Spectroscopic tomography of a wind-collision region

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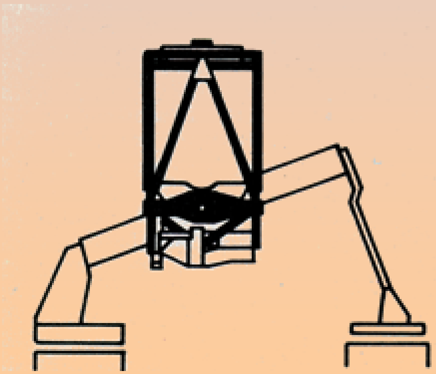
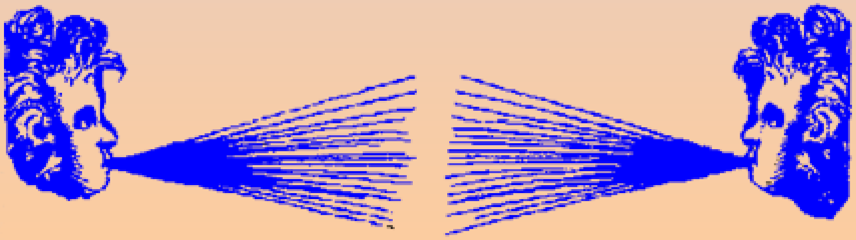
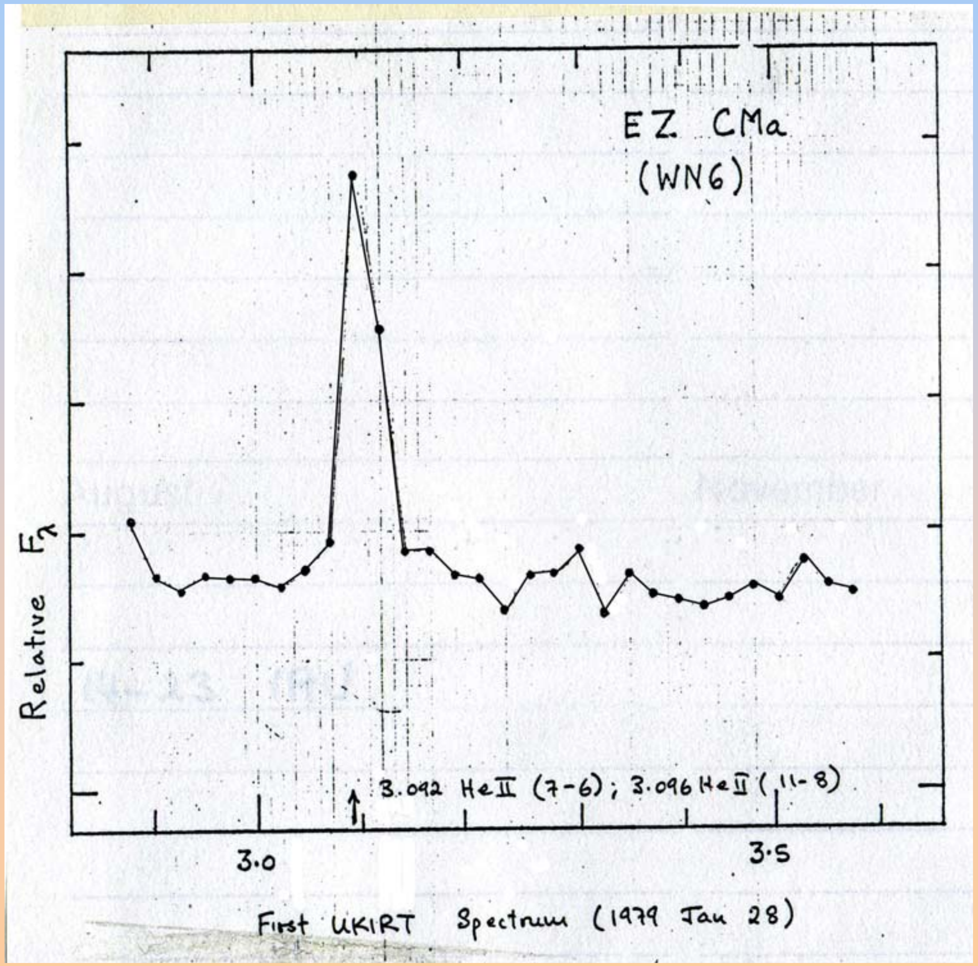
and Andy Adamson





UKIRT at 30 : Edinburgh 2009

UKIRT spectroscopy: January 1979



1% resolution 2.3-4.6 μm CVF in UKT2 at f/9 with focal-plane chopper, controlled by LSI-11 microprocessor

By the end of 1979, we had the instrument computer and hard-copy – polaroid camera

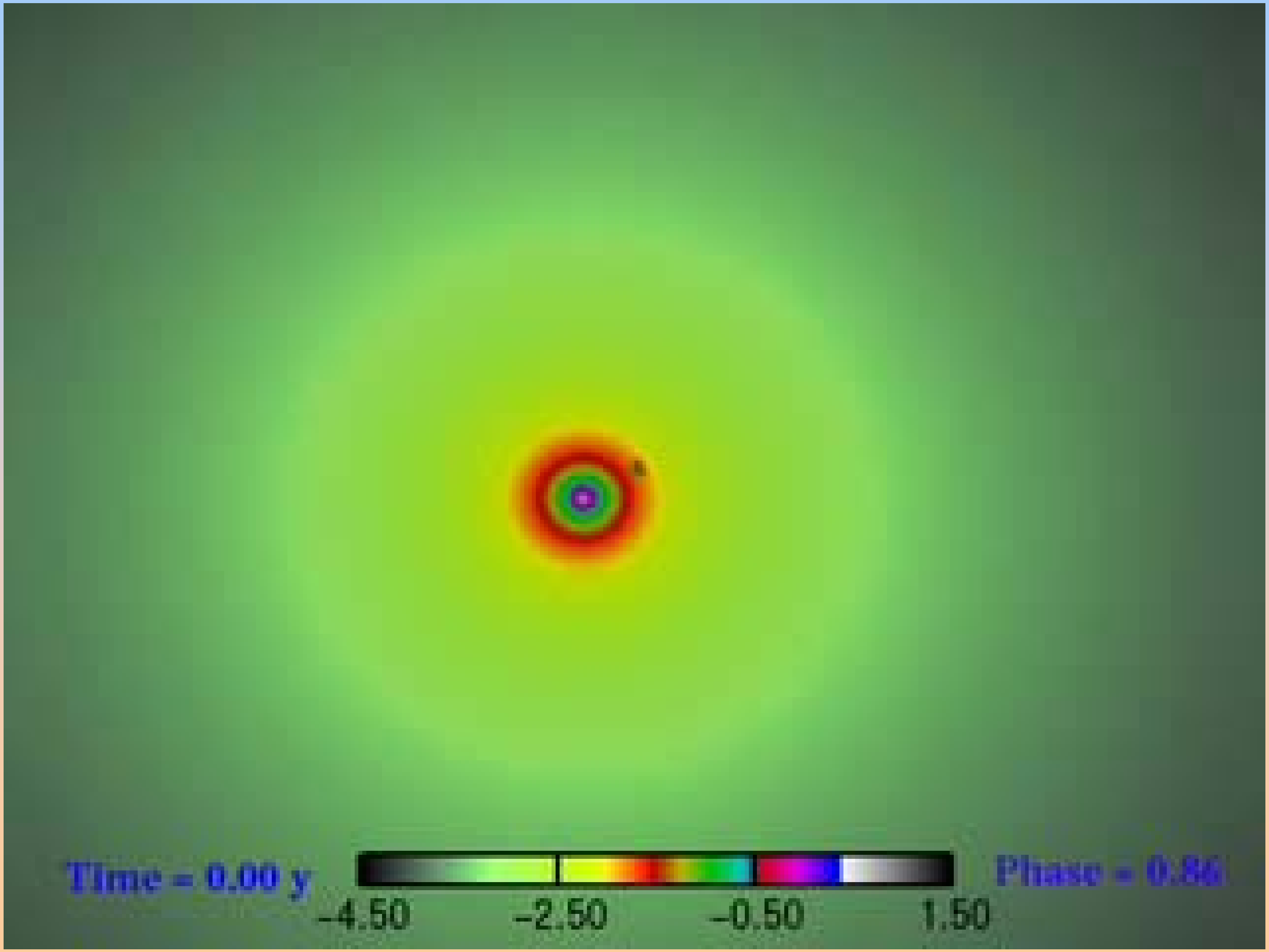
Colliding stellar winds

- Luminous, hot (O and WR) stars have fast (~ 2000 km/s), radiatively driven winds carrying ~ 10^{-6} to 10^{-5} Msun/y mass loss with ~ 10^{3} to 10^{4} Lsun kinetic energy
- In binary system, KE is dissipated where the winds collide leading to shock heating to ~ 10^{7} K - producing X-rays
- Electrons accelerated - synchrotron emission
- Dust made in some WC+O systems, pinwheels.

