The spin-axes orbital alignment within the eclipsing binary system V1143 Cyg using the Rossiter-McLaughlin effect

Simon Albrecht, Sabine Reffert, Ignas Snellen, Andreas Quirrenbach and David S. Mitchell

Sterrewacht Leiden

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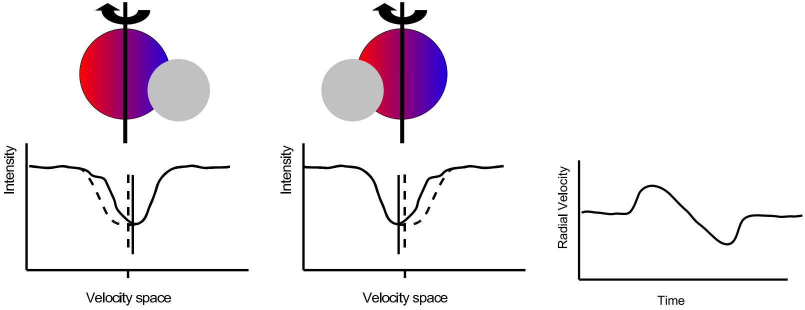
Stellar rotation axes: Why care?

The orientation of stellar rotation axes relative to the orbital spin axes might shed new light on questions of:

- Binary/planetary system formation
- Binary/planetary system evolution

How: Rossiter-McLaughlin (RM) effect

Crossing of companion in front of rotating star:



→ Light integrated over part of the disk

→ Radial velocity anomaly

→ Function of the orientation of the rotation axis

⇒ **spatially resolved information on the stellar surface scales**

How: Rossiter-McLaughlin (RM) effect

- First discovered: β Lyrae (Rossiter 1924) and Algol (McLaughlin 1924)
- Recently the effect has been observed for transiting planets (e.g. Queloz 2000)

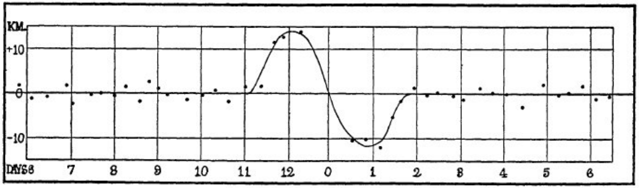
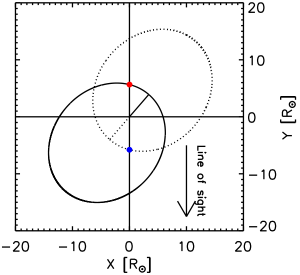


FIG. 2

Rossiter 1924

System: V1143 Cygni



- Well studied system with two F5V stars
- Bright (V$_{mag}$ = 5.9)
- Period = 7.64 days
- High eccentricity (e = 0.54)
- Measured apsidal motion does not fully agree with the expected apsidal motion

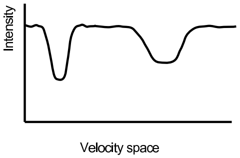
Observations

Observations at the Lick Observatory:

- 0.6 m CAT telescope & Hamilton spectrograph
- Primary eclipse ($\approx$ 4 hours) 9 observations
- Secondary eclipse ($\approx$ 8 hours) 11 observations
- Out of eclipse 26 observations

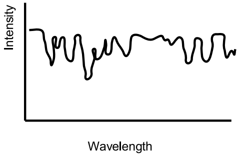
Broadening function (BF)

We want:
High S/N absorption line:

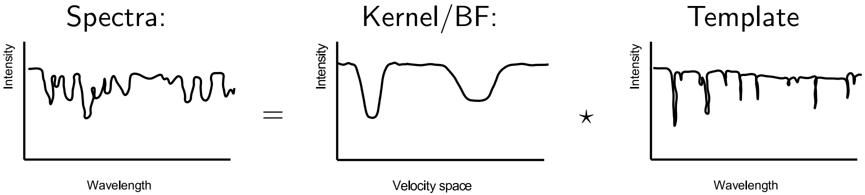


- Orbital velocity
- Stellar rotation
- Velocity fields on the stellar surface
- Limb darkening
- Possible covering by companion

We have:
Spectra of both stars:



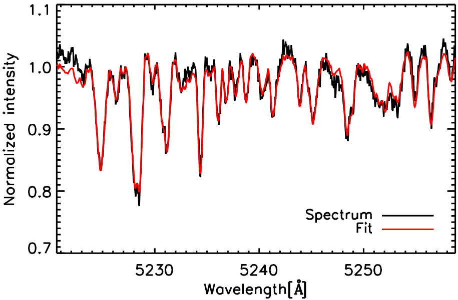
Broadening function (BF)



Use of : Singular Value Decomposition (SVD) (Rucinski 1998)

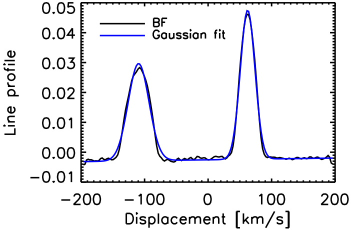
- Template: Deconvolved spectrum of HD222368
- Conditioning of matrix consisting of the shifted template
- Suppress influence of noise

Broadening function (BF)

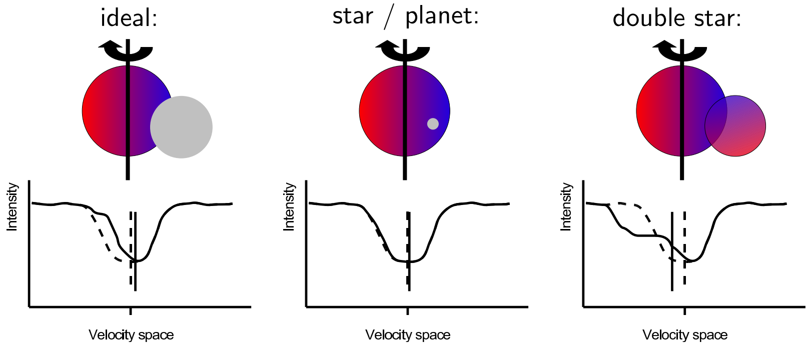


Template & BF represent the observed spectrum

Outside of eclipse:



Challenge: Too much light



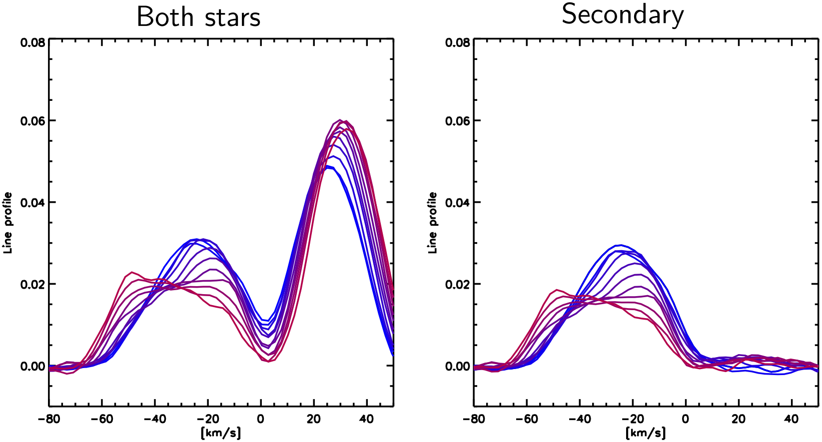
2 methods

1. Influence of the foreground star is subtracted: **'center'** is used.
2. The profile of **both** stars are used: **'shape'** is used

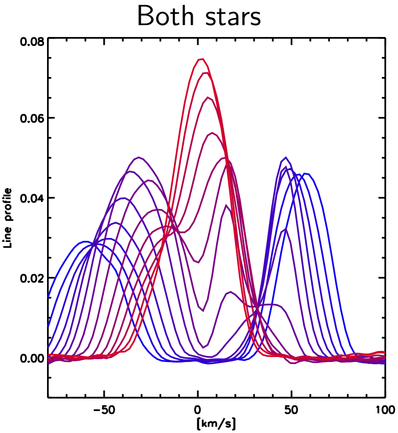
Method 1: Center

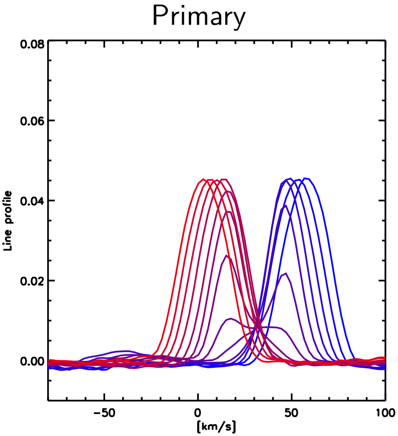
1. Obtain orbital parameter from out of eclipse data
2. Extract spectra of components using tomography (William et al. , 1991)
3. Subtract spectra of foreground star
4. Calculation of BF of the eclipsed star
5. Now the RM effect can be calculated

