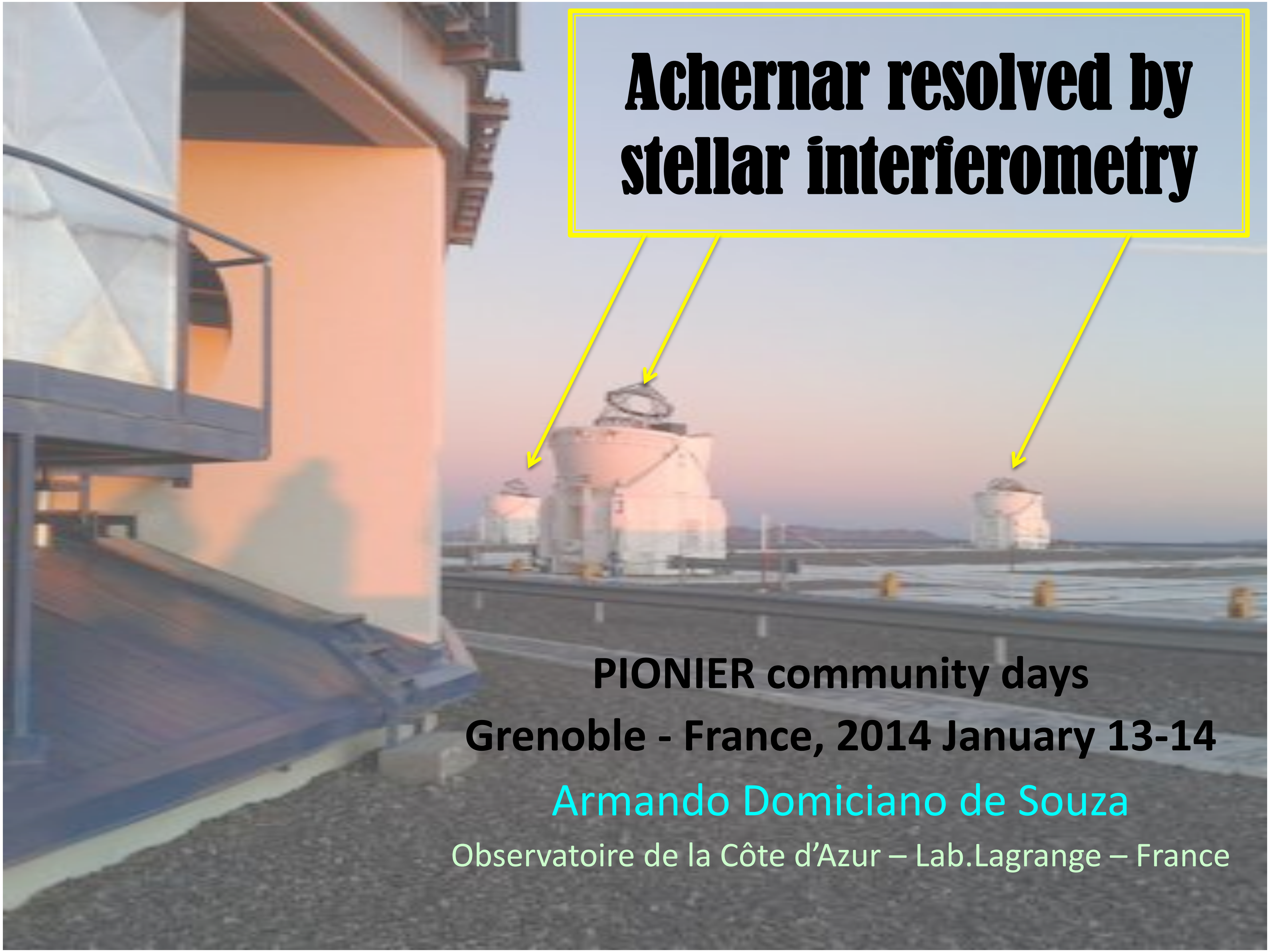

Achernar resolved by stellar interferometry

PIONIER community days

Grenoble - France, 2014 January 13-14

Armando Domiciano de Souza

Observatoire de la Côte d’Azur – Lab.Lagrange – France

Main collaborators
(France, Brazil, ESO)

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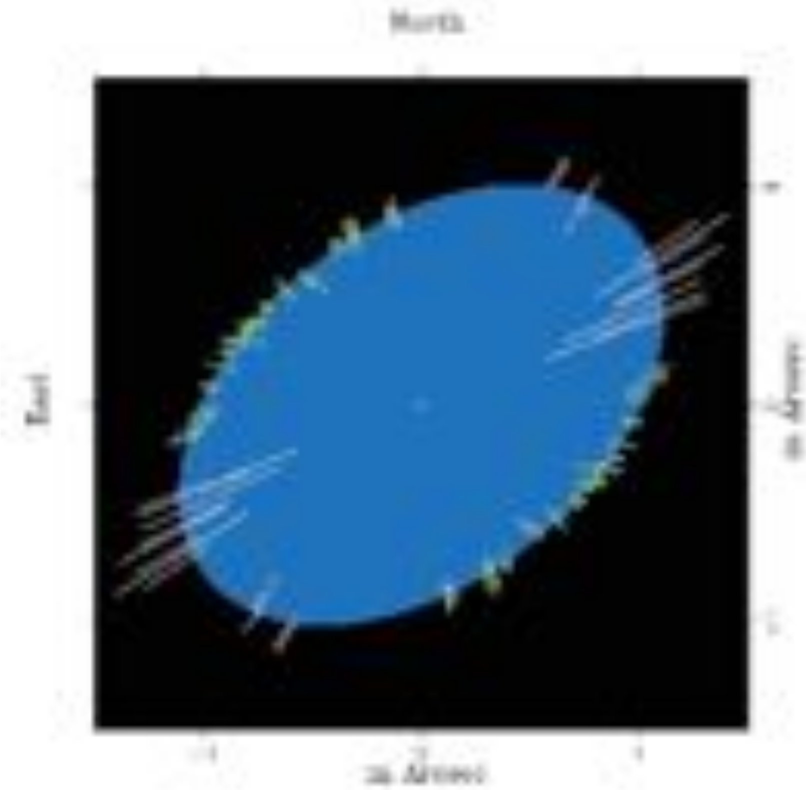
J. Zorec
M.Hadjara (PhD)
E. Janot-Pacheco
F. Vakili
PIONIER team

The fast-rotating Be star Achernar



Some information on Achernar:

✧B3-6Vpe star

✧V=0.5 (brightest Be star)

✧M ~ 6 Msun

✧d=42.75 pc (closest Be star)

✧Mean T_{eff}~15000K

✧V sini i ~220-400 km/s (wide range of values in the litterature)

✧Strong rotation flattening

Domiciano de Souza, Kervella et al. 2003
(VLTI/VINCI Sep-Nov/2002 data)

The fast-rotating Be star Achernar

Study Achernar as a fast-rotator but…
keep in mind that this is star is also a:

✧Be star, episodic emission phases
(variations at several time scales)
✧binary (several years period)
(Kervella, Domiciano et al., in prep.)
✧pulsating star (freq. ~ 0.7-0.8 c/d)

