WISE Morphological Study of Wolf-Rayet Nebulae

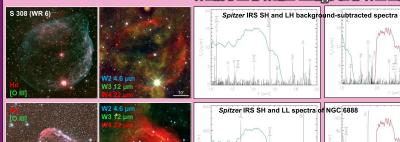
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Wind Blown Bubbles around Wolf-Rayet Stars

During the Wolf-Rayet (WR) phase of the late evolution of massive stars $(M_i > 35 M_{\odot})$, large nebulae are blown in the circumstellar medium of these stars. The powerful WR wind is expected to have important effects, altering the morphologies of these nebulae in short timescales. We have used optical (mostly H α) and WISE IR images of nebulae around Galactic WR stars to investigate their morphology and to assess their evolutionary stage.

What's in a WISE image of a WR nebula?



WR nebulae appear especially prominent in the WISE $\mbox{W3}$ and $\mbox{W4}$ bands:

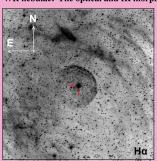
- W2 at 4.6 µm: background stars,
- W3 at 12 jum: nebula and diffuse ISM,
- W4 at 22 µm: mostly nebular emission.

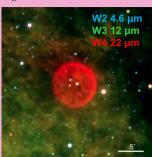
High-resolution *Spitzer* IRS spectra of S 308 and NGC 6888 reveal nebular H I, [Ne II] and [Ne III] lines and a PAH band, but also ISM emission lines of low excitation species in the \(\mathbb{W3}\) band.

The W4 band presents emission lines of He I, [O IV] and [Mg IV], the latter from high excitation ions in the nebular shell. The thermal continuum from hot dust may also contribute to the emission in this band.

Morphological Classification of Wolf-Rayet Nebulae: Clues for Nebular Evolution

We have examined archival H α (mainly from the Super COSMOS Sky Survey and Sloan Digital Sky Survey) and WISE IR images of a sample of 35 Galactic WR nebulae. The optical and IR morphologies have been classified into three broad groups which can be linked to the nebular evolution.





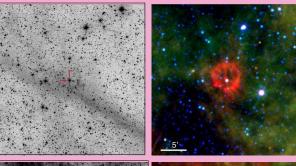
WR Bubble

WR nebulae presenting a complete shell or bubble both in $H\alpha$ and IR images.

Early stage on the formation of a WR nebula:

Immediately after the star enters the WR phase, its strong stellar wind sweeps up the slow and dense wind ejected in previous evolutionary phases (RSG, YSG or LBV), forming a WR bubble.

WR 16



Clumpy/Disrupted WR Nebulae

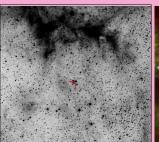
WR nebulae with clumpy $\mbox{H}\alpha$ and IR images. Clumps and knots are usually connected in partial shells and arcs.

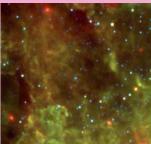
Intermediate stage on the formation of a WR nebula:

After a few 10^4 yr, Rayleigh-Taylor and thin shell instabilities induced by the powerful WR wind disrupt the dense shell of the WR bubble into clumps and filaments.

The shell disruption may be enhanced by the star motion throughout the ISM which will lead to the formation of bow shocks and incomplete shells.

WR 8





Mixed WR Nebulae

WR nebulae that do not show a definite morphology, neither a clear correspondence between their $H\alpha$ and IR images.

Final stage of the interaction of a WR nebula with the ISM:

The clumps and filaments created in previous phases diffuse and mix with the ISM, producing patterns with no specific shape.

WR 35b