

The past and the present of NGC 1316 through Gemini + GMOS

Favio R. Faifer
Leandro A. Sesto
Carlos Escudero
Analía Smith Castelli
Juan C. Forte



Facultad de Ciencias
**Astronómicas
y Geofísicas**
UNIVERSIDAD NACIONAL DE LA PLATA



Science and Evolution of Gemini Observatory 2018

Motivation: globular clusters (GCs)

- GCs are ancient stellar systems formed **before or with** their parent galaxies (**ages > 10 Gyrs**).
- It is believed that GCs have been originated from **massive molecular clouds** during the most **intense star formation episodes** in the life of galaxies ($z \sim 2-3$).
- GCs are **compact** and **bright objects**. Therefore they are **relatively easy to observe** in near galaxies.
- CGs are the closest realizations of SSPs in nature.



Motivation: globular clusters (GCs)

- GCs are ancient stellar systems formed **before or with** their parent galaxies (**ages > 10 Gyrs**).
- it is believed that GCs have been originated from **massive molecular clouds** during the most **intense star formation episodes** in the life of galaxies ($z \sim 2-3$).
- GCs are **compact** and **bright objects**. Therefore they are **relatively easy to observe** in near galaxies.
- GCs are the closest realizations of SSPs in nature.
- **Early type galaxies** have GC systems of **thousands of clusters**.

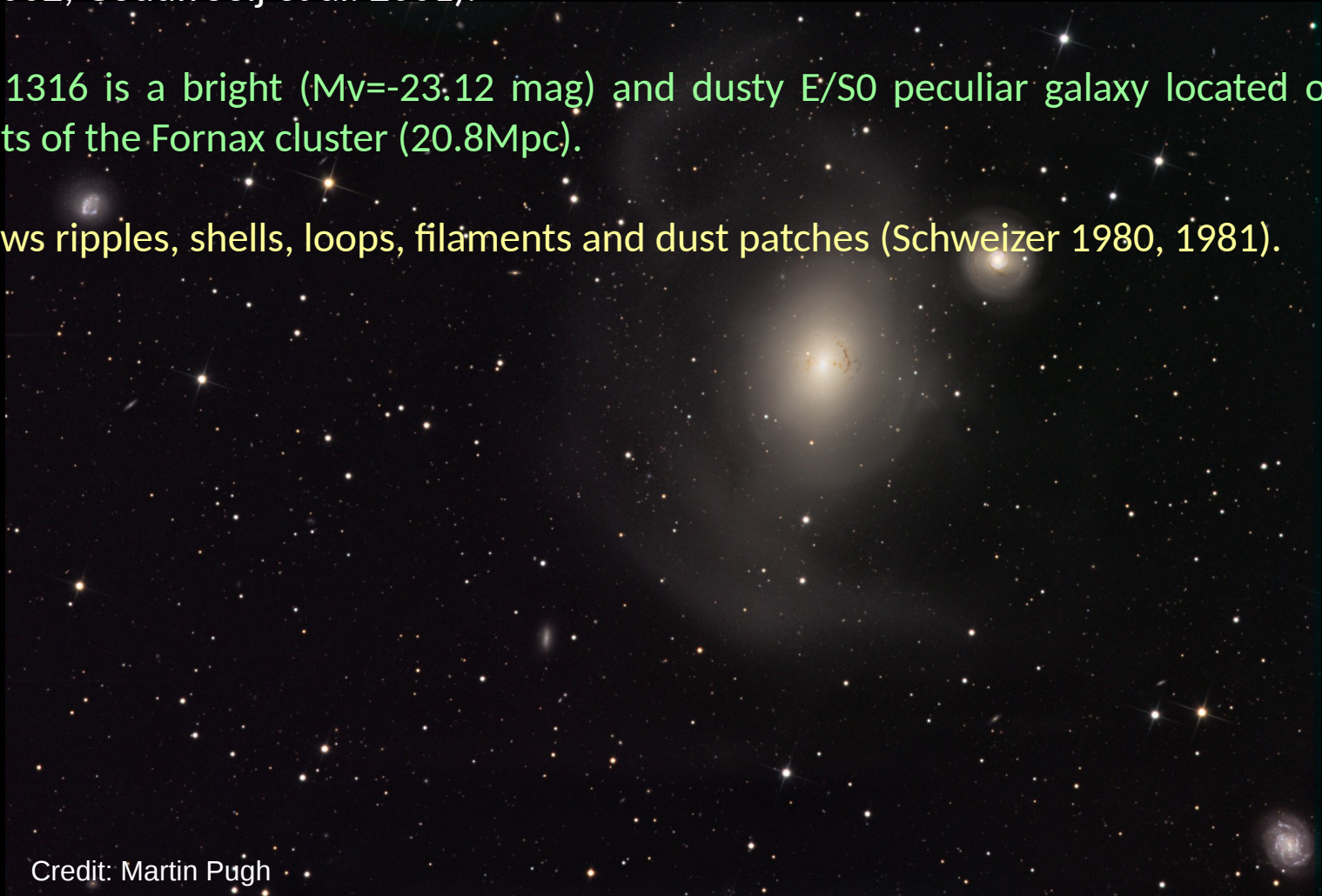


Gemini Observatory / AURA

Gemini Observatory Legacy Image

Motivation: NGC 1316 (Fornax A)

- Some GCs could be still forming in galaxy mergers in the local Universe (Schweizer 1982, 1987, 2002; Goudfrooij et al. 2001).
- NGC 1316 is a bright ($M_V = -23.12$ mag) and dusty E/S0 peculiar galaxy located on the outskirts of the Fornax cluster (20.8 Mpc).
- It shows ripples, shells, loops, filaments and dust patches (Schweizer 1980, 1981).



Motivation: NGC 1316 (Fornax A)

“Sketch of structures observed in the spheroid and envelope (dashed outline) of NGC 1316:

Ri-R5, ripples

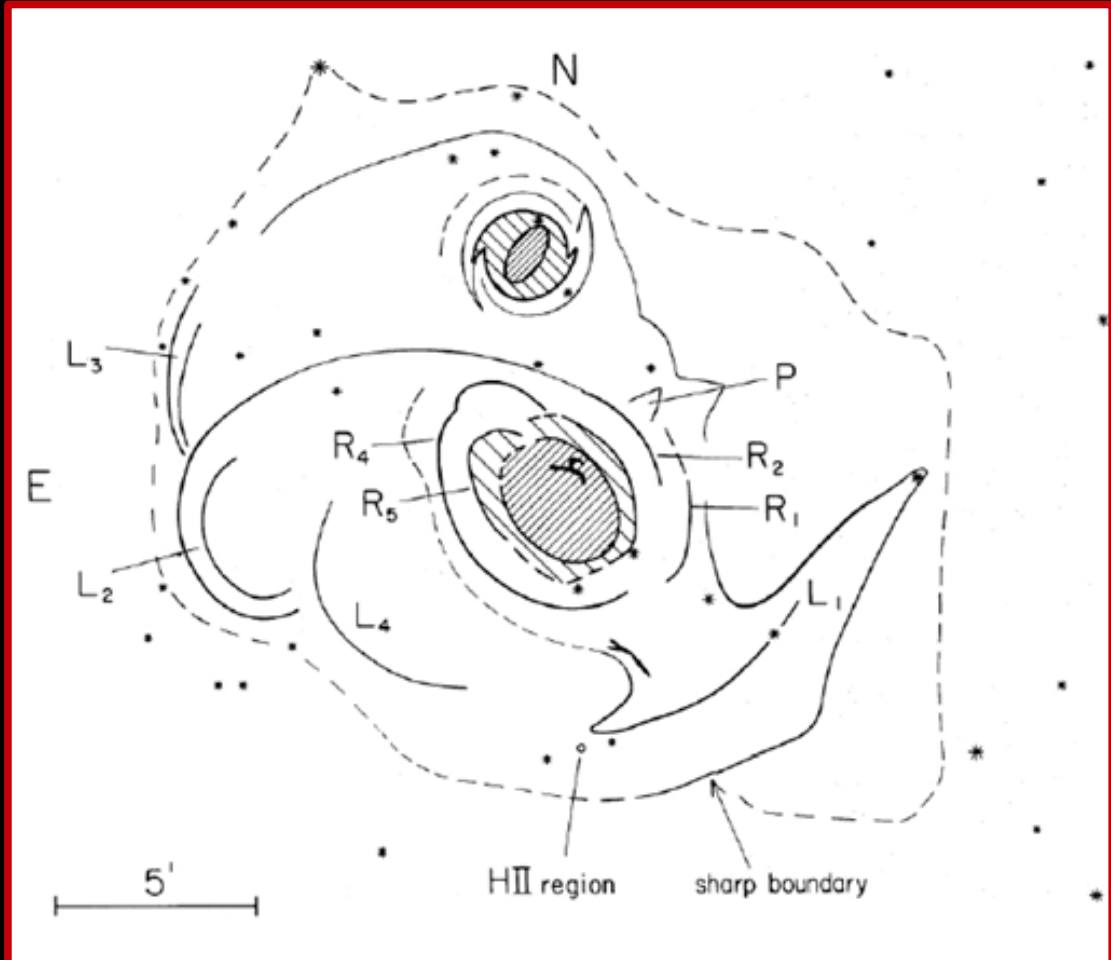
P, plume

Li-L4, loops.

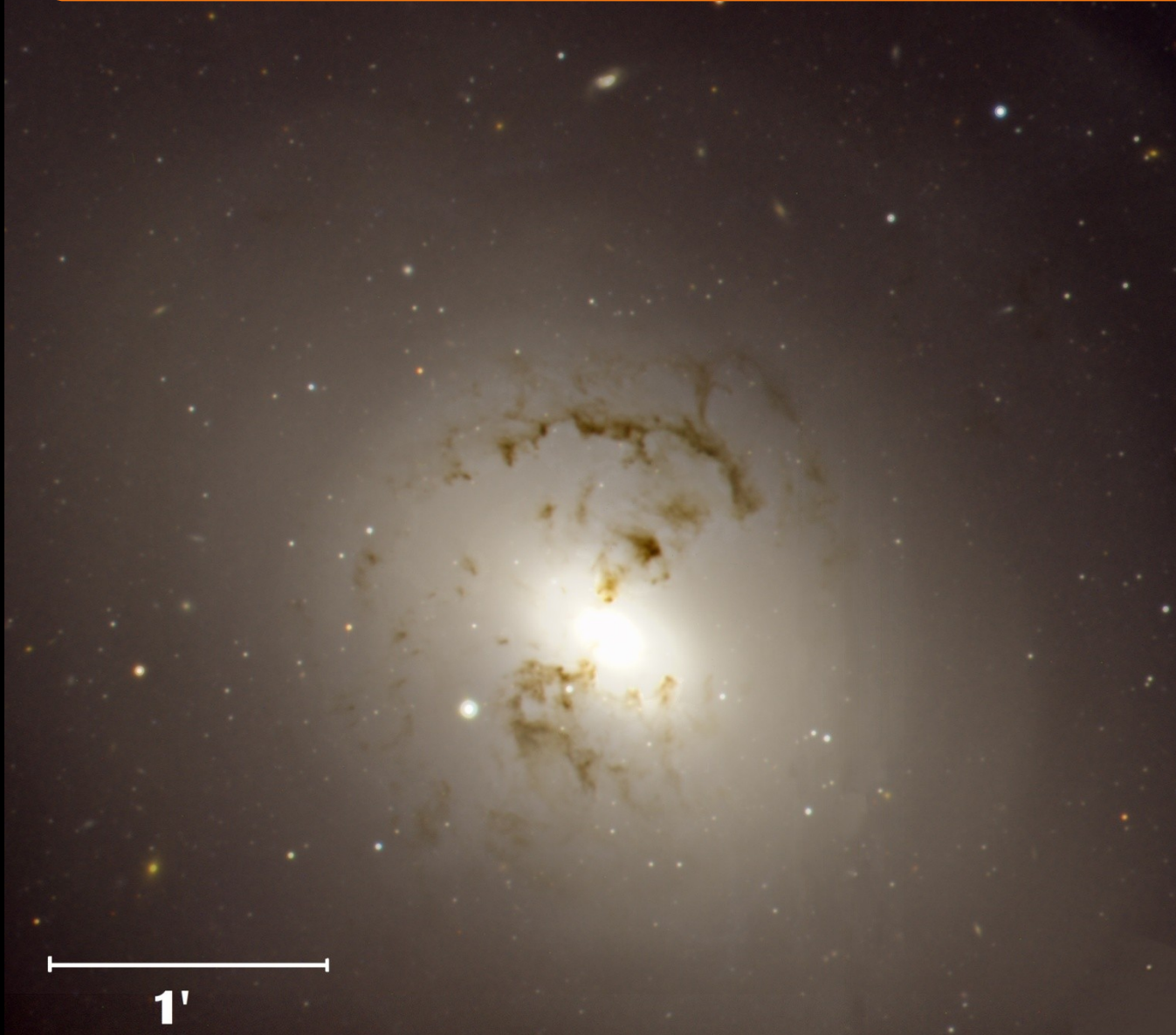
The two worm-like features (inside hatched area, and NW of H n region) represent major dust lanes. Notice the long arc connecting L2 with R2.

... we suggest that at least one, and possibly several, gas-rich companion galaxies fell in about 4×10^8 - 2×10^9 years ago.”

