

The upper sequence of young open clusters is shaped by binary interaction



Ignacio Negueruela

Garching, September 2023

Department of Physics, Universidad de Alicante



MINISTERIO
DE CIENCIA, INNOVACIÓN
Y UNIVERSIDADES



Plan de Recuperación,
Transformación y Resiliencia



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NextGenerationEU

- Berto Castro (AIP Potsdam)
- Amparo Marco (Alicante)



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Basic idea

- ◆ Most open clusters with an age ~ 10 to 25 Ma contain blue (mostly B-type) supergiants.
- ◆ In most cases these objects are far too bright for the cluster isochrone.
- ◆ *Gaia* has proved beyond doubt that they are cluster members.
- ◆ Spectroscopic programme to understand the upper sequence of young open clusters.



NGC 4755

The jewel box

HD 111990
B2 II

κ Cru
B3 Ia

Image ESO

HD 111904
B9 Ia

HD 111934
B1.5 Ib

NGC 2393

The gem cluster

HD 91969
B0 Iab

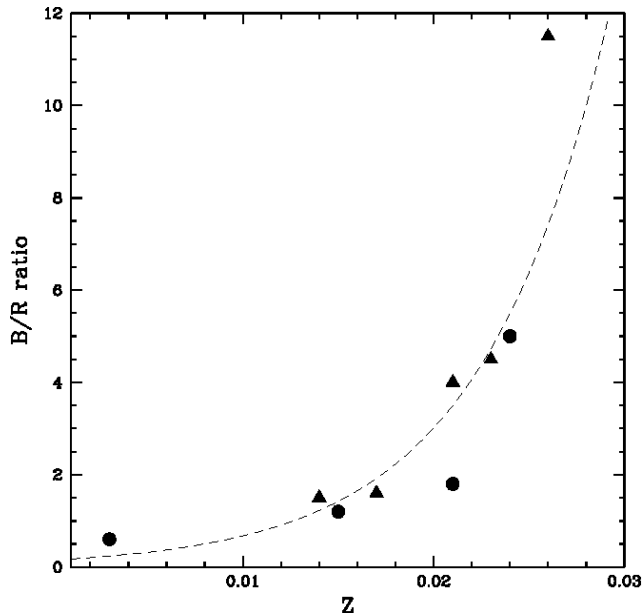
HD 91943
B0.7 Ib

Image ESO



The blue to red supergiant ratio in young clusters at various metallicities

P. Eggenberger, G. Meynet, and A. Maeder

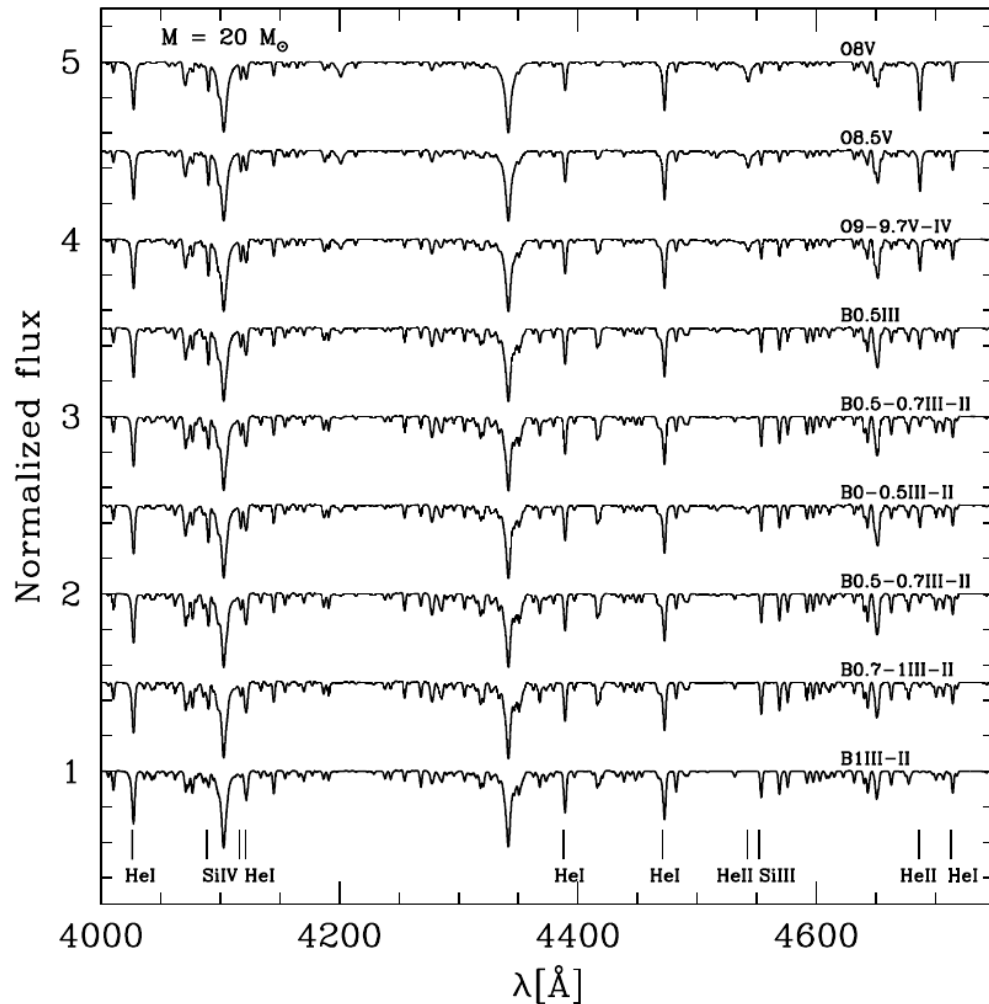
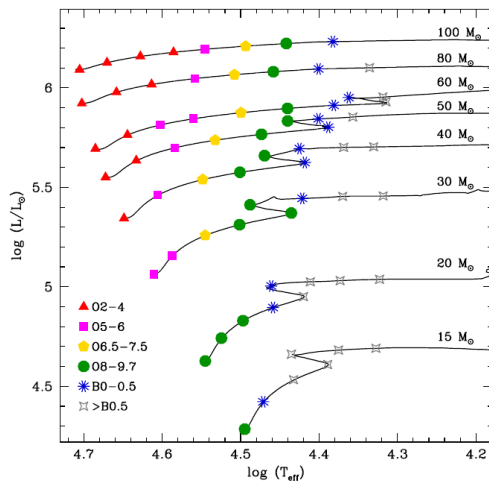
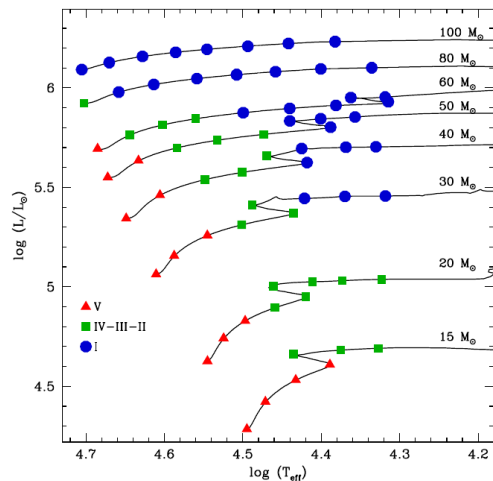


- What belongs to a cluster?
- How do you define a blue supergiant?
- Does this only make sense in the context of single-star evolutionary models?

Spectroscopic evolution of massive stars on the main sequence

F. Martins and A. Palacios

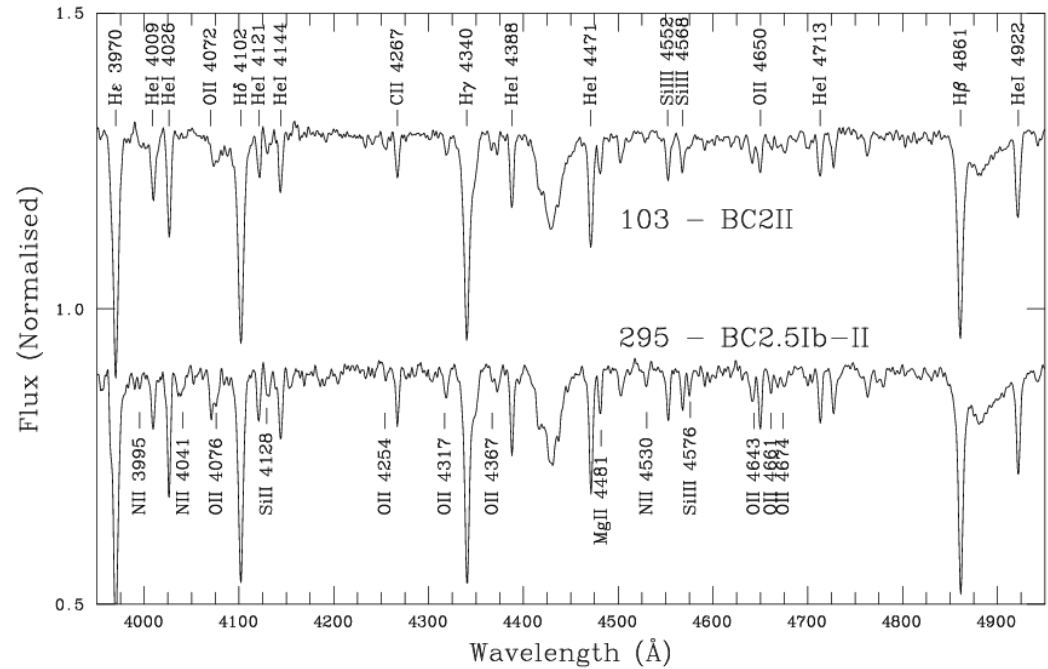
LUPM, Université de Montpellier, CNRS, Place Eugène Bataillon, 34095 Montpellier, France
e-mail: fabrice.martins@umontpellier.fr



NGC 7419 as a template for red supergiant clusters^{*,**,***}

A. Marco and I. Negueruela

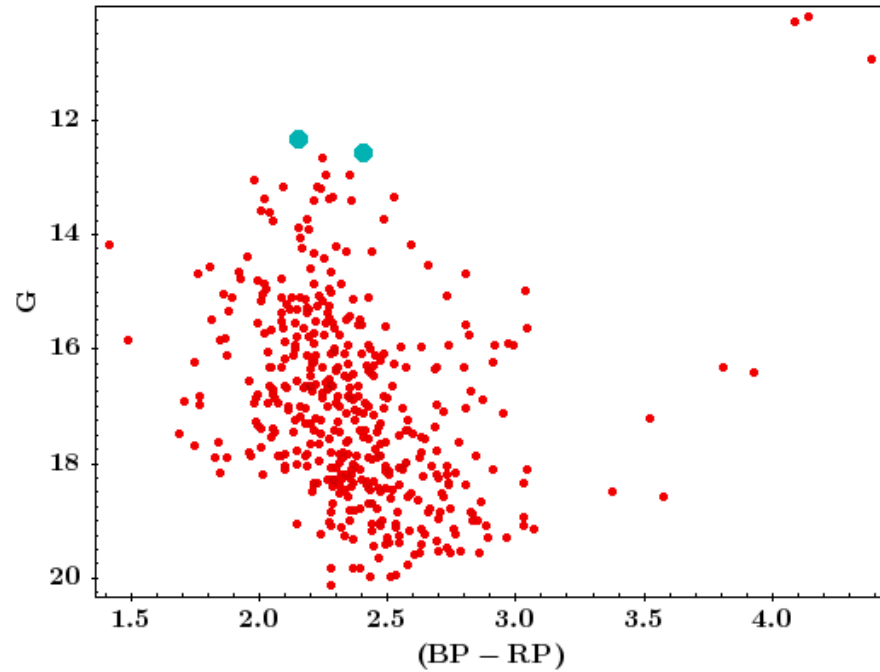
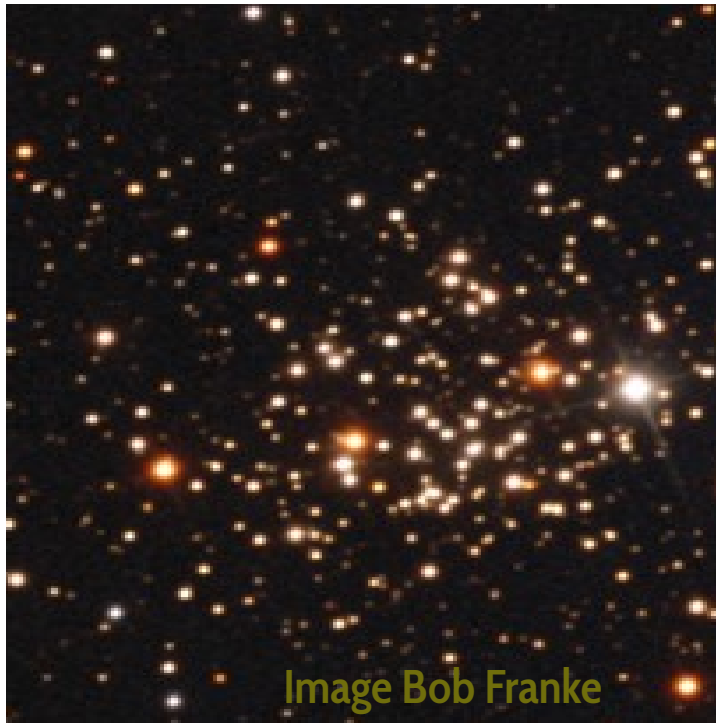
Departamento de Física, Ingeniería de Sistemas y Teoría de la Señal. Escuela Politécnica Superior, University of Alicante,
Apdo. 99, 03080 Alicante, Spain
e-mail: amparo.marco@ua.es



