STELLAR ATMOSPHERE AND HYDRODYNAMIC MODELING: ISOSCELES V2.0

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In collaboration with
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Natalia Machuca (Universidad de Valparaíso)
Catalina Arcos (Universidad de Valparaíso)

and many others…

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POEMS

Physics of Extreme Massive Stars

Marie-Curie-RISE project funded by the European Union

Physics of Extreme Massive Stars
25 June, 2024
Rio de Janeiro, Brazil

A quick introduction

Michel Curé's talk…

Momentum Equation

Radial Coordinate: r Time: t Density: ρ Velocity: v

Gas Pressure

Centrifugal Force

$$\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial r} = -\frac{a^2}{\rho}\frac{\partial \rho}{\partial r} - \frac{G\,M(1-\Gamma_{\mathrm{E}})}{r^2} + \frac{v_\phi^2}{r} + g_{\mathrm{rad}}^{\mathrm{line}}$$

Inertia

Gravity

Line Force

$$v_\phi = v_{\mathrm{rot}}(\theta) R_*/r$$

$$a = \mathrm{sound\,speed}$$

Line-Force Parameters

M-CAK

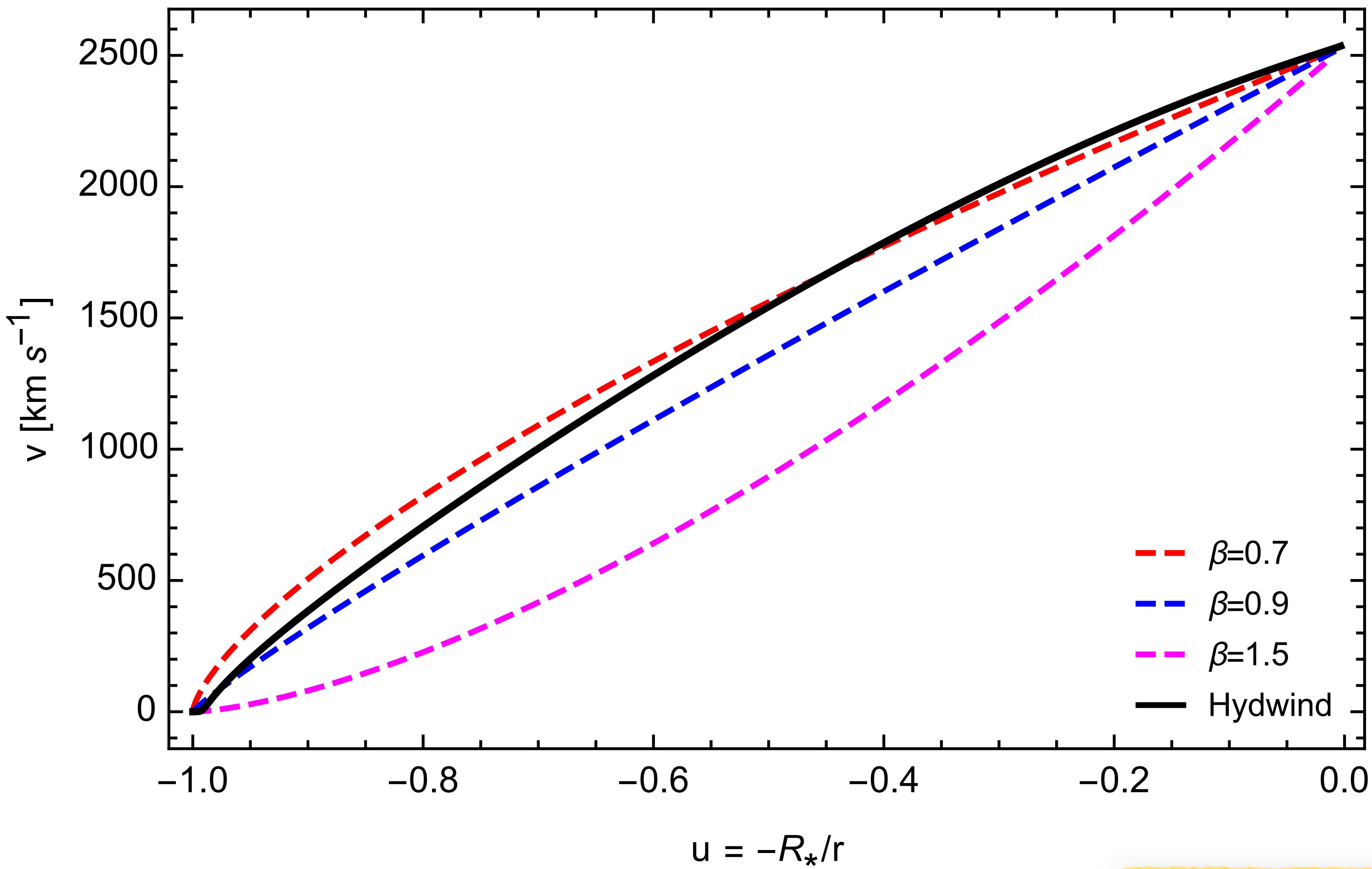
$$g_{\rm rad}^{\rm line} = \frac{\Gamma_{\rm E}\, G\, M\, k}{r^2} \left(\frac{1}{\sigma_{\rm E}\, v_{\rm th}}\right)^{\alpha} \left(\frac{1}{\rho}\frac{\partial v}{\partial r}\right)^{\alpha} \left(\frac{n_{\rm E11}}{W(r)}\right)^{\delta} f_{\rm CF}\left(r, v, \frac{\partial v}{\partial r}\right)$$

δ : changes in the ionization throughout the wind

k : related to the number of lines effectively contributing to the driving of the wind

α : ratio between the line-force from optically thick lines and the total line force

Fast Solution (Standard m-CAK)



