

MASSIVE YOUNG CLUSTERS IN THE MILKY WAY

Ignacio Negueruela

Astrofísica

en la

Universitat d'Alacant
Universidad de Alicante



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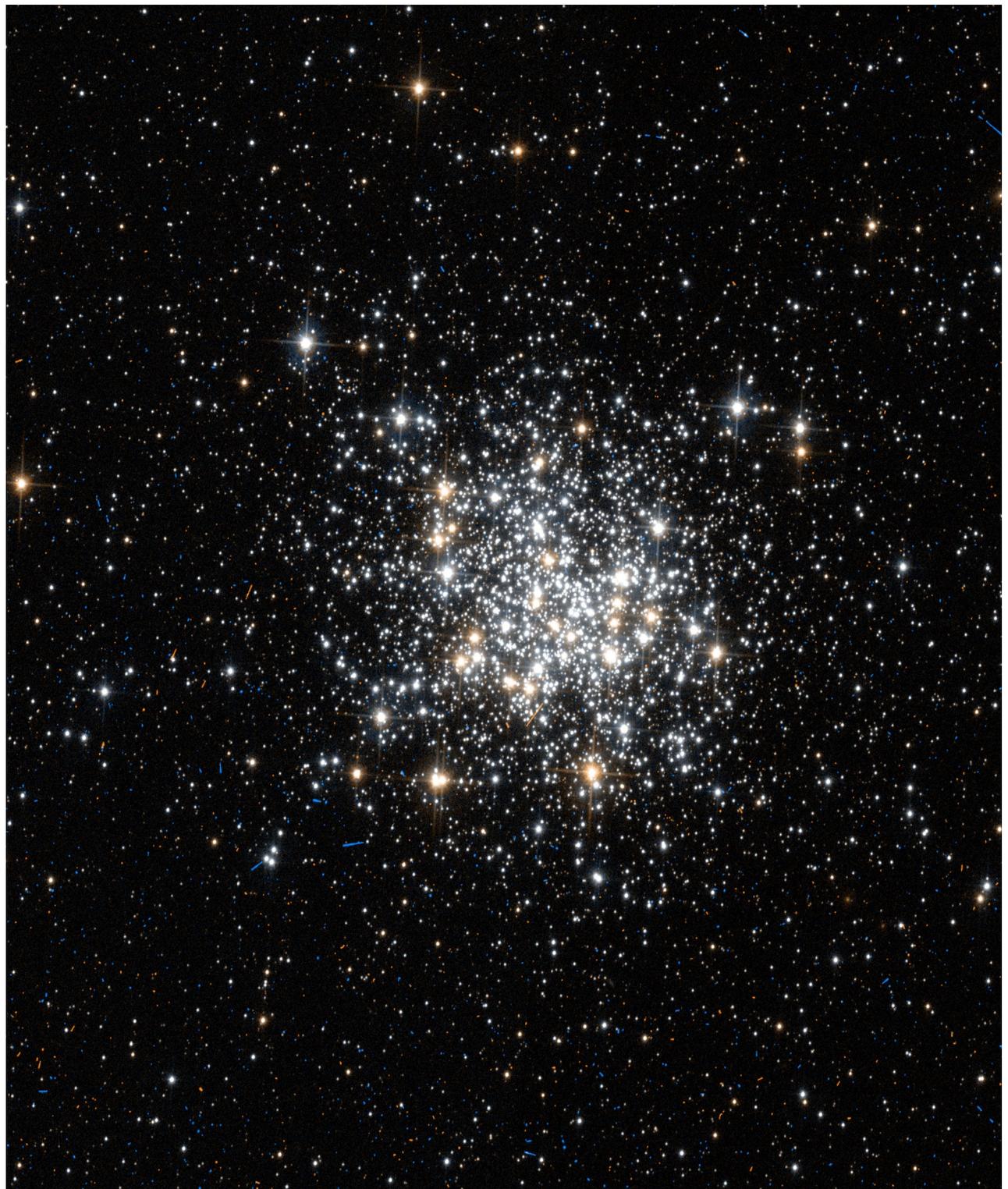
Outline

- Definition
- Astrophysical interest
- Gaia's limits
- Things we are missing

Alicante (Amparo Marco), CAB (Francisco Najarro,
Jesús Maíz), IAC (Artemio Herrero)

What are we calling a young massive cluster?

- Definition of “massive” depends on context
- In the Milky Way, we go for initial mass
 $M_{cl} \geq 10^4 M_{\odot}$ (Focus Meeting at the Beijing IAU GA, 2013)
- An astrophysical laboratory on its own - cf. upper limit to the stellar mass (Arches, **Figer 2005**; R136, **Crowther+ 2010**; stellar evolution; role of multiplicity; planet formation in harsh conditions)

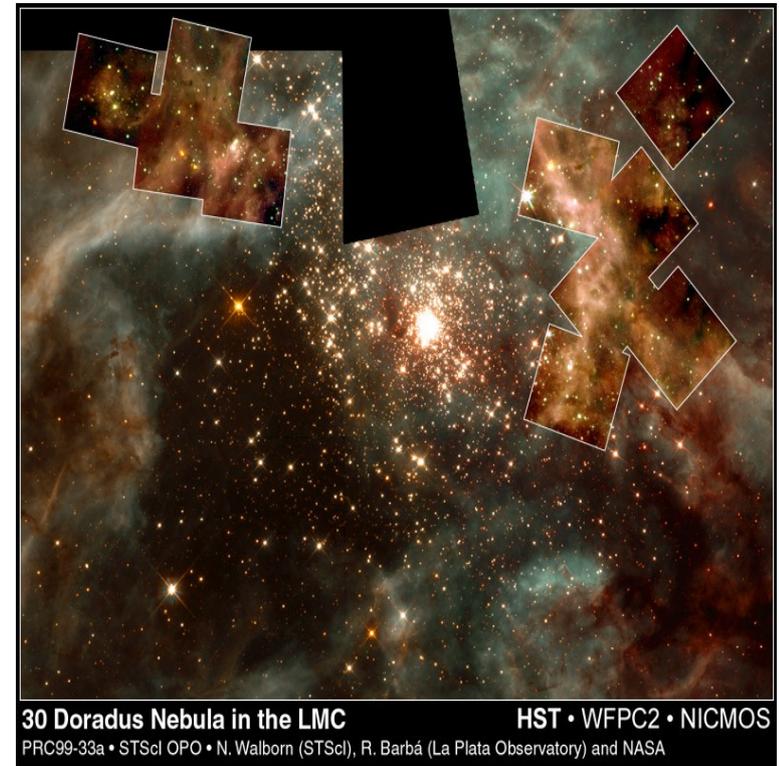


The young globular NGC 1755, in the LMC (HST image from Wikipedia)

Young massive clusters

” Even if these (LMC) clusters are not quite as spectacular as those found in genuine starburst galaxies, they are still more massive than any of the open clusters seen in the Milky Way today”

Larsen & Richtler 1999, A&A 345, 59



**Spiral starburst galaxy
NGC 3310**



The young globular NGC 1850, in the LMC

Bruch & Sanders (1983)

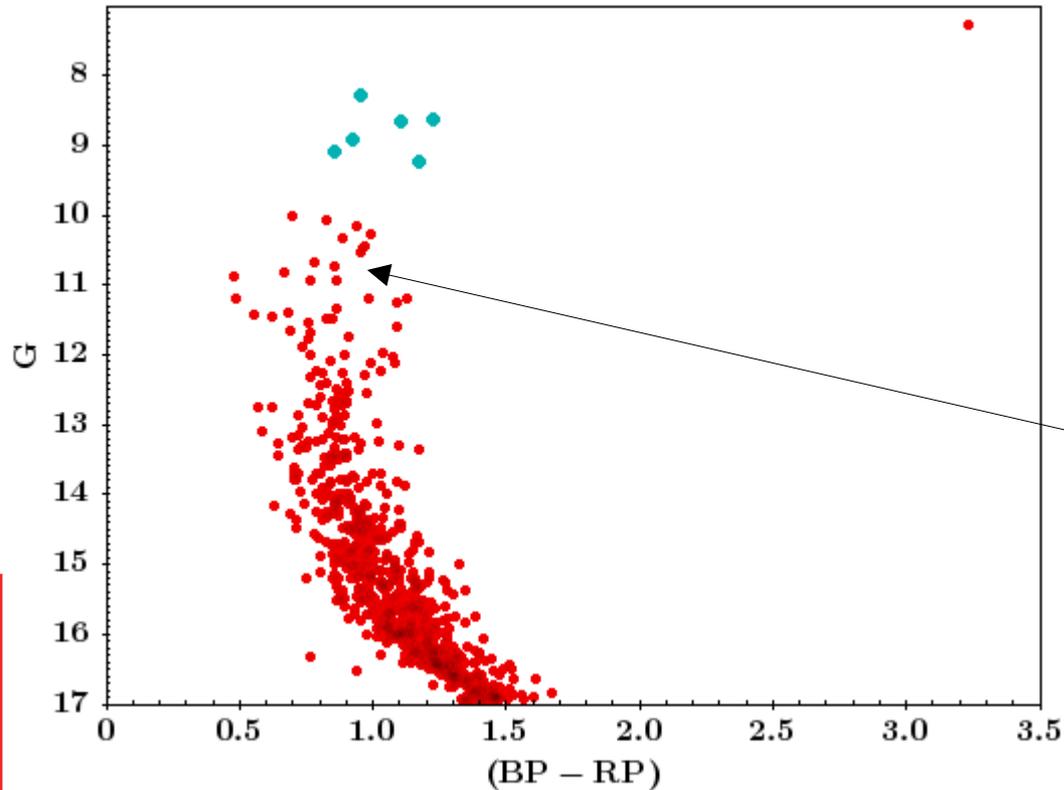
e.g. NGC 663: $800 M_{\odot}$

... but *Gaia* counts > 300 B-type stars in this image

- Age ~ 23 Ma
- Distance 2.7 kpc
- $A_V \approx 2.2$
- Mass $\sim 1 \times 10^4 M_{\odot}$



NGC 663



Stellar content:

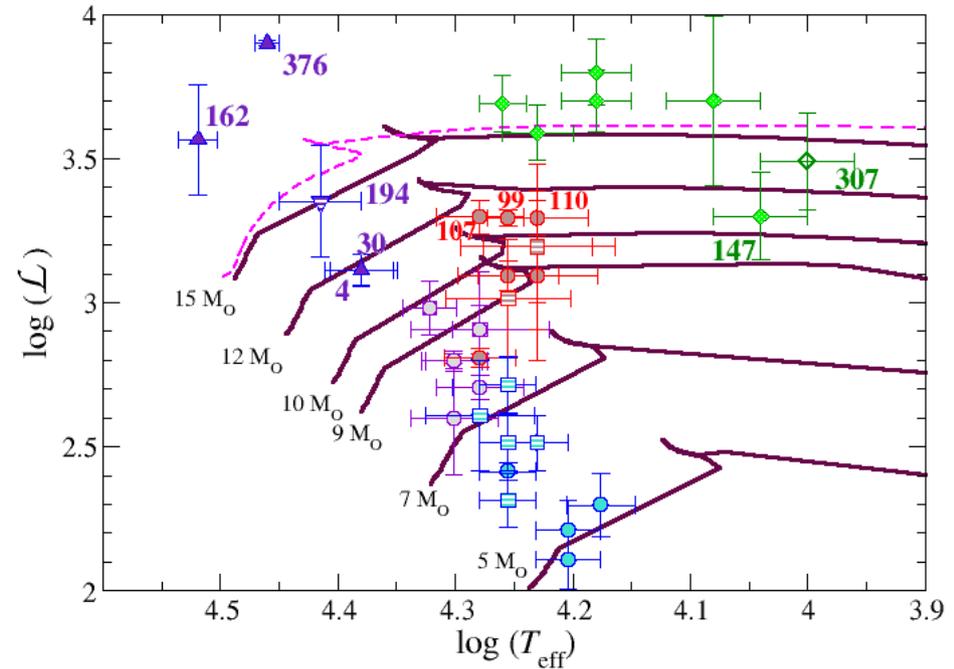
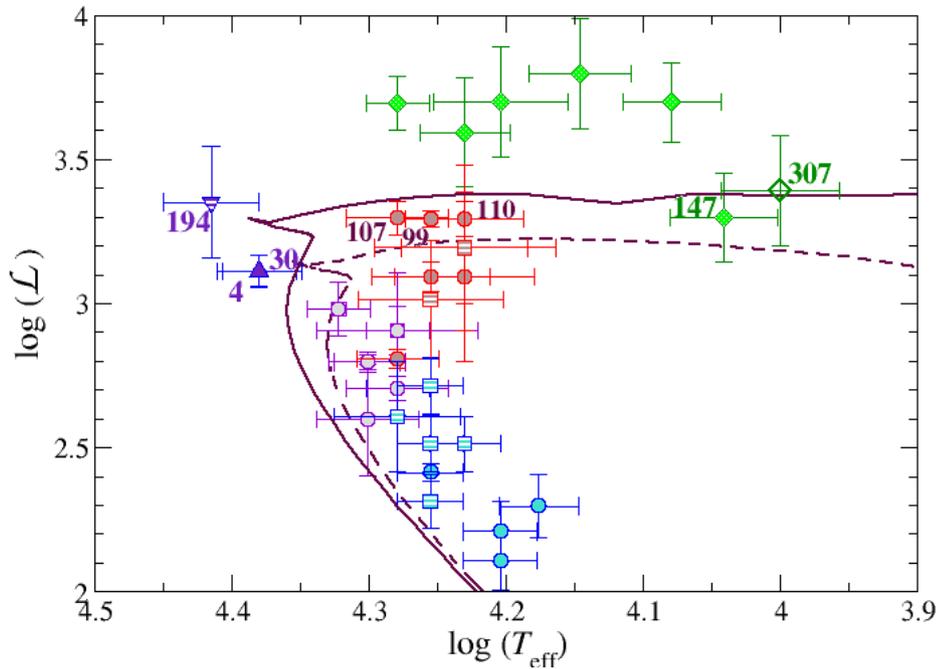
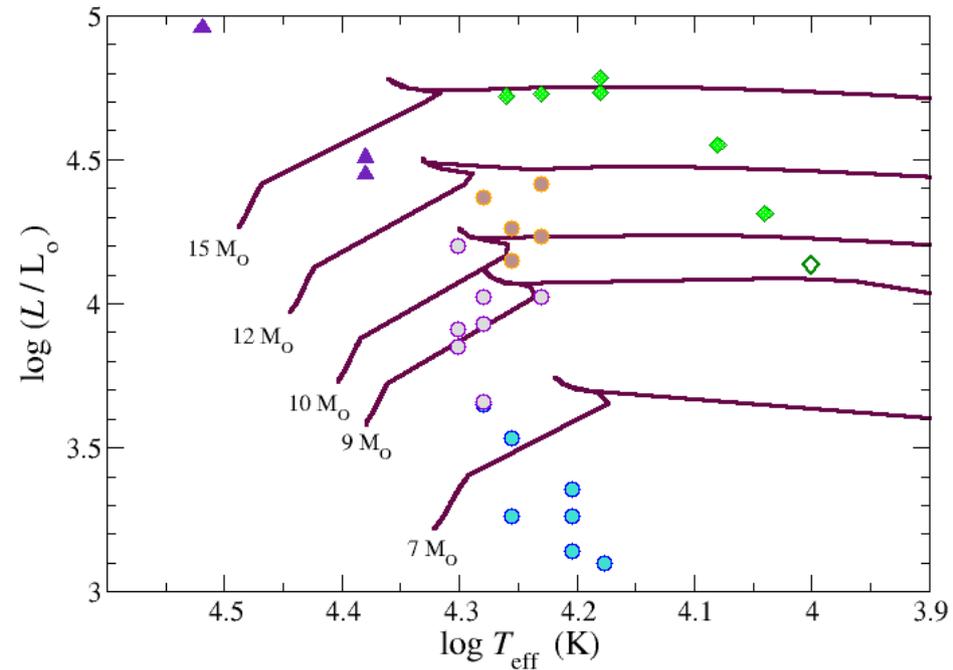
- **Class V**
 - A few B2 V, most Be
 - Many B2.5 V
 - B3-8 V
- **Class IV**
 - A few B2 IV, most Be
 - Many B2.5 IV
- **Class III**
 - B2 III, B2.5 III, one B3 III