NGC 7419 as a template for red supergiant clusters^{★,★★,★★★}

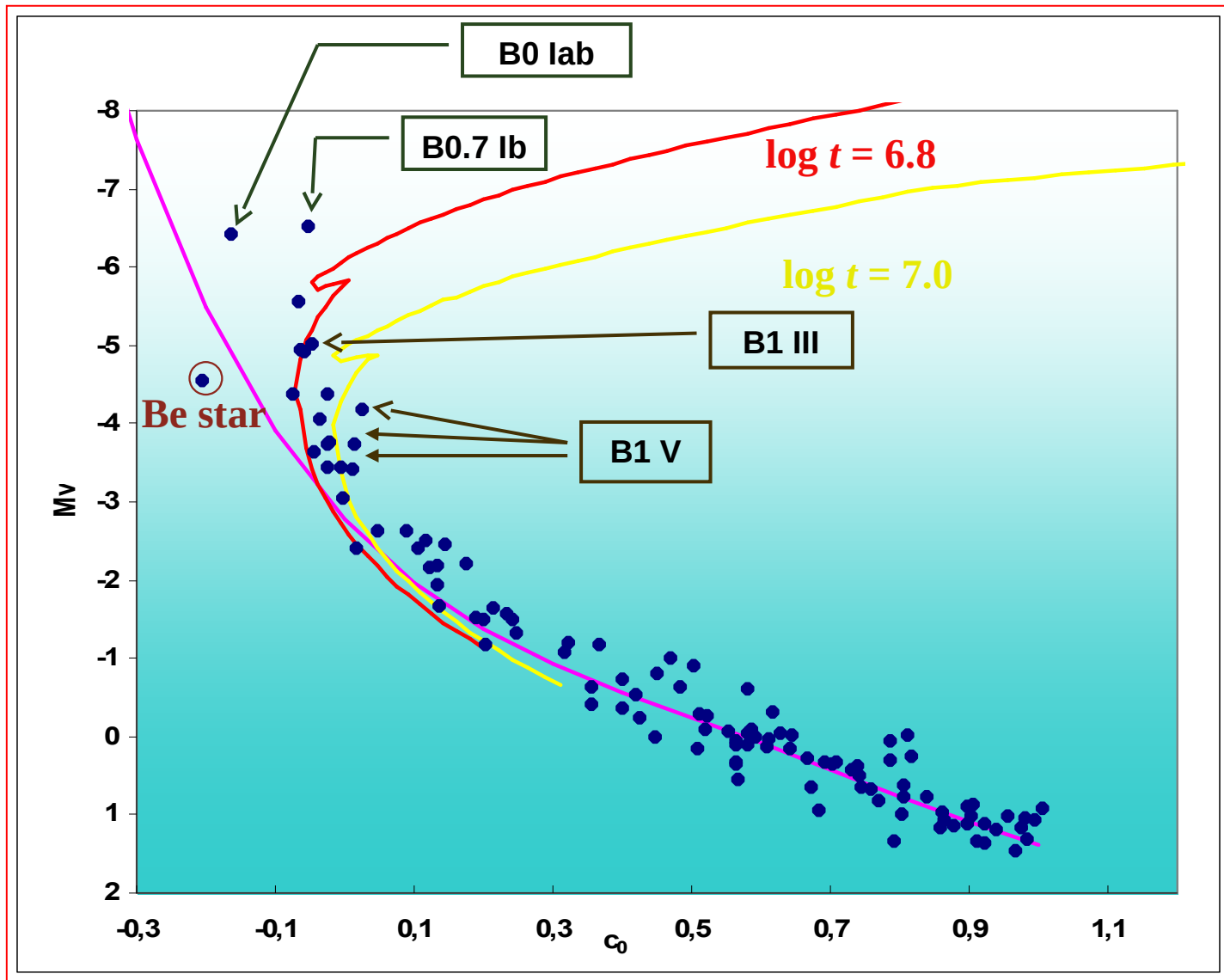
A. Marco and I. Negueruela

Departamento de Física, Ingeniería de Sistemas y Teoría de la Señal. Escuela Politécnica Superior, University of Alicante,
Apdo. 99, 03080 Alicante, Spain
e-mail: amparo.marco@ua.es



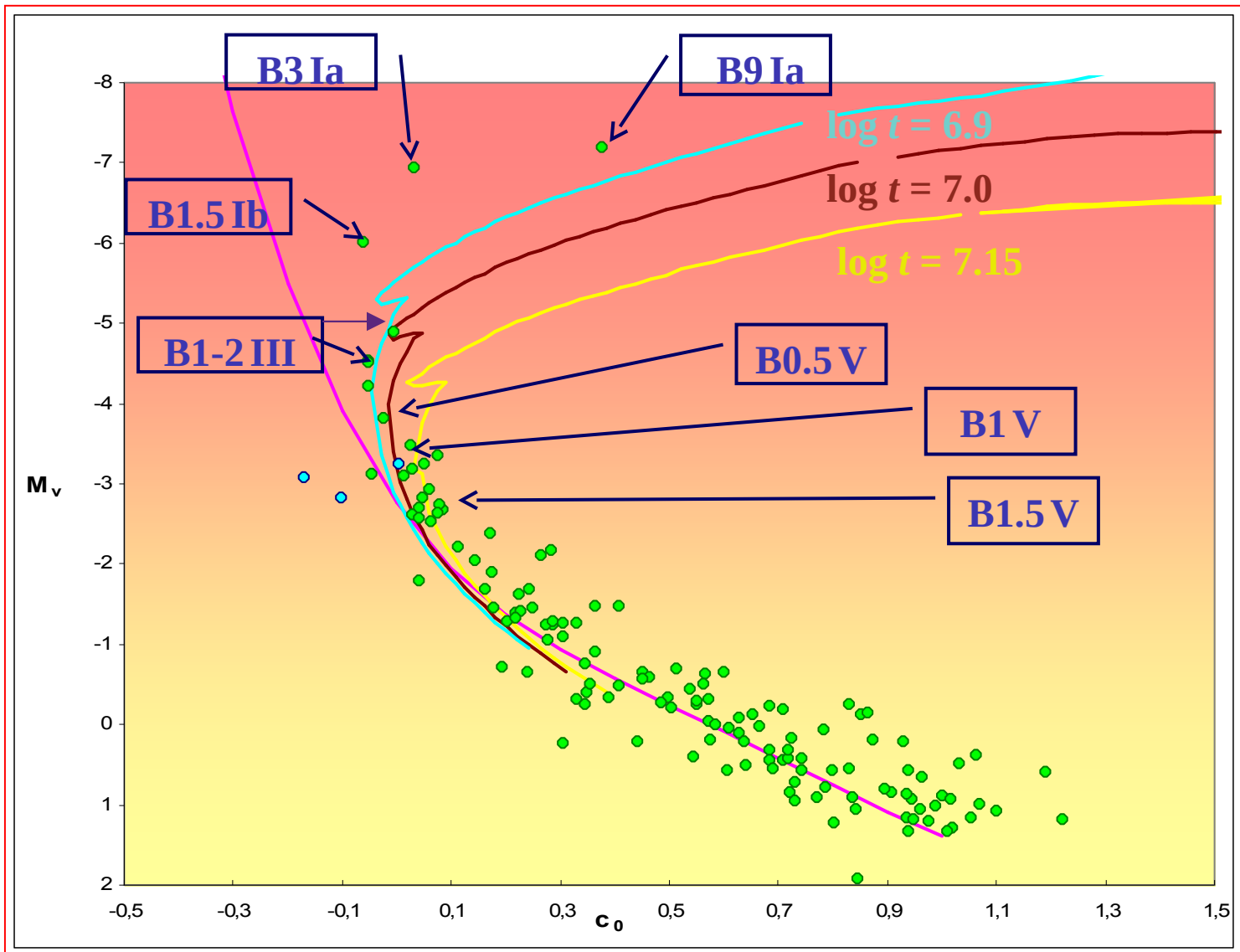
NGC 2393

Marco+ 2007
with spectral types
from Dufton+ 2006



NGC 4755

Marco+ 2007
with spectral types
from Dufton+ 2006




Is there a way to look into this?

- ◆ Luminosity does not map directly into mass.
- ◆ Let us try combining photometry and spectroscopy.
- ◆ Backup programme at the WHT 4.2 m for poor weather conditions running for several years.
- ◆ Targets in young open clusters in the Perseus Arm and in clusters with Cepheids.



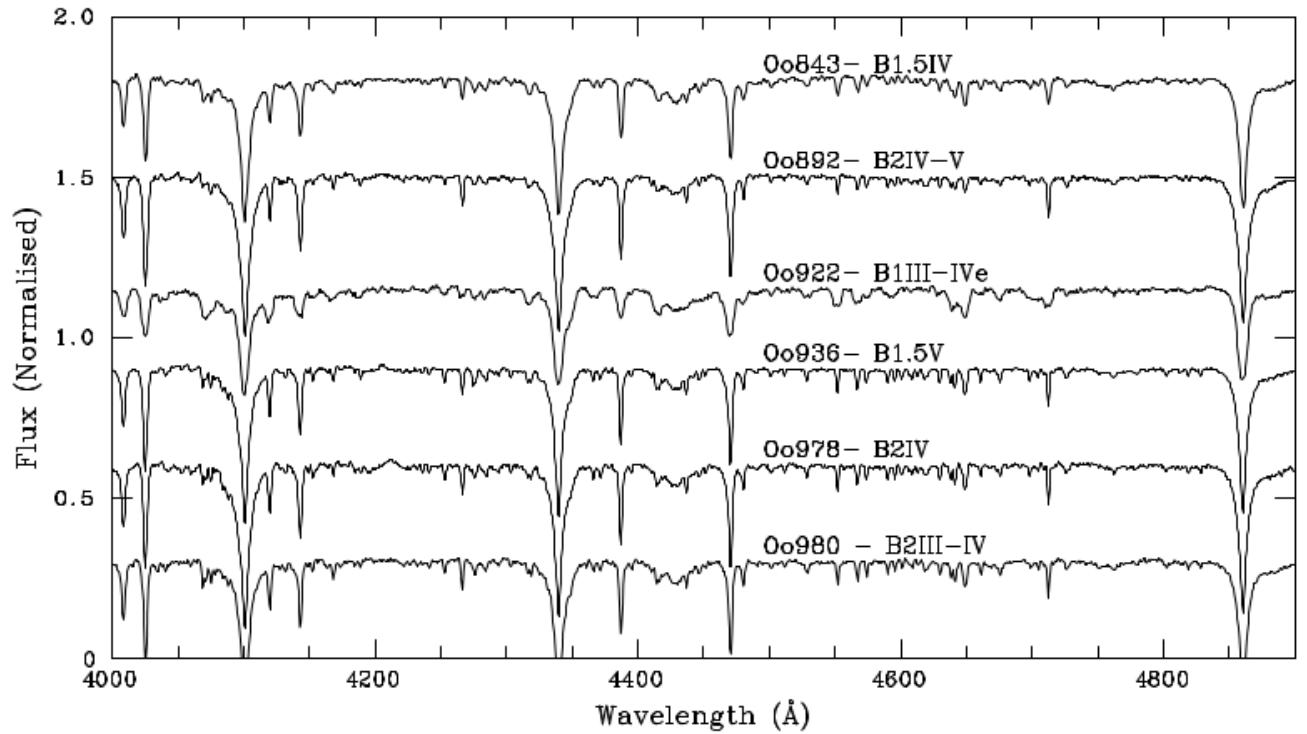
The ARAUCARIA project: Grid-based quantitative spectroscopic study of massive blue stars in NGC 55*

N. Castro¹, M. A. Urbaneja², A. Herrero^{3,4}, M. Garcia^{3,4}, S. Simón-Díaz^{3,4}, F. Bresolin², G. Pietrzyński^{5,6},
R. -P. Kudritzki^{2,7}, and W. Gieren⁵

