Hydrodynamic solutions for radiation-driven winds in transition regions

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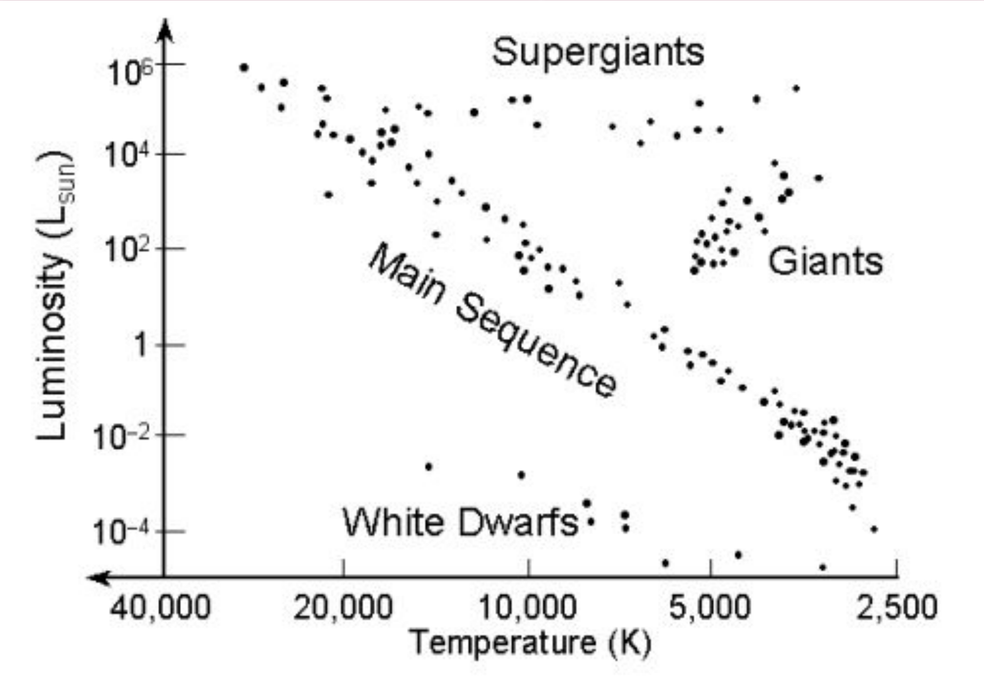
POEMS

