Detecting Signs of Wind Asymmetry in Wolf-Rayet Nebula

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Sitelle Science Meeting
Wendake (Qc), 11-14 May 2013,

WR Stars as Progenitors of GRB?

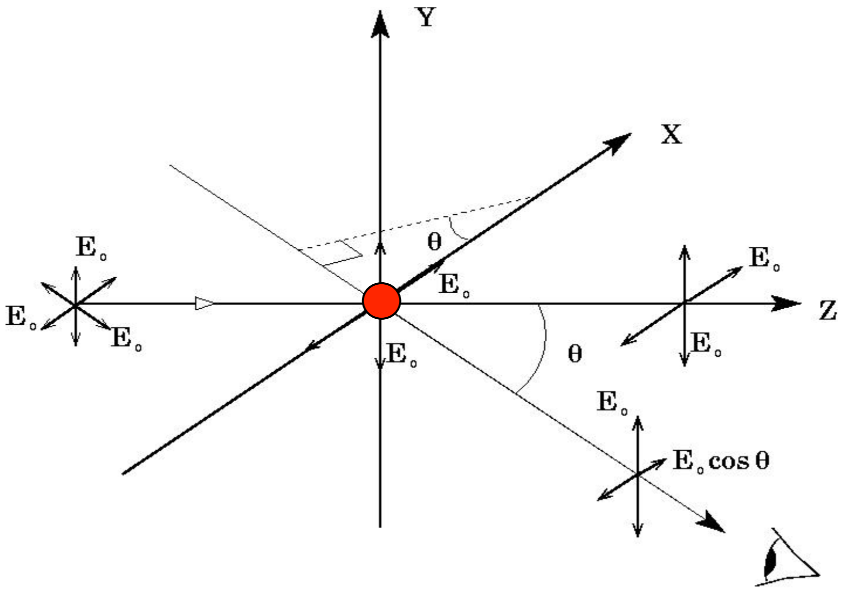
- WR stars are He-burning descendants of massive (> 25 $M_{\odot}$) O stars (although some can still be on Main Sequence). We still have a lot to learn on the evolution of massive stars
- Fast rotating WR stars have been identified as Gamma-Ray Burster progenitor candidates
- But do WR stars rotate fast? Evolution models predict that when the strong dense WR wind turns on, a large fraction of the angular momentum is lost
- So **fast rotating WR stars must be young** WR stars

WR Stars as Progenitors of GRB?

- How does one find young WR stars?
- Ejected nebula should dissipate after 80,000 years (van Marle et al. 2005), so **WR stars that have an ejecta nebula must be young**!
- Vink et al. (2010) find a strong correlation between the presence of an ejecta nebula and WR stars showing line de-polarization
- What is line de-polarization?

