Line Asymmetry of Cepheids

A NIR approach

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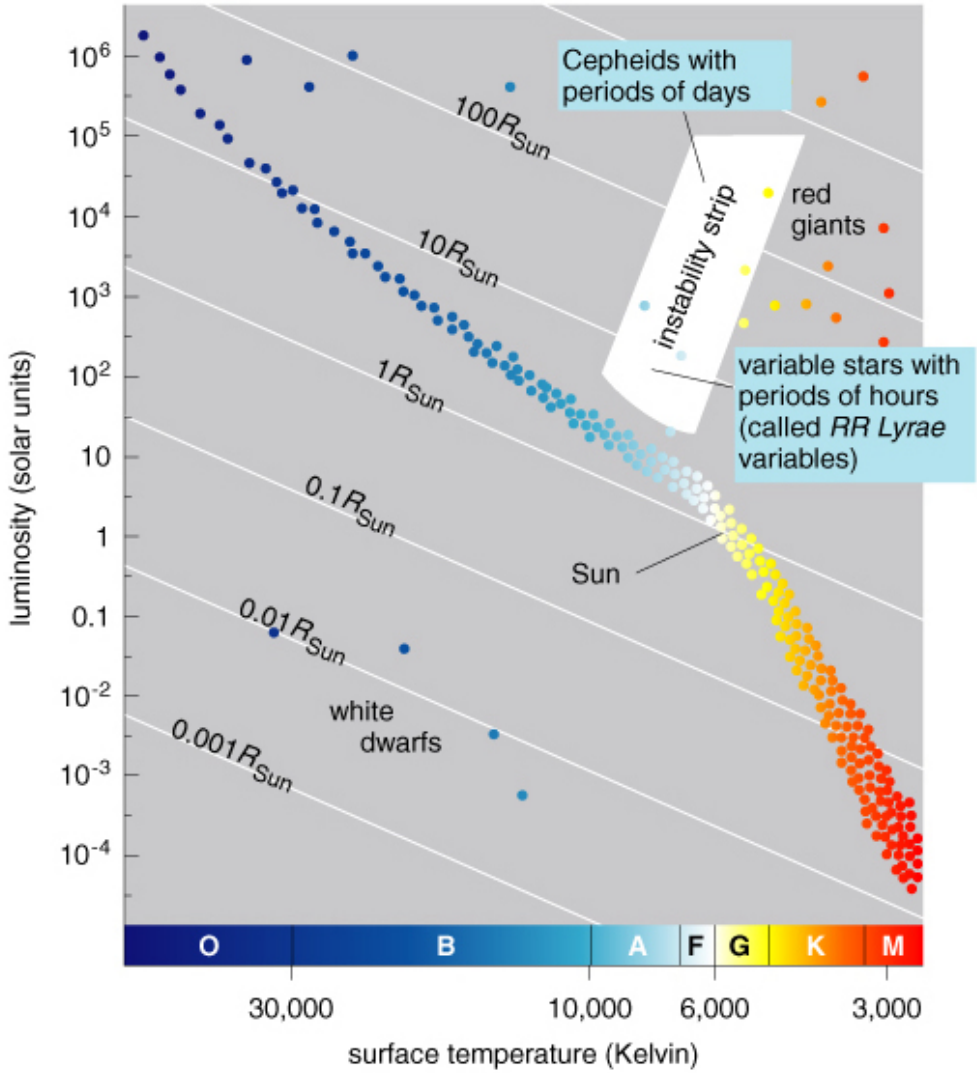
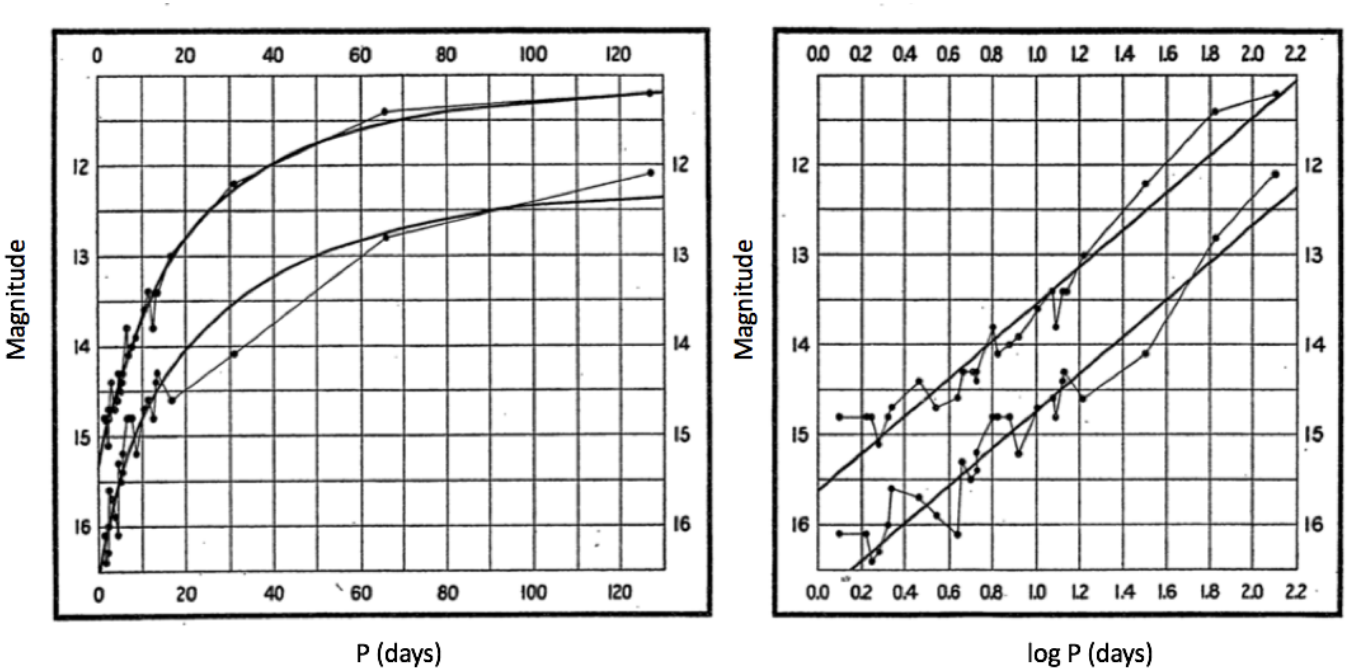
Cepheids

