The early Universe just around the corner: Fornax dSph

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Outline

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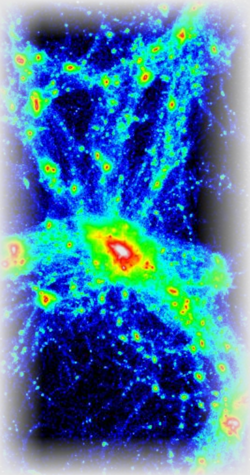
A dark matter Universe
Very brief description



Nowadays the most accepted scenario.

ΛCDM

- Small systems $\Longrightarrow$ Big structures.
- Dwarf galaxies survivors.

But there are some issues.

The missing satellites problem

- Few found dwarf galaxies.
- Models predict much more halos.

A dark matter Universe

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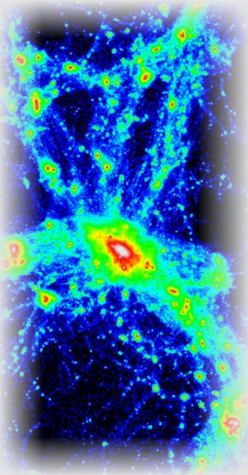

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A dark matter Universe
Quenching the star formation: Dark halos

Three main processes proposed as inhibitors of SF:

- Heating from the UV radiation arising from cosmic reionization (Barkana & Loeb 2001).

  Effects from UV { SF suppression. $M \lesssim 10^9 M_\odot$; keep forming stars. $M \gtrsim 10^9 M_\odot$

- SNe feedback mass ejection (Mac Low & Ferrara 1999).

  Effects from SNe { Gas completely blown away. $M_b \lesssim 10^7 M_\odot$; Galaxy conserve gas. $M_b \gtrsim 10^8 M_\odot$

- Tidal stirring (Łokas *et al.* 2011, Mayer *et al.* 2006, 2008).

Observed galaxies below these limits

These galaxies must be dark!

A dark matter Universe

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A dark matter Universe
Quenching too much.

Several theories have been proposed to overcome this apparent contradiction:

- Bullock et al. (2001): Halos formed during the prereionization era. 90% below observable limits.
- Stoehr et al. (2002): Masses of dark matter halos larger than those measured at the optical limit.
- Kravtsov et al. (2004): Larger halos in the pass.
- Susa & Umemura (2004): Self-Shielding effect.
- Busha et al. (2010): Inhomogeneous reionization.

Local Group Galaxies
A unique oportunity

Their proximity allow us to resolve their stars individually.

Dwarf Spheroidal Galaxies (dSph)

- The most common.
- Low surface luminosity ($\sum_V \lesssim 0.002 L_\odot pc^{-2}$).
- Small sizes (a few hundred of parsecs).
- Lack of gas.
- Relatively large velocity dispersion ($>$7 km s^{-1})
  - Abundant presence of dark matter.
  - $M/L \sim 5 - 500$ In solar units (virialized).

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Local Group Galaxies
The Milky Way satellites

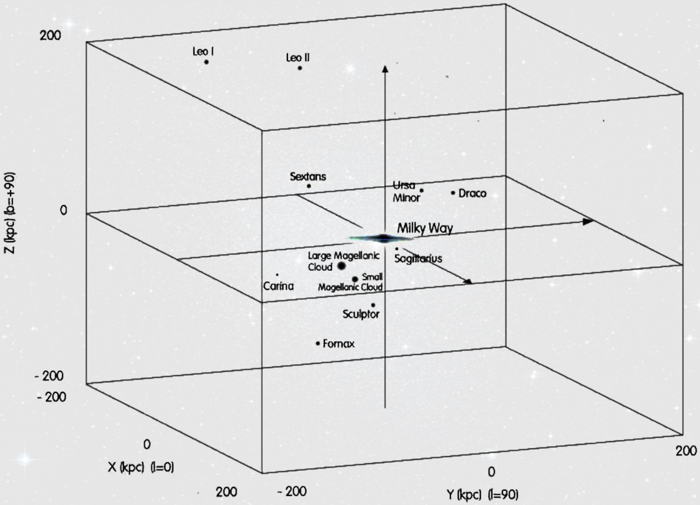

Figure: The Milky Way classic satellites

Fornax dSph
Our particular object

Fornax dSph
Some data

A quick look

- Complex system.
- The largest and most luminous of the dSphs companion of the MW.
- It host globular clusters.
- Shows two shell structures.

