ANR ESRR

Kick-off meeting 2017, March

Stellar rotation: Roche-von Zeipel model

Roche potential (point-like gravitational + centrifugal potentials):

$$\Psi = -\frac{GM}{R(\theta)} - \frac{\Omega^2 R^2(\theta)\sin^2\theta}{2} = -\frac{GM}{R_\mathrm{p}} = -\frac{GM}{R_\mathrm{eq}} - \frac{(\Omega R_\mathrm{eq})^2}{2}$$

$$\vec{g}_\mathrm{eff} = -\vec{\nabla}\Psi = \vec{g} + \vec{a}_\mathrm{cent}$$

$$\frac{\vec{\nabla}P}{\rho} = \vec{g}_\mathrm{eff} = -\vec{\nabla}\Psi$$ (hydrostatic equilibrium)

von Zeipel-like gravity darkening:

$$\vec{F} = -\chi\frac{dT}{d\Psi}\vec{\nabla}\Psi = \chi\frac{dT}{d\Psi}\vec{g}_\mathrm{eff} \equiv -C\vec{g}_\mathrm{eff}$$

$$F = \sigma T_\mathrm{eff}^4 = C g_\mathrm{eff}$$

von Zeipel (1924)

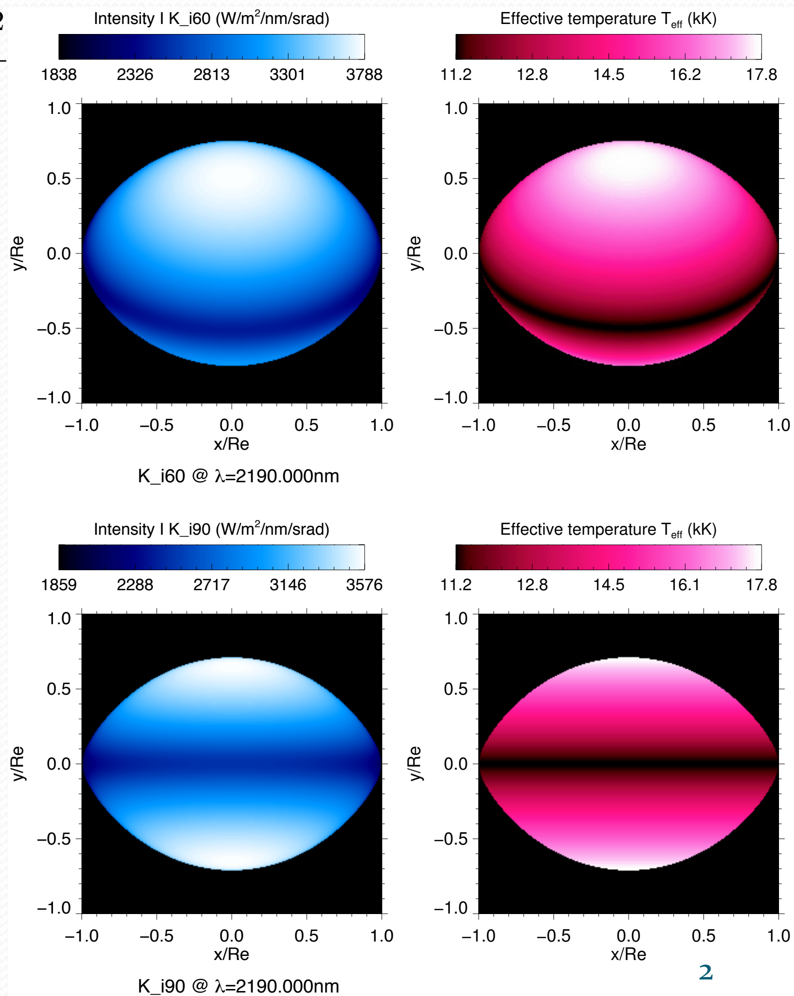
$$T_\mathrm{eff} = \left(\frac{C}{\sigma}\right)^{0.25} g_\mathrm{eff}^{0.25}$$

generalize

$$F = \sigma T_\mathrm{eff}^4 = C_\beta g_\mathrm{eff}^{4\beta}$$

β parameter

$$T_\mathrm{eff} = \left(\frac{C_\beta}{\sigma}\right)^{0.25} g_\mathrm{eff}^{\beta}$$



Apparent intensity distribution dependent on inclination. T_eff variable over photosphere.

CHARRON

Code for High Angular Resolution of Rotating Objects in Nature

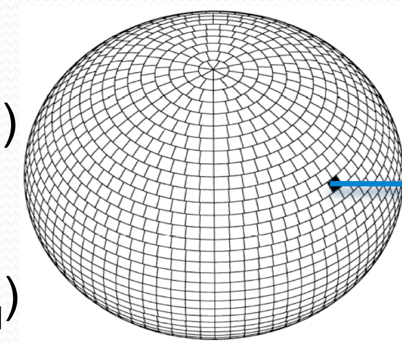
Domiciano de Souza et al. 2002, 2012

M, v_{eq}, R_{eq}, <T> (ou L), i, d, β

Surface potential Ψ (e.g. Roche potential)

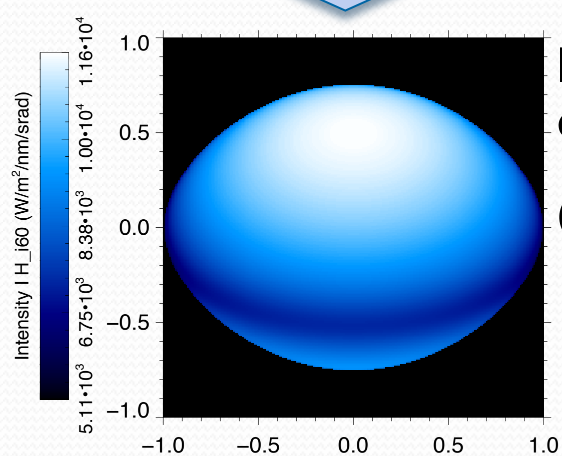
➔ $g_{eff} = |\text{-grad } \Psi|$

➔ $T_{eff} = C\, g_{eff}^{\beta}$;
$C = C(M, \langle T \rangle, v_{eq})$



At each surface grid element:
θ, ϕ, μ, T_{eff}, g_{eff}
v_{proj}, dS_{proj}

Specific intensities
$I_\lambda = I_\lambda(\mu, T_{eff}, g_{eff})$
from stellar atmosphere models
(e.g. Kurucz or TLUSTY + Synspec)

