The CARMA project: homogeneous ages of Globular clusters to probe the Galactic assembly

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The MW assembly tale, May 30, 2024

CARMA: Cluster Ages to Reconstruct the Milky Way Assembly

Objective:
homogeneous, self-consistent derivation of the age of all Galactic GC

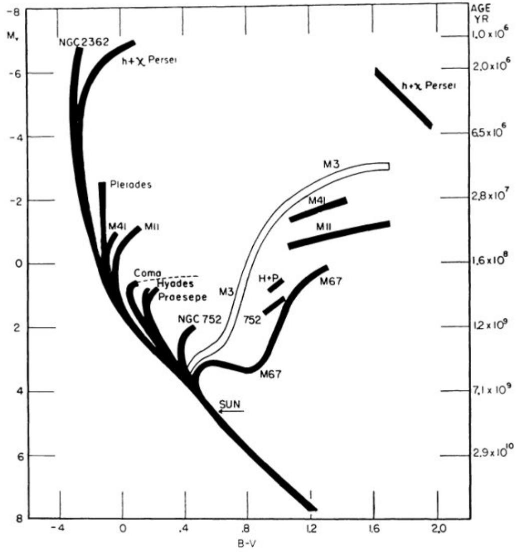
D. Massari - PI
F. Aguado-Agelet, M. Monelli, S. Cassisi
E. Pancino, S. Saracino
C. Gallart, T. Ruiz-Lara, E. Fernández-Alvar, F. Surot
A. Stokholm, M. Salaris, A. Miglio, E. Ceccarelli

Context: the age of Globular Clusters, a classical problem

➔ constraints to stellar evolution

➔ lower limit to the age of the Universe

➔ time scale for the formation of the Milky Way

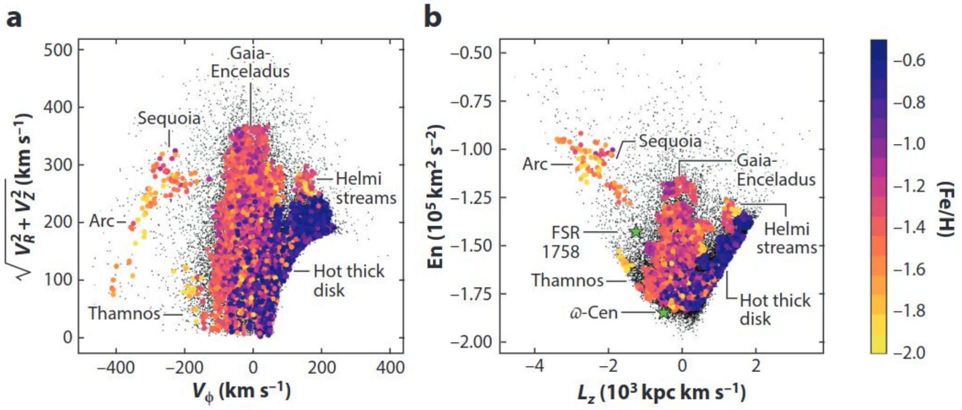


Sandage 1954

Context: the age of Globular Clusters, a classical problem

Eggen, lynden-Bell, / Sandage (1962)
➔ Monolithic Collapse

Searle & Zinn (1978)
➔ Hierarchical model

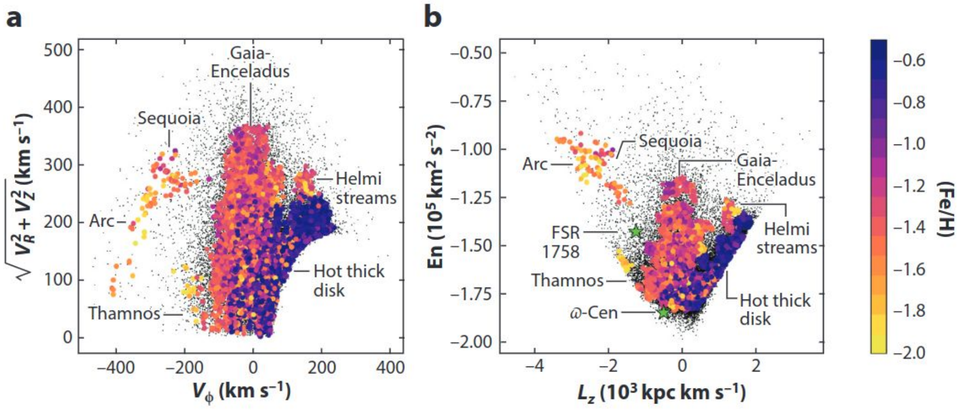


Helmi 2020

Context: the age of Globular Clusters, a classical problem

Eggen, lynden-Bell, / Sandage (1962)
➔ Monolithic Collapse

Searle & Zinn (1978)
➔ Hierarchical model



Helmi 2020

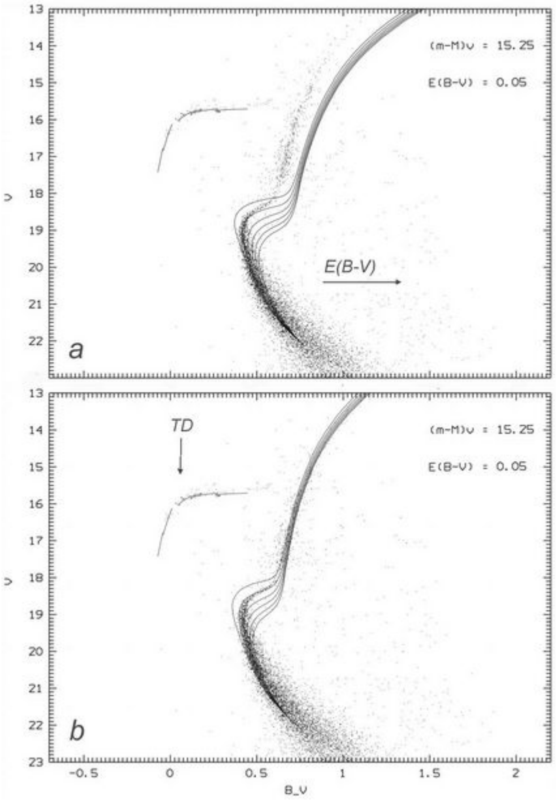
GCs ages provide independent and strong constraints complementary to the dynamical and chemical approaches

Context: the age of Globular Clusters, a classical problem

➔ Main Sequence Turn Off is the best age indicator

BUT

0.1 mag error on the TO positions propagates to 1 Gyr error on the age (e.g. Renzini 1993)



Castellani 1985

Context: the age of Globular Clusters, a classical problem

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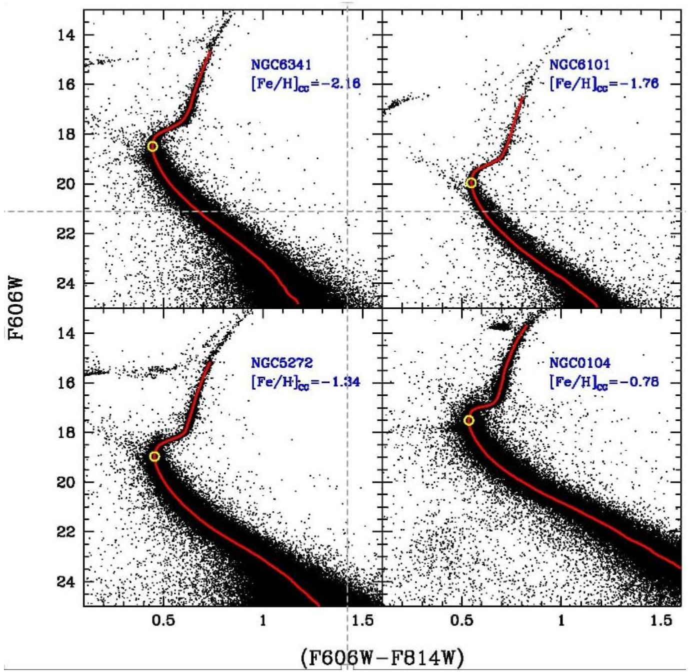