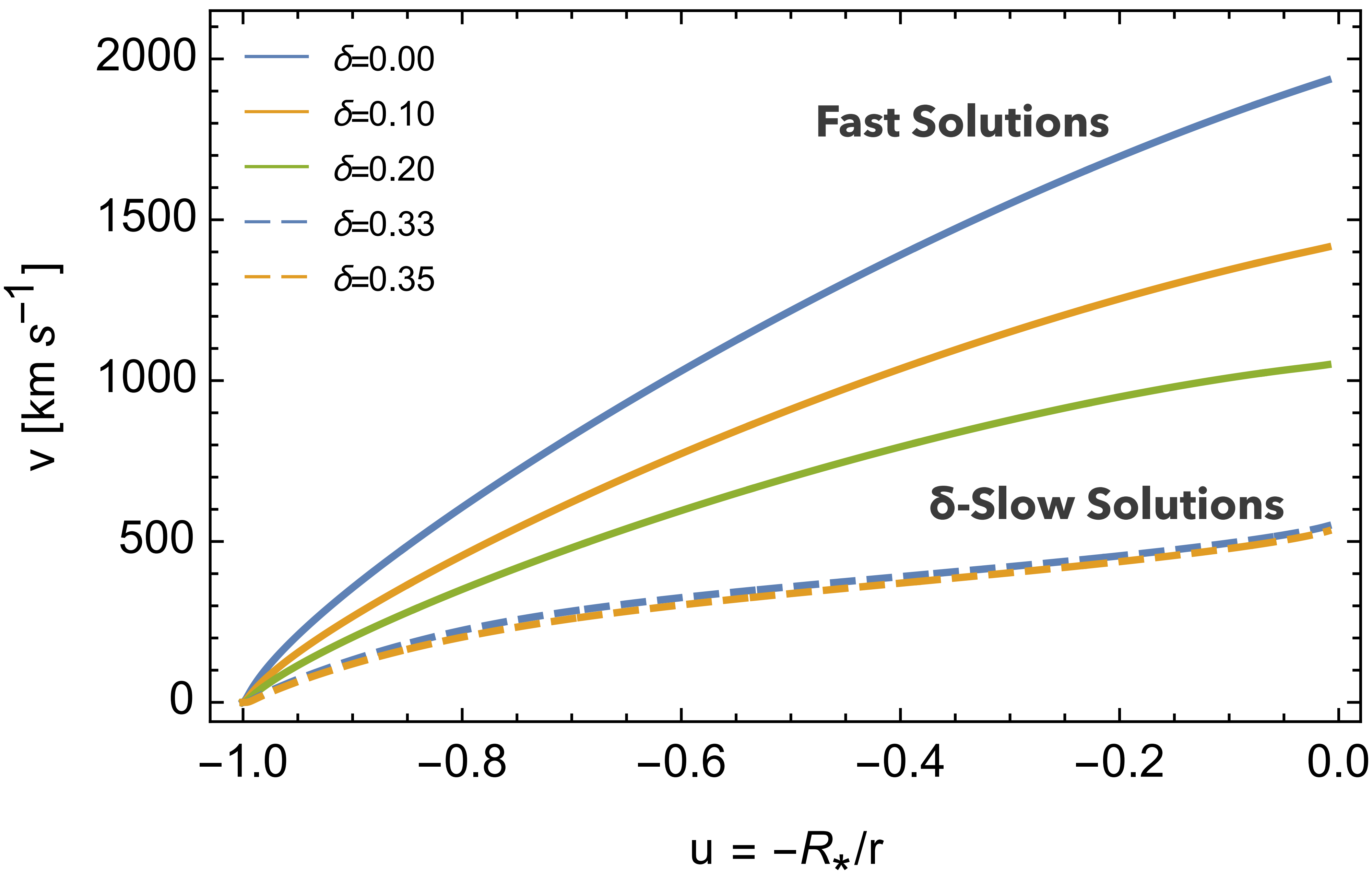
β-law

$$v(r) = v_\infty(1 - R_*/r)^\beta$$

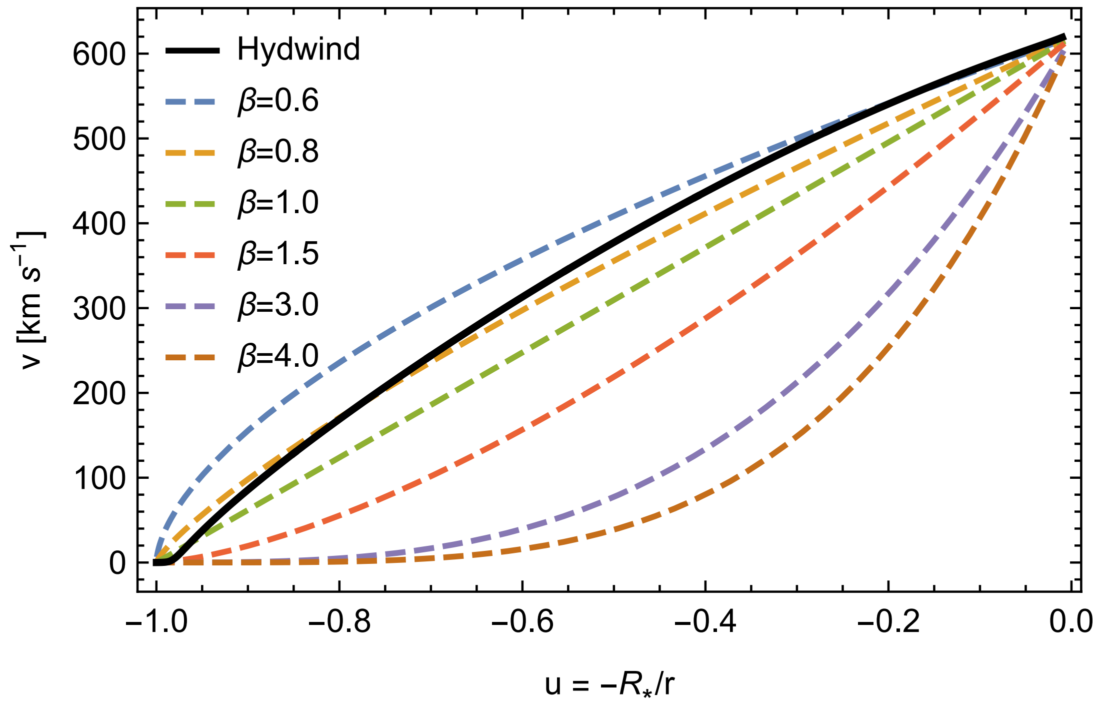
δ-Slow Solutions (Curé et al. 2011)

δ≳0.3

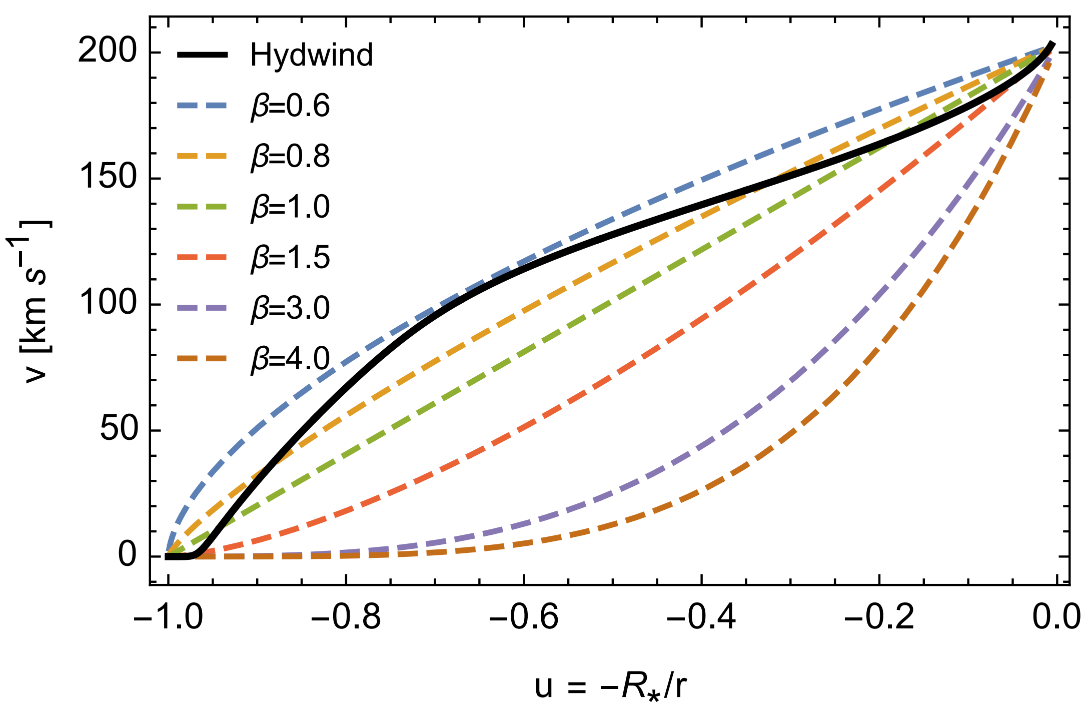
$$g_{\rm rad}^{\rm line} = \frac{\Gamma_{\rm E}\, G\, M\, k}{r^2} \left(\frac{1}{\sigma_{\rm E}\, v_{\rm th}}\right)^{\alpha} \left(\frac{1}{\rho}\frac{\partial v}{\partial r}\right)^{\alpha} \left(\frac{n_{\rm E11}}{W(r)}\right)^{\delta} f_{\rm CF}\left(r, v, \frac{\partial v}{\partial r}\right)$$



Fast Solution



δ-Slow Solution



β-law

$$v(r) = v_\infty(1 - R_*/r)^\beta$$

Typical Values:

O and B stars ➜ β=0.7 to 1.5

Puls et al. 1996, Kudritzki & Puls 2000

Late B and A supergiants ➜ β> 1.5

(Stahl et al. 1991, Lefever et al. 2007, Markova & Puls 2008)