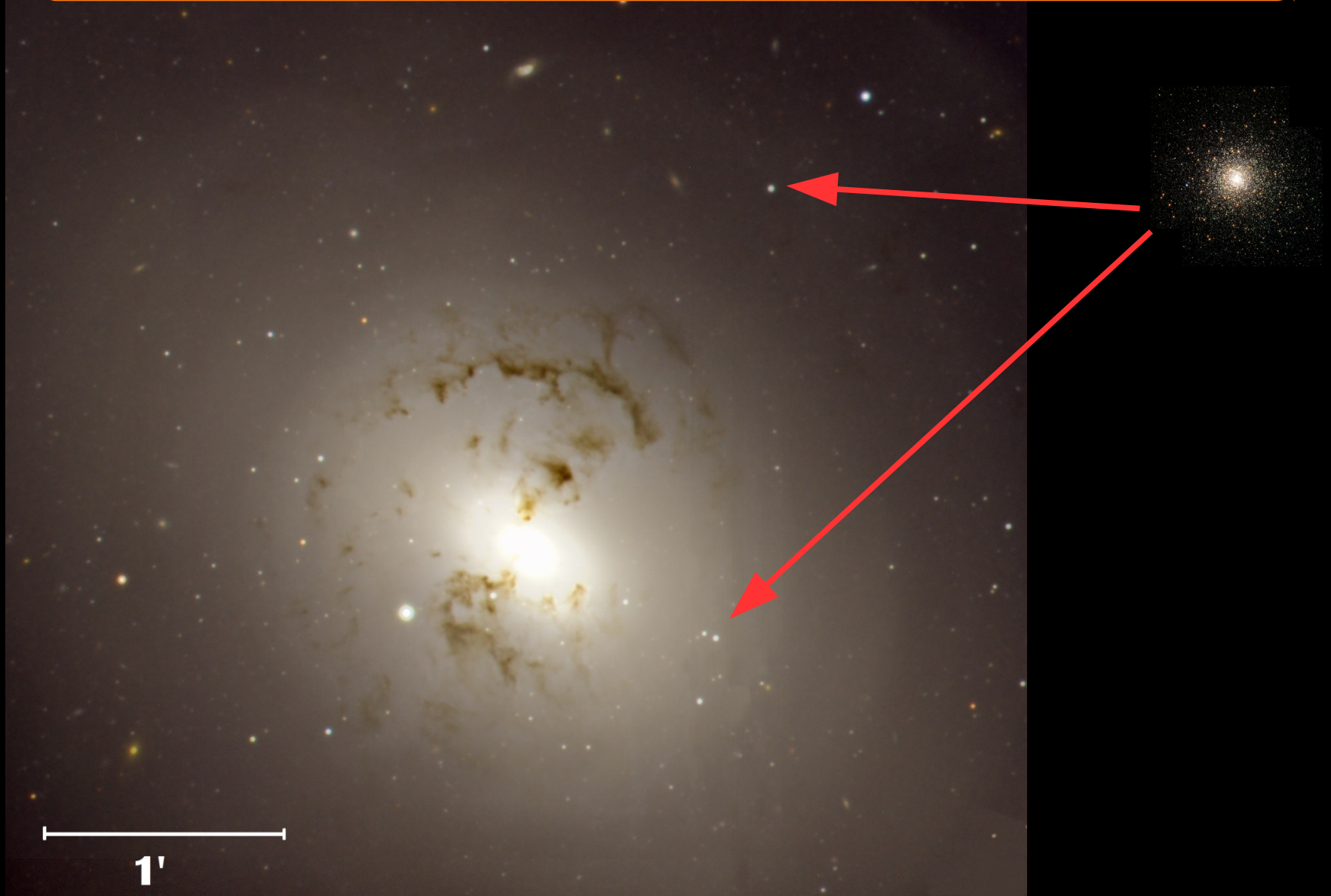
Schweizer (1980)



Motivation: NGC 1316 (Fornax A)



Motivation: NGC 1316 (Fornax A)



Motivation: NGC 1316 (Fornax A)

GCs in NGC1316 were previously studied by Goudfrooij et al. (2001a,b;2004), Gómez et al. (2001) and more recently by Richtler et al. (2012a,b; 2014)

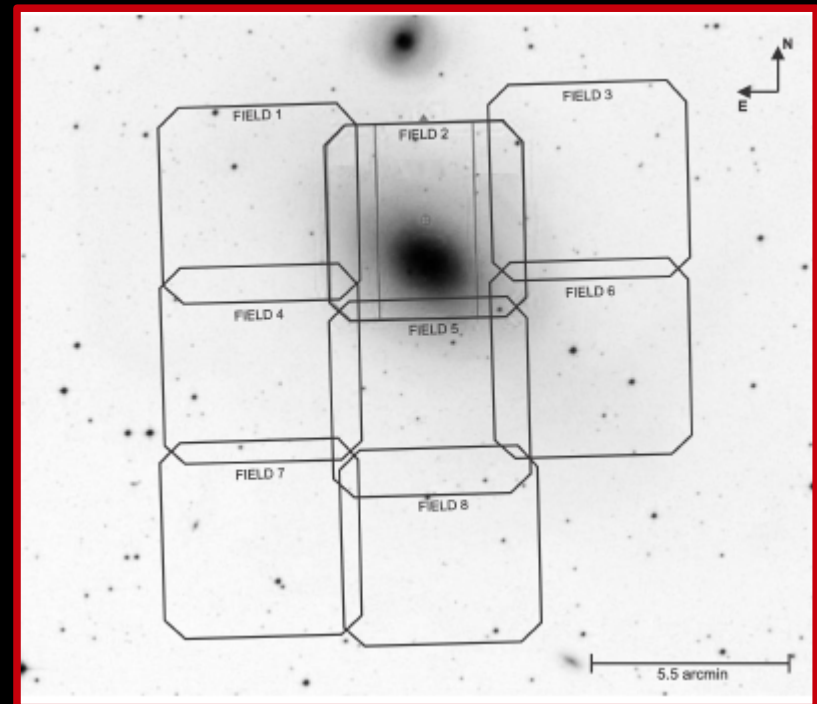
The GC system of NGC 1316 is not typical, and it seems to have an intermediate color subpopulation in addition to the “classical” blue and red GCs.

Goudfrooij et al. (2001b), measured the age and metallicities of three GCs. They result to be 3 Gyrs old and solar in metallicities ~ 0.2 dex

NGC 1316 is an interesting target to study the formation of GCs in the local Universe and the evolution of galaxies by mergers.

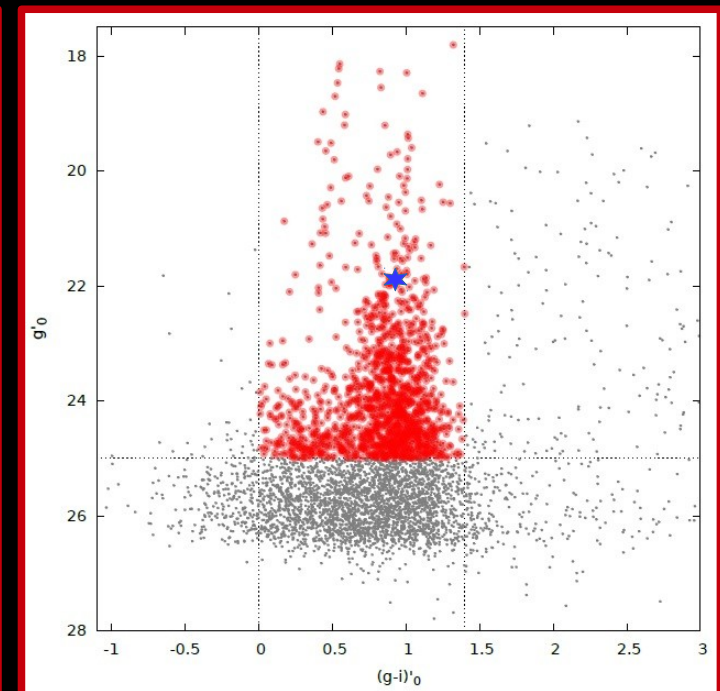
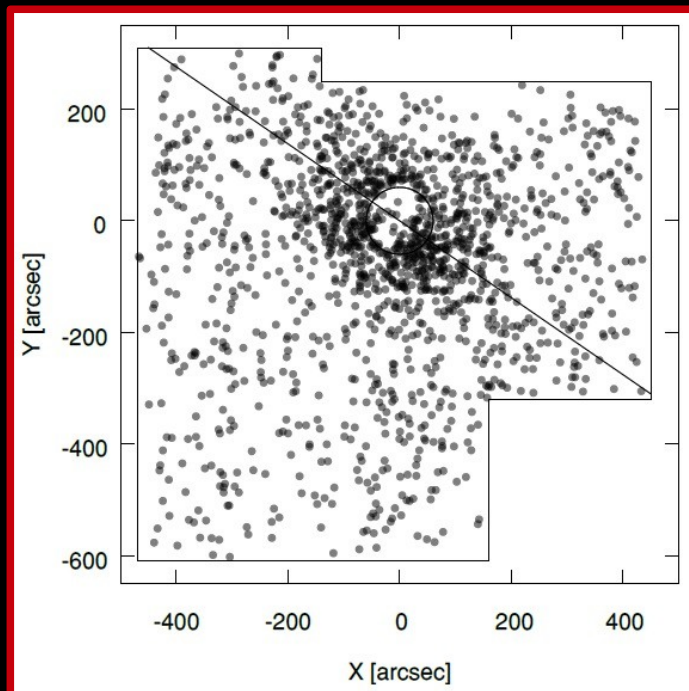
We started an study of this galaxy by using Gemini+GMOS in imaging (g,r and i) and MOS mode.

Sesto et al. (2016)



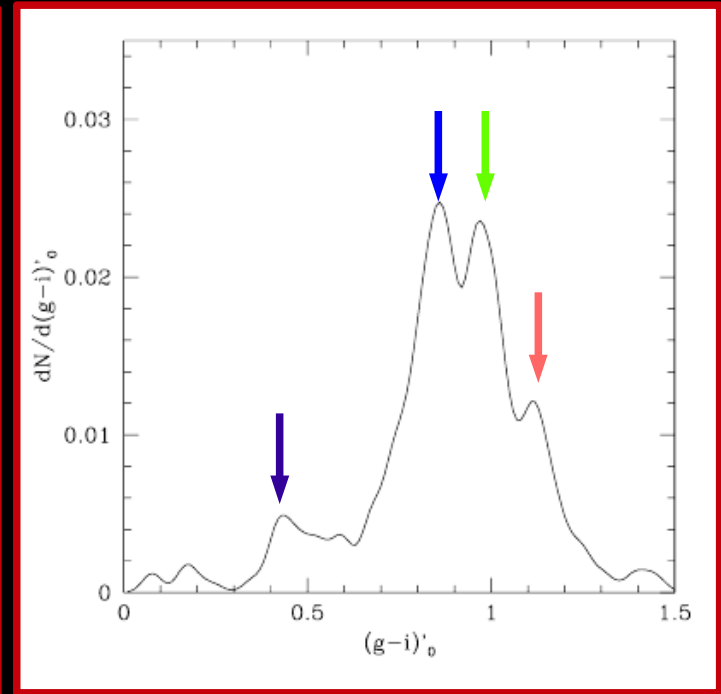
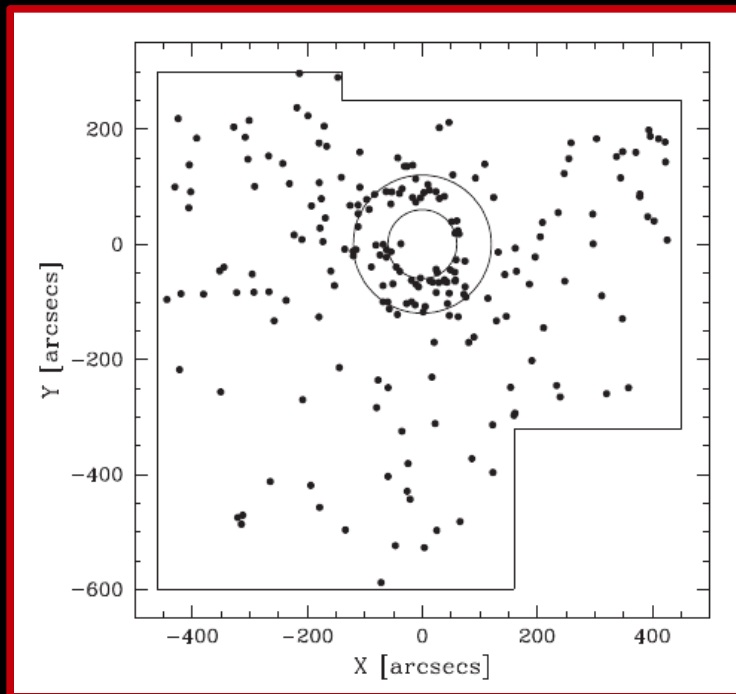
NGC 1316 (Fornax A): our photometric study

- NGC 1316 has a rich GCs system (~ 1500 candidates with $g' < 25$ mag).
- GCs in NGC1316 are multi-modal in colors, with three (possibly four) subpopulations.
- An intermediate color subpopulation stand out.
- “Blue” and “red” GCs show photometric properties similar to those observed in massive early type galaxies, but there is a no clear maximum in the GCLF for “red” ones.
- Intermediate color GCs are compatible with being a young subpopulation with ages < 5 Gyrs.



