Be stars observations with VEGA/CHARA

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VEGA consortium

VEGA / CHARA in the French Astronomical revue “Ciel Et Espace” !

REPORTAGE

Chara, l’interféromètre télécommandé

Au sommet du mont Wilson, en Californie, l’interféromètre Chara a atteint sa vitesse de croisière. Il est aujourd’hui le plus puissant à observer les étoiles en lumière visible. Un succès dû en partie aux astronomes français qui l’utilisent à distance, depuis la Provence.

Philippe Henarejos

LA Lune gibbeuse étincelle comme un cristal de quartz. Au-dessus de nos têtes, la voûte étoilée, parfaitement transparente, renforce cette sensation. Au loin, vers la Méditerranée, une masse de cumulus argentés s’illumine régulièrement d’éclairs. Le roulement du tonnerre, étouffé par la distance, ne résonne que longtemps après. Mais ici, à Grasse, en cette nuit du 5 novembre, le ciel est pur. D’excellentes conditions pour observer les astres.

Hélas, en Californie, ce n’est pas tout à fait la même chose. Denis Mourard, astronome à l’observatoire de la Côte d’Azur, le sait déjà. Après un coup d’œil distrait sur la voûte céleste, il affiche une mine contrariée. Il est presque 2 h 30 et, alors qu’en Provence la nuit est tombée depuis 9 heures, le Soleil vient juste de se coucher au mont Wilson, sur les hauteurs de Los Angeles. En principe, c’est le moment où s’ouvrent les coupoles de l’observatoire dans lequel Edwin Hubble a découvert l’expansion de l’Univers.

Mais, en retournant dans la douce chaleur de la salle de contrôle, Denis Mourard ne se berce guère d’illusions. Sur son écran d’ordinateur, quelques mots en anglais l’attendent dans •••

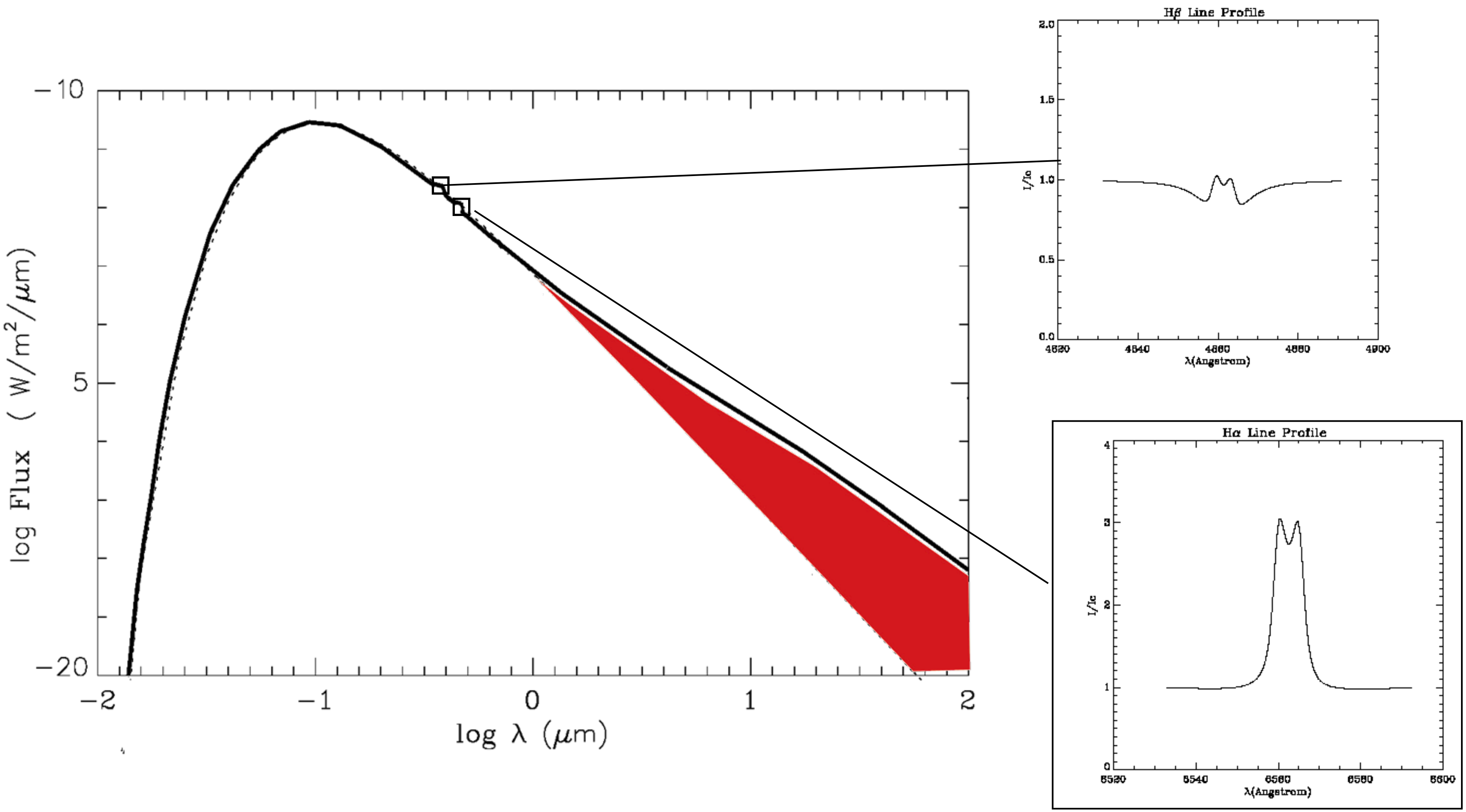
P.Henarejos/C&E Photos

Centre névralgique de Chara : le bâtiment des lignes à retard. Sur des rails de 44 m de long, les faisceaux optiques en provenance des six télescopes de 1 m de diamètre sont égalisés pour pouvoir être réunis en un même foyer, où se trouvent les instruments scientifiques.

P.Henarejos/C&E Photos

Observatoire de Paris — LESIA — The University of Michigan 1817 — NExScI NASA Exoplanet Science Institute — SUSI Sydney University Stellar Interferometer Australia — Observatoire de la Côte d’Azur

Presence of a circumstellar environment around Be stars

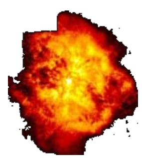


Problematic around Be Stars

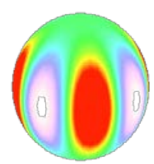
What is the Origin of the formation of disk around Be stars ?