See also Venero et al. 2024

ISOSCELES

GrId of Stellar atmOSphere and hydrodynamiC modELs of massivE Stars

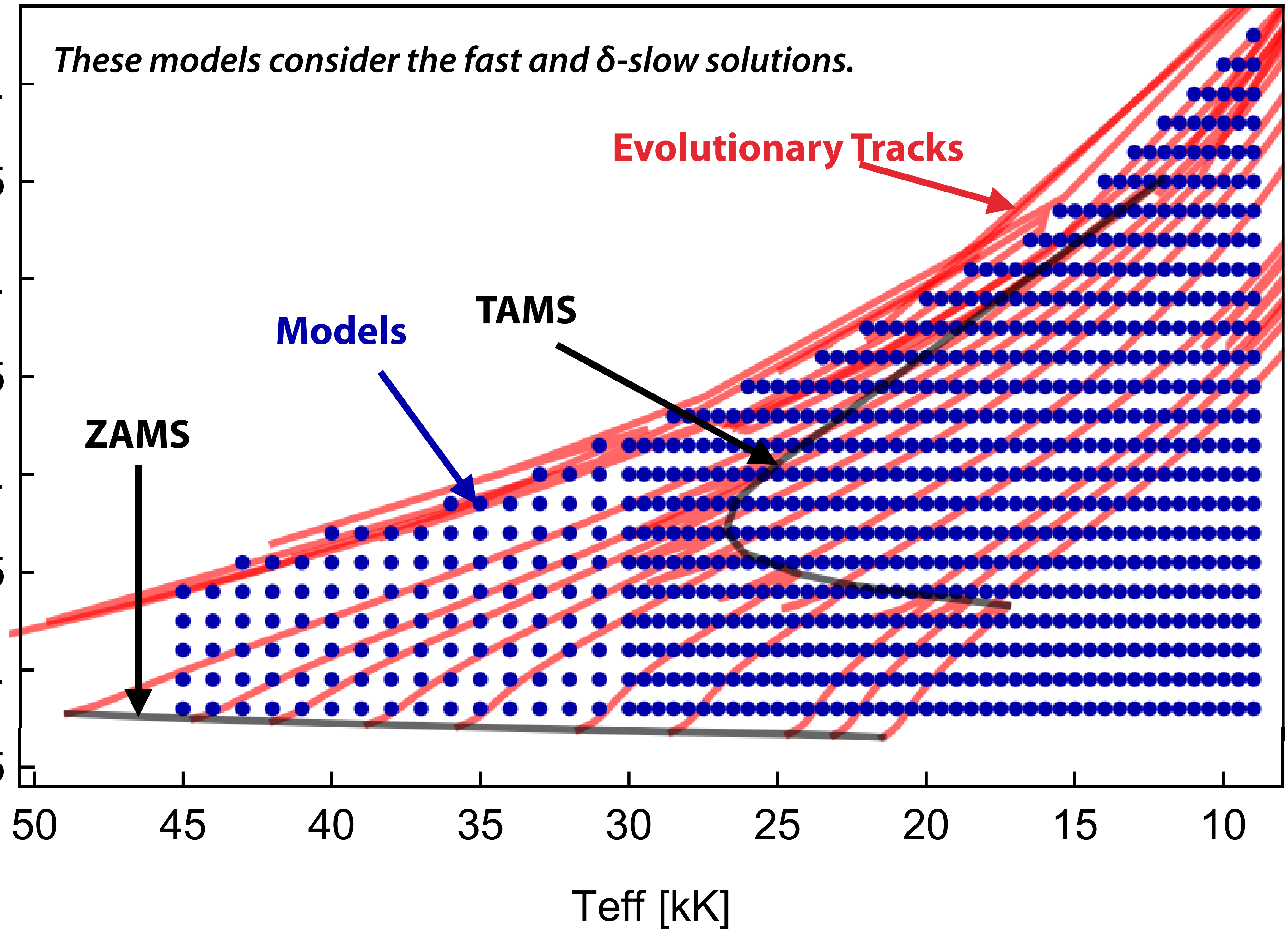
See proceeding Araya et al. 2023

Synthetic data grid for massive stars, integrating m -CAK hydrodynamics and NLTE radiative transport.

Step 1

Hydwind grid - without rotation

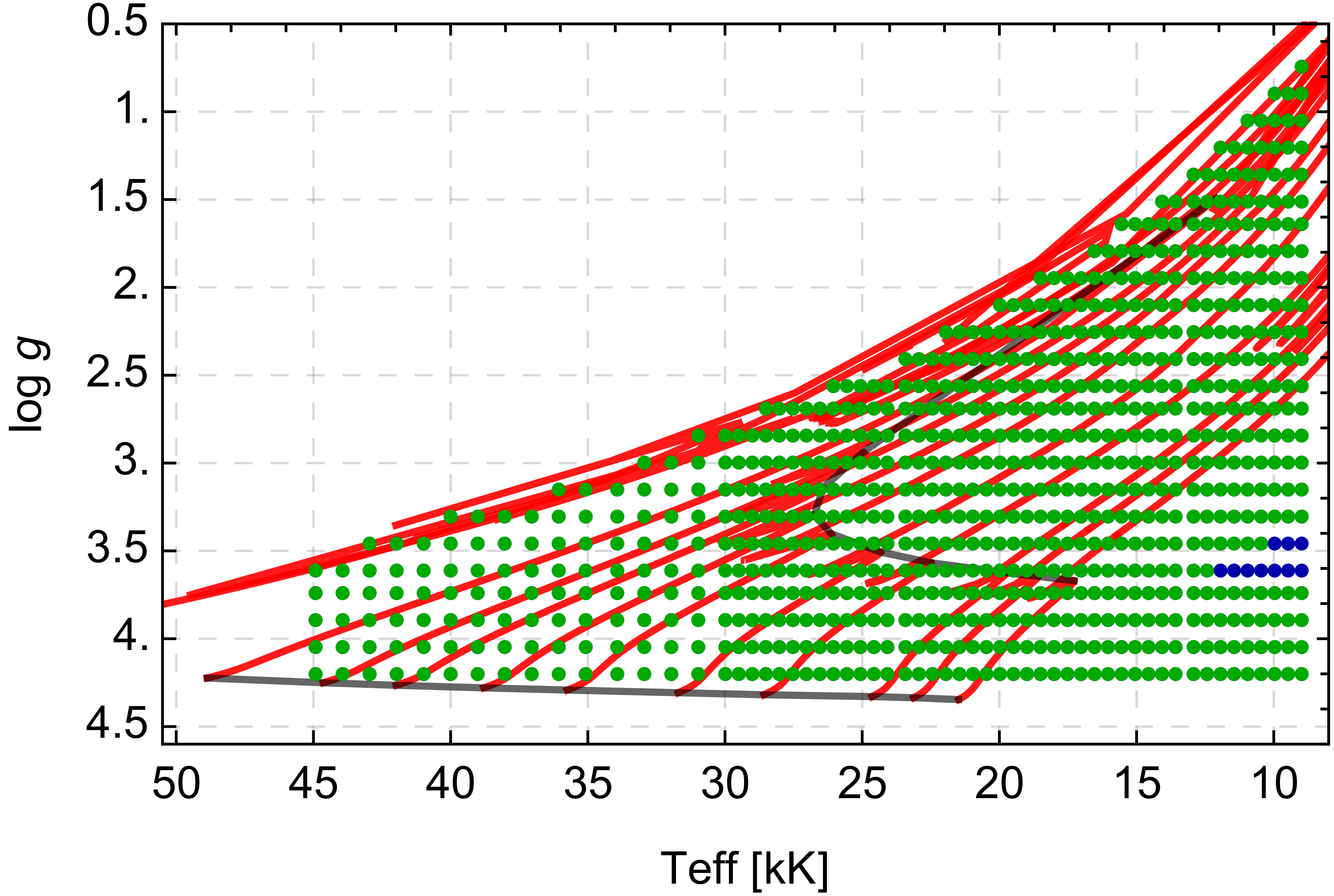
Hydwind (stationary hydrodynamic code, Curé 2004)



Step 2

Fastwind grid (without rotation)

FASTWIND (Fast Analysis of STellar Atmospheres with WINDs, Puls et al. 2005)



ISOSCELES Grid v1.0

Temperature:

9 kK - 30 kK (steps of 500 k)

31 kK - 45 kK (steps of 1000 k)

log g:

4.2 - 0.75 (steps of 0.15)

Line force parameters

α	0.45	0.47	0.51	0.53	0.55	0.57	0.61	0.65				
k	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
δ	0.	0.04	0.1	0.14	0.2	0.24	0.3	0.31	0.32	0.33	0.34	0.35

Si abundance log ϵ_{Si}:

7.21, 7.36, 7.51 (solar), 7.66, and 7.81 dex.