- Location in HR diagram.
- Massive stars ($\geq 3.5 - 4.0 M_{\odot}$)
- Young $\star$



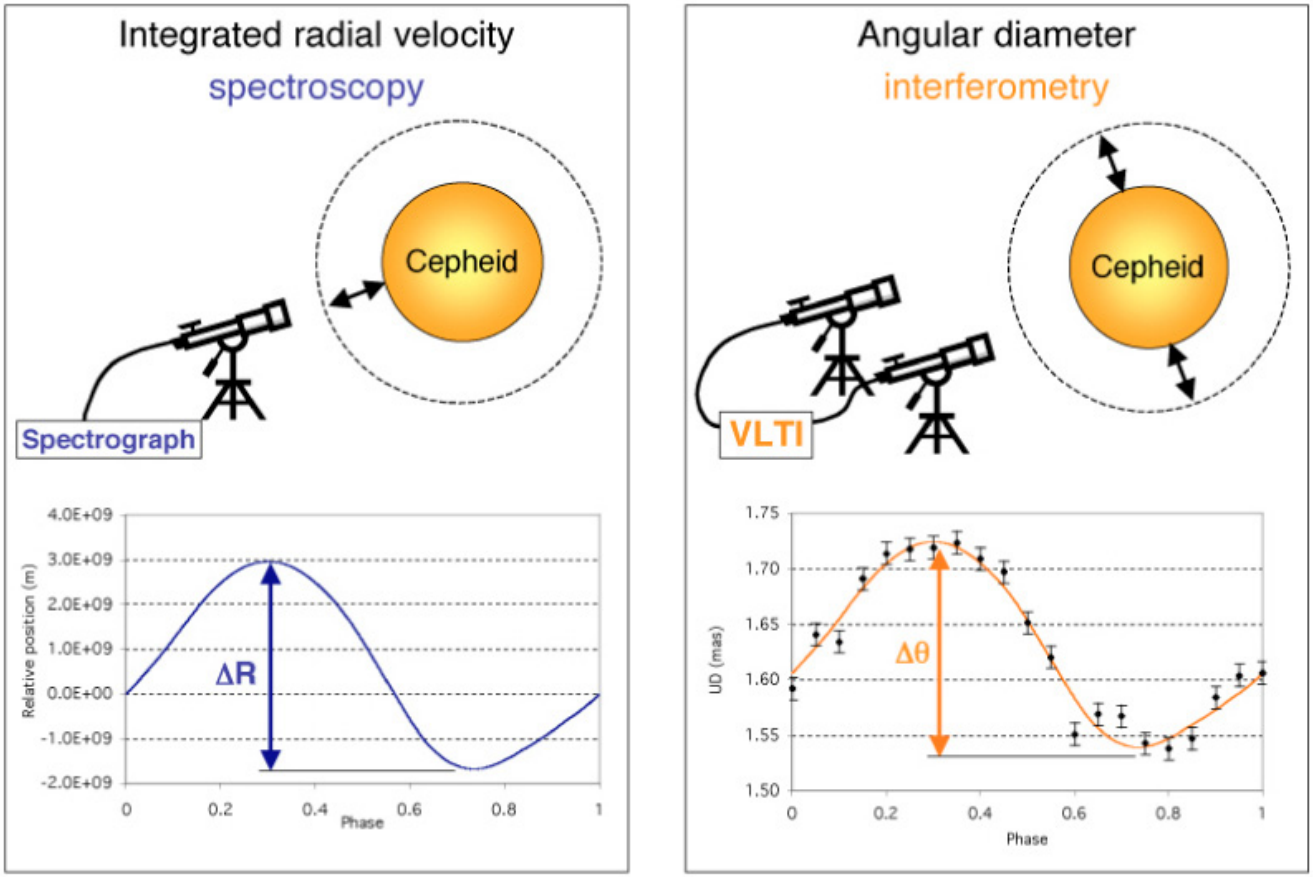
Cepheids

Discovery!: Henrietta Leavitt (P-L relation) (1912)



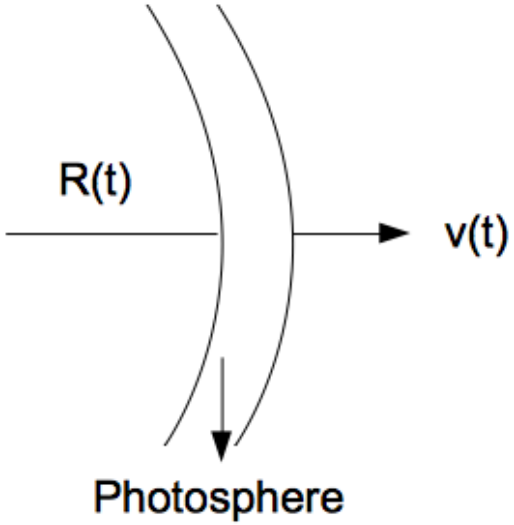
$$m - M = 5 \log (d) - 5$$

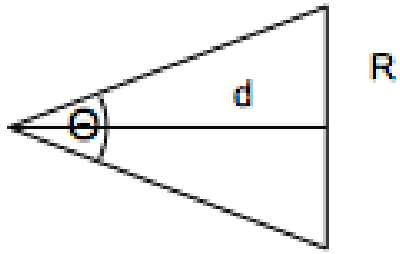
Baade-Wesselink Method



$$d\ [\mathrm{pc}] = 9.305\ \Delta R\ [R_\odot] / \Delta\theta\ [\mathrm{mas}]$$