- Spectra for > 140 cluster members
- Present-day mass $\sim 8000 M_{\odot}$
- Initial mass $\sim 12000 M_{\odot}$

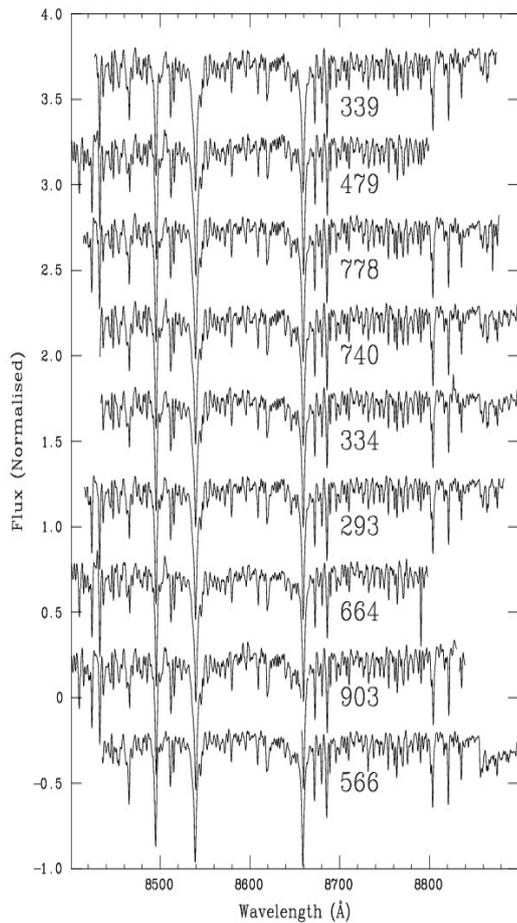
Marco+ 2025; MNRAS 542, 703

NGC 663

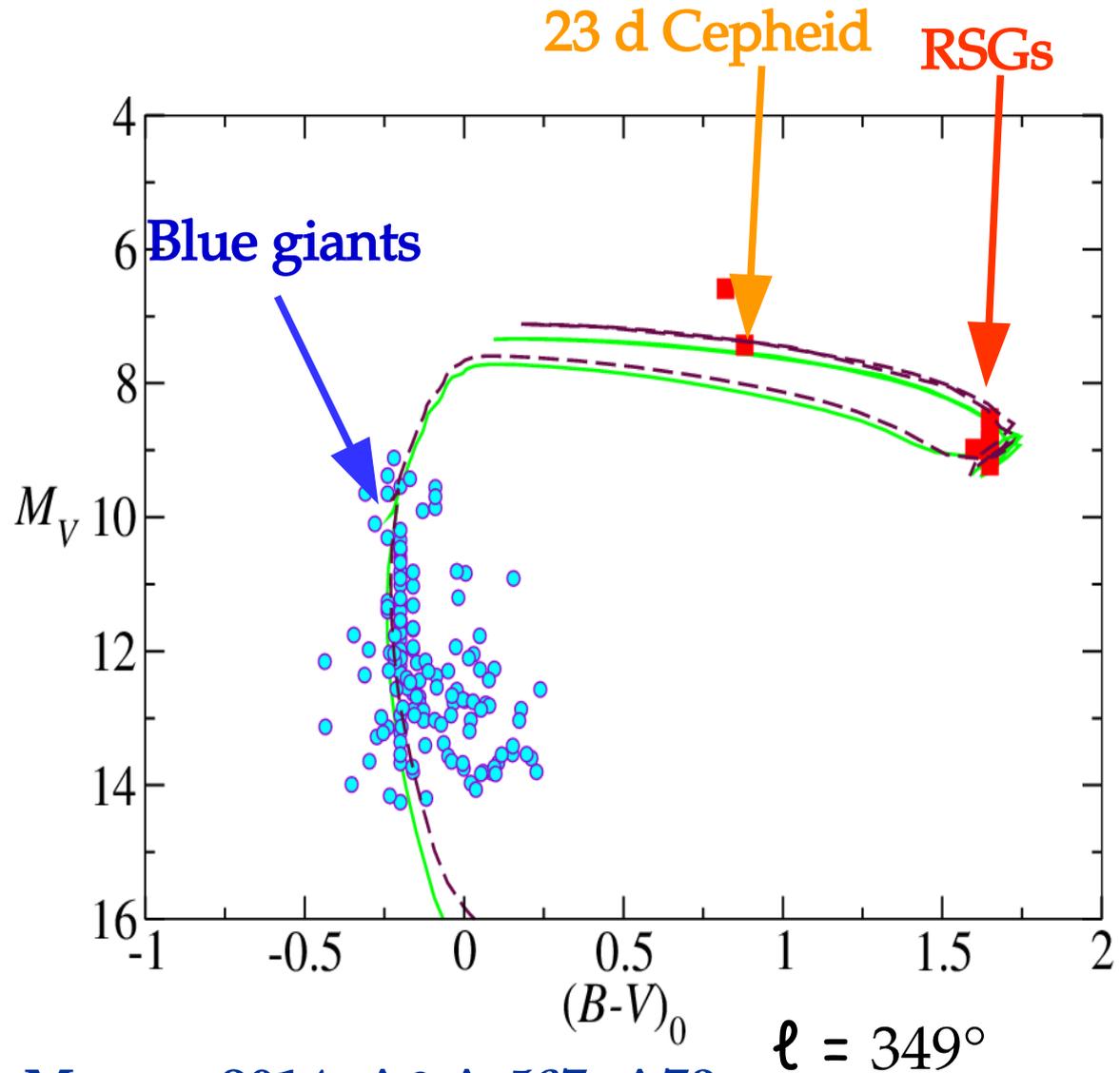
- About 50 B2-B2.5 stars (III to V)
- The evolution of most BSGs cannot be explained by single star tracks



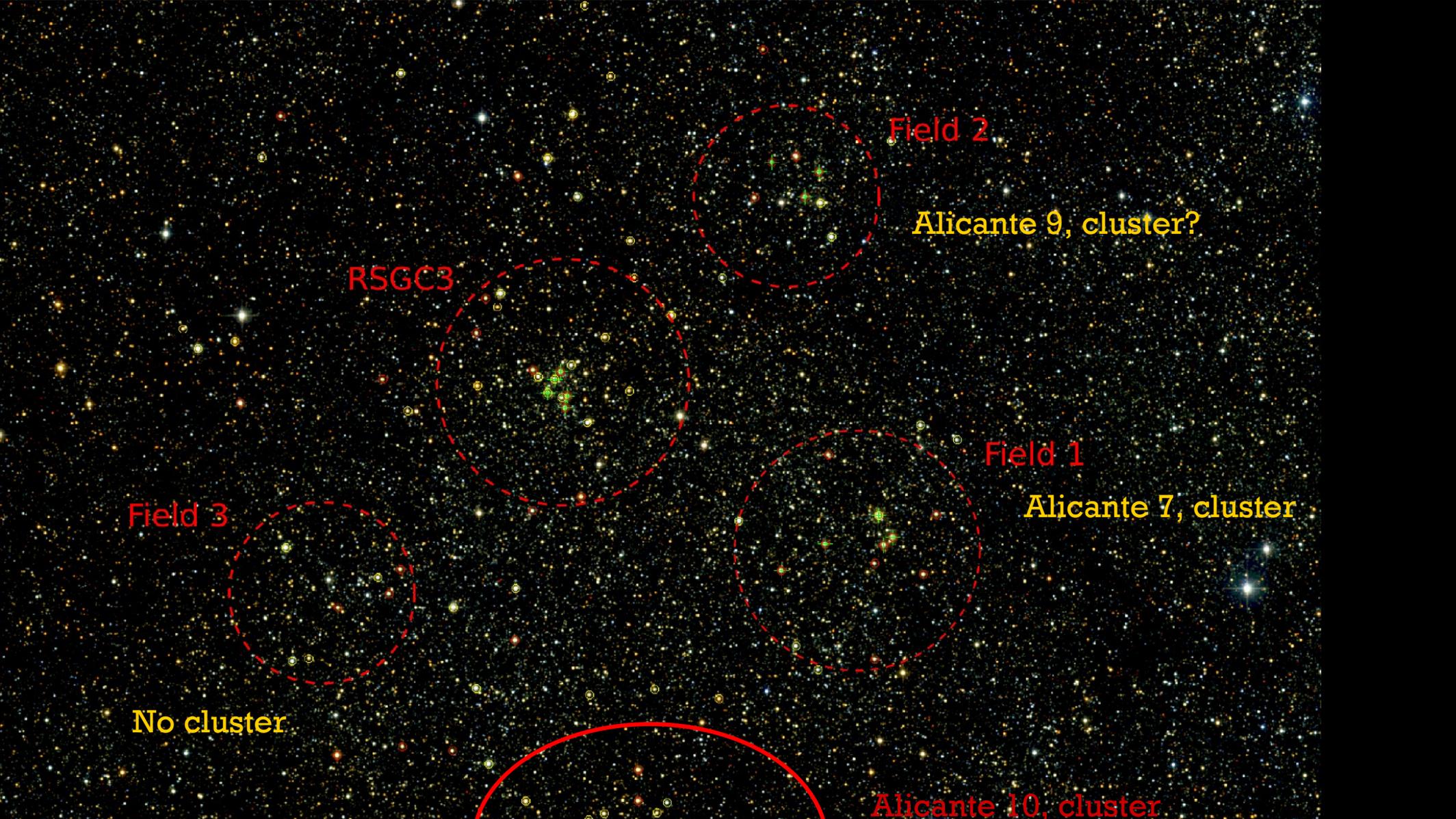
VdBH 222



- Age ~ 20 Ma
- Distance ~ 6 kpc
- Mass $\sim 2 \times 10^4 M_{\odot}$
- $A_V \approx 7.5$
- $v_{\text{LSR}} = -100 \pm 3$ km/s



Marco+ 2014; A&A 567, A73



Field 3

RSGC3

Field 2

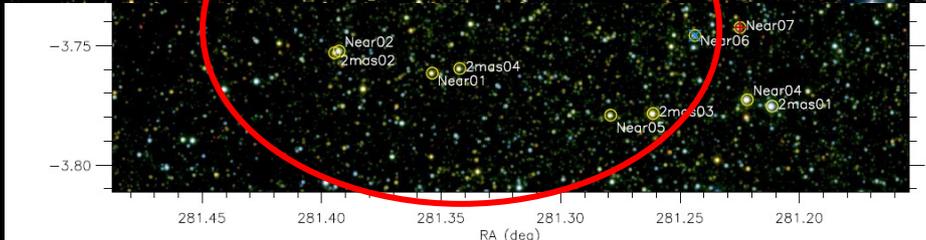
Alicante 9, cluster?