- ❖ Grid of FASTWIND models developed by **Castro et al. (2012)**.
 - ❖ Parameter determination via χ^2 -squared fit.
 - ❖ H/He models only, best fitted to MS stars.
 - ❖ Use of the spectroscopic HR diagram (sHRD), as it is independent of distance (**Castro et al. 2014**).
- 

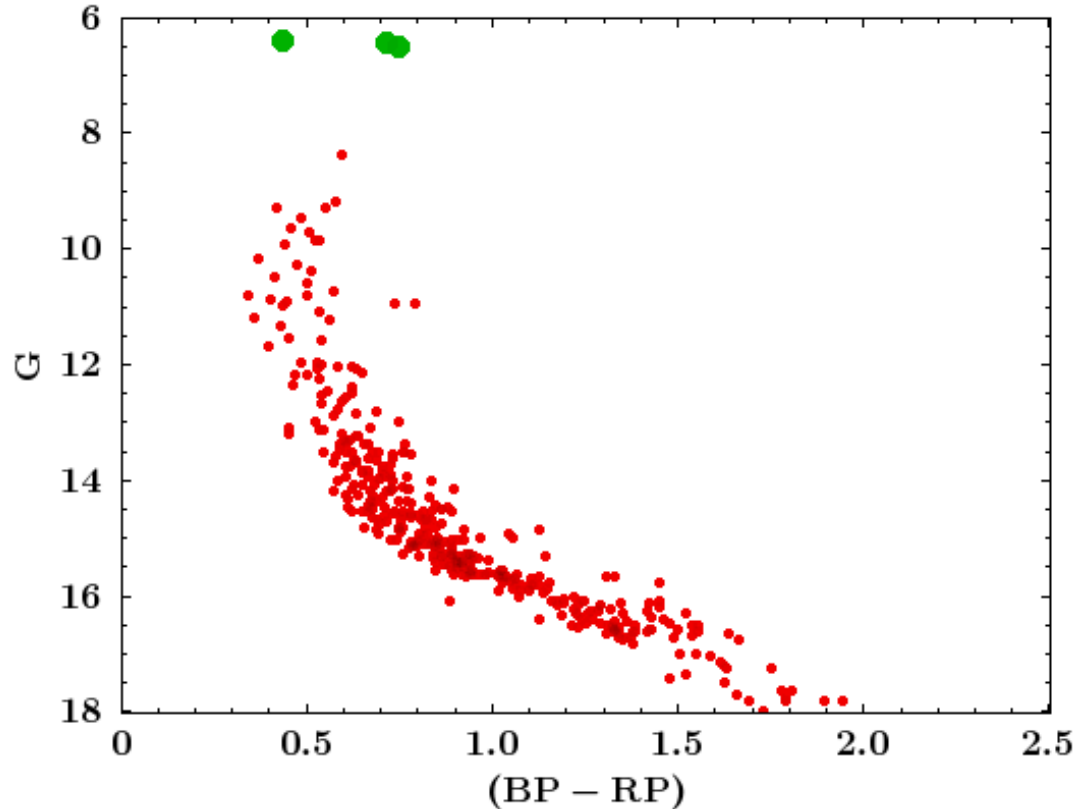


Sample



NGC 869

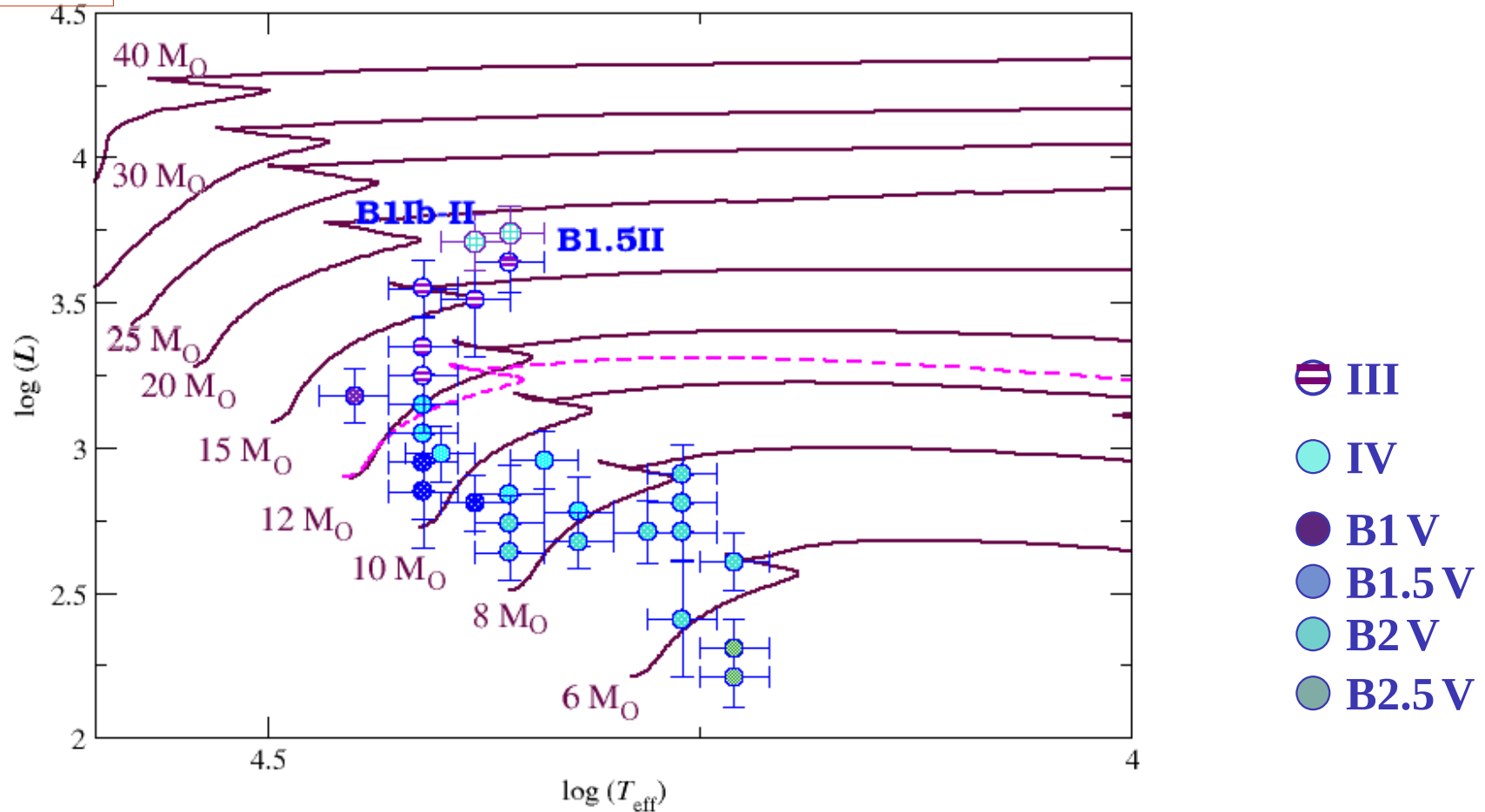
h Persei



Stellar content:

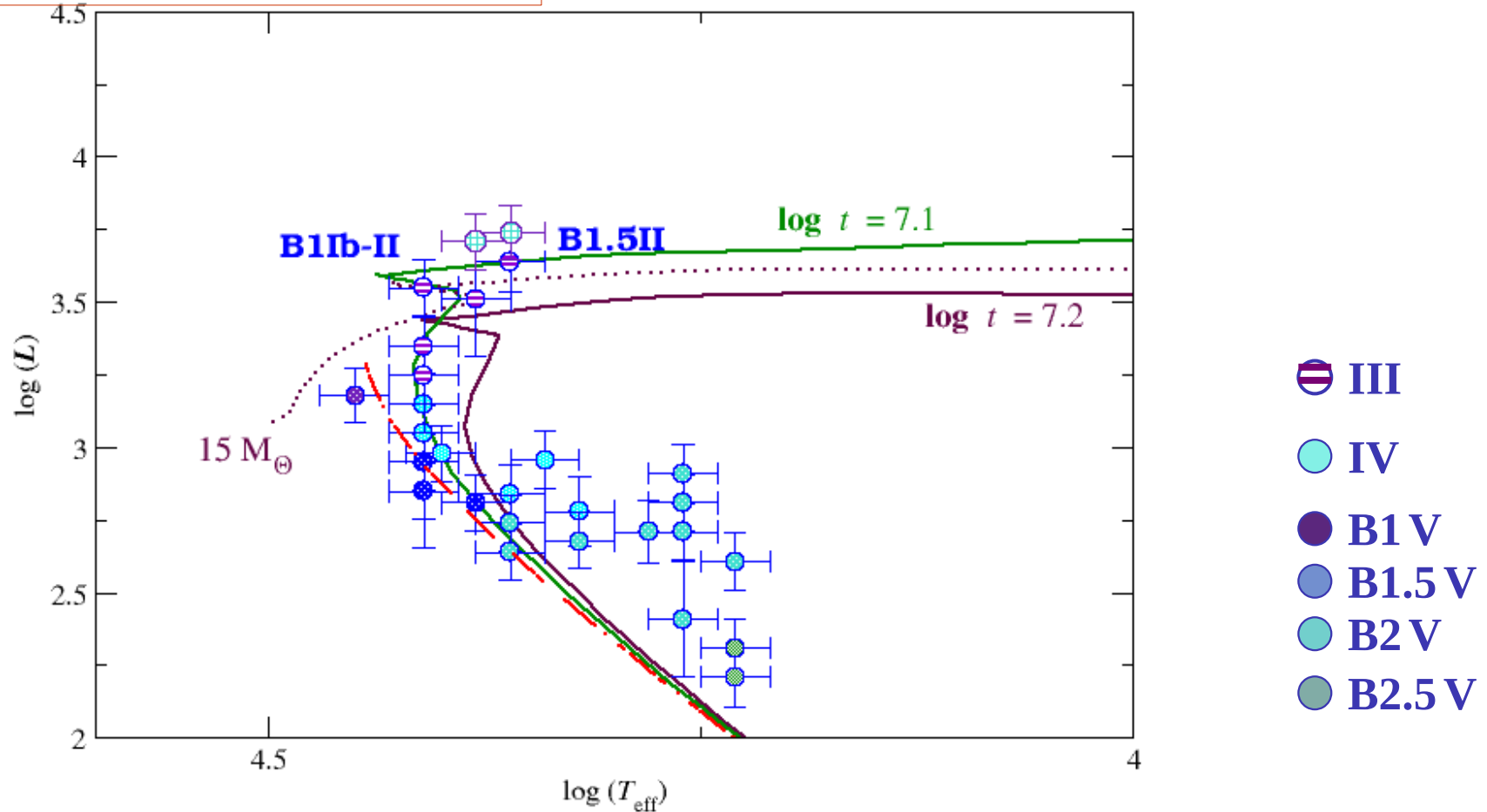
- **Class V**
 - A few B1V
 - Several B1.5V
 - B2-4V
- **Class IV**
 - B1.5 IV and B2 IV
- **Class III**
 - B0.7 III, B1 III, B1.5 III

