spectro photo interferometry of rotating stars: Altair

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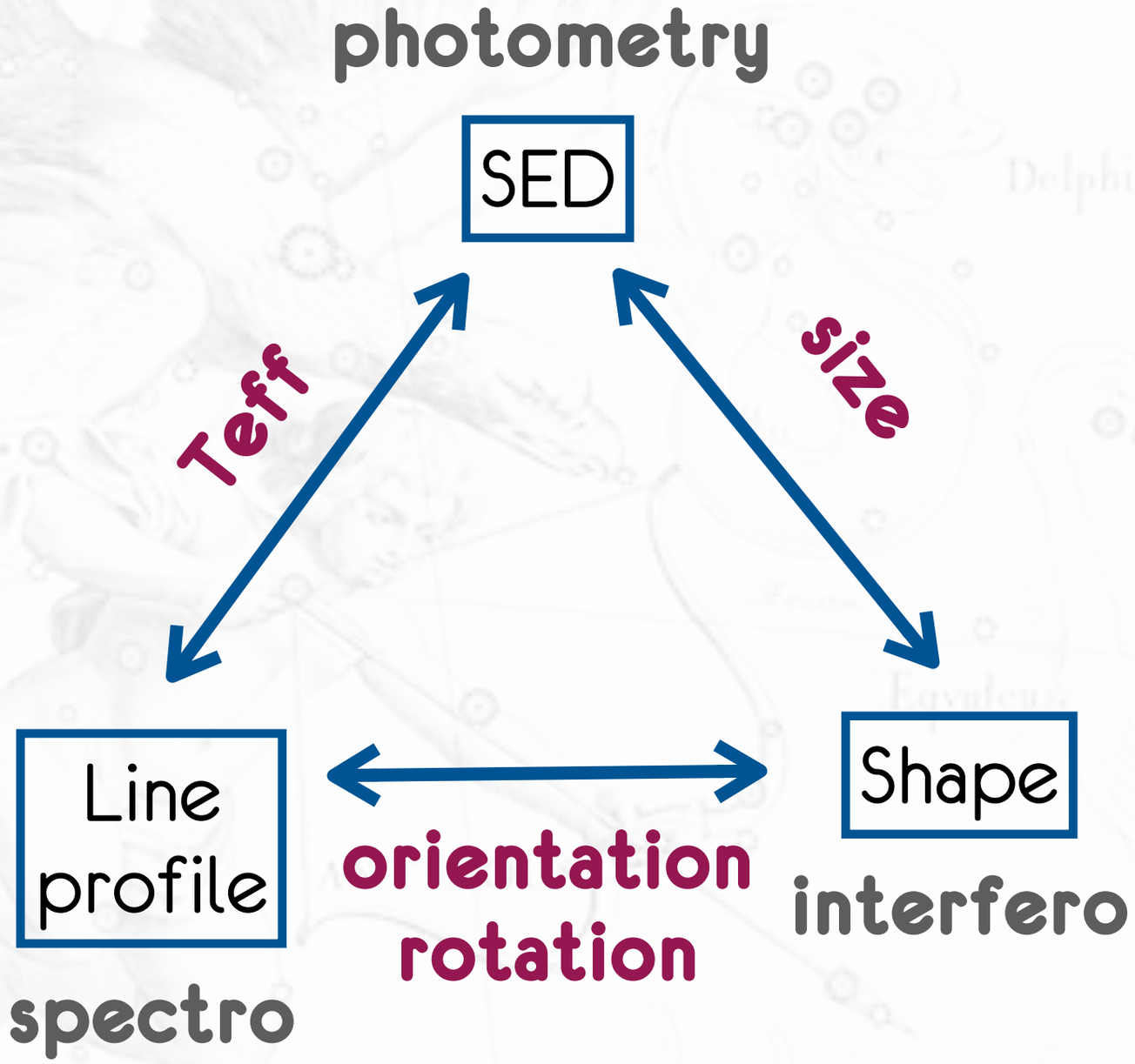
PIONIER science days - January 2014

inverse problem

- fundamental parameters → model → observations
- minimal dataset yields parameters but do not ensure model's consistency
- **Goal**: over constrain the model (fit everything) to check model's consistency



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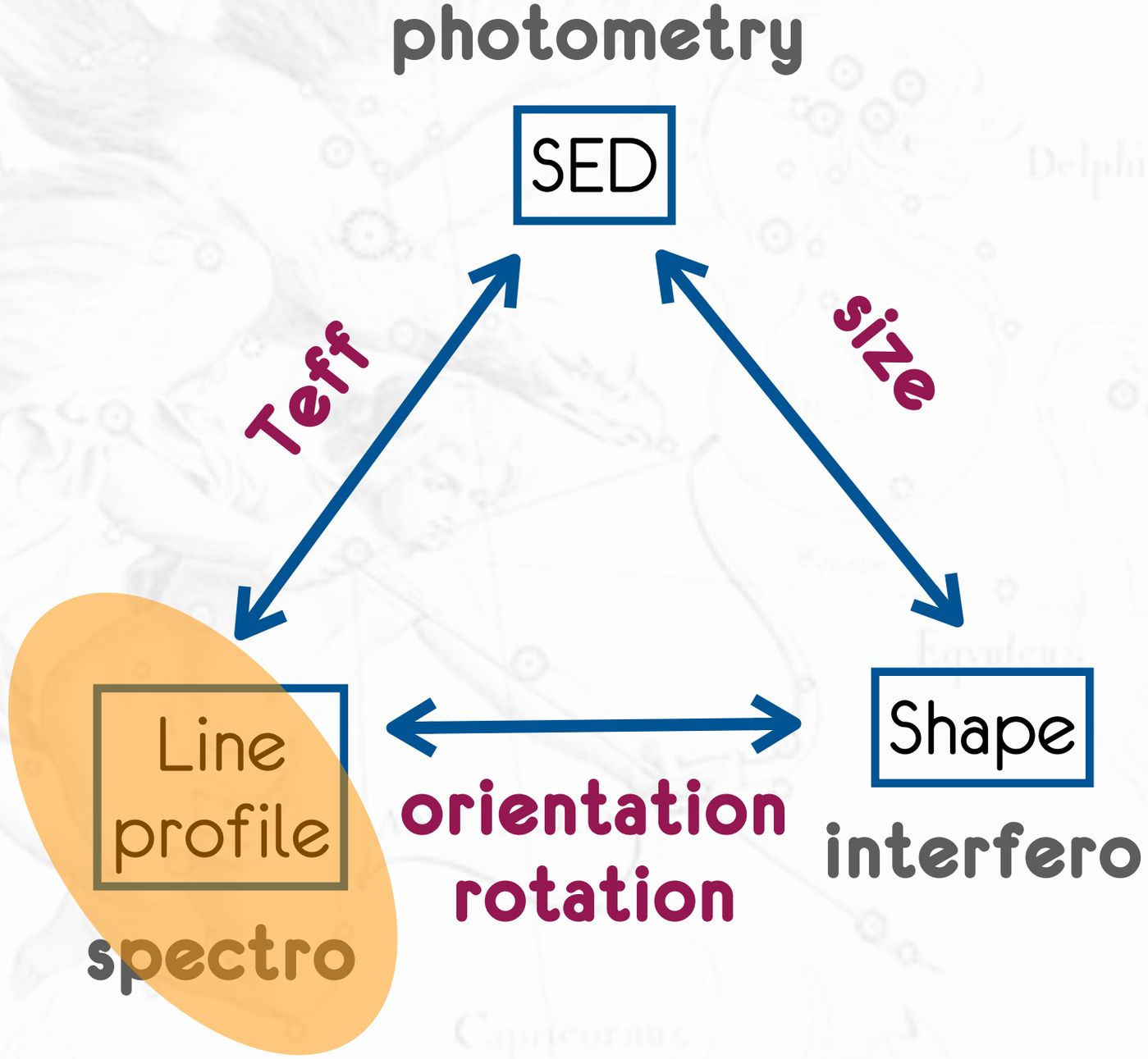

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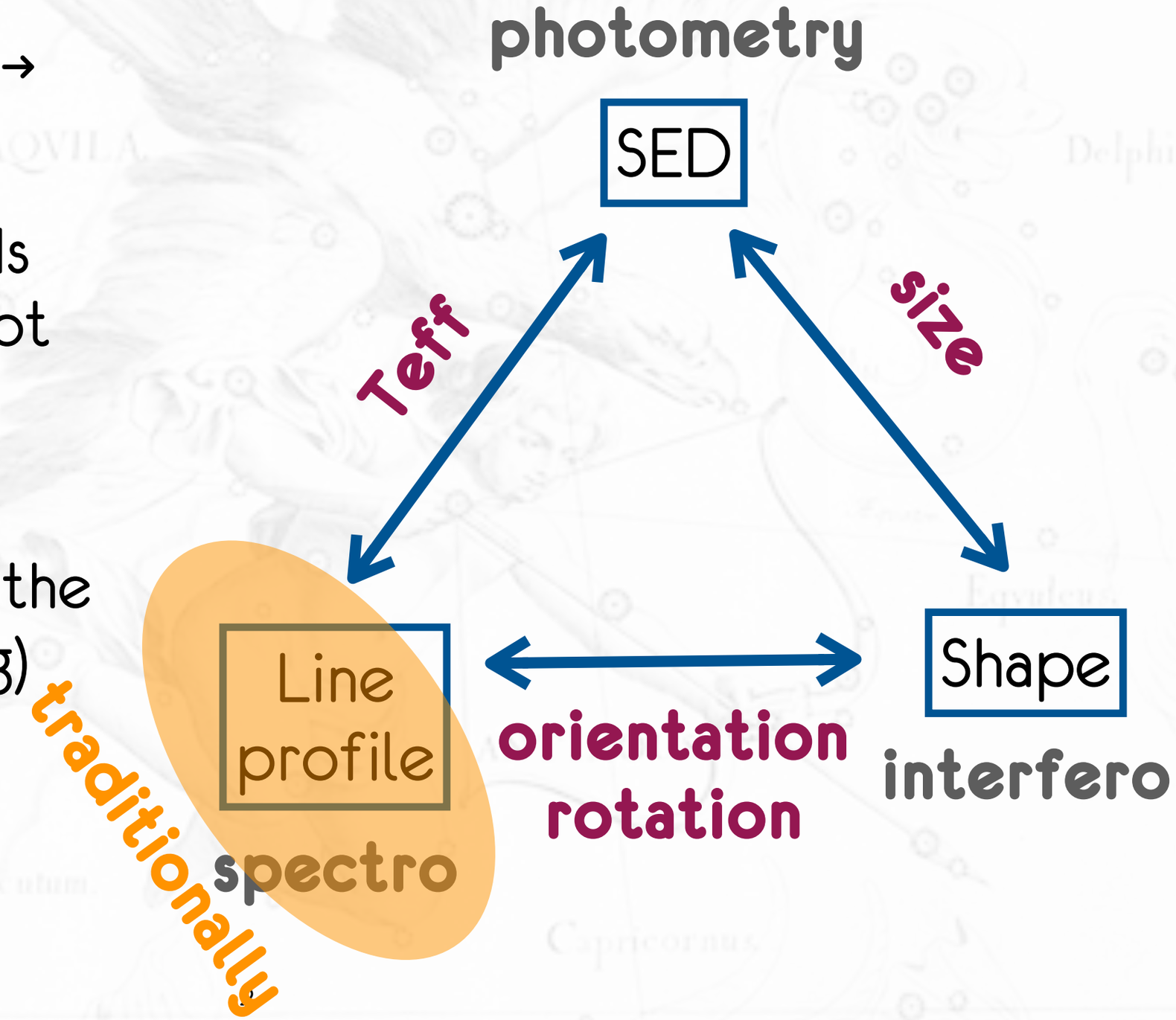

