First science results with VEGA II: differential interferometry

by **Ph. Stee**

With the help of the VEGA TEAM and the following slides dealers :

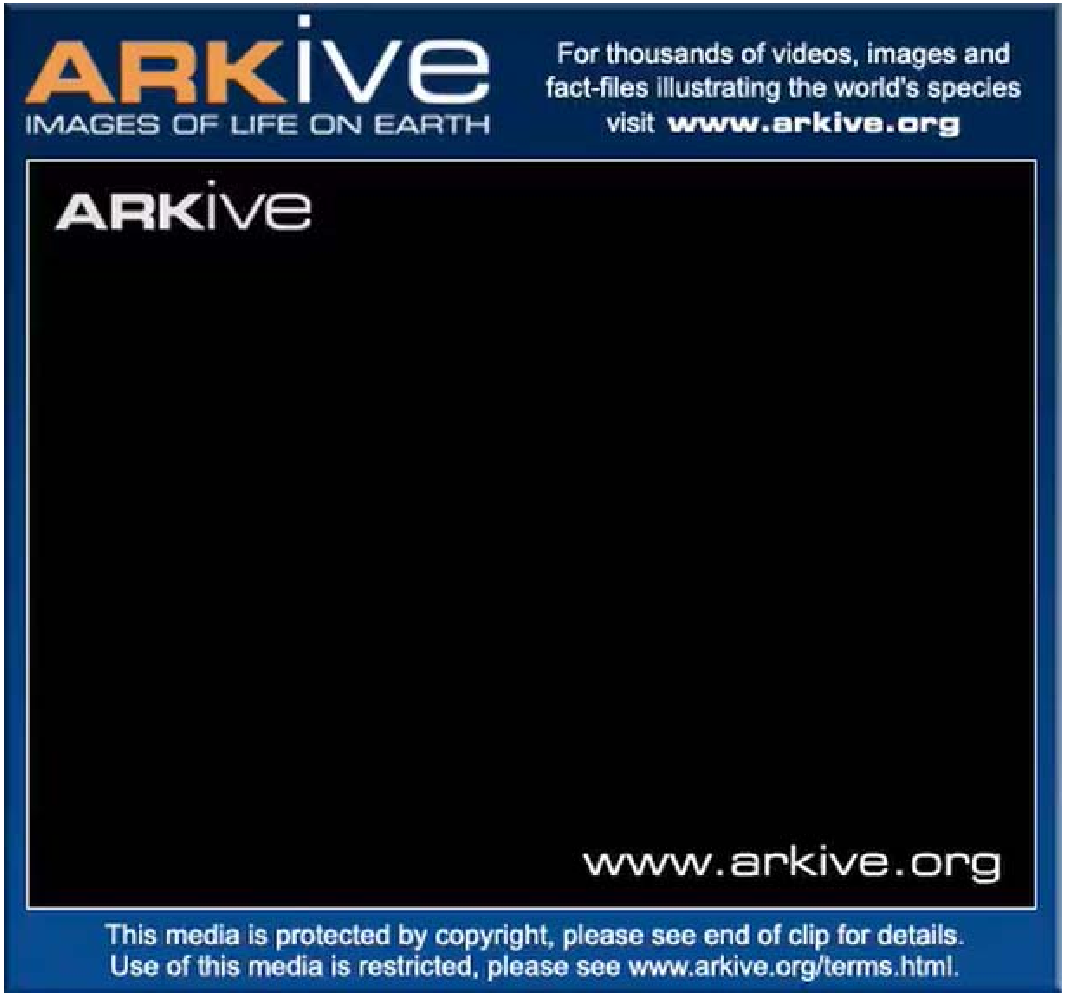






D. Bonneau O. Chesneau O. Delaa A. Domiciano A. Meilland D. Mourard K. Perraut

Fringes analysis



Differential analysis essentialy done with the R2 grating (medium resolution)

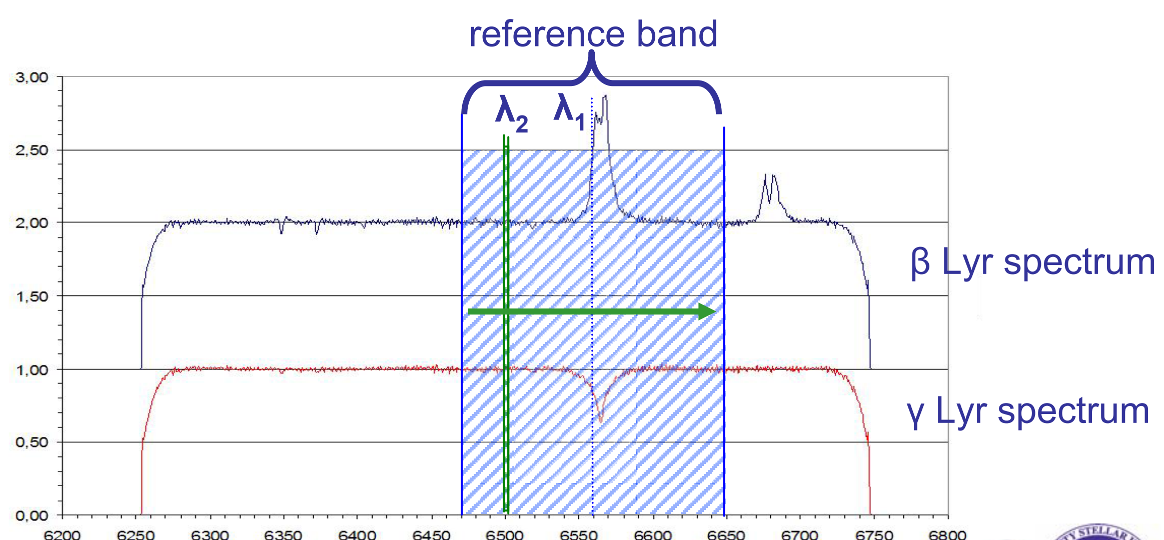
Grating	X-λ mode	Spectral distance between red and blue cameras
R1: 1800tr/mm	R=35000 $\Delta\lambda$=6.7nm	18 nm
R2: 300tr/mm	R=5000 $\Delta\lambda$=40nm	140 nm
R3: 100tr/mm	R=1700 $\Delta\lambda$=120nm	Not usable simultaneously

Parameters of the red and blue cameras of the spectrograph

Parameters	Red camera	Blue camera
λ_{min}	0.58μm	0.45μm
λ_{max}	0.87μm	0.75μm
λ_{ref}	0.7μm	0.57μm
Slit width	61μm	50μm
Maximum field of view (center of detector)	5.4''	4.2''
Number of spectral channels	173	156
Internal magnification of the spectrograph *(between the slit and the image plane)*	1.4	1.8

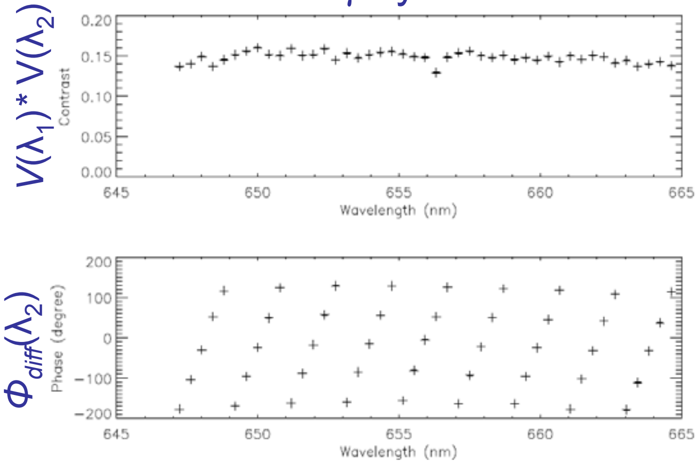
Differential Spectral Analysis

- Estimation of the fringe visibility modulus $V(\lambda)$ and the differential phase $\Phi_{diff}(\lambda)$
- Data processing around Hα
  - Reference band: fixed, λ_1 = 6560 Å with Δλ = 180 Å
  - Science band: Δλ = 4 Å, moving by step of 4 Å, λ_2 = 6572-6648 Å
- Data processing in the continuum
  - Reference band: fixed, λ1 = 6560 Å with Δλ = 180 Å
  - Science band: Δλ = 4 Å, moving by step of 4 Å, λ2 = 6572-6648 Å
- For each step we measure $V(\lambda_1)$* $V(\lambda_2)$ and $\Phi_{diff}(\lambda_2)$ for science target and calibrator
- Calibration process is used to deduce $V_{sci}(\lambda)$