Fornax dSph
Some data

Fornax at glance

RA, α (J2000.0)	2h 39' 53.1"
Dec, δ (J2000.0)	-34° 30' 16.0"
Galactic longitude, l (deg)	237.245
Galactic latitude, b (deg)	-65.663
Heliocentric distance (kpc)	138$\pm$8
Heliocentric radial velocity (km s^{-1})	55.3$\pm$0.1
Luminosity, L_V ($L_\odot$)	15.5×10^6
Ellipticity, e	0.30 ± 0.01
Position angle (deg)	41$\pm$6
Core radius (pc)	$\sim$460 (13.8$\pm$0.8 *arcmin*)
Tidal radius (kpc)	$\sim$2.4 (71$\pm$4 *arcmin*)

Table: Fornax main data.

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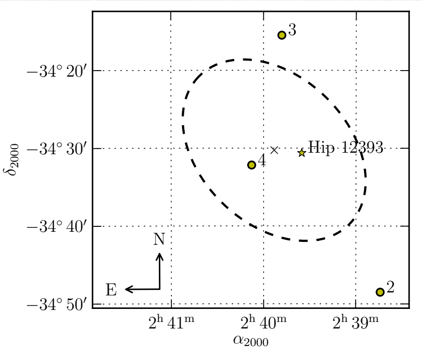
Data sets
Three kind of observations



Wide field photometry (Stetson 2000, 2005)

- $m_I \lesssim 23$
- ~ 0.7 *degrees*^{2} covered

Deep FORS1@VLT photometry

- $m_I \lesssim 25$
- ~ 135 *arcmin*^{2} covered

Spectroscopy (Battaglia *et al.* 2006)

- CaT metallicities of RGB stars

Data sets

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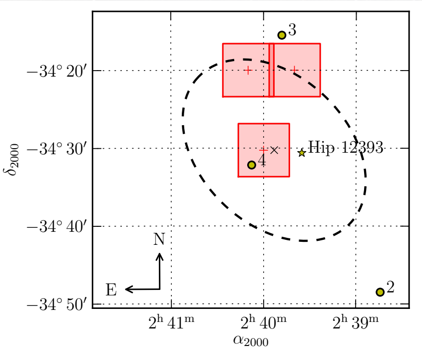

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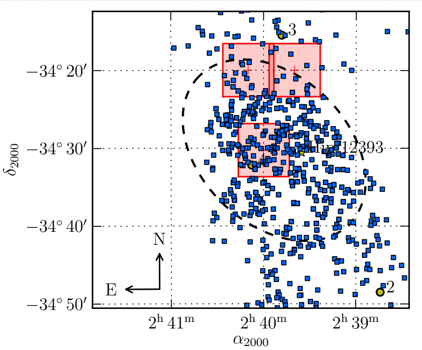

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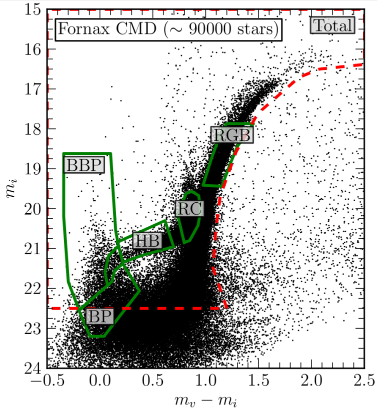
Wide field photometry
Obtaining the spatial distribution maps



Five regions in the CMD

- HB: Old ($\gtrsim 11 - 12 Gyrs$).
- RGB: Intermediate-old ($\gtrsim 1 - 2 Gyrs$).
- RC: Intermediate-young.
- BP: Young ($\gtrsim 1 Gyr, \lesssim 4 Gyrs$).
- BBP: Very young ($\lesssim 1 - 2 Gyrs$).

