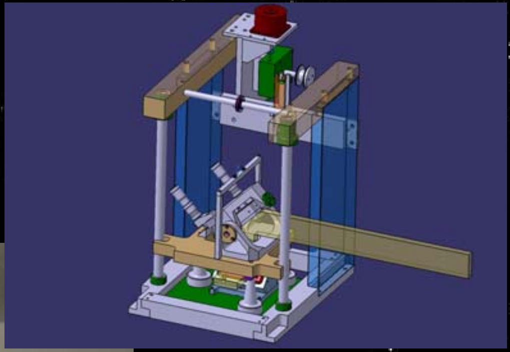
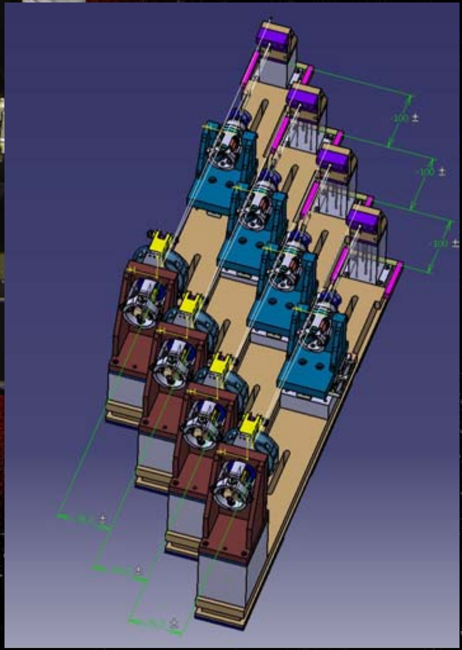
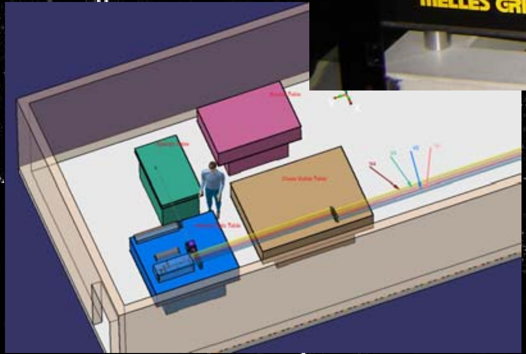


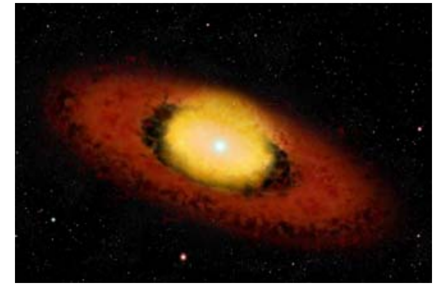
Science with VEGA





Ph. Stee
Observatoire de la Côte d’Azur
& the VEGA Science Group

Science rationale for VEGA



- Early science (with 2 T):

- The interacting binary β Lyrae (P =13 d), Hα, LR or MR, differential phase, June - October, baselines S1-S2, E1-E2, W1-W2, super-synthesis effect, simultaneous IR observations.

- Disc formation around δ Sco, MR, long term observational campaign, March-May, short baselines (S1-S2, E1-E2), simultaneous IR observations.

- Stellar activity and mass ejection of the supergiant RIGEL, MR & HR, Hα, Hβ, differential phase, October- November, S1-S2, E1-E2

- Coronal magnetospheric or disc wind from the HAe/Be star AB Aur, LR, S1-S2 & E1-E2, super-synthesis effect

- Measuring the disc dust and gas around the B[e] star HD 61623, LR & MR, Differential phase, S1-S2 & E1-E2, super-synthesis effect, simultaneous IR observations (Samer Kanaan's thesis)

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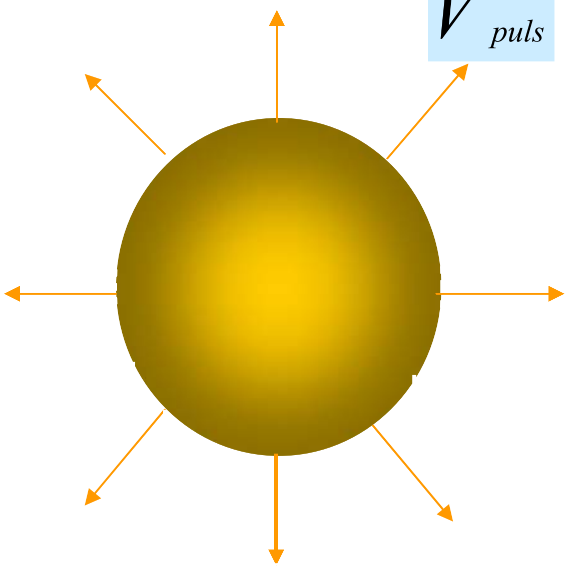
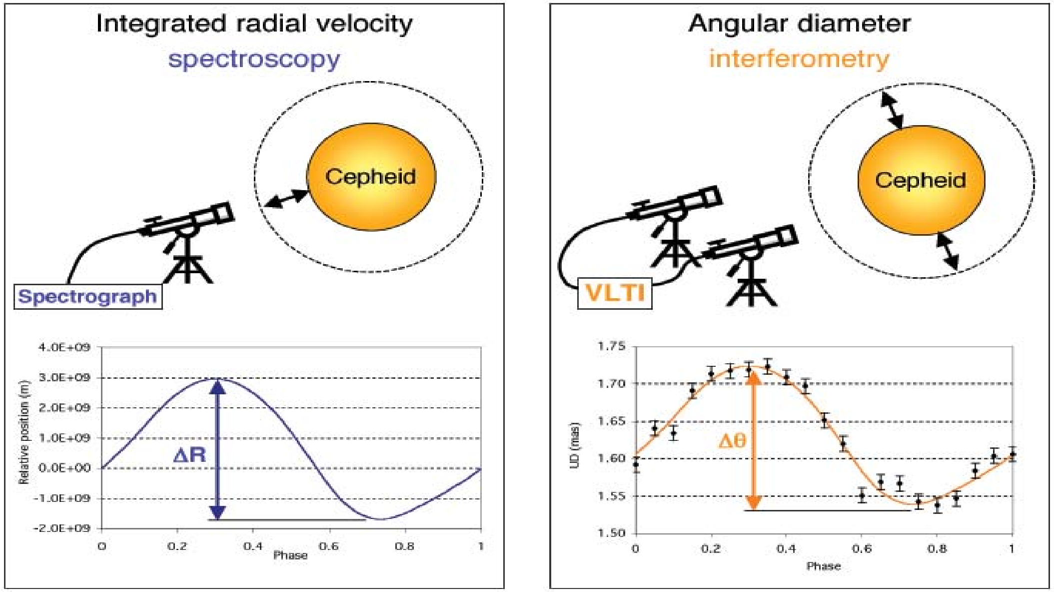
The interferometric Baade-Wesselink method



V_{puls}

V_{rad}

$$p = \frac{V_{puls}}{V_{rad}}$$



d [pc] = 9.305 ΔR [$R_\odot$] / $\Delta\theta$ [mas]

$\Delta R \Leftrightarrow \Delta \theta$

Important : study of systematics effects between Infrared and Visible (η, LD, p-factor)

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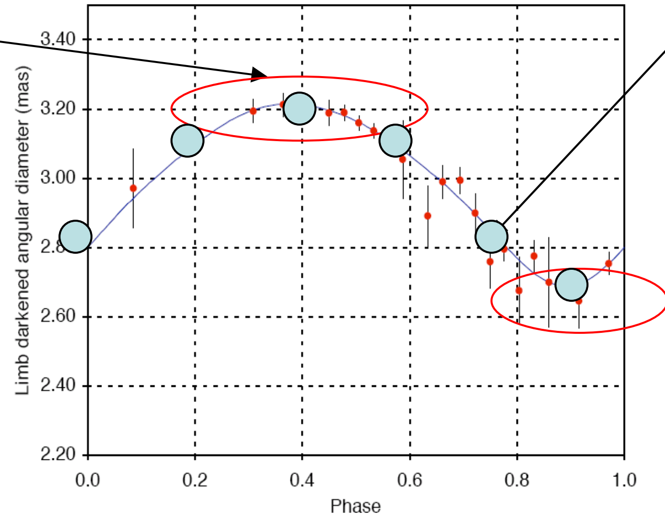
Cepheids with the VEGA/CHARA instrument

1. Distances (LR - easy – short term) : 32 Cepheids with VEGA/CHARA
6 (B<100); 10 (100<B<220); 16 (B> 220)

⇒**Precision of 0.01mag. on the PL relation.**

⇒**Exactitude : need of a study of the LD (average and variation) and p-factor …**
Comparison V/IR