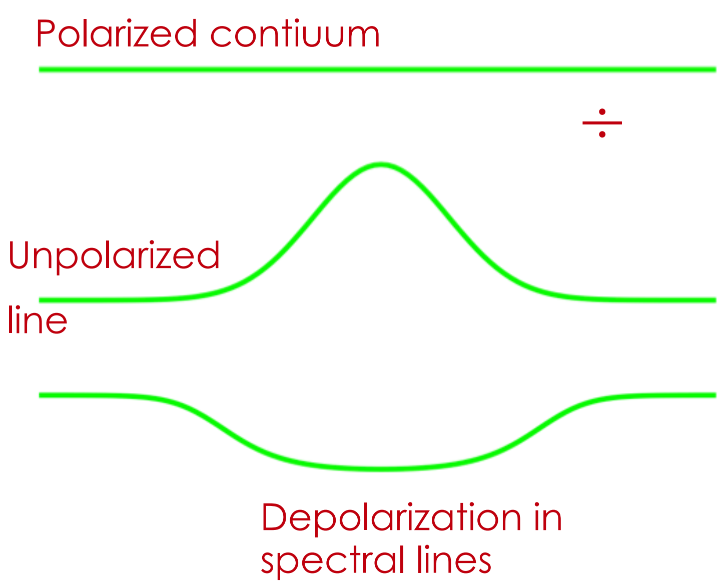
Line de-polarization

Polarisation by Thomson Scattering



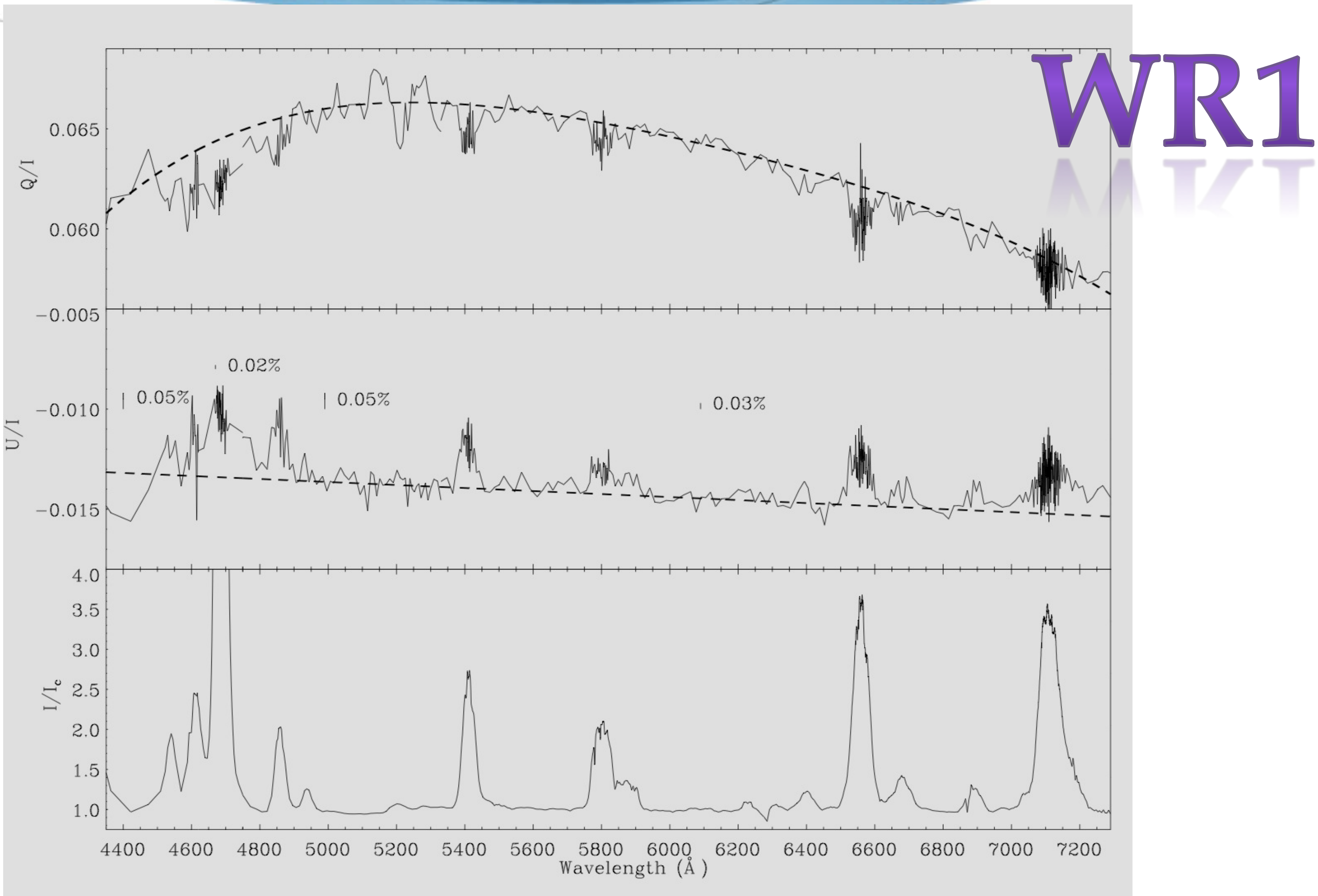
- Free electrons in WR winds scatter light generating linear polarization
- If the distribution of electrons is spherically symmetric, all contributions cancel, yielding no net polarization
- If there is an asymmetry in the wind, there will be a net polarization in the continuum

Line de-polarization



- The global asymmetry in the wind causes the continuum polarization by electron scattering
- Recombination lines will not be polarized; scattering lines will be but much less than continuum as they are formed further out in the wind were in electron density is less
- When polarized continuum is combined with un-polarized line flux, one has depolarisation of spectral lines

Example: ESPaDOnS Data of WR1



Signs of asymmetry of WR Winds

- A correlation between ejecta nebula and line de-polarization:

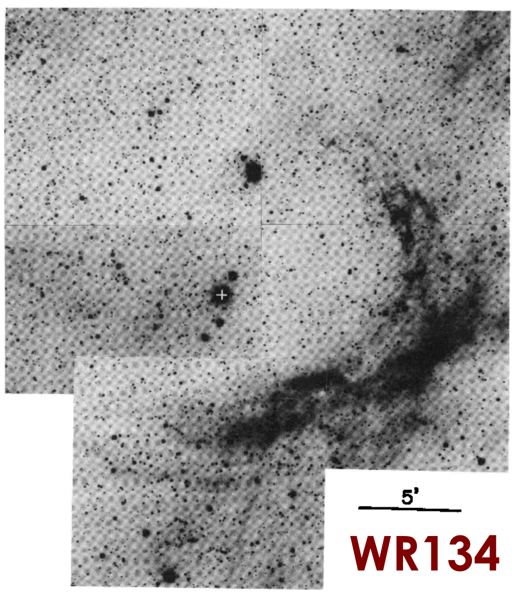
Young WR star (still fast rotating) ↔ asymmetric wind (fast rotation)

Table 1. Overlap between the WR ejecta nebula list of Stock & Barlow (2010) and the line-effect stars according to Table 3 of Harries et al. (1998).

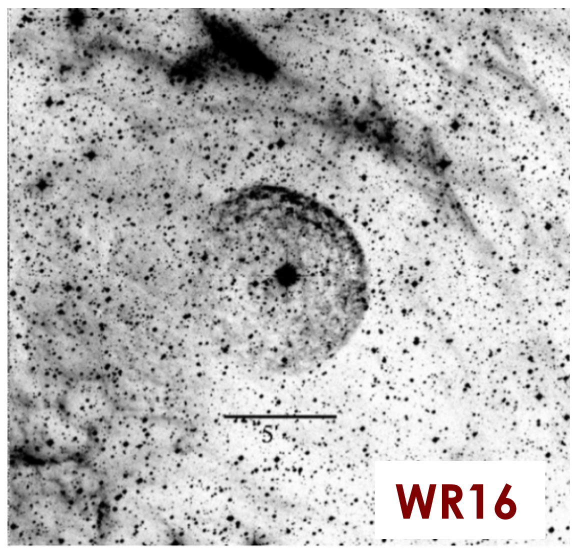
WR	Spec.Tp	Reported line-effect WR star?	
6	WN4	yes	Confirmed CIR
16	WN8	yes	
18	WN4	no	Candidate CIR
40	WN8	yes	
134	WN6	yes	Confirmed CIR
136	WN6	yes	P Cygni blue-edge variability