Method 1: BFs secondary eclipse



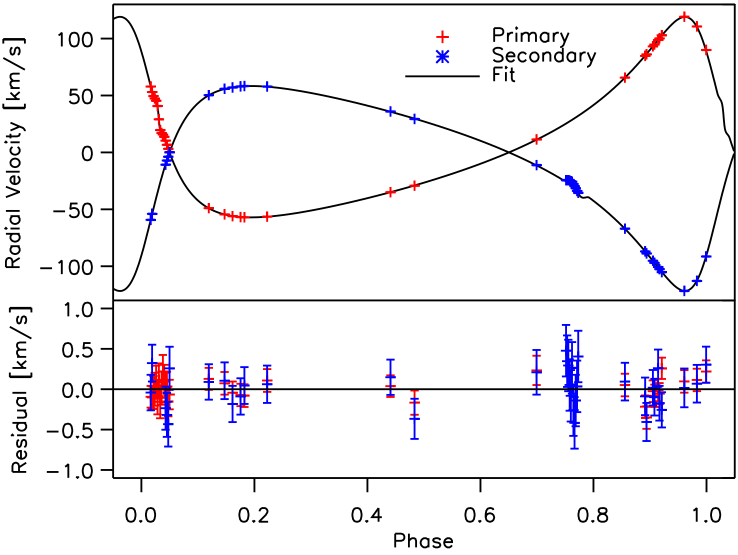
Method 1: BFs primary eclipse



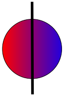


Method 1: Orbital & eclipse solution

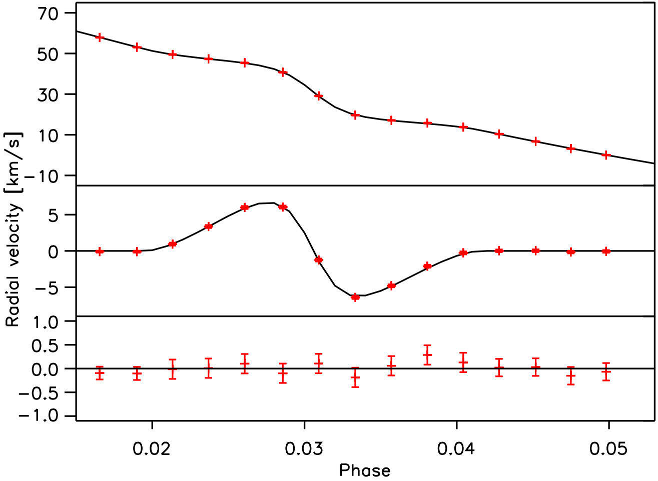
$\overline{\chi^2} = 0.96$



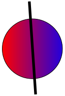
Method 1: Primary eclipse



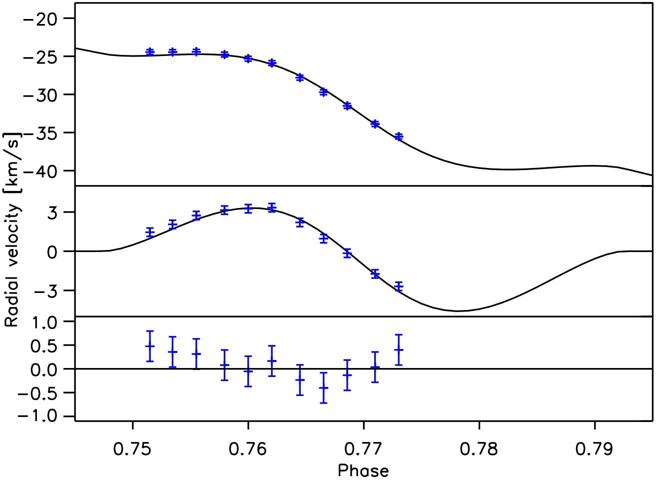
$$\beta_p = 0.5 \pm 4.0[^\circ]$$



Method 1: Secondary eclipse



$$\beta_s = -3.9 \pm 4.0[^\circ]$$

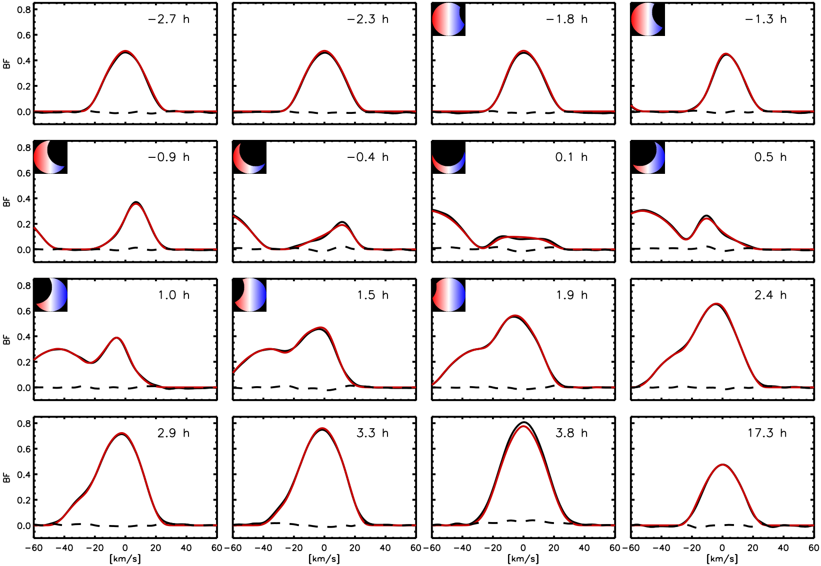


Method 2: Shape

1. Simulation of BFs of **both** stars due to:
   - Orbital movement
   - Stellar rotation / orientation of rotation axes
   - Linear limb darkening
   - Macro-turbulence
   - (Size of components)
   - (Differential rotation)
2. χ^2 fit of all 46 Observations