Five physical mechanisms possible :

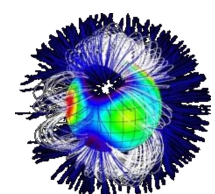
Rotation



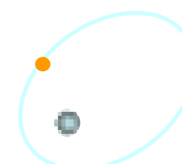
Stellar winds



pulsations



Magnetism



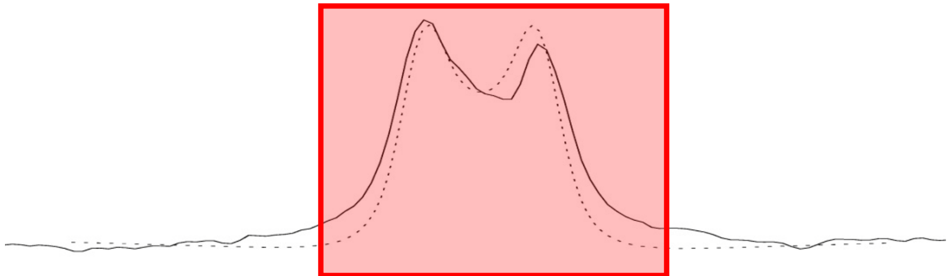
Binarity

Constrain the Geometry and kinematic of the disk by spectro - interferometry

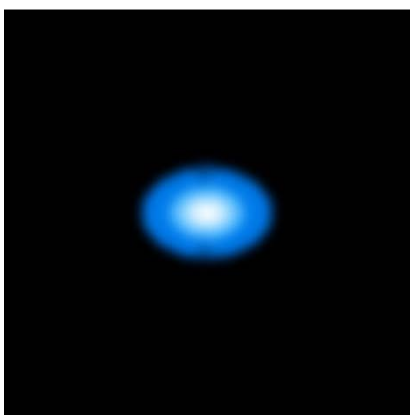
Spectro interferometry (1)

(Doppler effect)

- The geometry study

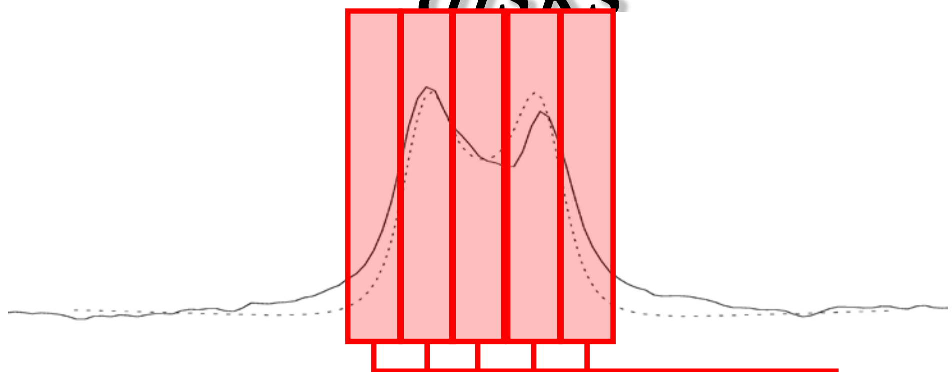


In the whole line



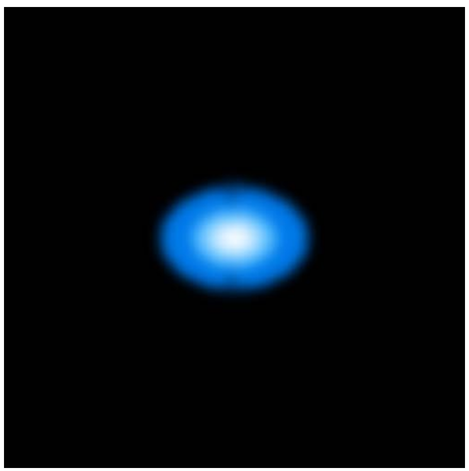
Geometry

Spectro-interferometric study of Be stars disks



(Doppler Effect)

In the whole line



Geometry

Narrow spectral bandwidth across the line

Variation of the visibility modulus and phase as a function of wavelength

Geometry + Kinematics

Expansion/rotation, rotational law, inhomogeneities…

Disk Geometry and kinematic of three Be Stars

Stee & Meilland (2009) , VLTI / MIDI

Equatorial Disk			
	α Arae	κ CMa	Achernar
Stellar Rotation	97 % V_c	52 % V_c	$\sim V_c$
Disk rotation (β parameter)	0.48 (quasi Keplerian)	0.3 (sub Keplerian)	no disk detected in 2000

Fast Rotation

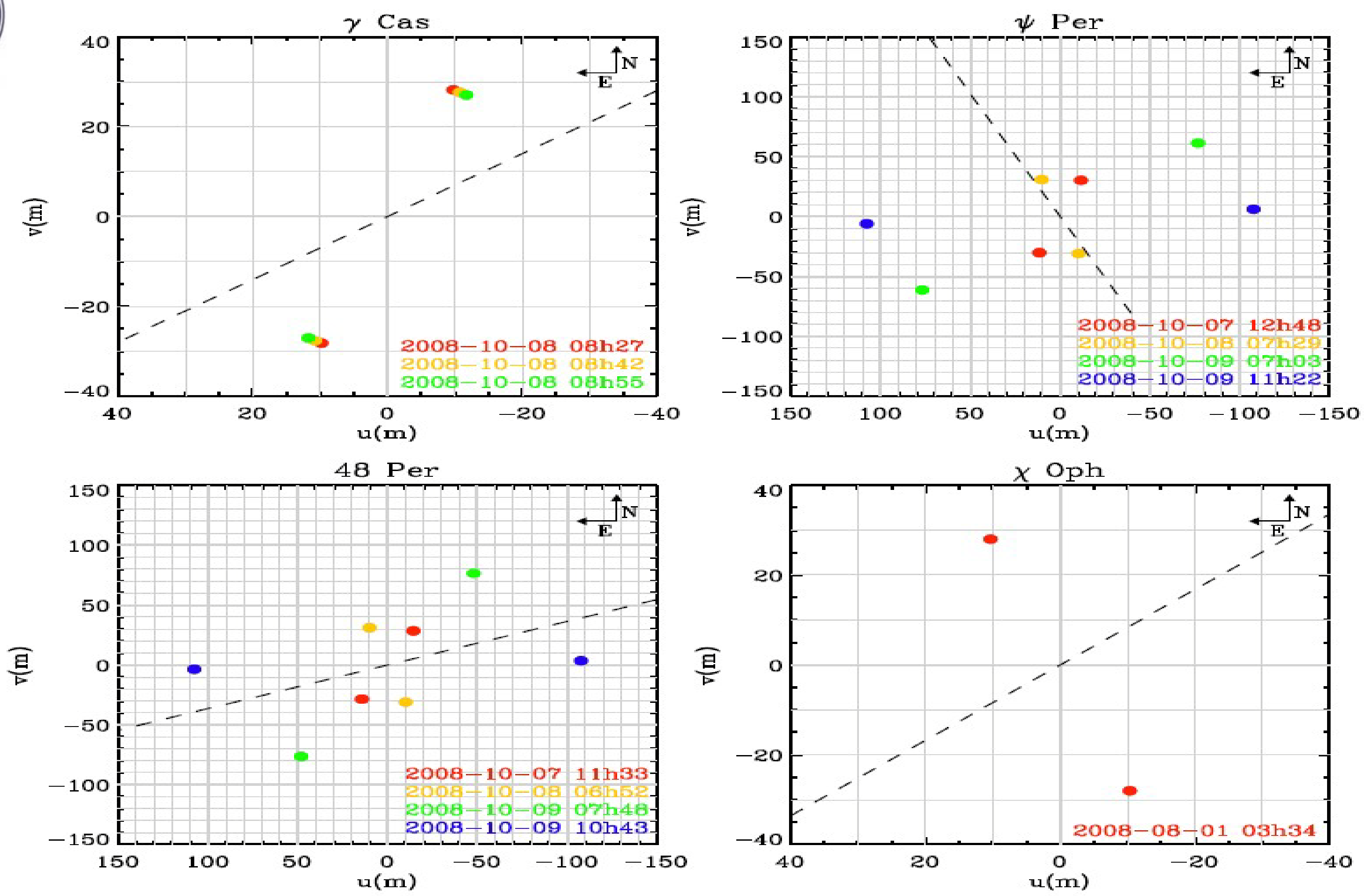
Fast Rotation + other physical processes (Binarity ?)