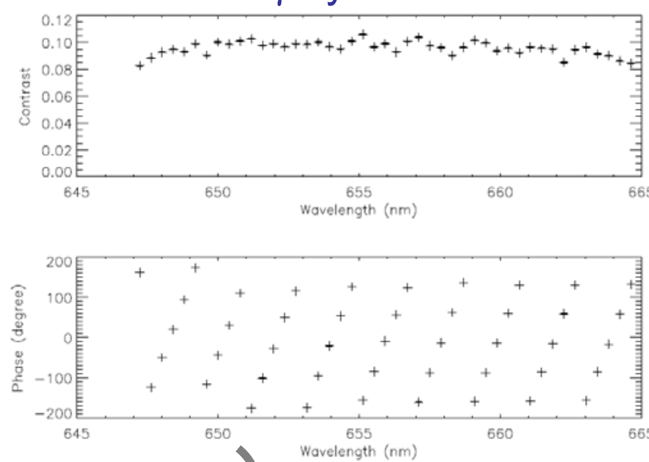


Data analysis of β Lyr around Hα

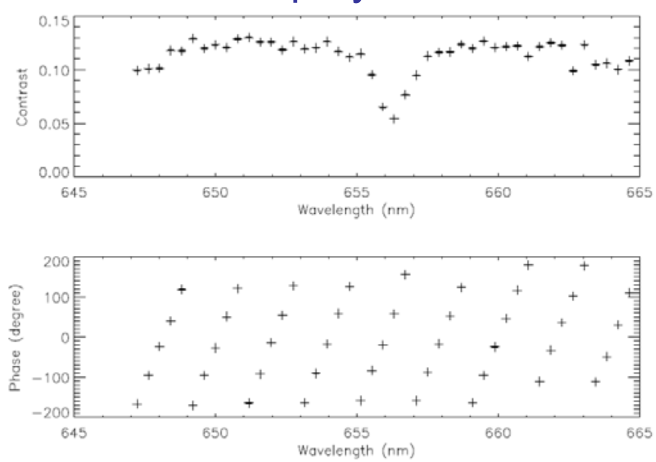
CAL : γ Lyr 08h59



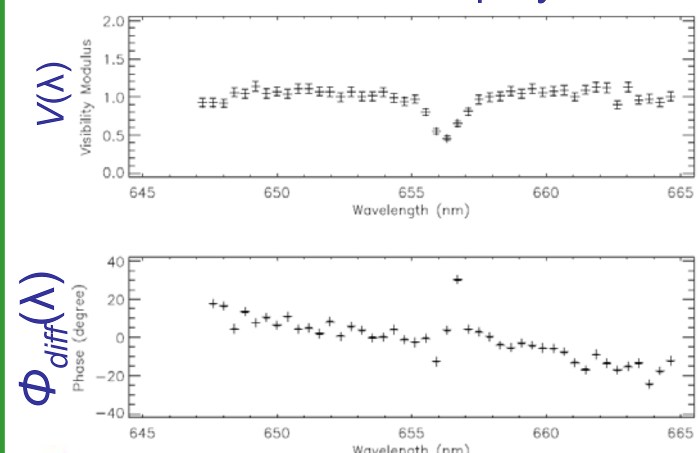
CAL : γ Lyr 09h39



SCI : β Lyr 09h20

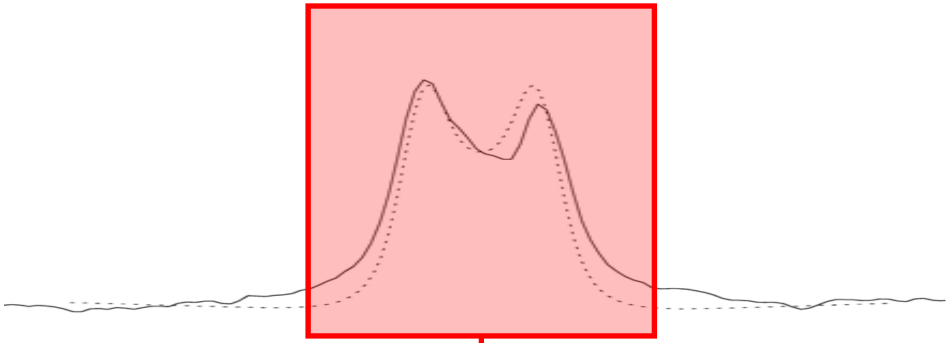


Calibration of β Lyr

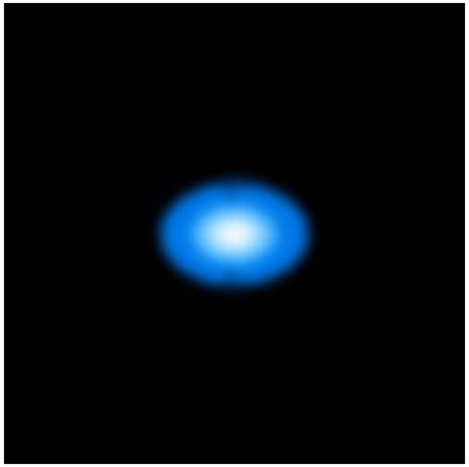


Spectro-interferometry

(Doppler Effect)



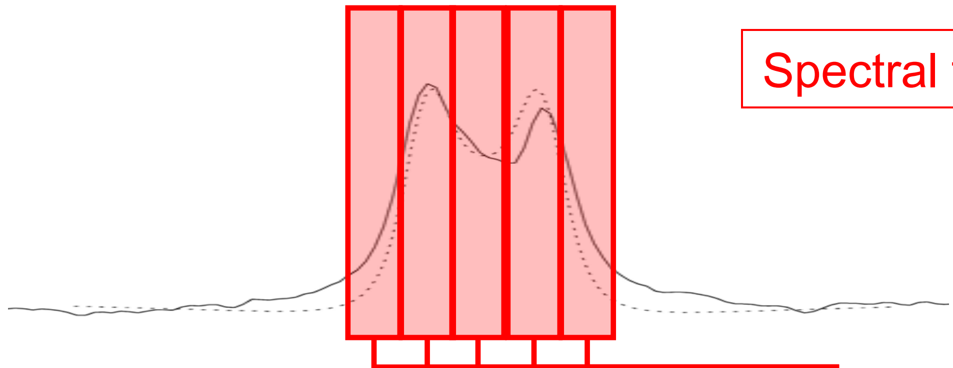
In the whole line



Geometry

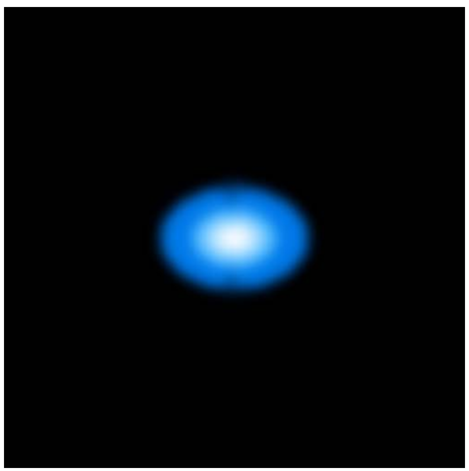
Spectro-interferometry

(Doppler Effect)



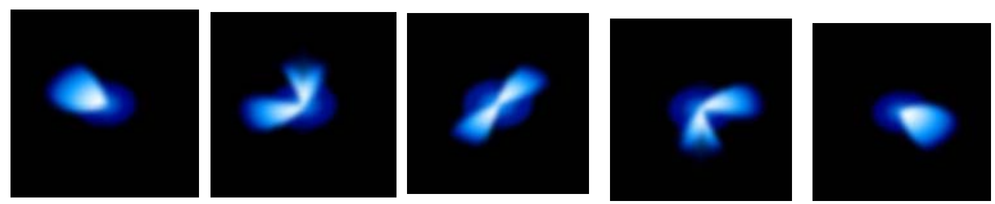
Spectral filter = spatial filter

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…

Relation phase shift - sky displacement (close to Hα)

$$\boxed{d(mas) = 0.37\,\frac{\phi(\deg)}{B(m)}}$$

Ex: S1S2 B=34m ϕ=20° ➔ d=0.21 mas

W1W2 B=107m ϕ=1° ➔ d=3.4 μas !

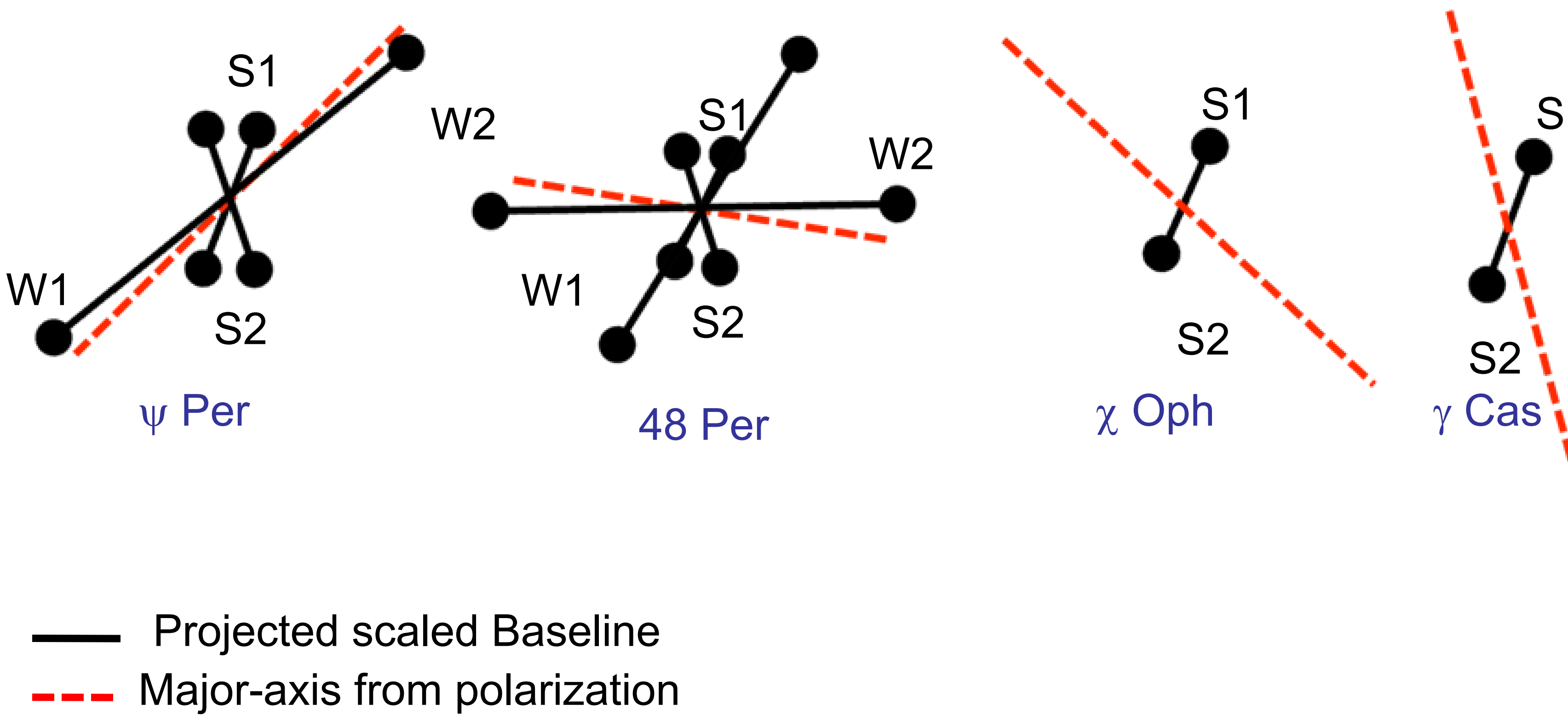
Be stars: open questions

- Origin of the Be phenomenon:
  - Why some hot stars are forming disks and some others not ?
  - What is the effect of the rotation ?
  - What is the effect of the magnetic field ?
  - What is the influence of stellar winds ?
  - What is the importance of these disks on the stellar evolution ?
  - What is the geometry and kinematics of Be stars’s disks?
  - Are all Be stars binaries ?

