
IACOB
EXCELENCIA
SEVERO
OCHOA
The power of
SONG
for studying massive
O stars and B Sgs
S. Simón-Díaz
Instituto de Astrofísica de Canarias
Credit: Mads Fredslund Andersen

The IACOB project has spent
more than 1000 hours
of SONG time since December 2014

Why?


The power of
SONG
for studying massive
O stars and B Sgs
Act I
IACOB
Credit: Mads Fredslund Andersen

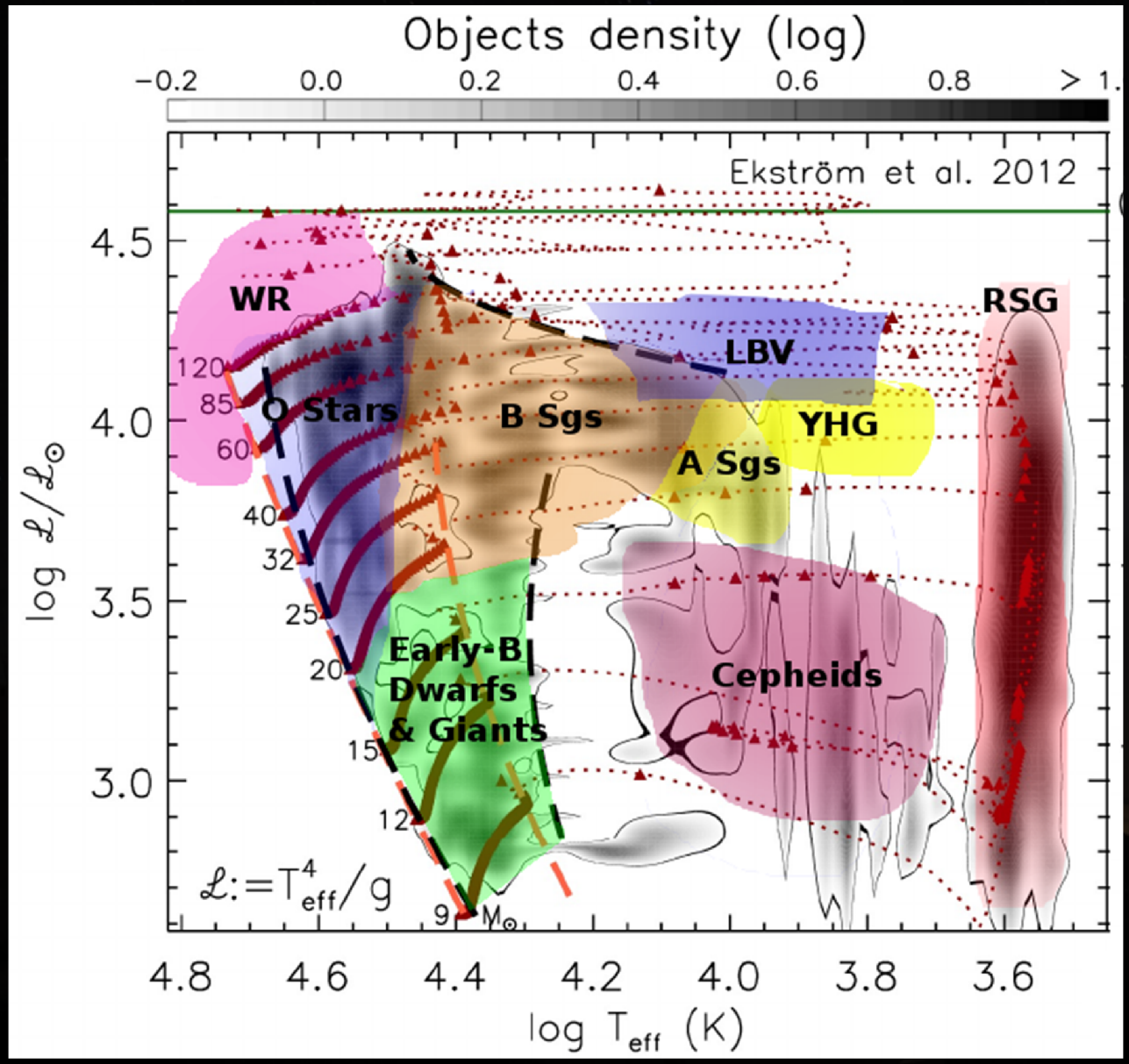
P.I. S. Simón-Díaz

IACOB

EXCELENCIA SEVERO OCHOA

Main Scientific Goal

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.



Courtesy of G. Holgado (IAC)

Figure adapted from Castro et al. (2014)

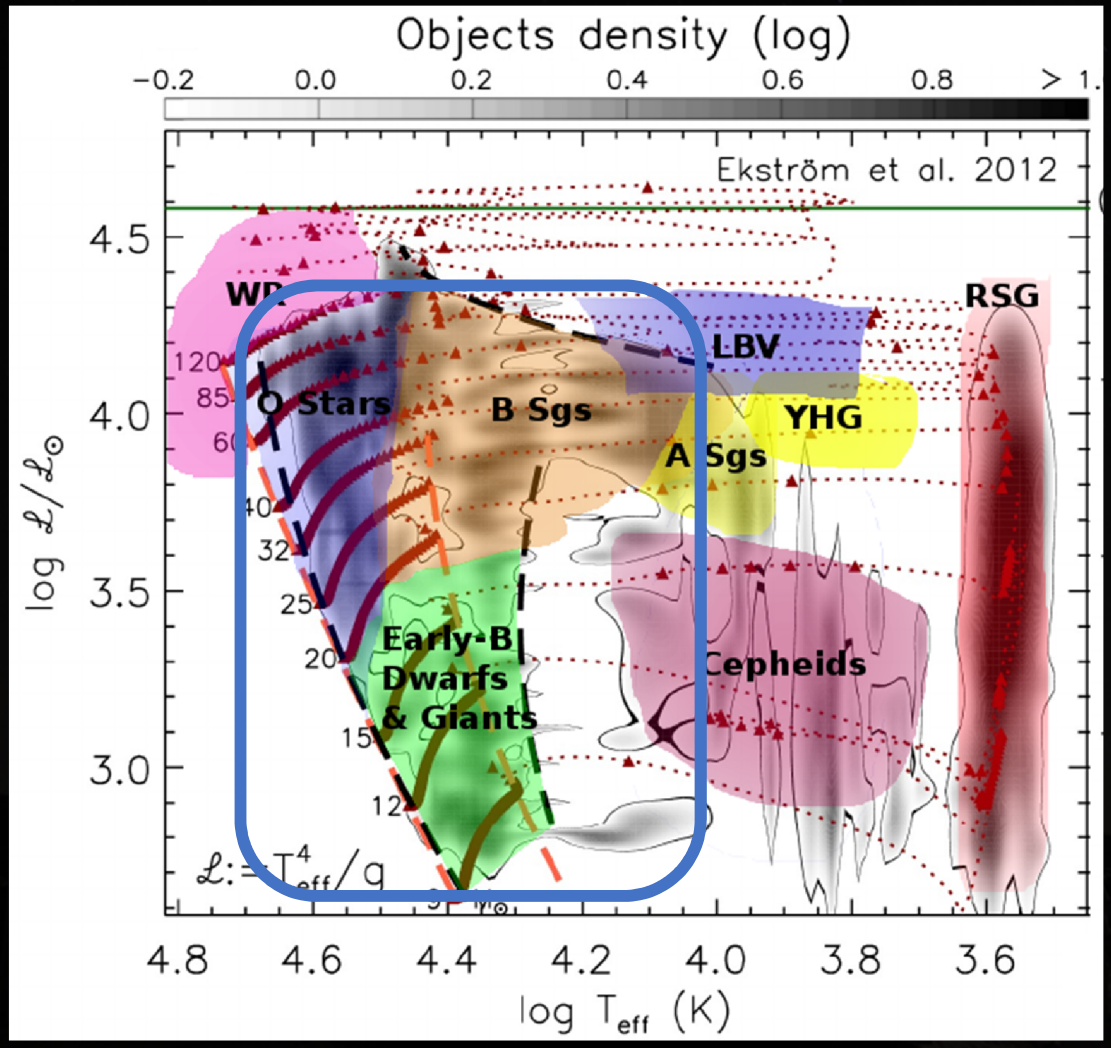


Figure adapted from Castro et al. (2014)

Courtesy of G. Holgado (IAC)

IACOB

OB stars:

Main physical properties

Massive ($M > 8\ M_\odot$)

Hot ($T_{eff} > 10$ kK, $T_{eff,\ ZAMS} > 20$ kK)

Large ($R = 5 – 200\ R_\odot$)

Luminous ($L = 10^3 – 10^6\ L_\odot$)

Windy ($M_{dot} = 10^{-9} – 10^{-5}\ M_\odot$/yr)

Some immediate objectives

IACOB

1. Full empirical characterization of a large sample of (~700) Galactic massive stars covering the full O and B star domain:

   - Determination of the whole set of stellar and wind parameters
   - Determination of a set of surface abundances of interest
   - Identification of binary/multiple systems
   - Identification of spectroscopic variability phenomena

2. Asteroseismic characterization of a selected sample of single & binary systems among O-type stars and B Supergiants

3. Detailed empirical characterization of a selected sample of massive binary/multiple systems

OBSERVATIONS: AN IMPORTANT PILLAR OF THE IACOB PROJECT

IACOB Spectroscopic database

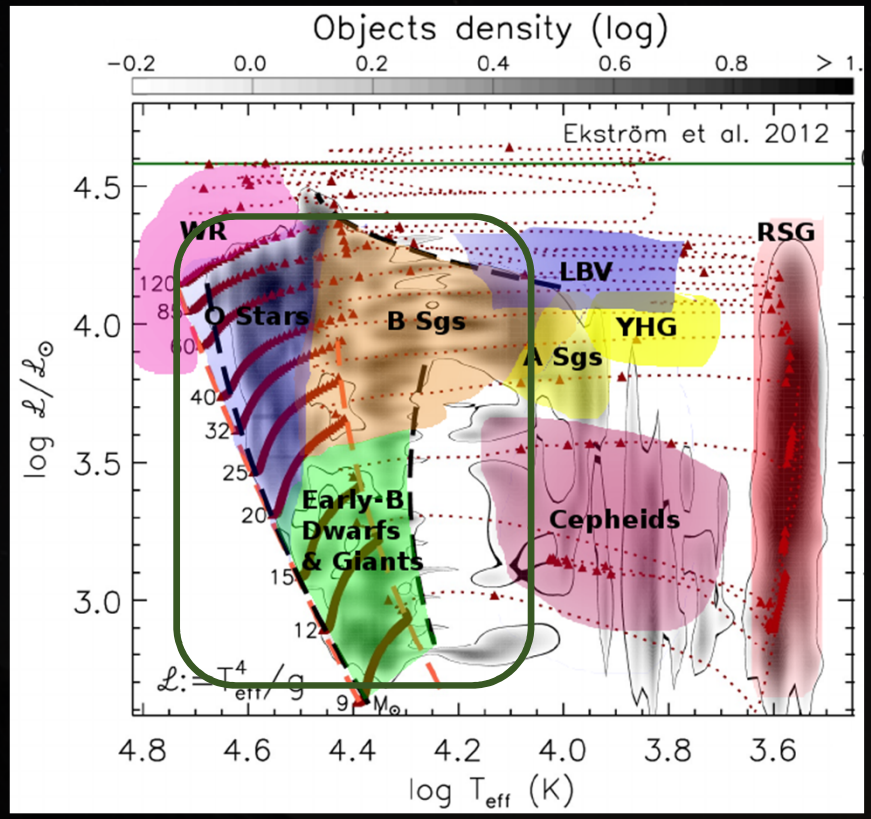
Homogeneous optical spectroscopic dataset *

+ Covering the whole O and B star domain

+ High resolution

+ Large statistics

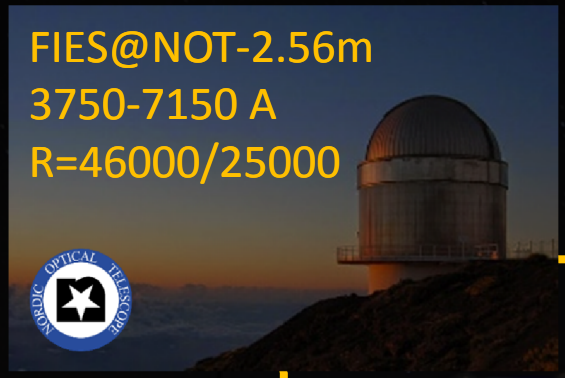
+ Time-resolution



* To be complemented with:

- UV & IR spectroscopy
- Multi-color photometry & distances
- Time-resolved photometry

OBSERVATIONS: AN IMPORTANT PILLAR OF THE IACOB PROJECT



IACOB Spectroscopic database

Last described in:

Simón-Díaz+ (2015)

After 9 years of observations (150+ observing nights)

5500+ spectra (FIES@NOT & HERMES@Mercator)

600+ Galactic O and B stars (O4-B9, all LCs)

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

and increasing …

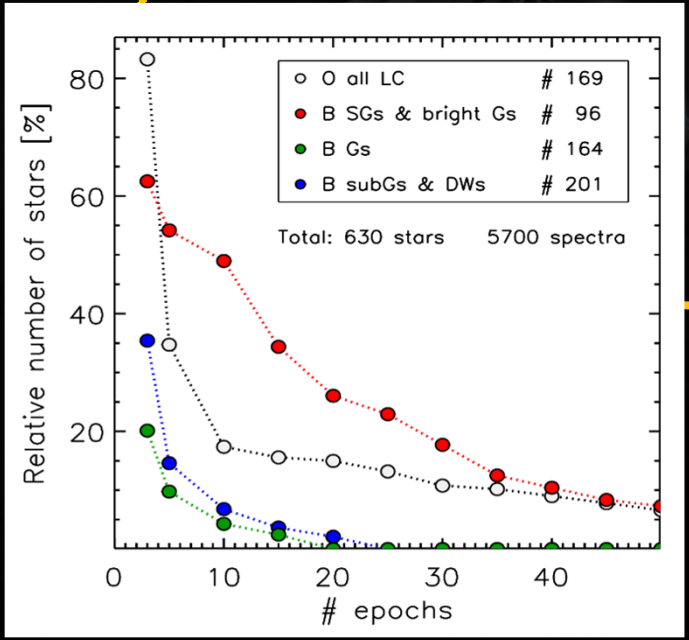
OBSERVATIONS: AN IMPORTANT PILLAR OF THE IACOB PROJECT