Micro-turbulent velocity

1 ,5 , 10, 15, 20, 25 km/s

Lines H He Si:

IR - Optical

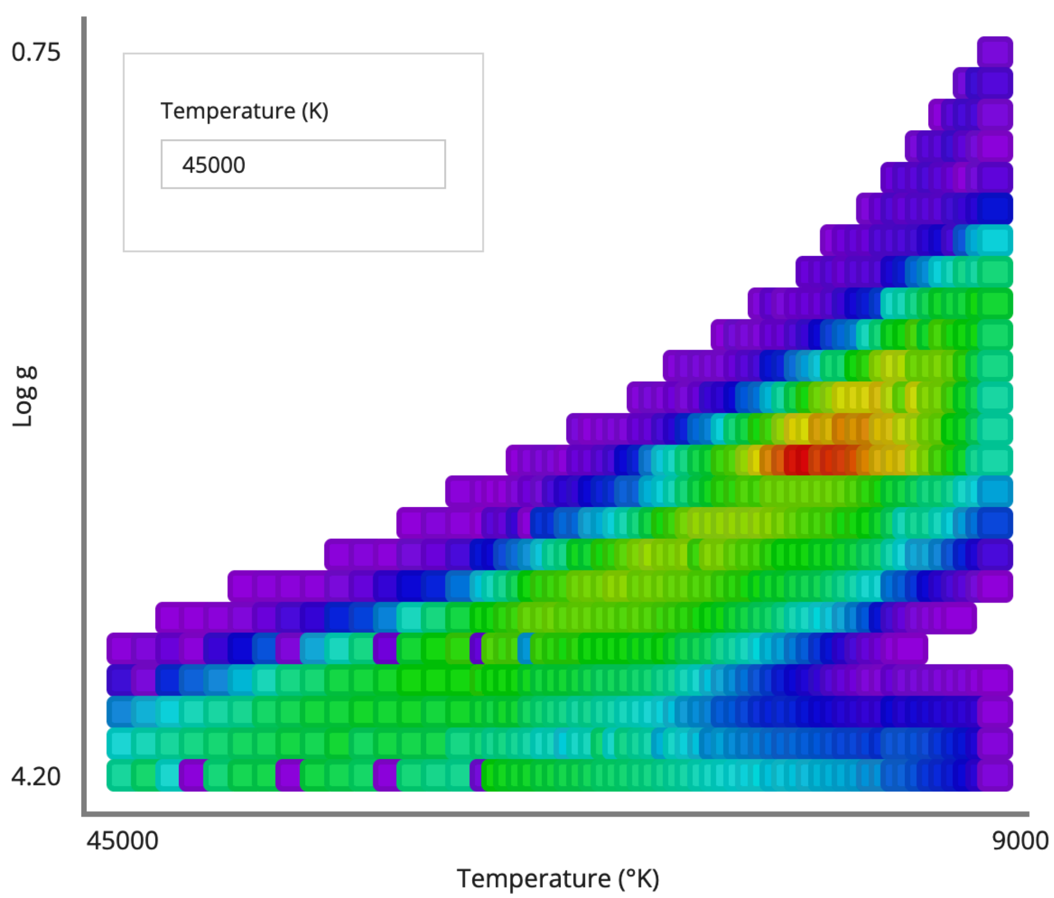
Total = 573 423 converged models

ISOSCELES Explorer

https://ifa.uv.cl/grid

Log g/Temp Graph

Select a Log g/Temp pair by clicking on any point in the graph, or by selecting in the selection box



Models list

First, select a model from the chosen Log g/Temp

Parameter selection

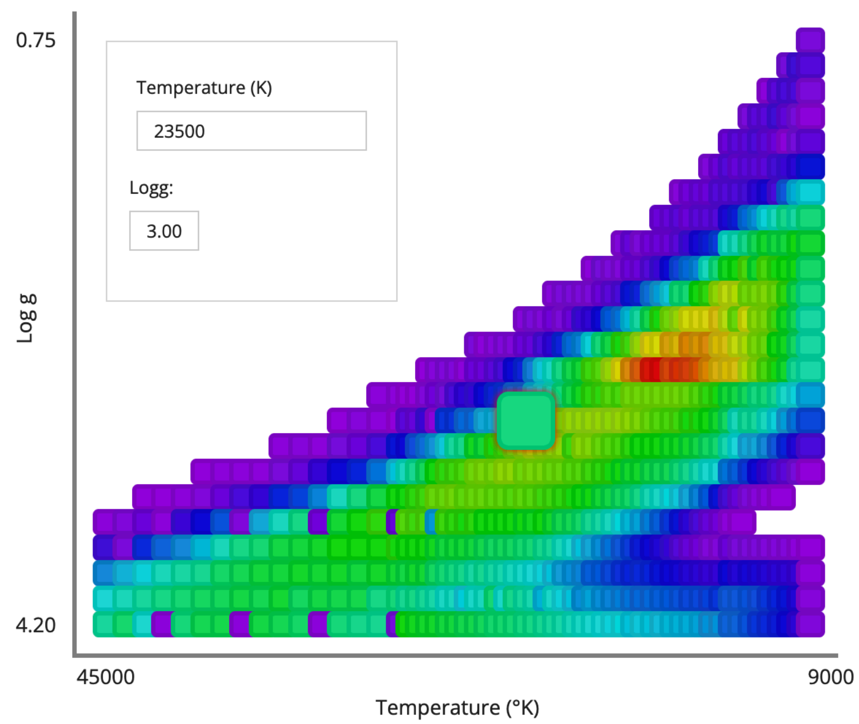
Click here to select the parameter(s) of interest. None selected means all selected.

Get

ISOSCELES Explorer https://ifa.uv.cl/grid

Log g/Temp Graph

Select a Log g/Temp pair by clicking on any point in the graph, or by selecting in the selection box



Models list

Temperature 23500 °K

Log g 3.00

Total of models 949

The table below shows a sample of these models

	Temp (°K)	Log g	k	alpha	delta	si	mdot	vinf
○	23500	3.00	0.25	0.61	0.10	7.81	1.3710222e-6	1.1007462e+3
◉	23500	3.00	0.15	0.55	0.10	7.66	2.0969853e-7	8.8840028e+2
○	23500	3.00	0.25	0.45	0.32	7.66	2.6928484e-8	3.0495954e+2
○	23500	3.00	0.25	0.55	0.24	7.66	9.5403302e-7	5.9674206e+2
○	23500	3.00	0.25	0.61	0.14	7.51	1.5671467e-6	9.7650579e+2
○	23500	3.00	0.25	0.61	0.14	7.66	1.5671467e-6	9.7650579e+2
○	23500	3.00	0.25	0.61	0.20	7.81	1.9966341e-6	8.2119768e+2
○	23500	3.00	0.30	0.45	0.10	7.36	1.9203121e-7	6.4988458e+2
○	23500	3.00	0.30	0.65	0.24	7.36	6.1899429e-6	8.4175889e+2
○	23500	3.00	0.60	0.65	0.14	7.81	1.3285612e-5	1.1509216e+3

Parameter selection

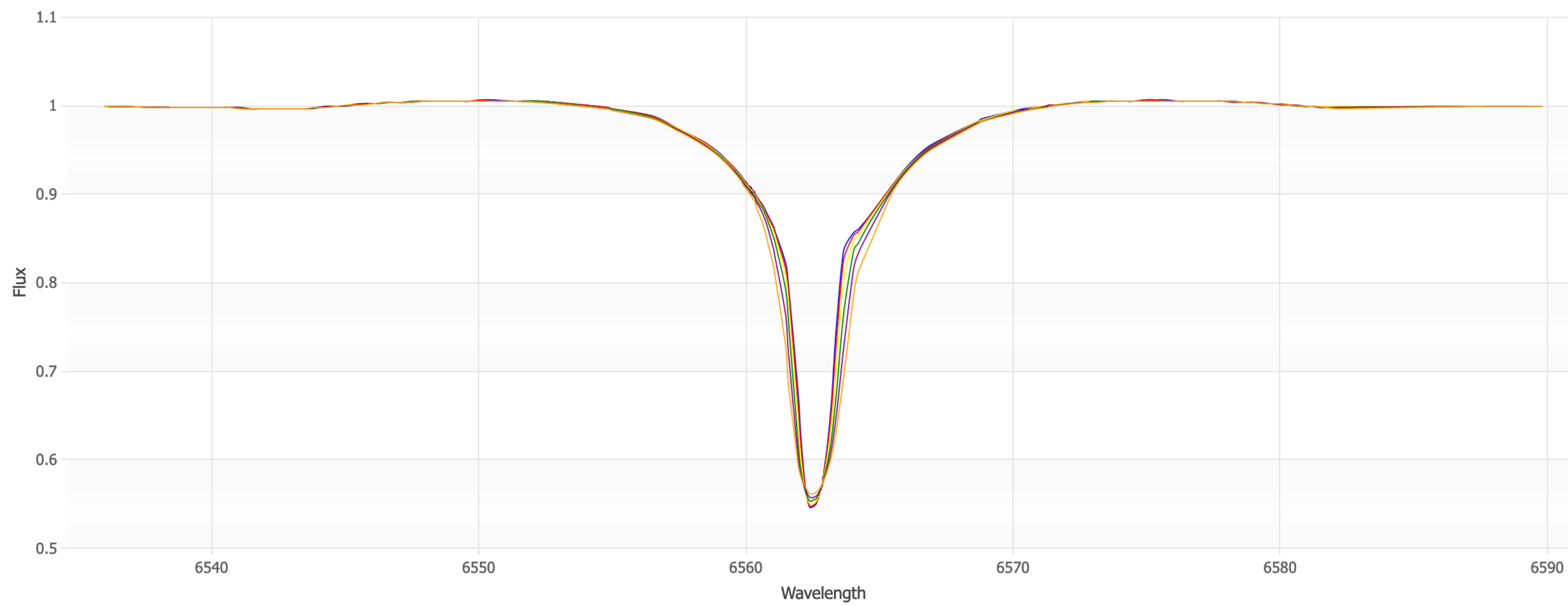
Click here to select the parameter(s) of interest. None selected means all selected.