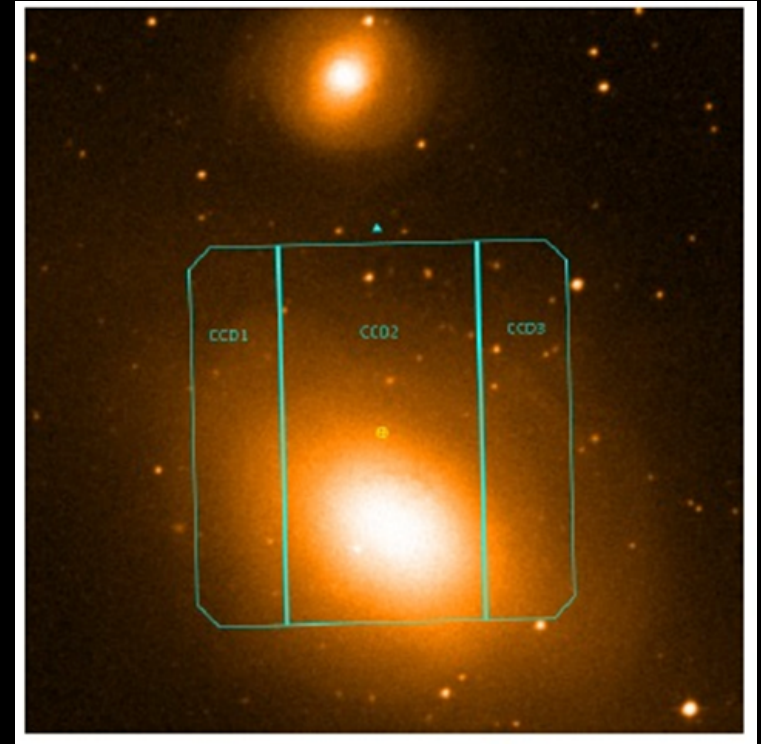
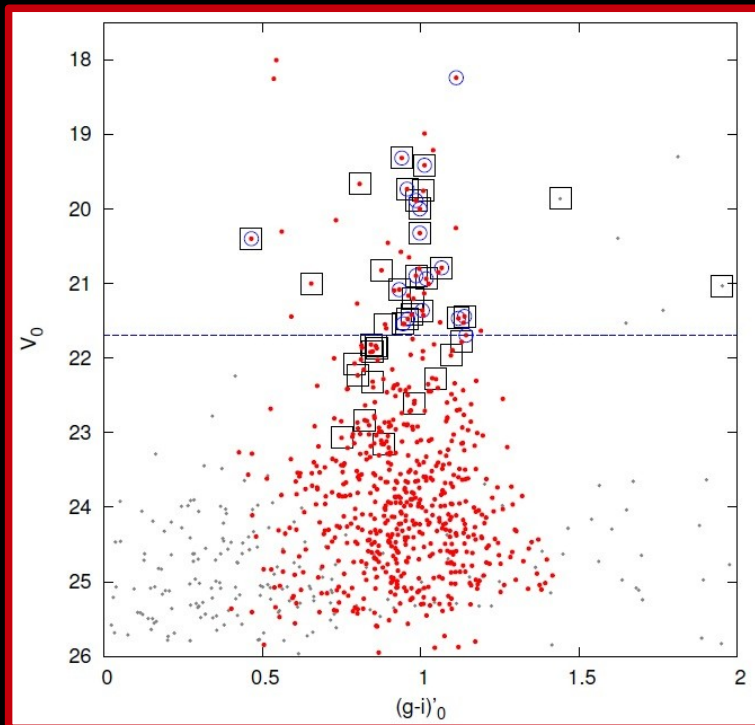
NGC 1316 (Fornax A): our photometric study

- NGC 1316 has a rich GCs system (~ 1500 candidates with $g' < 25$ mag).
- GCs in NGC1316 are multi-modal in colors, with three (possibly four) subpopulations.
- An intermediate color subpopulation stand out.
- “Blue” and “red” GCs show photometric properties similar to those observed in massive early type galaxies, but there is a no clear maximum in the GCLF for “red” ones.
- Intermediate color GCs are compatible with being a young subpopulation with ages < 5 Gyrs.

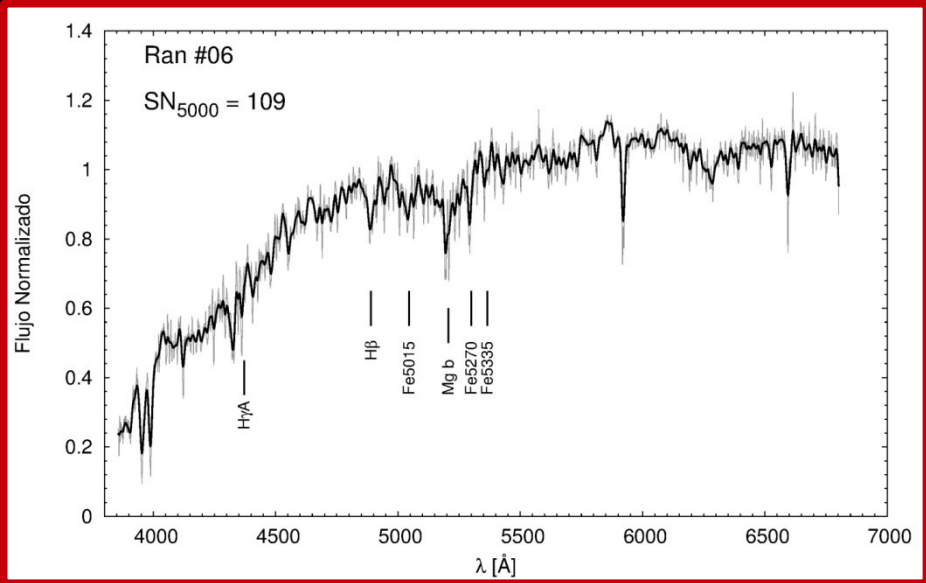


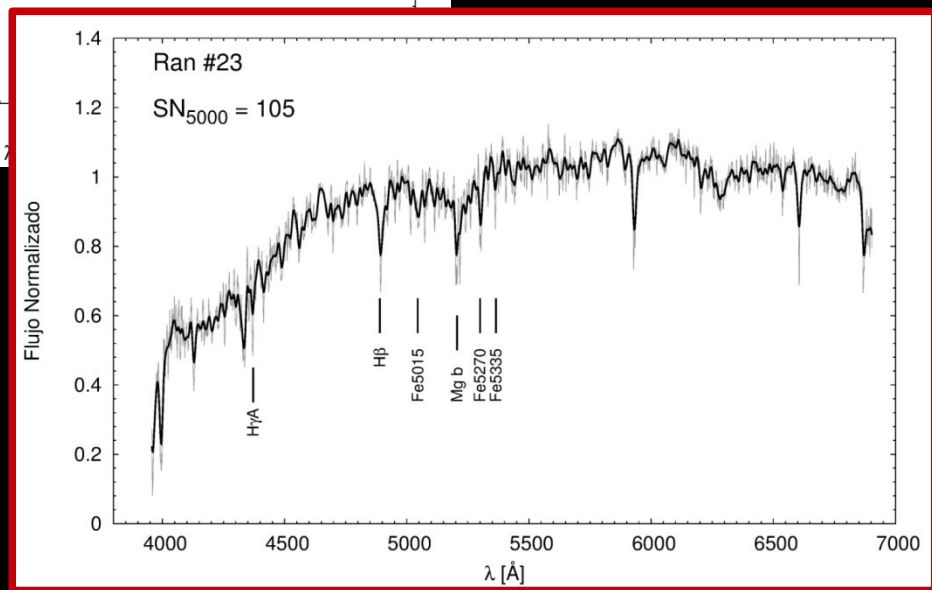
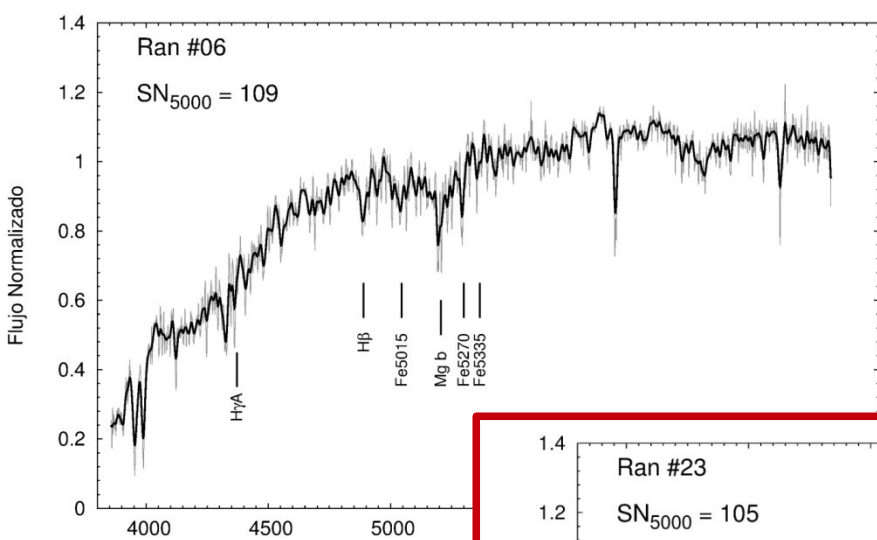
NGC 1316 (Fornax A): our spectroscopic study

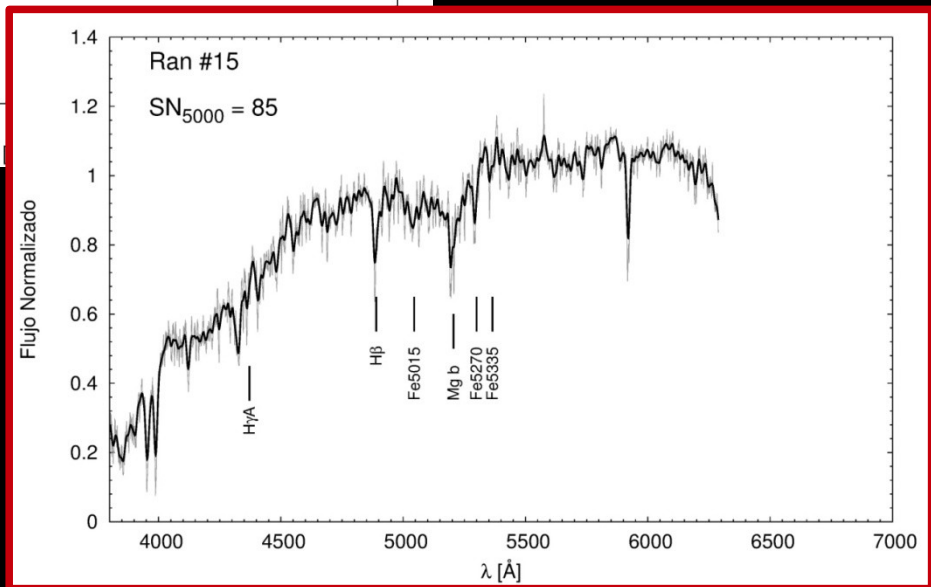
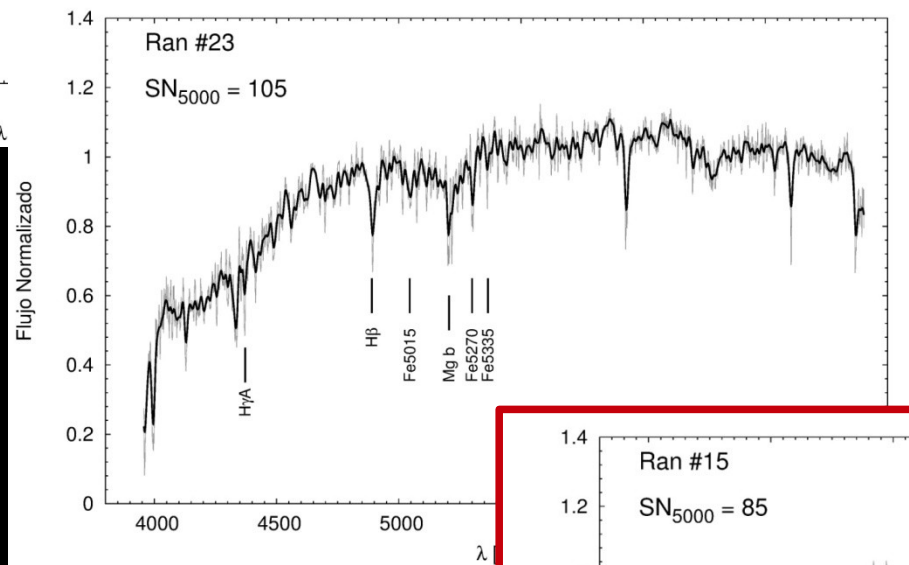
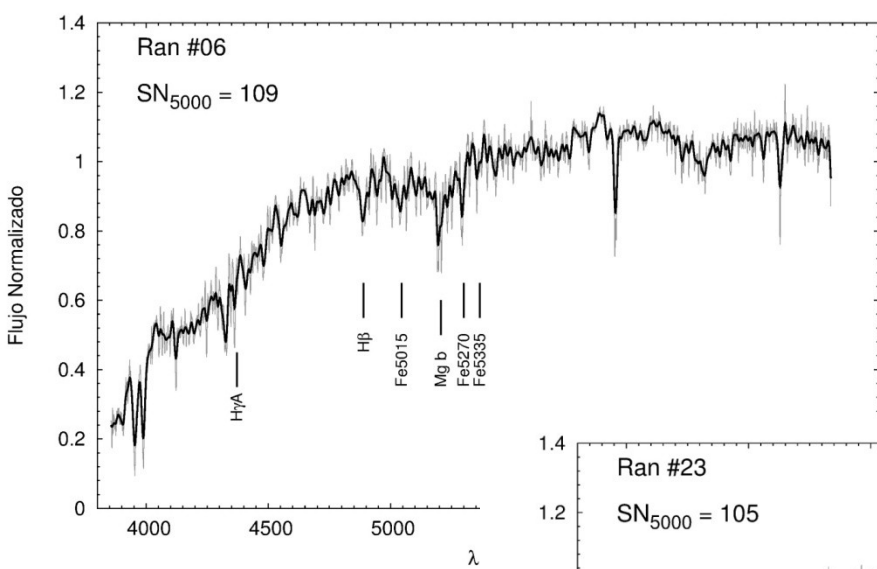
For the design of the MOS mask, the central field of the photometric mosaic was used as a pre-image.