Field 1

Alicante 7, cluster

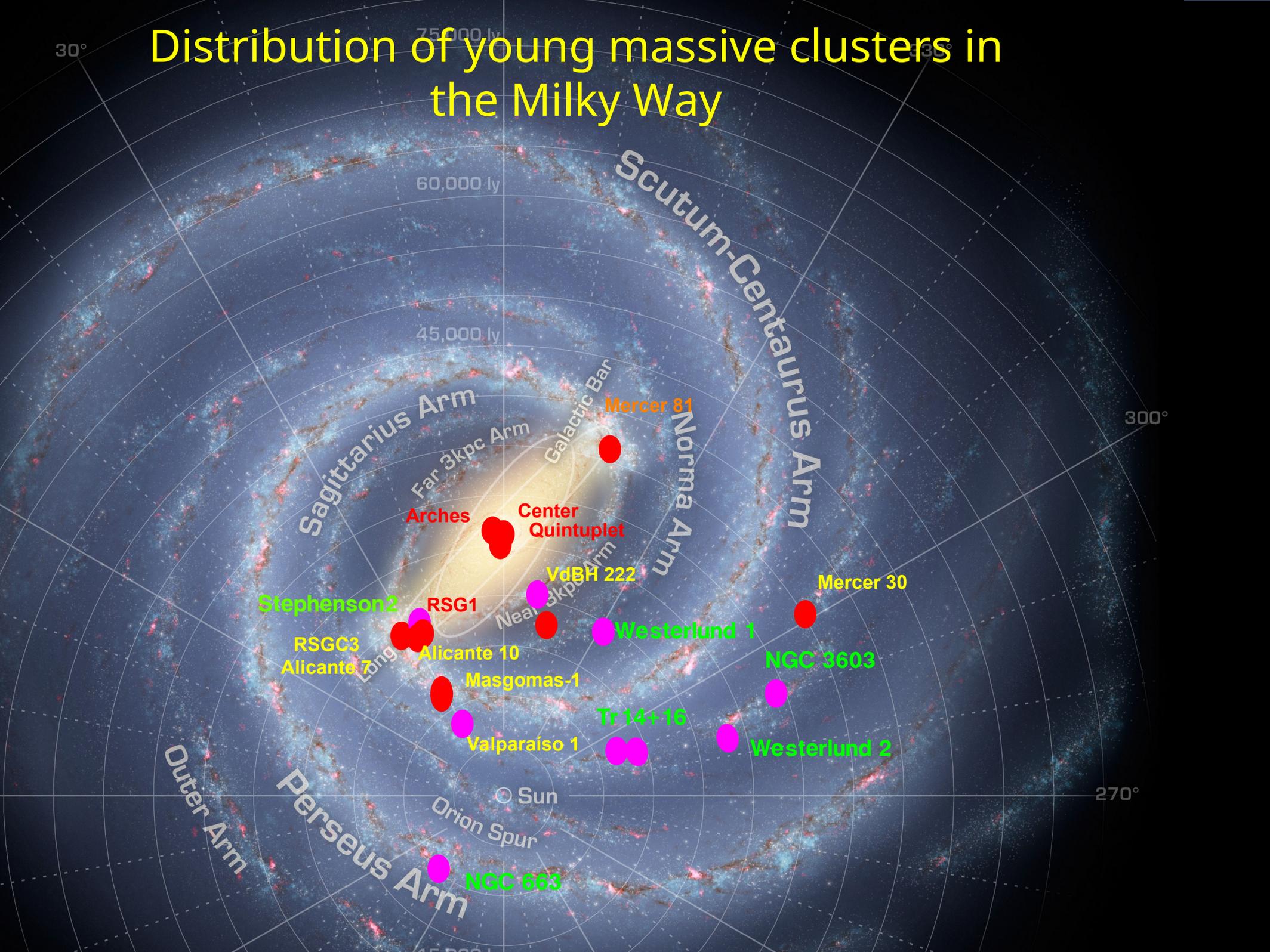
No cluster

Alicante 10, cluster



VLT/ISAAC
González-Fernández &
Negueruela 2012, A&A 539,
A100

Distribution of young massive clusters in the Milky Way



M 11

McNamara & Sanders (1977)

Star counts: $2900 M_{\odot}$

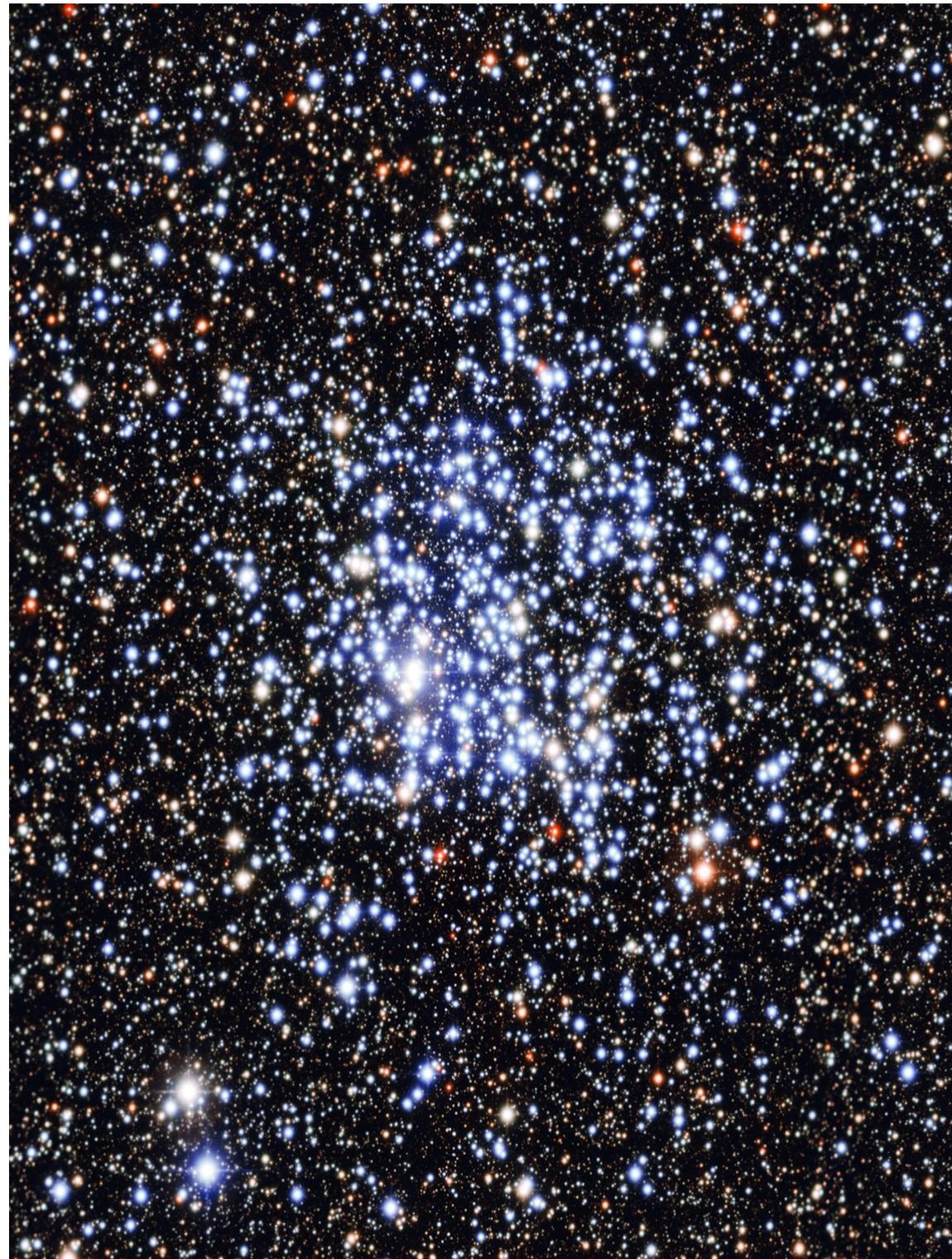
Virial: $6000 M_{\odot}$

- Sagittarius Arm cluster
- Nearby (1.8 kpc), low extinction ($E(B-V)=0.4$), age 250 Myr

- Present day mass

$$M \approx 10^4 M_{\odot}$$

(**Santos+2005; Cantat Gaudin+2014; Bavarsad+2016**).



Why are young massive clusters so interesting?

- **Proxies of starburst conditions**
- **IMF under extreme conditions**
- **Disc survival in harsh environments**
- **The most massive stars are found there**
- **High-mass star evolution in context**

Gaia's magic

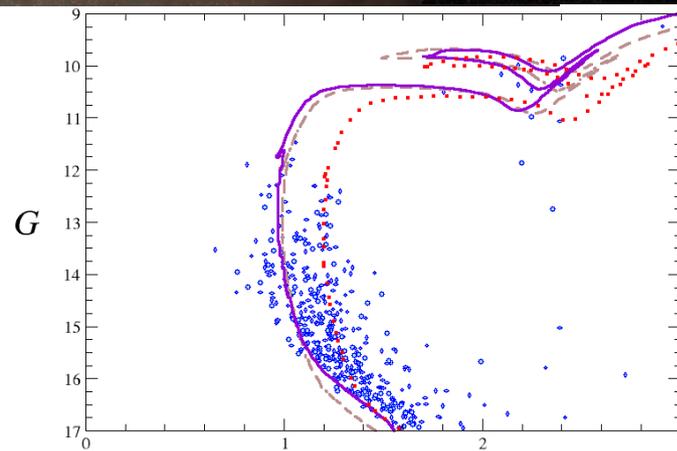


Gaia's magic



Valparaiso 1 = UBC 106

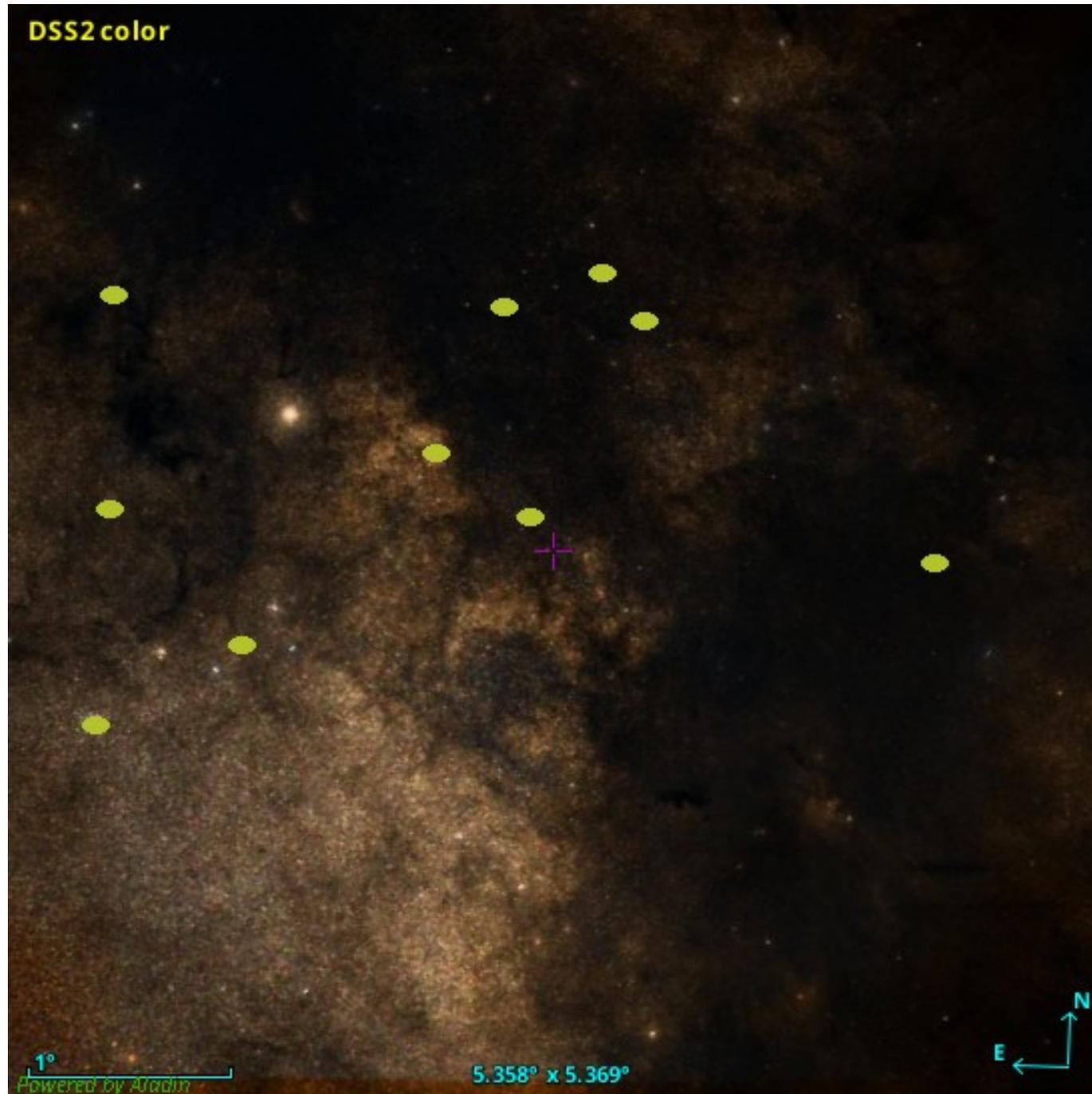
- Age ~ 75 Ma
- Distance ~ 2.3 kpc
- Mass $\sim 10^4 M_{\odot}$
- $A_V \approx 2.3$