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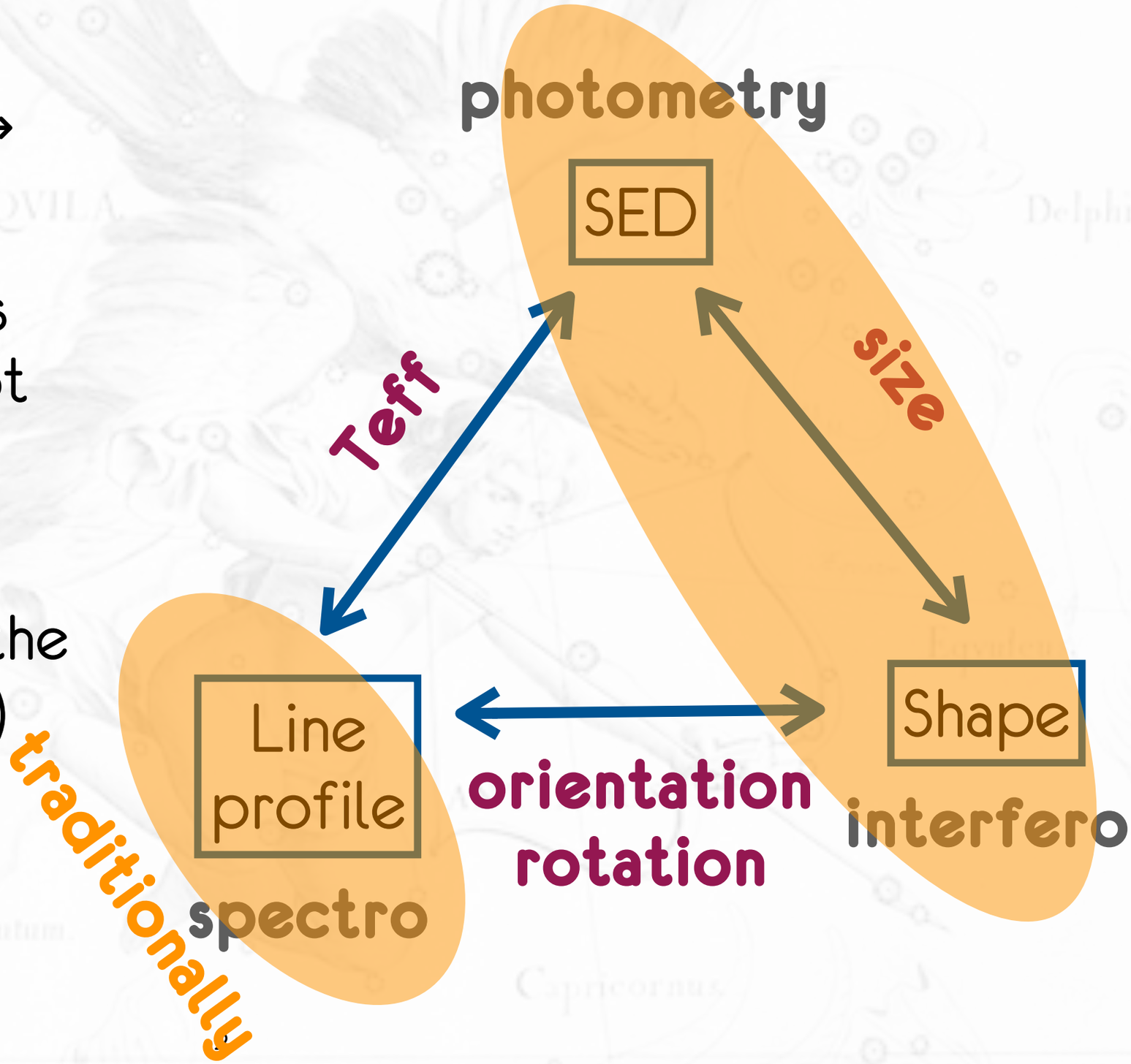

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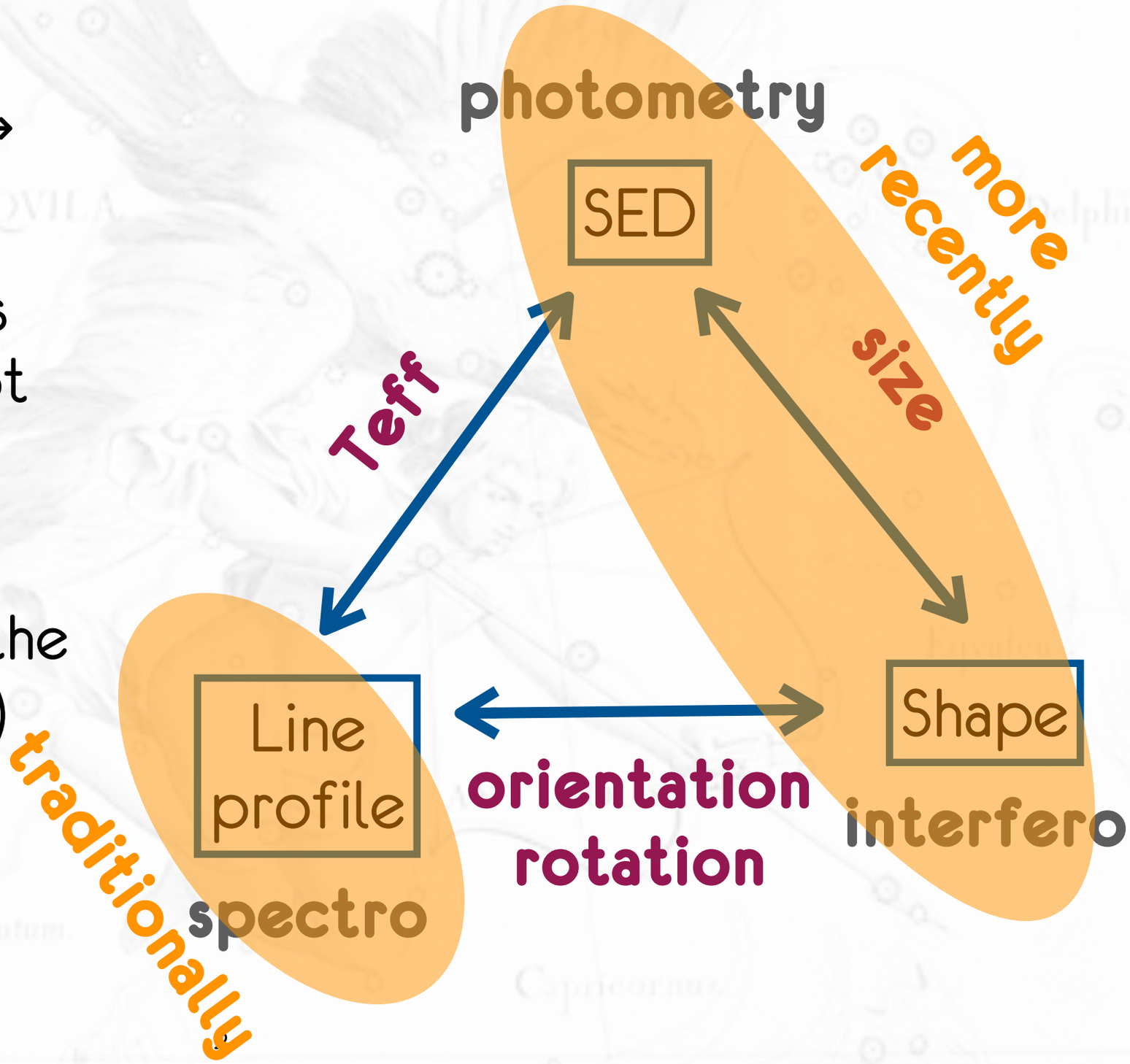

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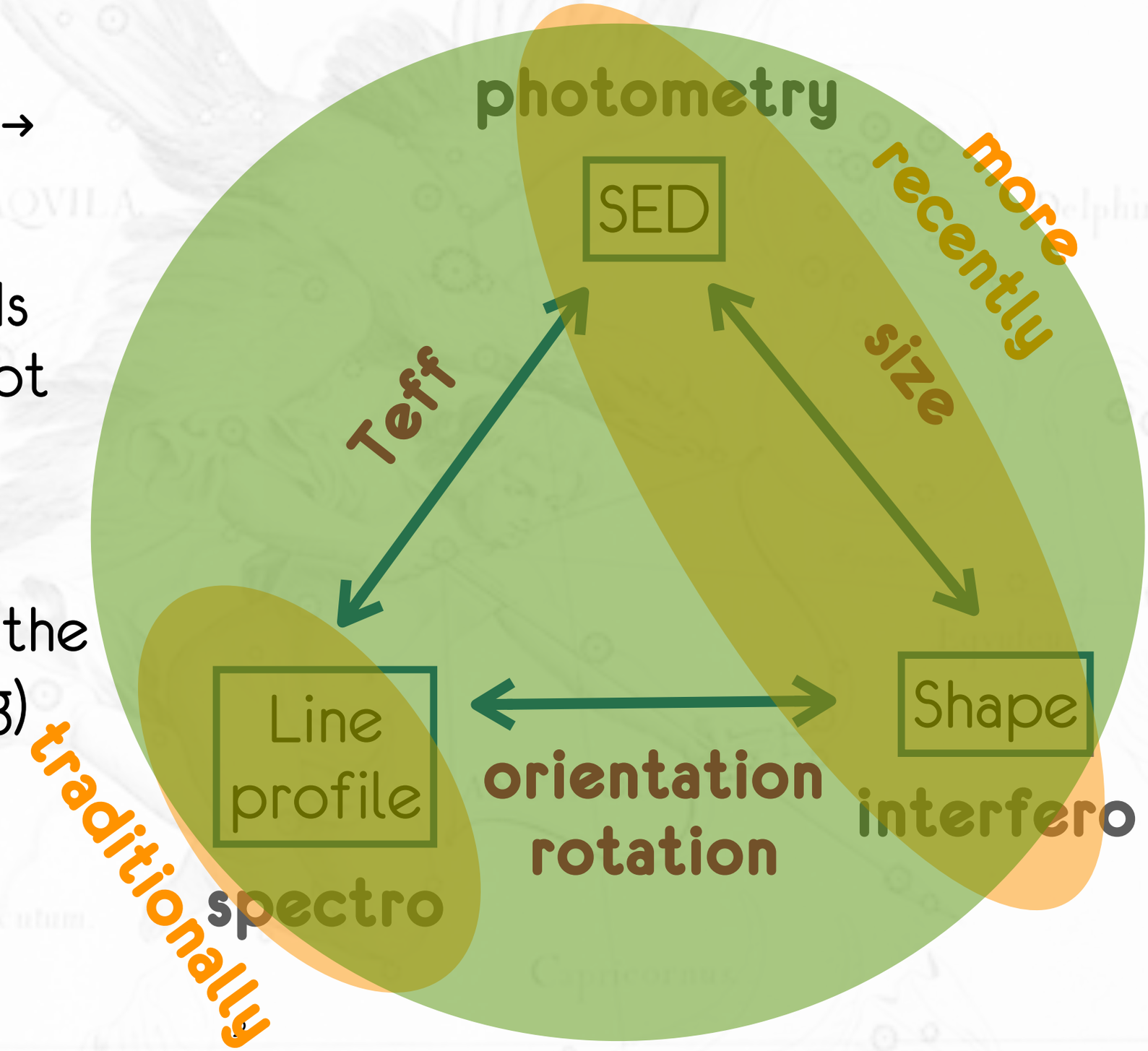
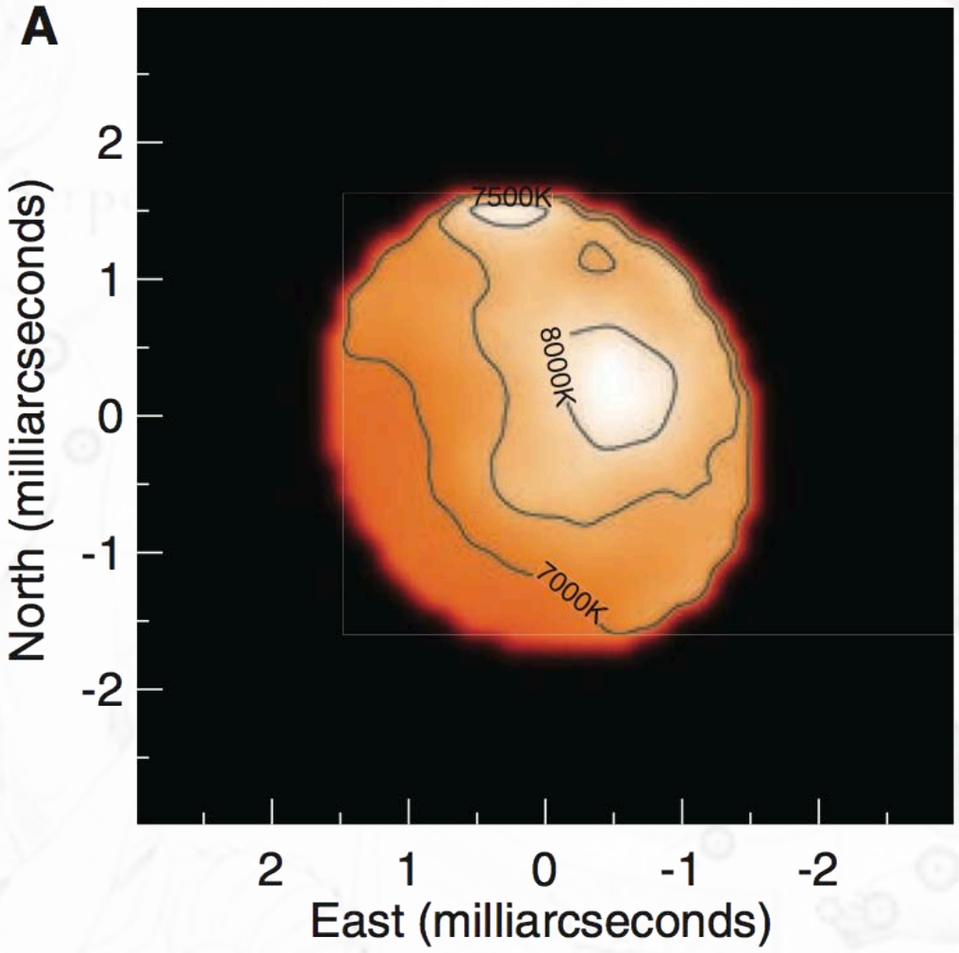