The sHRD



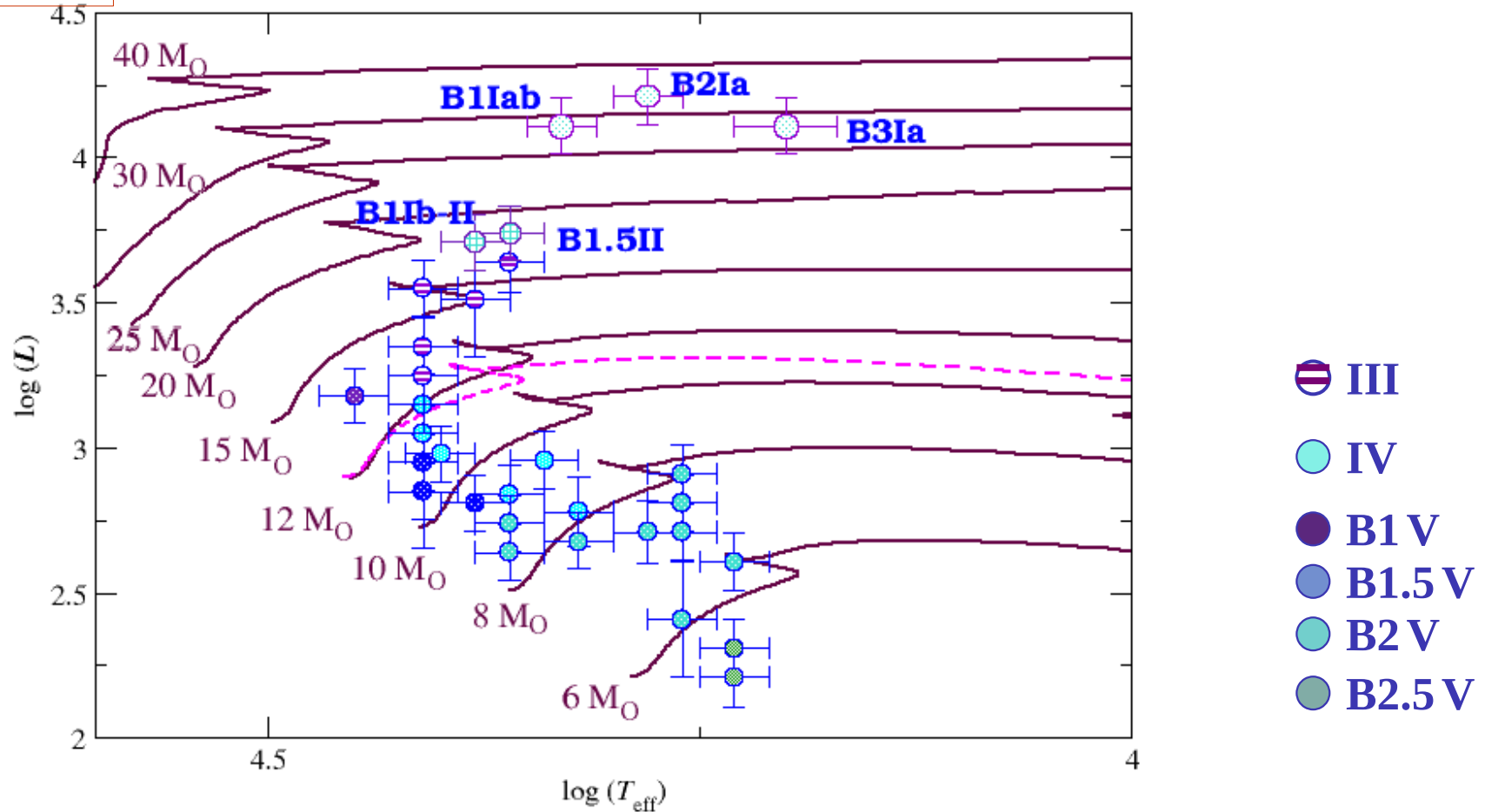
Geneva tracks with “standard” rotation

The sHRD with isochrones



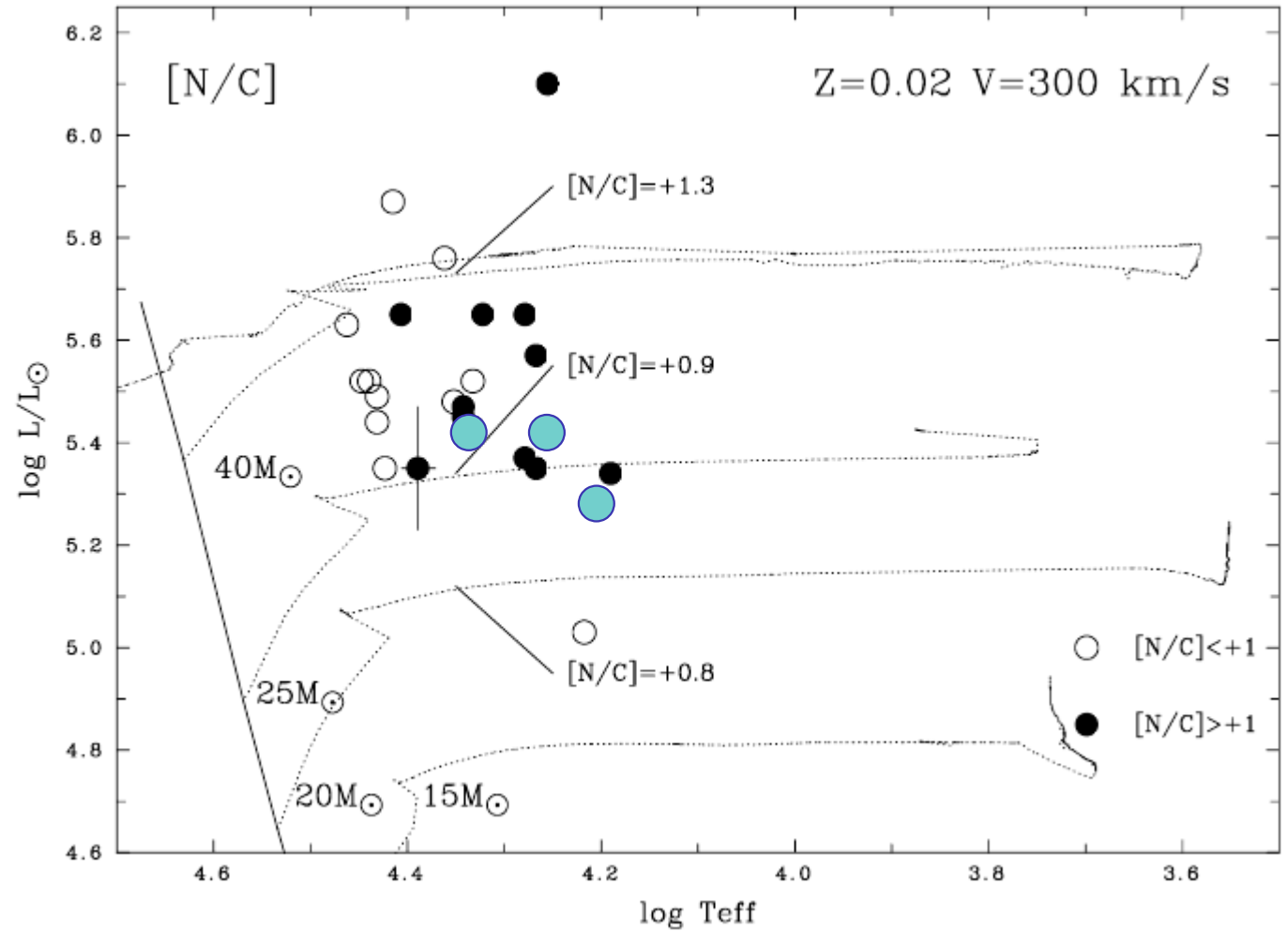
Geneva isochrones with “standard” rotation

The sHRD



Geneva tracks with “standard” rotation

A standard HRD



Non-rotating Geneva isochrones (2000)

Crowther+ 2006

Where are the blue stragglers?

A&A 643, A116 (2020)
<https://doi.org/10.1051/0004-6361/202039019>
© ESO 2020

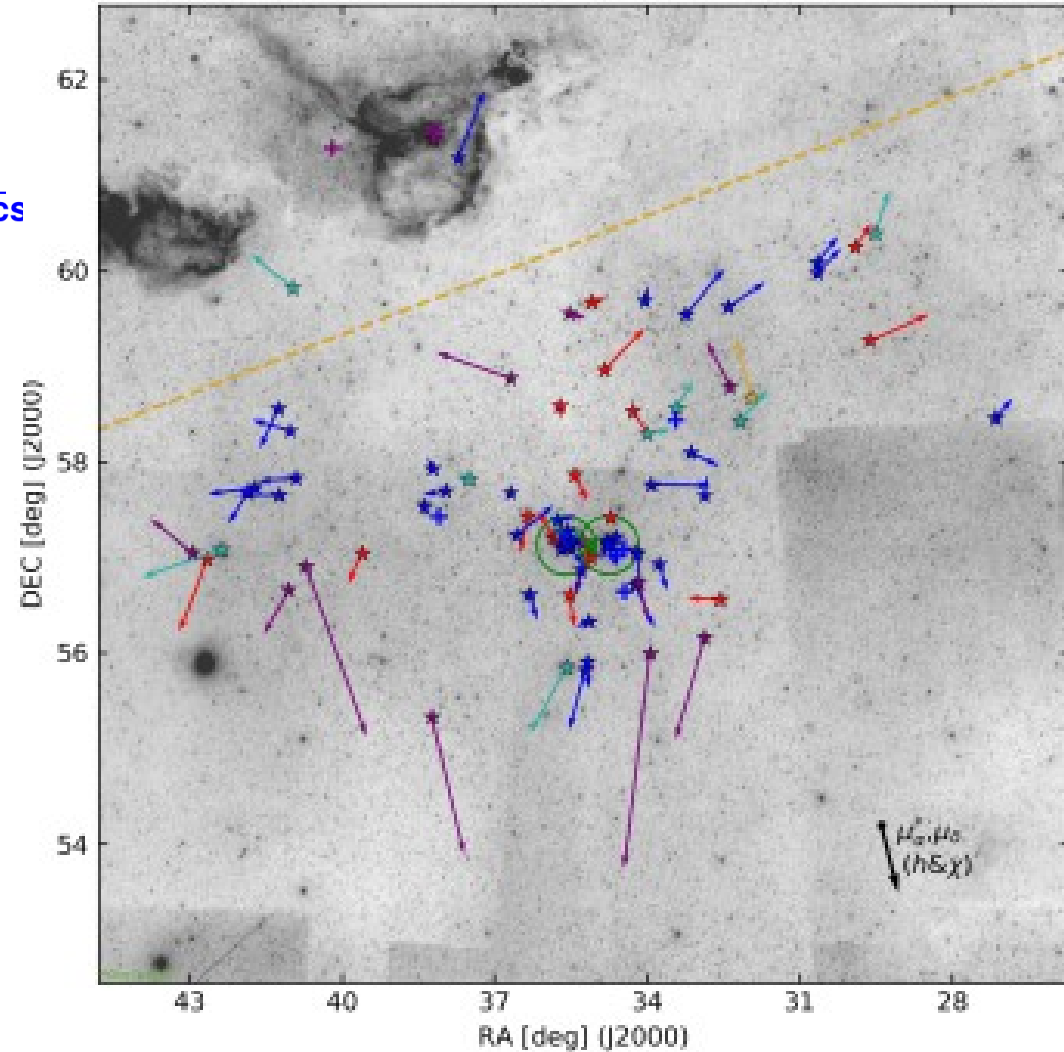
Astronomy
&
Astrophysics

High-resolution spectroscopic study of massive blue and red supergiants in Perseus OB1

I. Definition of the sample, membership, and kinematics*

A. de Burgos^{1,2,3}, S. Simon-Díaz^{3,4}, D. J. Lennon^{3,4}, R. Dorda^{3,4}, I. Negueruela⁵, M. A. Urbaneja⁶,
L. R. Patrick^{3,4,5}, and A. Herrero^{3,4}

Most likely, flying away

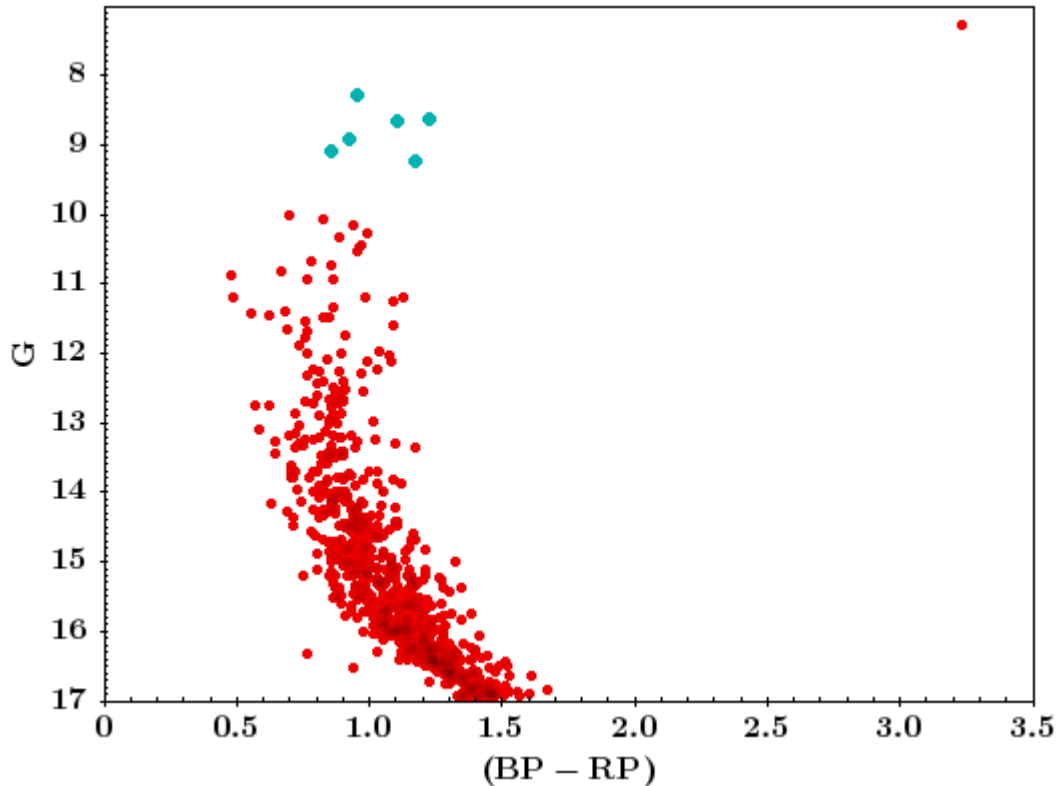


NGC 663

- More distant and obscured Perseus Arm cluster
- Known for its very high Be star fraction
- Core of the Cas OB8 association



NGC 663



Stellar content:

- **Class V**
 - A few B2 V, most Be
 - Many B2.5 V
 - B3-8 V
- **Class IV**
 - A few B2 IV, most Be
 - Many B2.5 IV
- **Class III**
 - B2 III, B2.5 III, one B3 III

NGC 663

- Persistent low-luminosity Be/X-ray binary with Be shell companion ([Reig+ 1997](#)).
- Little X-ray variability.
- B0.7 IV



RX J0146.9+6121

- Persistent low-luminosity Be/X-ray binary with B1Vshell companion ([Reig+ 1997](#)).
- Persistent Be/X-ray binaries are a rare subclass with wide (~300 d?), close-to-circular orbits and no X-ray outbursts.
- Suggested association to electron-capture supernovae.