Kanaan et al. 2008

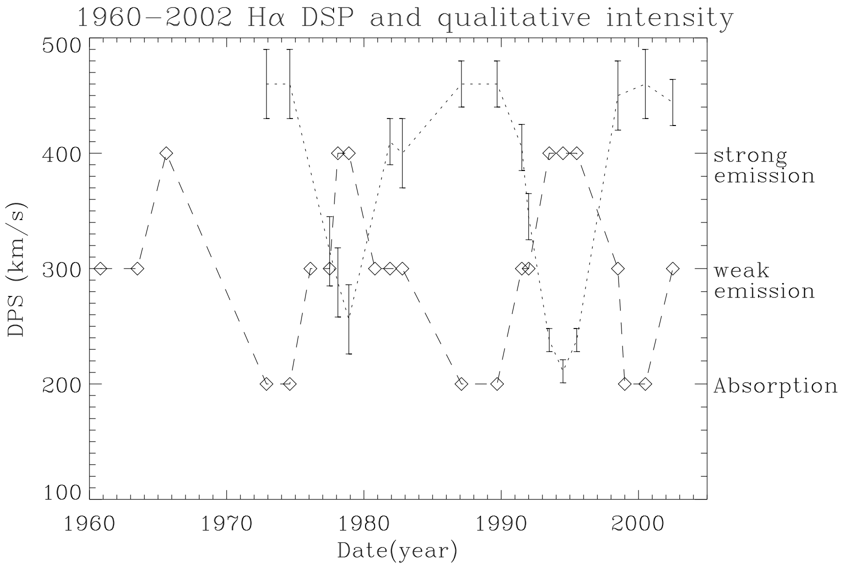
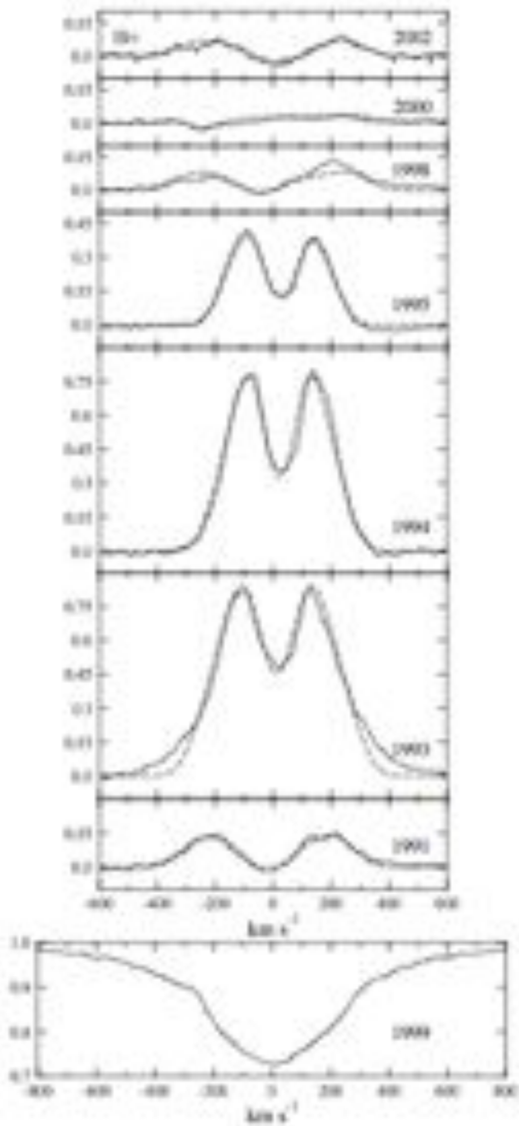


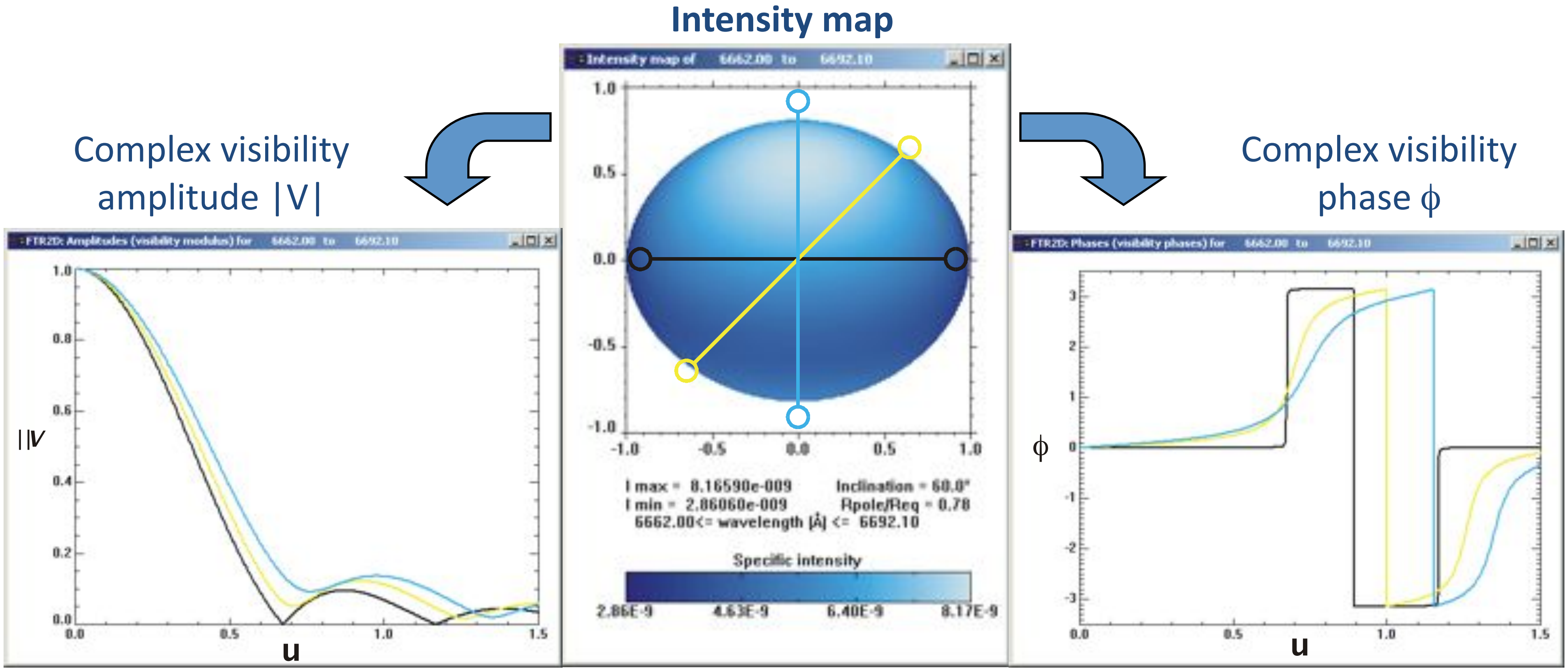
Fig. 16. Hα DPS (dotted line with error bars) and qualitative intensity (dashed line and diamonds) variations between 1960 and 2002 from various authors: Jaschek et al. (1964); Andrews et al. (1966); Dachs et al. (1977, 1981, 1986, 1992); Hanuschik et al. (1988, 1996); and Vinicius et al. (2006).



Vinicius et al. 2006

Rapid rotation from interferometry

- Rotational flattenning
  (Roche approximation)
- Gravity darkening
  (von Zeipel effect)



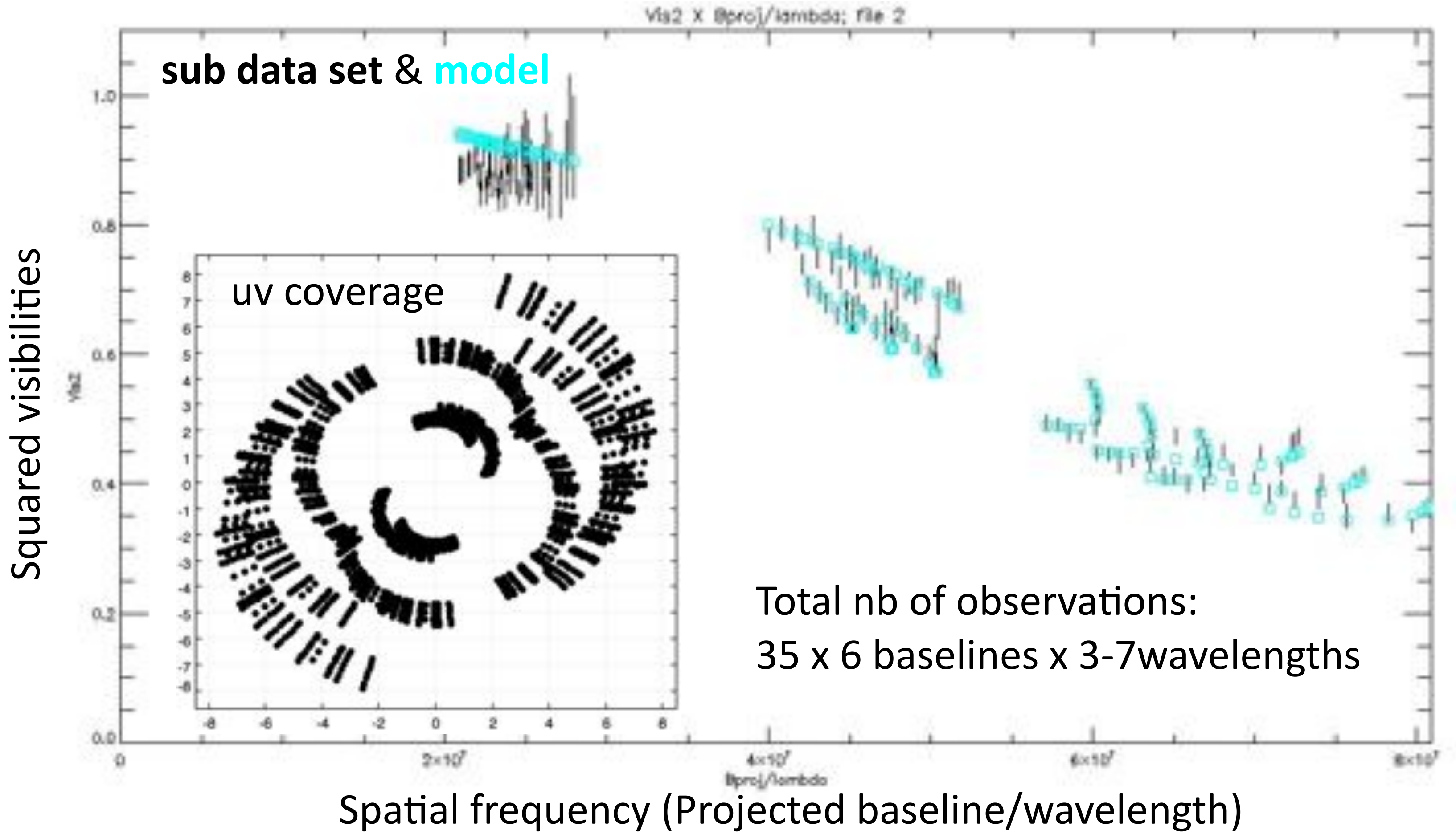
CHARRON code (Domiciano de Souza et al. 2002, 2012, A&A)

