Wolf-Rayet stars: extremely hot, luminous and massive

Wolf-Rayet stars are named after Charles Wolf (1827 - 1918) and George Rayet (1839 - 1906), French astronomers who discovered these unusual stars at the Paris Observatory in 1867, using the 40-cm Foucault telescope. 150 years later, we know of only 580 in the Milky Way galaxy, and a few hundred in the surrounding galaxies, so they are rare. Wolf-Rayet are evolved, massive, extremely hot (up to ~50,000 K) and very luminous stars, 10^5 to 10^6 times brighter that of the Sun.

The Wolf-Rayet stars represent an advanced stage of massive stars evolution and are characterized by an extraordinary spectrum which is dominated by emission lines of highly ionized elements, with lack of hydrogen. They are thought to mostly be dying supergiants with their hydrogen layers blown away by stellar winds. These stars are likely to end their lives spectacularly as either a Type Ib or Type Ic supernova explosion. Wolf-Rayets are massive stars. Masses can generally only be estimated from binary systems, which are commonly WR+O systems. The spectral types of the O companions show no correlation with W-R subtype (Massey, 1982).

Most of early studies of WR stars were confined to the WR+O binaries. By simply measuring the velocities of both components in a WR+O system, the minimum masses and the mass ratio of the two stars can be find. Known orbit inclination allows to calculate the mass of the WR star directly (Massey, 1982). Typical masses are around 16 to 18 M_0, but the range is very great: from 5 M_0 to 48 M_0 or, in one case (WR 22, HD 92740), 77 M_0. Masses of the O star in WR+O binary systems range from 14 to 57 M_0, with a mean of 33 M_0 (Cherepashchuk, 1992).

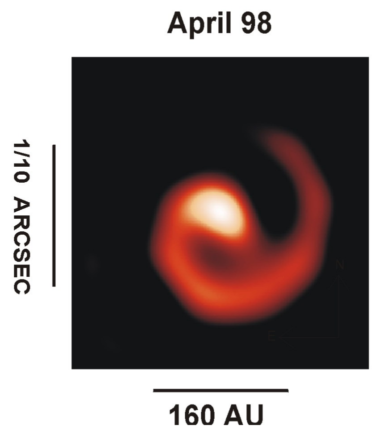
NGC 2359 *(Thor's Helmet) - the nebula which is located about 15,000 light-years away in the constellation Canis Major. Known as a Wolf-Rayet star, the central star is an extremely hot giant thought to be in a brief, pre-supernova stage of evolution. The nebula is about 30 light-years across. The central star is known as **WR 7** or **HD 56925.***

Image Credit: *Steve Mazlin, Jack Harvey, Rick Gilbert, and Daniel Verschatse (APOD; June 5, 2010)*

Overall pattern of the WR distribution within our galaxy suggests spiral arms: the stars are strongly concentrated to the inner edges of the HI and OB spiral features in Cygnus and Carina (Lindsey, 1968). Moreover, WR population varies qualitatively within the galactic plane. (van der Hucht et al., 1988).

The classification of WR stars assumes dividing into subclasses according to relative strength of nitrogen and carbon emission lines in their spectra (Smith & Maeder, 1988). Two main subclasses are: type **WN,** where the ions of helium and nitrogen are dominating, and WC type exhibiting strong lines of carbon (Crowther, 2007). Rare WO stars contains strong Oxygen lines in their spectra.

Examples of Wolf-Rayet stars occurring in clusters include two in the ~3 million year old NGC 6231 in Scorpius, one in NGC 2359 in Canis Major (widely known as Thor's Helmet), one (HD 148937) associated with NGC 6164-65 in Norma, and another (HD 192163) associated with NGC 6888 in Cygnus (Johnson & Hogg, 1965) . Studies of WR stars in open clusters and associations are important as there is a chance to get a reliable information regarding their absolute magnitudes and intrinsic colours. For detailed analysis of WR stars in open clusters, see Lundstrom & Stenholm (1984).



Many different proposals on scenarios for the formation of Wolf-Rayet stars were made in the literature (Maeder, 1982, 1983; Langer, 1988). In addition to the mentioned papers, there is a good resource containing details on WR models: PoWR (The Potsdam Wolf-Rayet Models), available online at the following address: http://www.astro.physik.uni-potsdam.de/~wrh/PoWR

WR 104 (left) is a Wolf-Rayet star discovered in 1998, located 8,000 light years from Earth. It is a binary star with a class OB companion. The stars have an orbital period of 220 days and the interaction between their stellar winds produce a spiral outflow pattern over 200 AU long (Tuthhill, 2009).

Left: The Twisted Tale of Wolf-Rayet 104 at 2.27 microns. First of the Pinwheel Nebulae.
Photo Credit: U.C. Berkeley Space Sciences Laboratory/W.M. Keck Observatory
Online: http://www.physics.usyd.edu.au/~gekko/wr104.html

M1-67 (left, *Credit: ESO*) is the youngest wind-nebula around a Wolf-Rayet star in the constellation Sagittarius, called **WR124**, in our Galaxy. These Wolf-Rayet stars start their lives with dozens of times the mass of our Sun, but loose most of it through a powerful wind, which is ultimately responsible for the formation of the nebula. The image is based on FORS1 data obtained by the Paranal Science team with the VLT through 2 wide (B and V) and 3 narrow-band filters. (*Source Credit: ESO*).