2. Dynamical structure of Cepheid atmosphere (HR, difficult) :
B=50->300;
6 pulsations phases:

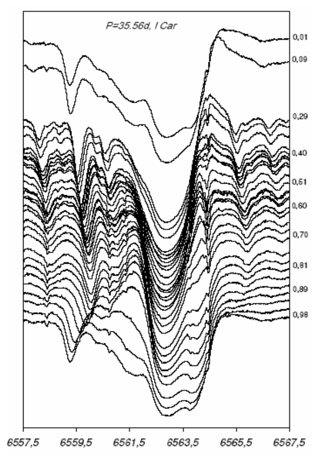
⇒**p-factor**

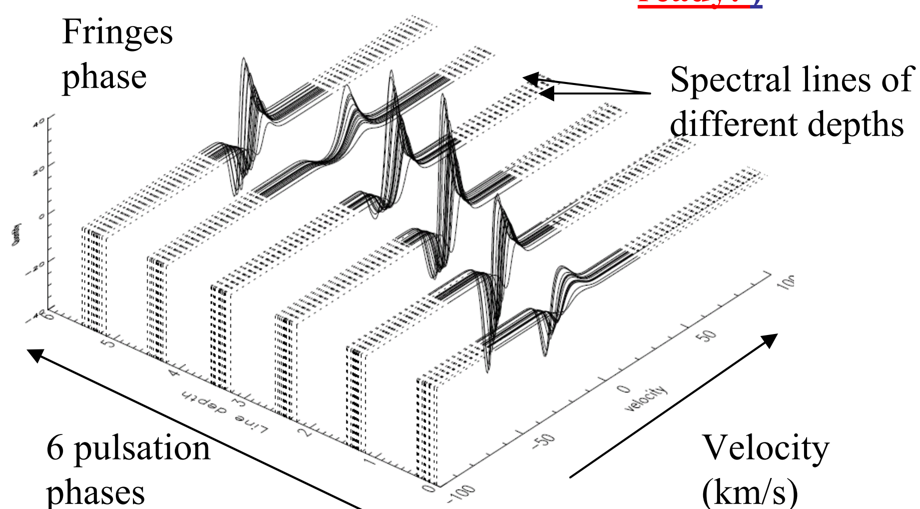
⇒**Vrot.sini**

⇒**Δη (distant Cepheids, LMC)**

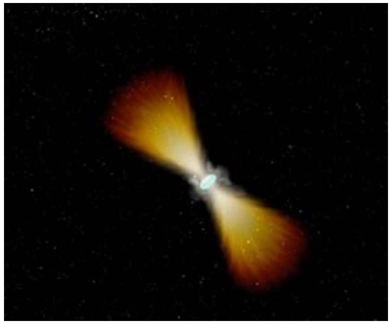
Geometric and hydrodynamic modelling (Interpretation Tools ready!)

3. Hα line – circumstellar environment: HR (difficult)





Science rationale for VEGA



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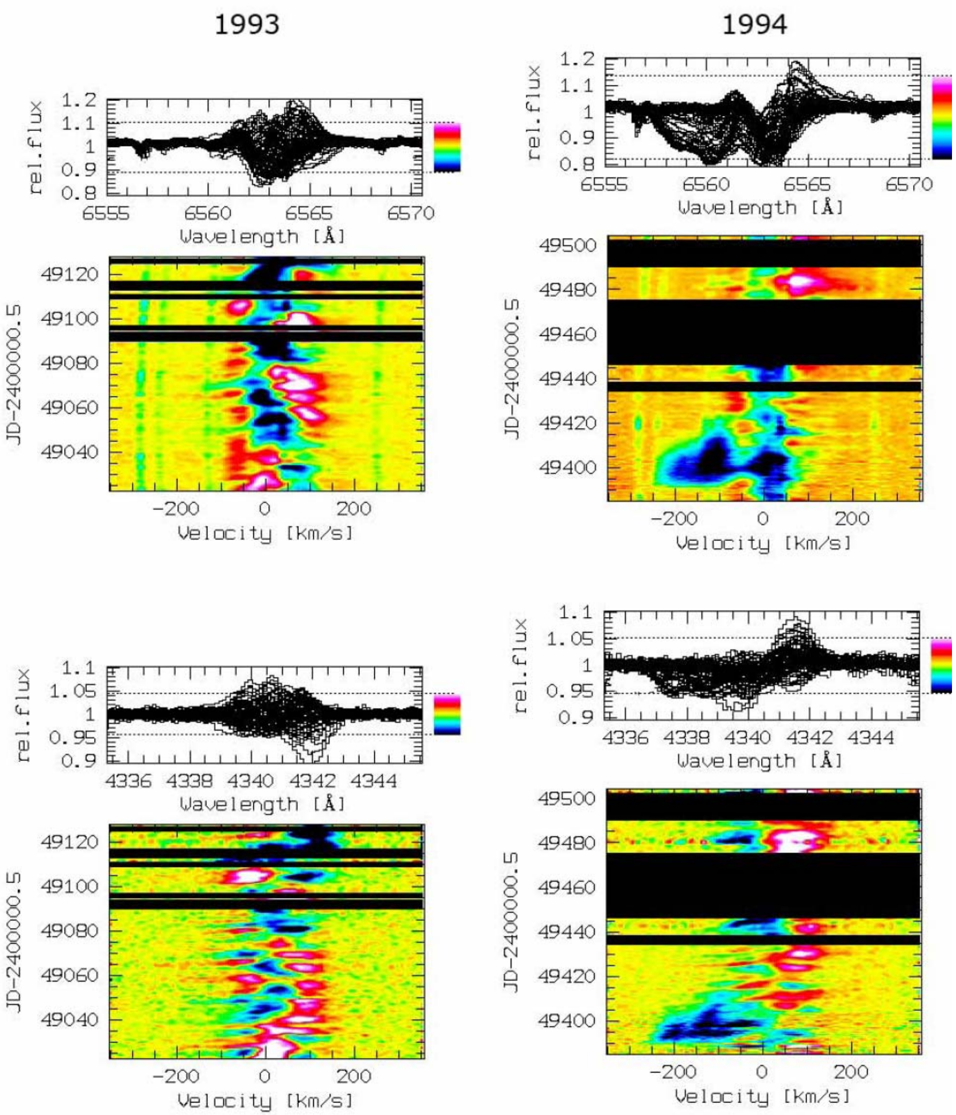
A & B Supergiants: RIGEL



mv=0.1, ϕ = 2.77 mas:

S1-S2 (34m, v=0.4)

E1-E2 (65m, v=0.1, 1er visibility lobe max, tracking IR ?)

Kaufer et al. 1996

Science rationale for VEGA

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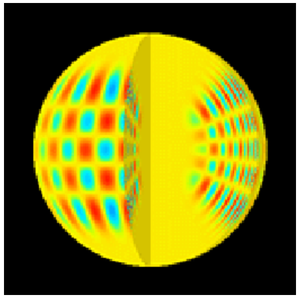
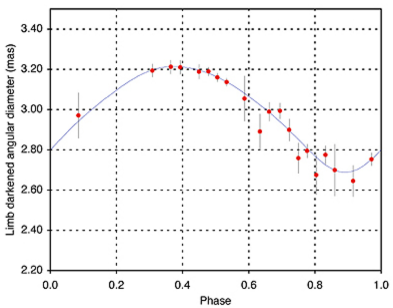
Science rationale for VEGA



- Early science (continue):

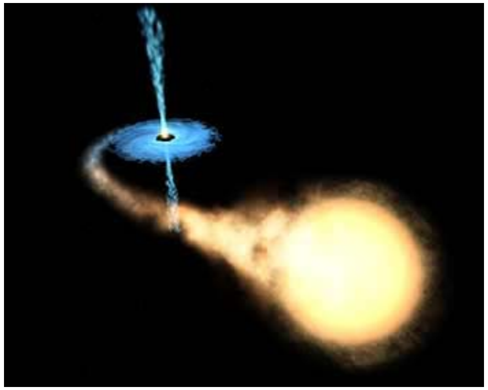
- Measuring the optically thin atmosphere of pop. II MIRA: RT Cyg, LR, June - October, S1-S2, E1-E2, W1-W2, IR tracking & visible measurement.

- Measuring the Limb-darkening and projection factor of pulsating Cepheides, ζ Gem, δ Cep, simultaneous IR observations (FLUOR).



