Mass Loss from Red Giants

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Halo stars - Pop II

Only *indirect* evidence:

- masses of RR Lyr stars
- subdwarfs

⇒ A star of 1 $M_\odot$ loses ~ 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!

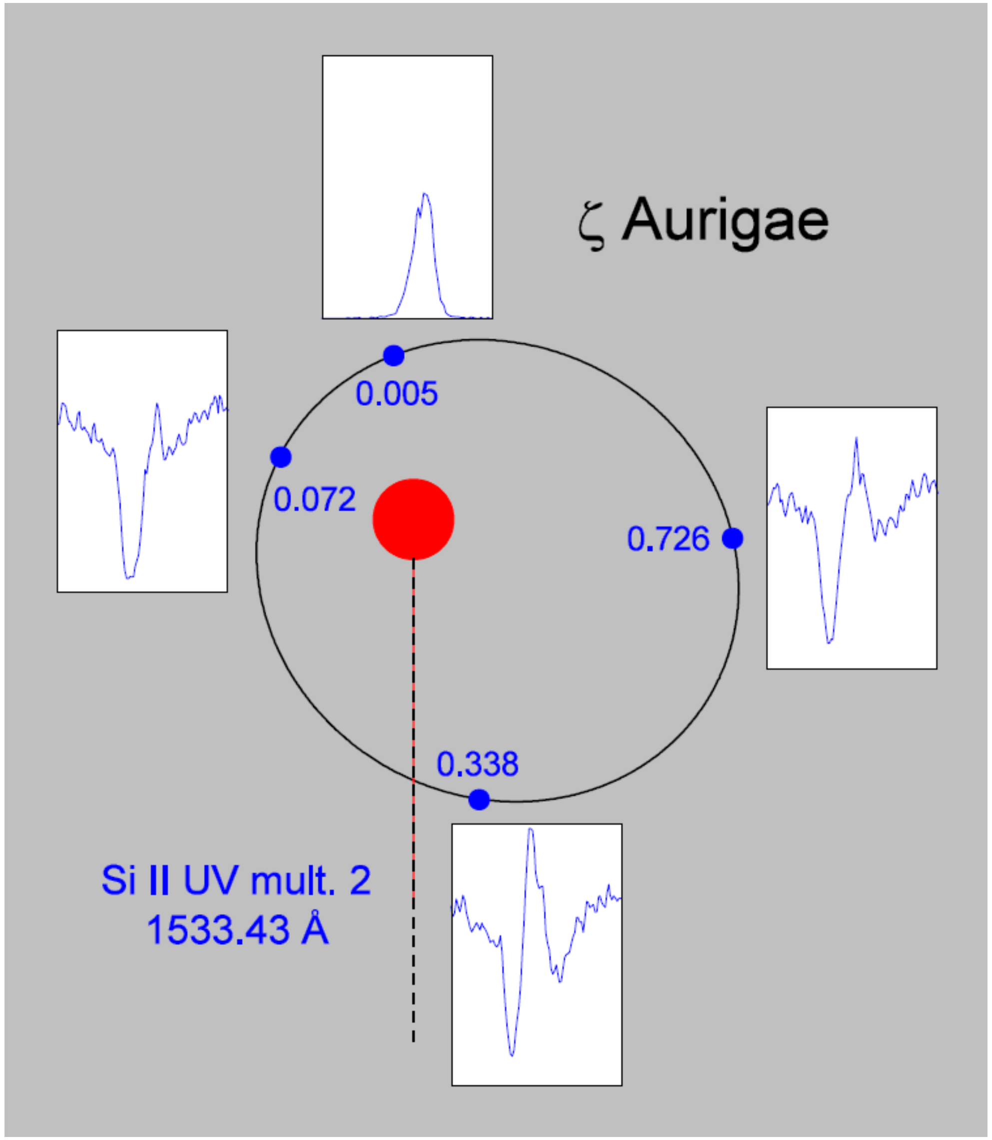
Mechanism known?
- red giants: no
- AGB stars: may be

Best indirect evidence

white dwarfs in galactic clusters:

- 4 WDs in NGC 2516: $M_{\mathrm{WD}} \approx 8\ \mathrm{M}_{\odot}$
- Initial - final mass relation for white dwarfs

Most reliable mass-loss rates are from binaries where a companion probes the wind of the giant.



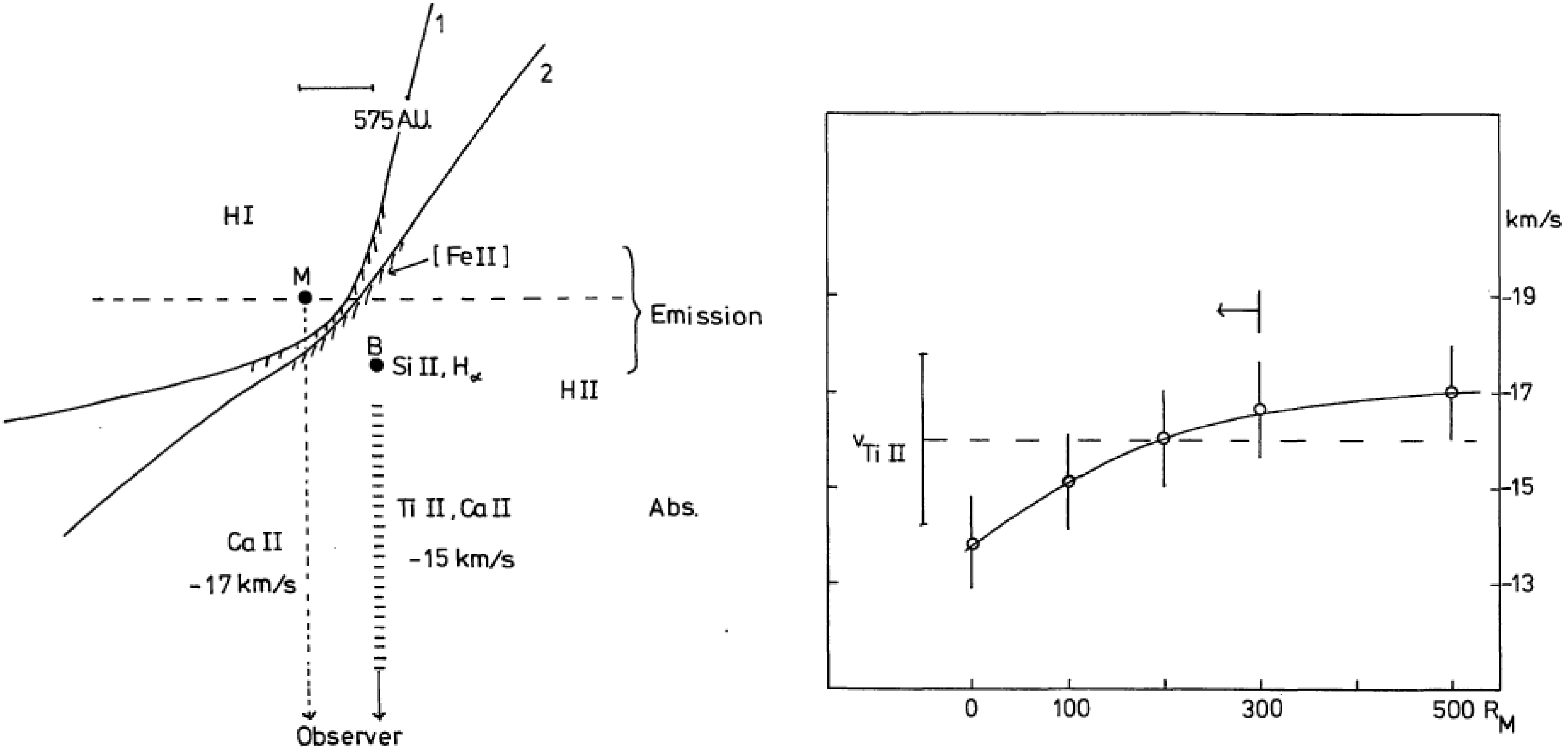
	$\dot{M}$ ($M_\odot$ yr^{-1})	v_w (km/s)
α Her	2.4×10^{-7}	8
ζ Aur	5×10^{-9}	70
α Sco	$\sim10^{-6}$	20
32 Cyg	1.5×10^{-8}	90
Further stars: 31 Cyg, 22 Vul, δ Sge, HR 6902		
α Ori	2×10^{-6} (21 cm H I)	11

How reliable are these numbers?
The most (best) studied system is α Sco A + B:

- Optical: Kudritzki & Reimers (1978) $\Rightarrow 7\times10^{-7}\ M_\odot\ yr^{-1}$
- Radio: Hjellming & Newell (1983) $\Rightarrow 2\times10^{-6}\ M_\odot\ yr^{-1}$
- IUE: Hagen, Hempe & Reimers (1987) $\Rightarrow$ $2.5\times10^{-7} \ldots 1.6\times10^{-6}\ M_\odot\ yr^{-1}$
- HST: Baade & Reimers (2007) $\Rightarrow$ Mass loss episodic, continuous wind ~ $3\times10^{-7}\ M_\odot\ yr^{-1}$
- UVES / VLT Nebula $\Rightarrow 7.9\times10^{-7}\ M_\odot\ yr^{-1}$

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) ⇒ Location of α Sco B relative to plane of the sky: 500 AU in front
- Spectral analysis of α Sco B
  ⇒ N (LyC)
  ⇒ H II - region predicted
  ⇒ $M \approx 7 \times 10^{-7}\, M_\odot\ \mathrm{yr}^{-1}$



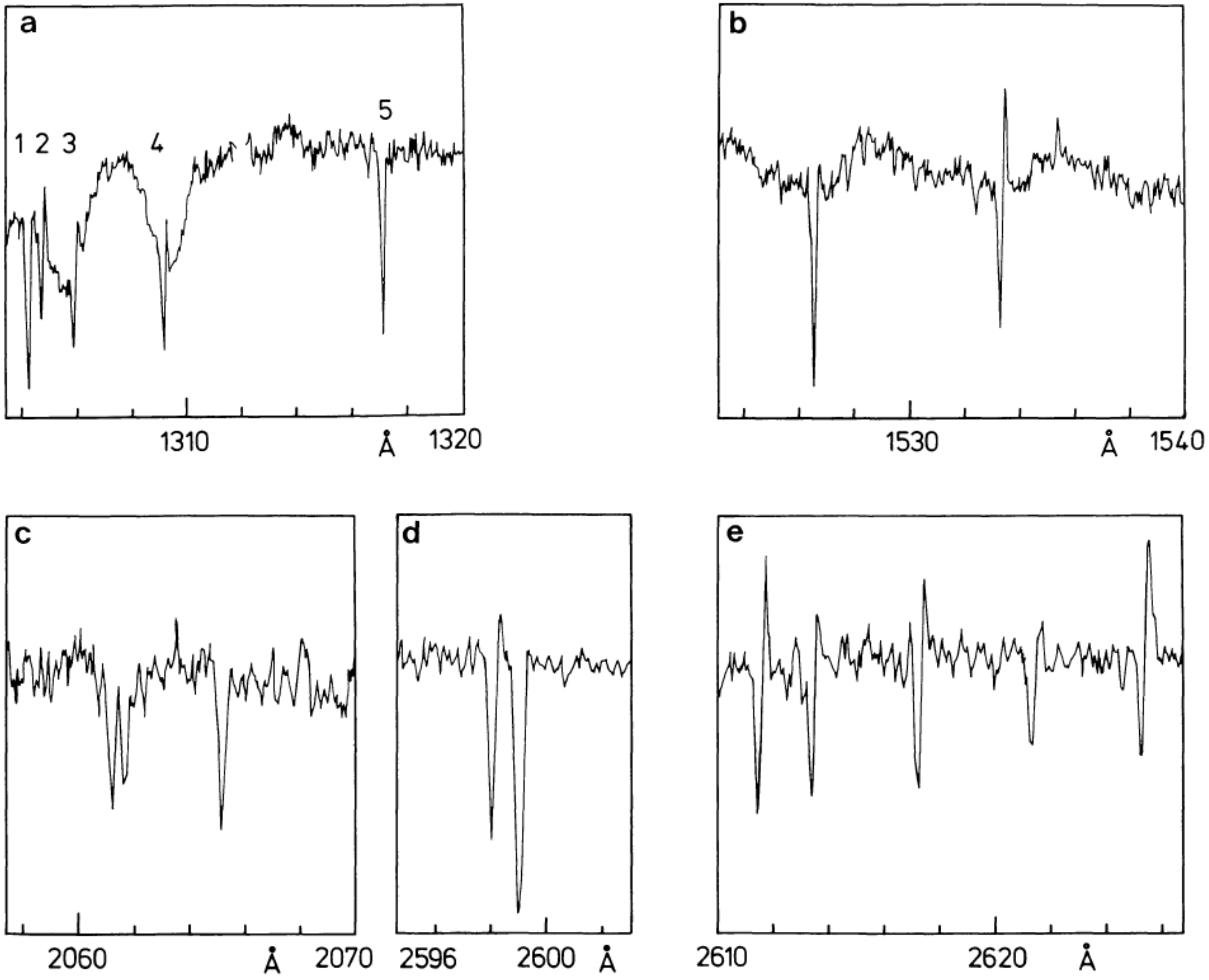
Kudritzki & Reimers (1978)

IUE

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

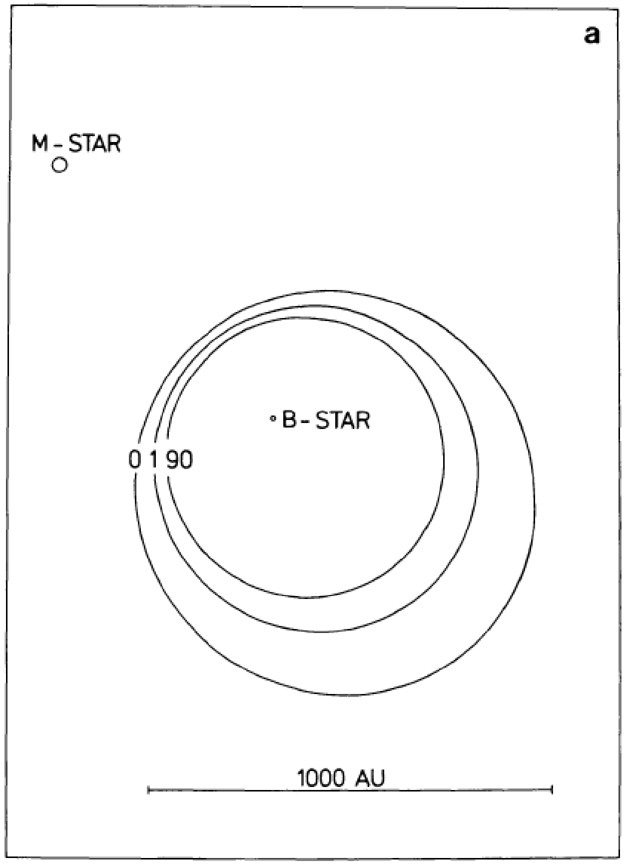
- v.d. Hucht et al. (1980), Bernat (1982)
  $\Rightarrow 10^{-5} M_{\odot} yr^{-1}$
  (from 0 eV lines!)
  IS Contamination

- Hagen, Hempe & Reimers (1987) ⇒
  Fe II, Si II: $10^{-6} M_{\odot} yr^{-1}$ ± factor 3

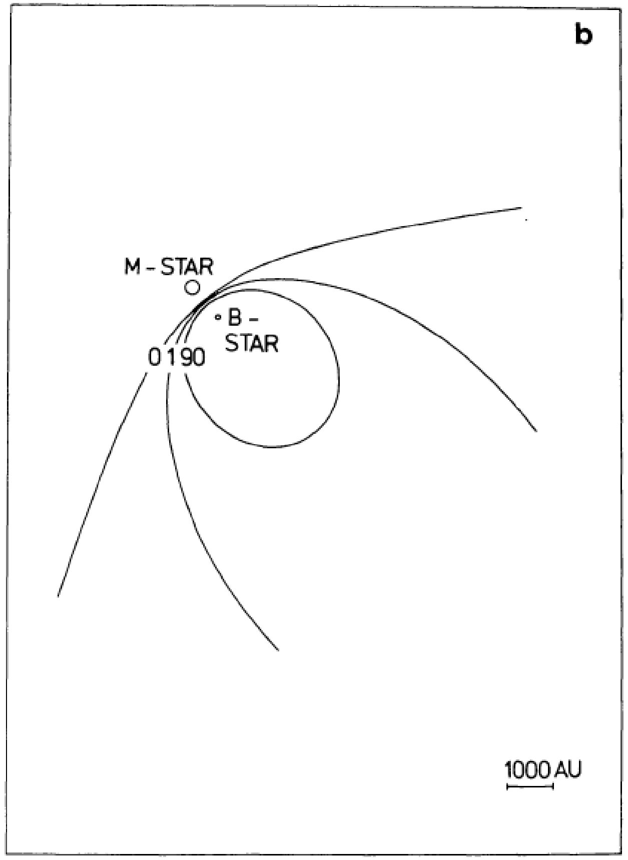


Hagen et al. (1987)