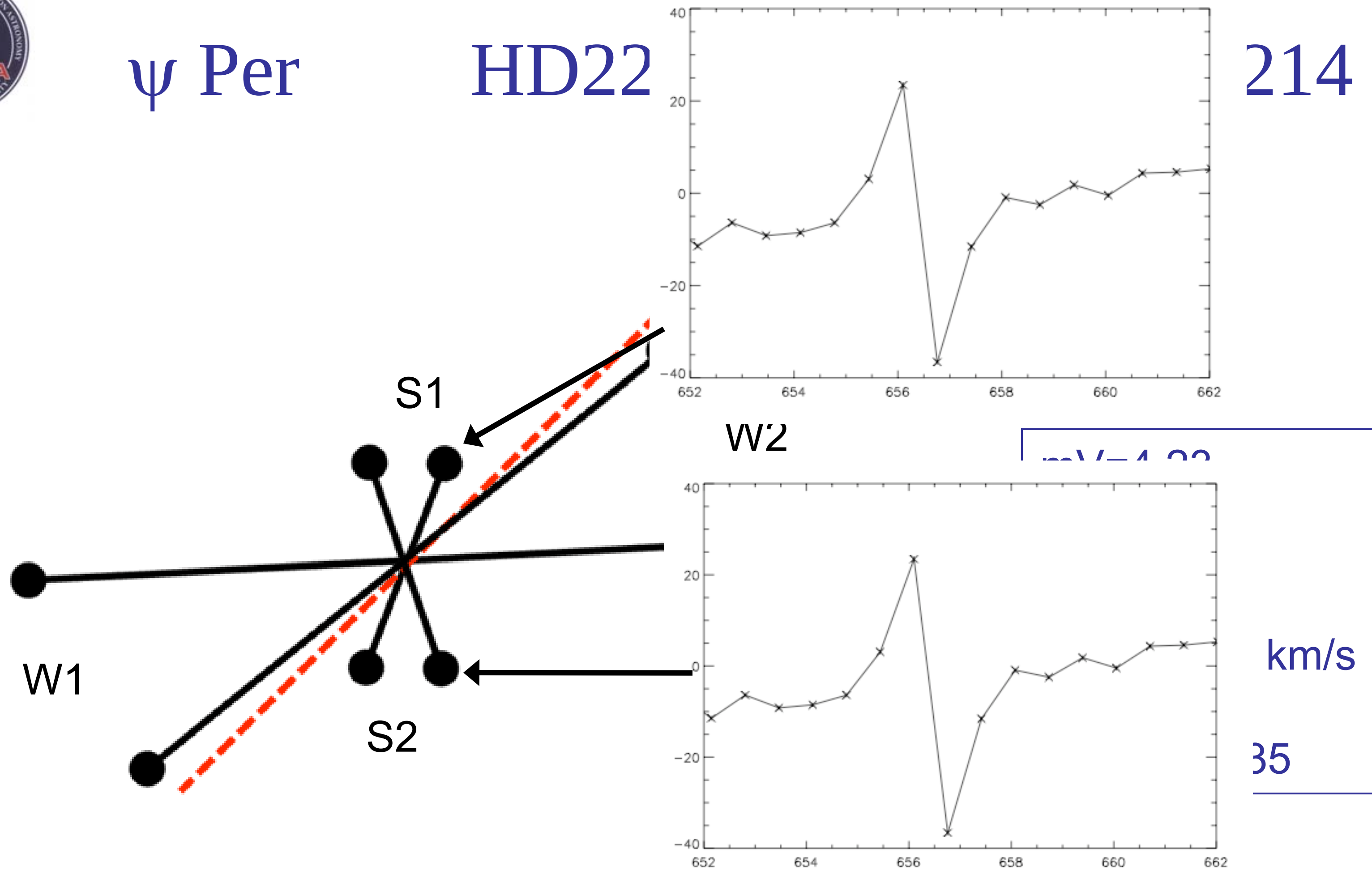
The CHARA/VEGA stars sample

□ ψ Per	HD22192	B5Ve	d=214 pc
• 48 Per	HD25940	B3 Ve	d=169 pc
□ χ Oph	HD148184	B1.5 Ve	d=150 pc
□ γ Cas	HD5394	B0 IVe	d=187 pc
• P-Cyg	HD193237	B2 pe	d=1923 pc
□ β Lyr	HD174638	B7Ve	d=270 pc
□ υ SgR	HD181615	F2p	d=513 pc