Baade-Wesselink Method





$$\frac{R}{d} = tan\frac{\Theta}{2} \approx \frac{\Theta}{2}$$

$$d[pc] = \frac{2\Delta R}{\Delta\Theta[mas]}$$

$$\Delta R[R_\odot] = R(t) - R(t_0) = \int_{t_0}^{t} v(t)dt$$

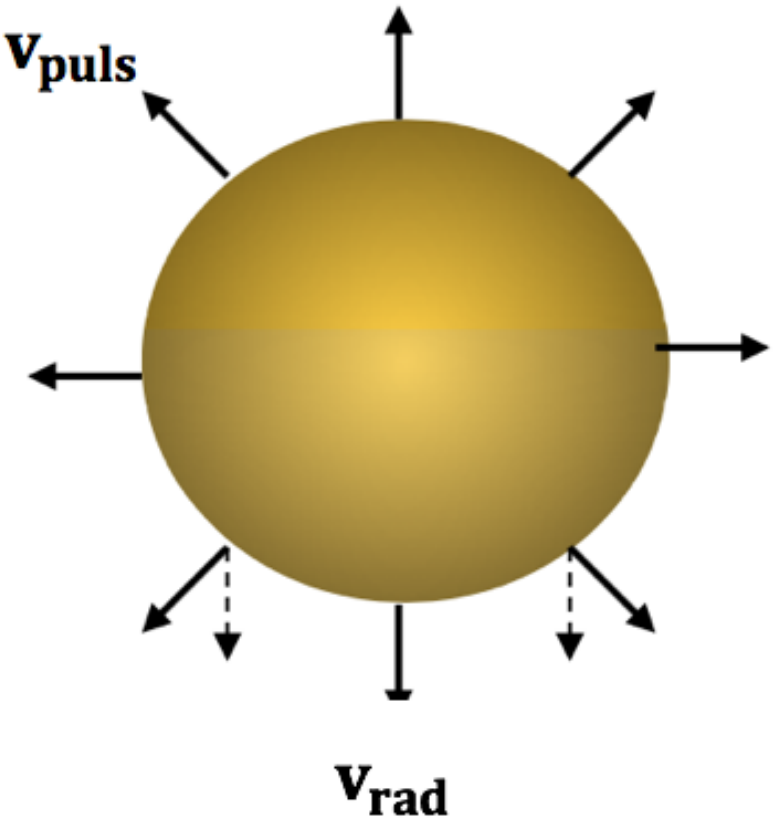
From the latter:

$$d \propto \frac{\Delta R}{\Delta \Theta}$$

With

$$R(t) = \int p V_{rad}\, dt$$

Then, p allows us to *convert* radial into pulsation velocities.