Physics of Extreme Massive Stars

Marie-Curie-RISE project funded by the European Union



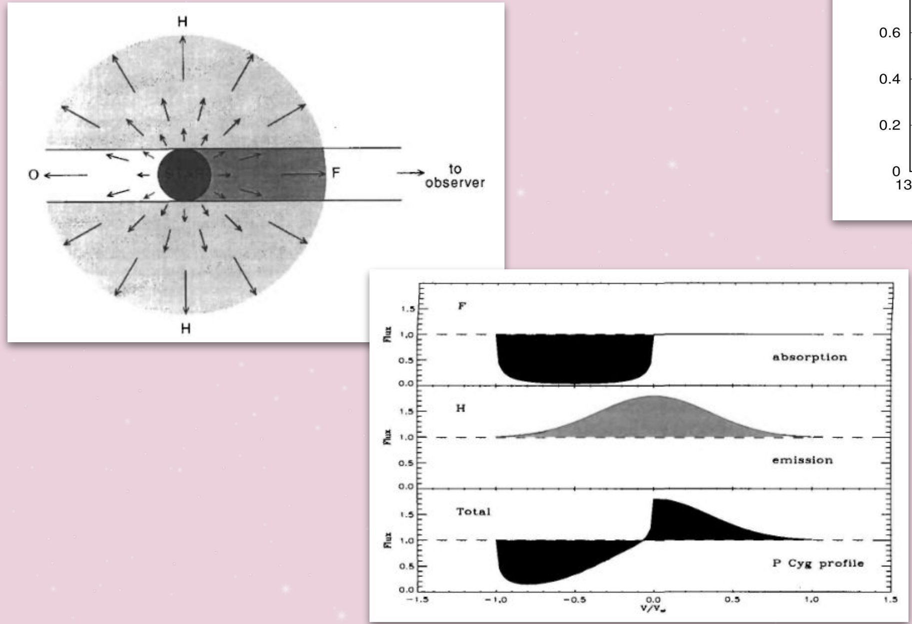
B supergiant stars

$8 < M/M_{\odot} < 50$

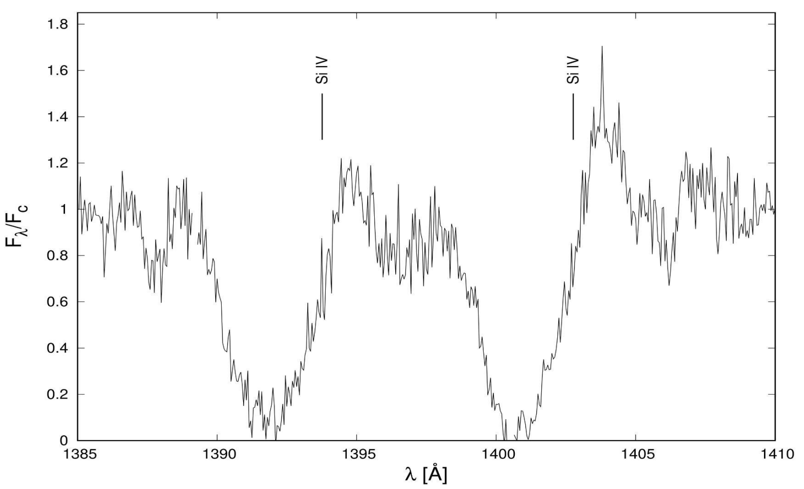
$5 < \log(L/L_{\odot}) < 5.6$

Stellar winds

Evidences: P Cygni profile



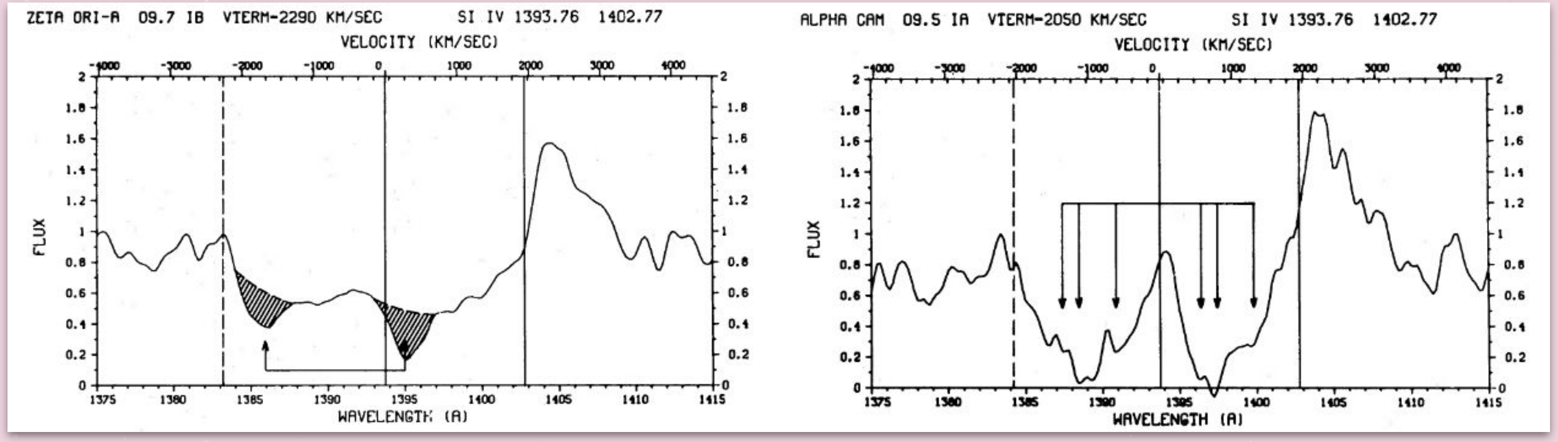
Taken from Lamers & Cassinelli (1999)



Wind parameters:

- Mass loss rate $\dot{M}$
  between 10^{-6} and 10^{-7} $M_\odot$/yr
- Terminal velocity of the wind V_∞
  between 100 and 2000 km/s

Discrete Absorption Components (DACs)



Taken from Lamers+ (1982)

Objectives:

- exploring solutions for radiation-driven winds,
- obtaining the synthetic profiles of Si IV searching for a possible relation with DACs,
- incorporating an additional broadening mechanism (Stark) to the code that solves the radiative transfer equation,
- comparing synthetic profiles with observations of a B supergiant star.