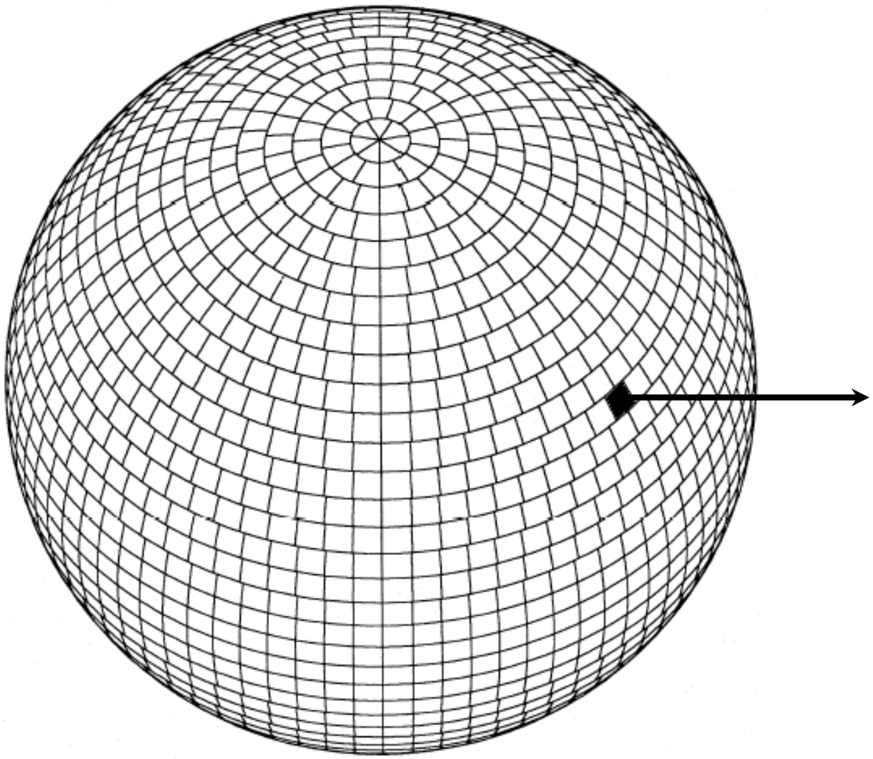


Intensity maps $I_\lambda(\theta, \phi)$ of stellar photosphere

(computation time ~10-30s)

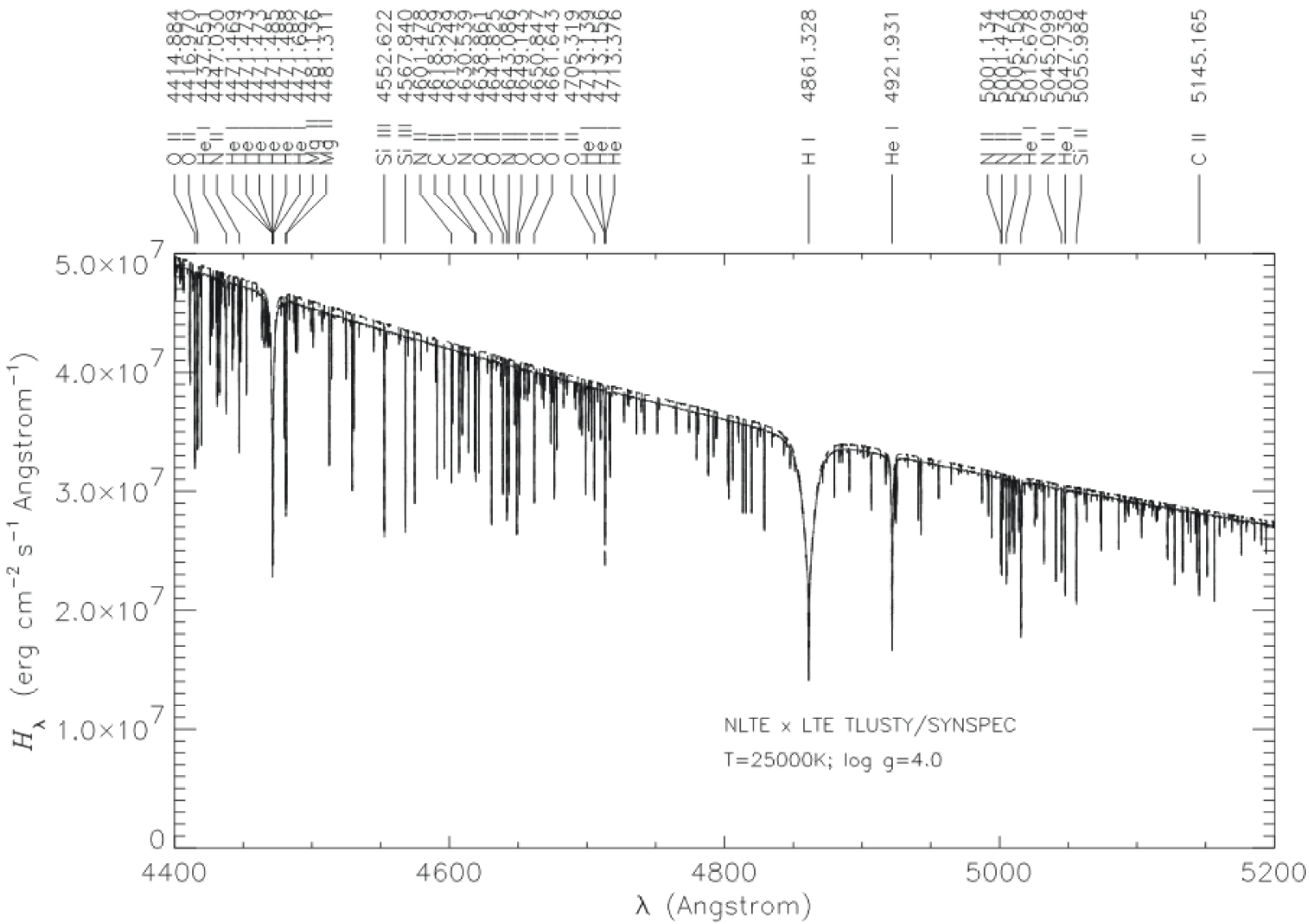
CHARRON: ancien métier; spécialiste du bois, maître de tout ce qui tourne et roule.

Paramètres physiques et grille numérique



- T_{eff}
- $\log g$
- v_{proj}
- dS_{proj}
- μ
- x,y
- ...