Vink, Gräfener & Harries 2011, A&A, 536, L10

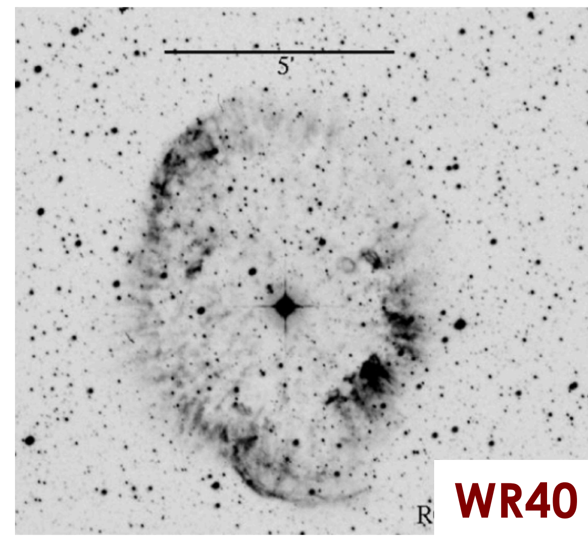
Nebula Ejection by Wolf-Rayet Stars



WR134

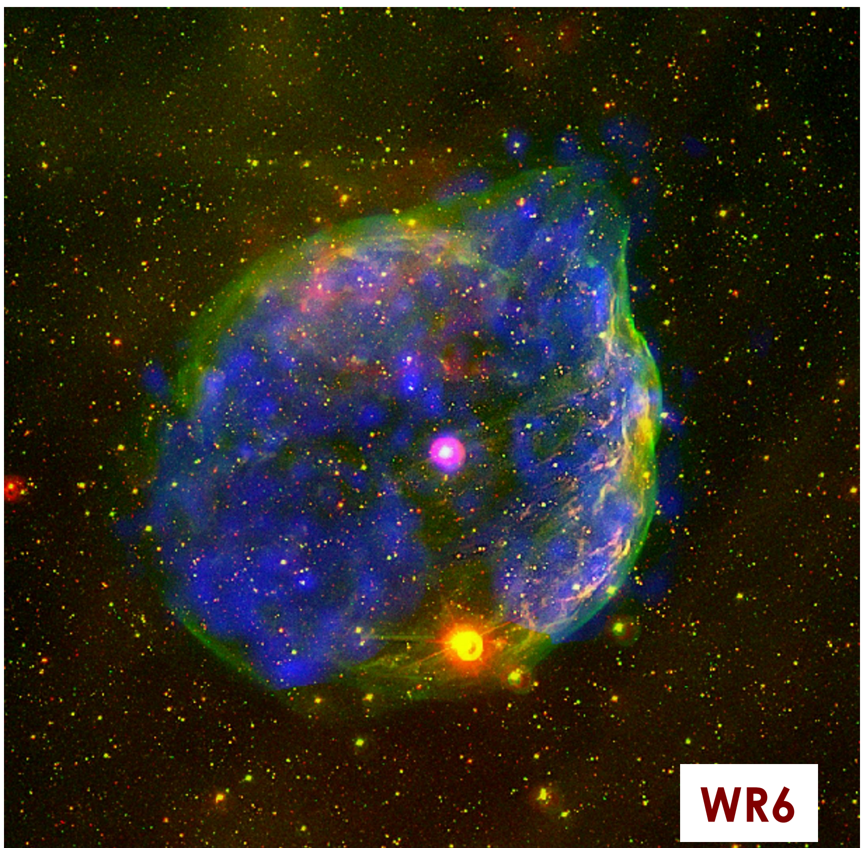


WR16



WR40

Nebula Ejection by Wolf-Rayet Stars



S308, a Wolf-Rayet Bubble Imaged by XMM-Newton in its Full Glory

Image courtesy of J.A. Toala and M.A. Guerrero (IAA-CSIC), Y.-H. Chu and R.A. Gruendl (UIUC), S.J. Arthur (CRyA - UNAM), R.C. Smith (NOAO/CTIO), and S.L. Snowden (NASA/GSFC) and G.Ramos-Larios (IAM)

European Space Agency

WR6/S308: a prototype

- WR6 (S308) : a prototype a=06h54m13.05s, b=-23°55’42.1’’

A) It shows line de-polarization

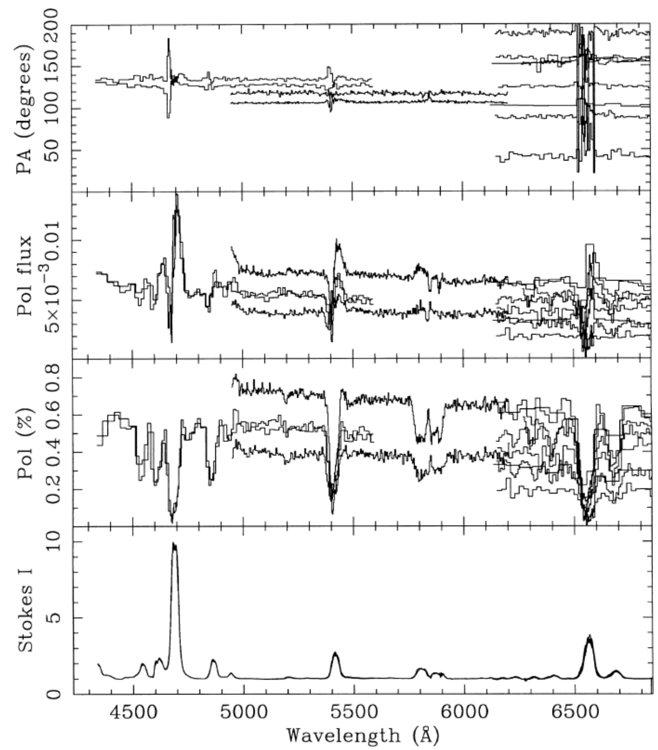


Figure 5. The ISP subtracted polarization spectra of EZ CMa] The ISP subtracted polarization spectra of EZ CMa. The observations of 1991 Jan., 1992 March and 1994 May are binned to a constant error of 0.02 per cent.

