Galactic OB Stars

as seen by

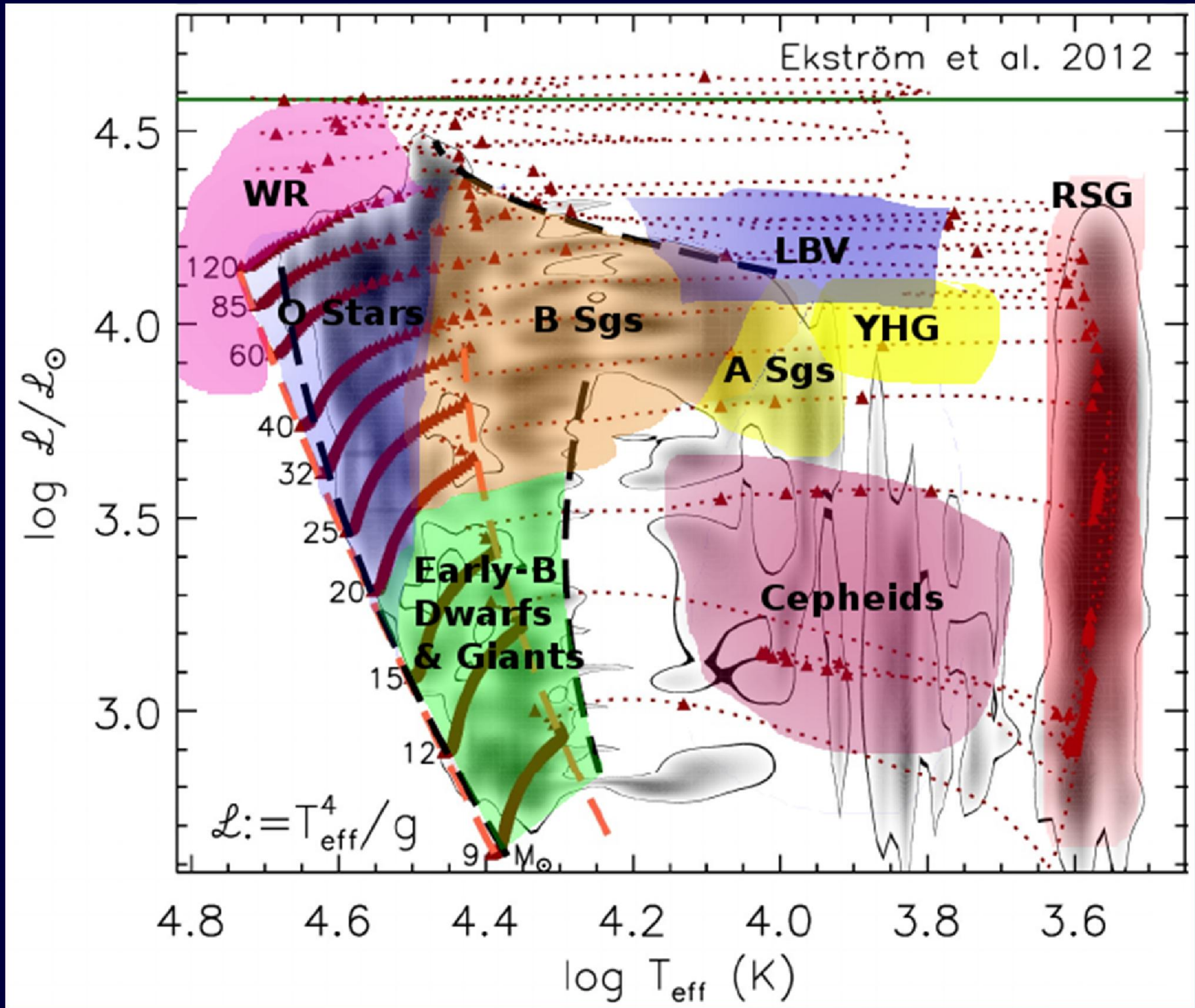
IACOB, Gaia and TESS

Sergio Simón-Díaz

Instituto de Astrofísica de Canarias

+ G. Holgado (CAB) & S. Burssens (KULeuven)

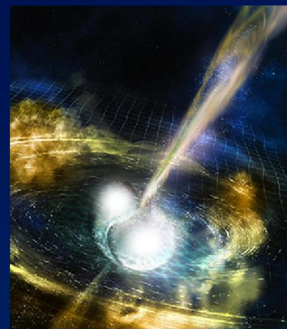
THE REALM OF MASSIVE STARS



Courtesy of G. Holgado

Figure adapted from Castro et al. (2014)

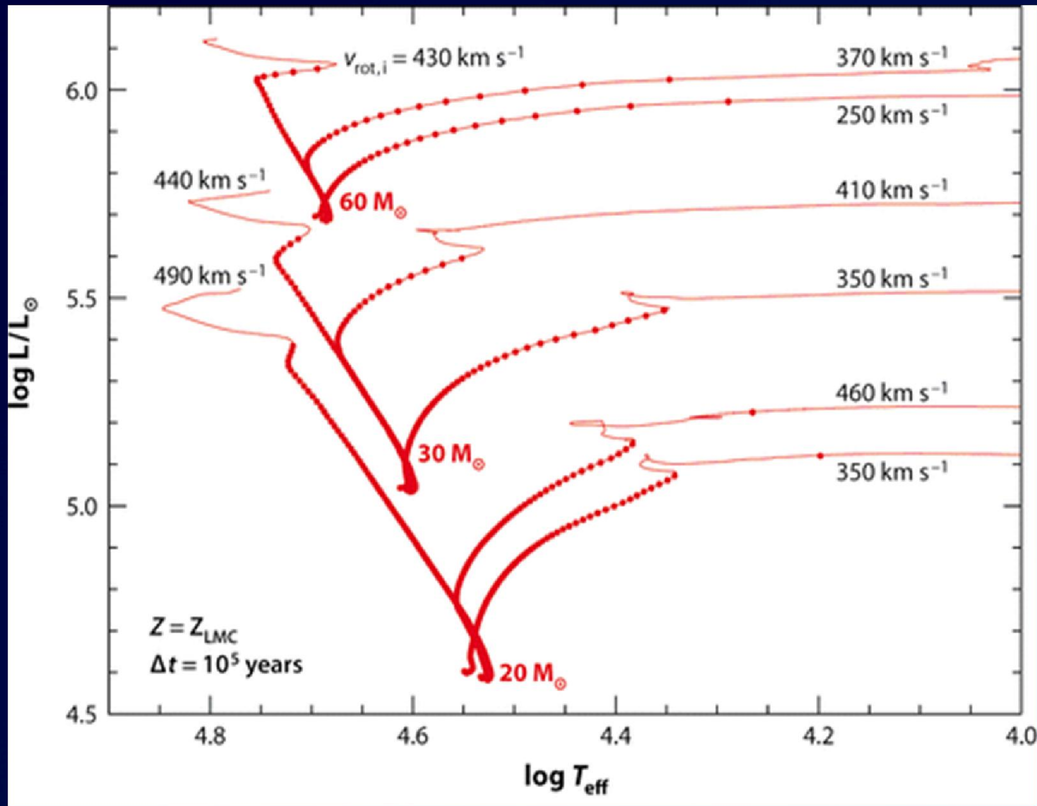
+ End products



The evolution of massive stars depends not only on mass

Example 1

Rotation



NOTE: The measured vsini of main sequence OB stars ranges from a few to 600 km/s

(e.g., Ramirez-Agudelo et al. 2013)

Figure from Langer (2012)

The evolution of massive stars depends not only on mass

Example 2

Binary interaction

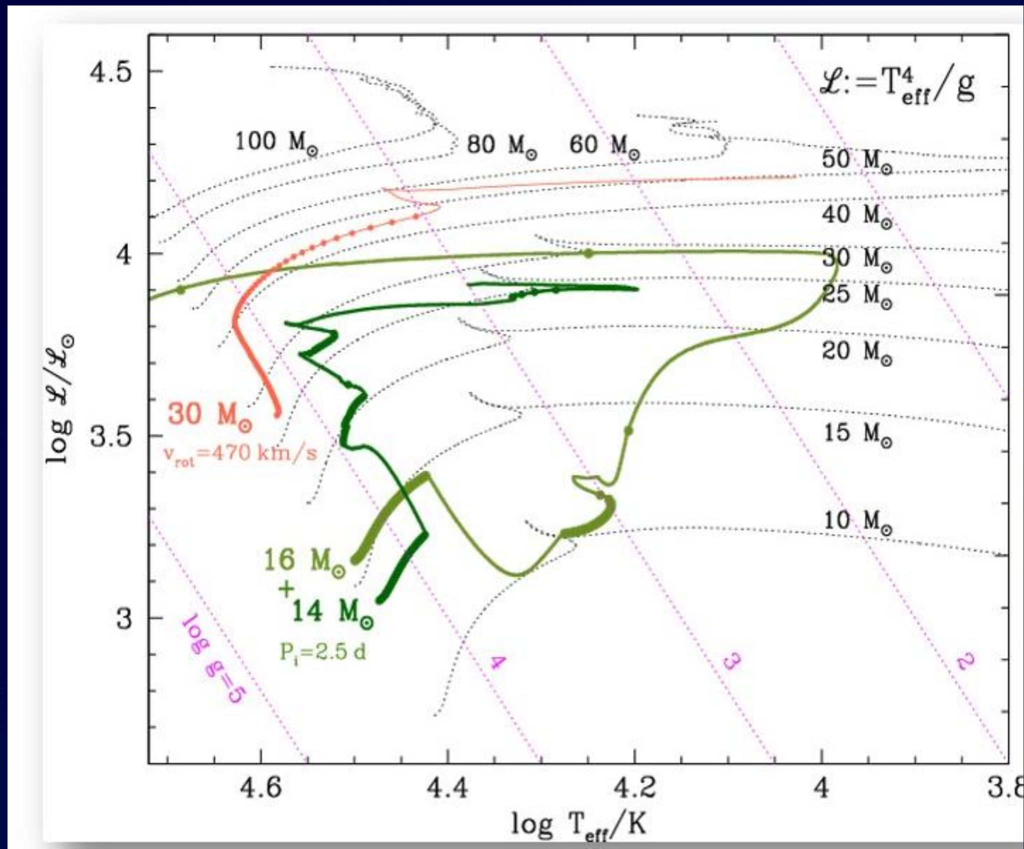


Figure from Langer & Kudritzki (2014)

