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Wolf-Rayet Stars
Outline

- What are W-R stars?
- How do we characterize them?
- What is the life of these stars like?
  - Early stages
  - Evolution
  - Death
- What can we learn from them?
  - Spectra
  - Dust
Discovery

- 1867: Charles Wolf and Georges Rayet at Paris Observatory
- 1892: First spectra recorded by Campbell
- Early 1900’s: Found to be present in many planetary nebulae.
Wolf-Rayet (W-R) Stars

- Massive stars typically 20 to 80 $M_\odot$
- Extremely hot! $\sim 50,000$ K
- Lifetimes $\sim 0.5$ million years
- Identified by intense, broad emission lines from stellar winds
- Absence of Hydrogen ($< 15\%$ H)
Wolf-Rayet (W-R) Stars

- Believed to originate from type O or B stars
- First to leave the main sequence
- Evolution greatly dependent on mass of O-type star and composition as W-R star
3 basic types of W-R Stars

- **WN (Nitrogen rich) (~ 1% N)**
  - Strong He and N emission lines

- **WC (Carbon rich) (~ 10 - 60% C)**
  - Strong C, O and He emission lines
  - Little or no N present ( > 0.05%)

- **WO (Oxygen rich)**
  - Strong O lines
Early evolution

- Originate from type O or B stars with masses typically from 20 to 80 $M_{\odot}$
- Found close to galactic plane
- Follow massive star evolution
  - Hydrogen burning
  - Shell burning (H and He; heavy element core)
  - End up in CNO cycle in core
- Evolve into Super Giants or Luminous Blue Variable (LBV) stars
Strong Stellar Winds

- Huge luminosities are generated (~$3 \times 10^5$ times larger than the sun)
- Wind velocities ~ $2,500$ km/s
- Blow off outer layers (including most/all of its hydrogen).
- Lose approximately $10^{-5} M_\odot$ each year
Early evolution (cont.)

- Nuclear core is revealed
- Leftover hydrogen is burned into He
- Helium is still abundant
  - Fusion reactions continue CNO cycle
  - Higher effective temperatures
- Mixing (rotational and convective) creates diverse surface environment
- Hard to resolve beyond winds
Type O star

LBV star

W-R star

Super Nova
Life’s End

- Have only been around $5 \times 10^5$ years
- Have lost $>40\%$ of initial mass
- Very dense core composed of heavy elements
Life’s End (cont.)

- Tend to end in some sort of Super Nova
  - WC stars will go as type Ic SNs
  - WN stars will go as type Ib SNs or type IIls
Spectra

- No observed absorption lines in W-R stars
  - Stellar wind is massive and hot
  - Absence of Hydrogen
- Stars classified by chemical abundance
Spectral evolution from O type to W-R

- O7 Main Sequence
- O8 Super Giant
- WN7 Wolf-Rayet
- WC8 Wolf-Rayet

http://vela.astro.ulg.ac.be/themes/stellar/massive/wr_e.html
Dust and Gases

- Circum stellar gases can form dust (larger molecules)
  - Generally formed by cooler stars (RSGs)
  - Also formed in collisions of stellar winds – shocks
- Optically thick to long wavelengths
  - Difficult to see inside of the stellar winds
  - Difficult to determine properties of star
Can learn about dust formation and radiation production

- Formation of dust is present in large mass stars, binaries, and supernovae
- Can determine properties of stellar interior from observations in this range.
Dust (properties)

- Excess temperatures could be explained by free-free emission in the circumstellar clouds.

- Grain Temperature:
  \[ T_g = T_\star \left( \frac{F_\star}{4F_s} \right)^{1/3} \]

- Radius of star:
  \[ R_s = R_\star \left( \frac{T_\star F_s}{T_s F_\star} \right)^{1/2} \]

- Variables:
  - \( T_g \): grain temp
  - \( T_\star \): star temp
  - \( T_s \): shell temp
  - \( F_\star \): radiation flux from star
  - \( F_s \): radiation flux from shell
W-R stars are very hot, massive stars characterized by strong stellar winds, lack of H, and intense, broad emission lines.

Accepted to be part of normal evolution of very massive stars

Spectra and dust formations of these stars can tell us about the star’s properties