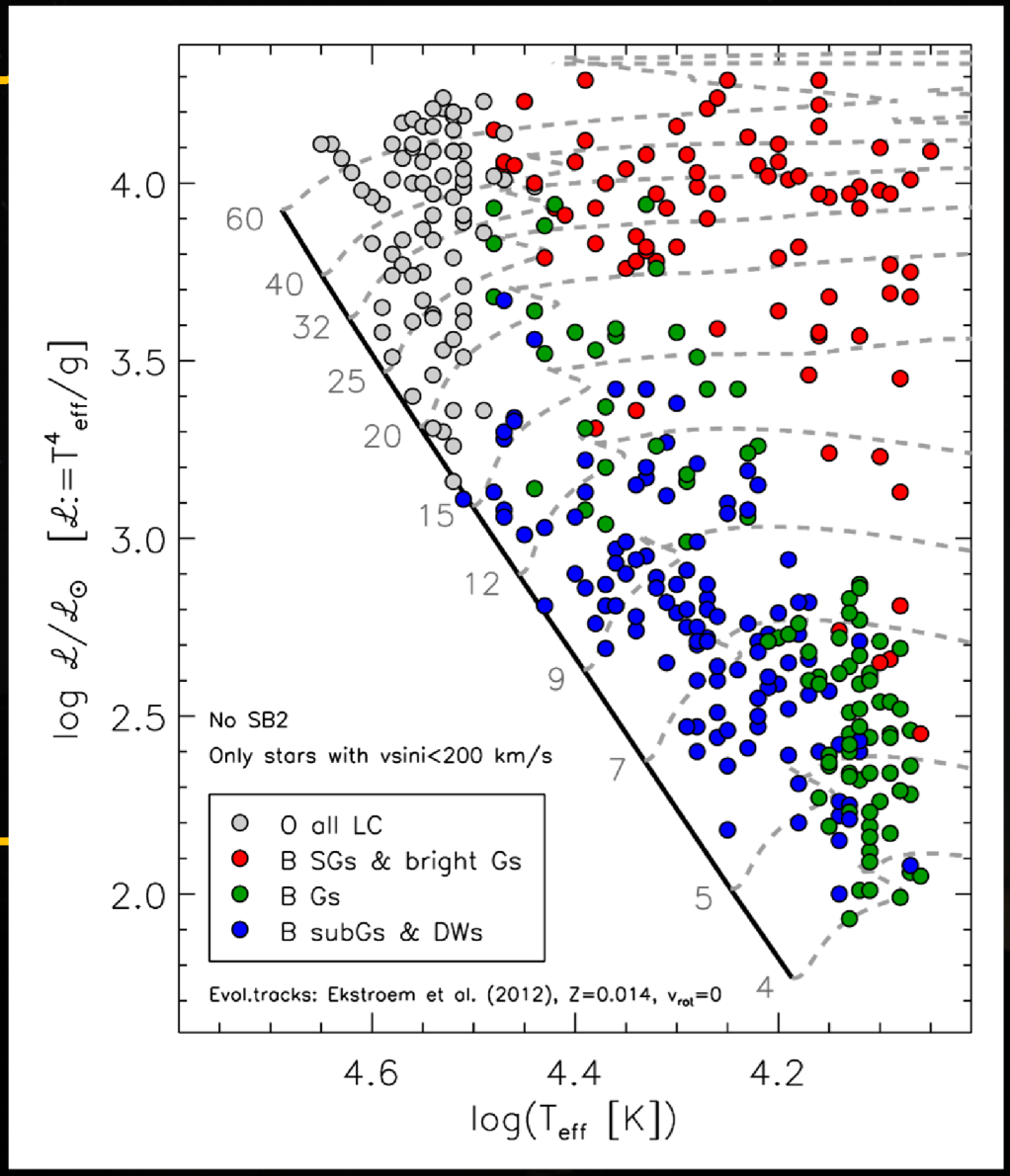
IACOB Spectroscopic database

Coverage

Statistics

	Stars	Spectra
O stars	182	2312
B stars	461	3420
B (I & II)	96	2408
B (III)	164	378
B (IV & V)	201	634





OBSERVATIONS: AN IMPORTANT PILLAR OF THE IACOB PROJECT

IACOB has also benefited from more than 1000 hours of SONG time since December 2014

Mads, don't worry, I'll come back soon


The power of
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Act II
SONG
Stellar Observations Network Group
Credit: Mads Fredslund Andersen

STELLAR OBSERVATIONS NETWORK GROUP

Hertzsprung-SONG (Tenerife)

Delingha node (China)

Main Scientific Goals

- To study the internal structure and evolution of stars using asteroseismology.
- To search for and characterize planets with masses comparable to the Earth in orbit around other stars.


As a network of 1-m telescopes, SONG capabilities are mostly limited to bright stars
SONG
Stellar Observations Network Group
Credit: Mads Fredslund Andersen

THE BRIGHTEST STARS IN THE ORION CONSTELLATION

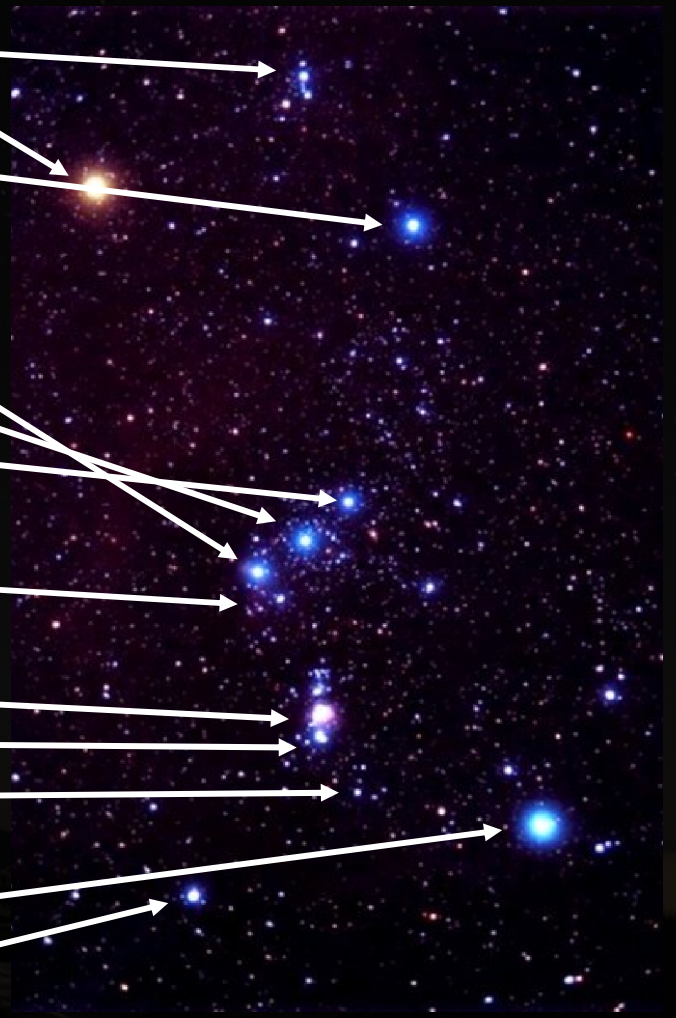
λ Ori (Meissa)
α Ori (Betelgeuse)
γ Ori (Bellatrix)

ζ Ori (Alnitak)
ε Ori (Alnilam)
δ Ori (Mintaka)

σ Ori

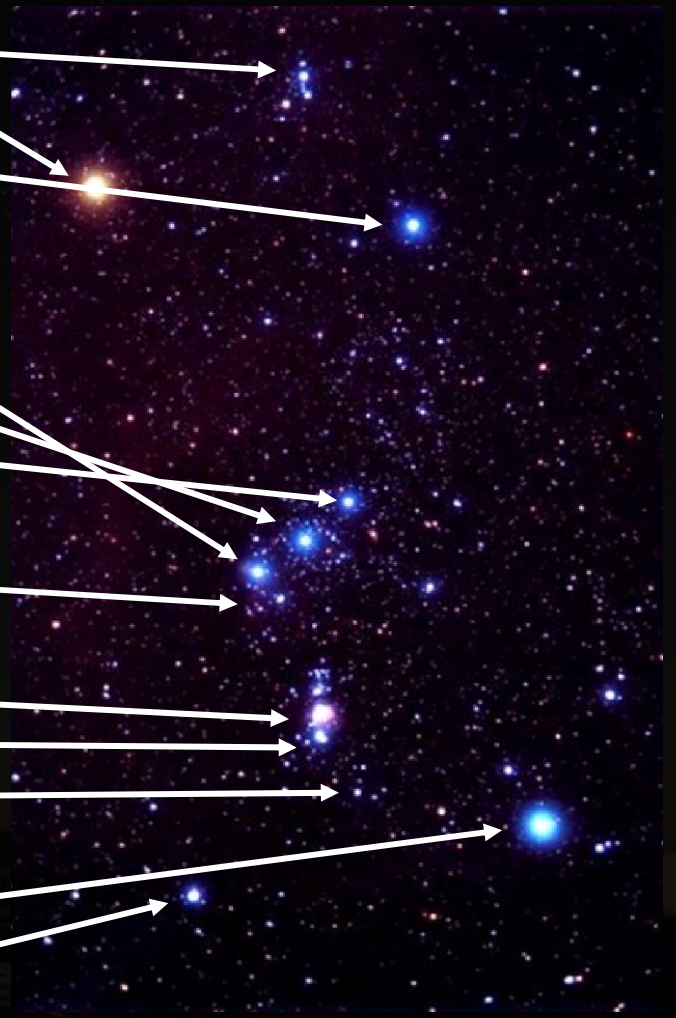
Θ^1 Ori C
ι Ori
υ Ori

β Ori (Rigel)
κ Ori (Saiph)



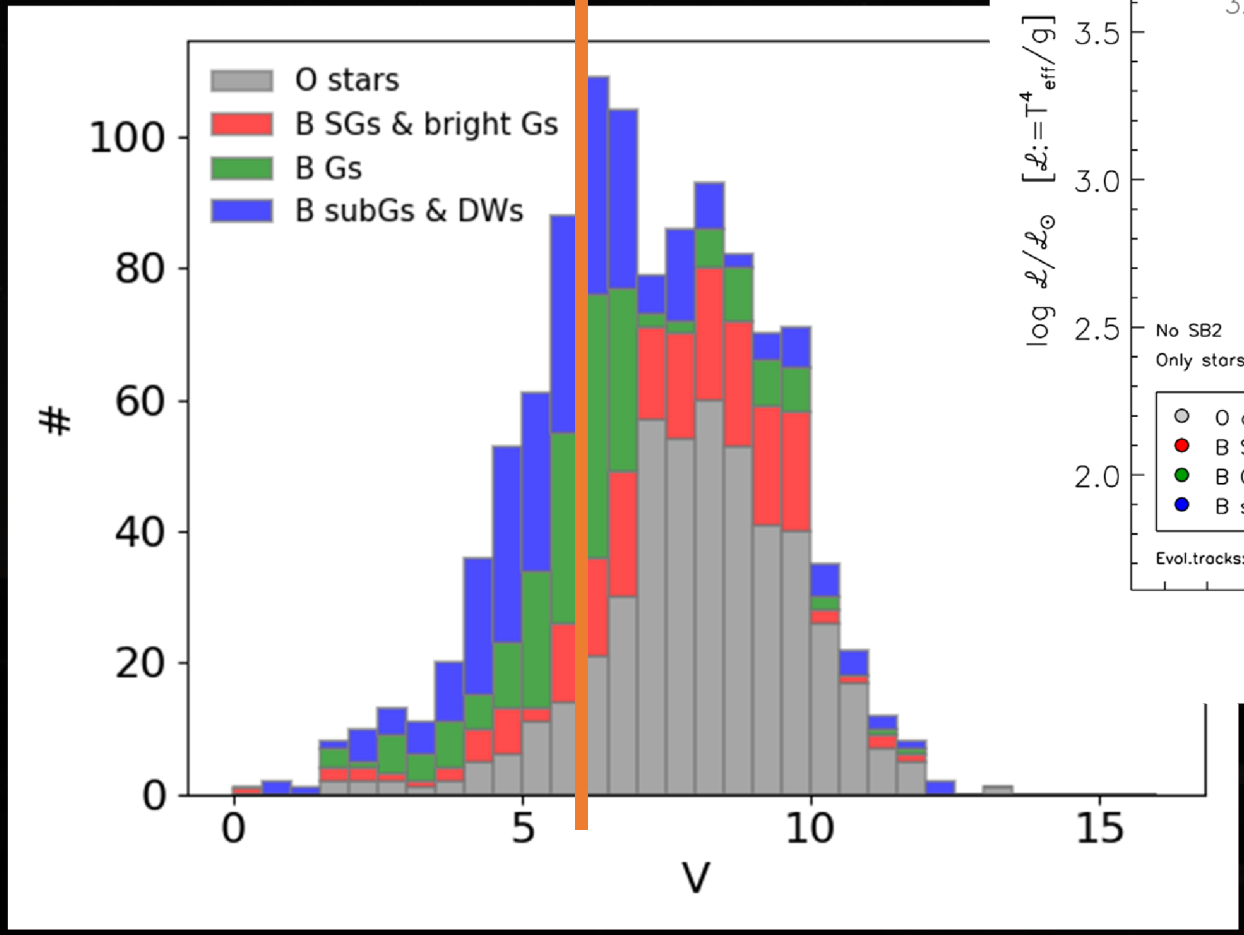
THE BRIGHTEST STARS IN THE ORION CONSTELLATION

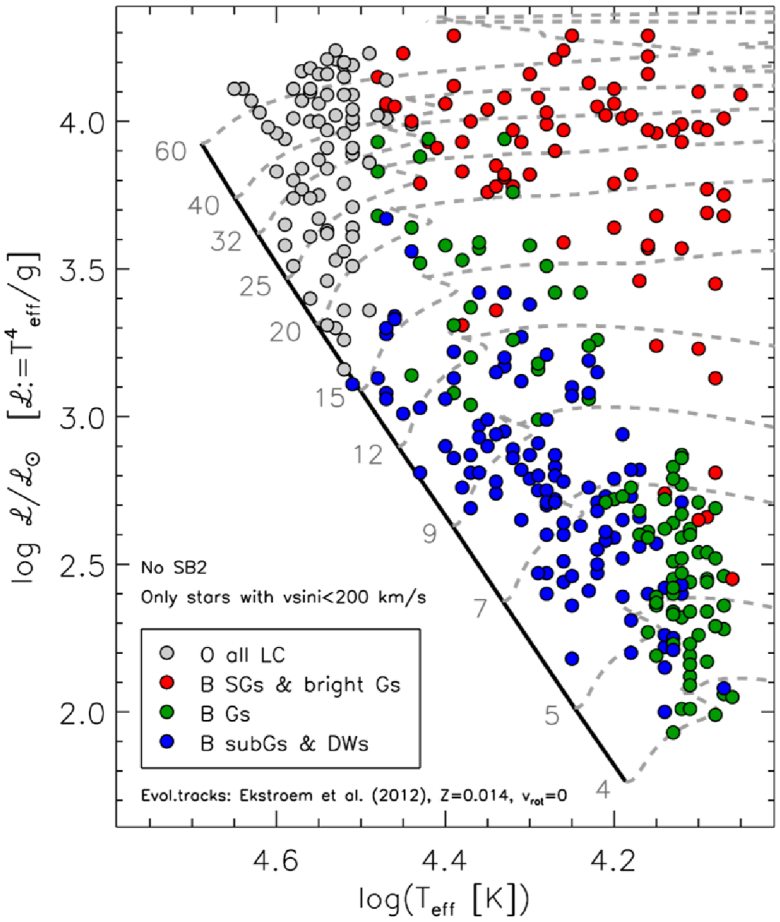
V=3.47	O8 III((f))	λ Ori (Meissa)
V=0.42	M1-M2 Ia-Ib	α Ori (Betelgeuse)
V=1.64	B2 V	γ Ori (Bellatrix)
V=1.79	O9.7 Ib (SB3)	ζ Ori (Alnitak)
V=1.69	B0 Ia	ε Ori (Alnilam)
V=2.41	B0 III (SB1)	δ Ori (Mintaka)
V=3.80	O9.5 V (SB3)	σ Ori
V=5.13	O7 Vp	Θ^1 Ori C
V=2.77	O9 III (SB2)	ι Ori
V=4.63	O9.7 V	υ Ori
V=0.13	B8 Ia	β Ori (Rigel)
V=2.06	B0.5 Ia	κ Ori (Saiph)



Most of the brightest stars in Orion are massive OB-type stars

APPARENT MAGNITUDE DISTRIBUTION IN THE IACOB SAMPLE






The power of
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Act III
IACOB meets
SONG
Credit: Mads Fredslund Andersen

Some immediate objectives

IACOB

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   - Identification of binary/multiple systems
   - Identification of spectroscopic variability phenomena