Ingredients Models

- Isochrones from the **BaSTI database**

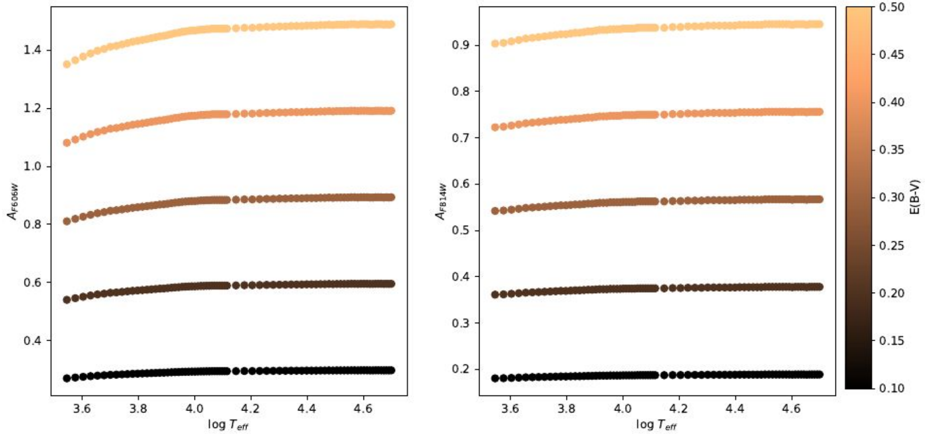
- Models with diffusion (Hidalgo+18)

- **solar-scaled**

- grid: 6 < age < 14 Gyr (0.1 Gyr step)
  -2.5 < [M/H] < 0 (0.01 dex step)

- temperature-dependent reddening correction
  E(B-V) > 0.1 mag

- shifted to the observational plane (distance, reddening) → Harris



Ingredients Code

- New version of the original version by Saracino+19
  - user friendly input/ouput;
  - parallelized (< 30 min per cluster)
  - prepared for different photometric systems: Johnson, HST (ACS, WFC3), Gaia

- MCMC approach to derive age, metallicity, distance, reddening
  - Priors: metallicity, distance, reddening
  - $\sigma_{[M/H]}=0.1$ $\sigma_{E(B-V)}=0.05$ $\sigma_{DM}=0.1$

Ingredients Data

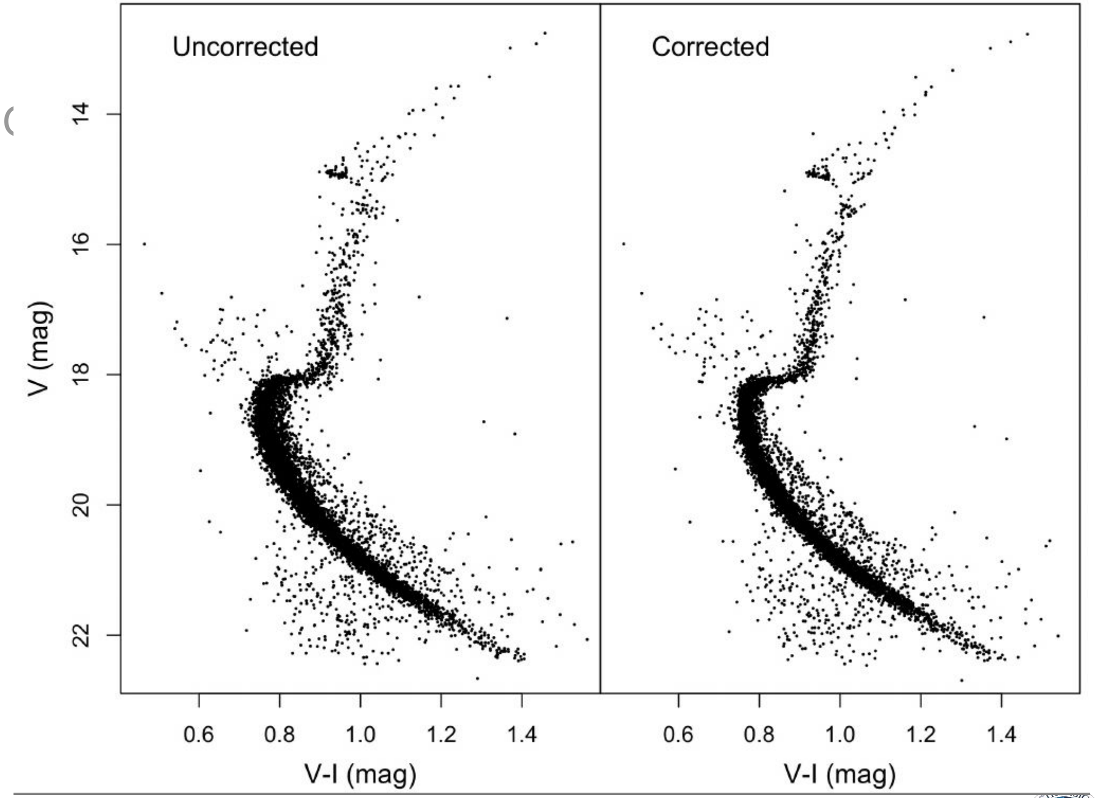
- Photometric compilation from the HUGS project (Piotto+15, ACS F606W, F814W)

1. proper-motion cleaning (P>90%)

Ingredients Data

- Photometric compilation from the HU(

1. proper-motion cleaning (P>90%)
2. differential reddening correction



Ingredients Data

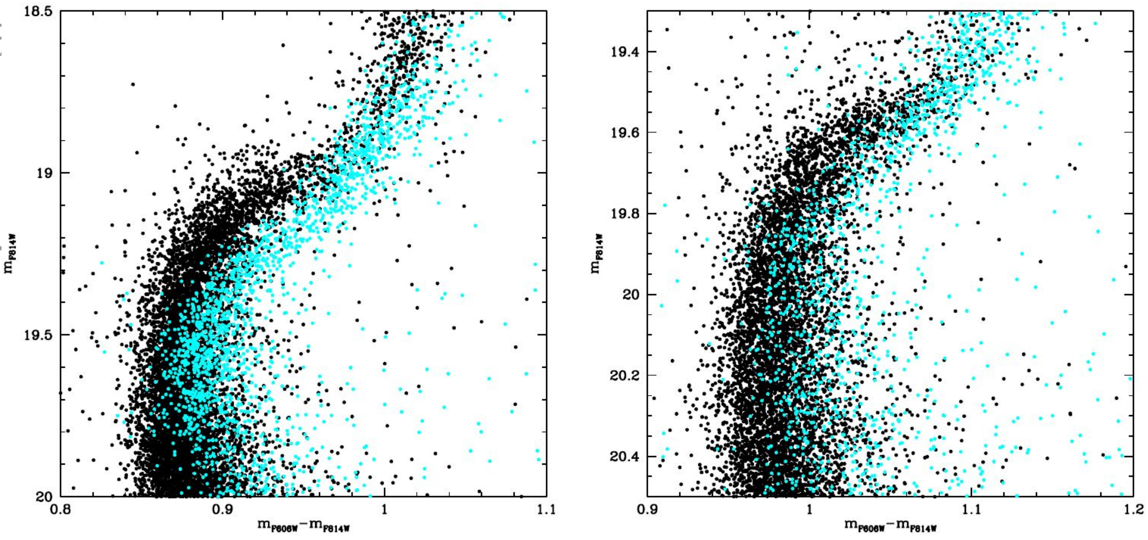
- Photometric compilation from the HUGS project (Piotto+15, ACS F606W, F814W)

1. proper-motion cleaning (P>90%)
2. differential reddening correction
3. exclude the inner regions (20”-60”)

Ingredients Data

- Photometric compilation from the HUGS project (Piotto+15, ACS F606W, F814W)