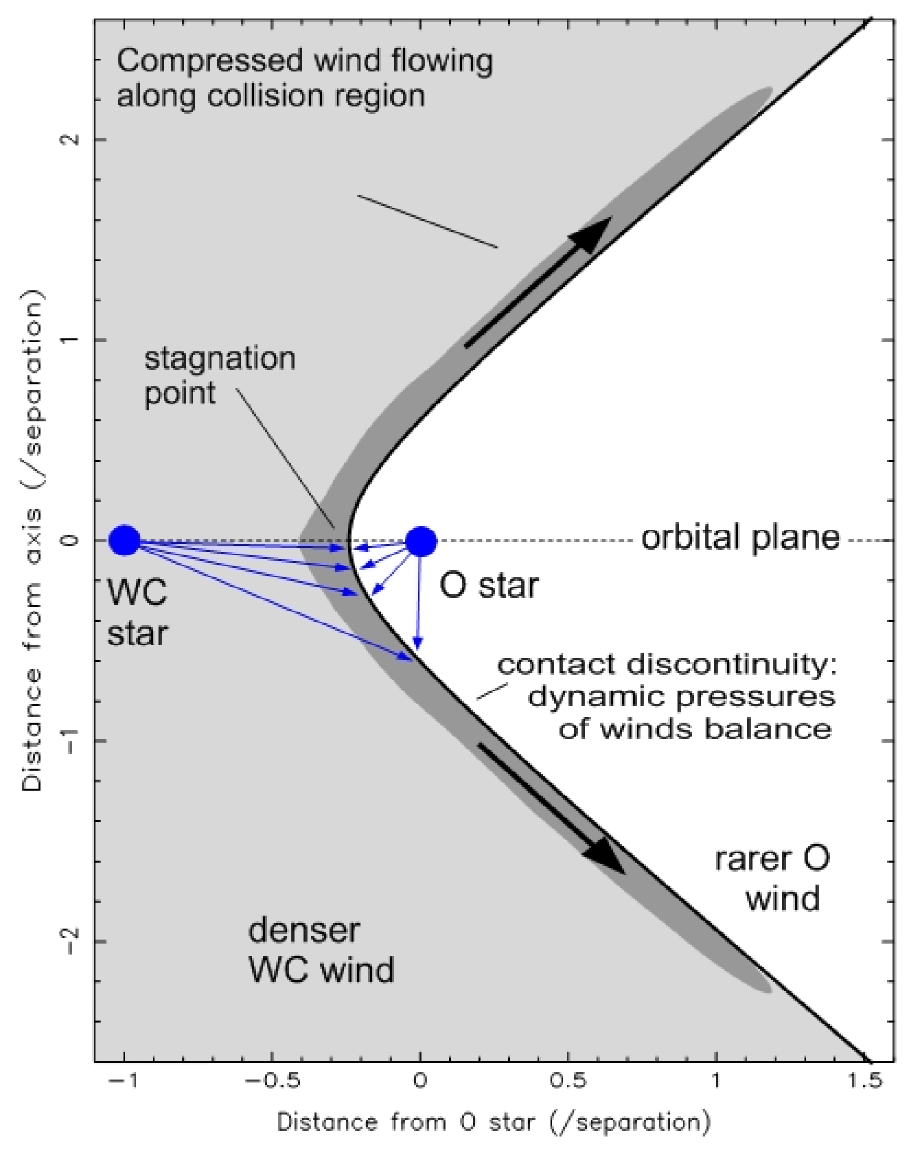
Prototype CWBinary WR140

- WC7 Wolf-Rayet star in orbit with O5 star, P=7.94 y
- high eccentricity (e = 0.88), separation varies by factor ~16, so CW effects vary massively round the orbit
- highly variable angular velocity, swings round 3/4 of the orbit in only 4% of the period
- variable X-ray source
- variable non-thermal radio source
- laboratory for studying high-energy phenomena
- makes expanding dust cloud each periastron passage (also imaged with UKIRT, see Feb 2009 MN)
- template for understanding systems like η Carinae

Model WR140 Colliding Winds: AMRCART 3-D hydro code: Doris Folini & Rolf Walder



Stellar Wind Collision Region (WCR)



Shape determined by ratio of wind momenta:

$$\eta = \left(\dot{M}v_\infty\right)_O / \left(\dot{M}v_\infty\right)_{WC}$$

The WCR wraps around the star with the lesser wind momentum.

Both stellar winds are shocked at the WCR in regions which are wide if the shocks are adiabatic (most of the time in WR140) and thin if they are radiative (around periastron).

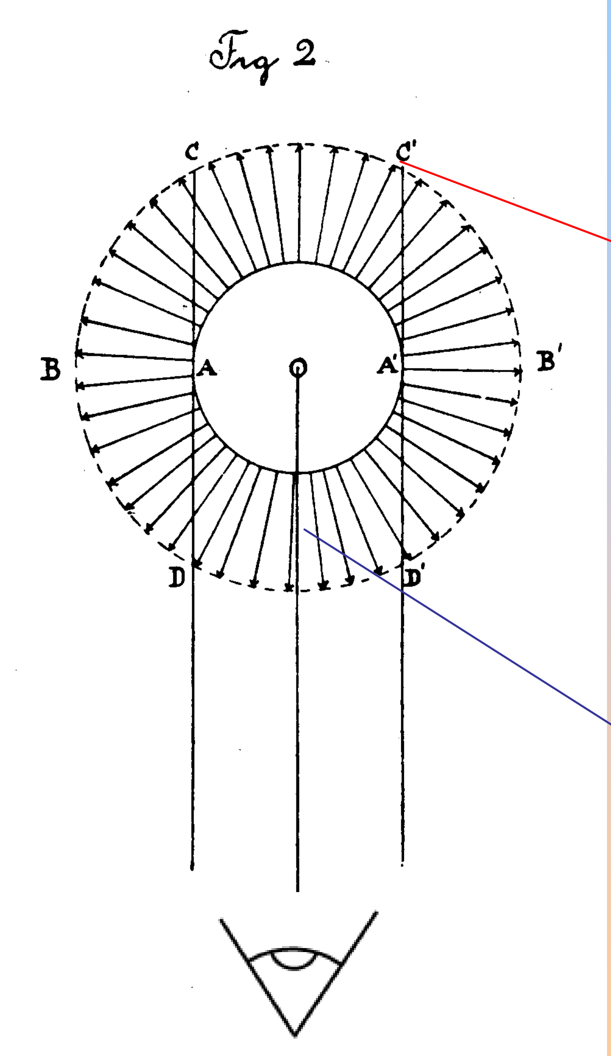
[Only the WC star compressed wind is shown in the figure]