2. Asteroseismic characterization of a selected sample of single & binary systems among O-type stars and B Supergiants

3. Detailed empirical characterization of a selected sample of massive binary/multiple systems

SONG is cool for this part of the project

OBSERVATIONS: AN IMPORTANT PILLAR OF THE IACOB PROJECT

Hetzsprung-SONG-1m
4400-6900 A
R=77000

IACOB meets SONG

1000 hours of SONG time from Dec. 2014 to Feb. 2018*

20000+ spectra

50 O stars and B Sgs

Combining two different observing modes

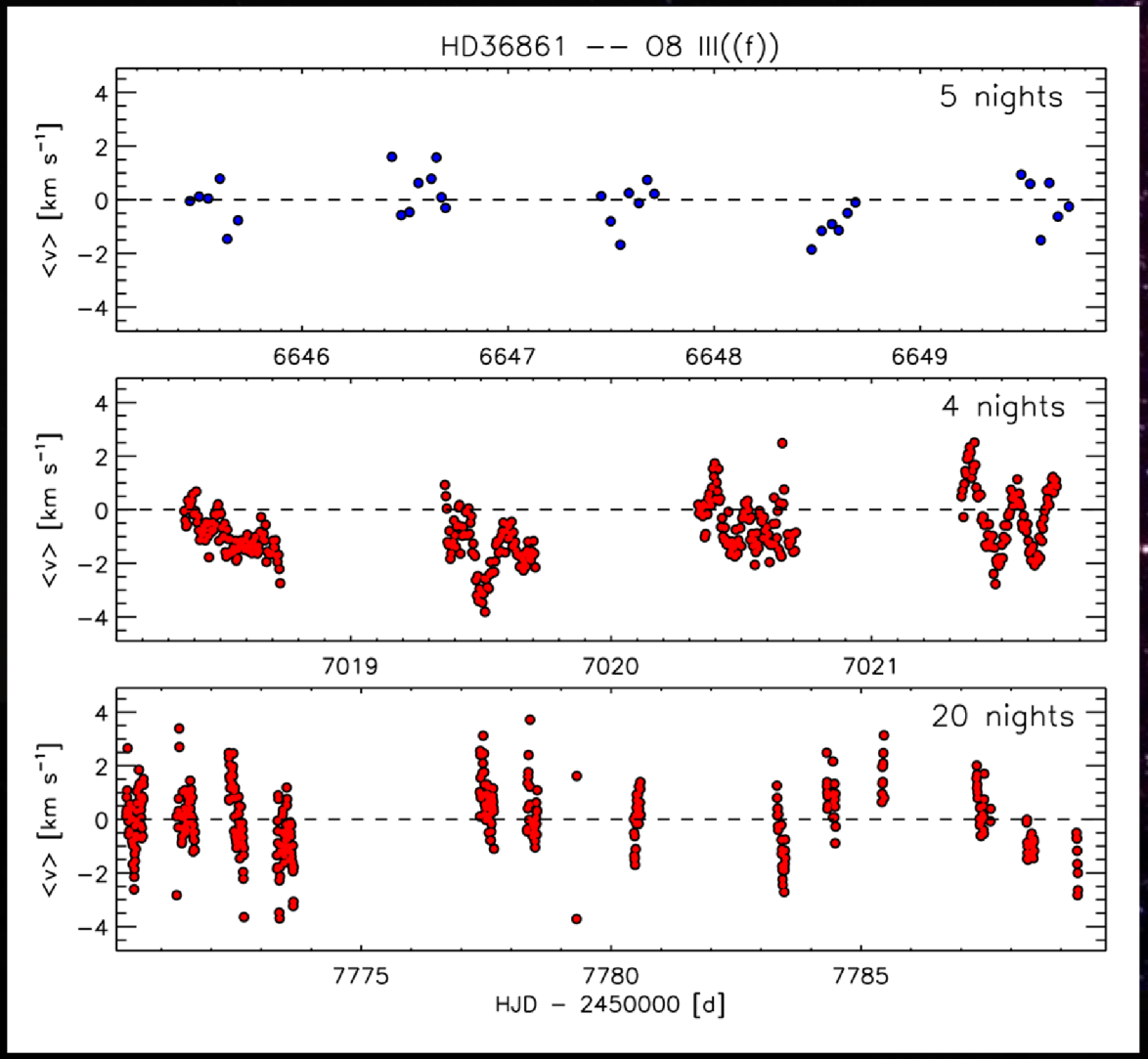
Short term (days), high cadence
Long term (weeks/months), low cadence

Mainly Hertzsprung-SONG, but also a few test data from Delingha

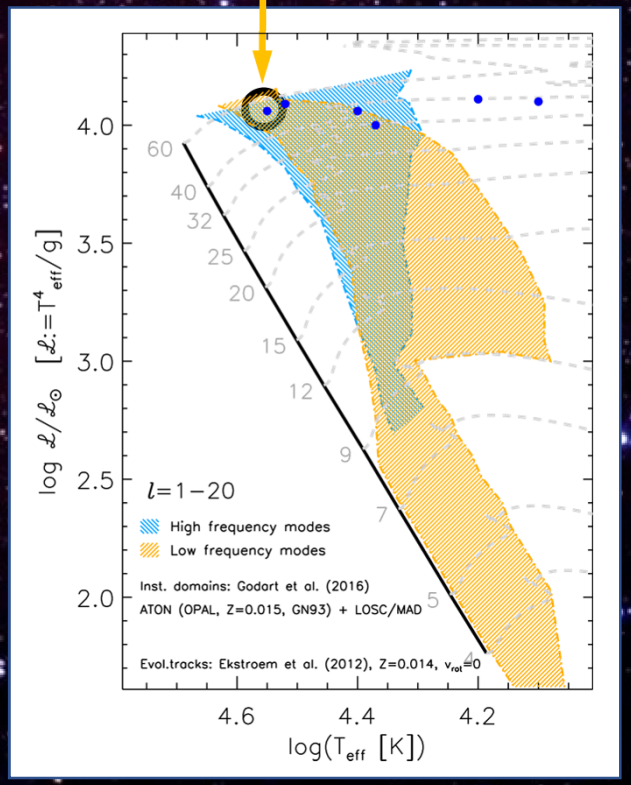
* As I said: Mads, don't worry, I'll come back soon