1. proper-motion cleaning (P>90%
2. differential reddening correctio
3. exclude the inner regions (20”-
4. remove peculiar population



NGC6388

Ingredients Data

- Photometric compilation from the HUGS project (Piotto+15, ACS F606W, F814W)

1. proper-motion cleaning (P>90%)

2. differential reddening correction

3. exclude the inner regions (20”-60”)

4. remove peculiar population

5. Aged derived from both the (F606W-F814W, F606W) and (F606W-F814W, F814W)

NGC6388

Ingredients

Star Formation History

CMDft.Gaia

ChronoSynth
Synthetic CMD computation

PRODUCES
mother CMD

INPUT
flat age [age_{max}, age_{min}]
flat Z [Z_{min}, Z_{max}]
IMF
binaries: β, q_{min}
stellar evolution library
bolometric corrections
N_{stars} to M_{lim}

DisPar-*Gaia*
Error & completeness simulation
(Ruiz-Lara+2022, Fernández-Alvar+2024)

PRODUCES
mother CMD w/errors

INPUT
photometric errors
distance errors
reddening map (*)
quality cuts (*)
completeness 5D/6D(*)

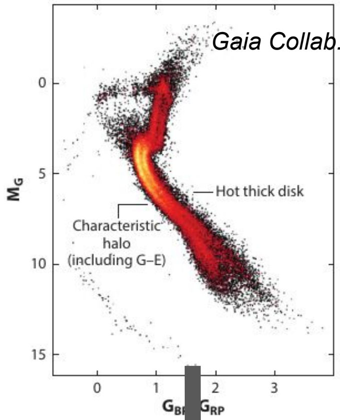
*Not considered for the GCNS

*Dir*SFH
Finding best SSP combination

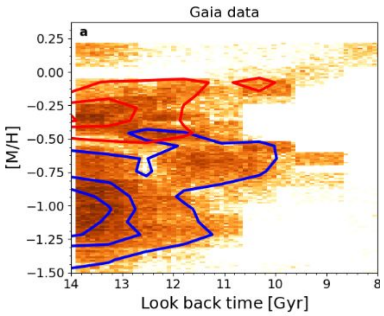
PRODUCES
deSFH, solution CMD

INPUT
observed & mother CMDs
age (Z) seed points → SSP bundle
weight across bundle
colour-magnitude shift
minimisation algorithm (Skellam)
number of SSP realisations

Carme Gallart's talk this morning (Gallart+2024)
➔ **FULLY CONSISTENT AGE SCALE**



Gaia Collab. 2018



Gallart+19

Results

I. NGC6388, NGC6441

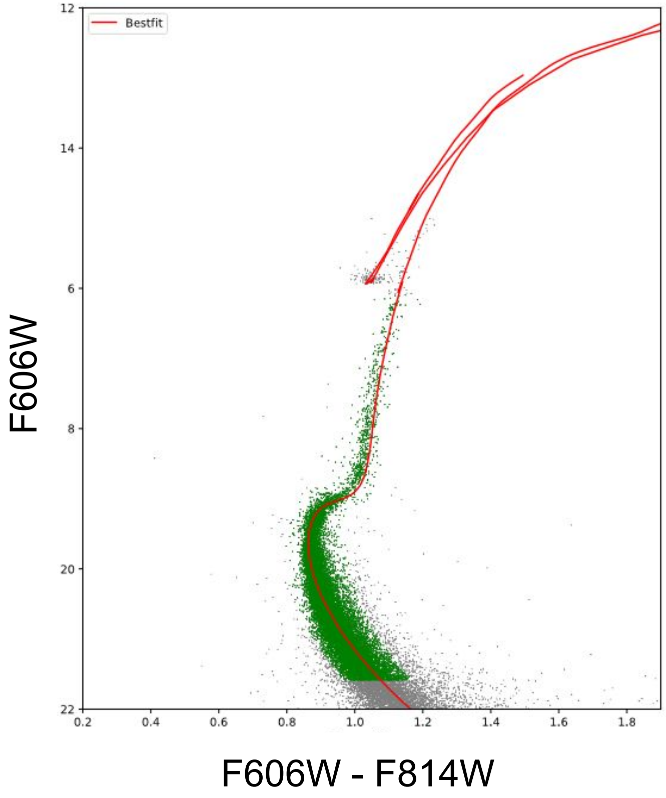
Bulge clusters, [Fe/H] ~ -0.5

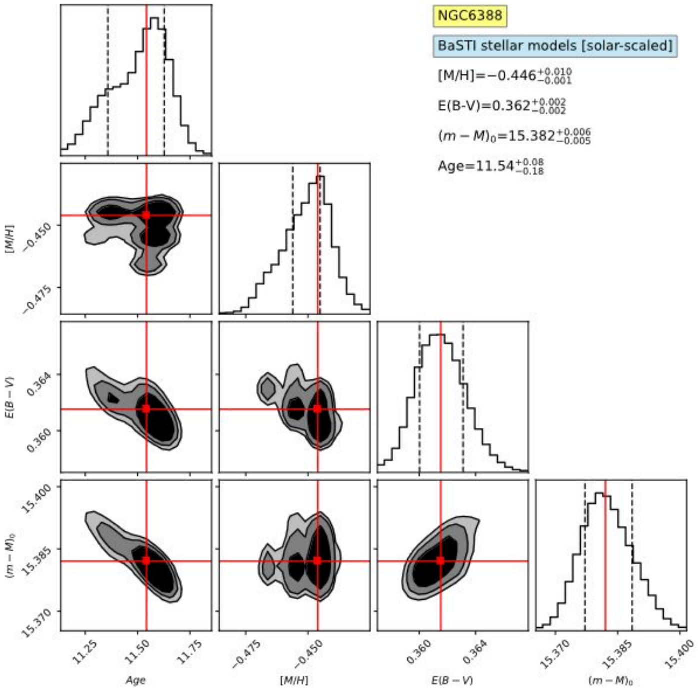
Control sample: NGC5927, NGC6304, NGC6352, NGC6496

	Dynamics		Chemistry	
	in situ	accreted	in situ	accreted
NGC6388	Massari+19* Forbes 2020 Callingham+21		Carretta & Bragaglia 2022	Minelli+21, Horta+20
NGC6441	Forbes 2020 Callingham+21	Massari+19*	Carretta & Bragaglia 2022	Minelli+21