- [ ] BR10
- [ ] BR11
- [ ] BR12
- [ ] BRALPHA
- [ ] BRBETA
- [ ] BRGAMMA
- [x] HALPHA
- [ ] HBETA
- [ ] HDELTA
- [ ] HEI170
- [ ] HEI205
- [ ] HEI211
- [ ] HEI4026
- [ ] HEI4387
- [ ] HEI4471
- [ ] HEI4713
- [ ] HEI4922
- [ ] HEI6678
- [ ] HEII218
- [ ] HEII4200
- [ ] HEII4541
- [ ] HEII4686
- [ ] HEII57
- [ ] HEII611
- [ ] HEII6406
- [ ] HEII6527
- [ ] HEII6683
- [ ] HEII67
- [ ] HEII712
- [ ] HEII713
- [ ] HEPS
- [ ] HGAMMA
- [ ] PALPHA
- [ ] PBETA
- [ ] PF10
- [ ] PF9
- [ ] PFGAMMA
- [ ] PGAMMA
- [ ] SiII4128
- [ ] SiII4130
- [ ] SiII5041
- [ ] SiII5056
- [ ] SiIII4552
- [ ] SiIII4567
- [ ] SiIII4574
- [ ] SiIII4716
- [ ] SiIII4813
- [ ] SiIII4819
- [ ] SiIII4829
- [ ] SiIII5739
- [ ] SiIV4089
- [ ] SiIV4116
- [ ] SiIV4212
- [ ] SiIV4950
- [ ] SiIV6667
- [ ] SiIV6701

ISOSCELES Explorer

https://ifa.uv.cl/grid

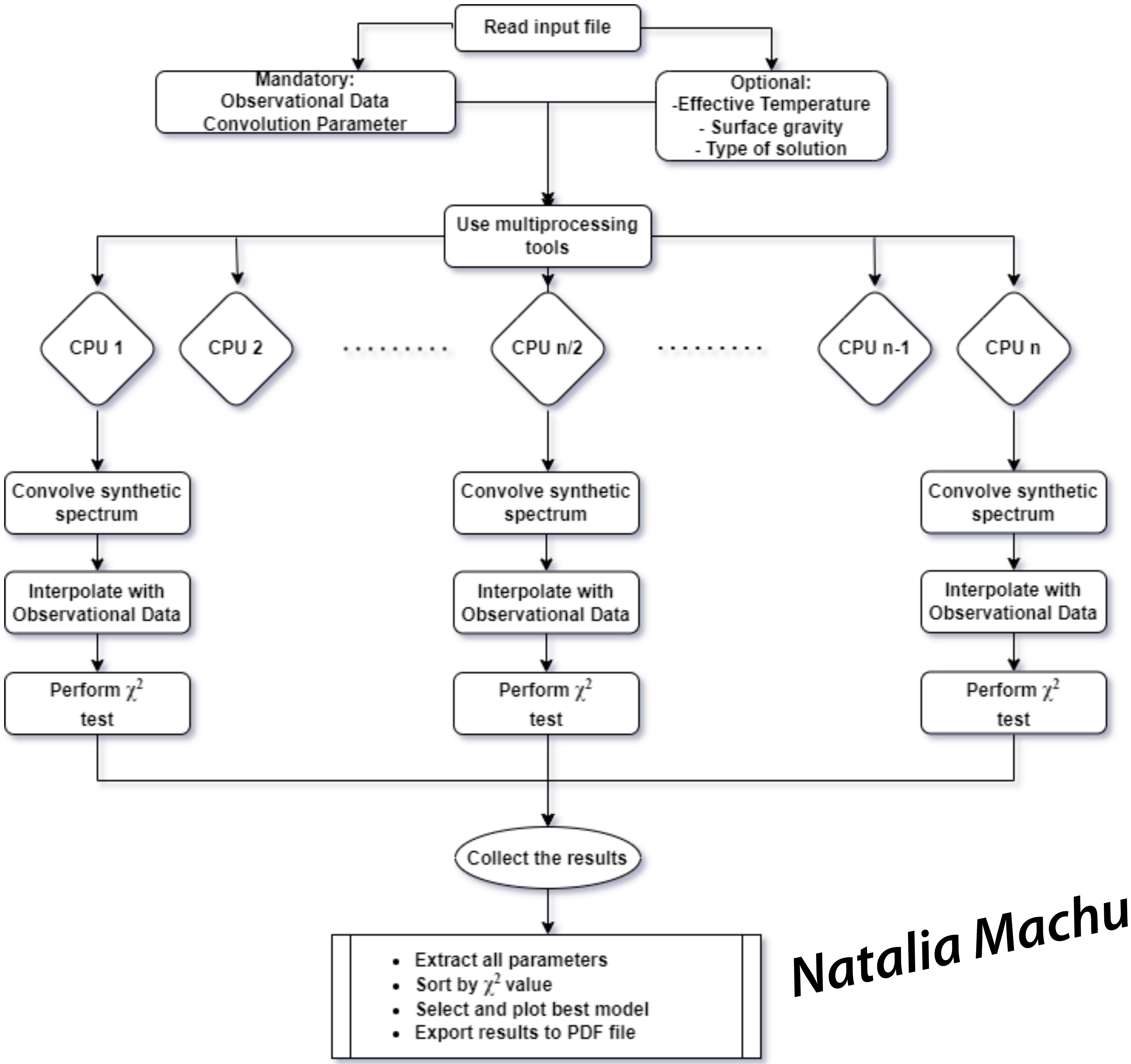
HALPHA



Series	VT 1	VT 5	VT 10	VT 15	VT 20	VT 25
Visible	☑	☑	☑	☑	☑	☑
Highlight	☐	☐	☐	☐	☐	☐