THE POWER OF SONG FOR STUDYING MASSIVE O STARS AND B SGS: A FEW EXAMPLES

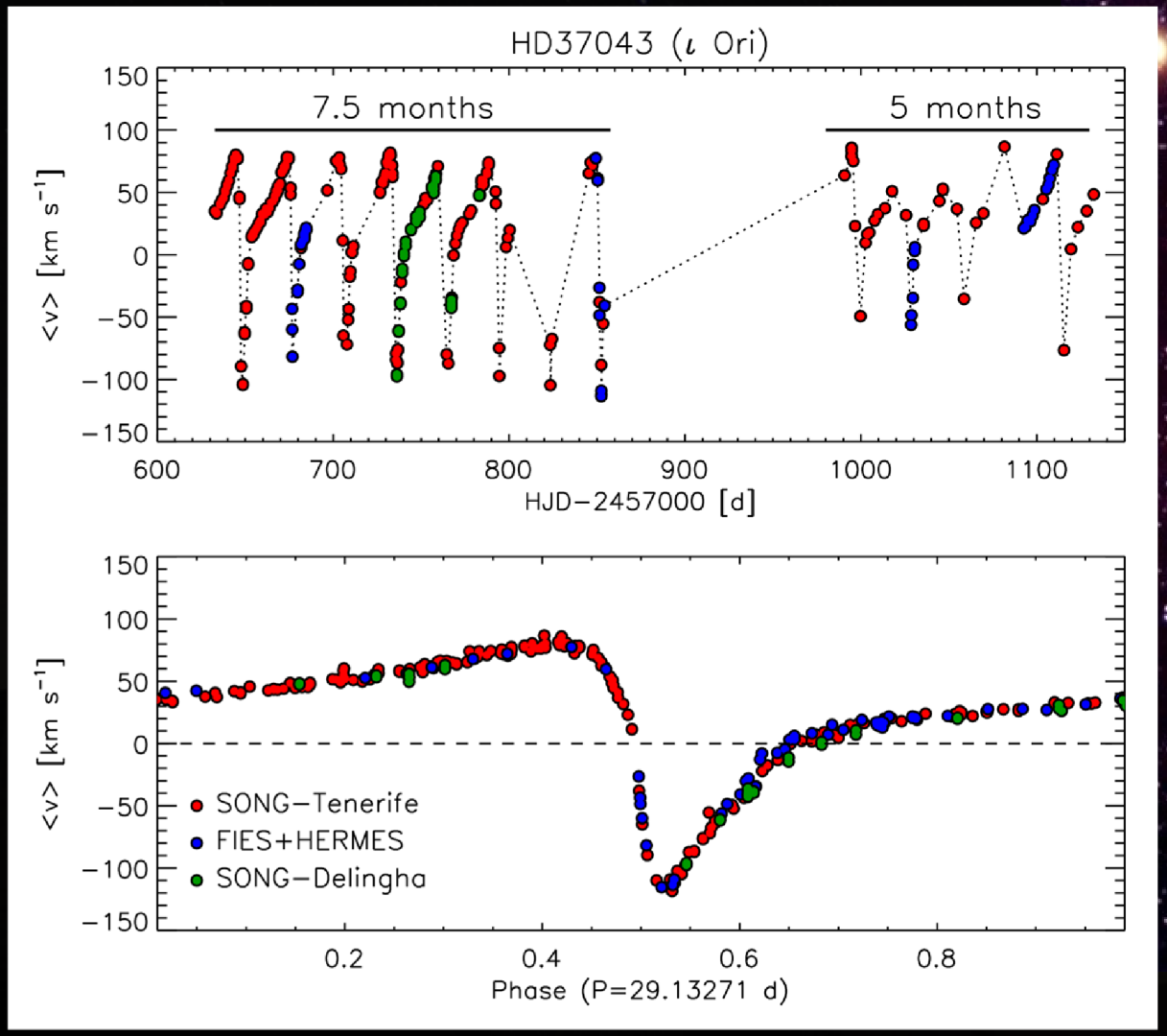
λ Ori (HD 36861) – O8 III((f)) – V=3.47



A massive β-Cep type pulsating star



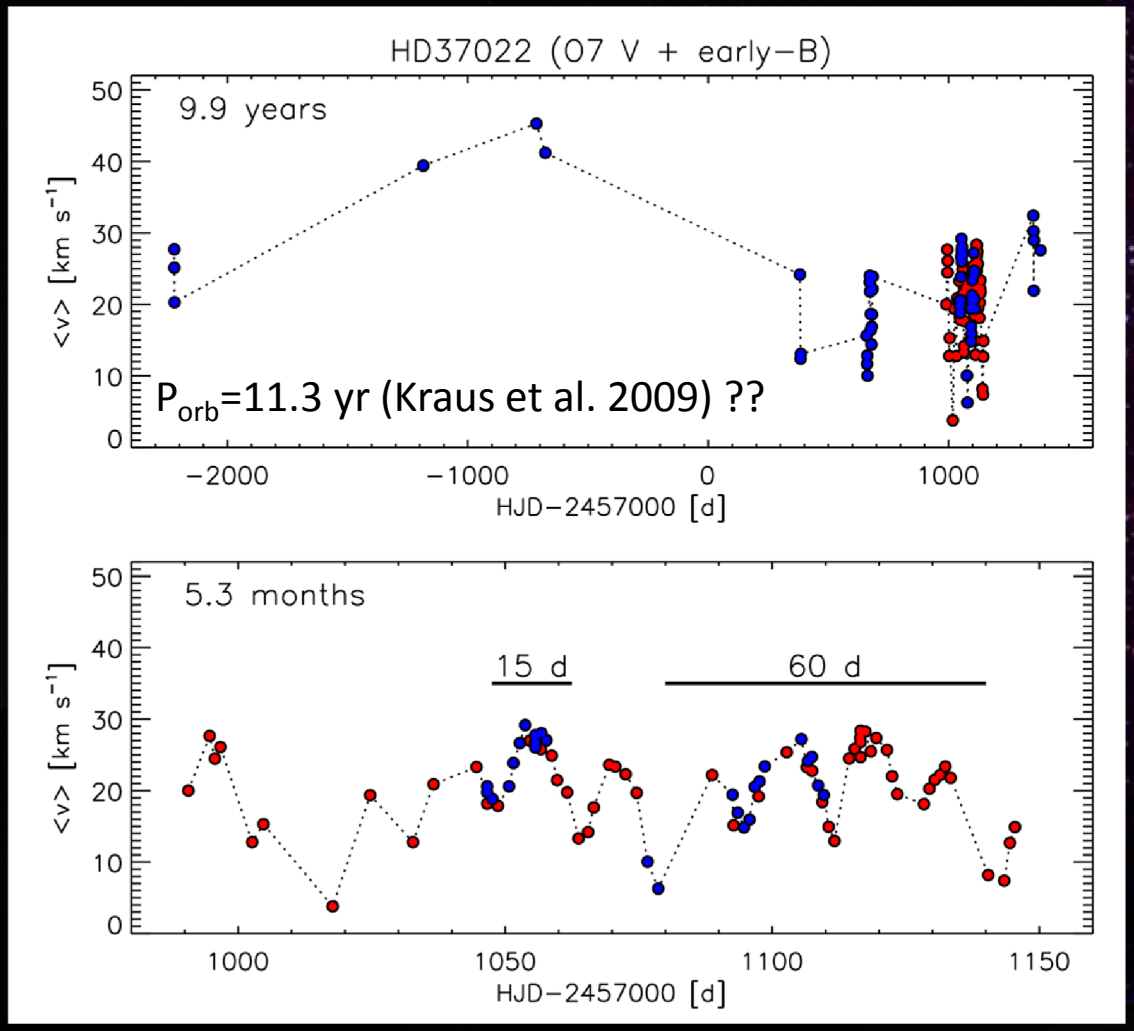
ι Ori (HD 37043) – O8 III + B0 – V=2.77

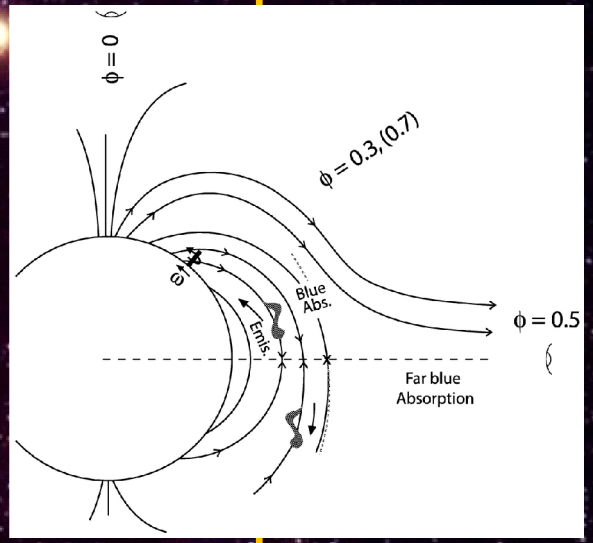


A massive eccentric binary with a very interesting past

See also ***Pablo et al. (2017)*** A massive heartbeat star

θ^1 Ori (HD 37022) – O7 Vp + early-B – V=5.13



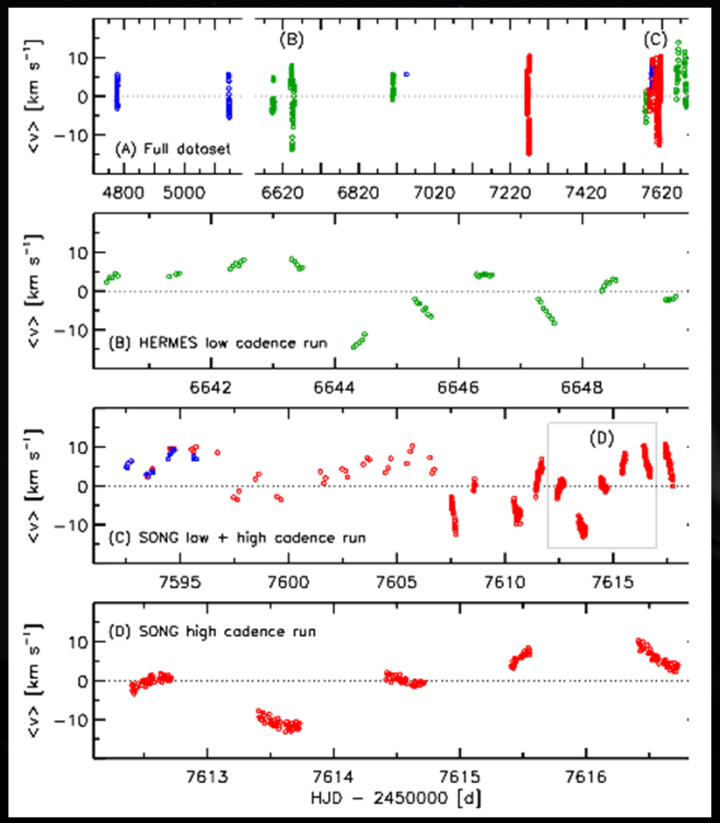


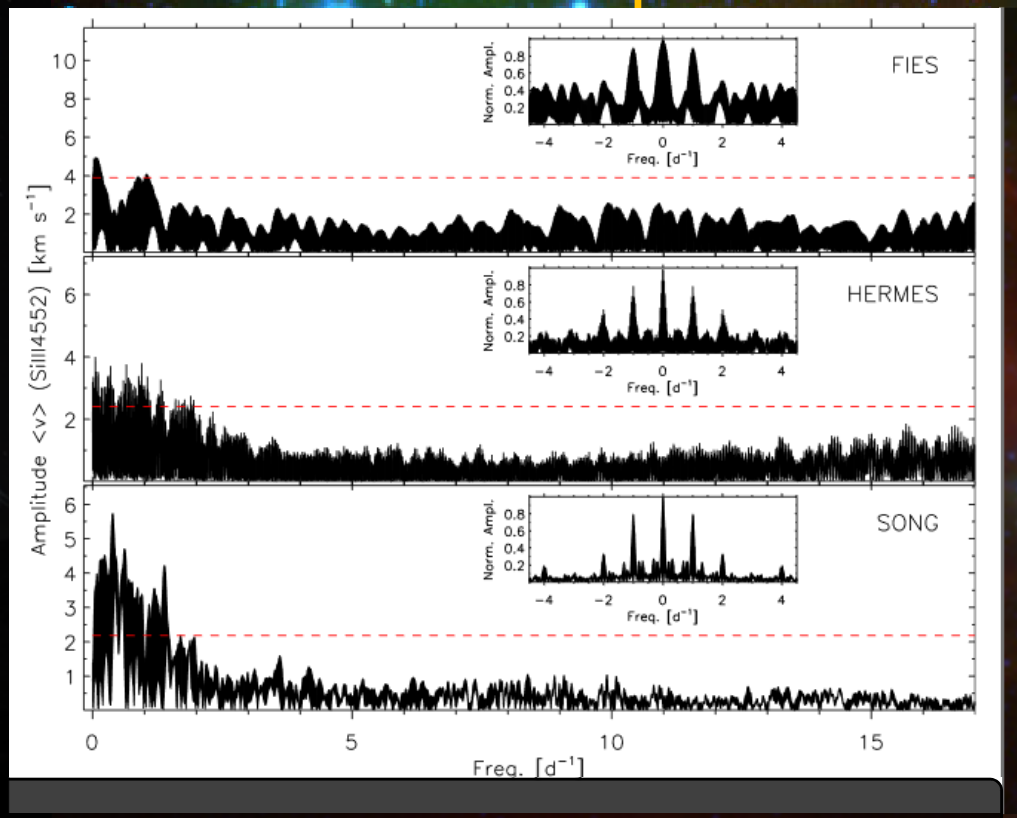
One of the most famous massive magnetic stars

P_{rot}=15.4 d ***(Stahl et al.2008)***
B=1.5 kG ***(Donati et al. 2002)***

THE POWER OF SONG FOR STUDYING MASSIVE O STARS AND B SGS: A FEW EXAMPLES

κ Cas (HD 2905) – B1 Ia – V=4.16





A prototipical example of phostospheric variability in O and early-B supergiants

Simón-Díaz et al. 2018

WHAT IS THE PERCENTAGE OF MASSIVE BINARIES?

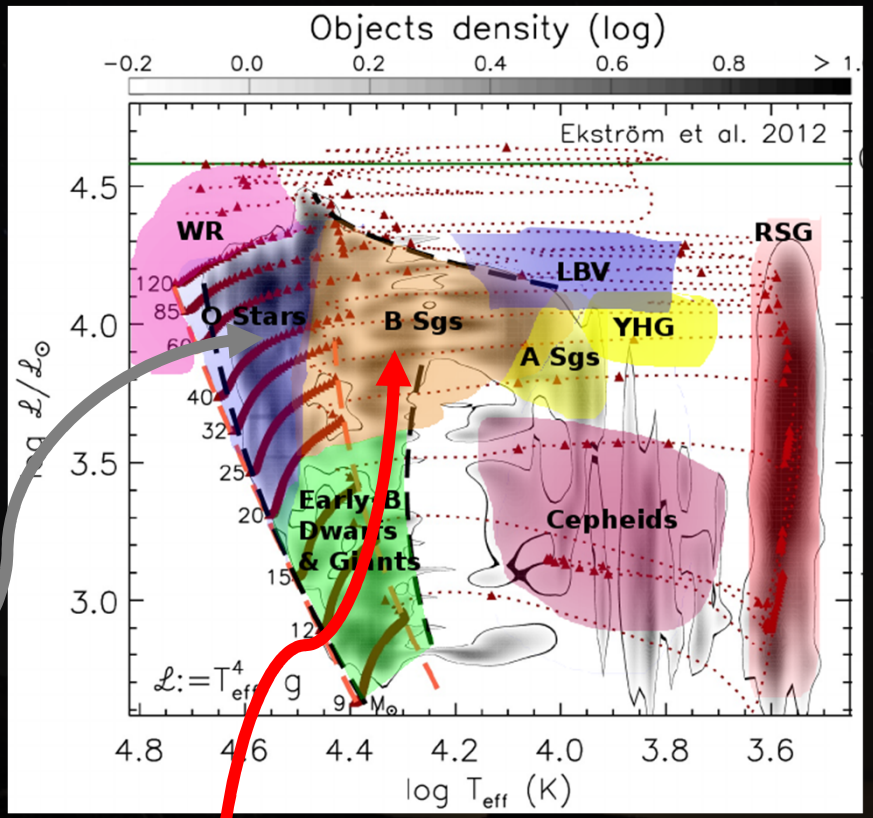
(One of the hot topics in the field of massive stars in the last decade)

Modern surveys → mostly concentrated in the **O star domain**

Mason+ 2009, Sana+ 2011, 2012, 2013, Chini+ 2012, Sota+ 2014, Kobulniky+ 2014, Barbá+ 2014

Fraction of detected spectroscopic binary/multiple systems with at least one O-type star

35-75%



What about their more direct evolved descendants (the B Sgs) ???

WHAT IS THE PERCENTAGE OF MASSIVE BINARIES?

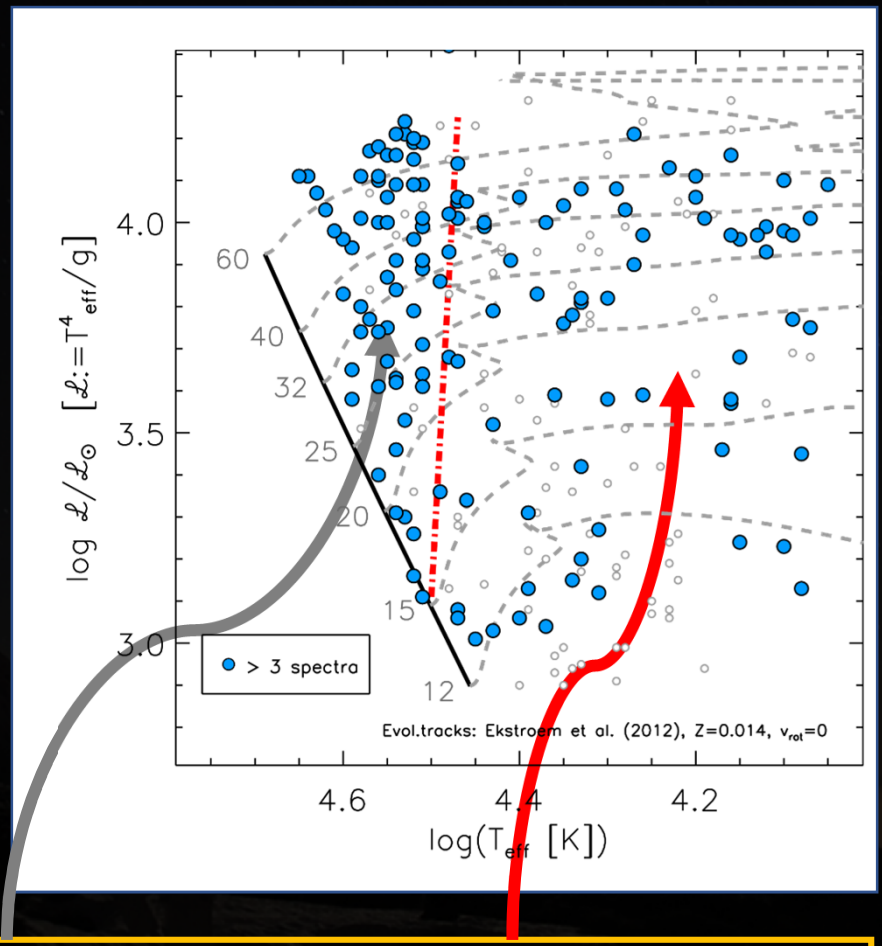
(One of the hot topics in the field of massive stars in the last decade)

Using the IACOB Spectroscopic database

(only stars with more than 3 spectra)

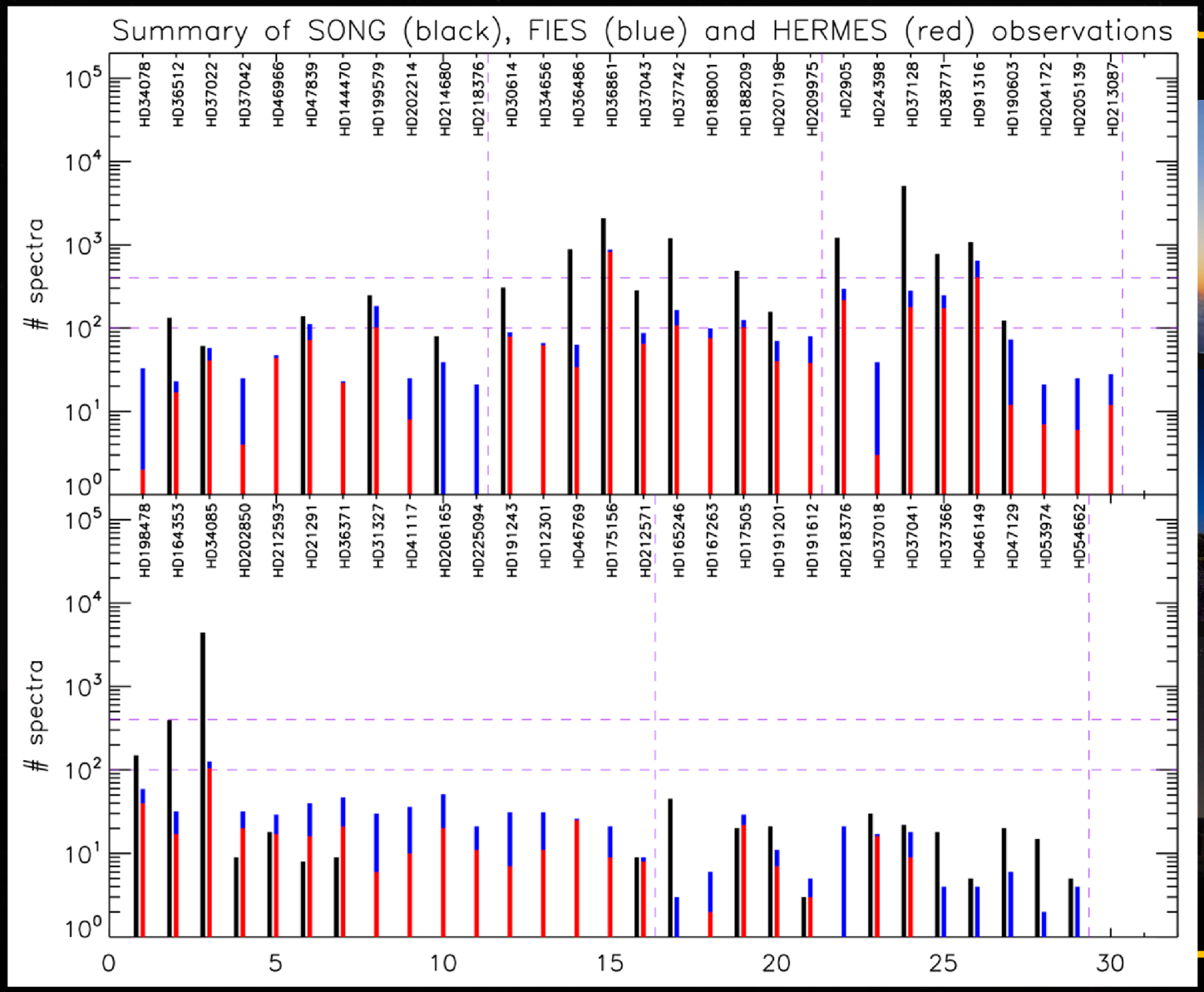
	O stars	B Sgs
Total	141	56
SB2	28 %	5 %
SB1 [1]	19 %	64 %
Likely single [1]	53 %	31 %

[1] Assumed boundary between SB1 and Likely Single: $\langle v \rangle_{pp}$ = 5 km/s