Numerical model for rotating stars

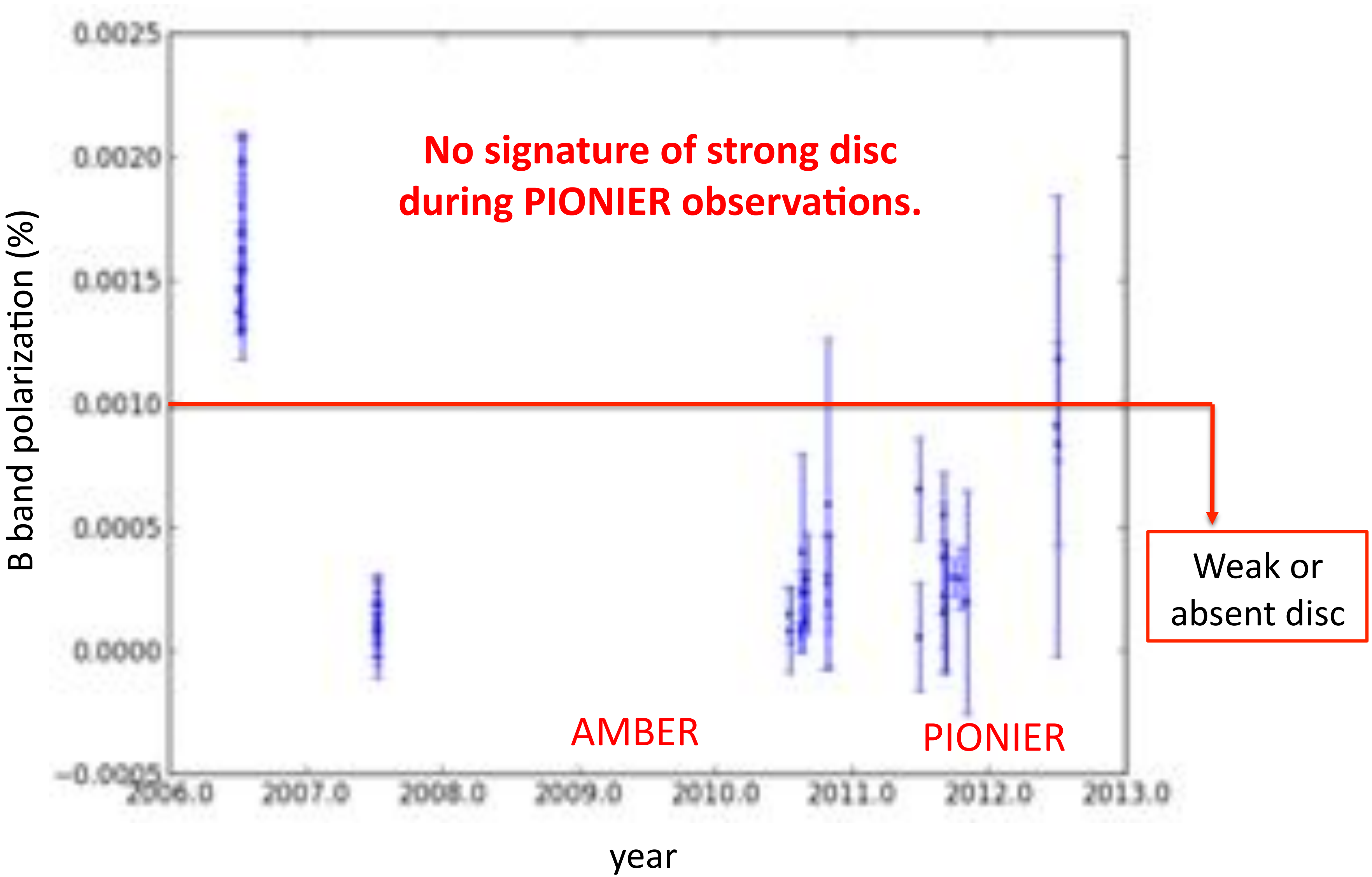
VLTI/PIONIER observations of Achernar

Some information on VLTI/PIONIER:
Baselines from ~ 30 to 120 m
Observations in 2011-2012
Nb of data points (V^2+CP): ~ 1780

2011-08-06	4pts	v2= 67.0 +- 2.8%	nSpec=3
2011-09-22	10pts	v2= 67.2 +- 2.1%	nSpec=7
2011-09-23	9pts	v2= 69.8 +- 1.9%	nSpec=7
2012-09-16	9pts	v2= 69.1 +- 1.7%	nSpec=3
2012-09-17	3pts	v2= 72.0 +- 3.1%	nSpec=3