Fast Rotation for the formation and binarity for dissipation of the disk

Hα line more intense than Brγ line ➔ Study in the visible Wavelength

VEGA/CHARA Targets

ψ Per	Vsini = 297 km/s	B5Ve	d=214 pc
γ Cas	Vsini = 243 km/s	B0 IVe	d=187 pc
48 Per	Vsini = 198 km/s	B3 Ve	d=169 pc
χ Oph	Vsini = 139 km/s	B1.5 Ve	d=150 pc



--------------------- : *Disk orientation*

Model

- ***Star + Circumstellar disk only in rotation***
  - *Modeling of Visibility and phases as function of wavelength*
- ***Output parameter :***
- ***Stellar Inclination, Stellar radii, Øenv in line,Øenv in continuum, P.A.***

- ***Kinematic of the disk :***

$$V_\phi = V_{rot} \cdot \left(\frac{r}{R_\star}\right)^\beta$$

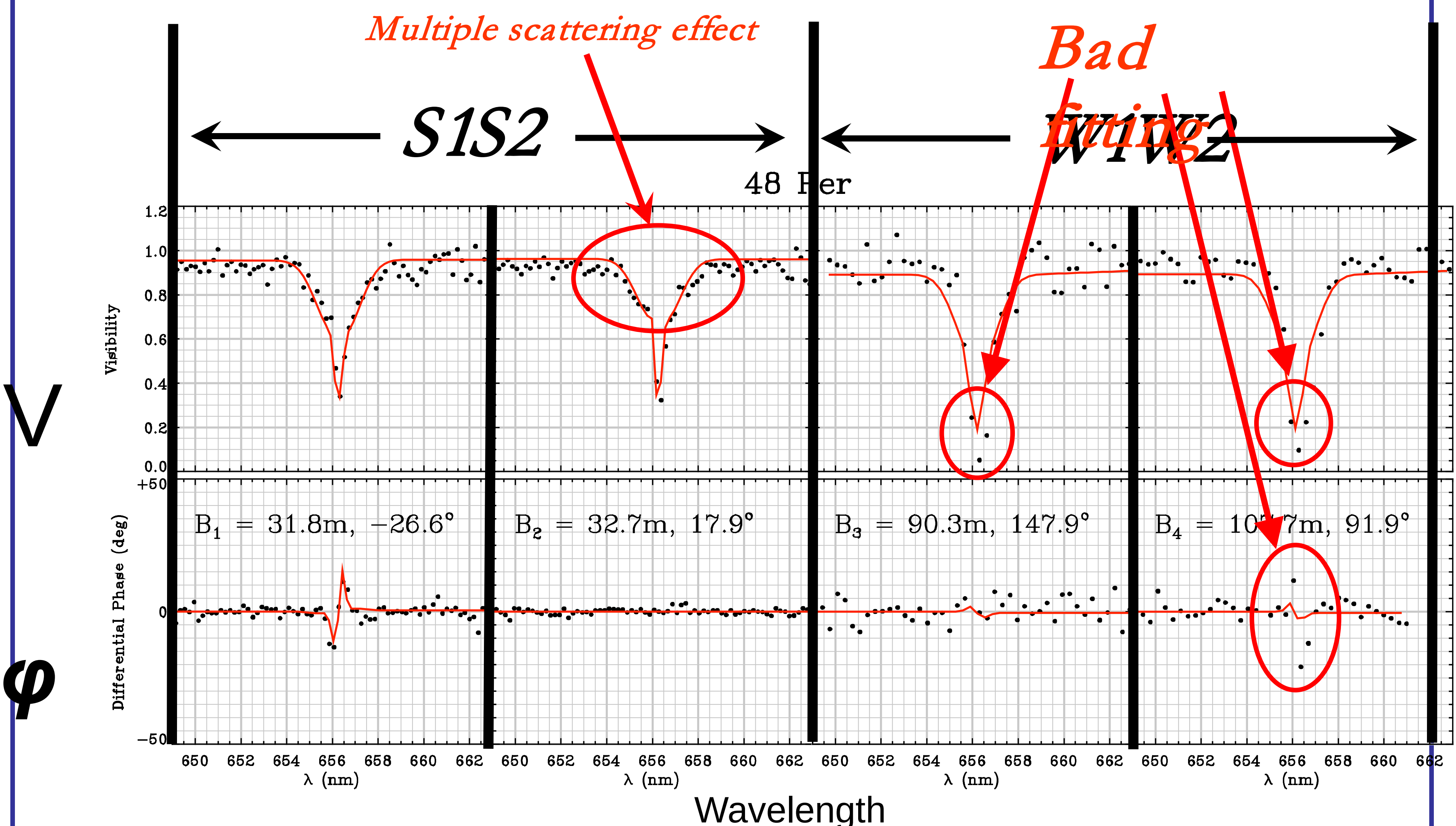
r = *Distance to the center of the*

V_{rot} = *Stellar rotational velocity*

$R_\star$ = *Stellar radius*

β = *Free parameter*

48 Per results around Hα line