example: Altair



Interferometric Image of Altair using CHARA/MIRC

Monnier+ 2007

- bright "A7V" rotator imaged by CHARA/MIRC
- among most resolved fast-rotator, only first lobe for PIONIER
- v.sini ~ 240 km/s
- available archival data (spectroscopy, spectro-interferometry)

surface modeling

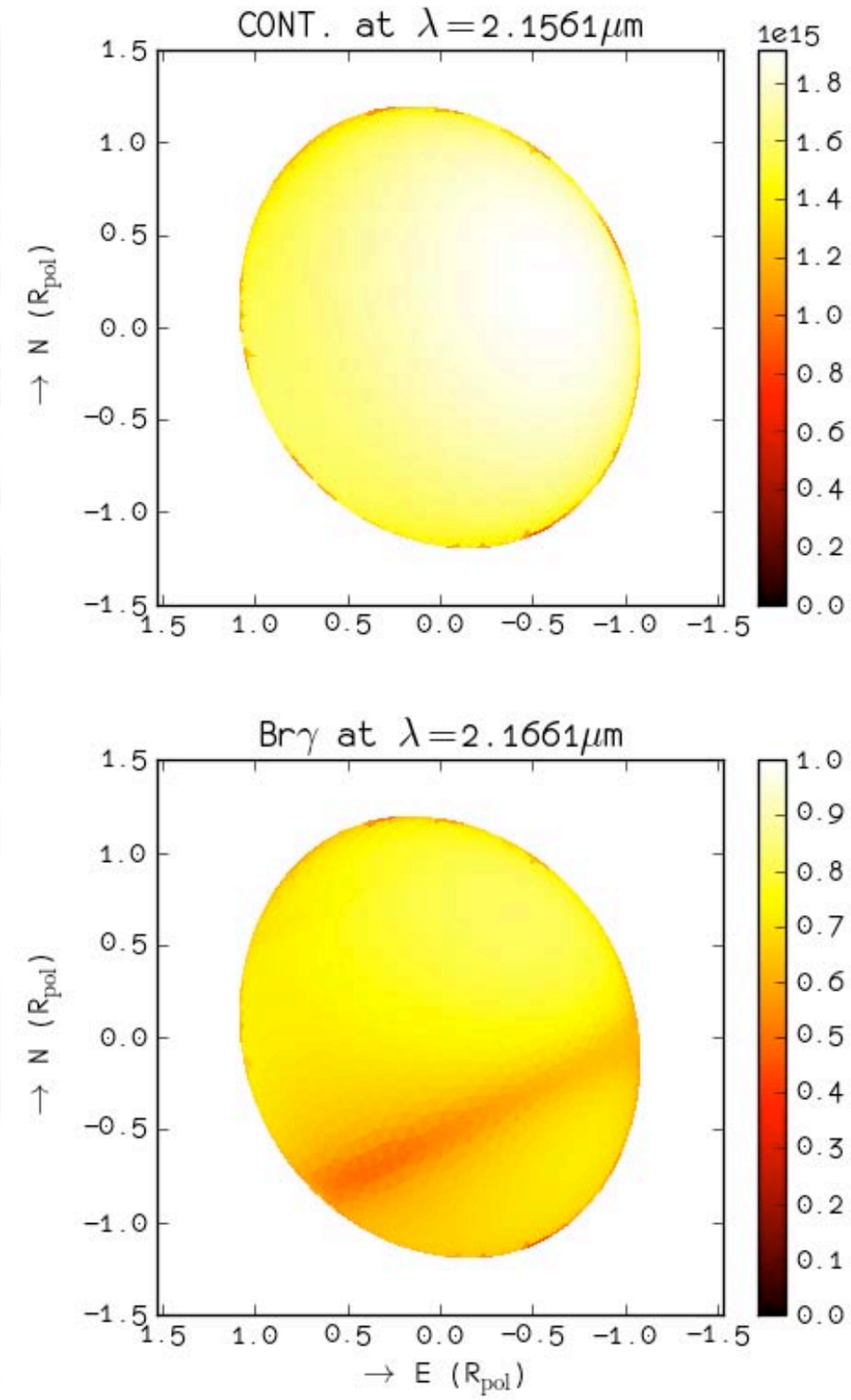
- Roche spheroid, solid rotation and gravity darkening:

  $T_{eff} \propto grav^{\beta}$

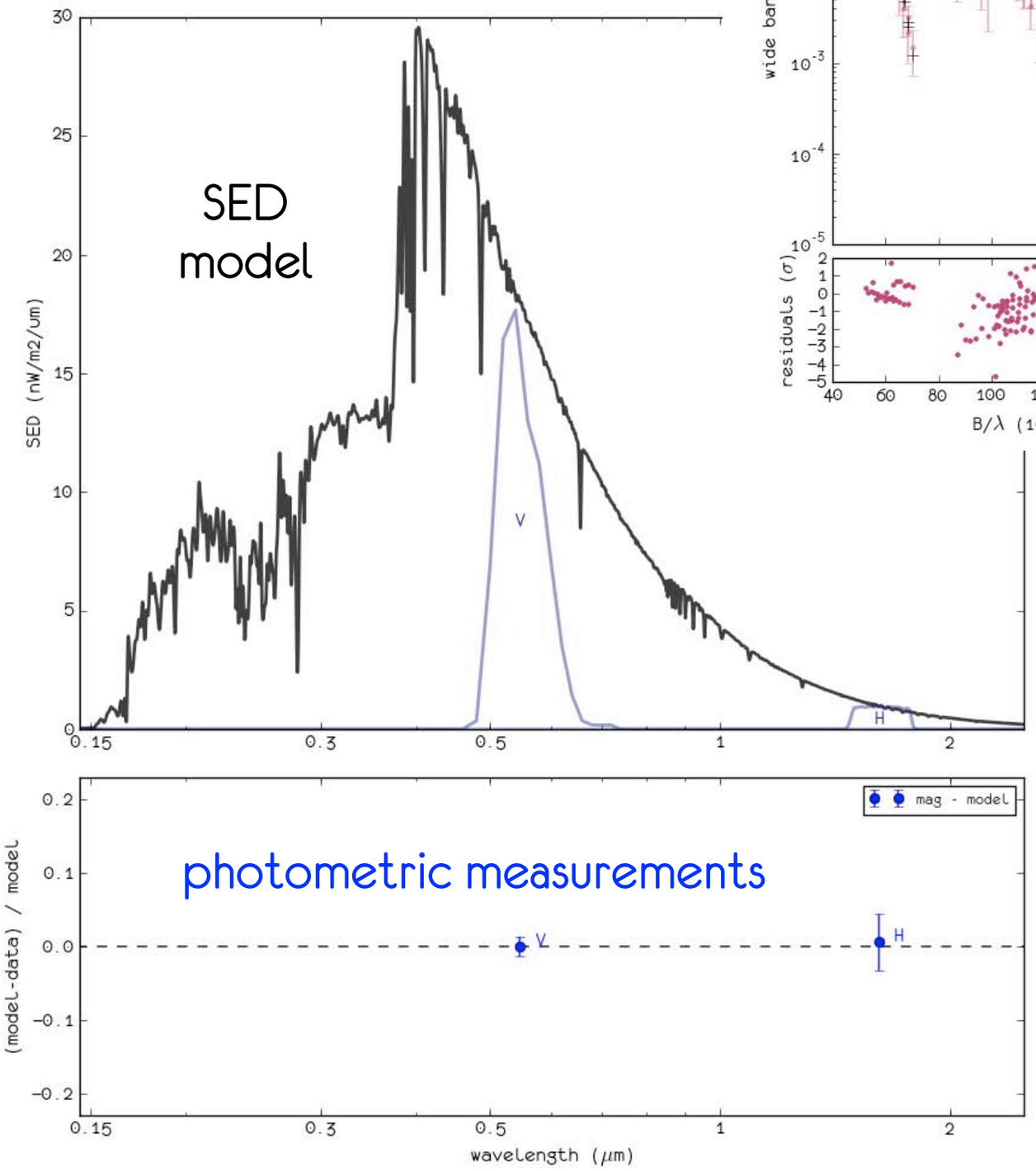
- same modeling principle as Aufdenberg+ 2006 and Monnier+ 2007, Mérand+ 2011 etc. (also Dominciano de Souza code)

- latitudinal mapping of hydrostatic non-LTE PHOENIX photospheric models (Teff, Logg)