p factor: δ Cep

method	p	reference
Geometrical models		
centroid	1.415	Getting (1934)
centroid	1.375	van Hoof & Deurinck (1952)
centroid	1.360	Burki et al. (1982)
centroid	1.328	Neilson et al. (2012)
Hydrodynamical models		
bisector	1.34	Sabbey et al. (1995)
Gaussian	1.27 ± 0.01	Nardetto et al. (2004)
cc-g (Pp)	1.25 ± 0.05	Nardetto et al. (2009)
Observations		
cc-g	$1.273 \pm 0.021 \pm 0.050$	Mérand et al. (2005)
cc-g	$1.245 \pm 0.030 \pm 0.050$	Groenewegen (2007)
cc-g	$1.290 \pm 0.020 \pm 0.050$	Merand et al. (2015)
cc-g (Pp)	1.47 ± 0.05	Gieren et al. (2005b)
cc-g (Pp)	1.29 ± 0.06	Laney & Joner (2009)
cc-g (Pp)	1.41 ± 0.05	Storm et al. (2011b)
cc-g (Pp)	1.325 ± 0.03	Groenewegen (2013)

p factor "decision"?

p factor decomposition

$$p = p_0 \cdot f_{grad} \cdot f_{o-g}$$

$$p_0 = \frac{\Delta V_l^g}{\Delta RV_c}$$

Geometrical

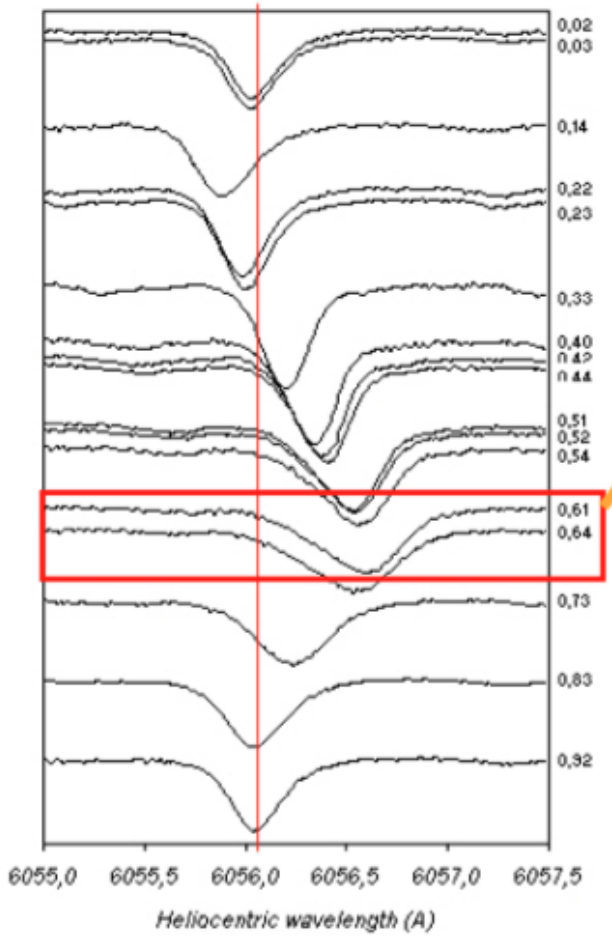
$$f_{grad} = \frac{\Delta V_p^g}{\Delta V_l^g}$$