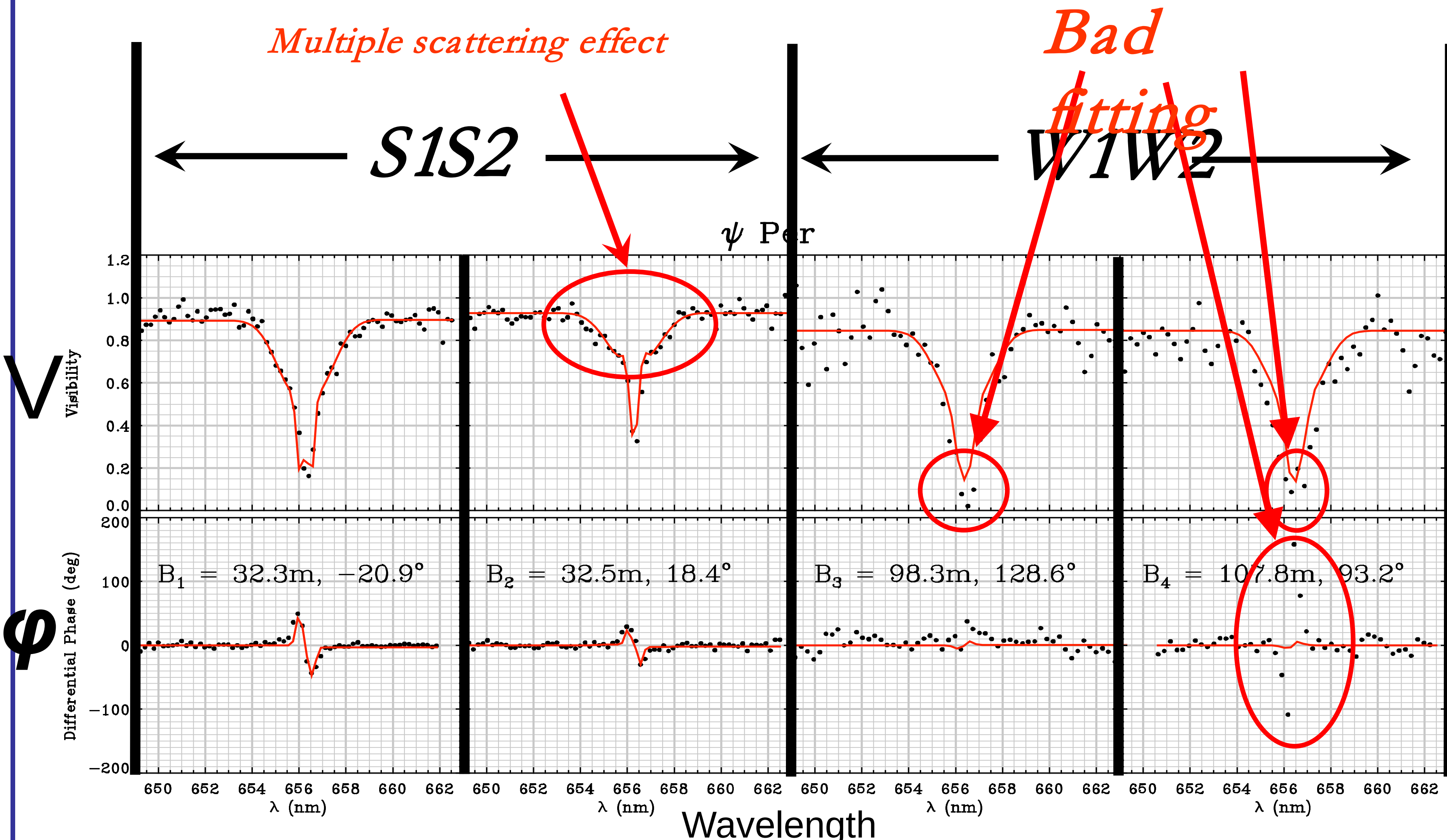
48 Per parameters around Hα line

inclination (deg)	R star (Rsolar)	$Ø_{env}$ in line (Rstellar)	$Ø_{env}$ in continuum (Rstar)	P.A. (degree)	% of emission scattered in the line
30 ± 5	4.8 ± 0.5	10 ± 2	?	125 ± 5	40 ± 5

Stellar rotational velocity (km/s)	Exponent β of the rotational velocity law
440 ± 50 (Critical velocity)	-0.5 ± 0.1

Disk in Keplerian rotation

ψ Per results around Hα line



ψ Per results around Hα line

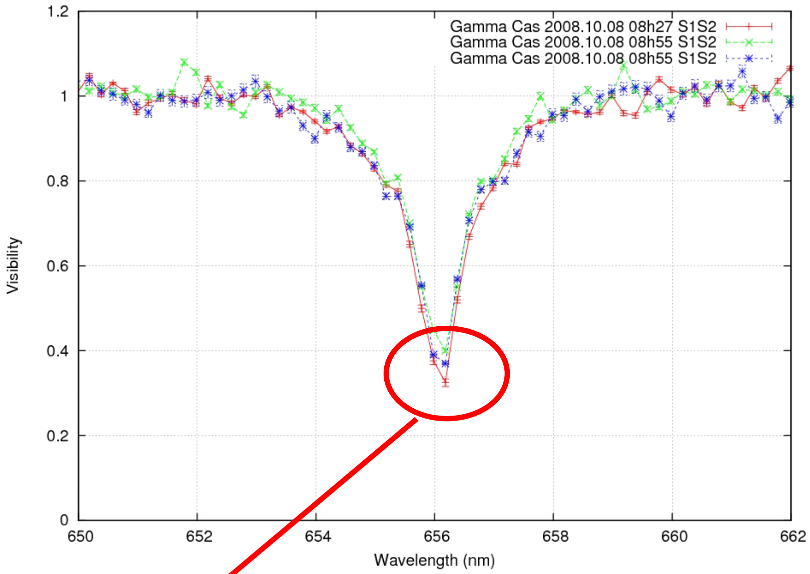
inclination (deg)	R star (R_{solar})	$Ø_{env}$ in line ($R_{stellar}$)	$Ø_{env}$ in continuum (R_{star})	P.A. (degree)	% of emission scattered in the line
78 ± 10	5.9 ± 0.59	20 ± 7.5	10 ± 10	108 ± 1	40 ± 5

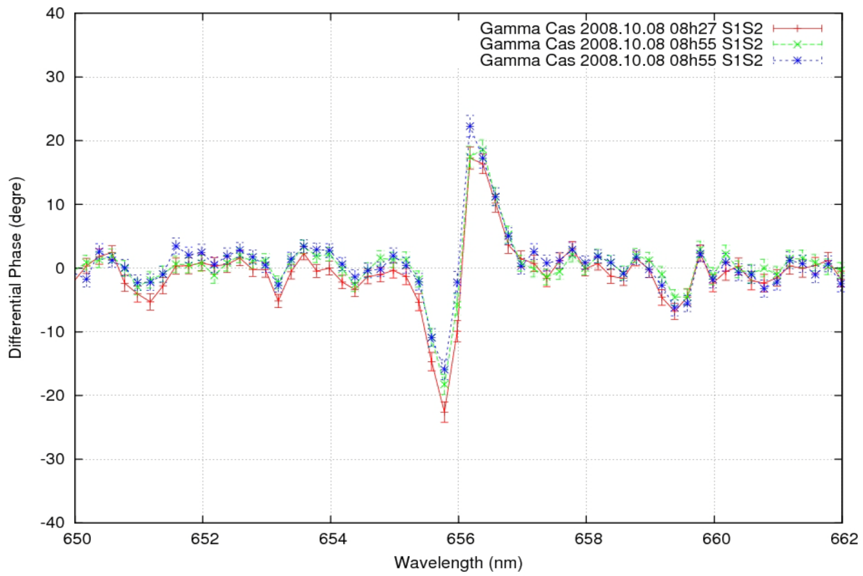
Stellar rotational velocity (km/s)	exponent β of the rotational velocity law
400 ± 50 (Critical Velocity)	-0.37 ± 0.05