Download CSV

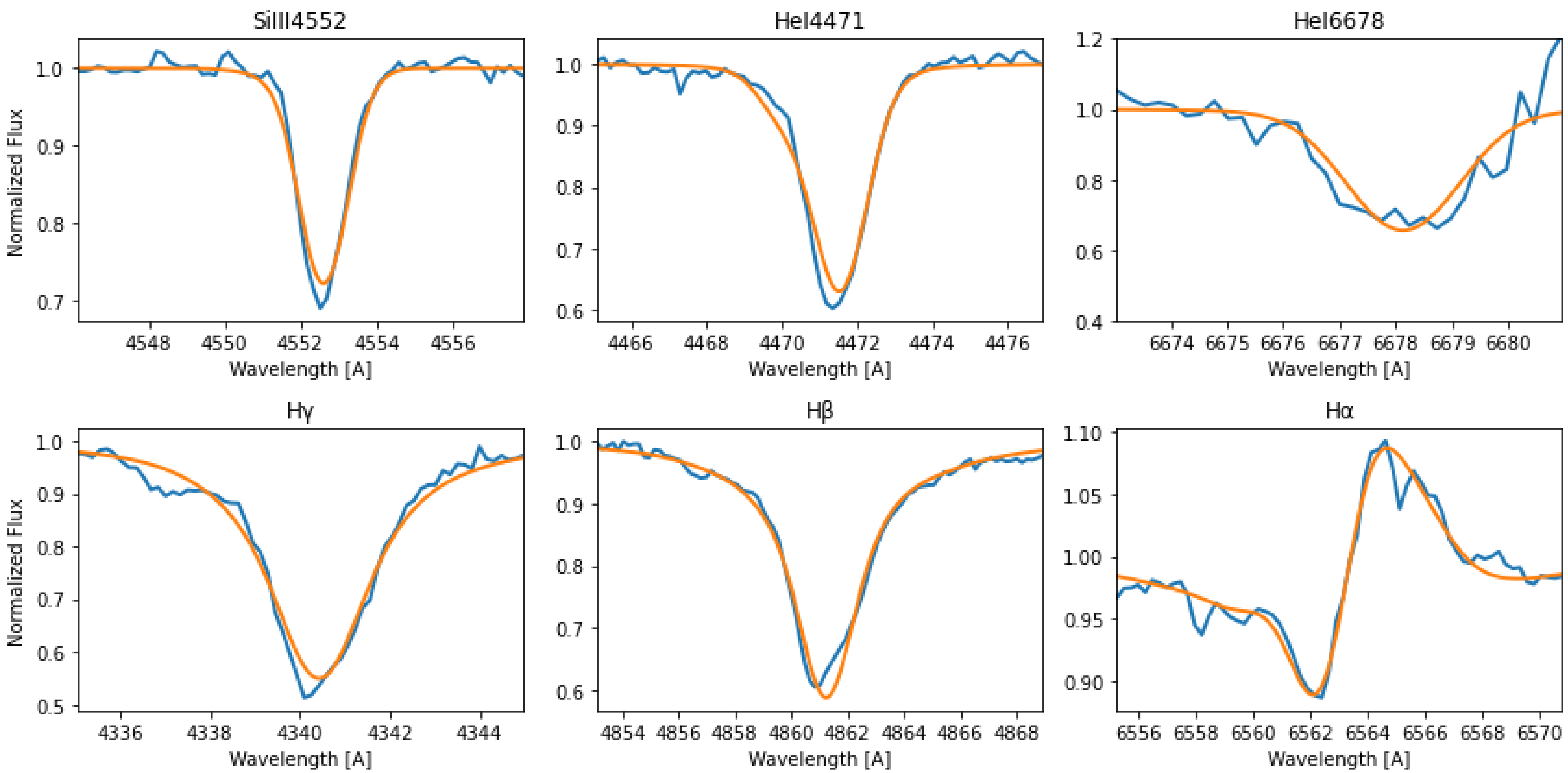
Optimization problem of spectral line fitting



Natalia Machuca's work

Some Results

HD 99953

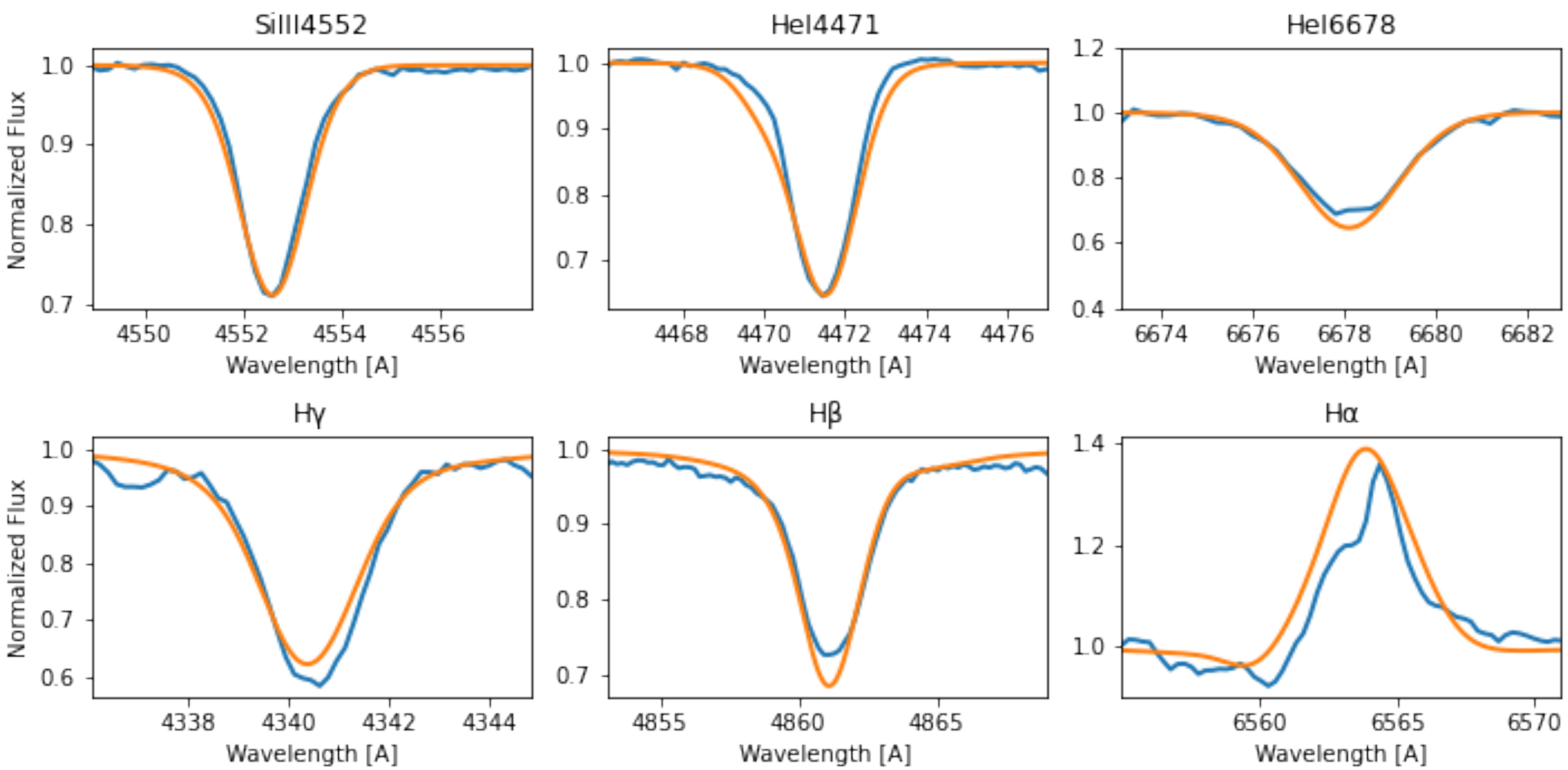


Observations from Haucke et al. 2018

	Haucke et al. 2018	This work
T_{eff} [K]	19000	18500
log g	2.30	2.40
α	—	0.53
k	—	0.15
δ	—	0.34
β	2.0	—
$\dot{M}$ [$10^{-6} M_\odot$ /yr]	0.13	0.24
v_∞ [km/s]	500	254

