Mass Loss from Red Giants

D. Reimers, R. Baade, H.-J. Hagen
Hamburger Sternwarte, Universität Hamburg
Halo stars - Pop II

Only indirect evidence:

• masses of RR Lyr stars
• subdwarfs

⇒ A star of 1 $M_{\odot}$ loses $\sim 0.2$ $M_{\odot}$ on the 1. RGB

Where is the gas from red giant mass loss in globular clusters?

There is not a single measurement of $dM/dt$ for a Pop II star!
Pop I stars

Extensive direct evidence
Winds in red giants, AGB stars, …

Reliable mass-loss rates available?
For only half a dozen stars!

Reliable mass-loss rates available as a function of stellar parameters? No!
Mechanism known?

- red giants: no
- AGB stars: may be

Best indirect evidence

white dwarfs in galactic clusters:

- 4 WDs in NGC 2516: $M_{\text{WD}} \approx 8 M_{\odot}$
- Initial - final mass relation for white dwarfs
Most reliable mass-loss rates are from binaries where a companion probes the wind of the giant.
<table>
<thead>
<tr>
<th>Star</th>
<th>$\dot{M}$ ($M_\odot$ yr$^{-1}$)</th>
<th>$v_w$ (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$ Her</td>
<td>$2.4 \times 10^{-7}$</td>
<td>8</td>
</tr>
<tr>
<td>$\zeta$ Aur</td>
<td>$5 \times 10^{-9}$</td>
<td>70</td>
</tr>
<tr>
<td>$\alpha$ Sco</td>
<td>$\sim 10^{-6}$</td>
<td>20</td>
</tr>
<tr>
<td>32 Cyg</td>
<td>$1.5 \times 10^{-8}$</td>
<td>90</td>
</tr>
<tr>
<td>Further stars: 31 Cyg, 22 Vul, $\delta$ Sge, HR 6902</td>
<td></td>
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<tr>
<td>$\alpha$ Ori</td>
<td>$2 \times 10^{-6}$ (21 cm H I)</td>
<td>11</td>
</tr>
</tbody>
</table>
How reliable are these numbers?
The most (best) studied system is \( \alpha \) Sco A + B:

- Optical: Kudritzki & Reimers (1978) \( \Rightarrow 7 \times 10^{-7} \, M_\odot \, \text{yr}^{-1} \)
- Radio: Hjellming & Newell (1983) \( \Rightarrow 2 \times 10^{-6} \, M_\odot \, \text{yr}^{-1} \)
- IUE: Hagen, Hempe & Reimers (1987) \( \Rightarrow 2.5 \times 10^{-7} \ldots 1.6 \times 10^{-6} \, M_\odot \, \text{yr}^{-1} \)
- HST: Baade & Reimers (2007) \( \Rightarrow \) Mass loss episodic, continuous wind \( \sim 3 \times 10^{-7} \, M_\odot \, \text{yr}^{-1} \)
- UVES / VLT Nebula \( \Rightarrow 7.9 \times 10^{-7} \, M_\odot \, \text{yr}^{-1} \)
Optical observations of $A + B$

- Ti II in optical UV at 3383.8 Å + excited fine structure lines with the assumption of a spherically expanding wind

- $v($Ti II$) \Rightarrow$ Location of $\alpha$ Sco B relative to plane of the sky: 500 AU in front

- Spectral analysis of $\alpha$ Sco B
  \Rightarrow N (LyC)
  \Rightarrow H II - region predicted
  \Rightarrow M \approx 7 \times 10^{-7} M_\odot \text{ yr}^{-1}$
Kudritzki & Reimers (1978)
IUE

- Many ions: Fe II, Si II, O I, S II, Al II, ...
  P Cyg type profiles

- v.d. Hucht et al. (1980), Bernat (1982) ⇒ $10^{-5} \, M_\odot \, yr^{-1}$
  (from 0 eV lines!)
  IS Contamination

- Hagen, Hempe & Reimers (1987) ⇒ Fe II, Si II: $10^{-6} \, M_\odot \, yr^{-1} \pm \text{factor 3}$
Hagen et al. (1987)
Theoretical H II regions

\[ \dot{M} \approx 1.3 \times 10^{-6} \, M_\odot \, \text{yr}^{-1} \]

\[ \dot{M} \approx 4 \times 10^{-7} \, M_\odot \, \text{yr}^{-1} \]