Synthèse de profils spectraux



Questions

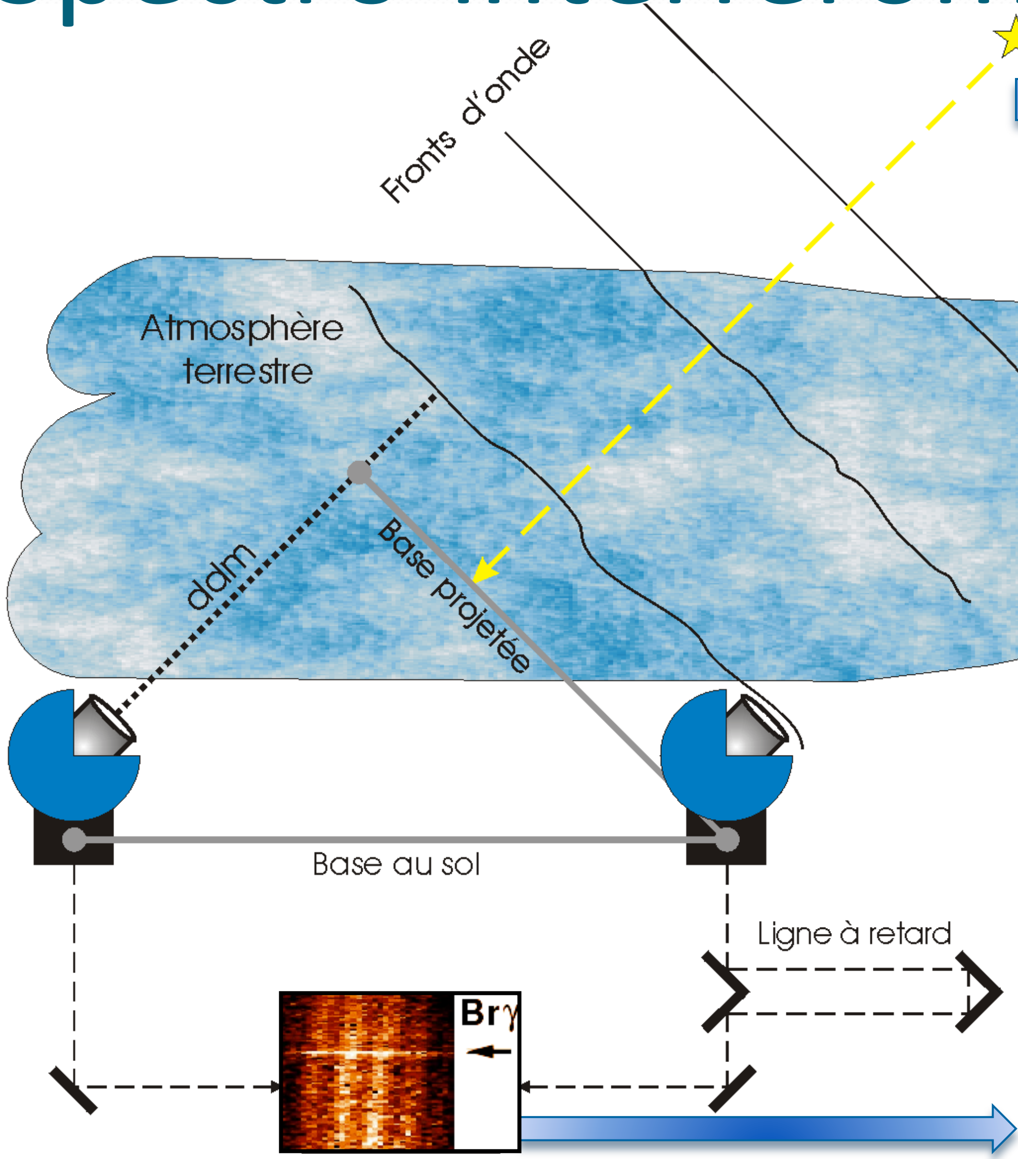
Comment associer des modèles d'atmosphère plan-parallèles (e.g. Kurucz, TLUSTY) et des spectres (e.g. SYSNPEC, PHOENIX, MARCS) à ESTER ?

Quelle « profondeur » prendre dans les modèles ESTER pour associer un spectre synthétique ?

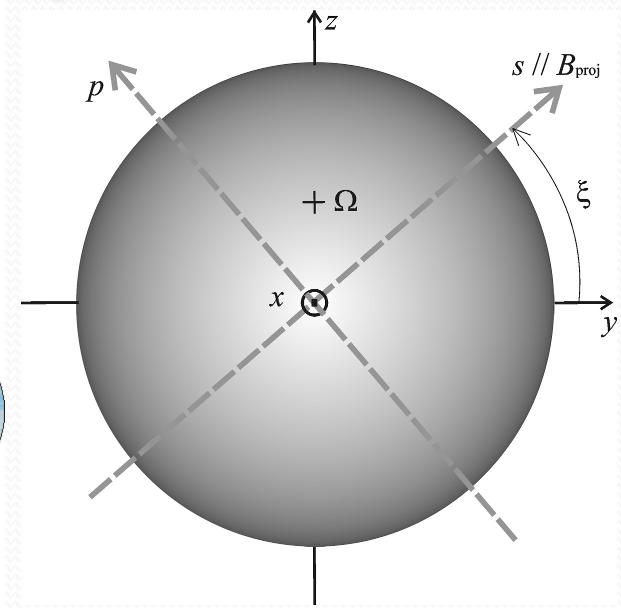
Ce problème ne se pose pas dans un modèle de Roche, et plusieurs personnes l'ont fait (e.g. Domiciano de Souza et al. Papers). Il y a aussi un papier de Kurucz de 2014 qui traite cette question.

Observations interférométriques d'étoiles en rotation rapide

Spectro-interferometry



Intensity map $I(y,z,\lambda)$



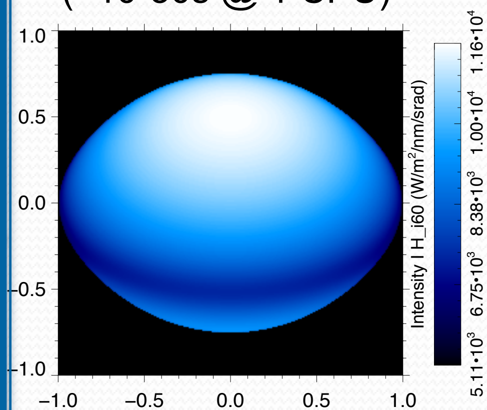
Interference fringes ➔ complex visibility V (Fourier trasnform of I):

$$V(u,v,\lambda)= FT[I(y,z,\lambda)](u,v)/FT[I(y,z,\lambda)](0,0)$$

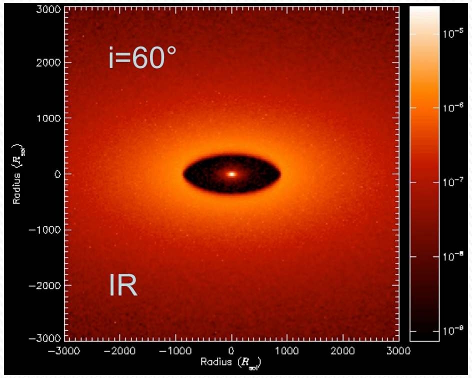
Spectro-interferometry

Intensity maps from physical models

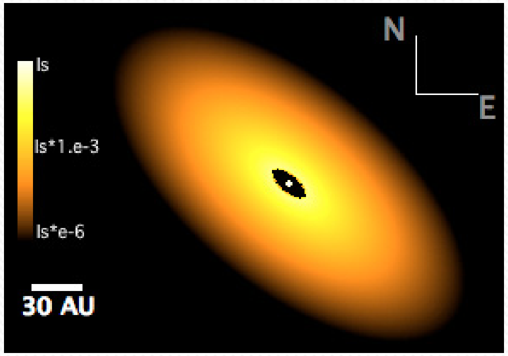
CHARRON
(~10-30s @ 1 CPU)



HDUST
(~5-10h @ 100 CPU)



FRACS
(~1-10s @ 1 CPU)