[Published: 09 November 2011](#)

Two populations of X-ray pulsars produced by two types of supernova

[Christian Knigge](#) , [Malcolm J. Coe](#) & [Philipp Podsiadlowski](#)

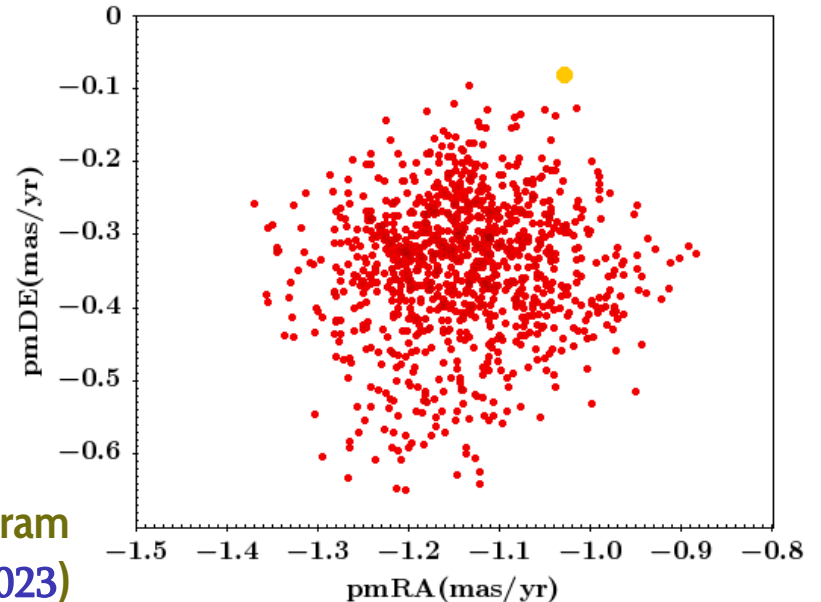
[Nature](#) 479, 372–375 (2011) | [Cite this article](#)

RX J0146.9+6121

- Persistent low-luminosity Be/X-ray binary with B1Vshell companion ([Reig+ 1997](#)).
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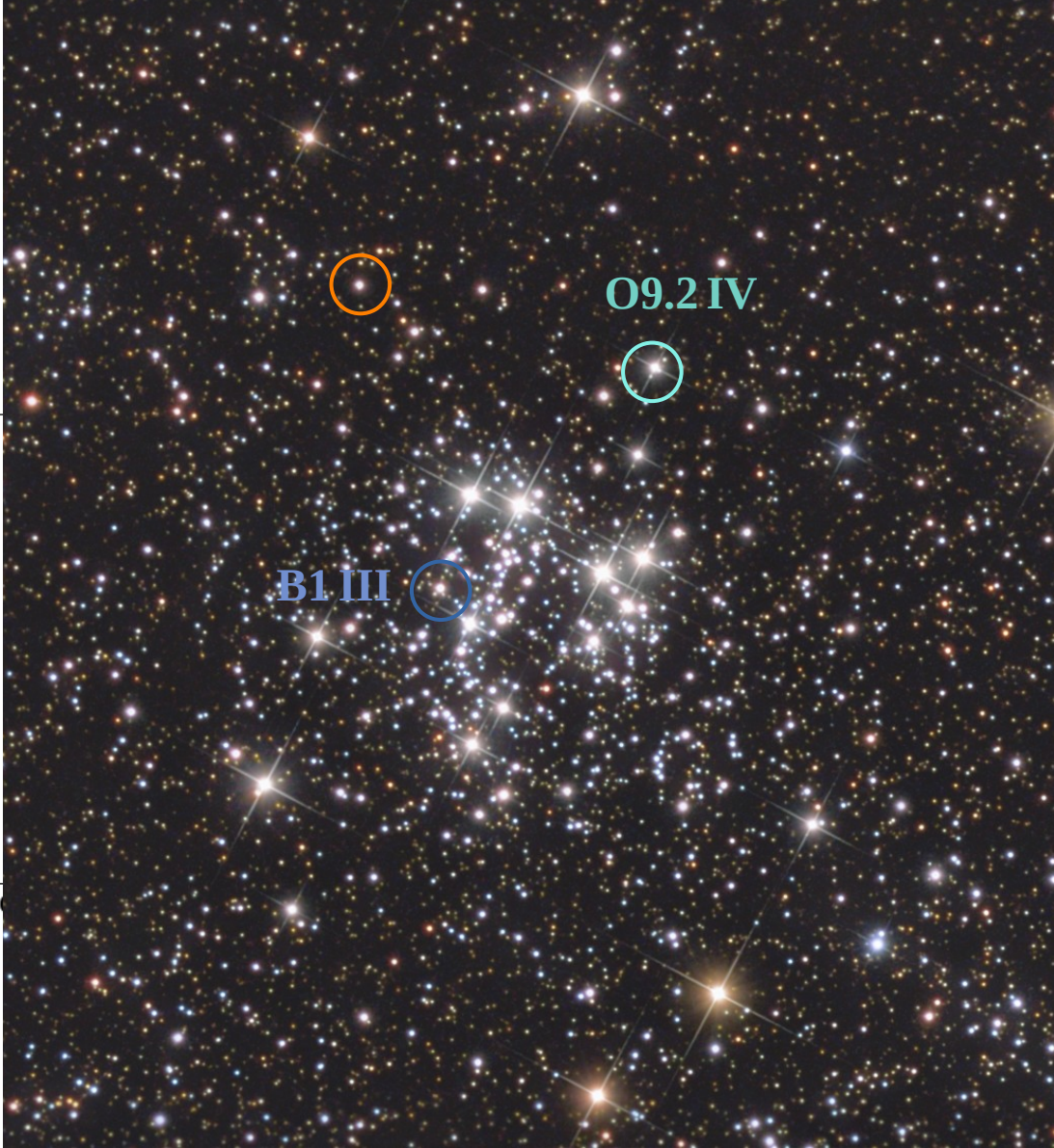
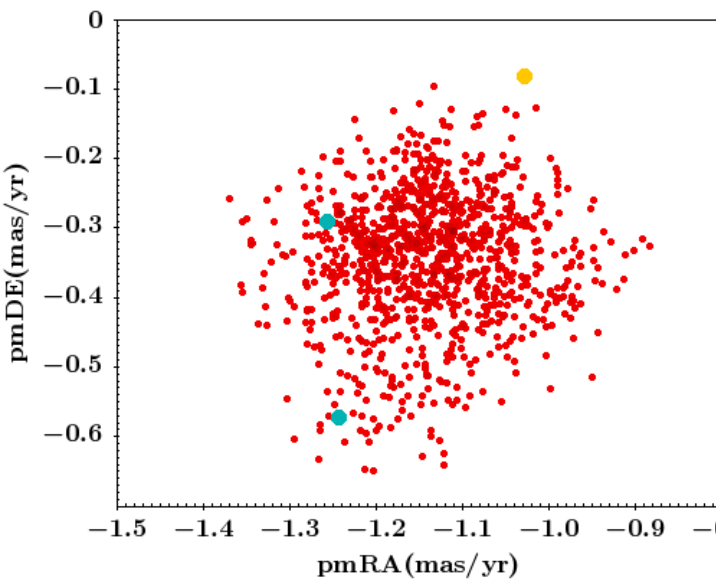
This object cannot have experienced a significant supernova kick.

Putative members of NGC 663 in the vector point diagram
([Hunt & Reffert 2023](#))