All subtypes of WRs show a correlation between variability and luminosity similar to other supergiants. That is increasing variability with higher luminosity which corresponds to cooler WR stars: as they become hotter, they become more stable. The microvariability time scale is in the order of one day. The Wolf-Rayet progenitor stars and formation processes are not yet clearly understood. It appears that W-Rs can evolve from any sufficiently massive star. It is feasible that the most massive stars, ~120 solar masses, may lose their original envelope during H burning, evolving directly from Of to W-R stages (Maeder, 1989). Eventually the WR star will run out of fusible material, ending its life as an early WC (WO) star in a type Ib supernova.

About half of WR stars are noticeably variable, with WN8 stars being considered to have the highest level of variability, with typical ranges of 0.1-0.2 mag. There are 32 WR stars listed in the GCVS4. The question of pulsation in WR stars is not settled though. WR stars are among the targets for ultra-precise photometry by the MOST satellite. Clear variability was measured for *EZ CMa* (P=3.763 days), *V919 Sco* (P~2 days), *V444 Cyg* (P=4.212424), *DI Cru* (P=0.3319).

Notable Wolf-Rayet stars

The most massive star and probably most luminous star currently known, ***R136a1***, is also a Wolf–Rayet star of the WNh type indicating it has only just started to evolve away from the main sequence. It is a member of R136, a super star cluster near the center of the 30 Doradus complex (also known as the Tarantula Nebula), in the Large Magellanic Cloud. The star is estimated to be of 265 solar masses and among the most luminous star known at 8.7 million times the luminosity of the Sun. (Crowther, 2010).

Gamma 2 Velorum

No WR star is so easily found as the bright naked-eye (1.81m) Gamma ^{2} Velorum in the southern constellation Vela, a famous visual multiple with a brilliant Wolf-Rayet primary. Gamma 2 Velorum is not only the closest Wolf-Rayet star but one of the brightest stars in the sky. At a distance of about 1,000 light-years away, it is part of a six-member star system. The primary star is a spectroscopic binary, the unseen component being a giant type O7 star. Though it's currently nine times our sun's mass, it has lost a considerable amount of its matter. Most likely, it started off with over 35 times the mass of the sun!

Theta Muscae

The second brightest is Theta Muscae (apparent magnitude of 5.66). It is a remote triple star system, the primary component of which is a carbon-sequence Wolf–Rayet star. The triple star is composed of two parts: a spectroscopic binary system of the Wolf–Rayet star and an O-type main sequence star that orbit each other every 19 days, and a blue supergiant. All three are highly luminous: combined, they are over a million times brighter than the Sun.

Eta Carinae

When Eta Carinae was first catalogued in 1677 by Edmond Halley, it was of the 4th magnitude, but by 1730, observers noticed it had brightened considerably and was, at that point, one of the brightest stars in Carina. The system contains at least two stars, of which the primary is a luminous blue variable (LBV) that initially had around 150 solar masses, of which it has lost at least 30. This stellar system is currently one of the most massive that can be studied in great detail. In 2005 it was proved to be a binary system.

AB7 nebula.(Credit: ESO)

HD 5980

HD 5980 (var. type: EA/GS/WR+SDOR) is the brightest star in the Small Magellanic Cloud and is located in *NGC 346*. It has three components, all amongst the most luminous stars known. In 1991, HD 5980 was observed to have changed spectral type and decreased in temperature after a slow increase in brightness. This is known eclipsing binary with possible eruptions occurring within an accretion disk around the companion. The variability period is 19.266 days.

Wolf-Rayet stars catalogs

- *The Seventh Catalogue of Galactic Wolf-Rayet stars*, by van der Hucht
  VizieR Catalog: http://cdsarc.u-strasbg.fr/viz-bin/Cat?III/215
- *Galactic Wolf-Rayet Catalog* - http://www.pacrowther.staff.shef.ac.uk/WRcat
- *A catalog of northern Wolf-Rayet Stars and the Central Stars of Planetary Nebulae*
  https://www.cfa.harvard.edu/~pberlind/atlas/htmls/wrcat.html
- *Wolf-Rayet Spectroscopic Survey*
  http://www.astrosurf.com/buil/survey/wrstars/wrstars.html

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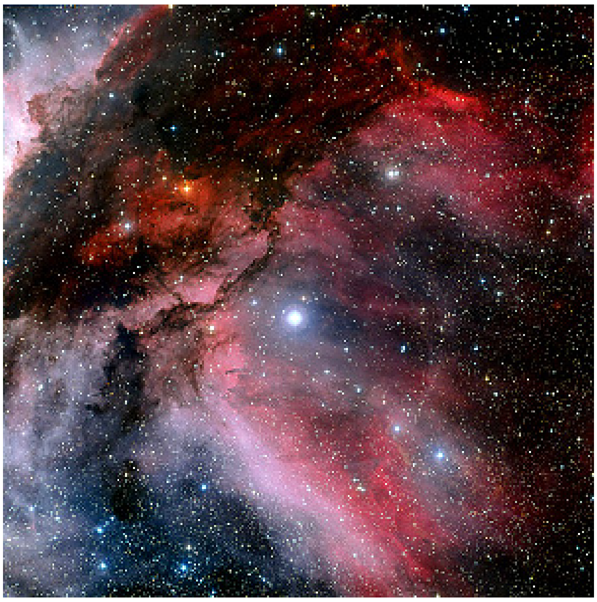
References and Resources for further reading:



Carina Nebula around the Wolf–Rayet star WR 22.
Credit: ESO

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