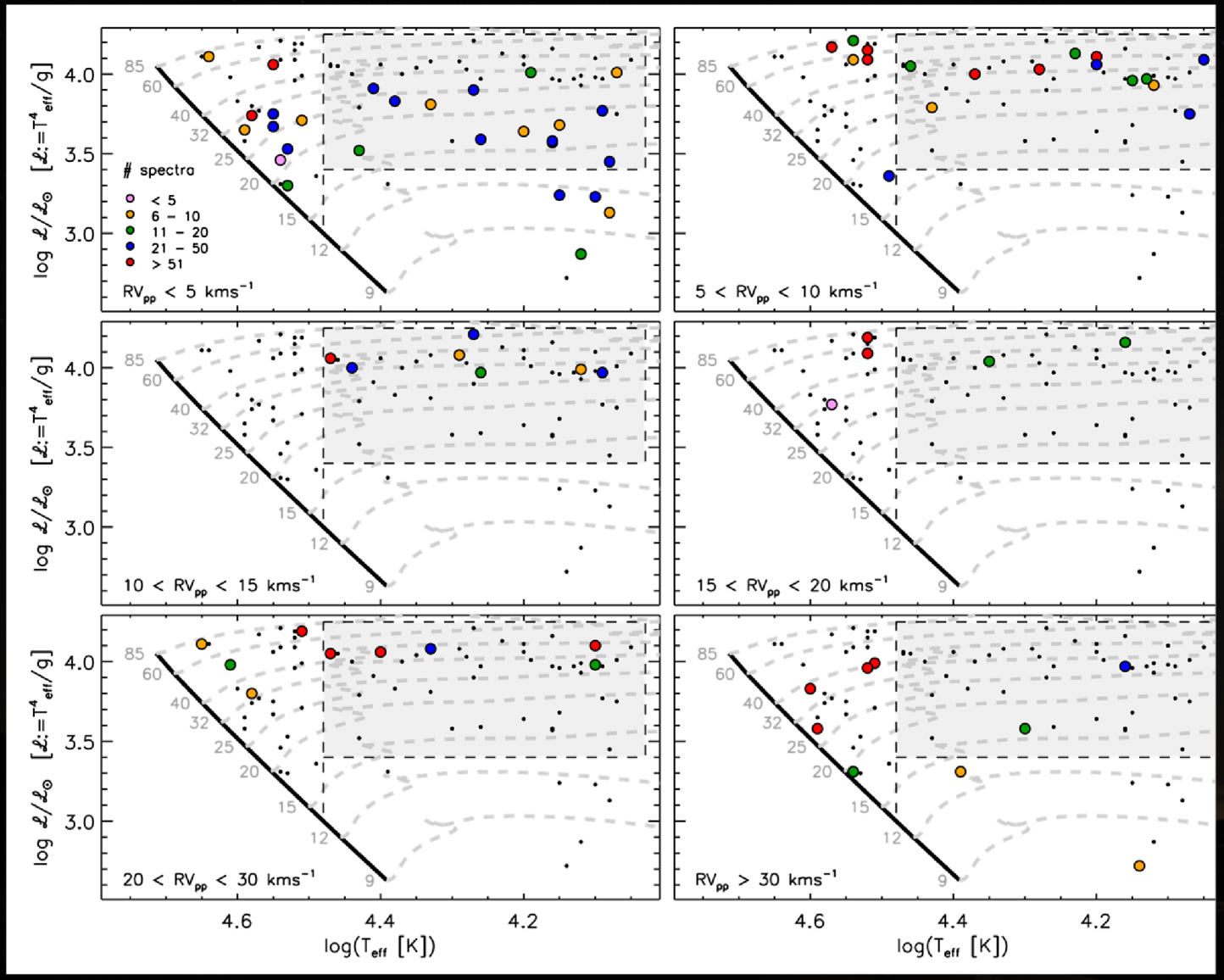


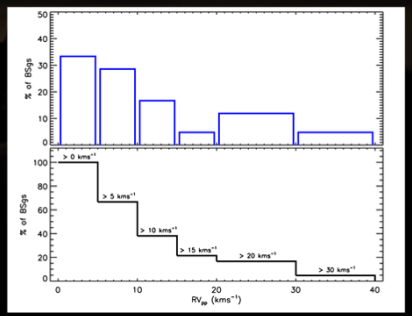
% spectroscopic binaries → O stars: (47%) ok! , B Sgs: (69%) ???

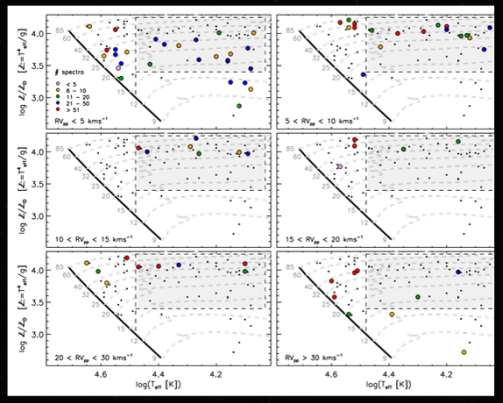
IMPROVING TIME RESOLUTION IN IACOB SPECTROSCOPIC DATABASE



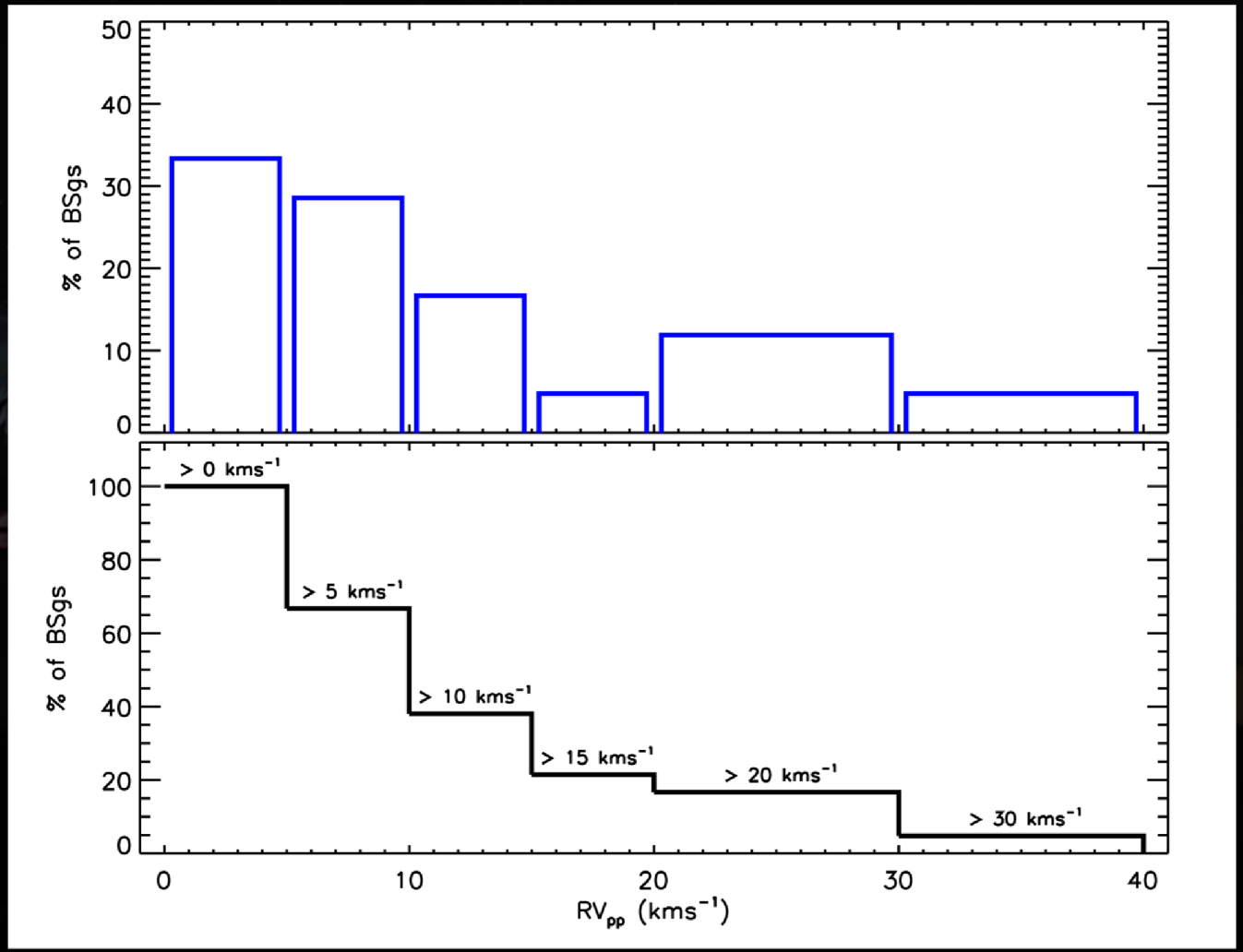
HUNTING FOR SPECTROSCOPIC BINARIES IN THE OB SGS DOMAIN



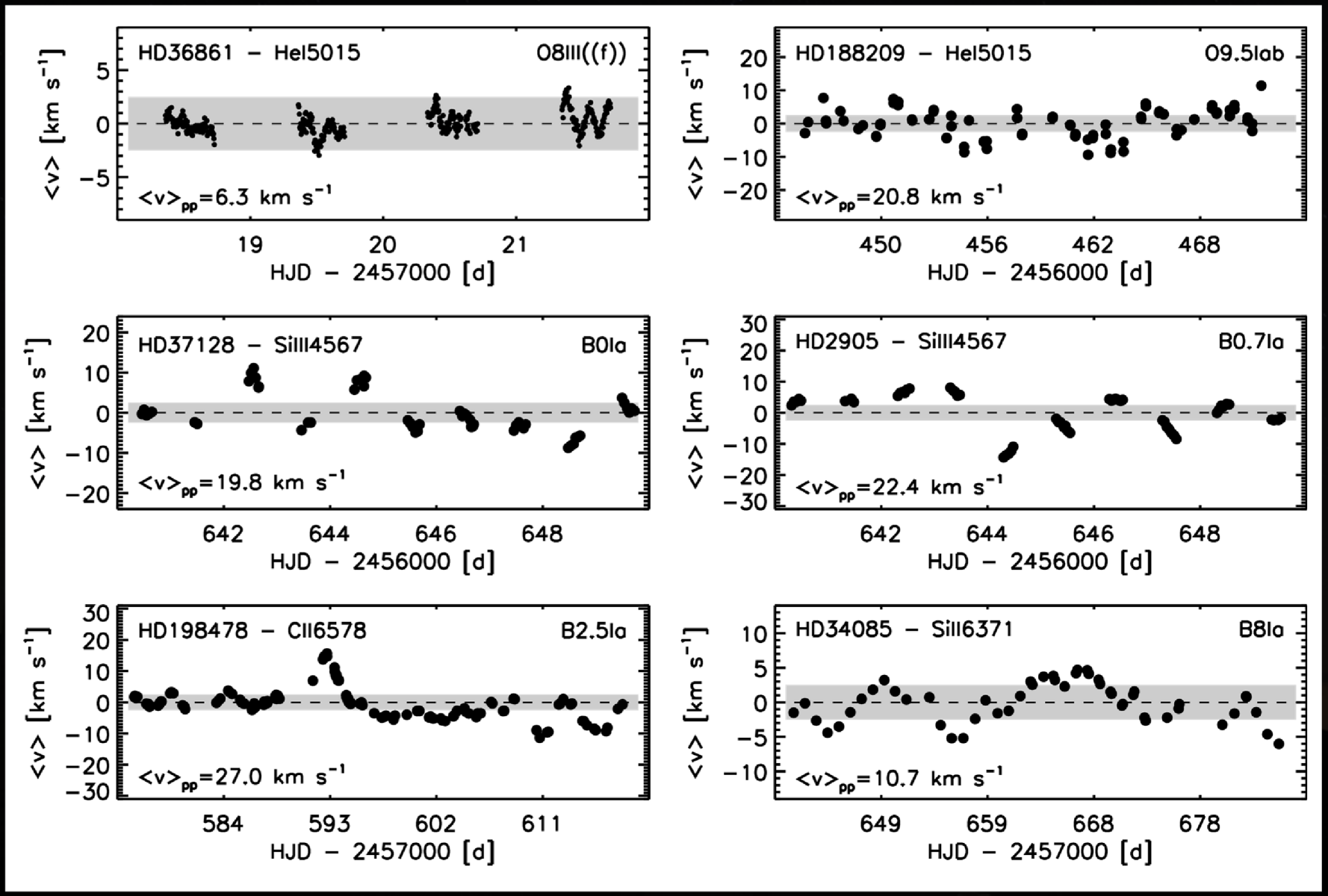




The percentage of SB1 depends on the considered threshold in RV

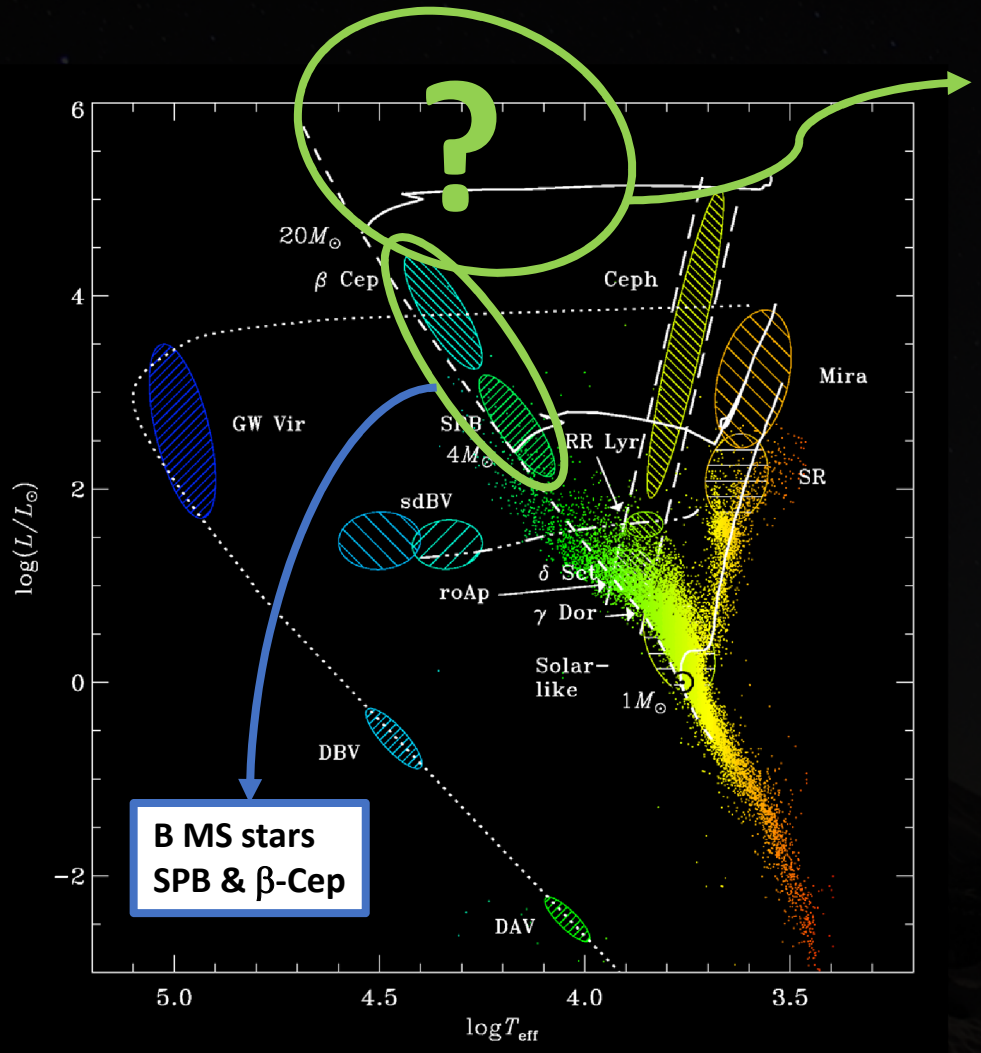


HUNTING FOR SPECTROSCOPIC BINARIES IN THE OB SGS DOMAIN



Main take away message

A reliable empirical assessment of the incidence of spectroscopic binaries among O and B Sgs necessarily requires to account for the effect of pulsational-type phenomena (and other effects producing spectroscopic variability) present in these stars



O stars and B Sgs:

A more uncharted territory from both the observational and theoretical side

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

…

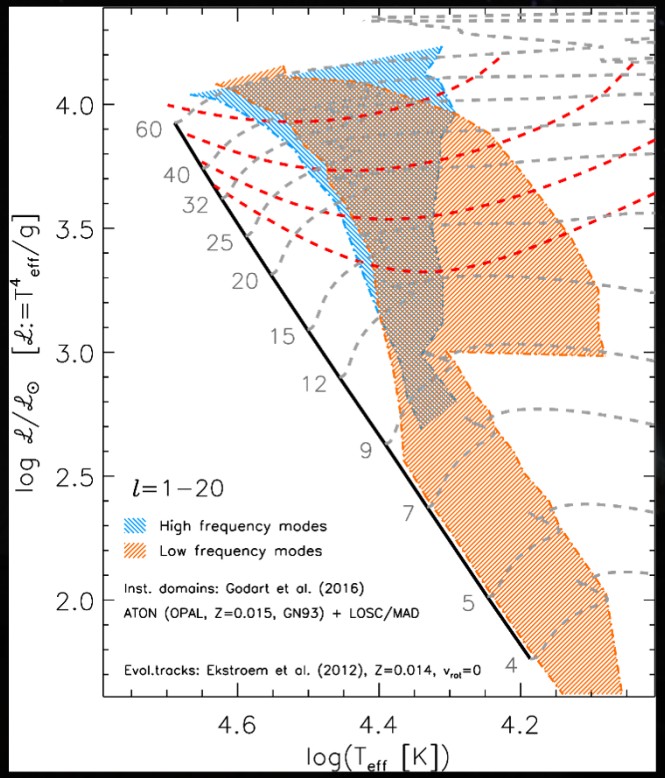
- Long and short time-scales (h's. to w's)
- Multi- & quasi-periodicities
- High and low amplitudes