Pulsation of the Cepheid Star L Carinae
(VLTI + VINCI)

ESO PR Photo 30c/04 (29 October 2004) © European Southern Observatory



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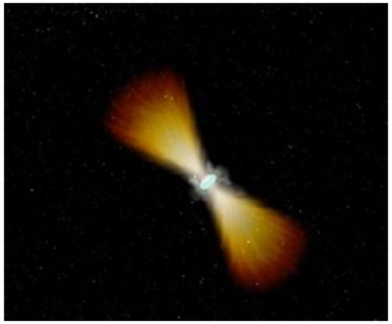

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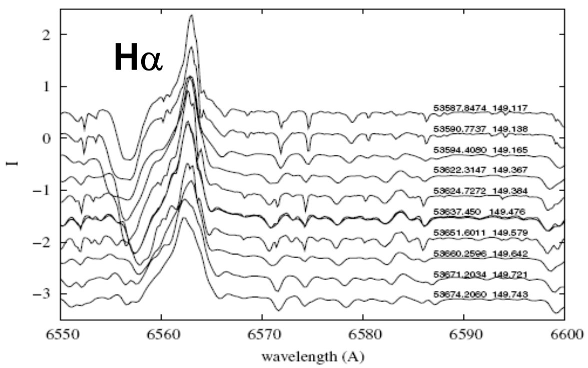
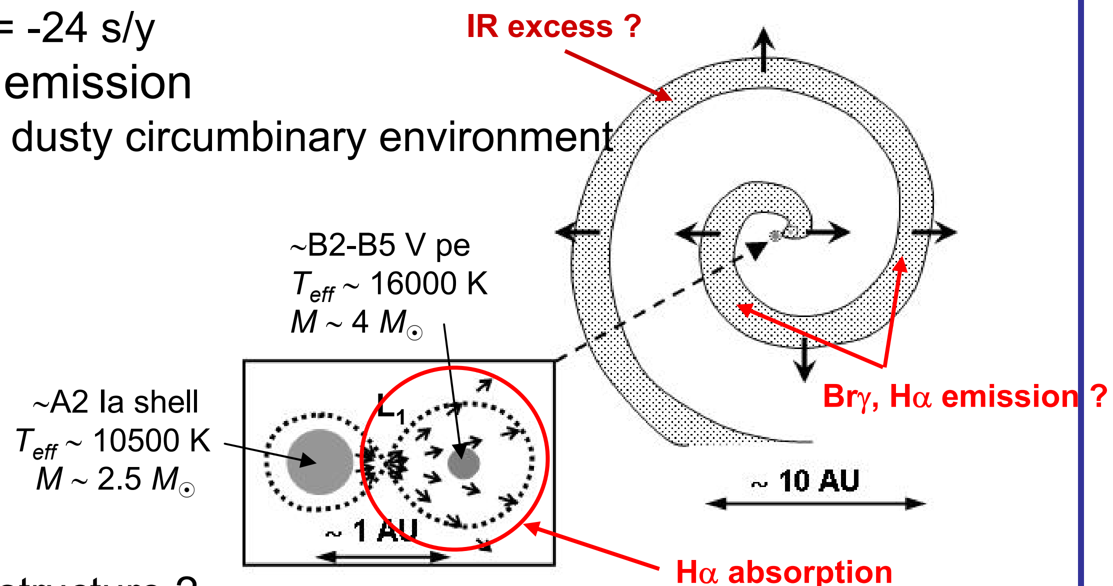
Massive stars in interacting binaries

Ups Sgr (HD 181615, δ = - 16°, $d \approx$ 500 pc)

- brighter member of the type of extremely hydrogen-deficient binary stars (HdB stars)
- HdB are evolved binary systems in a second phase of mass transfer
  - SB2, P ≈ 137.9 d dP/dt = -24 s/y
  - intense and variable Hα emission
  - strong IR excess ⇔ very dusty circumbinary environment





- possible accretion disc and jet-like structure ?

(Koubsky et al., 2006)

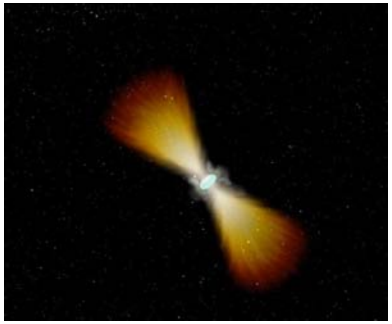
- Spiral nebulae ?

(Narai, 1967)

Mass transfer and mass loss study

- association of observations with high angular and spectroscopic resolution
- to raise the ambiguities of the interpretation of the spectro-photometric data
  - extension of the circumbinary envelope (VLTI- MIDI & AMBER)
  - origin of the Hα emission (VEGA on CHARA)

Science rationale for VEGA



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The Wind Structure of the O9.5Ia Supergiant α Cam

Why do we study the wind of massive stars?

- mass loss and stellar evolution
- momentum deposition and chemical enrichment of the ISM

Evidences of structured winds in O stars

- X-ray wind emission resulting from micro-shocks
- Discrete variable absorption features in wind lines
- UV wind line profiles cannot be matched by homogeneous wind models

Consequences of structured winds

- Lower mass loss rates by a factor of 3 to 10 at least
- Structures are formed deep in the wind
- Lower momentum deposition in the ISM (affect evolution of SN remnants)
- Effect on the predicted ionizing fluxes not assessed fully yet

→ ***Mass loss rates derived from homogeneous wind models need urgent revision. We need to constrain empirically the density structure of O star winds to build new realistic wind models of massive stars***

The Wind Structure of the O9.5Ia Supergiant α Cam

How do we constrain the wind structure of O stars?
- mid-IR, sub-mm, and radio observations
- Hα interferometry

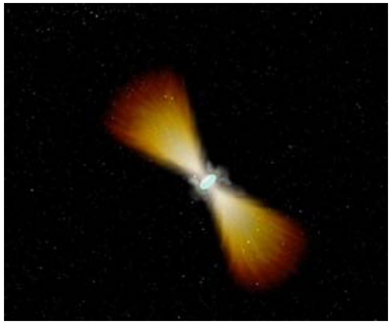
Density diagnostics
- UV lines are sensitive to the wind density
- Recombination lines (Hα) are sensitive to the ***density-squared***
- Free-free continuum is sensitive to the ***density-squared***

Mid-IR to radio observations
- Free-free continuum probes further in the wind at longer wavelengths
- ***Spitzer*** (GO cycle 3, PI: Lanz) IRS observations of the mid-IR continuum and hydrogen recombination lines of α Cam obtained in late 2006
- VLA radio fluxes existing in the litterature; sub-mm obs. in planing stage

Proposed CHARA/VEGA campaign on α Cam
- Wavelength-dependent visibilities in Hα (also mapping through the wind)
- Several bases and orientations to look for non-spherical wind
- Hα known to vary on several timescales: repeat the observations on daily, monthly, and yearly timescales to map changes in the wind (rotation, …)
- Photospheric radius: ≈ 30 R_{sun} ; distance: ≈ 800 pc ; V = 4.3

Wind extends from 0.15 to 0.4 mas

Science rationale for VEGA



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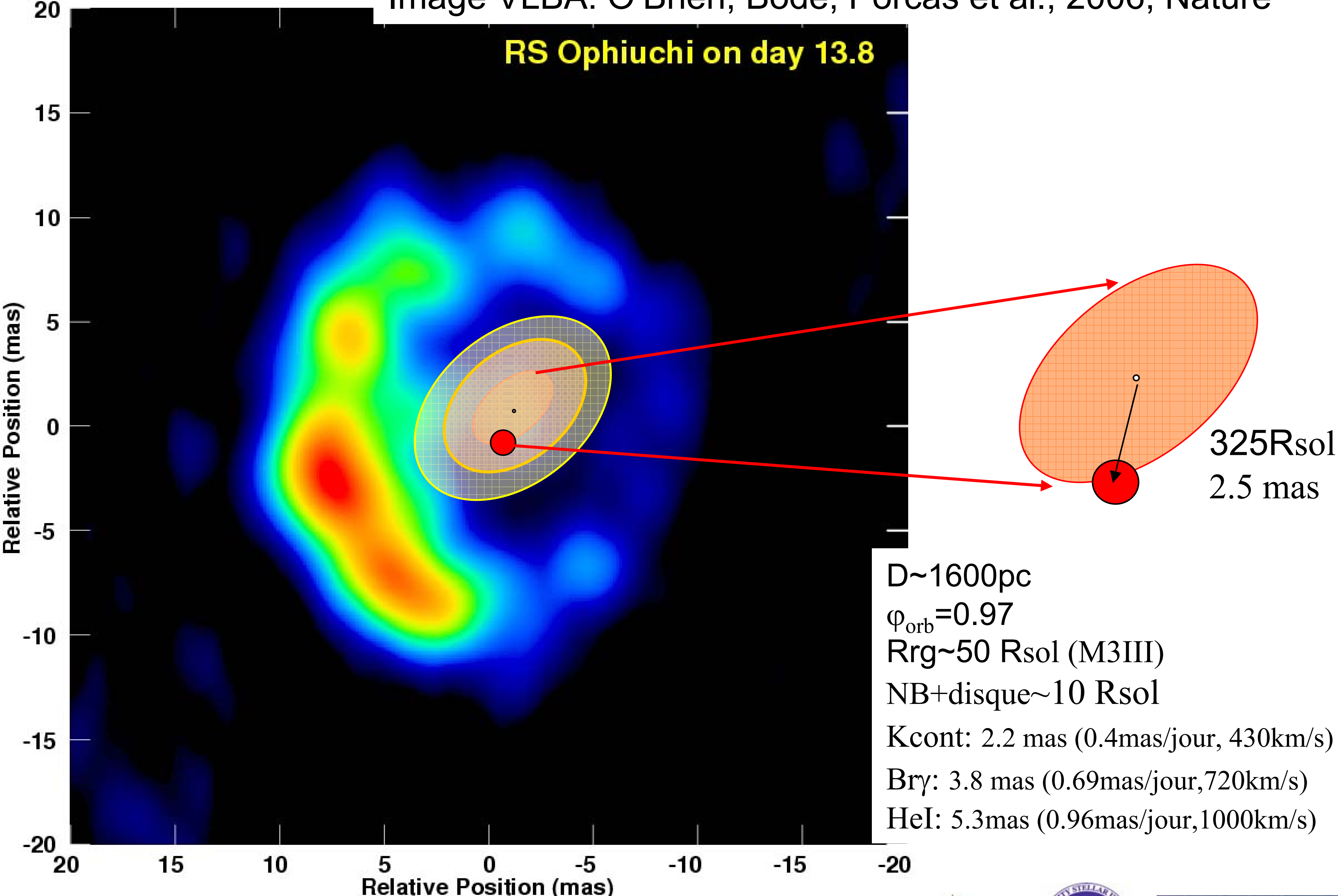
Science rationale for VEGA

- **Second phase (continue):**
- ➢ Extragalactic targets: need AO, BLR characterization, larges baselines, LR
- ➢ A Galaxy far, far away: other Galactic Cepheids
- ➢ Target of Opportunity (Novae, etc…)

QuickTime™ et un
décompresseur TIFF (non compressé)
sont requis pour visionner cette image.