Theoretical H II regions

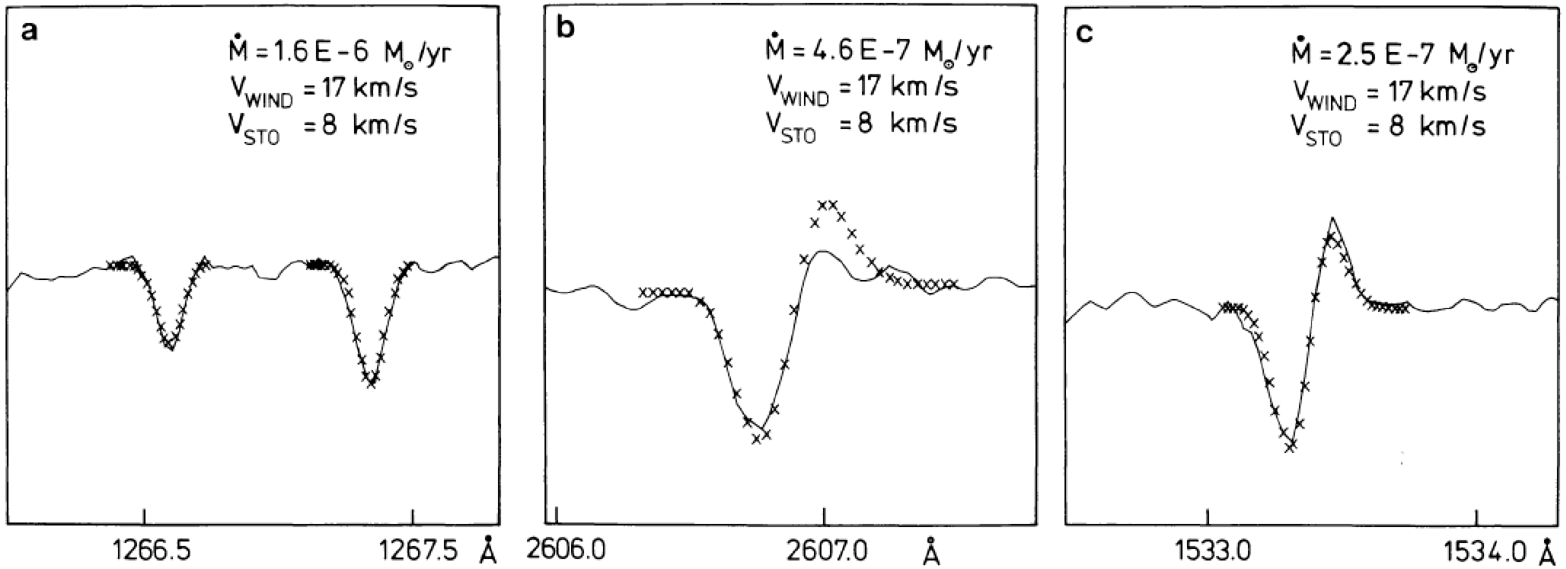


$\dot{M} \approx 1.3\times10^{-6}\,M_\odot\ \mathrm{yr}^{-1}$



$\dot{M} \approx 4\times10^{-7}\,M_\odot\ \mathrm{yr}^{-1}$

Hagen et al. (1987)



Hagen et al. (1987)

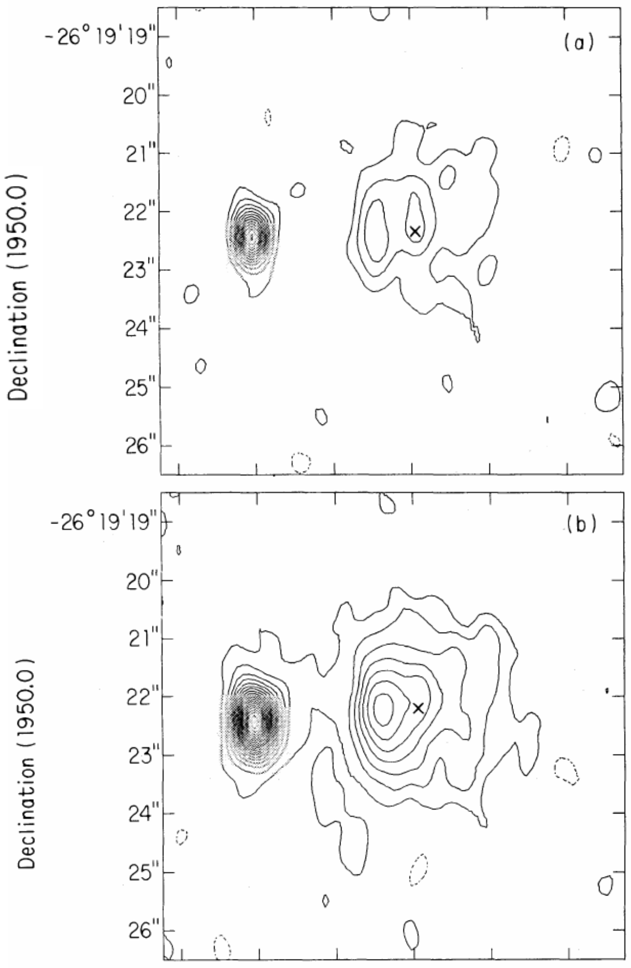
VLA

Hjellming & Newell (1983)

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

$\Rightarrow N_{LyC} \approx 3\times10^{43}$ photons/s

$\Rightarrow \dot{M} \approx 2\times10^{-6}\,M_{\odot}\,yr^{-1}$
(with an assumed position of B behind the plane of the sky)

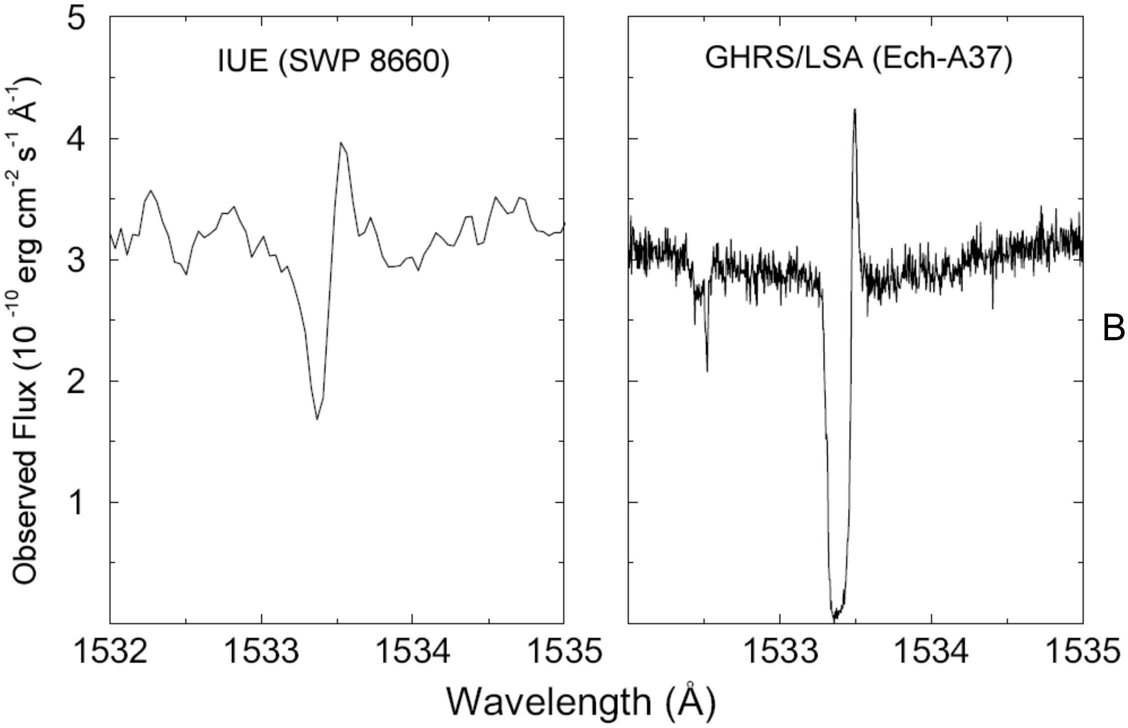


Hjellming & Newell (1983)

