AN *IRAS*-BASED SEARCH FOR NEW DUSTY WCL WOLF-RAYET STARS

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Abstract. I have examined all *InfraRed Astronomy Satellite* (*IRAS*) data relevant to the 173 galactic Wolf-Rayet (WR) stars in an updated catalogue provided by van der Hucht (priv. comm.), including the 13 stars newly discovered by Shara *et al.* (1991). Using the exact coordinates given in these lists, I have examined the *IRAS* Point Source Catalog (PSC), the Faint Source Catalog, Faint Source Reject Catalog, and generated 1-dimensional spatial profiles ("ADDSCAN"s), and 2-dimensional full-resolution images ("FRESCO"s). The goal was to assemble the best set of observed *IRAS* colour indices for different WR types, in particular for known dusty WCL objects. These colour indices define zones in the *IRAS* colour-colour([12]-[25],[25]-[60]) plane. By searching the PSC for otherwise unassociated sources that satisfy these colours, I have identified potential new WR candidates, too faint to have been recognized in previous optical searches. I have extracted these candidates' *IRAS* Low Resolution Spectrometer (LRS) data and compared the spectra with the highly characteristic LRS shape for known dusty WCL stars. Any surviving candidates must now be examined by optical spectroscopy. This work represents a much more rigorous and exhaustive version of the LRS study that identified IRAS 17380-3031 (WR98a) as the first new WR (WC9) star discovered by *IRAS* (Cohen *et al.* 1991).

Key words: stars: Wolf-Rayet – WCL – *IRAS* colours – circumstellar dust

1. Introduction

Traditional photographic techniques for seeking WR stars have been superseded by more efficient methods using CCD detectors and narrow passbands designed to recognize specific emission lines or line complexes (cf. Shara *et al.* 1991: SPMS). Nevertheless, all these techniques are still optically based. While infrared (IR: longward of 2 μm) spectroscopy of WRs has been pursued (*e.g.,* Eenens *et al.* 1991), it has not yet developed into a survey tool to seek new WRs. However, I suggested at IAU Symposium No. 143 on Bali that the *IRAS* LRS (8–23 μm) spectral shape of dusty WCLs was uniquely diagnostic of this special subgroup. I even volunteered a new dusty WCL candidate, IRAS 17380-3031, on this basis alone. Subsequent optical spectroscopy has vindicated this prediction (Cohen *et al.* 1991).

The thermal IR regime offers a complementary approach to an optical search for finding new WR candidates, especially those dusty WCLs whose circumstellar envelopes have successfully absorbed most, if not all, the UV and optical starlight. Such stars are IR-bright, emitting chiefly in the 5–25 μm region, where thermal emission from hot (a few hundred to about 1000 K) dust grains overwhelms photospheres and free-free wind emission. Further, optical searches are often regarded as highly incomplete even to a distance of 2–3 kpc (SPMS). Consequently, it seemed worthwhile to at-

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tempt a purely IR-based search because its biases would be totally different from those afflicting optical surveys. In particular, one might well expect to discover IR-bright counterparts to previously unknown dusty WRs that are virtually invisible optically.

2. The value of the *IRAS* LRS spectra

An LRS survey of all known WRs reveals few useful spectra, essentially because WRs inhabit the galactic plane where *IRAS* suffers the greatest confusion by high source density. However, the census is intriguing: one WO1, one WN8, one WC7, two WC8s, and seven WC9s! Moreover, it is obvious that the seven WC9s exhibit startlingly similar spectral shapes. Clearly the LRS could play a valuable role in recognizing new dusty WCLs if we could restrict the number of *IRAS* sources whose spectra we must examine.

Efforts have been made to define IR flux-density-limited LRS surveys of the PSC (Volk & Cohen 1989, Volk *et al.* 1991). Indeed, it was from the earliest (and brightest) of these that IRAS 17380-3031 emerged. However, my attempts to enlarge the sample of dusty WCLs by isolating more *IRAS* sources ostensibly with the "same" characteristic LRS shape have been entirely unsuccessful. The likeliest candidate, akin to IRAS 17380-3031, was IRAS 18405-0448, also suggested by Volk & Cohen (1989). But its optical and near-IR (Cohen & Williams 1992, unpublished) spectra indicate an extreme emission-line star, definitely not of WR type. It seemed that a method for sharpening the *IRAS* criteria was needed, rather than systematic browsing of thousands of LRS spectra (which alternative we have, of course, also pursued) to ever decreasing flux density levels.

3. An *IRAS*-based strategy

The logical route was to assemble every piece of *IRAS* data on all known WR stars and extract the quintessential attributes for the class. The easiest searches were those through the PSC and Faint Source databases because relational queries could be run. The FSC represents the most reliable sources from the entire Faint Source data set (that results from co-adding *IRAS* data from all separate HCONs [months' separated passes]), namely those at preferentially higher galactic latitudes where confusion is not an issue. At lower latitudes, extracted point sources are passed to the FS Reject Catalog, which yielded much useful data on the WRs. However, because relational searches necessarily involve some limiting radius, there is always the question of whether a "matched" source is truly the WR. Therefore, I also examined 2-dimensional images that preserved the full spatial resolution of each *IRAS* band, for all WRs, at all four wavelengths ("FRESCO"s). Given accurate coordinates, the most reliable way to detect the faintest

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matches to WRs comes from coadding all the 1-dimensional *IRAS* crossings through the WR star's position ("ADDSCAN"s), using 2D images to help disentangle neighbouring sources).