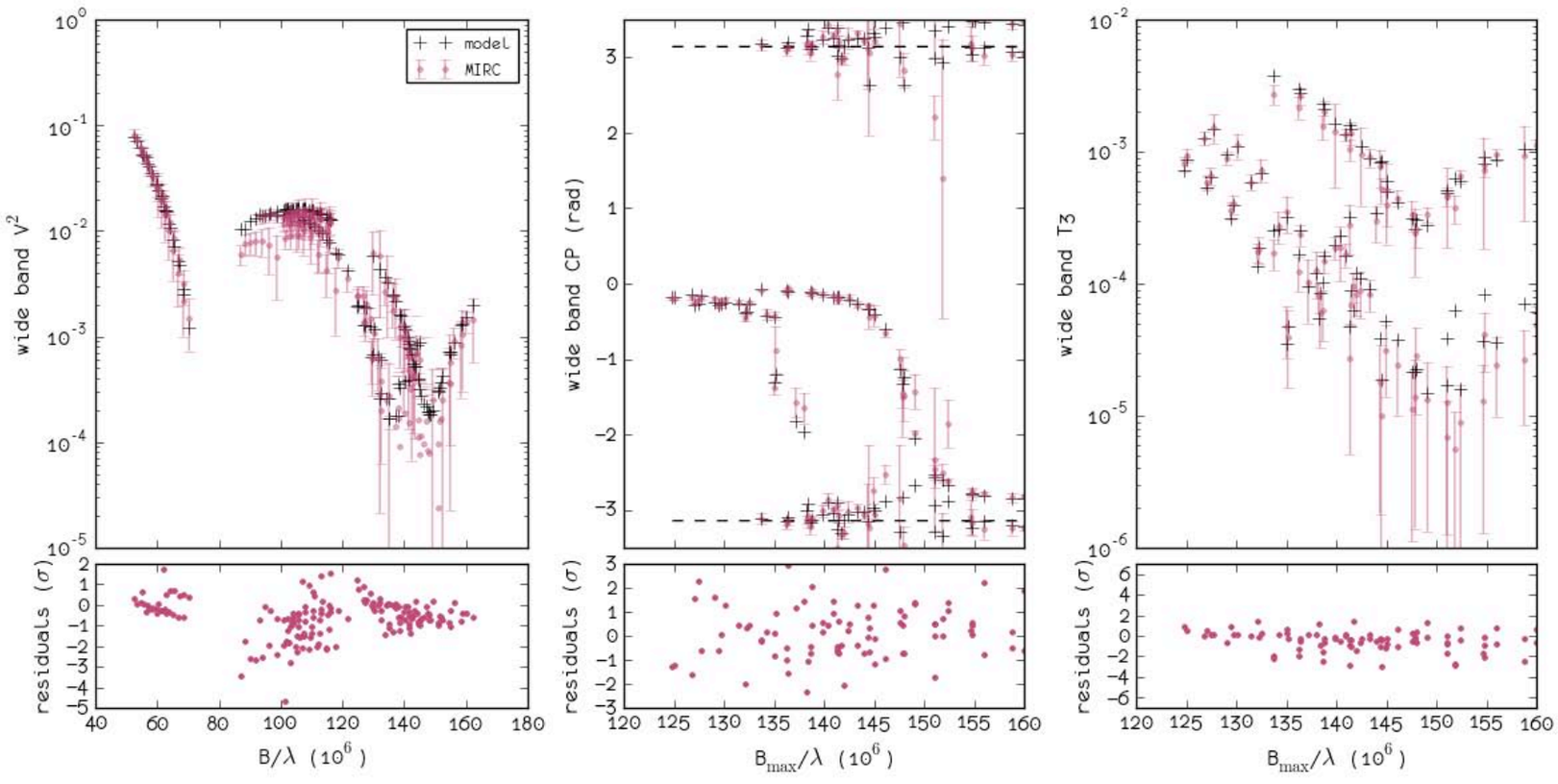
model for VLTI/AMBER in Brγ

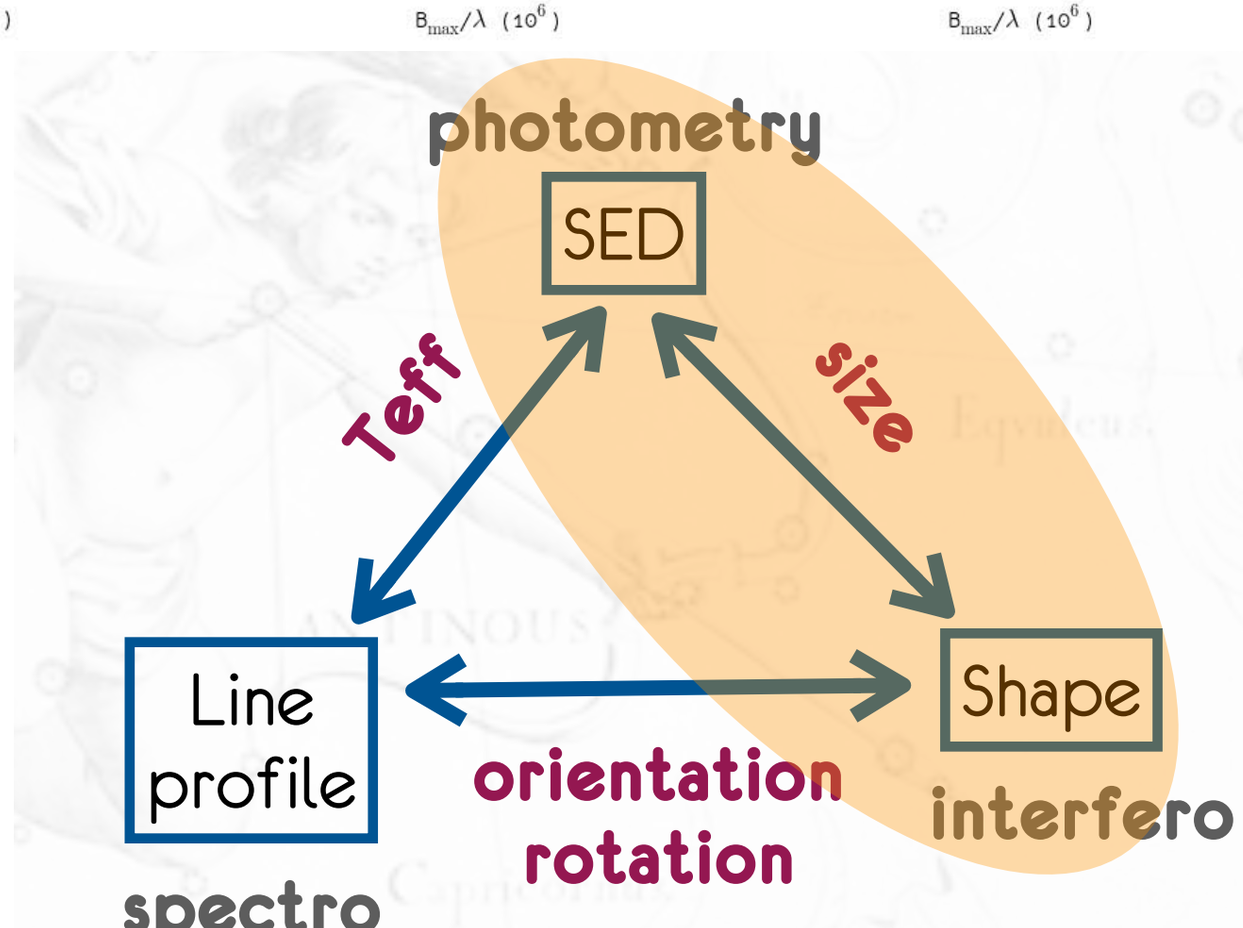


Our Altair parameters agree with Monnier+07 on the same dataset

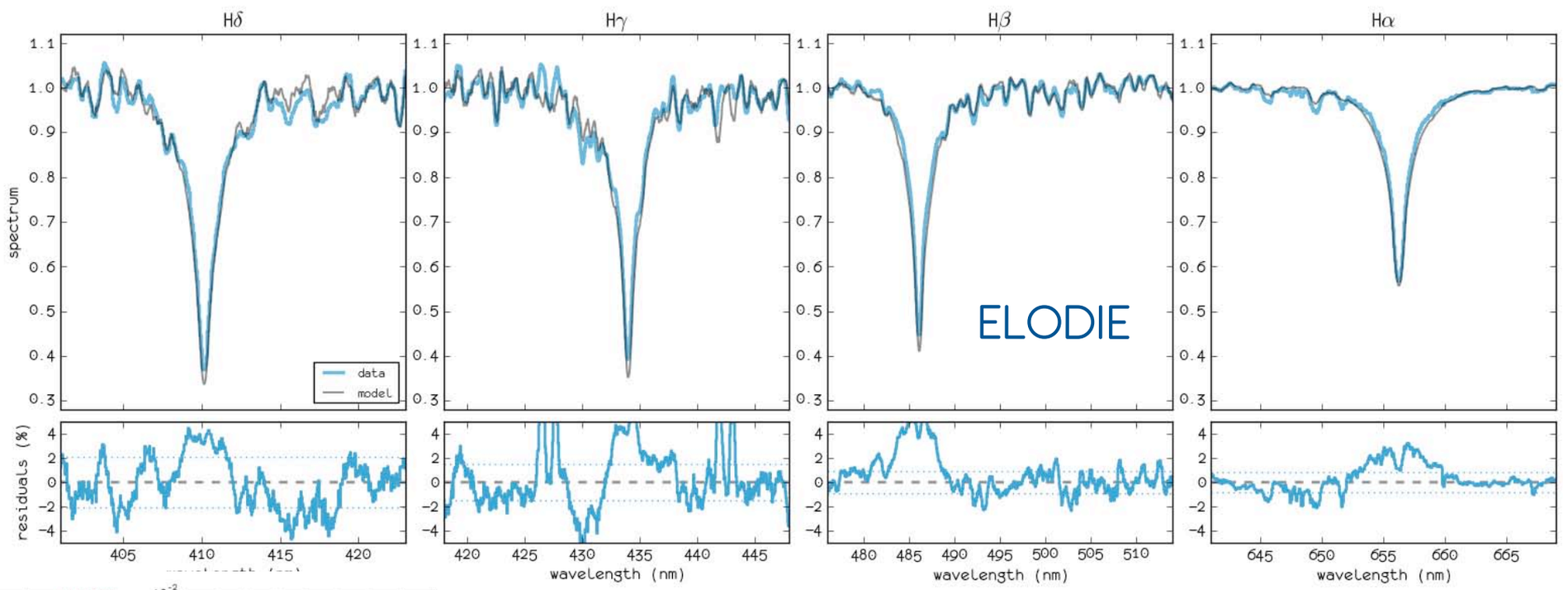


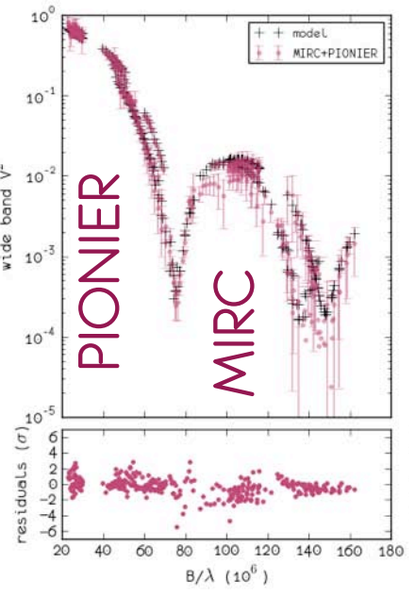
CHARA/MIRC interferometry

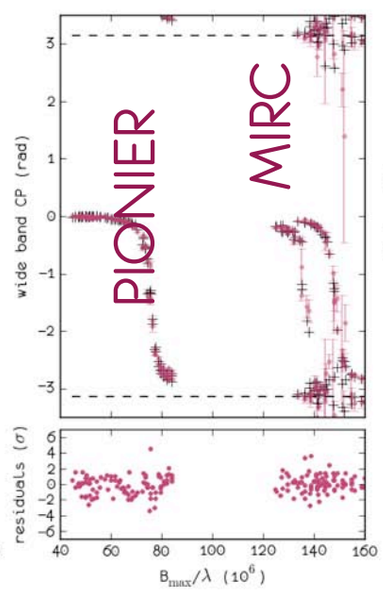


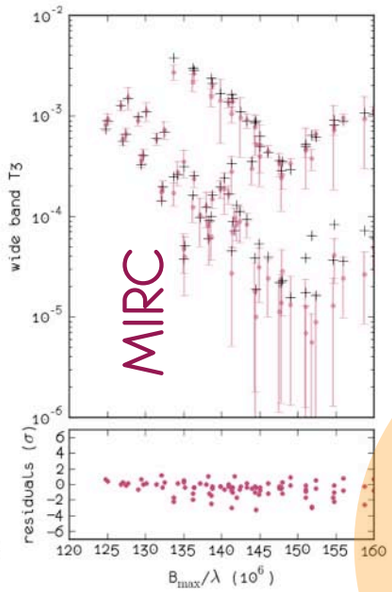


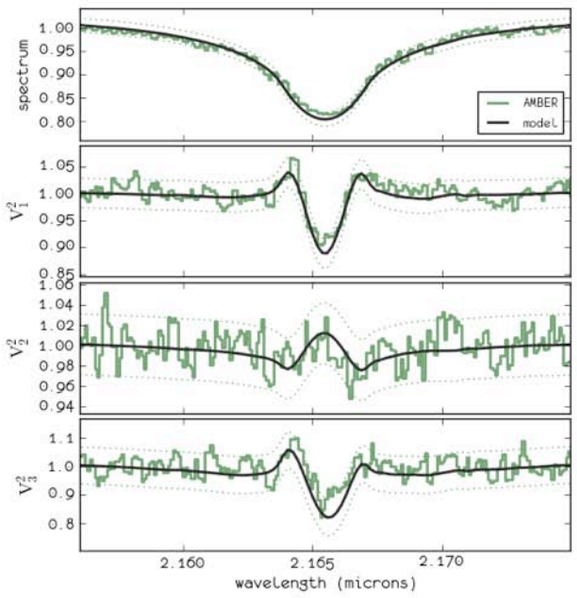
Our Altair model fits the extended data set quite well

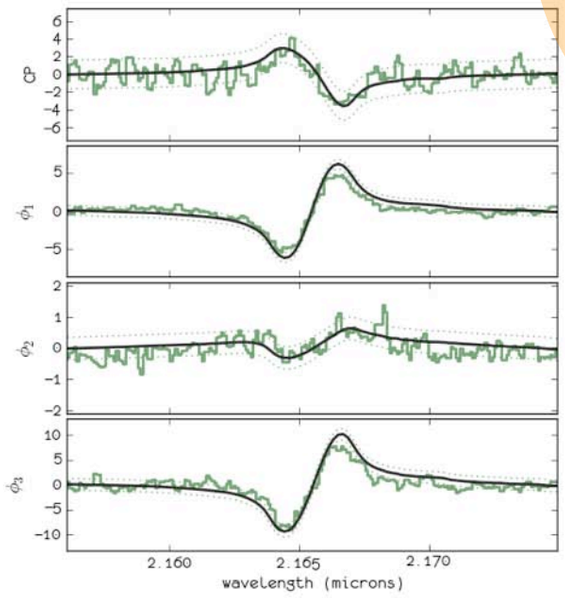




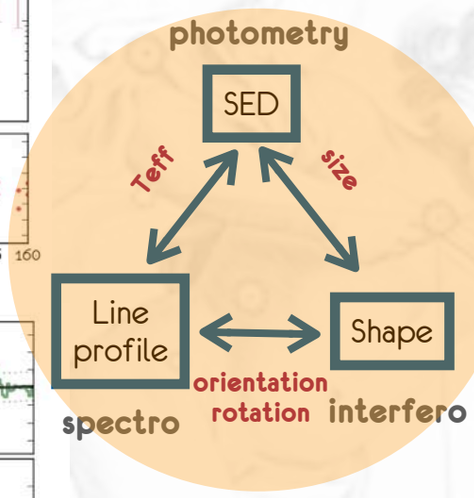


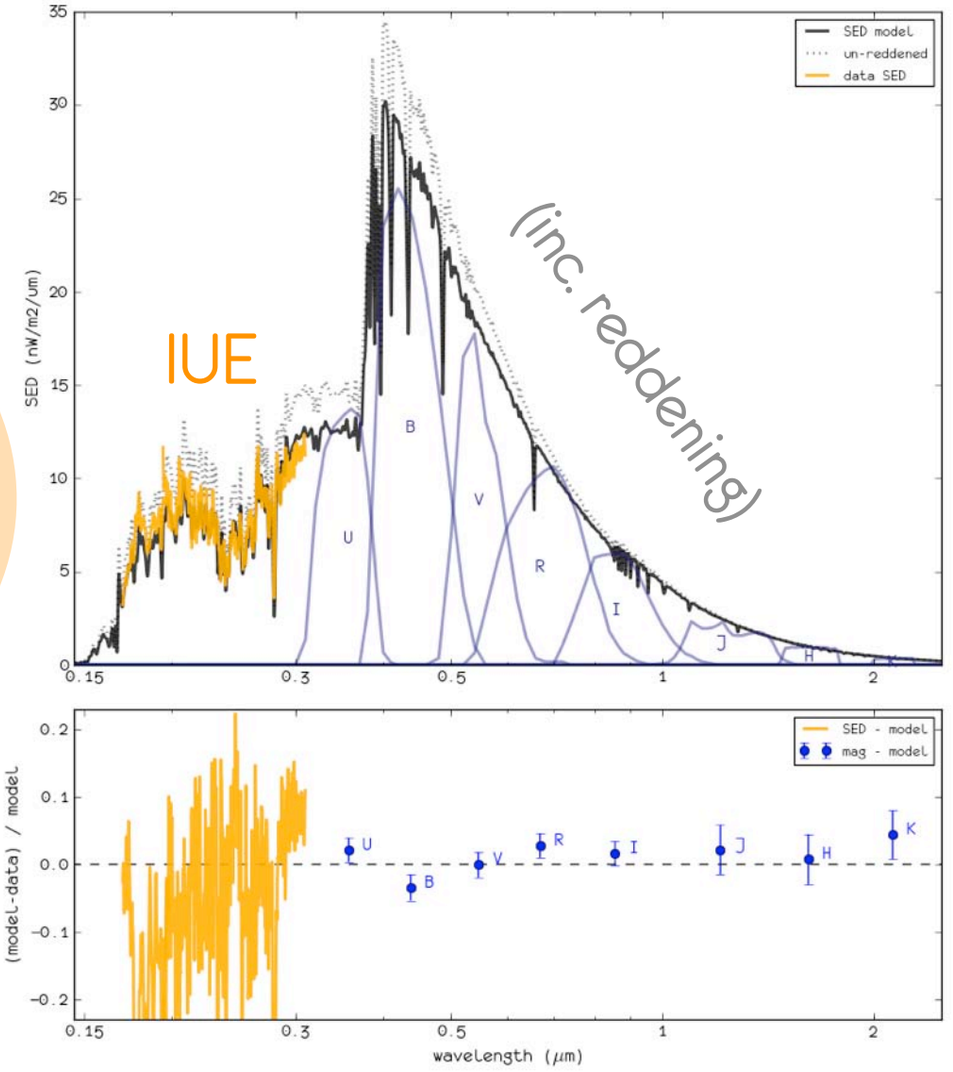




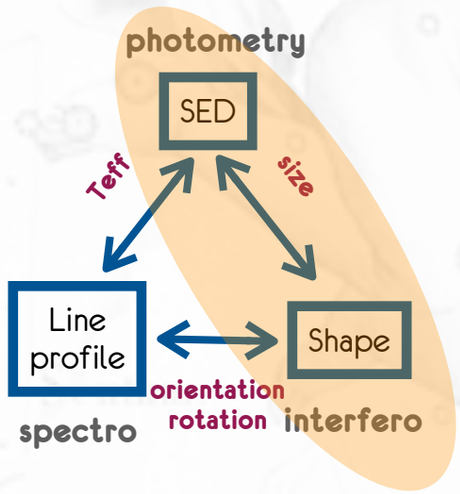


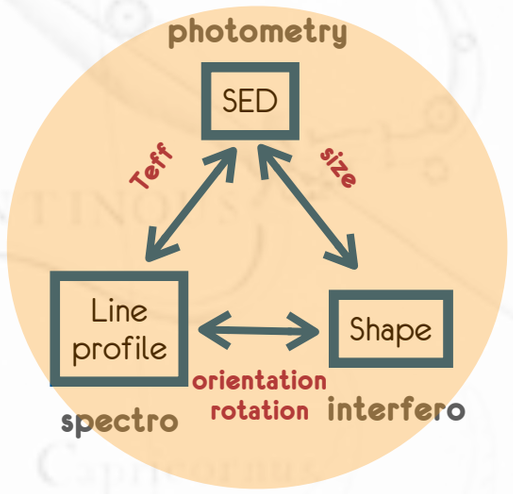
AMBER (BrγX)





	Monnier+ 2007	this work
	MIRC / V,H	MIRC+PIONIER / IUE+UBVRIJHK spectro / spectro-interf.
χ2	1.2 / 0.0	1.2+1.7 / 1.2 / 2.6 / 1.3
R Polar ($R_\odot$)	**1.634** ± 0.011	**1.636** ± 0.015
Teff Polar (K)	**8450** ± 140	**8600** ± 150 (8400)
E(B-V)	**0.0**	**0.033** ± 0.015 (0)
inc (º)	**57** ± 2	**57** ± 2
PA (º)	**-62** ± 1	**-64** ± 1
β	**0.190** ± 0.011	**0.196** ± 0.015