HST / GHRS

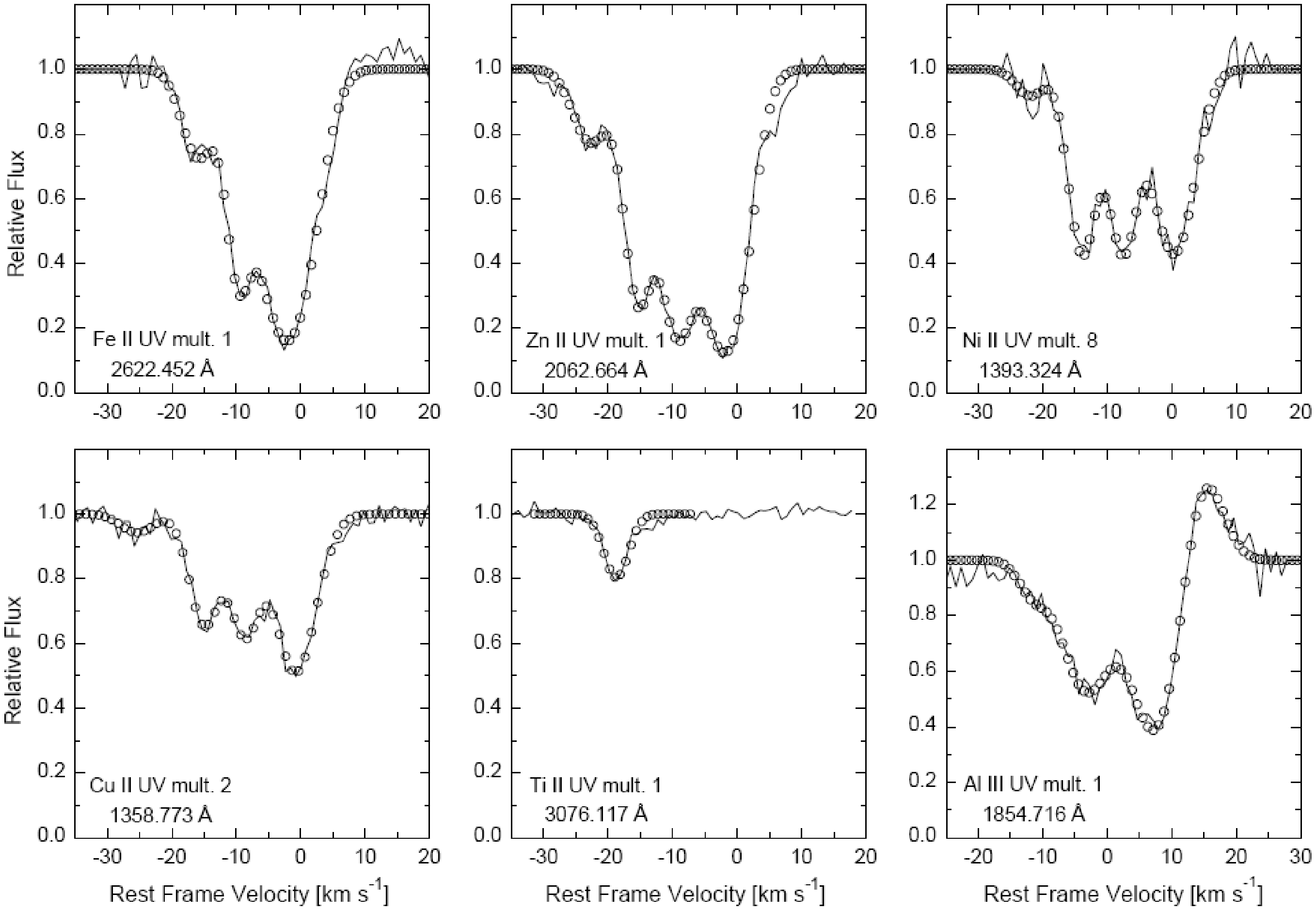
Baade & Reimers (2007)

- P Cyg profiles with little reemission (small aperture compared to IUE LAP)



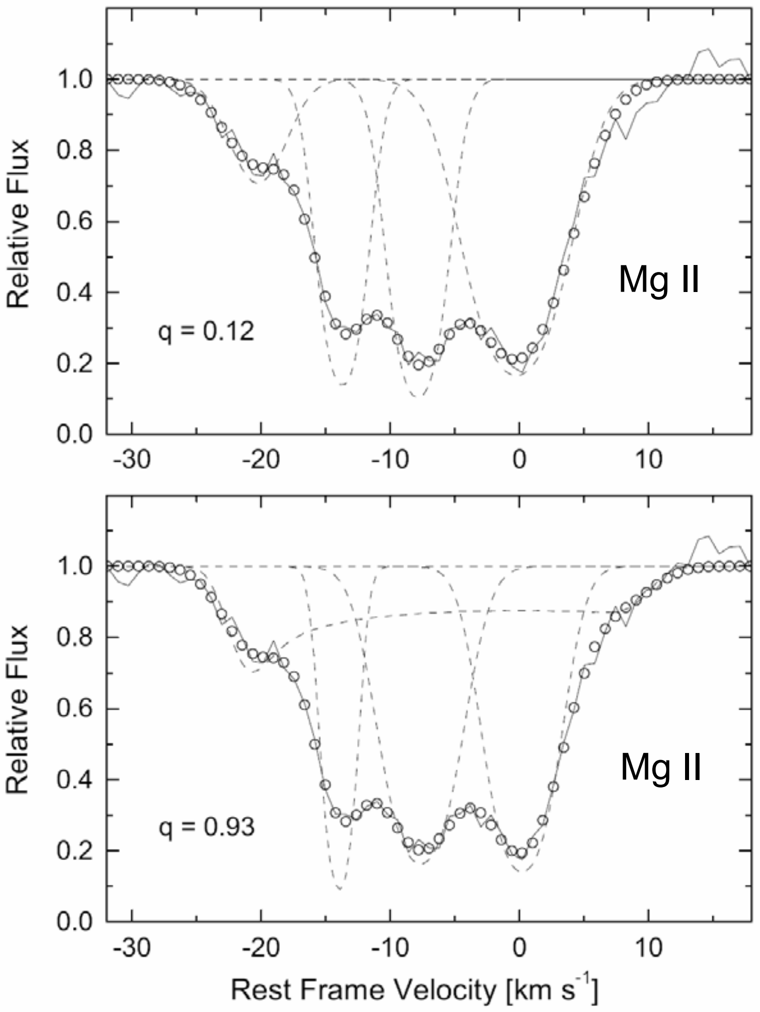
Baade & Reimers (2007)

- multiple absorption lines (4 components)



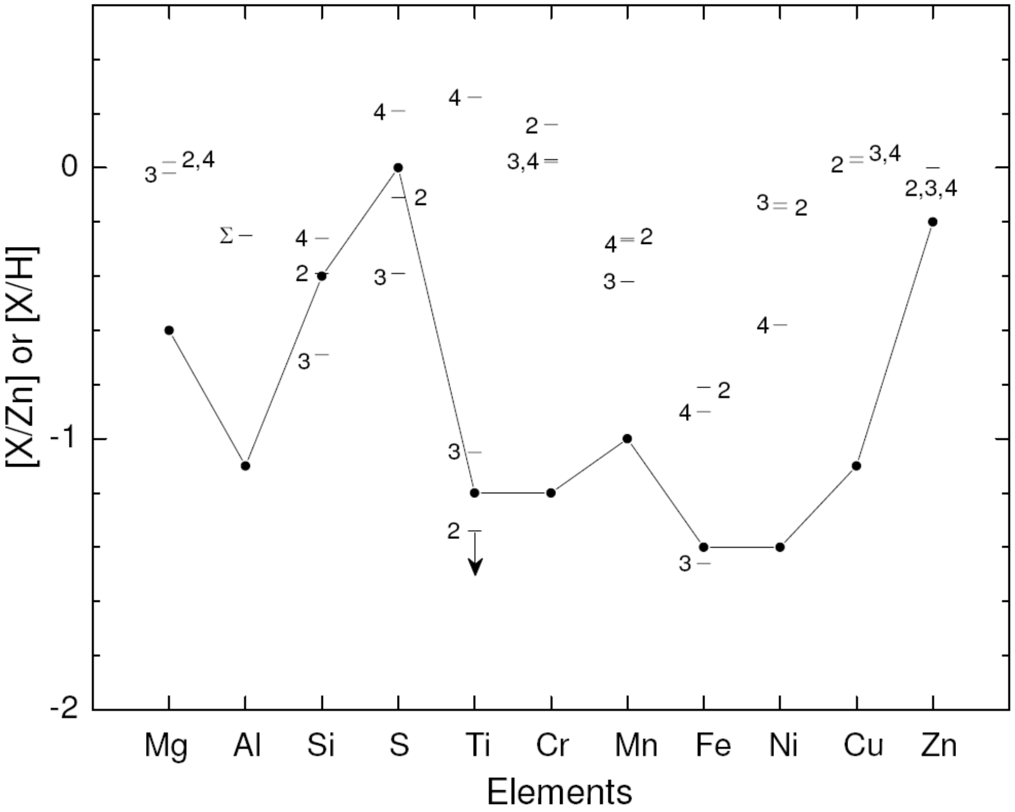
Baade & Reimers (2007)