Disk doesn't appear in Keplerian rotation

Limitation of the model

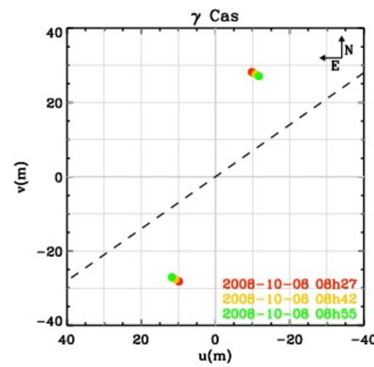
γCas results around Hα line





$$V_l = \frac{V_{\star l} F_{\star l} + V_{el} F_{el}}{F_{tot}}$$

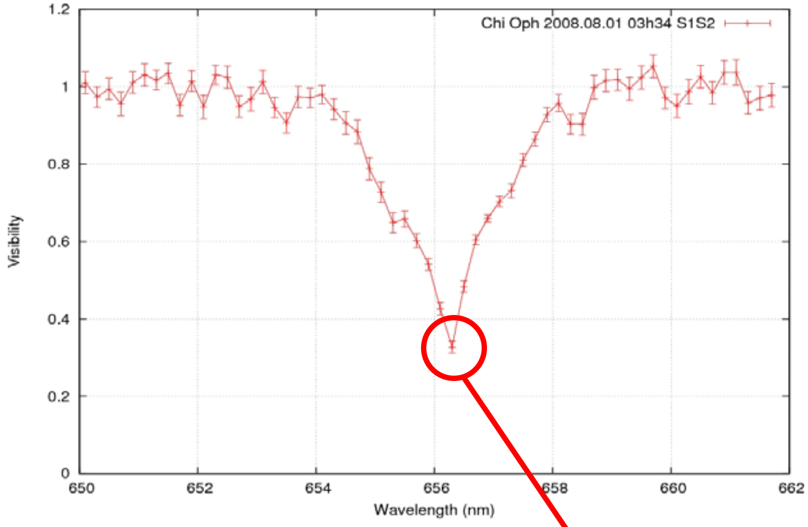
Baseline S1S2 ➔ $V_{\star l}$ = 1

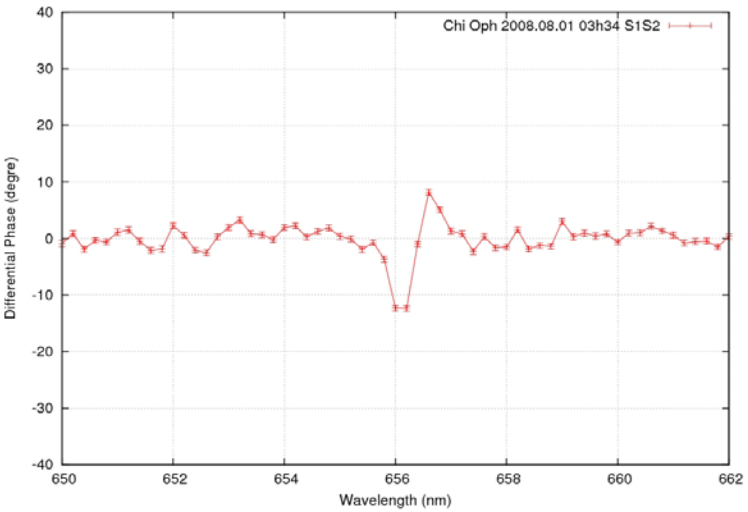


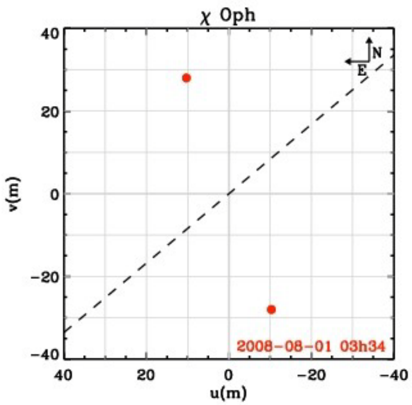
With $F_{tot} = F_{\star l} + F_{el}$ = 0.1 + 0.9

Star	HA	base (m)	$V_{measured}$	V_{env}	Envelope diameter (mas)
γ Cas	00h51m50	29.85	0.35 ± 0.030	0.19 ± 0.028	4.47 ± 0.13
γ Cas	01h05m51	29.67	0.38 ± 0.033	0.22 ± 0.032	4.36 ± 0.15
γ Cas	01h19m16	29.48	0.39 ± 0.027	0.23 ± 0.029	4.34 ± 0.13

χOph results around Hα line







Star	HA	base (m)	$V_{measured}$	V_{env}	Envelope diameter (mas)
χ Oph	00h48m14	23.64	0.31 ± 0.049	0.26 ± 0.048	5.25 ± 0.26

Conclusions on Be stars study

- *48 Per :*
  - *Fast rotation (critical velocity)*
  - *Disk in Keplerian rotation*

  ➔ *Consistent with αArae study*
- *Psi Per*
  - *Fast rotation (critical velocity)*
  - *Disk doesn't appear in Keplerian rotation (Not consistent with the previous results on 48 Per and αArae)*

  ➔ *Limitation of the model*
- *χ oph and γCas : poor uv coverage plan*

Perspective on Be stars

- *Complete the uv coverage plan for χ Oph and γ Cas (Data remain to be reduced)*
- *Precise modeling with SIMECA code*
- *Long baselines observation of γ Cas in the continuum :*
  - *Photospheric size of γ Cas*
  - *Contribution of the envelope*

First interferometric CHARA/VEGA observations of the Be stars 48 Per, χ Oph, γ Cas, and ψ Per

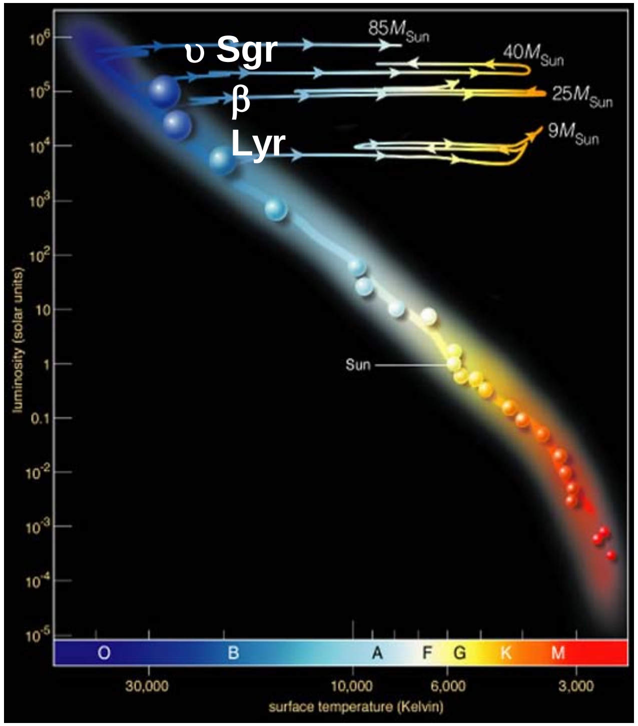
O. Delaa[1] et al.