NOTE: More than 70% of all massive stars will exchange mass with a companion along their life

(Sana et al. 2012)

The evolution of massive stars depends not only on mass

Example 3

Outcome of state-of-the-art evolutionary models

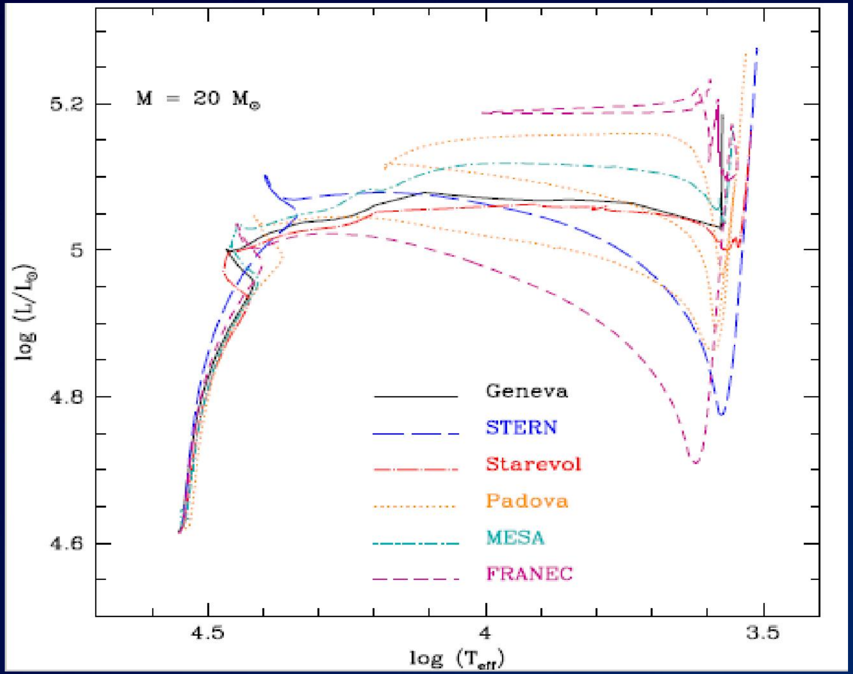


Figure from Martins & Palacios (2013)

NOTE: Other important ingredients to take into account (in addition to rotation) …

- Mass loss
- Metal mixture … Opacities
- Core-overshooting
- Treatment of convection
- Treatment of internal angular momentum transport
- Internal magnetic field
- Mass and angular momentum transfer (in binary evolution)

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.

P.I. S. Simón-Díaz

IACOB

EXCELENCIA SEVERO OCHOA

Main Scientific Goal

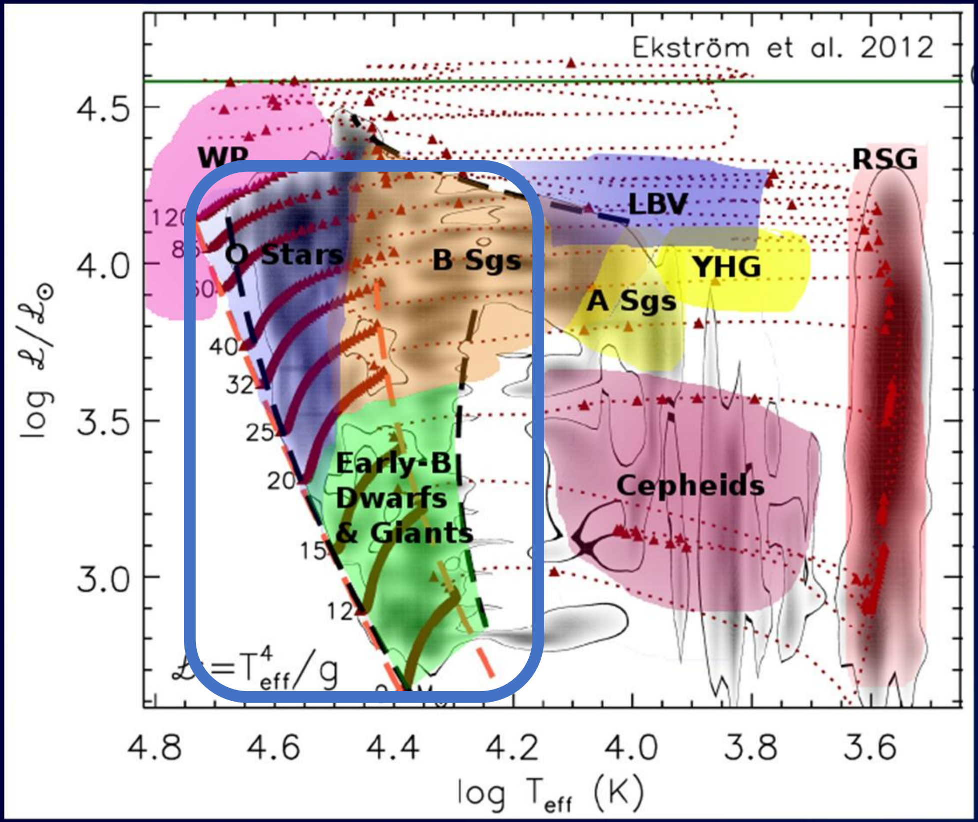
Provide an unprecedented empirical overview of the main physical properties of Galactic massive O- and B-type stars which can be used as definitive anchor point for our theories of stellar atmospheres, winds, interiors and evolution of MASSIVE STARS.

Added value:

- Provide a unique homogeneous, high-resolution optical spectroscopic database of Galactic OB stars.
- Serve as the necessary ground-based support for the successful exploitation of data from Gaia and TESS.

gaia

TESS



Massive stars spent most of their life as:

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)

Young (age < a few Myr)

In the Milky Way …

They are mainly found in (young) star forming regions across the (thin) Galactic disk

Some immediate objectives

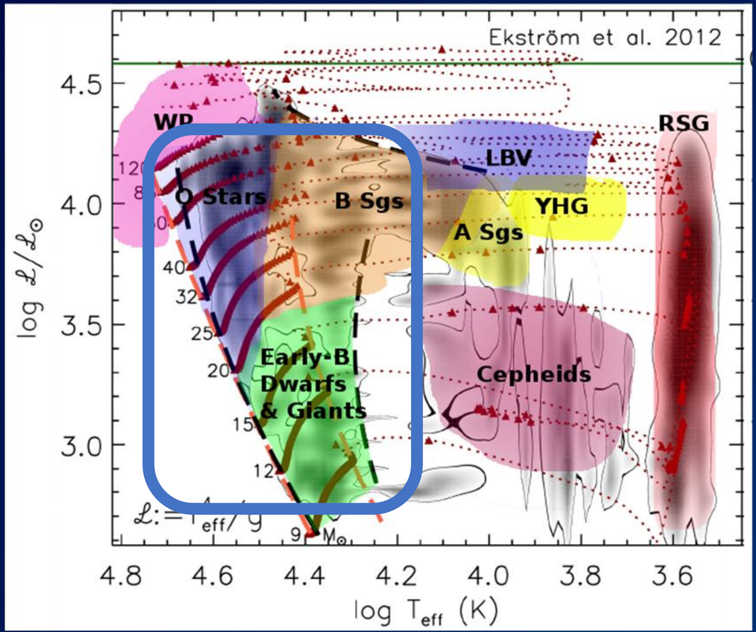
IACOB

1. Full empirical characterization of a large sample of (~1000) Galactic massive stars covering the full O- and B-type star domain:

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

2. Asteroseismic characterization of a selected sample of single & binary systems among O-type stars and B Sgs *(ft. MAMSIE)*

3. Detailed empirical characterization of a selected sample of massive binary/multiple systems *(ft. MONOS & OWN)*



OBSERVATIONS: AN IMPORTANT PILLAR OF THE IACOB PROJECT

IACOB Spectroscopic database

Last described in: *Simón-Díaz+ (2015)*

After 11 years of observations (170+ observing nights)

8500+ spectra (FIES@NOT & HERMES@Mercator)

875+ 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

Updated Feb. 2020

>1000 hours of SONG time from Dec. 2014 to Mar. 2020

20000+ spectra (60 O stars and B Sgs)

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

OBSERVATIONS: AN IMPORTANT PILLAR OF THE IACOB PROJECT

Updated Feb. 2020

~ 880 stars
~ 29000 spectra

IACOB Spectroscopic database

~1000 stars
~ 30000 spectra

* To be complemented with:

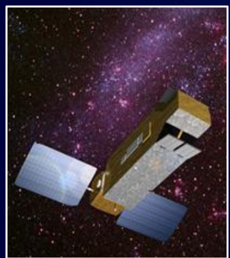
- FEROS spectroscopy (OWN & ESO Archive)
- UV spectroscopy (HST, IUE, FUSE)
- Proper motions & parallaxes (Gaia)
- Time-resolved photometry (TESS)

gaia

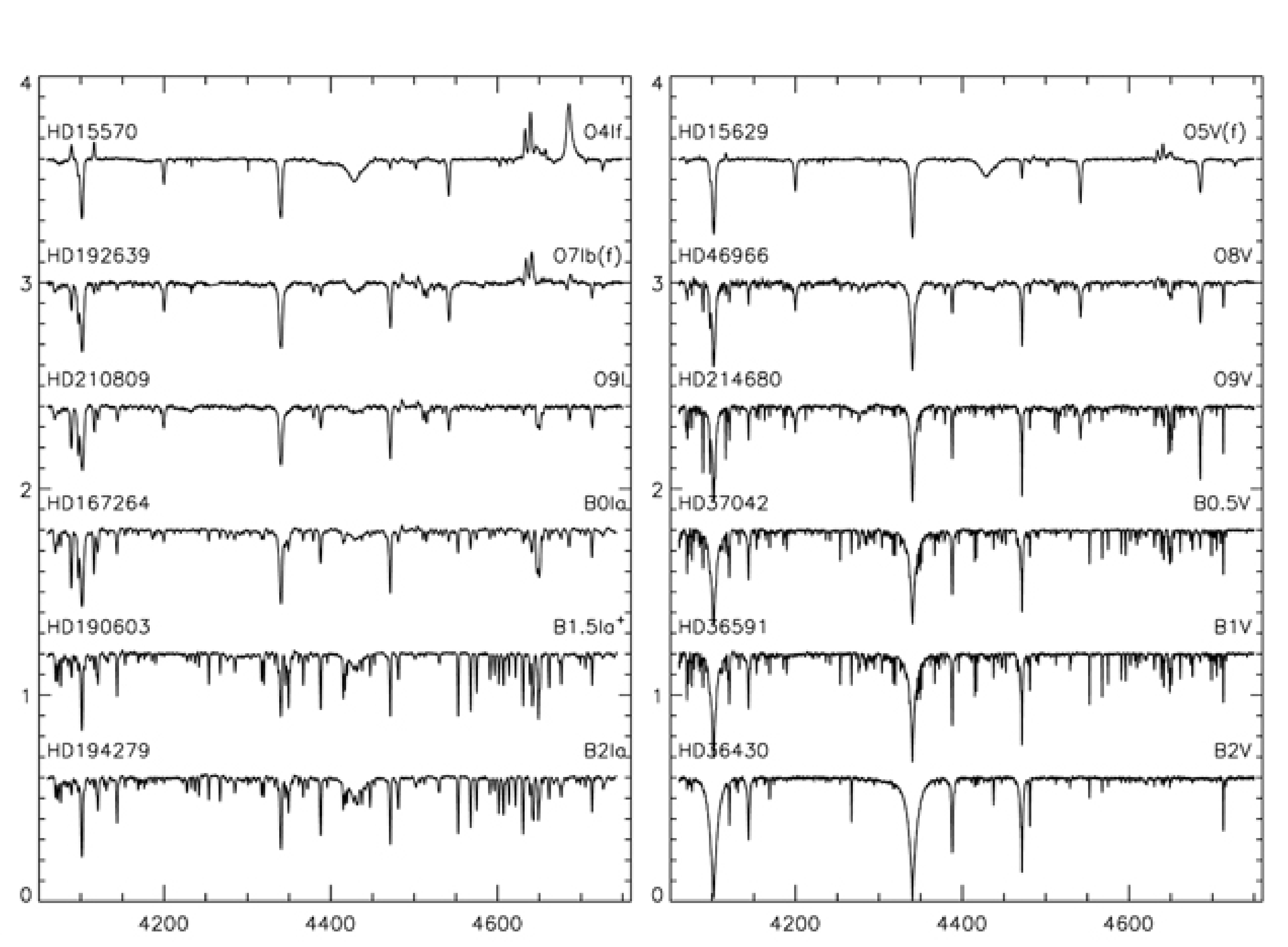
TESS

Galactic OB stars as seen by ...

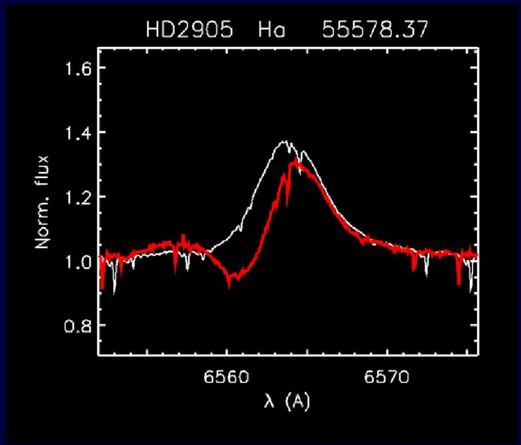


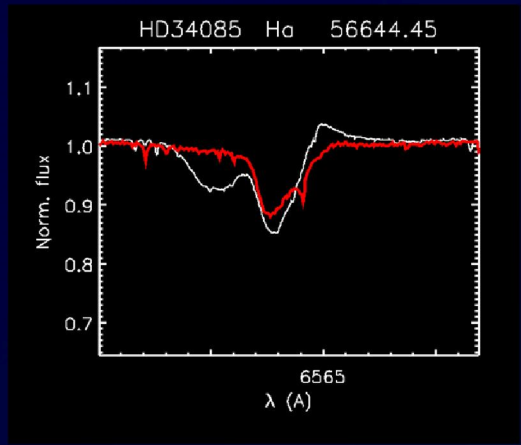


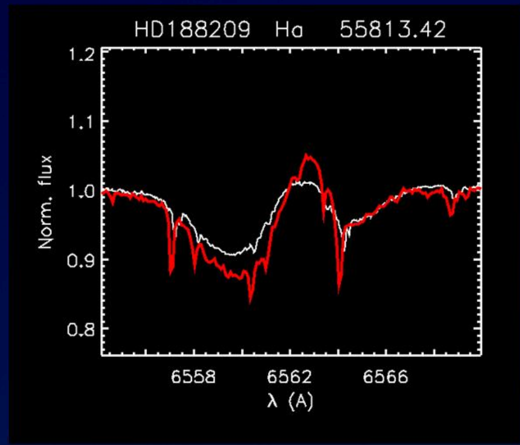
From single snap-shot spectroscopy

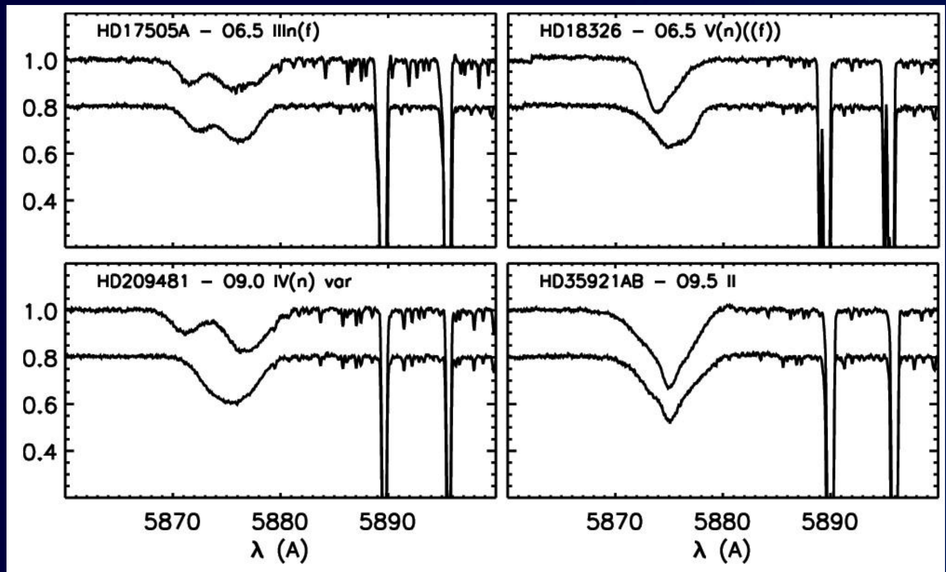


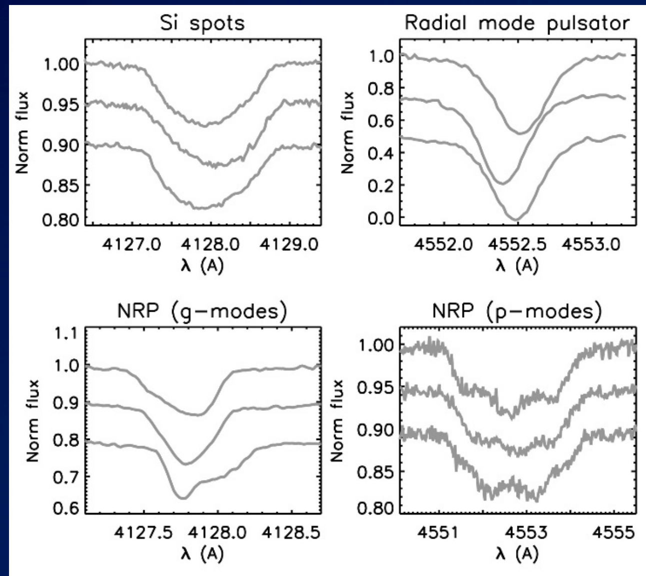
When adding multi-epoch spectroscopy ...