Image VLBA: O'Brien, Bode, Porcas et al., 2006, Nature



D~1600pc

φ_{orb}=0.97

Rrg~50 Rsol (M3III)

NB+disque~10 Rsol

Kcont: 2.2 mas (0.4mas/jour, 430km/s)

Brγ: 3.8 mas (0.69mas/jour,720km/s)

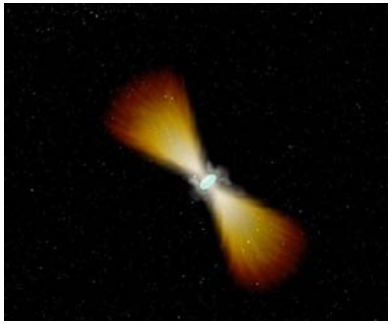
HeI: 5.3mas (0.96mas/jour,1000km/s)


See you soon on the mountain !
MELLES GRIOT

Rapid rotators: differential rotation, flattening, gravity darkening

Name	V sin i Km/s	Spectral Type	Mag V	Angular diameter
Altair	240	A7V	0.77	~ 3 mas
Regulus	353	B7V	1.35	~1.4 mas
zeta Ophiuchi	295	O9.5Ve	2.5	~0.5

Science rationale for VEGA



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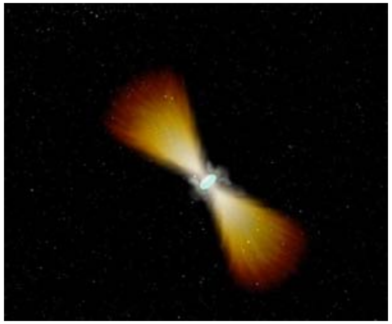
Fundamental parameters of stars with exo-planets: Diameter and Teff (cf Ellyn talk)

star name	distance (pc)	V mag	K mag	_RAJ2000	_DEJ2000	ang diam (mas)
Gamma Cephei	11.8	3.22	1.04	23 39 20.84	+77 37 56.4	2.98
HD 219449	45	4.21	1.60	23 15 53.47	-09 05 15.8	2.48
Epsilon Eridani	3.2	3.73	1.78	03 32 55.91	-09 27 29.9	2.04
HD 59686	92	5.45	2.92	07 31 48.38	+17 05 09.9	1.33
HD 104985	102	5.79	3.27	12 05 15.10	+76 54 20.6	1.13
Ups And	13.47	4.09	2.86	01 36 47.85	+41 24 20.1	1.09
70 Vir	22	5.00	3.50	13 28 25.85	+13 46 44.7	0.85
Tau Boo	15	4.50	3.51	13 47 15.81	+17 27 25.0	0.78
47 Uma	13.3	5.10	3.75	10 59 28.02	+40 25 48.6	0.74
HD 19994	22.38	5.06	3.75	03 12 46.44	-01 11 45.8	0.74
rho CrB	16.7	5.40	3.86	16 01 02.65	+33 18 12.5	0.73
55 Cnc	13.4	5.95	4.02	08 52 35.79	+28 19 51.0	0.72
51 Peg	14.7	5.49	3.91	22 57 27.96	+20 46 07.7	0.71
HD 3651	11	5.80	4.00	00 39 21.87	+21 15 02.4	0.71

Science rationale for VEGA



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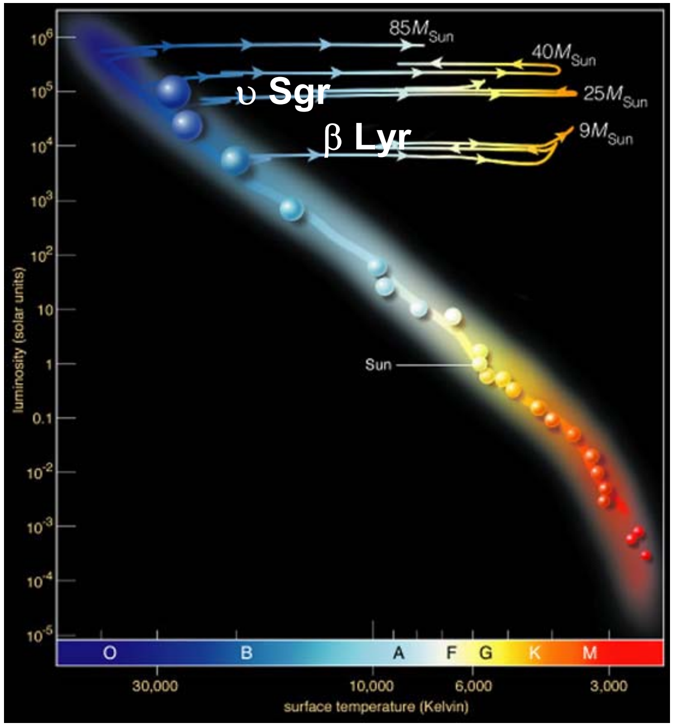
Massive stars in interacting binaries

Massive stars
- very hot and luminous
- main source for galactic UV flux
- impact on the interstellar medium and on the stellar formation process
- evolution affected by a strong stellar wind
- uncertain fundamental stellar parameters

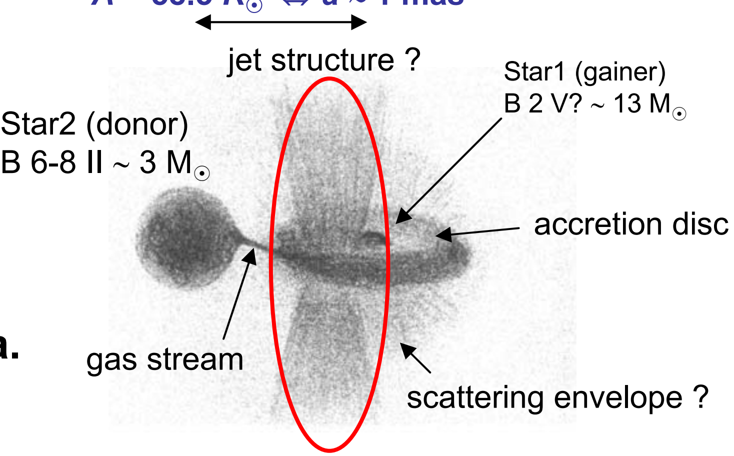


Massive interactive binary systems
- mass transfer and mass loss
- Complex circumstellar environment, rich in hot gas and dust

- system with exchange of mass ($M \sim$ 10-20 $M_\odot$)
  a donor star losing mass towards a star hidden in an accretion disc or a circumbinary structure (β **Lyr** et υ **Sgr**)
  collaboration with the czech group of the Ondrejov observatory

A new vision of β Lyrae

- **Polarimetric observations:**
  - orbital axis θ ≈ 160° (Rudy, 1979)
  - UV line polarization θ ≈ 162° (Nordsieck et al., 1995)
- **radio observations:**
  - resolved source with MERLIN array at ν = 5 Ghz (λ = 6 cm)
  - size ~ 60 x 47 mas à θ ≈ 157° (Umana et al., 2000)
- **Light curves and UV spectrum modeling.** (Linnel et al., 1998)
- **3-D gas dynamical simulations of mass transfer.** (Bisikalo et al., 2000)
- **Disentangling of donor and accretion disc spectra. No strong dependency of Hα emission during the orbital cycle.** (Ak et al., 2007)

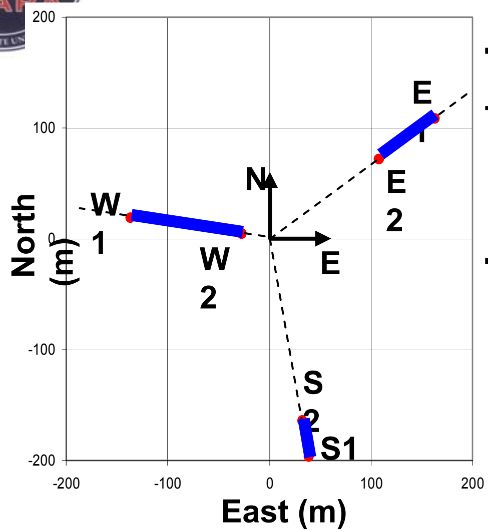


Localization of the Hα and He I emissions

Mass transfer and mass loss study with CHARA

- association of observations with high angular and spectroscopic resolution
- to solve the ambiguities of the interpretation of the spectro-photometric data
  - Visible (VEGA-CHARA) ⇒ origin of the Hα emission, resolution of the binary
  - Near IR (CHARA, AMBER-VLTI) ⇒ free-free emission and Brγ emission

β Lyrae observed with VEGA-CHARA ?



