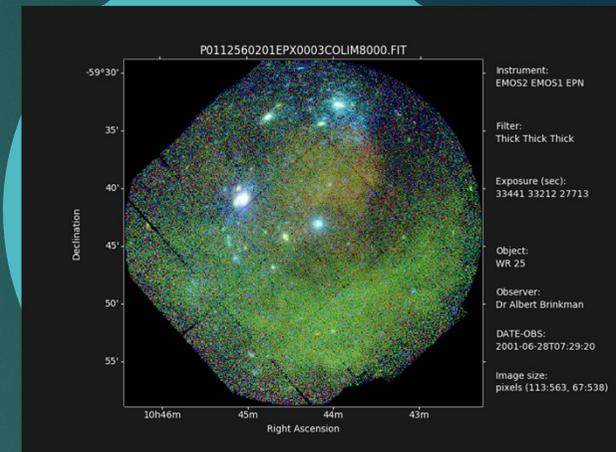


*New progresses on the spectroscopic  
orbital solution for the colliding-wind  
binary* **WR25**



Gosset E., Gamen R., Mahy L., Morrell N., Sana H., Barba R.

▶ **WR 25** is one of the three WN in the Carina classified WN7+abs (WR22, WR24)

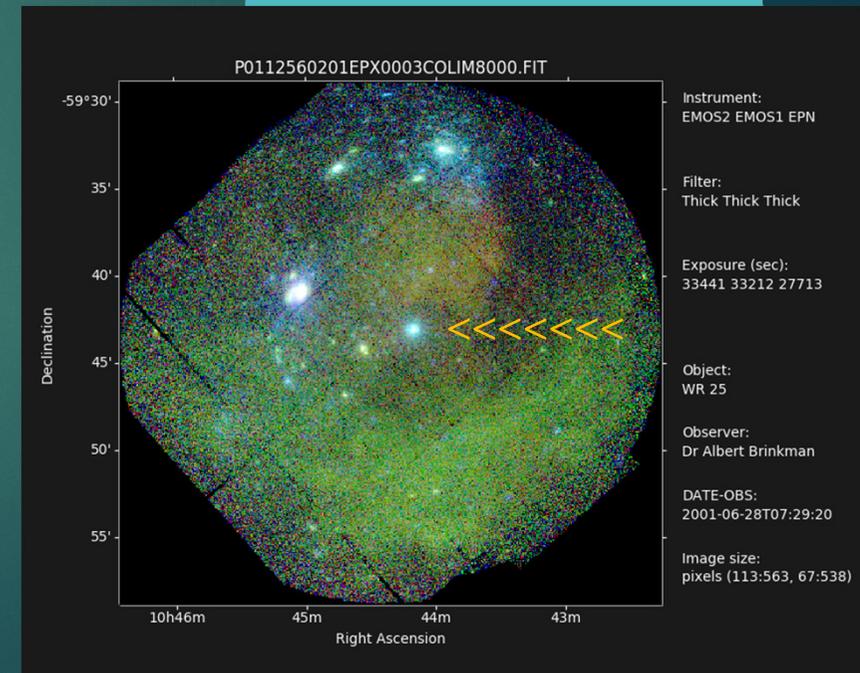
▶ WNLh, a late WN containing Hydrogen (non-classical WR), massive star probably still core-hydrogen burning ? .... or not (see also first day talk by K. Sen)

▶ One of the first WR detected exhibiting a strong emission in X-rays by the *EINSTEIN* satellite (Seward et al. 1979)

▶ Important X emission probably due to a colliding-wind phenomenon (Prilutskii & Usov 1976, Cherepashchuk 1976, Luo et al. 1990, Stevens et al. 1992, Pollock 1987, Pollock et al. 1995)

▶ BUT not detected as a binary (before 2006)

▶ Sister of WR 22, the first discovered WN+O binary with the WN component being markedly more massive than the O-star secondary (Rauw et al, 1996)

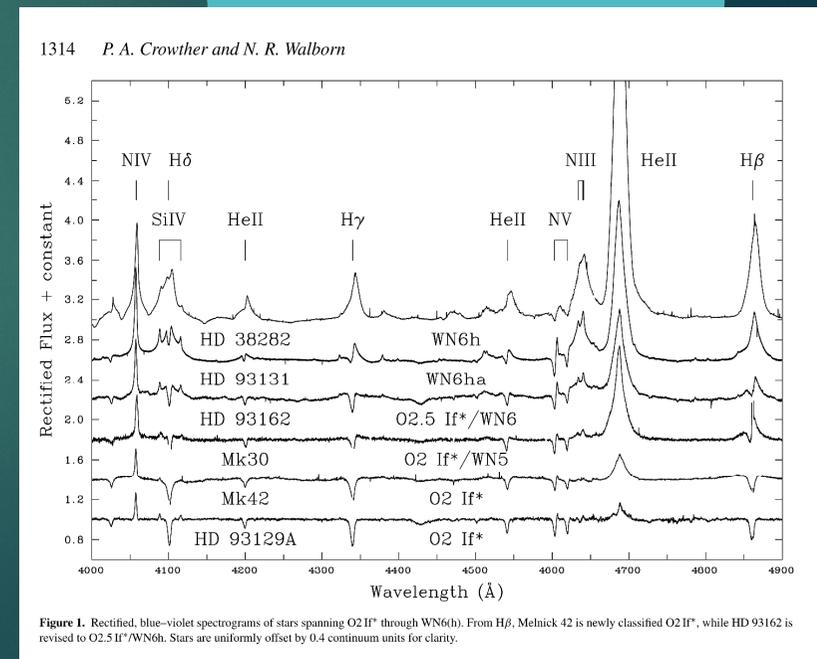


# Spectral type:

- WN7+abs (WNLh) (Smith 1968, van der Hucht 2001)
- WN6ha (Smith et al. 1996)
- O2.5f\*/WN6 (Crowther & Walborn, 2011)

WR24 = HD93131 (WN6ha)

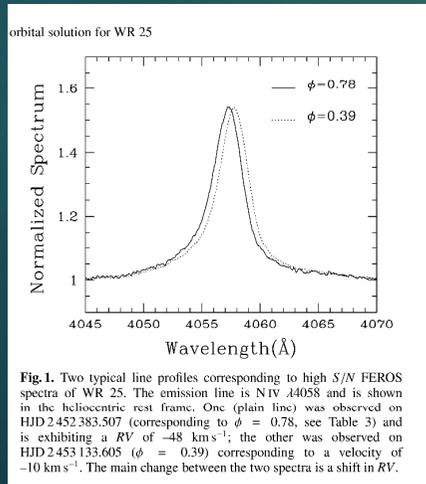
WR25 = HD93162



# Discovery of the spectroscopic variability

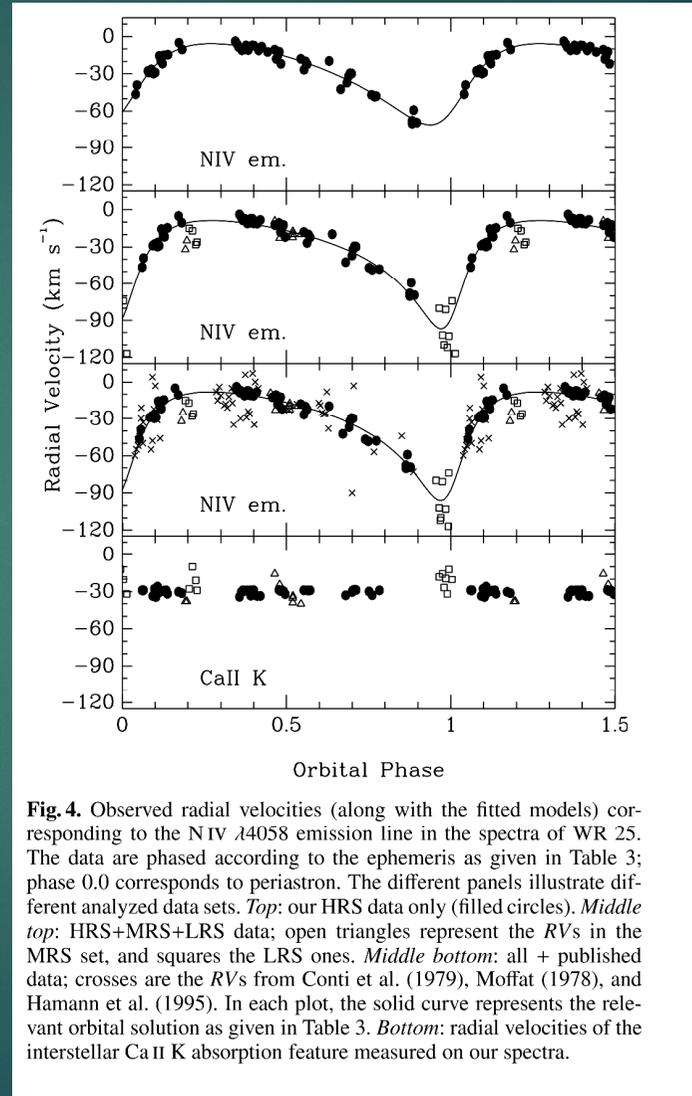
Gamen et al., 2006

On the basis of the N IV  $\lambda 4058$  line



First SB1 solution

First period value  
207.8 days



High Resolution only

High+Median+Low Res.

# First trace of the companion discovered

Gamen et al., 2008

Phase 0.98 corresponds to the maximum separation in velocity

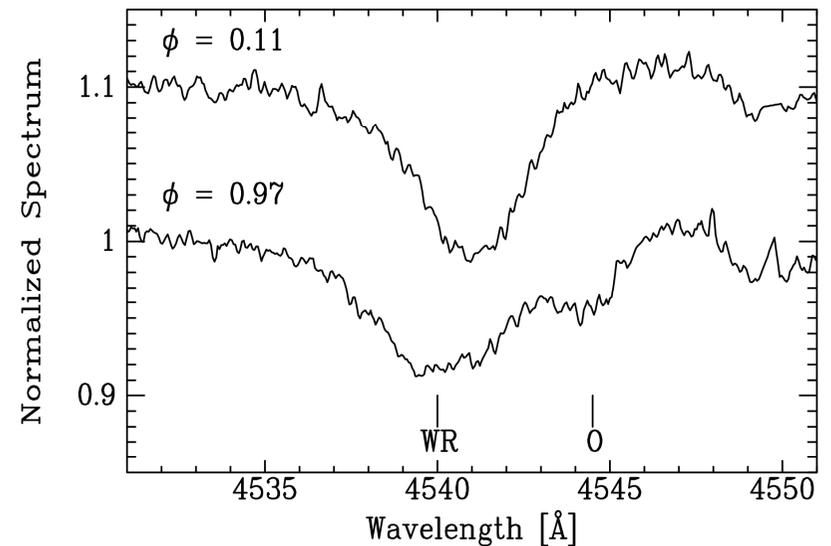


Fig. 1. The He II  $\lambda 4541$  absorption line observed on April, 2005 ( $\phi \equiv 0.11$ ), and May, 2006 ( $\phi \equiv 0.97$ ). The bottom spectrum shows how the lines from both components are debleded due to their extreme orbital radial velocities.