CHARA/VEGA baselines used



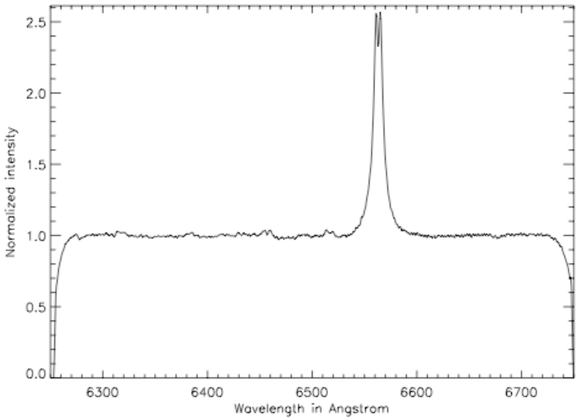
ψ Per HD22 214 pc

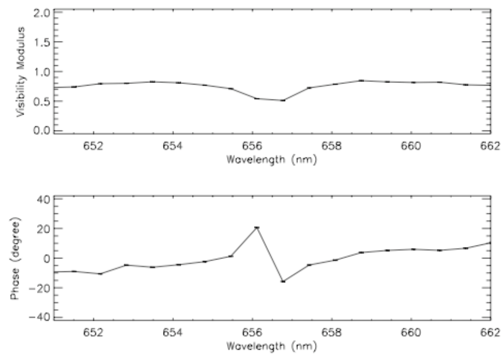


Projected scaled Baseline

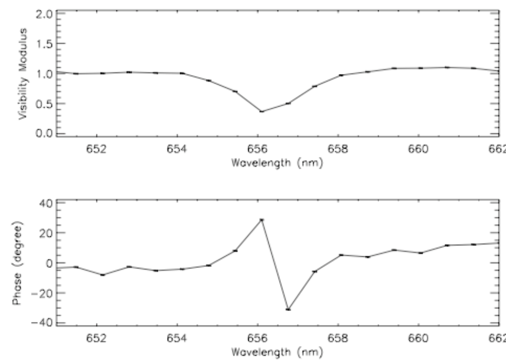
Major-axis from polarization

ψ Per HD22192 B5Ve d=214 pc

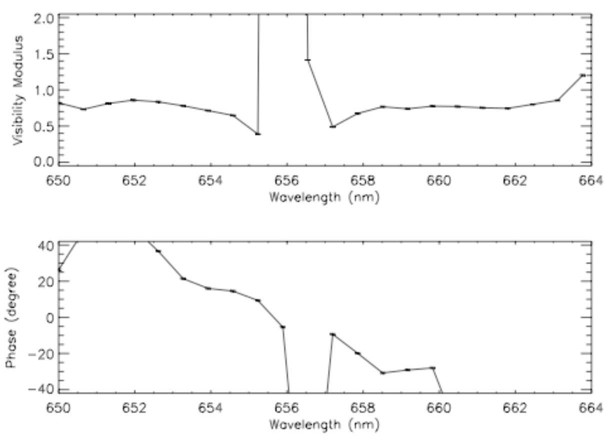




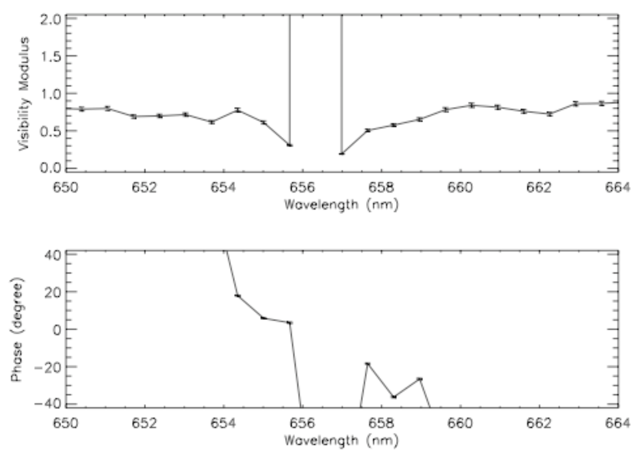
S1S2 -03h21



S1S2 01h15

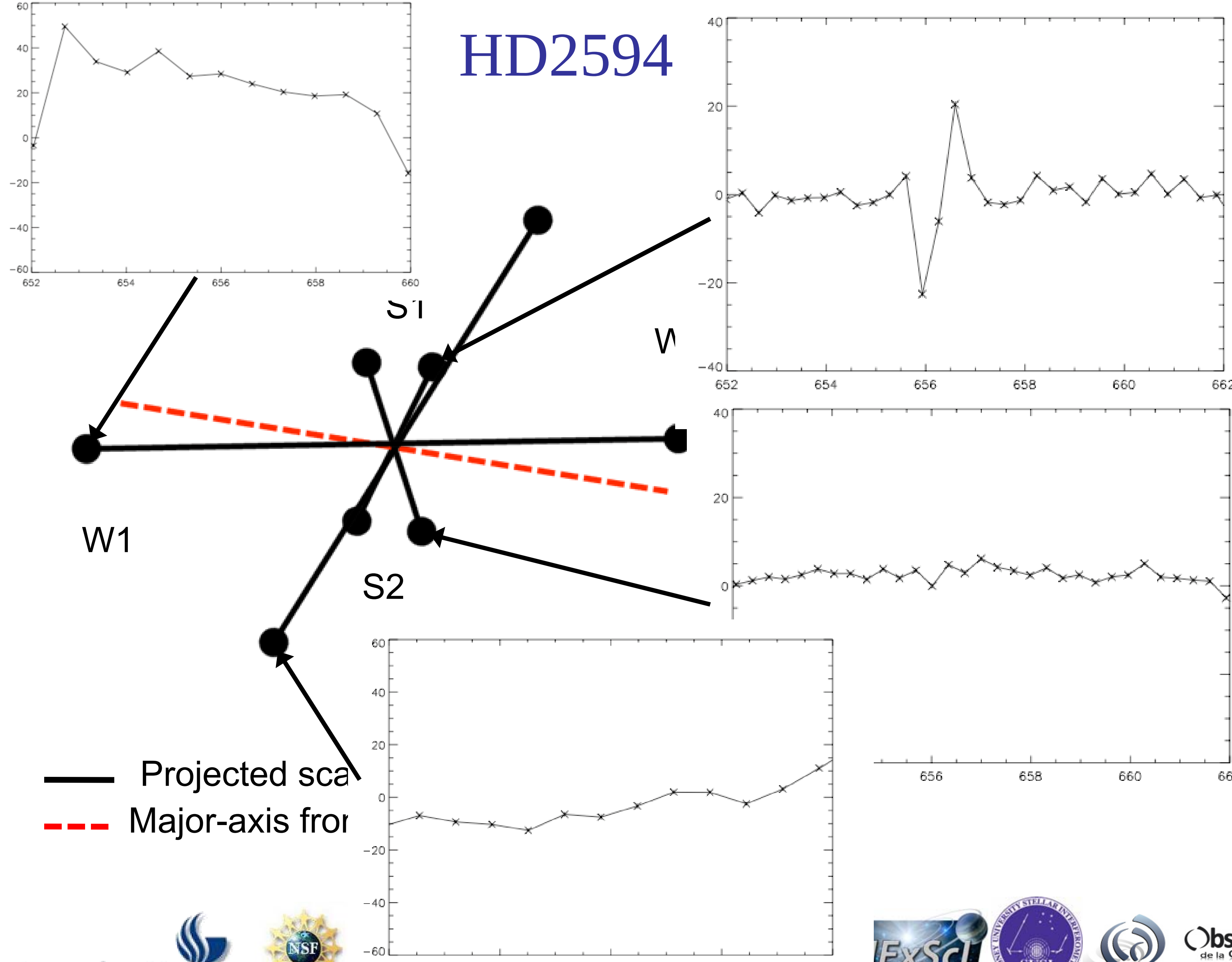


W1W2 -02h20

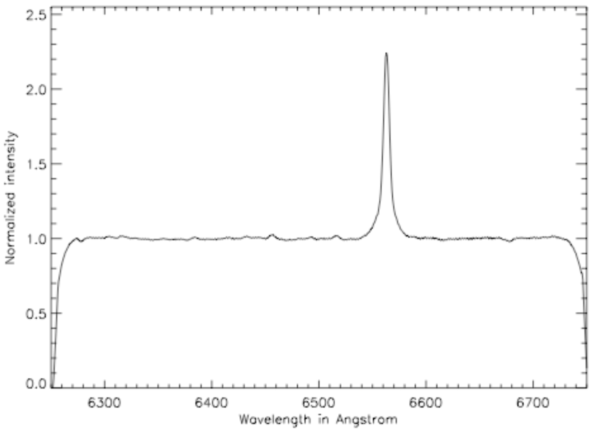


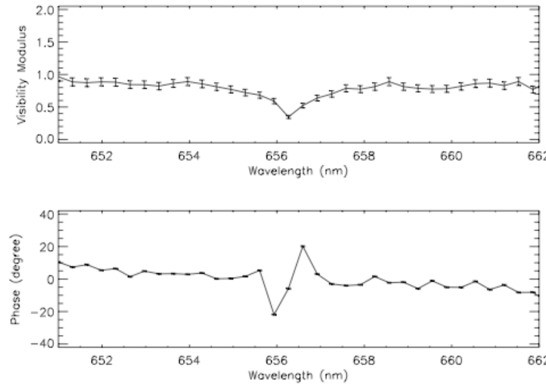
W1W2 00h35

HD2594

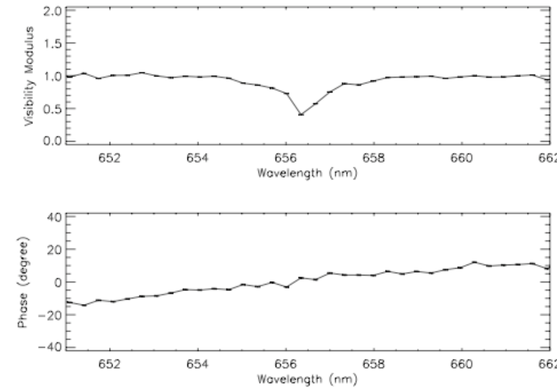


48 Per HD25940 B3 Ve d=169 pc

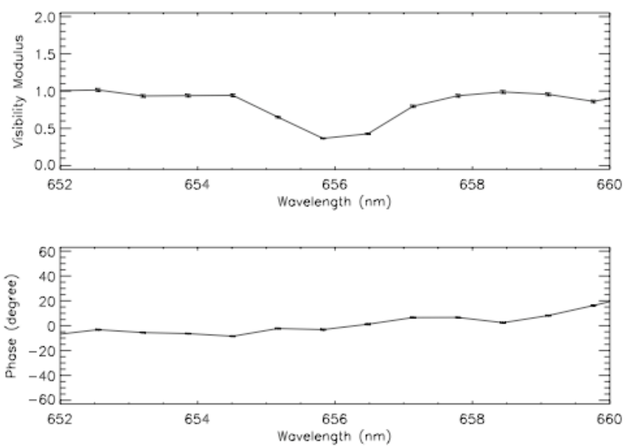




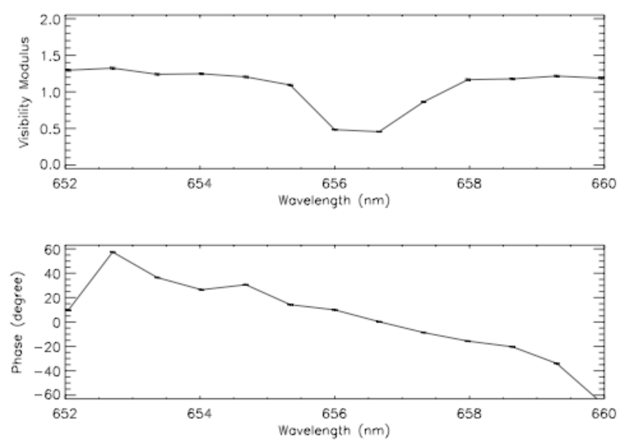
S1S2 01h59



S1S2 -03h17

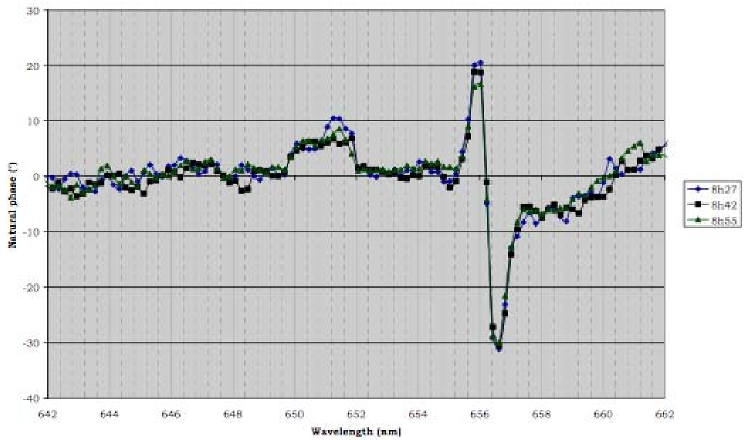


W1W2 -03h36



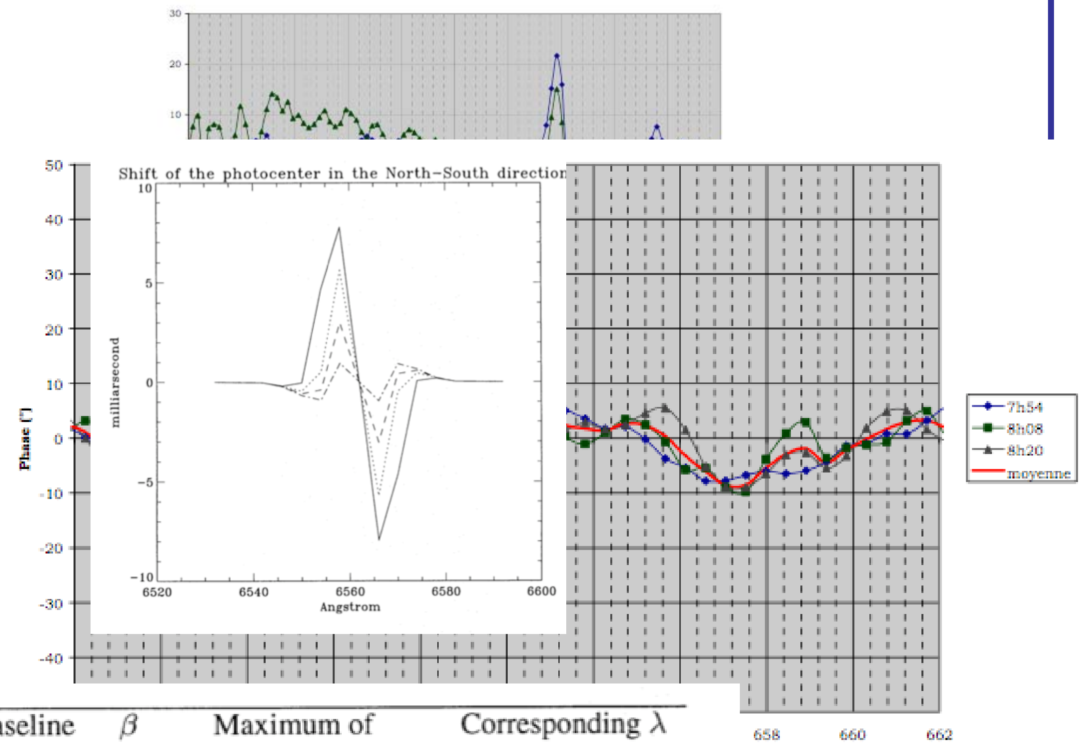
W1W2 00h42

γ Cas HD5394 B0 IVe d=187 pc



γ Cas natural light

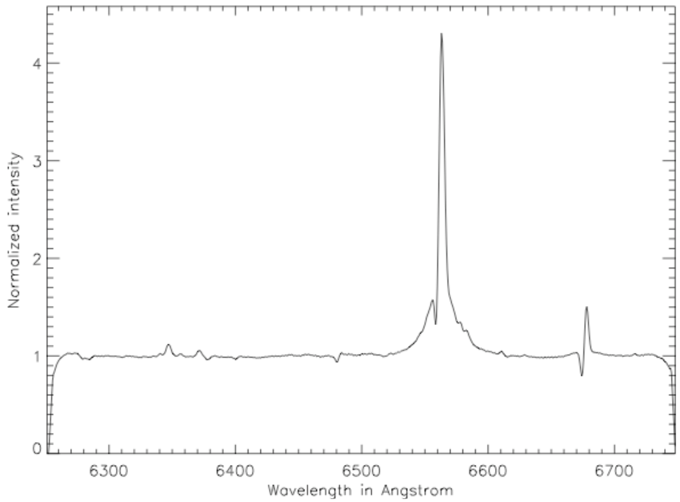
Stee 1996, A&A, 311, 945

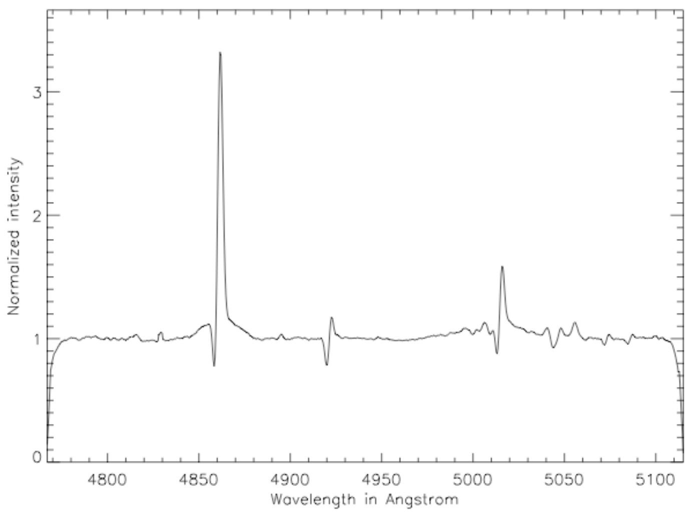


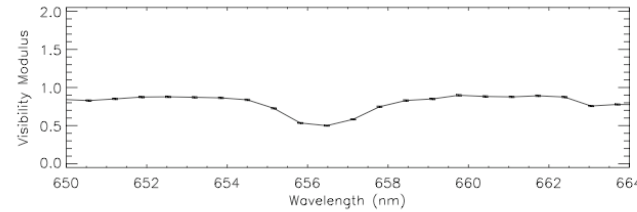
Baseline direction	β	Maximum of the shift (in mas)	Corresponding λ of the shift
N-S	0.0	± 7.75	6558 & 6566 Å
N-S	0.25	± 5.6	6558 & 6566 Å
N-S	0.5	± 3.00	6558 & 6566 Å
N-S	1.0	± 0.95	6558 & 6566 Å
E-W	0.0	± 3.92	6554 & 6570 Å
E-W	0.25	± 3.04	6554 & 6570 Å
E-W	0.5	± 2.76	6554 & 6570 Å
E-W	1.0	± 2.63	6554 & 6570 Å