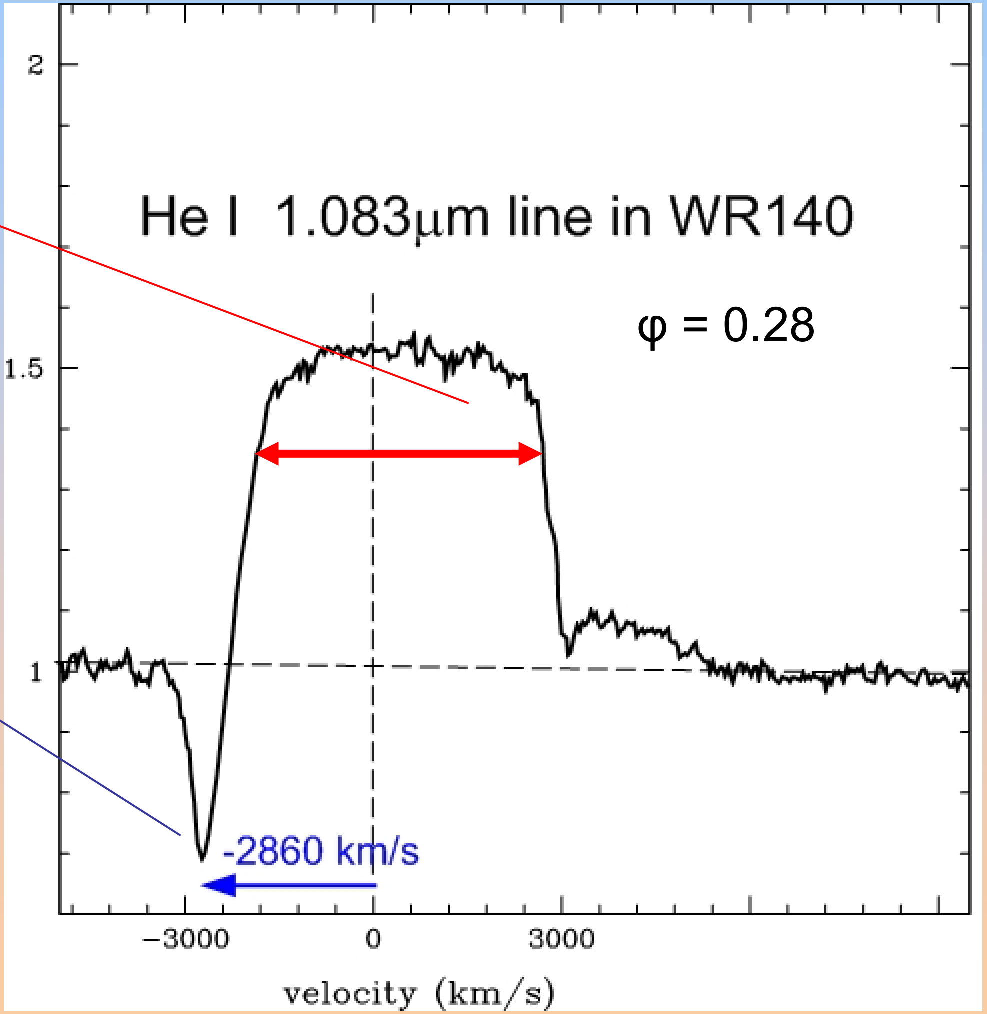
UKIRT observations of the P Cygni profile of the 1.083-μm He I line in the CWB WR140 with UIST and shortJ grism (R ~ 200km/s) in 2008 June-December

- strength of absorption component
- transient sub-peak on flat-topped emission component

to map the interaction region

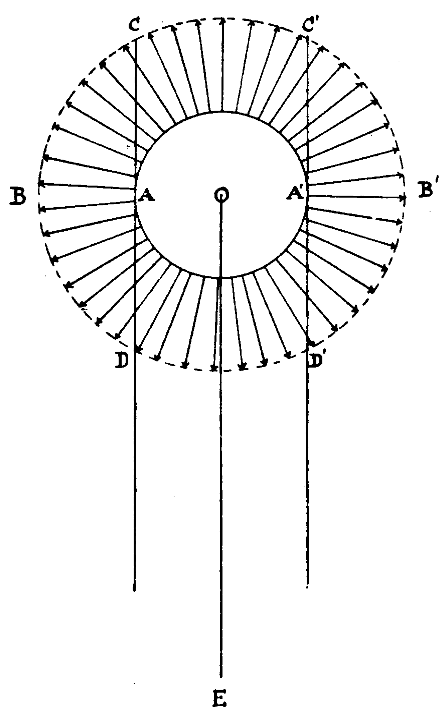
Expanding wind gives a P Cygni line profile

