Celebrating the life's work of Don Kurtz

New insights about stellar oscillations in O stars and B supergiants

from NOT, Mercator and SONG spectroscopic observations

Sergio Simón-Díaz
Instituto de Astrofísica de Canarias

EXCELENCIA SEVERO OCHOA

IACOB

+ M. Godart, A. Herrero, N. Castro, C. Aerts, J. Puls, J. Telting, L. Grassitelli

+ the valuable help of many observers

The IACOB project: a new era in the study of Galactic O and B stars

Main objective

Provide an **unprecedented empirical overview** of the main physical properties of Galactic massive **O- and B-type stars** which can be used as **definitive anchor point** for our theories of stellar atmospheres, winds, interiors and evolution of massive stars.

IACOB

P.I. S. Simón-Díaz
IAC-SO Advanced fellow

Working packages

WP-1: The IACOB spectroscopic database.
WP-2: Line-broadening in OB stars.
WP-3: Quantitative spectroscopic analyses.
WP-4: Theory and models vs observations.
WP-5: Spectroscopic variability phenomena.
WP-6: Massive binary/multiple systems.
WP-7: Massive stars and the ISM.

The IACOB project: spectroscopic observations

After 8 years of observations (150+ observing nights) with

FIES@NOT & HERMES@Mercator

IACOB Spectroscopic database

500+ Galactic O and B stars
(O4-B9, all luminosity classes)
5000+ spectra

… and increasing

The largest multi-epoch, high-resolution spectroscopic database of Northern Galactic O- and B-type stars compiled to date

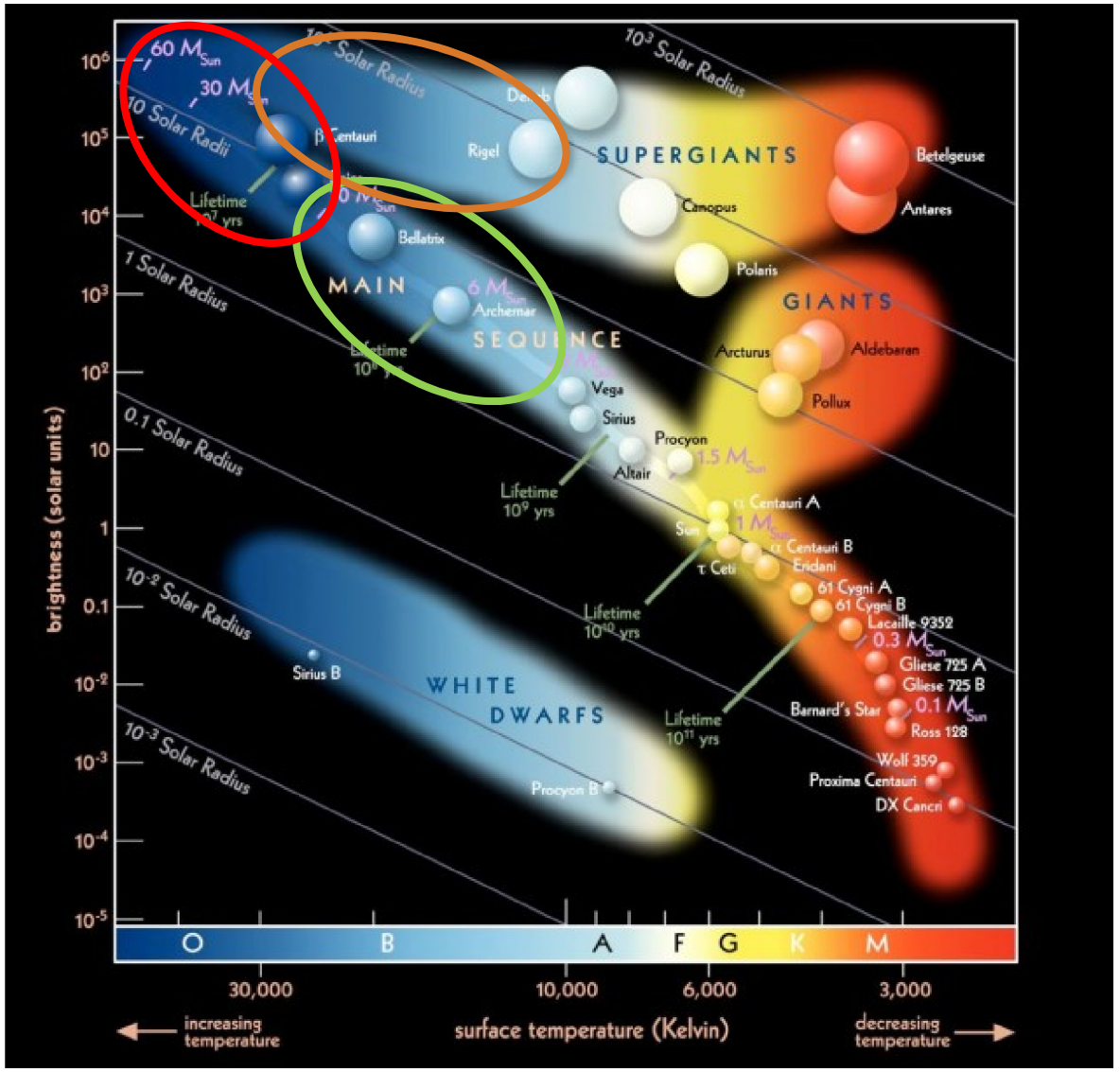
Last described in Simón-Díaz et al. (2015)