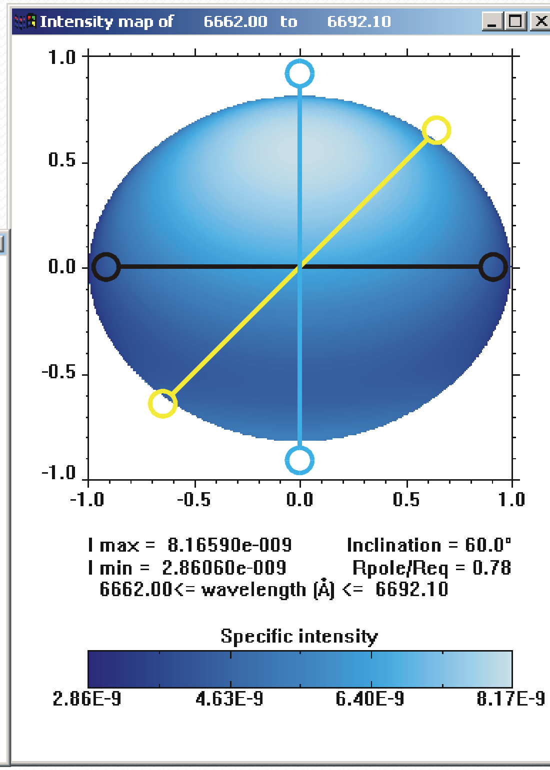
Model fitting

Integrate or Fourier transform

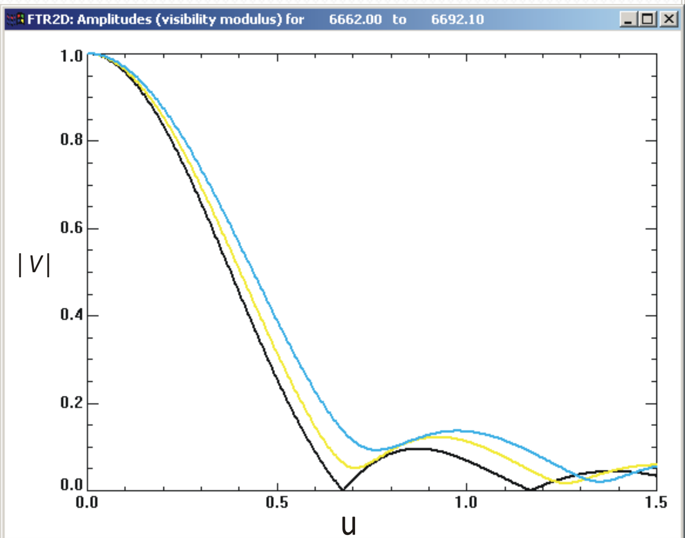
Spectro-interferometric observables: fluxes (spectra), SED, photometry, absolute and differential visibilities (amplitudes and phases), closure phases.

Spectro-interferometry

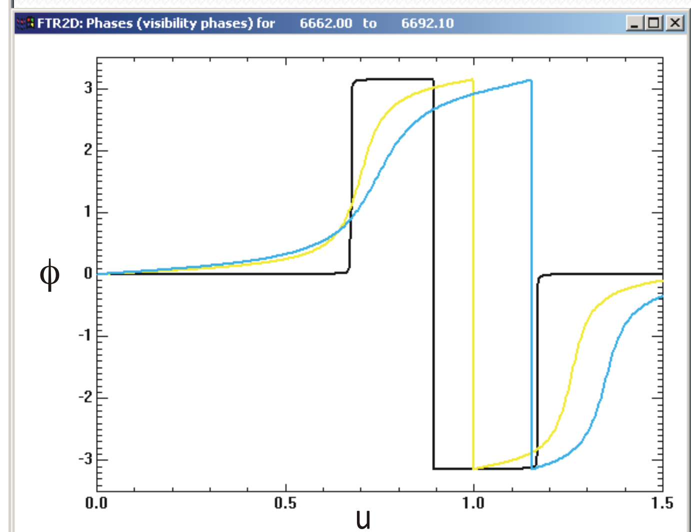
Intensity map



Complex visibility amplitude |V|
(fringe contrast)



Complex visibility phase ϕ
(fringe position)



ϕ not directly accessible

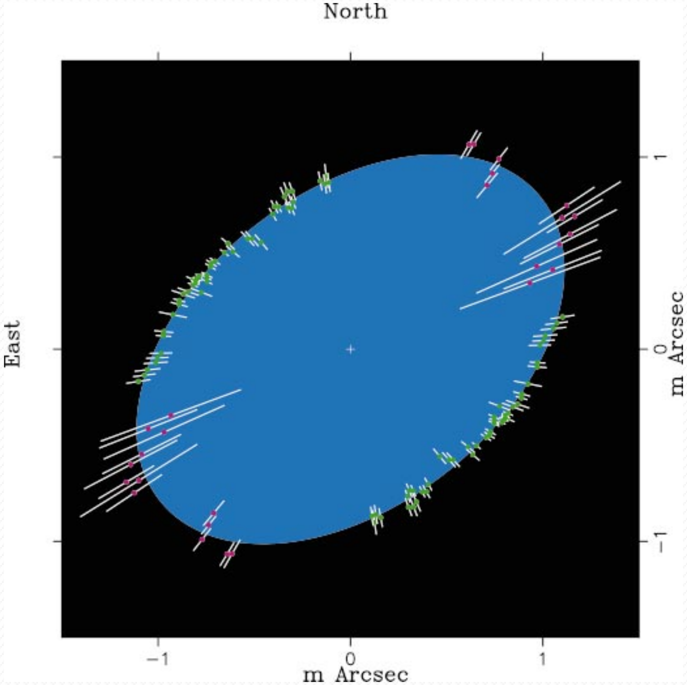
Closure phase

$$\Phi_{ijk} = \phi_{obs}(u_{ij}, v_{ij}) + \phi_{obs}(u_{jk}, v_{jk}) + \phi_{obs}(u_{ki}, v_{ki}) = \phi(u_{ij}, v_{ij}) + \phi(u_{jk}, v_{jk}) + \phi(u_{ki}, v_{ki})$$

Differential phase

$$\phi_{diff} = \phi - \left(a + \frac{b}{\lambda}\right)$$

Achernar: ideal fast-rotator target for HRA



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

Some information on Achernar:

✧B3-6Vpe star

✧V=0.5 (brightest Be star)

✧M ~ 6 M_{sun}

✧d=42.7 pc (closest Be star)