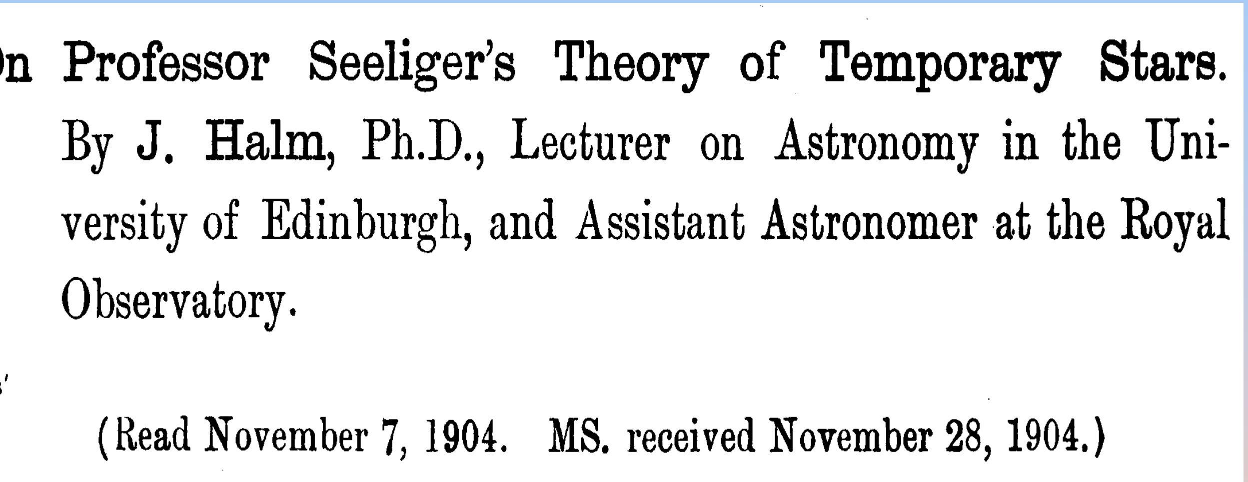




First interpretation of a P Cygni profile

Fig 2

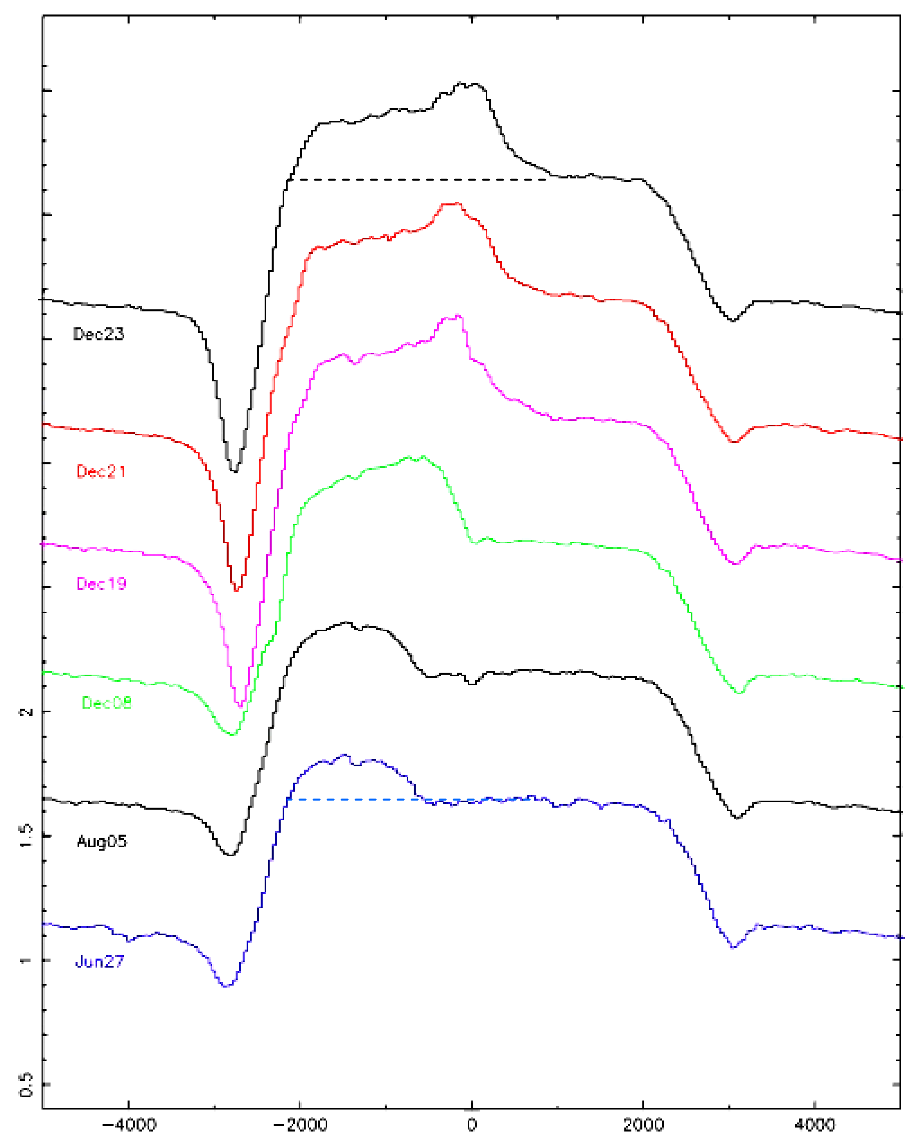




On Professor Seeliger's Theory of Temporary Stars. By **J. Halm**, Ph.D., Lecturer on Astronomy in the University of Edinburgh, and Assistant Astronomer at the Royal Observatory.

(Read November 7, 1904. MS. received November 28, 1904.)

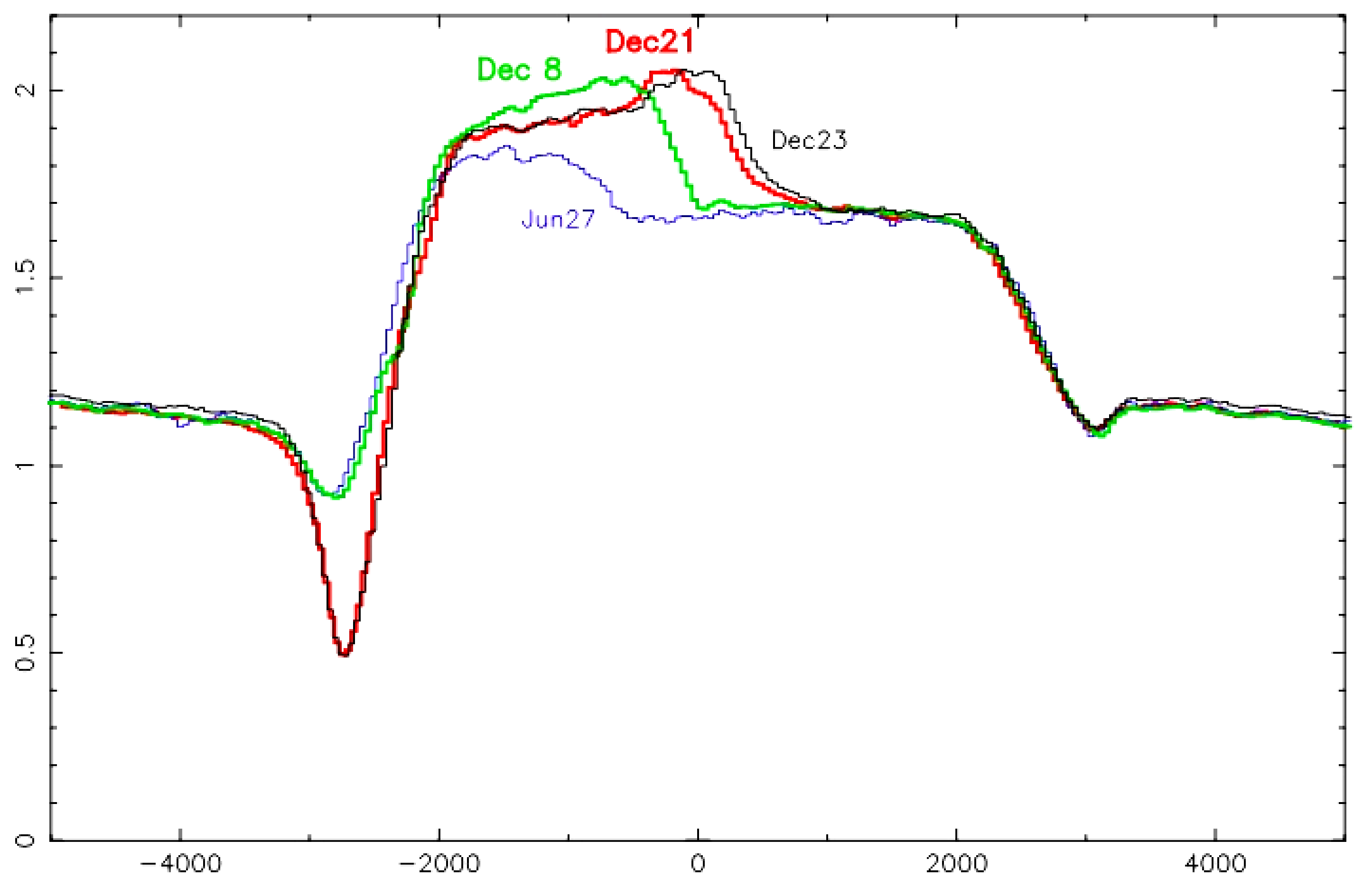
Proc. Roy. Soc. Edinburgh, 25, 513, 1904



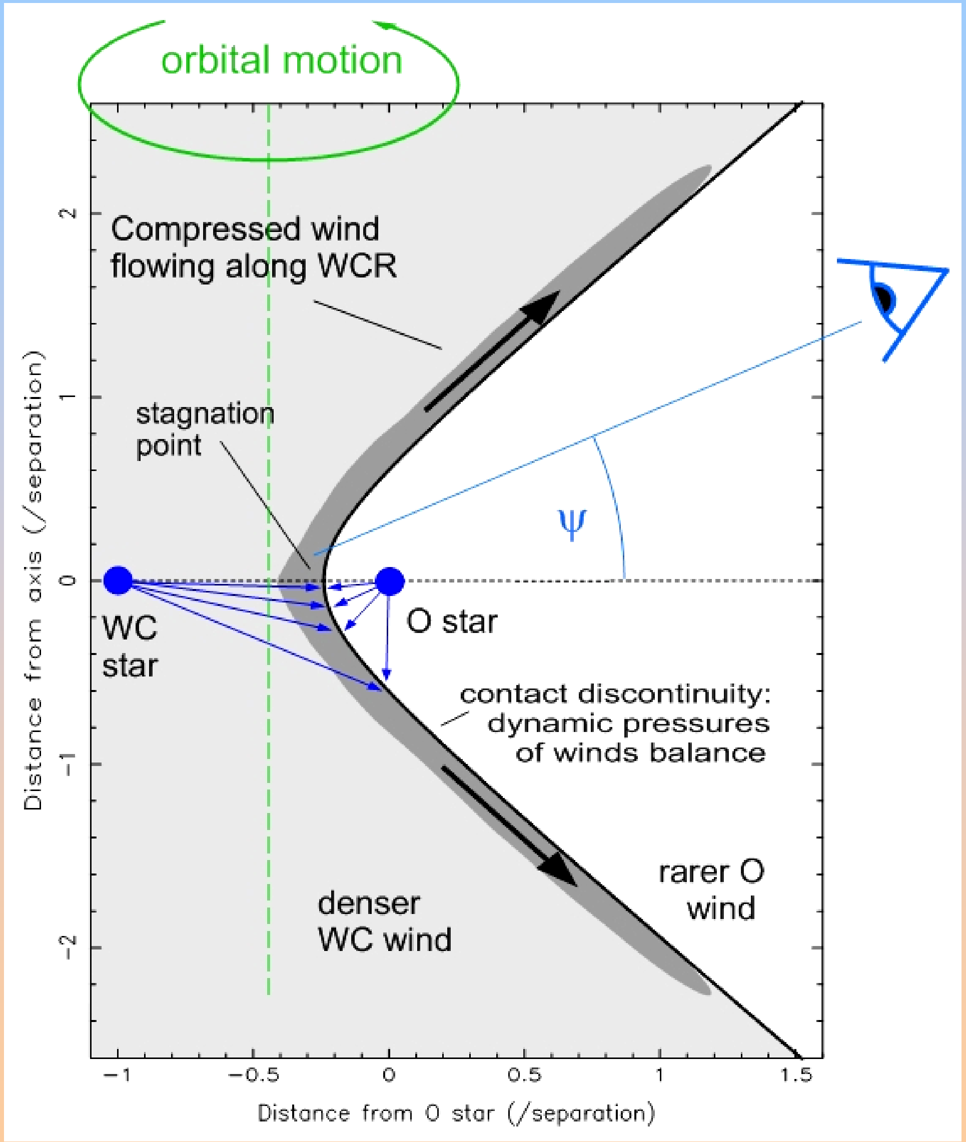
2008 June - December observed spectra show evolution of emission 'sub-peak' structure and absorption component.

