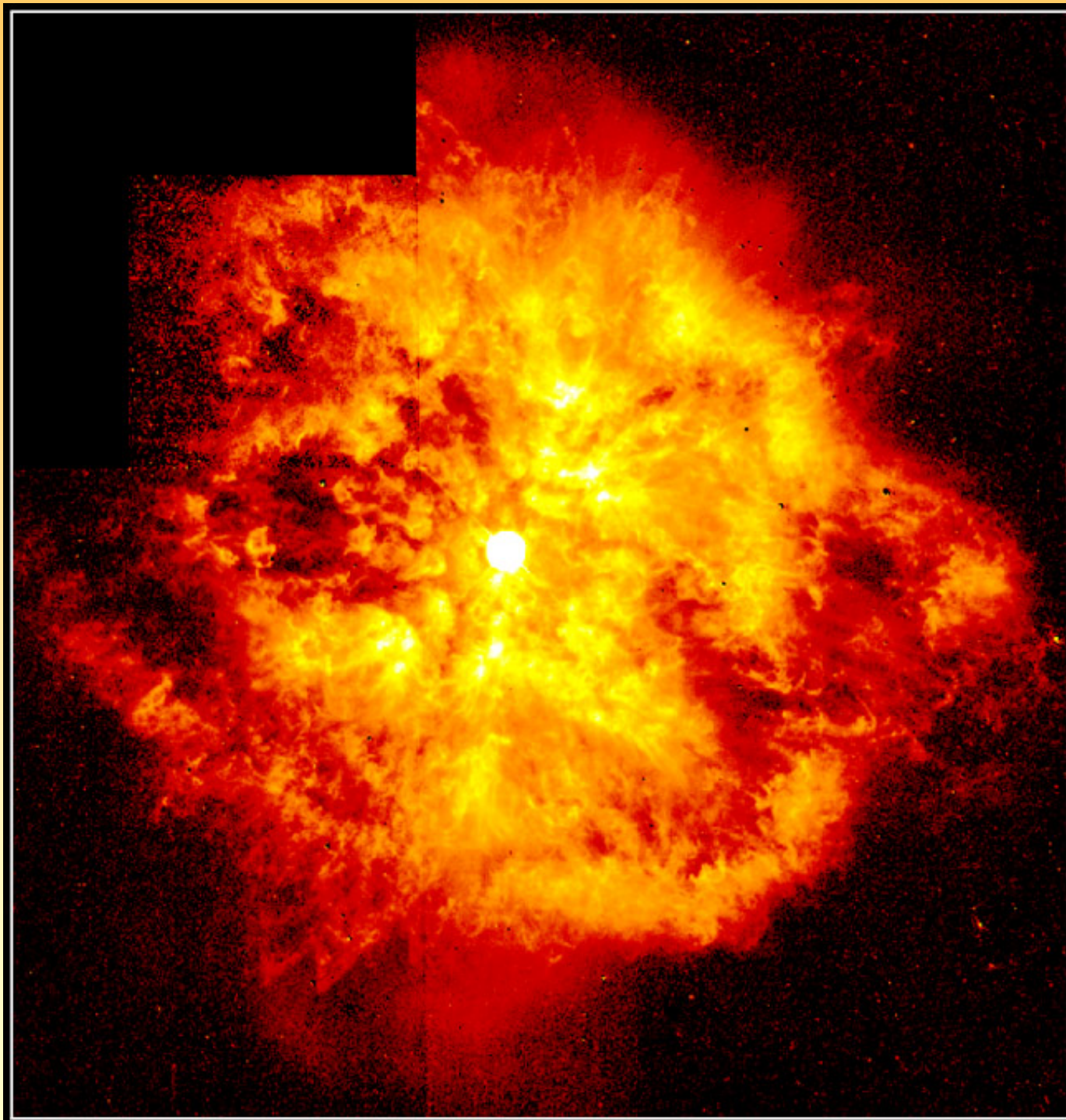


# Wolf Rayet Stars

*Modern Research*

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*Picture made by Hubble Space Telescope, of Wolf Rayet Star WR 124*

# Overview

- Introductory
- Spectral lines
- Stellar winds
- Summary

# Introductory

- Mass 10-25  $M_{\odot}$
- Origin: 40  $M_{\odot}$  O-type stars
- Limit for solar metallicity 25  $M_{\odot}$
- Findings
  - ~150 in Milky Way
  - ~100 in Large Magellanic Cloud
  - 12 in Small Magellanic Cloud

# Subtypes

- WN type
  - He and N lines
- WC type
  - He and C lines and some O
- WO type
  - Rare
  - Much like WC

# Evolution

- $M > 75 M_{\odot}$ 
  - $O \rightarrow WN(H\text{-rich}) \rightarrow LBV \rightarrow WN(H\text{-poor}) \rightarrow WC$   
 $\rightarrow SN$
- $M = 40 - 75 M_{\odot}$ 
  - $O \rightarrow LBV \rightarrow WN \rightarrow WC \rightarrow SN$
- $M = 25 - 40 M_{\odot}$ 
  - $O \rightarrow LBV/RSG \rightarrow WN \rightarrow SN$