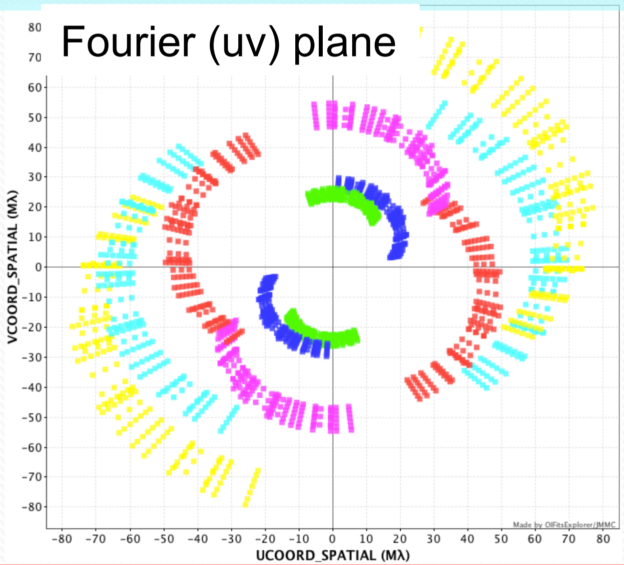
✧Mean T_{eff}~15000K

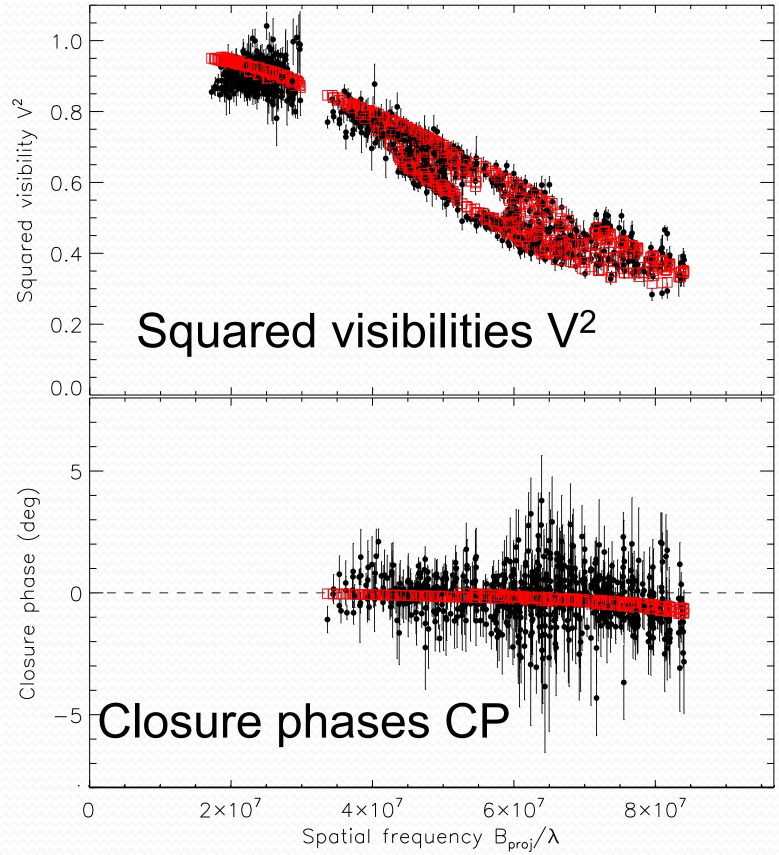
✧v sini i ~260 km/s (wide range of values in the literature)

✧Strong rotation flattening (beyond Roche limit)

Achernar: VLTI/PIONIER observations

- Simultaneous observations 4 AT
- V^2 and CP
- H band (3 & 7 spectral channels)
- Baselines from ~ 30 to 120 m
- Observations in 8-9/2011 and 9/2012





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

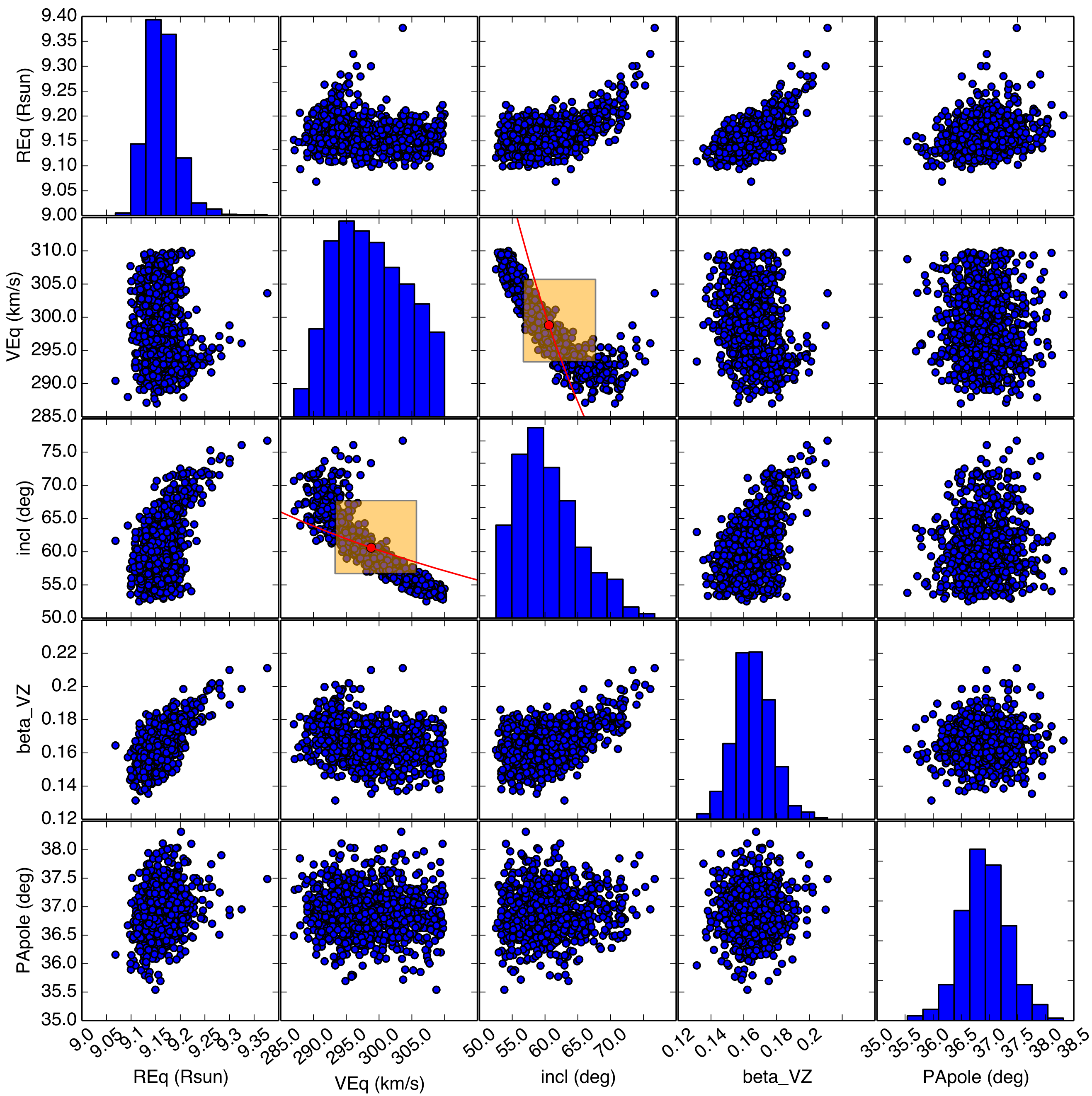
✧Be star: episodic emission phases from disque (variations at several time scales)