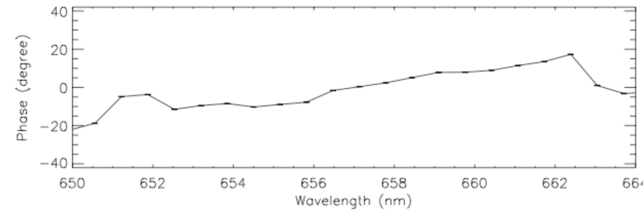
ht)

P-Cyg HD193237 B2 pe d=1923 pc

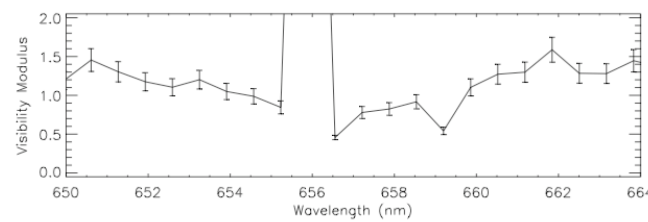


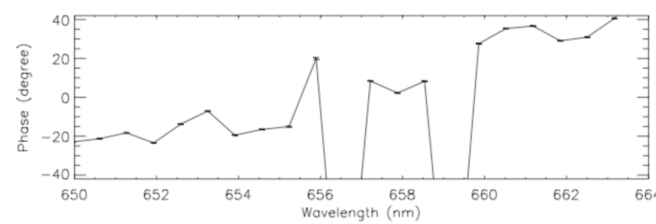






S1S2 04h17





W1W2 -00h39

Preliminary conclusions

- ψ Per: S1S2 @ 2 A.H. Well resolved in Hα, clear S signature of a rotating disk (seen nearly edge-on), W1W2 still need some work, blue data unusable.

- 48 Per: S1S2 @ 2 A.H. Well resolved in Hα, S shape @ 1 baseline but not for the 2 baseline, close in the sky plane (?), 35°<i<45° Resolved with W1W2 in Hα but no S signature for the differential phase: disk + wind ?

- χ Oph: S1S2 @ 1 A.H. Resolved in Hα, small S signal in the line (compatible with i= 20° ?)

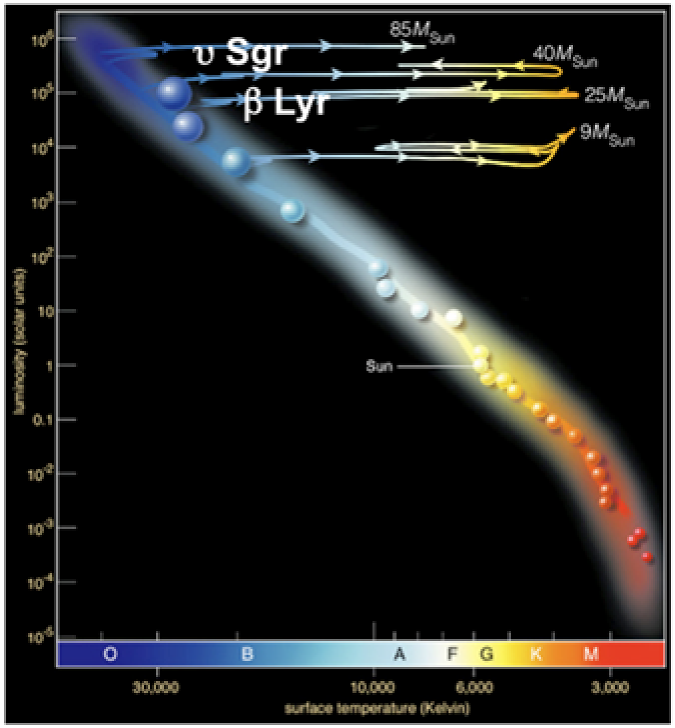
- γ Cas: S1S2 @ 3 A.H. in natural and 2 polarized directions: S shape different in Natural and Polarized light: need to work on the interpretation (i=45°).

- P-Cyg: S1S2 @ 1 A.H. Well resolved in Hα, No signature of a rotating disk (wind !), W1W2 still need some work…

Observations of interacting massive stars with CHARA/VEGA

Massive binary systems

- υ Sgr, binary system harboring an hydrogen deficient star (evolved system)
- β Lyrae: binary system with current mass-exchange



υ Sgr: D. Bonneau, O. Chesneau, P. Koubsky, D. Mourard , P. Stee, M. Netolicky
β Lyrae: D. Bonneau , O. Chesneau, D. Mourard , P. Stee

Interferometric observations of β Lyrae

1994

GI2T: 2T, B =51 m + spectro-interferometry

λ/Δλ ≈ 5000 @ Hα , λ/B ≈ 2.7 mas

- Resolved Hα jet like structure
- Binary system unresolved

Harmanec et al, 1996

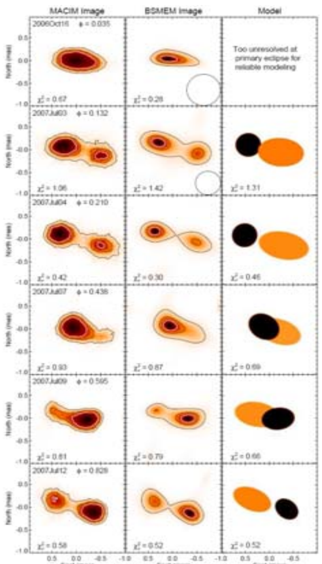
2005

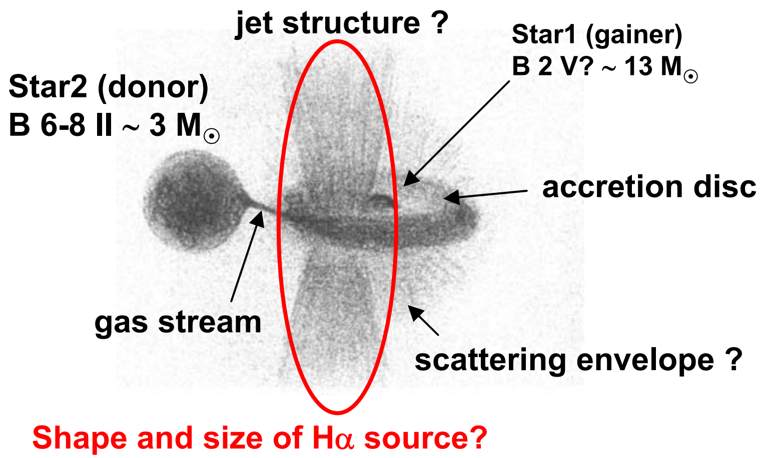
NPOI: 3T recombination, B = 19-53 m + differential phases

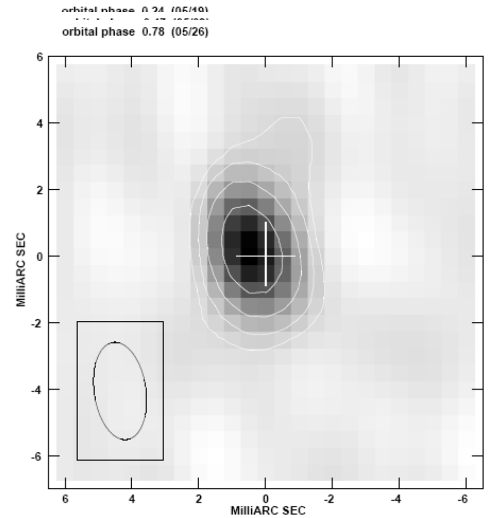
λ/Δλ ≈ 36 @ Hα , λ/B_{max} ≈ 2.6 mas

- Images of the Hα emitting region

Schmitt et al. 2009







2007

CHARA/MIRC: 4T recombination, B = 34-331 m

Interferometric imaging in H band , λ/B_{max} ≈ 1.0 mas

- Eclipsing binary resolved

Zhao et al. 2008

2008 …

VEGA-CHARA, 2T (3T), B = 34-331 m

Spectro-interferometry + differential phase imaging

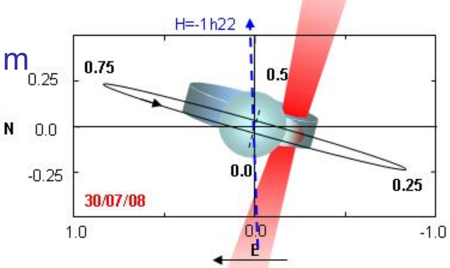
λ/Δλ ≈ 5000 @ Hα , λ/B_{max} ≈ 0.4 mas

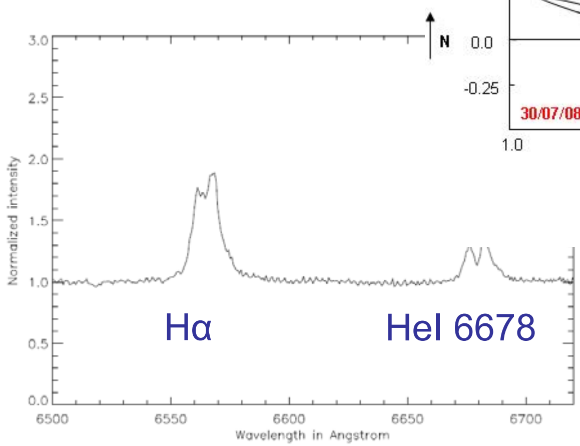
- **Shape and size of the Hα emitting region ?**
- **Morphology of the binary system?**