S308: a prototype

B) It show large-scale periodic variability

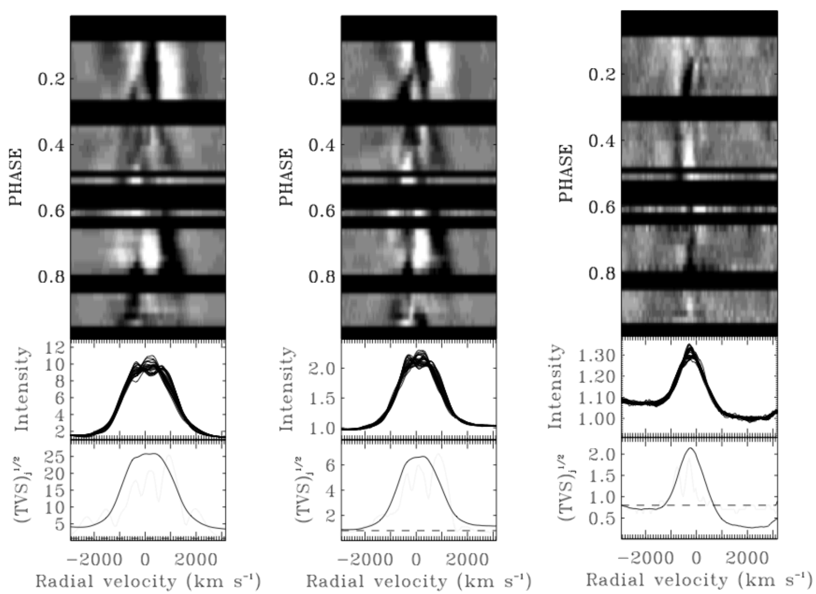
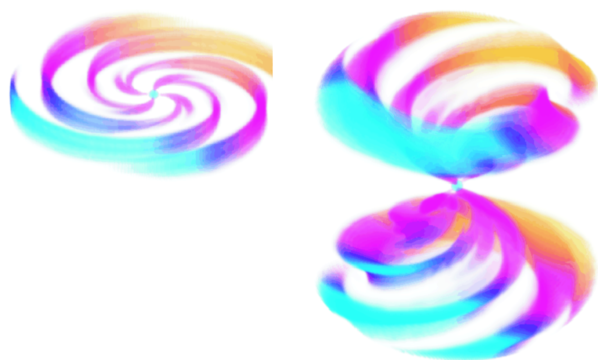


FIG. 4*a* FIG. 4*b* FIG. 4*c*

FIG. 4.—Gray-scale plots of the time series of the residuals of (*a*) He II λ4686 (range: −0.7 to 0.7), (*b*) He II λ4859 (range: −0.1 to 0.1), and (*c*) N V λ4945 (range: −0.03 to 0.03) for epoch I. These residuals (the mean profile of the epoch subtracted from the individual profiles) were binned to 0.02 phase resolution. Excess emission components appear brighter in these plots. The middle portion of each panel presents the superposition of the different rectified profiles. The values of $(\mathrm{TVS})^{1/2}$ (§ 3.4) and the mean profile (in arbitrary units) are displayed in the lower portion of each panel. The horizontal dashed line indicates the 99.0% variability detection threshold.

Corotating Interaction Regions (CIRs)

Cranmer & Owocki (1996)



rotation

Dessart & Chesneau 02; Dessart et al. 04

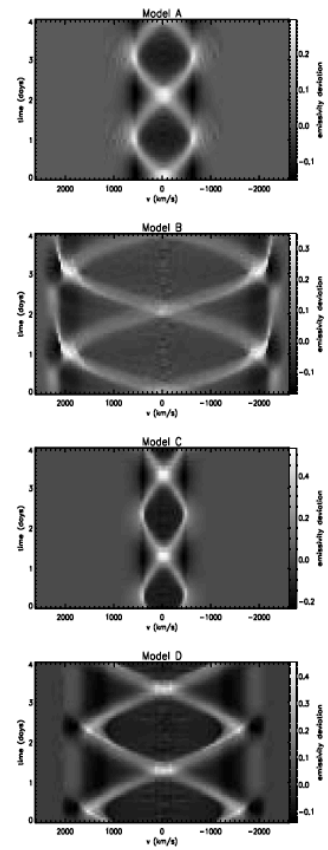
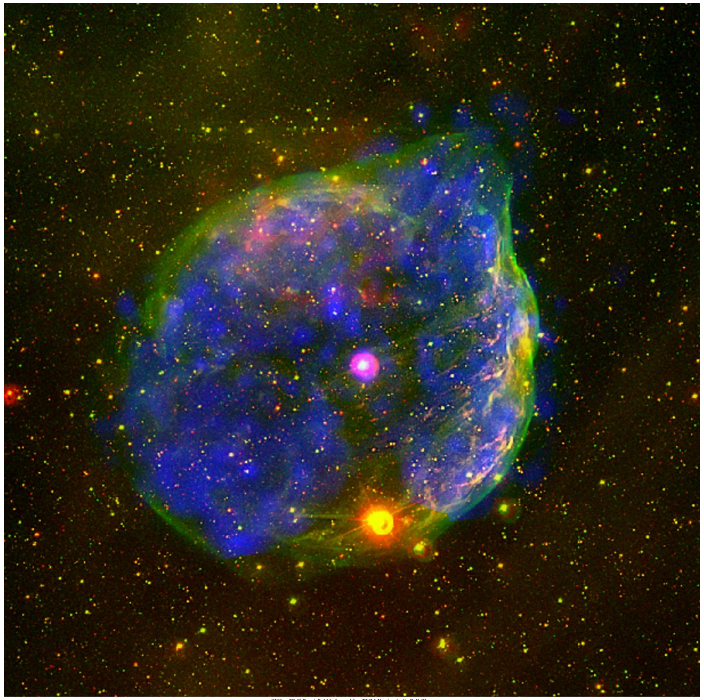