most of the time, $0.2<\varphi<0.8$, the emission component has a flat top, consistent with its formation in the outer winds where velocity = v_∞ (constant)

Base emission profile, formed in expanding wind, is constant but structure varies systematically



We observe:

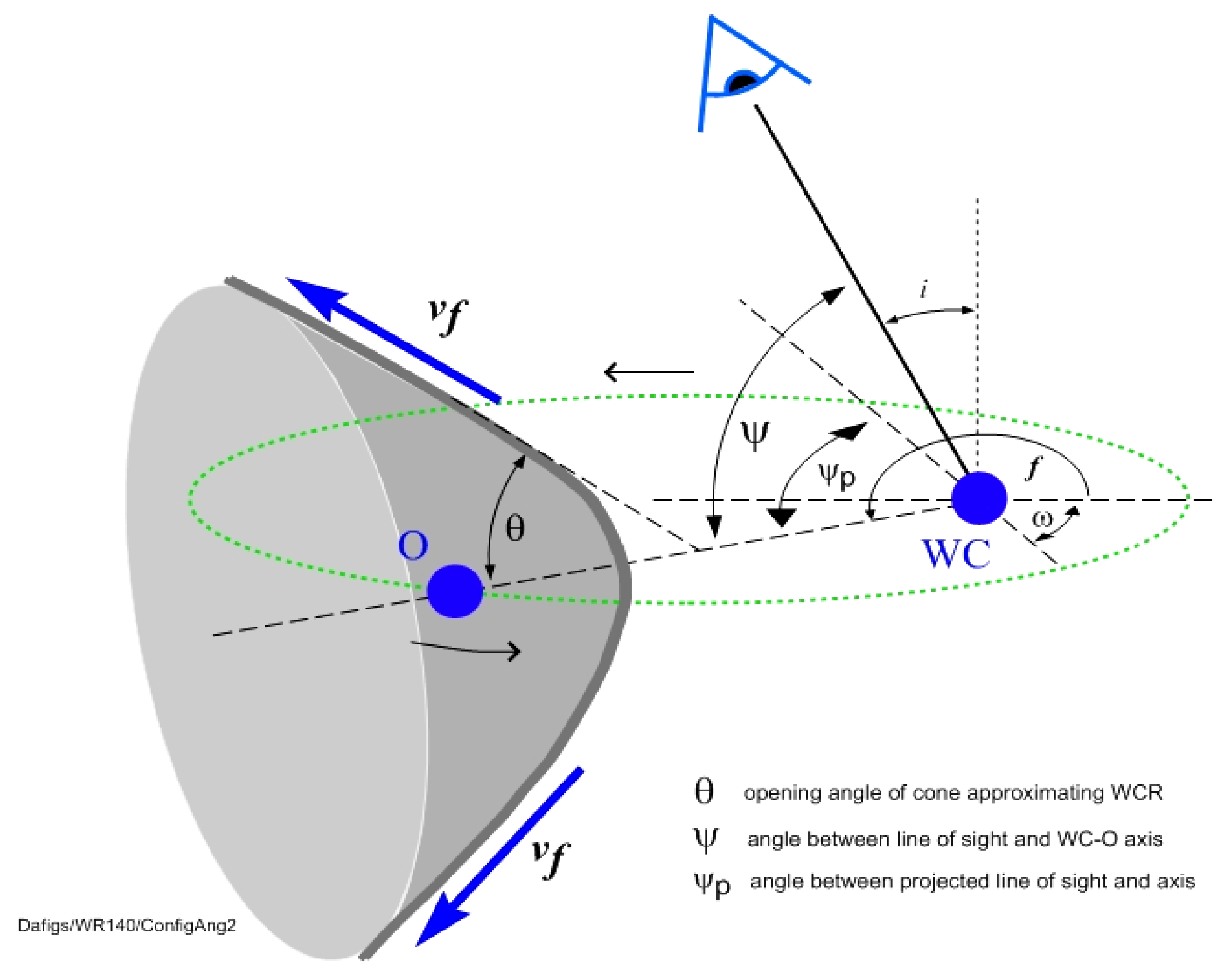


1. Variable absorption component as we view stars through dense, He-rich WC wind and rarer O star wind

2. Extra line emission from shock-compressed wind, which accelerates as it moves along the WCR from the stagnation point to the asymptotic region

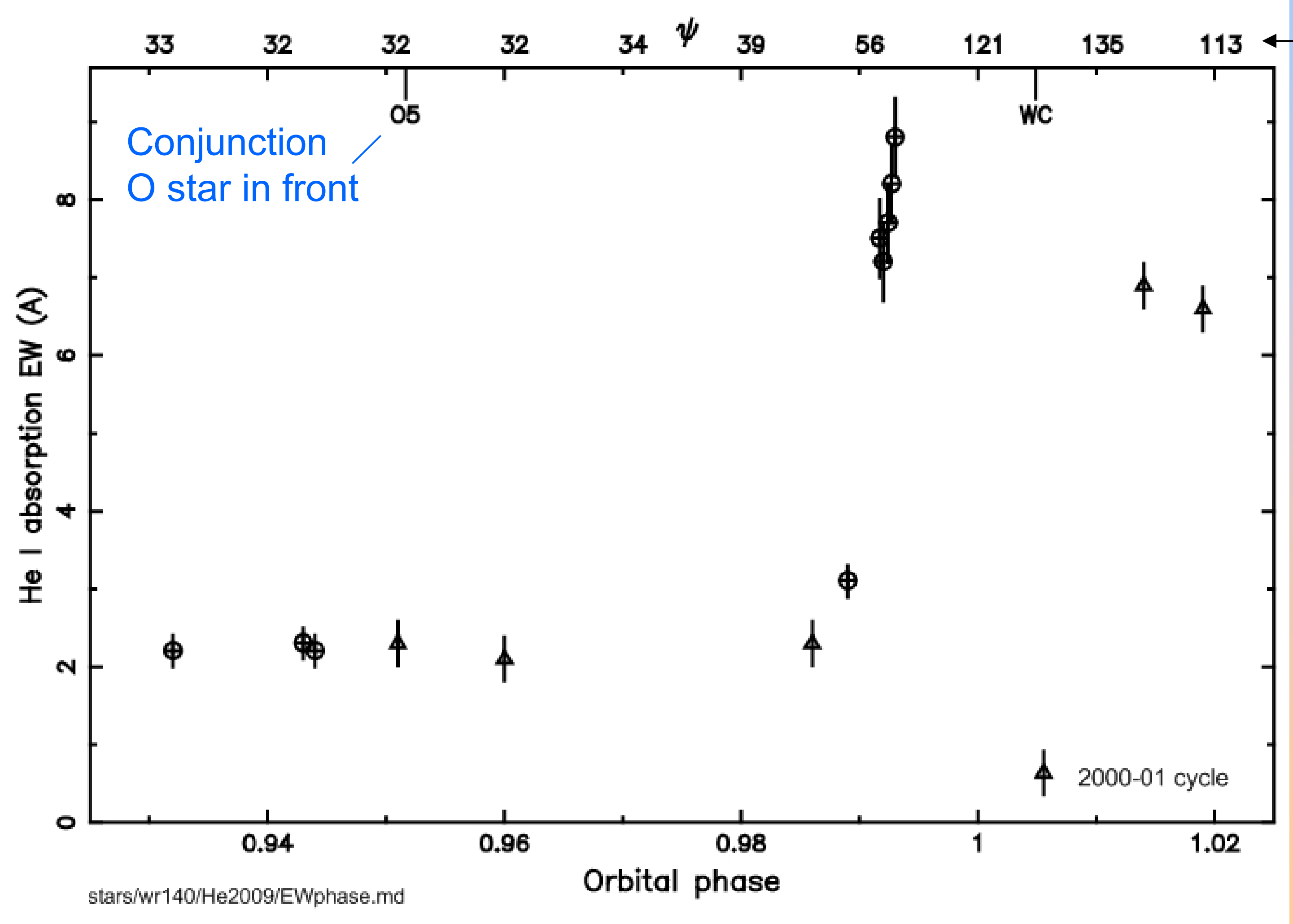
Viewing angle ψ varies round the orbit: $\cos(\psi) = -\sin(i)\,\sin(f+\omega)$