Directly available from optical (+UV*) spectroscopy

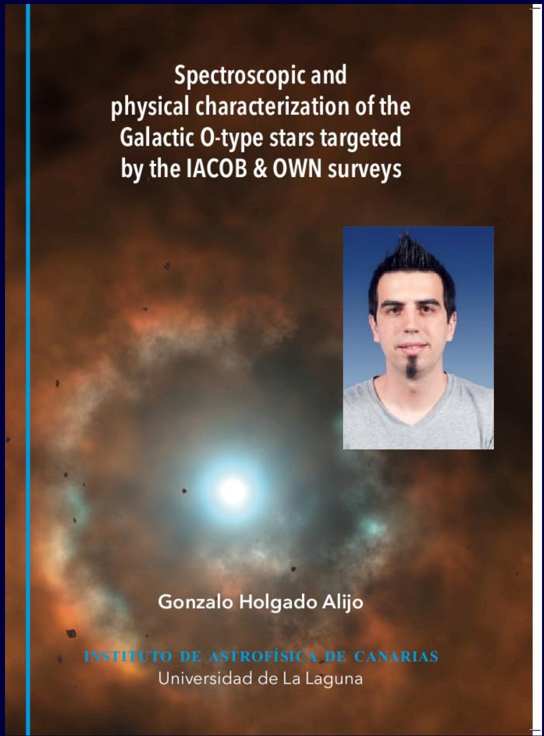
IACOB

- Line-broadening parameters ($v$sin$i$, v_{mac})
- Spectroscopic parameters (T_{eff}, log$g$, log$Q$, β + M_{dot}*, v_{∞}*)
- Surface abundances (He, C, N, O, Si, Mg …, + v_{mic})

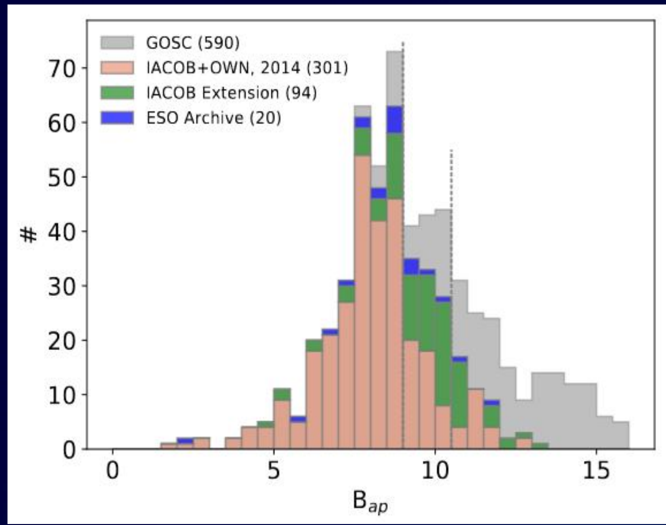
- Radial velocity (v_{rad})
- Spectroscopic binarity (SBx, x $\geq$ 1)
- Spectroscopic variability

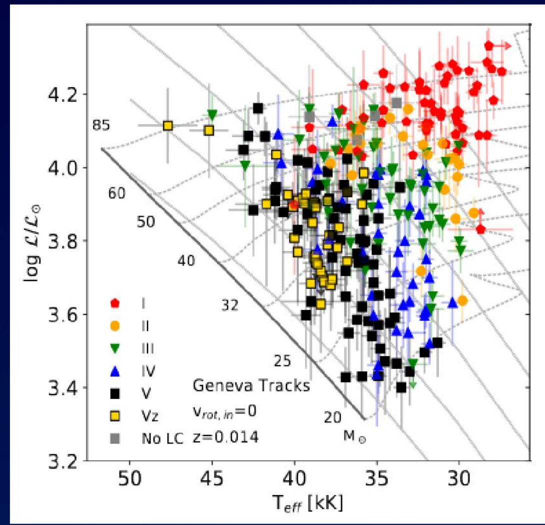
Quantitative spectroscopy

GALACTIC MASSIVE OB-TYPE STARS AS SEEN BY IACOB



Spectroscopic parameters for 285 likely single and SB1 stars

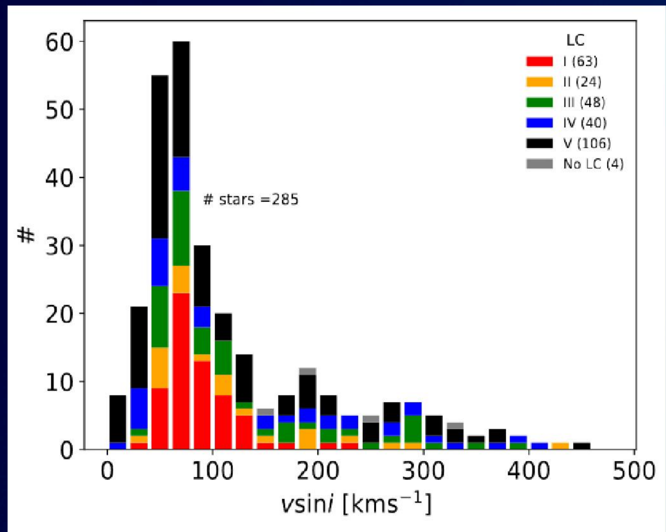


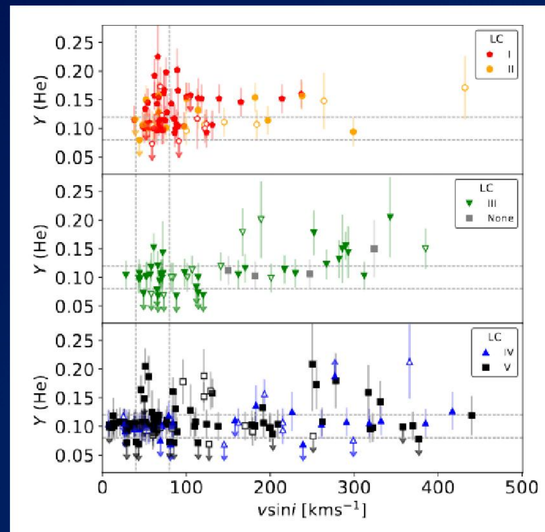


415 Galactic O stars
(70% GOSC)

2900 spectra

59 SB1 (14%)
113 SB2 (27%)

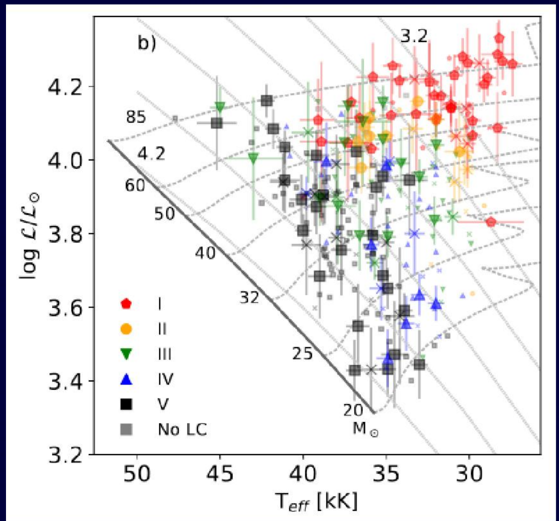


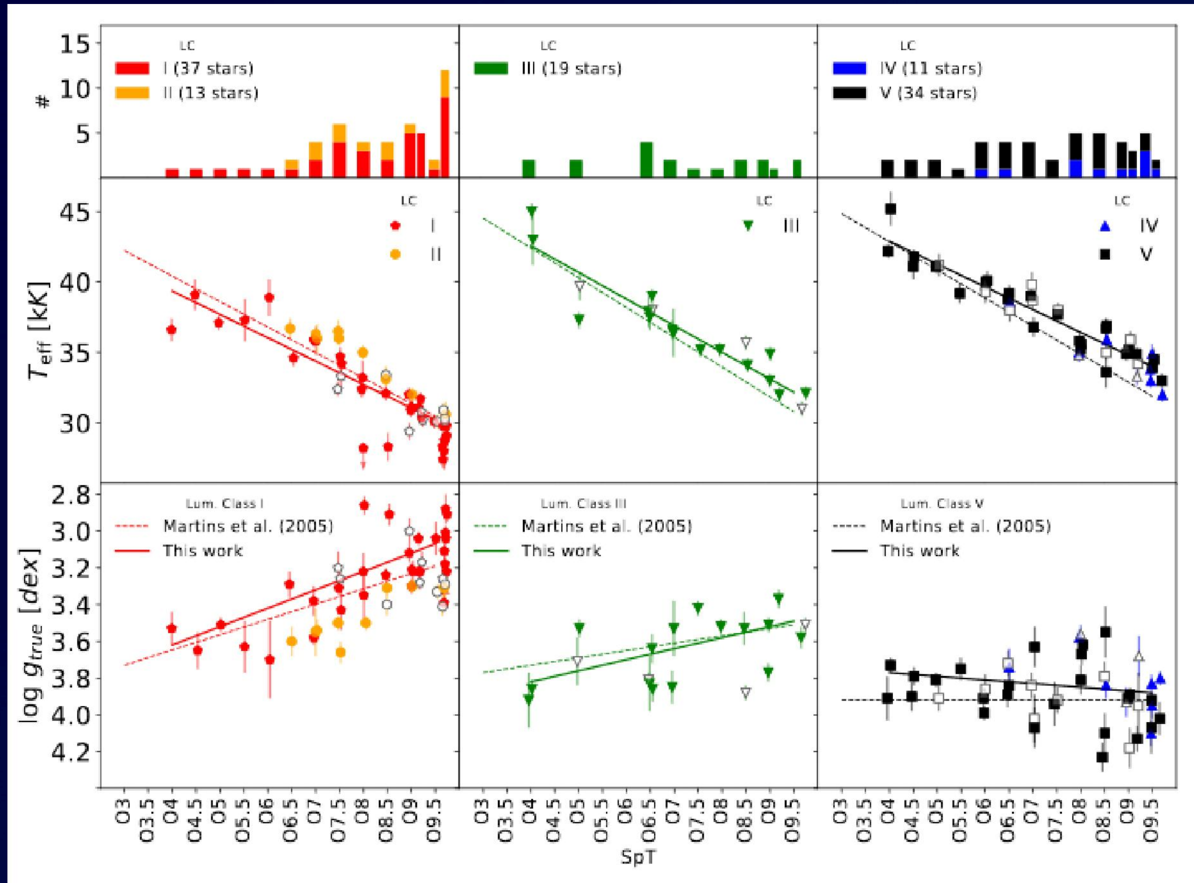


A necessary/useful result:

Holgado, S.-D. et al. (2018, A&A, 613, 65)

Spectroscopic parameters of O stars in the grid of standards for spectral classification





128/131 O-type stars from the GOSSS v2.0 grid of standards

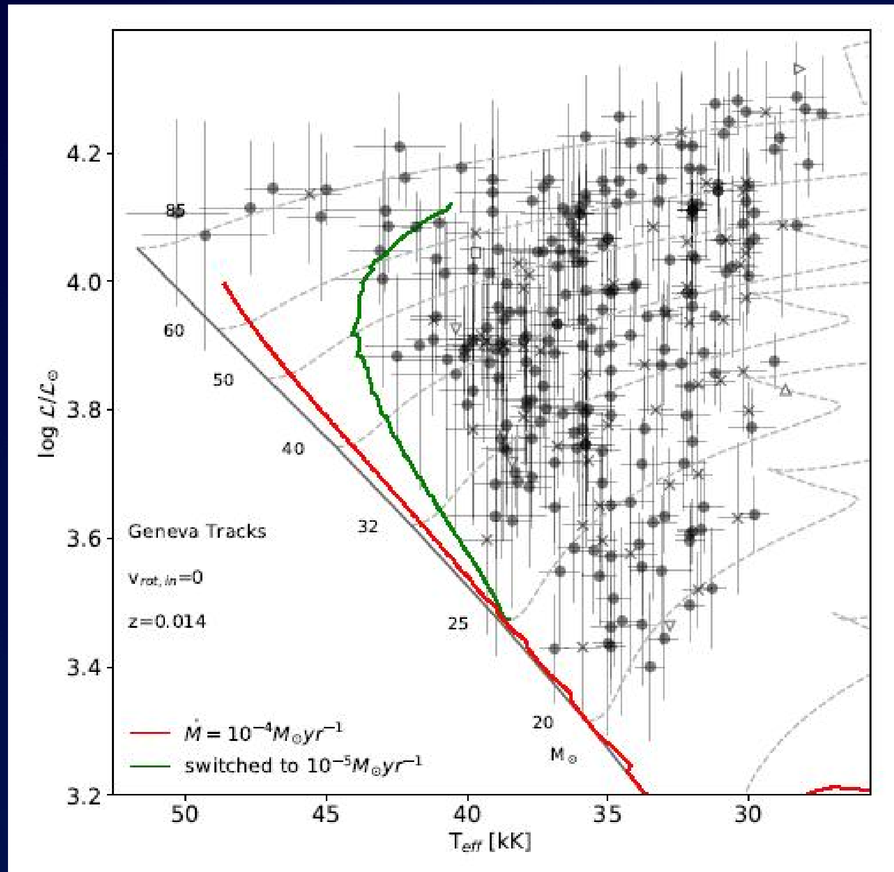
(Maíz Apellániz et al. 2015)

1216 spectra (28 SB1 + 7 SB2)

An annoying/challenging result: *Holgado, S-D. et al. (A&A, submitted)*

On the elusive detection of O-type stars close to the ZAMS

- The empirical dearth of O-type stars close to the ZAMS is becoming a more and more solid result
- Empirical evidence of the need of a lower accretion rate?
- Are all stars heavier than 70 M_{sol} the result of mergers?



GALACTIC MASSIVE OB-TYPE STARS AS SEEN BY …

Directly available from optical (+UV*) spectroscopy

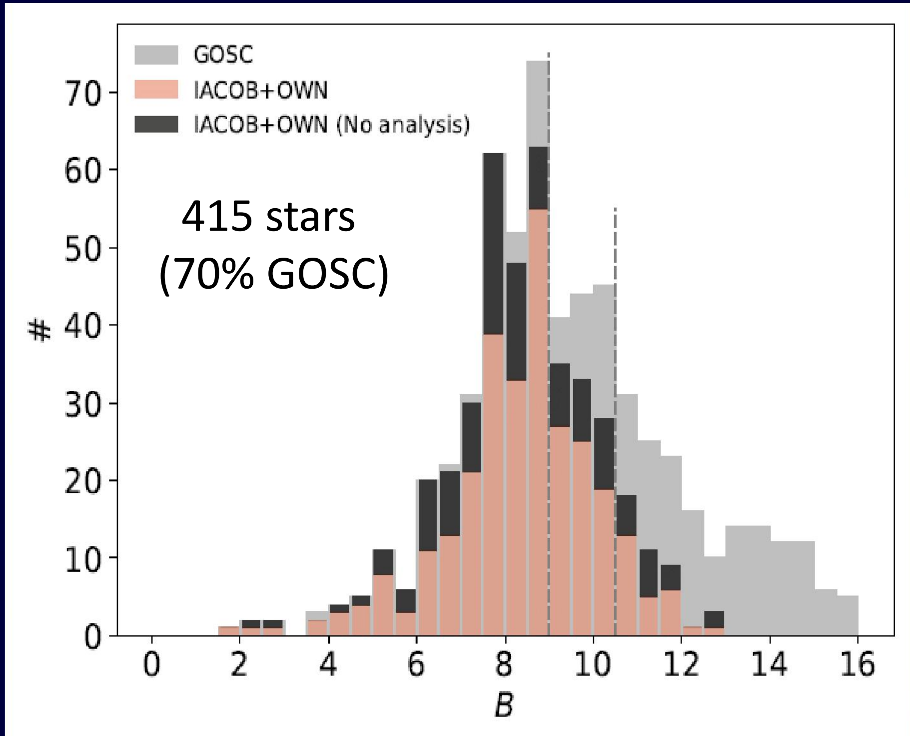
- Line-broadening parameters (*v*sin*i*, v_{mac})
- Spectroscopic parameters (T_{eff}, log*g*, log*Q*, β + M_{dot}*, v_{∞}*)
- Surface abundances (He, C, N, O, Si, Mg …, + v_{mic})
- Radial velocity (v_{rad})
- Spectroscopic binarity (SBx, $x \geq 1$)
- Spectroscopic variability

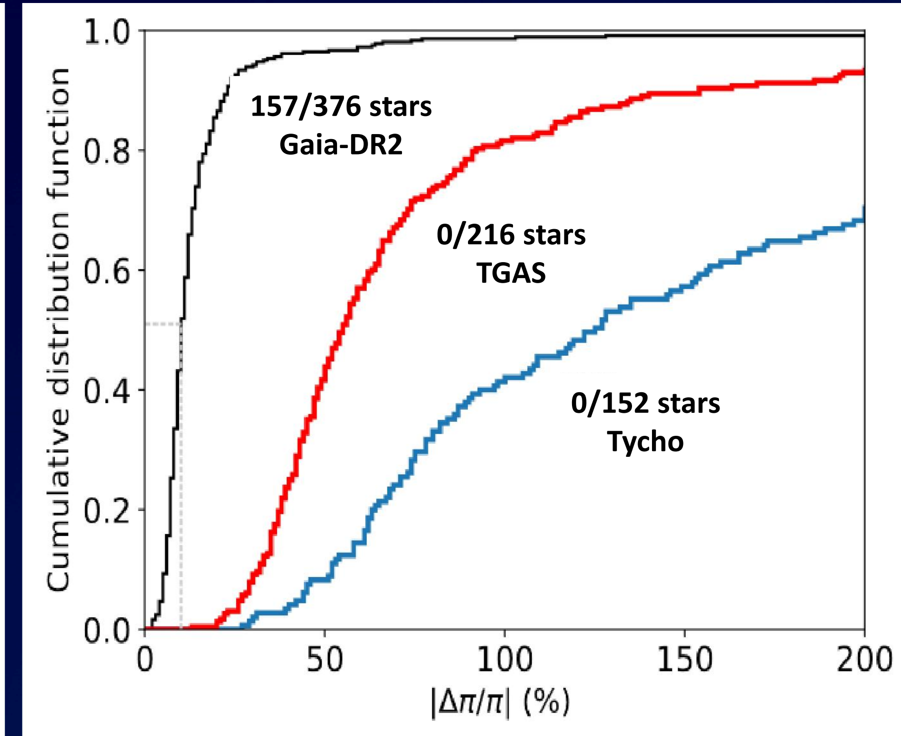
Quantitative spectroscopy

But not …

- Fundamental parameters (*L*, *M*, *R*) ← Distance and extinction needed!!!