ω/ω_{crit}	**0.923** ± 0.006	**0.915** ± 0.011
Mass ($M_\odot$)	**1.791**	
distance (pc)	**5.14**	





	Monnier+ 2007	this work	
	MIRC / V,H	MIRC+PIONIER / IUE+UBVRIJHK spectro / AMBER	PIONIER / IUE+UBVRIJHK spectro / AMBER
X2	1.2 / 0.0	1.2+1.7 / 1.2 2.6 / 1.3	1.7 / 0.7 2.6 / 1.5
R Polar ($R_\odot$)	**1.634** ± 0.011	**1.636** ± 0.015	**1.637** ± 0.020
Teff Polar (K)	**8450** ± 140	**8600** ± 150	**8930** ± 200
E(B-V)	**0.0**	**0.033** ± 0.015	**0.035** ± 0.020
inc (º)	**57** ± 2	**57** ± 2	**65** ±8
PA (º)	**-62** ± 1	**-64** ± 1	**-60** ±3
β	**0.190** ± 0.011	**0.196** ± 0.015	**0.230** ± 0.040
ω/ω_{crit}	**0.923** ± 0.006	**0.915** ± 0.011	**0.910** ± 0.020
Mass ($M_\odot$)	**1.791**		
distance (pc)	**5.14**		

over-resolved interferometry (2nd lobe with CHARA/MIRC) provides the highest constraint on gravity darkening

Results

- Sucessful simultaneous spectro-photo-interferometric modeling of a rotating star
- **MIRC / PIONIER cross validated**: same model explains both datasets
- PIONIER data are not the highest constraints: **not enough spatial resolution** *(gravity darkening study needs 2nd lobe!)*