CHARA baselines

Base	B (m)	Az(°)
S1-S2	34,0	170.3
E1-E2	65,9	56.6
W1-W2	107,9	99,1

+

VEGA

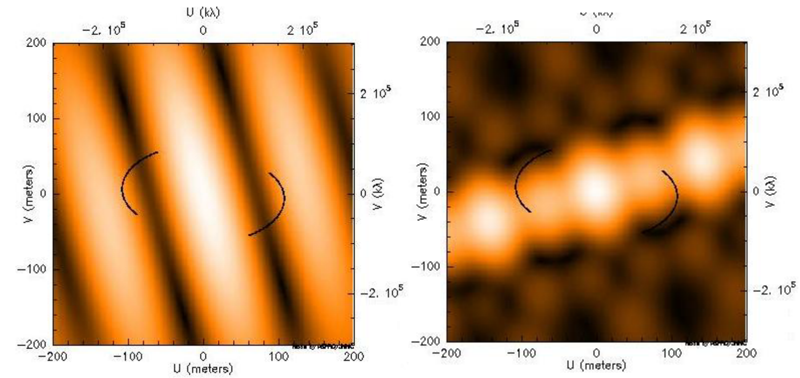
λ = [around Hα]

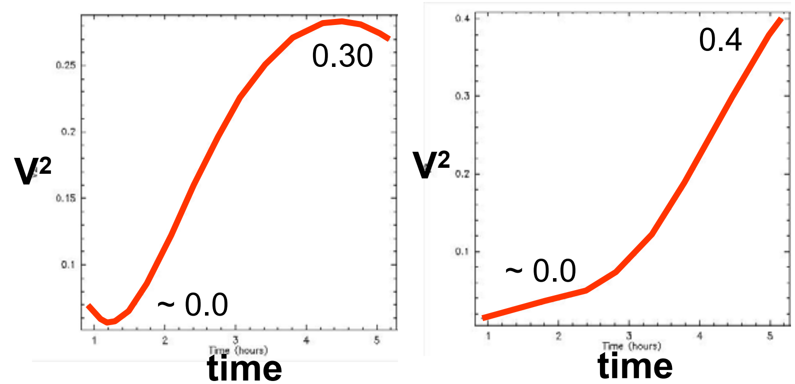
low resolution

(λ / Δλ = 1500)

W1-W2 baseline

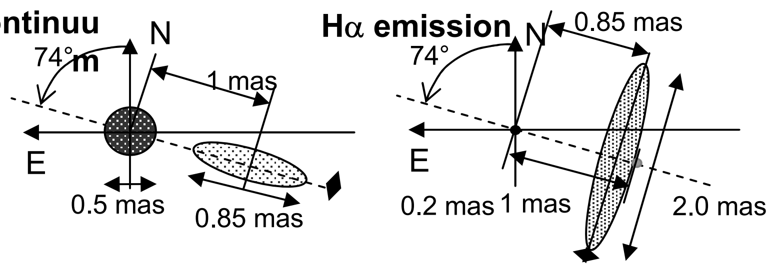
continuum | Hα emission





➢ **a toy model for β Lyrae**

At maximum elongation



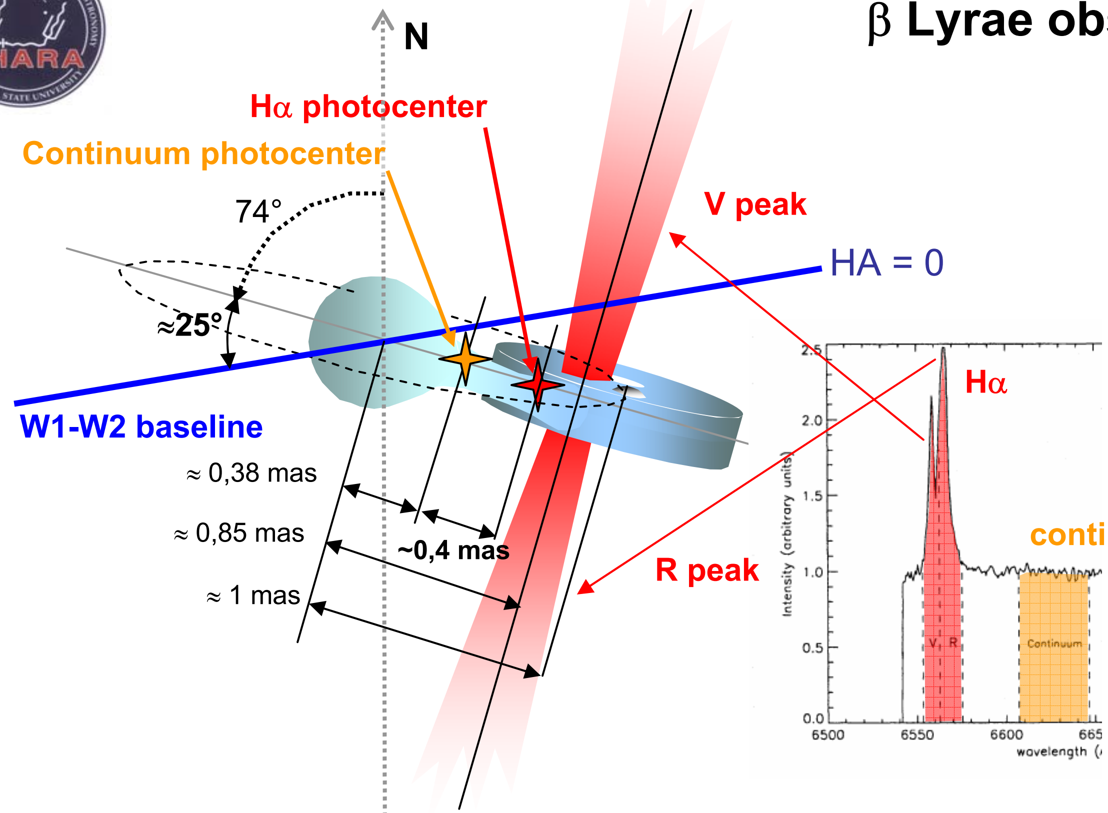
$F_{donor} = 0.62$, $F_{disc} = 0.38$ $F_{bin} = 0.18$, $F_{jet} = 0.82$

at φ_{orb} = 0.25 and 0.75, using aperture synthesis effect:

➢ **the "donor-accretion" binary can be resolved with E1-E2 and W1-W2**

➢ **the Hα emission source can be resolved**

β Lyrae observed with VEGA-CHARA ?



CHARA WI-W2 baseline
+
VEGA
λ = [around Hα]
medium resolution (λ / Δλ = 5000)

- Photocenter location depends of the central wavelength and of the flux ratio of the different emitting regions.
- In Hα line, observed light come from the bulk of the emission in addition to subjacent continuum.
- The Interferometric Differential Imaging technique (Vakili et al., 1997) allows to measure the relative phase of the fringe visibility and to determine the relative position of the emitting regions.

- At λ ≈ 656 nm, for the 107 m baseline, the fringe spacing is i ≈ 1.26 mas.
- photocenter separation ~ 0.4 mas ⇔ ~ 110° bump in the curve of the visibility phase across the spectral line.
- **refine the location and extension of the Hα emission?**

Science rationale for VEGA

- Early science (with 2 T):

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- Disc formation around δ Sco, MR, long term observational campaign, March-May, short baselines (S1-S2, E1-E2), simultaneous IR observations.

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- Measuring the disc dust and gas around the B[e] star HD 61623, LR & MR, Differential phase, S1-S2 & E1-E2, super-synthesis effect, simultaneous IR observations (Samer Kanaan's thesis).

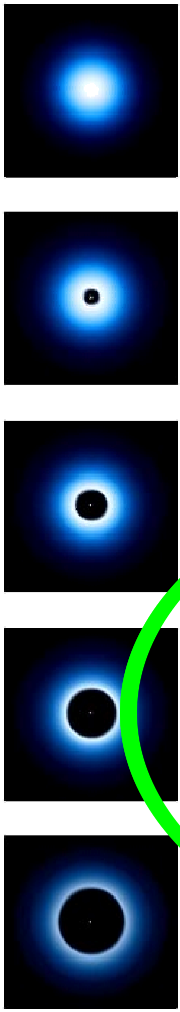
δ Sco basic parameters

- One of the closest Be star d=123 pc
- One of the brightest V=2.2 K=2.7
- Spectral type: B0.2 IVe
- Well known non-eclipsing binary system with a 1.5 mag fainter companion with P=10.6 years and e=0.94
- Next periastron in 2011: interesting ! (may trigger disk formation/destruction)

Disk Formation and Dissipation

Be Stars : One Ring to rule them all?