## New campaign (high resolution only):

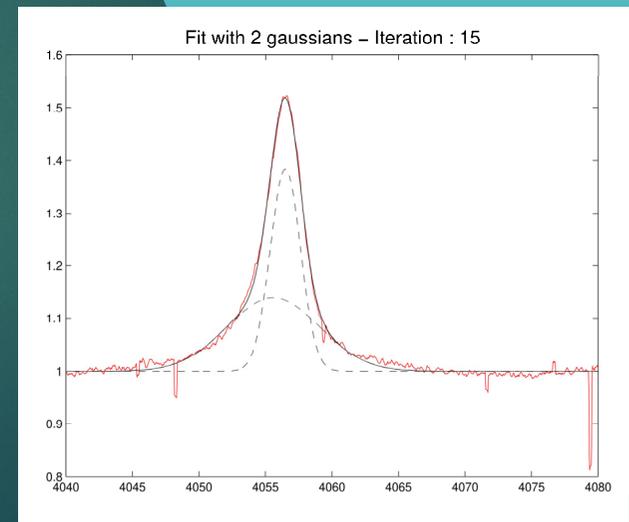
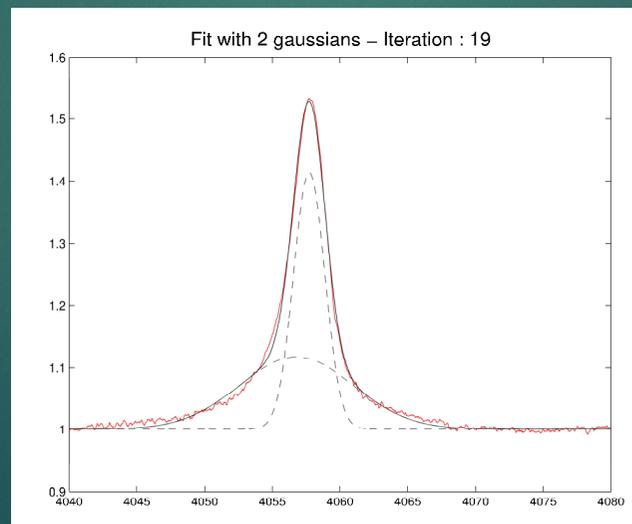
- New FEROS spectra from ESO/MPI 2.2m telescope at ESO La Silla 2006-2009 (27)
- Spectrum from MIKE at the Magellan II Clay telescope at Las Campanas 2007 (1)
- New spectra from Echelle at Irene du Pont 2.5m telescope at Las Campanas 2006-2007 (12)
- Reprocessing of the old FEROS spectra (2001-2004) (15)
- [High Res. N IV  $\lambda 4058$  spectra already measured by Gamen et al. (2006) ] (35)

# Lines from highly ionized elements for the WN component

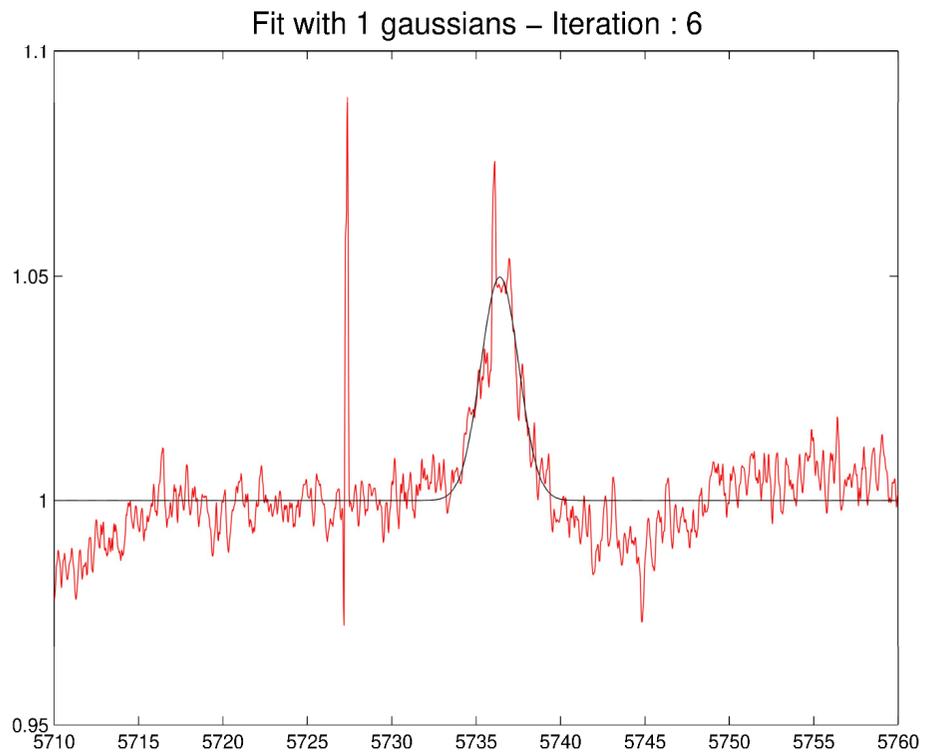
- N IV  $\lambda$ 4058
- N V  $\lambda\lambda$  4604-4620
- N V  $\lambda$ 4945
- N IV  $\lambda\lambda$ 6212-6219
- N IV  $\lambda$ 5737
- N IV  $\lambda\lambda$ 7103-7127
  
- N III  $\lambda$ 4321
- N III  $\lambda\lambda$ 4511-4515
- N III  $\lambda\lambda$ 4634-4641
- N III  $\lambda$ 4905
  
- Si IV  $\lambda\lambda$ 4089-4116
- C III  $\lambda$ 5696

Position measurement by Gaussian fitting

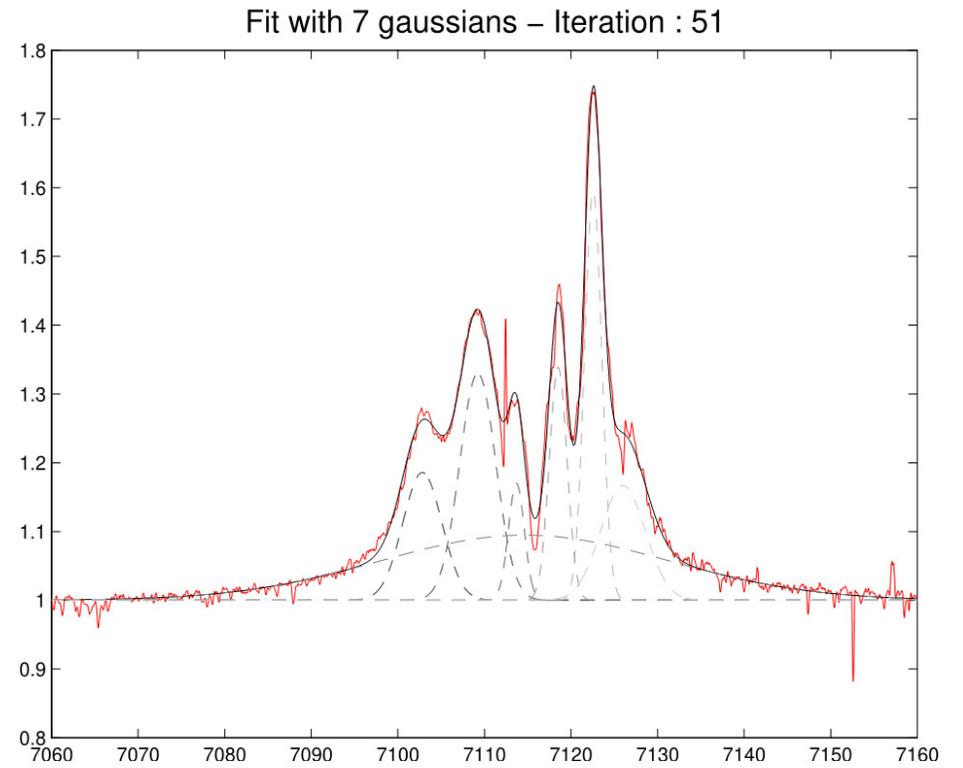
Simultaneous multi-Gaussian fitting if necessary

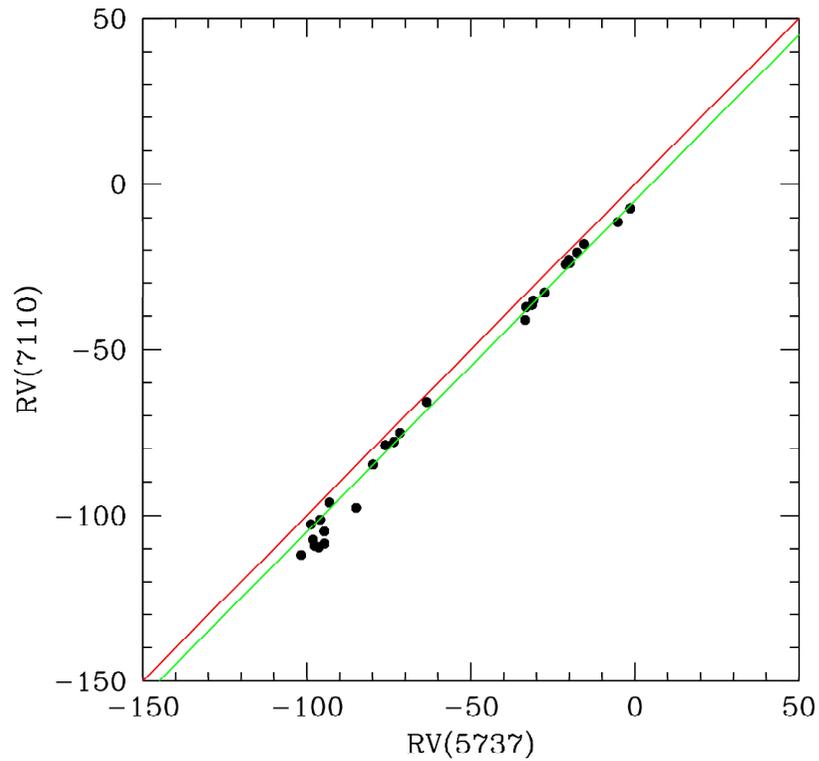


## N IV $\lambda 5737$



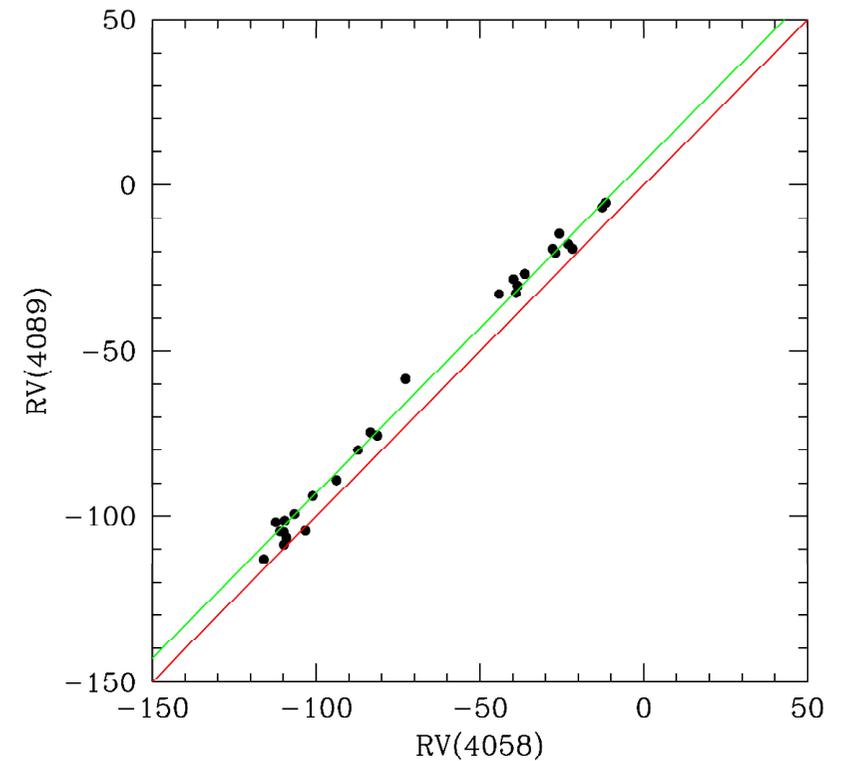
## N IV $\lambda 7110$ multiplet





Red: one to one

Green: offset



RVs from different lines are correlated but offsets are present

Possible reasons: blends (WR lines), local slope, rest wavelengths, shape of the lines, zone of formation in the wind