CHARA/VEGA observations of β Lyrae

2008/07/30

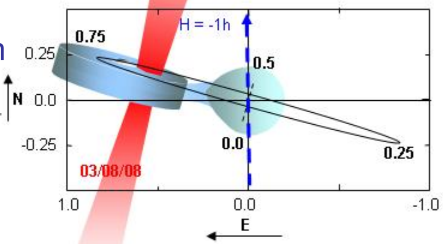
TU 04h48 φ_{orb}=0.496 B=34.1 m

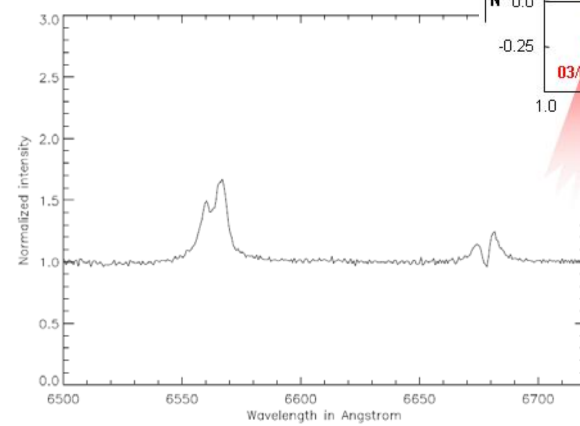




2008/08/03

TU 04h51 φ_{orb}=0.805 B=34.0 m

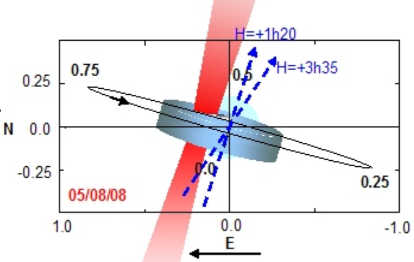


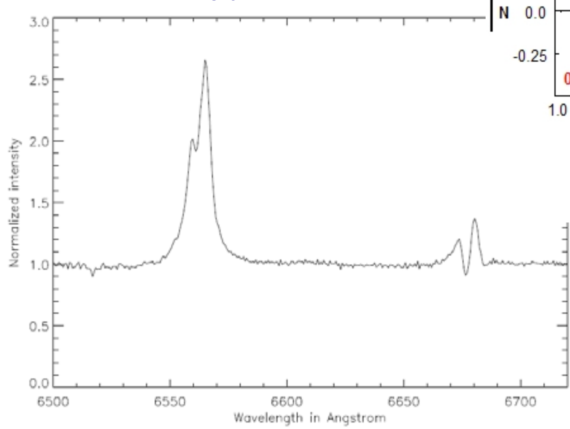


2008/08/05

TU 06h55 φ_{orb}=0.966 B=34.0 m

TU 09h20 φ_{orb}=0.974 B=32.5 m

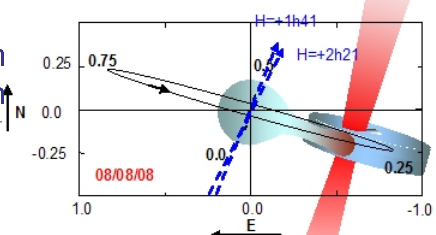


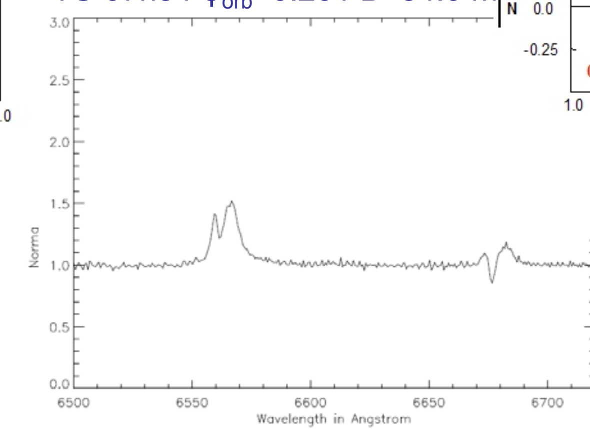


2008/08/08

TU 07h15 φ_{orb}=0.199 B=33.9 m

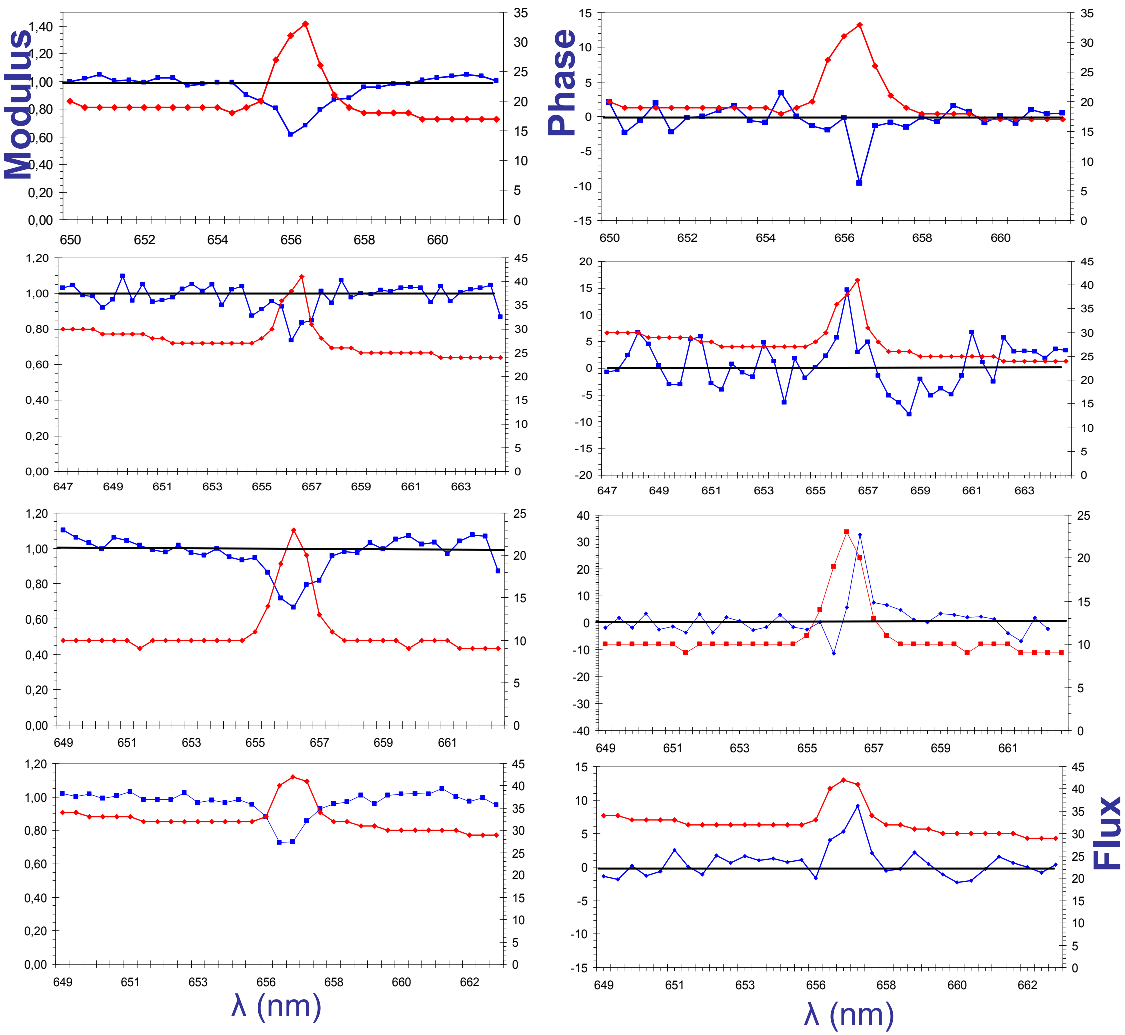
TU 07h54 φ_{orb}=0.201 B=34.0 m





Differential Spectral analysis of β Lyrae observations

Modulus and Phase of the visibility around Hα



2008/07/30

- $V_{obs} \approx 0.65$
  $c_{cont} \approx 0.36 \Rightarrow$ **V_{jet} (Hα) ≈ 0.45**
- $\Phi_{diff} \approx -9°$
  σ_{Φ} (cont) = 1.4°

2008/08/03

- $V_{obs} \approx 0.75$
  $c_{cont} \approx 0.40 \Rightarrow V_{jet}$ (Hα) ≈ 0.58
- $\Phi_{diff} \approx +15°$
  σ_{Φ} (cont)= 4.5°

2008/08/05

- $V_{obs} \approx 0.67$
  $c_{cont} \approx 0.30 \Rightarrow$ **V_{jet} (Hα) ≈ 0.53**
- $\Phi_{diff} \approx -11°$ and $\Phi_{diff} \approx +32°$
  σ_{Φ} (cont) = 3.2°

2008/08/08

- $V_{obs} \approx 0.73$
  $c_{cont} \approx 0.36 \Rightarrow$ **V_{jet} (Hα) ≈ 0.52**
- $\Phi_{diff} \approx +8°$
  σ_{Φ} (cont) = 1.4°

Observations β Lyrae with CHARA/VEGA

Preliminary results

- the source is unresolved in the spectral continuum.
- the source associated with the Hα emission is clearly resolved.
  the value of the visibility is nearly constant with the orbital phase.
- the differential phase exhibits significant offset in the Hα line.
  offset is correlated with the orbital phase.

Next step

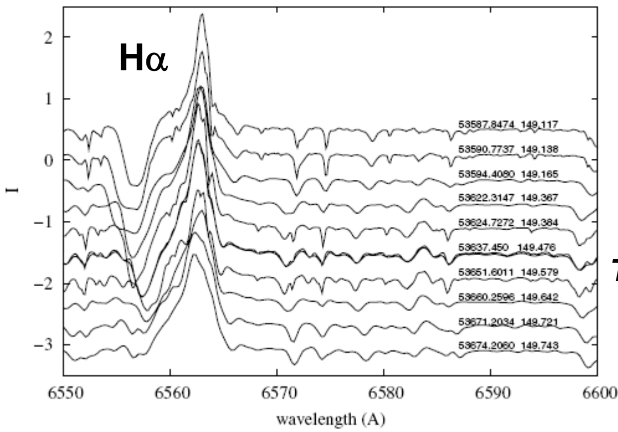
- to precise the present analysis of the Hα and HeI observations.
- observations with longer baseline to resolve the binary system.
- interpretation of the results using a morphological model of β Lyrae.