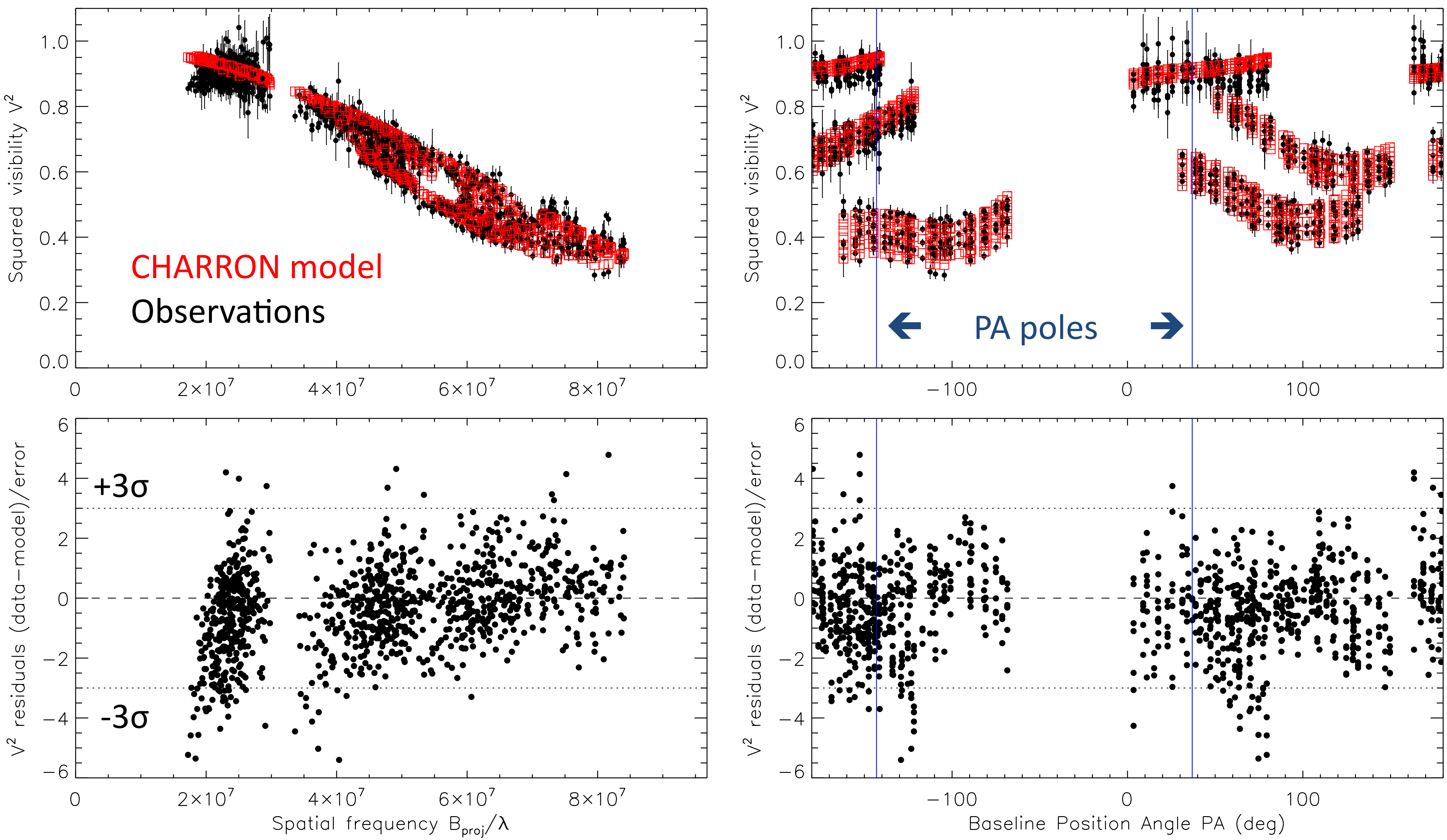
Achernar's polarization x time



VLTI/PIONIER observations of Achernar

V^2 X Spatial frequency

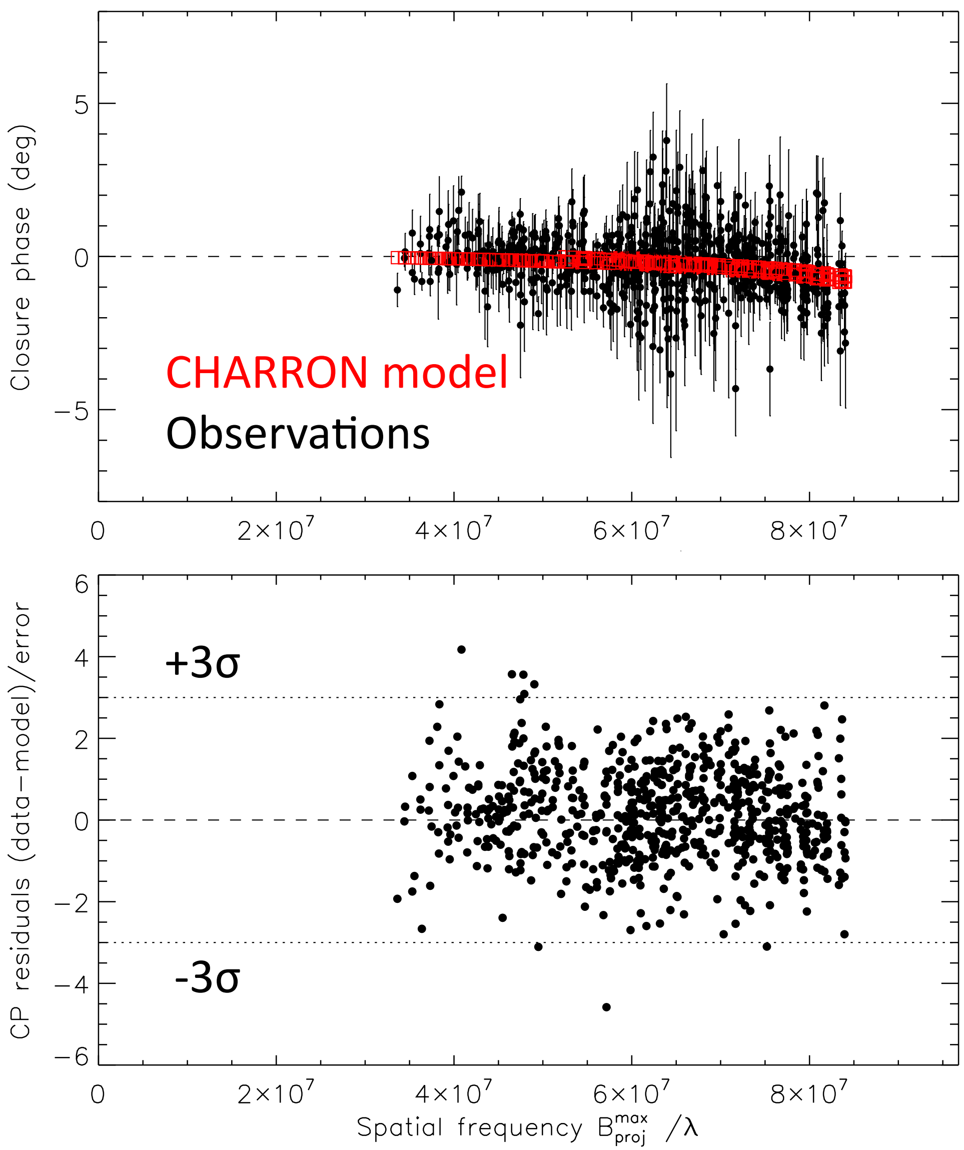
V^2 X PA



Domiciano de Souza, Kervella et al. 2014 (in prep.)

VLTI/PIONIER observations of Achernar

CP X Spatial frequency

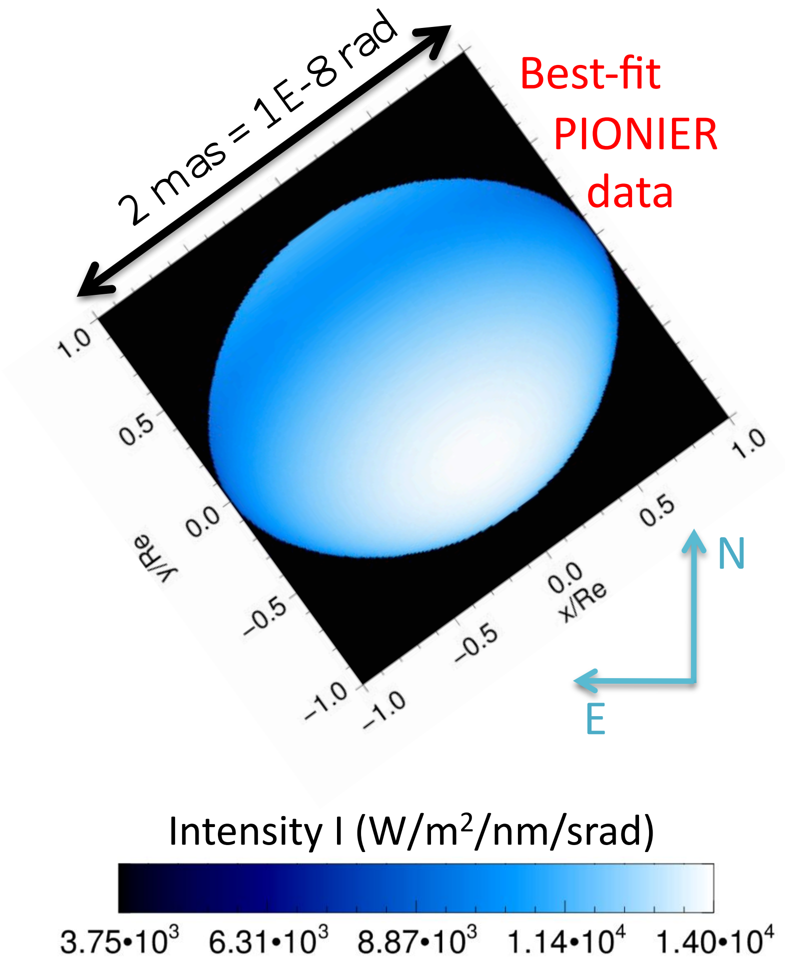


Domiciano de Souza, Kervella et al. 2014 (in prep.)

Best-fit CHARRON model to PIONIER data on Achernar (χ^2_{red}=1.8; MCMC fit method)

Physical parameter	PIONIER/ VLTI (CHARRON)
Req (Rsun) Θeq (mas)	9.16±0.22 1.99±0.05
Req/Rp	1.35
Veq sin i (km/s)	260±7 (88%Vcrit)
PArot (deg)	36.9±0.4
β (gravity darkening)	0.17±0.01

Domiciano de Souza et al. 2014 (in prep.)