**Consequence: access to K but not to systemic velocity  $\gamma$**

# Search for the period

90 data points from N IV  $\lambda$ 4058

## SuperFourier Periodogram

Measuring the power for the fundamental and N harmonics

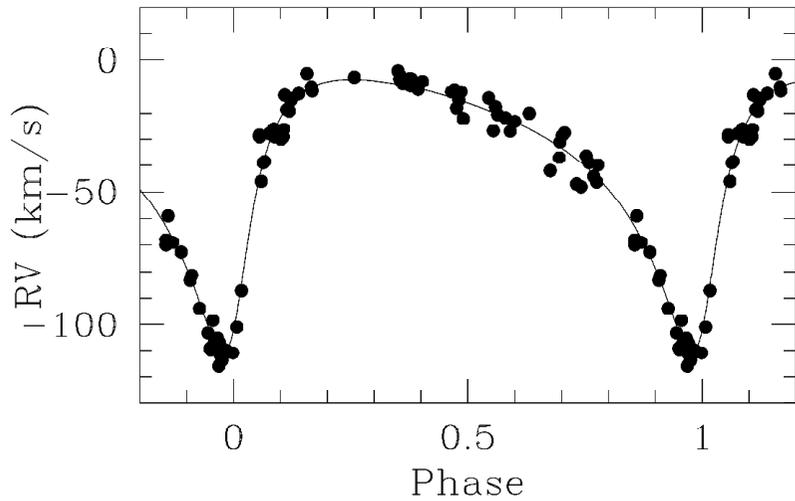
N freq.	Best Period (days)
1	209.660
2	207.646
3	207.447
4	207.633
Keplerian fit	207.638
One $\sigma$ error	0.093

Old period 207.85

Multifrequency approach described in Gosset et al. 2001

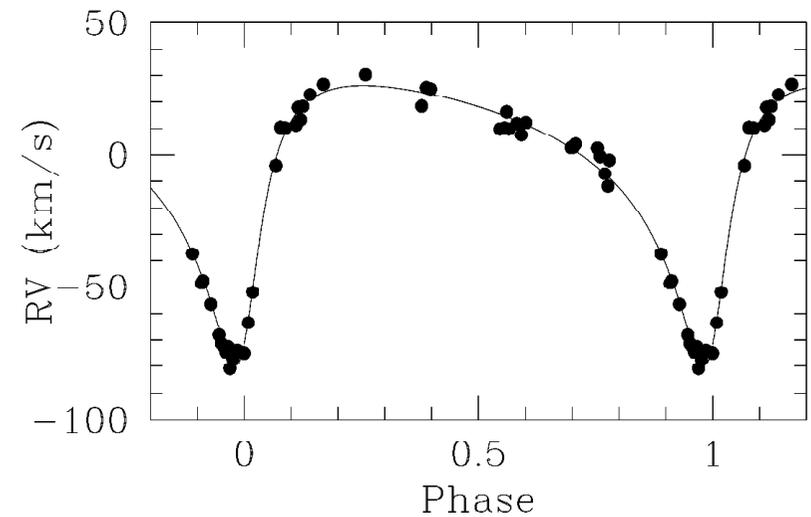
# The RV curve for the WN component

From the N IV  $\lambda 4058$  line  
N=90,  $\sigma_{\text{fit}} = 4.8$  km/s



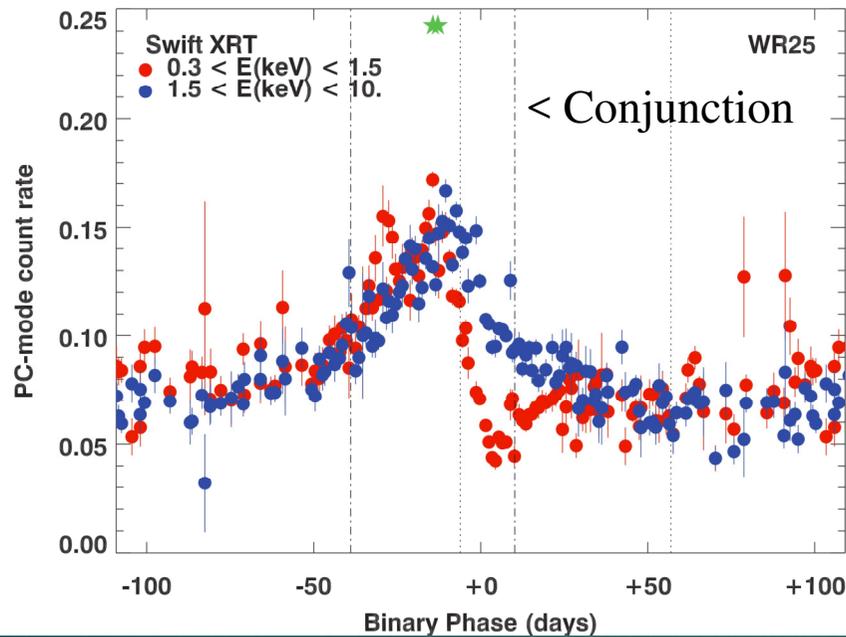
$K = 53.2$  km/s  
 $e = 0.59$   
 $f_m = 1.765$

From a selected set of 7 lines  
with good quality fit ( $\gamma=0$  km/s)  
N=45,  $\sigma_{\text{fit}} = 3.4$  km/s

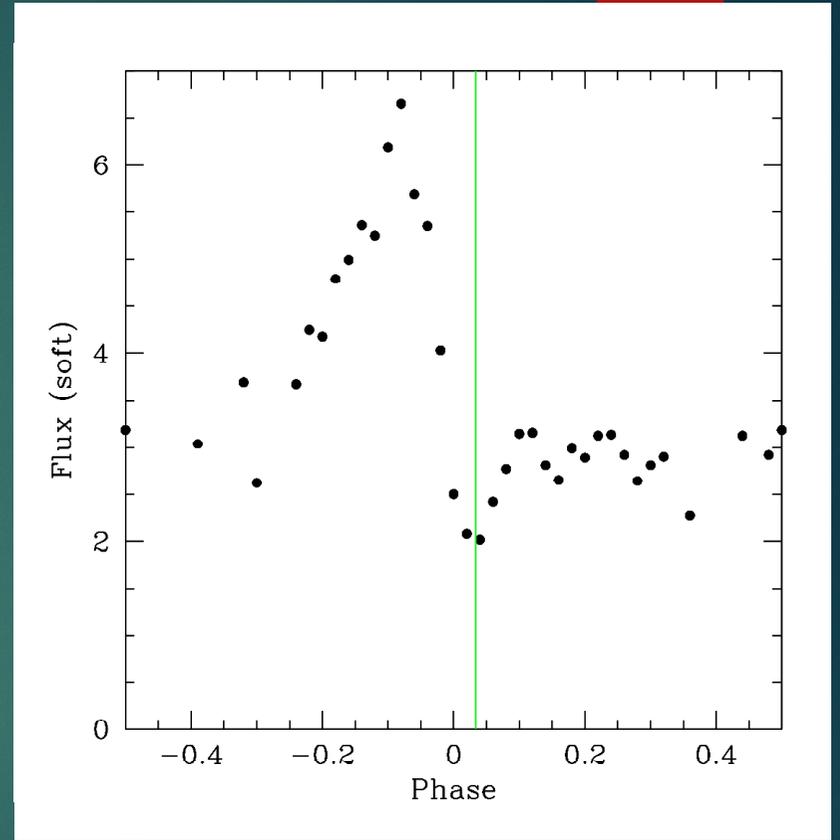


# Soft X-ray emission (red curve)

THE ASTROPHYSICAL JOURNAL, 915:114 (16pp), 2021 July 10



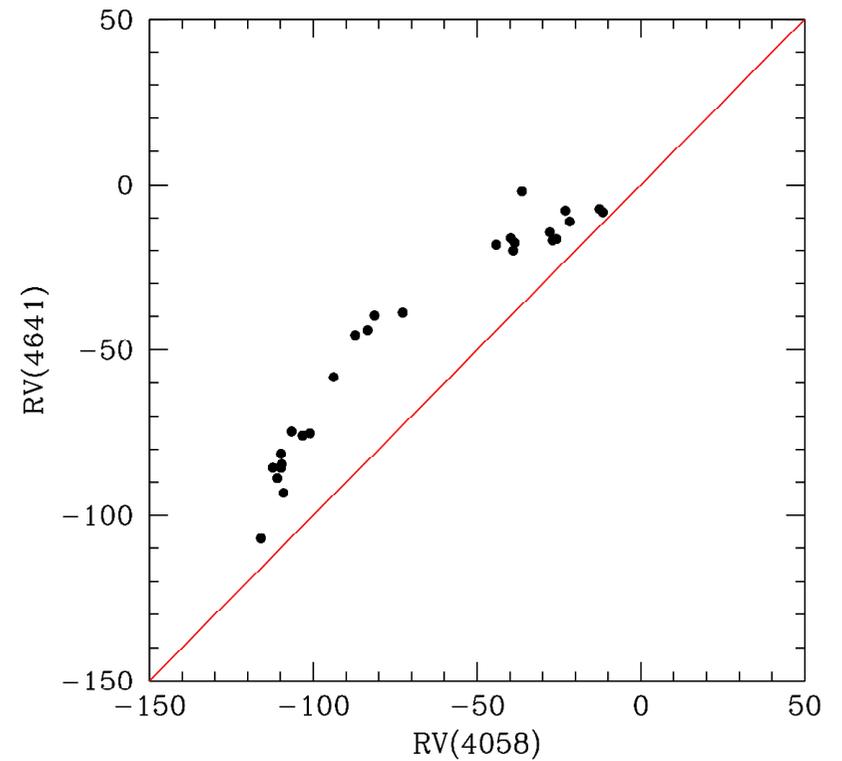
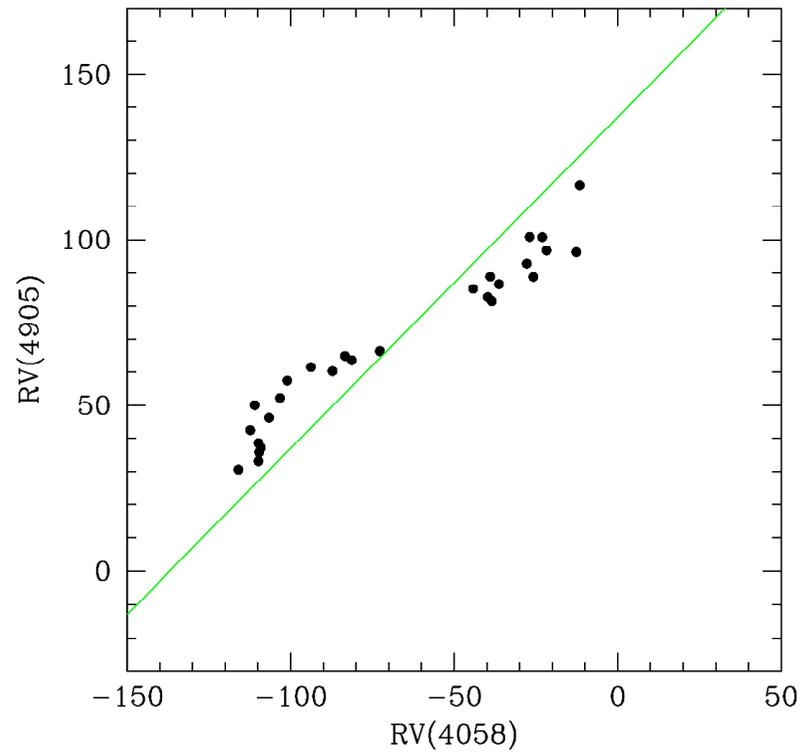
Pradhan et al (2023), old ephemerides