Results

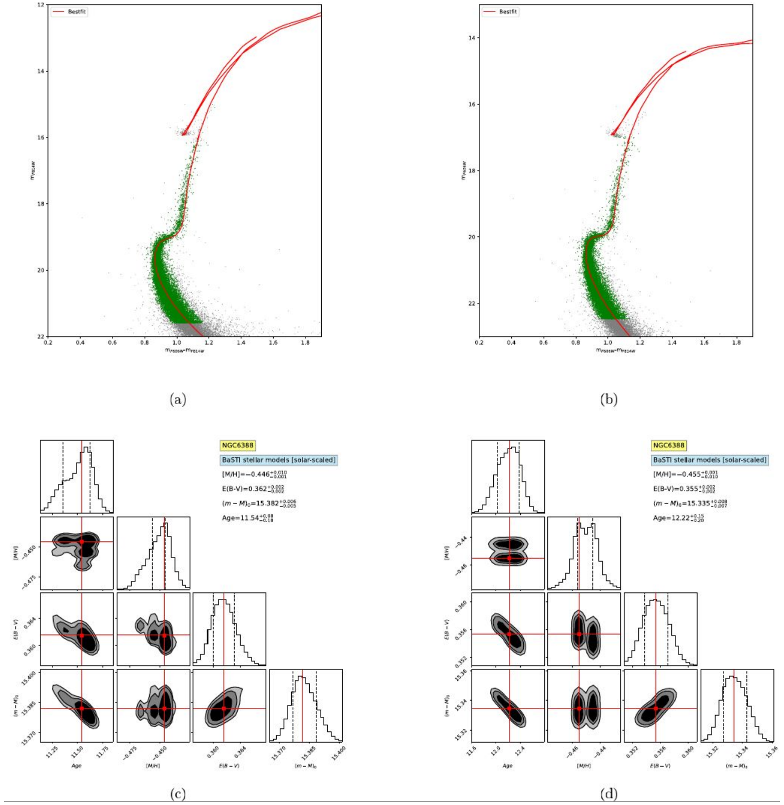
NGC6388, NGC6441

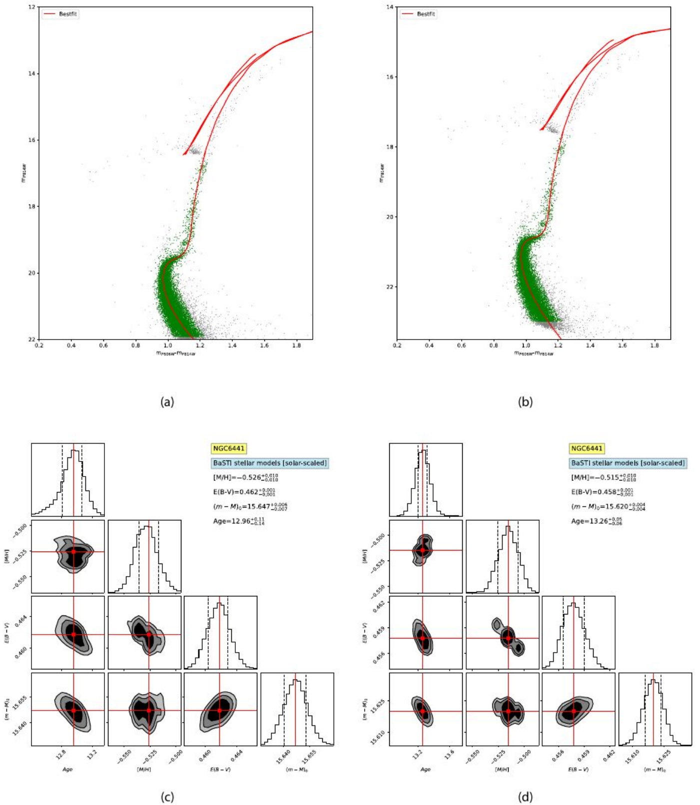




Results

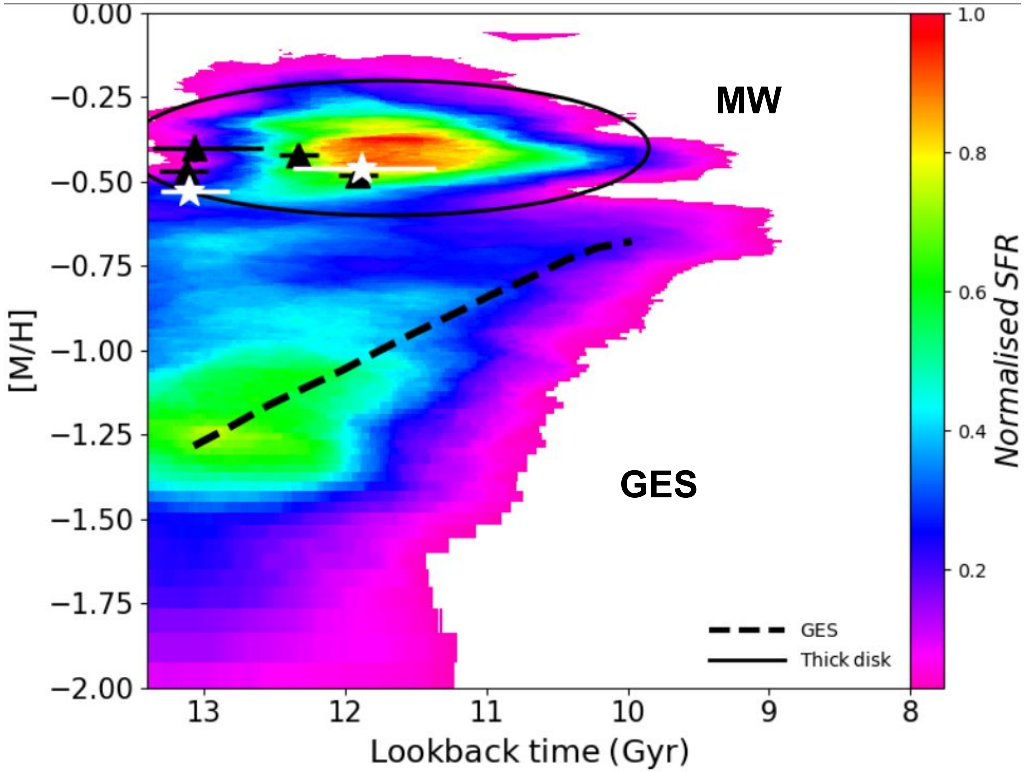
NGC6388, NGC6441





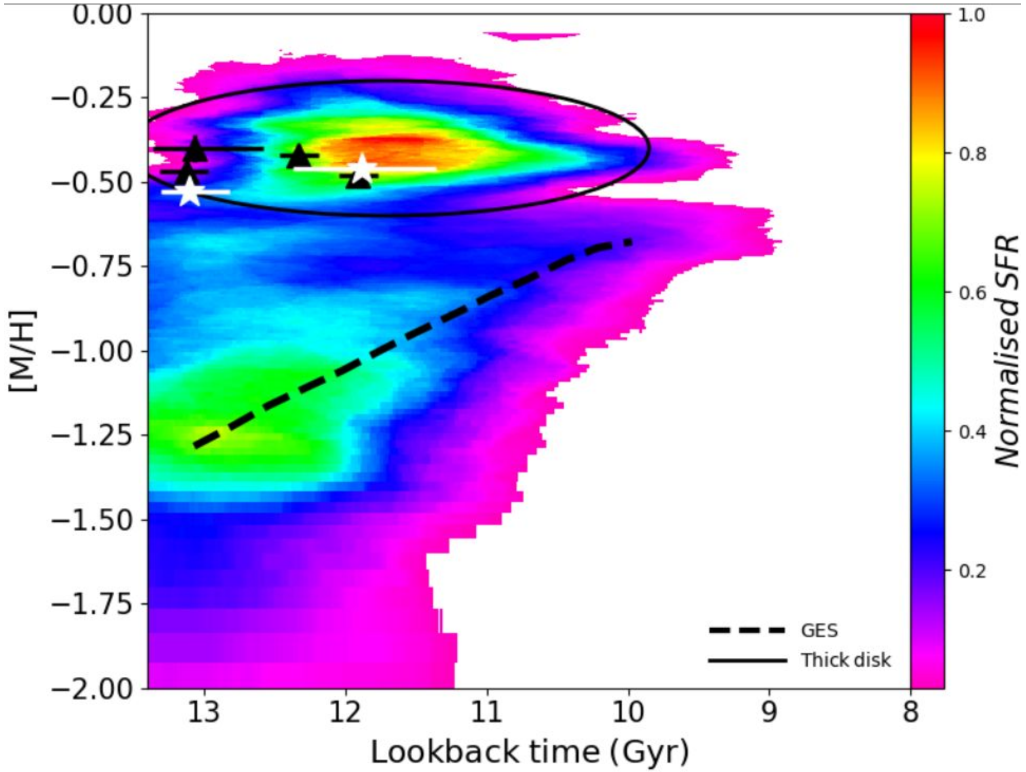
Results

NGC6388, NGC6441



Field star selection:
R < 1 kpc, |Z| < 3.5 kpc
v_t > 200 km/s

Results NGC6388, NGC6441



Field star selection:
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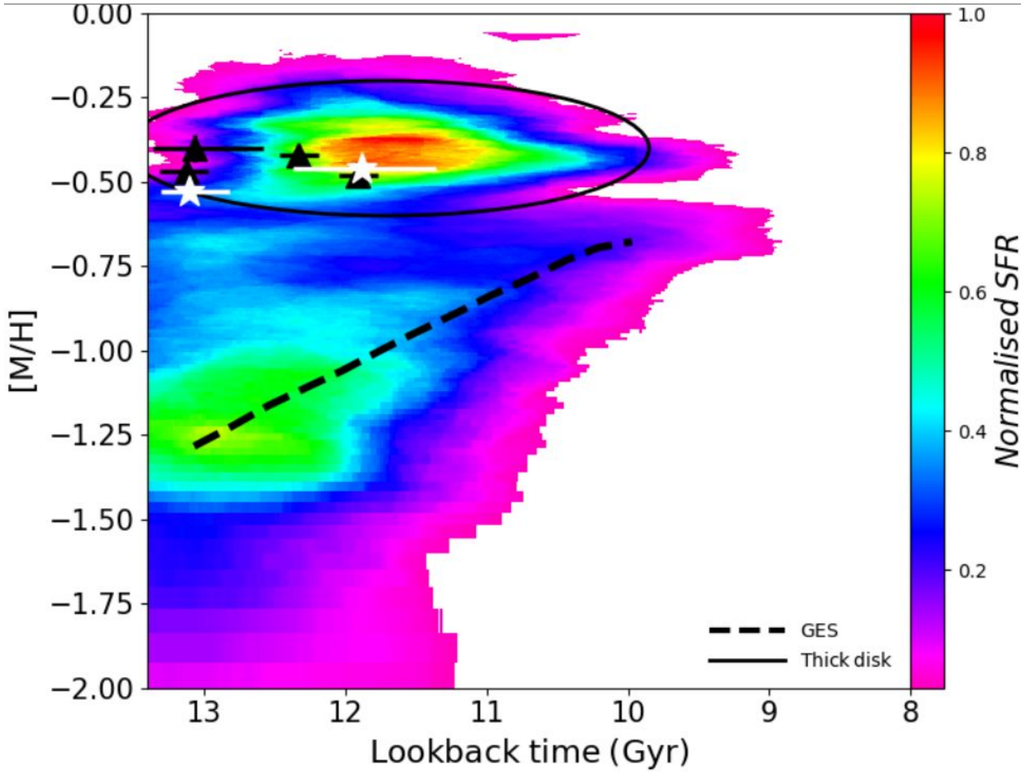
v_t > 200 km/s

NGC5927	$12.33^{+0.14}_{-0.14}$
NGC6304	$13.07^{+0.29}_{-0.49}$
NGC6352	$11.91^{+0.14}_{-0.14}$
NGC6388	$11.88^{+0.49}_{-0.52}$