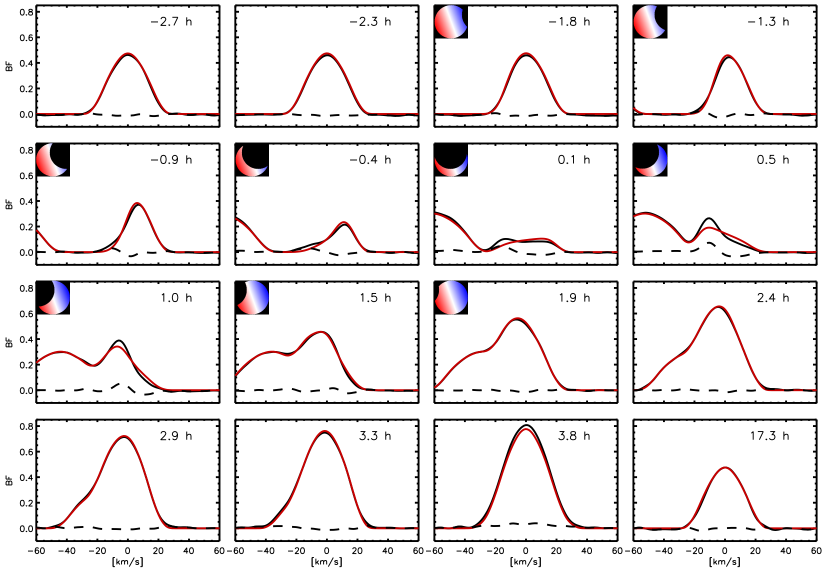
Method 2: primary eclipse

$\beta = 0.3 \pm 1.5[^\circ]$



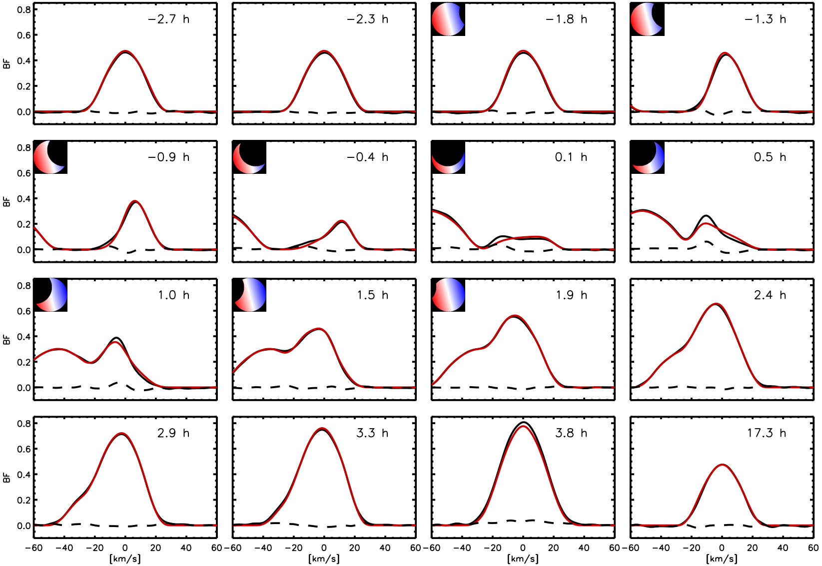
Method 2: primary eclipse

$\beta = -20\,[^\circ]$



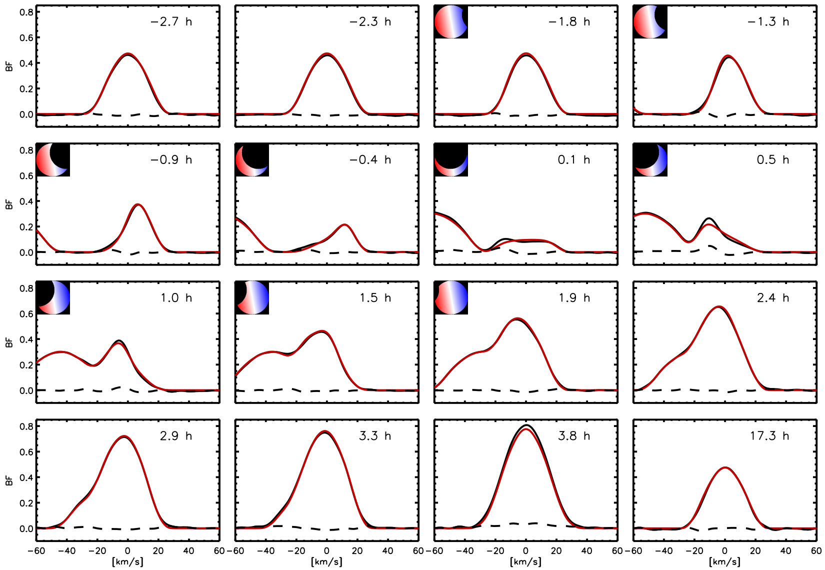
Method 2: primary eclipse

$\beta = -15\,[^\circ]$



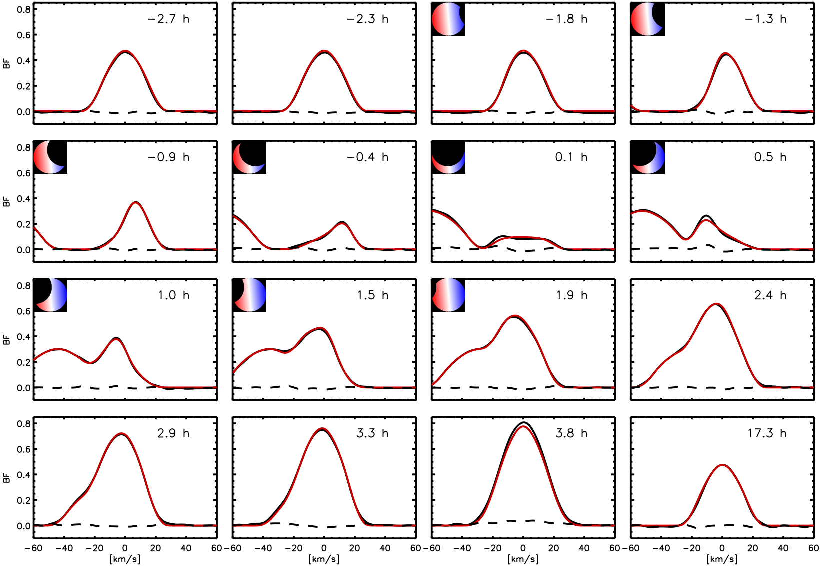
Method 2: primary eclipse

$\beta = -10\,[^\circ]$



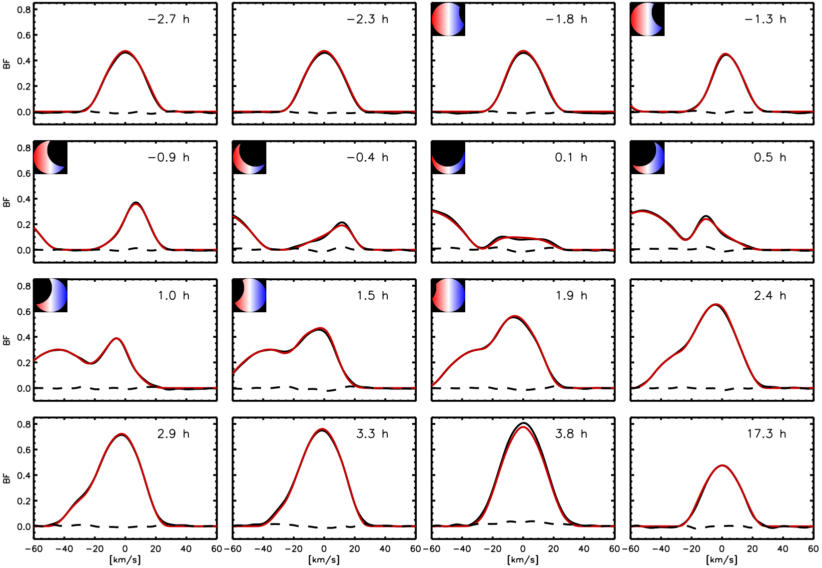
Method 2: primary eclipse

$\beta = -5\,[°]$



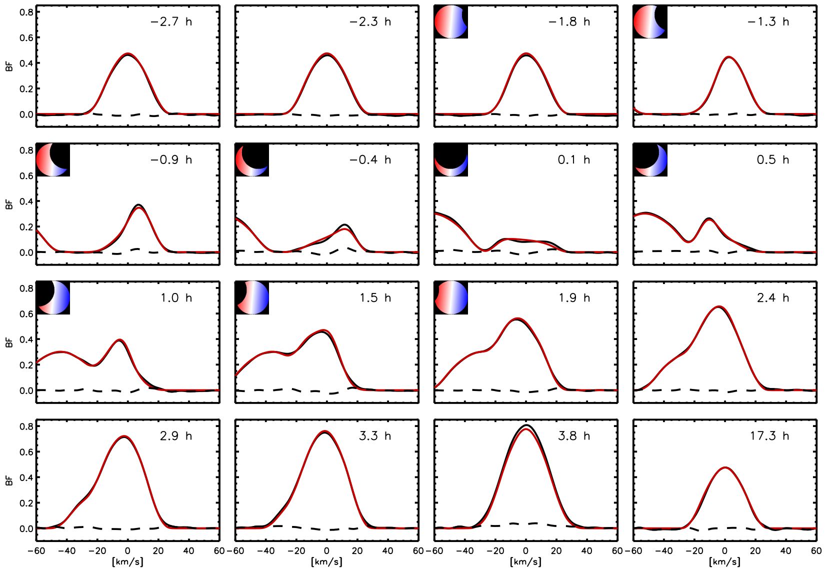
Method 2: primary eclipse

$\beta = 0\,[^\circ]$



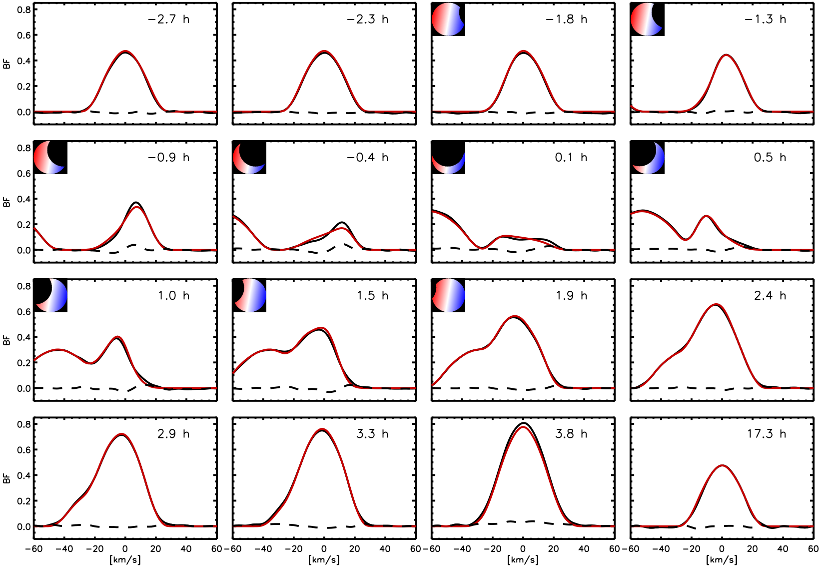