Science 317 (2007) 342-317

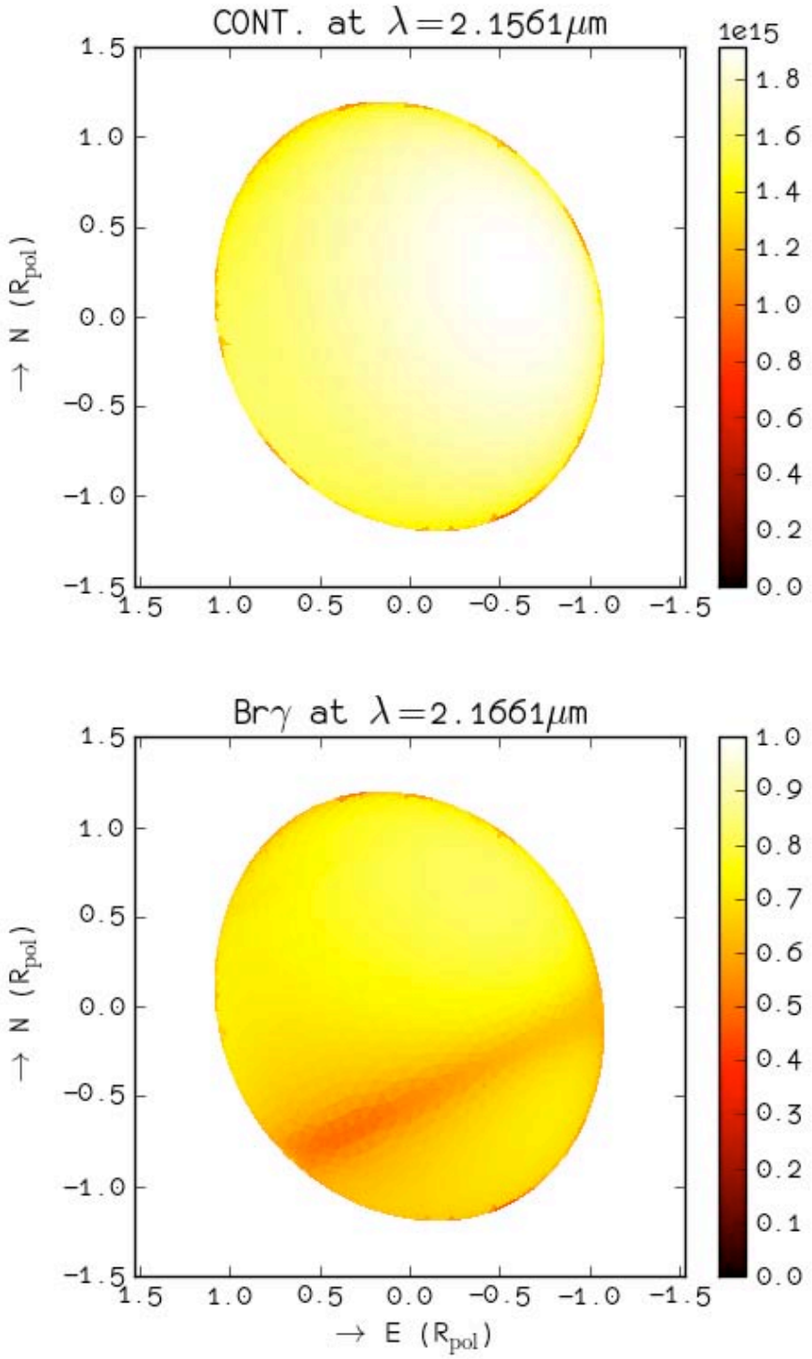
Imaging the Surface of Altair

John D. Monnier,[1]* M. Zhao,[1] E. Pedretti,[2] N. Thureau,[3] M. Ireland,[4] P. Muirhead,[5] J.-P. Berger,[6] R. Millan-Gabet,[7] G. Van Belle,[7] T. ten Brummelaar,[8] H. McAlister,[8] S. Ridgway,[9] N. Turner,[8] L. Sturmann,[8] J. Sturmann,[8] D. Berger[1]

Spatially resolving the surfaces of nearby stars promises to advance our knowledge of stellar physics. Using optical long-baseline interferometry, we constructed a near-infrared image of the rapidly rotating hot star Altair with a resolution of <1 milliarcsecond. The image clearly reveals the strong effect of gravity darkening on the highly distorted stellar photosphere. Standard models for a uniformly rotating star cannot explain our findings, which appear to result from differential rotation, alternative gravity-darkening laws, or both.