NGC6441	$13.11^{+0.20}_{-0.29}$
NGC6496	$13.12^{+0.20}_{-0.15}$

Results

NGC6388, NGC6441

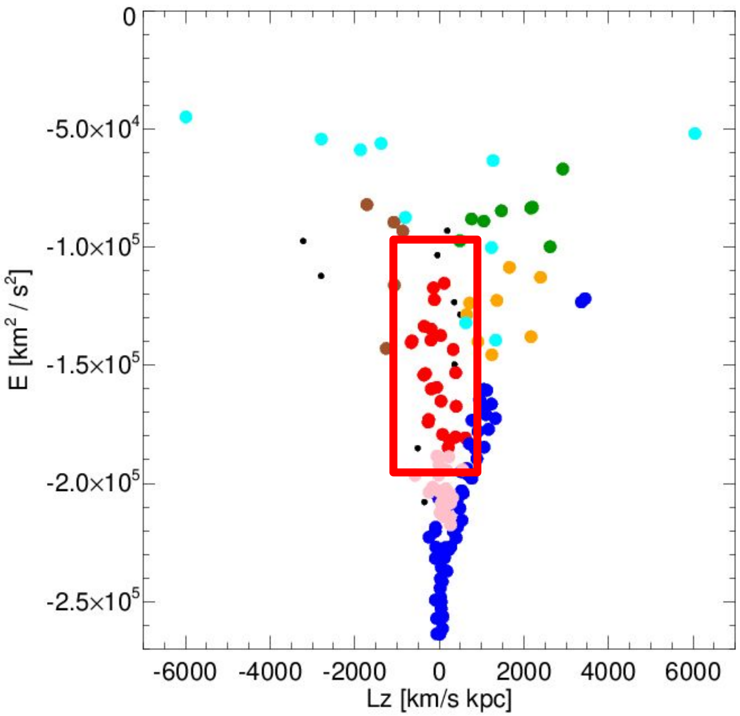


The AMR clearly discriminates the origin of NGC6388 and NGC6441 and places them as **formed in situ**

NGC6388	$11.88^{+0.49}_{-0.52}$
NGC6441	$13.11^{+0.20}_{-0.29}$
NGC6496	$13.12^{+0.20}_{-0.15}$

Results

II. Gaia Enceladus clusters



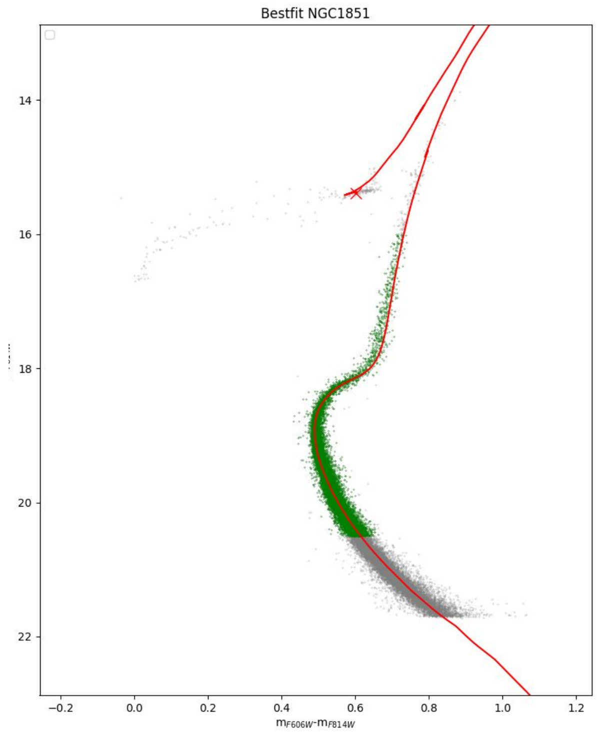
NGC288
NGC362
NGC1261
NGC1851
NGC2298
NGC2808
NGC5286
NGC5897
NGC6205 M13
NGC6341 M92
NGC6779
NGC7089 M2
NGC7099

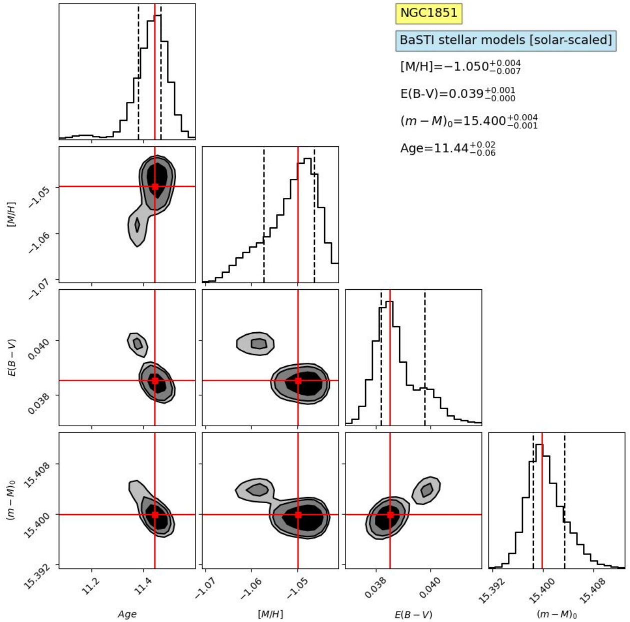
- In common with Koppelman+19
- ACS photometry