Some Results

HD 41117

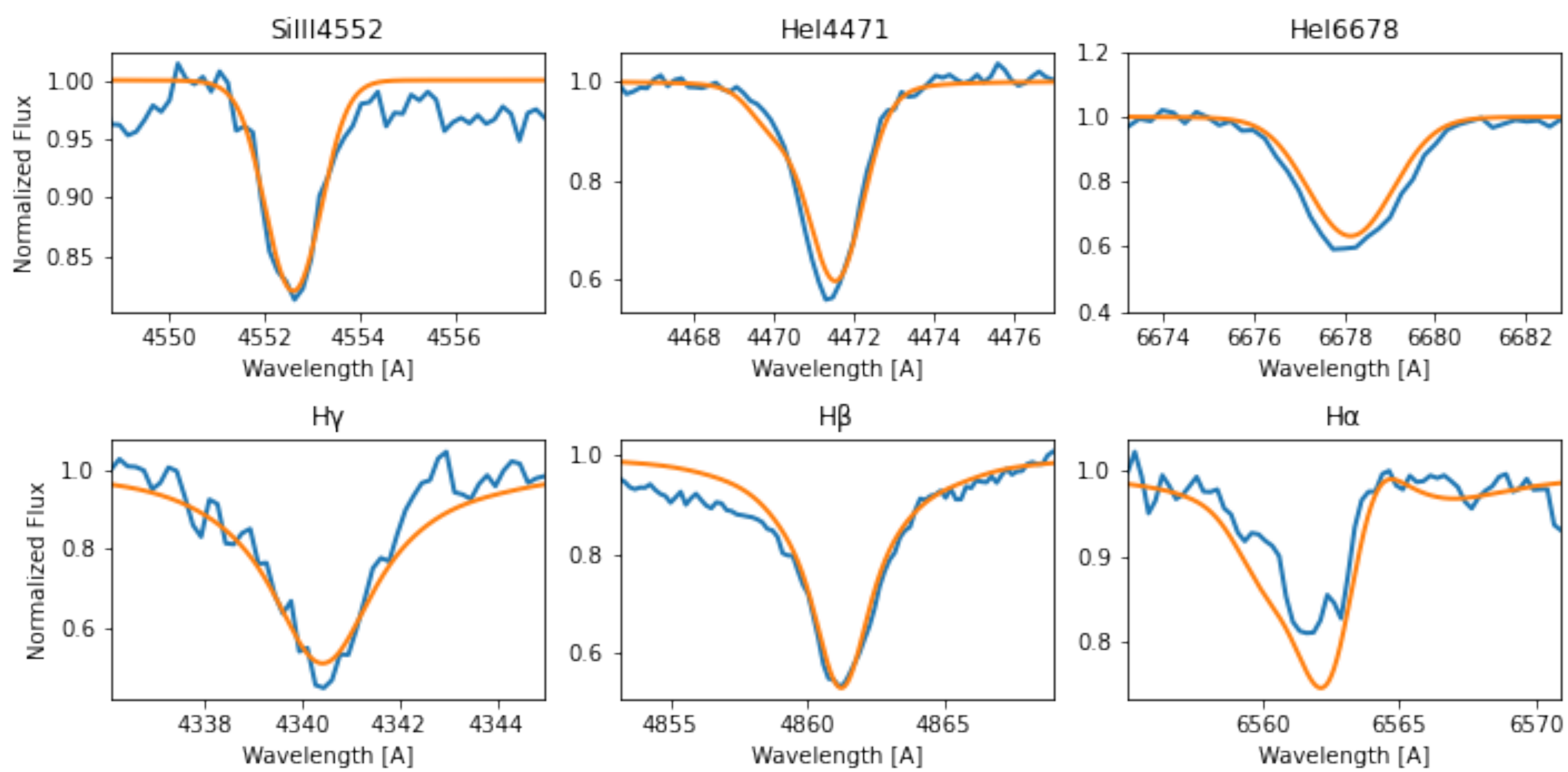


Observations from Haucke et al. 2018

	Haucke et al. 2018	This work
T_{eff} [K]	19000	19000
log g	2.30	2.25
α	—	0.53
k	—	0.1
δ	—	0.33
β	2.0	—
$\dot{M}$ [$10^{-6} M_\odot$ /yr]	0.17	0.55
v_∞ [km/s]	510	223

Some Results

HD 75149



Observations from Haucke et al. 2018

	Haucke et al. 2018	This work
T_{eff} [K]	16000	16500
log g	2.10	2.25
α	—	0.51
k	—	0.2
δ	—	0.33
β	2.5	—
$\dot{M}$ [$10^{-6} M_\odot$ /yr]	0.16	0.19
v_∞ [km/s]	400	228

Natalia Machuca's Poster

Instituto de **Física y Astronomía**

Spectral modelling of OB-type stars and the Wind momentum Luminosity Relationship

Natalia Machuca[1], Michel Curé[1] and Ignacio Araya[2]

[1]Universidad de Valparaíso, [2]Universidad Mayor

Universidad de Valparaíso CHILE

Results

Wind momentum depends on the mass-loss rates, terminal velocity and radius of the star as shown in the *y-axis*. With this, we defined the WLR as $\log(D_{\mathrm{mom}}) = x \log(L/L_\odot) + D_0$.

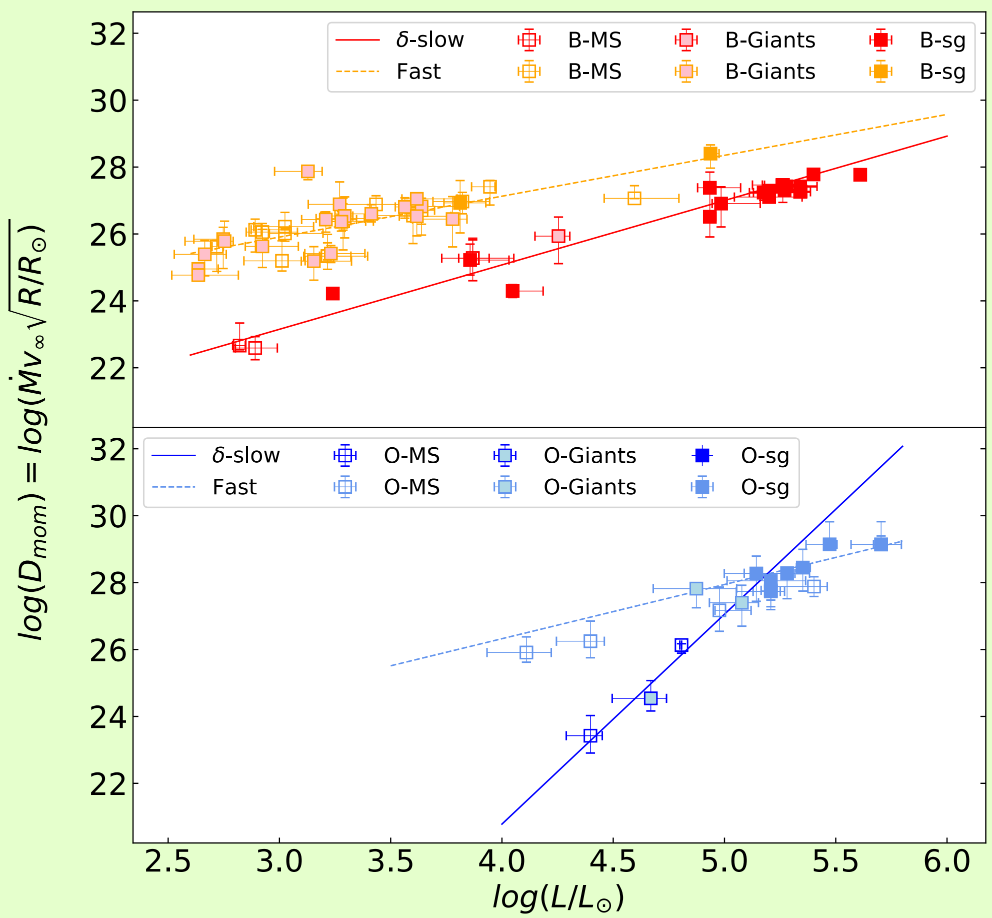


Figure 2. WLR for O and B-type stars. Dashed lines are linear fits for both hydrodynamical solutions. Filling styles represent different luminosity classes. Values of the WLR found for B-type stars are $x = 1.92^{\pm 0.14}$ and $D_0 = 17.37^{\pm 0.65}$ for δ-slow solutions and $x = 1.22^{\pm 0.17}$ and $D_0 = 22.23^{\pm 0.58}$ for fast solutions. For O-type stars, these values are $x = 6.27^{\pm 1.85}$ and $D_0 = -4.31^{\pm 8.57}$ for δ-slow solutions and $x = 2.07^{\pm 0.20}$ and $D_0 = 17.23^{\pm 1.07}$ for fast solutions.

Felipe Ortiz's Poster

Classification of spectral Hα lines from massive stars using machine learning methods

F. Ortiz[1], R. Pezoa[2], I. Araya[3] & M. Curé[1]

[1] Instituto de Física y Astronomía, Universidad de Valparaíso.

[2] Escuela de Informática, Universidad Técnica Federico Santa María, CCTVal-UTFSM.

[3] Centro Multidisciplinario de Física, Universidad Mayor.