+ **SONG** observations added to the pool since 2015

15 O stars & B Sgs **14000+ spectra**

… and increasing

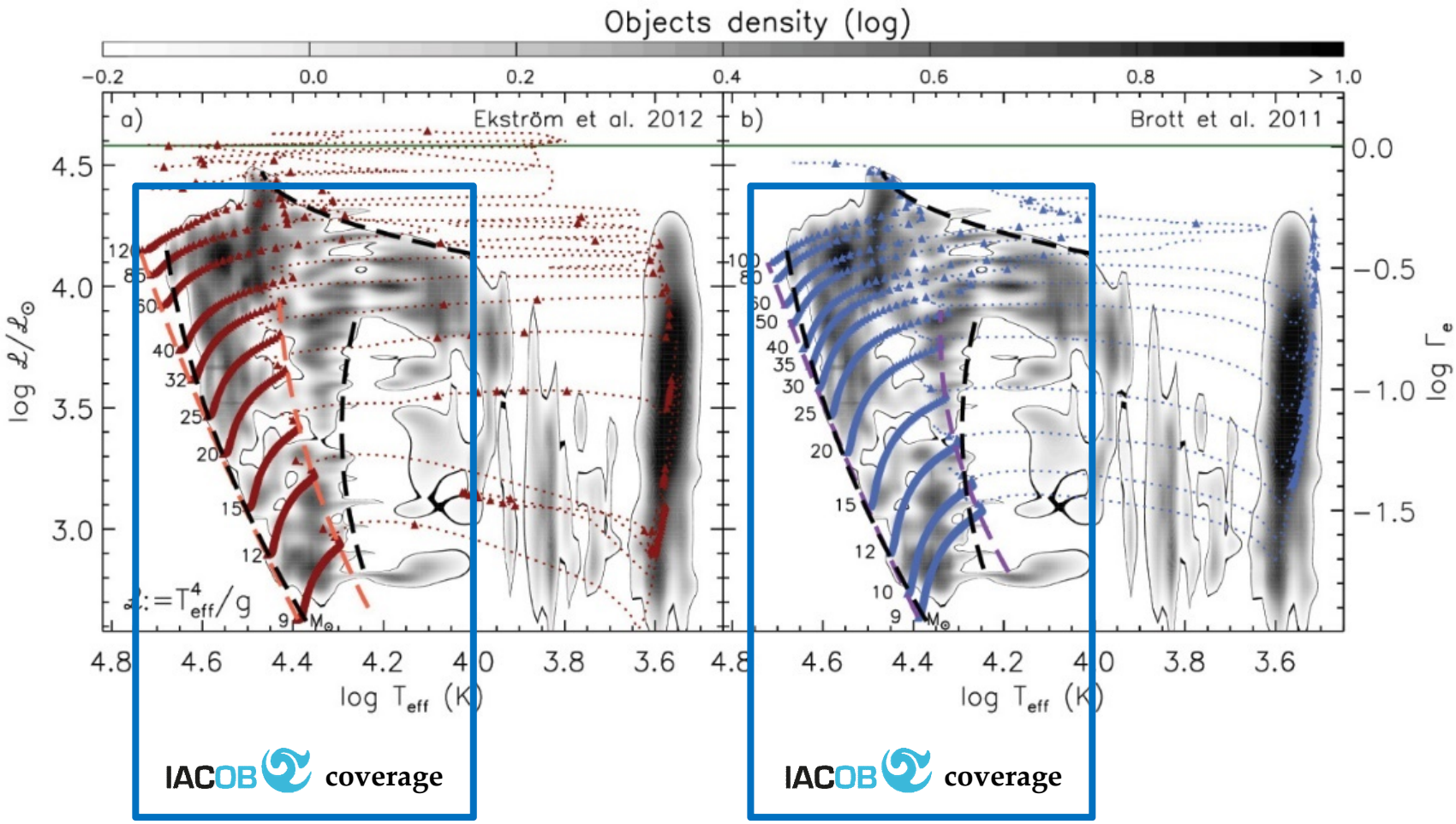
The IACOB sample in a broader context



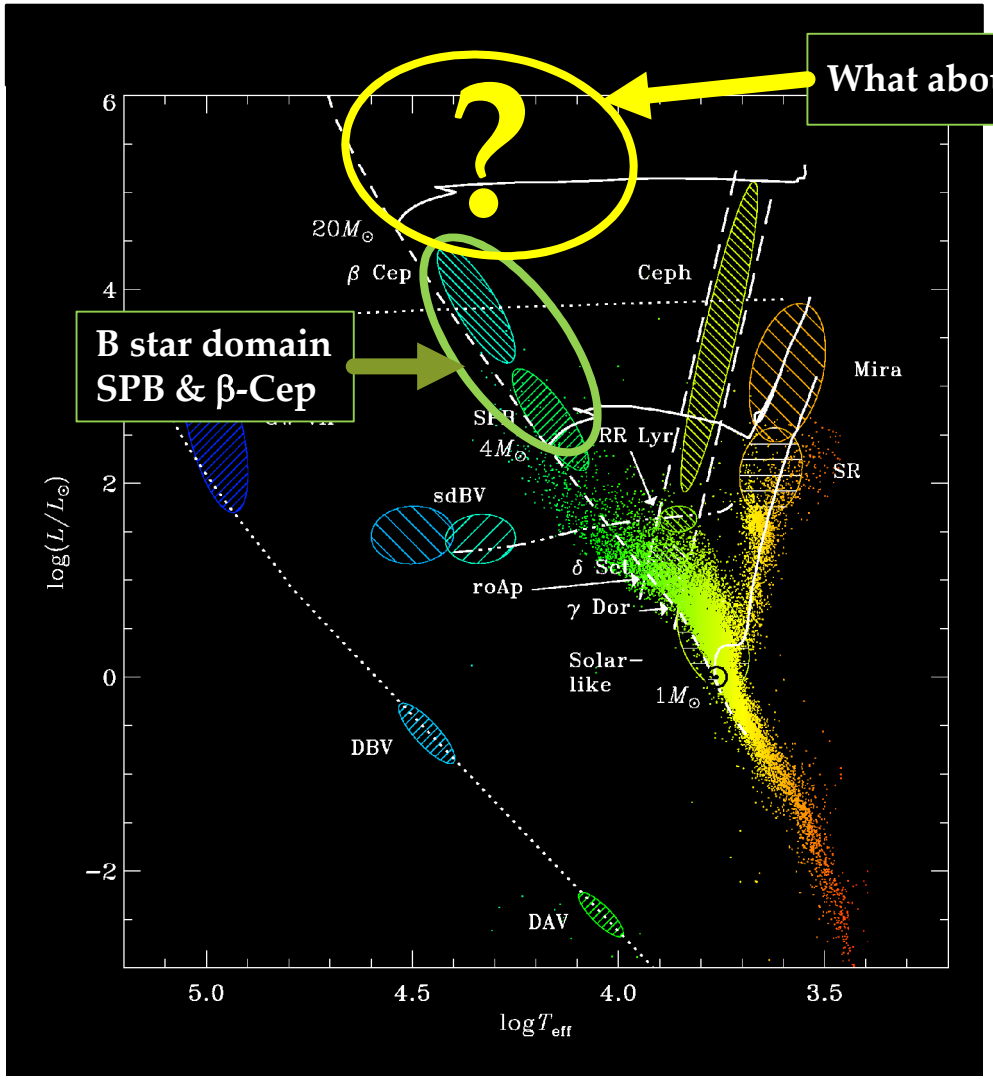
The IACOB sample in a broader context

The empirical spectroscopic HR diagram of massive stars

Castro et al. (2014)



The IACOB sample in a broader context



Variability of diverse origins, some of them not fully understood and/or observationally confirmed yet:

- Heat-driven gravity modes
- Heat-driven pressure modes
- Oscillatory convective modes
- Stochastically-excited waves
- Solar-like oscillations
- Internal gravity waves
- Modes excited by the ε-mechanism
- Strange mode instabilities
- Radiation-driven wind variability …

- Long and short time-scales
- Quasi-periodicities
- High and low amplitudes
- Mass loss episodes …

The IACOB project: a new era in the study of Galactic O and B stars

Main objective

Provide an **unprecedented empirical overview** of the main physical properties of Galactic massive **O- and B-type stars** which can be used as **definitive anchor point** for our theories of stellar atmospheres, winds, interiors and evolution of massive stars.

IACOB

P.I. S. Simón-Díaz
IAC-SO Advanced fellow

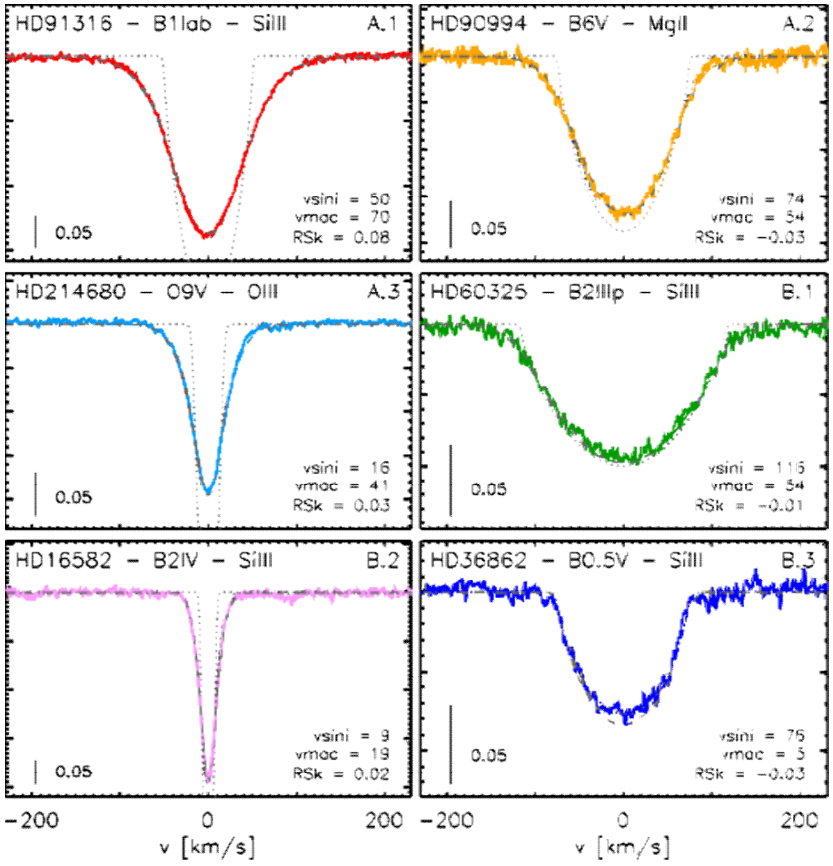
EXCELENCIA SEVERO OCHOA

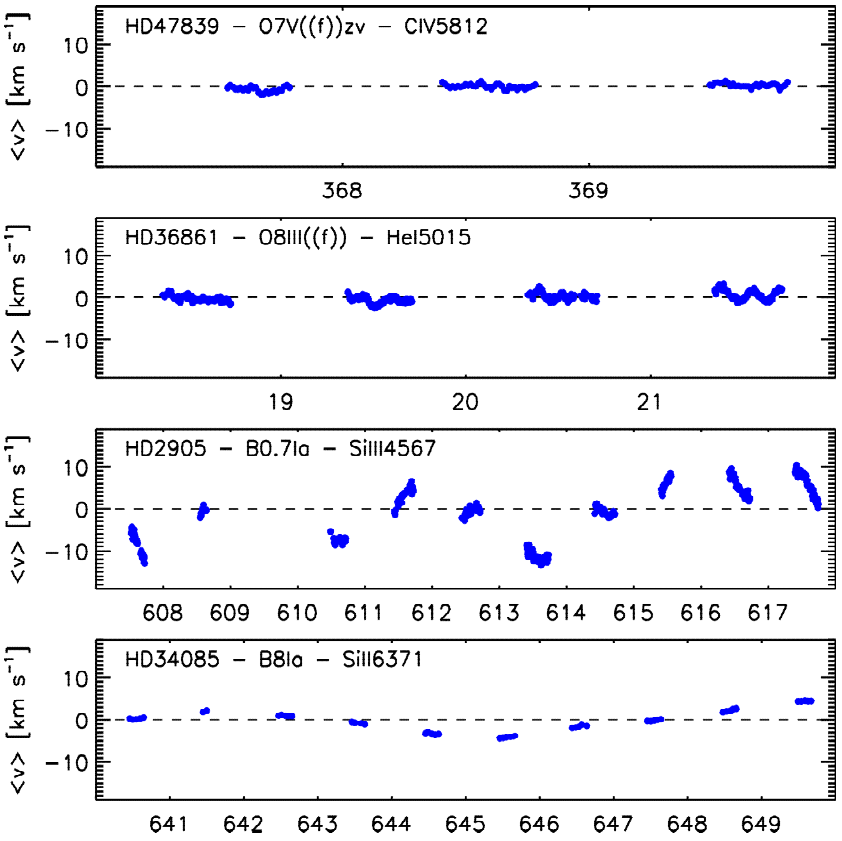
Working packages

WP-1: The IACOB spectroscopic database.
WP-2: Line-broadening in OB stars.
WP-3: Quantitative spectroscopic analyses.
WP-4: Theory and models vs observations.
WP-5: Spectroscopic variability phenomena.
WP-6: Massive binary/multiple systems.
WP-7: Massive stars and the ISM.