Spatial distribution maps

- 2d histogram of 142 x 128 pixels.
  - Normalized & convolved with a gaussian filter.

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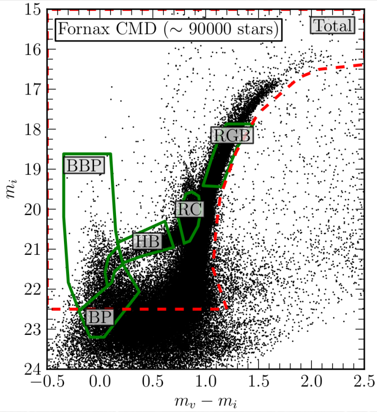

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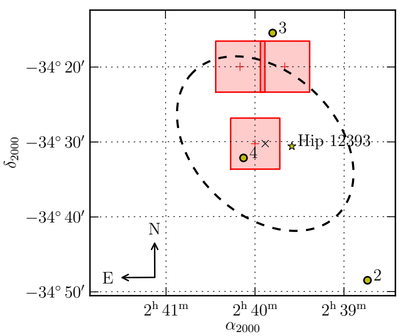
Deep photometry
The stars position

Deep photometric list selection

- We define three regions:

Name of Region	Surface (pc^2)	Galactocentric dist. (pc)	No. of stars
Inside the Core 1 (IC1)	75770.1	56.8	69590
Inside the Core 2 (IC2)	84248.6	360.4	69712
Outside the Core (OC)	59181.5	473.6	38643



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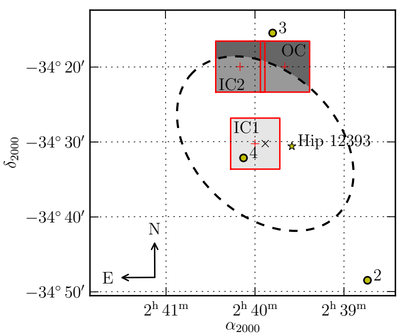
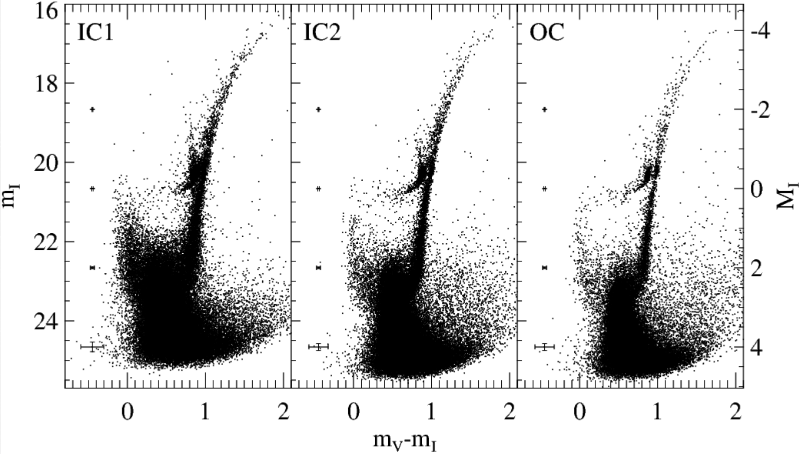


Deep photometry
Observed CMDs



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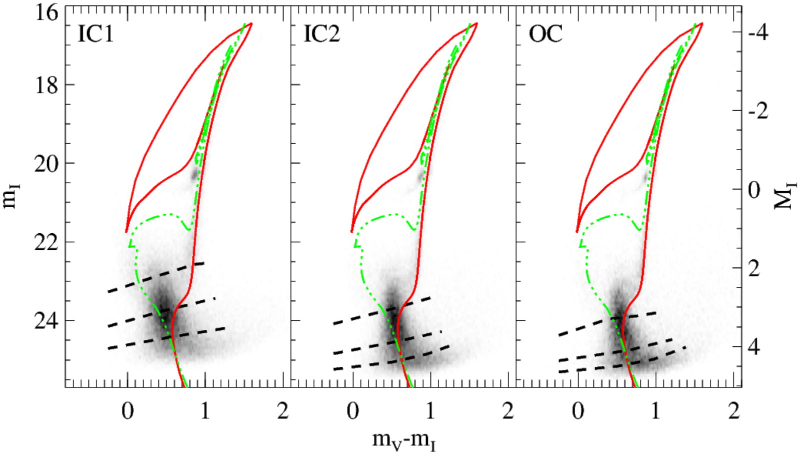

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Synthetyc CMDs fitting techniques (Aparicio & Hidalgo 2009; Hidalgo *et al.* 2011).