[1] Lab. H. Fizeau, CNRS UMR 6525, Univ. de Nice-Sophia Antipolis, Obs. de la Côte d?Azur, Avenue Copernic, 06130 Grasse, France

Observations of interacting massive stars with CHARA/VEGA

❑ *Massive binary systems*

- **upsilon Sgr,** *binary system harboring an hydrogen deficient star (HdB star)*
- **beta Lyr:** *binary system with current mass-exchange*



since 2008

❑ *VEGA/CHARA interferometric observations*

2T , B = 34

mains goals

- *Shape and size of the Hα emitting region ?*
- *Morphology of the binary system?*

υ Sgr: O. Chesneau, D. Bonneau, P. Koubsky, D. Mourard , P. Stee

β Lyrae: D. Bonneau , O. Chesneau, D. Mourard , P. Stee

2008 CHARA/VEGA observations of β Lyrae

Base S1S2   MR 656 – 487 nm   Four orbital phases

Preliminary results

- *In the continum β Lyr is unresolved at any orbital phase*

- *Hα: significantly resolved at any Φ_{orb}, photocenter shift correlated with Φ_{orb}*

- *Hβ: resolved at some Φorb, suspicious of photocenter shifts*

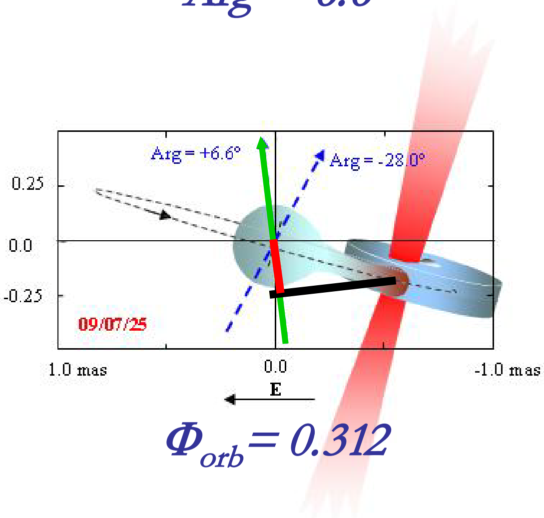
- *HeI (6678 A) : marginally resolved at any Φ_{orb}, no clear photocenter shift detected*

"Spectro-interferometric observations of interacting massive stars with VEGA/CHARA"
D. Bonneau, O. Chesneau, D. Mourard & P. Stee,
Presentation at the conference "Binaries - Keys to comprehension of the Universe, Brno, 8-12 June 2009, to be published in ASP Conference Series.

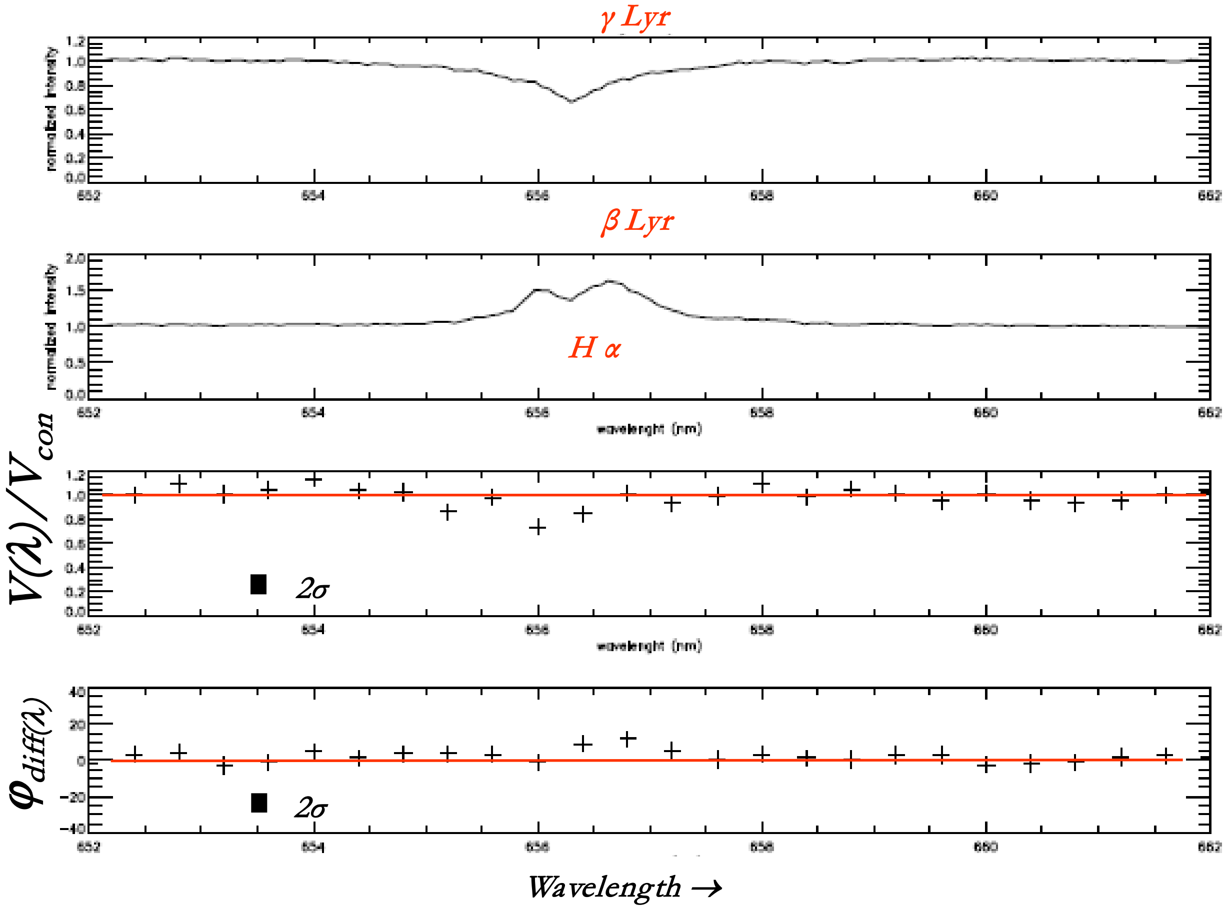
Differential Spectral analysis of β Lyrae observations

