of the R 136 cluster at the heart of the 30 Doradus nebula - the coordinates published by Malumuth & Heap (1994) were adopted.

For the stars appearing on different plates or CCD frames, the astrometric measurements were repeated. This resulted in 30% and 10% of the stars having their coordinates determined independently two times and three times respectively, thus allowing an estimation of the internal error. The obtained accuracy is ± 0.045 sec in right ascension, and $\pm 0\farcs20$ in declination.

4.2. Nomenclature

To comply with the IAU nomenclature recommendations, the star designations adopted in the *Dictionary of Nomenclature of Celestial Objects* are provided. When different, the more traditionally used acronyms are also given for convenience.

The running catalogue number **BAT99-nnn** is IAU registered.

4.3. Finding charts

Our goal has been to present finding charts as uniform as possible for the greatest number of objects. Except for 30 Doradus and the enlargements of the compact

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clusters, the charts have a $3' \times 3'$ field. They are all oriented with north at the top and east to the left.

The Digital Sky Survey (DSS) was used for 70% of the stars. The charts corresponding to the MG stars (Morgan & Good 1985; Morgan 1998) were made from SuperCOSMOS scans of *UKST* plates kindly made available to us by D.H. Morgan. The 30 Doradus image, obtained with the *ESO/MPI* 2.2m telescope, at La Silla,, was provided by G. Meylan.

For stars located in crowded regions, CCD frames obtained with the *ESO* 3.6m telescope were used. The high-resolution images were retrieved from the *HST* archive.

The Fourth Catalogue of LMC WR Stars has been submitted to A&AS in December 1998.

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Discussion

Garmany: What fraction of the WR stars in your catalog are in LH associations or clusters?

Breysacher: About 60% of the LMC WR stars are found in LH associations

Lépine: What is the overall spatial distribution of WR stars from your catalogue and how does this compare with the general stellar distribution in the LMC?

Breysacher: About 85% of the LMC WR stars are in H II regions, nearly 40% being located in 30 Doradus.

Moffat: In many ways, the SMC is even more intriguing than the LMC because of its very low metallicity. Is the current WR census in the SMC (nine WRs) complete?

J.Breysacher: Since the discovery, in 1991, of the ninth SMC WR star by Morgan *et al.* no additional WR has been found in this galaxy, at least not to my knowledge.

Massey: Just a comment: a few years ago Taft Armandroff and I imaged many of the SMC OB associations with the *CTIO* 4m + our 'optimal' WR-filters and we didn't find any new ones.

Breysacher: Thank you.

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