Contents

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Radiation-driven winds

m-CAK theory, hydrodynamic codes Hydwind and ZEUS-3D

Mass conservation $\dot{M} = 4\pi r^2 \rho v = constant$

Energy conservation Temperature law

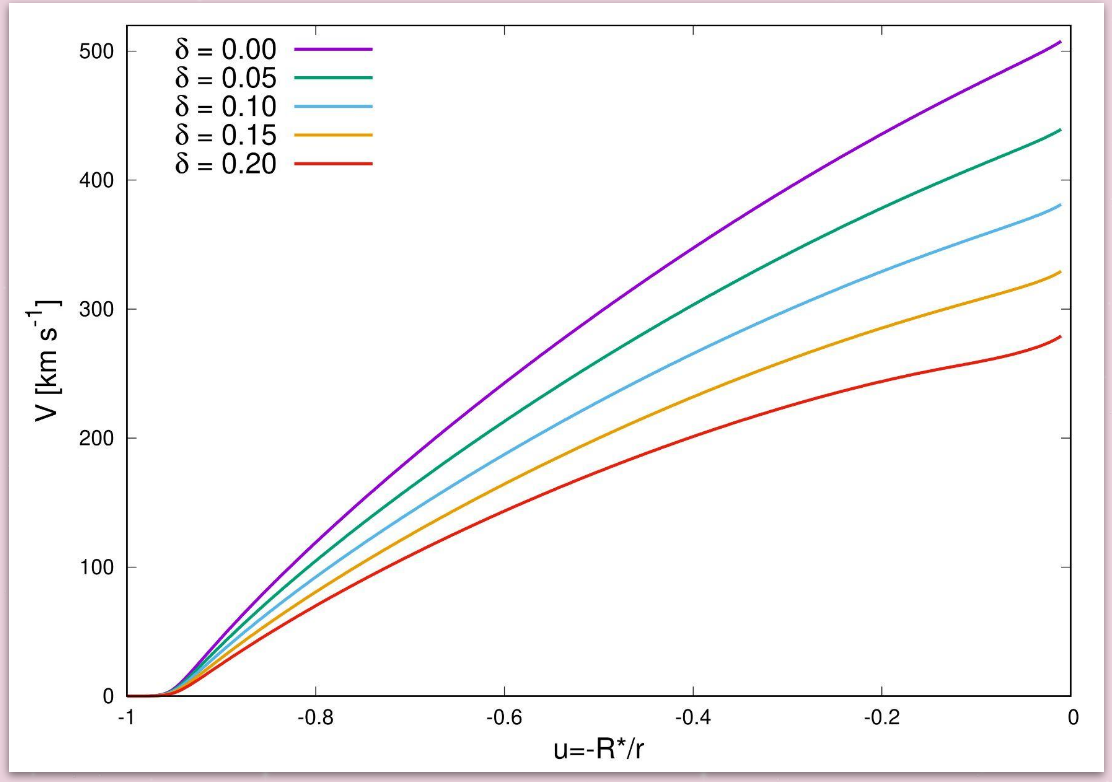
Momentum conservation Velocity law

m-CAK theory

Pauldrach+ (1986)
Friend & Abbott (1986)

$$g_{\text{rad}}^{L} = \frac{C}{r^2} CF \left(\frac{n_e}{W(r)} \right)^{\delta} \left(r^2 v \frac{\mathrm{d}v}{\mathrm{d}r} \right)^{\alpha} \quad C = k G M_* \Gamma \left(\frac{4\pi}{\sigma_e \dot{M} v_{th}} \right)^{\alpha}$$

$$\left(1 - \frac{a^2}{v^2} \right) v \frac{dv}{dr} = \frac{2a^2}{r} + g_{\text{eff}}(r) + g_{\text{rad}}^{L}(r, v, dv/dr)$$



Fast solutions (classical)

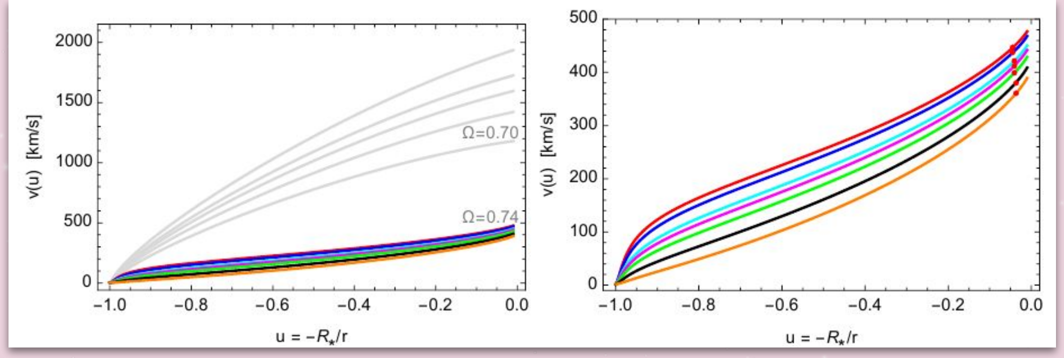
Slow rotation $\Omega \lesssim 0.8$

$\delta \lesssim 0.2$

Ω-slow solutions

Curé (2004)