- component 4 (at -20 km/s) is the continuous wind



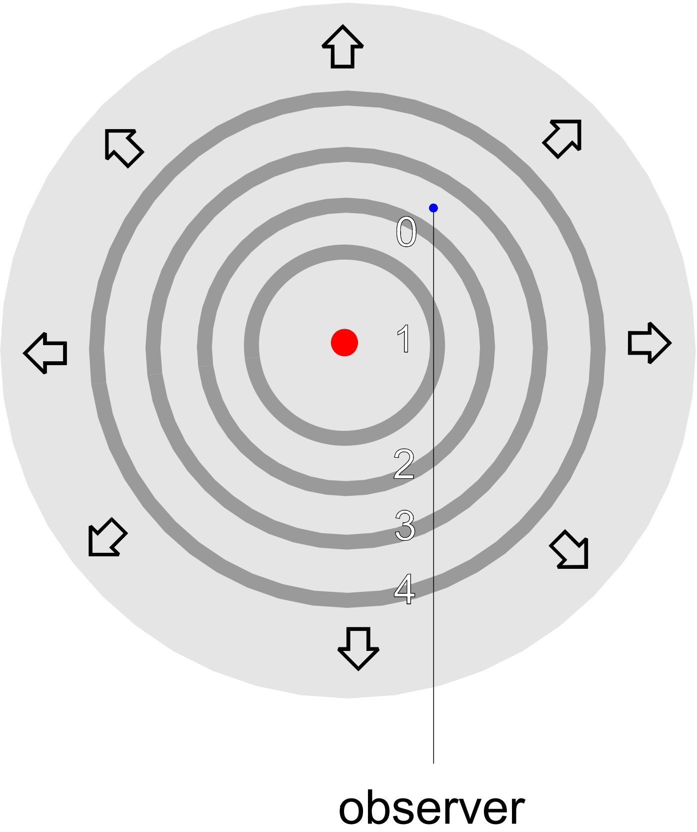
Baade & Reimers (2007)

- Ti II only seen in component 4
- depletion in components 2 and 3, IS contamination in component 1

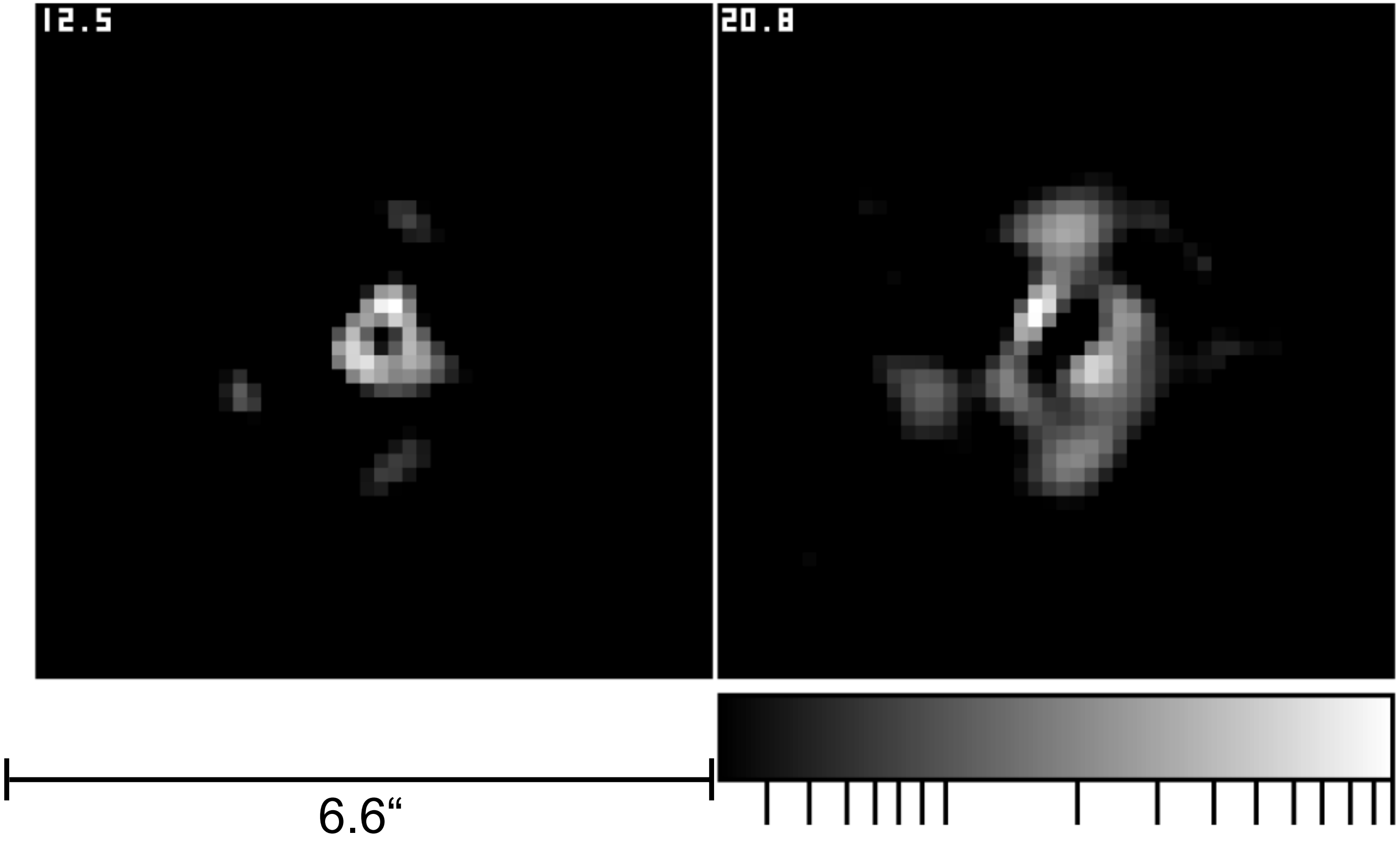


Baade & Reimers (2007)

- Al III shows that the B star is ~ 200 AU behind the plane of the sky
- continuous wind ~ $3\times10^{-7}\ M_\odot\ \mathrm{yr}^{-1}$
- 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 SiII 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.

$\Rightarrow$ [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)

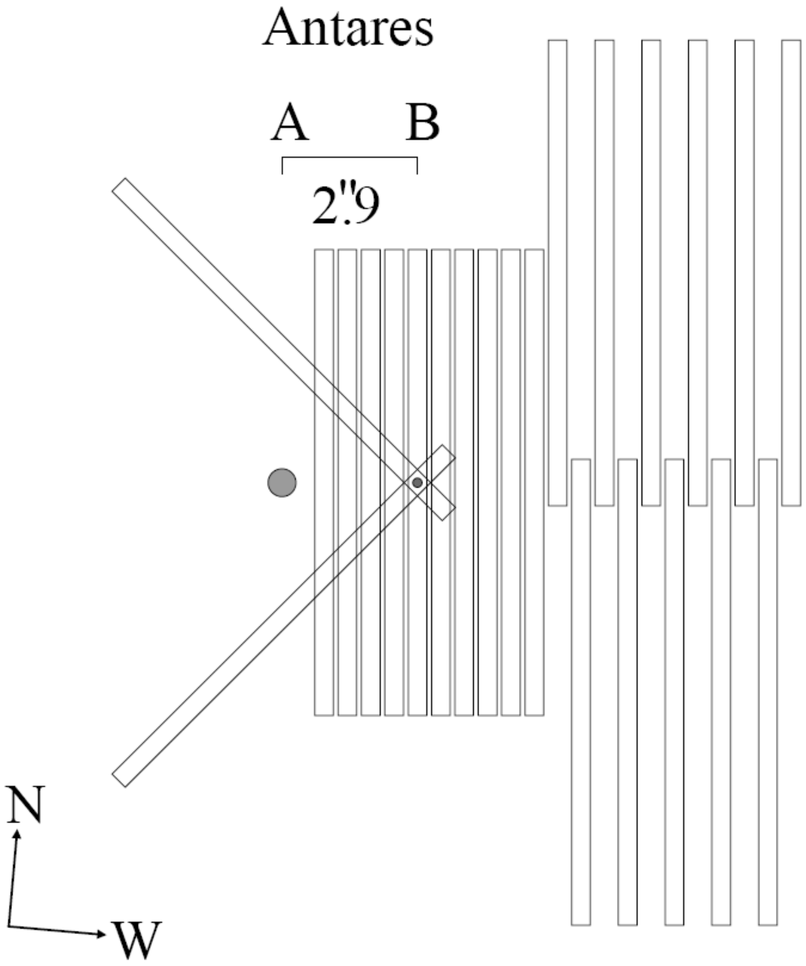
R = 80 000 long slit 0.3 /10”, Seeing 0.5” - 0.7”,
100 spectra