Method 2: primary eclipse

$\beta = 5\,[^\circ]$



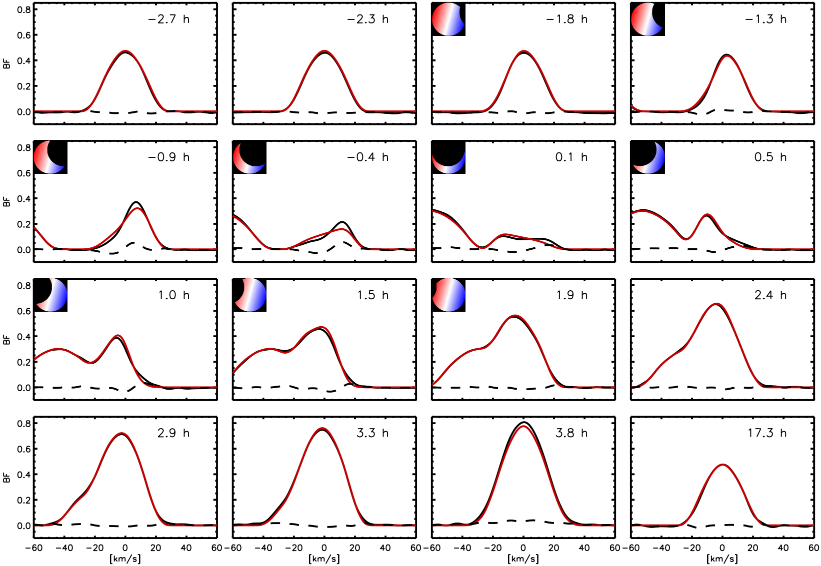
Method 2: primary eclipse

$\beta = 10\,[^\circ]$



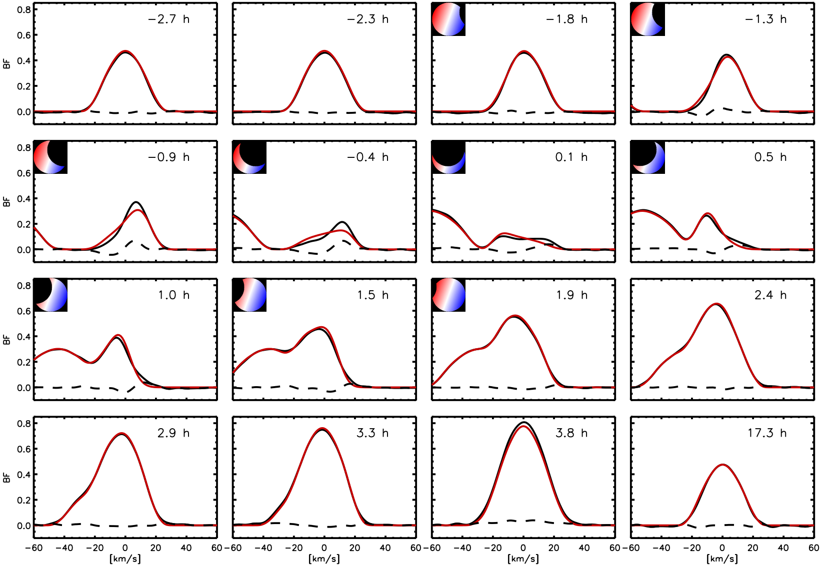
Method 2: primary eclipse

$\beta = 15\,[^\circ]$



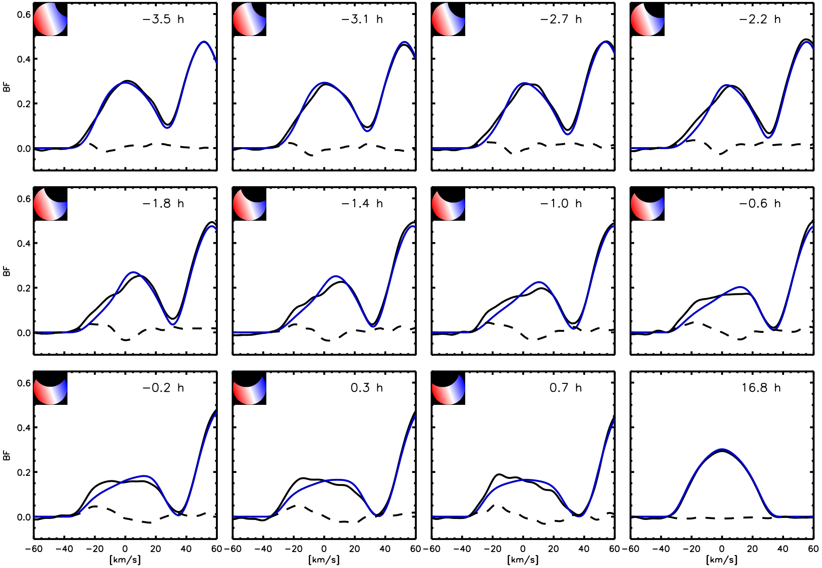
Method 2: primary eclipse

$\beta = 20\,[^\circ]$



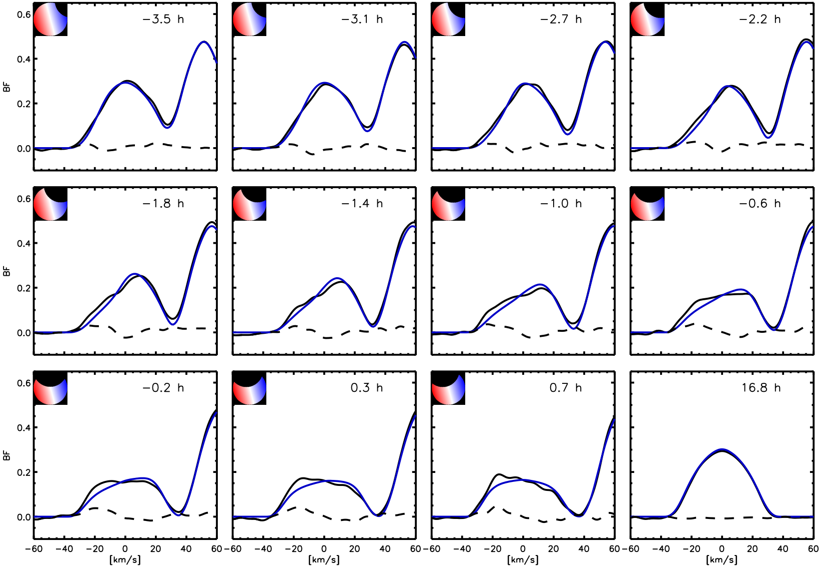
Method 2: secondary eclipse

$\beta = -20\,[^\circ]$



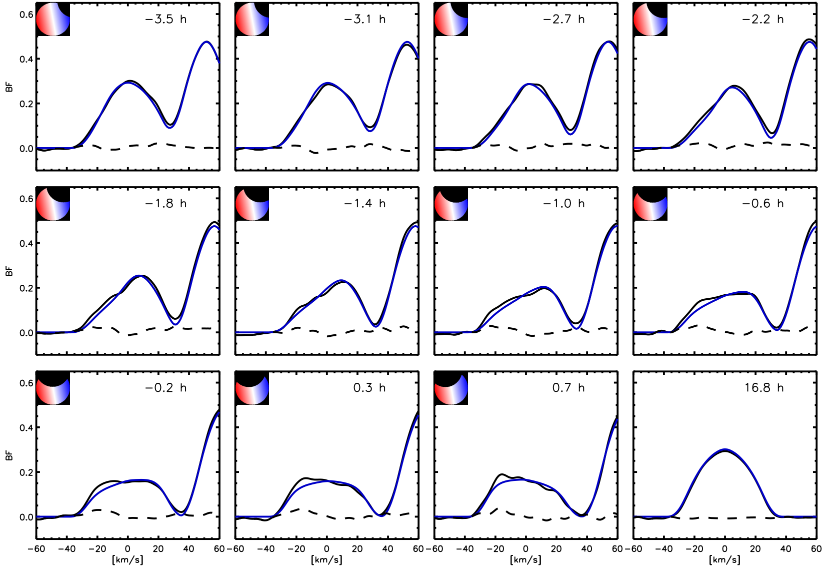
Method 2: secondary eclipse

$\beta = -15\,[^\circ]$



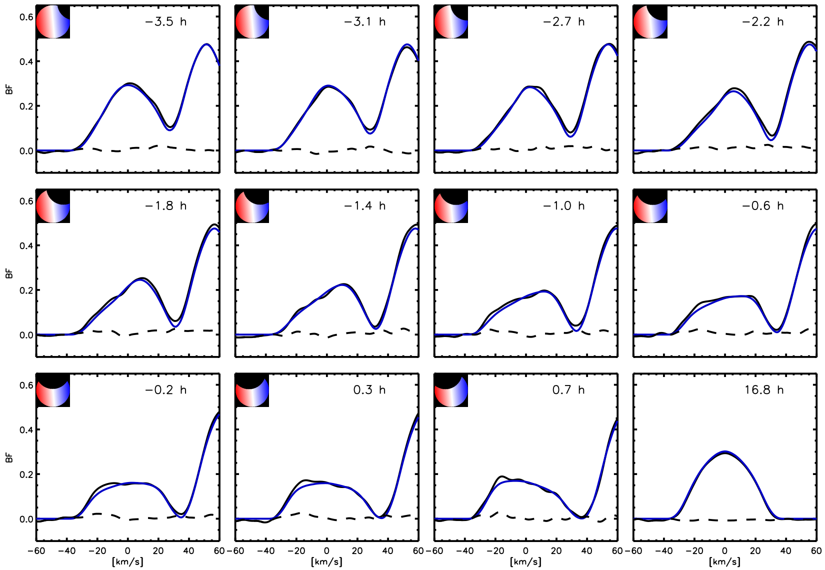
Method 2: secondary eclipse

$\beta = -10\,[^\circ]$