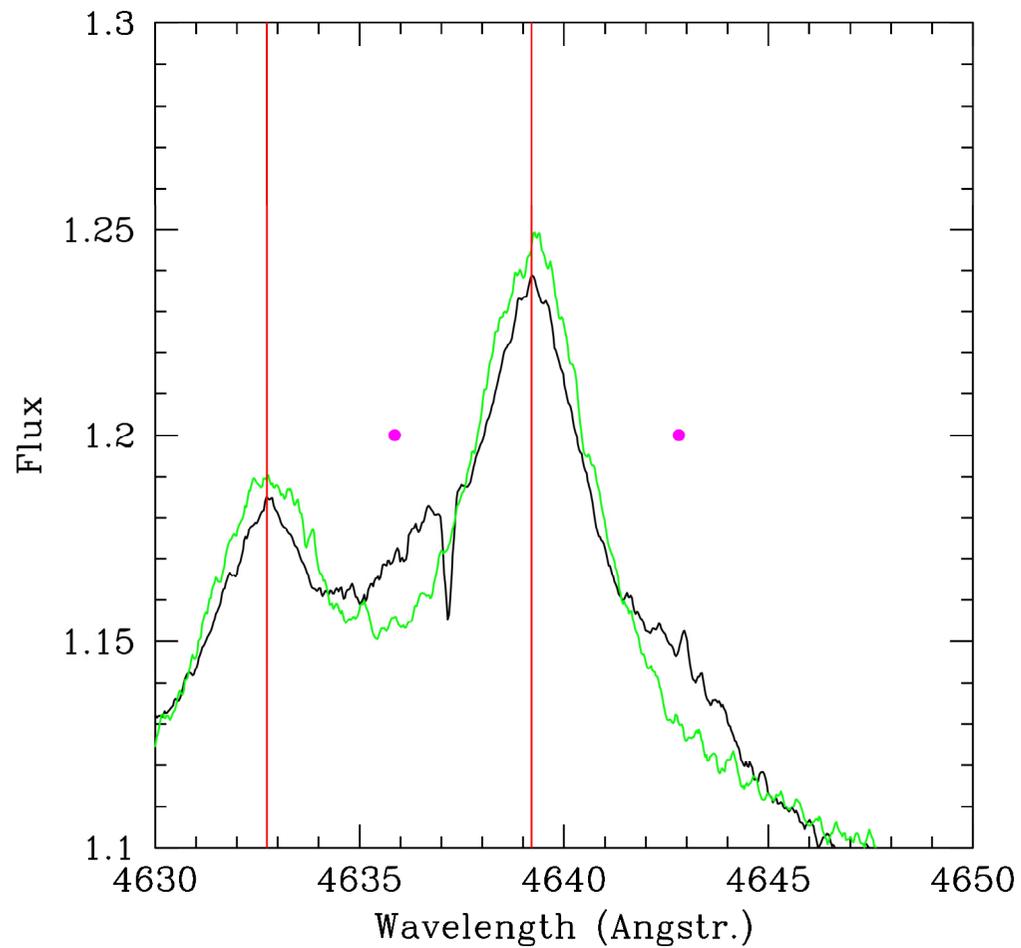
New ephemerides and Swift data (Arora et al)

Thanks to the change of eccentricity from  $\sim 0.5$  to  $0.59$ , the conjunction is better positioned

## Some lines do not exactly follow the orbital motion



Cause: blend (with O lines), anomalies in the line formation region



Green: spectrum at phase 0.14

Black: spectrum at phase 0.98  
(maximum separation)  
shifted to allow comparison of the profiles

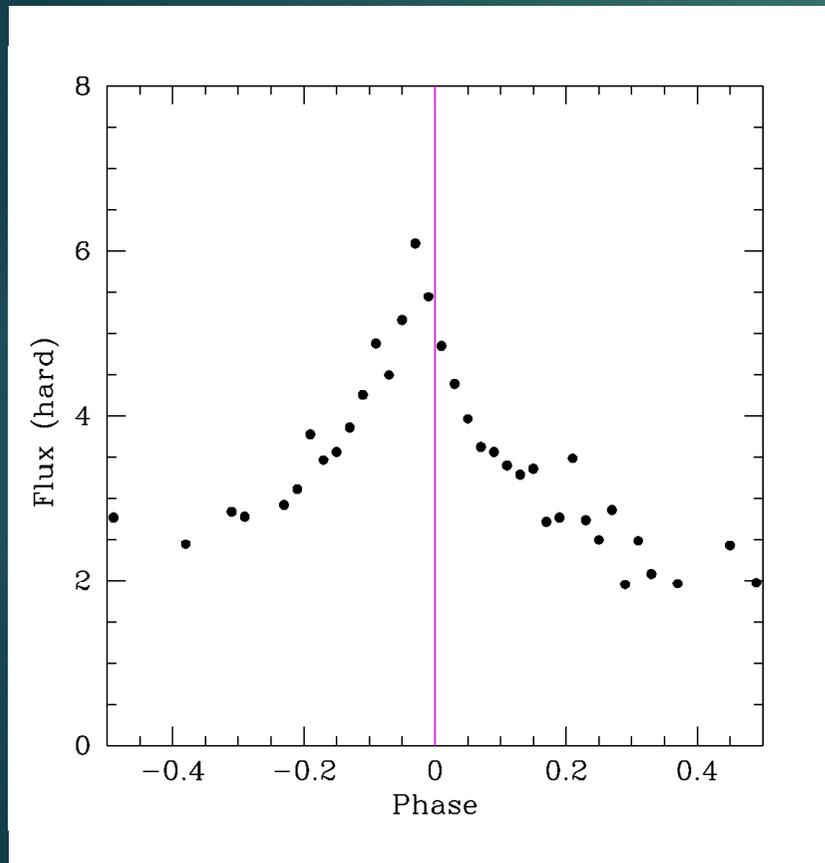
Magenta dots: presence of additional flux

Evidence for presence of N III lines  
in emission from the O star

# Validation through hard X-ray emission of WR 25

Expected behaviour: in the adiabatic regime, hard flux should be in  $1/\text{separation}$

Maximum should be at periastron



With old ephemerides (Gamen et al.),  
Behaviour essentially adiabatic  
(Gosset 2007, Pandey et al. 2014)

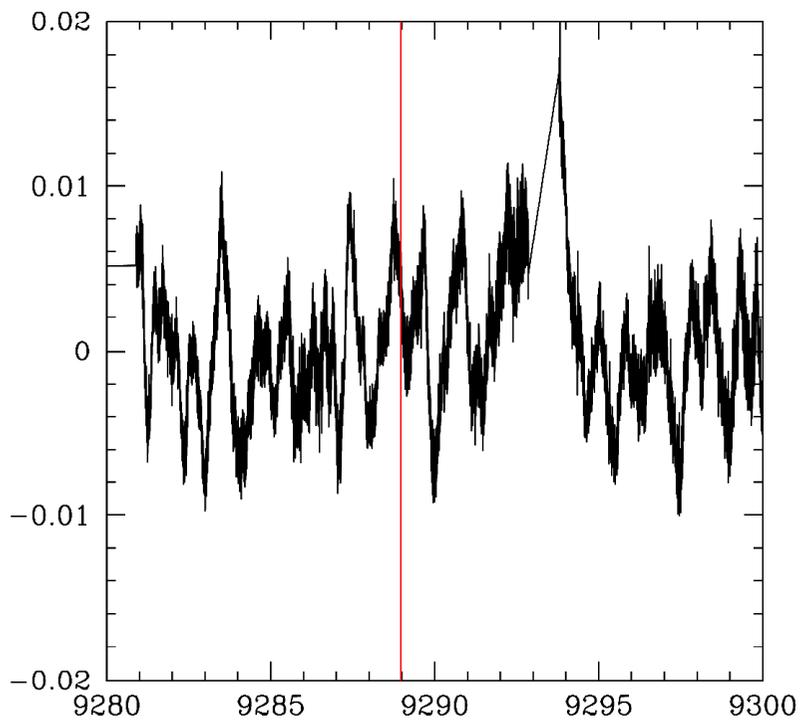
BUT Arora et al. (2019) report a slight deviation with  
maximum slightly before periastron.

<<<< Hard X-ray lightcurve of Arora et al.  
(2019, Swift XRT data)      New ephemerids

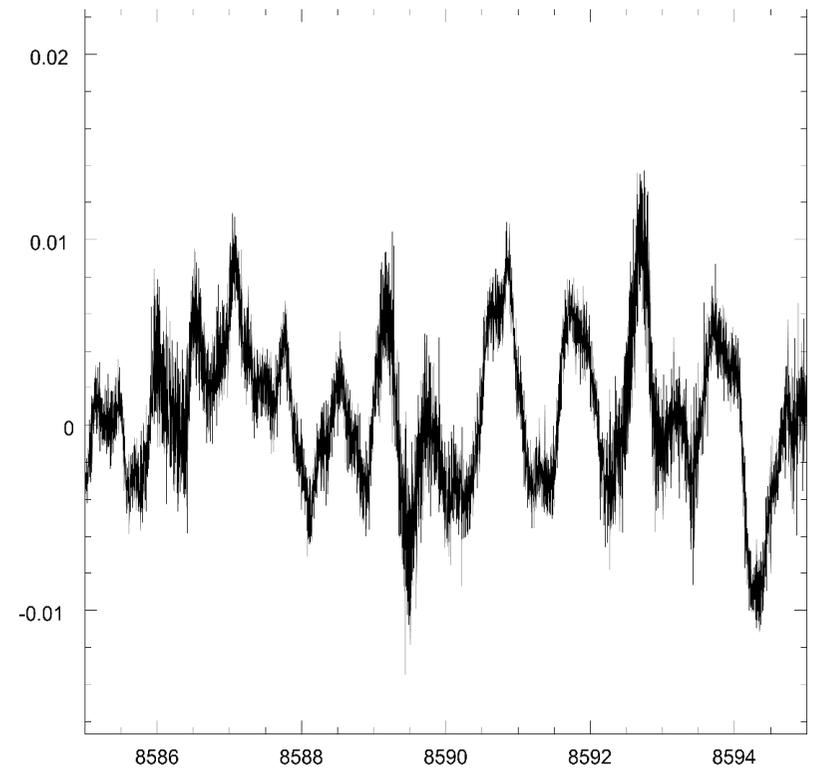
With the new ephemerides, the anomaly is confirmed  
(from the point of view of RVs)