CHARRON model UBVJHK photometry also compatible with phtometric observations

Best-fit parameters of Achernar

Free parameters for emcee fit with CHARRON model	**Best-fit values from CHARRON model**	**Values computed with the ELR model**[a]
Equatorial radius: R_{eq} ($R_\odot$)	$9.163^{+0.034}_{-0.026}$	9.163
Equatorial rotation velocity : V_{eq} (km s^{-1})	$298.8^{+6.9}_{-5.5}$	298.9
Rotation-axis inclination angle: i (°)	$60.6^{+7.1}_{-3.9}$	–
Gravity-darkening coefficient: β	$0.166^{+0.012}_{-0.010}$	0.166/0.165 [b]
Position angle of the visible pole: PA_{rot} (°)	$216.9^{+0.4}_{-0.4}$	–
Derived parameters	**Values**	**Values**
Equatorial angular diameter: $⌀_{eq} = 2R_{eq}/d$ (mas)	1.994	1.994
Polar radius: R_p ($R_\odot$)	6.780	6.780 (input)
R_{eq}/R_p; $1 - R_p/R_{eq}$	1.3515; 0.2601	1.3515; 0.2601 (input)
Mean angular diameter: $\overline{⌀}$ (mas)	1.773	1.773
$V_{eq} \sin i$ (km s^{-1})	260.2	–
Critical rotation rate[c]: V_{eq}/V_c; Ω/Ω_c	0.883; 0.980	0.883; 0.980
Keplerian rotation rate[d]: V_{eq}/V_k; Ω/Ω_k	0.838; 0.838	0.838; 0.838
Polar temperature: T_p (K)	17 124	17 124 (input)
Equatorial temperature: T_{eq} (K)	12 673	12 696
Luminosity: $\log L/L_\odot$	3.4795	3.4676
Equatorial gravity: $\log g_{eq}$	2.7720	2.7725
Polar gravity: $\log g_p$	3.5607	3.5613
Rotation period: P_{rot} (h)	37.25	37.22
Rotation frequency: ν_{rot} (d^{-1})	0.644	0.645

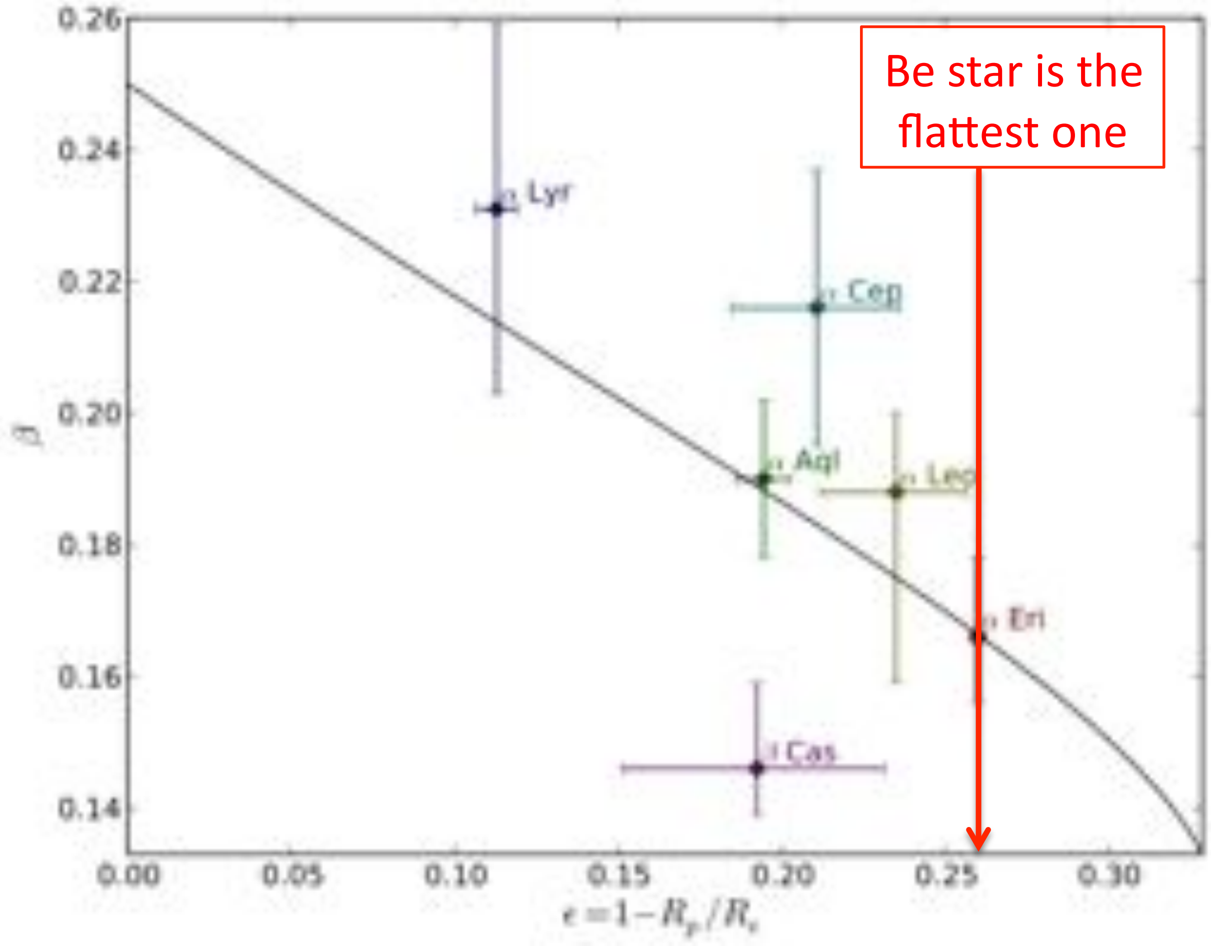
Observed x modeled F_{bol} and photometry of Achernar

Model UBVJHK photometry of Achernar compatible with phtometric observations (within 0.5-0.1 mag)

Catalogue or reference	U	B	V	J	H	K	F_{bol} (10^{-9} W m^{-2})
2MASS [a]				0.815 ± 0.254	0.865 ± 0.320	0.880 ± 0.330	
NOMAD Tycho-2 [b]		0.473	0.527				
Johnson et al. (1966)		0.32	0.47				
Code et al. (1976)							54.4 ± 4.3
Jaschek & Egret (1982)	-0.36	0.30	0.46				
Nazé (2009)							48.98
Best-fit model (Table 2)	-0.279	0.339	0.472	0.783	0.828	0.886	53.05

[a] Cutri et al. (2003); Skrutskie et al. (2006).
[b] Hog et al. (2000); Zacharias et al. (2005).

Gravity darkening: T_{eff}=const g_{eff}^{β}



Interferometric results indicate a gravity darkening parameter lower than β=0.25 (von Zeipel law).

This is in agreement with stars not being barotropic.

<u>Espinosa Lara & Rieutord (2011)</u>

↓

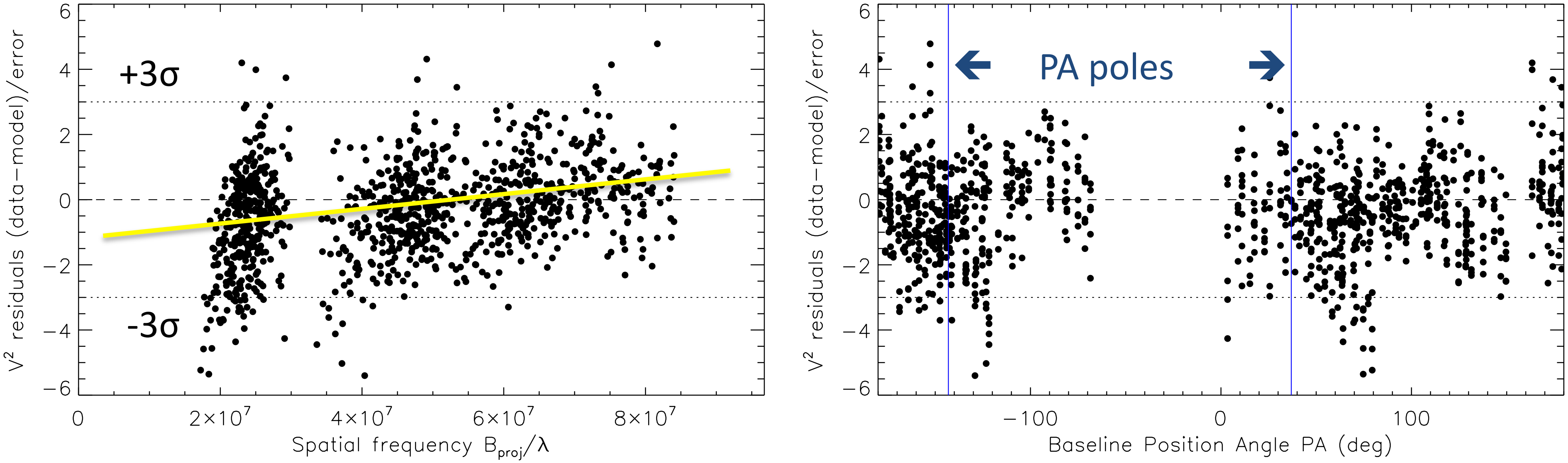
Energy flux is a divergence-free vector that is antiparallel to the effective gravity: Flux = $f(r,\theta)\ g_{eff}$

↓

Gravity darkening parameter β decreases with flattening.