✧Binary (orbital period ~7 years) ➔ out of FOV from PIONIER

Domiciano de Souza et al. 2014, A&A

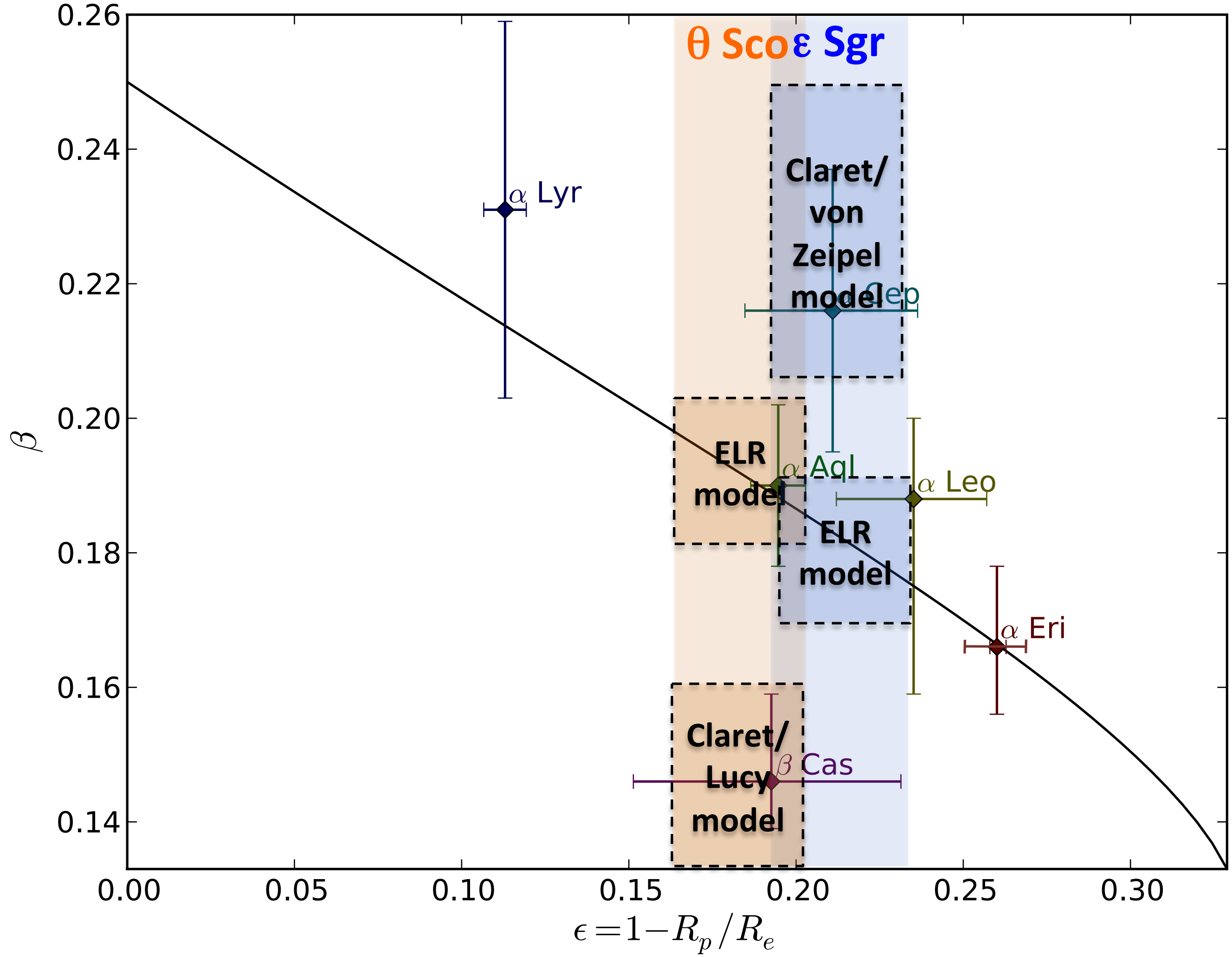
Achernar parameters

MCMC fitting