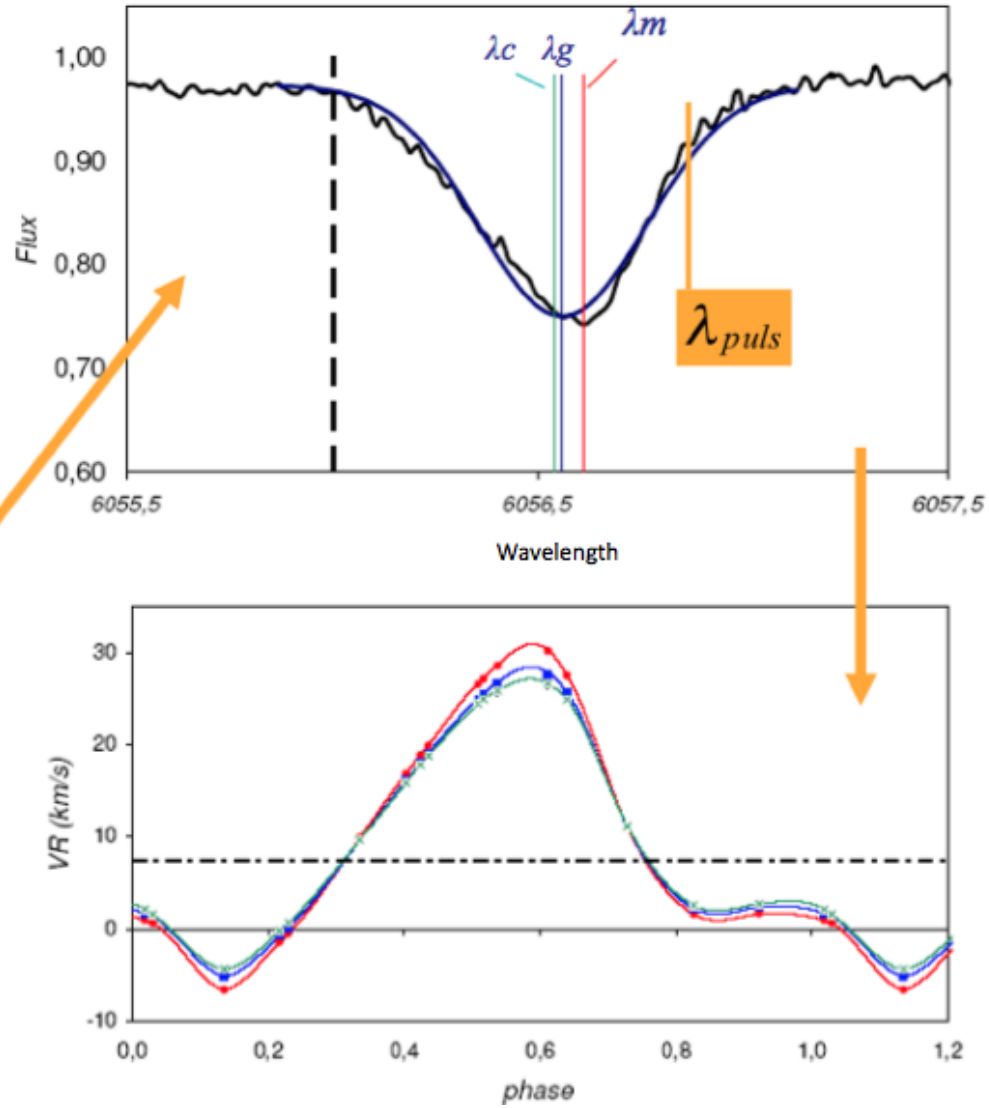
Velocity gradient

$$f_{o-g} = \frac{\Delta V_p^o}{\Delta V_p^g}$$

Distinction between optical and gas photospheric layers

Radial Velocity Definition





RV importance

$$\boxed{d[pc] = 9.3\frac{\Delta R}{\Delta\theta}}$$

$$\Delta R = R(t) - R(t_0) = \int_{t_0}^{t} v(t)\,dt$$

$$R(t) = \int p\, v_{rad}\,dt$$

$$p_g = \frac{v_{puls}}{RV_g}$$

$$p_c = \frac{v_{puls}}{RV_c}$$

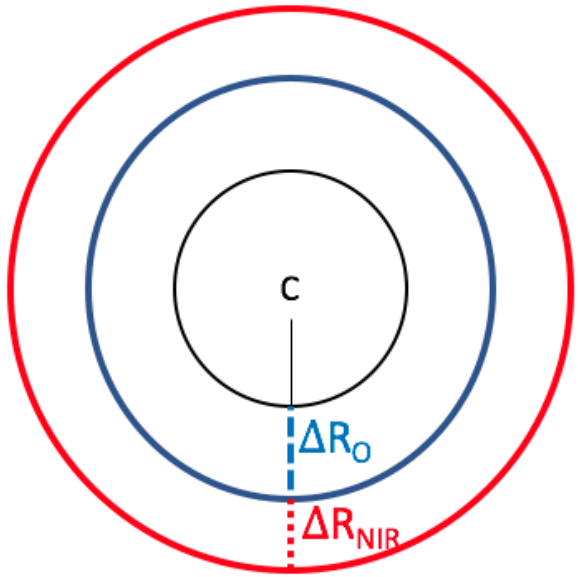
$$p_m = \frac{v_{puls}}{RV_m}$$

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

$$v_{puls}(\varphi) = v_{max}(\cos 2\pi\varphi_i)$$

Optical or Near Infrared?