What we observe depends on angle ψ between axis of symmetry and sightline



θ	opening angle of cone approximating WCR
ψ	angle between line of sight and WC-O axis
ψp	angle between projected line of sight and axis

He absorption rises rapidy around φ 0.99 as stars are eclipsed by denser WC wind



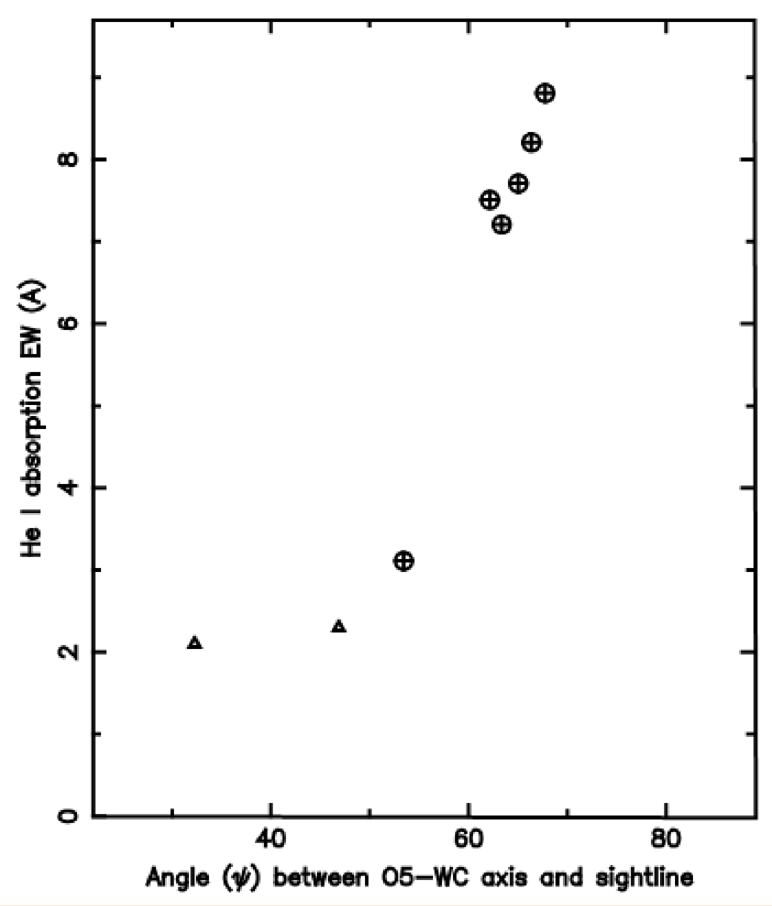
Conjunction
O star in front

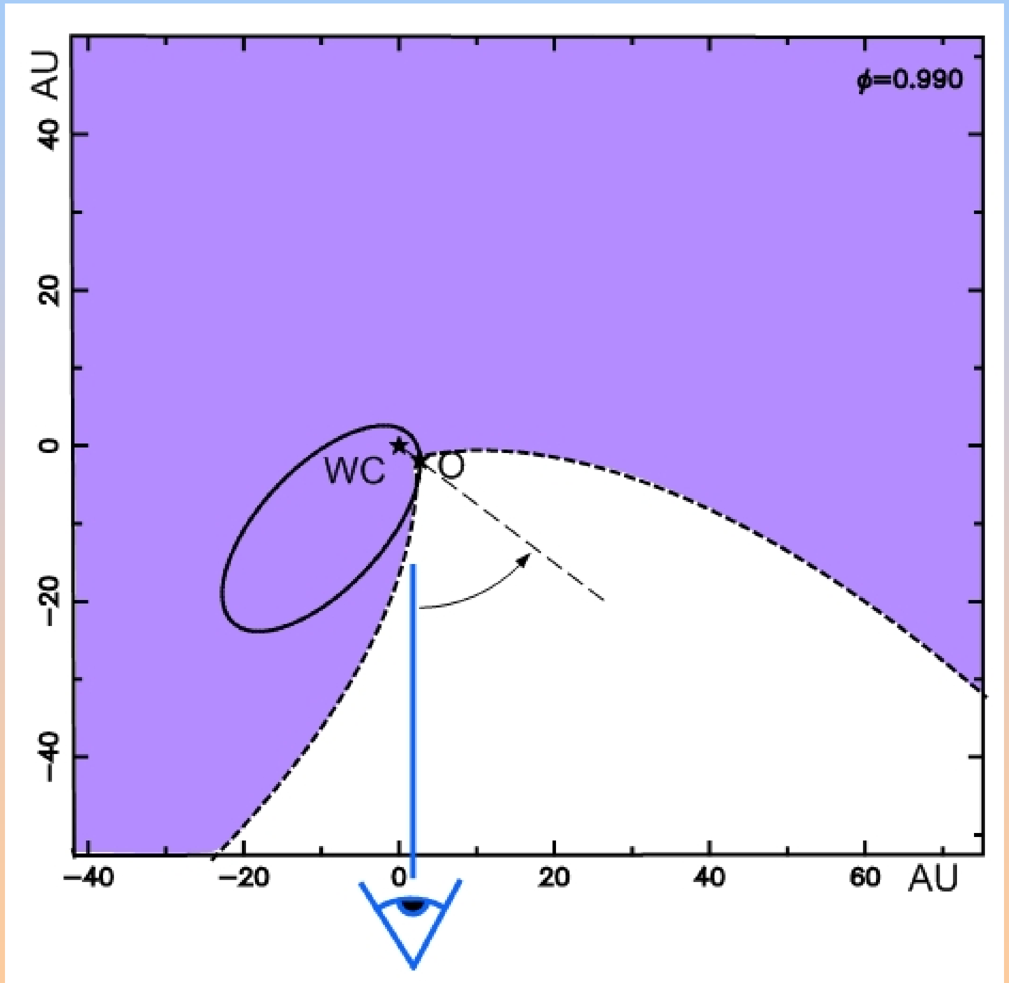
stars/wr140/He2009/EWphase.md

but note rapid variation of ψ with phase

interval betweeen conjunctions only 0.05P

Modelling eclipse gives opening angle θ and thence wind-momentum ratio η



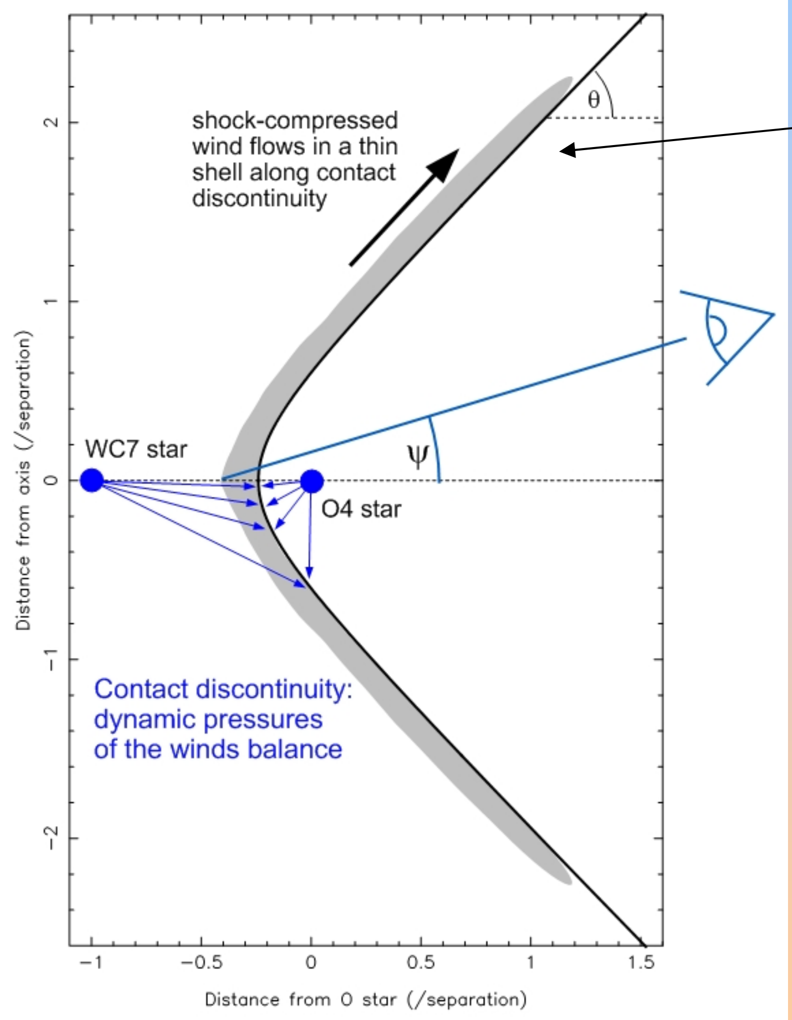