NGC 663

● There are other blue stragglers

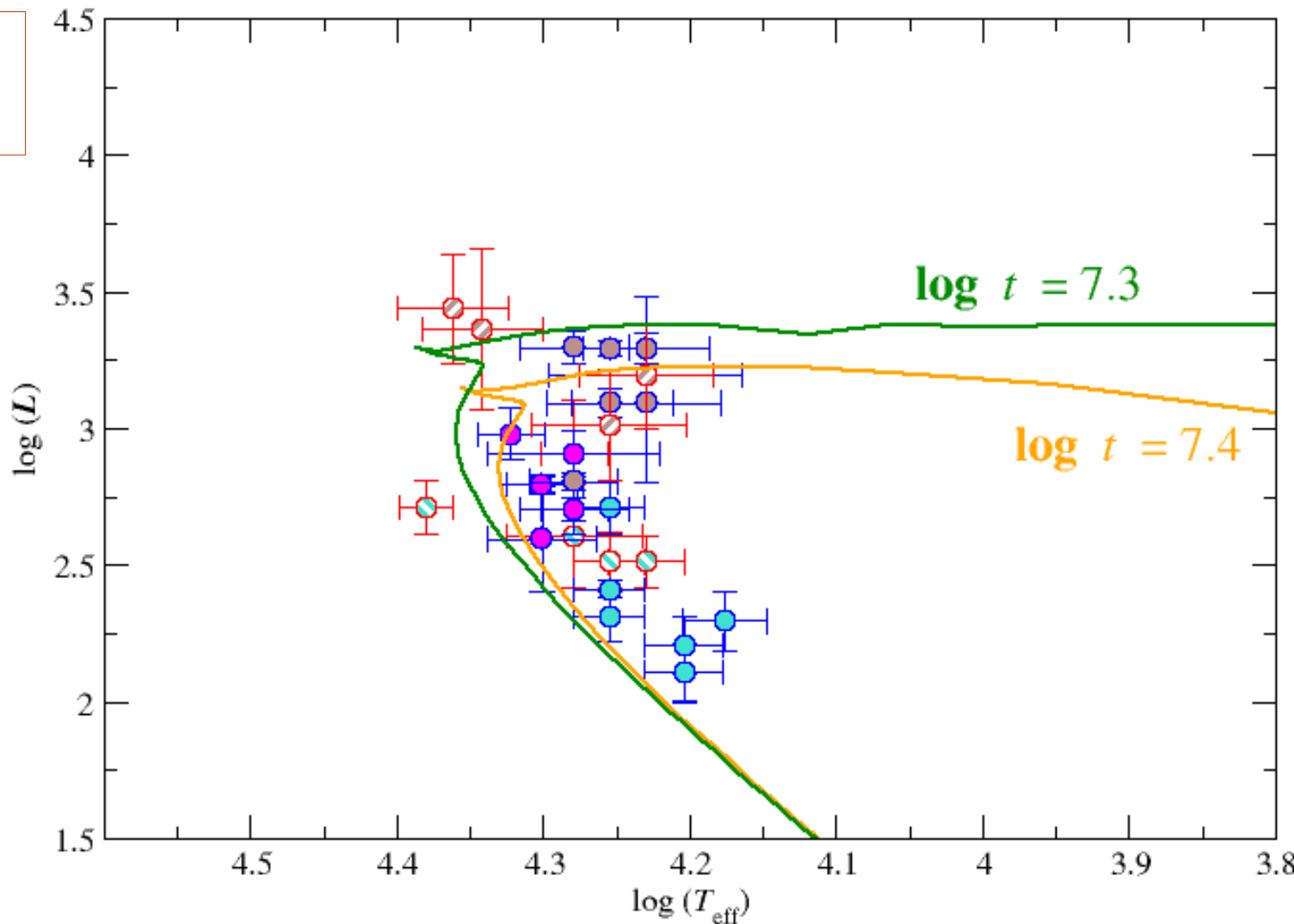


The sHRD with isochrones

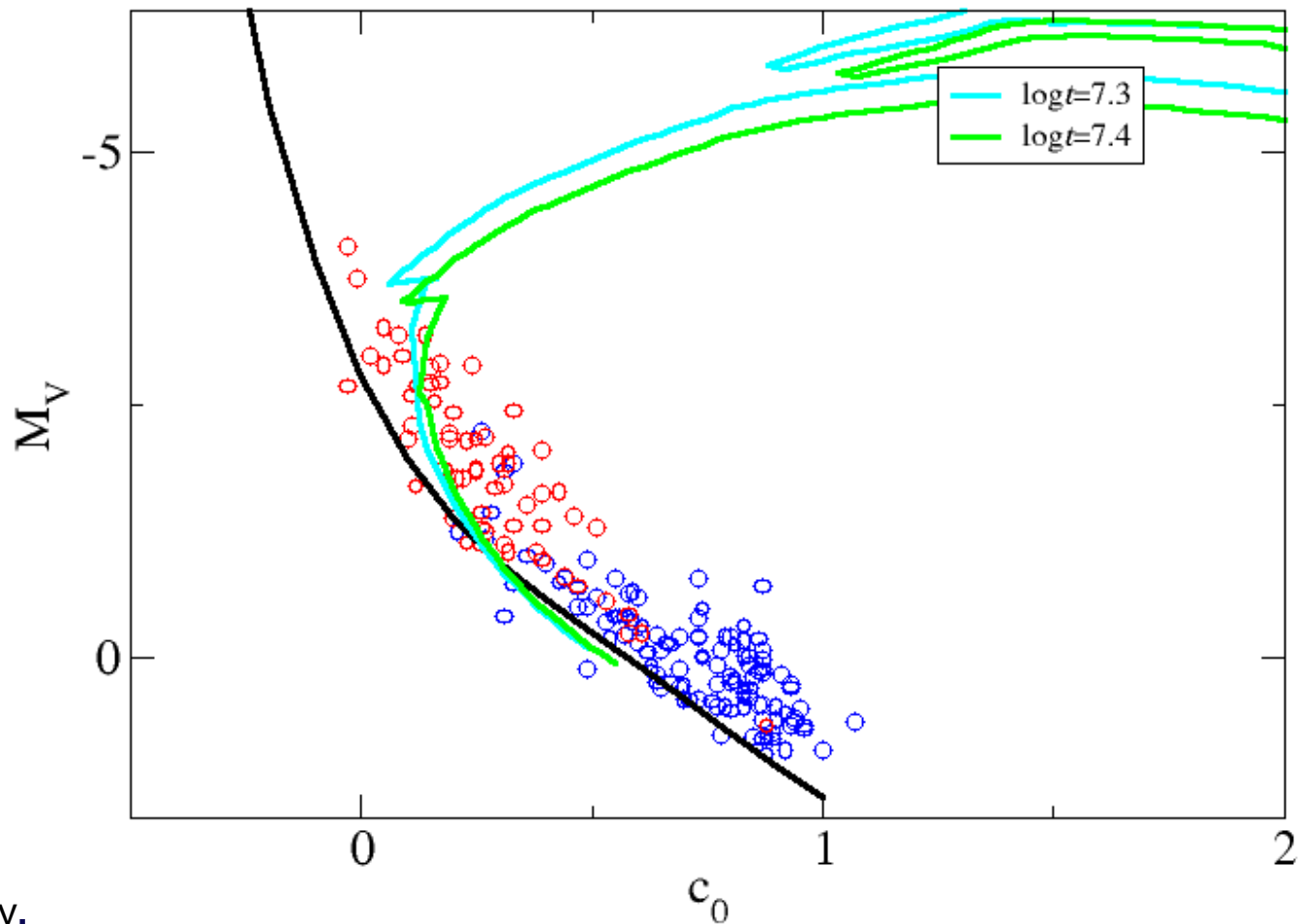
○ Normal stars
solid

○ Be stars are
hatched

● V
● IV
● III



The CMD



Marco+ 2024

with Strömgren photometry.

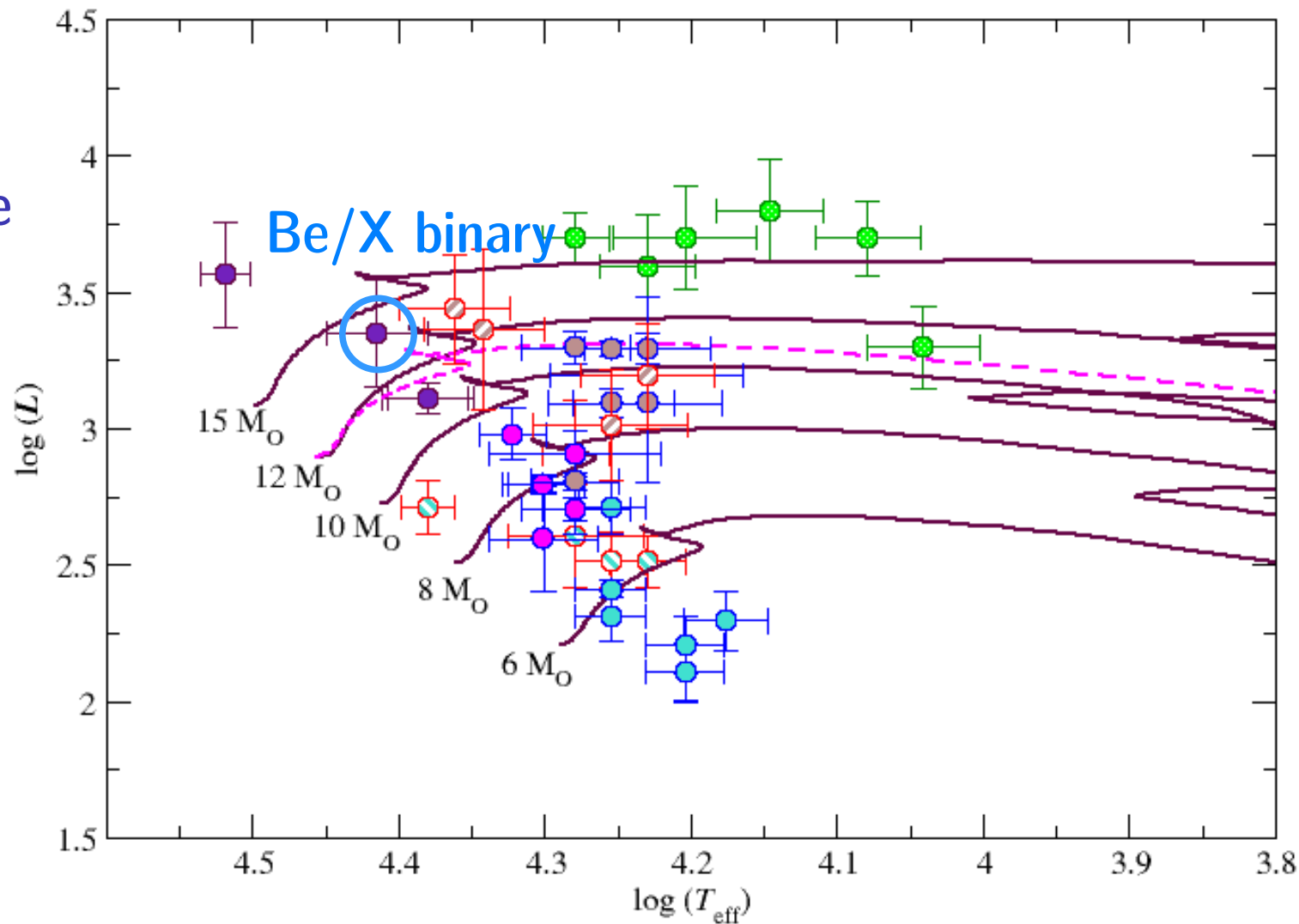
All objects in red have spectra.