# Spectral lines: subtypes

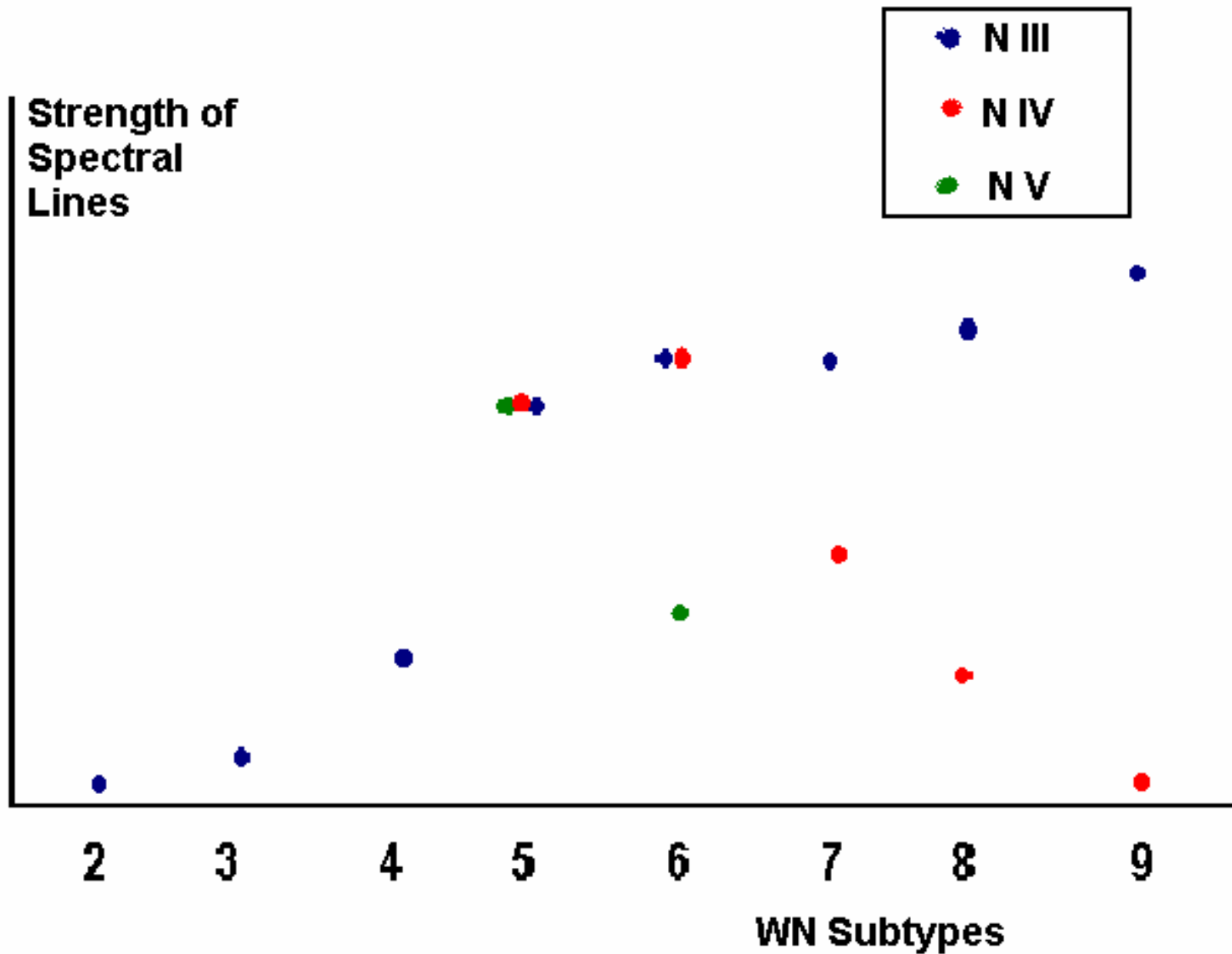
- Subtypes based on spectral lines
  - (WN, WC)
- Subtypes can be divided

# WN Subtype

- WN
  - He and N lines
- WN 2 to WN 5 : early WN stars
- WN 7 to WN 9: late WN stars
- WN 6: early or late