This talk: Main purpose

Illustrate what can we learn about **stellar oscillations in O stars and B supergiants** from **IACOB single snapshot** and **time resolved** **spectra**





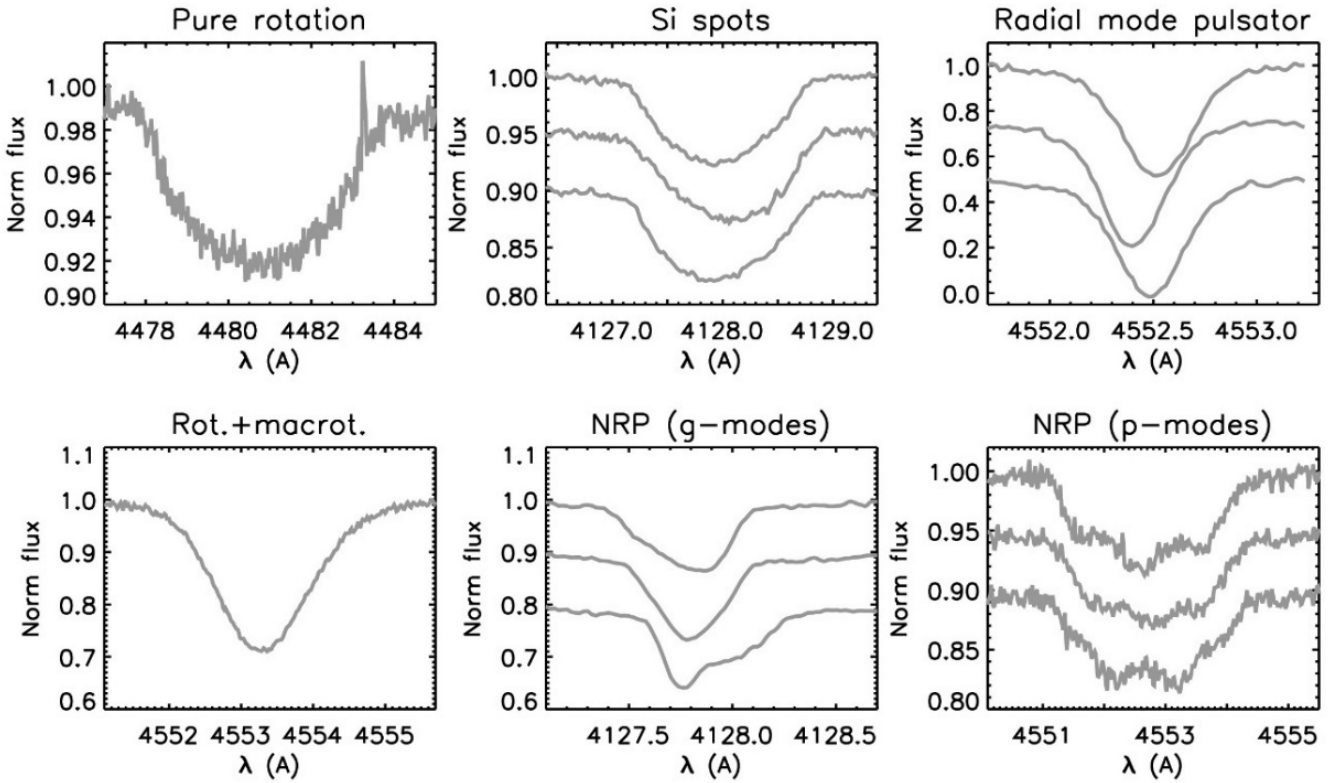
Asteroseismology of OB stars with hundreds of single snapshot spectra

Or …

Is macroturbulent broadening in OB stars a spectroscopic signature of stellar oscillations?

Photospheric line-profiles in O- and B-type stars

High-resolution spectra clearly show that **rotation is not the only macroscopic line-shaping (incl. broadening) agent** in OB-type stars

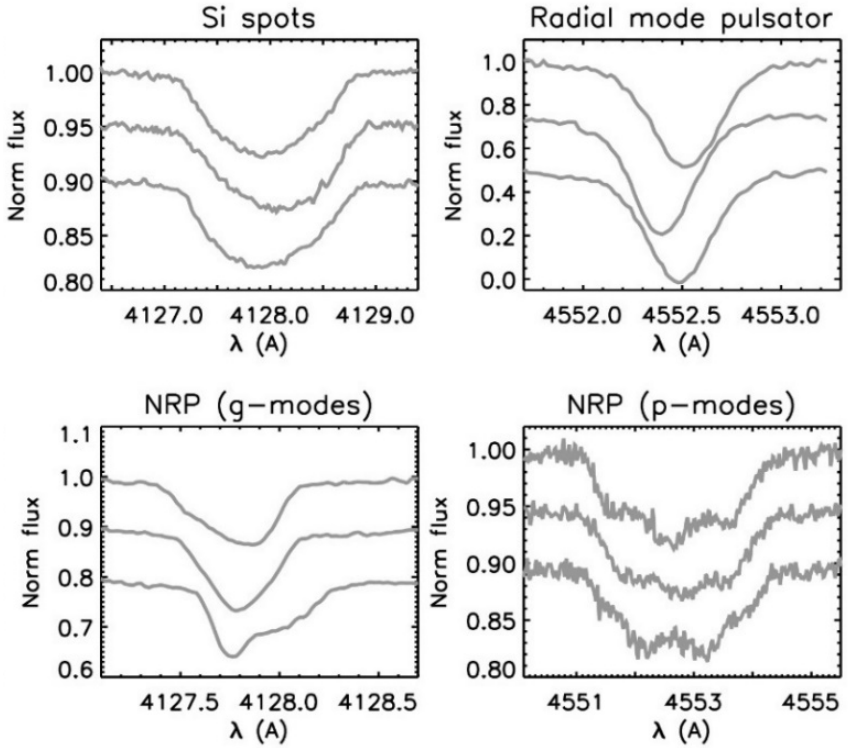


+ effect of magnetic fields, stellar winds …

Photospheric line-profiles in O- and B-type stars

In the **B main sequence** domain,
stellar oscillations and **spots**
leave clear (variable) signatures
on the shape and global broadening
of the line-profiles

e.g., Aerts et al. (2014)



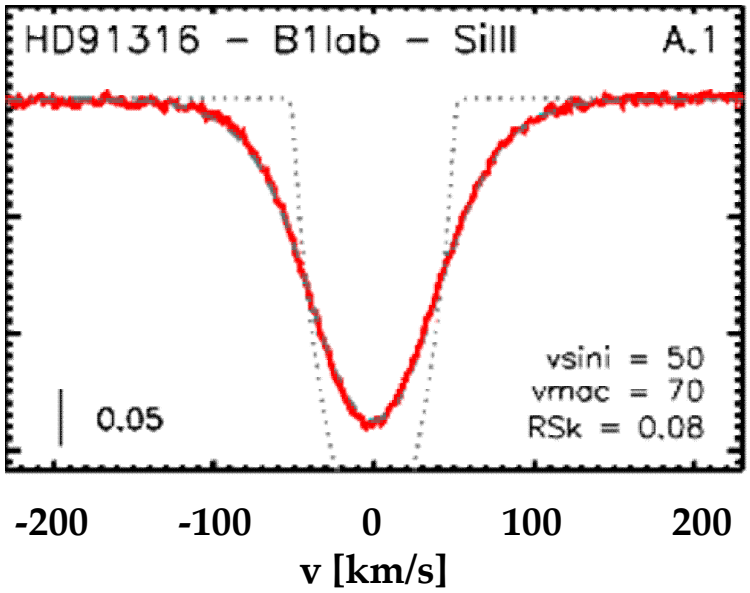
What about **O stars** and **B supergiants** (i.e. stars with higher masses) ???

Photospheric line-profiles in O- and B-type stars

What about **O stars** and **B supergiants** (i.e. stars with higher masses) ???

All **B supergiants** are found to have **apparently symmetric V-shape profiles**

Also low and intermediate vsini **O-type stars** have similar profiles



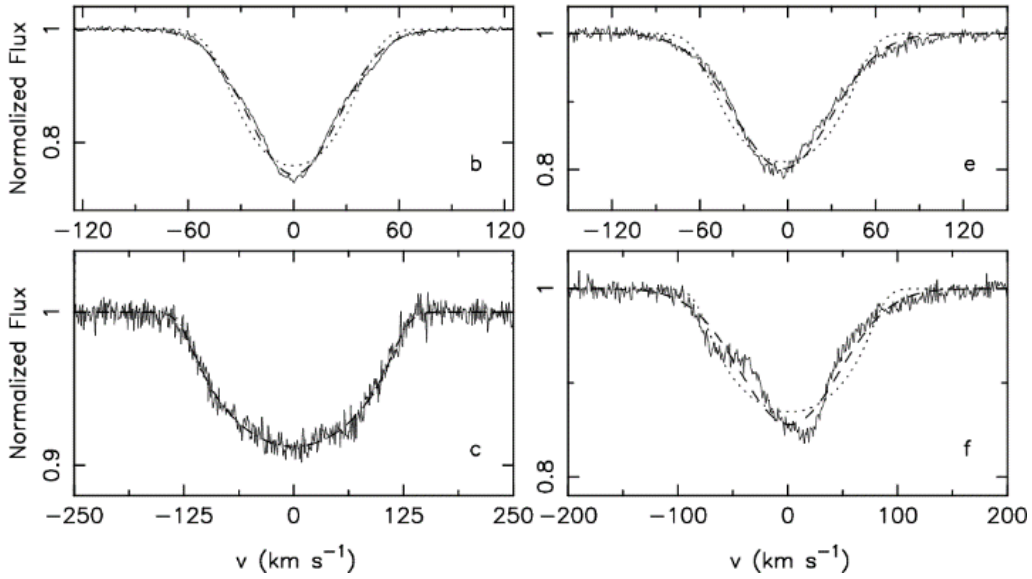
Non-rotational broadening contribution traditionally quantified using a Gaussian (isotropic or radial-tangential) profile and called **macroturbulent broadening (v_{mac})**

v_{mac} up to **≈ 100 km/s** in some cases !!??!!