Parallaxes of “bright” O-type stars in the Milk Way: from Tycho to Gaia-DR2

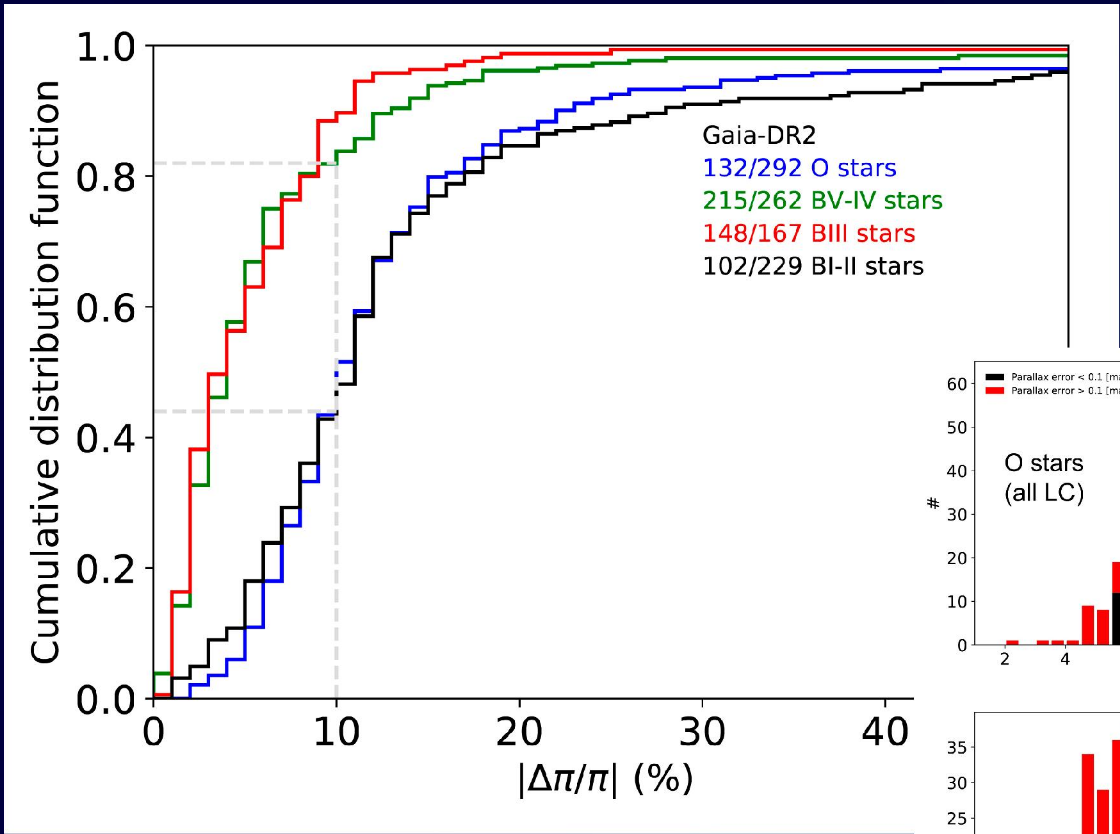




Holgado et al. (2018, PhD, ULL)

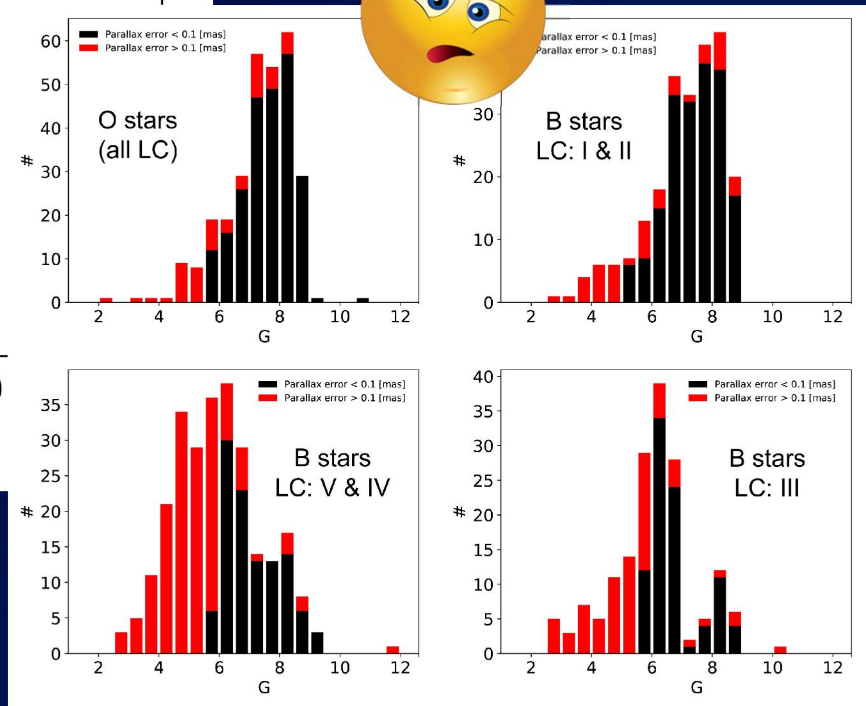
Improving, improving !!!

Gaia-DR2 parallaxes of “bright” OB-type stars in the Milky Way



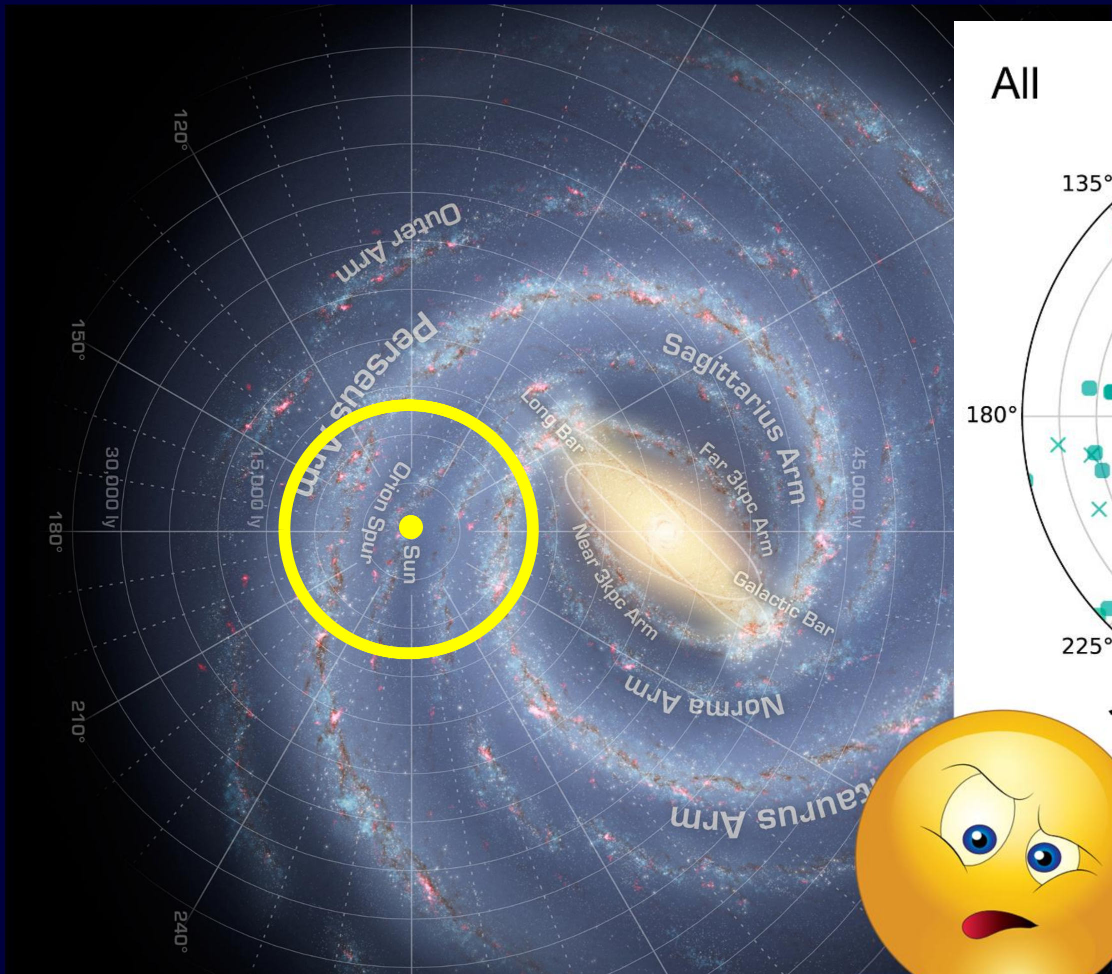
Improving, improving !!!