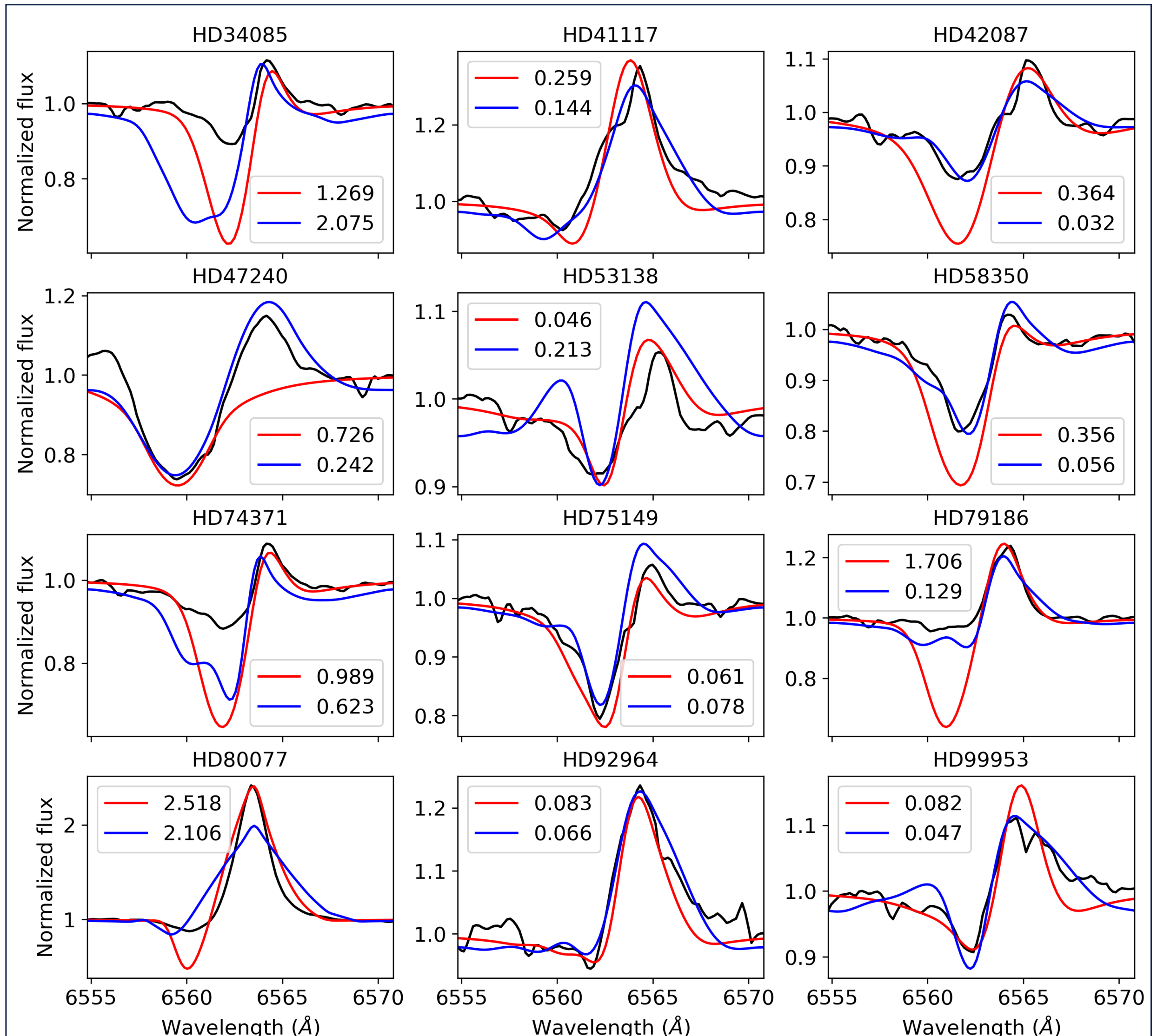


Fig. 3: Hα lines for 12 stars studied in [6]. In blue there are our fits, and in red the fits from [6]. The labels show the χ^2 values.

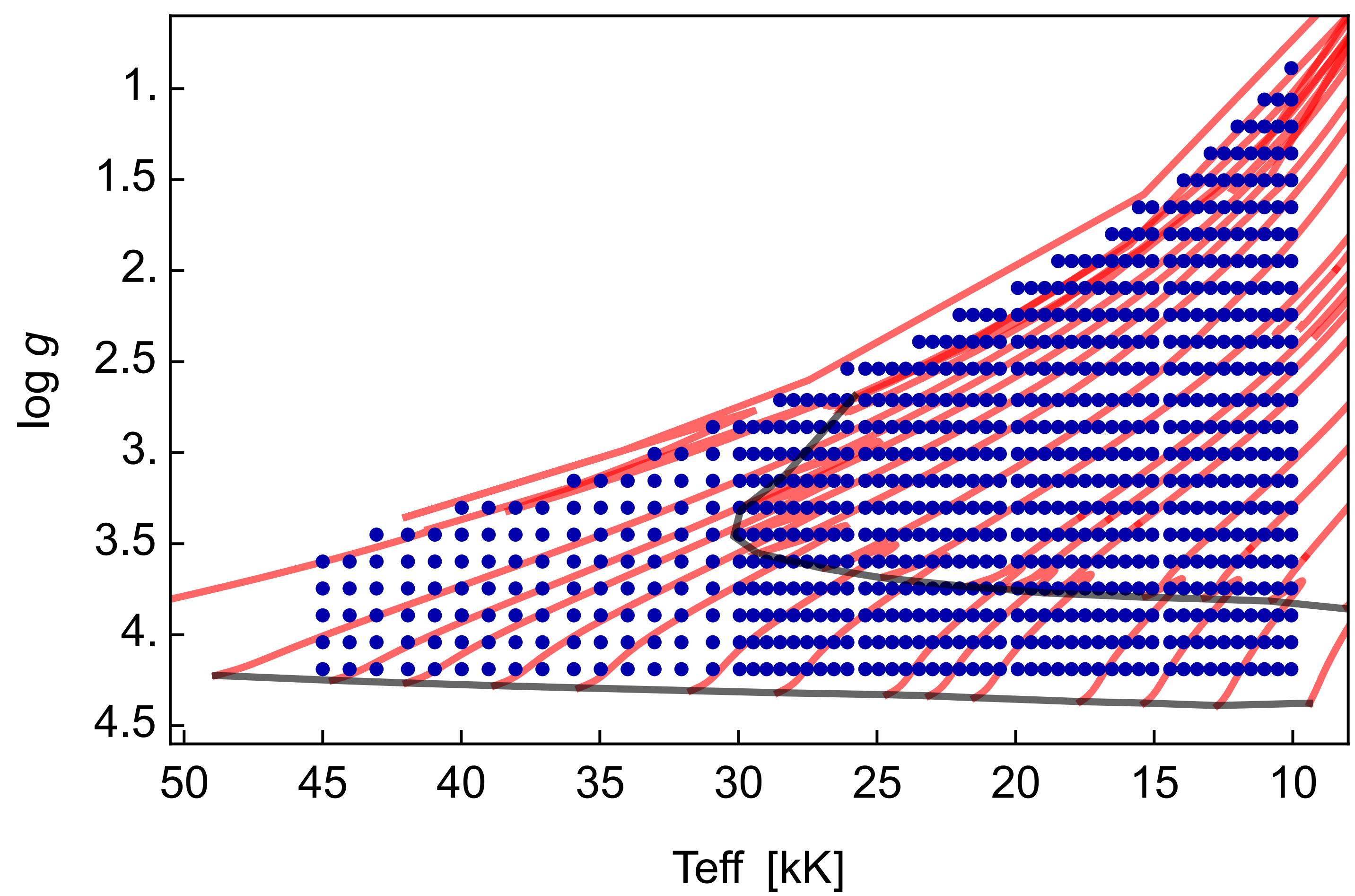
ISOSCELES Grid v2.0

Temperature:

10 kK - 30 kK (steps of 500 k)
31 kK - 45 kK (steps of 1000 k)

log g:

4.2 - 0.75 (steps of 0.15)



Micro-turbulent velocity

1 ,5 , 10, 15, 20, 25 km/s

Line force parameters

α	0.4	0.43	0.46	0.49	0.52	0.55	0.58	0.61	0.64	0.67	0.7		
k	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65
δ	0.	0.04	0.1	0.14	0.2	0.24	0.29	0.3	0.31	0.32	0.33	0.34	0.35

Lines profiles - H He Si C N O

IR - Optical - UV

ISOSCELES Grid - Differences

	ISOSCELES v1.0	ISOSCELES v2.0
Wavelength Range	*IR, Optical*	*IR, Optical, UV*
Explicit Elements	*H, He, Si*	*H, He, Si, C, N, O*
# Line profiles	*57*	*167*
# Models	*~ 0.5 M*	*~ 2.5 M*
CAK parameters	*k: 12 values* α*: 8 values* δ*: 12 values*	*k: 13 values* α*: 11 values* δ*: 13 values*
Size (binary format)	*~300 Gb*	*~1.4 Tb*

Final Remarks and Future Work

- ISOSCELES is the first grid of synthetic data for massive stars that involves both, the m-CAK hydrodynamics and the NLTE radiative transport.
- The results obtained from ISOSCELES should have a better justification than the currently and widely calculated models with a β-law in quantitative spectroscopic analyses, especially for high values of β
- ISOSCELES v2.0 will cover the UV region
- We are implementing Machine-learning methods for the spectral line fitting.
- The next steps are new grids with other metallicities.

If anyone wants to use ISOSCELES, please feel free to contact me (ignacio.araya@umayor.cl)!

HYDRODYNAMICS
RADIATIVE TRANSFER
ISOSCELES
DATABASE

Thanks!

QUESTIONS?

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