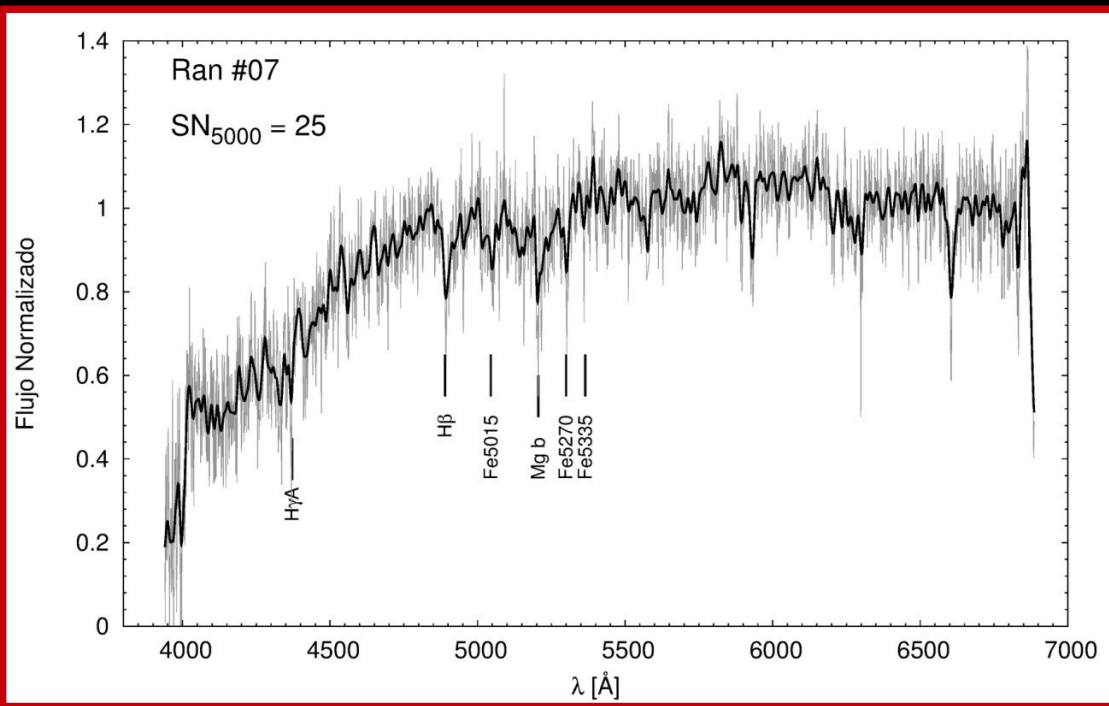
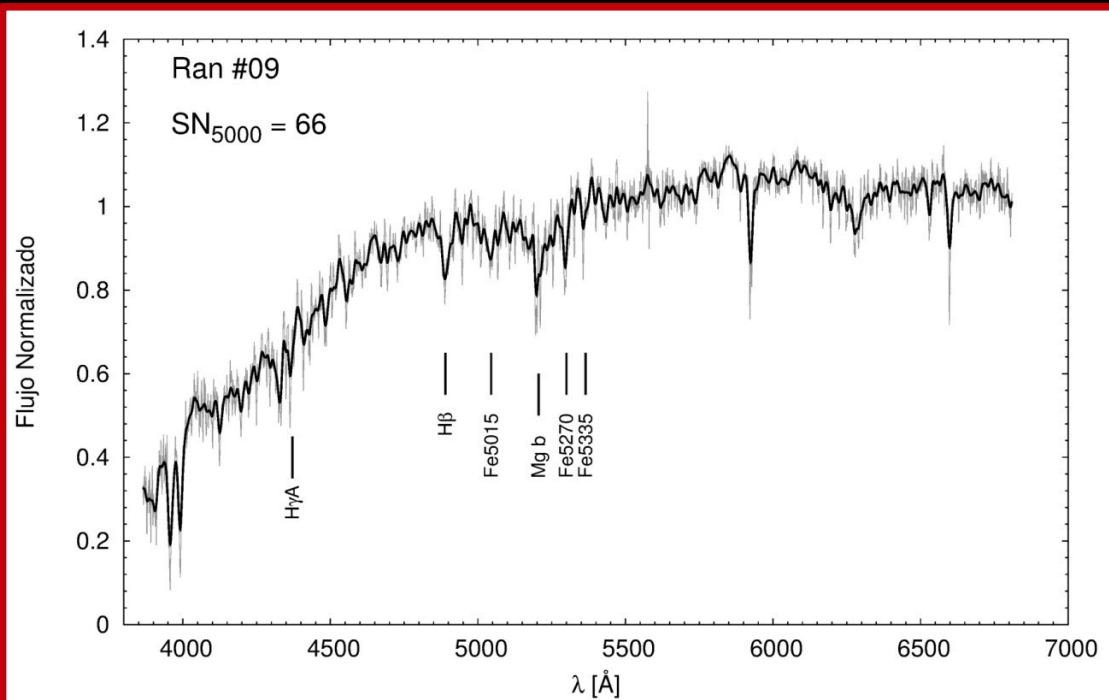


- ❖ The MOS mask consisted of 40 slits of 1 arcsec width and 4–6 arcsec length
- ❖ B600 grating centered at 5000 and 5100 Å (to cover the CCD chip gaps)
- ❖ 8 hours of on-source integration time









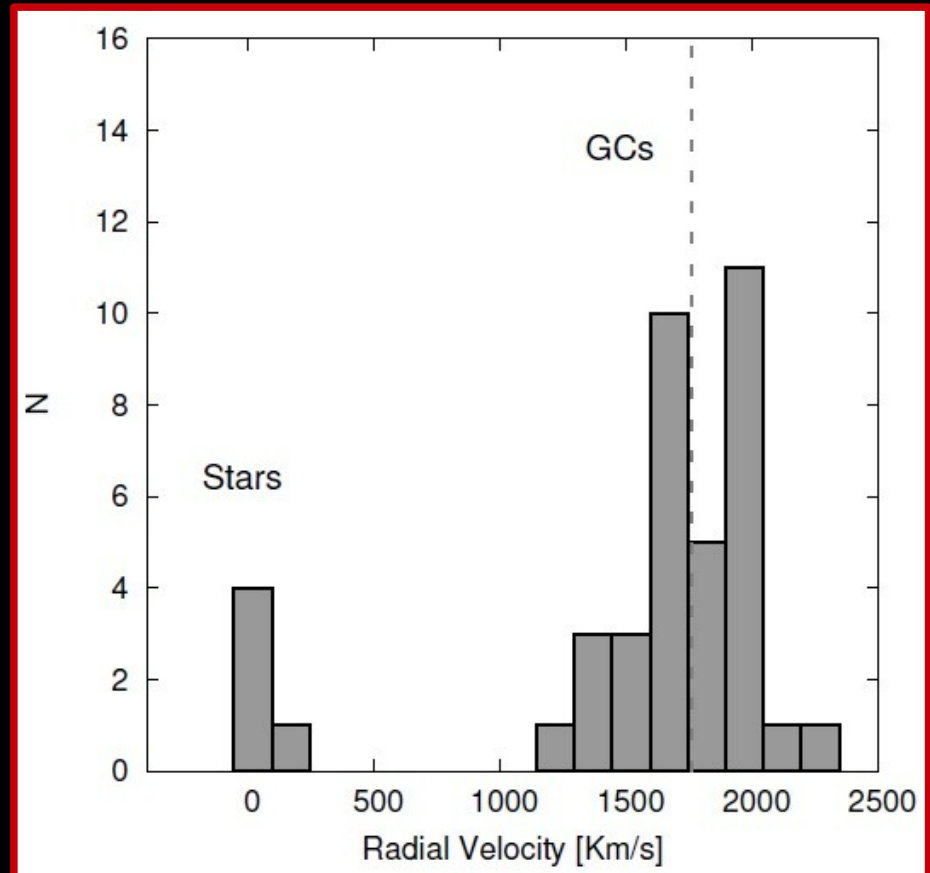
NGC 1316 (Fornax A): kinematic

RV: Cross correlation using
FXCOR/IRAF (Tonry & Davis
1979)

As template spectra we used SSP
models, obtained from the
MILES libraries (Vazdekis et al.
2010).

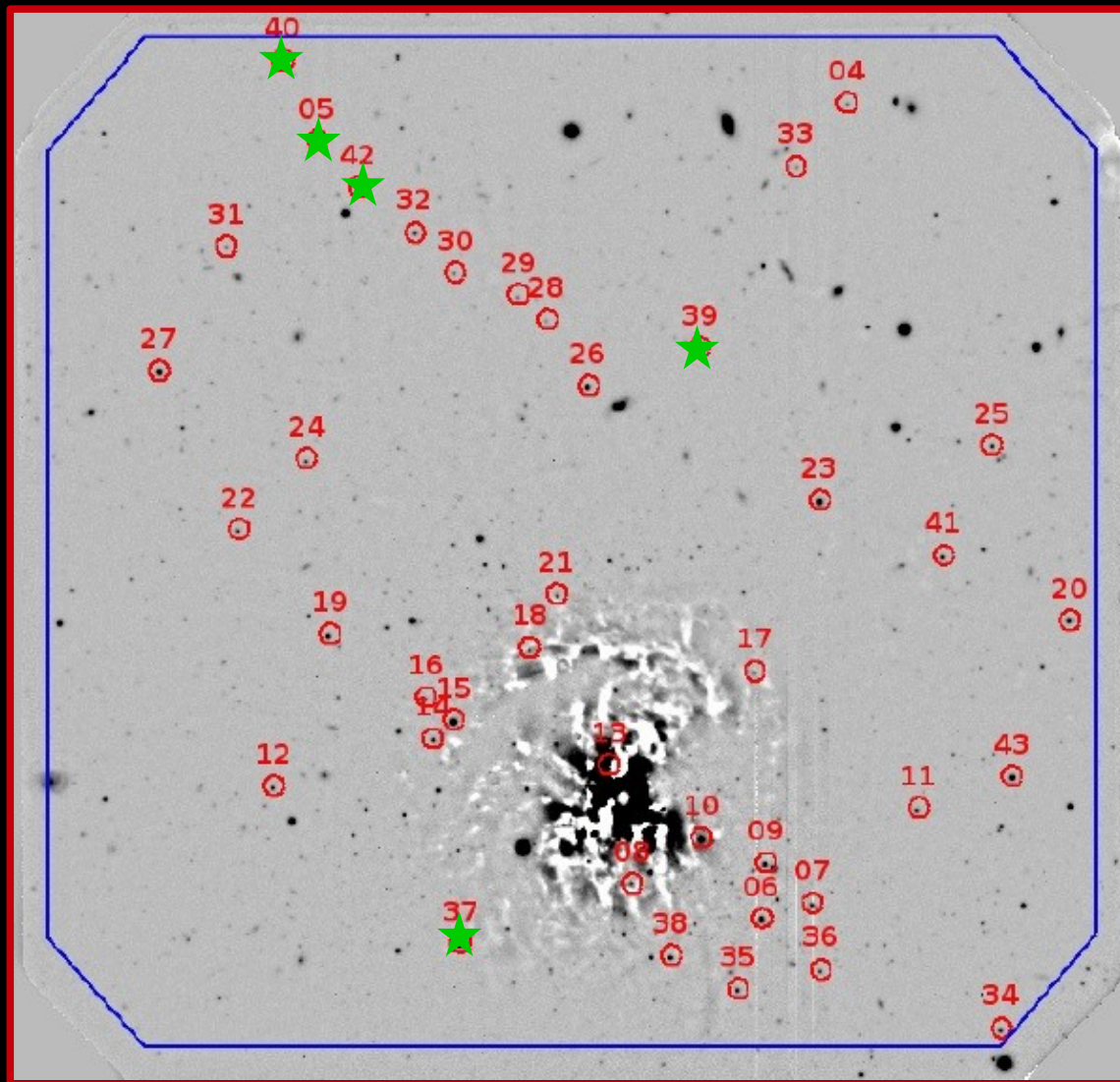
Ages: 2.5, 5 and 12.6 Gyr

$[Z/H] = -2.32; -1.71; -1.31; -0.71;$
 $-0.4; 0; 0.4$ dex



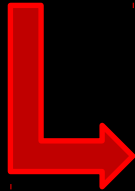
- Thirty-five genuine globular clusters were confirmed, which presented radial velocities close to 1760 km/s, adopted as the systemic velocity of NGC 1316 (Longhetti et al. 1998).
- Five objects present in the sample resulted to be field MW stars.