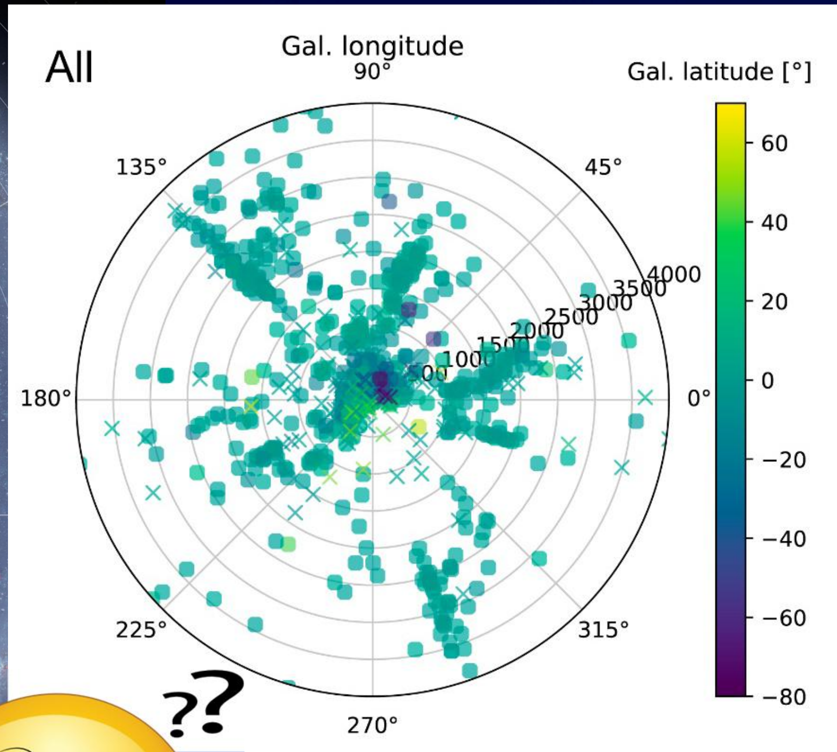
But not yet there with DR2



1000 Galactic OB-type stars
in IACOB with V<9

Distribution of OB-type stars within the IACOB sample in the Galactic plane



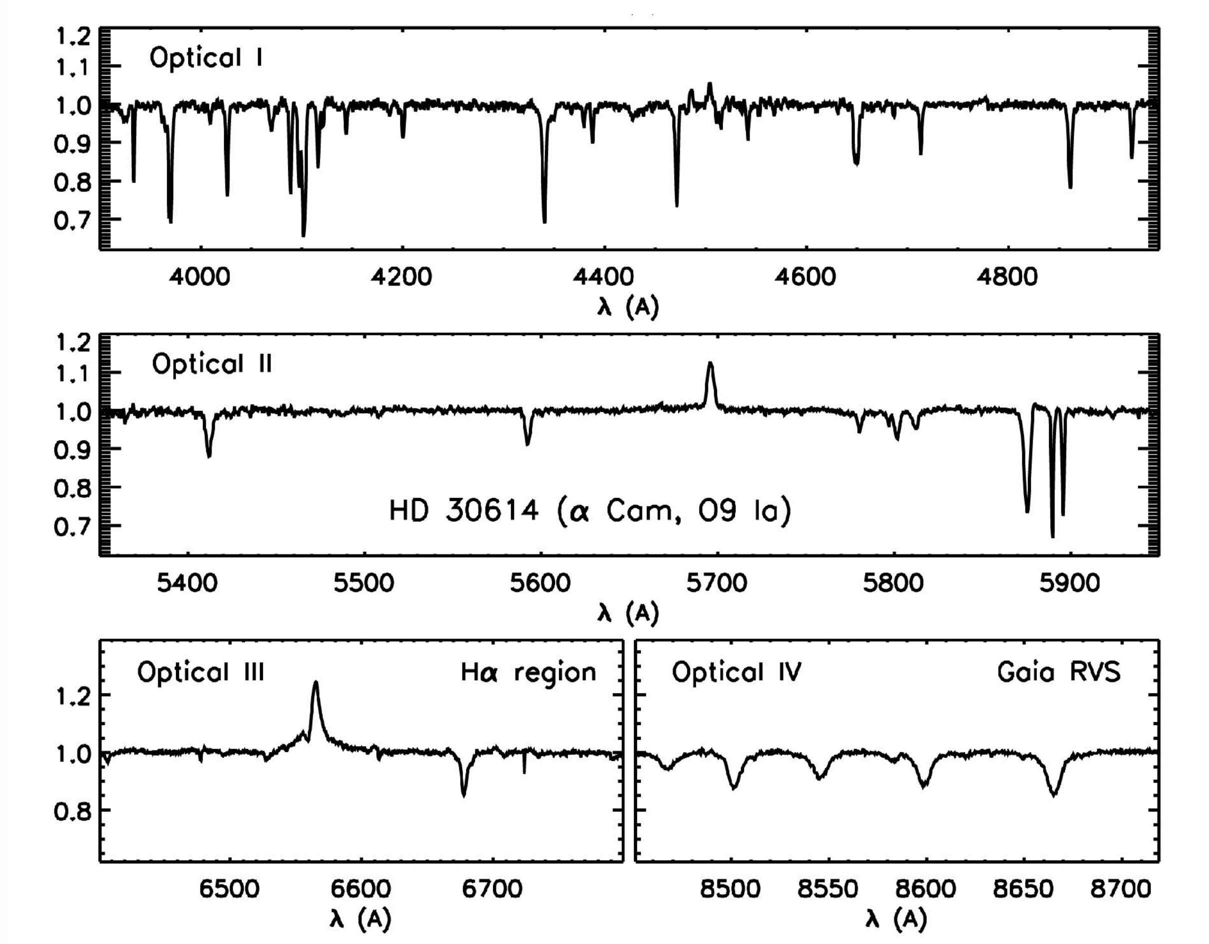


Spurious radial structure

Something still not completely fine-tuned in DR2

WARNING: Just taking distances from Bailer-Jones+ (2018)

Addendum: Optical vs. Gaia-RVS spectroscopy of OB-type stars



The Gaia-RVS range is quite boring in the case of OB stars

Optical spectroscopy is a MUST to get reliable accurate info on:

- RV
- Stellar parameters
- Surface abundance

Expading the Gaia legacy in the OB star domain (Recap – part 1)

- The IACOB project is doing a huge effort in providing accurate and reliable empirical information about Galactic massive OB-type stars.
- To this aim, we are building and performing quantitative spectroscopy of a large database of high resolution optical spectra of Galactic OB-type stars obtained with ground based facilities.
- Optical spectroscopy is a MUST to extract information about radial velocities spectroscopic parameters, surface abundances and spectroscopic binarity.
- Gaia spectroscopic data is quite useless in this regards
- But Gaia data on parallaxes is CRUCIAL to have access to stellar luminosities, radii and masses.

Expading the Gaia legacy in the OB star domain (Recap – part 2)

- Regarding distances to Galactic OB stars, things are improving A LOT with respect to what we had with Hipparcos
- But we are still not there with Gaia-DR2
- Can anyone in the Gaia team help with the stars brighter than G<6

- The compiled information is mainly aimed to shed light in our knowledge about the physical properties and evolution of massive stars
- But certainly useful for other purposes (e.g., the study of the structure and chemo-dynamical evolution of the Milky Way)

Directly available from optical (+UV*) spectroscopy

IACOB

- Line-broadening parameters ($v\sin i$, v_{mac})
- Spectroscopic parameters (T_{eff}, $\log g$, $\log Q$, β + M_{dot}*, v_{∞}*)
- Surface abundances (He, C, N, O, Si, Mg …, + v_{mic})
- Radial velocity (v_{rad})
- Spectroscopic binarity (SBx, $x \geq 1$)
- Spectroscopic variability

Quantitative spectroscopy

But not …

gaia

- Fundamental parameters (L, M, R) ← Distance and extinction needed!!!

Other empirical information of interest:

- Astrometric binarity (gaia)
- Proper motions (gaia)
- Photometric variability (TESS)

Despite not being its main scientific objective …

TESS is providing

- high-cadence (2 & 30 min),
- high-precision (at μmag)

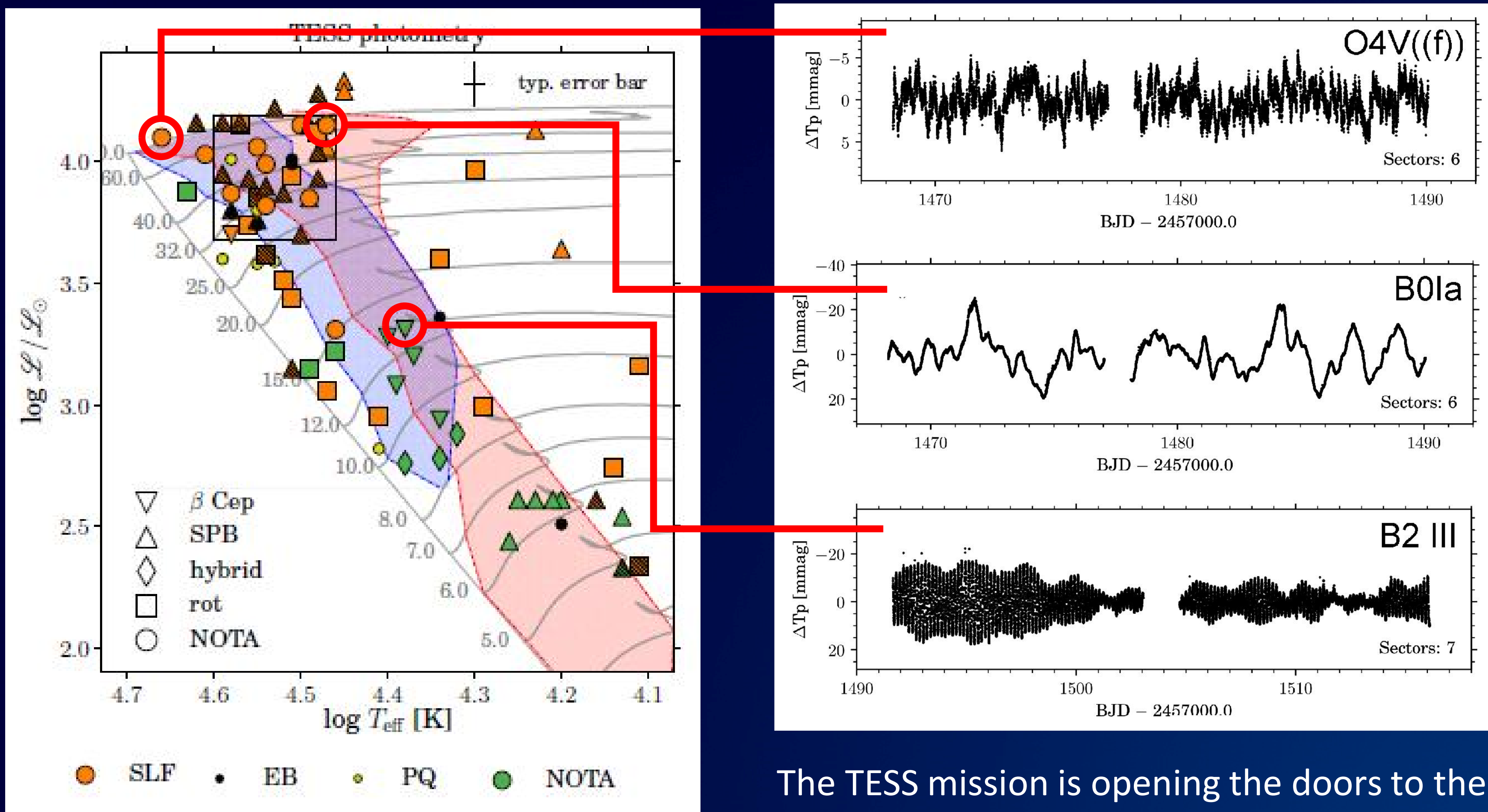
photometric observations of thousands of OB-type stars

during at least 27 days

The TESS mission is opening the doors to the interiors of thousands of massive OB stars