- BW Method: Where are we looking to?
- Radial Velocity Amplitudes.
- Advantages



Optical photospheric layer $\neq$ Infrared photospheric layer

How? : WINERED

Warm **IN**frared **E**chelle spectrograph to **R**ealize **E**xtreme **D**ispersion and sensitivity

- Made in Japan, now in Chile :)
- Warm Optics
- Wide spectral coverage: $0.9 - 1.35[\mu m]$
- Throughput $\sim$ 50 %

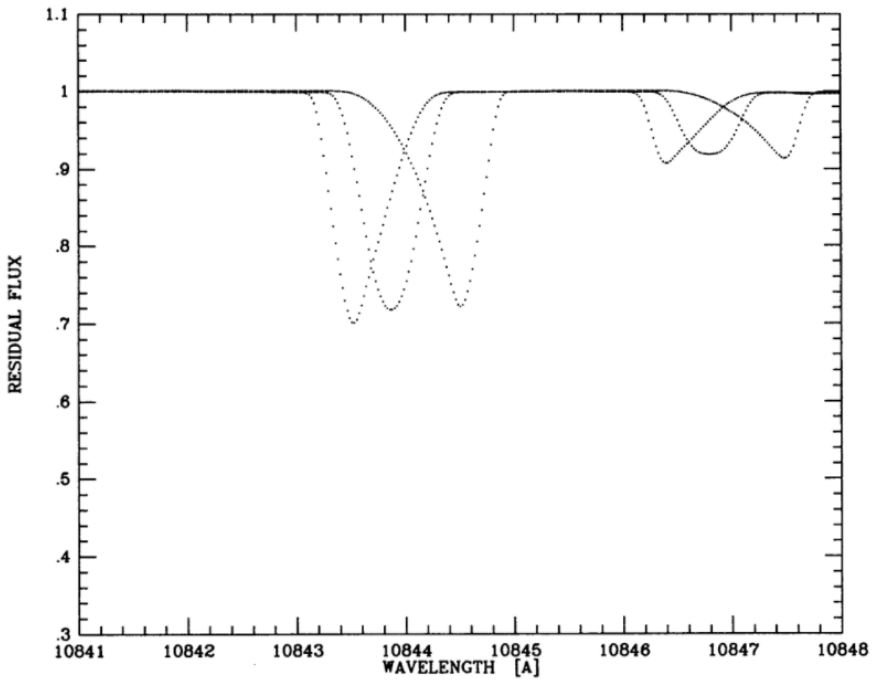
3 Observing modes:

- WIDE:$0.9 - 1.35[\mu m]$, R=30000
- HIRES-Y:$0.96 - 1.11[\mu m]$, R=80000
- HIRES-J: $1.14 - 1.35[\mu m]$, R=80000

Name	Period
Su Cas	1.94932
DT Cyg	2.49922
SZ Tau	3.14873
V1334 Cyg	3.33282
RT Aur	3.72812
Polaris	3.9696
T Vul	4.43546
FF Aql	4.47092
δ Cep	5.36634
V367 Sct	6.29307
η Aql	7.17664
DL Cas	8.00067
S Sge	8.38209
ζ Gem	10.15073
X Cyg	16.38633

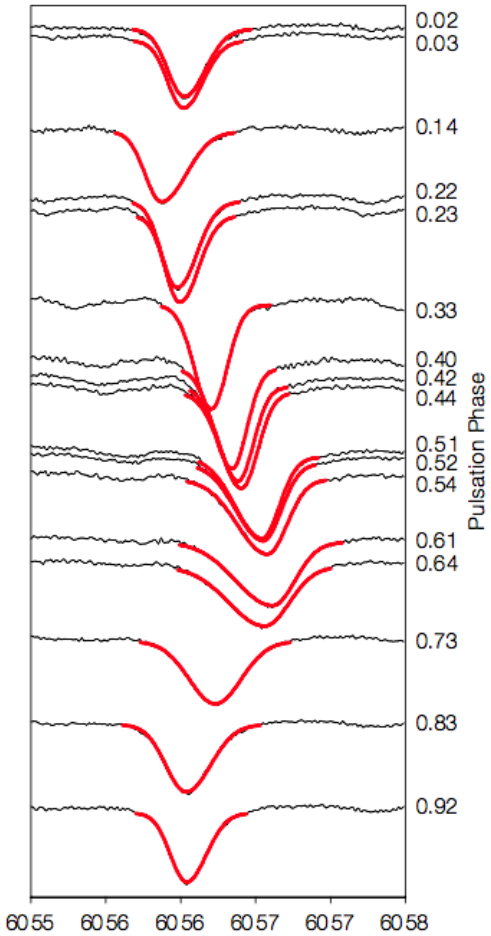
Line Asymmetry

Sasselov & Lester in 1990:



What's going on in here?