differential rotation effects

uniform rotation

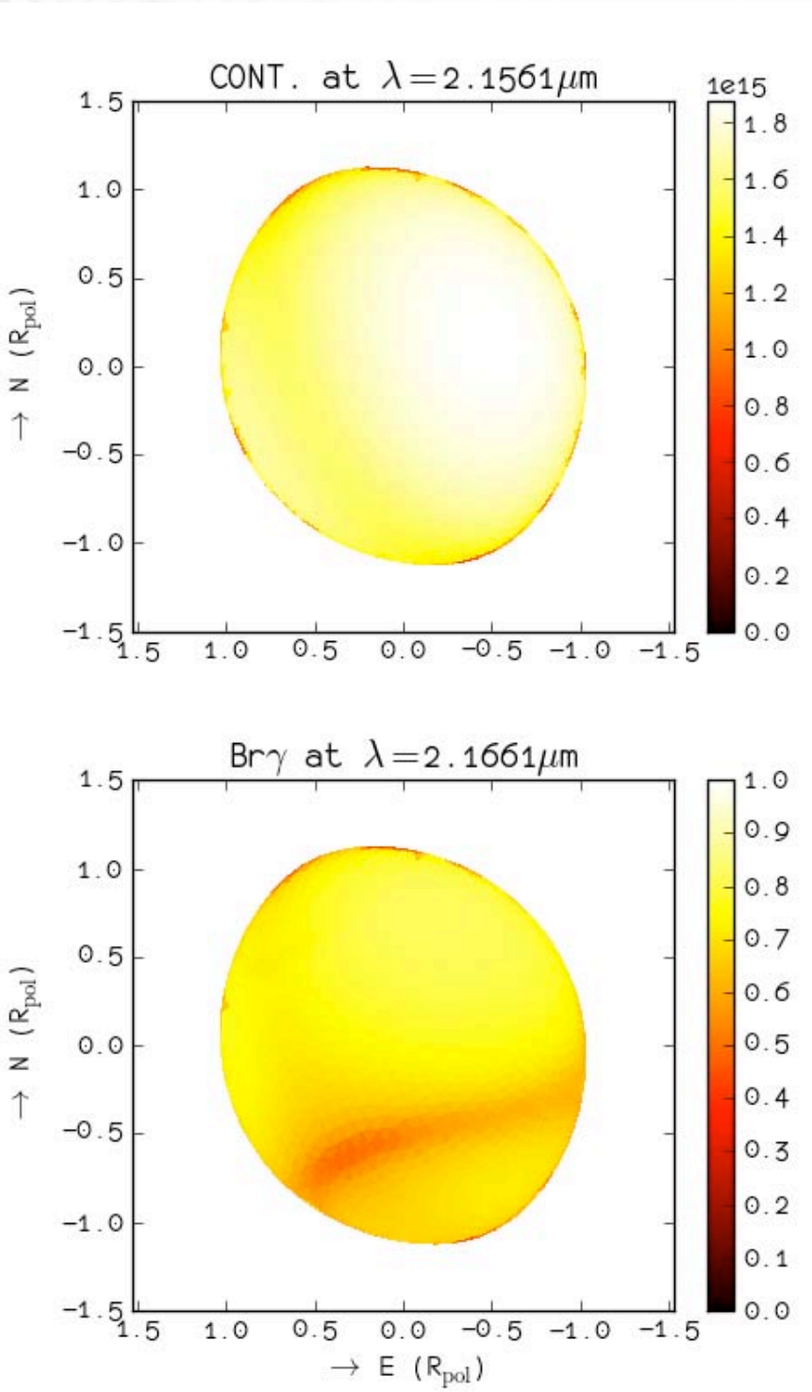


size:
smaller for equivalent apparent luminosity

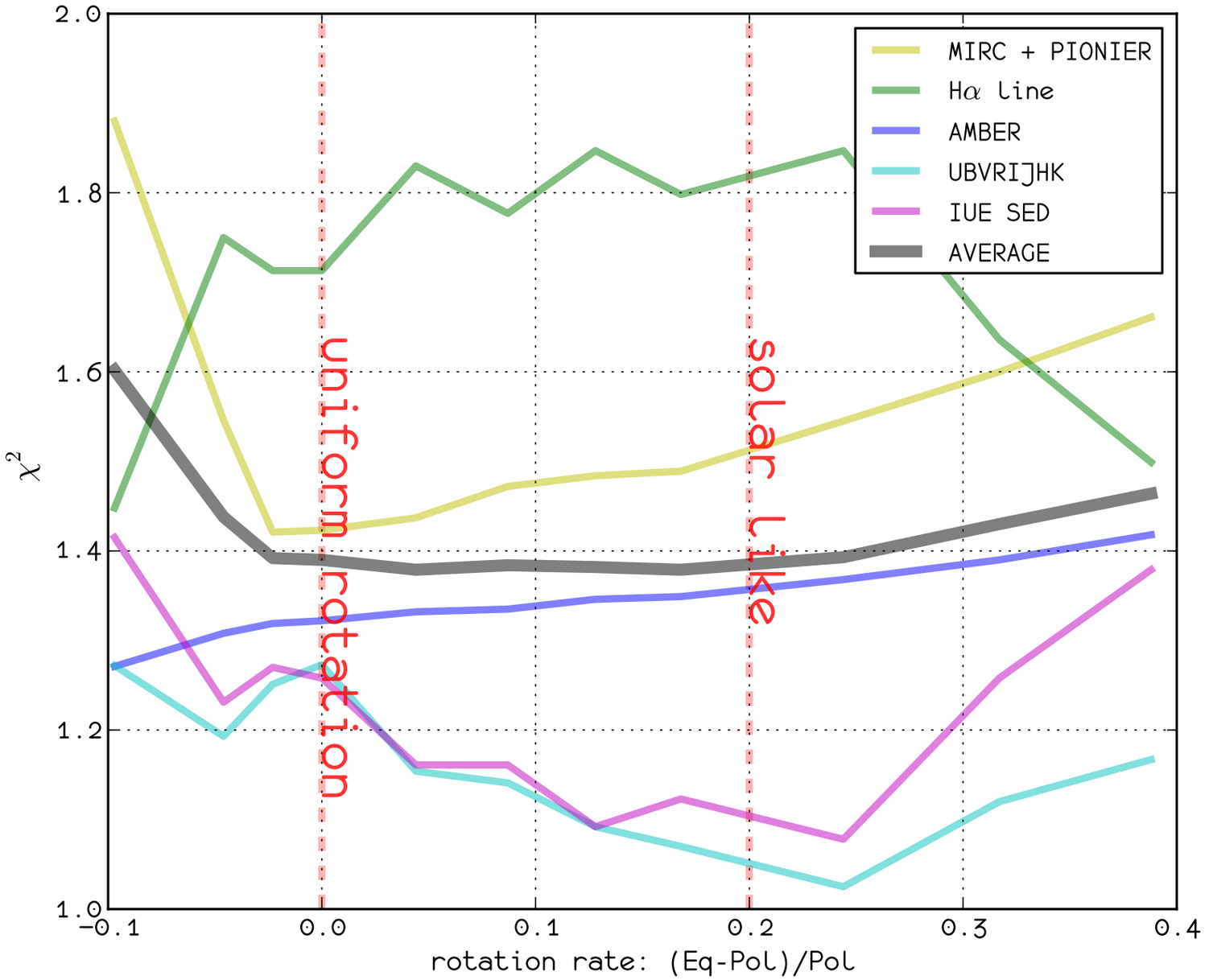
shape:
less oblate

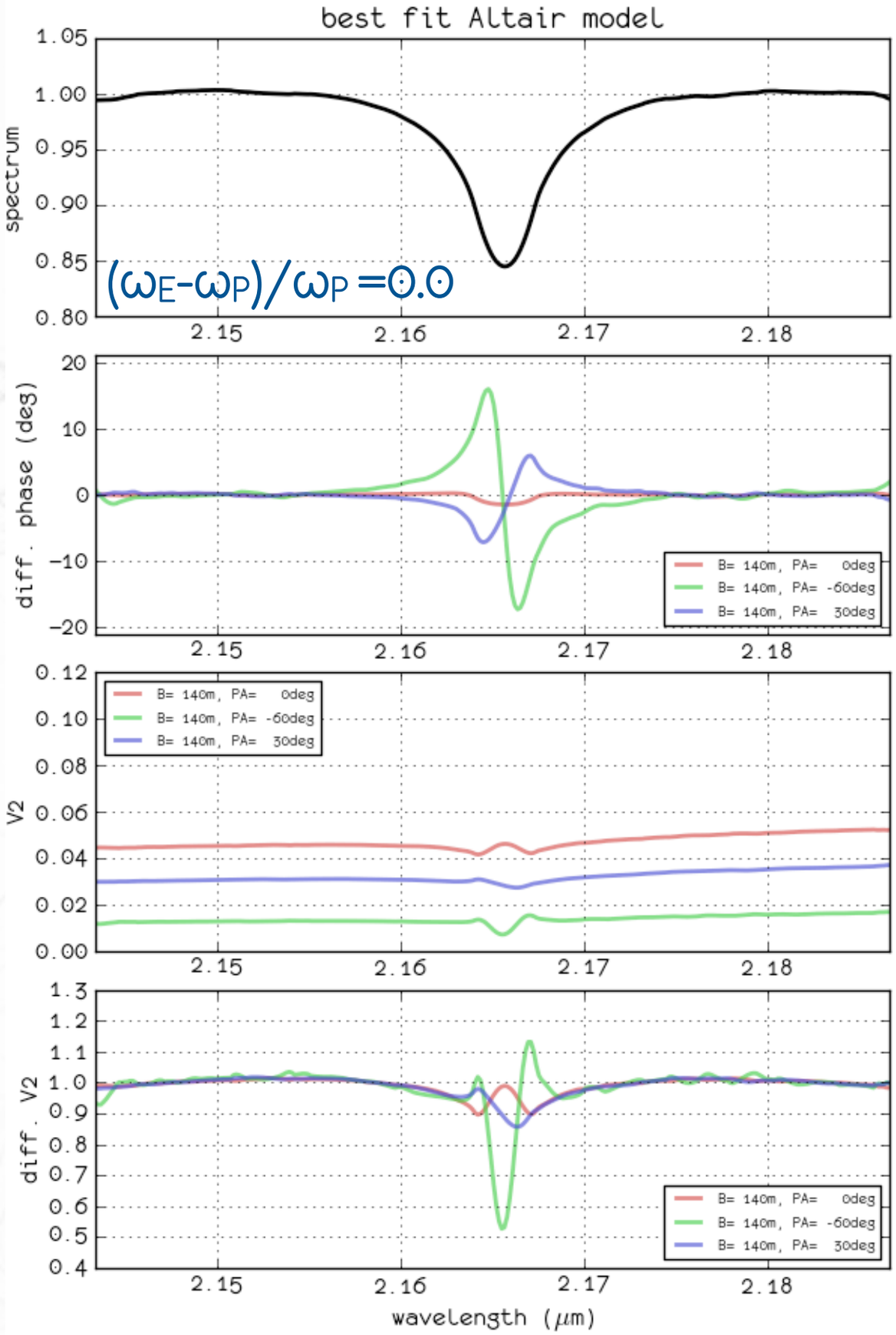
velocity field:
lines are twisted

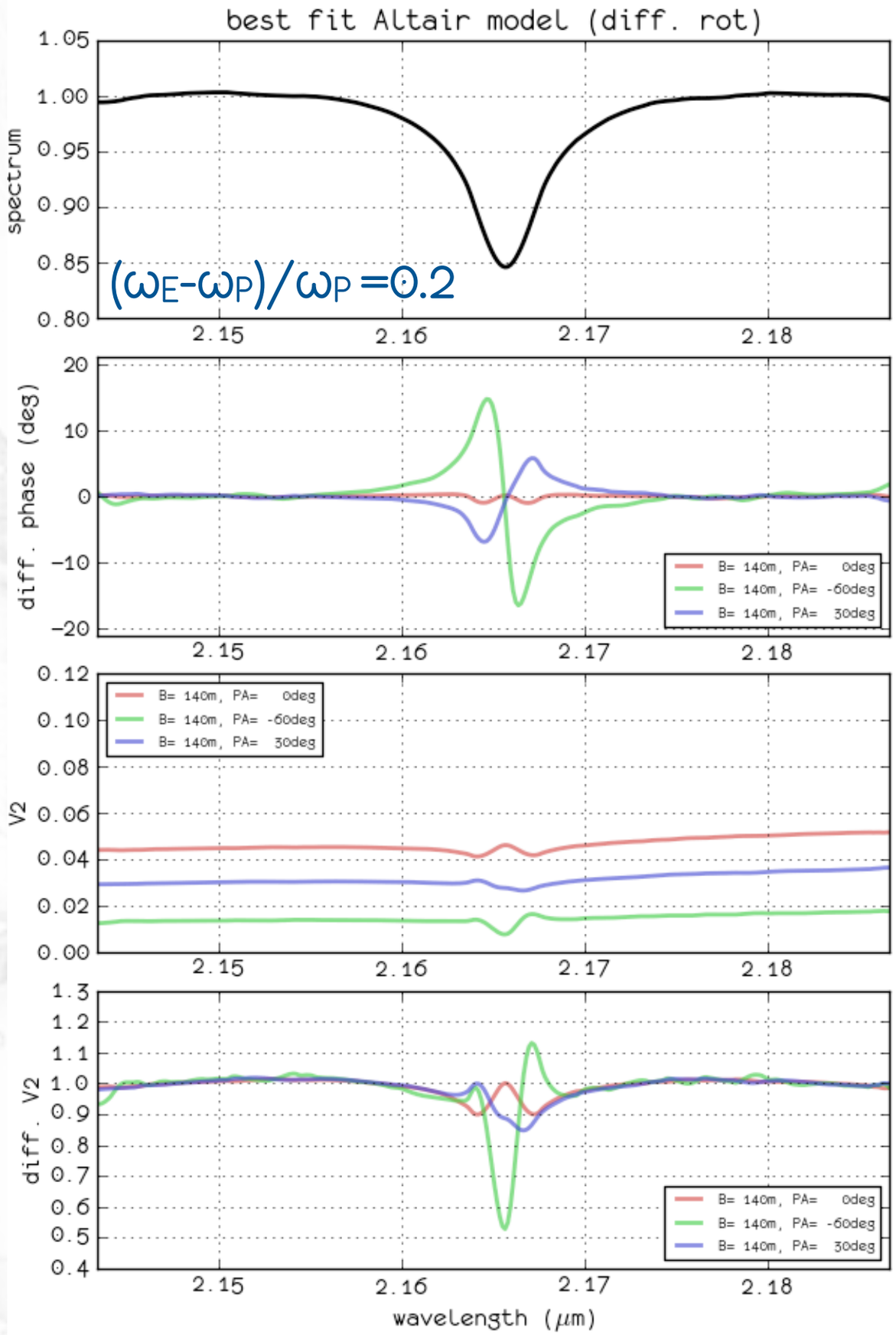
solar like lat. diff. rotation



Constraining the differential rotation

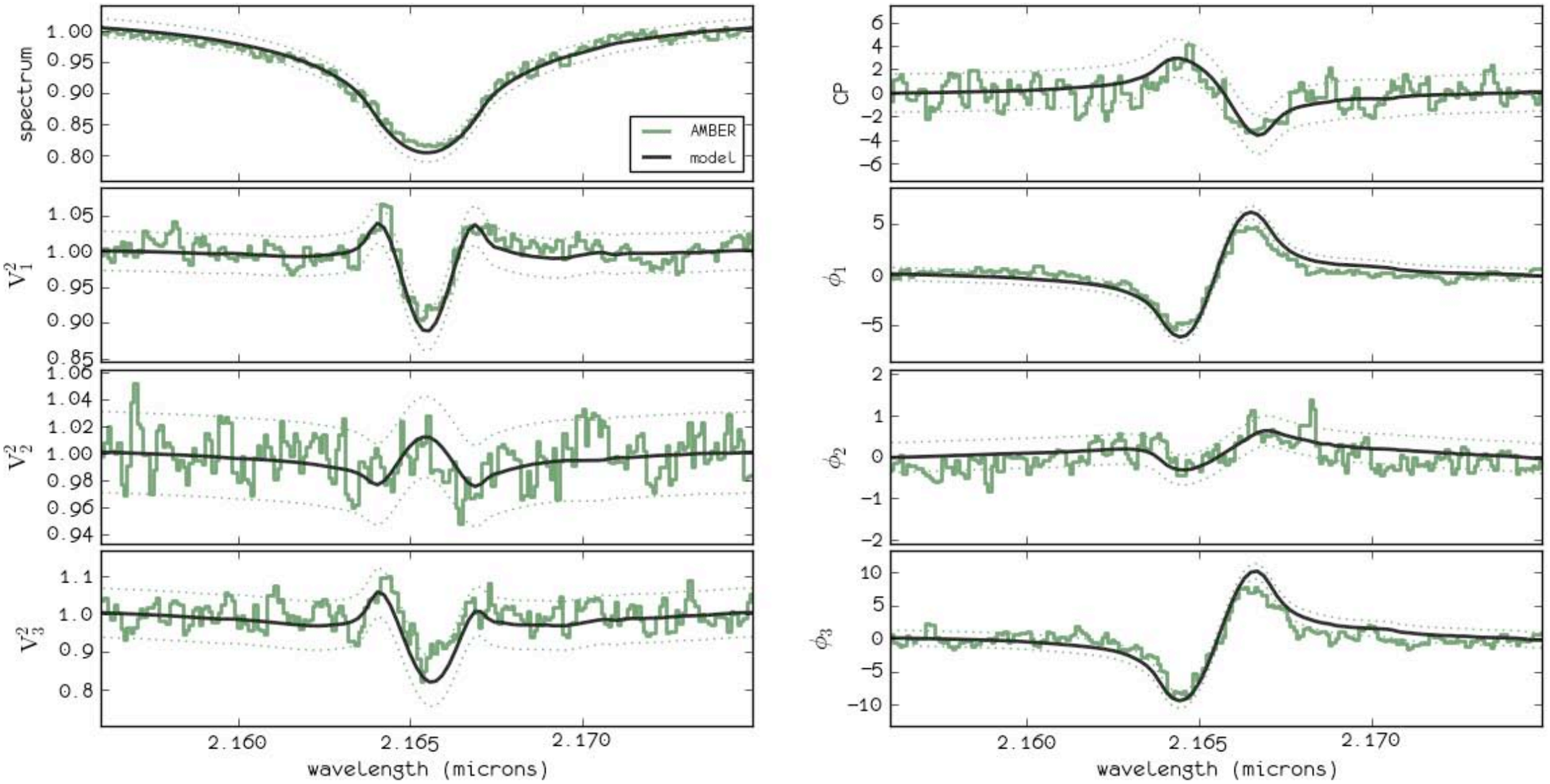


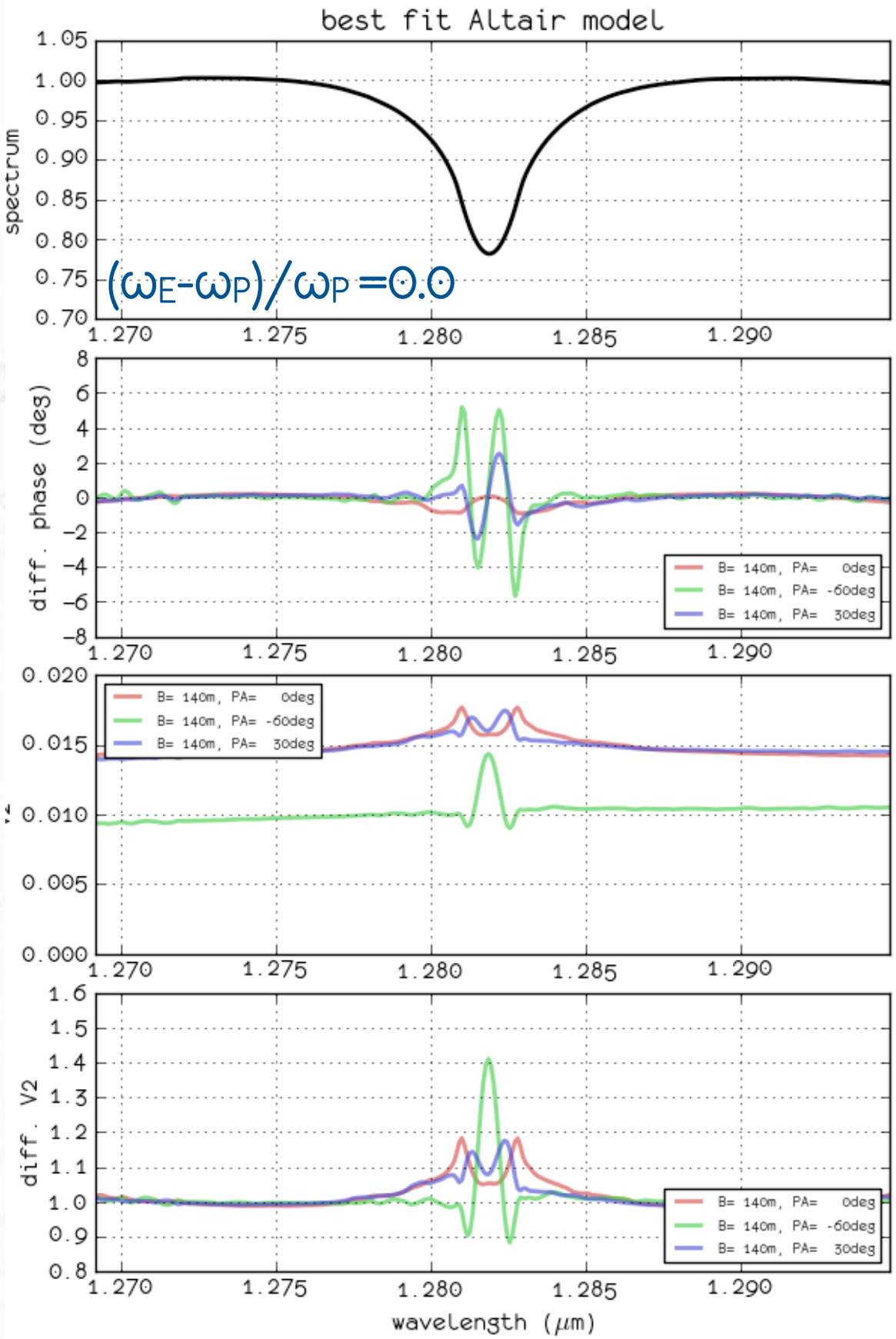


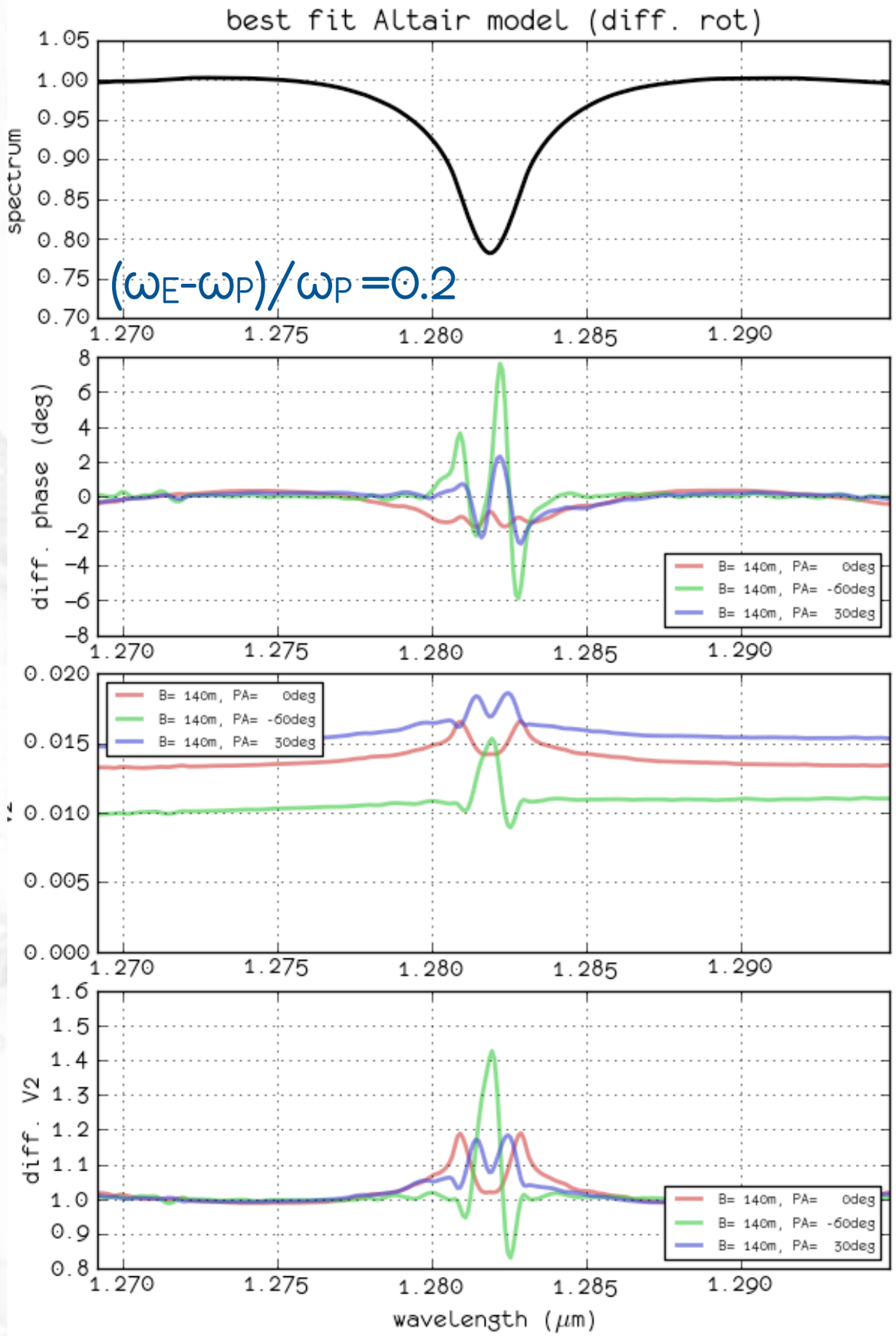


currently: K band with Baseline of 140m

AMBER (Brγ)


spectrum
AMBER
model
V_1^2
V_2^2
V_3^2
CP
ϕ_1
ϕ_2
ϕ_3
wavelength (microns)
wavelength (microns)