# TESS photometry of WR 25

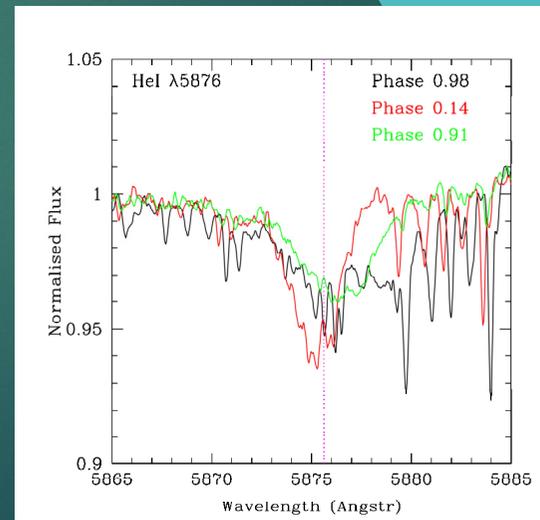
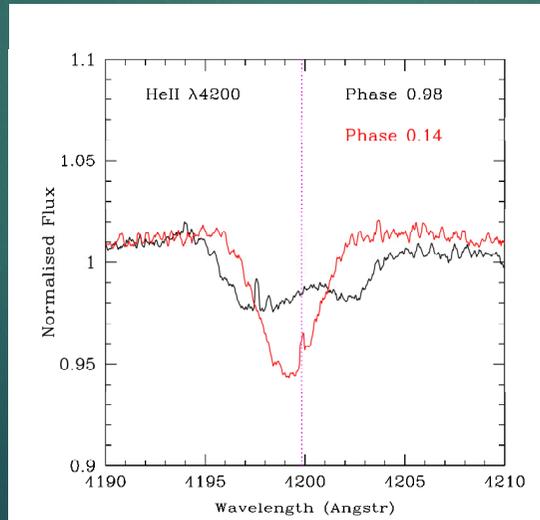
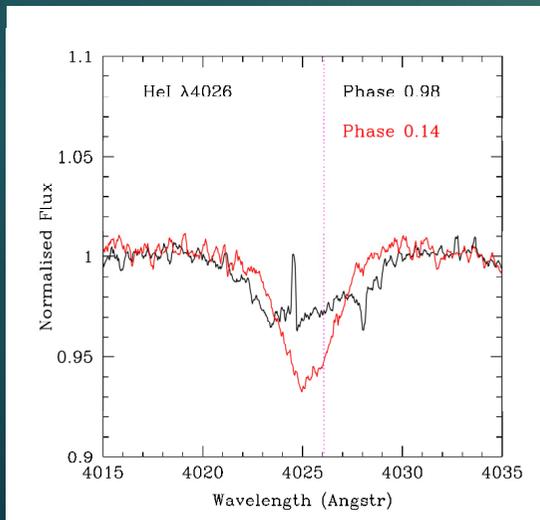
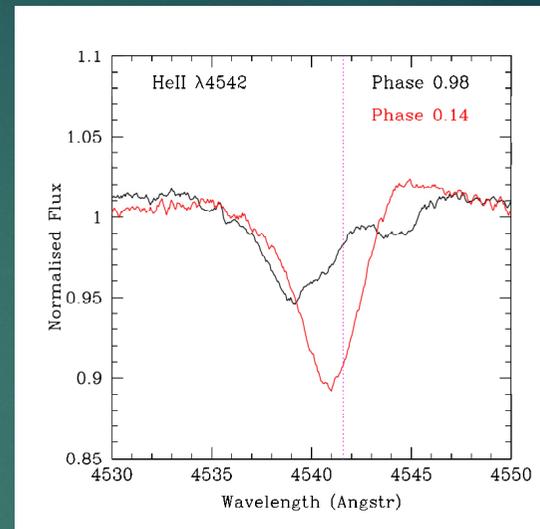
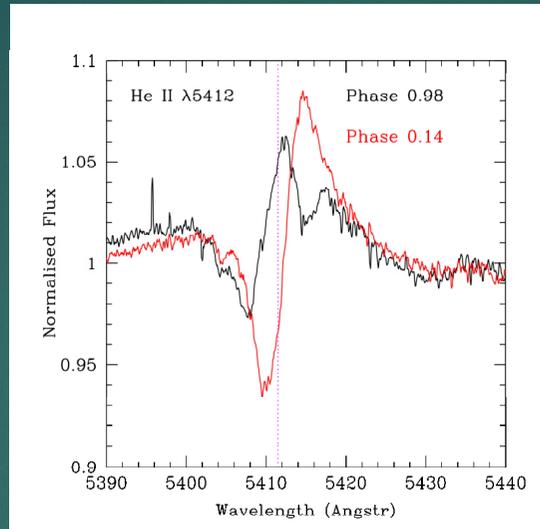
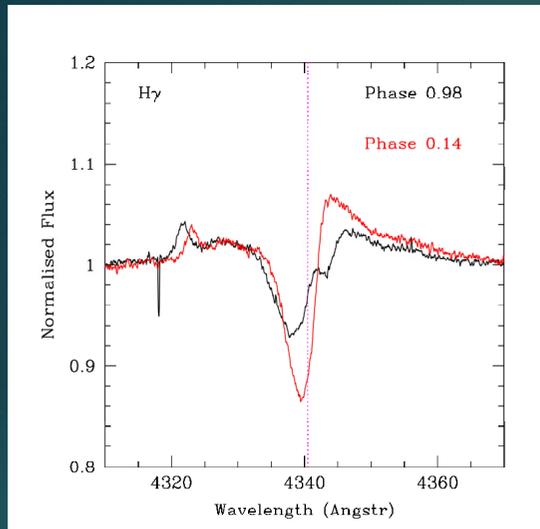
No trace of eclipse when WR in front  
(conjunction at red line)

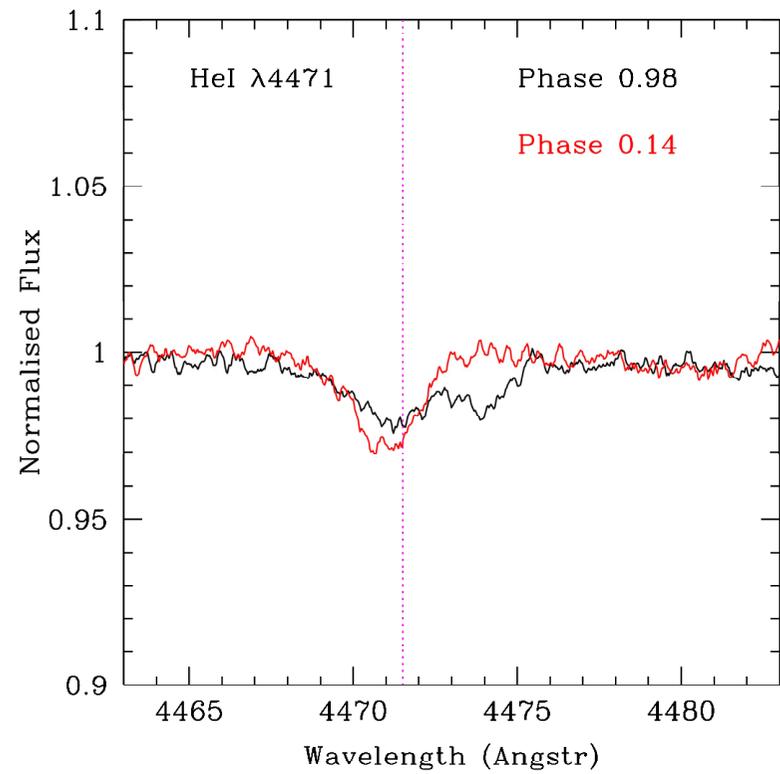
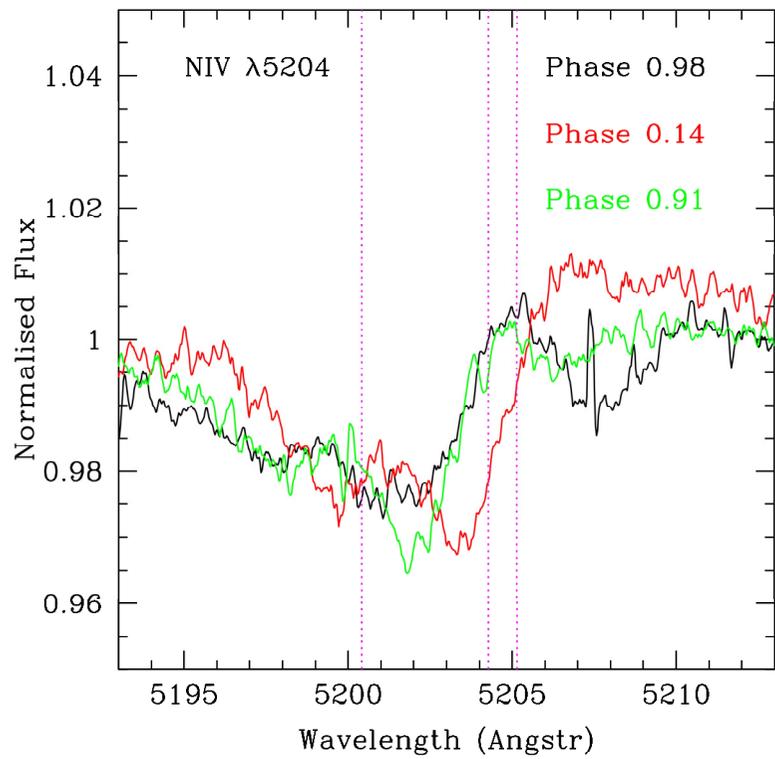