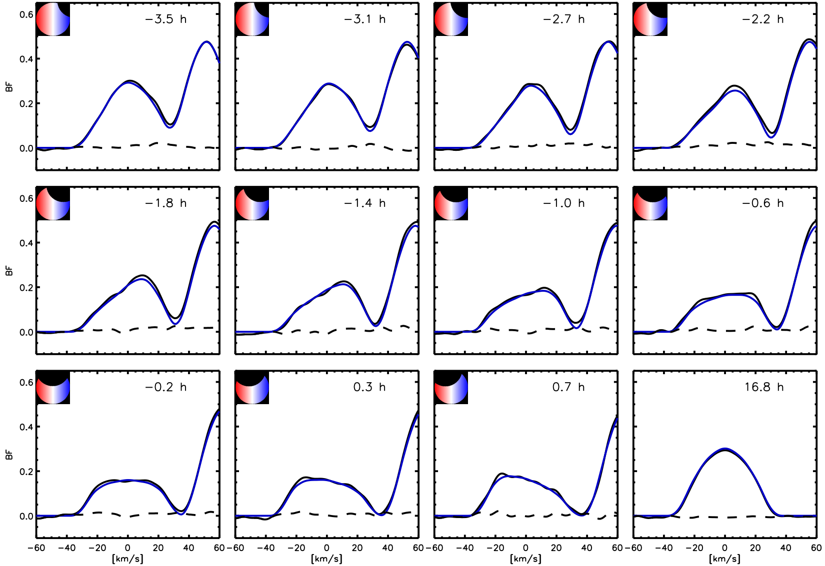
Method 2: secondary eclipse

$\beta = -5\,[^\circ]$



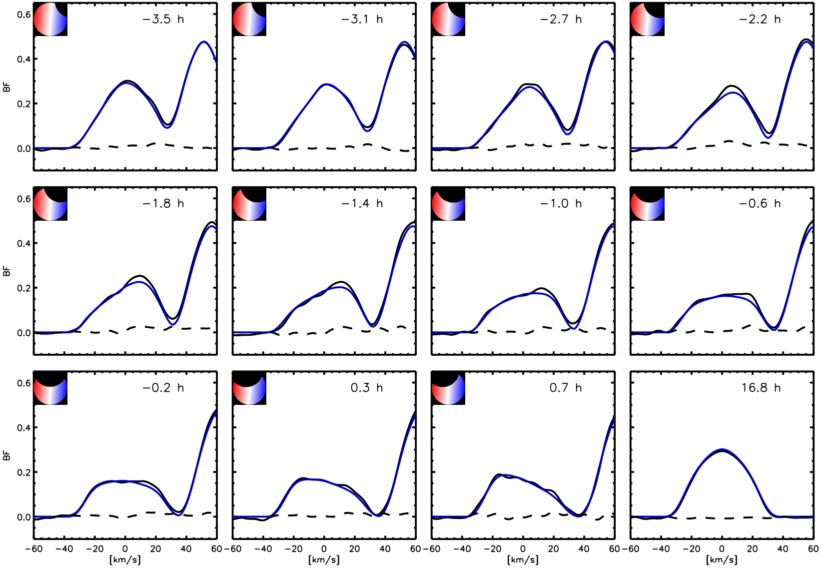
Method 2: secondary eclipse

$\beta = 0\,[^\circ]$



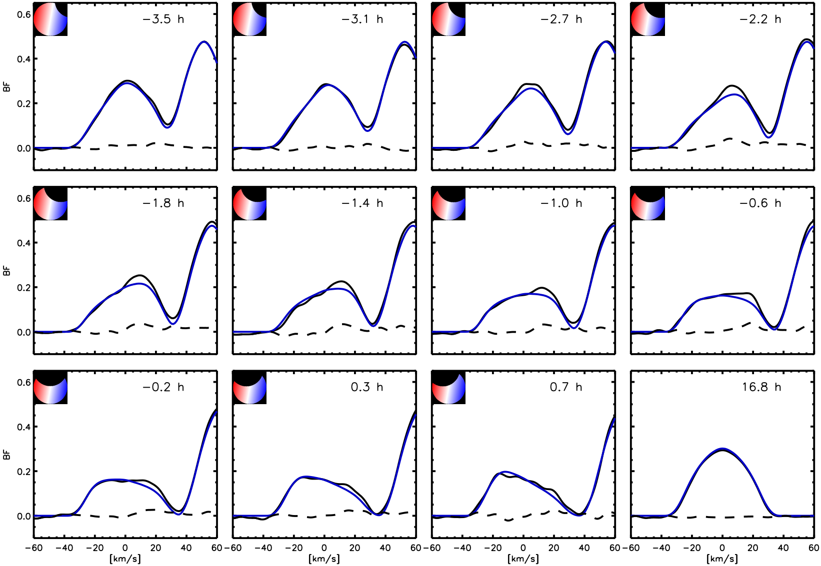
Method 2: secondary eclipse

$\beta = 5\,[^\circ]$



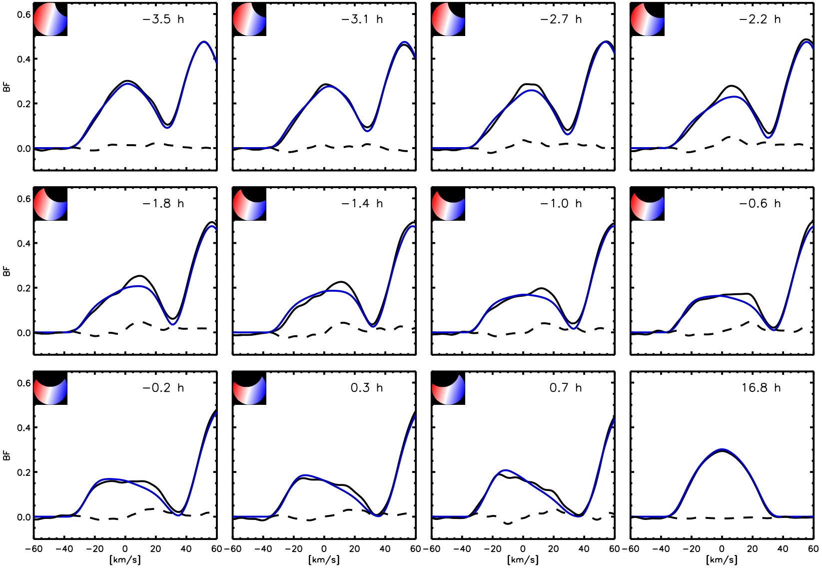
Method 2: secondary eclipse

$\beta = 10\,[^\circ]$



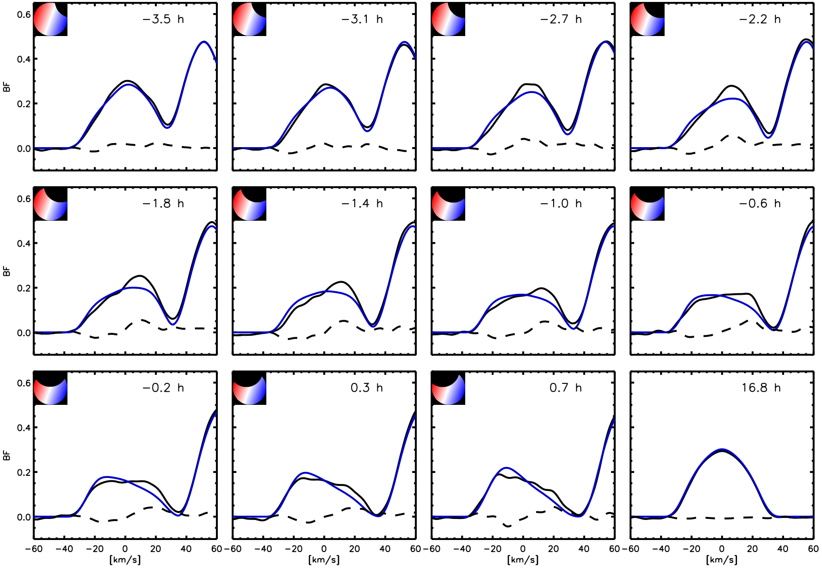
Method 2: secondary eclipse

$\beta = 15\,[^\circ]$



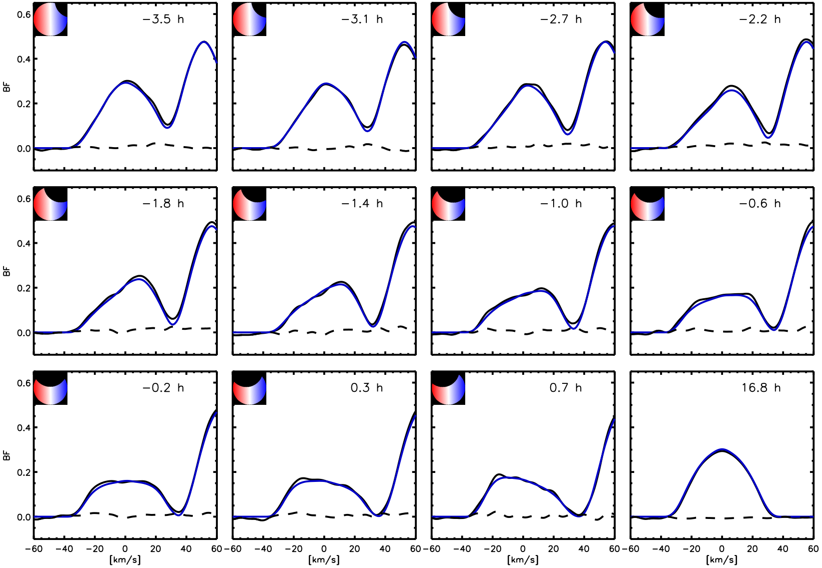
Method 2: secondary eclipse

$\beta = 20\,[^\circ]$



Method 2: secondary eclipse