Fast rotation $\Omega \gtrsim 0.8$

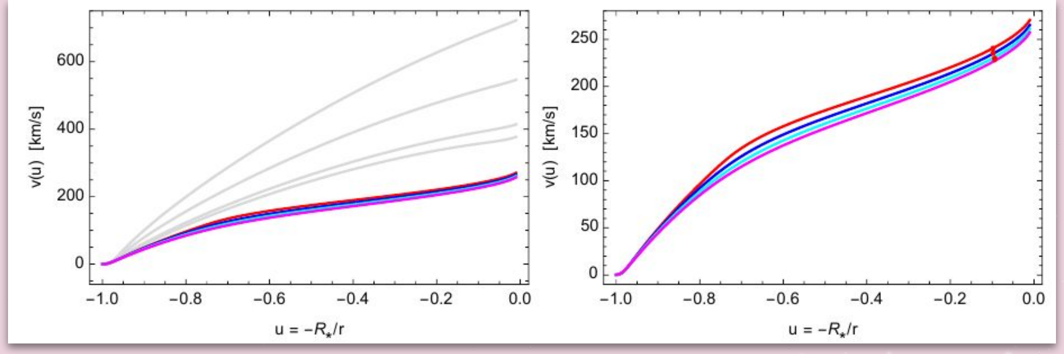


δ-slow solutions

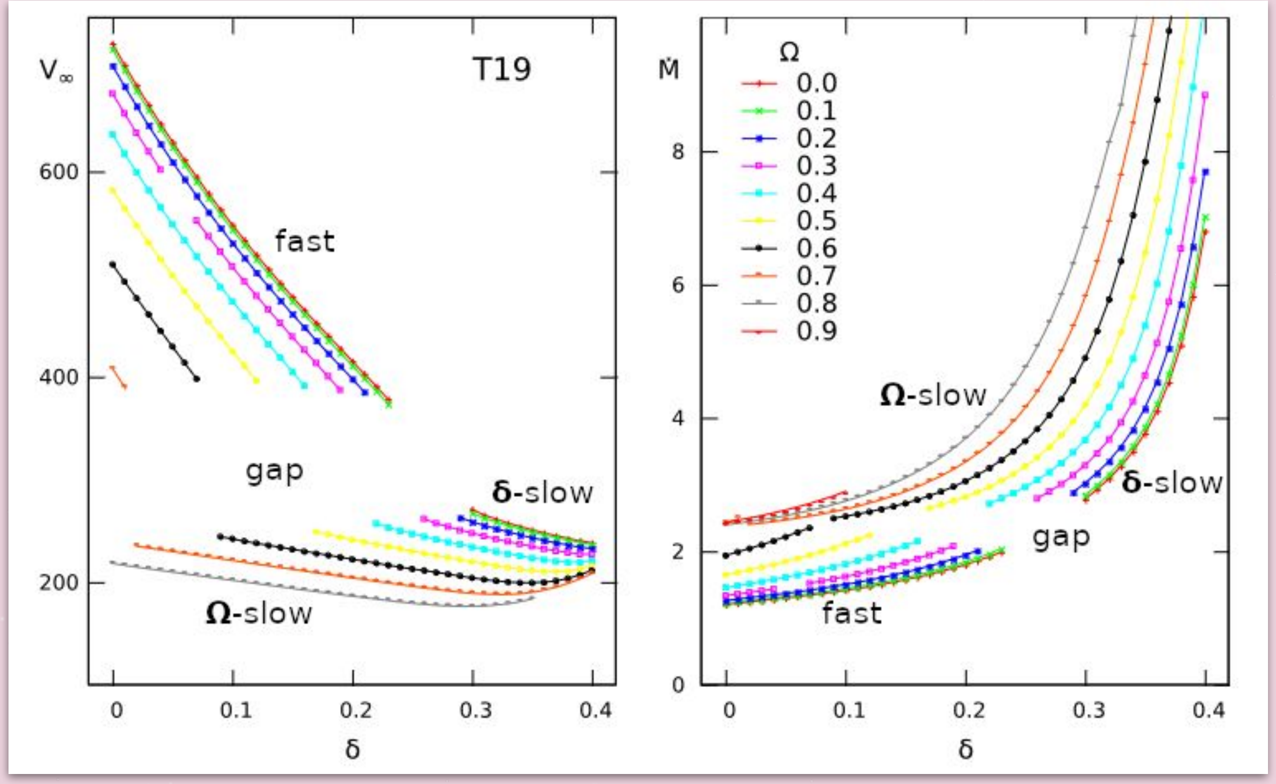
Curé+ (2011)

Slow rotation $\Omega < 0.8$

$\delta > 0.2$



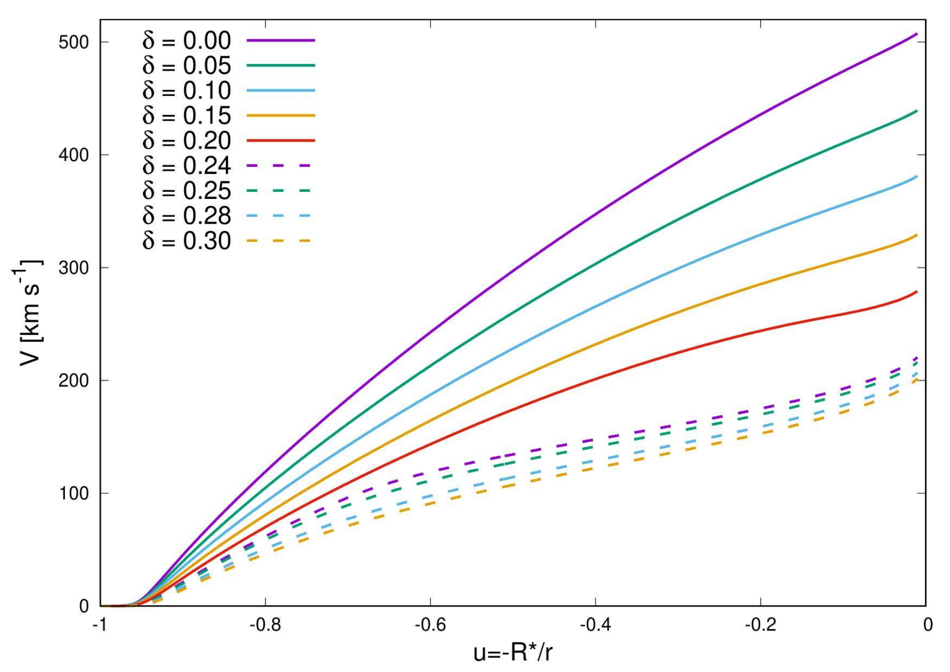
Taken from Curé & Araya (2023)



Taken from Venero+ (2016)

Hydwind code

Curé (2004)