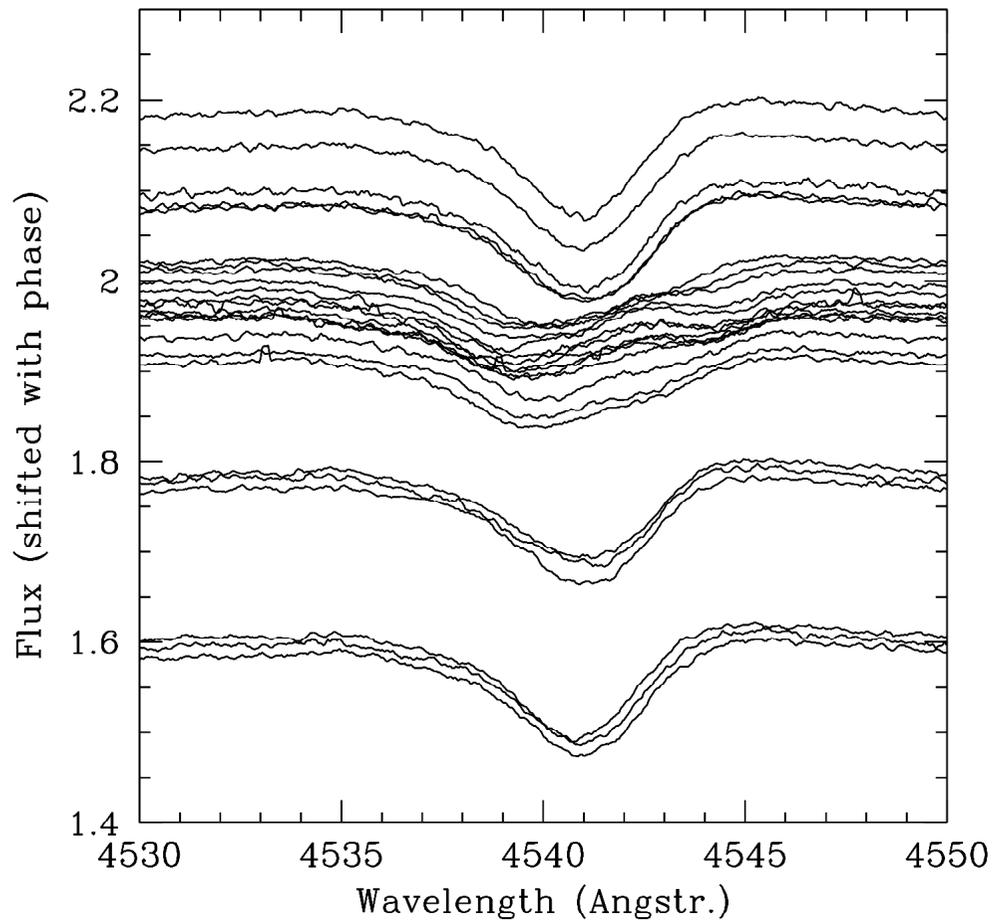
## Red Noise variations



# Searching for the companion (spectral lines from O and WR)



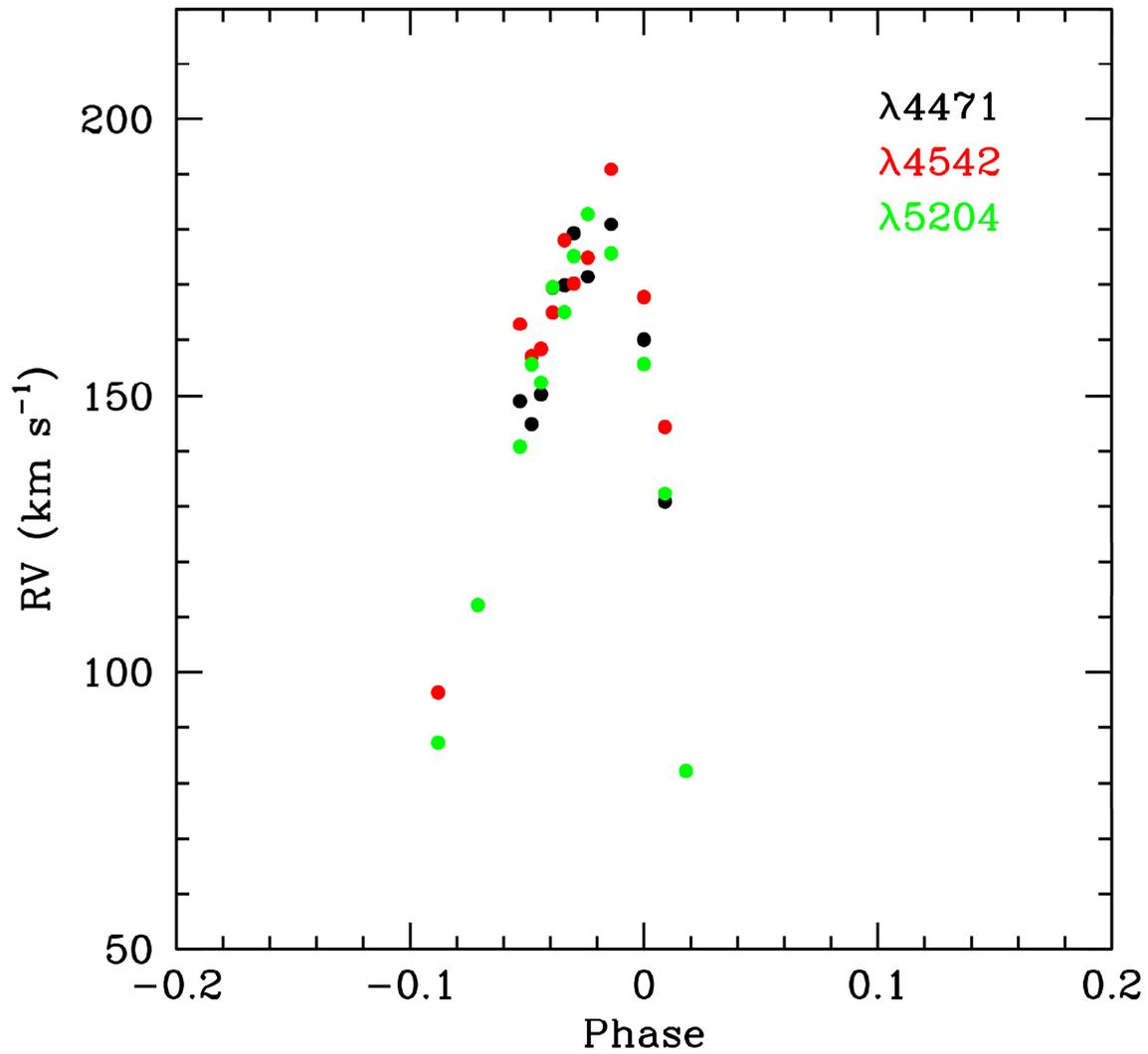




He II  $\lambda 4542$

Red excursion of O star well visible

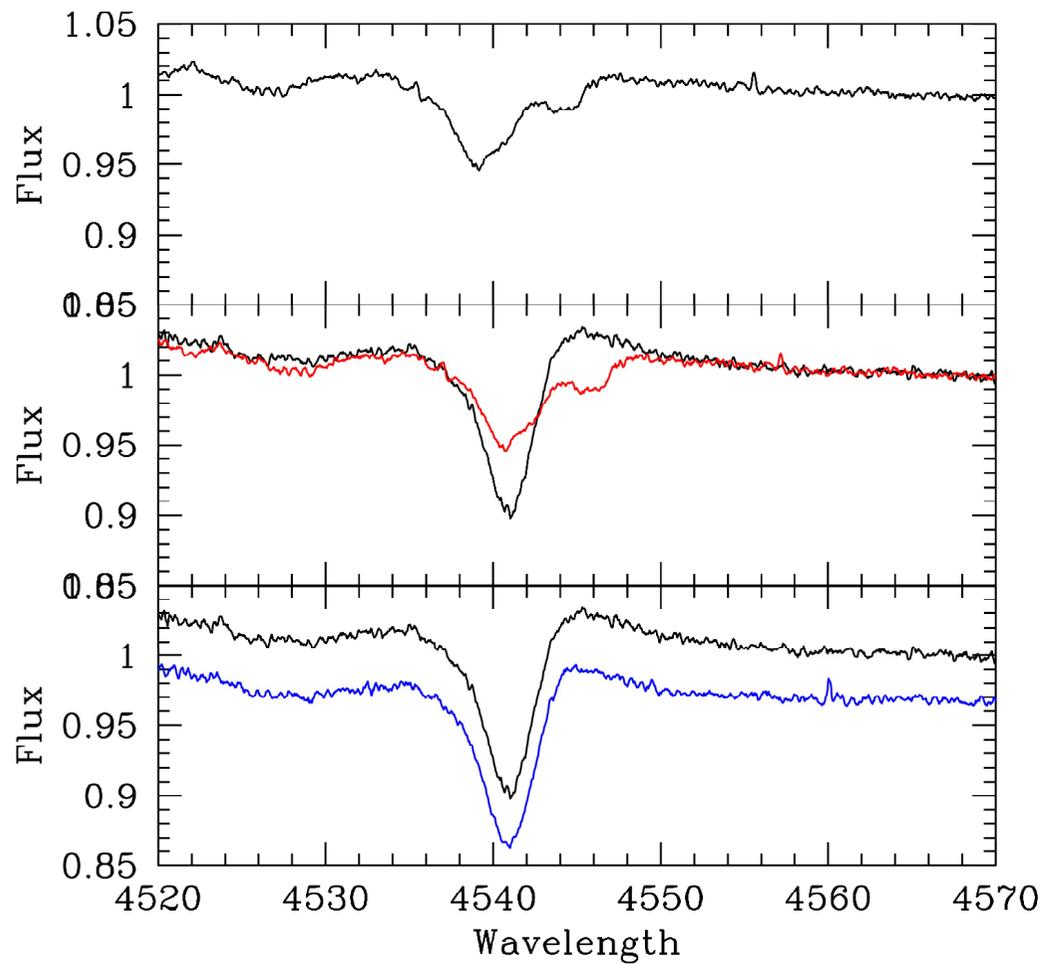
No trace on the blue side except EW



For the O star, the extremum of velocity is constrained

BUT it is not on the other side

We need measurements on the other side or a knowledge of the systemic velocity



## He II $\lambda 4542$

Phase 0.98

Phase 0.14

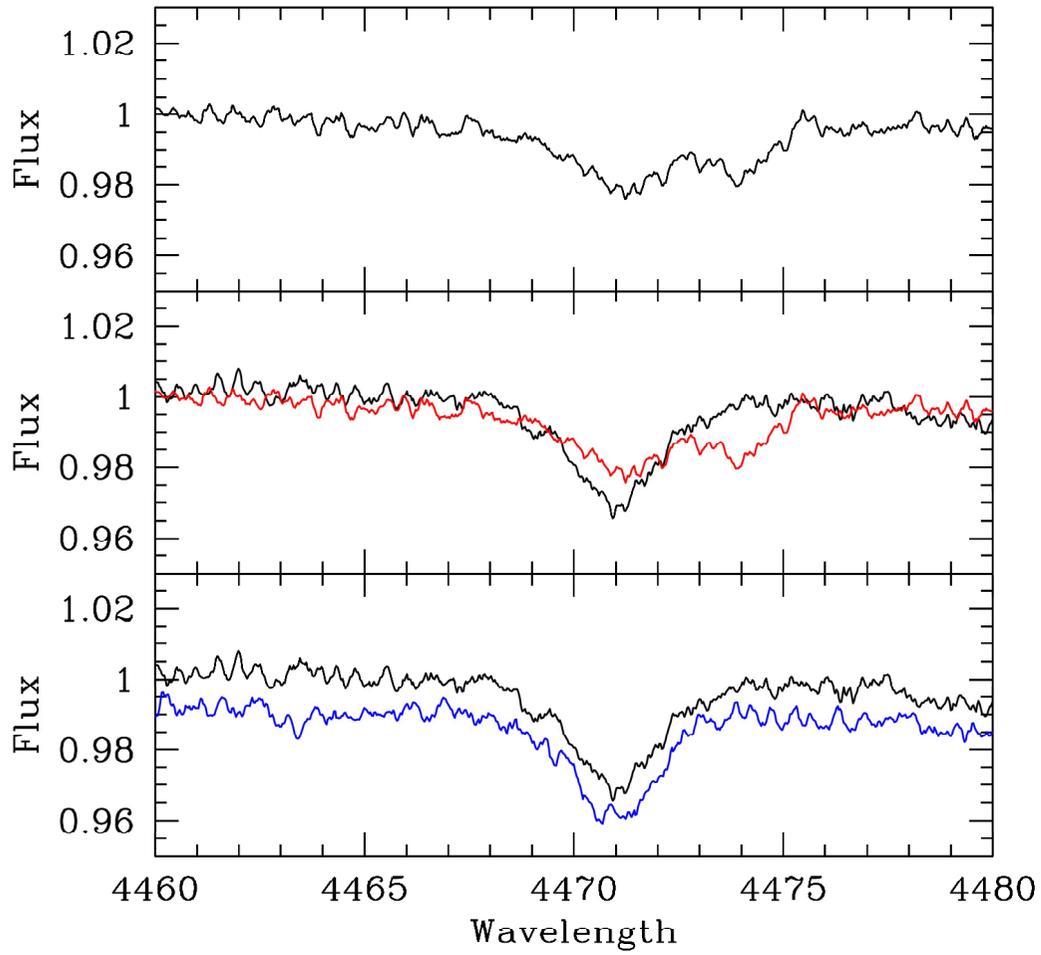
Red: phase 0.98 shifted by two  $K_{WR}$