Macroturbulent broadening in B Sgs = **Collective effect of non-radial pulsations**

Aerts et al. (2009), also proposed by Lucy (1976)

Simulated line-profiles broadened by rotation and by
hundreds of low-amplitude non-radial gravity-mode pulsations
can reproduce the observed profiles for realistic pulsation amplitudes



Macroturbulent broadening in B Sgs = **Collective effect of non-radial pulsations**

Test it!

Use it!

Or maybe better …

Do both at the same time !!

Simón-Díaz (2015)

Macroturbulent broadening in O and B stars: a global empirical overview

Observations

- Single-epoch FIES+HERMES spectra from IACOB
- S/N = 150 - 300
- Selected sample: (1) vsini < 200 km/s, (2) SB2, Oe, Be, excluded

430 OB stars

Tools and methods

[1] Line broadening parameters: *vsini, vmac*

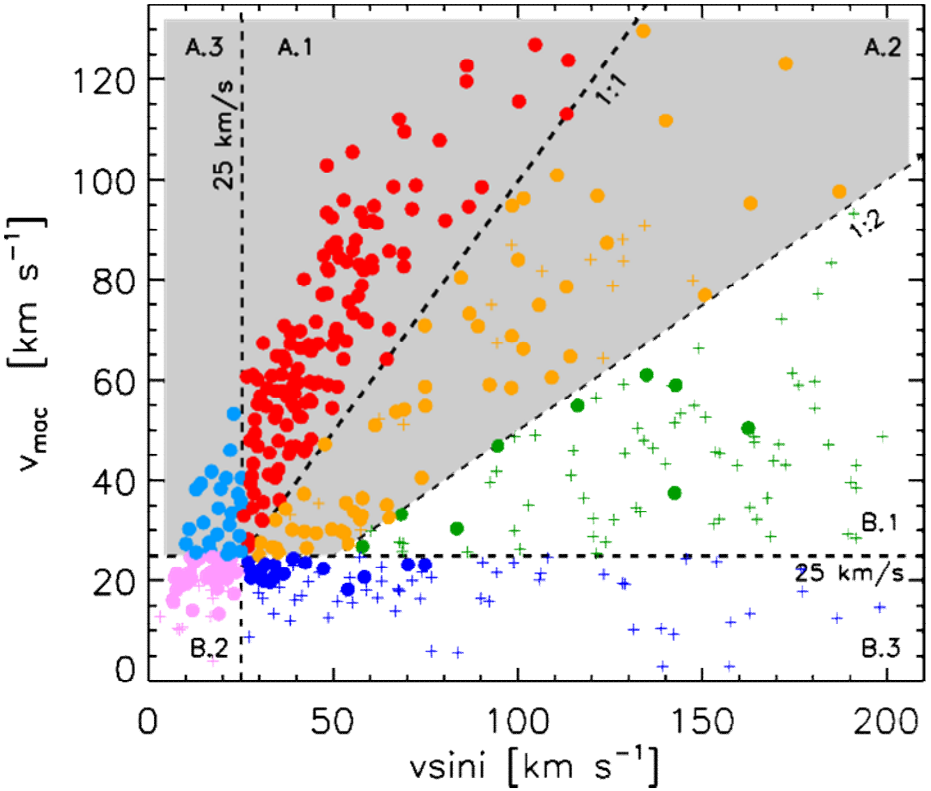
- Combined FT+GOF technique *(Gray 1976; Simón-Díaz & Herrero, 2007, 2014)*
- Diagnostic lines: OIII 5591, SiIII 4552, MgII 4481, CII 4267

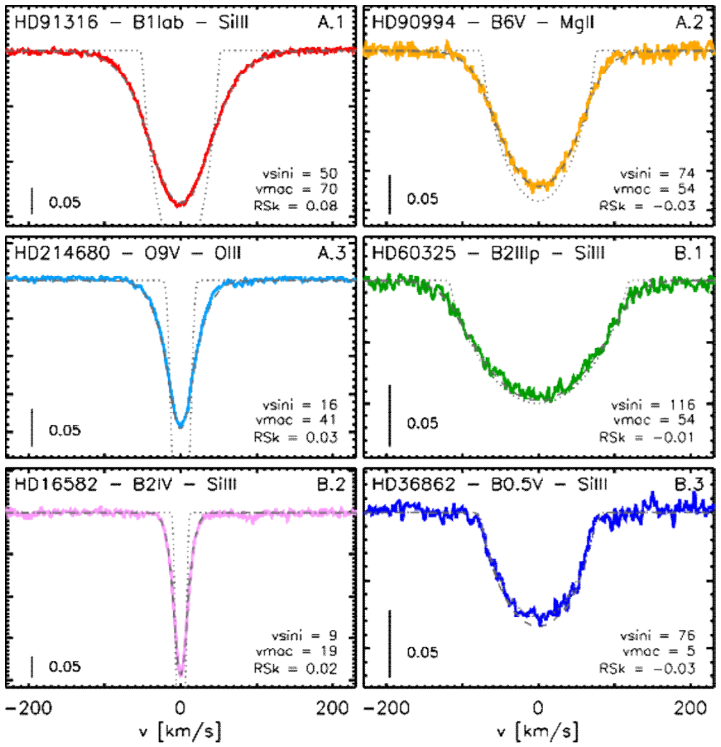
[2] Spectroscopic parameters: Teff, logg …

- Stellar atmosphere code: FASTWIND *(Puls et al. 2005)*
- (Semi)-automatized grd-based tools *(Simón-Díaz et al. 2011; Castro et al. 2011)*
- Diagnostic lines: Mainly HI, HeI-II Si II-III-IV, but also O II, N II, Mg II

Macroturbulent broadening in O and B stars: a global empirical overview

(Single-snapshot) line-broadening characterization of line-profiles of O and B stars in terms of vsini and v_{mac}

