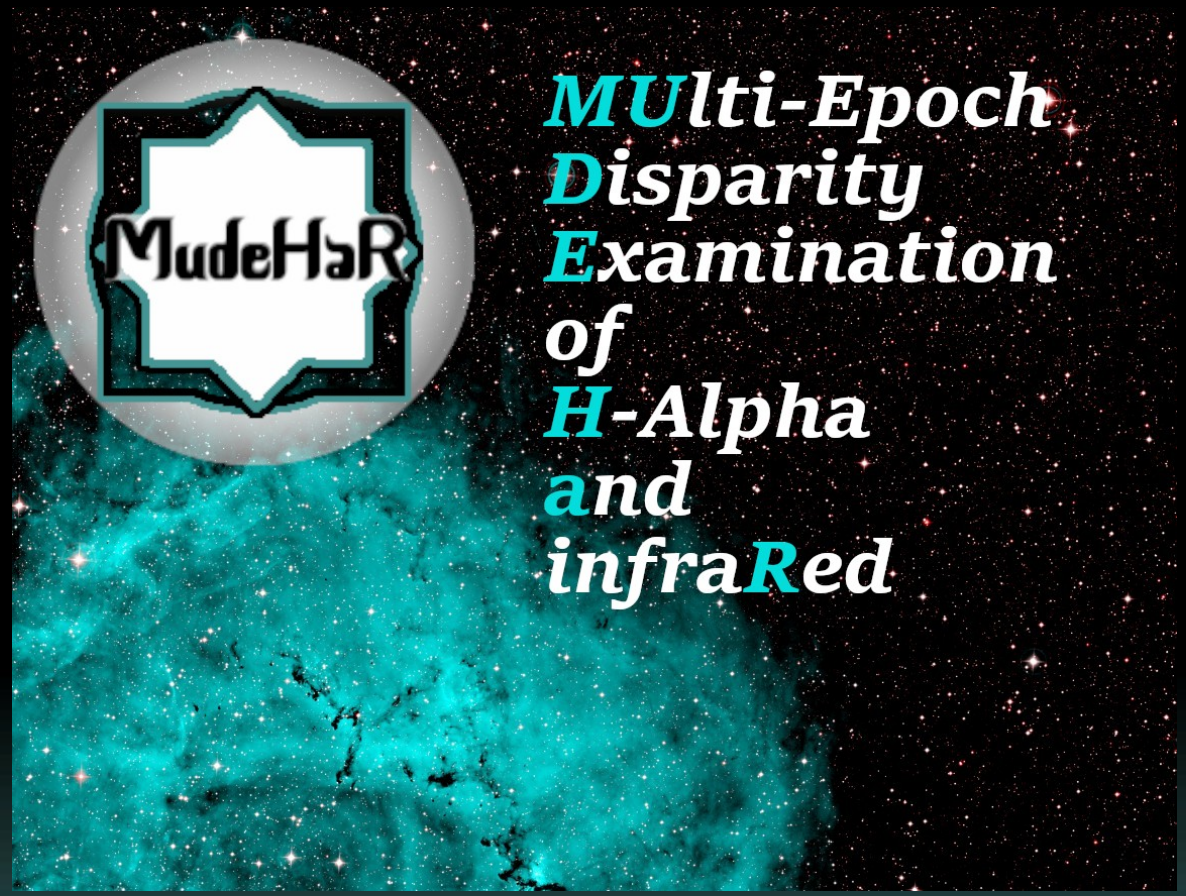


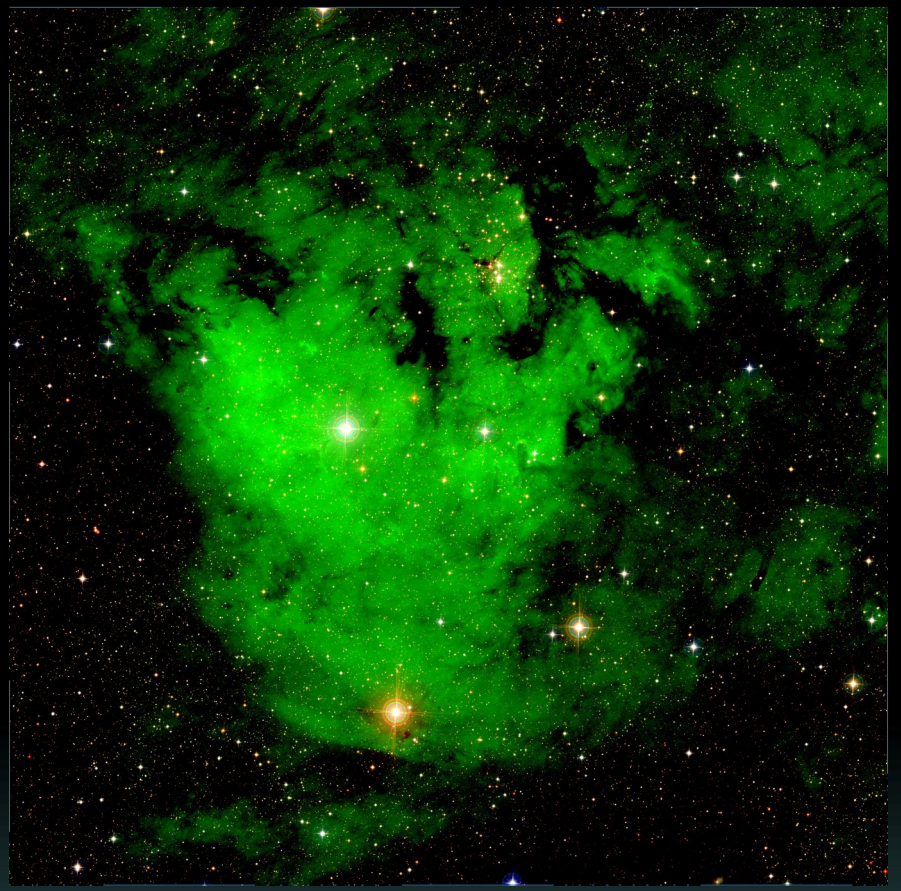
+

G. Holgado (Instituto de Astrofísica de Canarias, IAC)
+J. Maíz Apellániz, J. A. Caballero (Centro de Astrobiología, CSIC-INTA)
+MUDEHaR team

JAST/T80

MUDEHaR and Gaia

- What is **MUDEHaR** ?
- **Gaia astrometry** and **photometry** in **MUDEHaR**
- **Gaia epoch photometry** as a training tool in **MUDEHaR**



MUDEHaR in a nutshell

- **MUDEHaR** is a **multi-epoch** photometric survey of two narrow filters: **Hα** and the **calcium triplet window**.
- Using the T80Cam camera installed on the **JAST/T80** telescope of the Javalambre astronomical observatory
- **100 epochs** per field, **20 fields** of 2^{o2} each.
- **Variability** on a days-months-years scale, for **tens of thousands** of stars
- Already started!
- Same observation and data **reduction strategy as GALANTE** survey, operated on the JAST/T80 between 2016-2021.

Scientific Context

- Existing/ongoing photometric surveys with Hα are many, and some examples are:

I. EGAPS (IPHAS+UVEX+VPHAS+)
II. J-PLUS, S-PLUS
III. OmegaWhite

MUDEHaR defining and unique characteristics:

- the **multi-epoch** nature,
- targeting the **Galactic disk**,
- extensive **dynamic range** (AB mag 3-17),
- powerful **pixel-scale** (0.55 arcsec/pix)

Scientific Objectives

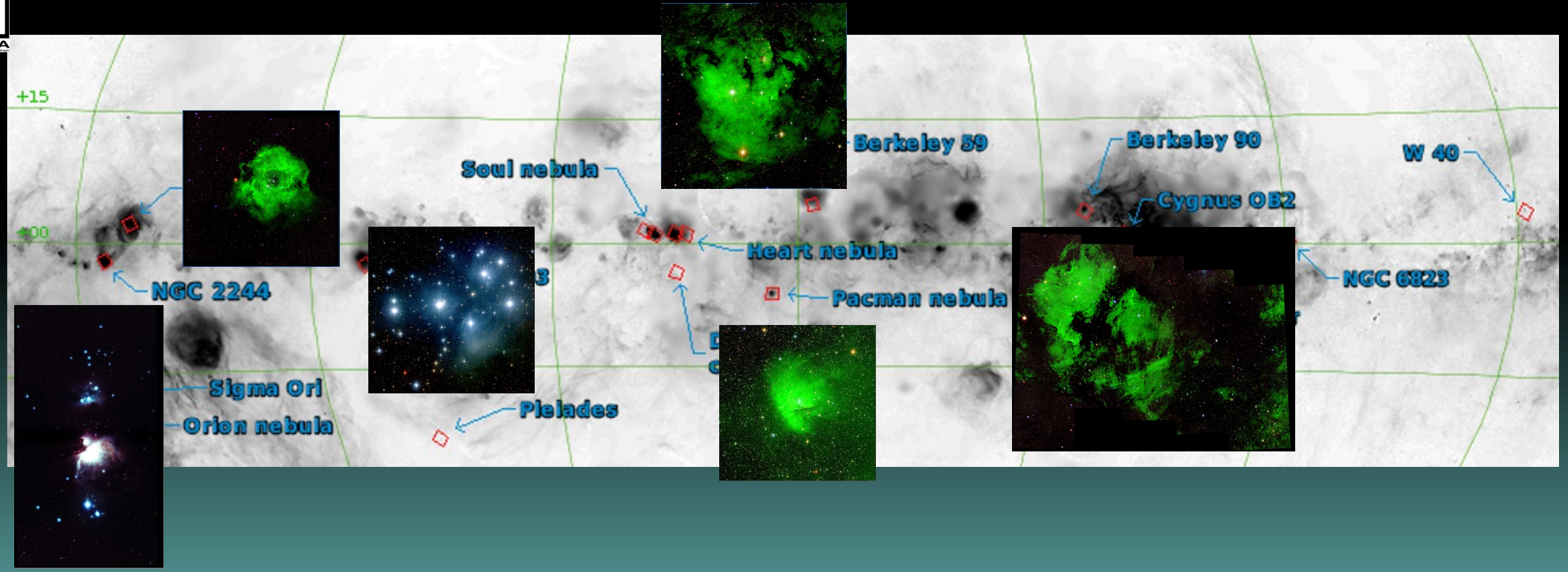
Massive OB stars (GALANTE) that present emission/variability in Hα. Peculiar objects with magnetic fields or disk emission (Oe and Be), eclipsing binaries, pulsating stars, etc.

We try to understand the star formation of these powerful cosmic engines.

List of variable stars as legacy (active M stars, LBV stars,etc.), and sky-map of Hα and IR variability.

Layout

- Selection:
  I. **20** fields of 2^{o2}, from the 600^{o2} f observed by GALANTE
  II. 16 in **Galactic disk**, + interesting out-of-plane fields
  III. Prioritizing stellar clusters of recent **star formation**, and HII regions,
  IV. Homogeneous distribution for observation

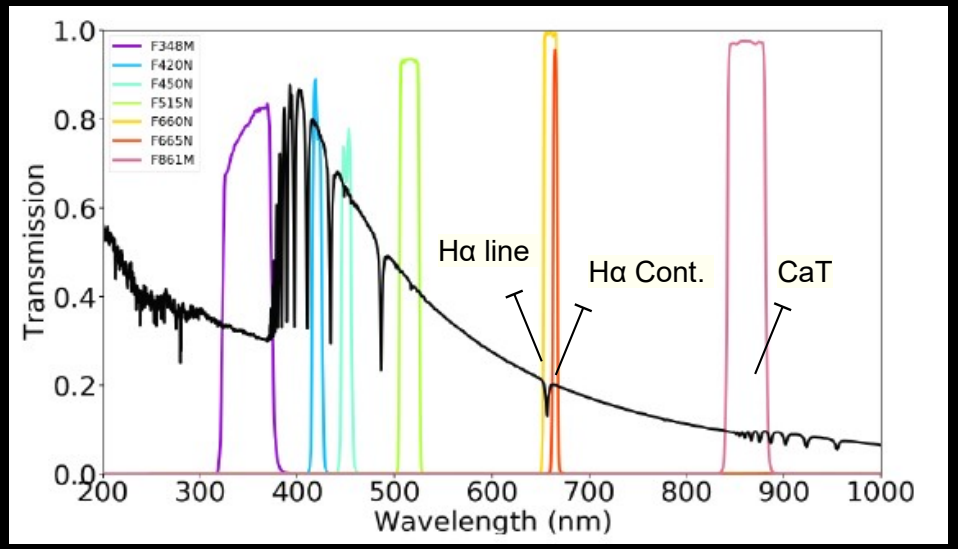


Filters

- Two narrow filters included in the standard J-PLUS filter wheel :

I. **J0660** is a narrow-band filter situated on top of the Hα line. Main line of stellar activity.

II. **J0861** is an intermediate filter in the calcium triplet window. It will be used to detect the largest possible number of stars to tie the astrometry and photometry with 2MASS.



Observing protocol

- 100 epochs per year for each field/star, the two filters.
- 10 weeks covering hours-days-months scale, then next year again.

Exp. Times:
(0.1 s + 1s + 10s + 50 s x2) x 200

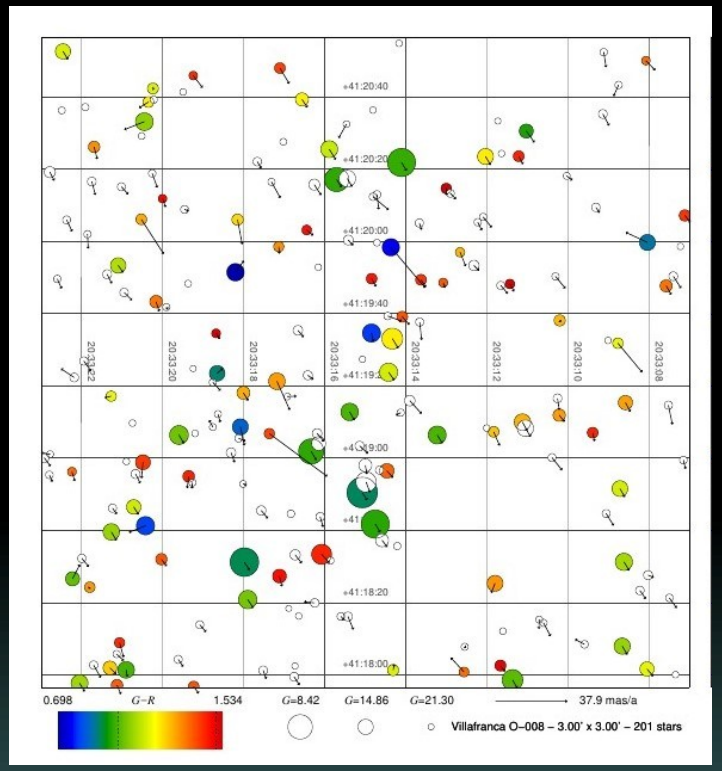
Legacy

Thousands of variable stars, of all types.