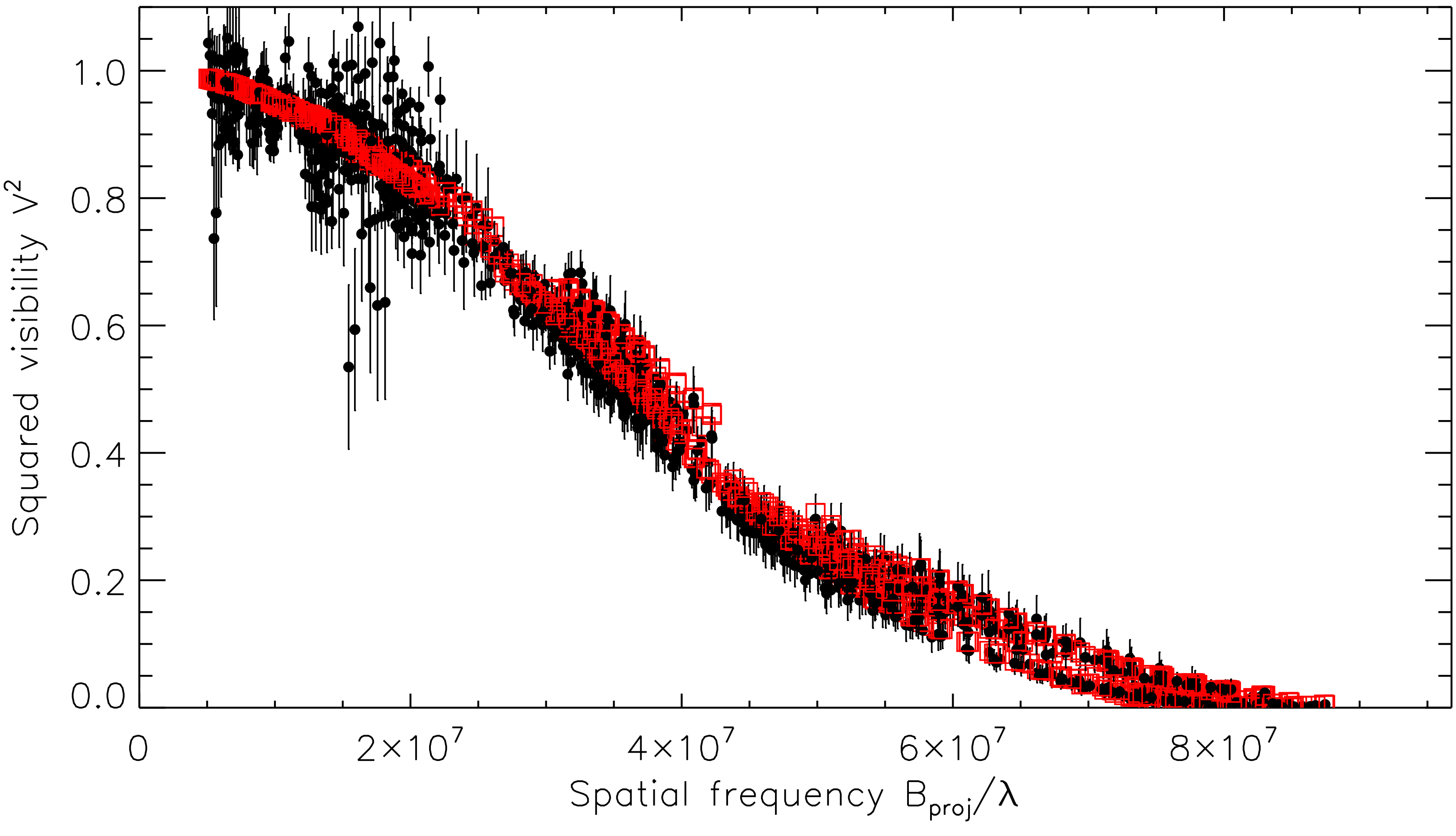


ESO P97

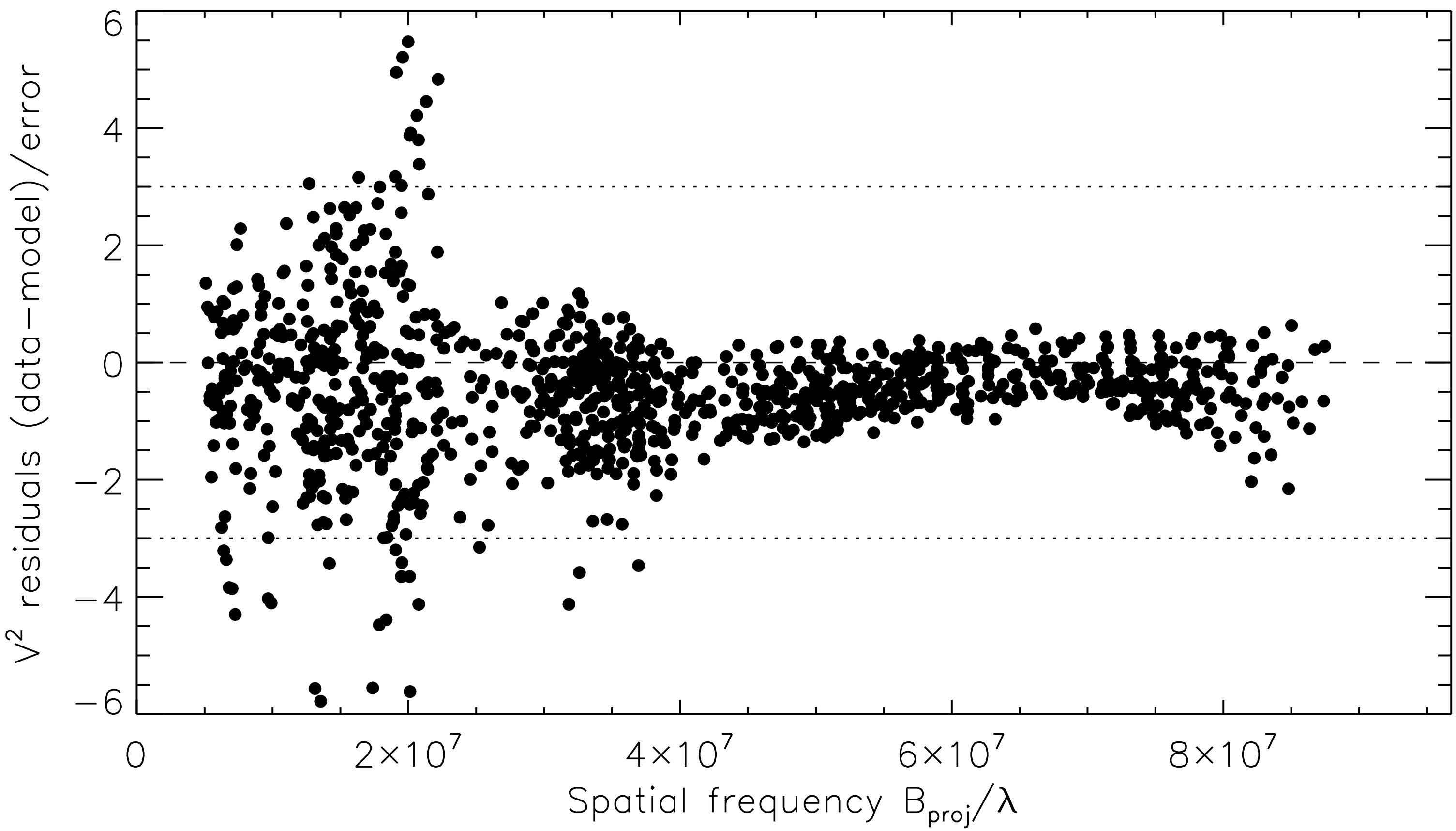
Stellar gravity darkening put into test



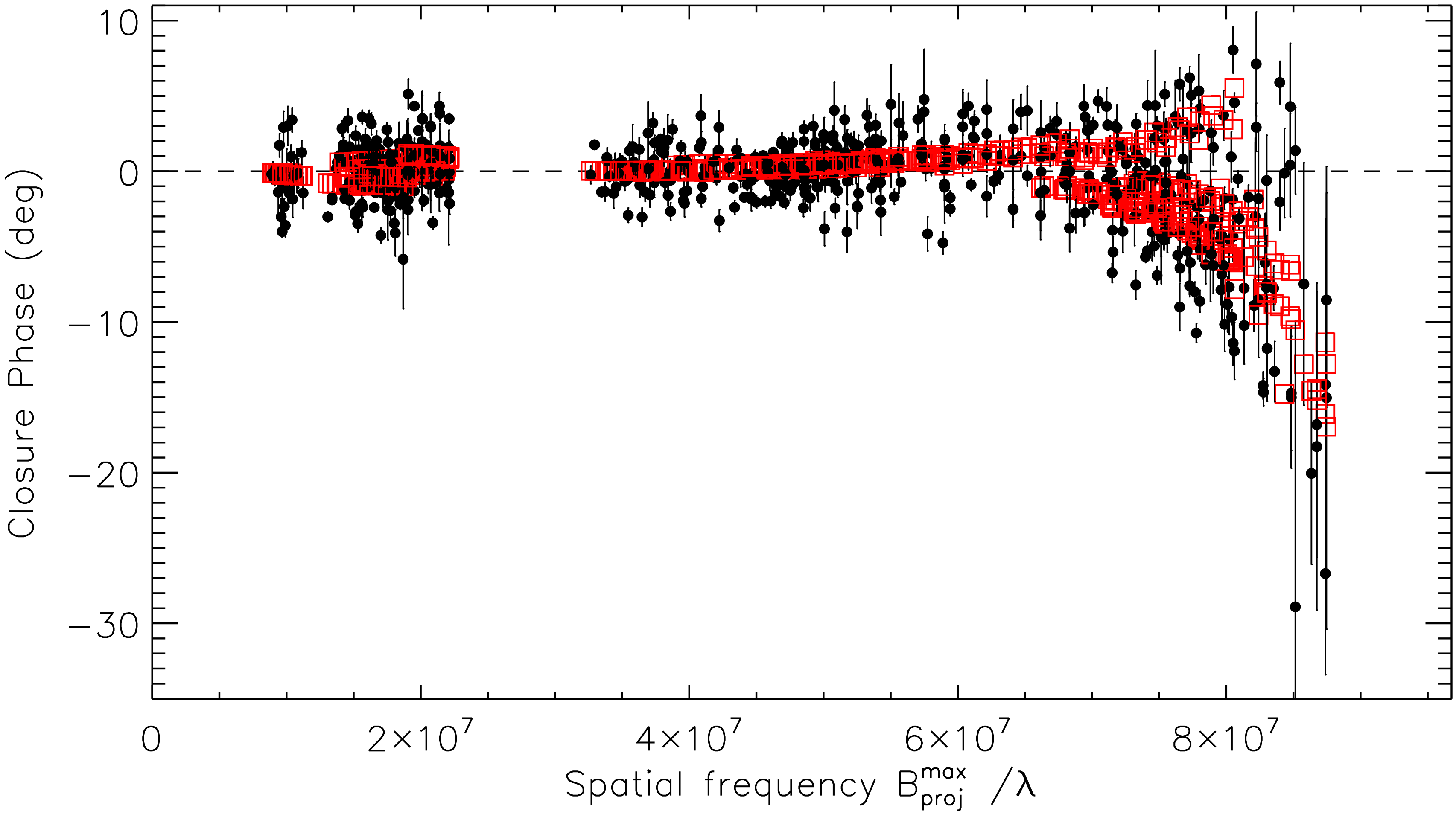
theta Sco (F1III)