Phase 0.14

Blue: Phase 0.17

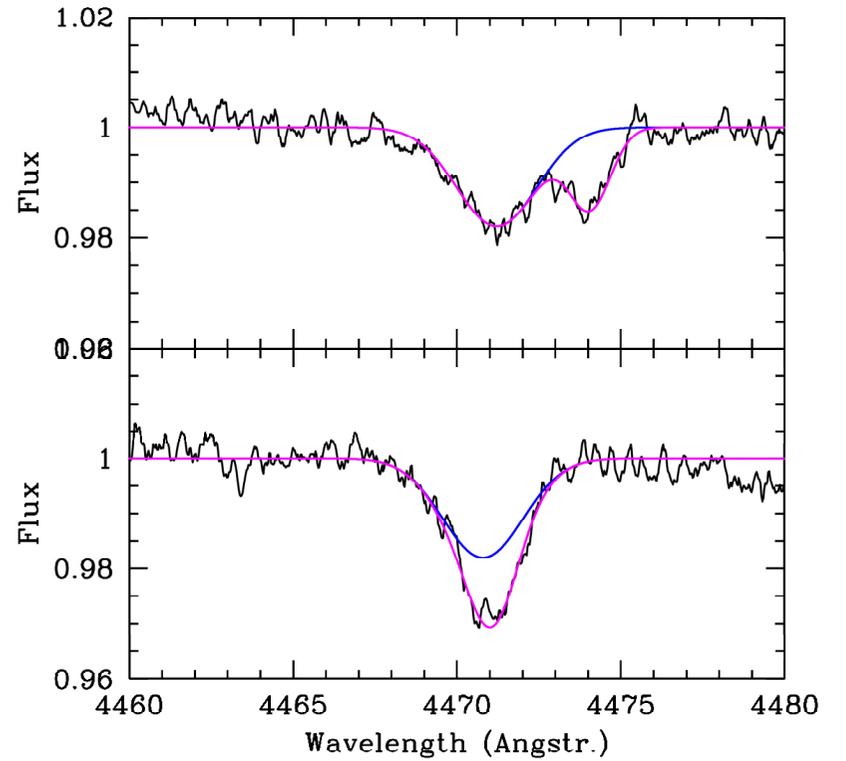
# He I $\lambda 4471$

Phase 0.98

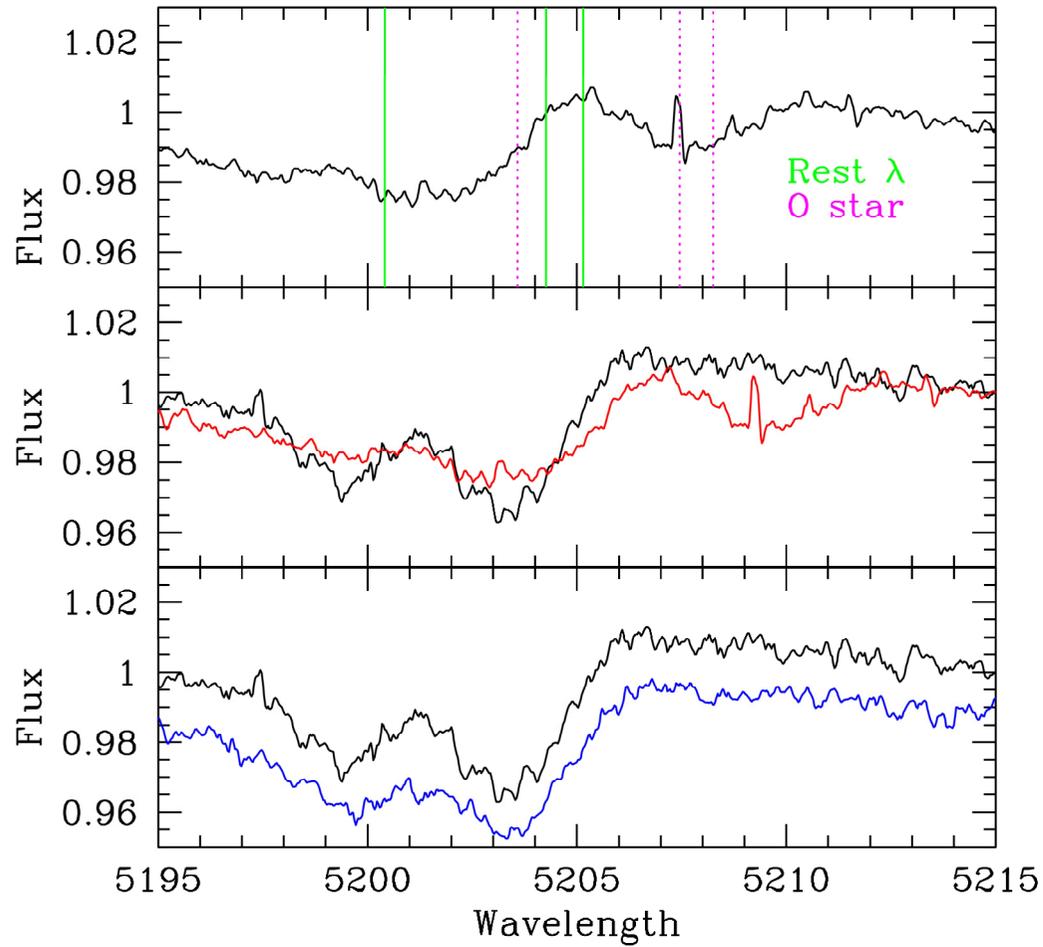


Ph  
Re

Ph  
Bl



# N IV $\lambda 5204$ (multiplet)



Phase 0.98

Phase 0.14

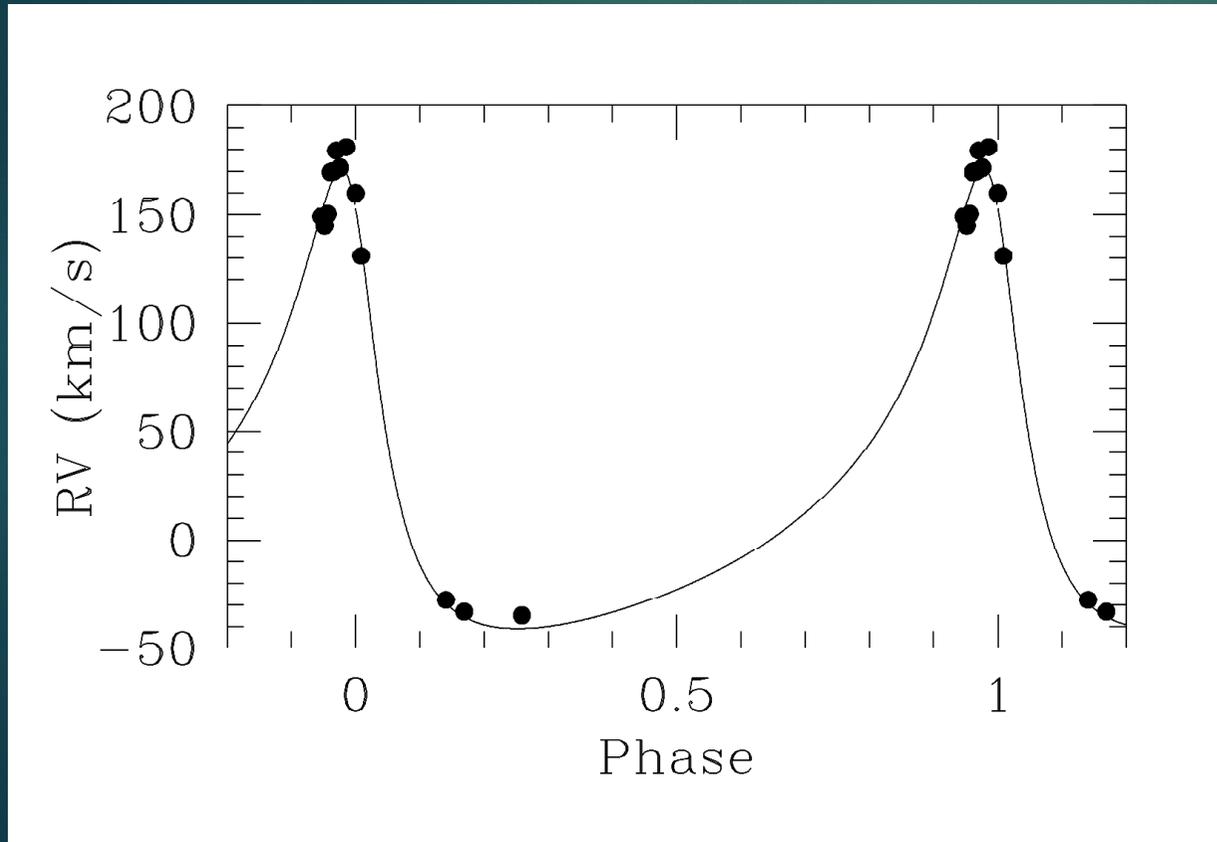
Red: phase 0.98 shifted by two  $K_{WR}$

Phase 0.14

Blue: Phase 0.17



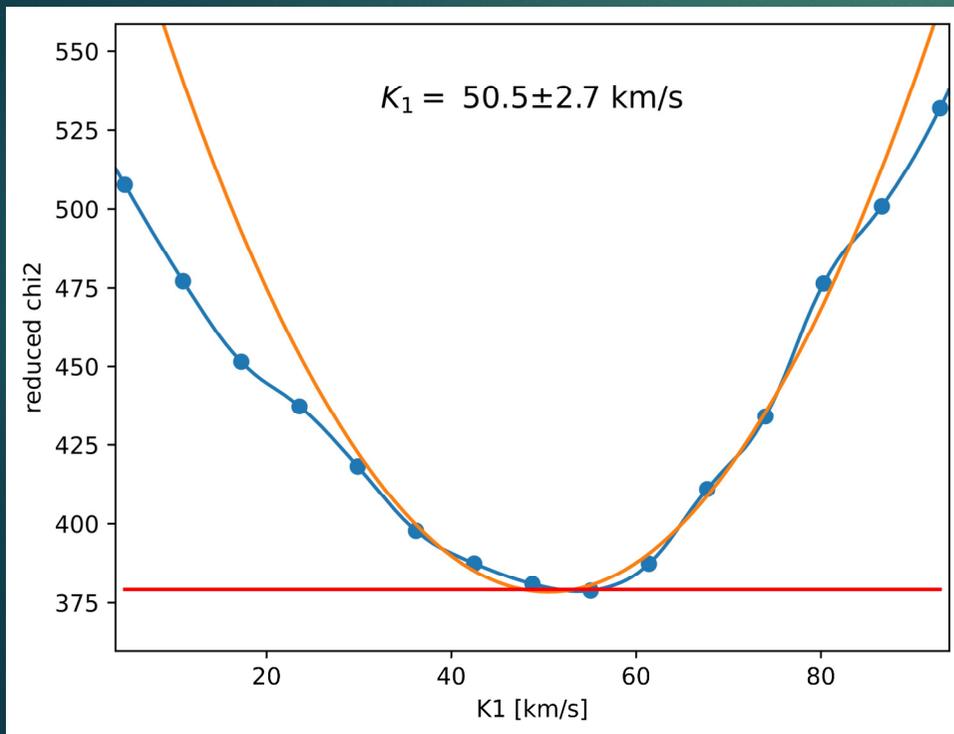
# RV fit of the O star through the He I $\lambda 4471$ line



Resulting  $K_2 = 106$  km/s  
 $\gamma_2 = 15$  km/s

# Disentangling of the spectra

## The WR motion



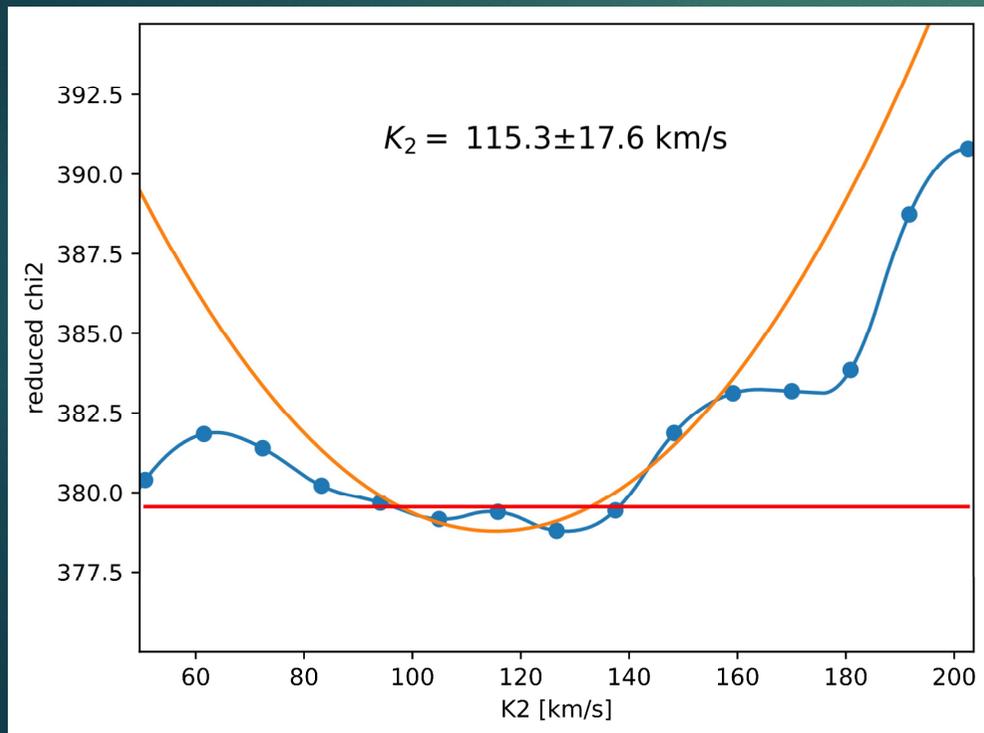
Global minimum  $K_1 = 50.5 \text{ km/s}$  (orange curve)