BP-RP
Negueruela+ 2021; MNRAS 505, 1618

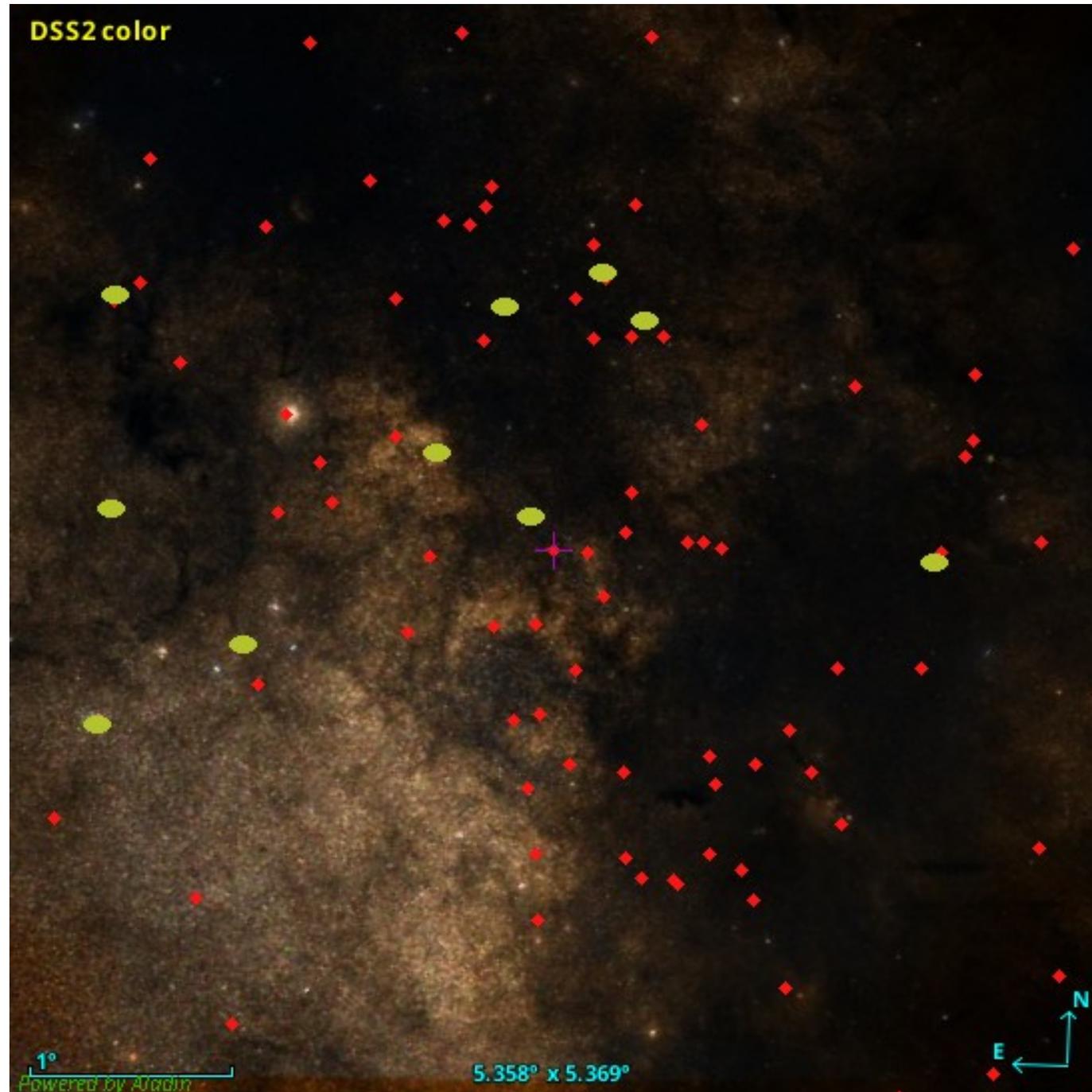
The Scutum Star Cloud

● Clusters from
Cantat-Gaudin+ 2020



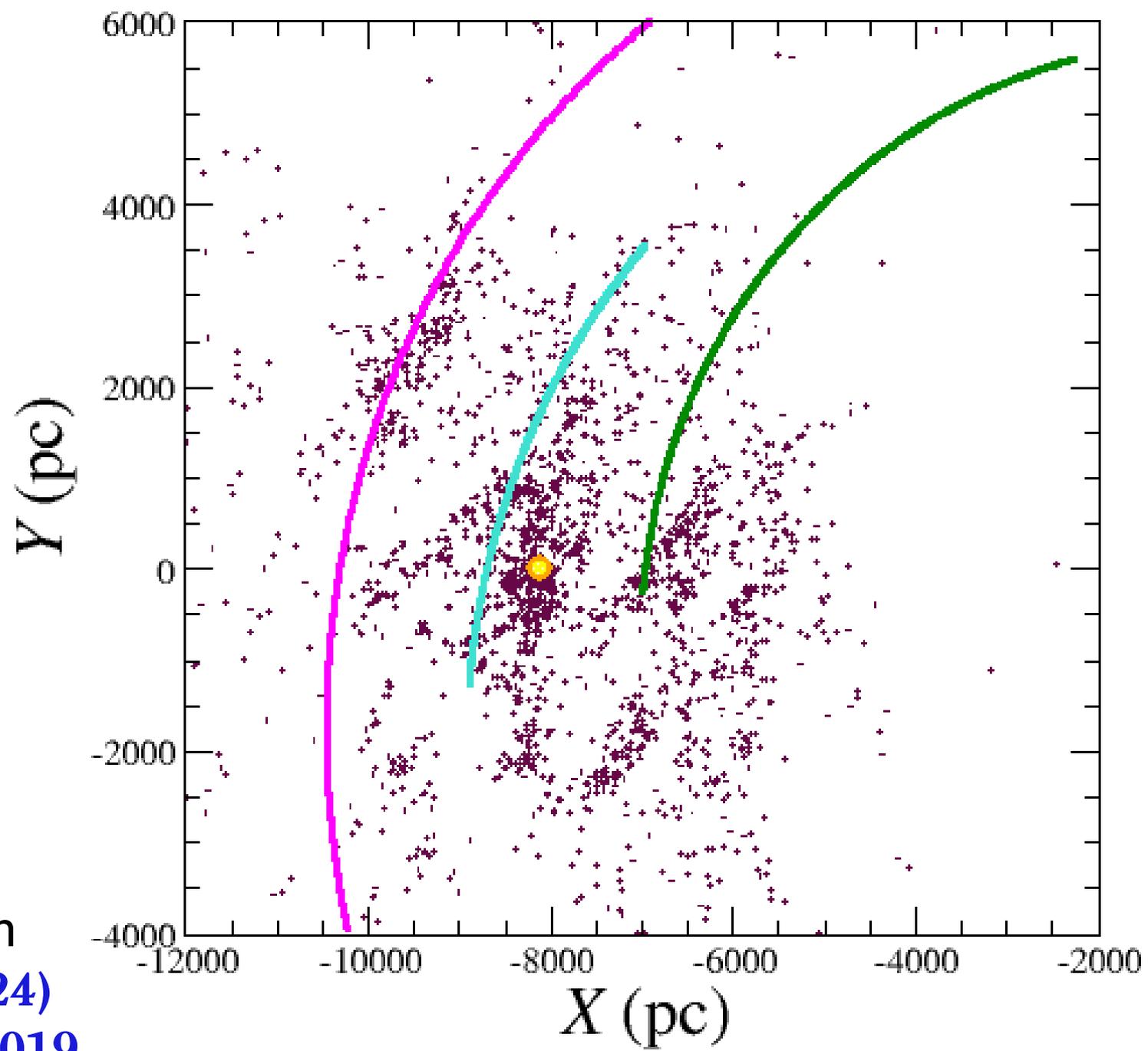
The Scutum Star Cloud

- Clusters from **Cantat-Gaudin+ 2020**
- ◆ Clusters from **Hunt & Reffert (2024)**





- Young clusters from **Hunt & Reffert (2024)**
- Arms from **Reid+ 2019**



Westerlund 1 is the most massive young open cluster in the Milky Way.

- At least 150 evolved massive ($M > 30 M_{\odot}$) stars observed imply $M \approx 10^5 M_{\odot}$ (Clark et al. 2005, A&A 434, 949)
- Star counts in the IR imply $M \geq 5 \times 10^4 M_{\odot}$ (Gennaro et al. 2011)



OPEN ACCESS

Gaia EDR3 Confirms that Westerlund 1 is Closer and Older than Previously Thought

Mojgan Aghakhanloo¹ , Jeremiah W. Murphy², Nathan Smith¹ , John Parejko³, Mariangelly Díaz-Rodríguez² , Maria R. Drout⁴, Jose H. Groh⁵, Joseph Guzman², and Keivan G. Stassun^{6,7} 

Published January 2021 • © 2021. The Author(s). Published by the American Astronomical Society.

[Research Notes of the AAS, Volume 5, Number 1](#)

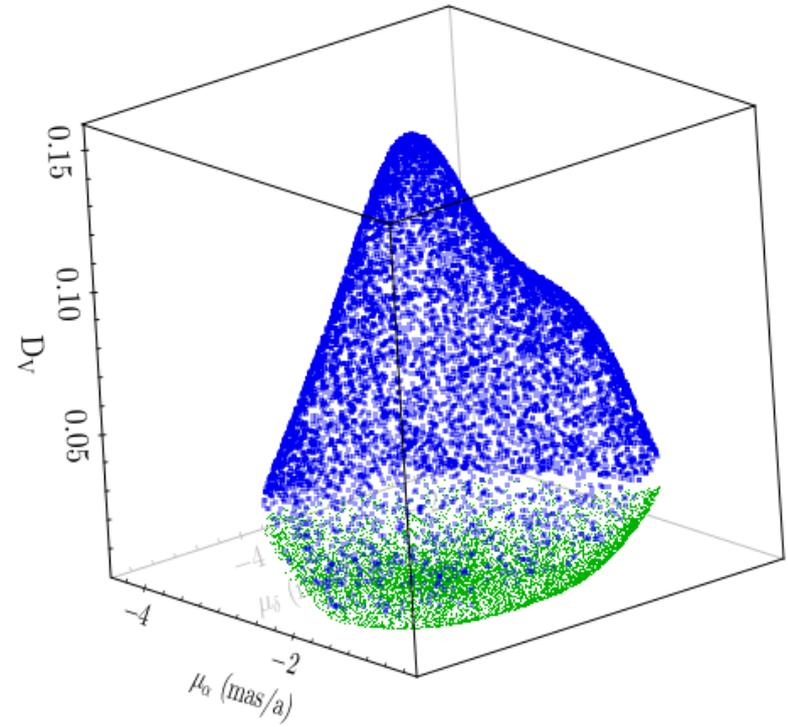
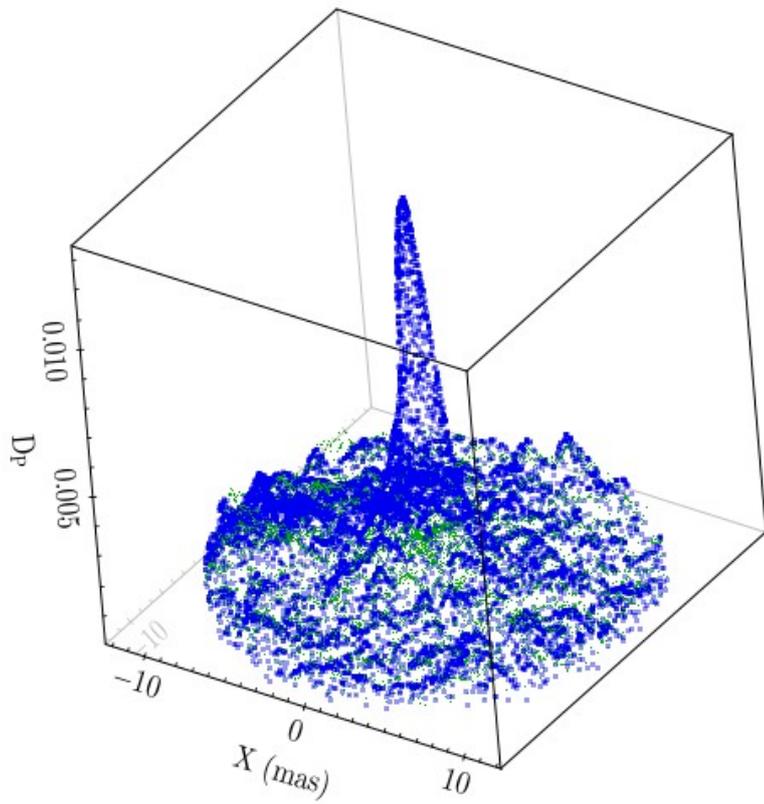
Citation Mojgan Aghakhanloo et al 2021 *Res. Notes AAS* **5** 14

[Figures](#) ▾ [References](#) ▾

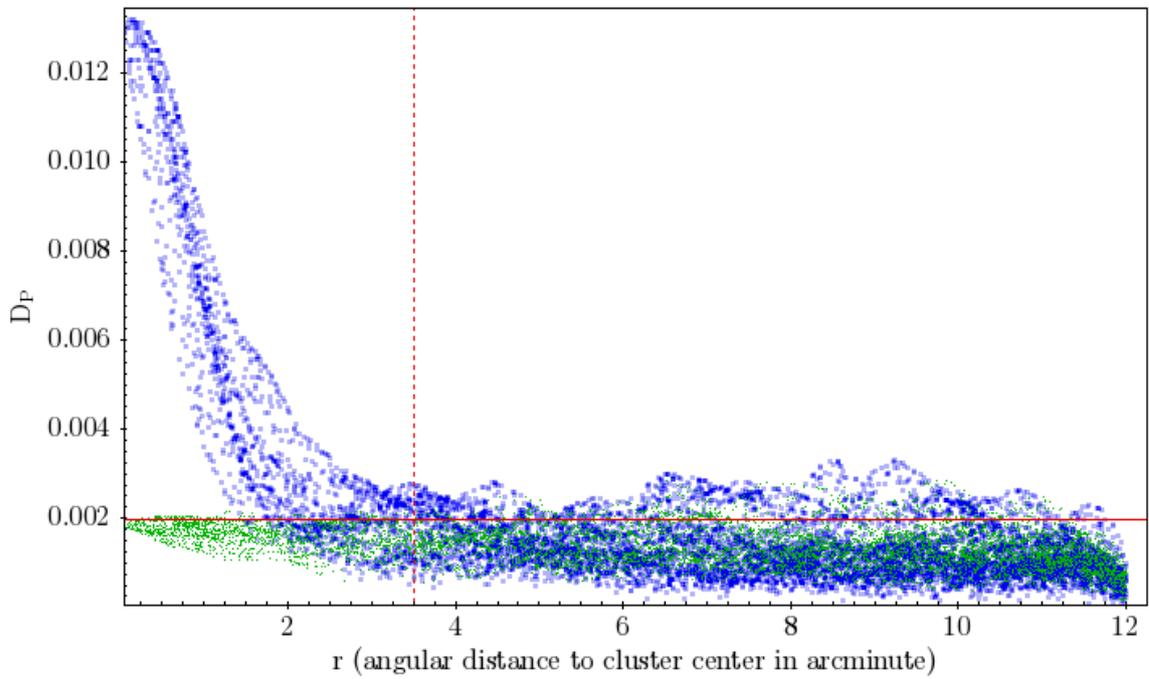
[+ Article information](#)