Aerts (2015)

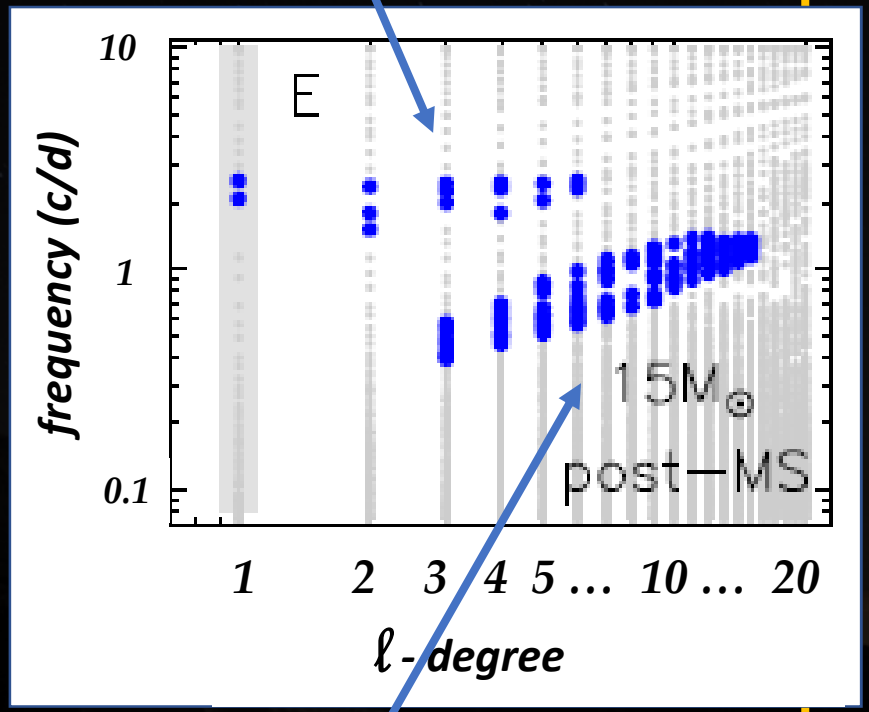
Godart+ 2016

An homogeneous prediction for non-radial instability domains of massive stars for degree l = 1 up to 20

κ-mechanism
Fe op. bump



β Cep-type (p-) modes



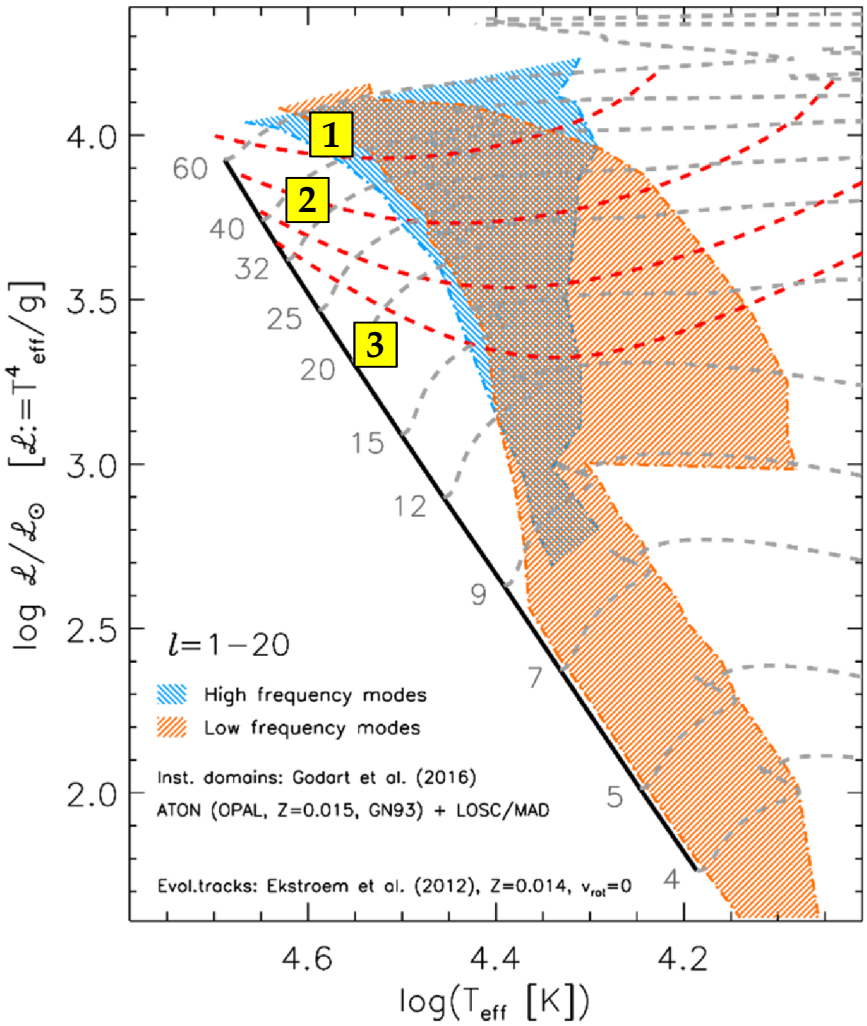
SPB-type (g-) modes

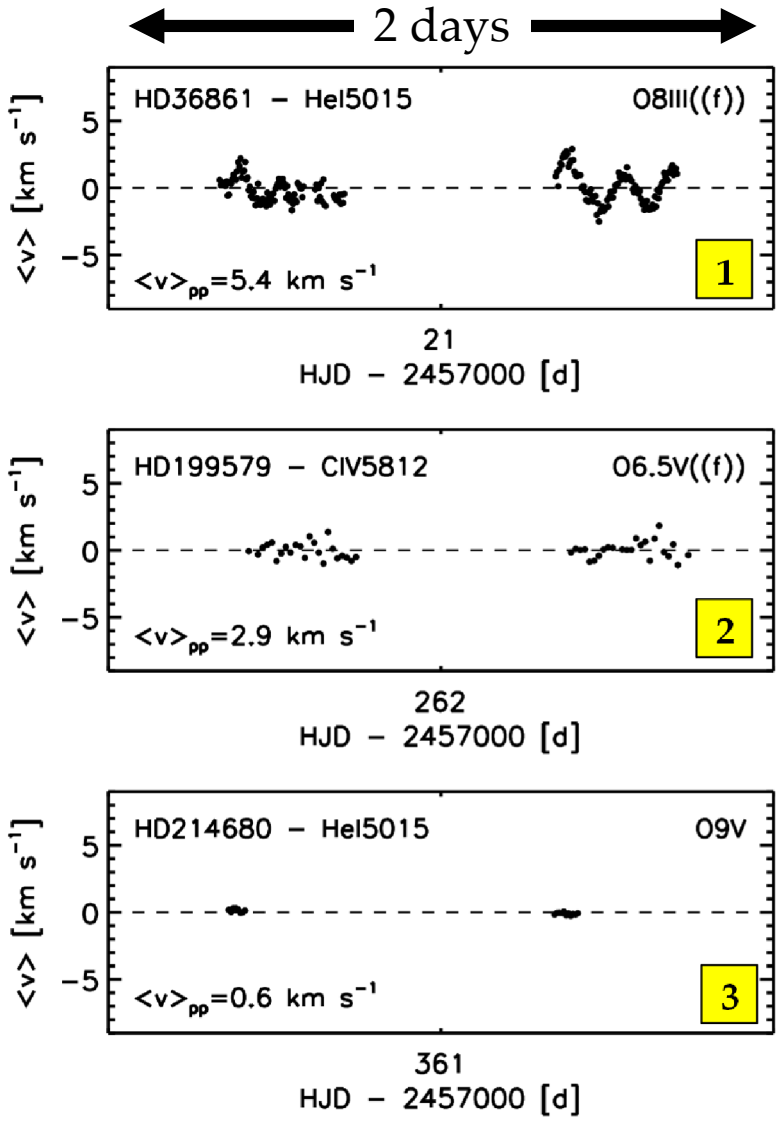
(see also Saio+2006)

See also: Pamyatnykh 1999, 2007: Miglio+ 2007; Salmon+ 2012; Turck-Chièze & Gilles 2013; Saio 2006, 2011, 2015; Moravveji 2016

KNOCKING ON ASTEROSEISMOLOGY OF MASSIVE STARS' DOOR

Towards a global overview of spectroscopic variability





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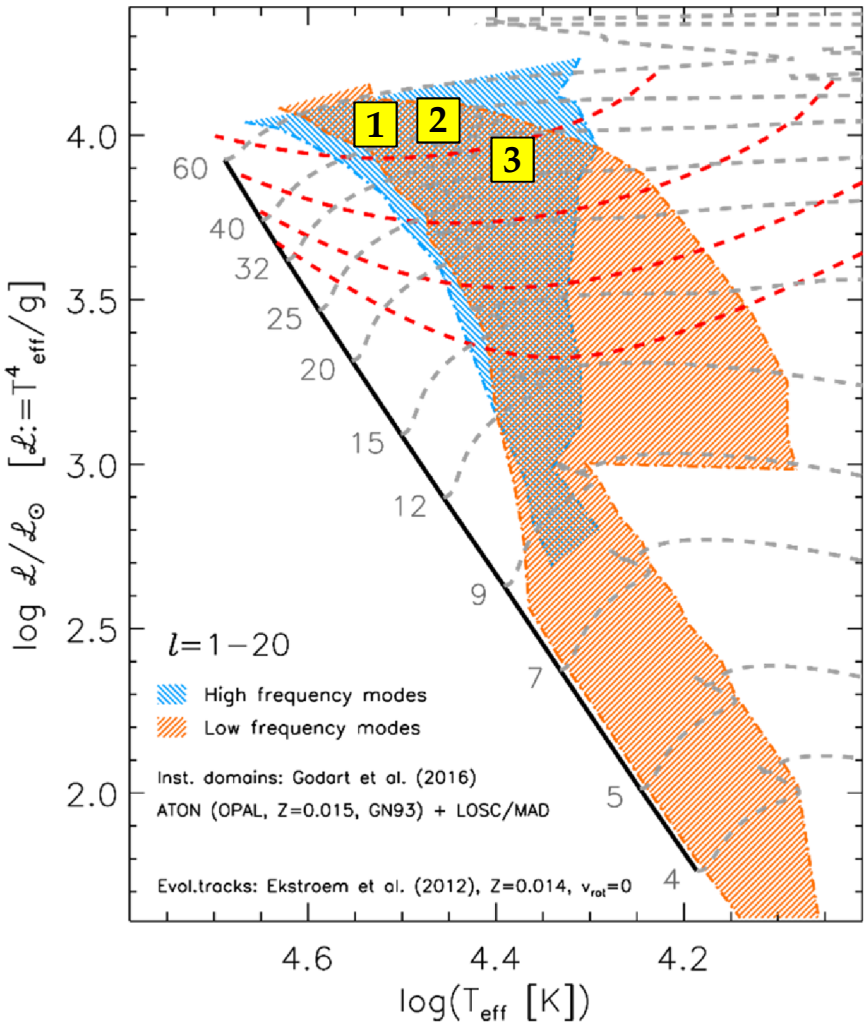
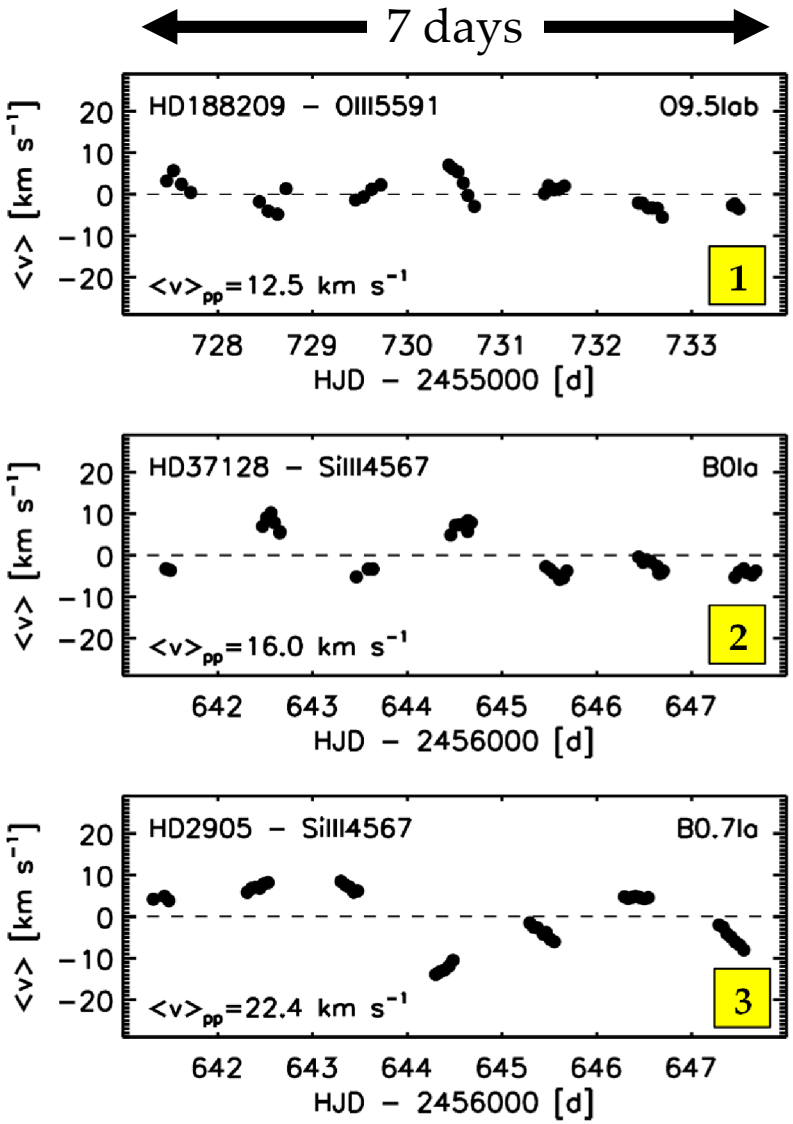
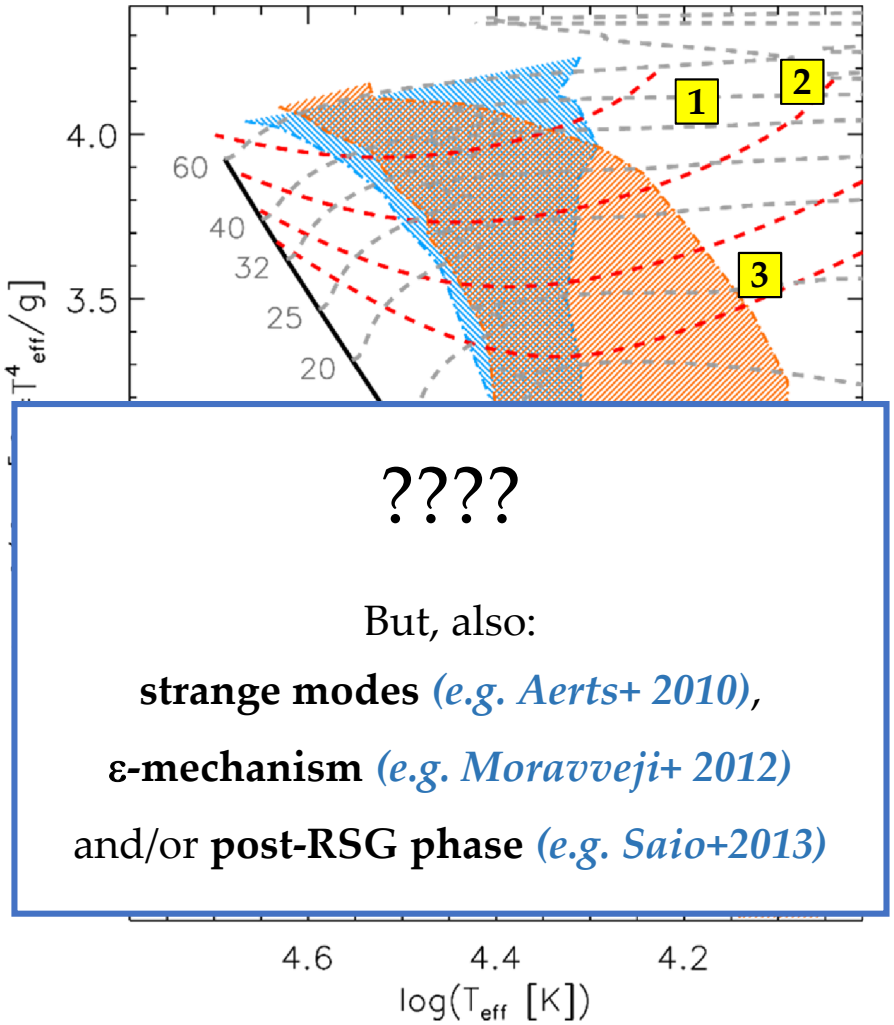