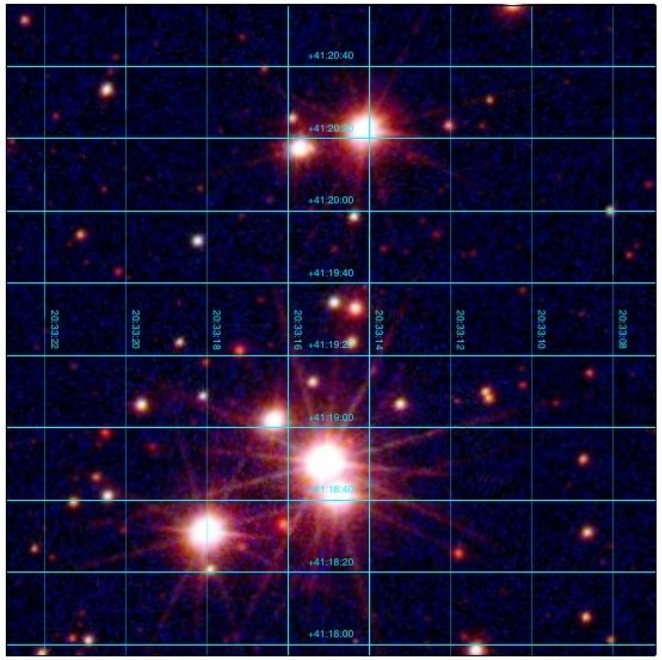
Sky-map of H*α and IR variability.*

Gaia astrometry in MUDEHaR

Gaia



GALANTE



F861M+F525N+F348M

- Gaia astrometry already implemented in GALANTE
- Comparing to *Gaia, 70-80%* complete in a given field
- Homogenous calibration for the two filters, and the 5 of **GALANTE**

Gaia photometry in MUDEHaR

Flux calibration

Steps are:

- Generate **synthetic photometry** of each star with 2MASS+GaiaDR3 data using CHORIZOS. Estimations for temperature and extinction are inferred in this process.
- Obtain the **combined uncalibrated magnitude** for each star, using all exp. times, and diffraction corrections with two air masses. Uncertainty used as weight.
- Define a **calibration sample** of stars in the field using photometric quality flags, colour cuts, and limiting to low extinction stars. ~100 stars.
- The synthetic photometry of the calibration sample is used as standard values to derive a unique **zero point,** which is applied to the rest of the field sample.

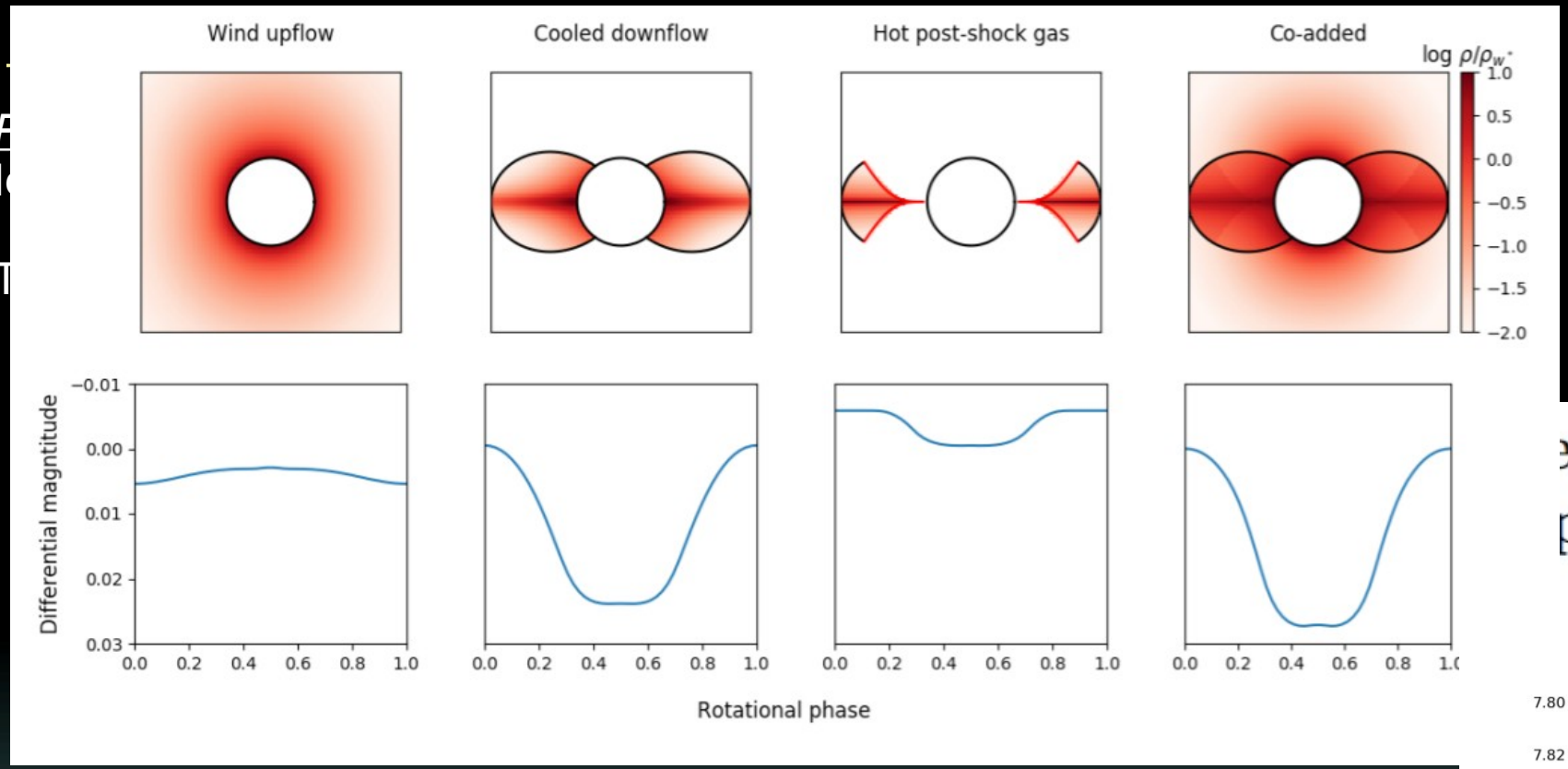
What to do with MUDEHaR

Principal objective:
Identification of all variable OB+WR stars in the observed fields.

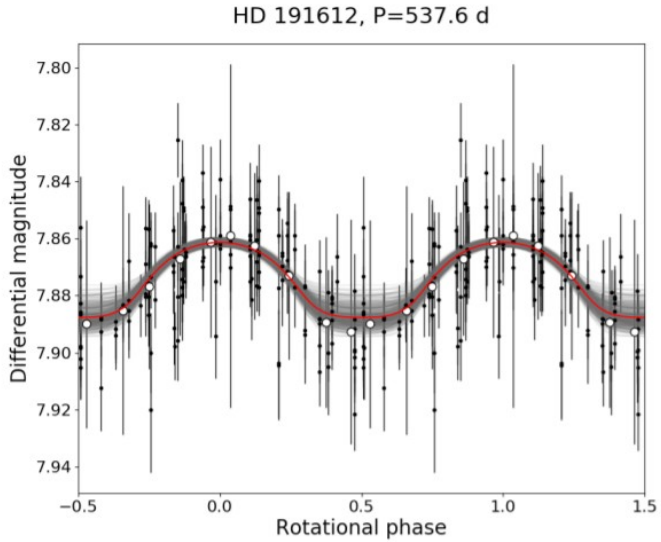
This includes Magnetic OB stars:

Modelling the photometric variability of magnetic massive stars with the Analytical Dynamical Magnetosphere model

M. S. Munoz,[1⋆] G. A. Wade,[2] Y. Nazé,[3†] J. Puls,[4] S. Bagnulo[5] M. K. Szymański[6]



etic massive phere model



What to do with MUDEHaR

Principal objective:

Identification of all variable OB+WR stars in the observed fields.

This includes Magnetic OB stars:

And other variable stars:

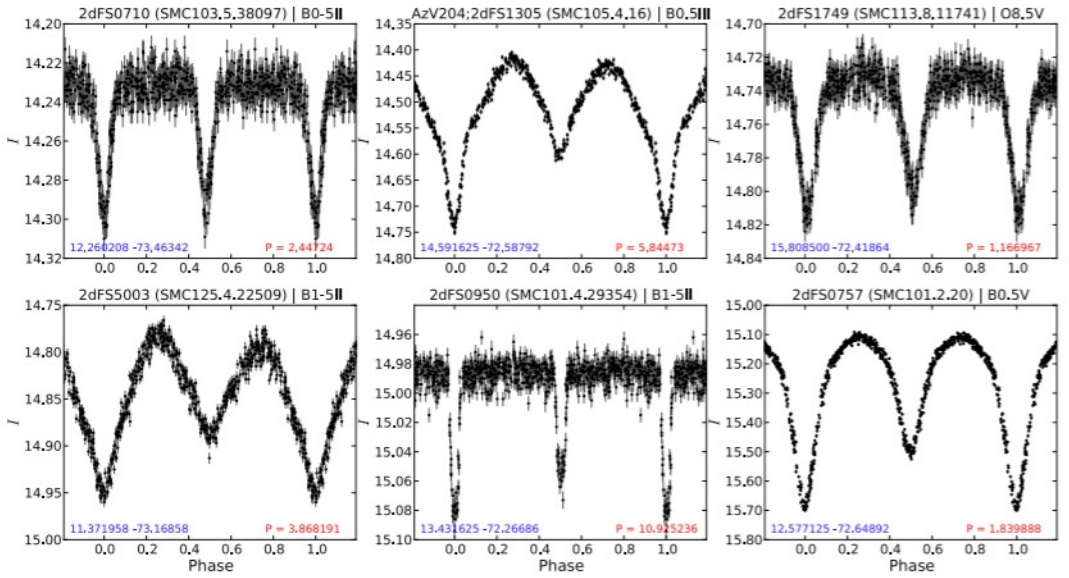
What to do with MUDEHaR

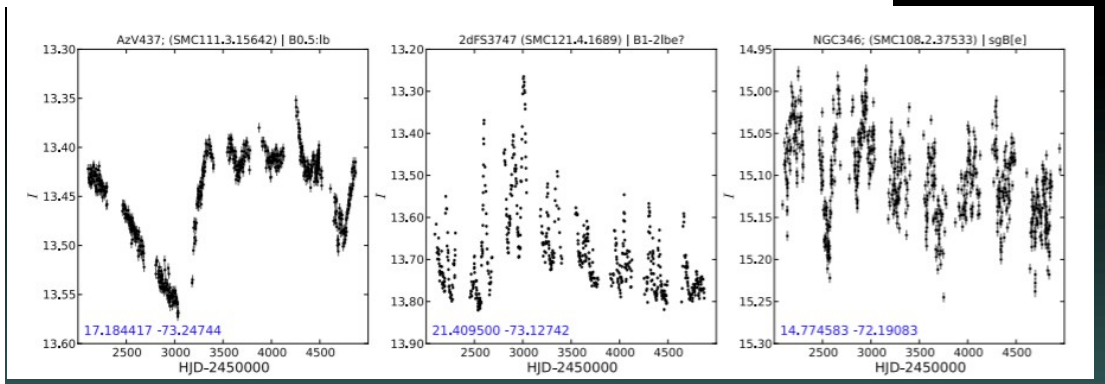
Principal objective:

Identification of all variable OB+WR stars in the observed fields.

Variability of massive stars with known spectral types in the Small Magellanic Cloud using 8 years of OGLE-III data*

M. Kourniotis[1,2], A. Z. Bonanos[1], I. Soszyński[3], R. Poleski[3,4], G. Krikelis[2], A. Udalski[3], M. K. Szymański[3], M. Kubiak[3], G. Pietrzyński[3,5], Ł. Wyrzykowski[3], K. Ulaczyk[3], S. Kozłowski[3], and P. Pietrukowicz[3]





Oe and Be stars (disk emission variability)

Eclipsing binaries

What to do with MUDEHaR

Principal objective:

Identification of all variable OB+WR stars in the observed fields.

This includes Magnetic OB stars:

And other variable stars:

Additional objectives:

Active M stars, LBVs, symbiotic stars (WD+RG)

Period determination: Use Gaia DR3 epoch photometry as training tool

GAIA Epoch-photometry for Galactic O(and B)-type stars:

- Present our methods for period determination
- Evaluate periods from *Gaia* data
- Apply in the future to MUDEHaR

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OB stars

Main physical properties

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

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

Large ($R = 5 - 80\ R_\odot$)

Luminous ($L = 10^3 - 10^6\ L_\odot$)

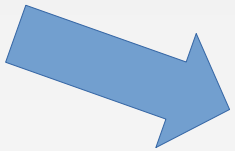
Windy ($M_{dot} = 10^{-9} - 10^{-5}\ M_\odot$/yr)

Strong ionizing radiation ($T_{eff} > 30$ kK, mainly O stars)

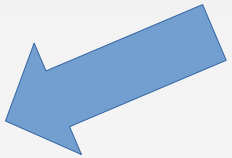
Young (a few Myr)

Sample of O(and B) stars:

2 sources



Periods



GOSC + GOSSS

+(OWN, IACOB, MONOS-MOSOS)

1 811 709 771 variables sources in DR3, 11 754 237 with epoch photometry

34 months, ~50 epochs

0.001 mag average variations

G between 3.5 and 23 mag

Spectroscopy (+ auxiliary photometry) for over decades

Variability/binarity flag

Orbital parameters

Sample of O(and B) stars:

2 sources

151 O with epoch photometry

Periods

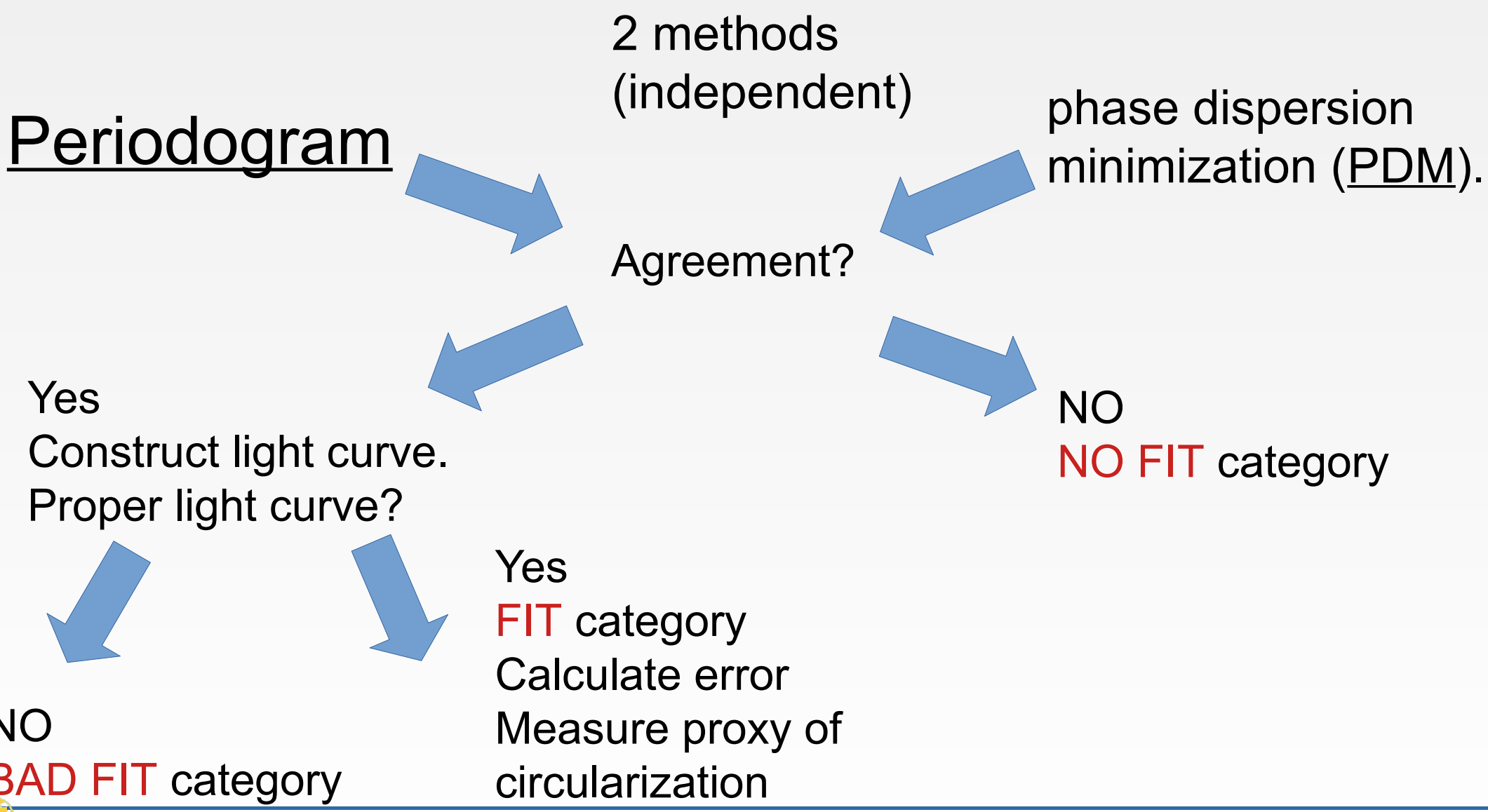
GOSC + GOSSS

+(OWN, IACOB, MONOS-MOSOS)

184 OB studied

- 1018 O (1007 with GaiaID)
- 66 with GOOD period determination with Gaia (the rest with no period)
- So we add known B SB2 binaries stars, to reach 200 and make a robust test

Calculation of the *Gaia* period:



Results:

Syst.	Fitting		
	FIT	BAD FIT	NO FIT
184	91 (49%)	27 (15.5%)	66 (35.5%)

Syst.	Status		
	CONFIRM	IMPROVE	NEW
91	71 (78%)	7 (8%)	13 (14%)

- Comparison with GOSC period
  (+ SIMBAD if necessary)

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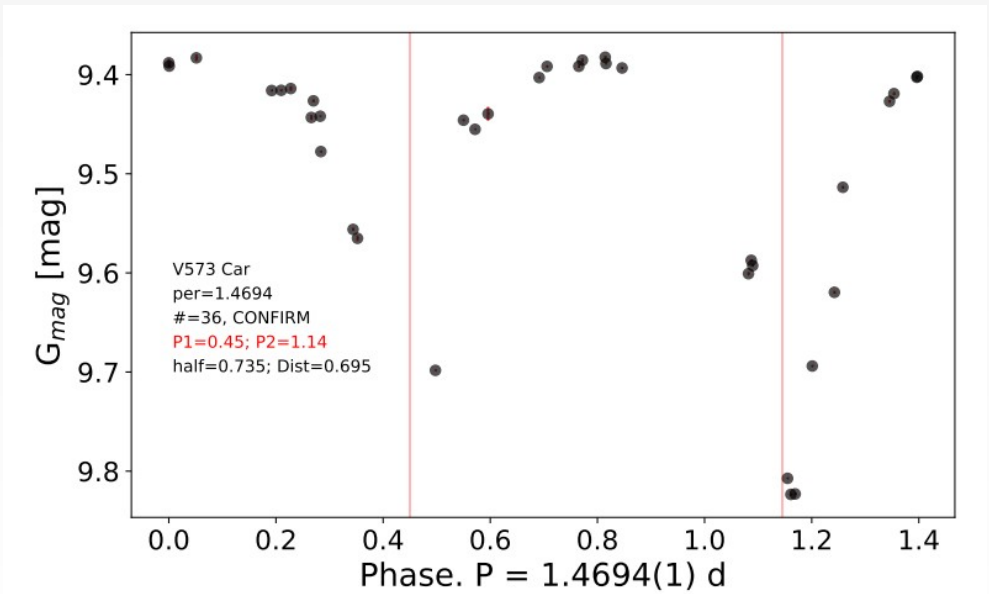
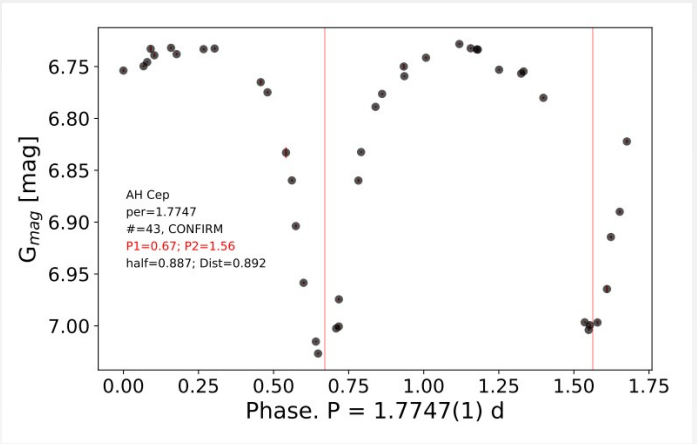
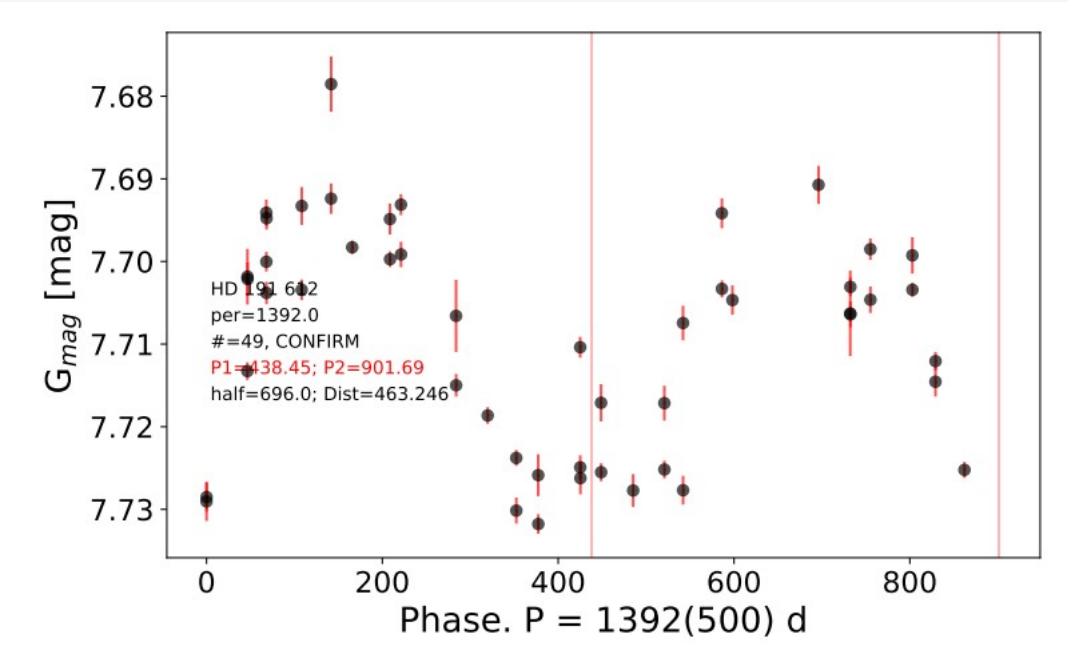


- Comparison with GOSC period

(+ SIMBAD if





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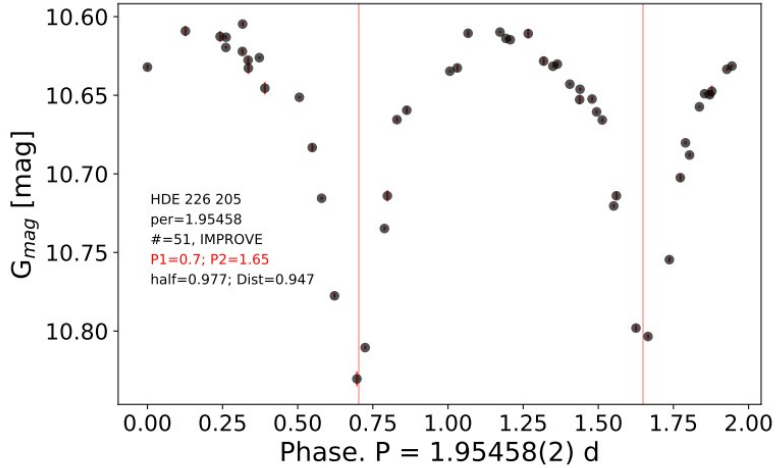