Abstract

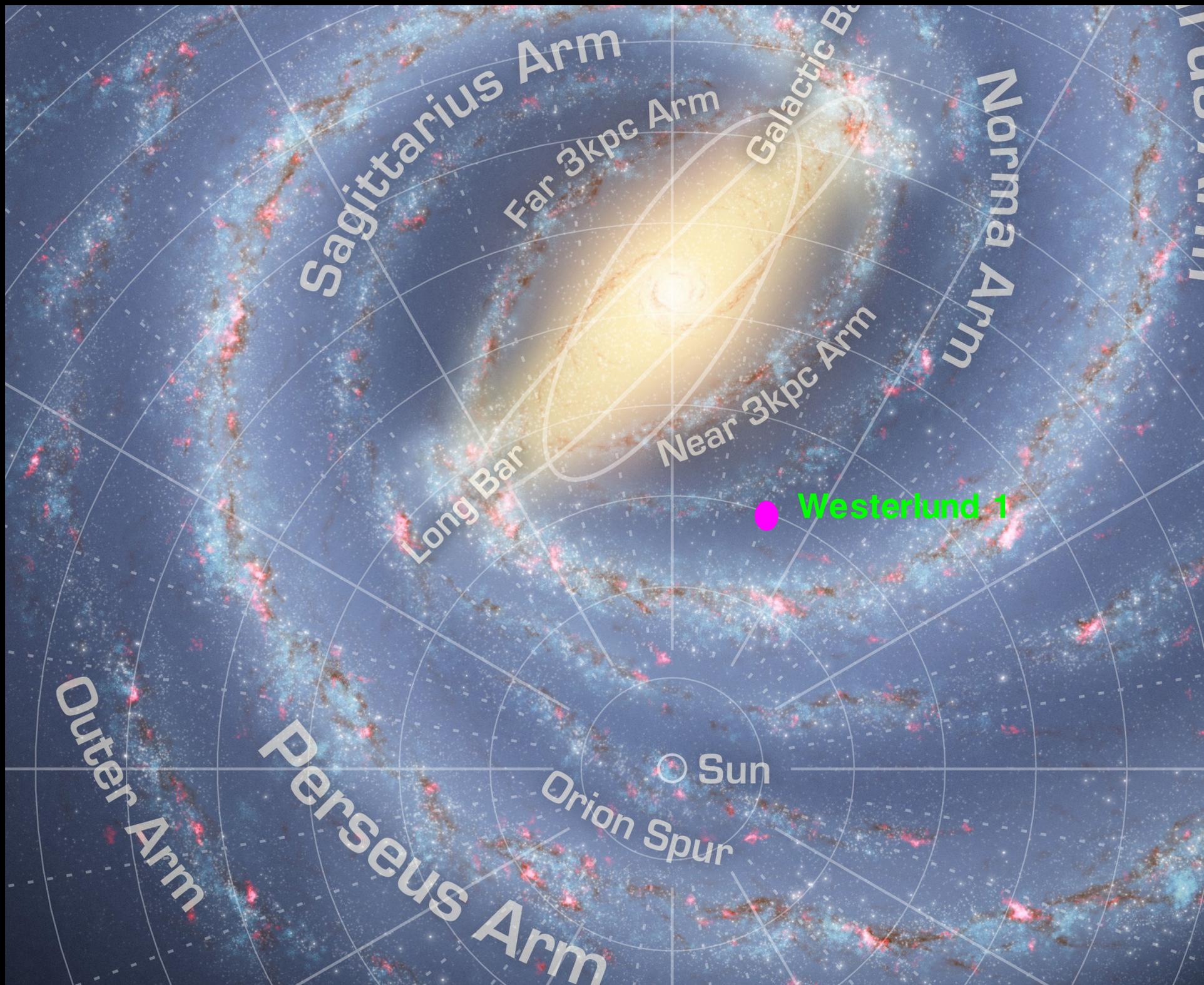
Using Gaia Early Data Release 3 (EDR3) parallaxes and Bayesian inference, we infer a parallax of the Westerlund 1 (Wd1) cluster. We find a parallax of 0.34 ± 0.05 mas corresponding to a distance of $2.8^{+0.7}_{-0.6}$ kpc. The new Gaia EDR3 distance is consistent with our previous result using Gaia Data Release 2 (DR2) parallaxes. This confirms that Wd1 is less massive and older than previously assumed. Compared to DR2, the EDR3 individual parallax uncertainties for each star decreased by 30%. However, the aggregate parallax uncertainty for the cluster remained the same. This suggests that the uncertainty is dominated by systematics, which is possibly due to crowding, motions within the cluster, or motions due to binary orbits.