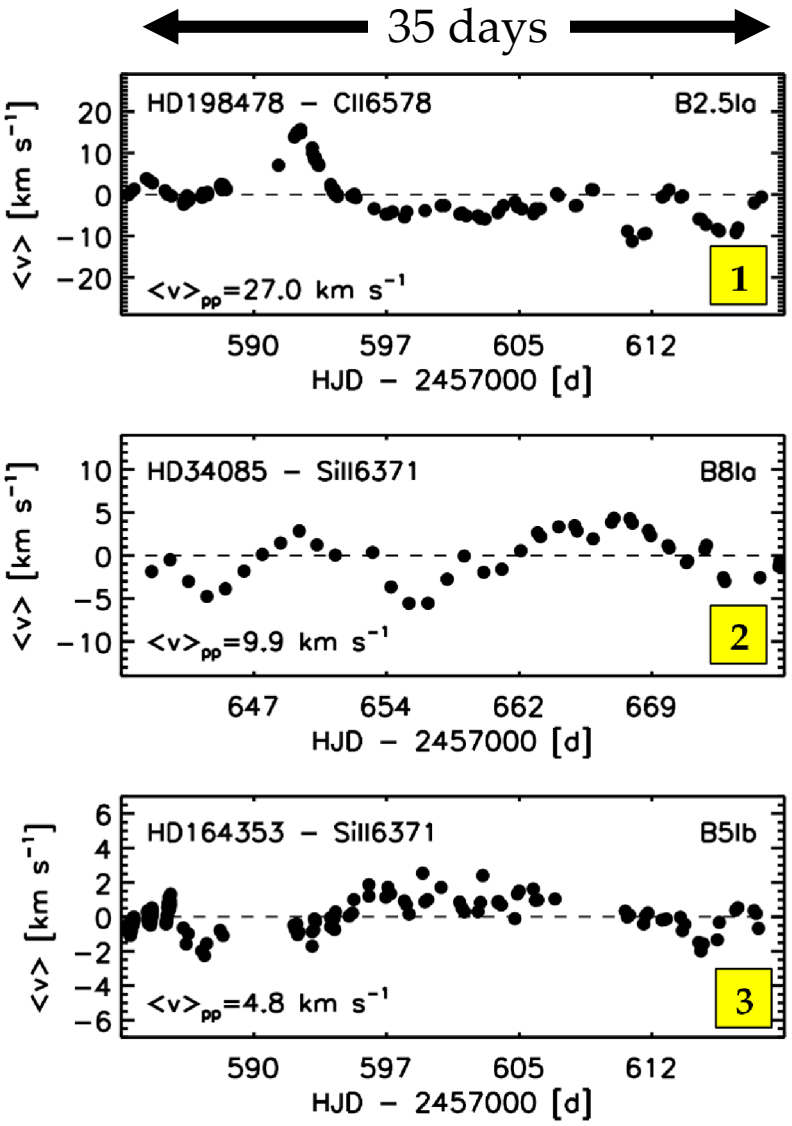
????

But, also:

strange modes *(e.g. Aerts+ 2010)*,

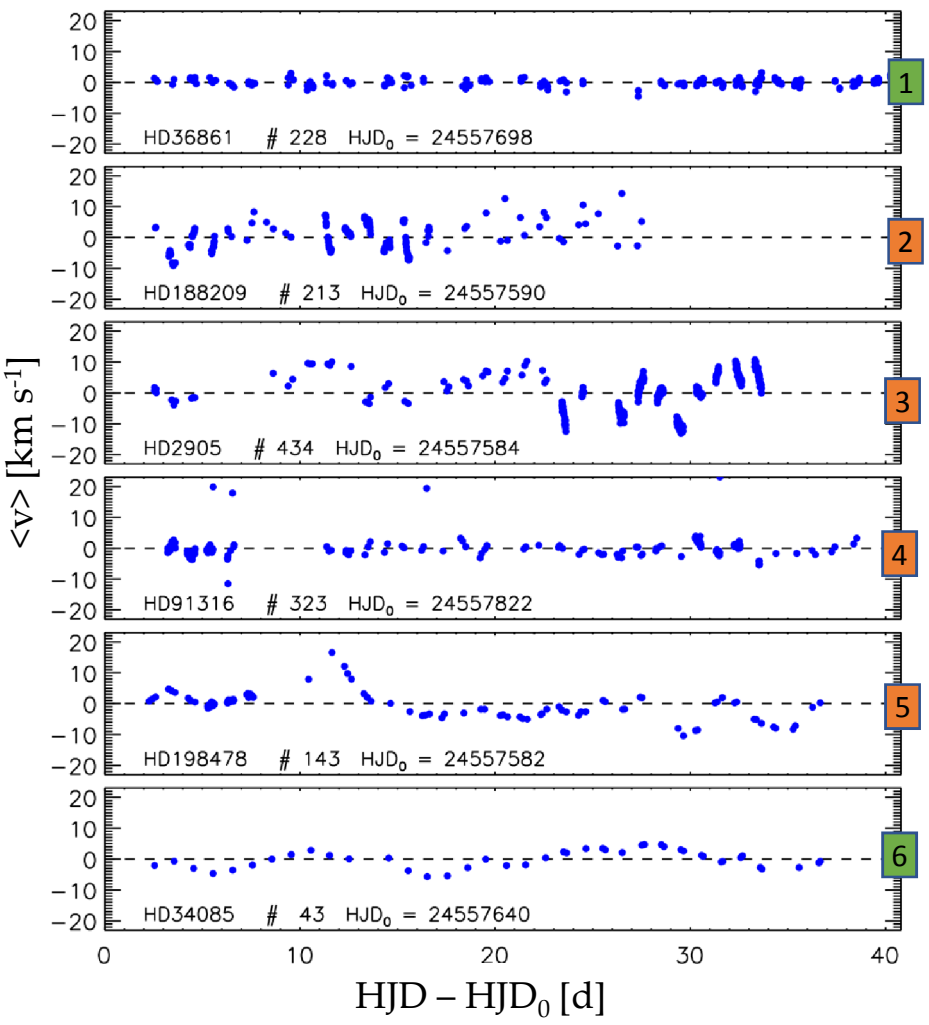
ε-mechanism *(e.g. Moravveji+ 2012)*

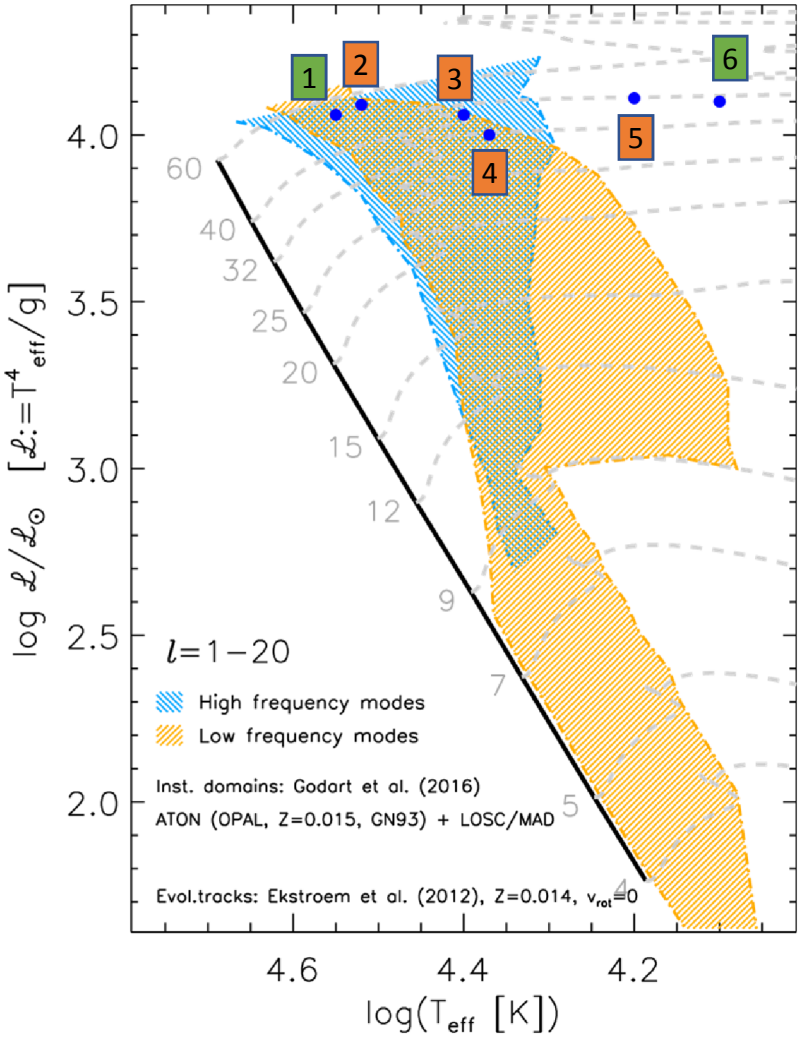
and/or **post-RSG phase** *(e.g. Saio+2013)*



KNOCKING ON ASTEROSEISMOLOGY OF MASSIVE STARS' DOOR

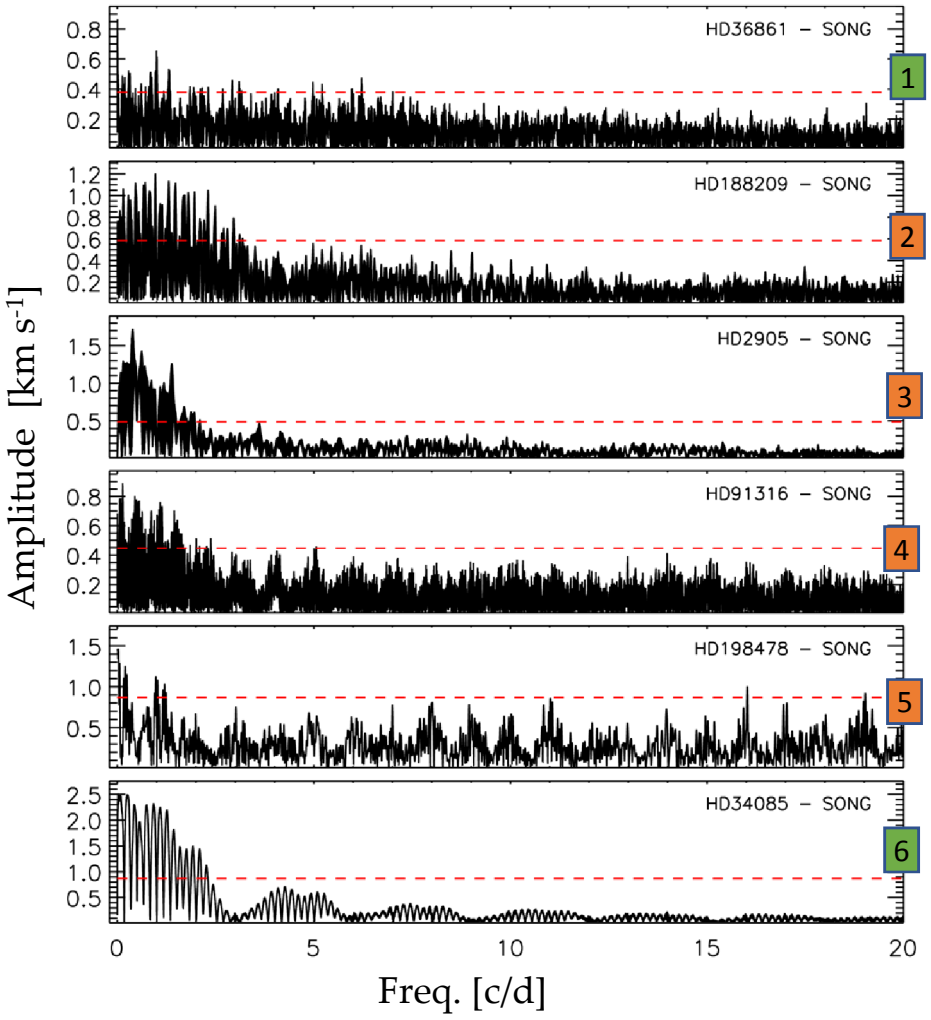
Towards a global overview of spectroscopic variability