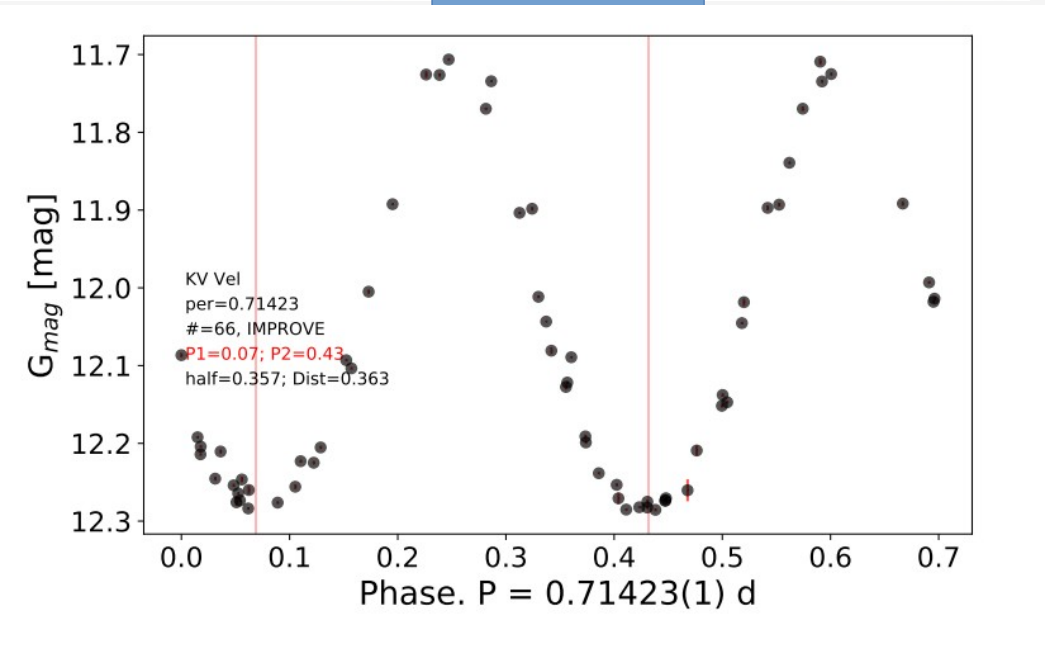

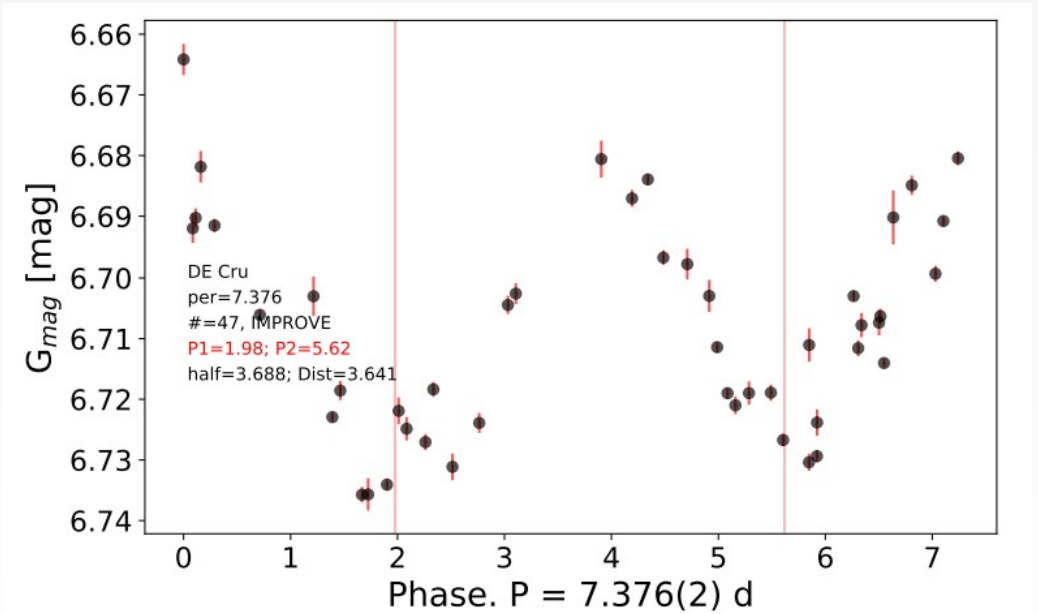

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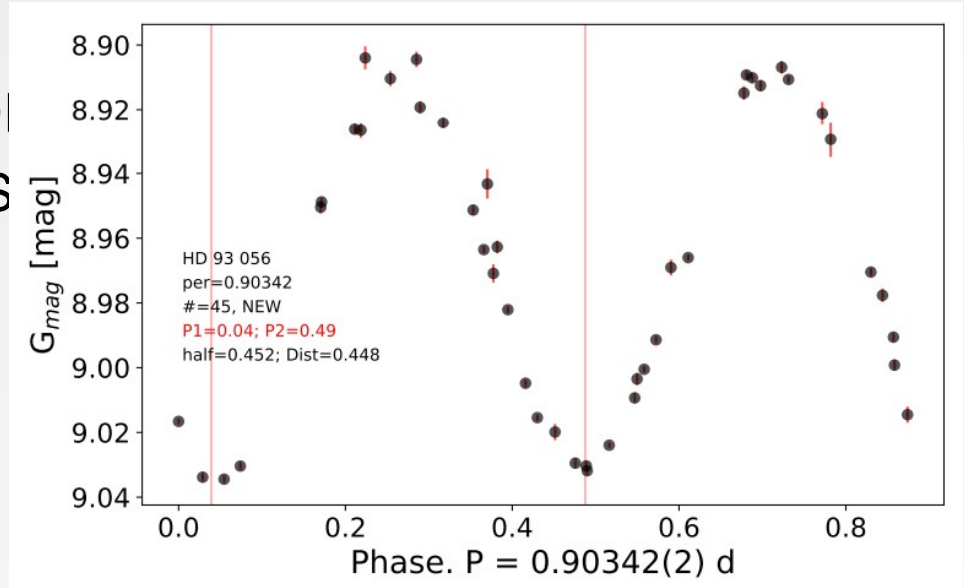
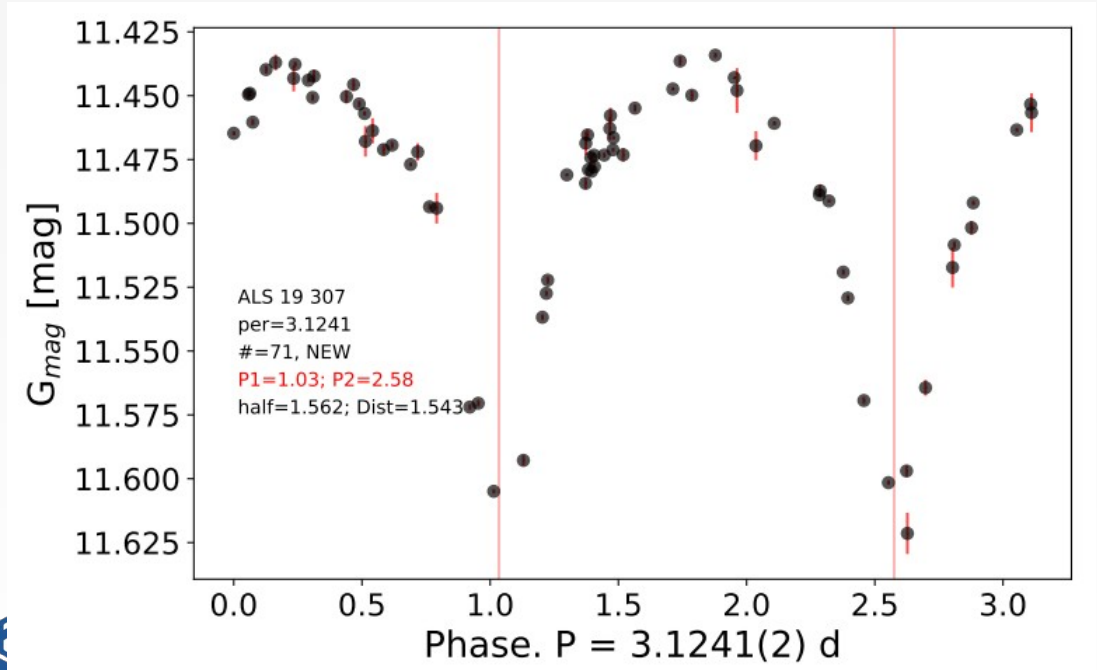
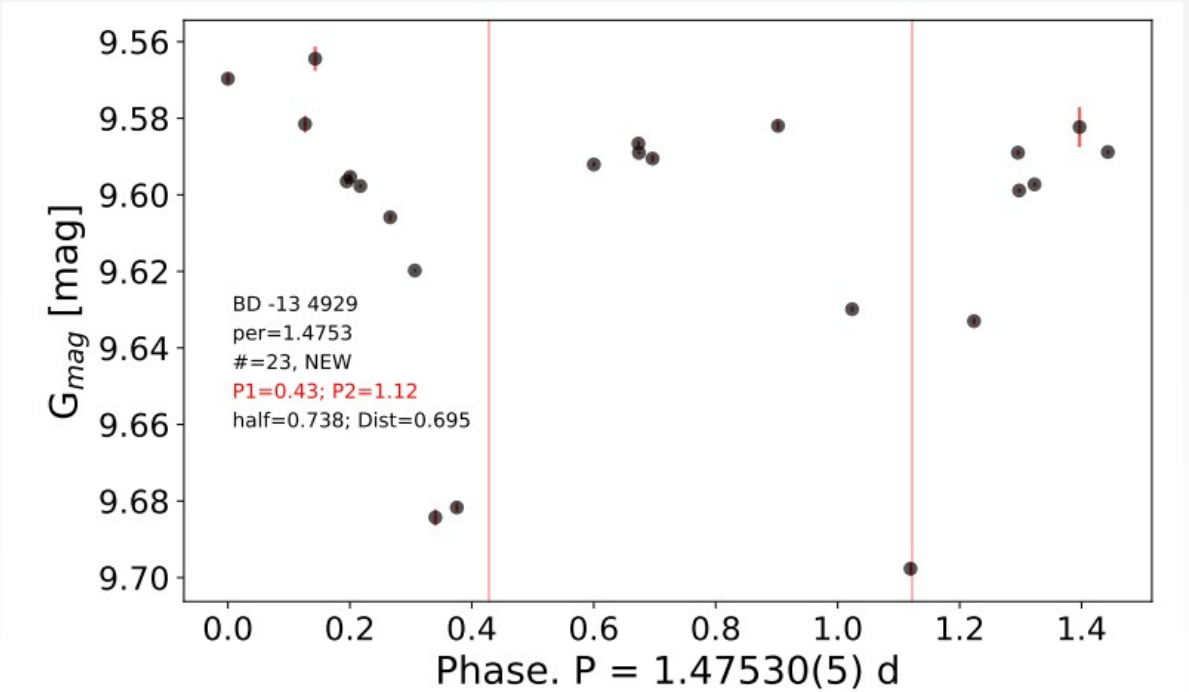
- Co
(+ S







- Present our methods for period determination

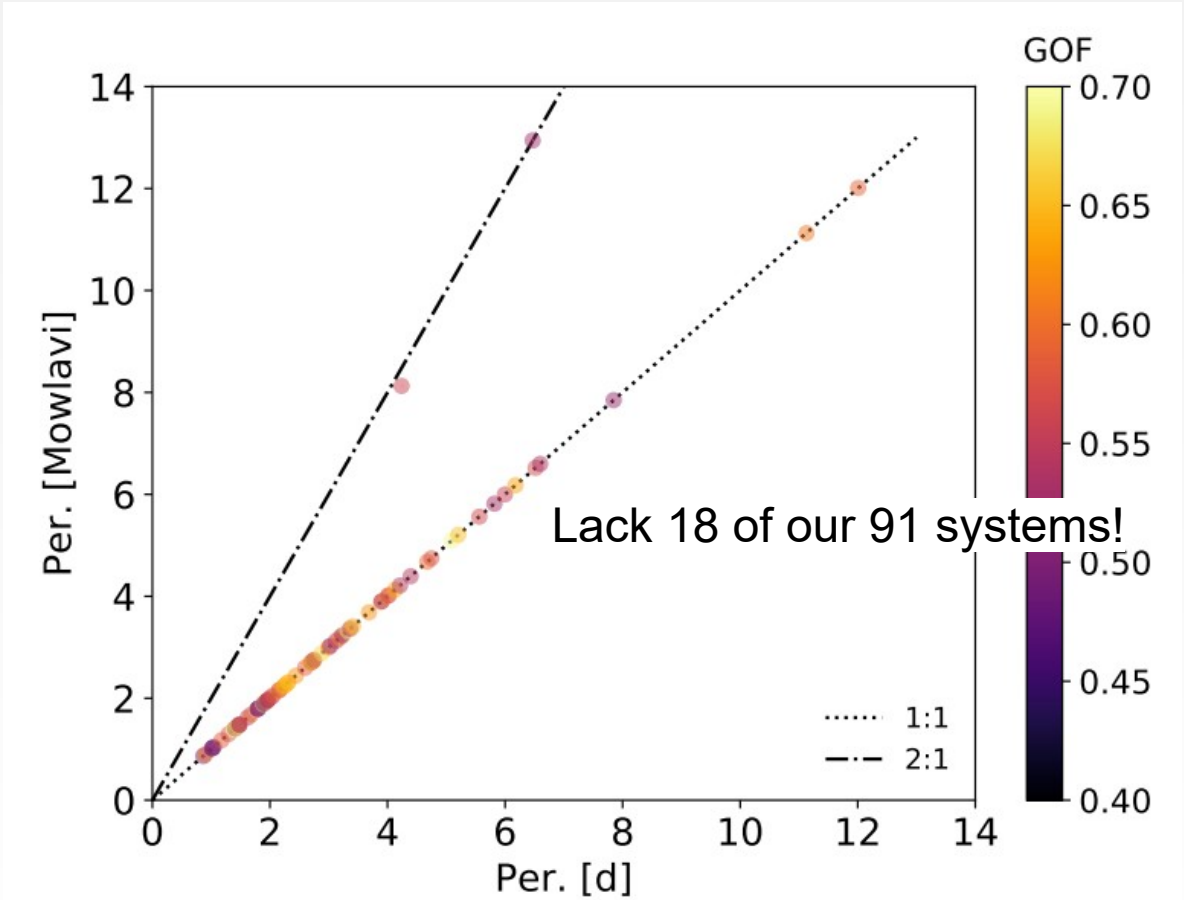
Presented. But checked?

- Mowlavi et al. (2022)

Gaia consortium period determination

Bayesian methods

Perfect agreement



- Present our methods for period determination

Pres

- Mowlavi et al. (2022)

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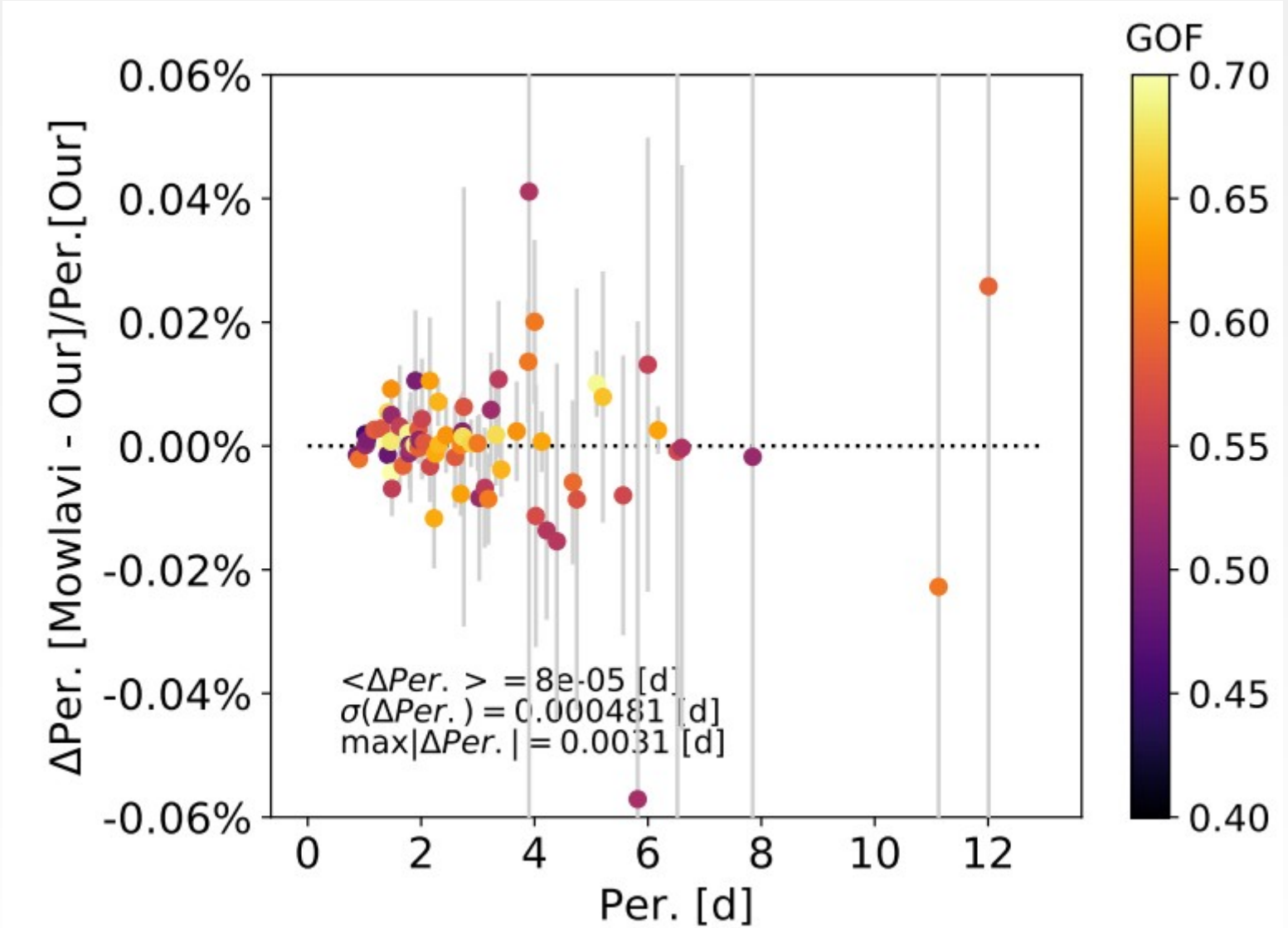
Perfect agreement



Conclusions:

- *Gaia* already capable of providing accurate periods in OB binaries

  (+ 13 new systems, good as anchor to MUDEHaR)

- Comparison with Mowlavi et al. (2022)'s *Gaia* shows perfect agreement

  - Robust methodology

  - 18 systems unresolved by them

- MUDEHaR will soon have epoch photometry similar to that of Gaia, with better resolution. Attention if you are interested!

Conclusions:

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Thanks!

Thanks!