Domiciano de Souza, Kervella et al. 2014 (in prep.)

Additional component in the data ?



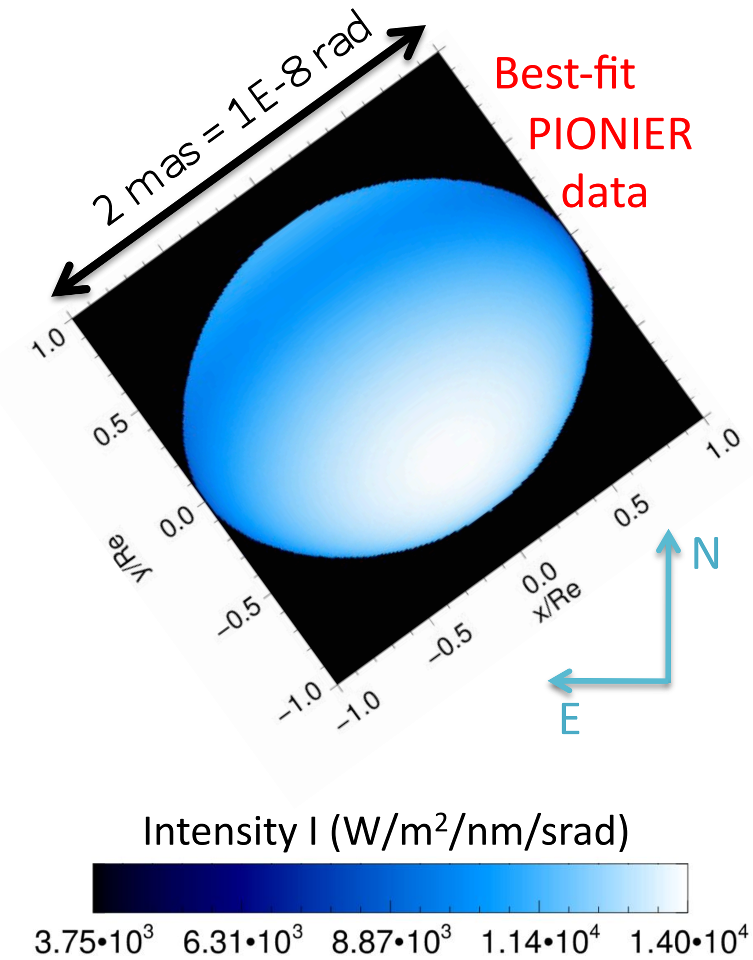
Domiciano de Souza, Kervella et al. 2014 (in prep.)

Very weak if present:

- Weak flux: ~ 0.7% F_{star}
- No clear elongation/orientation
- χ^2_{red}=1.8 ➔ χ^2_{red}=1.6
- Could also be due to a different gravity darkening law ?

Comparing different instruments, wavelenghts, spectral resolutions, epochs: *a rich but delicate task*

Physical parameter	PIONIER/ VLTI (CHARRON)	AMBER/ VLTI (CHARRON)	VINCI/ VLTI (UD ellipse)
Req (Rsun) Θeq (mas)	9.16±0.22 1.99±0.05	11.6±0.3 2.45±0.09	>10.1 >2.13
Req/Rp	1.35	1.45	>1.41
Veq sin i (km/s)	260±7 (88%Vc)	292±10 (96%Vc)	N/A
PArot (deg)	36.9±0.4	34.9±1.6	41.6±1.4
β (gravity darkening)	0.17±0.01	0.2 (fixed)	0.25 (fixed)

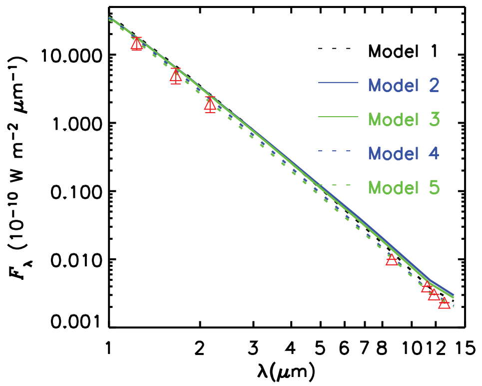


Domiciano de Souza et al. 2003, 2012, 2014 (in prep.)
Kervella & Domiciano de Souza 2006

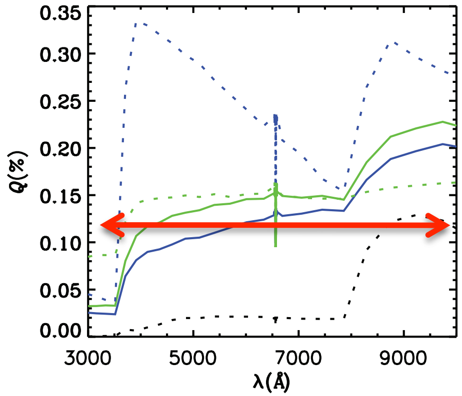
Model UBVJHK photometry also compatible with phtometric observations

Be tween B and Be

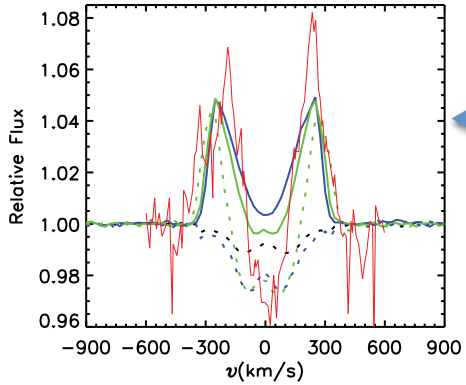
flux



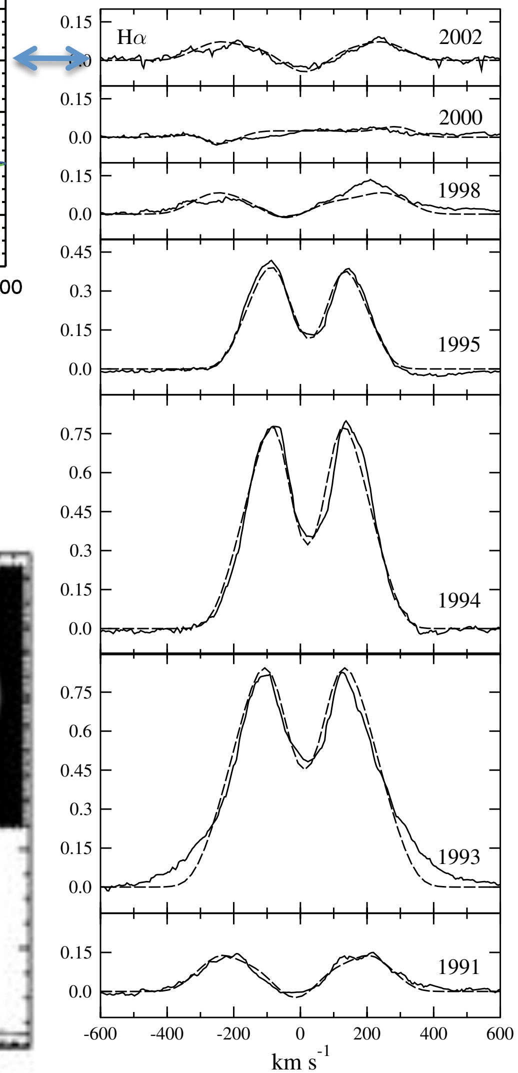
polarization



Hα line 2002 (residuals)