The sHRD

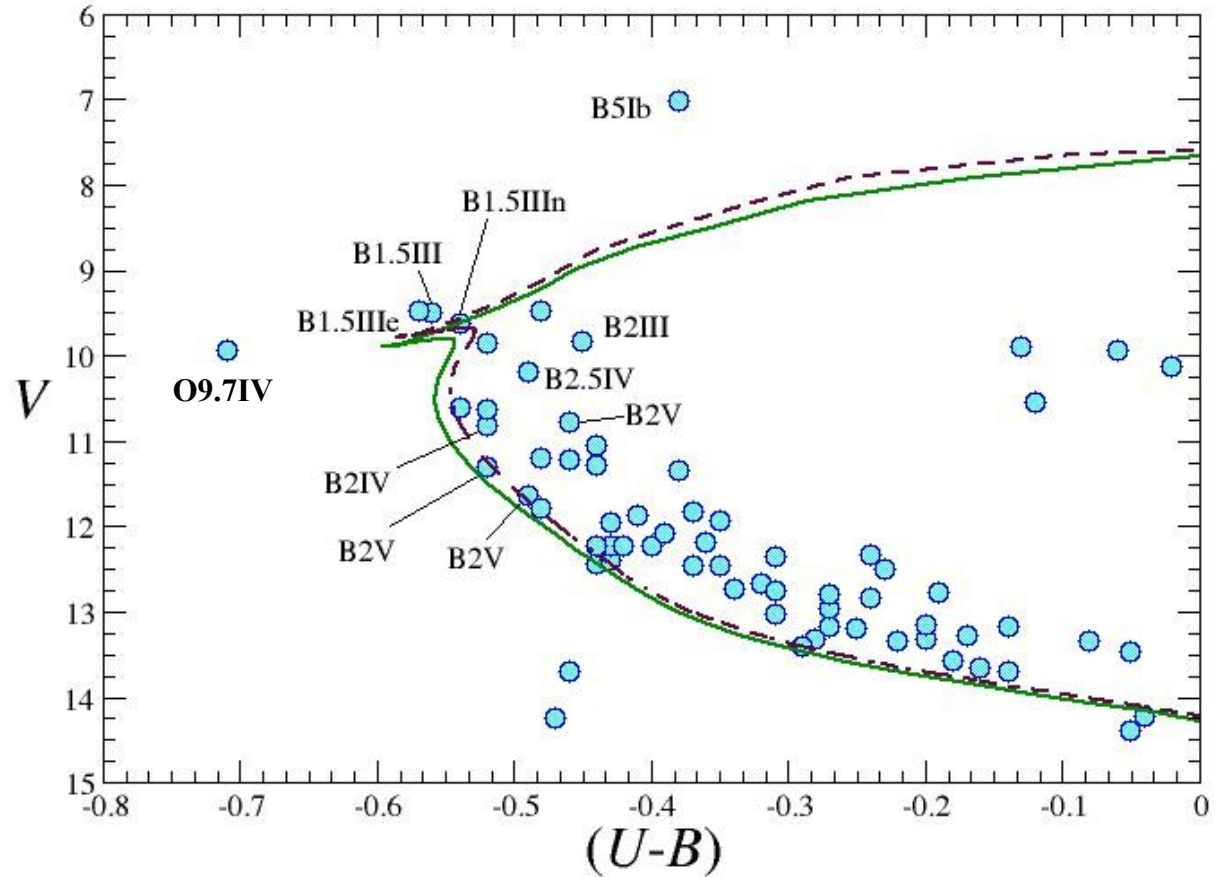
○ Normal stars are solid

○ Be stars are hatched

● V
● IV
● III
● Ib



NGC 457

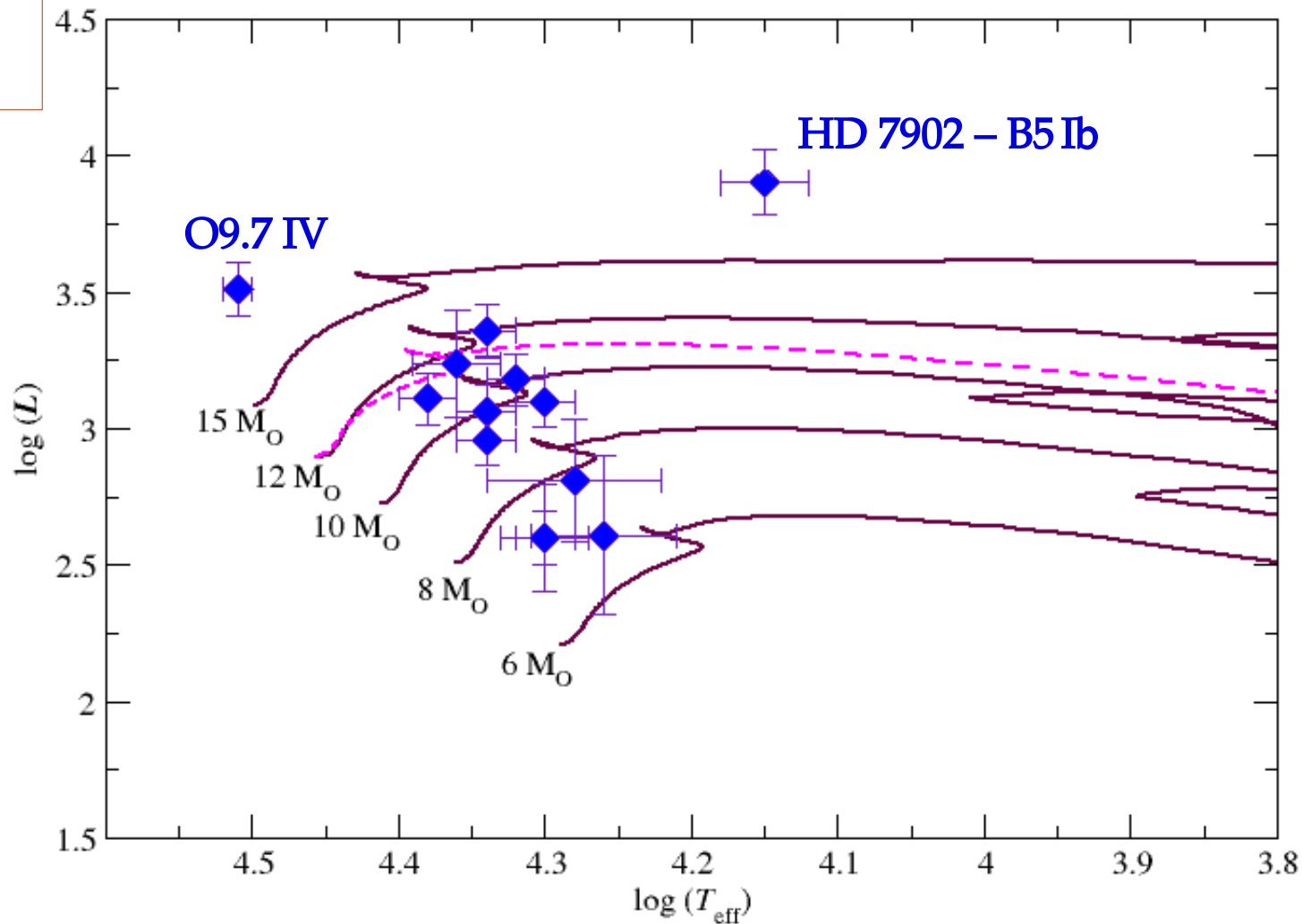


Tracks by **Georgy+ (2013)**

16 Ma with $\Omega_{\text{ini}} = 0$

20 Ma with $\Omega_{\text{ini}}/\Omega_{\text{cri}} = 0.3$

NGC 457



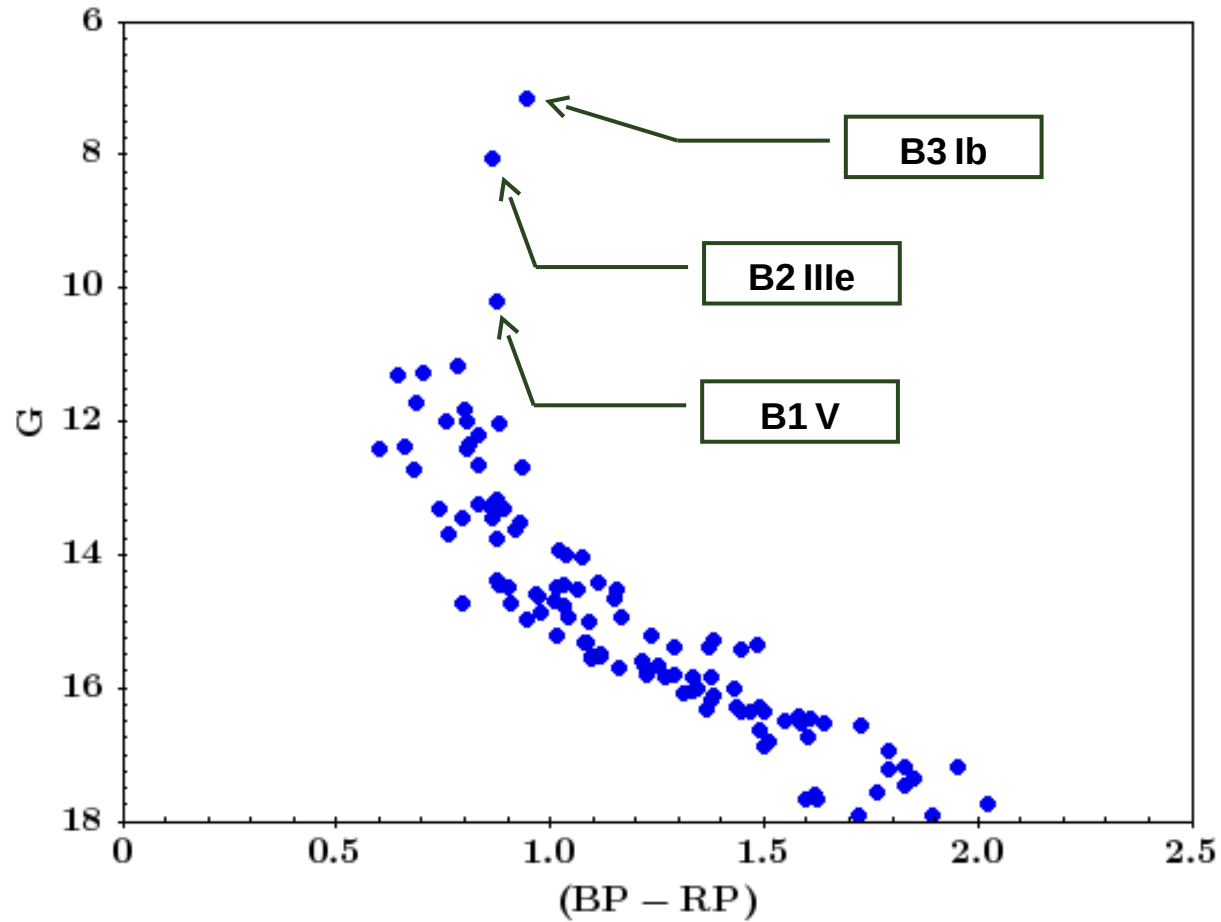
Quantitative spectroscopy of B-type supergiants

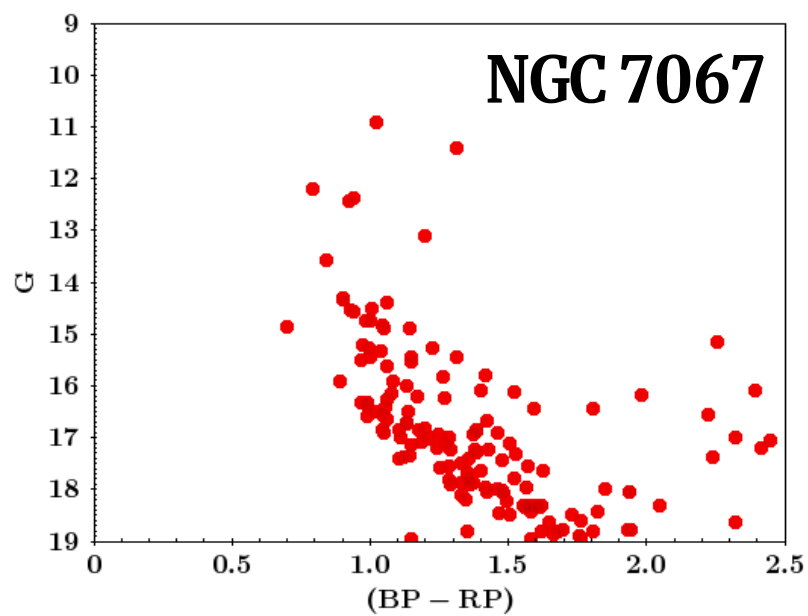
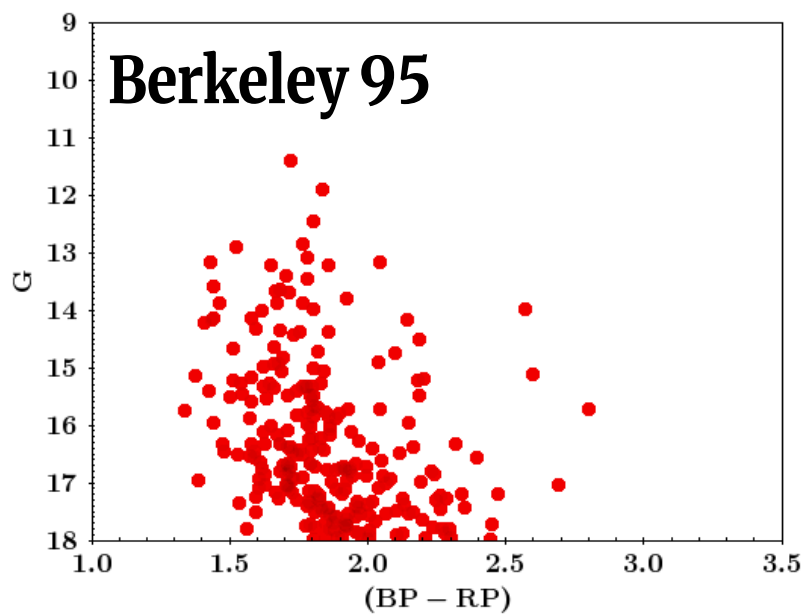
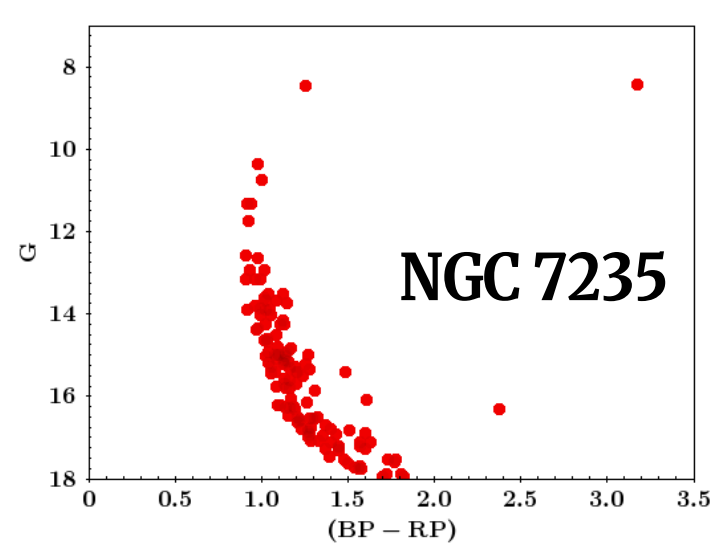
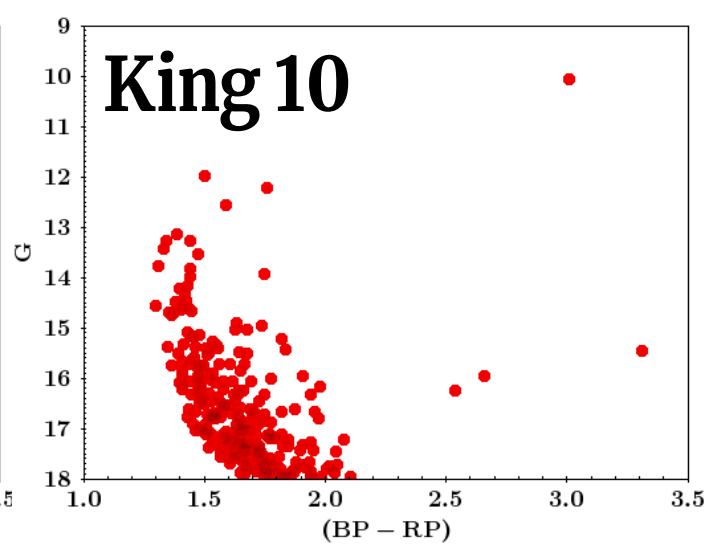
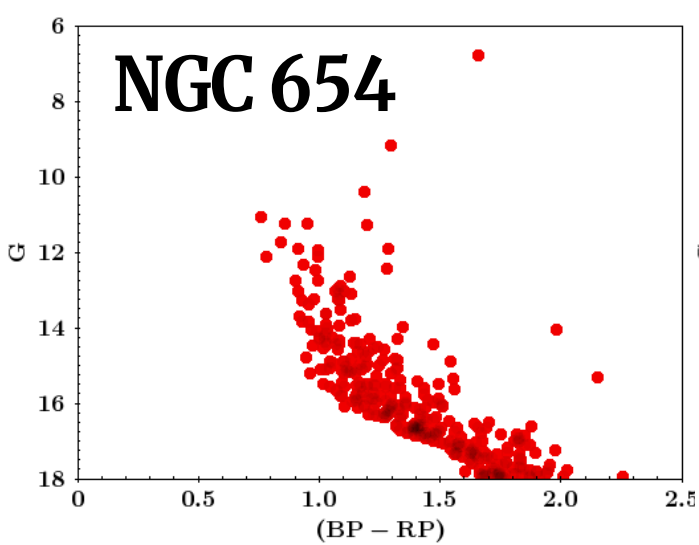
D. Weißmayer¹ , N. Przybilla¹ , and K. Butler²

Recently, **Wessmayer+** argue that these two objects are a few hundred parsecs behind the cluster based on slightly disagreeing parallaxes, but ...