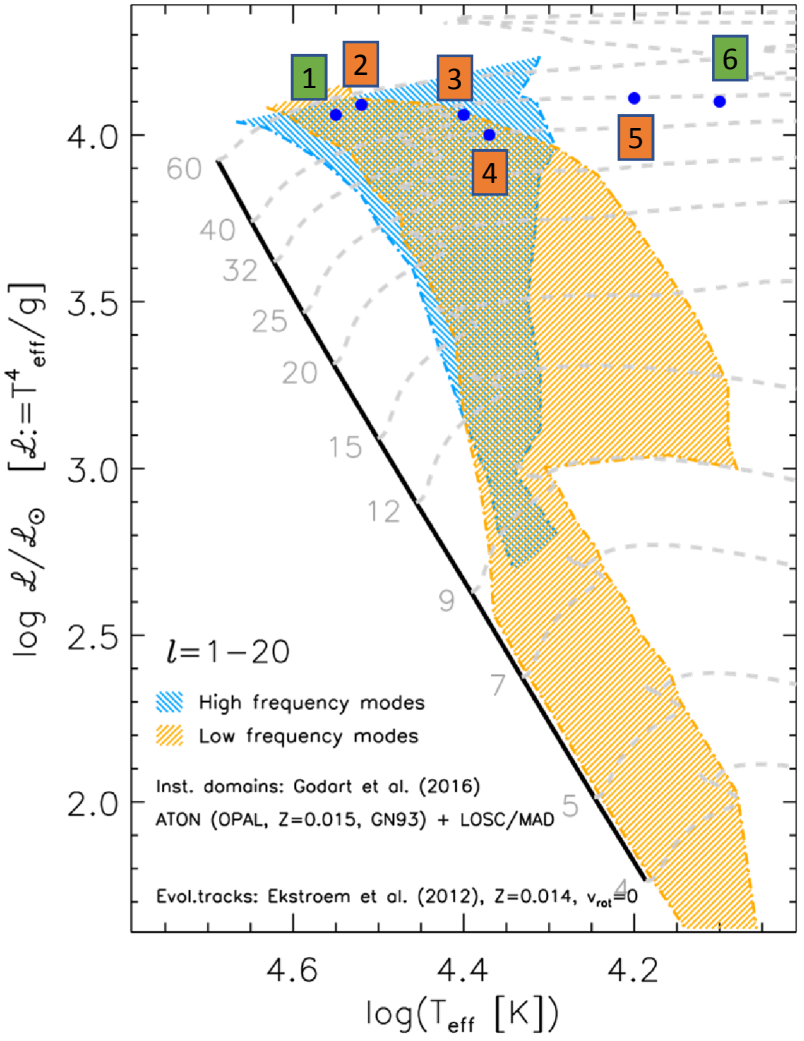




KNOCKING ON ASTEROSEISMOLOGY OF MASSIVE STARS' DOOR

Towards a global overview of spectroscopic variability

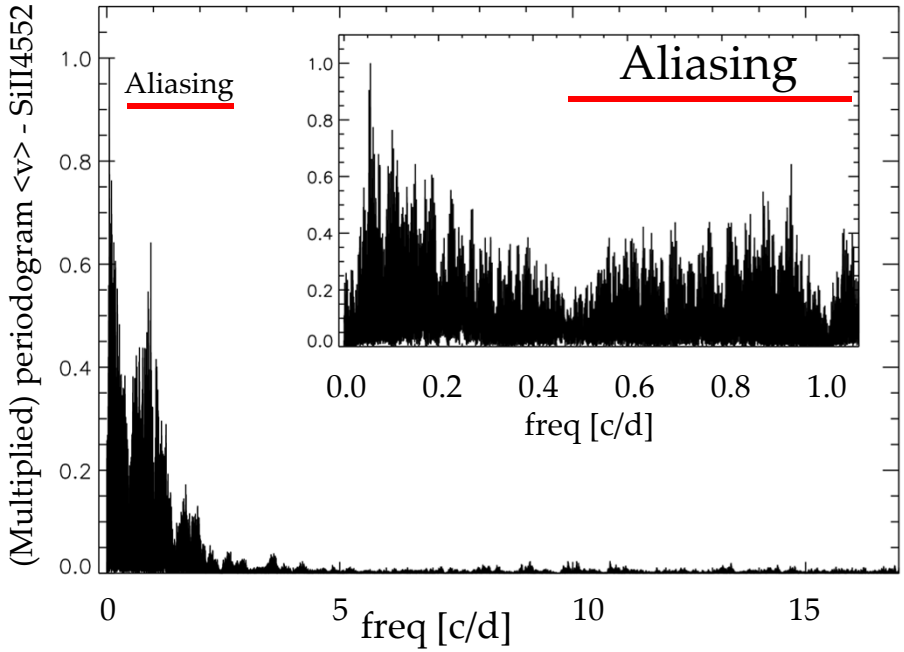


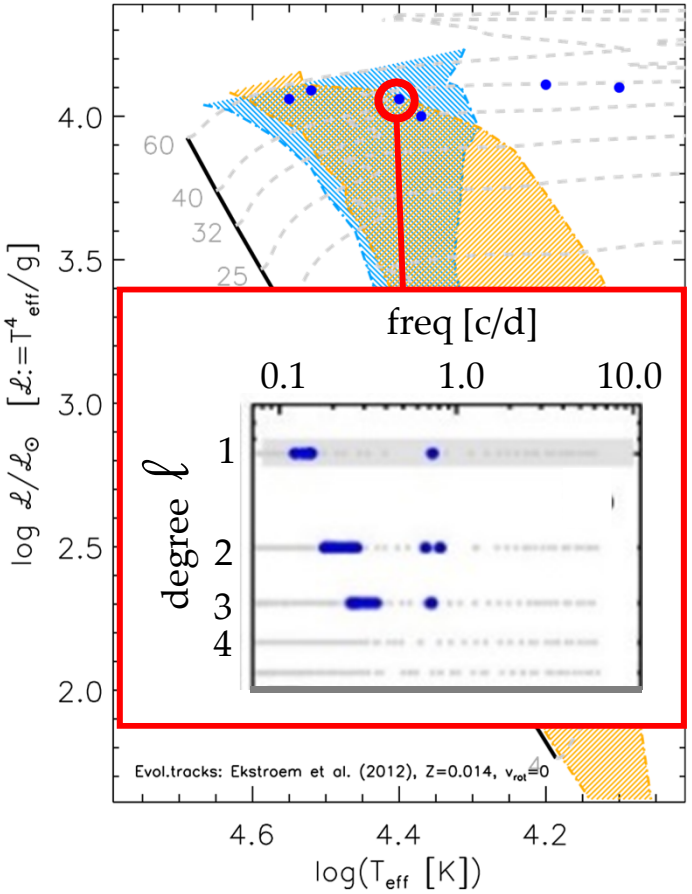


Detailed study of specific targets

Low-frequency photospheric and wind variability in the early-B supergiant HD 2905

S. Simón-Díaz[1,2], C. Aerts[3,4,5], M.A. Urbaneja[6], I. Camacho[1,2], V. Antoci[7], M. Fredslund Andersen[7], F. Grundahl[7], P.L. Pallé[1,2]





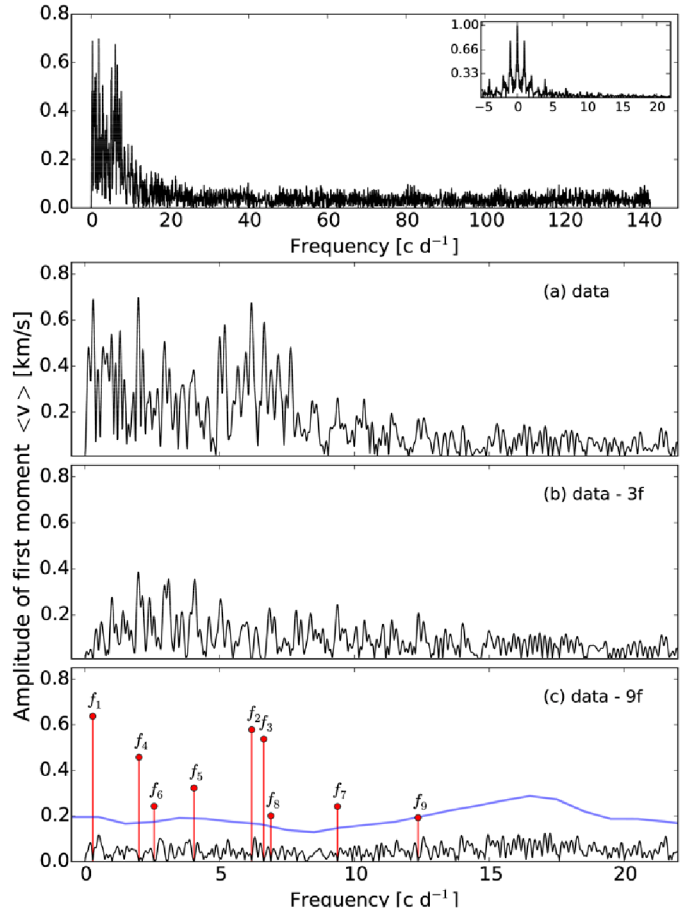
- Coherent (long-standing) g-modes?
- Convectively driven (internal/stochastic) waves?
- … ?

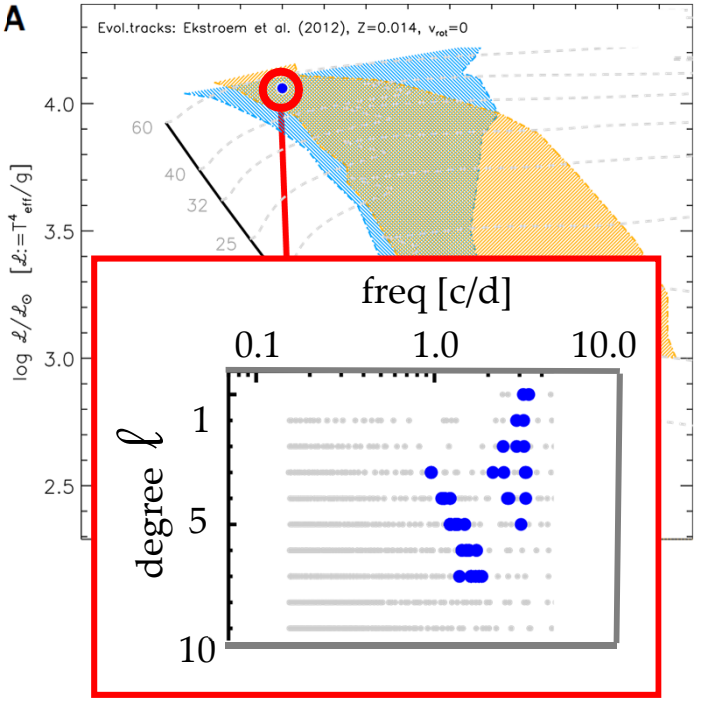
See also:

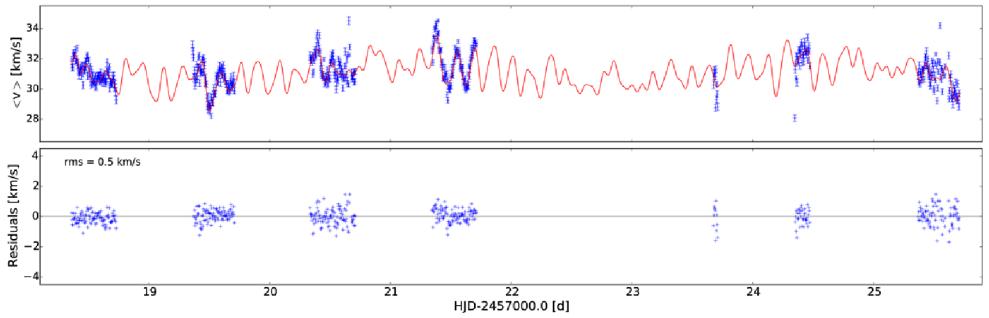
Aerts et al. (2017): HD188209 – O9.5 Ib
Aerts et al. (2018): HD91316 – B1 Iab

Multi-periodic spectroscopic variability in the O giant star λ Ori A as revealed by the Herzsprung-SONG telescope*

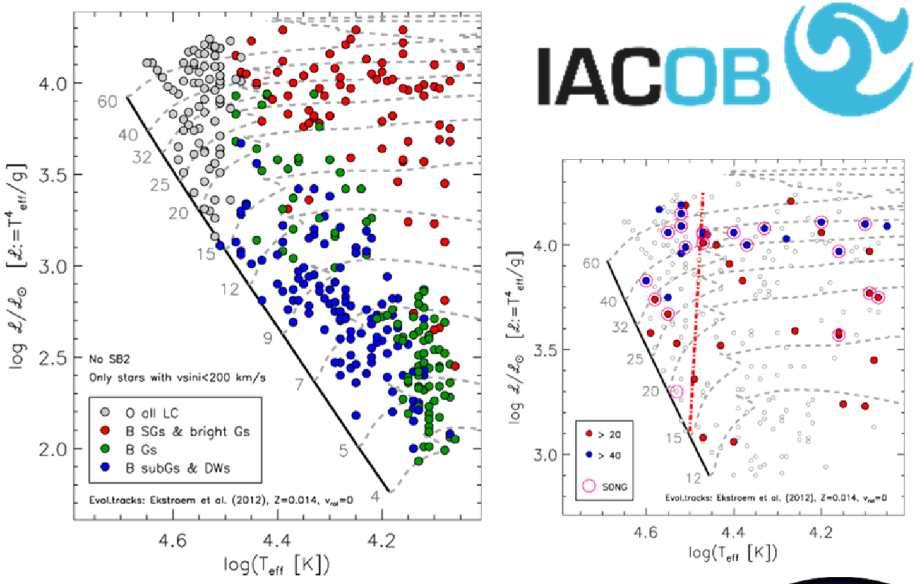
S. Simón-Díaz[1,2], P. G. Beck[1,2], M. Godart[3] et al.

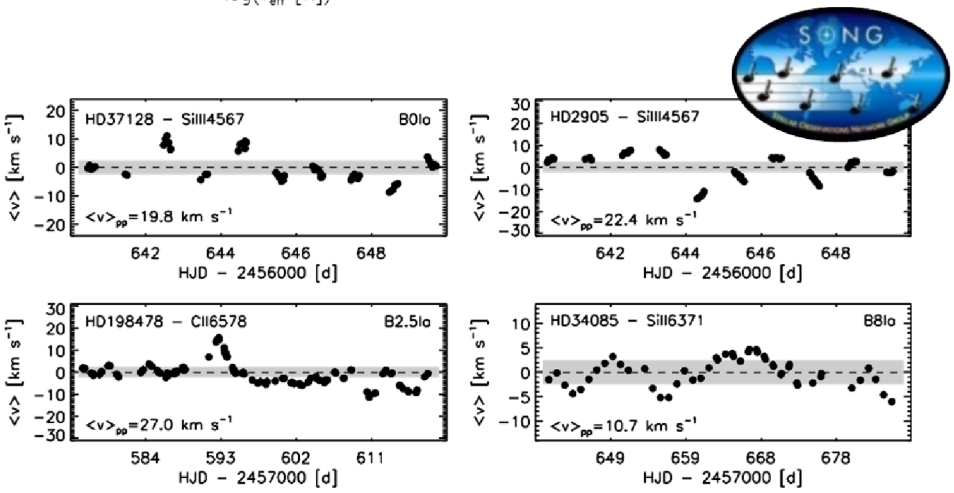


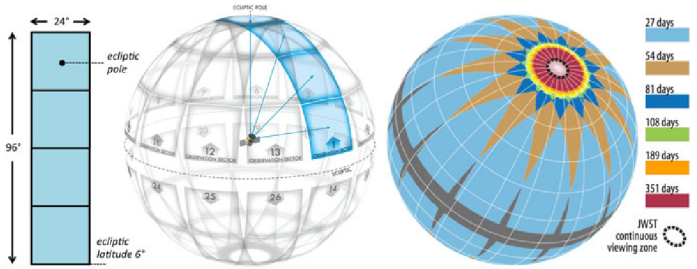




Asteroseismology of massive O stars and B Sgs with IACOB and TESS (ft. SONG)







Main take away message

Time-resolved spectroscopy is very useful (**and needed*!!**) observational tool to step forward in our understanding of the pulsational properties (i.e. the internal structure) of massive stars along their evolution

* Photometric observations from space missions improve the duty cycle, but:

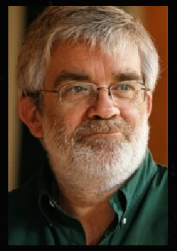
[1] some of the variabilities revealed by spectroscopy are averaged out &

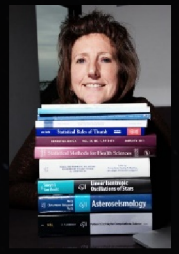
[2] photospheric and wind variability cannot be properly disentangled.

Special thanks to …


Mads F. Andersen


Frank Grundahl

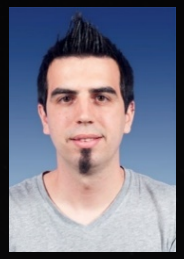

Pere Pallé


Conny Aerts


Berto Castro


Melanie Godart


Paul Beck


Gonzalo Holgado


Nikolay Britavskiy

The power of

SONG

for studying massive

O stars and B Sgs

S. Simón-Díaz

Instituto de Astrofísica de Canarias