β - Dor spectral evolution:



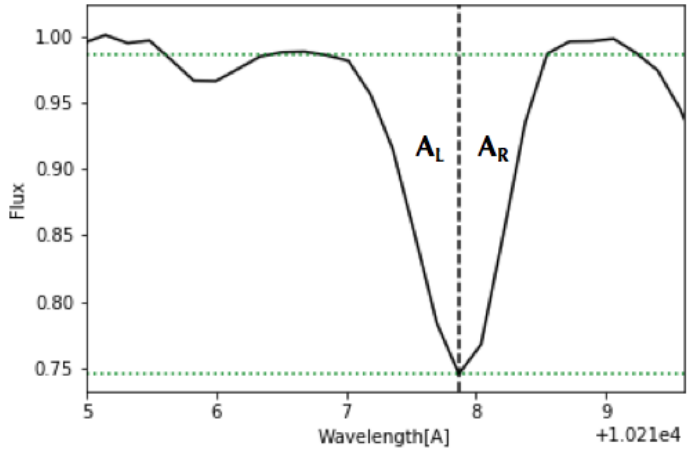
Line Asymmetry

Spectral line profile → Asymmetry
Involved phenomena:

- Photospheric pulsation velocity V_{puls}
- Limb Darkening
- Velocity Gradients ⋆
- Turbulence

All of them can be merged into one quantity ⇒ **Projection Factor!**

How is it defined?



Center determined by parabolic fit.

$$\frac{A_L - A_R}{A_{Total}} \times 100$$

Asymmetry percentage

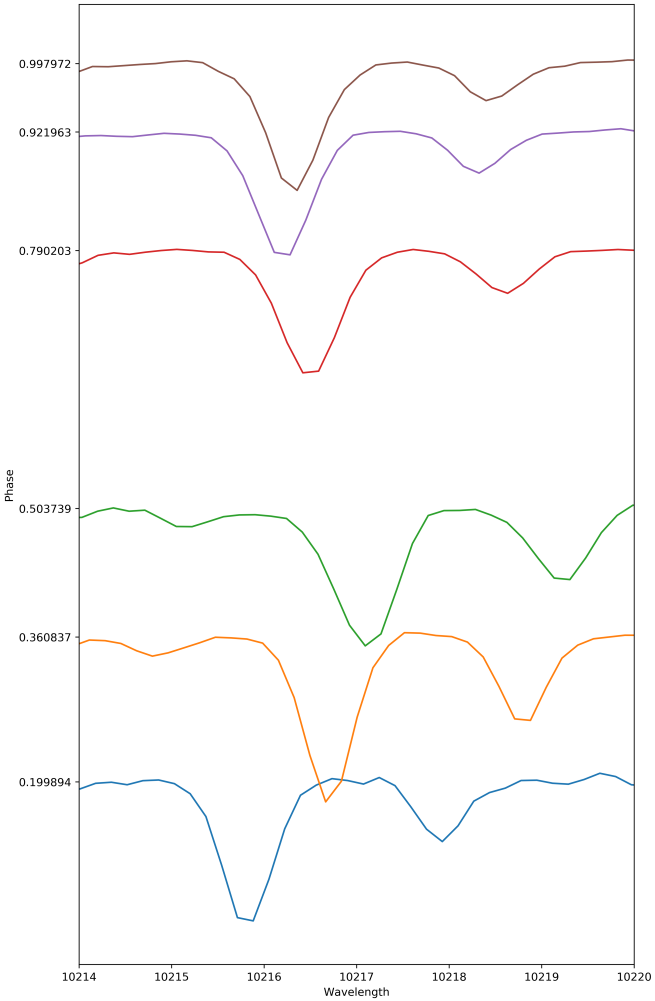
Solving the puzzle!