The resulting several data sets were combined into a unified *IRAS* data base for known WRs, from which colours were defined for each of the WN and WC subtypes, as well as for the entire class of WRs. Likewise, by appending distances from Conti & Vacca (1990) (who used a homogeneous set of intrinsic colours to determine WR distances via reddening), absolute *IRAS* magnitudes were later defined, to assess the volume likely to have been sampled by *IRAS*.

4. Colour-colour separations

Fig. 1 illustrates the zones of the *IRAS* [12]-[25]-[60] colour-colour plane occupied by different astronomical categories of object (Walker *et al.* 1989). The average for all WNs is [12]-[25] = 1.59±0.13 (54 stars), [25]-[60] = 2.70±0.19 (23); for all WCs, 1.09±0.09 (55) and 2.70±0.26 (26), respectively (excluding hybrid types). Finally, of particular relevance, Williams & van

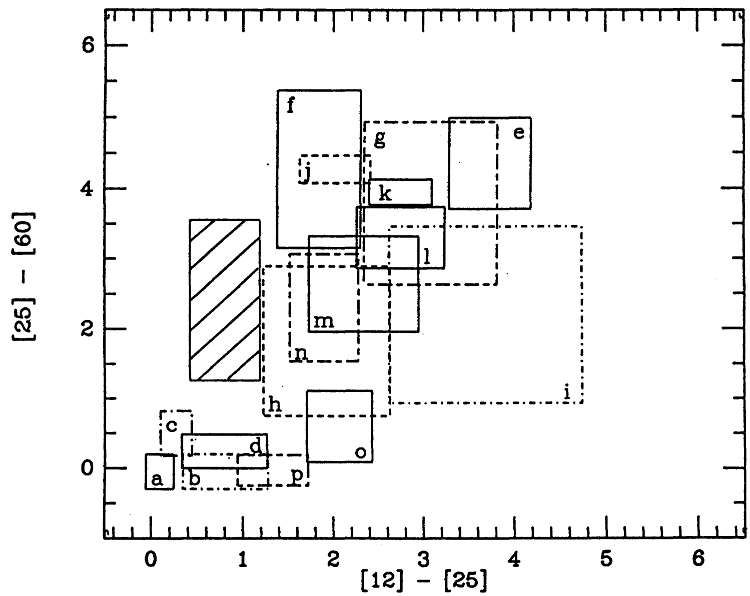

Fig. 1. Colour-colour zones in the *IRAS* [12]-[25]-[60] plane for astronomical sources (Walker *et al.* 1989 detail letter codes). The cross-hatched box is the dusty WCL zone.

der Hucht (1992) have listed the set of WCs established to show either permanent or variable dust emission. I have *IRAS* data for 21 of these 25 stars that define a colour zone centred on [12]-[25] = 0.84±0.13, [25]-[60] = 2.40±0.42, [60]-[100] = 2.01 ±0.58. Because of the great danger of confusion

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at 100 μm at these low galactic latitudes, I chose to ignore the third colour to avoid eliminating potential WR candidates too soon. The cross-hatched rectangle corresponds to the zone characteristic for dusty WCLs as defined by the methods described here (with extent in each axis of $\pm 2.78\sigma$ about the mean colour). A query on the PSC using this colour-colour domain yielded 219 candidates that were unassociated in the PSC, had $|b| \leq 5°$, and secure *IRAS* detections. I extracted all LRS spectra for each of these candidates, finding spectra to exist for 132 sources (a total of over 500 individual spectra, typically 4 per candidate).

Many objects are, of course, very faint to *IRAS* and their LRS spectra are correspondingly noisy. However, I have generated a short list of 13 *IRAS* sources (in both hemispheres) having LRS spectral signatures like known dusty WCLs. Their locations need to be examined for optical counterparts, then pursued spectroscopically (or at least using pairs of narrow passbands isolating WC line and continuum regions in a CCD survey).

5. Likely completeness of the *IRAS* sample

Based on the absolute magnitudes, M12 and M25, of dusty WCLs to which the PSC is complete (determined from Cohen's (1994) SKY model in different galactic directions), [12]-[25] is complete out to about 5.5 kpc in most longitudes. Toward the innermost regions of the Galaxy, where the bulge dominates and high source densities prevail, this completeness distance drops to about 2.5 kpc. At 60 μm, the density of extended sources (typically H II regions) dictates the degree of confusion in the inner Galaxy. However, the great sensitivity of *IRAS* at this long wavelength suggests that the existence of [25]-[60] does not reduce the 5.5 kpc survey depth determined from the existence of [12]-[25].

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