Detector:	1.°4×1.°4 continuous FOV with 0.″55 pixels.
Footprint:	17 fields in the Galactic north plane: $\|l\| < 3^{\circ} + \|\delta\| > 0^{\circ}$.
	3 fields in the Orion region; total of ∼40 sq. dg., Fig. 1
Epochs:	100 per field
Exposure time total:	200×0.1 s (when required) + 200×1 s + 200×10 s + 200×50 s (low z) + 200×50 s (high z)
Magnitude range:	Unsat. AB mag 3-17 with S/N > 100 in both filters, detect. to AB mag 19-20.
Precision threshold:	F660N: 0.01 mag; F861M: 0.005 mag.
Survey dates:	2023-2028.
Filters:	F660N Hα line, pure nebular images + emission-line star detection.
	F861M CaT, tie-in with Gaia-RVS and 2MASS, extinction typing.

Table 1: MUDEHaR in a nutshell

Legacy

Thousands of variable stars, of all types.

Sky-map of H*α and IR variability.*

TESS

- Pixel size crowding effect.
- Mag 6-18, good

EGAPS

- No multi-epoch
- Saturation at 12 mag

GAIA

- Crowding in clusters, limitations with bright targets

OW (OmegaWhite)

- wide-field, high cadence, in the **south**, short period variable stars,
- g band (broad Hα)...and use VPHAS Hα when available (1/3 fields)

HAWKs Width Kilo-degree survey

- No Multi-epoch

Zwicky Transient Facility ZTF 2019

- G filter (broad Hα)
- 14-20 mag

PASHION

- Pα

ADHOC. Accretion Disks in Hα with OmegaCam

- No Multi-epoch
- photometric study of pre-main sequence (PMS) stars, south

PTF/iPTF

- Very recent incorporation of narrow Hα

What to do with MUDEHaR

Pr
Id

Th

Ar

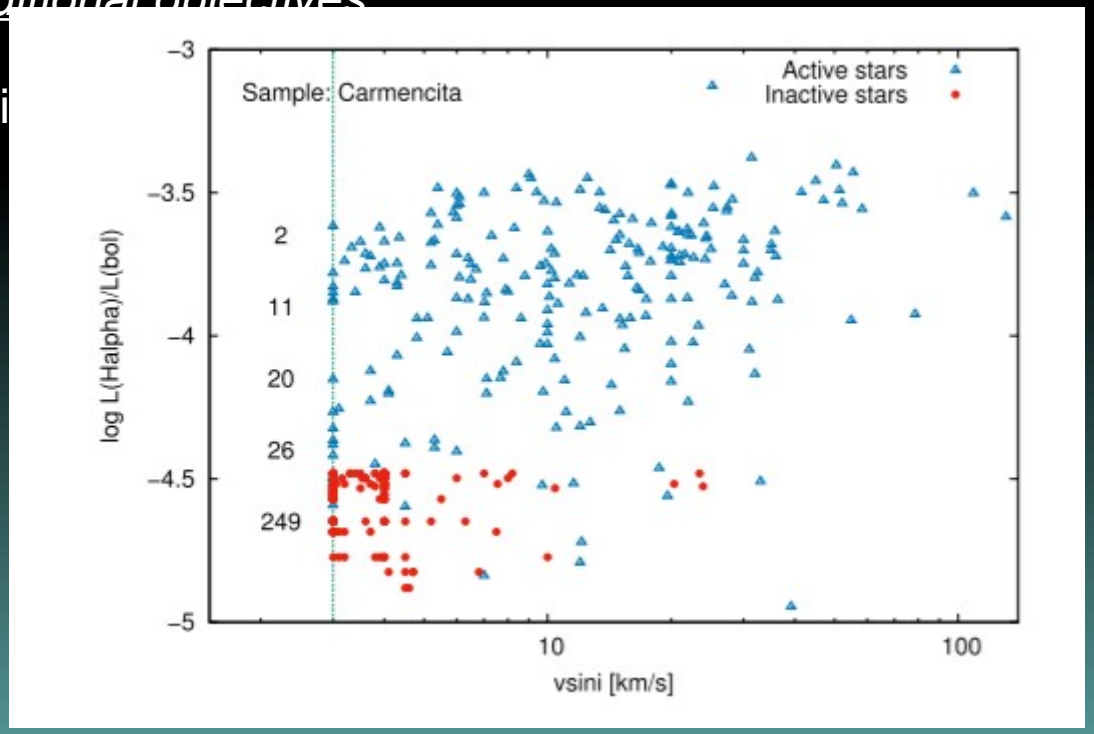
Additional objectives:

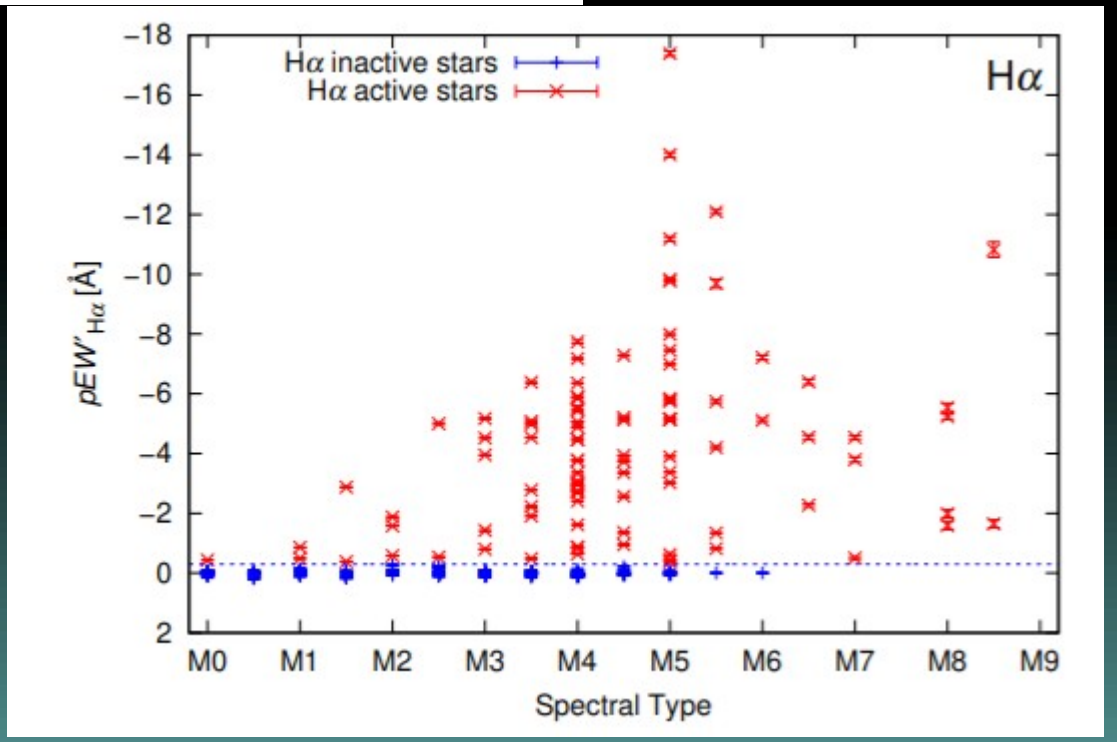
Acti

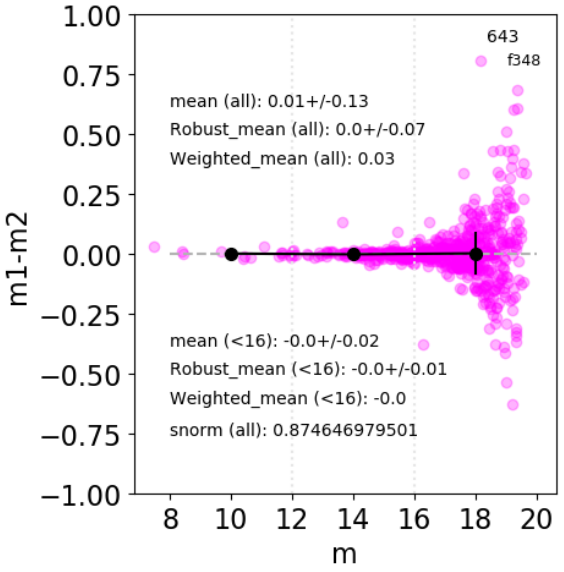
The CARMENES search for exoplanets around M dwarfs

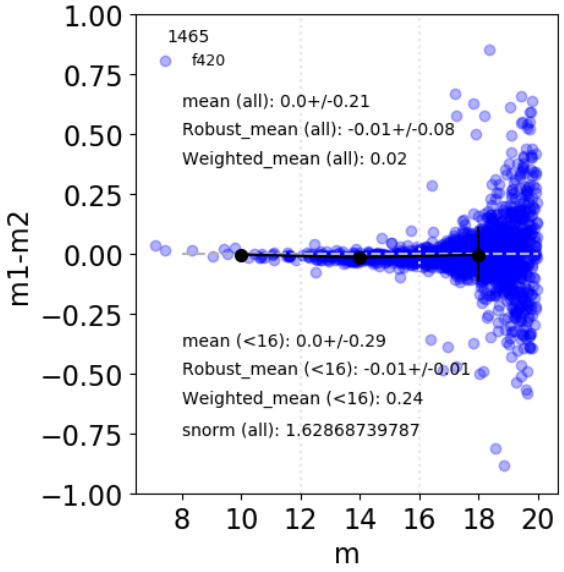
Activity indicators at visible and near-infrared wavelengths★

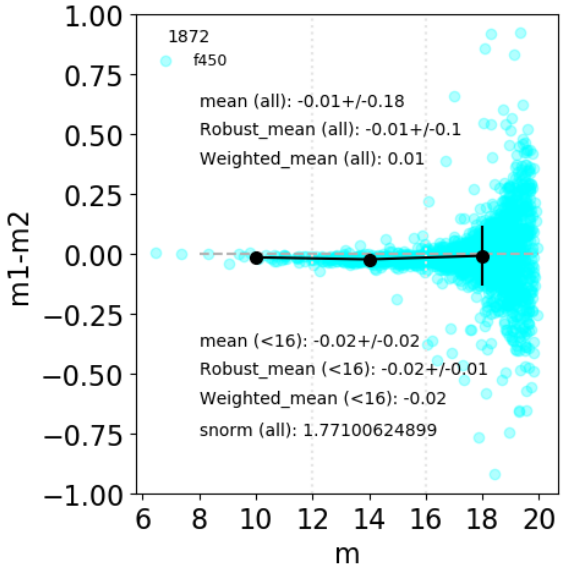
P. Schöfer[1], S. V. Jeffers[1], A. Reiners[1], D. Shulyak[2], B. Fuhrmeister[3], E. N. Johnson[1], M. Zechmeister[1], I. Ribas[4,5], A. Quirrenbach[6], P. J. Amado[7], J. A. Caballero[8], G. Anglada-Escudé[7,9], F. F. Bauer[7], V. J. S. Béjar[10,11], M. Cortés-Contreras[8], S. Dreizler[1], E. W. Guenther[12], A. Kaminski[6], M. Kürster[13], M. Lafarga[4,5], D. Montes[14], J. C. Morales[4,5], S. Pedraz[15], and L. Tal-Or[1,16]

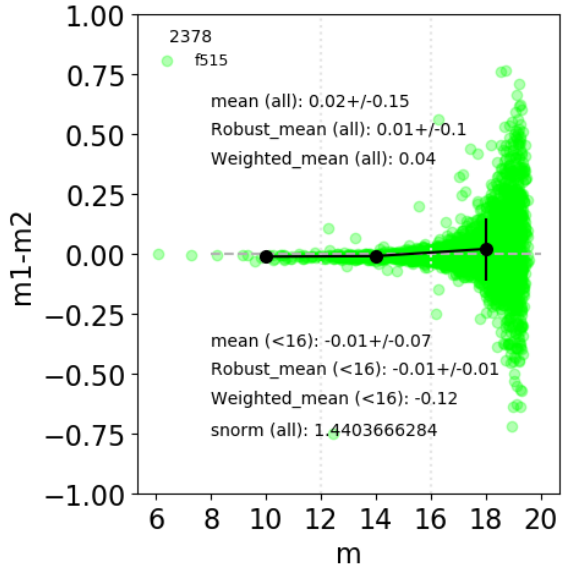


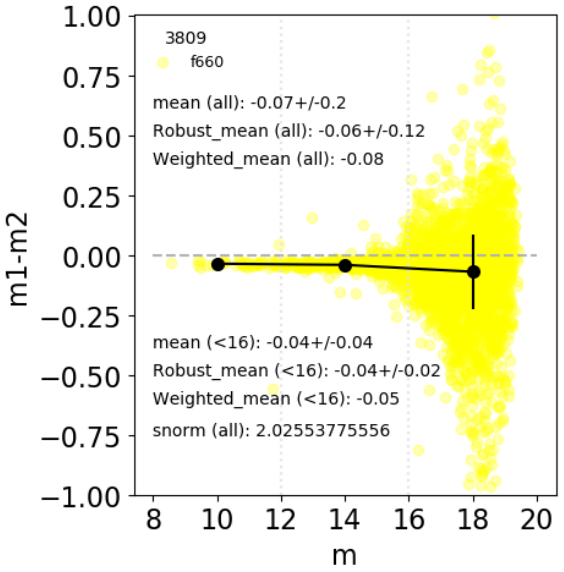


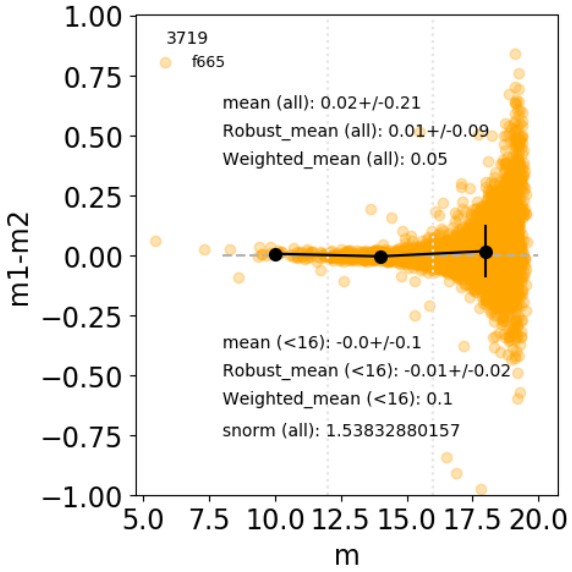

643
f348
mean (all): 0.01+/-0.13
Robust_mean (all): 0.0+/-0.07
Weighted_mean (all): 0.03
mean (<16): -0.0+/-0.02
Robust_mean (<16): -0.0+/-0.01
Weighted_mean (<16): -0.0
snorm (all): 0.874646979501
m1-m2
m