- Formal errors in *Gaia* parallaxes are underestimated (**Maíz-Apellániz+ 2021**)
- All Bayesian algorithms take them as cluster members (**Cantat Gaudin+2020, DR2; Hunt & Reffert 2023, DR3**)
- This is a widespread phenomenon

NGC 2129





Is there a way to look into this?

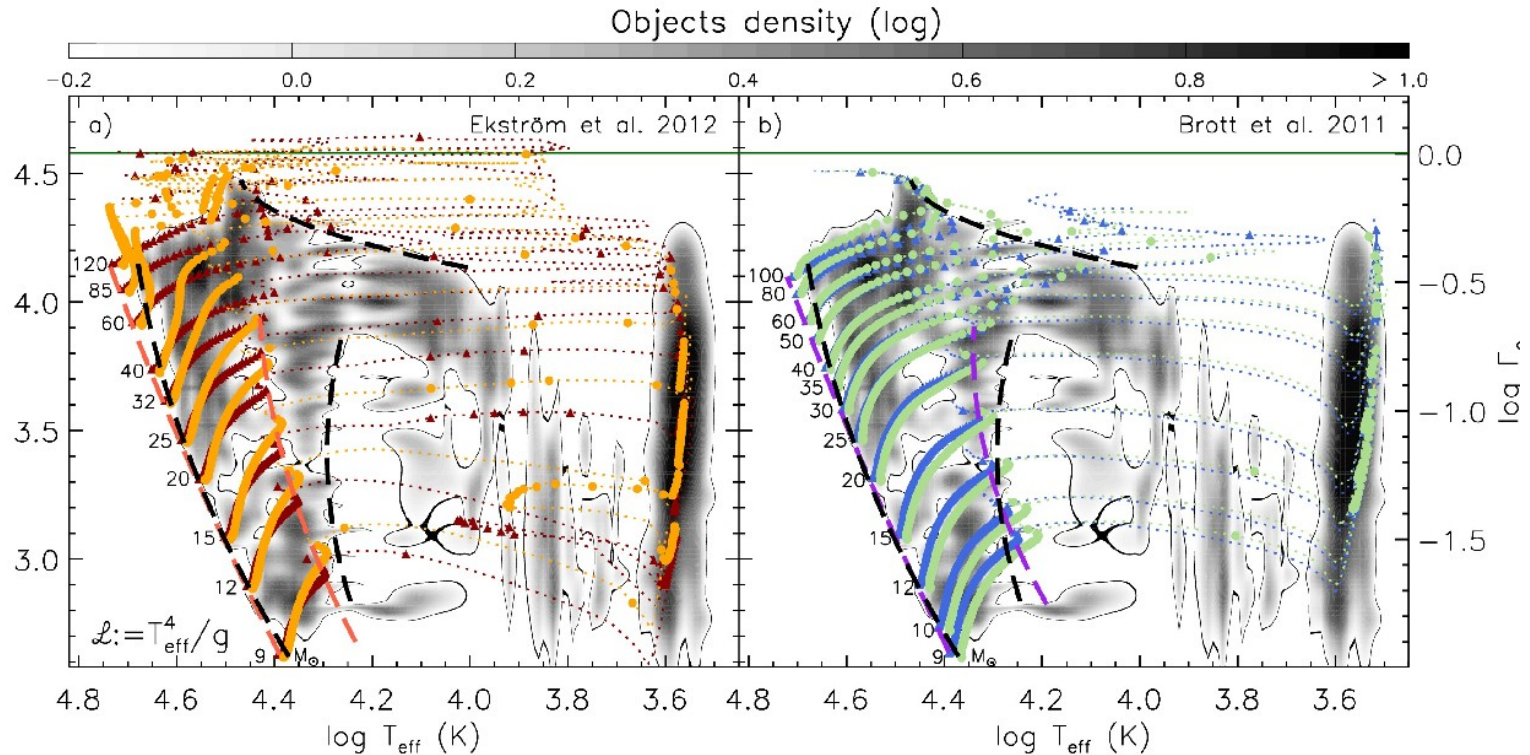
- ◆ The sequences of young open clusters broaden considerably around the turn-off (cf. [Bodenstainer+2020, 2023](#)).
- ◆ They broaden to the red because of rotation, but also to the blue because of binary evolution.
- ◆ Blue stragglers are common, and generally display evidence of being ejected.
- ◆ Blue supergiants generally are much brighter than the isochrone and have spectroscopic masses around twice that of turn-off stars.

What are B-type supergiants?

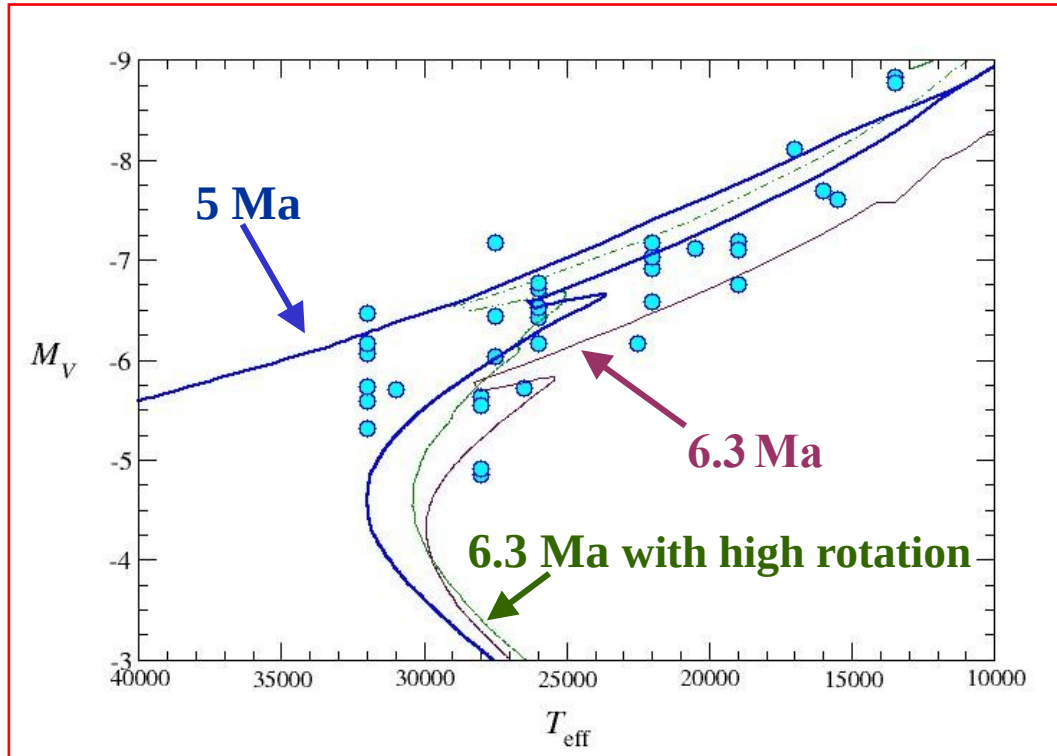
- ◆ They are separate in CMDs, HRs and sHRDs.
- ◆ They are not weird. In fact, these objects are the MK standards.
- ◆ They have typical cluster-member kinematics.
- ◆ They do not show effects of extreme CNO mixing.
 - **Post-RSG stars on their way to WR phase?**
 - **Merger products**
 - **Any suggestions?**

What are B-type supergiants?

Why are they consistent with an extended TAMS (Castro+ 2014; de Burgos+, in prep.)?



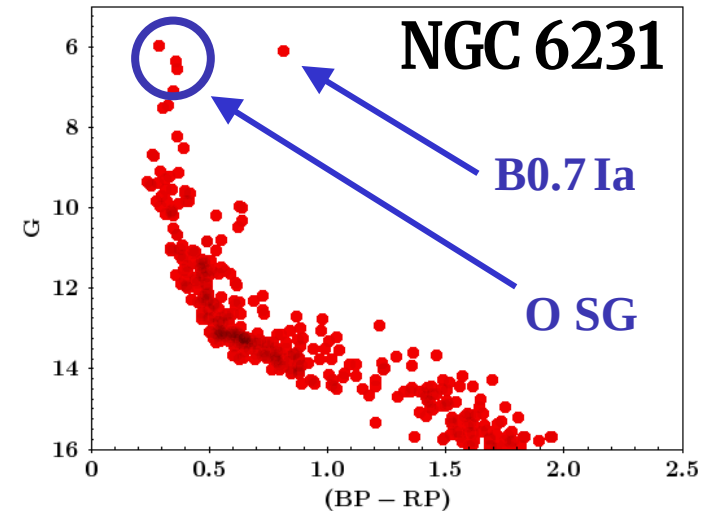
How do BSGs look in younger clusters?



Negueruela+ 2010

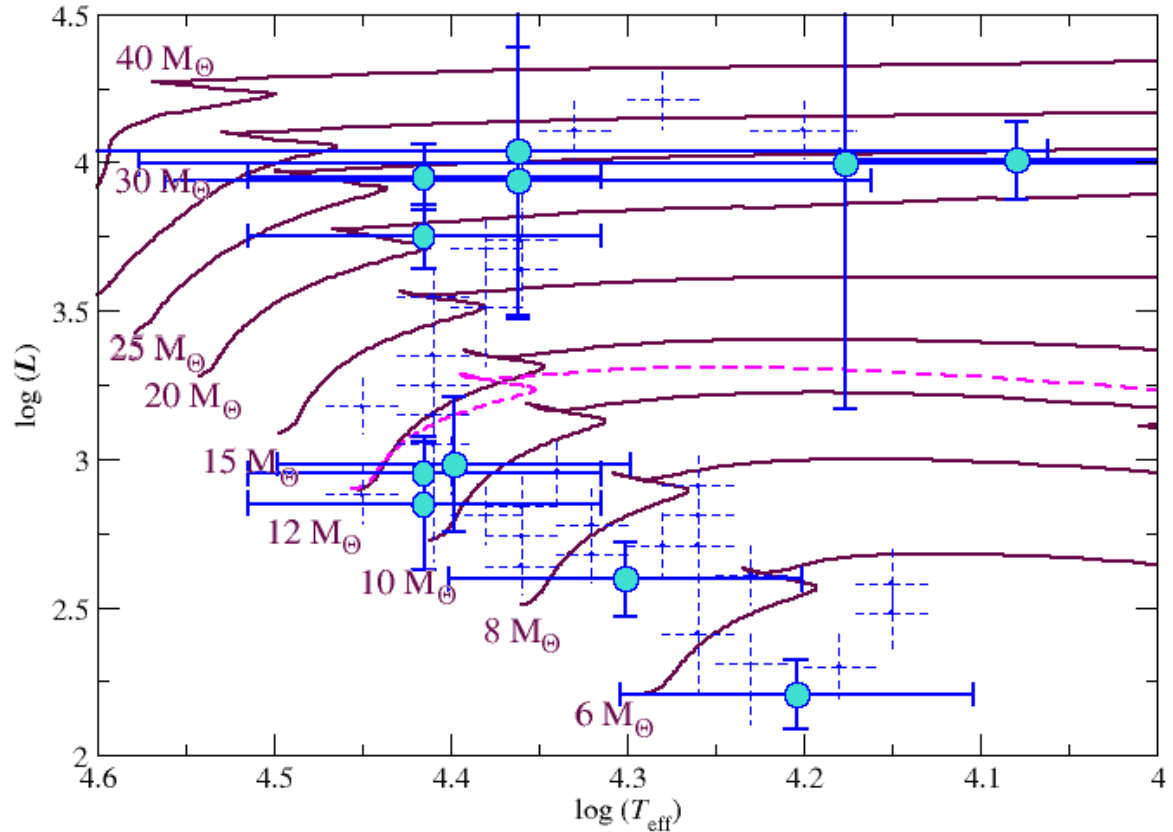
Older Geneva isochrones; take ages with care

A sequence of supergiants extending from O9 to A2 Ia in Westerlund 1



How do BSGs look in younger clusters?

NGC 7510





The upper sequence of young open clusters is shaped by binary interaction



Ignacio Negueruela

Garching, September 2023

Department of Physics, Universidad de Alicante