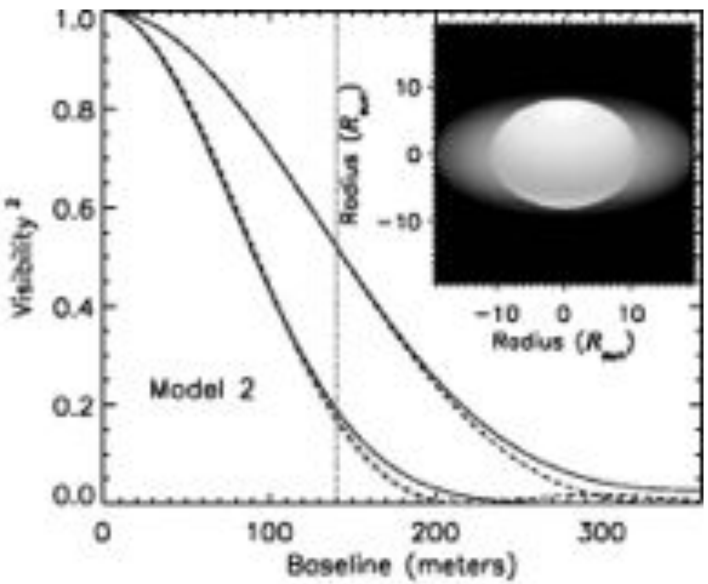
Hα line x time (residuals)

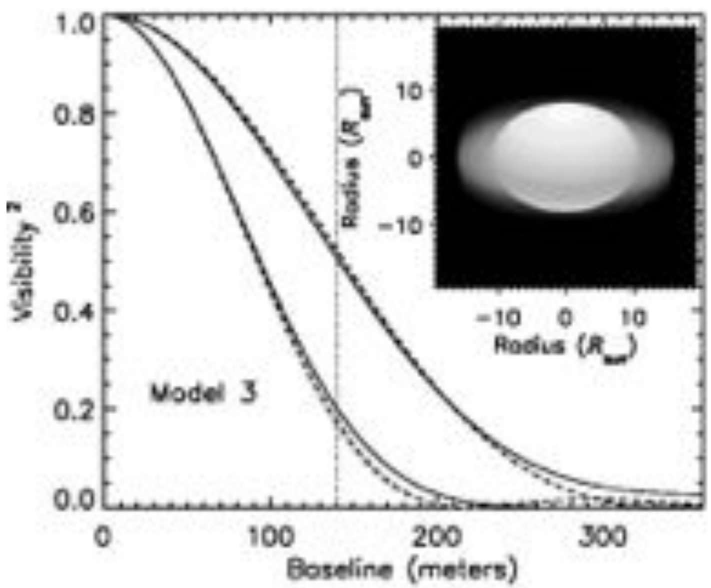


Vinicius et al. 2006

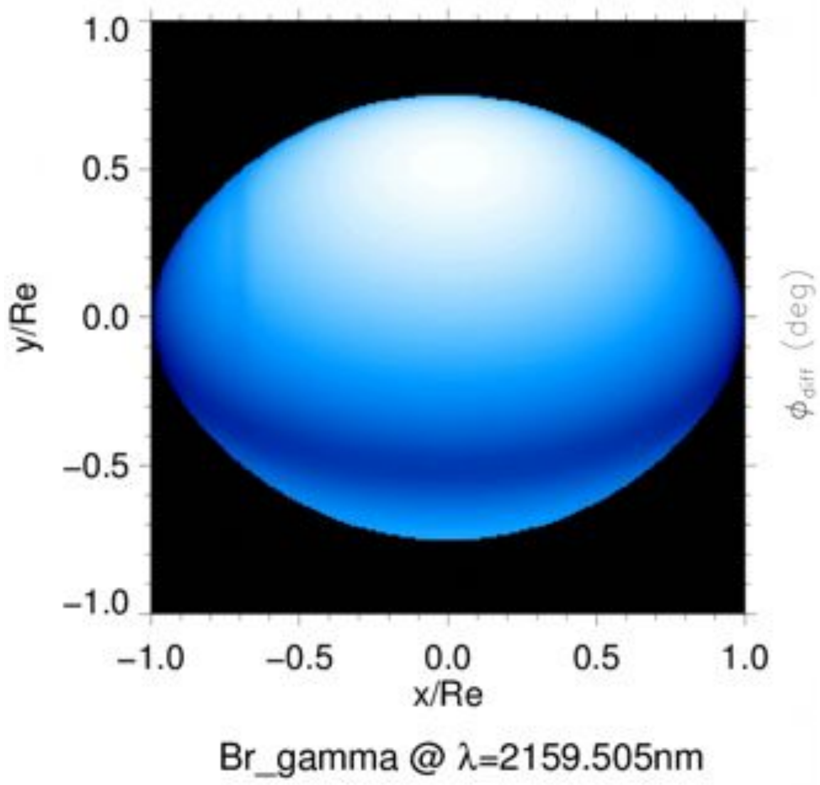
Model of star + small disc is compatible with interferometric 2002-2003 VINCI visibilities, polarization, SED, and H lines.

Carciofi et al. 2008

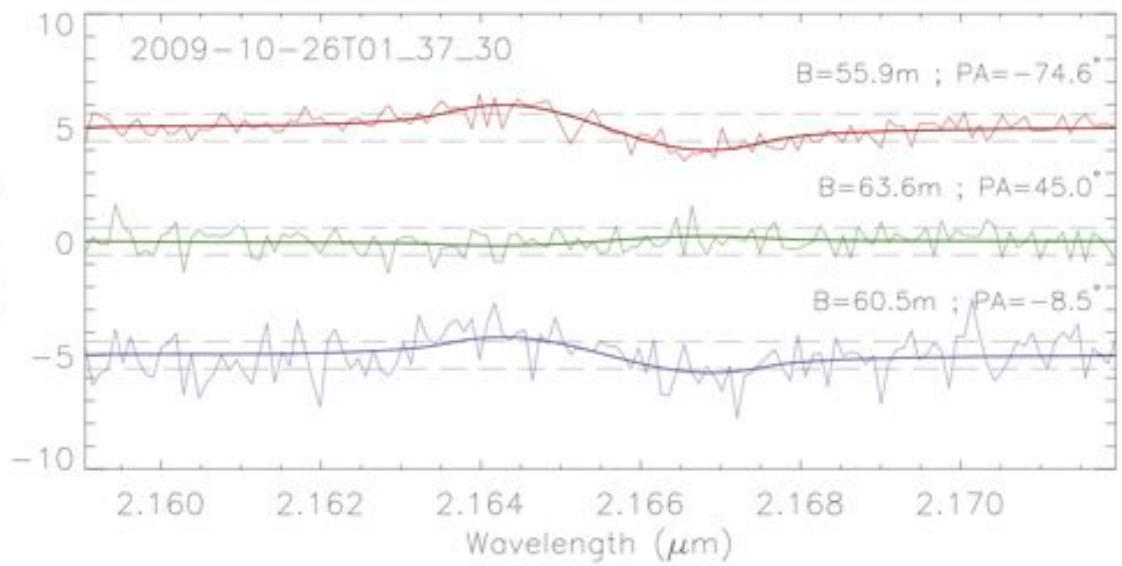




VLTI/AMBER differential phases on Achernar



VLTI/AMBER HR at Br γ H line



VLTI/AMBER differential phases from 3 ATs measured in 2009.

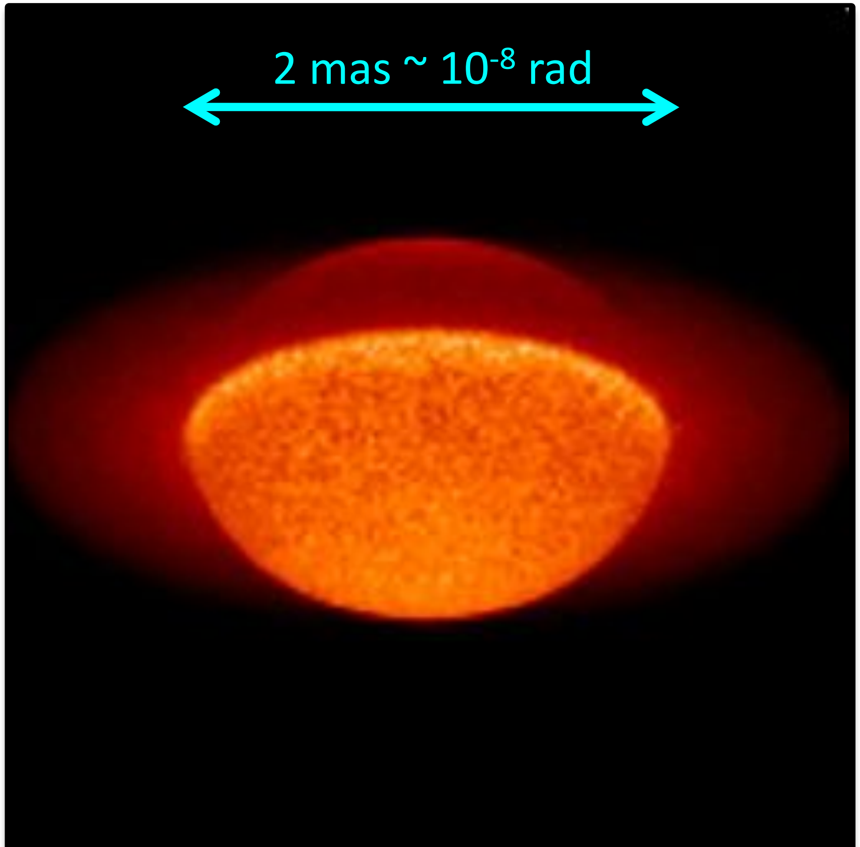
Signature of rotation: "S" shape.