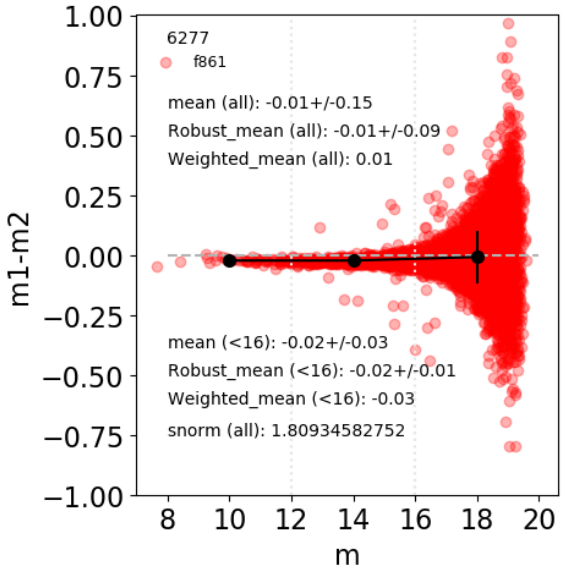

1465
f420
mean (all): 0.0+/-0.21
Robust_mean (all): -0.01+/-0.08
Weighted_mean (all): 0.02
mean (<16): 0.0+/-0.29
Robust_mean (<16): -0.01+/-0.01
Weighted_mean (<16): 0.24
snorm (all): 1.62868739787
m1-m2
m


1872
f450
mean (all): -0.01+/-0.18
Robust_mean (all): -0.01+/-0.1
Weighted_mean (all): 0.01
mean (<16): -0.02+/-0.02
Robust_mean (<16): -0.02+/-0.01
Weighted_mean (<16): -0.02
snorm (all): 1.77100624899
m1-m2
m


2378
f515
mean (all): 0.02+/-0.15
Robust_mean (all): 0.01+/-0.1
Weighted_mean (all): 0.04
mean (<16): -0.01+/-0.07
Robust_mean (<16): -0.01+/-0.01
Weighted_mean (<16): -0.12
snorm (all): 1.4403666284
m1-m2
m


3809
f660
mean (all): -0.07+/-0.2
Robust_mean (all): -0.06+/-0.12
Weighted_mean (all): -0.08
mean (<16): -0.04+/-0.04
Robust_mean (<16): -0.04+/-0.02
Weighted_mean (<16): -0.05
snorm (all): 2.02553775556
m1-m2
m


3719
f665
mean (all): 0.02+/-0.21
Robust_mean (all): 0.01+/-0.09
Weighted_mean (all): 0.05
mean (<16): -0.0+/-0.1
Robust_mean (<16): -0.01+/-0.02
Weighted_mean (<16): 0.1
snorm (all): 1.53832880157
m1-m2
m

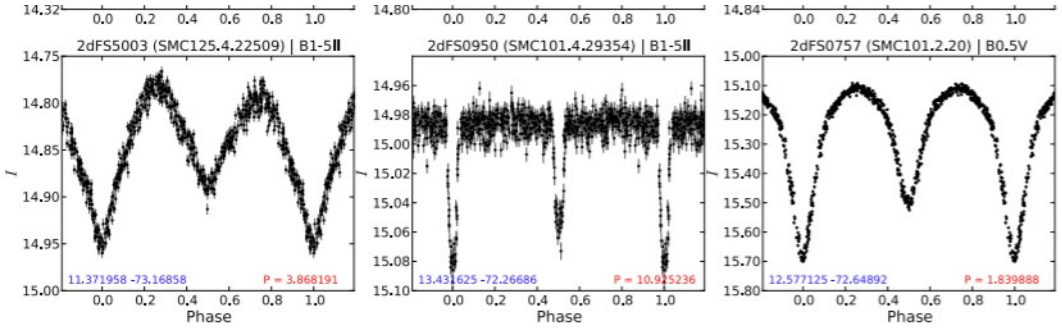

6277
f861
mean (all): -0.01+/-0.15
Robust_mean (all): -0.01+/-0.09
Weighted_mean (all): 0.01
mean (<16): -0.02+/-0.03
Robust_mean (<16): -0.02+/-0.01
Weighted_mean (<16): -0.03
snorm (all): 1.80934582752
m1-m2
m

NGC 2244 N & S

ARTICLES
https://doi.org/10.1038/s41550-019-0768-1
nature astronomy

Low-frequency gravity waves in blue supergiants revealed by high-precision spac

Dominic M. Bowman[1*], Siemen Burssens[1], May G. Pederse
Bram Buysschaert[1,3], Mathias Michielsen[1], Andrew Tkachenk
Philipp V. F. Edelmann[4], Rathish P. Ratnasingam[4], Sergio Si
Ehsan Moravveji[1], Benjamin J. S. Pope[9], Timothy R. White[10] and



Oe a

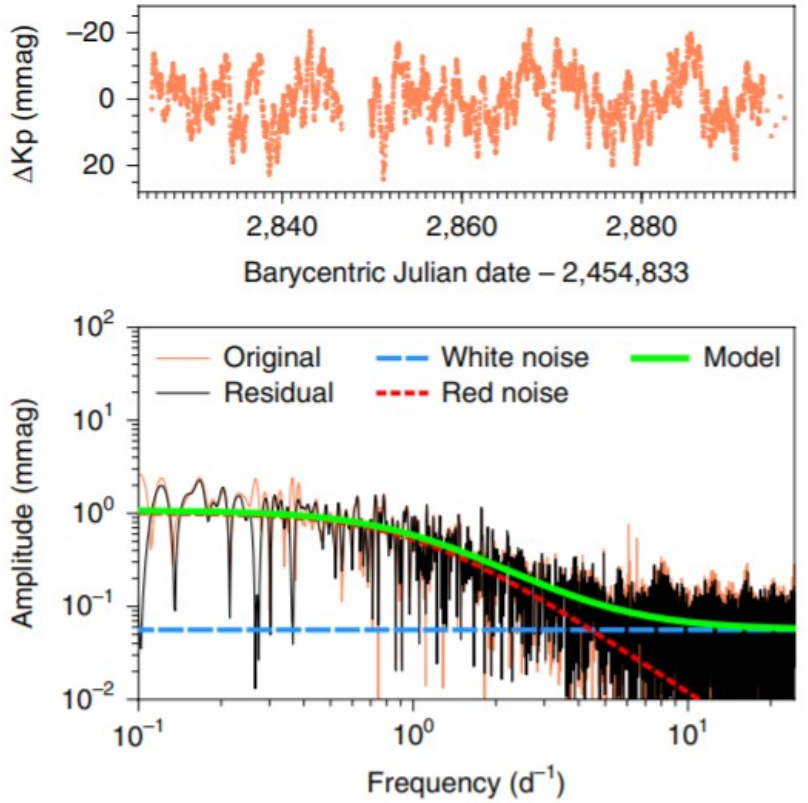


Fig. 2 | K2 data of the blue supergiant star EPIC 240255386. The light

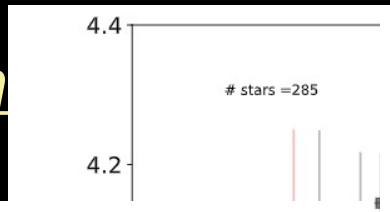
Eclipsing binaries

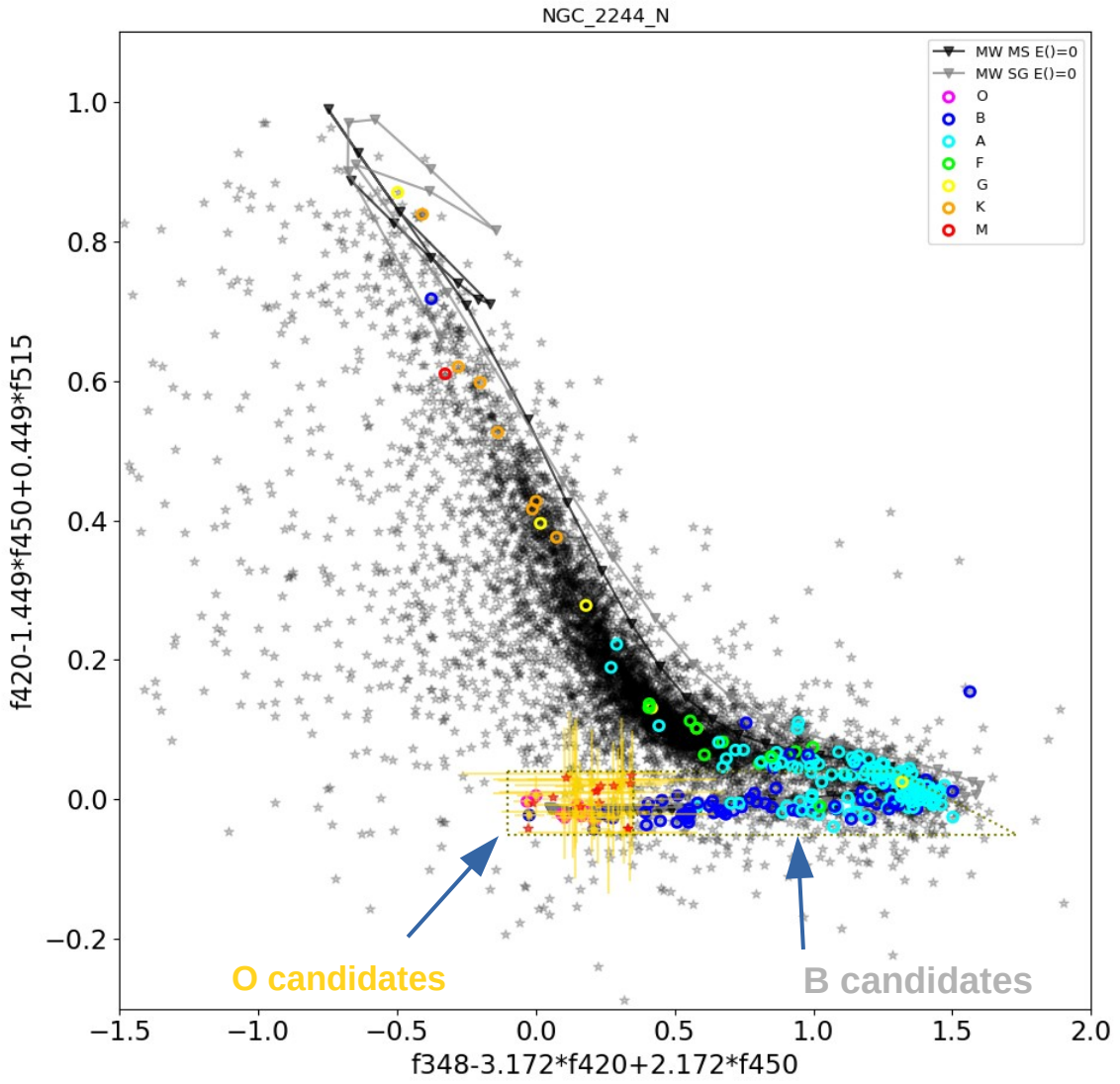
MUDEHaR:

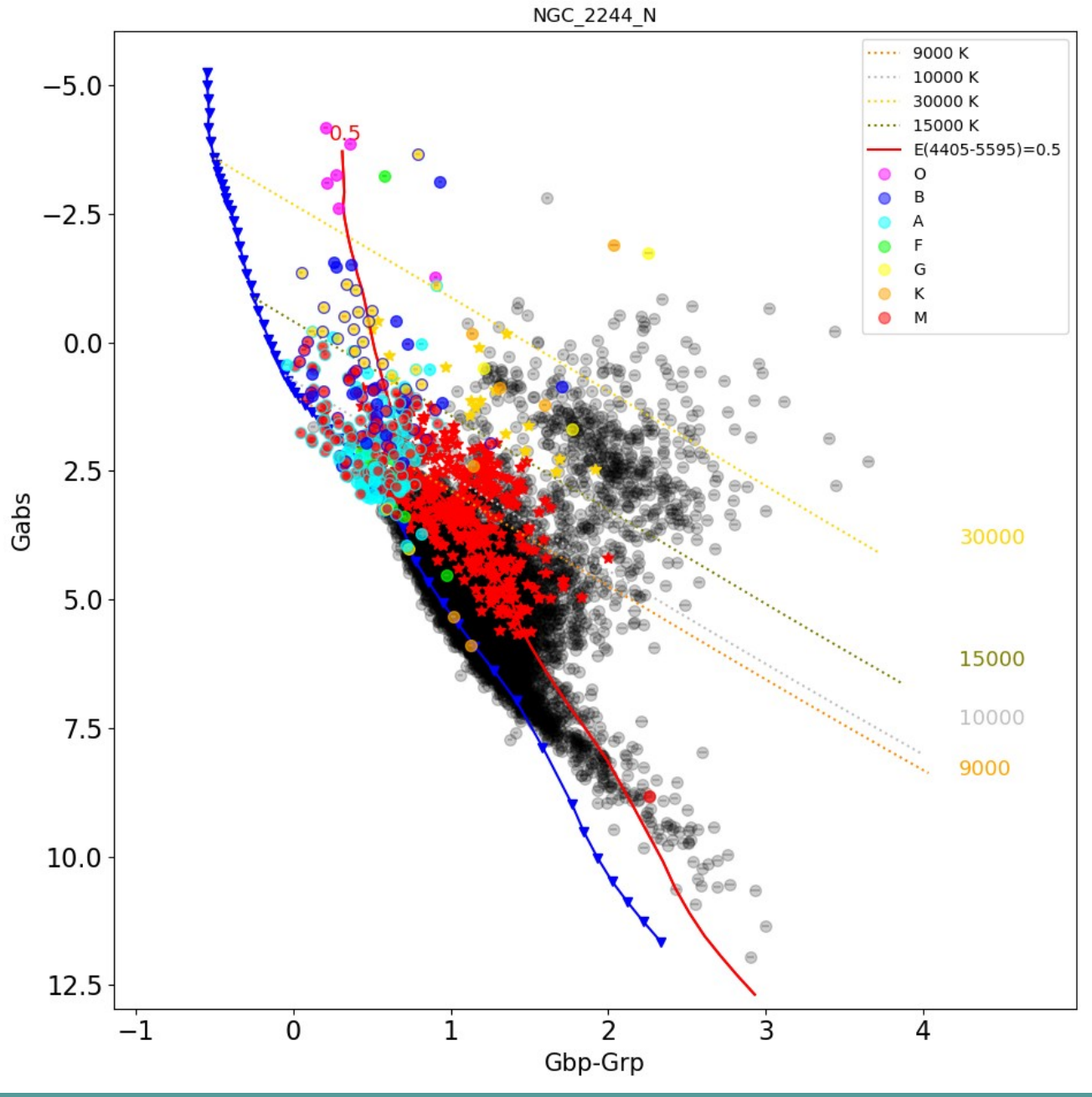
JAST/T80

Unión Europea
Fondo Europeo
de desarrollo Regional
"Una manera de hacer Europa"