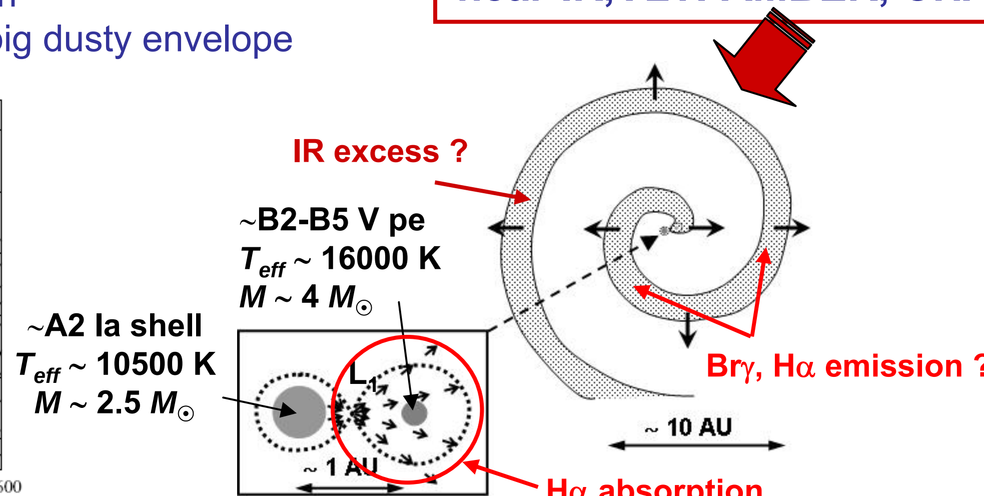
υ Sgr binary system

Ups Sgr (HD 181615, δ = - 16°, *magV* = 4.6)
- ➢ the brightest of the Hydrogen deficient stars (HdB stars)
- ➢ mass transfer stage.
- SB2, P ≈ 137.9 j d*P*/d*t* = -24 s/an
- Intense and variable Hα emission
- Strong IR excess! ⇔ large and big dusty envelope

Interferometric observations

mid-IR , VLTI-MIDI
near-IR,VLTI-AMBER, CHARA-MIRC





Visible, CHARA-VEGA

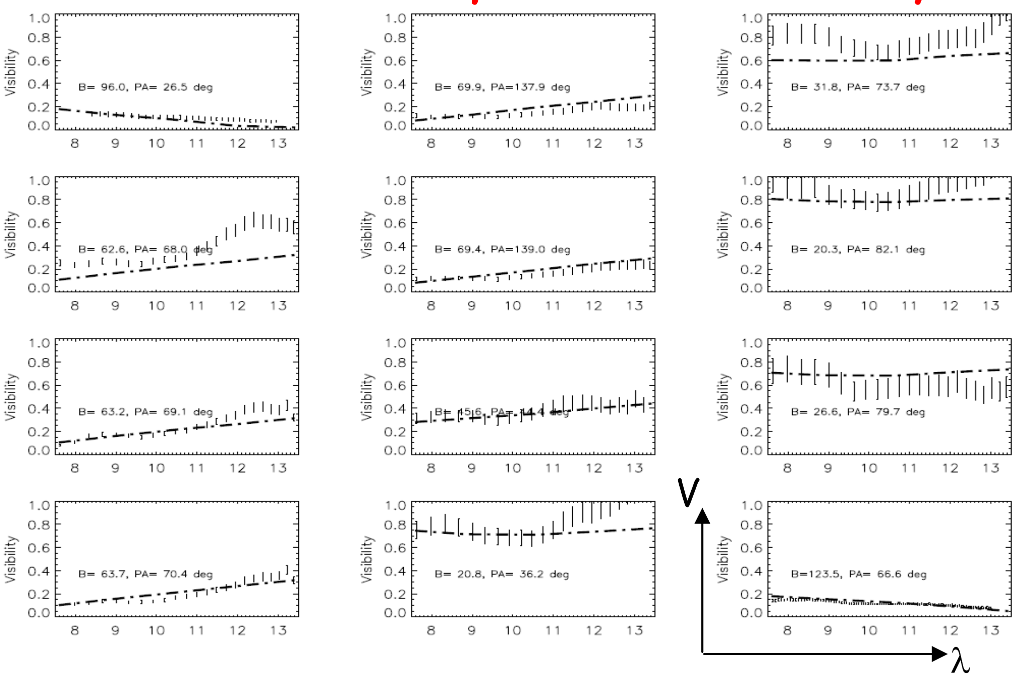
Characteristics of the system from spectroscopic monitoring
Orbital radius: *a sin i* = 207.4 $R_\odot$ = 0.965 UA
d = 595 pc (HIP, van Leeuwen 2007) ⇒ *a" sini* ≈ 1.6 mas
(Koubsky et al. 2006)

Stellar discs (Dudley et Jeffery, 1990)
R_1 ~ 60 $R_\odot$ Φ_1 ~ 0.9 mas and R_2 ~ 4 $R_\odot$ Φ_2 ~ 0.06 mas

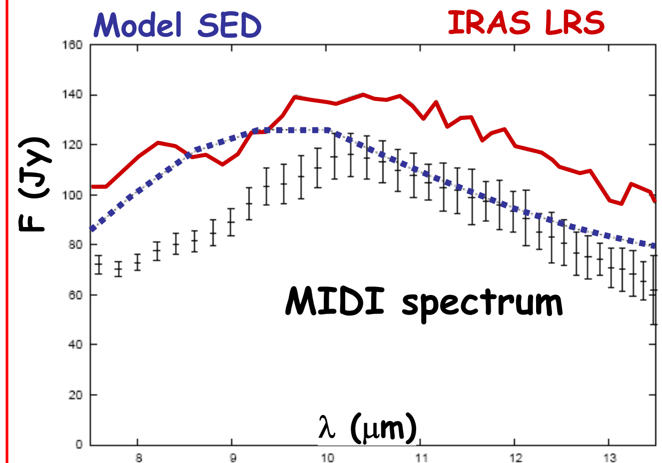
Georgia State University NSF NOAO l'Observatoire de Paris LESIA The University of Michigan 1817 NExScI NASA Exoplanet Science Institute SUSI Sydney University Stellar Interferometer Australia Observatoire de la Côte d'Azur

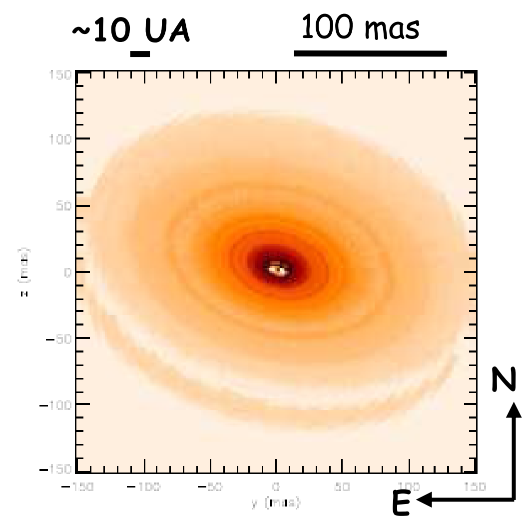
The dusty disk of υ Sgr constrained by MIDI/VLTI observations

Observed Visibility ⇔ modeled Visibility



Mid-IR spectrum of υ Sgr





- geometry of the circumbinary dusty envelope
- constraints on the orbital parameters

  Inclination *i* ~ 50°, P.A. of major axis *Ω* ~ 80°

  Total mass of the system > 15 $M_\odot$

Netolicky, Bonneau, Chesneau, Kousky et al. 2009

Promising CHARA/VEGA observations of Ups Sgr

VEGA configuration

- mid-spectral resolution R = 5000
- Blue channel ($\lambda \sim 500$ nm)
- Red channel ($\lambda \sim 650$ nm including Hα)

Results

- S1S2 baseline (B_{sky} = 23 m PA = -16°):
  - In the continuum, $V^2 \sim 0.7$
  - In Hα, dip of the visibility, phase offset of ~ 30°
- W1W2 baseline (B_{sky} = 107 m, PA = 97°):
  - In the continuum, $V^2 \sim 0.6$
  - In Hα, $V^2 < 0.1$

Preliminary conclusions

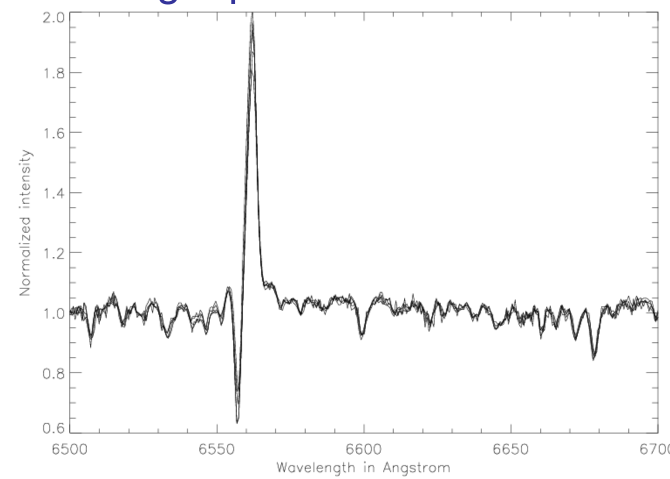
- **High continuum visibility in both baseline**
- **over-resolved source + compact source**

  Compact source probably dominated by the primary flux.

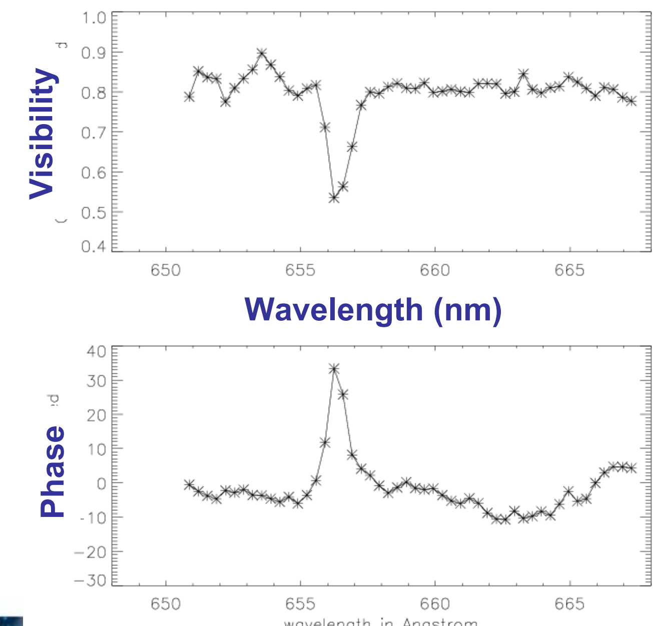
  Extended source due to the scattered light from the dusty disk.
- **Extended source in Hα** FWHM ~2.5mas

  i.e. surrounding the 2 stellar components.
- Position of the Hα photocenter ≠ of the continuum source