fast

δ-slow

Fast and **δ**-slow solutions

Teff = 18000 K
log(g) = 2.5

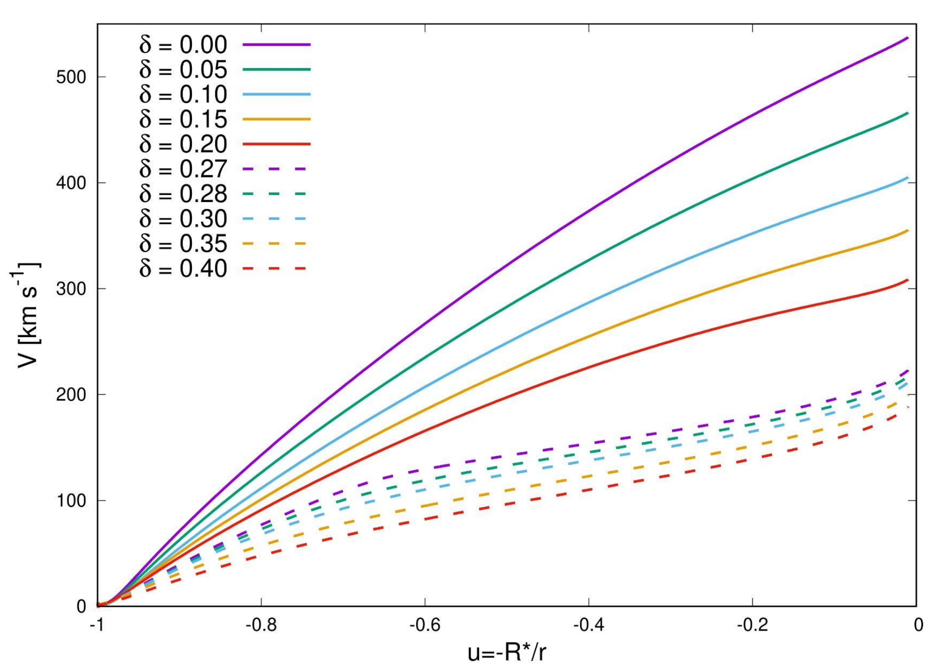
R = 23 R_*
Ω = 0.27
k = 0.104
α = 0.515
$\dot{M} = 0.05 \times 10^{-7} M_\odot$/yr

gap in

$$0.20 < \delta < 0.24$$

ZEUS-3D code

Clarke (1996, 2010), Araya+ (2018)



fast

δ-slow

Fast and **δ**-slow solutions

Teff = 18000 K
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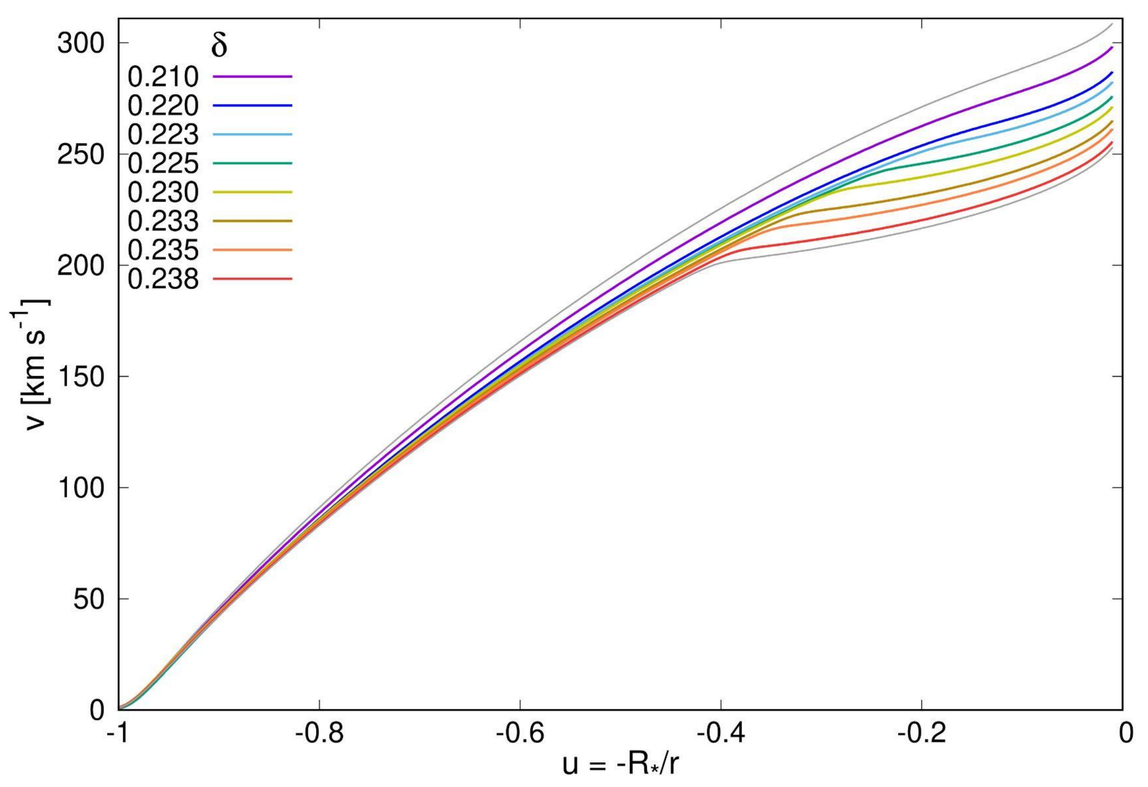
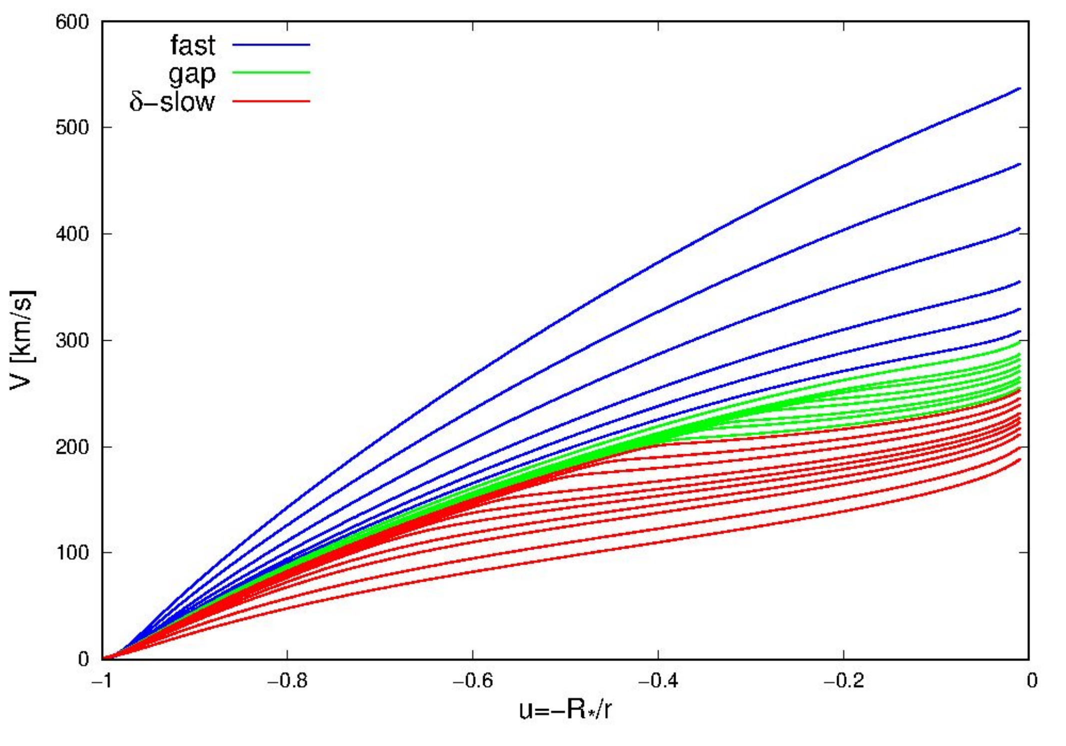
2
New solutions