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

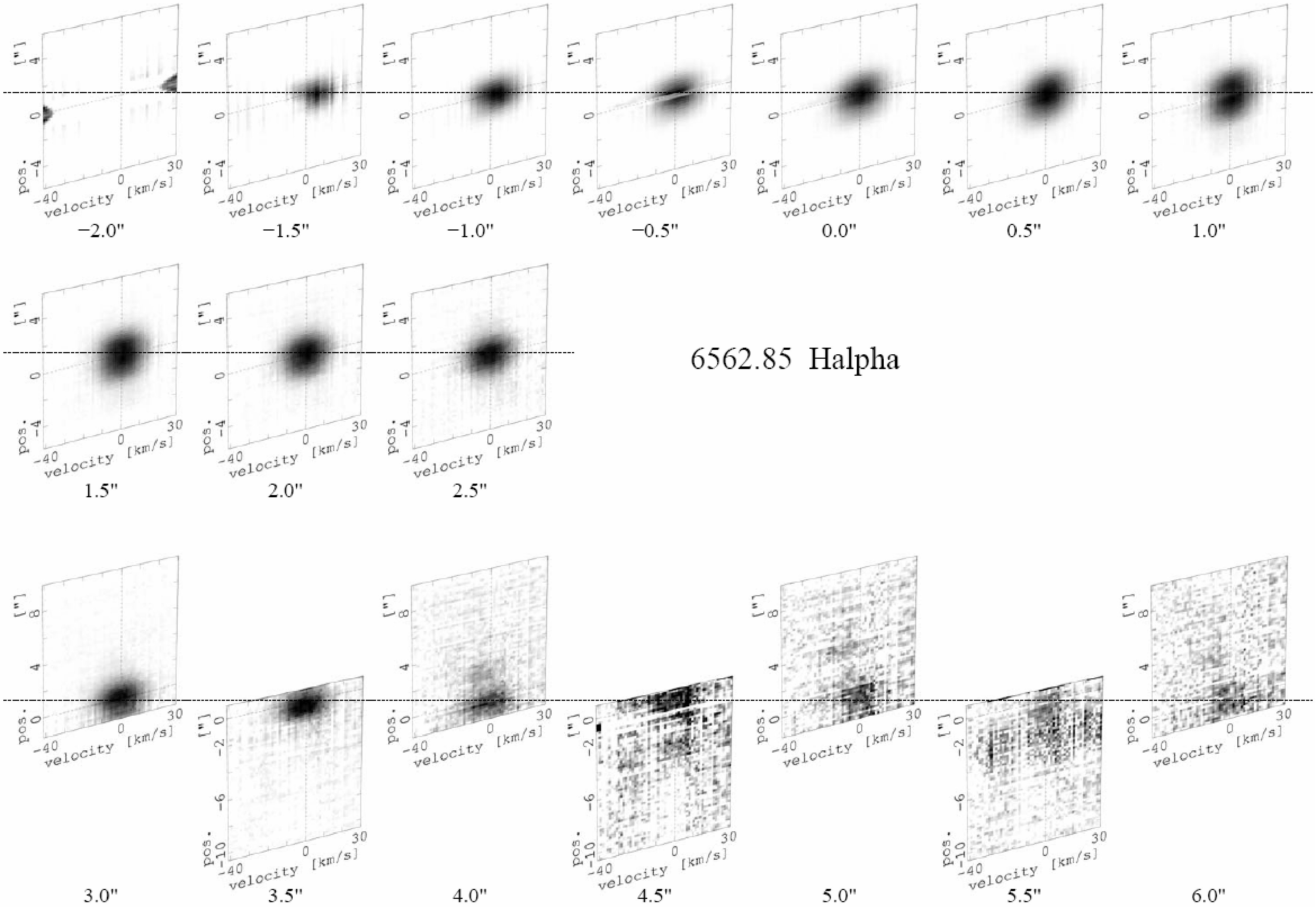
New results:

– 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], ...


Antares
A
B
$2''\!.9$
N
W

6562.85 Halpha

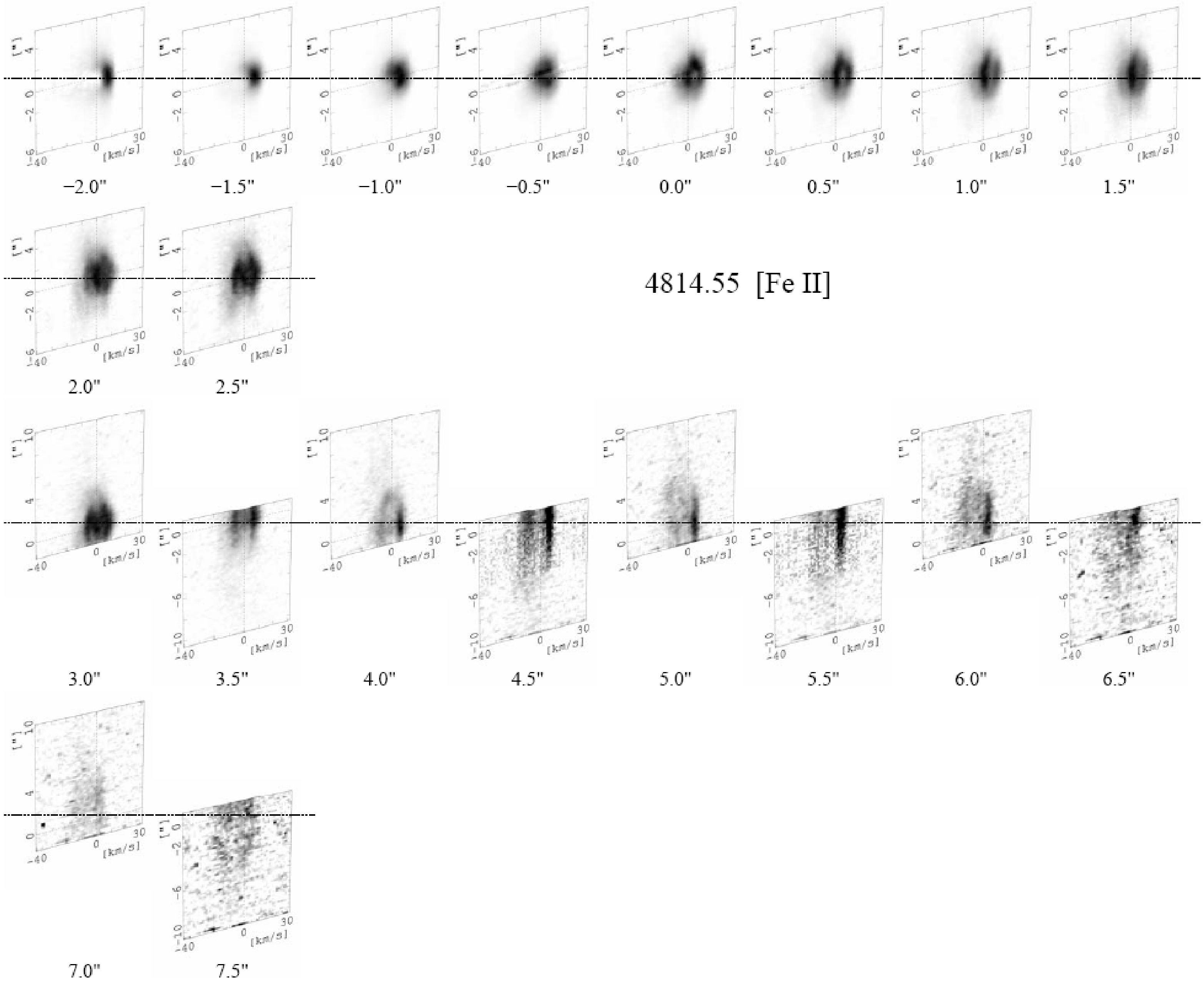


−2.0" −1.5" −1.0" −0.5" 0.0" 0.5" 1.0"

1.5" 2.0" 2.5"

3.0" 3.5" 4.0" 4.5" 5.0" 5.5" 6.0"

4814.55 [Fe II]