Meilland et al. 2006 A&A, 455, 953



Ring
vs
Mass-Flux variation

Study the variation of observables during the Disk dissipation

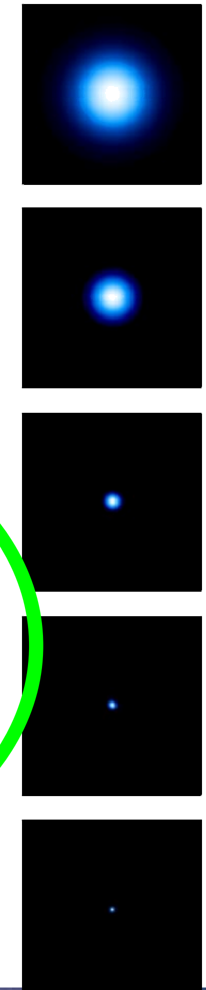
Visibilities

Amplitude and position
Of the visibility second lobe

SED

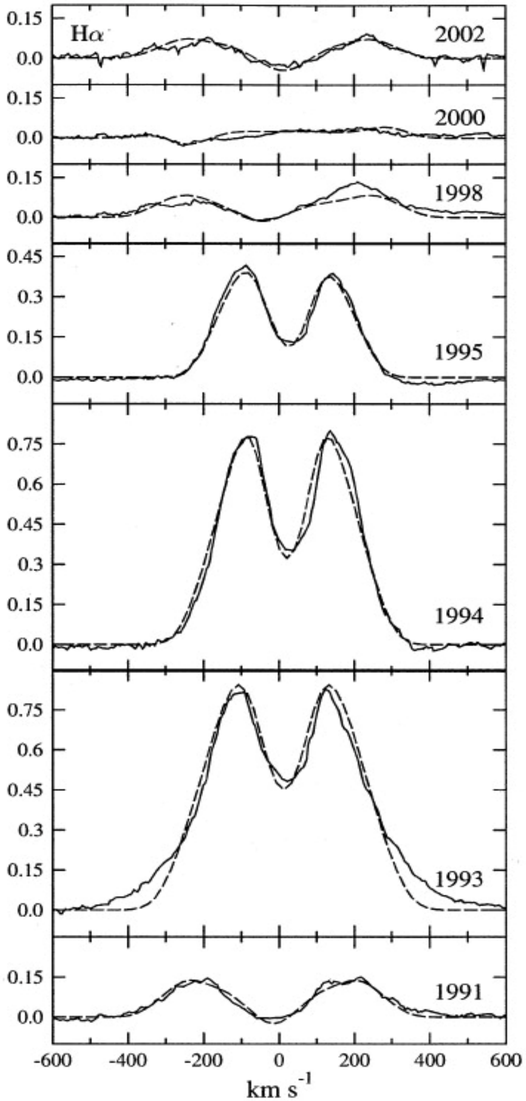
Line profiles

Double-pics separation
Time of the dissipation

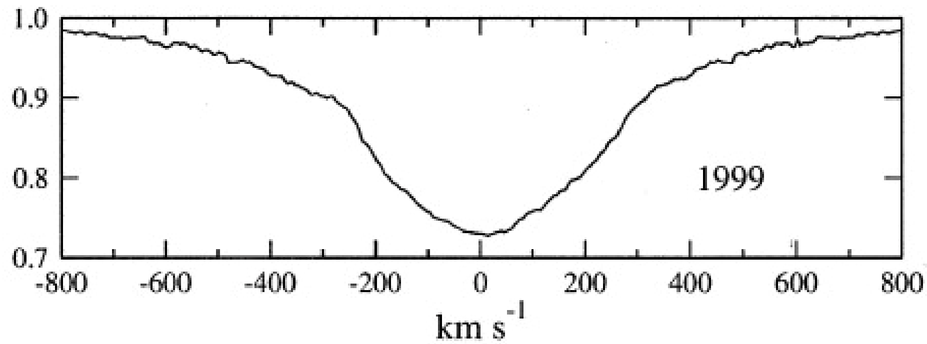


Disk Formation and Dissipation

Achernar's case



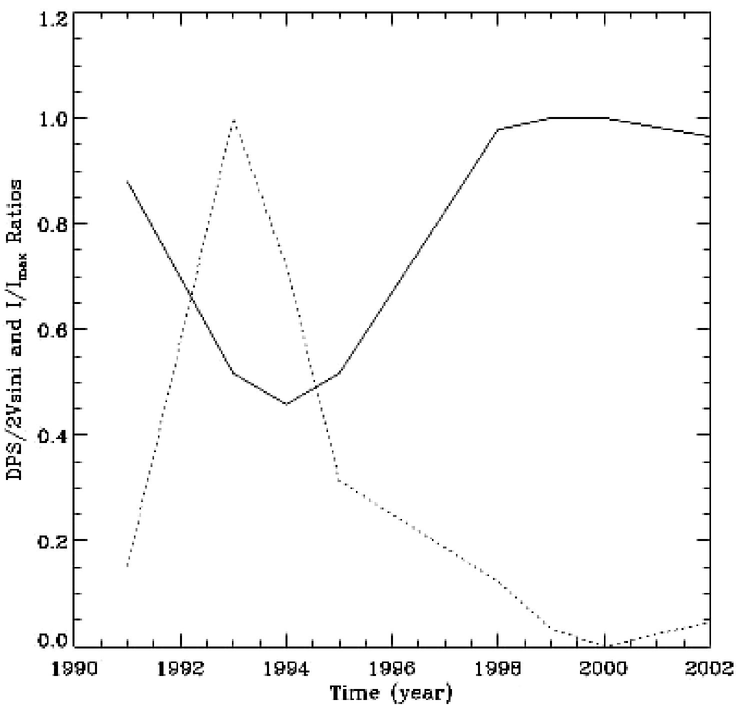
Vinicius, Zorec et al. (2005)



- Variation of the equivalent width (EW)
- Variation of the double-pics separation (DPS)
- DPS_{max}=460kms^{-1}~2.vsin i
- DPS_{min}=160kms^{-1}

Disk Formation and Dissipation

A Correlation ?



Intensity and DPS as a function of time

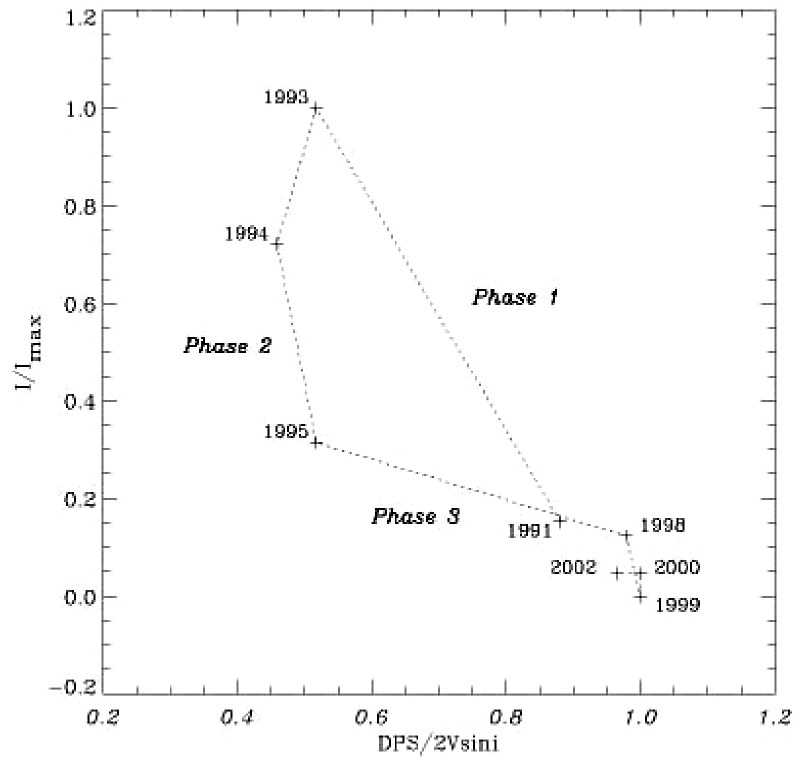
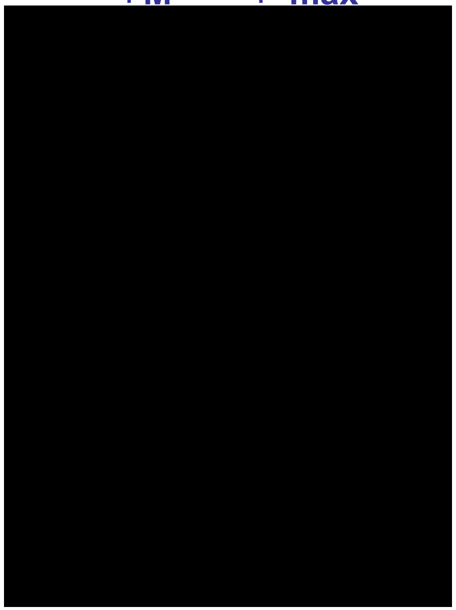