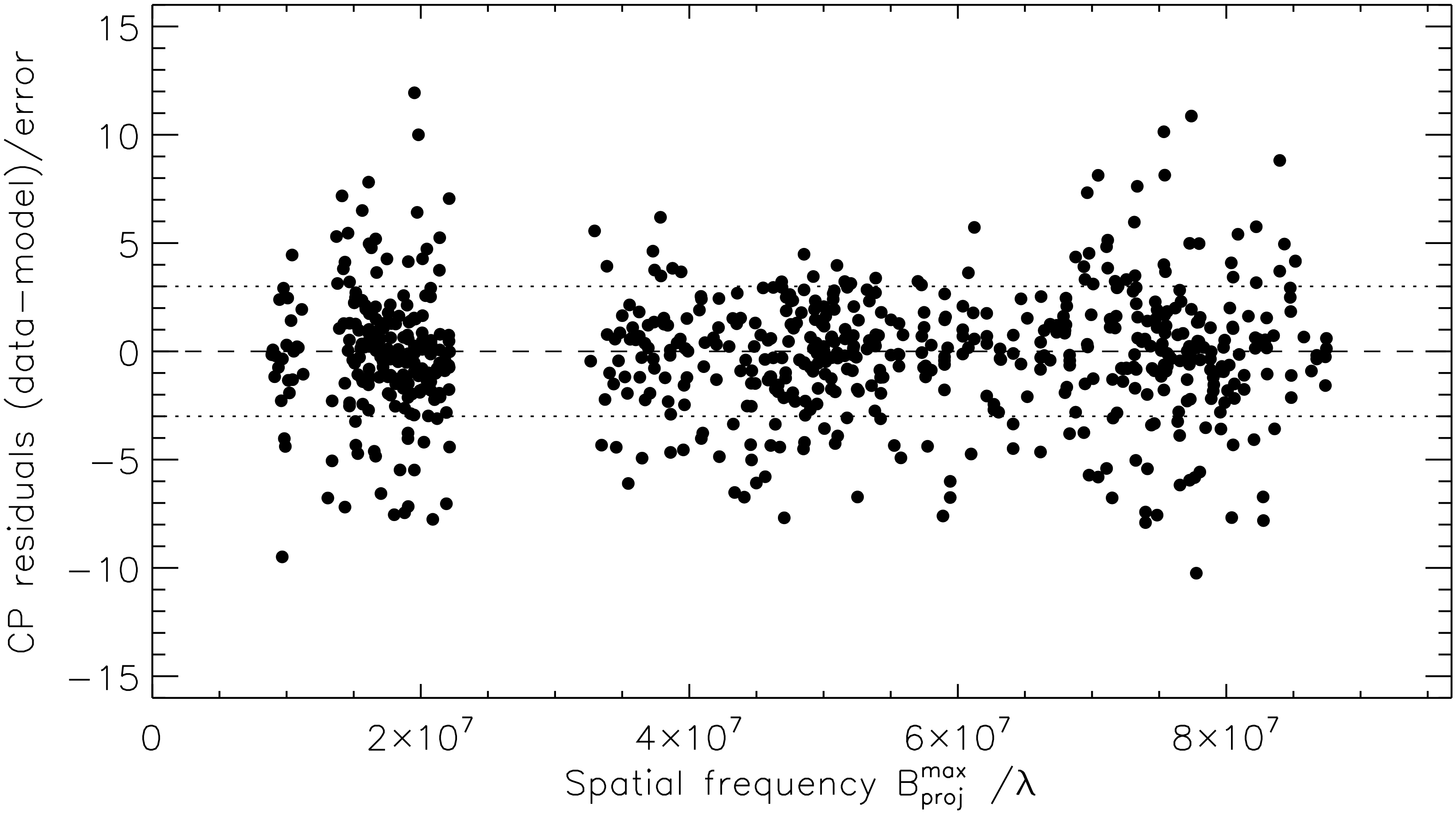
theta Sco (F1III)



theta Sco (F1III)



theta Sco (F1III)



theta Sco (F1III)

Distance d (pc)	= 91.158	Polar axis inclination i (deg)	= 58.721
Equatorial Radius Req (Rsun)	= 29.996	Equatorial angular diameter (mas)	= 3.0618
Polar Radius Rpol (Rsun)	= 25.436	Polar angular diameter (mas)	= 2.5964
Req/Rpol	= 1.1793	Rpol/Req	= 0.84799
Equal Area Radius (Rsun)	= 28.28	Equal Volume Radius (Rsun)	= 28.202
Equatorial Temperature Teq (K)	= 6231.8	log Equatorial Gravity log geq (cgs dex)	= 2.0437
Polar Temperature Tpol (K)	= 7681.4	log Polar Gravity log gpol (cgs dex)	= 2.3798
Mean Temperature Tmean (K)	= 6836.7	Stellar Mass M (Msun)	= 5.66
Stellar Luminosity L (Lsun)	= 1568.1	log(L/Lsun)	= 3.1954
Mean bolom. flux Fbol=L/(4PI*d^2) (W/m^2)	= 6.0657E-09	Mean mag_bol=-2.5log(Fbol/2.53E-8)	= 1.5506
Equatorial rotation velocity Veq (km/s)	= 113.59	Equatorial rotation period Peq (h)	= 320.8
Veq sin i (km/s)	= 97.084	Equatorial angular vel. Omega_eq (cyc/day)	= 0.074822
Veq/Vcrit (eta=1)	= 0.59876	Omega_eq/Omega_crit (eta=1)	= 0.59876
Veq/Vcrit (Roche)	= 0.67529	Omega_eq/Omega_crit (Roche)	= 0.85897
eta = Omega_eq^2 Req^3/GM	= 0.35851	tau = E_cinet/E_pot	= 0.0071777
von Zeipel coefficient beta	= 0.27029		