Negueruela+ 2022, A&A 664, A146



Emilio Alfaro's codes



Sagittarius Arm

Far 3kpc Arm

Galactic Bar

Norma Arm

Long Bar

Near 3kpc Arm

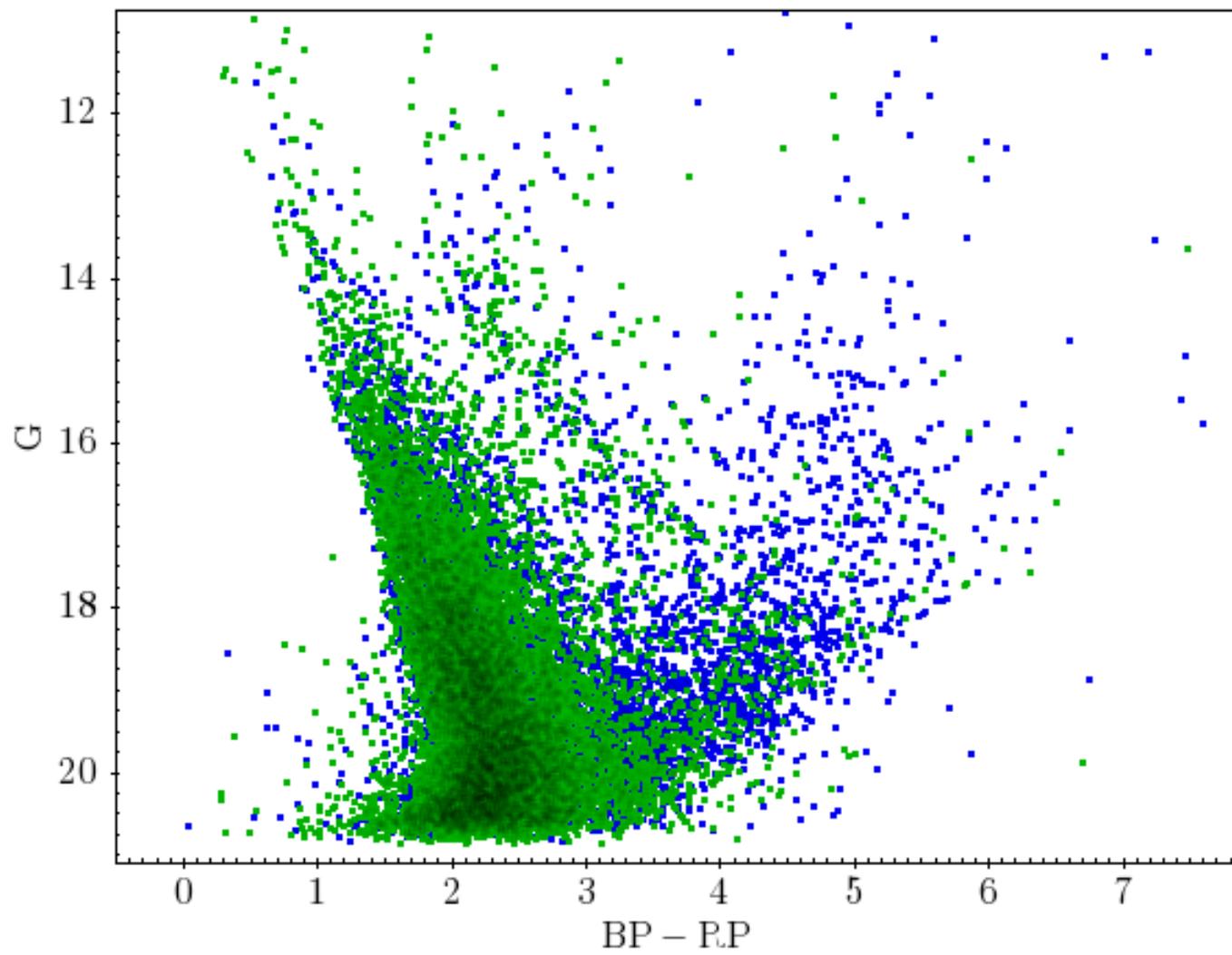
Westerlund 1

Outer Arm

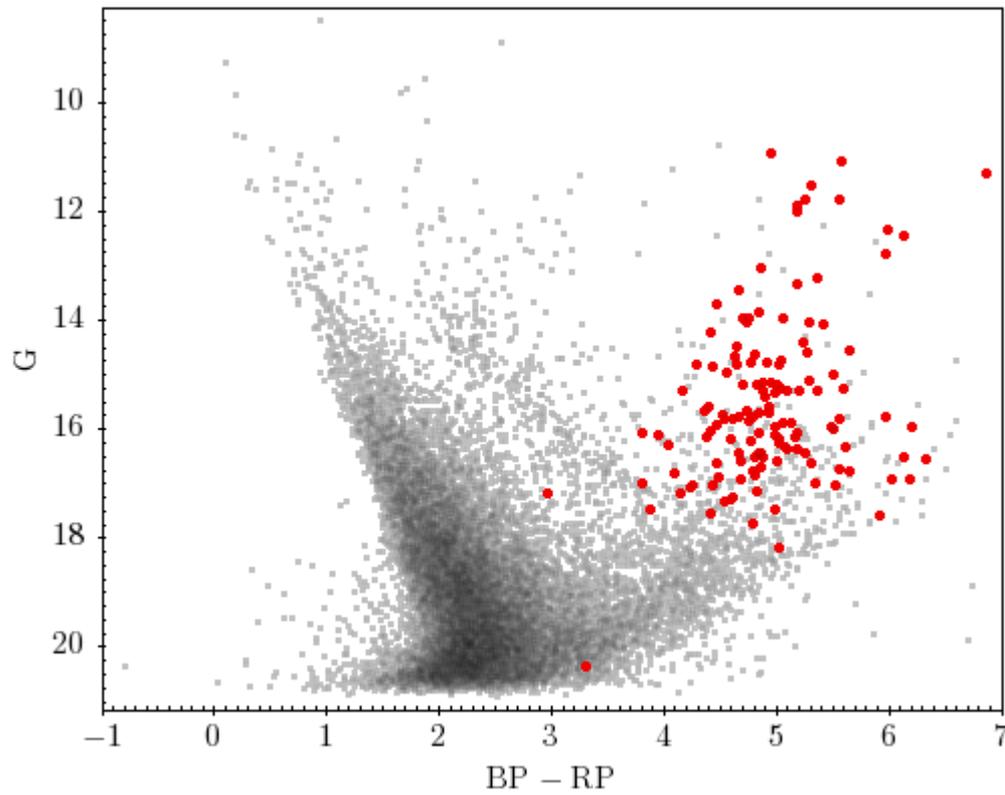
Perseus Arm

Sun

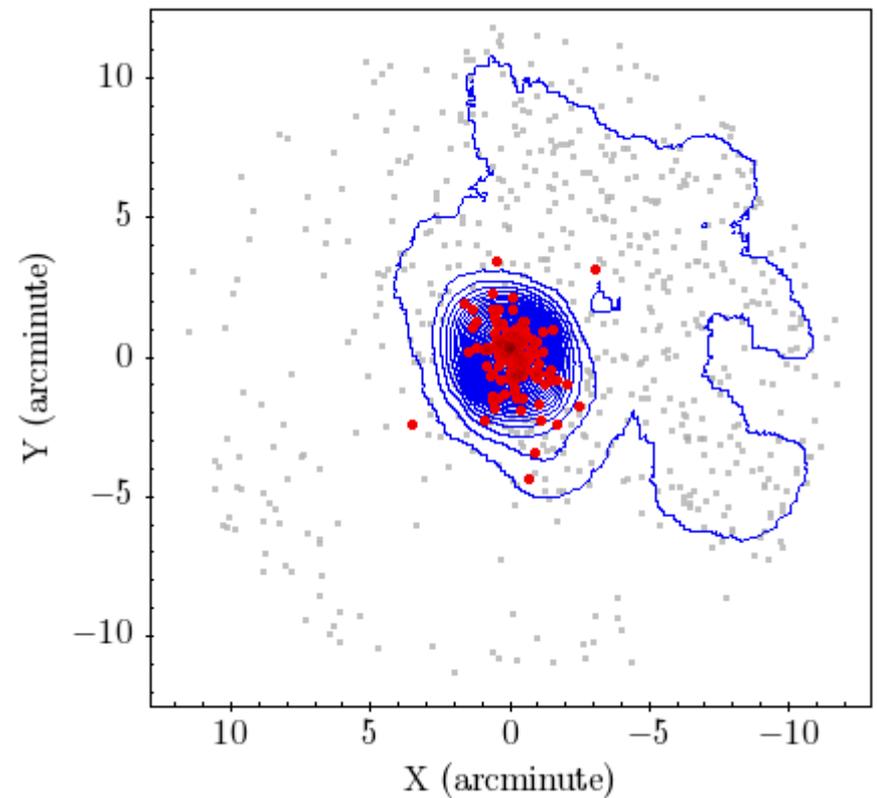
Orion Spur

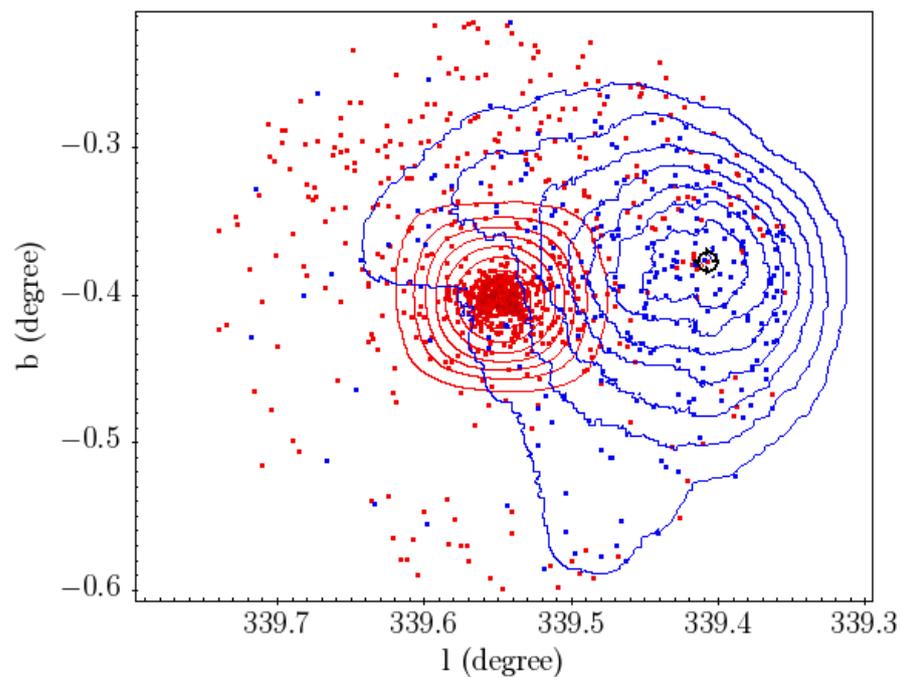
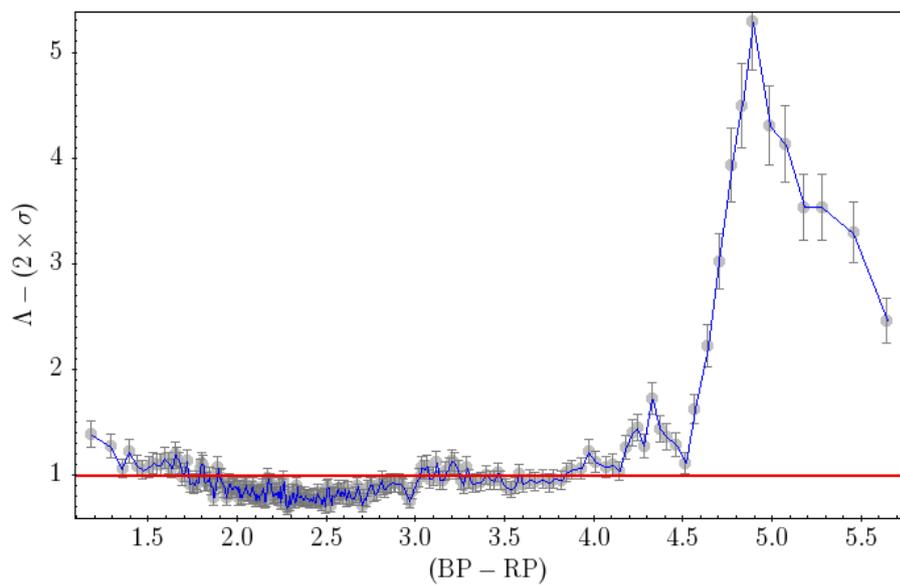
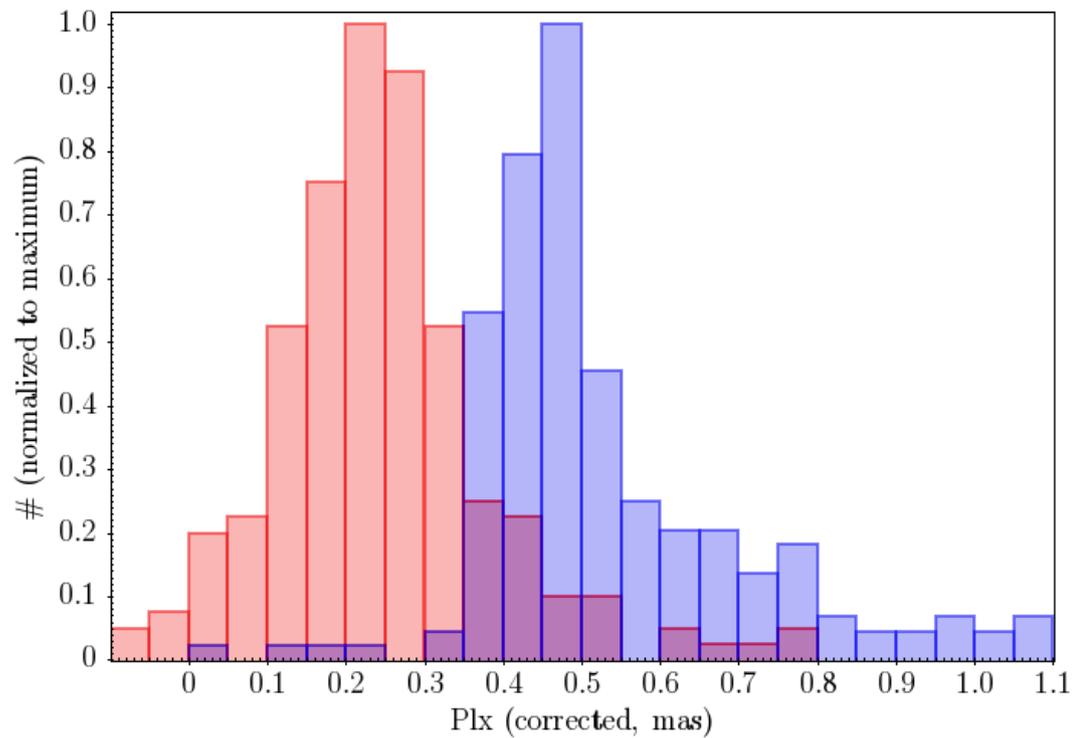
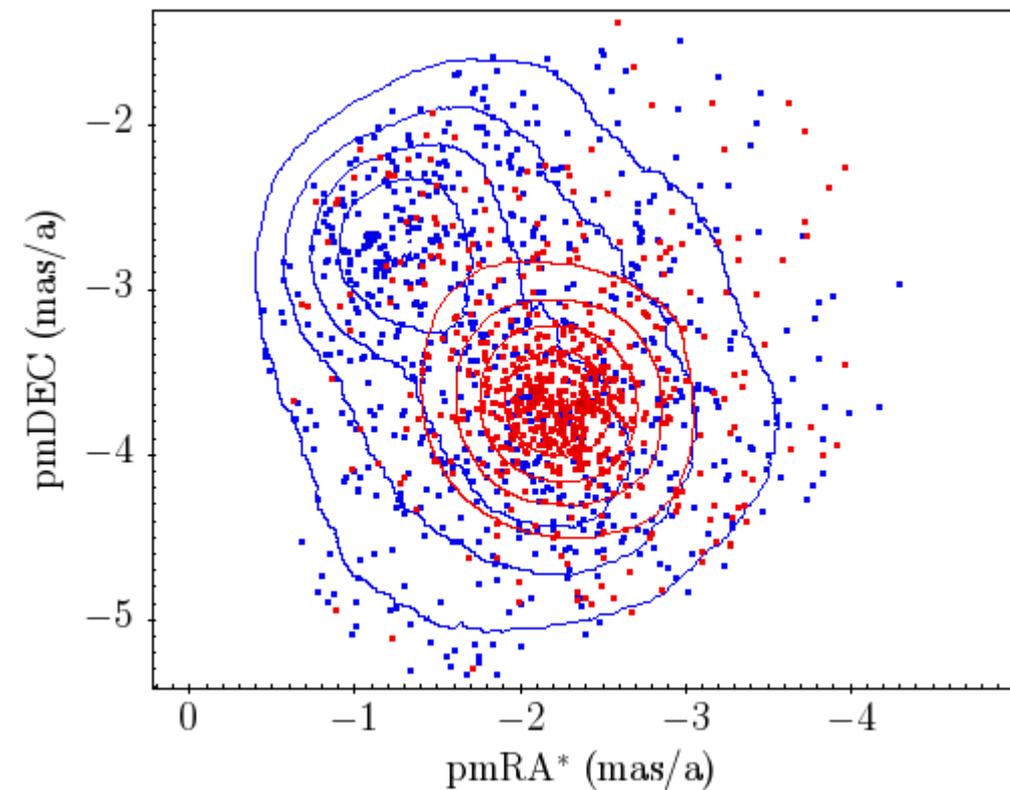