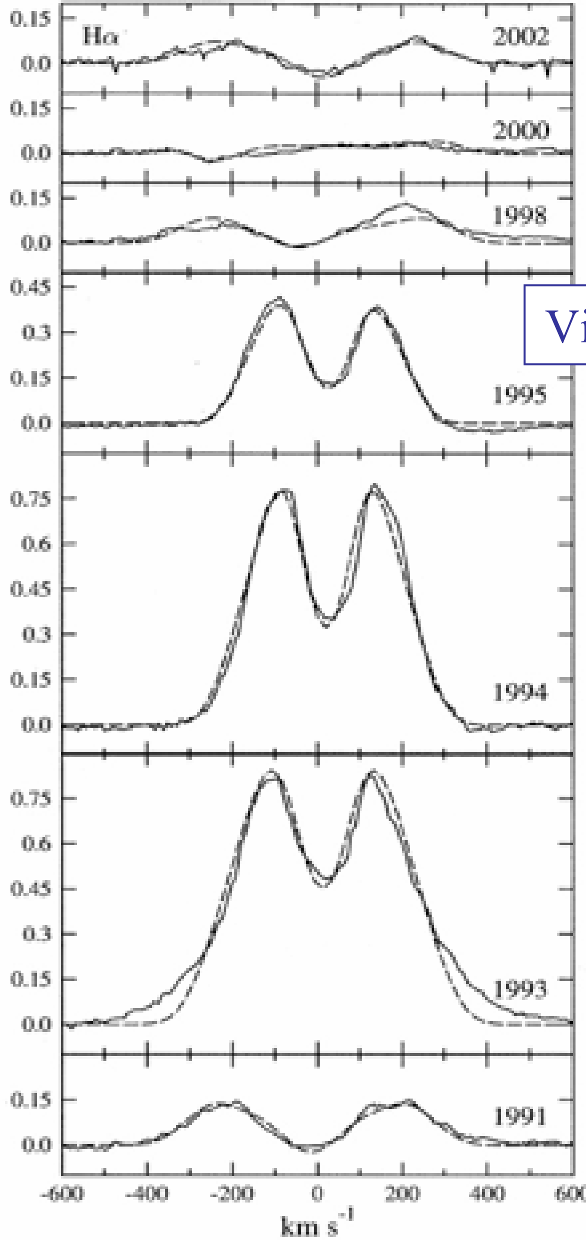
Diagram DPS/normalized Intensity

Outburst

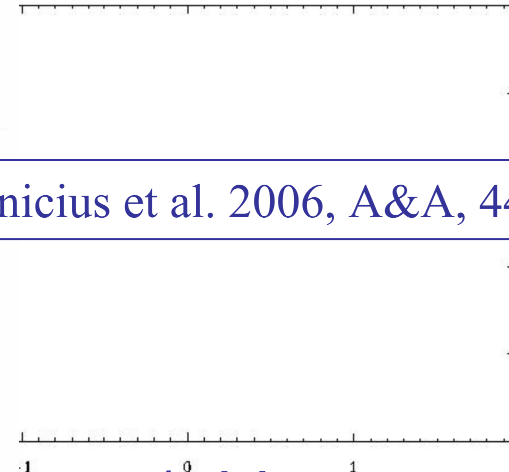
$\phi_M = \phi_{max}$ de

$v_r = 0.2\ km.s^{-1}$

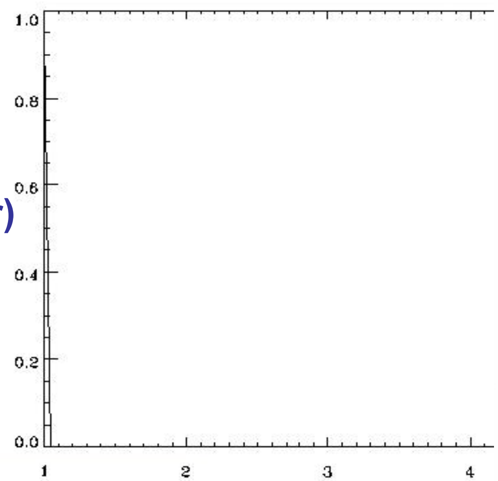




Vinicius et al. 2006, A&A, 446, 643

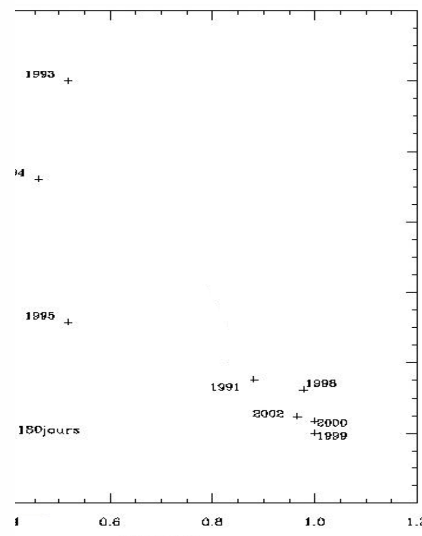


$v_x/v\sin i$



ρ(r)

r (R*)



Disk Formation and Dissipation

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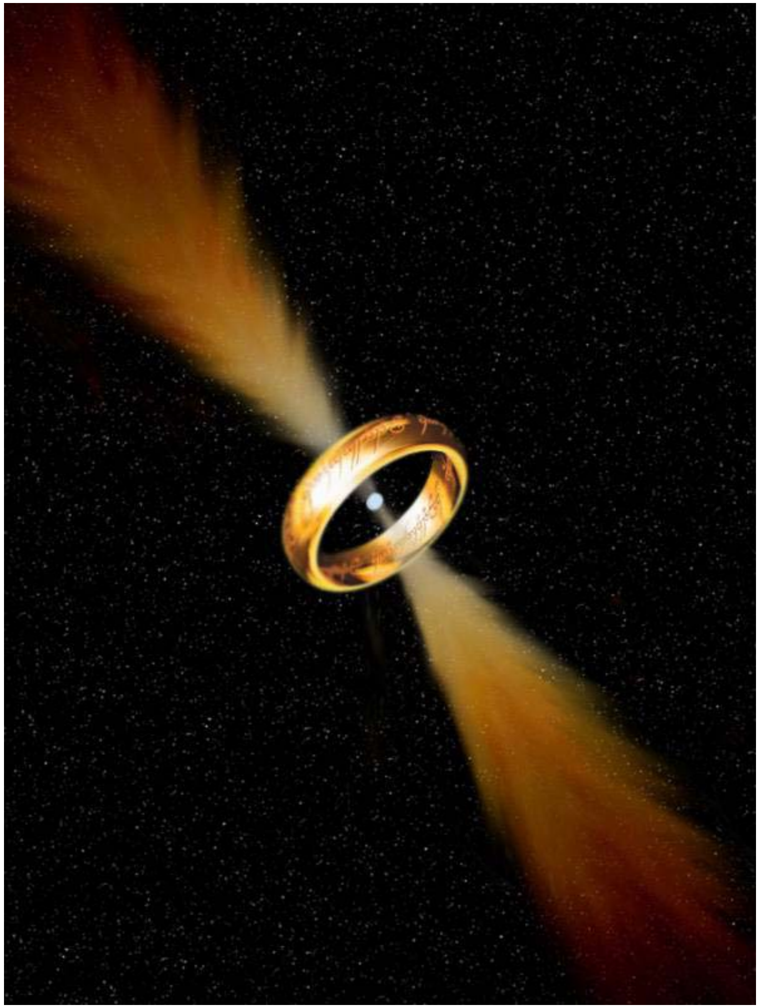
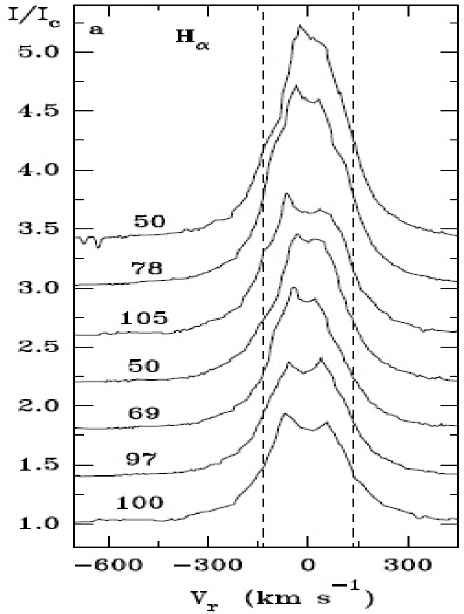