Hagen et al. (1987)
Hagen et al. (1987)
VLA

Hjellming & Newell (1983)

Radio f-f emission from the H II region (optically thin)

⇒ \( N_{\text{LyC}} \approx 3 \times 10^{43} \) photons/s

⇒ \( \dot{M} \approx 2 \times 10^{-6} \, M_\odot \, \text{yr}^{-1} \)

(with an assumed position of B behind the plane of the sky)
HST / GHRS

Baade & Reimers (2007)

- P Cyg profiles with little reemission (small aperture compared to IUE LAP)
• multiple absorption lines (4 components)

Baade & Reimers (2007)
component 4 (at -20 km/s) is the continuous wind
• Ti II only seen in component 4
• depletion in components 2 and 3, IS contamination in component 1
• Al III shows that the B star is ~ 200 AU behind the plane of the sky
• continuous wind ~ $3 \times 10^{-7} \, M_\odot \, yr^{-1}$
• Episodic mass-loss? Shells, clouds? Geometry unknown!
Mid-infrared images of the CS dust

Marsh et al. (2001)
The Antares Nebula

• Discovered by O.C. Wilson & R.F. Sanford (1937) at Mt. Wilson ⇒ [Fe II] lines around the B star

Extensive discussion in Struve & Zebergs: Astronomy of the 20th Century p. 302 ff:
“It is strange that the nebulously around the B type star shows only emission lines of [FeII] and Sill but not those of hydrogen”

“metal rich environment”, “vaporized meteors”

Struve: “Improbable hypothesis which may have to be abandoned in the light of future work” (1962)
• Mapped by Swings & Preston (1978) with photographic long slit spectra taken with Coudé at 100” Mt. Wilson and 200” Mt. Palomar.

⇒ [Fe II] lines + Si II 3856/3862

Possibly Hα: very weak (apparently seen on one of Deutsch‘s plates)

Strong lines in a region with 3.5” diameter

Weak emission extends up to 15”
• UVES / VLT (2006)

R = 80 000 long slit 0.3 /10”, Seeing 0.5” - 0.7”, 100 spectra

UVES spectra show heavy contamination with M giant light even 10” from the M star
⇒ extremely elaborate data reduction

New results:
– Hα, Hβ, Hγ, Hδ, Hε seen, weaker than [FeII]
  Hα extent identical with f-f emission (VLA)
– [Fe II], Fe II, Si II, [Ni II]
  but no [O II], [O III], [S II], ...
6562.85 Halpha
6347.11 Si II
– [FeII] also observed outside the H II region

At 45° position, [Fe II] extends all along the slit
⇒ excitation by Fe II UV resonance scattering
e.g. scattering on UV FeII 2344.2 Å (observed)
⇒ downward transition 5169, 5018, 4924 Å (observed)
⇒ upper level of strong [Fe II] 4287, 4359 Å
Fe II
IRON Z = 26
H II region geometry

• Hα, Si II come from the H II region
• [FeII] from the H II/H I boundary = shock front
• bow shock with bended tail due to movement of the B star and \( t_{\text{rec}} \leq t_{\text{wind travel}} \)
• the B star is \( \sim 200 \) AU behind the plane of the sky of the M star
• orbit of \( \alpha \) Sco A + B: \( \sin i \approx 1 \)
  \( P \approx 2600 \) years
• mass-loss rate from the shape of the H II region:
  \( (7.9 \pm 3.5) \times 10^{-7} \) M\(_\odot\) yr \(^{-1}\)
Contour plot of the Hα emission compared to the radio data
Conclusions

• Mass loss rates of red giants are difficult to measure
• Multiple shells (episodic mass loss) common
• A lot of research is necessary before we understand mass loss in red giants
• At present, indirect methods for determining the total loss of mass in advanced stages of evolution are probably more accurate
Figure References

• Hagen, H.-J., Hempe, K., & Reimers, D. 1987, A&A 184, 256