δ
0.210
0.220
0.223
0.225
0.230
0.233
0.235
0.238
v [km s-1]
300
250
200
150
100
50
0
-1
-0.8
-0.6
-0.4
-0.2
0
u = -R*/r



δ = 0.00

δ = 0.20

δ = 0.24

δ = 0.40

Continuous transition between fast and **δ**-slow solutions!

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Line profile calculations

MULITAS code

MULITAS code

MUlti LIne Transfer for Active Stars


Radiative transfer equation (radiation continuum + lines) ⟷ Statistical equilibrium equations for Si IV populations

↓

Emergent flux

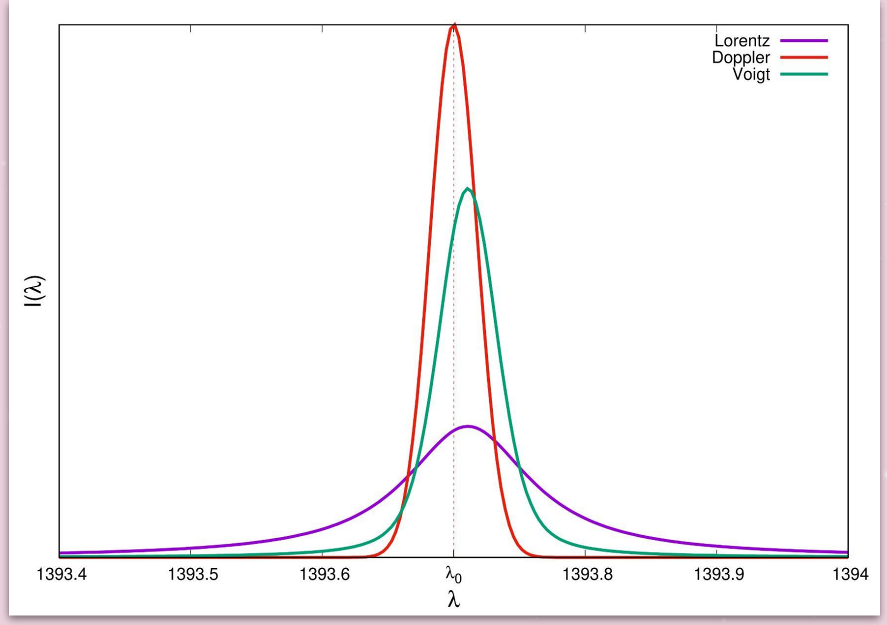
need:

- Model parameters
- Temperature law
- Velocity law

Si IV atom with 6 levels + continuum

Line profiles

$$\nu_0 = \frac{E_f - E_i}{h}$$



Radiative (or natural) broadening
Lorentz profile

Thermal (or Doppler) broadening
Gauss profile

Collisional broadening (Stark)
Lorentz profile

width and frequency shift

STARK - B database

Sahal-Brechot+ (2008)

Improvement to the MULITAS code: Stark effect for Si IV through using a voigt profile

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Synthetic line profiles

HD 41117 B2 Ia Teff = 19000 K, log(g) = 2.3, R = 23 R_*, v sen(i) = 40 km/s, **Ω** = 0.27

Hα

Haucke+ (2018)

β law

$\beta = 2.0$

$\dot{M} = 0.17 \times 10^{-6} M_\odot/yr$

$V_\infty = 510$ km/s

Vmacro = 65 km/s
Vmicro = 10 km/s

Venero+ (2023)