NGC 1316 (Fornax A): our spectroscopic study



NGC 1316 (Fornax A): kinematic

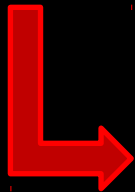
- Goudfrooij et al. (2001a)



23 GCs

Presented multi-object spectroscopy of 24 GCs, using observations from the New Technology Telescope (NTT). These authors reported ages and metallicities just for 3 GCs.

- Richtler et al. (2014)



Presented wide-field multi-object spectroscopy for GC candidates, obtained through the FORS2 instrument mounted in the Very Large Telescope (VLT). They confirmed 177 GCs. Due to the low S/N presented by these spectra, they were only able to obtain RVs.

NGC 1316 (Fornax A): kinematic

Our spectroscopic sample included:

16 object previously confirmed as GCs by Goudfrooij, who reported ages and met. for one of them.

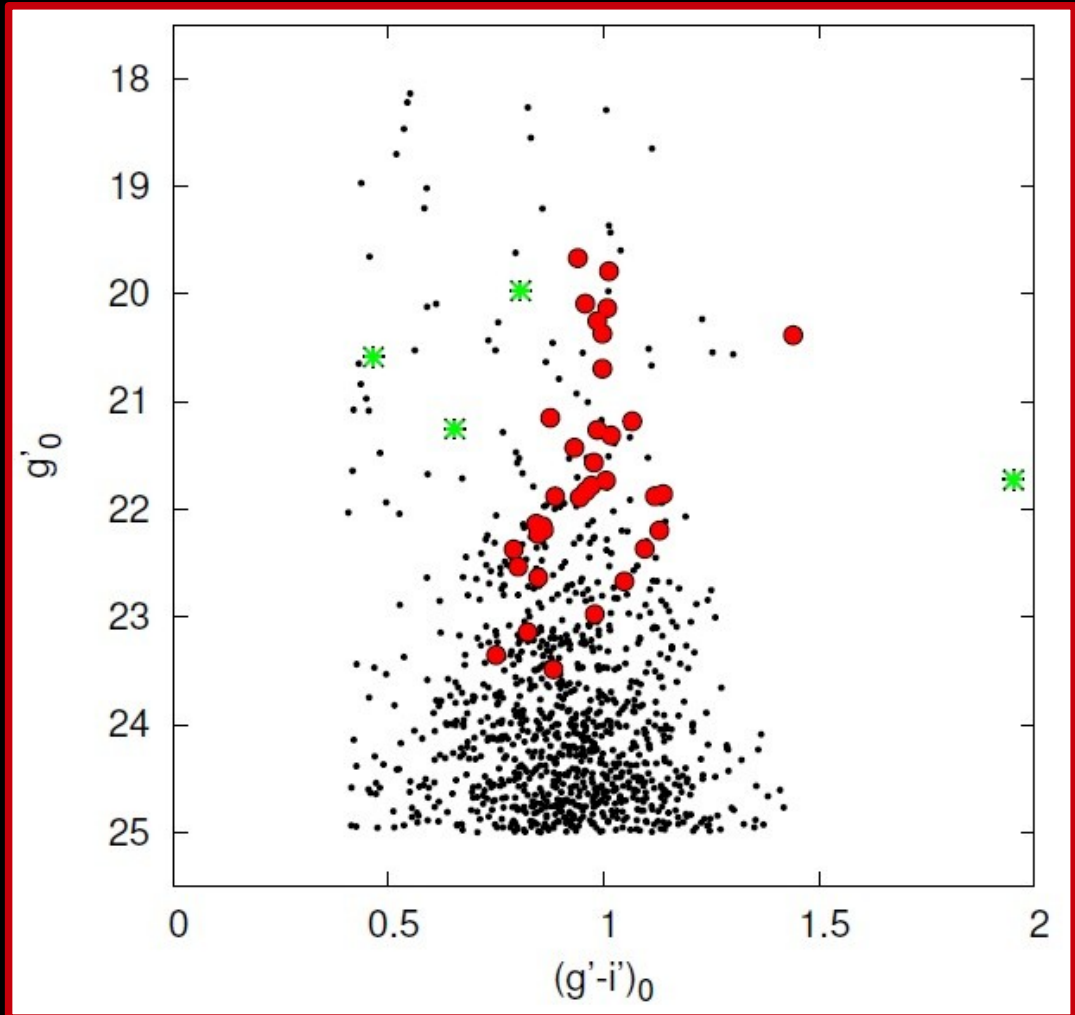
We re-confirm 15 GCs. **ID#119 resulted to be a MW star.**

6 GCs previously detected by Richtler (4 in common with Goudfrooij).

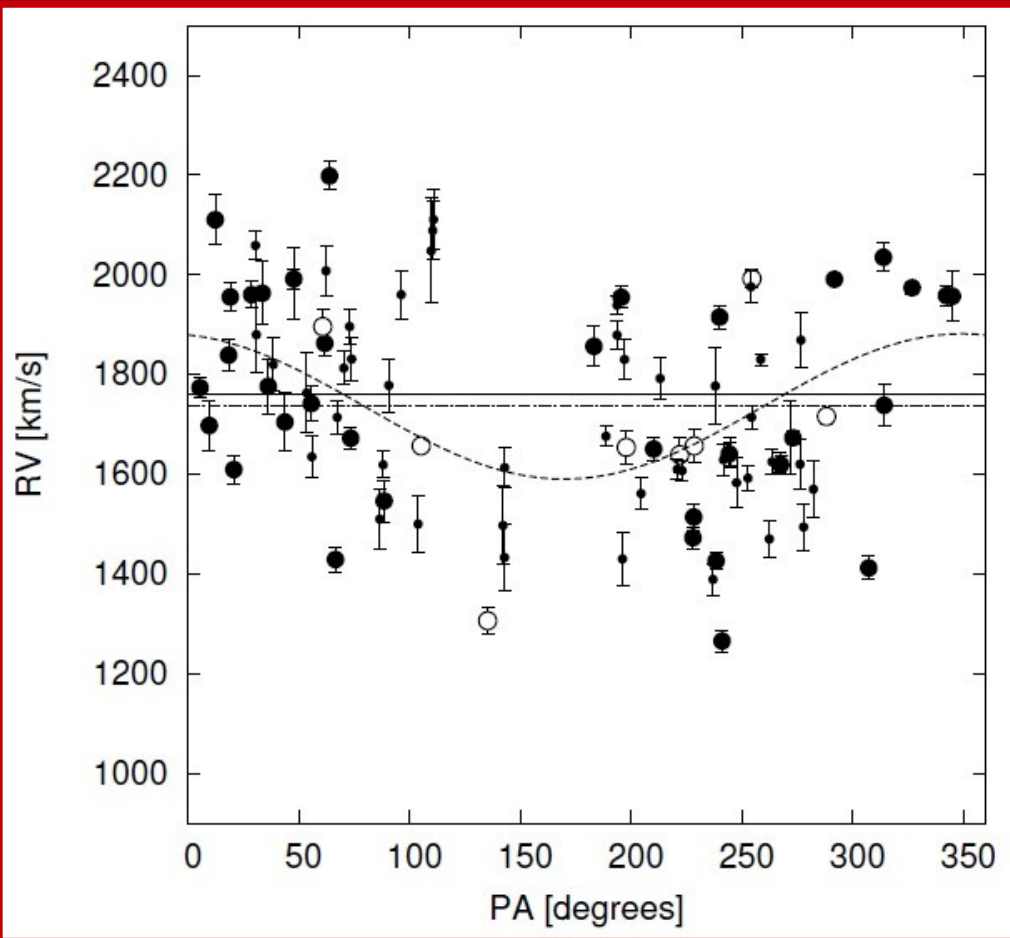
We re-confirm all of them.

We reported 17 not previously known GCs at the inner zone of this GC system.

See Sesto et al. (2018)



NGC 1316 (Fornax A): kinematic



$$V_r = v_{sis} + v_0 \cdot \cos(\theta - \theta_0)$$

GCs with $R_{gal} < 4$ arcmin:

35 Vr from GMOS

8 Vr from NNT

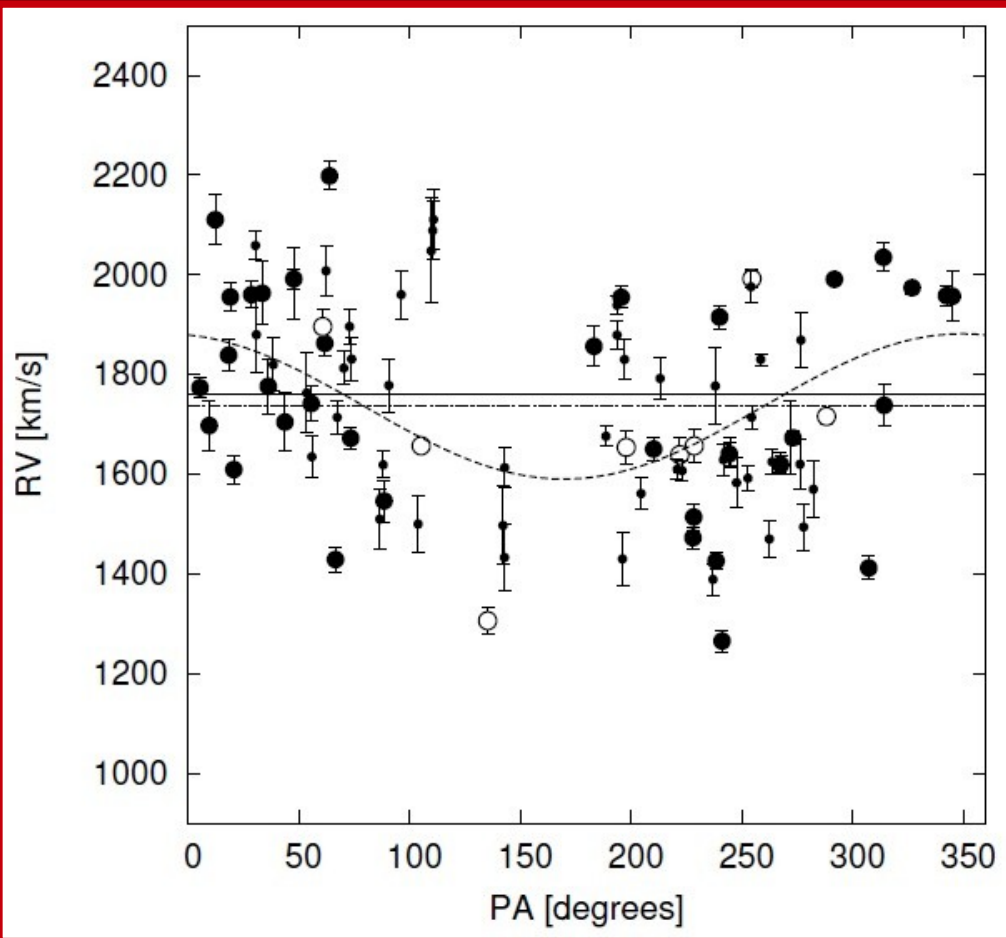
47 Vr from FORS2

Result: the GC system rotates with a PA of $350 \pm 8^\circ$ (along its minor axis) and with an amplitude of 145 ± 32 km/s.

The diffuse stellar component of NGC 1316 is rotating with a PA of $\sim 70^\circ$ (along its major axis) and with an amplitude of 130 km/s (McNeil-Maylan et al. 2012; Richtler et al. 2014)

See Sesto et al. (2018)

NGC 1316 (Fornax A): kinematic



Polar ring structure?
Whitmore et al., (1990)

$$V_r = v_{sis} + v_0 \cdot \cos(\theta - \theta_0)$$

GCs with $R_{gal} < 4$ arcmin:

35 Vr from GMOS

8 Vr from NNT

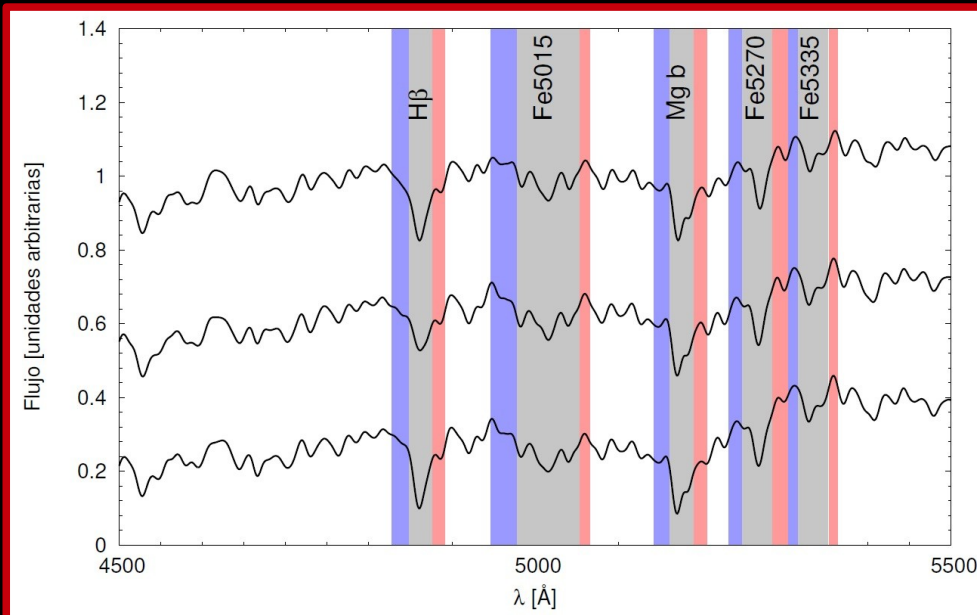
47 Vr from FORS2

Result: the GC system rotates with a PA of $350 \pm 8^\circ$ (along its minor axis) and with an amplitude of 145 ± 32 km/s.