Results II. Gaia Enceladus clusters

NGC1851

F606W

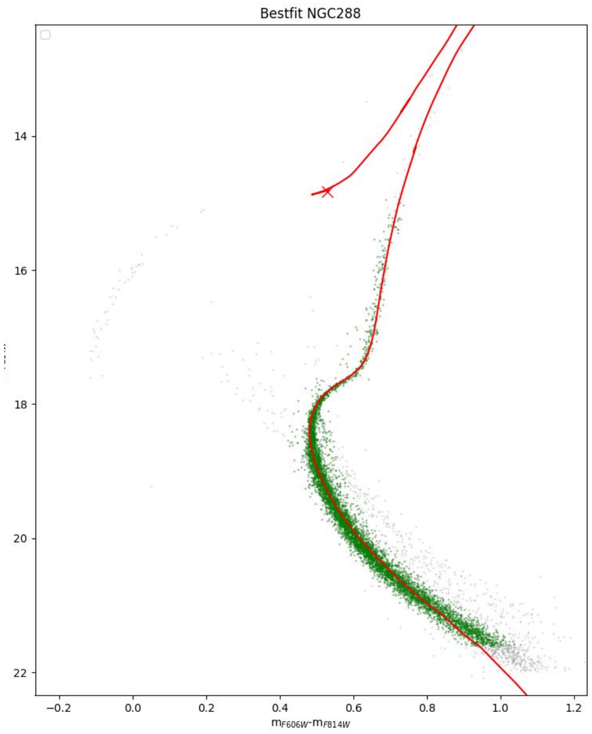




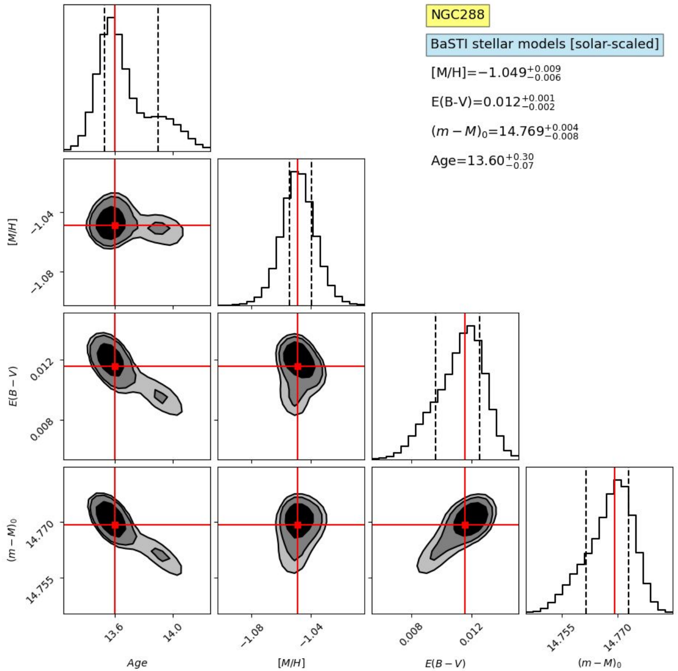
Results

II. Gaia Enceladus clusters

F606W

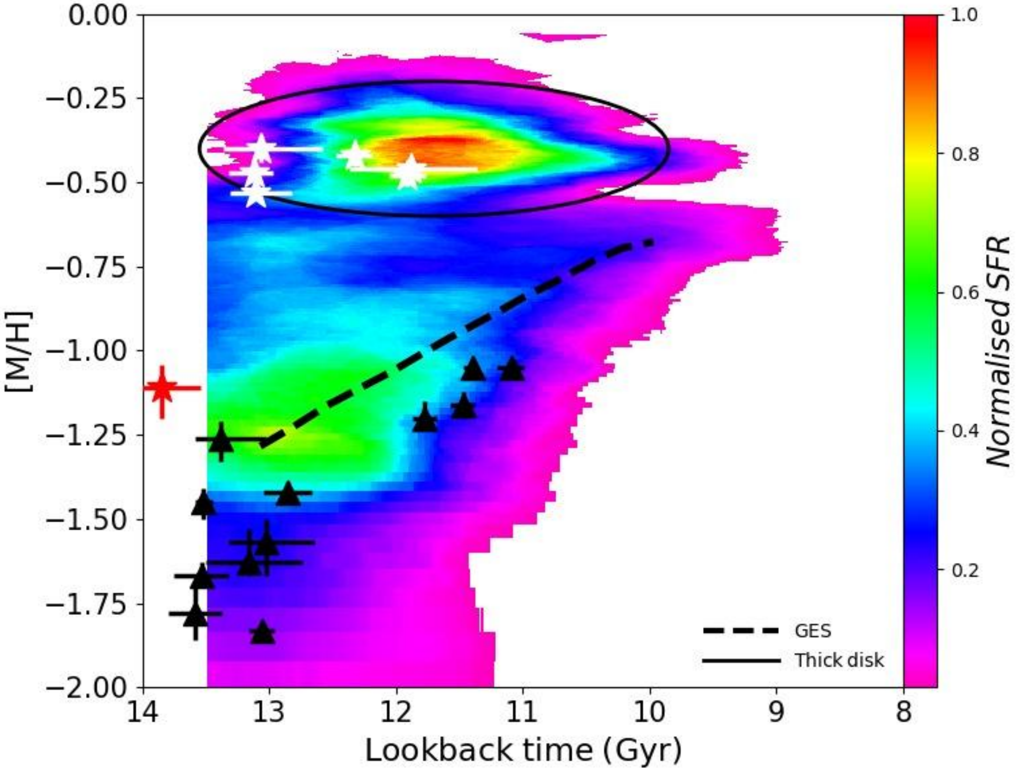


NGC288



Results

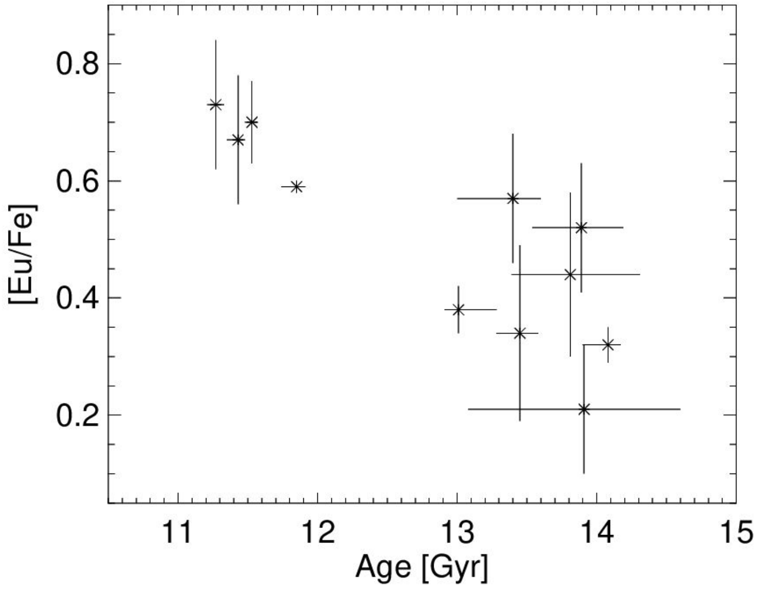
II. Gaia Enceladus clusters

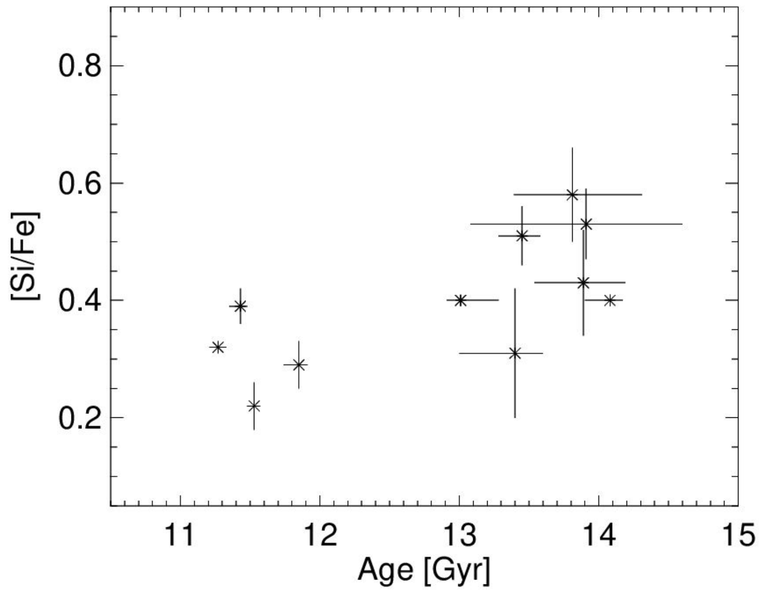


- GES clustes follow a remarkably tight age metallicity relation
- we confirm the accreted origin of the selected clusters
- two epochs of formation?