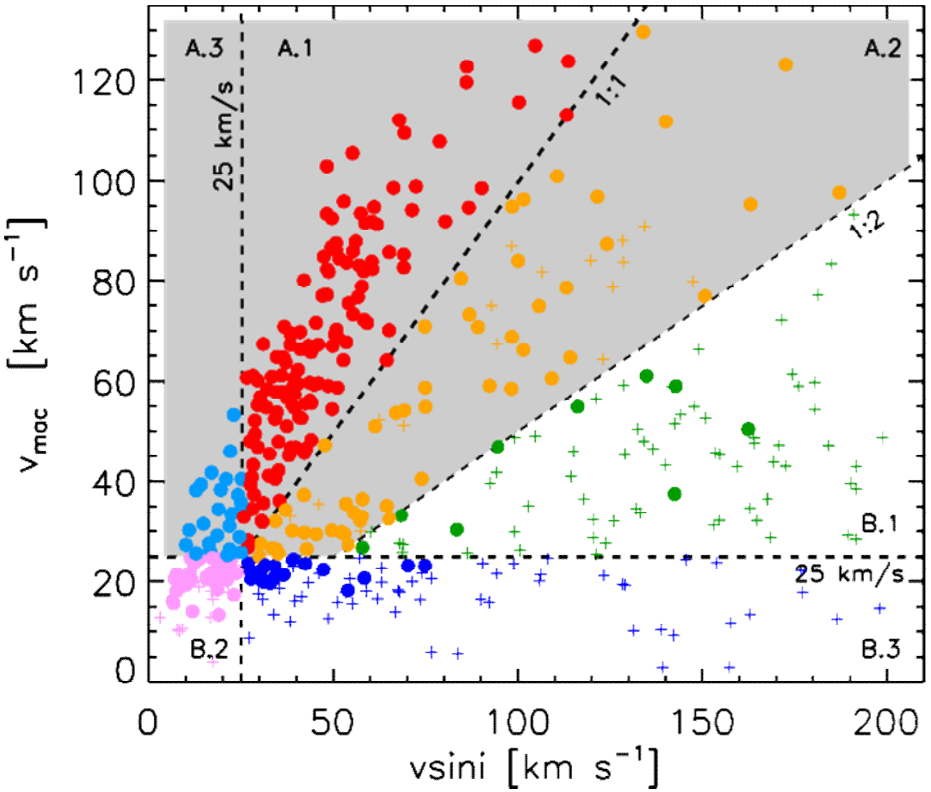


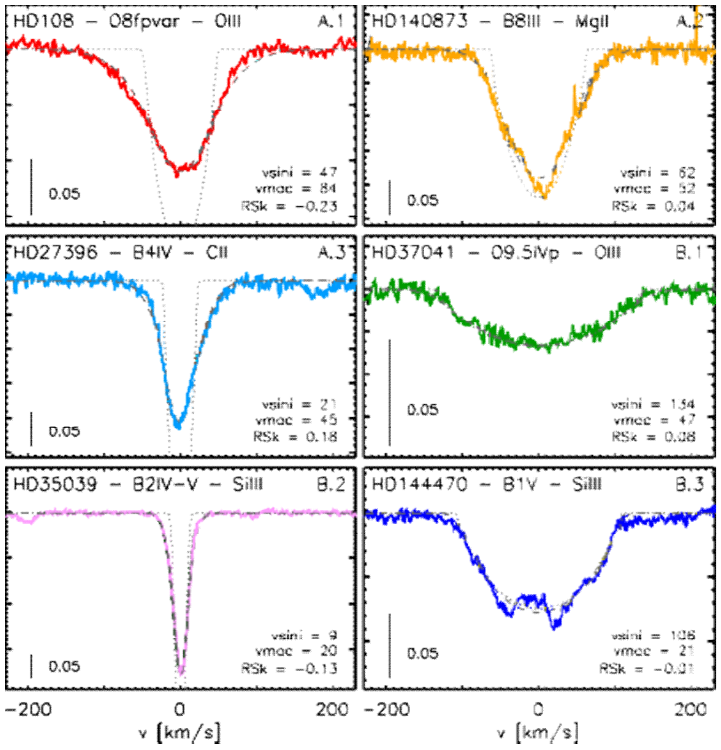


Simón-Díaz et al. (2016)

Macroturbulent broadening in O and B stars: a global empirical overview

(Single-snapshot) line-broadening characterization of line-profiles of O and B stars in terms of vsini and v_{mac}

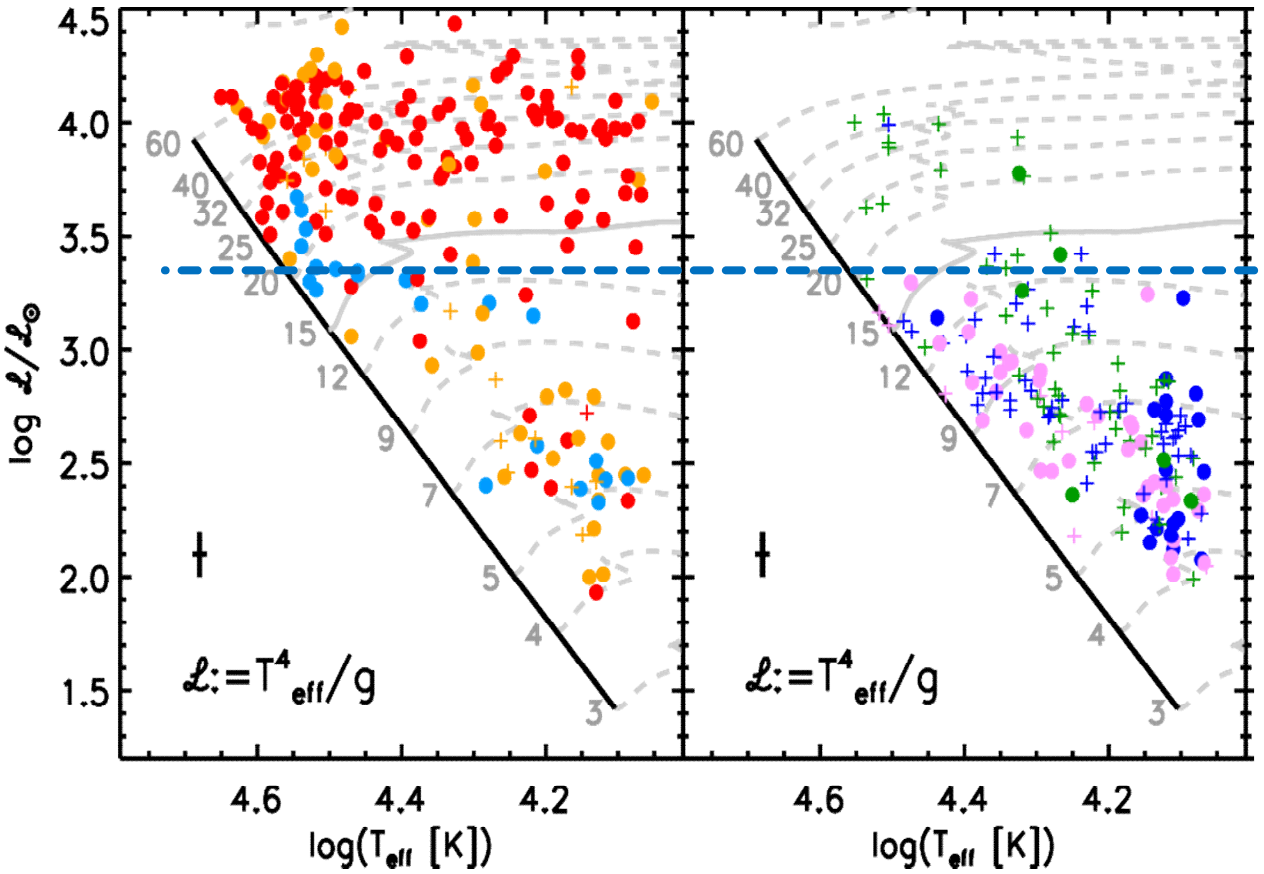




Simón-Díaz et al. (2016)

Macroturbulent broadening in O and B stars: a global empirical overview

(Single-snapshot) line-broadening properties of O and B stars in the sHRD



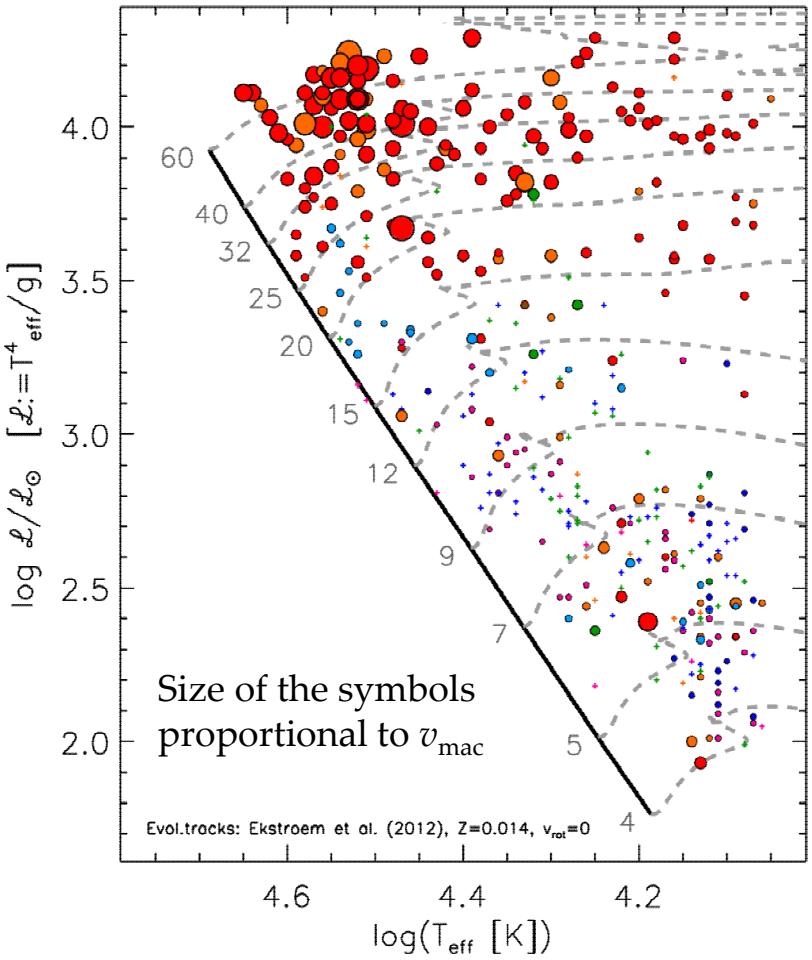
1 dominant source of non-rotational broadening

Various types of non-rotational broadening agents

Simón-Díaz et al. (2016)

Macroturbulent broadening in O and B stars: a global empirical overview

(Single-snapshot) line-broadening properties of O and B stars in the sHRD



There is something going on in the O star and B supergiant domain that is not happening in the B star domain

What driving mechanism of stellar oscillations (if any!) can reproduce these empirical results?