$\theta \approx 50 \Rightarrow$ wind-momentum ratio $\eta \approx 0.10$

We know terminal velocities of WC (2860 km/s from IR) and O5 (3200 km/s from UV) stellar winds so we now have ratio of mass-loss rates.

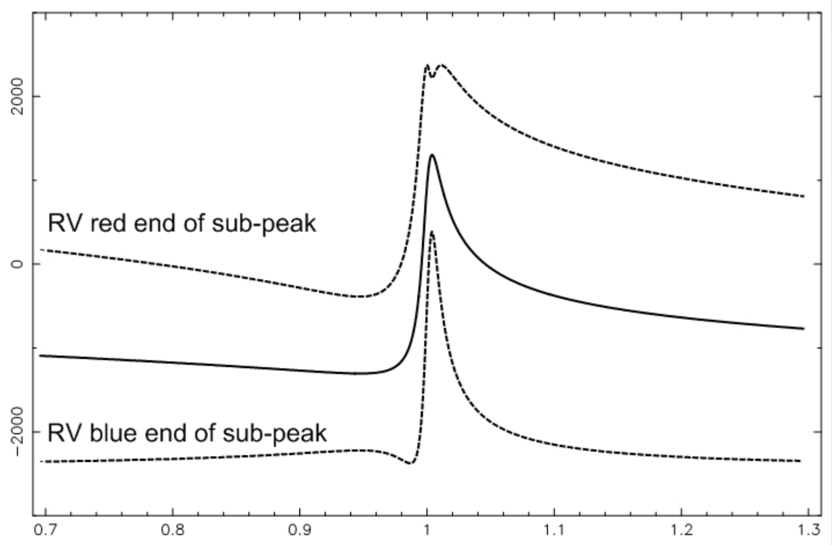
That of WC star from radio (~ 5.7 x 10^{-5} Mo/y) then implies ~ 5 x 10^{-6} Mo/y for the O5 star, anomalously high for its spectral type, but can be reconciled if WC wind is clumped with filling factor ~ 0.1 and mass-loss rates a factor of 3 lower.

Modelling emission sub-peak variations (1)



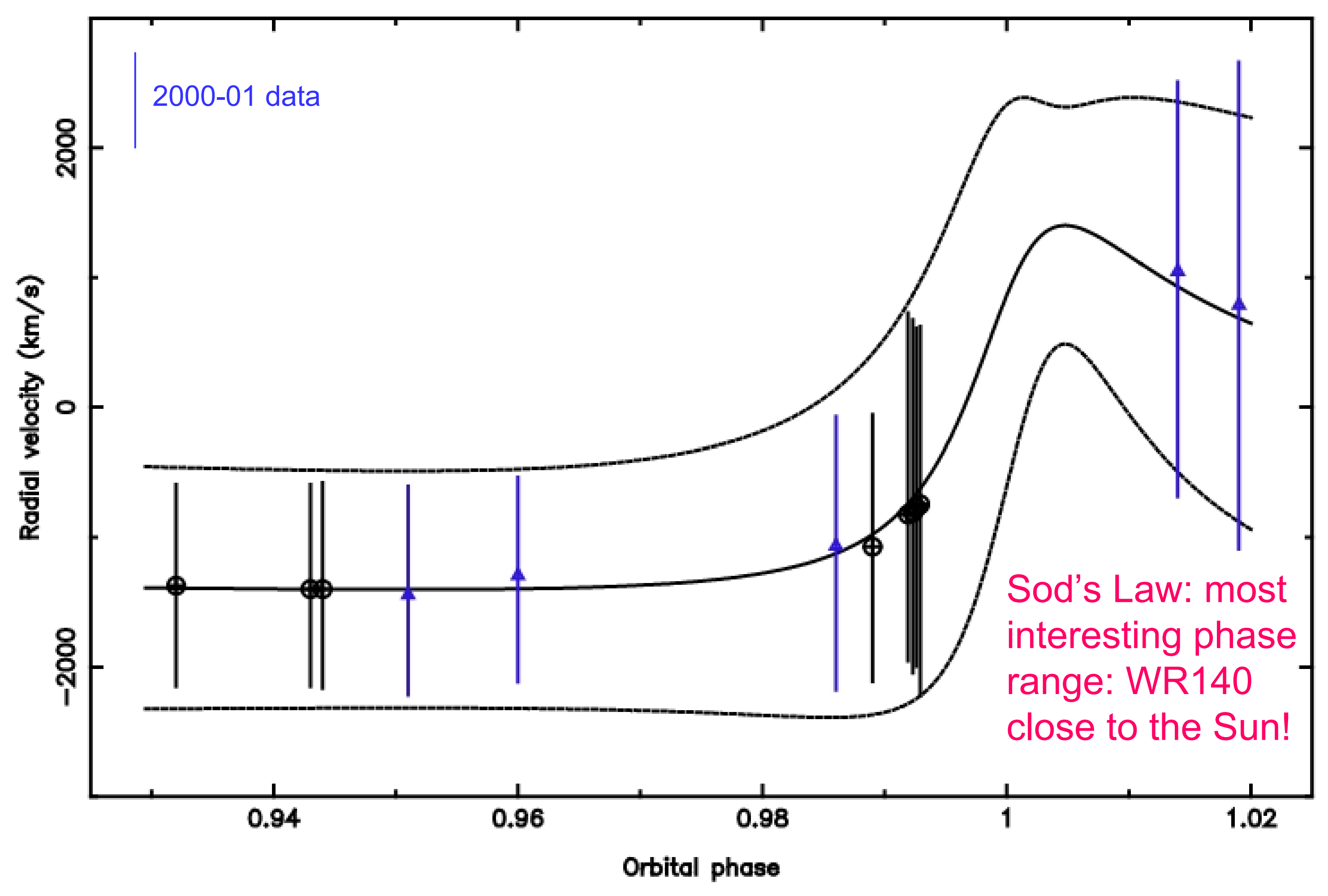
Assume emission occurs in asymptotic region of flow. Then: constant angle θ and constant velocity, Vflow.