Fast solution

$k = 0.113$

$\alpha = 0.520$

$\boldsymbol{\delta} = 0.0$

$\dot{M} = 0.179 \times 10^{-6} M_\odot/yr$

$V_\infty = 306.9$ km/s

δ-slow solution

$k = 0.095$

$\alpha = 0.510$

$\boldsymbol{\delta} = 0.240$

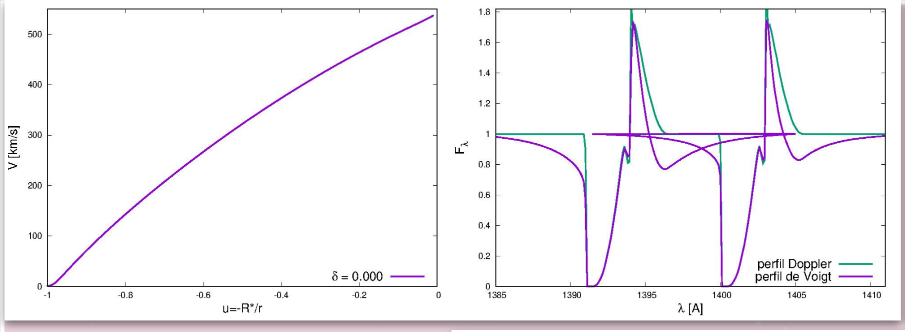
$\dot{M} = 0.089 \times 10^{-6} M_\odot/yr$

$V_\infty = 160.0$ km/s

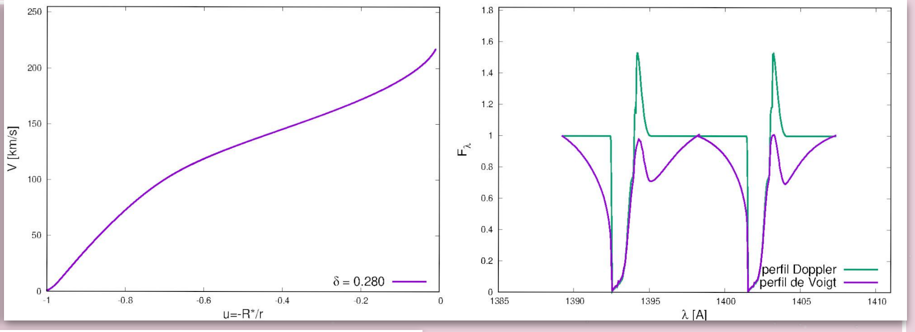
Teff = 18000 K, log(g) = 2.5, R = 23 R_*, v sen(i) = 40km/s, **Ω** = 0.27

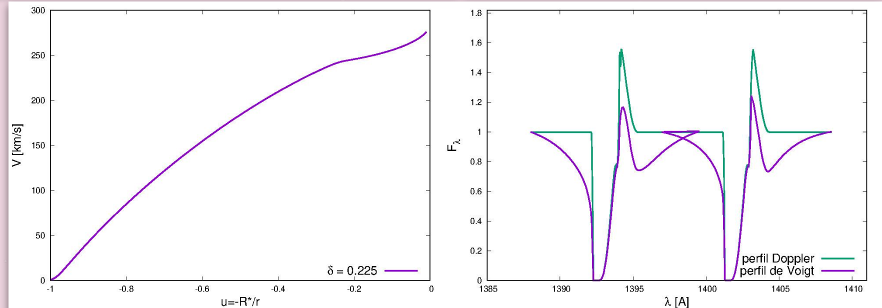
$\alpha = 0.515$, $k = 0.104$, $\dot{M} = 0.05 \times 10^{-6} M_\odot/yr$