υ Sgr spectrum around Hα



Differential spectral analysis

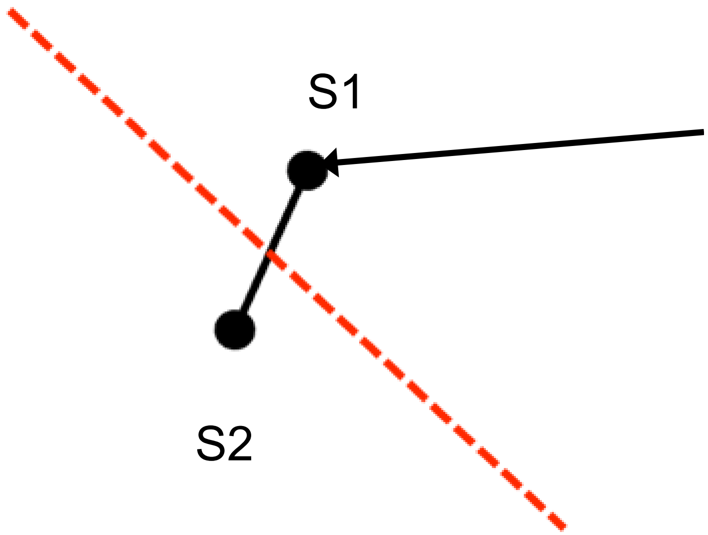


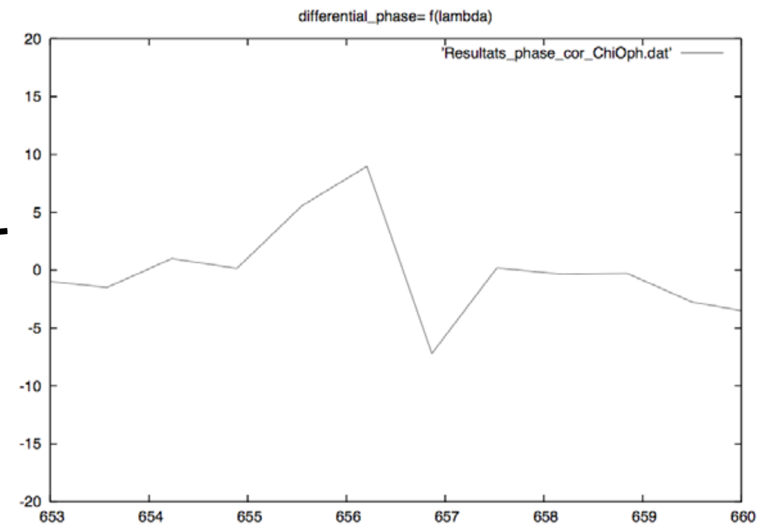
Future directions

- Clearly a vibration problem on W1W2 with W2 as a reference
- Very easy to obtain good fringes with S1S2
- To obtain usable data with the blue camera we need good seeing conditions (correlation SNR vs r0 to be done).
- Difficult to find (good) calibrators especially for the large baselines.
- At least 3-4 papers to come for 2009….

Thank you !

χ Oph HD148184 B1.5 Ve d=150 pc





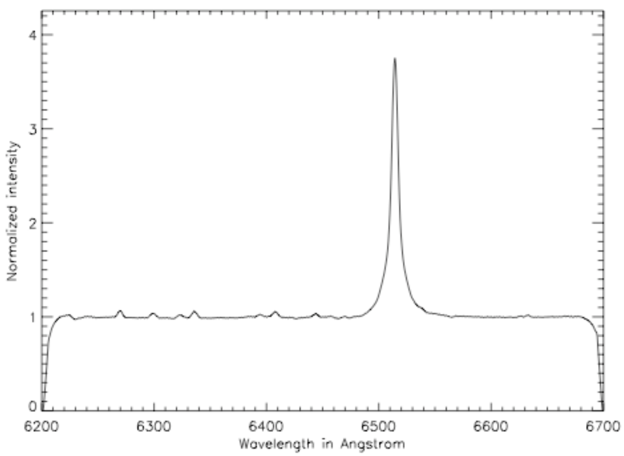
m/s

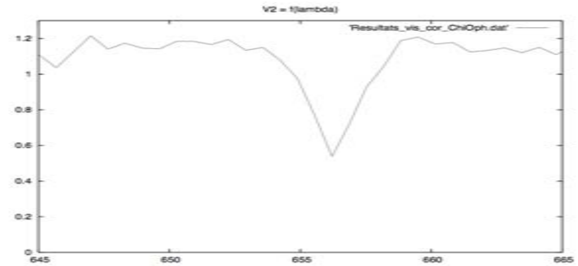
Φ(mas)=0.38

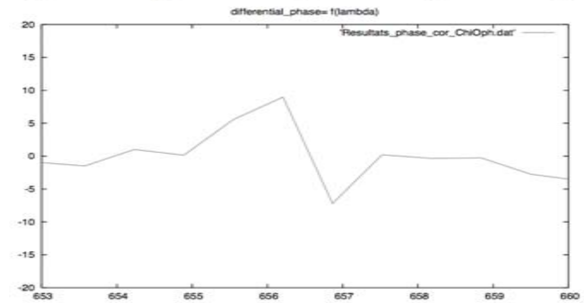
Projected scaled Baseline

Major-axis from polarization

χ Oph HD148184 B1.5 Ve d=150 pc

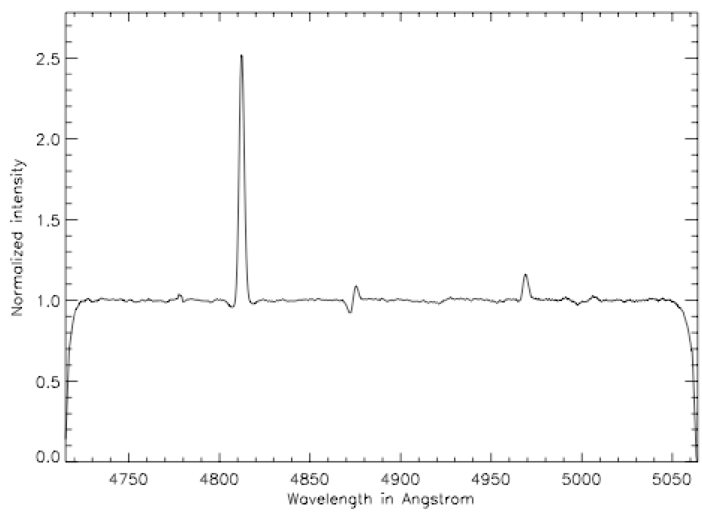


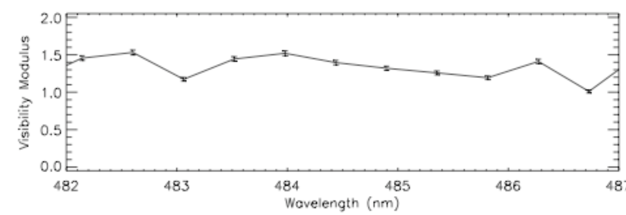


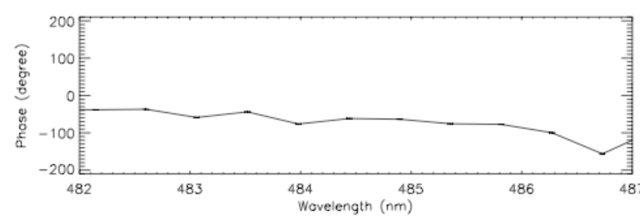


Red detector

S1S2 00h48

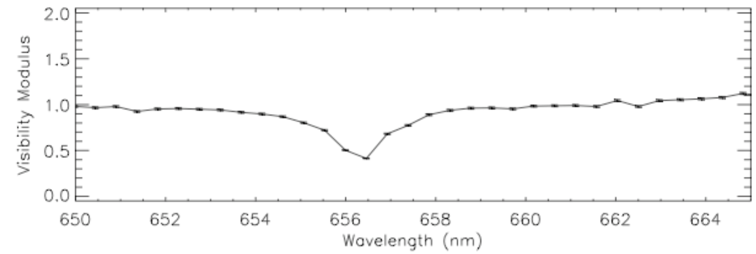


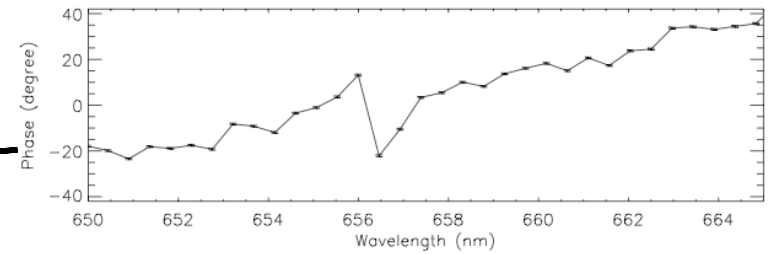


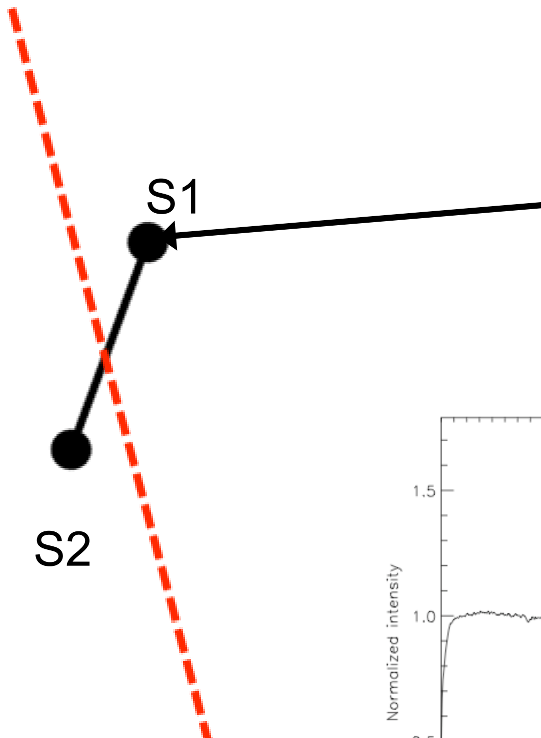


Blue detector

γ Cas HD5 … 7 pc







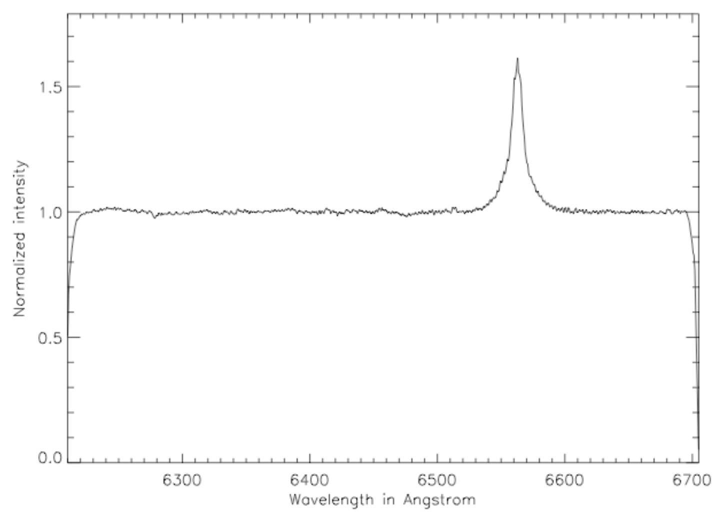
S1S2 00h51

$R=10\ R_\odot$

Vsini = 230 km/s

i=45°

Φ(mas)=0.45



Projected scale

Major-axis from