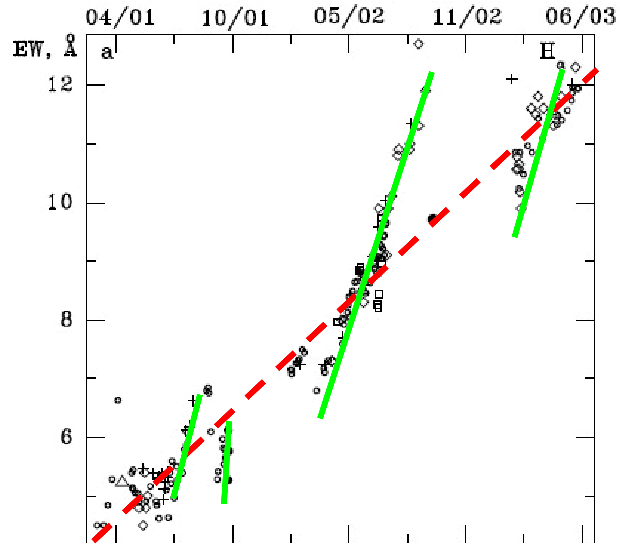
- Critical rotation
- wind > 10R*
- Wind and disk « independants »
- Outburst between 1991-1995
  - V_r~0.2kms^{-1}
  - R_{max}~8R* (If keplerian)
- 3d Phase?
- New Outburst till 2002 ?
- AMBER LR (Imaging)
  + AMBER HR (kinematics)

Meilland et al. In preparation

disk formation and Dissipation

δ Sco

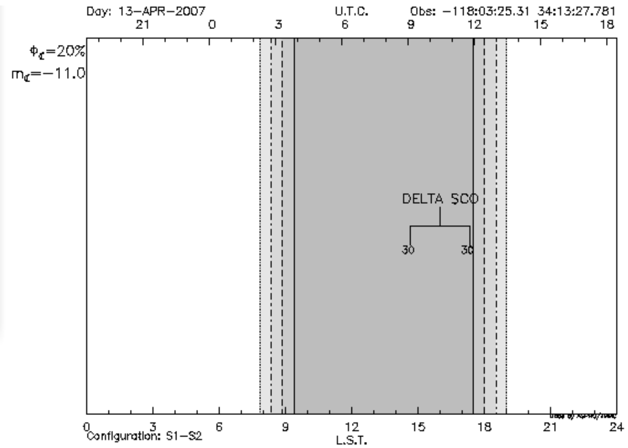


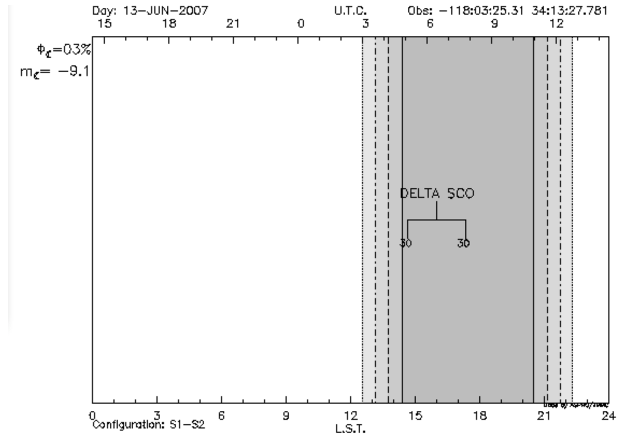


Miroshnichenko et al. 2003 A&A 408,305

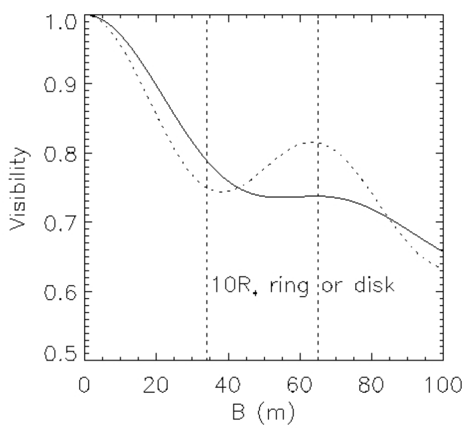
- Growing disk till 2000 (Periastron)
- $R_{disk}(2003) \sim 10R_*$
- $V_r \sim 0.4 kms^{-1}$
- Keplerian ?
- Multiple outbursts?

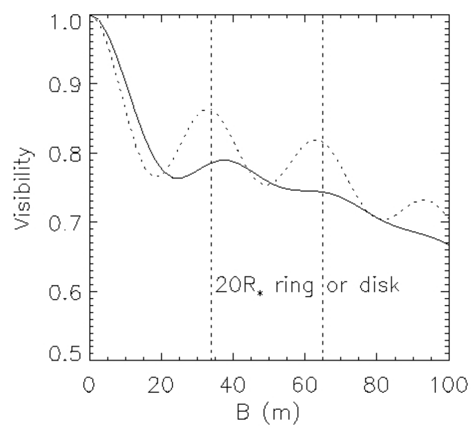
δ Sco simulations



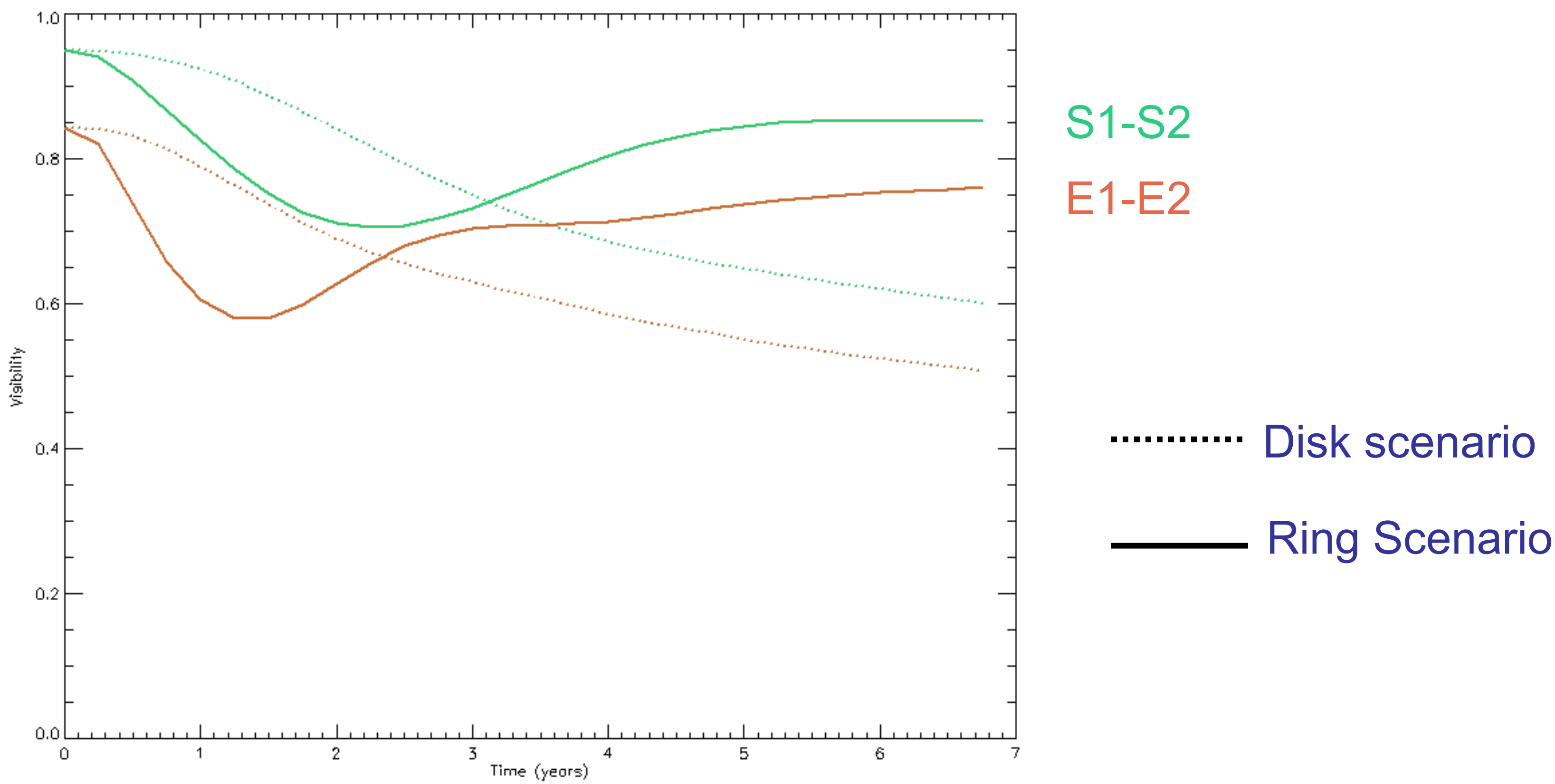


Ring vs Disk Formation





δ Sco: visibility variation as a function of time



See: Anthony Meilland's Thesis: Sept. 07

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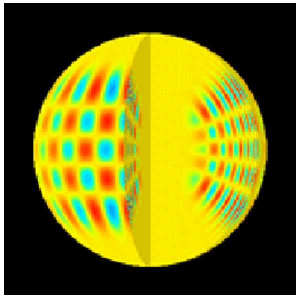

- Early science (continue):

- Measuring the optically thin atmosphere of pop. II MIRA: RT Cyg, LR, June - October, S1-S2, E1-E2, W1-W2, IR tracking & visible measurement.

- Measuring the Limb-darkening and projection factor of pulsating Cepheides, ζ Gem, δ Cep, simultaneous IR observations (FLUOR).