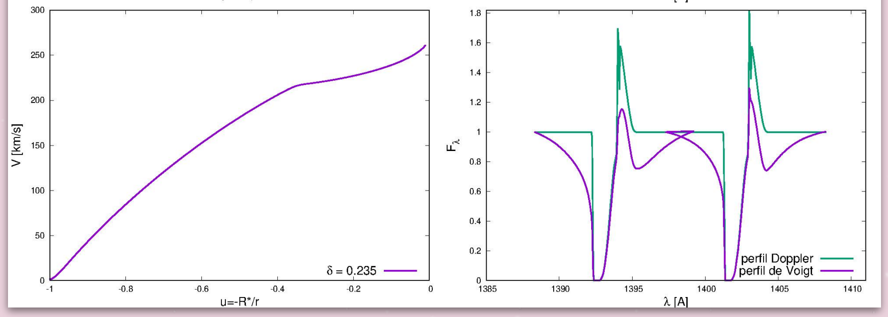
fast



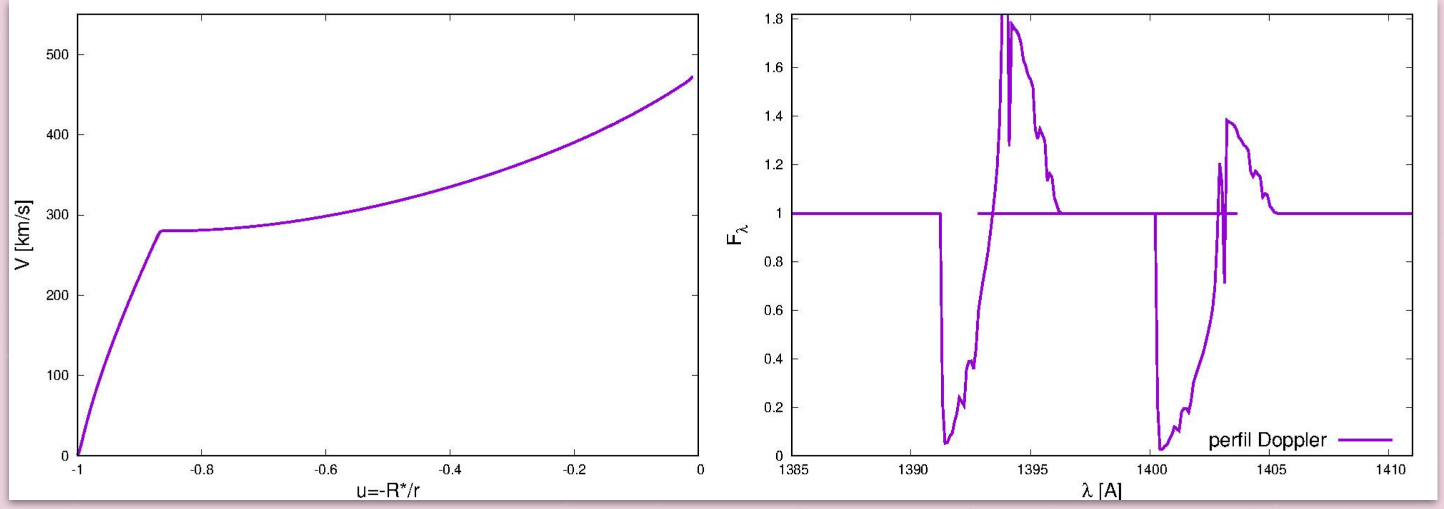
δ-slow



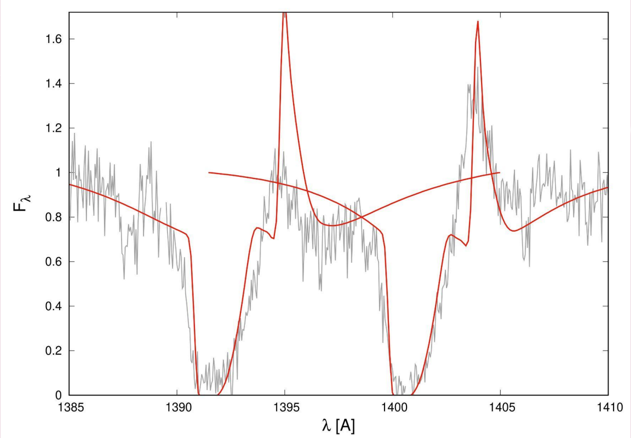




gap



V [km/s]
u=-R*/r
-1
-0.8
-0.6
-0.4
-0.2
0
100
200
300
400
500
F_λ
λ [A]
1385
1390
1395
1400
1405
1410
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
perfil Doppler



δ = 0.0 fast

V_∞ = 537.4 km/s

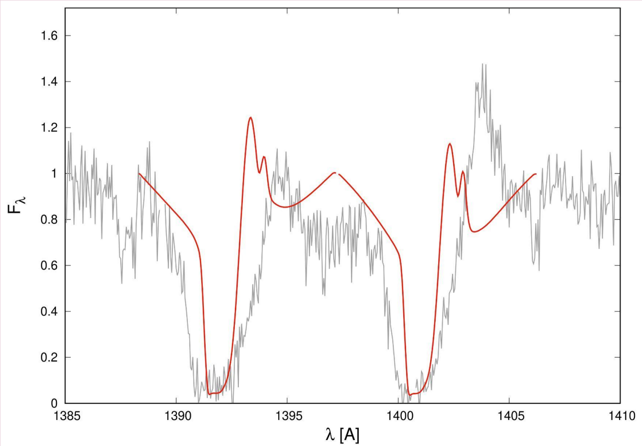
k = 0.104

α = 0.515

$\dot{M} = 0.05 \times 10^{-6} M_\odot$/yr

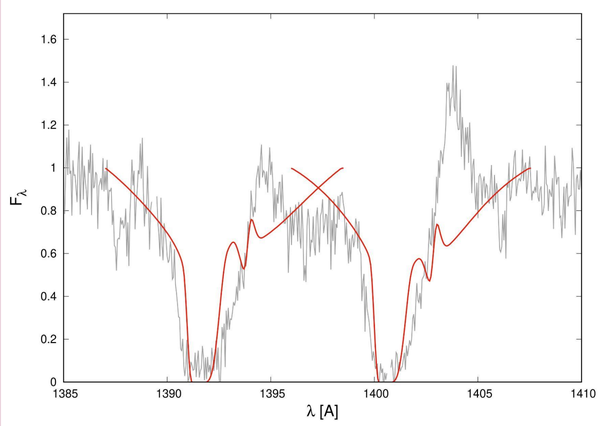
Vmacro = 40 km/s

Vmicro = 20 km/s



δ = 0.3 **δ**-slow

V_∞ = 211.9 km/s



δ = 0.225 gap

V_∞ = 276.1 km/s

Conclusions :D

Conclusions:

- new solutions in the transition regimen between fast and **δ**-slow solutions are stables, and have a kink. the convergence is independent on the initial solution,
- we calculated UV profiles, considering Stark broadening (incorporated in the MULITAS code),
- these kinks don't generate DACs, at least in the model explored,
- comparing with an observed spectra, the fast solution seems to be the more appropriate for modeling HD 41117.

Thanks!!💖💖💖