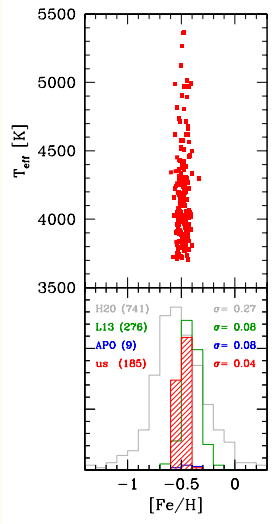
The massive globular cluster NGC 6388

Angela Bragaglia & Eugenio Carretta (INAF-OAS Bologna)

ABSTRACT: NGC 6388 is a massive bulge globular cluster, with a pivotal role in several modern astrophysical issues:
1) It is defined as Type II GC (Milone+2017) based on HST UV-VIS photometry. Hence it should in theory:
1a) show a spread in metallicity
1b) show a spread in s-process elements (with stars Fe-richer also n-capture-richer)
2) It was selected as example of a method to pin-point accreted GCs based on iron-peak elements (Minelli+2021)
Based on our analysis of a large sample of giants observed with high resolution spectroscopy, both claims seem clearly not well founded

1a-NGC6388 is very homogeneous in metallicity

- Previous works, such as Lanzoni+2013 (FLAMES) or Mészáros+2020 (APOGEE), did not find a significant metallicity dispersion (*see figure right, green and blue histograms, L13 and APO respectively*)
- There was a suggestion of a possible spread in [Fe/H] (Husser+2020) based on low-res MUSE spectra, using CaT-derived metallicity (*grey histogram, H20*). However H20 are very cautious and they say there may be an alternative explanation (e.g. problems in extracting and analyzing spectra in a high-met and very crowded GC)
- In our work (*red points in the [Fe/H] vs Teff plot, and red histogram*) we find from high-resolution spectra:
  [Fe/H]=-0.480 dex rms=0.045 dex (35 stars UVES)
  [Fe/H]=-0.488 dex rms=0.040 dex (150 stars GIRAFFE)
- ➔ **Compared to internal errors, we may exclude a significant intrinsic spread in metallicity**
- Apart from elements involved in multiple populations (O, Na, Al, Mg, Si), and possibly Zr, **NGC6388 is a very homogeneous GC**. The giants on the red sequence are neither more metal-rich nor particularly enhanced in s-process elements (*see figure in 1b*)



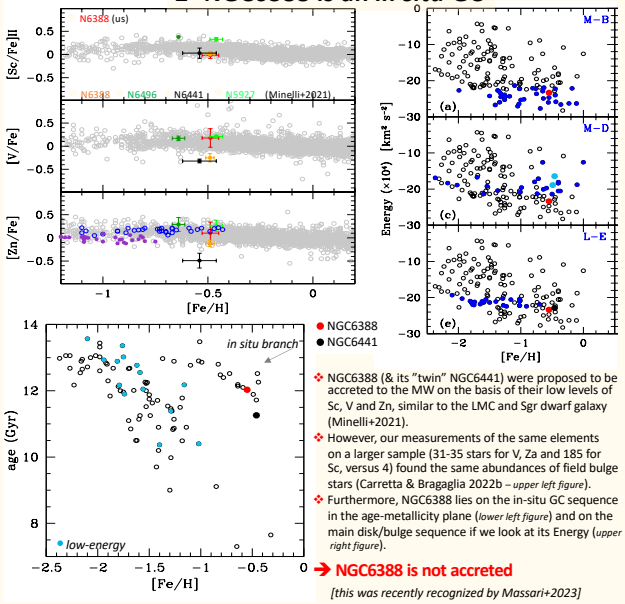
Poster based on:

Carretta & Bragaglia 2022a, A&A 659, 122
Metallicity of the globular cluster NGC 6388 based on high-resolution spectra of more than 160 giant stars

Carretta & Bragaglia 2022b, A&A 660, L1
The in situ origin of the globular cluster NGC 6388 from abundances of Sc, V, and Zn of a large sample of stars

Carretta & Bragaglia 2023, A&A 677, 73
Chemistry of multiple stellar populations in the mono-metallic, in situ, bulge globular cluster NGC 6388

2- NGC6388 is an *in situ* GC

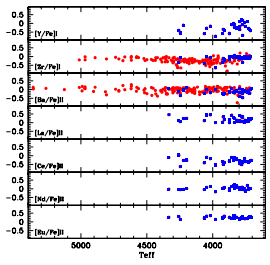


- NGC6388 (& its "twin" NGC6441) were proposed to be accreted to the MW on the basis of their low levels of Sc, V and Zn, similar to the LMC and Sgr dwarf galaxy (Minelli+2021).
- However, our measurements of the same elements on a larger sample (31-35 stars for V, Za and 185 for Sc, versus 4) found the same abundances of field bulge stars (Carretta & Bragaglia 2022b – *upper left figure*).
- Furthermore, NGC6388 lies on the in-situ GC sequence in the age-metallicity plane (*lower left figure*) and on the main disk/bulge sequence if we look at its Energy (*upper right figure*).