Fig. 3. Intensity plots of the emission deviation from the local time average for models described in Table 1 and in Sect. 3. From top to bottom, we present models A, B, C and D. Not shown here is the average profile, which has simply a square-box shape with a FWHM corresponding to twice the terminal velocity.

S308: a prototype

C) It has an ejecta nebula

- If the nebula was <u>ejected while</u> the star was <u>rotating fast</u>, the should be <u>signs in the gas kinematics</u>
- It is an ideal project for Sitelle because we most likely need a spectrum al over the nebula



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European Space Agency

Complications

Arnal & Cappa 1996

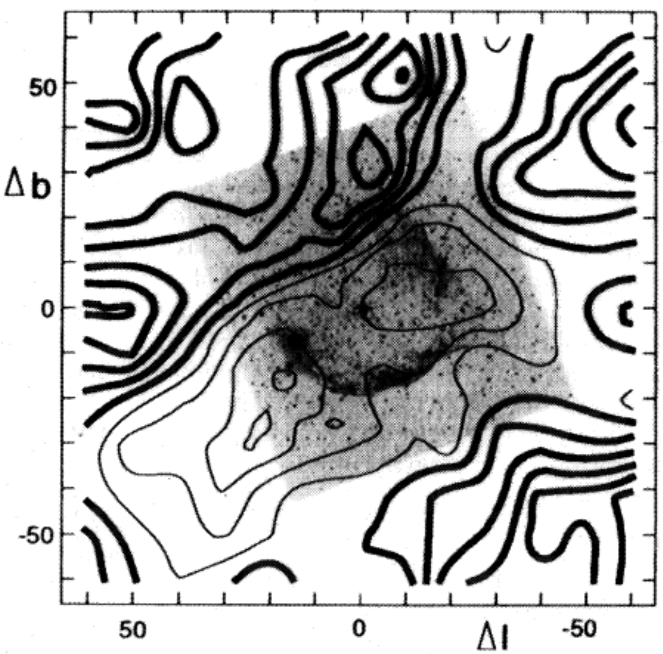


Figure 6. Same as Fig. 5, overlayed on to an [O III] $\lambda \sim 5007$ Å photograph of S308 (Chu et al. 1982).

The most interesting discovery is a huge ovoidal H I minimum spanning the velocity range $+1.5$ to $+10.0$ km s^{-1}, created, very likely, by the joint action of the progenitor of HD 50896 and the WR itself. Inside this cavity, two minima are clearly discernible. The WR star is offset with respect to either the geometrical centre of the main H I void or the inner H I minima. A physical link between S308, the ring nebula associated with HD 50896, and one of the H I minima is suggested by our data. A

Observation requirements

- Ha+[OIII]
- It is a big nebula! About 40'x40'
- Not necessary to mosaic but would be nice

Observation requirements

- Has been observed in the early 80s by Chu et al. 82 with a Fabry Perot at about 20 positions (with a photomultiplier)
- Quite bright in [OIII]; about three times fainter in Ha
- Flux about 10^{15} ergs s^{-1} cm^{-2}