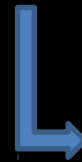
The diffuse stellar component of NGC 1316 is rotating with a PA of $\sim 70^\circ$ (along its major axis) and with an amplitude of 130 km/s (McNeil-Maylan et al. 2012; Richtler et al. 2014)

NGC 1316 (Fornax A): age and metallicities

We obtained ages, metallicities, and α -element abundances for each GC present in the sample, through the measurement of different Lick/IDS indices (Worthey 1994; Worthey & Ottaviani 1997; Trager et al. 1998) and their subsequent comparison with simple stellar populations models (SSPs).



SSP models of Thomas et al. (2003, 2004)



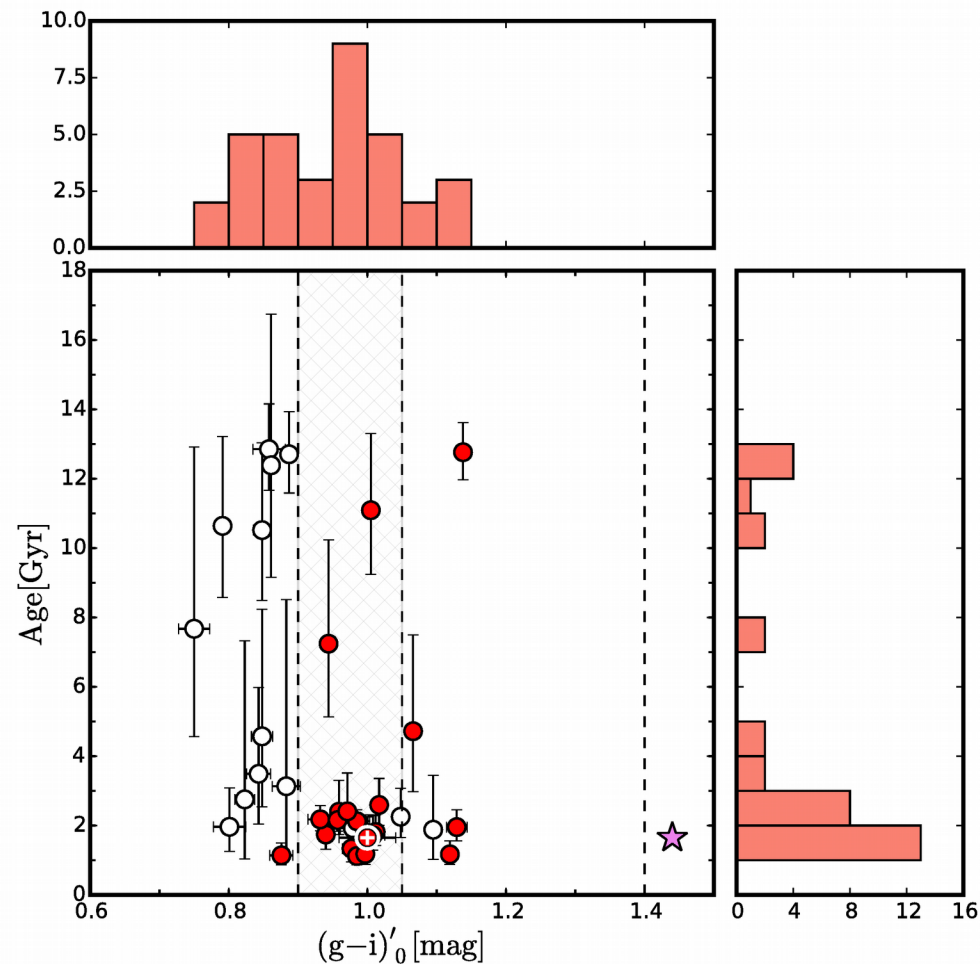
- ❖ Ages: 1 - 15 Gyr
- ❖ $[Z/H] = -2.25 - 0.67$ dex
- ❖ $[\alpha/Fe] = 0.0, 0.3$ and 0.5 dex

In order to determine the age, metallicity and alpha-element abundances of each GC, the χ^2 minimization method of Proctor & Sansom (2002) and Proctor et al. (2004) was used.

NGC 1316 (Fornax A): age vs color

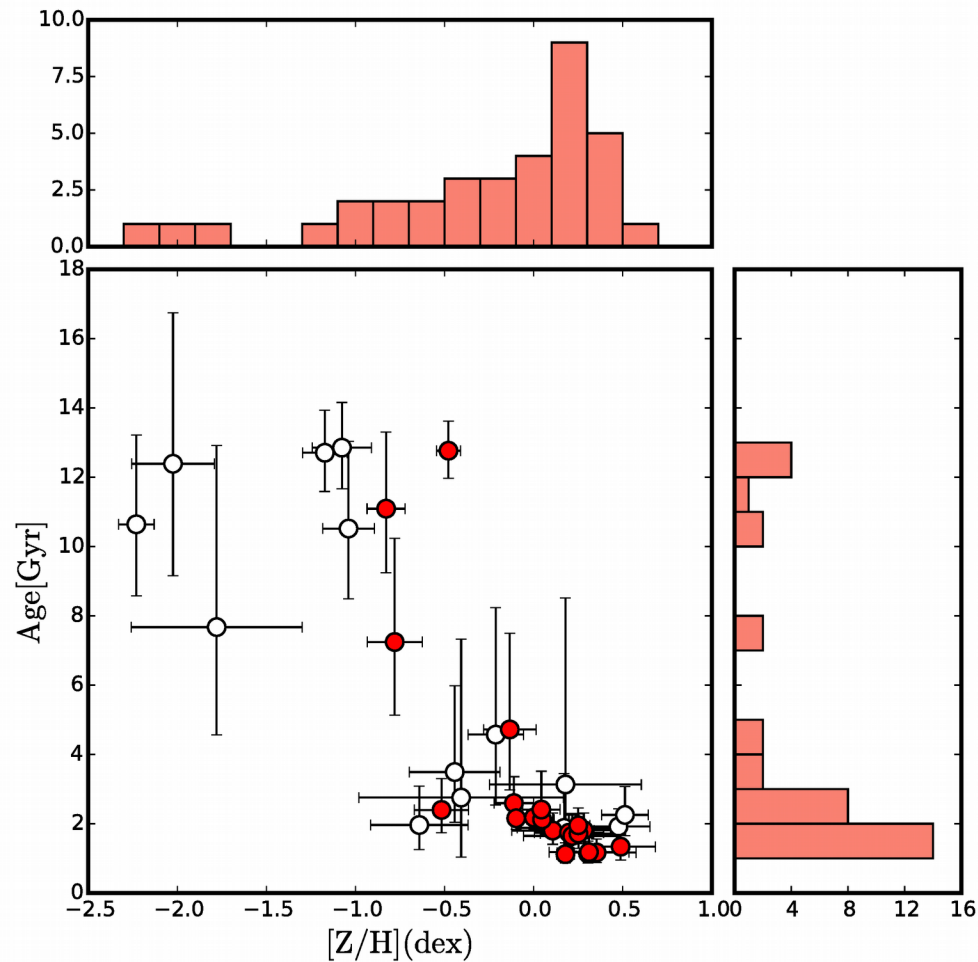
• $S/N_{5000} > 25 \text{ \AA}^{-1}$

◦ $S/N_{5000} < 25 \text{ \AA}^{-1}$



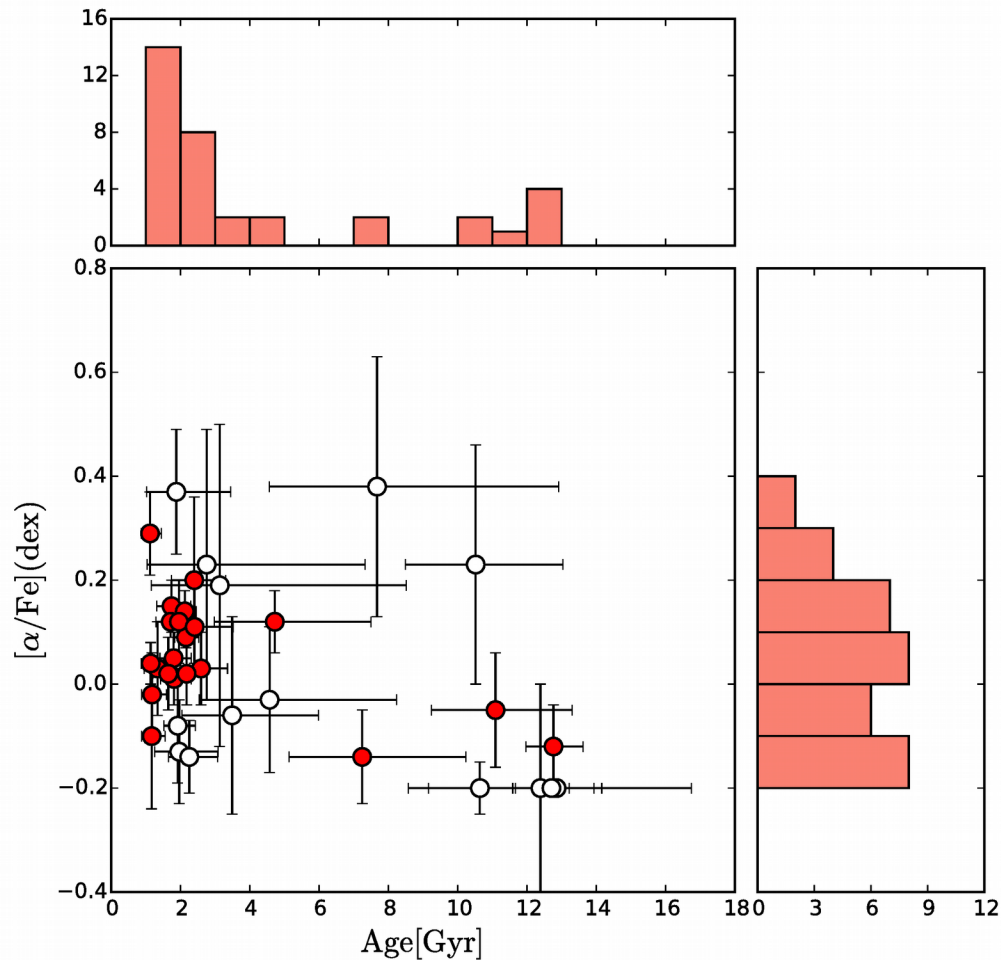
See Sesto et al. (2018)

NGC 1316 (Fornax A): age vs metallicities



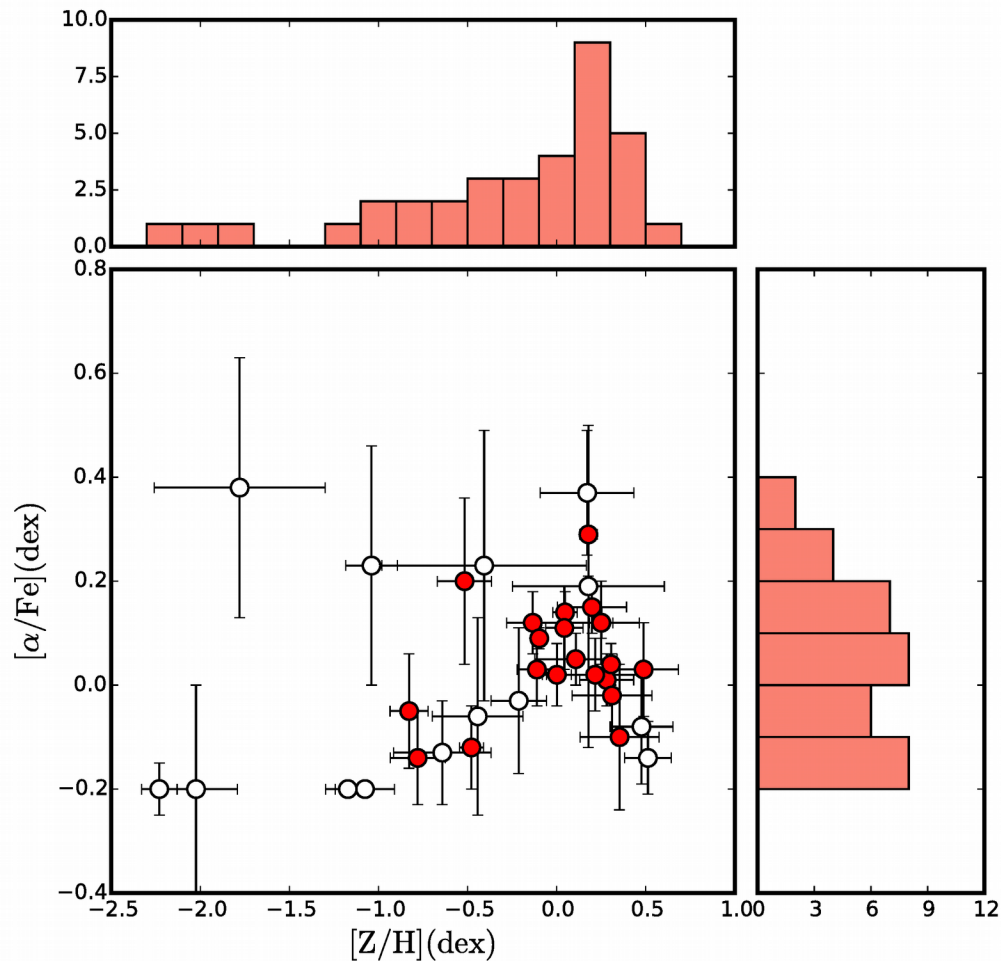
See Sesto et al. (2018)