A promising line of work: *Burssens, S-D. et al. (A&A, submitted)*

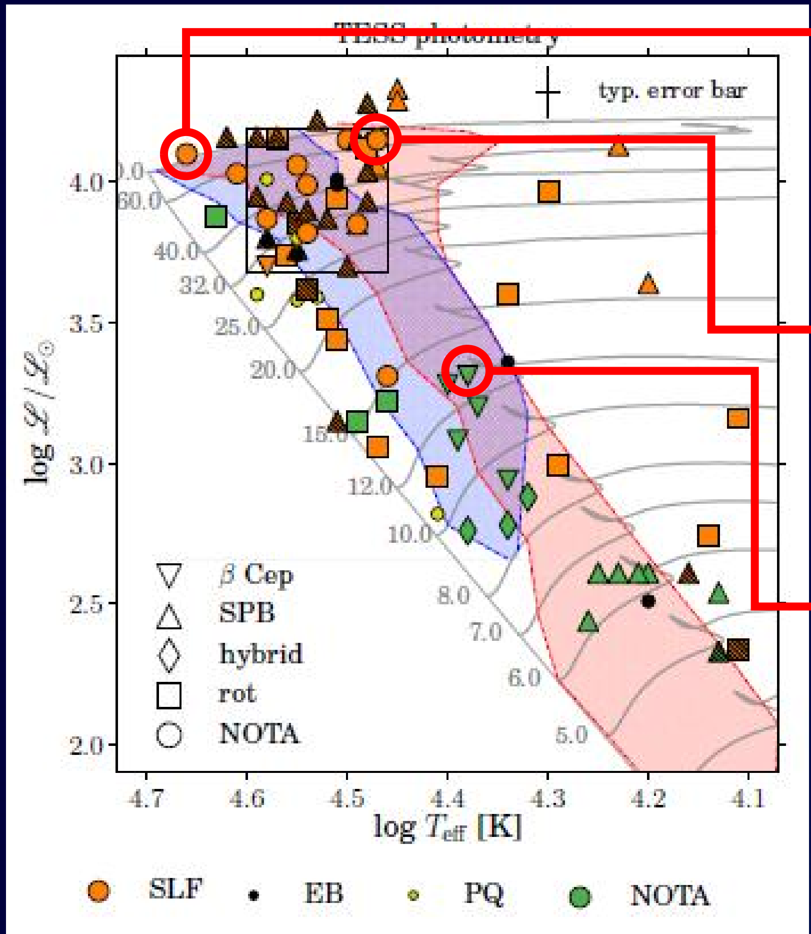
Variability of OB stars from TESS and IACOB spectroscopy

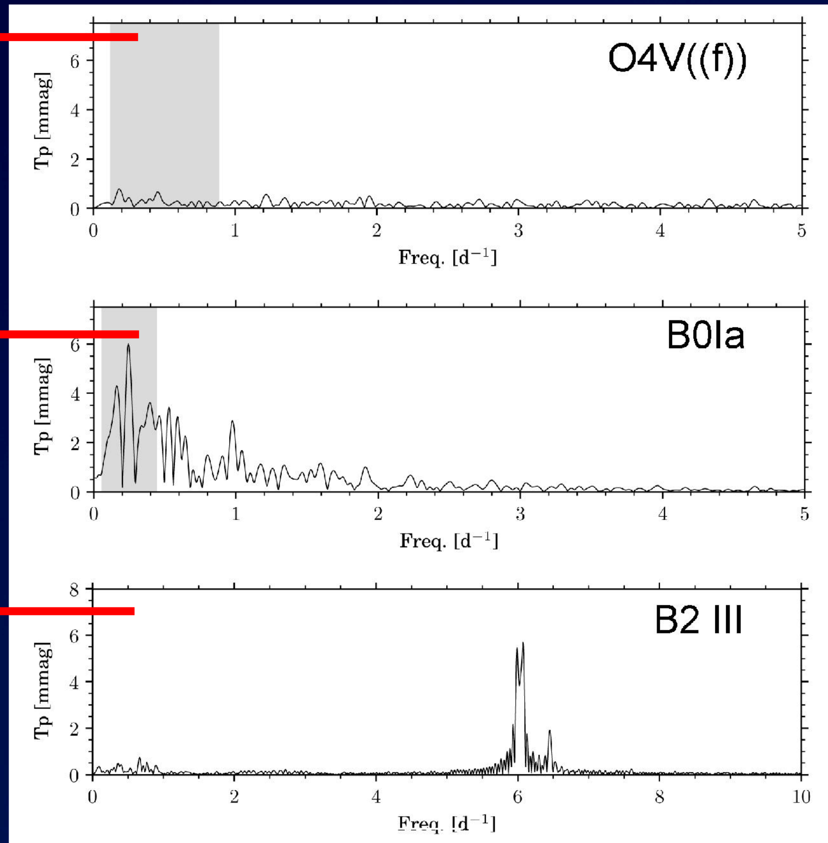


The TESS mission is opening the doors to the interiors of thousands of massive OB stars

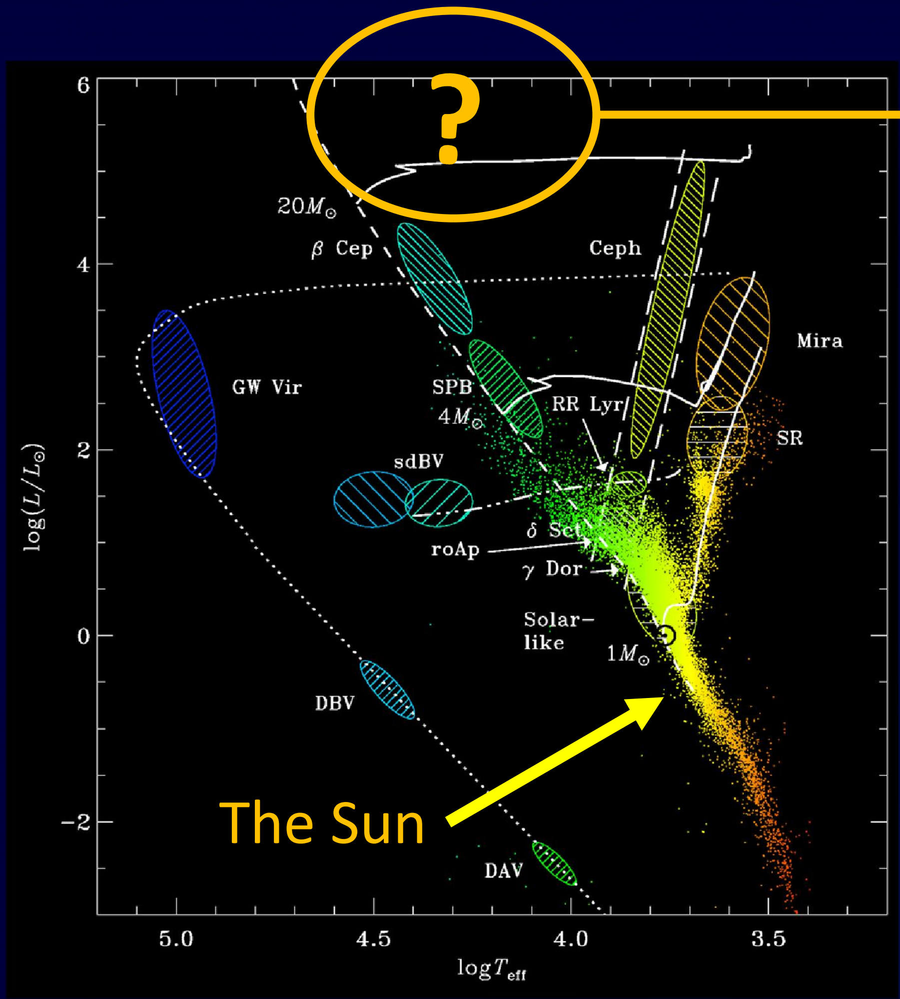
A promising line of work: *Burssens, S-D. et al. (A&A, submitted)*

Variability of OB stars from TESS and IACOB spectroscopy





The TESS mission is opening the doors to the interiors of thousands of massive OB stars



The asteroseismic HR diagram

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:

SPECIAL THANKS TO …

Gonzalo Holgado

Siemen Burssens

Abel de Burgos

AND MANY OTHER PEOPLE CONTRIBUTING TO THE IACOB PROJECT …

…

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.