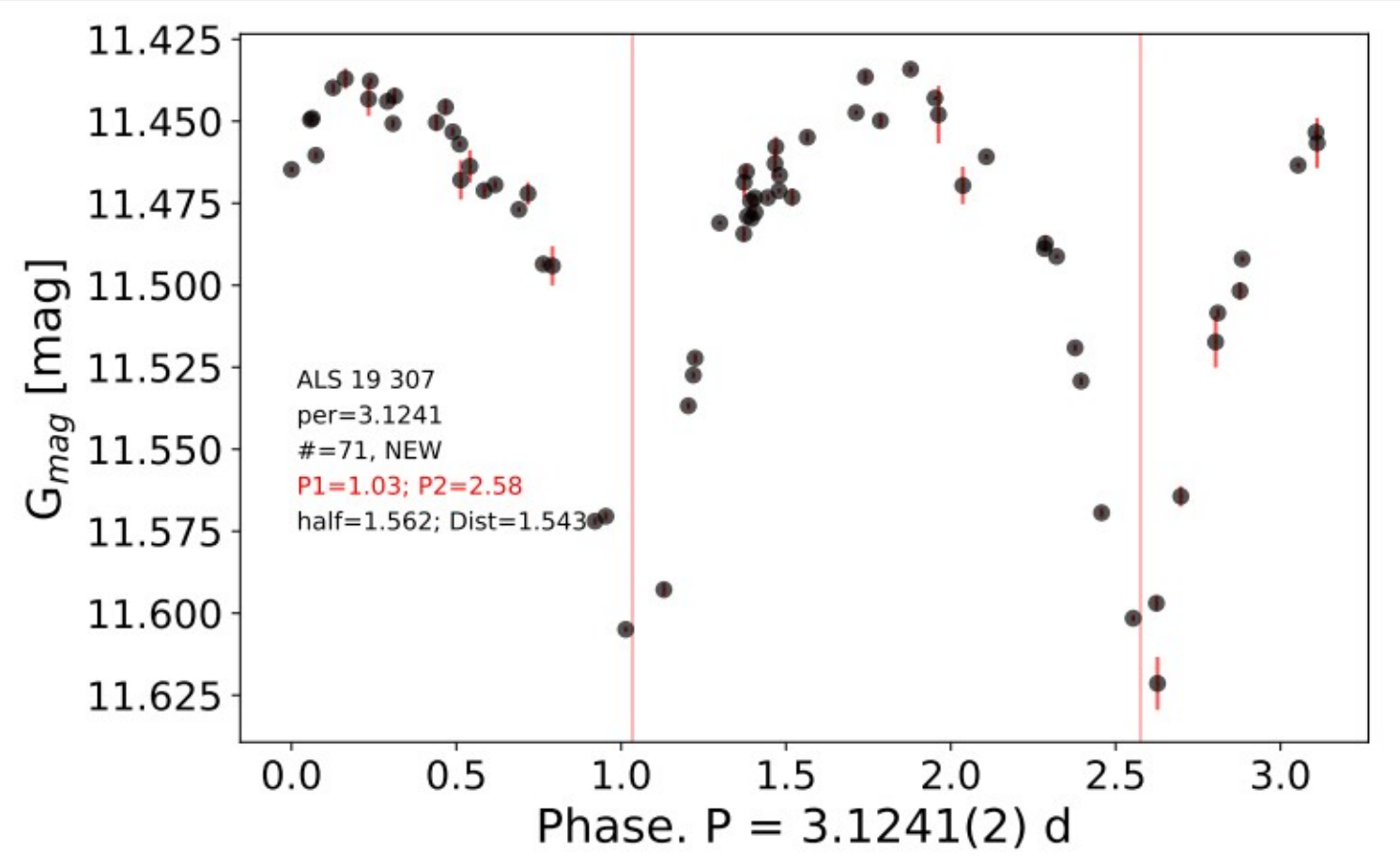
Steps to identify OB m







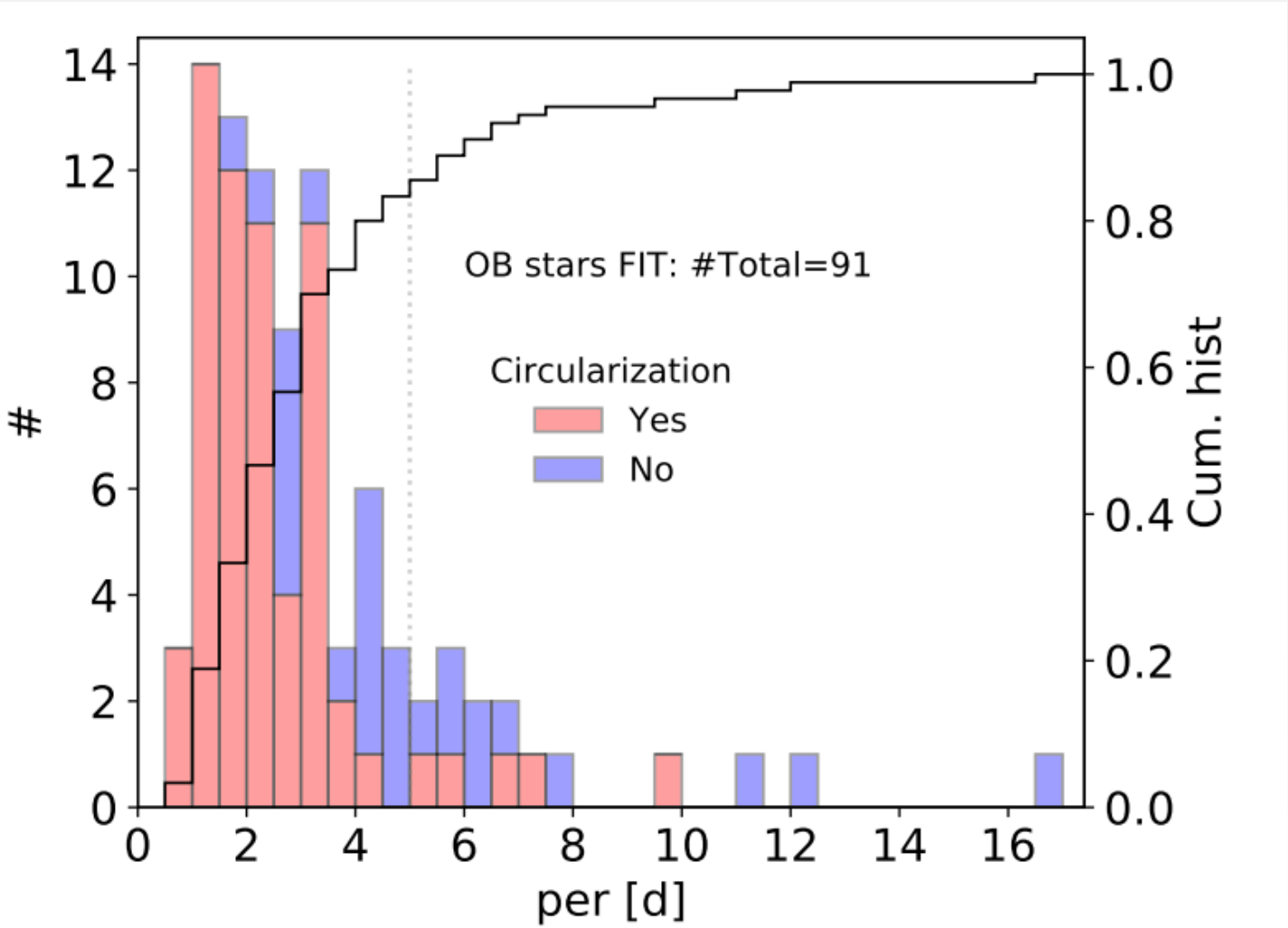
Proxy of circularization:



- Distance between minima = Half period → Orbit probably circular

- Some science discussion?

Period distribution:

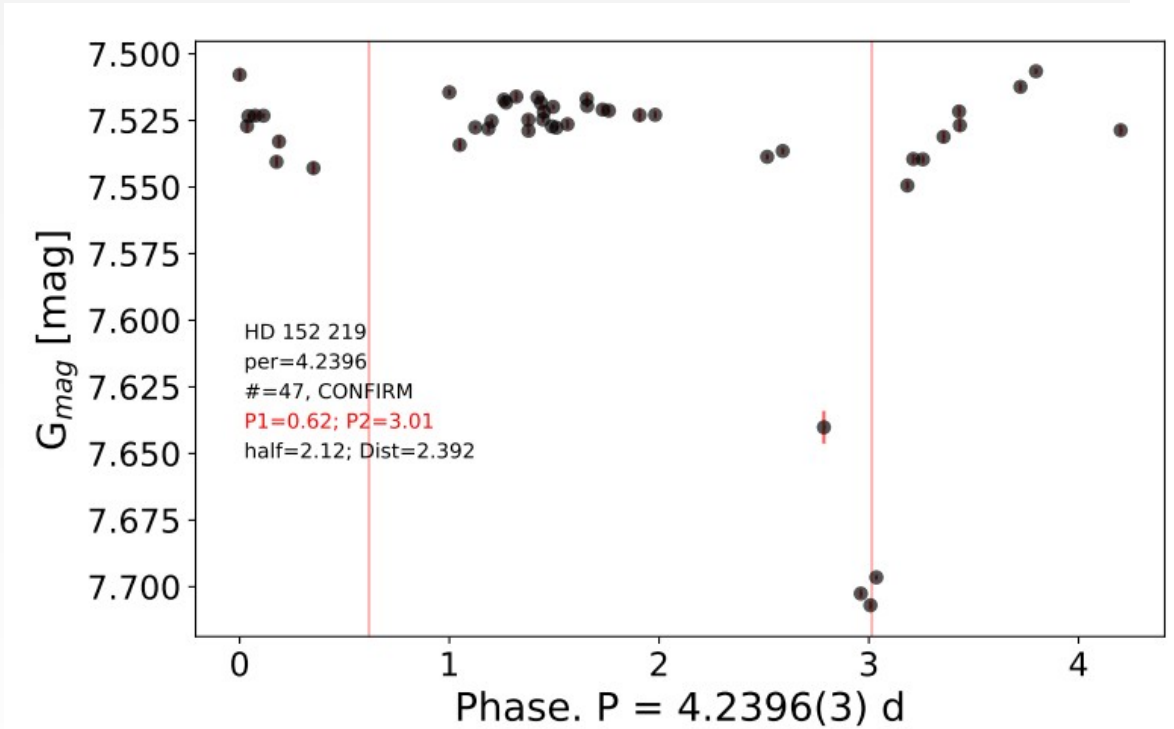


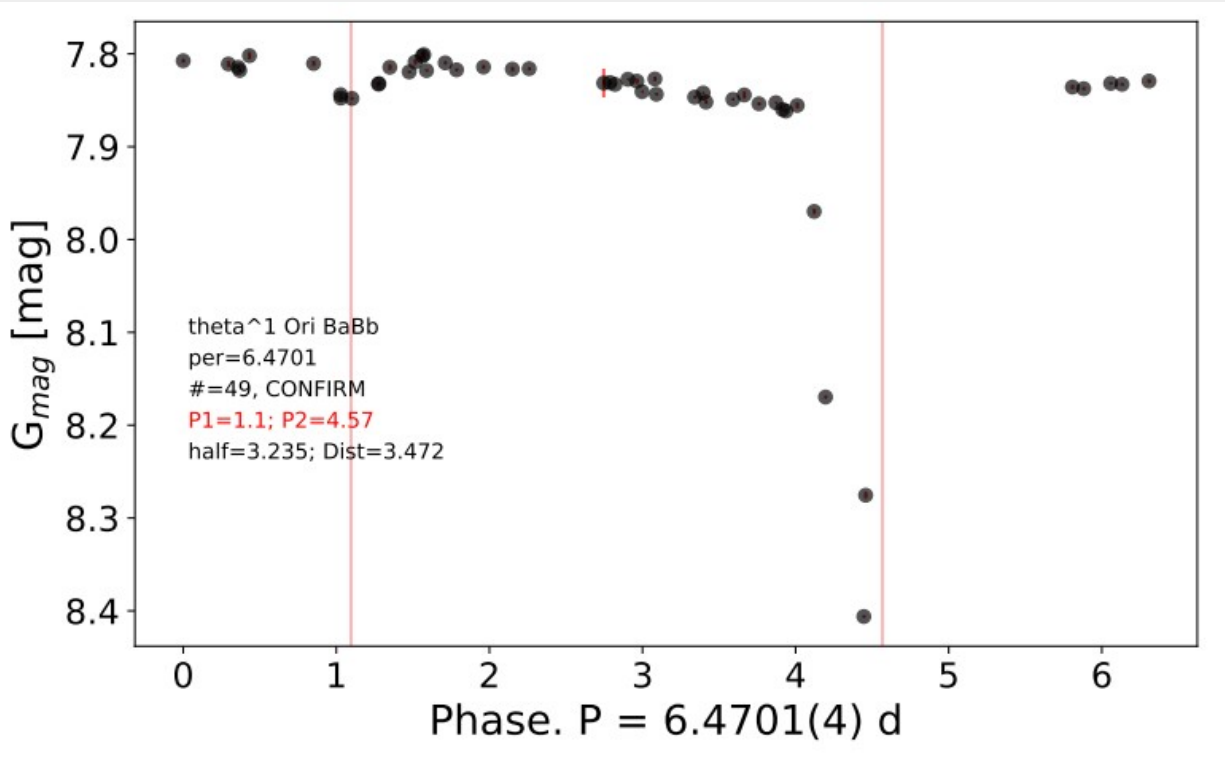
Biased by selection, only eclipsing binaries

Agree when compared with similar samples
(Mason et al. 1998; Kiminki & Kobulnicky 2012; Aldoretta et al. 2015;Barbá et al. 2017; Kim et al. 2018; Pozo Nuñez et al. 2019)

Accumulation in closer orbits than expected:
-Detection probability?
-Migration to lower orbits?

2 to 1 Mowlavi period:





GALANTE is a long-term ongoing observational project (2016-2025) contributing to the study of **Galactic star populations**. Specifically, GALANTE associated photometric system is designed to identify **all Galactic O+B+WR** stars with AB magnitudes 6-17 and derive **estimations** for T_{eff}, log (g), metallicity, and amount and type of extinction: **E(4405−5495)** and R_{5495}.