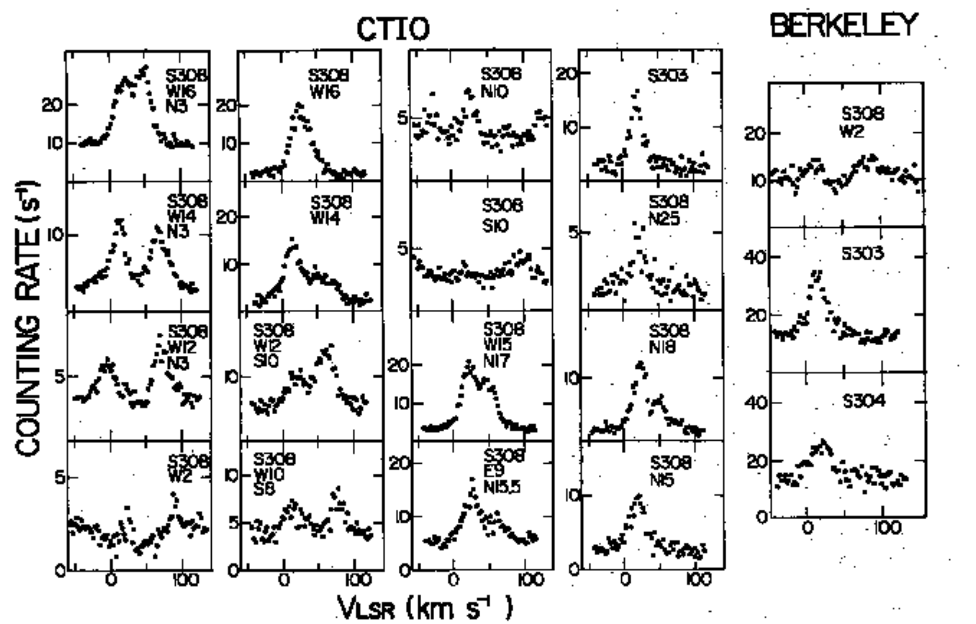


FIG. 2.—The [O III] line profiles for S303, S304, and S308. The offsets (in arcmin) from the star HD 50896 are labeled below the nebu names.

Observation requirements

- What kind of velocity differences can we expect?
- Models of fast rotating winds:
- Quite a bif difference in wind velocity between pole and equator for B stars
- Will be a somewhat smaller difference for much denser WR winds

Table 5.1: Oblate Finite Disk Wind Models

Model by S. Cranmer

	S-350	A	A1
$r_{\rm crit}(0^\circ)/R_p$	—	1.06910	1.05547
$r_{\rm crit}(90^\circ)/R_p$	—	1.35253	1.35253
$v_r(6R_p, 0^\circ)$ (km/s)	1221.54	1098.05	1304.39
$v_r(6R_p, 90^\circ)$ (km/s)	489.07	559.23	559.23
$\beta_{\rm eff}(2R_p, 0^\circ)$	0.65050	0.71712	0.77445
$\beta_{\rm eff}(2R_p, 90^\circ)$	1.41291	1.04191	1.04191
$\dot{M}(0^\circ)$ $(10^{-10}\, M_\odot/{\rm yr})$	3.158	5.926	6.269
$\dot{M}(90^\circ)$ $(10^{-10}\, M_\odot/{\rm yr})$	16.96	12.32	12.32
$\rho(2R_p, 90^\circ)/\rho(2R_p, 0^\circ)$	14.3948	8.66475	9.07238
$\max(v_\theta)$ (km/s)	74.593	60.168	58.637

Observation requirements

- Would need quite a high resolution. FP data have a resolution of R=20000
- Component at +25 km/s is due to a larger structure; the other one due to the expanding nebula at 60 km/s.