NGC 1316 (Fornax A): $[\alpha/\text{Fe}]$ vs ages



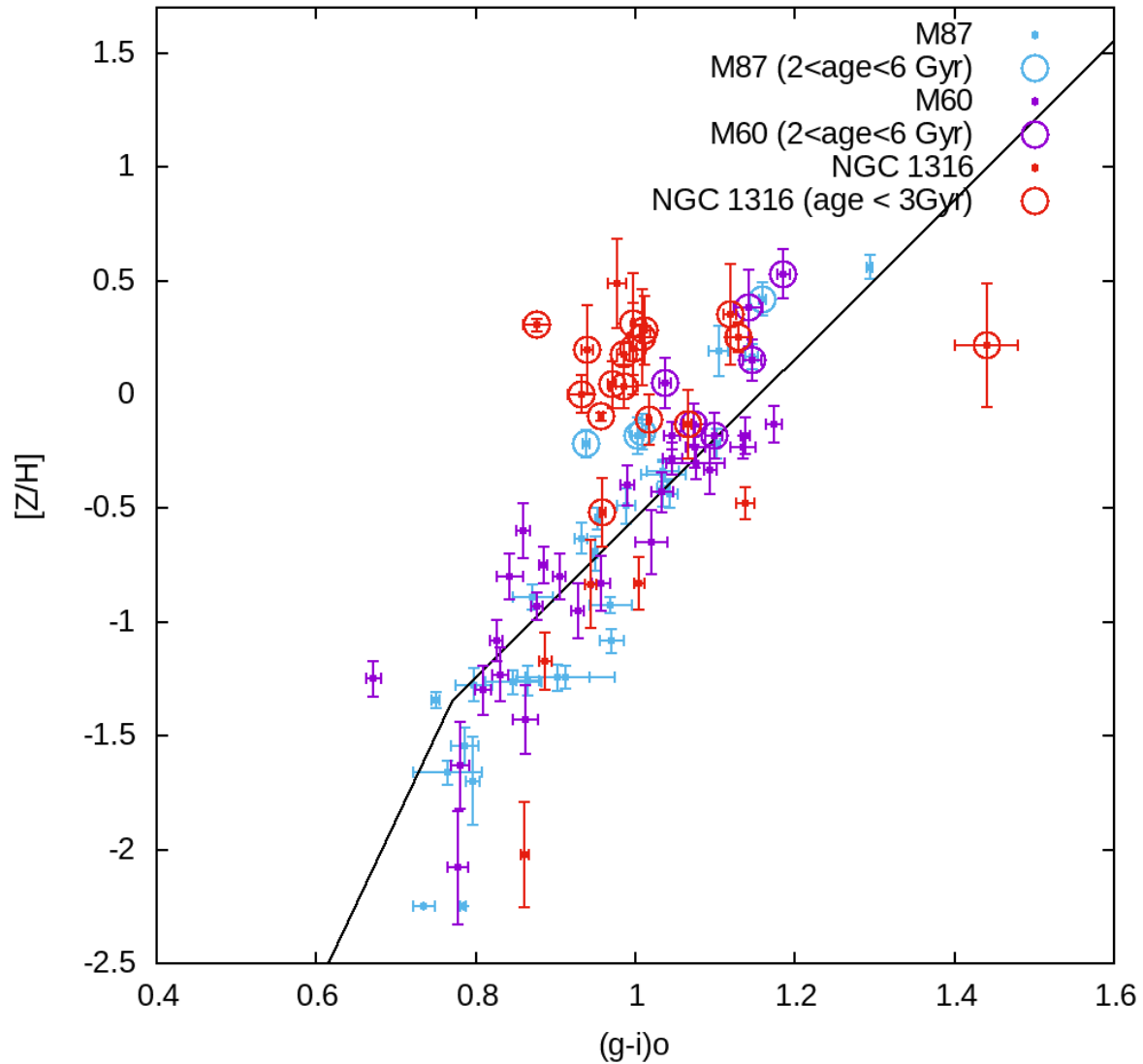
See Sesto et al. (2018)

NGC 1316 (Fornax A): $[\alpha/\text{Fe}]$ vs metallicities

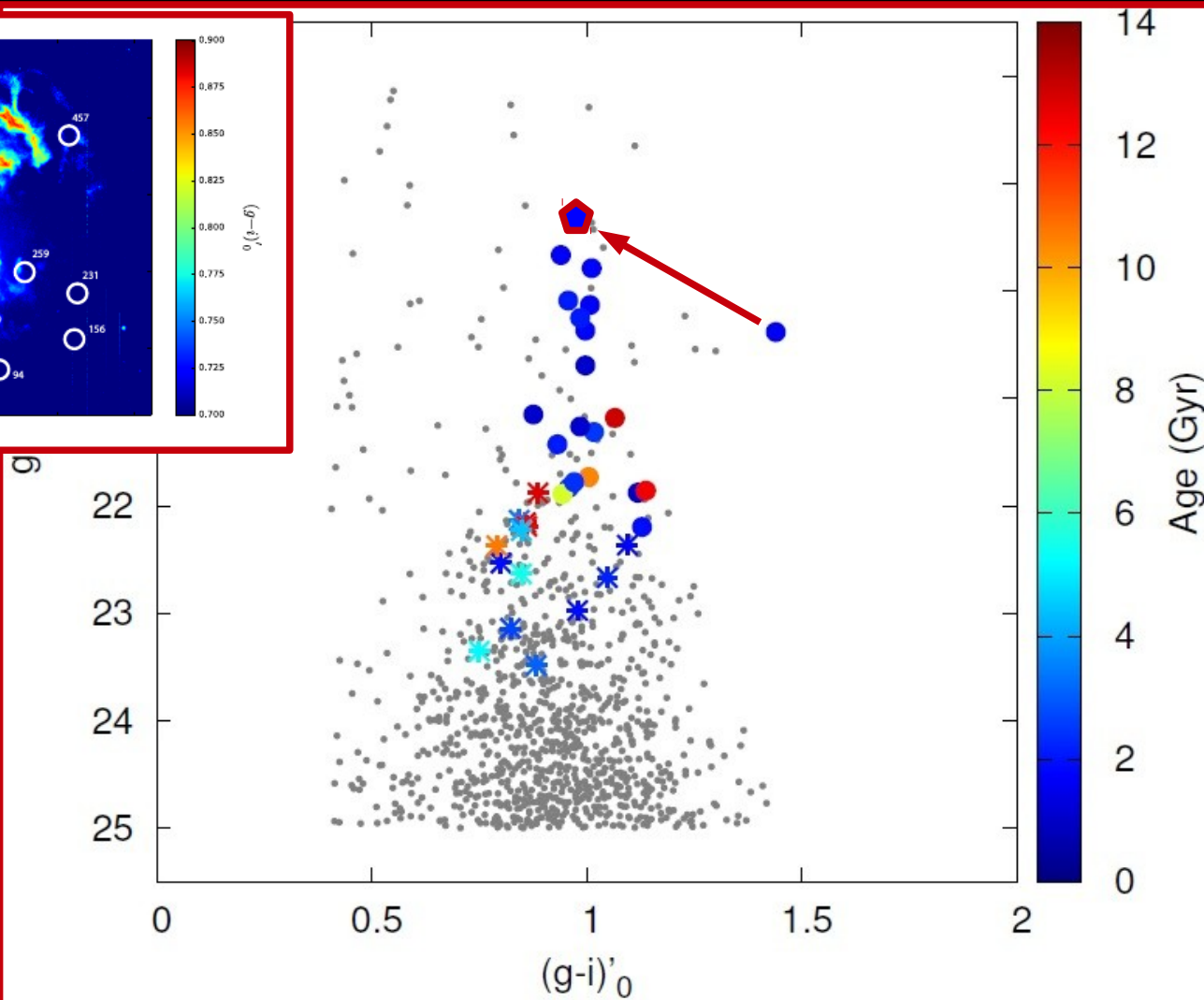
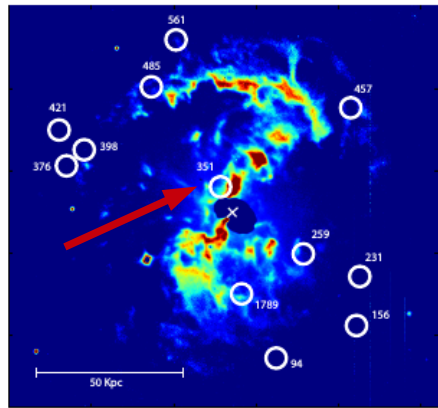


See Sesto et al. (2018)

NGC 1316 (Fornax A): metallicities vs color

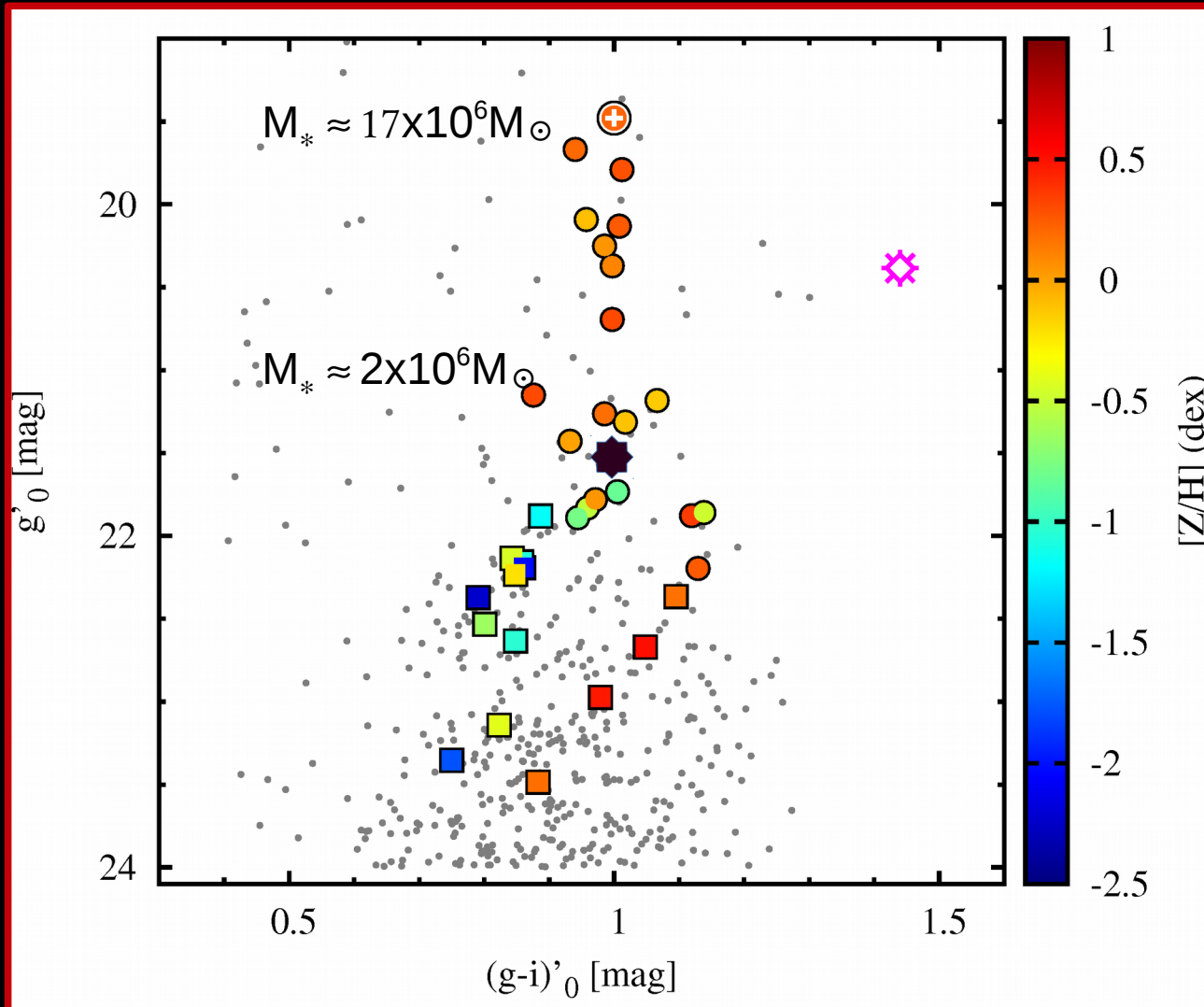


NGC 1316 (Fornax A): darkened GC



See Sesto et al. (2018)