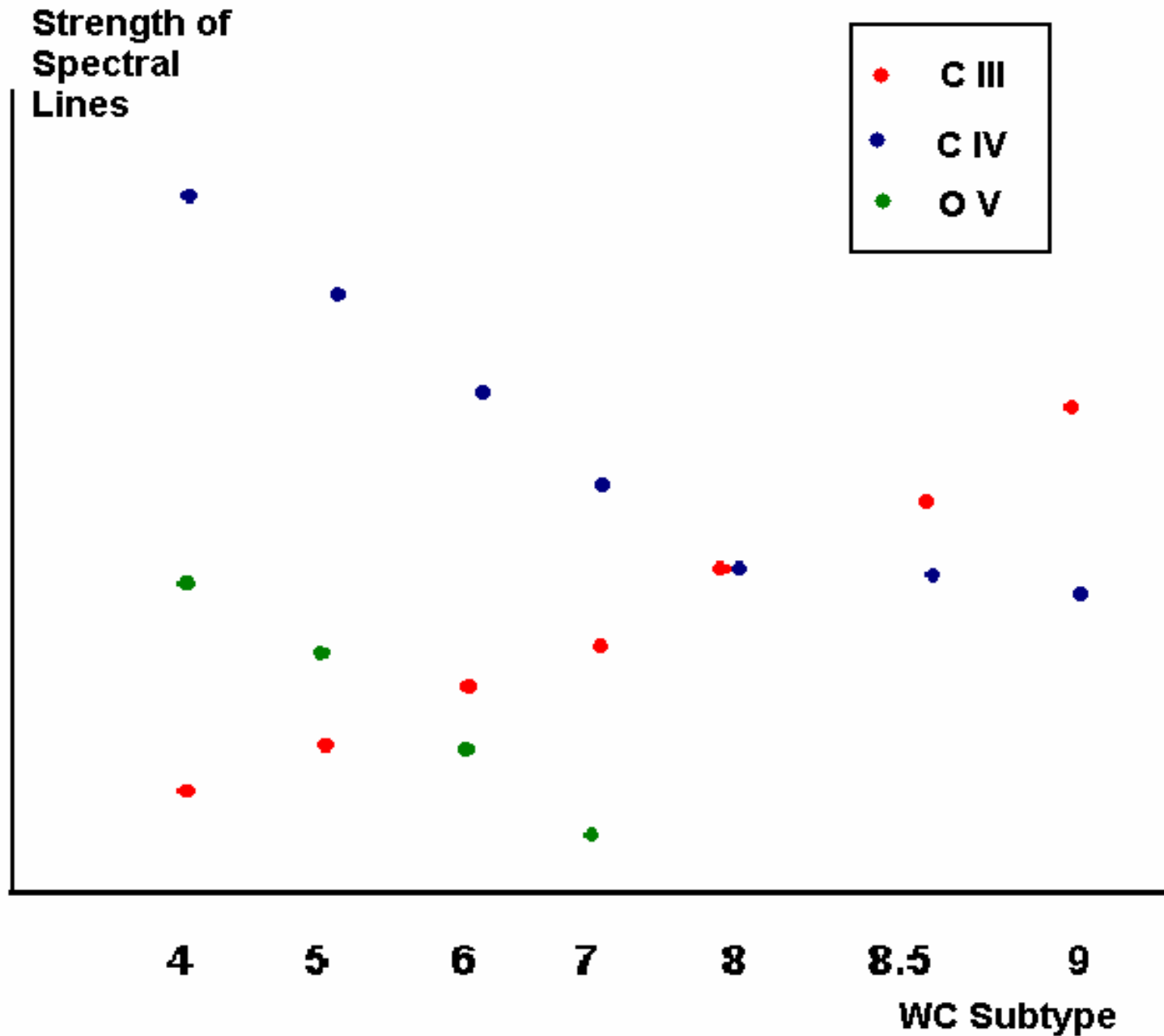
# WN Subtype



# WC Subtypes

- WC
  - He, C and some O
- WC 4 to WC 6 : early
- WC 7 to WC 9 : late

# WC Subtypes

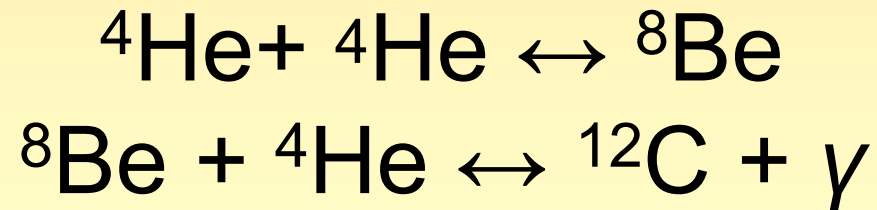


# Elements in WN Stars

- Late WN : some H ( $\sim 15\%$ )
- Early WN : H depleted
- Catalysts in the CNO cycle
  - N  $\sim 1\%$
  - C  $\sim 0.05\%$
  - O probably the same

# WN / WC Stars

- Transitional stage
- C ~ 5 %
- N ~ 1 %



# WC Stars

- He burning continues
- N lines are absent
- Heavier elements form
  - e.g. Fe, Ne, Mg

# Radiation driven winds

- Outflow of material
- Line driving
- Force of many spectral lines
- $v_{\infty} > v_{\text{esc}}$
- $v_{\infty} \sim 1500 \text{ km s}^{-1}$
- $dM/dt \sim -6 \cdot 10^{-6} M_{\odot} \text{ yr}^{-1}$

# Radiation driven winds

- Castor, Abbott & Klein (1975)

$$v(r) = v_{\infty} \left( 1 - \frac{R^*}{r} \right)^{\beta}$$

- Metallicity dependent winds

$$\log(\dot{M}/M_{\odot} \text{yr}^{-1}) = -11.00 + 1.29 \log L/L_{\odot} + 1.74 \log Y + 0.47 \log Z$$



# Summary

- Late stage of star evolution
- Originated from heavy stars
- Typical spectral lines
  - WN, WC
- Material swept out by radiation driven winds