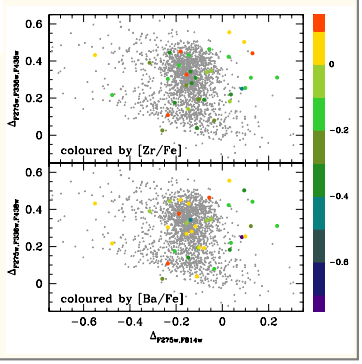
➔ **NGC6388 is not accreted**

[this was recently recognized by Massari+2023]

1b- The "red sequence" is not enhanced in s-elements



- We measured abundances of Y, Zr I, Ba, La, Ce, Nd, Eu in 35 stars (*UVES spectra, blue in figure left*) to 185 stars (UVES+GIRAFFE – *the latter in red*).
  No trend with Teff is visible
- None of the n-capture elements shows a spread (*for Zr, which is a possible exception, see box below*)
- We matched our stars with HST photometry covering the centre, recovering about 30% or our sample.
  We built the chromosome map using the photometry in Nardiello+2018 (*see figure below*)

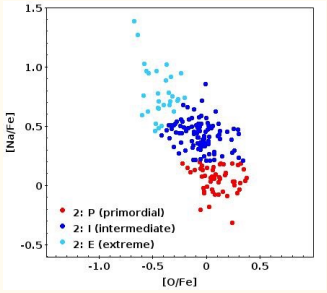


- The chromosome map separates first and second generations stars (*different He, C, N, etc produce effects in the photometric bands*) and, in Type-II clusters, also a sequence/cloud in the upper right part of the map
- There is no significant difference in Zr or Ba abundance level between the stars scattered to the red of the map and the other stars
- Also considering neutron-capture elements, NGC6388 **does not conform to the Type-II** GCs characteristics
- In turn, the red RGB stars in the HST pseudo-colour map are simply **not yet explained** by any observable change or alterations in their chemical composition

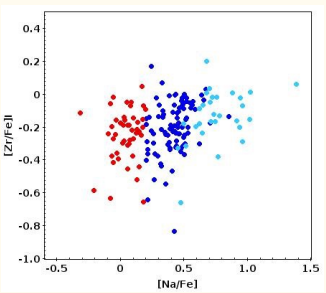
OTHER REFERENCES:

Carretta et al. 2007, A&A 464, 967
Carretta et al. 2010, A&A 516, 55
Husser et al. 2020, A&A 635, 114 (H20)
Kolomiecas et al. 2022, A&A 660, 46
Lanzoni et al. 2013, ApJ 769, 107 (L13)
Massari et al. 2023, arXiv:2310.01495
Mészáros et al 2020, MNRAS 492, 1641 (APO)
Minelli et al. 2021, ApJ 918, L32
Nardiello et al. 2018, MNRAS 481, 3382
Schiappacasse-Ulloa & Lucatello 2023 MNRAS 520, 5938

NGC6388 has the usual light-elements anti-correlations (plus an interesting Zr-Na correlation)



- We measured abundances of all the "classical" light elements involved in the (anti-)correlations: O, Na, Mg, Al, Si, Ca (only K is missing from the picture)
- We could separate primordial (P) and second generation stars (Intermediate and Extreme, P & I), using e.g. O and Na (*see figure left*)
- The fractions of P, I, E are 29, 54, 16 %
- The RGB stars show a more extended anti-correlation than the AGB or red HB stars
- A single class of first generation polluters seems able to reproduce all light elements variations
- The Na-O anti-correlation, the main spectroscopic indicator of multiple populations, is "short" for its mass: see the IQR([O/Na] vs Mv plot, a powerful diagnostic of MPs (Carretta+2007, Carretta+2010)
- In NGC 6388 the ratio [Zr/Fe]I shows significant correlations (*see figure right*) with both [Na/Fe] and [Al/Fe], two species enhanced in proton-capture reactions (two-tail probability $p=2.4 \times 10^{-5}$ and p=0.033, respectively)
- There is contrasting evidence in other GCs: no significant correlations found in NGC 6752 (Schiappacasse-Ulloa & Lucatello 2023), a positive correlation Zr-Na in 47 Tuc (Kolomiecas et al. 2022).
- More clusters are required to explore the relation between light and n-capture elements



Conclusions:

1- NGC 6388 is not a typical Type-II GC: there is no spread in metallicity nor in s-process elements among its stars. This occurrence then open a new question: what are the red sequence RGB stars in the pseudo-colours HST maps (the chromosome maps), supposed to be second generation stars?

2- NGC 6388 is an in situ globular cluster, not accreted. The suggested method based on iron-peak elements seems to work only in selecting the peculiar chemistry of Sagittarius GCs

We wish to remember our friend Antonio Sollima who, beside all its many accomplishments, was also a GC aficionado