$\beta = -1.2 \pm 1.6[^\circ]$



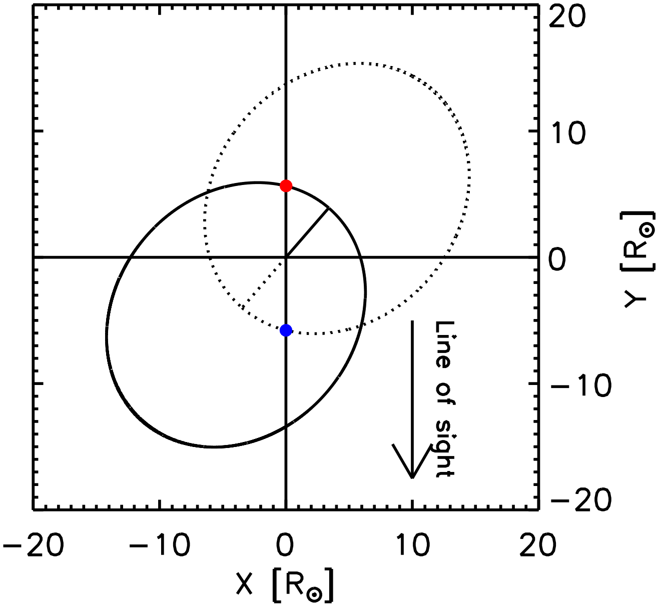
Conclusions

- Two methods to obtain the projection of the rotation axes in a double lined binary system
- Spin axes in V1143 Cyg are aligned with the orbital spin $\longrightarrow$ expected apsidal motion is unchanged
- Methods can be used in other systems (e.g. DI Herculis)

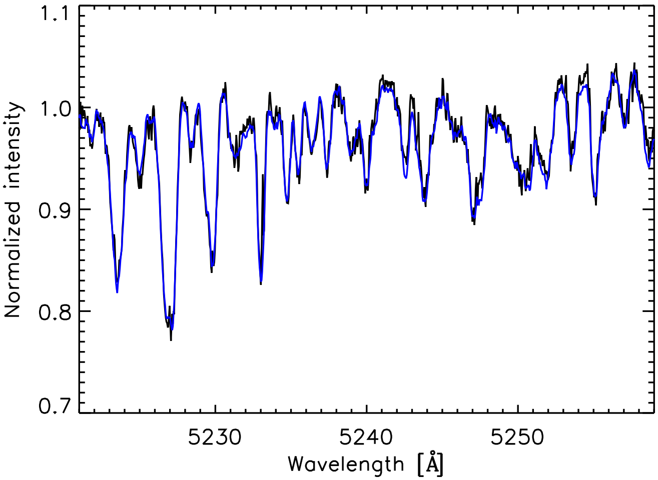
Results: V1143 Cyg

Parameter	Center		Shape	Andersen (1987)†
	Orbit	Joint fit		Gimenez (1985)⋆
T_0 [JD-2400000]	53536.130±0.002	53536.131±0.002	53536.1317±0.0006	
K_p [km/s]	88.1±0.04	88.1±0.1	88.01±0.05	88.2±0.2†
K_s [km/s]	90.1±0.08	90.1±0.2	89.9±0.1	91.1±0.4†
e	0.538±0.001	0.538±0.001	0.5378±0.0003	0.540±0.003†
ω [°]	49.1±0.2	49.1±0.2	49.27±0.05	49.31±0.06⋆
$a \sin i$ [$R_\odot$]	22.67±0.03	22.67±0.03	22.64±0.02	22.78±0.08†
γ [km/s]	−16.8±0.3	−16.8±0.3	−16.8±0.3	−16.5±0.7†
$v \sin i_p$ [km/s]		**16.9±1.0**	**19.6±0.1**	18±2†
$v \sin i_s$ [km/s]		**28.0±5.0**	**28.2±0.1**	27±3†
$\zeta_{RT} P$ [km/s]			3.4±0.1	
$\zeta_{RT} S$ [km/s]			3.3±0.1	
β_p [°]		**0.5±4.0**	**0.3±1.5**	
β_s [°]		**–3.9±4.0**	**–1.2±1.6**	

Orbit V1143 Cyg



Tomography



1.1
1.0
0.9
0.8
0.7
Normalized intensity
5230
5240
5250
Wavelength [Å]