Some characteristics of the survey are:

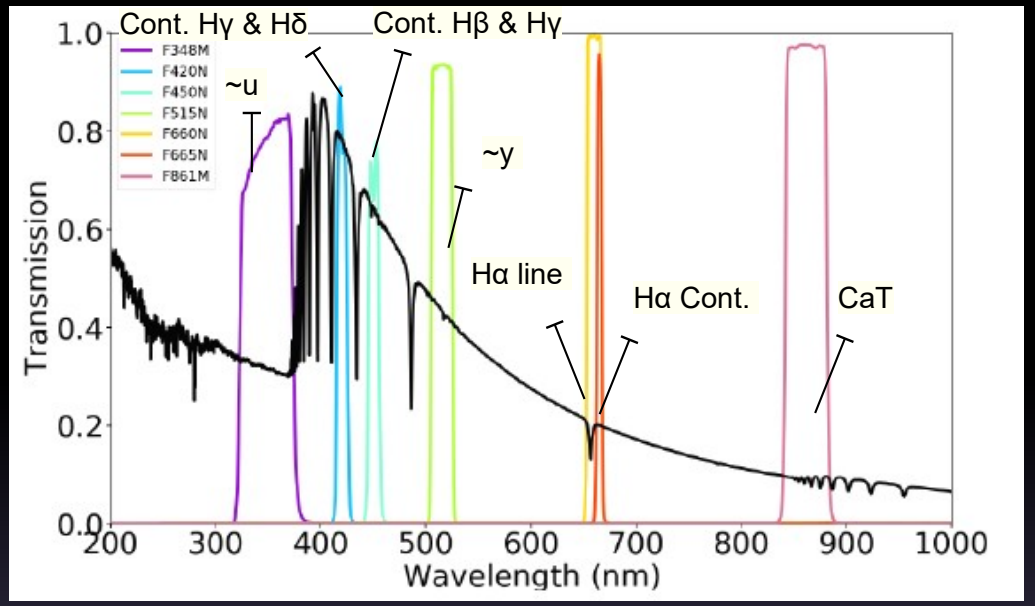
• Galactic Plane coverage + interesting out-of-plane fields: JAST/T80 at OAJ.

• 1.4°x1.4° FOV, 0.55”/px, no gaps.

• Exp. Times: 2 x (0.1s + 1s + 10s + 2 x 50/100 s, at two different airmasses). AB mag 6-17 with S/N > 100.

• Seven Medium and Narrow band filters. Four J-PLUS filters (F348M, F515N, F660N, and F861M) & three developed by the GALANTE team (F420N, F450N, and F665N).

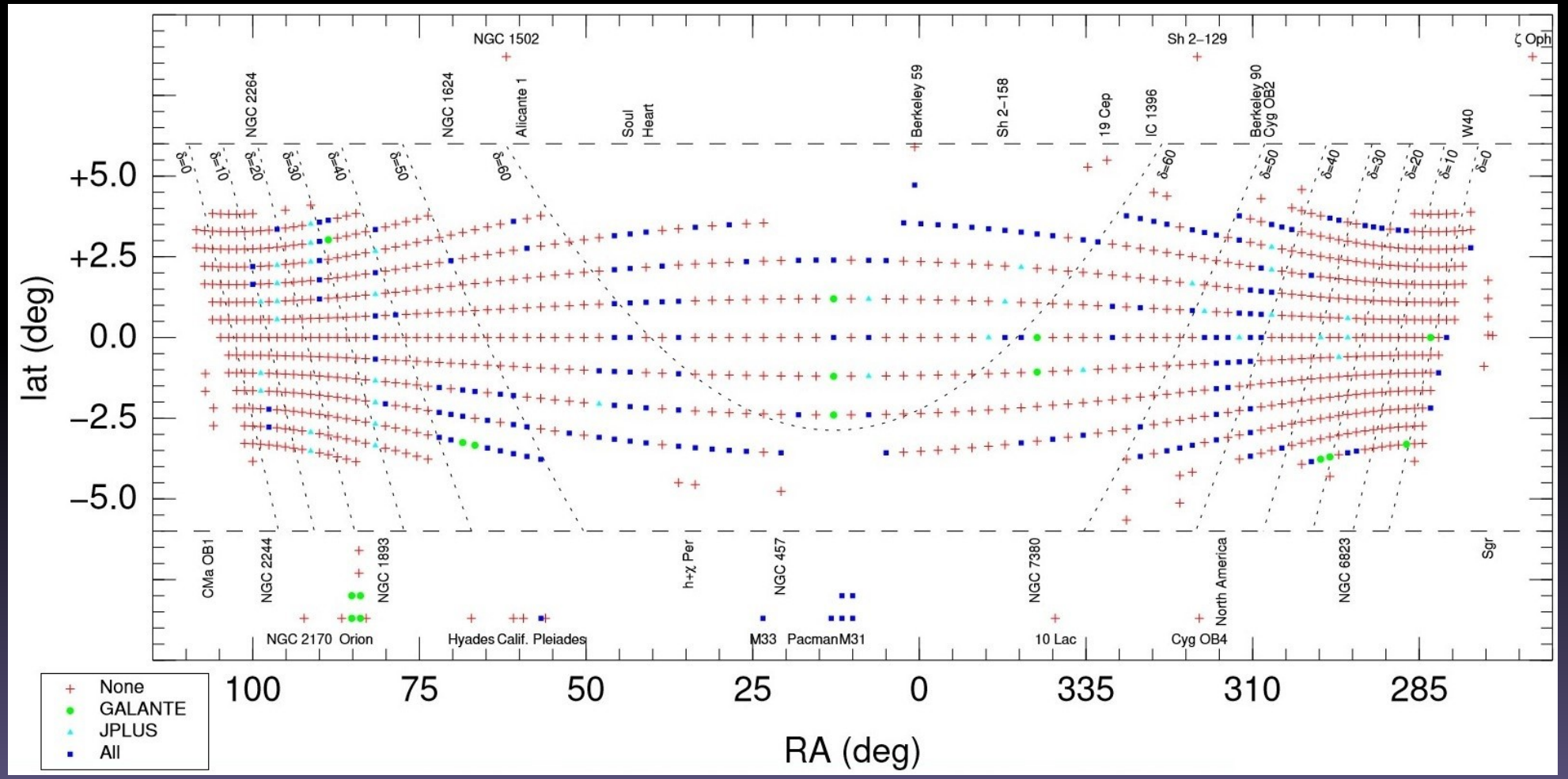
• Photometric and astrometric 2MASS and GaiaDR2 data for the input calibration catalog, and deriving synthetic photometry with CHORIZOS*.



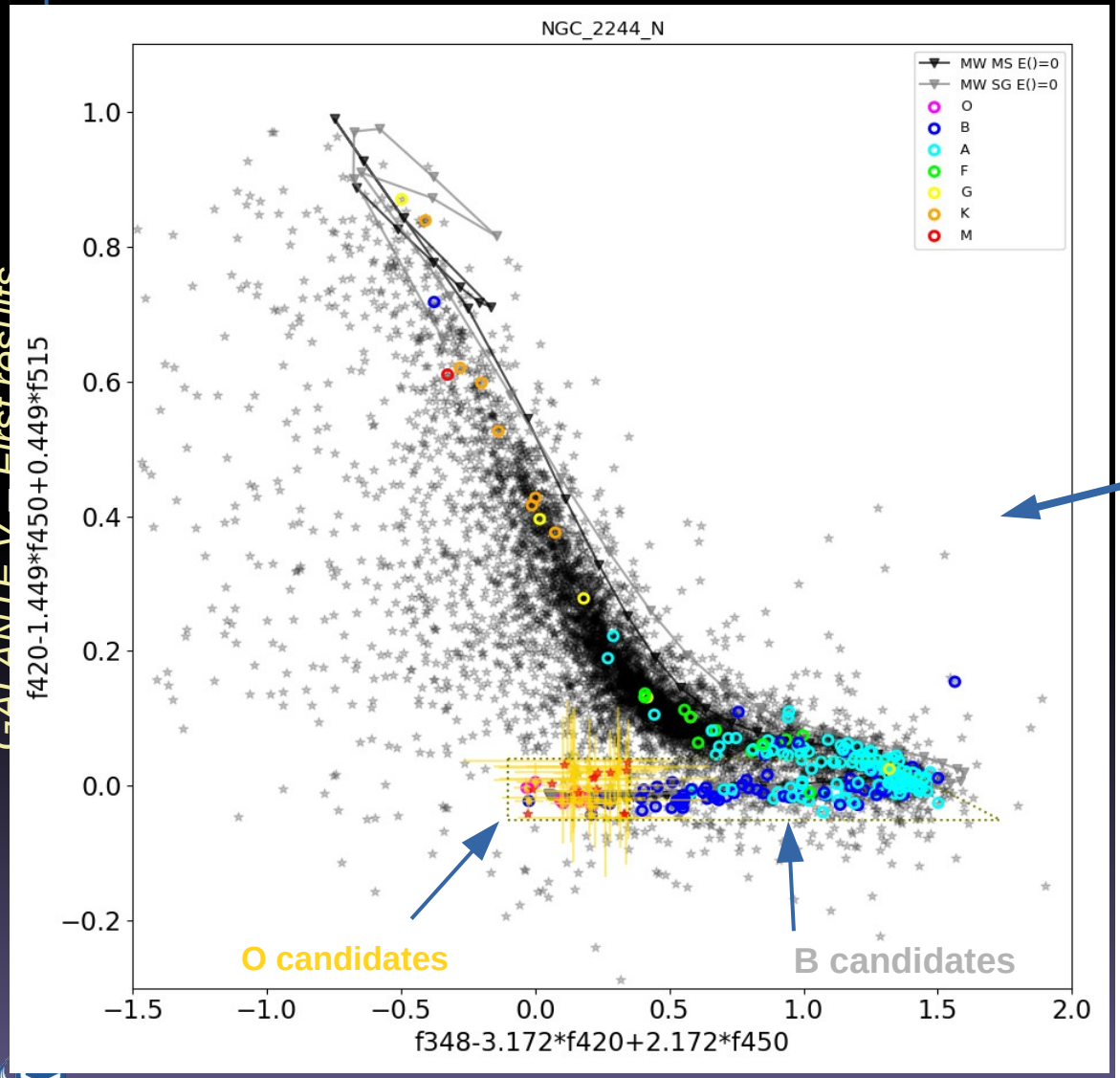
The number, width and effective wavelength of the filters compose an optimal system to accomplish temperature and extinction determination.

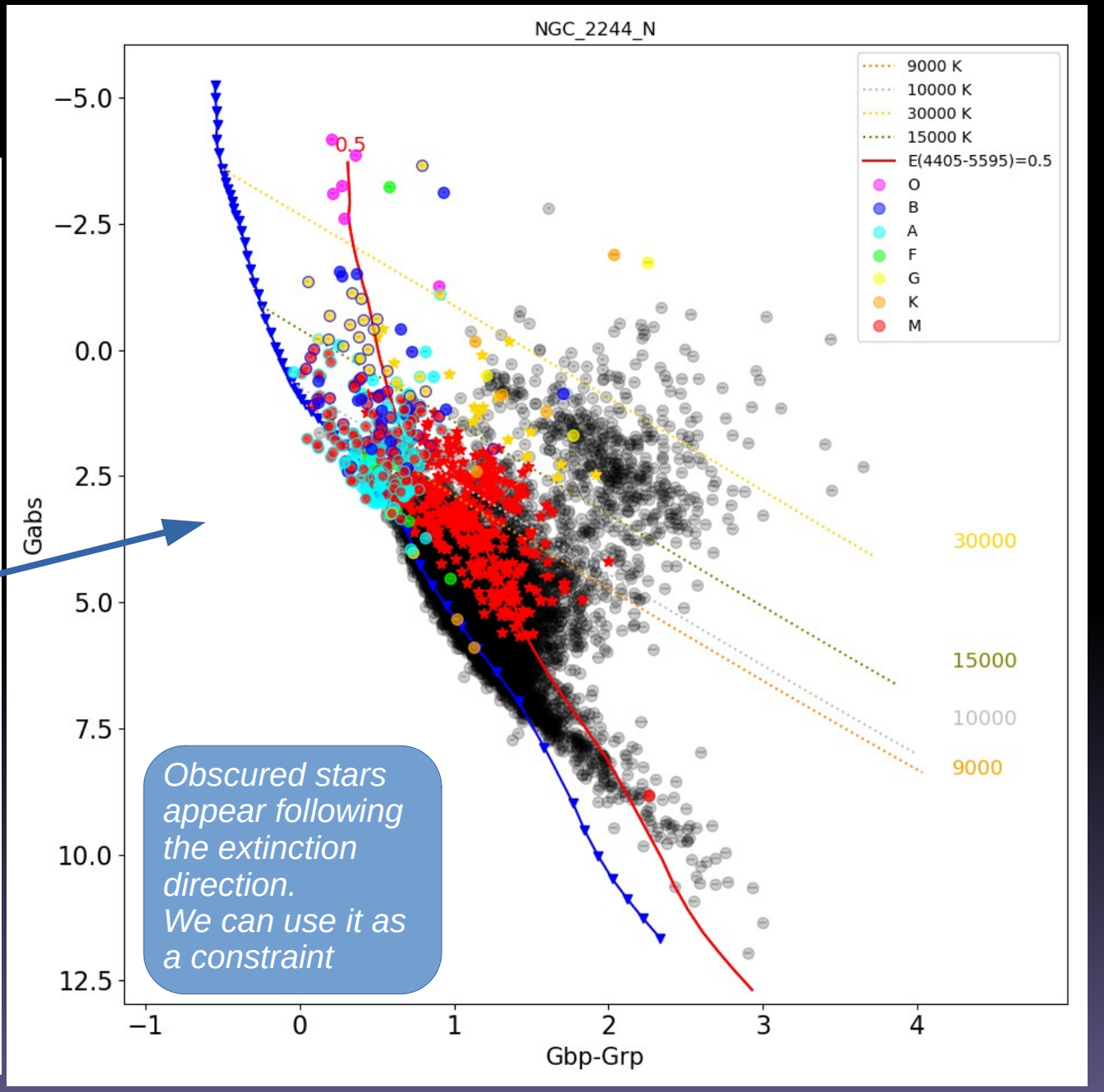
**CHORIZOS is a χ2 minimization algorithm for parametrized modelling and characterization of photometry and spectrophotometry (developed by Jesús Maíz Apellániz). The code is written in IDL and is available to the astronomical community.*

★ **150/1068** Northern fields finished, **90** partially observed (GALANTE or JPLUS filters). ~20% GALANTE North.



★ Preliminary results





Post-pipeline steps pending:

- **Apply new models** to generate synthetic photometry and results on the **test fields**, and **extrapolate** for the 10-15 fields in GALANTE DR1 currently in progress
- **PSF** photometry, and **comparison** with aperture photometry

GALANTE will ultimately provide:

- Identification of all OB+WR stars in the Northern Galactic plane down to magnitude 17
- Estimate T_{eff} for that sample
- Measurements of E(4405-5495) and R_{5495} for the OBA sample, by cross-matching with 2MASS

Some additional future objectives include:

- The study of emission-line stars
- The IMF of large-area clusters and associations
- A continuum-subtracted Hα map with subarcseconds pixel resolution
- **Gaia cross-calibration and WEAVE source identification**
- Generation of a set of standards, accurate photometric optical spectral SEDs to be used as a reference for improving the flux calibration of existing and future empirical stellar libraries