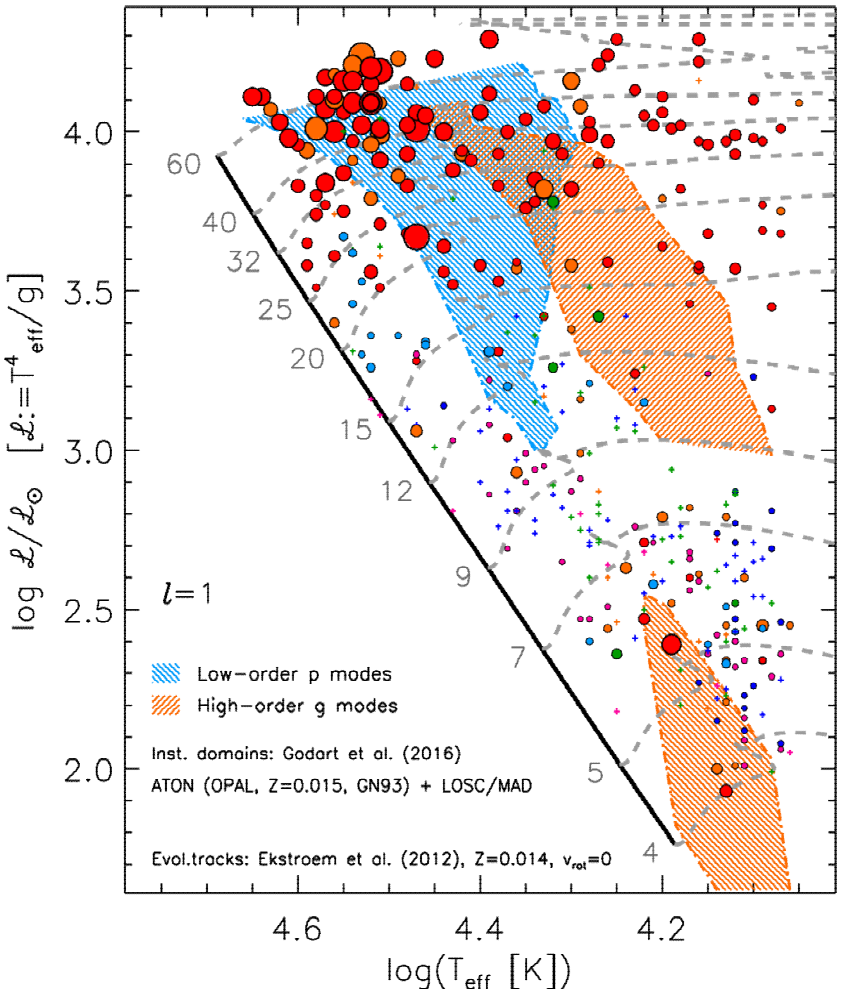
Is macroturbulent broadening in O stars and B Sgs a spectroscopic signature of stellar oscillations?

(single snapshot approach)

IMPORTANT NOTE (adapted from *Aerts et al. 2009*)

A **dense frequency spectrum of excited modes** is required ➔ Mainly g-modes

Scenario #1: Heat-driven modes (due to the Fe opacity bump)

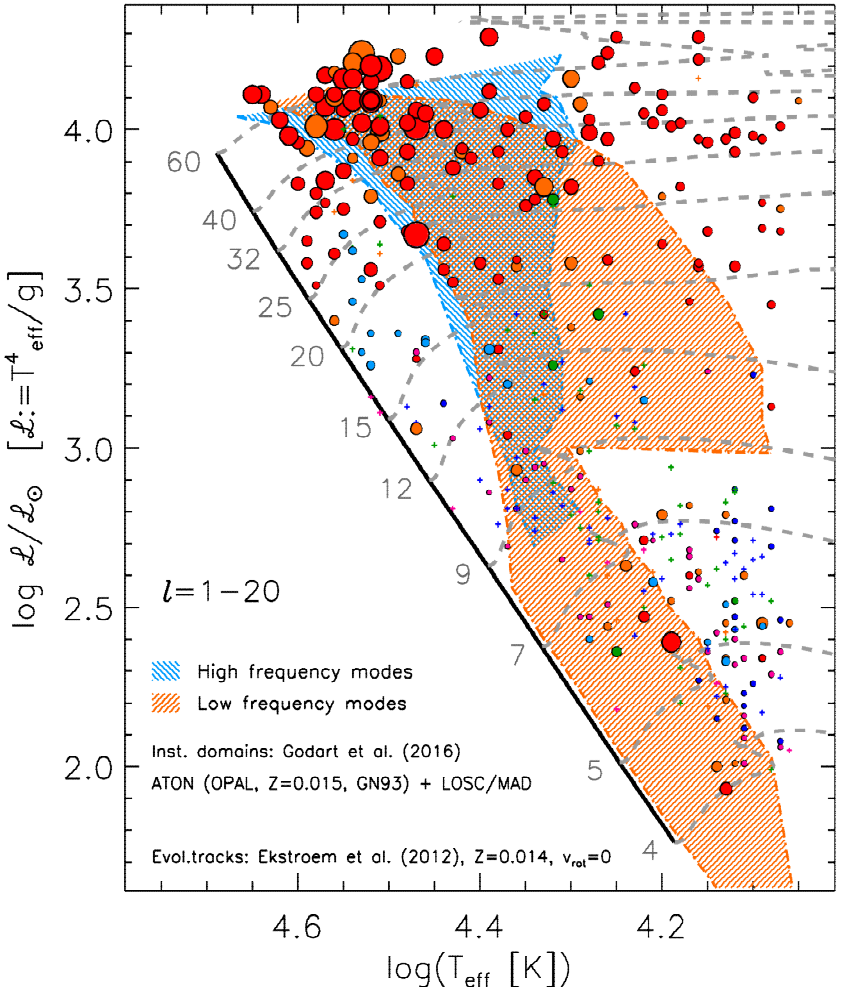


Adapted from ***Simón-Díaz et al. (2016)***

For $\ell = 1$, the situation is not very promising (except for early BSgs)

But higher degree modes should be also considered

Scenario #1: Heat-driven modes (due to the Fe opacity bump)



Adapted from *Godart et al. (2016)*

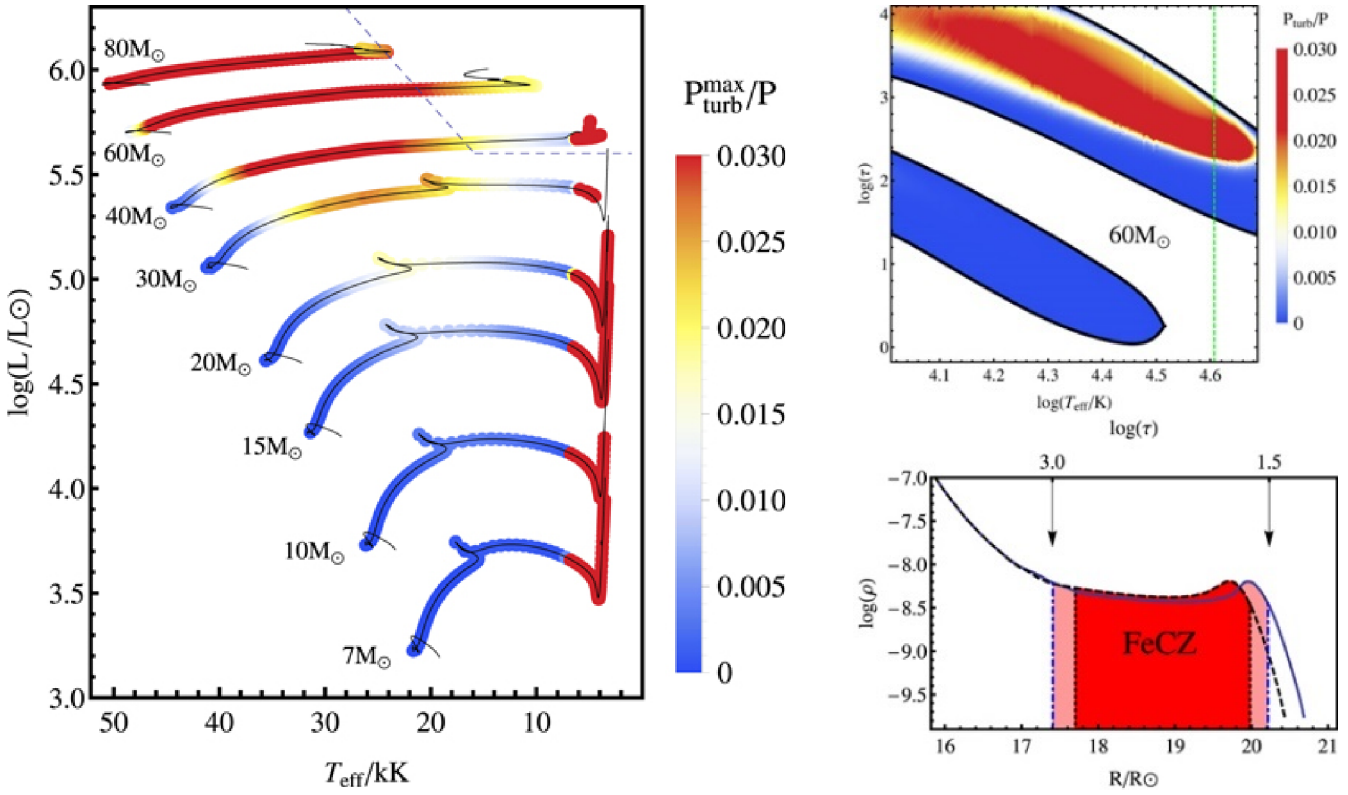
Better agreement, but still …

Stellar oscillations originated by a heat mechanism do not seem to be able to explain alone the ocurrence of the observed line-profiles in the O star and B Sg domain