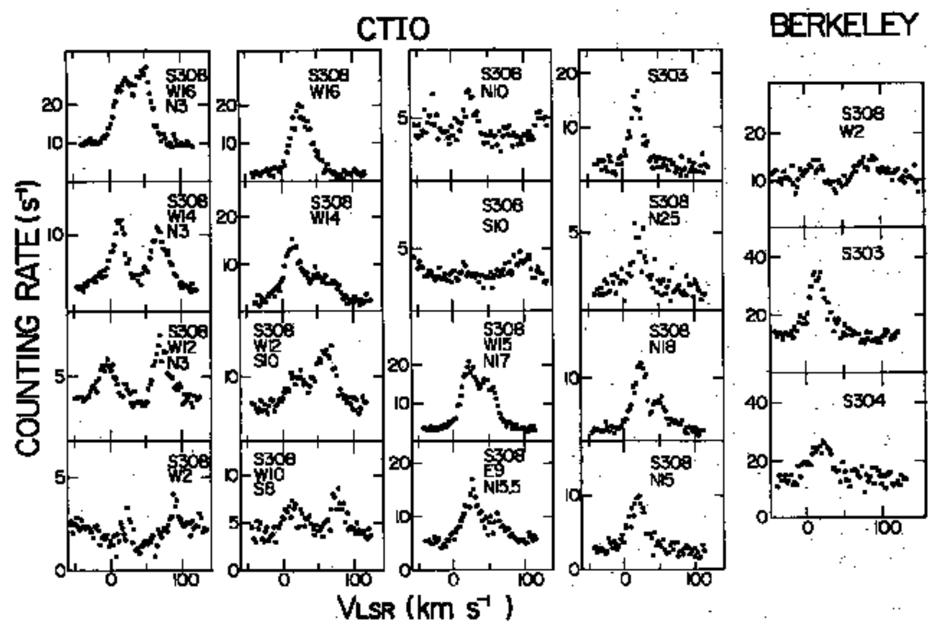
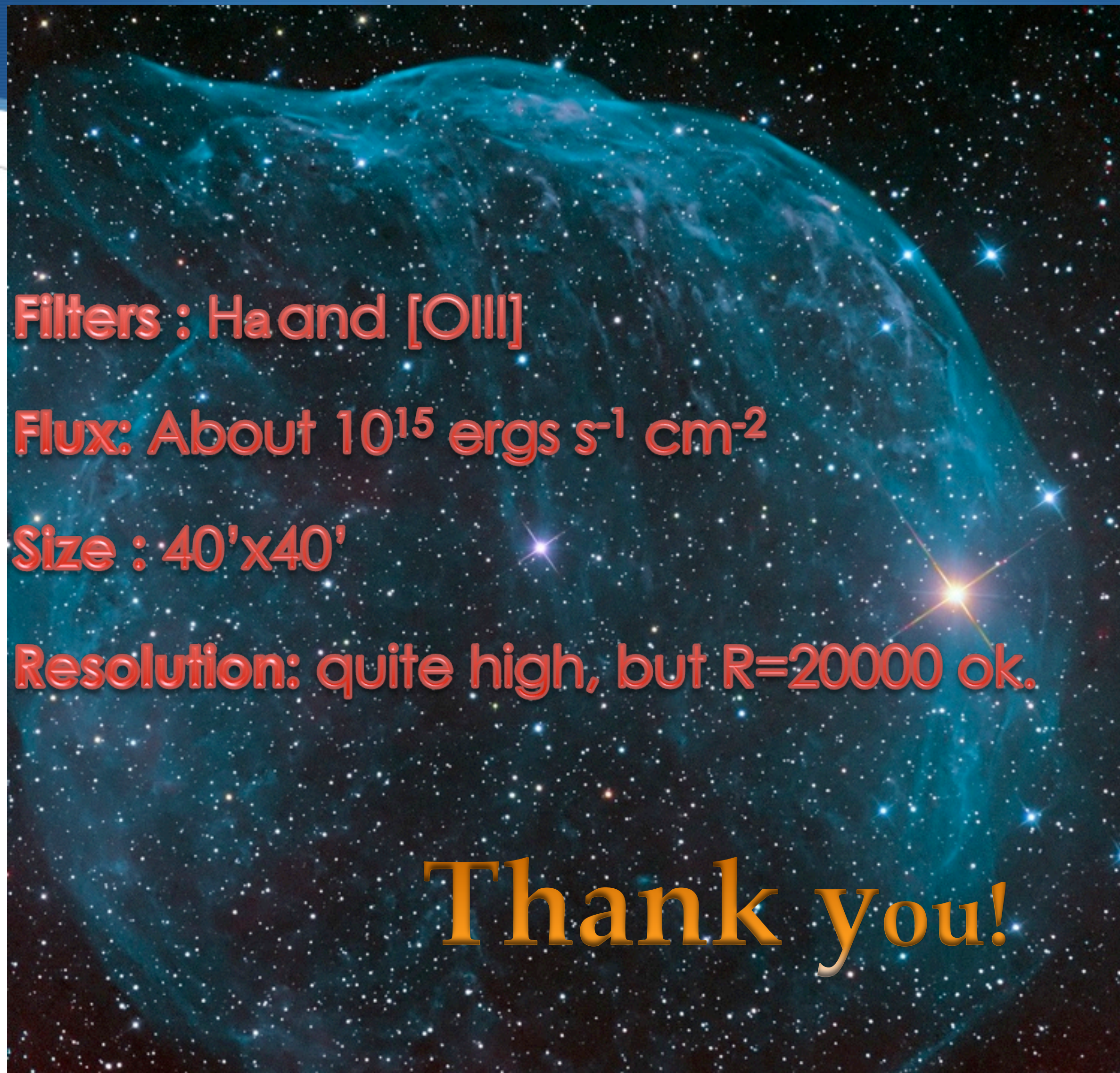


FIG. 2.—The [O III] line profiles for S303, S304, and S308. The offsets (in arcmin) from the star HD 50896 are labeled below the nebu names.

Summary of requirements



- **Filters** : Ha and [OIII]
- **Flux**: About 10^{15} ergs s^{-1} cm^{-2}
- **Size** : 40'x40'
- **Resolution**: quite high, but R=20000 ok.

Thank you!