Results

II. Gaia Enceladus clusters





Eu and Si from Monty+24

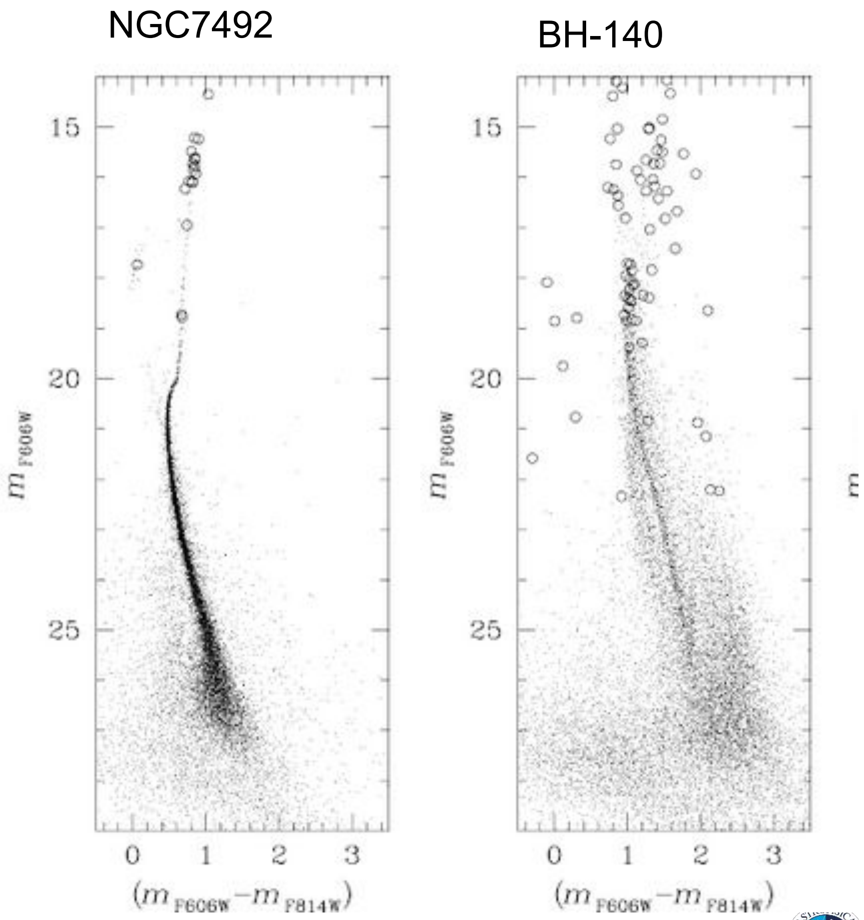
Conclusions

- ★ The **CARMA** project is deriving homogeneous, self consistent ages for all GCs
- ★ **Ages and AMR provide strong constraints to determine the GCs origin:** NGC6388 and NGC6441 were formed **in-situ**
- ★ GCs associated to GES follow a **very tight age-metallicity relation**, and experienced two formation epochs

Conclusions and future work

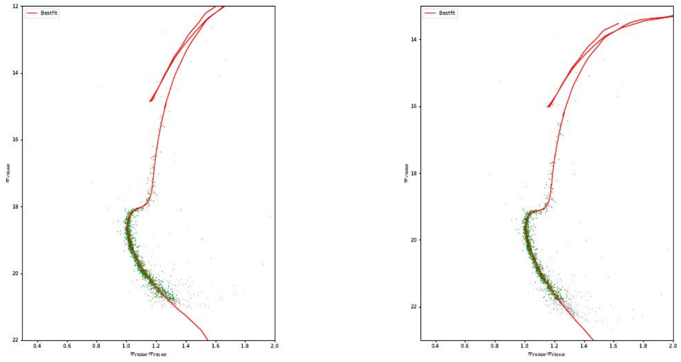
- ★ The **CARMA** project is deriving homog
- ★ **Ages and AMR provide strong const** NGC6388 and NGC6441 were formed
- ★ GCs associated to GES follow a **very t** experienced two formation epochs

- ➢ **HST project on neglected clusters**
  PI D. Massari,
  34 GCs being observed
- ➢ What can **RR Lyrae** stars add to this picture?



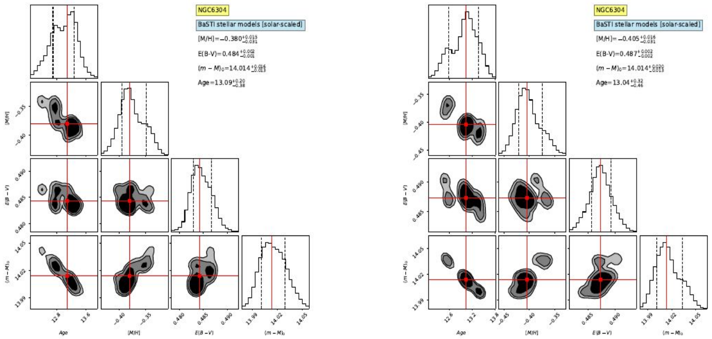
Results

I. NGC6388, NGC6441 - Control sample

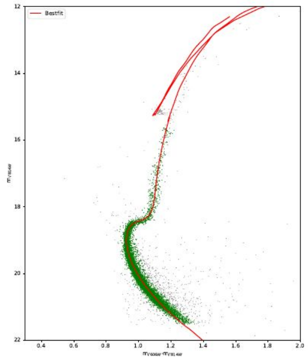


NGC 6304

(a) (b)

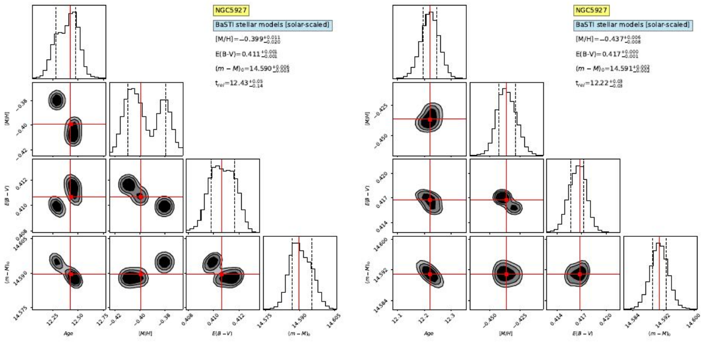


(c) (d)



NGC 5927

(a) (b)



(c) (d)