+ To be done: investigate the effect of metallicity, opacities, metal mixture

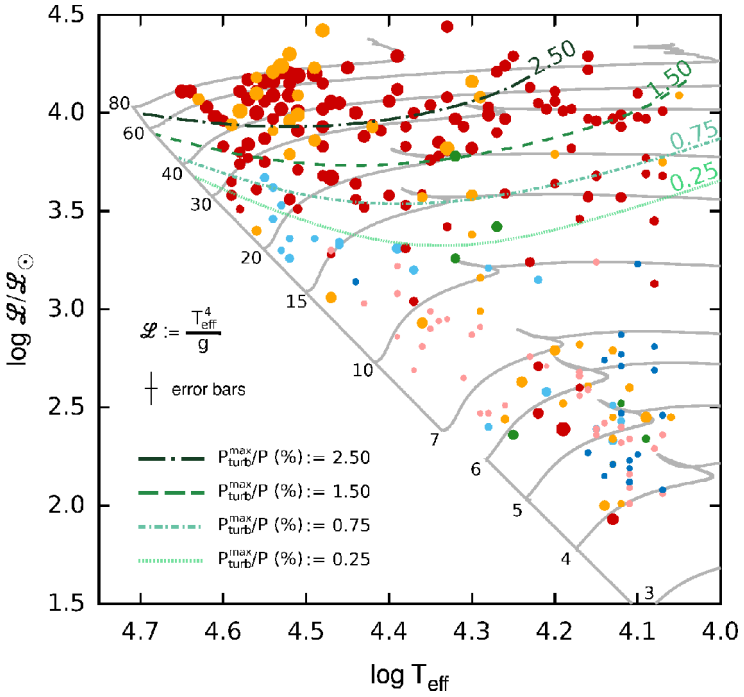
Scenario #2: Stochastically excited waves by turbulent motions in the FeCZ

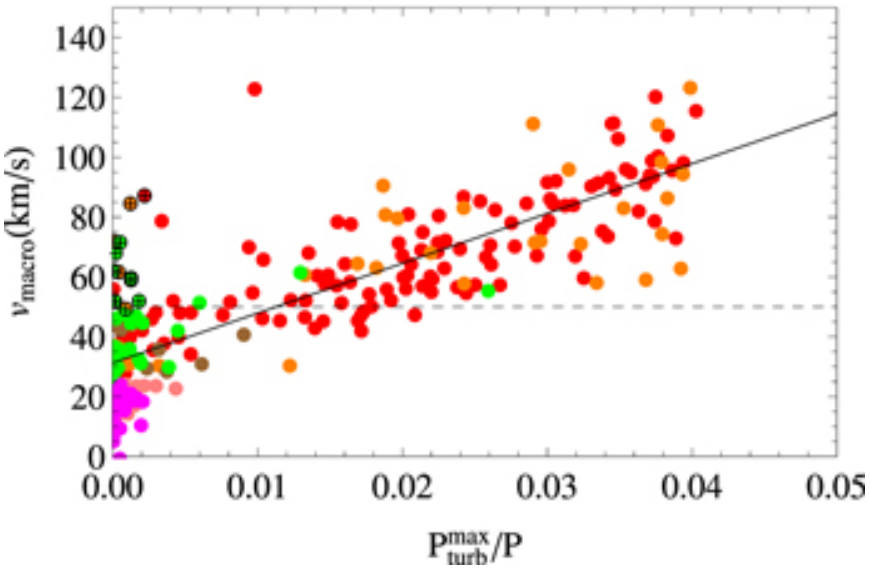
Grassitelli et al. (2015) proposed turbulent pressure fluctuations generated in sub-surface convection zones as a possible mechanism to explain the occurrence of macroturbulent broadening in luminous massive stars via the excitation of high-order oscillations



Scenario #2: Stochastically excited waves by turbulent motions in the FeCZ

The predictions by *Grassitelli et al. (2015)* are in very good agreement with the empirical results by *Simón-Díaz et al. (2016)*





Asteroseismology of O stars and B Sgs with FIES+HERMES+SONG time-resolved spectroscopy

Observations and work in progress …

Time-resolved spectroscopy of O stars and B Sgs

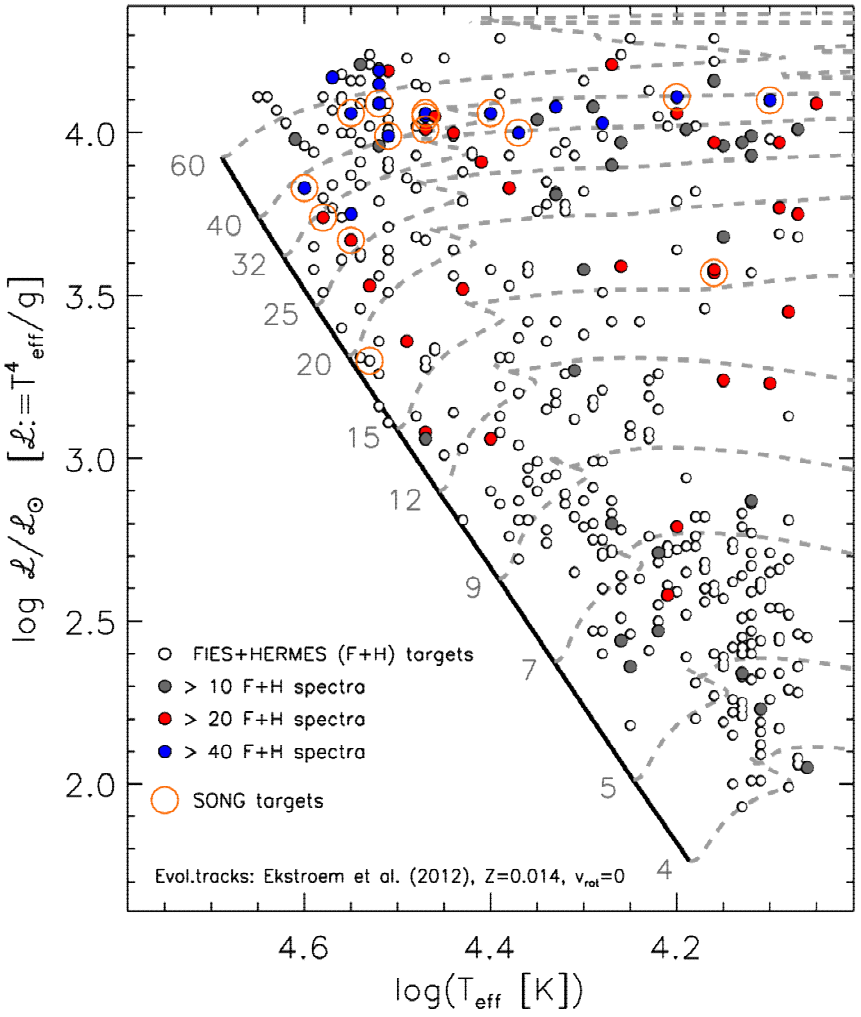
Observations

FIES+HERMES

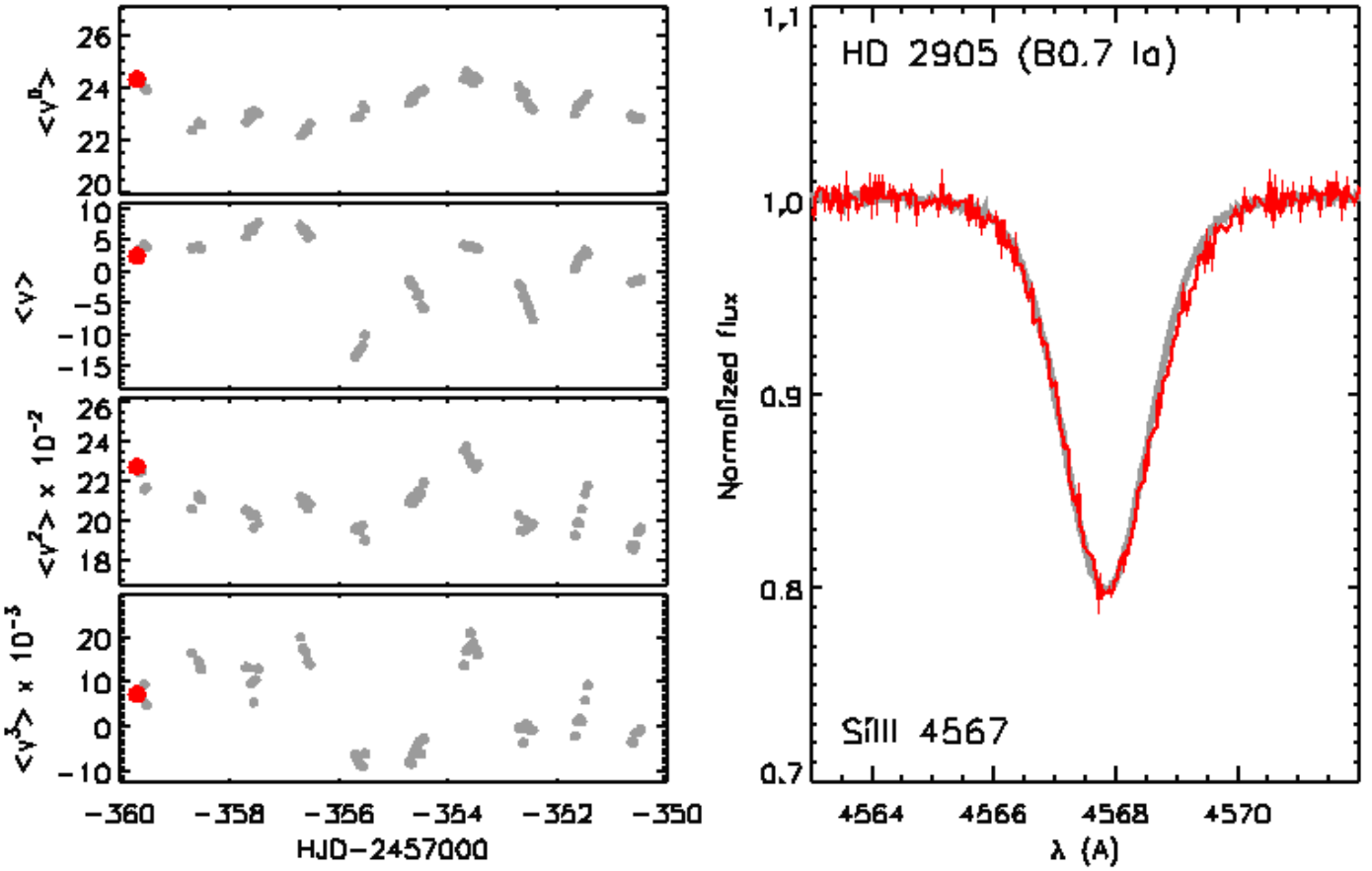
- 45 stars (mostly O stars and B Sgs)
- More than 20 spectra
- Time-span: 3-10 nights
- Cadence: 3-10 spectra per night