NGC 1316 (Fornax A): young, metal rich and massive clusters

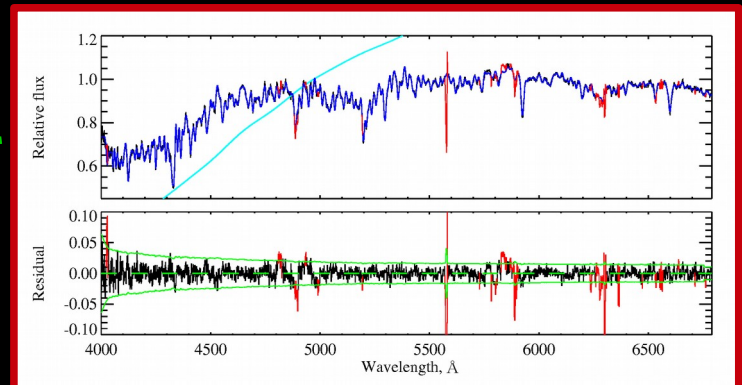
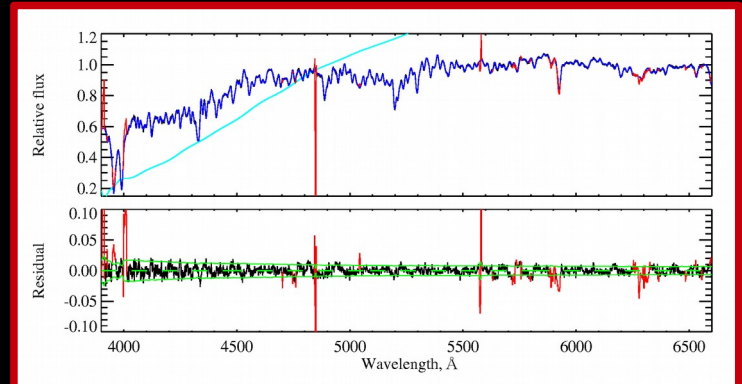
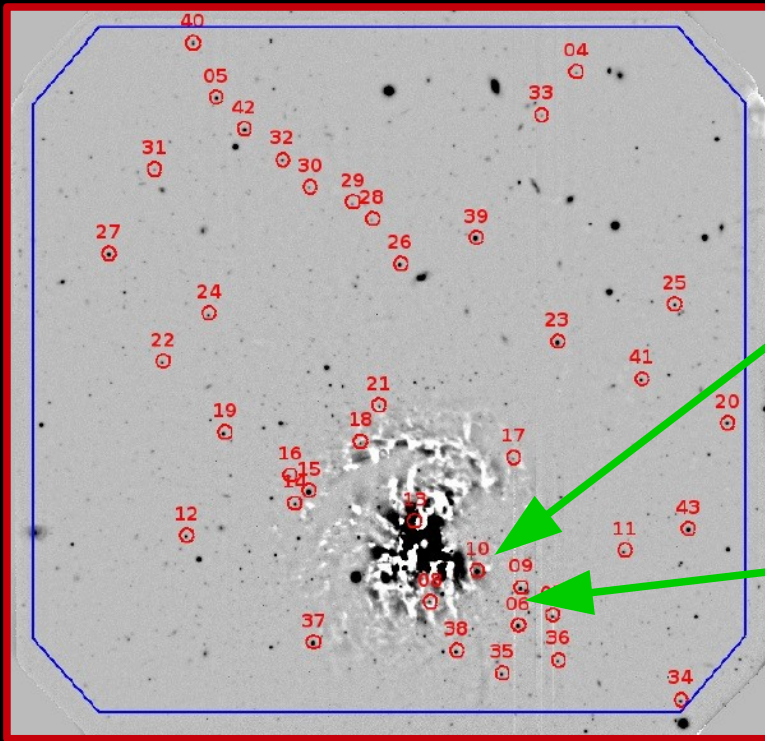


Stellar Mass-to-Luminosity relations from Maraston (2005)

NGC 1316 (Fornax A): halo age and metallicities

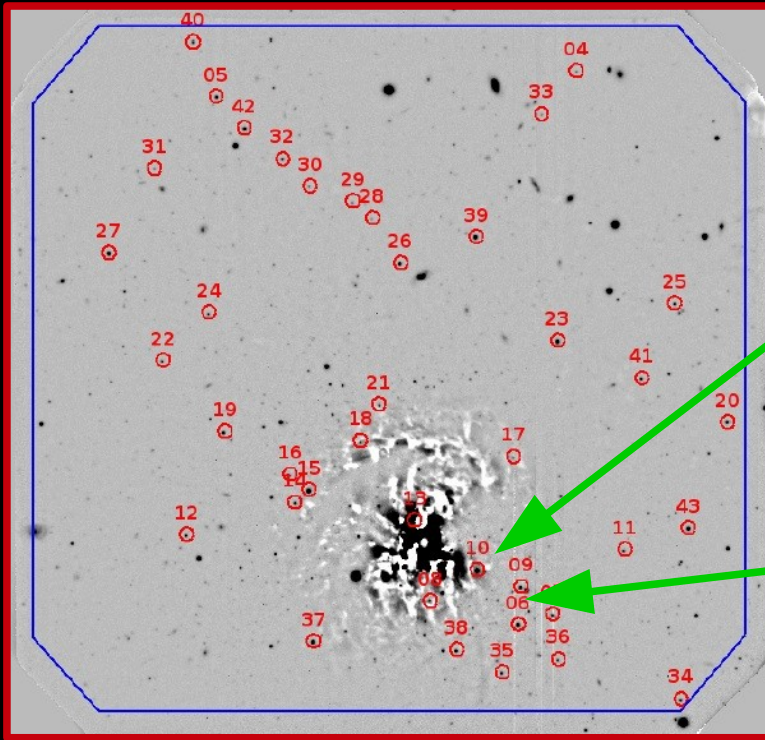
- In every slit in our mask we have light from a GCs + halo of NGC 1316 + sky.
- It is possible to get ages and metallicities for different zones of the halo by recovering the halo light from the slits $\equiv$ spatial resolution.
- We just started to recover these halo spectra...

Ulyss (Koleva et al 2009)
Pegase.HR/Elodie.3.2 SSP models



NGC 1316 (Fornax A): halo age and metallicities

- In every slit in our mask we have light from a GCs + halo of NGC 1316 + sky.
- It is possible to get ages and metallicities for different zones of the halo by recovering the halo light from the slits $\equiv$ spatial resolution.
- We just started to recover these halo spectra...



Ulyss (Koleva et al 2009)

Pegase.HR/Elodie.3.2 SSP models

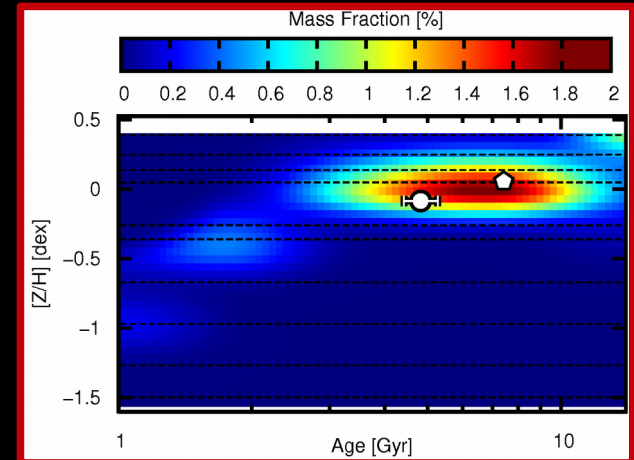
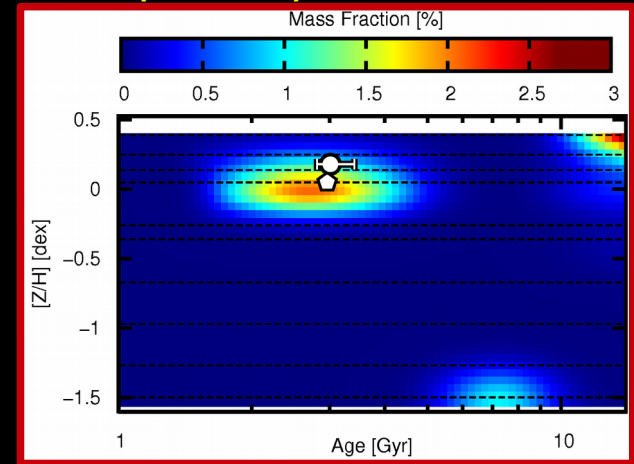
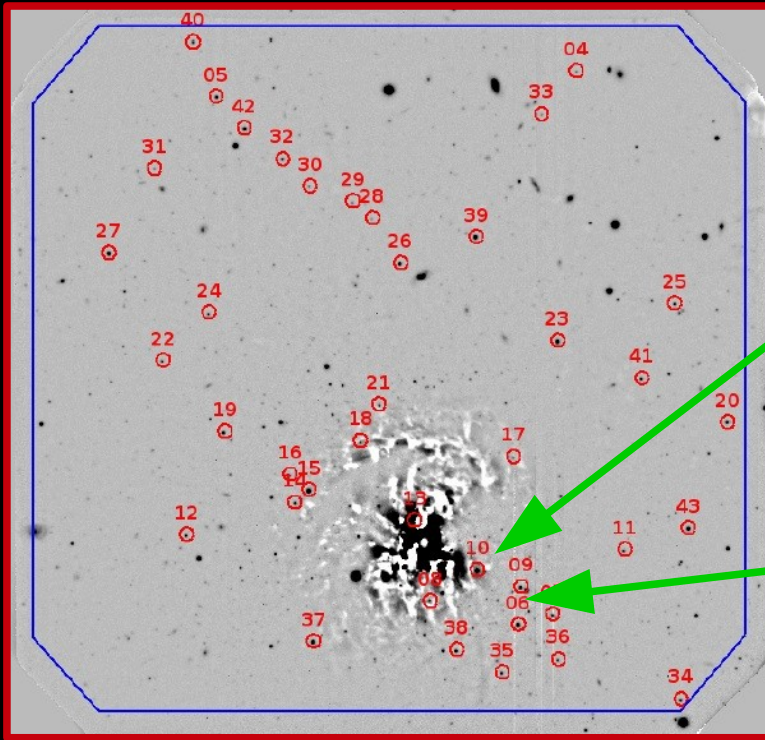
Vr : 1654 km/s
 σ : 245 km/s
Age : 3.1 +/- 0.1 Gyr
[Fe/H] : 0.06 +/- 0.03 dex
[Mg/Fe] : 0.07 +/- 0.01 dex

Vr : 1621 km/s
 σ : 217 km/s
Age : 3.1 +/- 0.2 Gyr
[Fe/H] : 0.00 +/- 0.03 dex
[Mg/Fe] : 0.03 +/- 0.02 dex

NGC 1316 (Fornax A): halo age and metallicities

- Other full spectrum fitting package: Penalized Pixel-Fitting (pPXF) allows us to get the SFH (Cappellari & Emsellem, 2004)

The halo of NGC 1316 is relatively young, metal rich and probably had an extended star formation history.



Conclusions

- ✓ NGC 1316 presents multiple GC populations: very blue, blue, green and red.
- ✓ GMOS photometry stands out the presence of a population of young (green) GCs.
- ✓ GMOS spectroscopy confirm 35 GCs (17 new!) inside 4 arcmin of Rgal.
- ✓ The young clusters present an average age of 1.8 Gyr, metallicities between $-0.5 < [Z/H] < 0.5$ dex and α -element abundances in the range $-0.2 < [\alpha/Fe] < 0.3$ dex (with a slight concentration towards solar values).
- ✓ The brightest clusters in our sample are young and massive objects.
- ✓ We clearly detect rotation in the inner zone of this GC system, with a PA almost perpendicular to the PA of the stellar component.
- ✓ We just started to recover kinematics and stellar population parameters for the inner halo and bulge of NGC 1316.
- ✓ At the moment, our results point to a dominant halo stellar component 3.1 Gyrs old, solar metallicities and abundances. There is some evidence of extended star formation.

Our results would be consistent with a scenario in which field stars and massive metal rich CGs were formed recently, in one or more very intense and brief episode, probably from previously enriched gas.

In agreement with Schweizer (1980), we think that this galaxy has cannibalized one or more gas-rich minor galaxies in the last Gyrs.

In that sense, NGC 1316 is still in an assembly stage. This result is in agreement with the scenario presented by Iodice et al. (2017), which indicates that the subgroup dominated by this galaxy is in a less evolved phase than the core of the Fornax cluster.

Future work:

... to obtain the SF history of the brightest objects in our sample and that of the halo of NGC 1316 from the remaining slits .

... to enlarge the sample.

Thanks!

Members



Sistemas Estelares Extragalácticos
y su Contexto Cosmológico

Favio Faifer

Analía Smith Castelli

Juan Carlos Forte

María Emilia De Rossi

Carlos Escudero

Leandro Sesto

Nélida Gonzalez

María Cecilia Scalia

Lucas Zenocratti