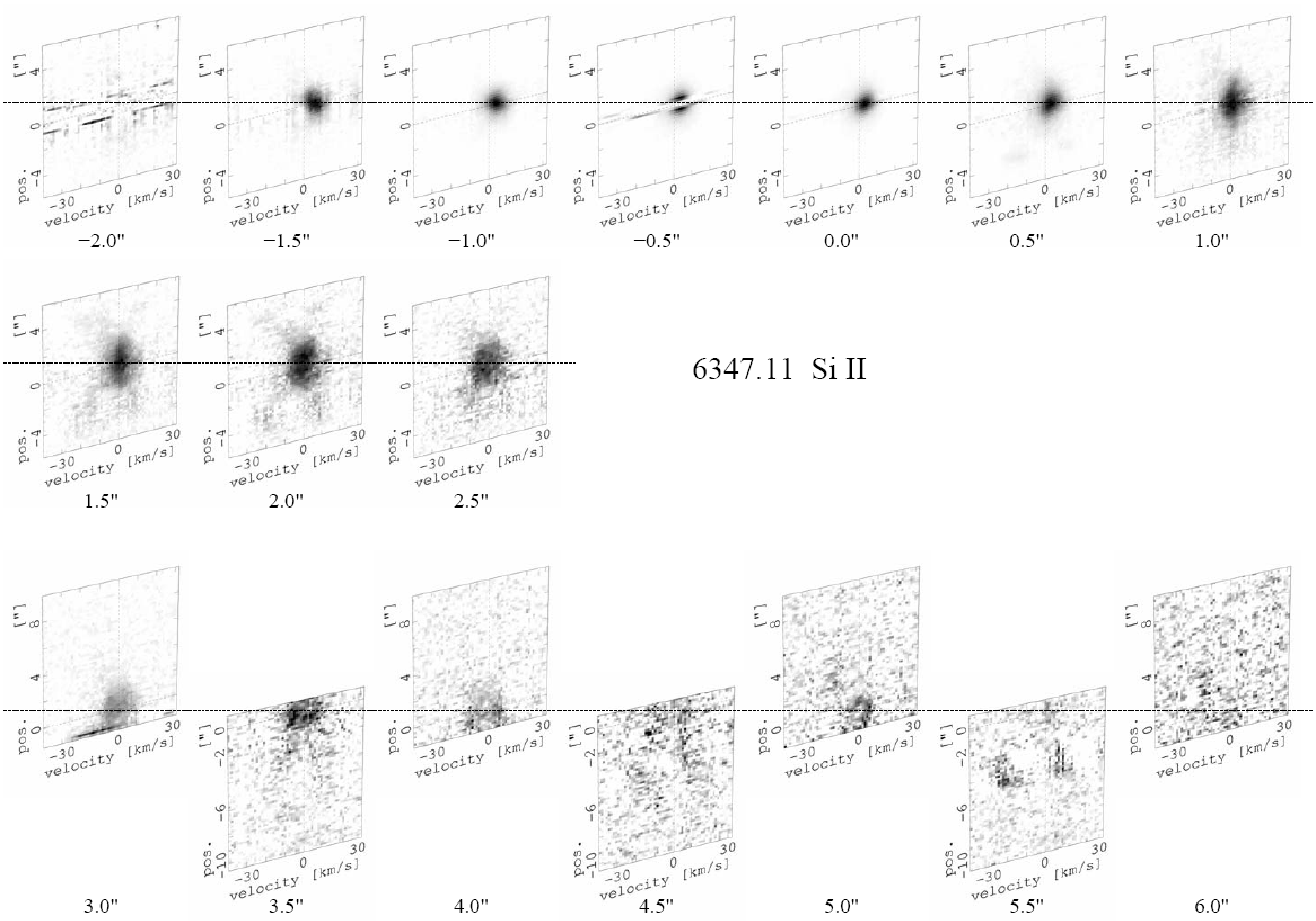

−2.0" −1.5" −1.0" −0.5" 0.0" 0.5" 1.0" 1.5"

2.0" 2.5"

3.0" 3.5" 4.0" 4.5" 5.0" 5.5" 6.0" 6.5"

7.0" 7.5"

6347.11 Si II



−2.0"
−1.5"
−1.0"
−0.5"
0.0"
0.5"
1.0"
1.5"
2.0"
2.5"
3.0"
3.5"
4.0"
4.5"
5.0"
5.5"
6.0"

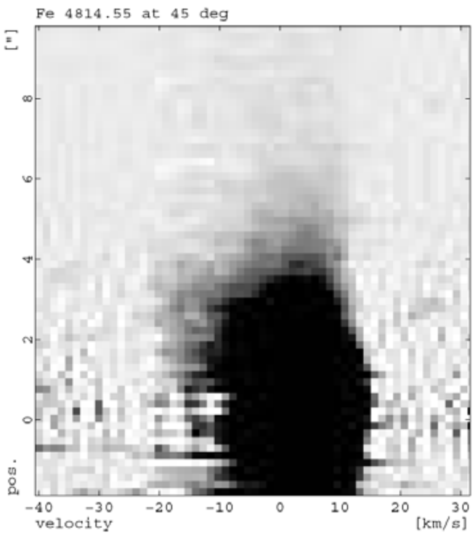
- [FeII] also observed *outside* the H II region

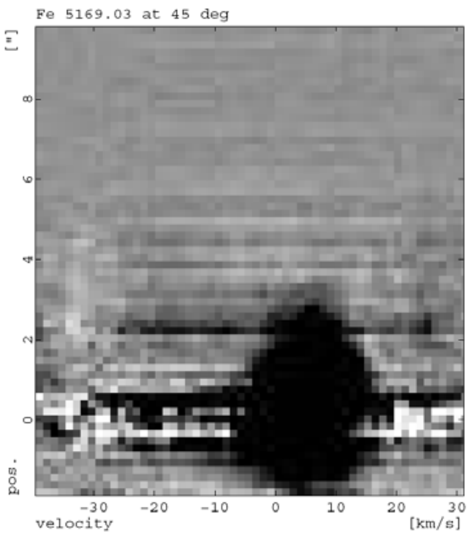
At 45° position, [Fe II] extends all along the slit

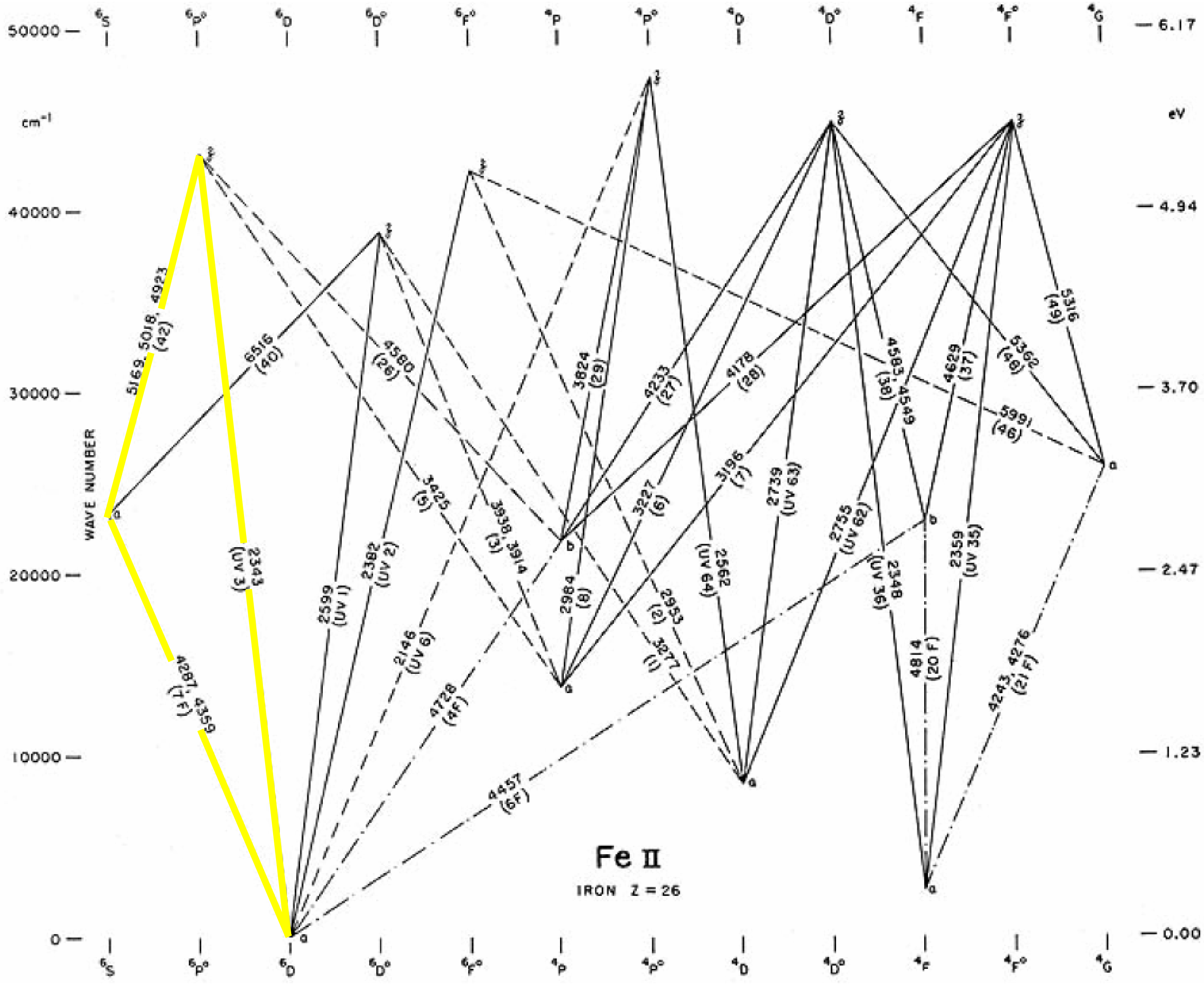
⇒ excitation by Fe II UV resonance scattering
e.g. scattering on UV FeII 2344.2 Å (observed)

⇒ downward transition 5169, 5018, 4924 Å (observed)