RVc = Vflow cos (θ) cos (ψ)
with amplitude
± Vflow sin (θ) sin (ψ)



Sub-peak RVs compared with simple model

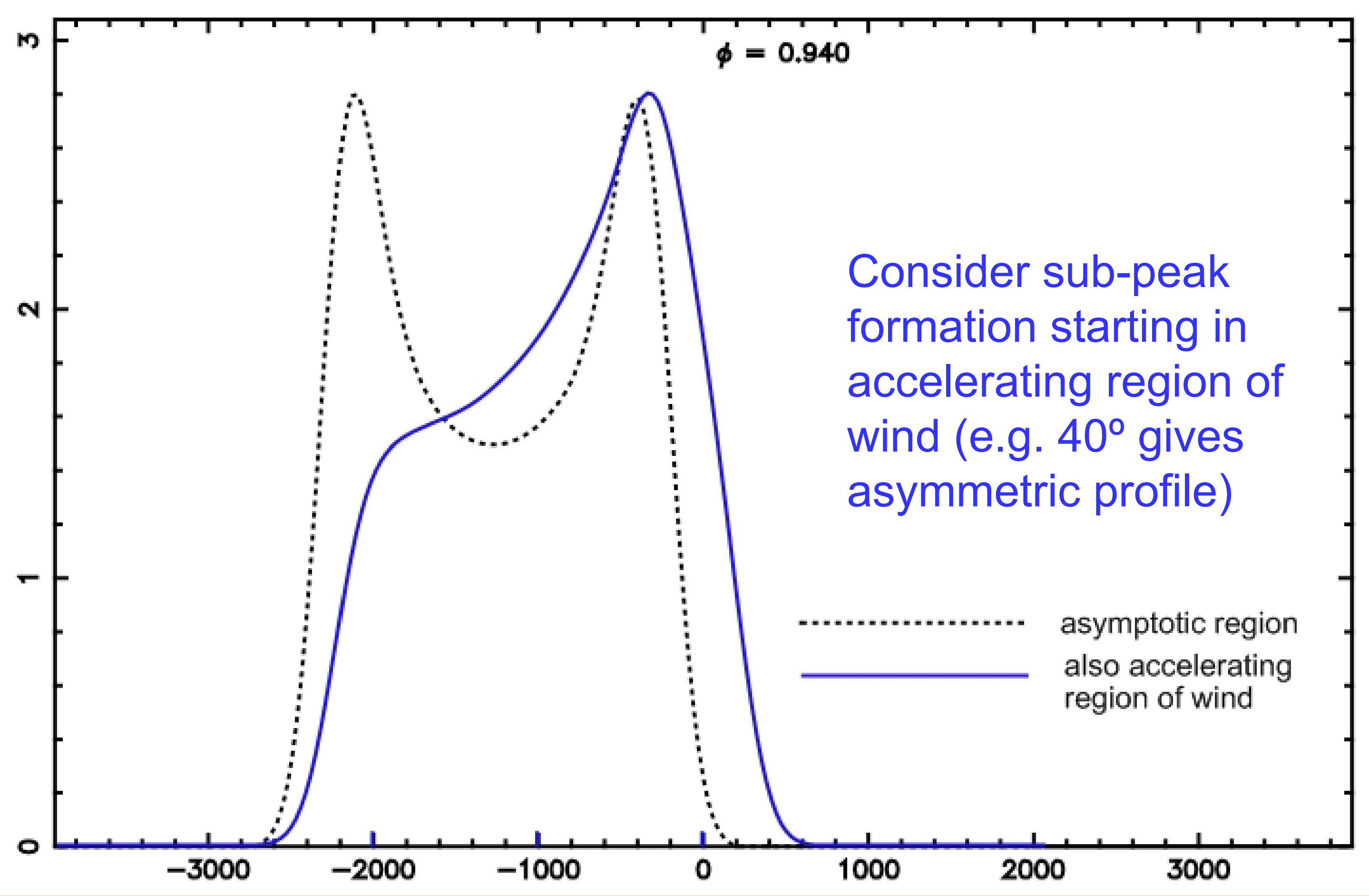
(not a fit – just plugging in Vflow, θ, and orbital parameters)



Sod's Law: most interesting phase range: WR140 close to the Sun!

Modelling emission sub-peak variations (2)

calculated profiles with these parameters double-peaked but observed profiles mostly asymetrical, single-peaked



Consider sub-peak formation starting in accelerating region of wind (e.g. 40º gives asymmetric profile)

1.083 μm line formed in accelerating wind?

shock-compressed plasma may be very hot nearer the shock apex ...

- He 1.083 μm line emission sensitive to temperature: the collisional rate q(2S,2P) prop to $T^{1.3}$
- also similar profile to X-ray lines at about the same phase:
- luminosity in subpeaks exceeds 2-6 keV X-ray flux – important coolant of shocked plasma

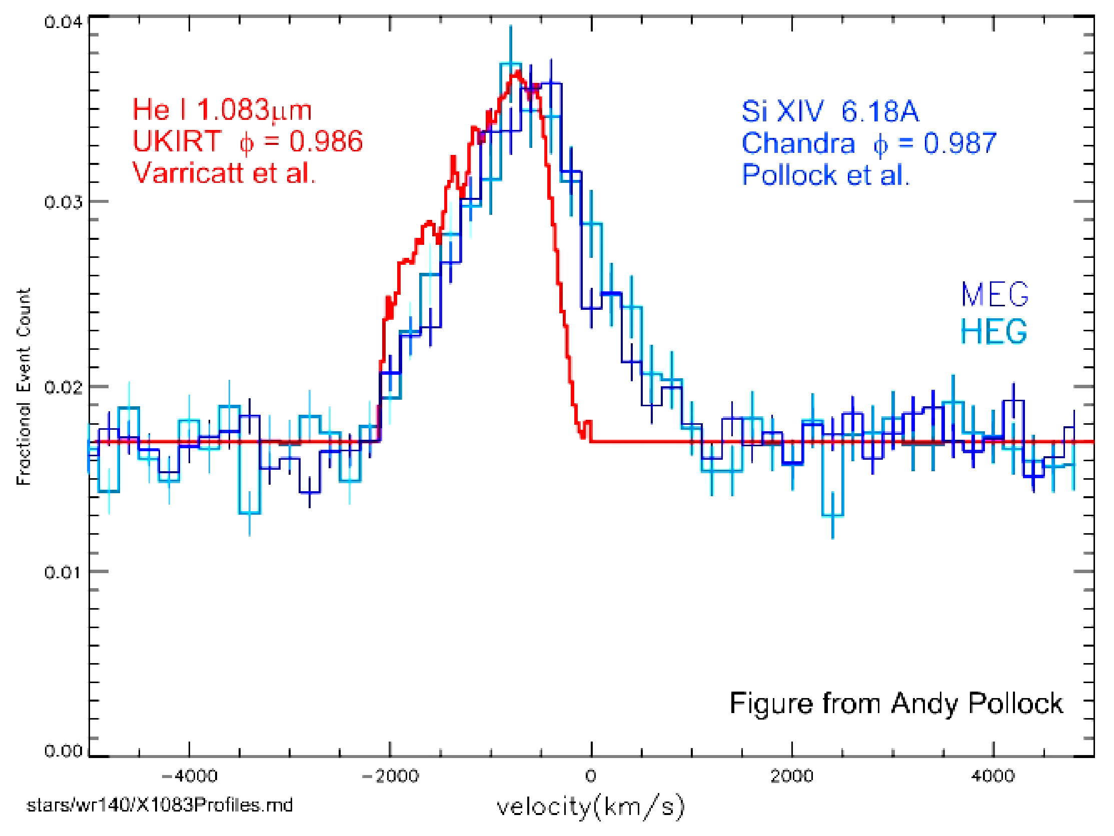


Figure from Andy Pollock

Conclusions

- Best measurement of WCR cone angle ~ 50° giving wind-momentum ratio $\eta \sim 0.1$
- Sub-peak emission arises in accelerating region of compressed flow, allowing us to map this – but there are more free parameters ...