Results

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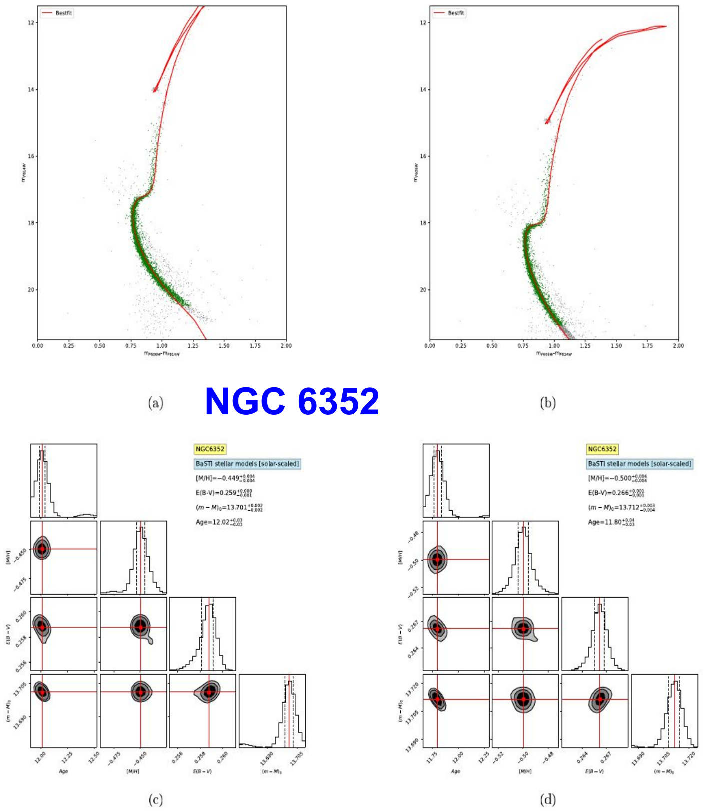
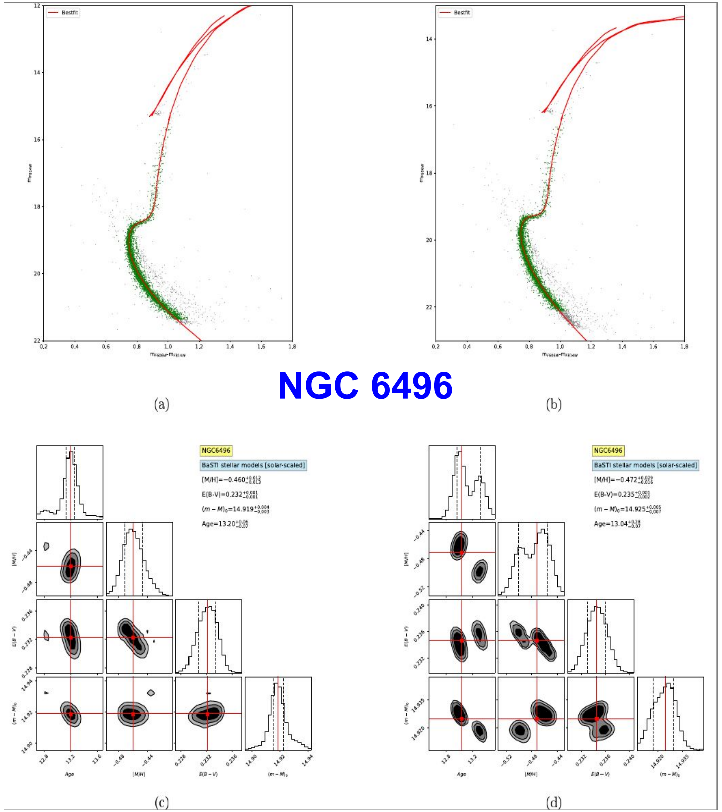
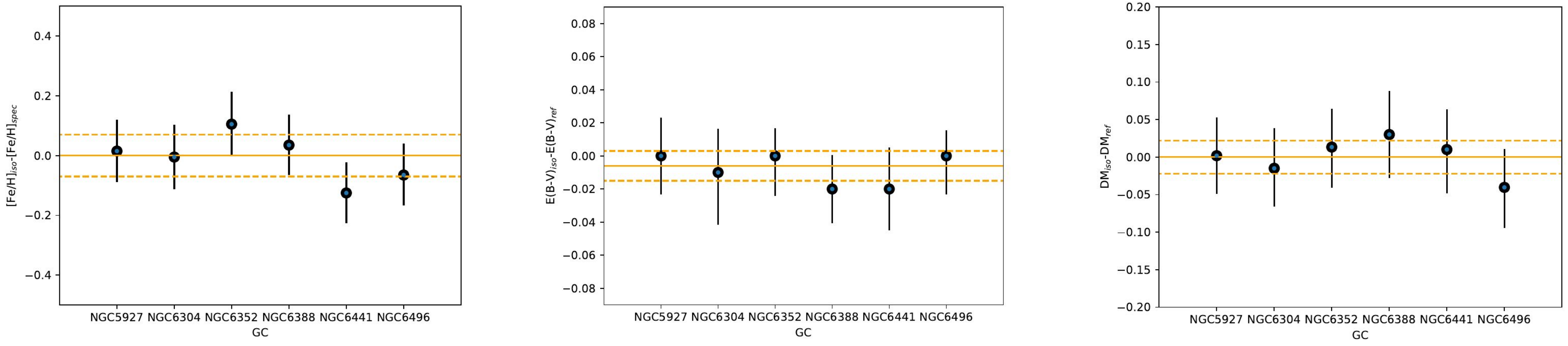


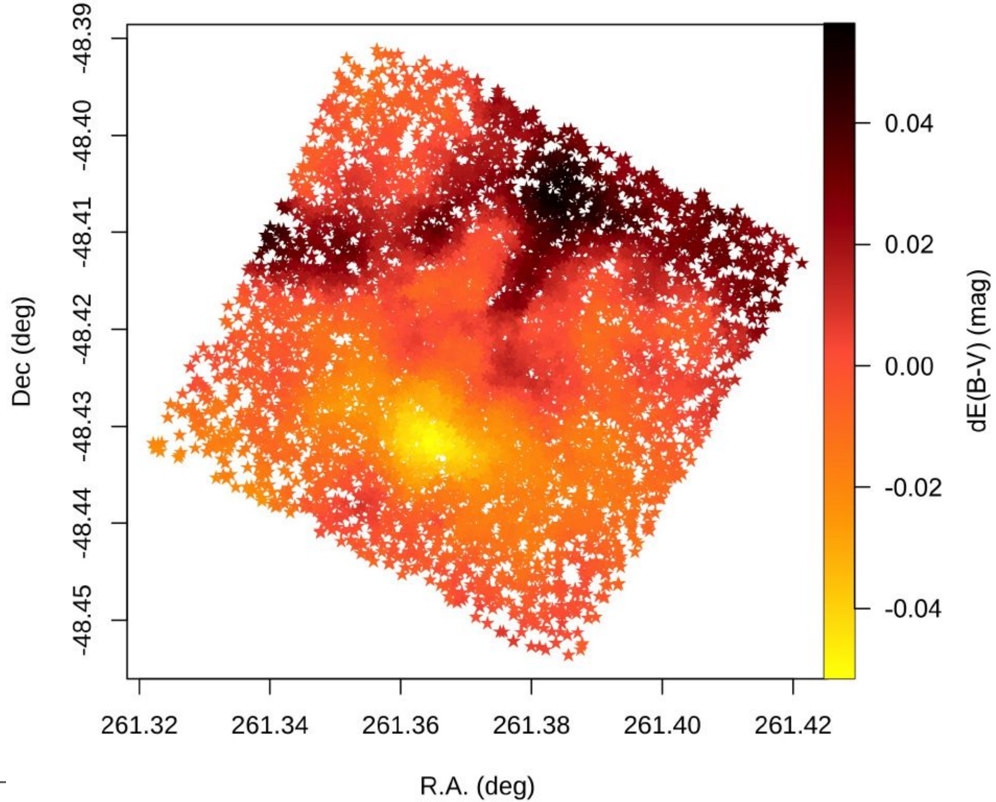
NGC 6352



NGC 6496

Results NGC6388, NGC6441





-48.39
-48.40
-48.41
-48.42
-48.43
-48.44
-48.45
Dec (deg)
261.32
261.34
261.36
261.38
261.40
261.42
R.A. (deg)
0.04
0.02
0.00
-0.02
-0.04
dE(B-V) (mag)