Lending *Gaia* a hand



Negueruela+ 2022, A&A 664, A146



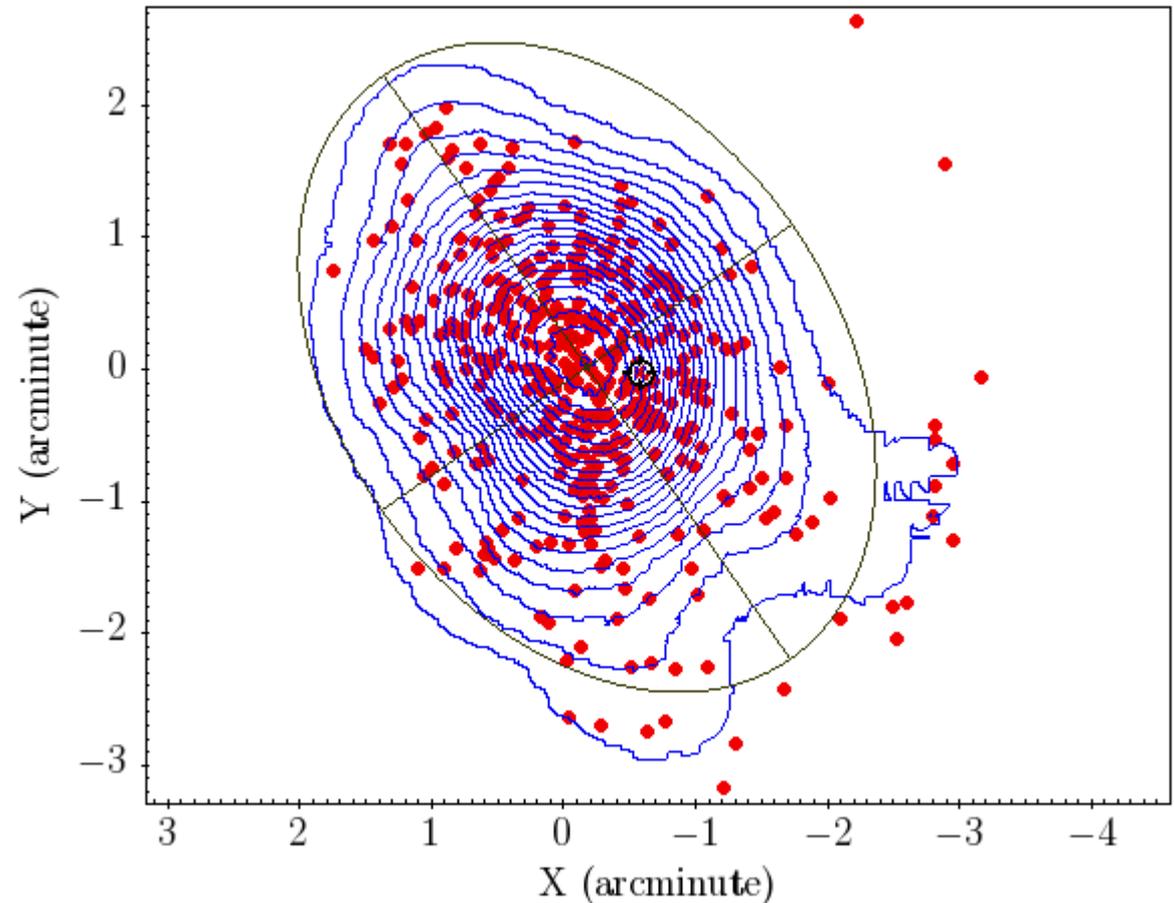


Cluster parameters

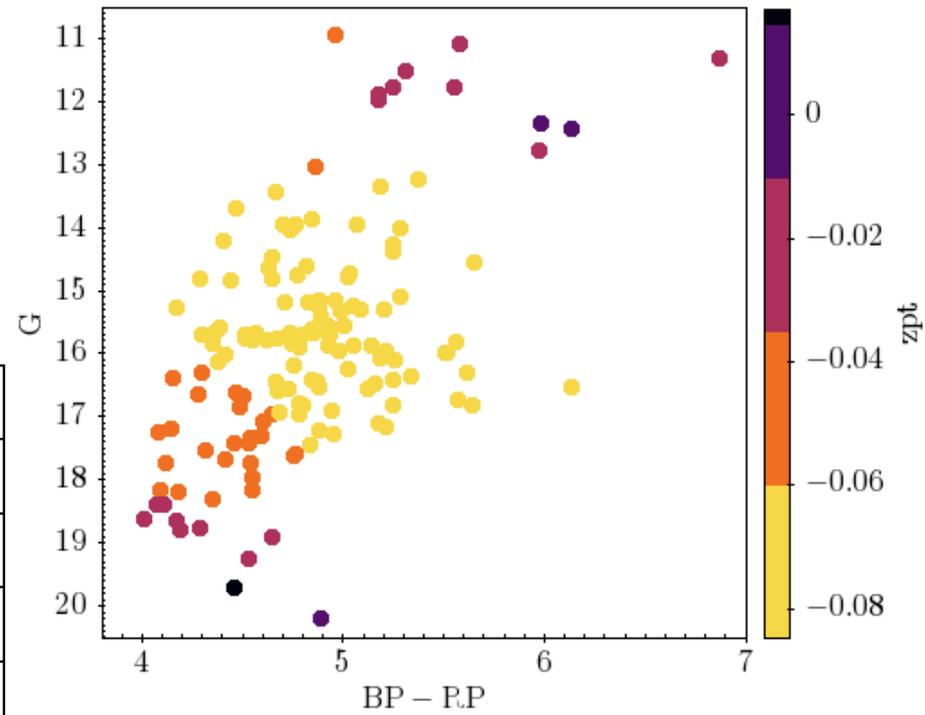
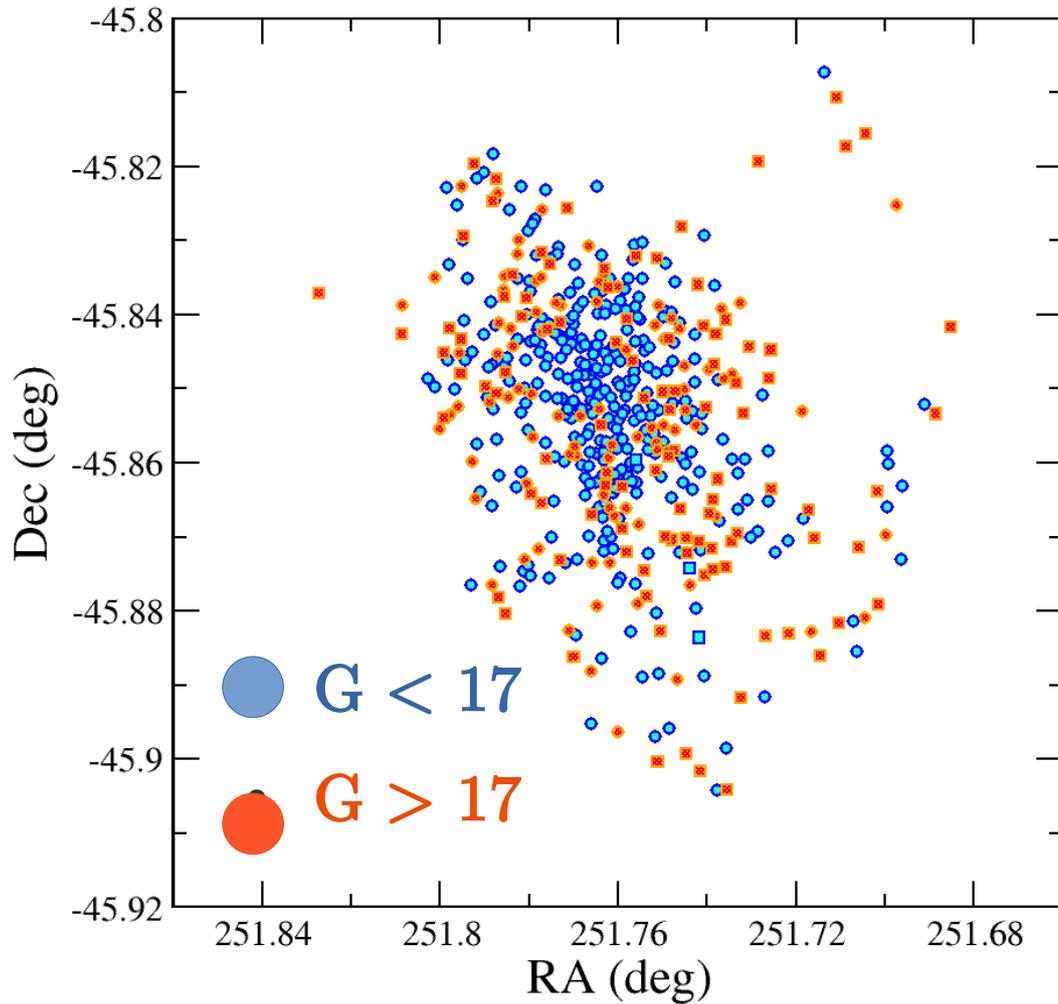
$$\mu_{\alpha} = -2.231 \pm 0.008 \text{ mas/a}$$

$$\mu_{\delta} = -3.697 \pm 0.008 \text{ mas/a}$$

$$\varpi = 0.236 \pm 0.014 \text{ mas} \Rightarrow 4.2^{+0.31}_{-0.27} \text{ kpc}$$