2009 07 25

- *baseline S1S2*
  - ✓ *TU 04h 14 mn*
  - ✓ $B_p = 34.08$ m
  - ✓ $Arg = 6.6°$



$\Phi_{orb} = 0.312$

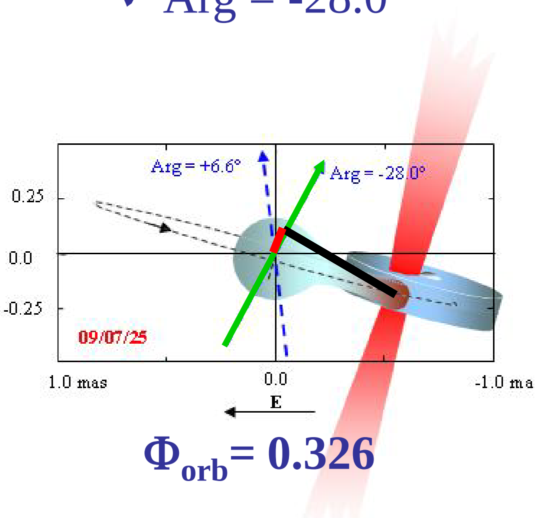


- *source slightly resolved in Hα with* $V_{line} / V_{cont} = 0.75 \pm 0.08$
- *slight differential phase offset in Hα with* $\varphi_{diff} = +15° \pm 5°$

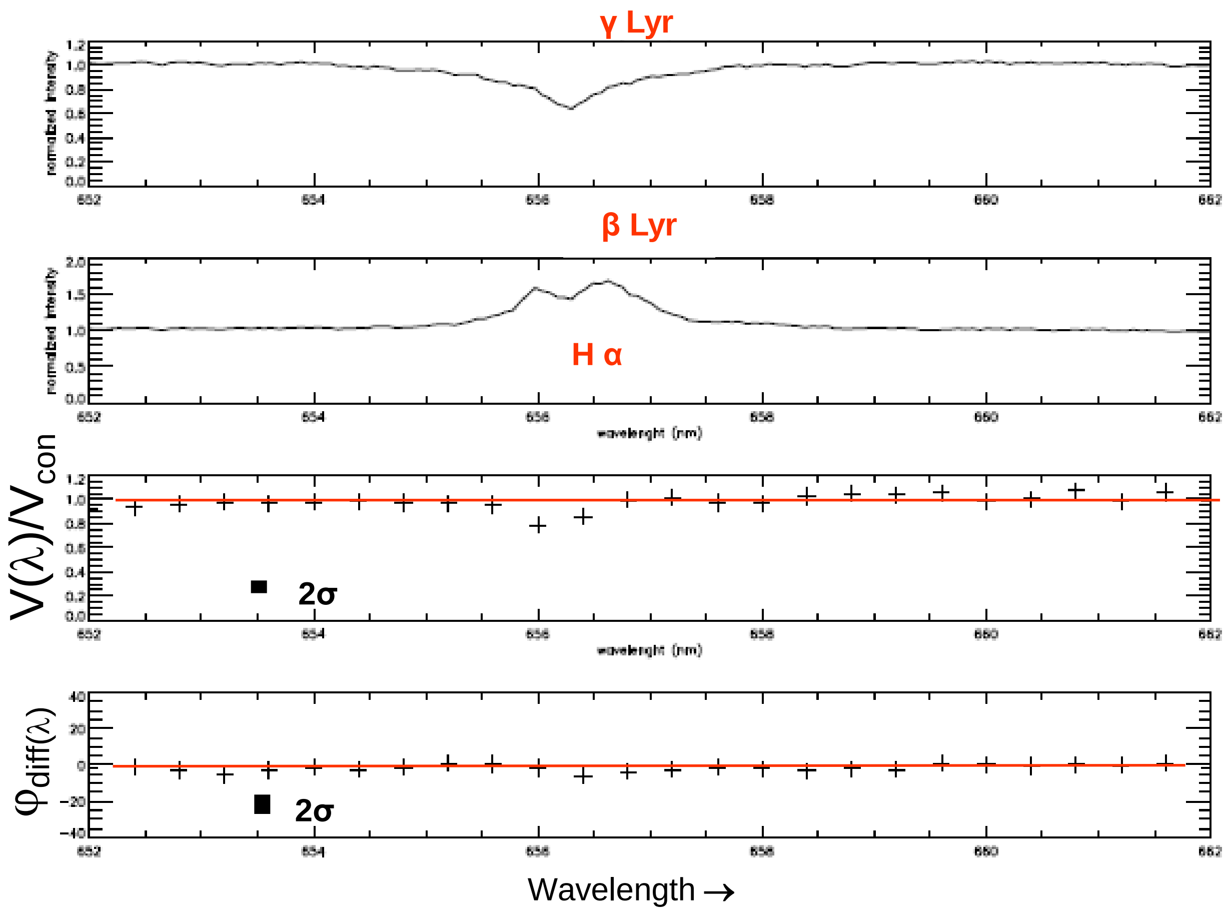
Differential Spectral analysis of β Lyrae observations

2009 07 25

- ➢ **baseline S1S2**
  - ✓ TU 08h 48 mn
  - ✓ B_p = 33.51 m
  - ✓ Arg = -28.0°



Φ_{orb}= 0.326

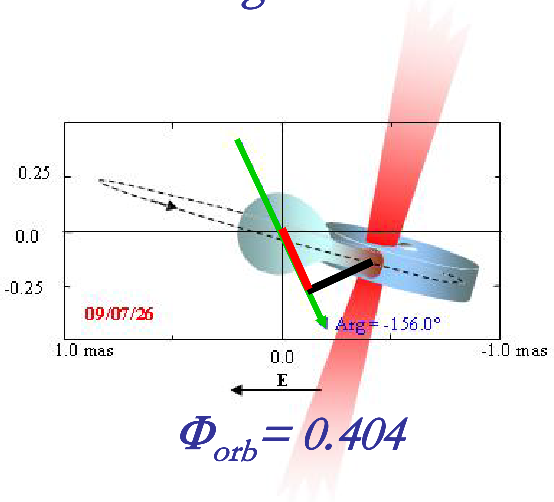


- ➢ **source slightly resolved in Hα with V_{line} / V_{cont} = 0.80 ± 0.05**
- ➢ **marginal differential phase offset in Hα with φ_{diff} = - 5 ° ± 5 °**