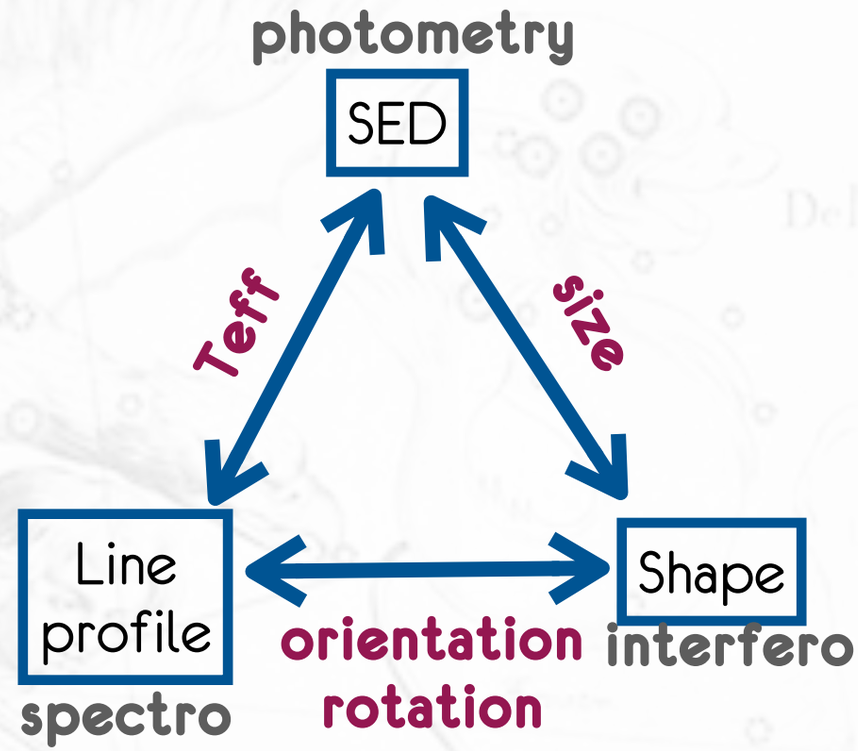
predicted: J band and Baseline of 140m (in 2nd lobe)

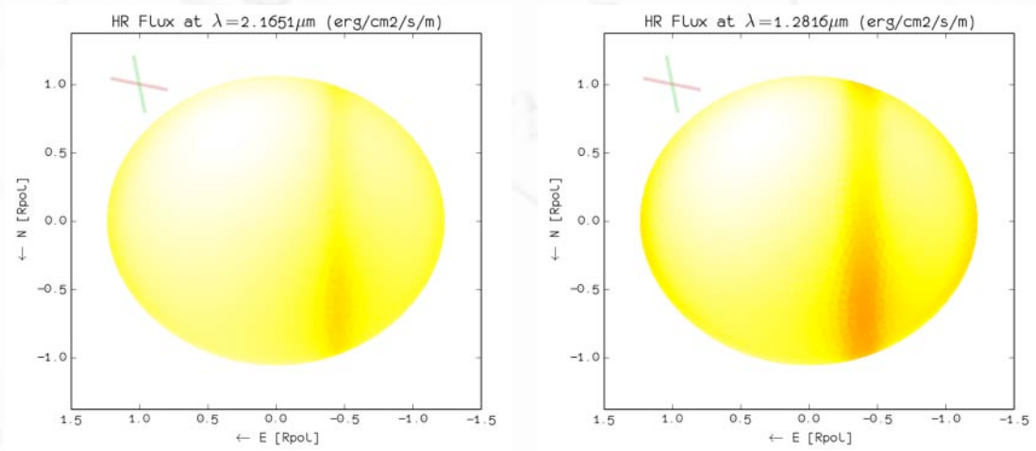
Conclusion

- **Modeling**:
  - confirmation of Monnier+07 parameters (inc. low gravity darkening)
  - multi-technics: all data interpreted successfully by (naive) model
- **Latitudinal differential rotation:**

  Altair: $0.0 \lesssim (\omega_E-\omega_P)/\omega_P \lesssim 0.2$

  confirmed by Michel Rieutord's model
- **PIONIER upgrade?**
  - PIONIER weak constraints for (most) rotating stars... (only 1rst lobe)
  - **R>5000 at λ~1µm:** higher spatial resolution and many more lines!





K Band -> J band

Paschen series B=50m