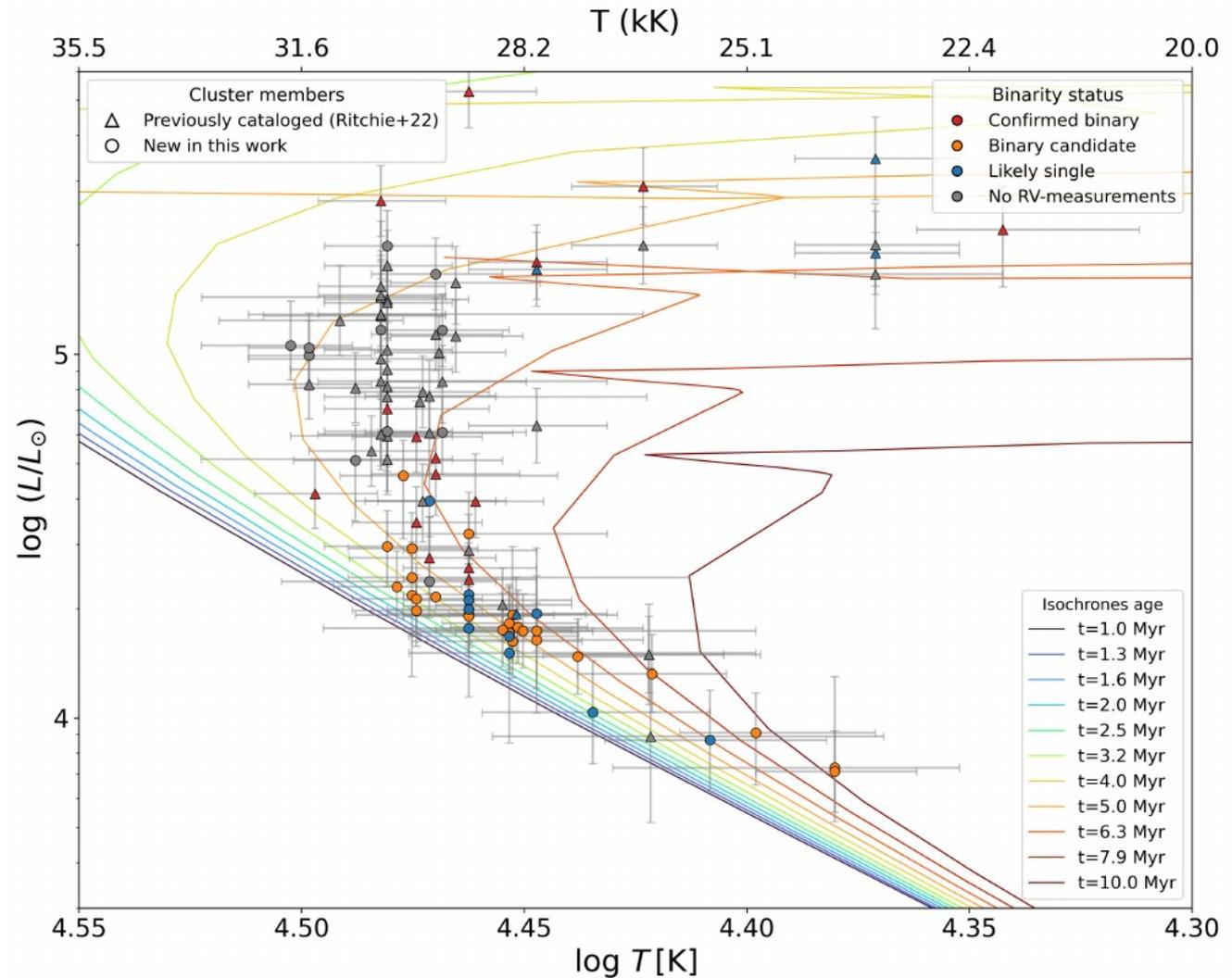
Completeness



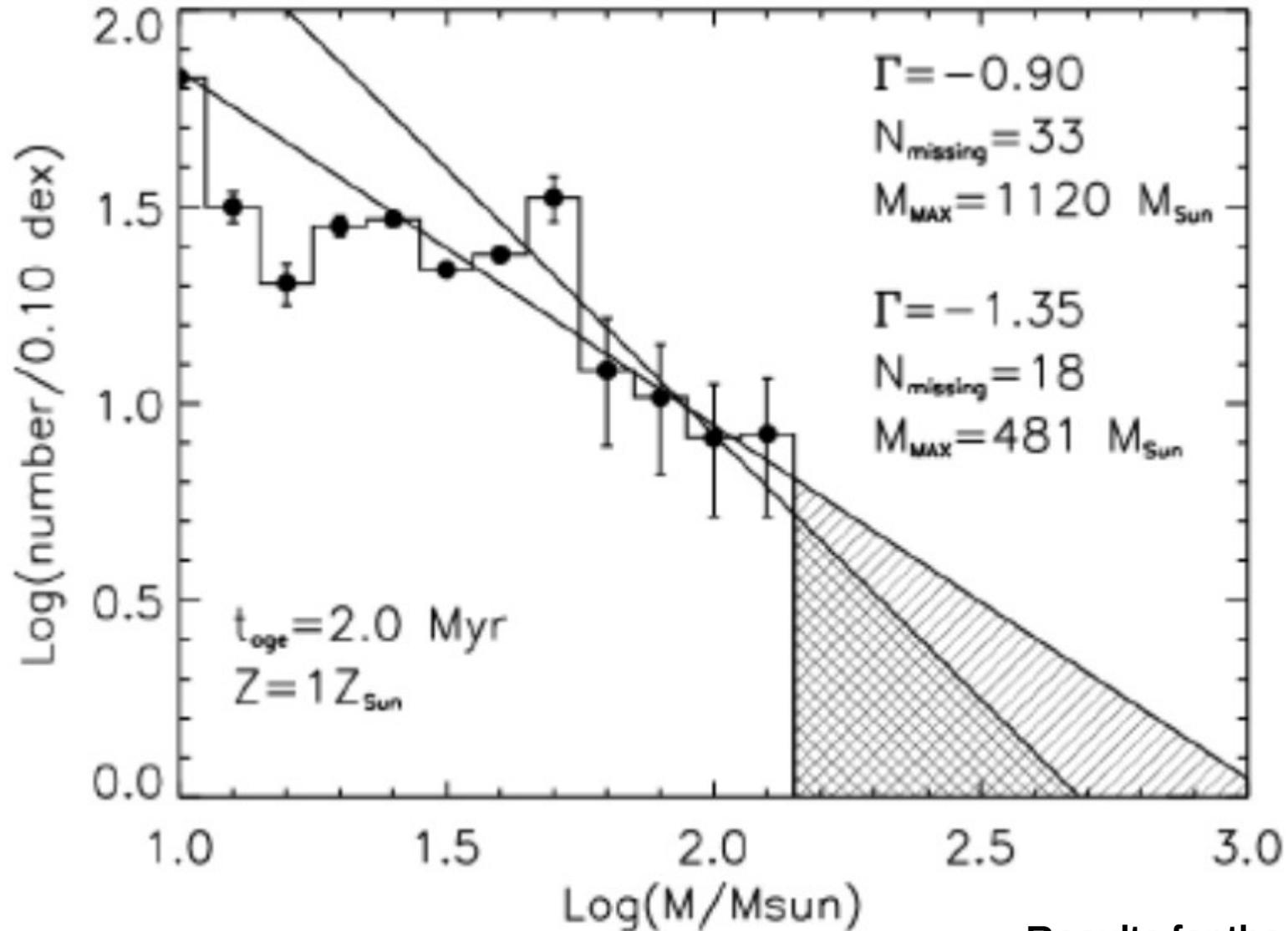
Zpt offset

Finally, accurate parameters

Quantitative spectroscopic analysis of KMOS data for > 130 members

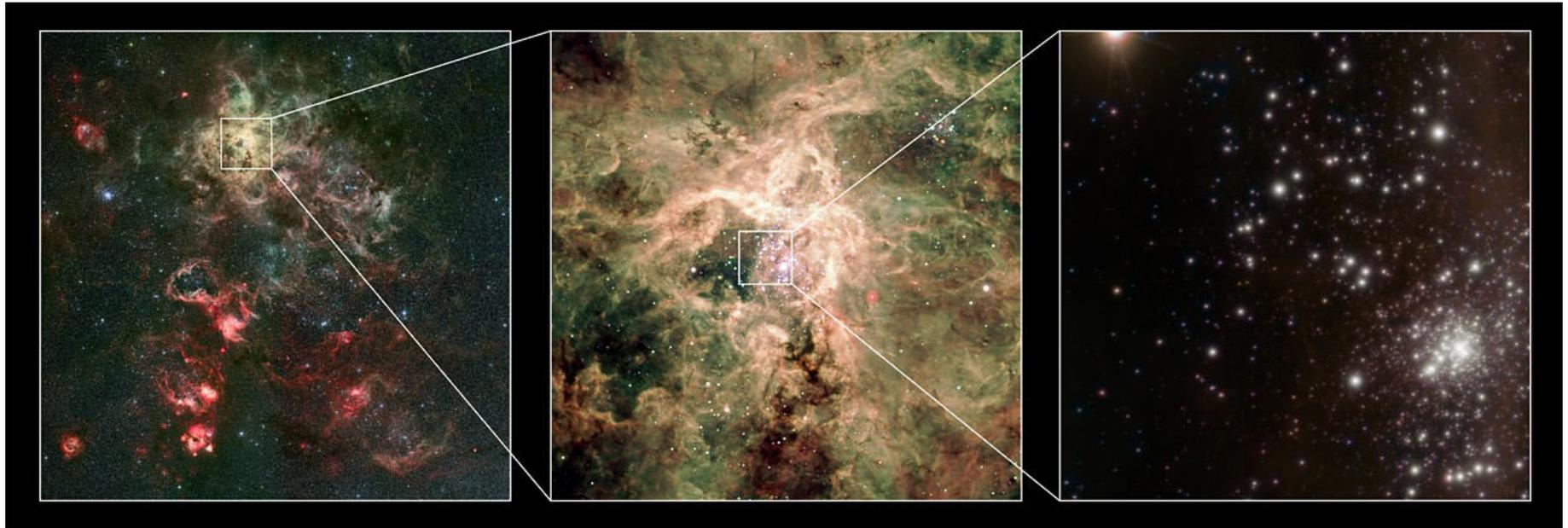


Upper limit to the masses of stars



Results for the Arches cluster
Figer 2005, Nature

The mass of R136a1

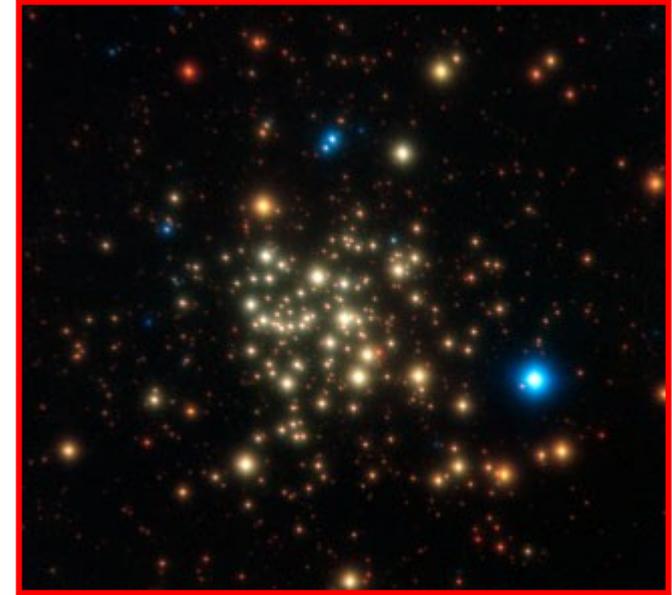


A $300 M_{\odot}$ star
Crowther+2010

... but this is controversial and
difficult to settle at ~ 50 kpc

The Arches cluster

- The Arches has many massive stars, some with $M_* > 100 M_\odot$. (e.g. [Figer+ 2002, ApJ 581, 258](#))
- The Arches has a top-heavy IMF ([Stolte+ 2002, A&A 394, 459](#)).
- Severe depletion of intermediate- and low-mass stars ([Stolte+ 2005, ApJ 628, L113](#)) → Total mass $M < 10^4 M_\odot$.
- Photometric transformation problems. New approach $M \sim 2 \times 10^4 M_\odot$ ([Spinoza+ 2009, A&A 502, 563](#))
- New extinction law results in $M \sim 2 \times 10^4 M_\odot$ ([Habibi+ 2013, A&A 556, A26](#))
- Dynamical estimate $M \approx 1.5 \times 10^4 M_\odot$ ([Clarkson+ 2012, ApJ 751, 132](#))
- Almost all very massive stars in the Arches are (at least) binary → mass needs re-estimation ([Clark et al. 2023, MNRAS 521, 4473](#))



ESO Press release (NACO image)

Westerlund 2

Long-term argument
about distance:

- 2.9 kpc **Carraro+2013**
- 7.9 kpc **Moffat+1991**

Gaia settles around
4.5 kpc

Maíz Apellániz+2022



NASA/HST image

Westerlund 2

Long-term argument about distance:

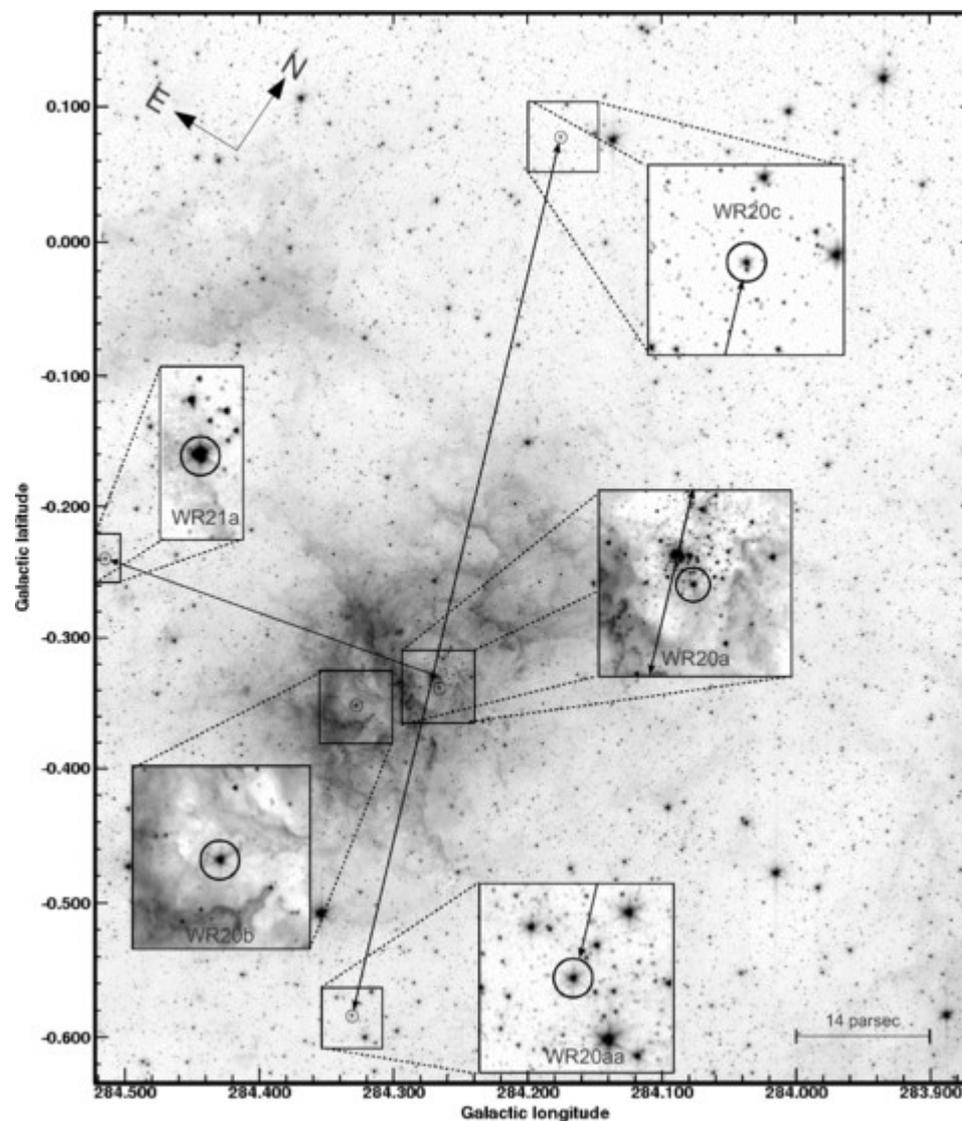
- 2.9 kpc **Carraro+2013**
- 7.9 kpc **Moffat+1991**

Gaia settles around 4.5 kpc

Maíz Apellániz+2022

$$M_{\text{cl}} \approx 3.5 \times 10^4 M_{\odot}$$

Zeidler+ 21



Ejection of very massive stars
Roman-Lopes+2013, MNRAS

NGC 3603

Obscured starburst cluster

~ 35 O-type or WR stars
(Moffat et al. 1994, *ApJ* 436, 183)

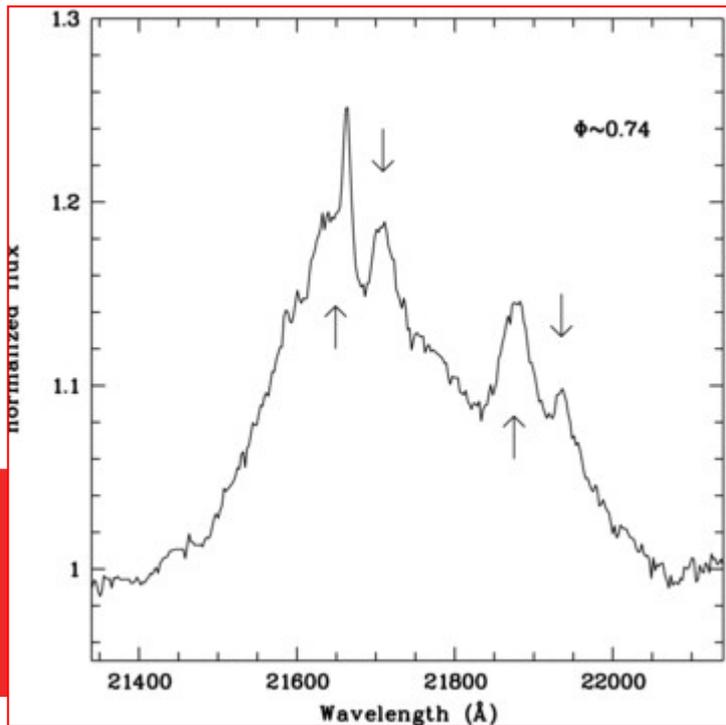
~ 20 early O or WR stars
(Melena et al. 2008, *AJ* 135, 878)

~ 35 early O or WR stars
(Morrell et al. 2013)



APOD image (Maíz Apellániz & de Davide)

NGC 3603



$$P_{\text{orb}} = 3.7724 \text{ days}$$

- $M_1 = 116 \pm 31 M_{\odot}$
- $M_2 = 89 \pm 16 M_{\odot}$



APOD image (Maíz Apellániz & de Davide)

NGC 3603

$A_V \approx 4.7$ mag

$d = 6.7$ or 7.6 kpc

$M_{cl} \approx 1.5 \times 10^4 M_{\odot}$

(Harayama et al 2008, ApJ
675, 1319;

Rochau et al. 2010, ApJ 716,
L90)

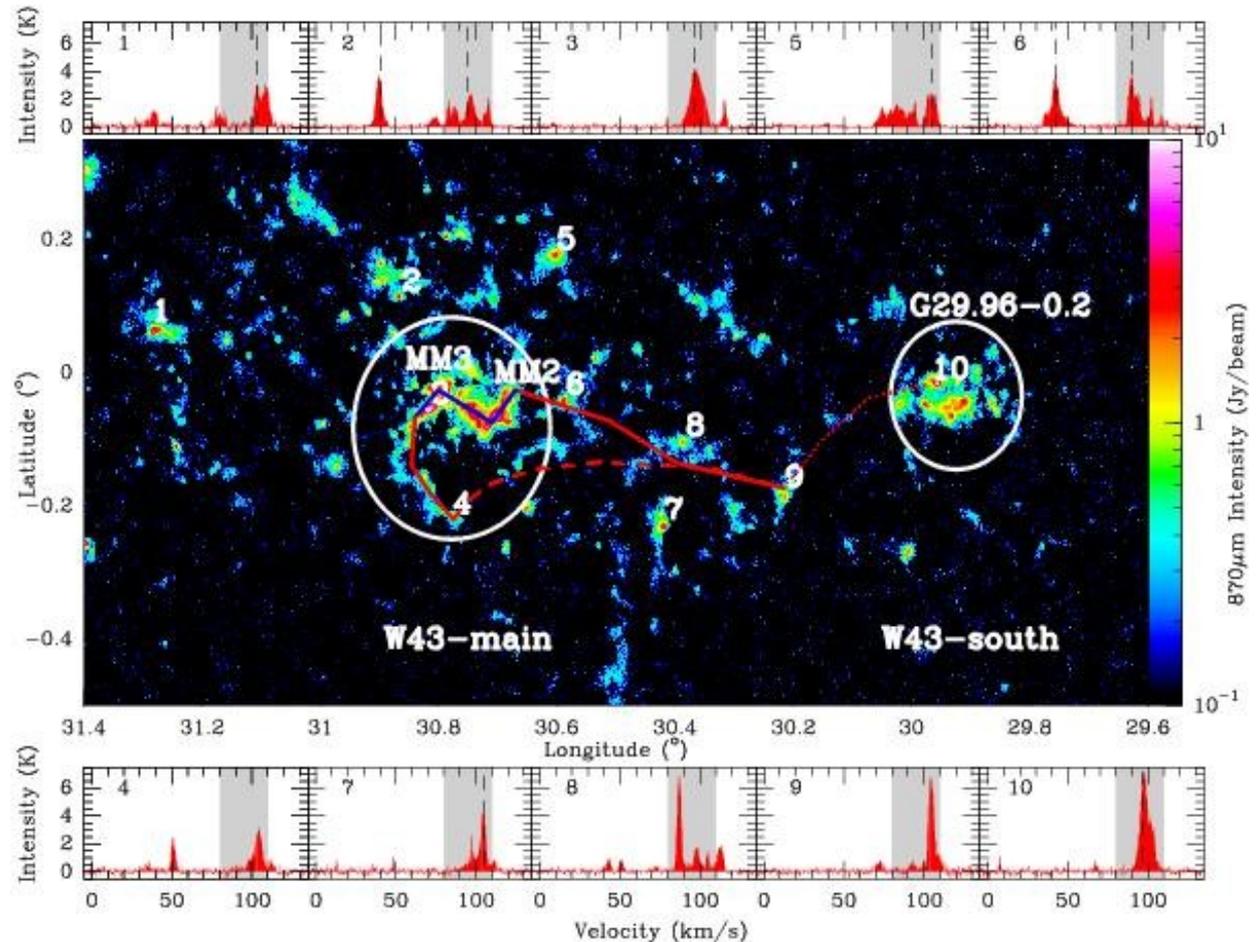


APOD image (Maíz Apellániz & de Davide)

Gaia favours the long distance → crowding

W43

The W43 complex contains perhaps up to $10^5 M_{\odot}$ in stars being formed.



This includes several extremely bright stars.

$d \approx 6$ kpc, only in the infrared

Summary

- There is a significant population of massive ($M_{cl} > 10^4 M_{\odot}$) in the Milky Way.
- Their detection is mainly hindered by high extinction.
- For many of them (e.g. Stephenson 2, with $M \approx 5 \times 10^4 M_{\odot}$), we only have very partial information based on RSGs.
- The two very young clusters where we may test the IMF cut-off are both very distant (~ 8 kpc) and heavily reddened.
- Westerlund 1, containing $10^5 M_{\odot}$, requires much better data for useful cinematic information – monolithic against fractioned star formation, ejections, etc ...
- The Galactic Centre is a wonderful laboratory for the physics of galaxies that is only accessible in the infrared.