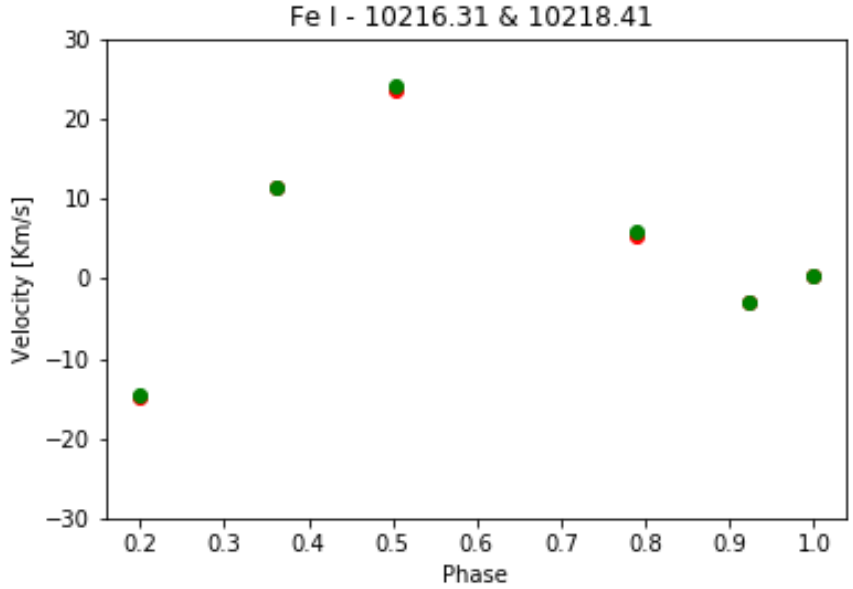
The corners...

- Target Feasibility
- Line List Creation
- Telluric Analysis
- Ephemeris !
- RV definition & precision?
- Toy model
- Interferometric Counterparts

ζ gem (P= 3.74 [days])

Spectral evolution of Fe I (10216-18 [A])



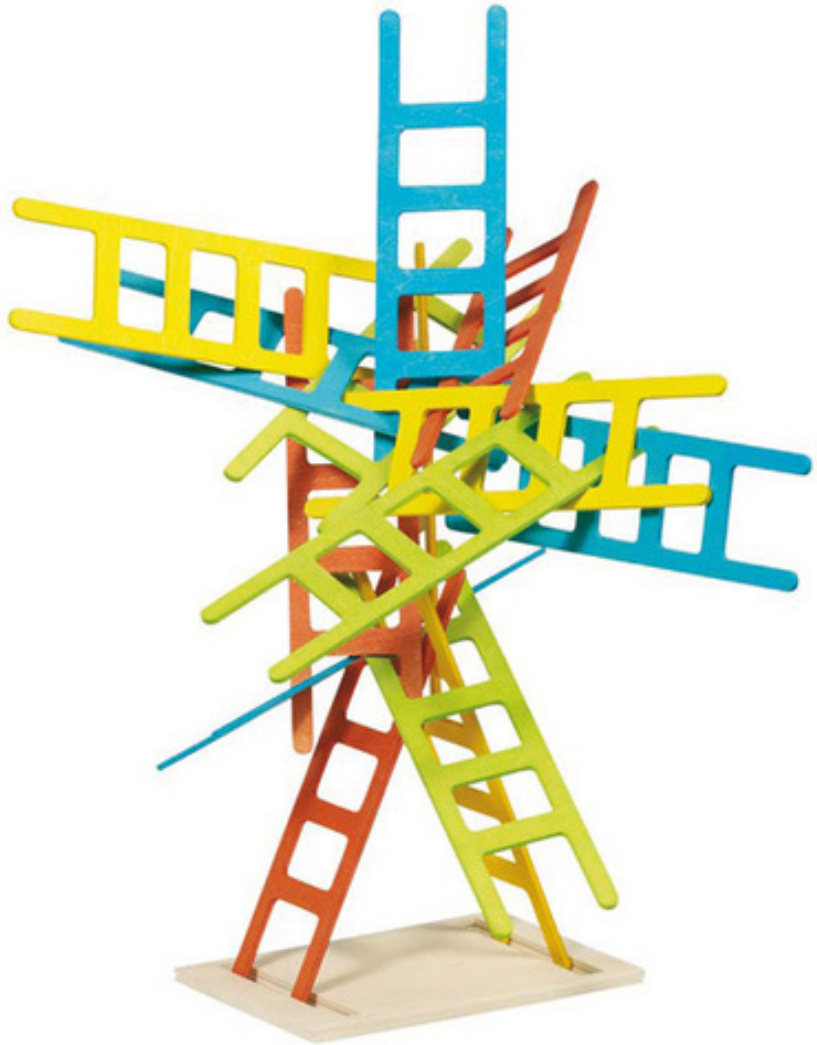


Radial Velocity curve using line minimum method.

Summary

- IBW Method limited by p!
- Distance biased up to the 6 % (See N. Nardetto 's Saga fron 2004)
- BW requirements satisfied(?)
- p and its phase (in)dependence?
- p and P-R and P-L relations(?)
- Unpredictable p!

Challenge accepted ... (?)



Thanks!