SONG

- 15 stars (all of them O stars and B Sgs)
- Time-span: 3-7 full nights (2-8h per night)
- Cadence: 30-900 s



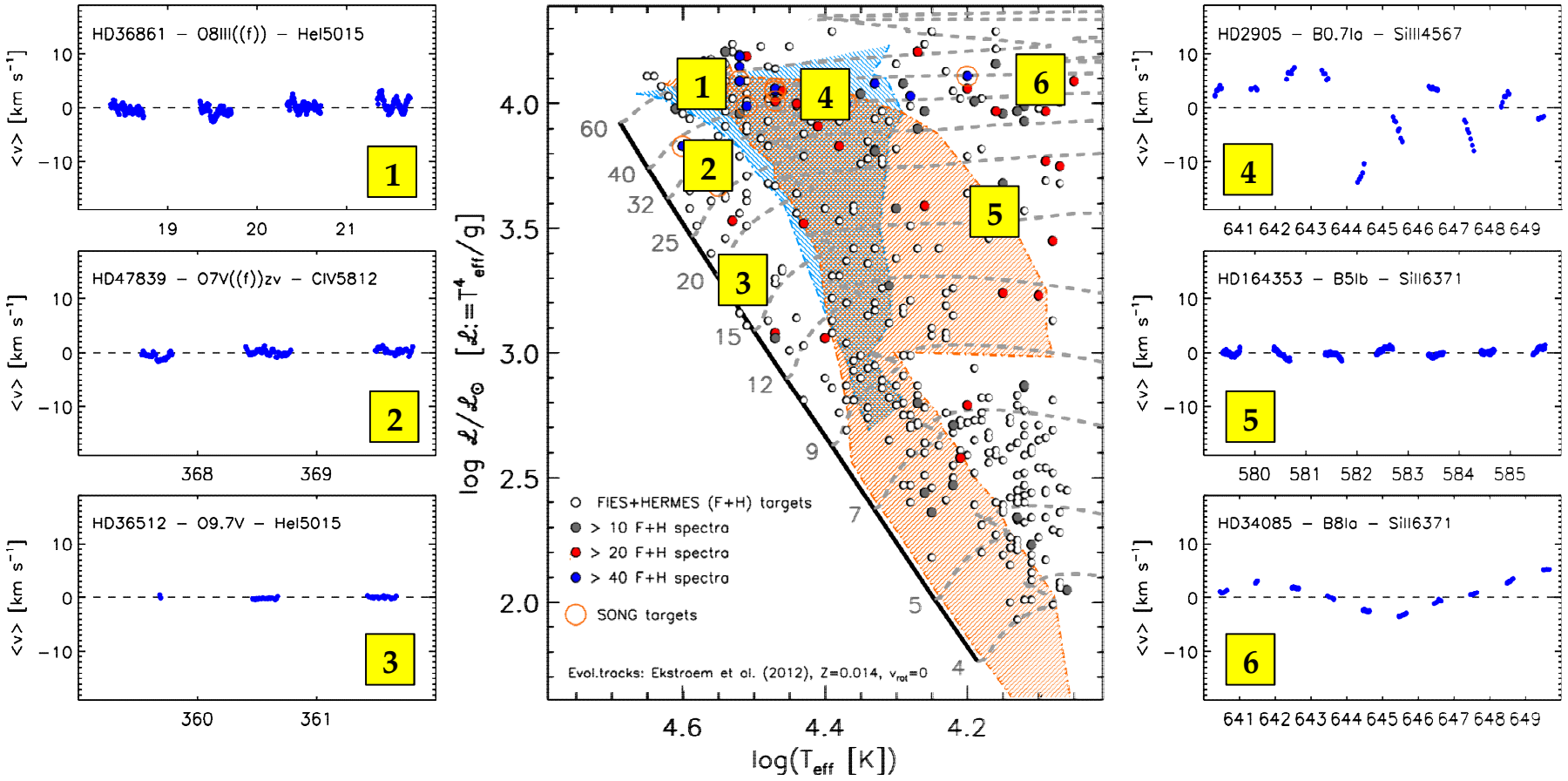
Time-resolved spectroscopy of O stars and B Sgs



Moments of the line ⟵ Line-profile variability

Spectroscopic variability of O stars and B Sgs in the sHRD: some examples

The plan is to end up with similar data for ≈ 70 – 80 stars (we already have 45)

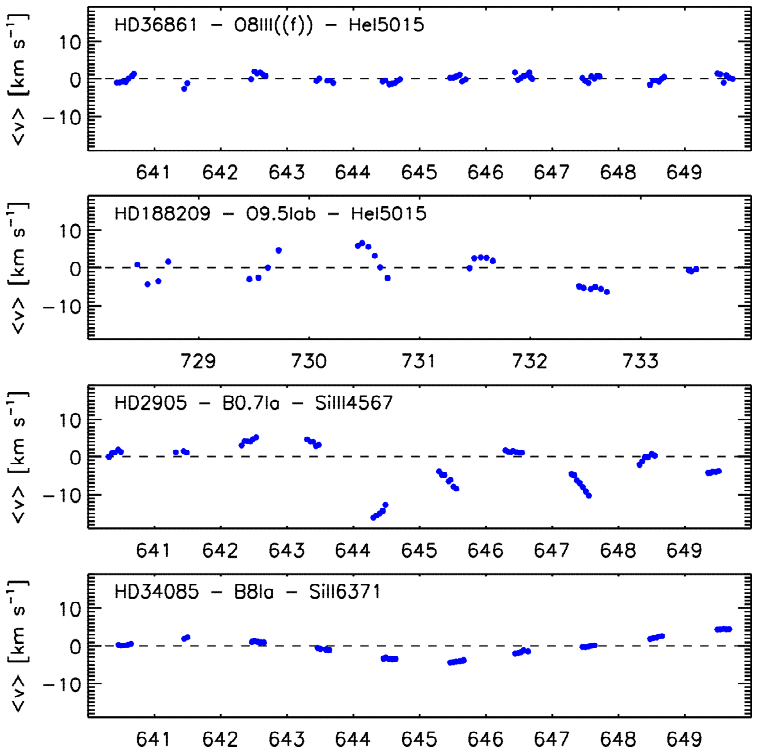


Main objective: Global overview + pulsational origing of macroturbulent broadening

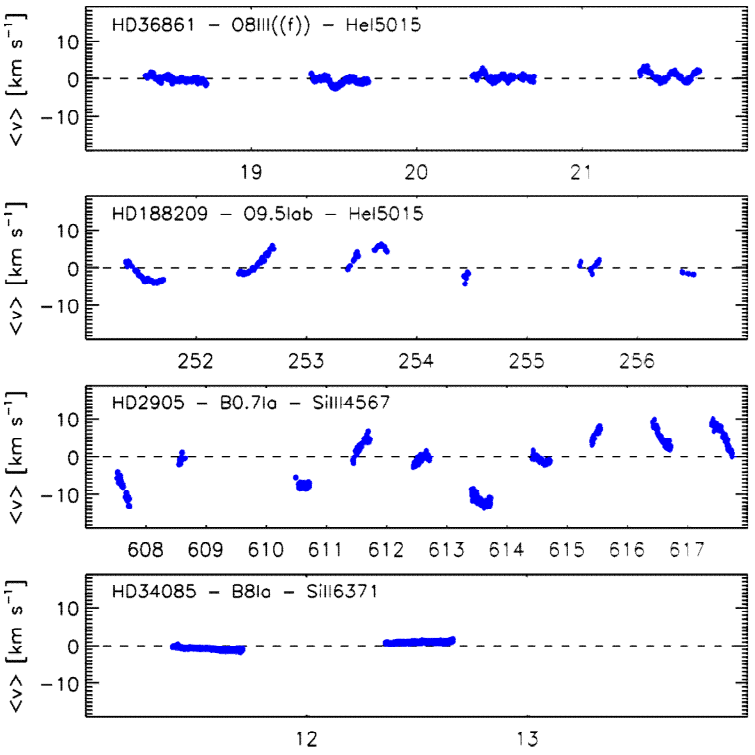
Also: utility for [1] TESS (BRITE?) [2] follow up observations for frequency analysis …

FIES+HERMES *vs.* SONG observing modes: some examples

FIES + HERMES



SONG



Depending of the región of the HRD a different cadence and time-span is needed

SONG has a enormous potential for especific follow up observations

Multi-site is a MUST !!!

Very well known stars can still reveal details never seen before