Nb of observations: 28x3 baselines

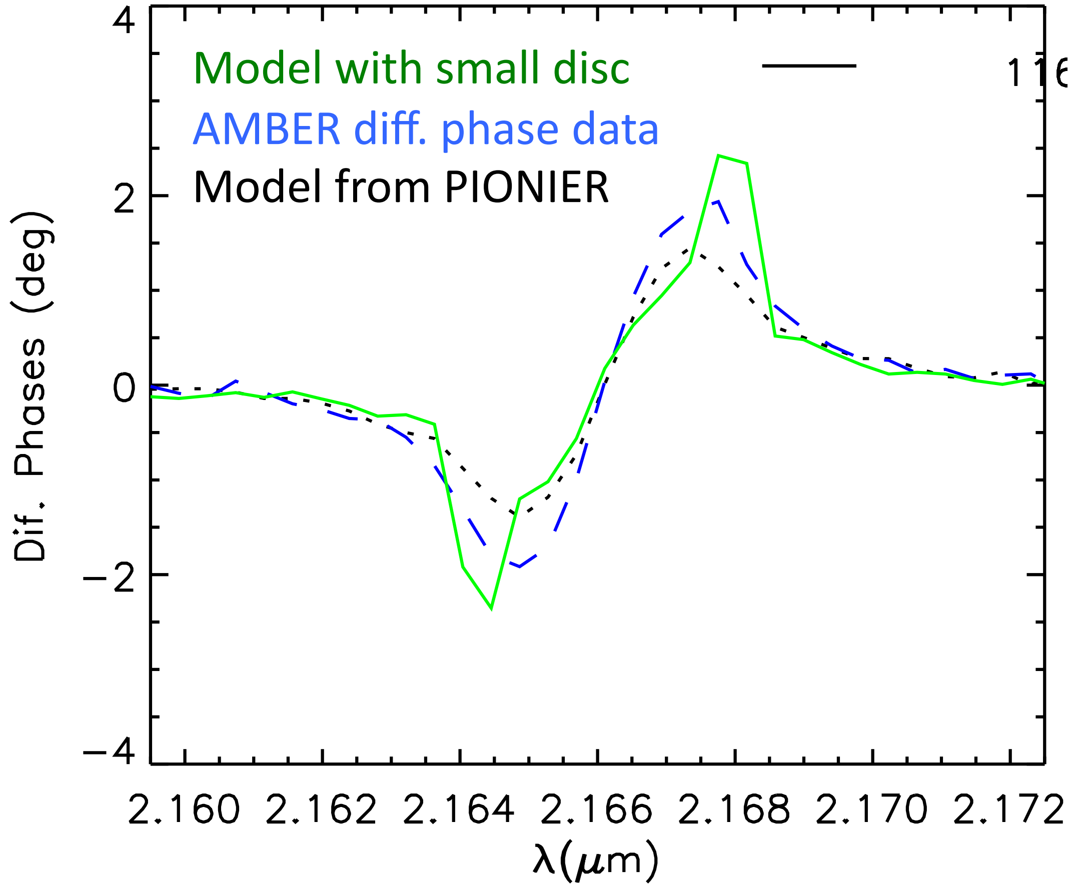
Angular size from differential phases: Domiciano de Souza et al. 2012, A&A

Be tween B and Be

Distinct radii from AMBER, PIONIER, and VINCI could be caused by a time changing small residual disc.

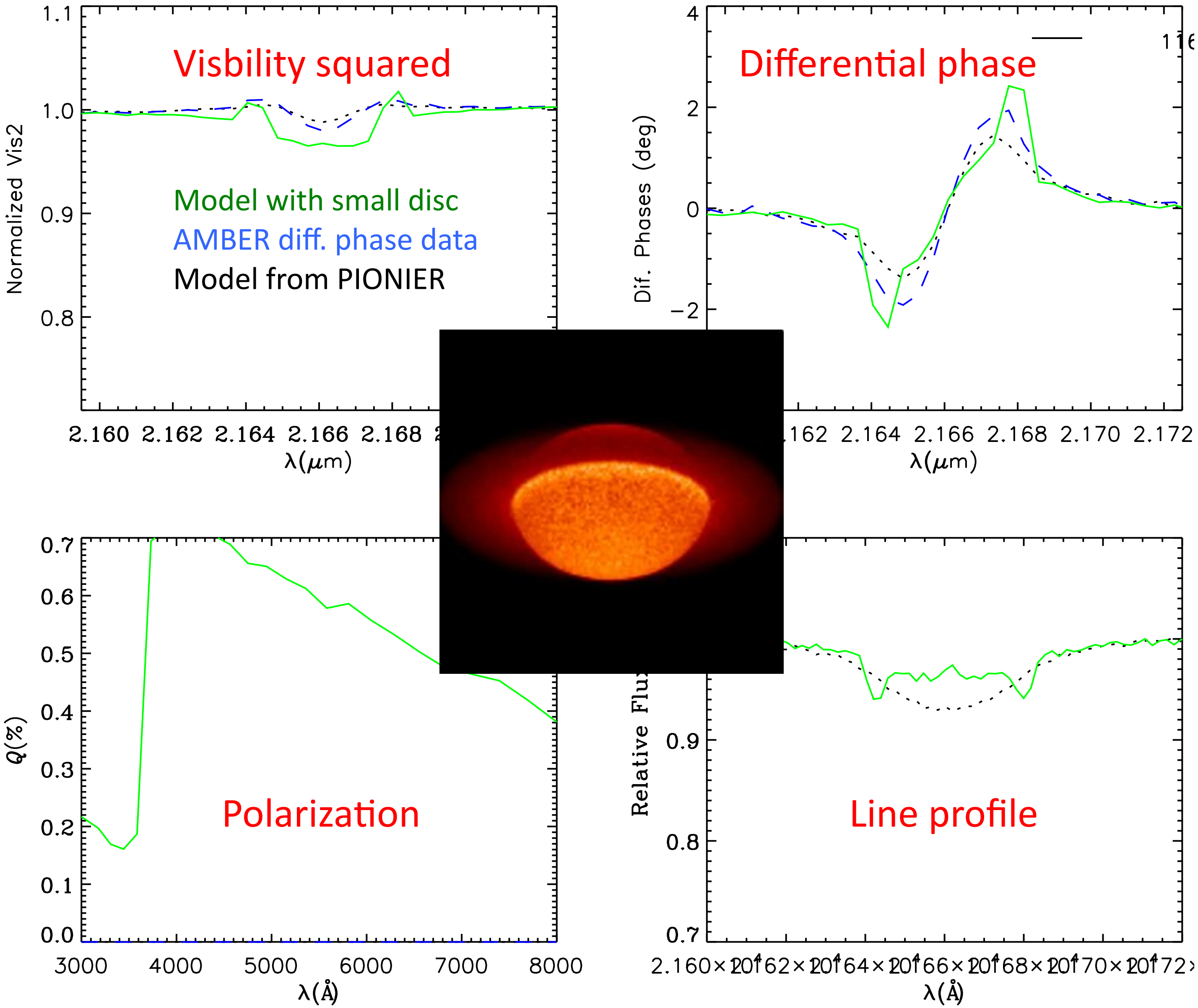


HDUST model (PIONIER star + small disc):
R_{disc}=1.75 Req
Density d0=7x10^{12} particles/cm^3
Densiy index n=2



Domiciano de Souza, Kervella et al. 2014 (in prep.)

Be tween B and Be



The End

Thank you