Local minimum  $K_1 \sim 55.0 \text{ km/s}$  (blue dots)

In very good agreement with  $K_1 = 53.2 \text{ km/s}$  ( $\sigma=0.8$ )  
(from the highly ionized nitrogen lines)

# Disentangling of the spectra

## The O motion (preliminary)



$$K_2 = 115.3 \pm 17.6 \text{ km/s}$$

In agreement with  $K_2 = 106$  km/s from the He I  $\lambda 4471$  line

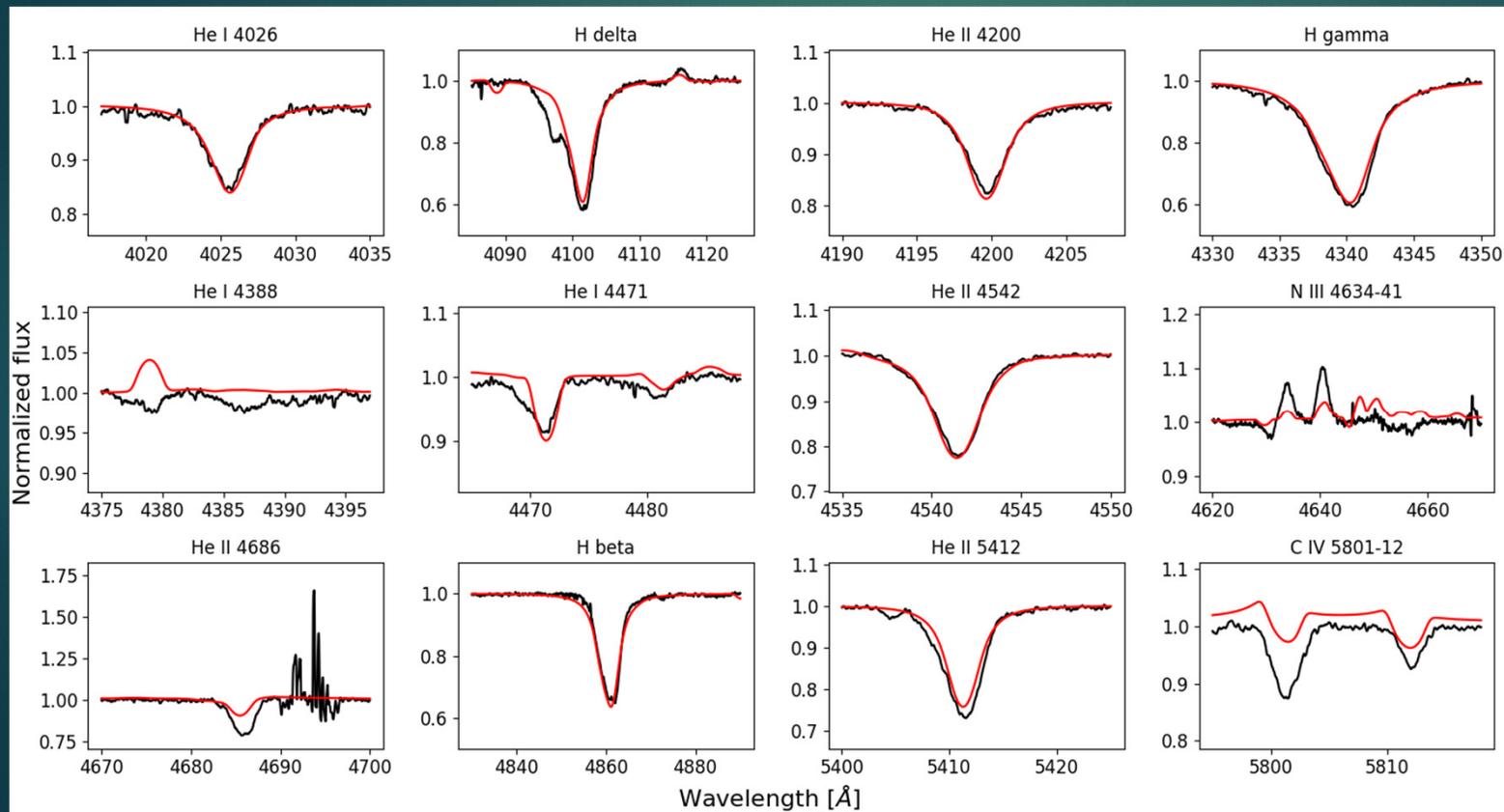
Mass ratio WN over O of 2.2 (1.8 to 2.5)

Minimum mass O =  $18 M_{\text{sol}}$

# Disentangled O-star spectrum and CMFGEN fit

Spectral type O5((f))

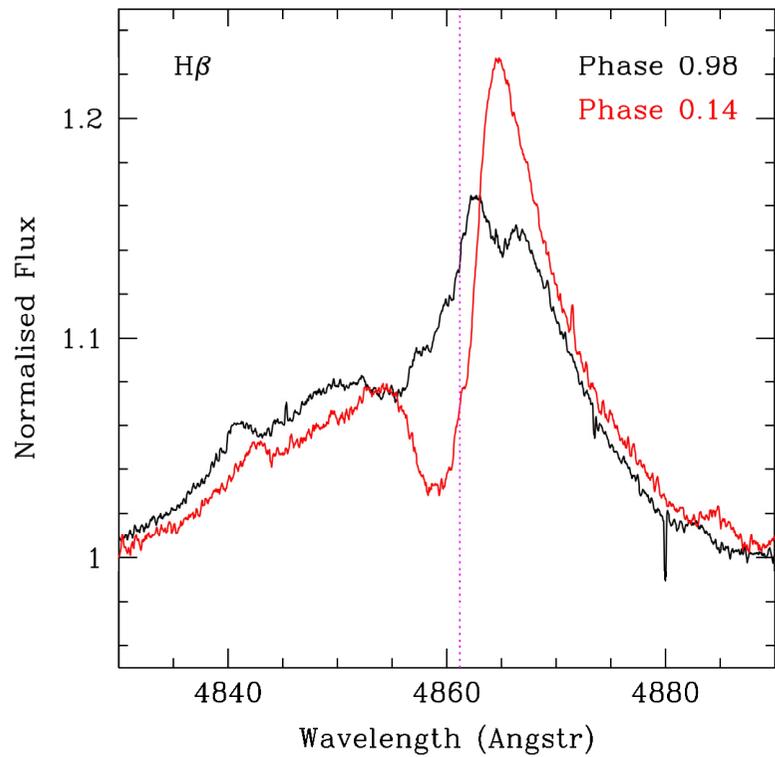
$T_{\text{eff}} = 41700 \text{ K}$



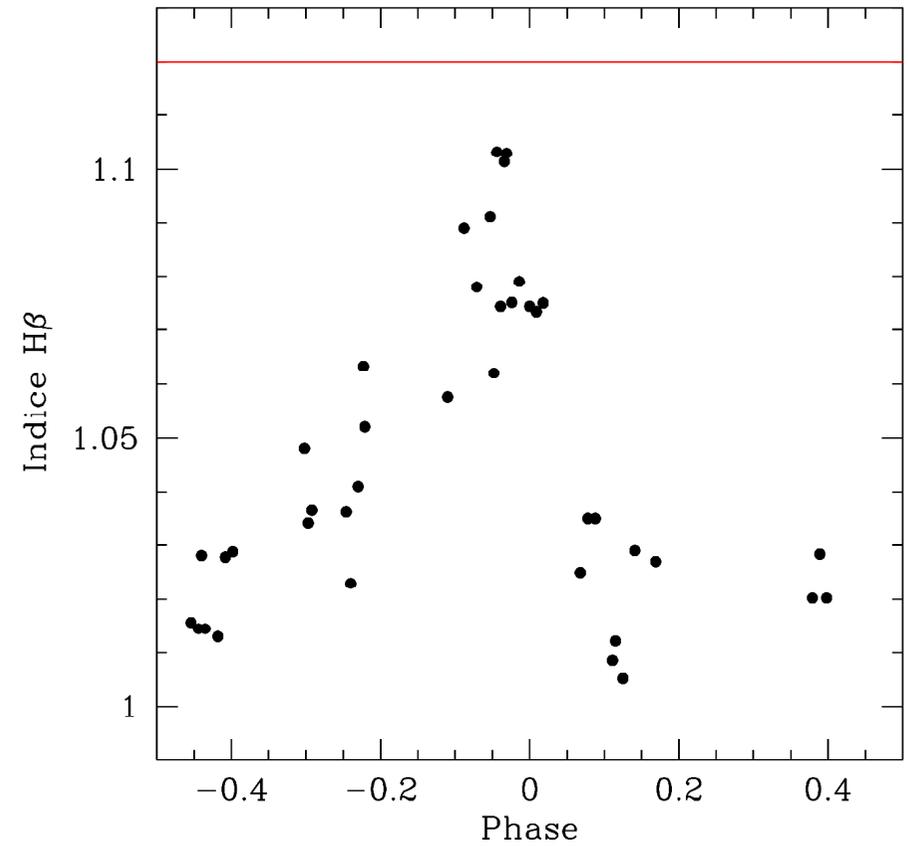
Black: observations

Red: CMFGEN fit

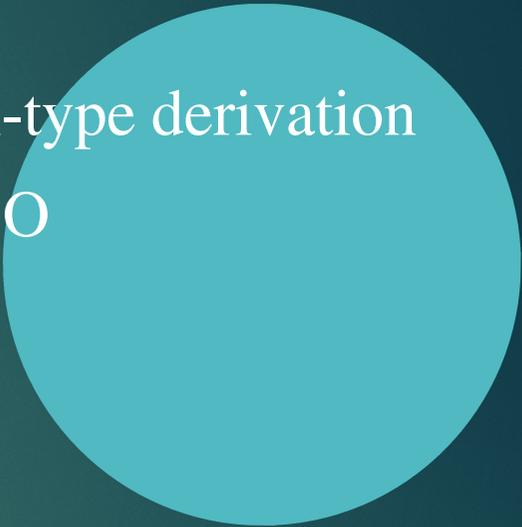
# The strange case of H $\beta$



Indice: is position in normalized flux of the bottom of the WR absorption trough



# Summary



- Very good SB1 solution for the WR
- First SB2 orbital solution for the O star and spectral-type derivation
- Confirmation that the WN is more massive than the O
- CMFGEN analysis of the disentangled spectra

## Future prospects

- To decrease the error bars on the O star motion
- Still a few enigma to solve (4905, Hbeta, 4471, ...)
- Beyond spectroscopy: constraints on the inclination