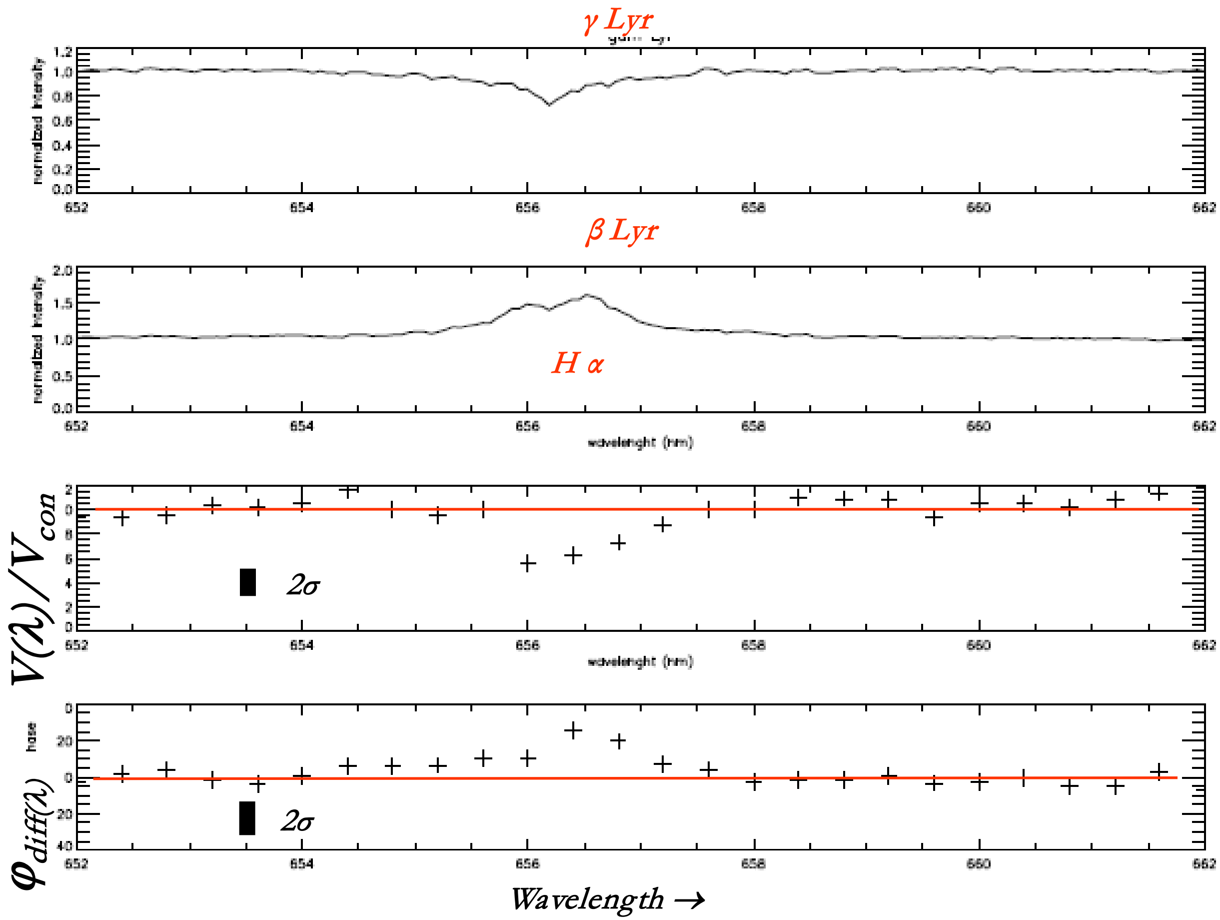
Differential Spectral analysis of β Lyrae observations

2009 07 26

- *baseline E1E2*
  - ✓ *TU 09h 09 mn*
  - ✓ $B_p = 58.62m$
  - ✓ $Arg = -156.0°$



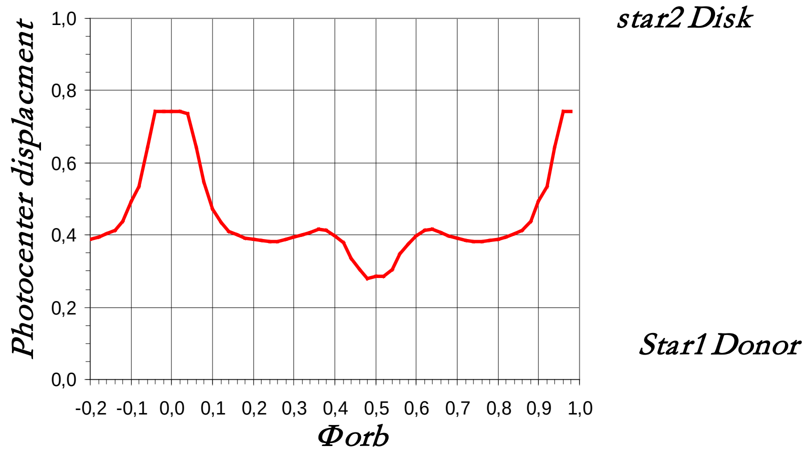
$\Phi_{orb} = 0.404$



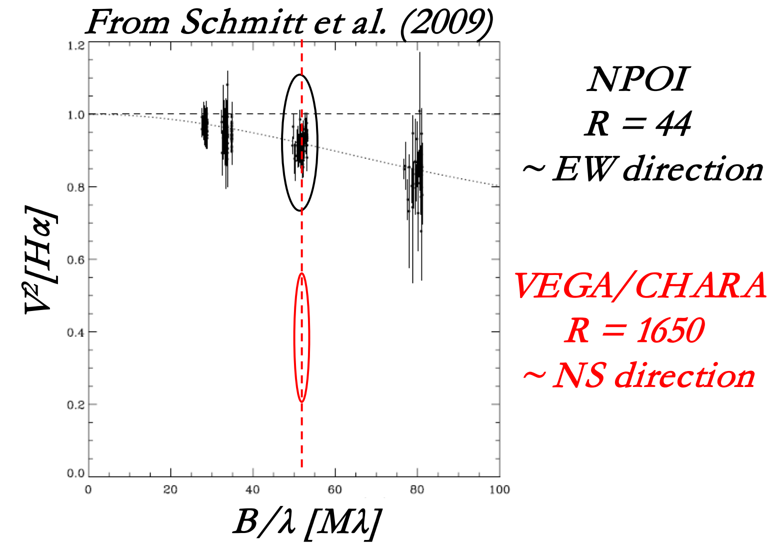
- source resolved in Hα with $V_{line} / V_{cont} = 0.60 \pm 0.12$
- differential phase offset in Hα with $\varphi_{diff} = +25 \pm 9°$

Analysis of the β Lyrae data

Model of the photocenter position in V-band computed from Ak et al. (2007)



Comparison with the work done with NPOI



Paper in preparation Bonneau et al


Los Angeles from Mount Wilson Observatory
THANK YOU
David Jurasevich