⇒ upper level of strong [Fe II] 4287, 4359 Å





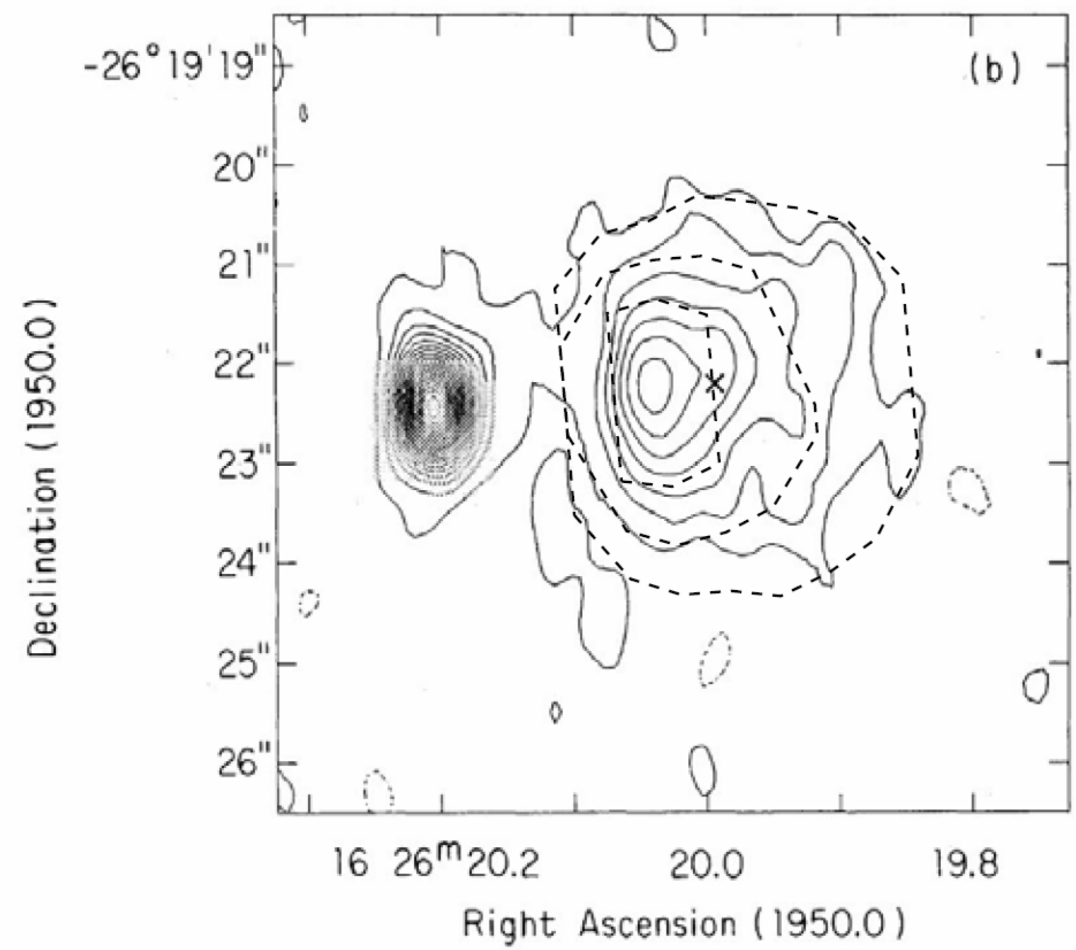


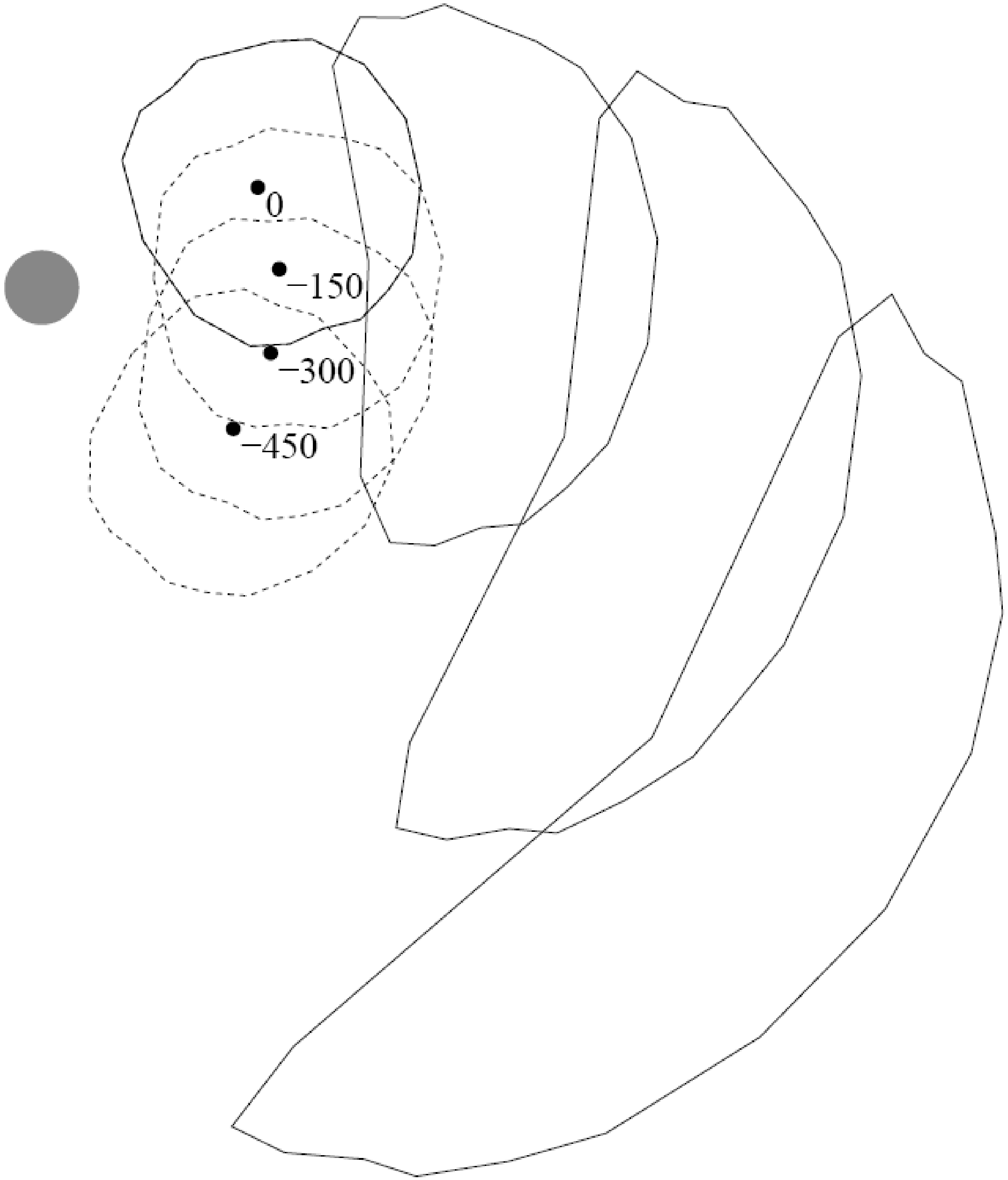
50000
40000
30000
20000
10000
0
cm⁻¹
WAVE NUMBER
eV
6.17
4.94
3.70
2.47
1.23
0.00
6S
6P°
6D
6D°
6F°
4P
4P°
4D
4D°
4F
4F°
4G
5169, 5018, 4923 (42)
4287, 4359 (7 F)
2343 (UV 3)
6516 (40)
4580 (26)
3425 (5)
3938, 3914 (3)
2599 (UV 1)
2382 (UV 2)
2146 (UV 6)
4728 (4F)
4457 (6F)
3824 (29)
2984 (8)
4233 (27)
3227 (6)
2953 (2)
3277 (1)
4178 (28)
3196 (7)
2562 (UV 64)
2739 (UV 63)
2755 (UV 62)
4583, 4549 (38)
2348 (UV 36)
4629 (37)
4814 (20 F)
2359 (UV 35)
5362 (48)
5991 (46)
5316 (49)
4243, 4276 (21 F)
a
b
z
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 $t_{rec} \leq t_{windtravel}$
- the B star is ~ 200 AU *behind* the plane of the sky of the M star
- orbit of α Sco A + B: sin i ≈ 1
  P ≈ 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




0
−150
−300
−450

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

- Baade, R., & Reimers, D. 2007, A&A (in press)
- Hagen,H.-J., Hempe, K., & Reimers, D. 1987, A&A 184, 256
- Hjellming, R. M., & Newell, R. T. 1983, ApJ 275, 704
- Kudritzki, R. P., & Reimers, D. 1978, A&A 70, 227
- Marsh, K. A., Bloemhof, E. E., Koerner, D. W., & Ressler, M. E. 2001, ApJ 548, 861