Basic functions.

- SFH defined as $\psi(t,z)$, $\psi(t,z)dtdz$ is the mass transformed in stars in t' $(t < t' < t + dt)$ with z' $(z < z' < z + dz)$.
- IMF, Frequency and distribution of binary stars masses $\beta(f, q)$, etc.

sCMD

- We created a sCMD populated by millions of stars.
- Stars distributed in $n \times m$ simple populations.

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Obtaining the SFH

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Deep photometry
Obtaining the SFH

Simulating observational effects in the sCMD

- Information provided by the completeness test.
  - S/N limitations.
  - Detector defects.
  - Stellar crowding.
  - etc.

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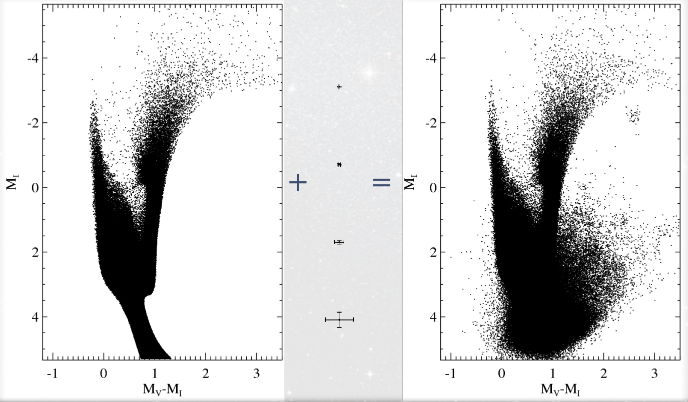


Deep photometry
Obtaining the SFH

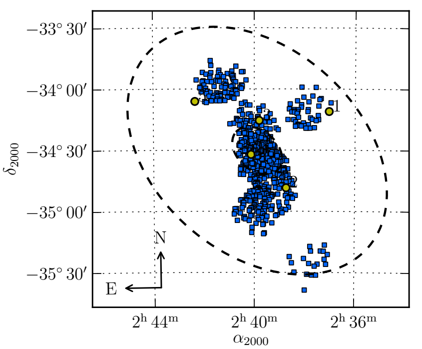
Sample and comparison of both CMDs

- Observed CMD ($\psi(t, z)$) vs. synthetic CMD ($\sum_i^{n\times m} \psi_i$).
- Process ends with the best solution found: $\psi(t, z) = A \sum_i \alpha_i \psi_i$.
- We used χ^2_γ defined by Mighell (1999) as merit function.

Used codes

- Four main codes are the mainstays of this method:
  - IAC-star (Aparicio & Gallart 2004).
  - *Obsersin* (Hidalgo *et al.* 2011).
  - IAC-pop (Aparicio & Hidalgo 2009).
  - MinnIAC (Hidalgo *et al.* 2011).

CaT spectroscopy
Obtaining the AMR and the metallicity map.



Metallicity and age Maps

- 2d histograms of 30 x 33 pixels.

Obtaining the AMR

- Stars lying inside the core.
- Combining metallicities from CaT with positions in CMD.
  - Polynomial relationship (Carrera *et al.* 2008).

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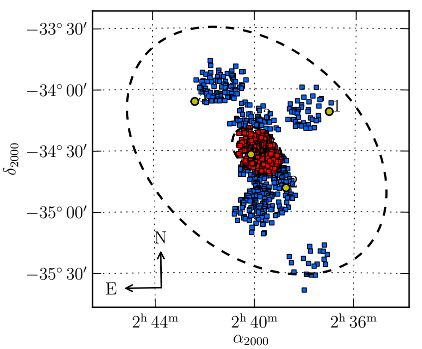

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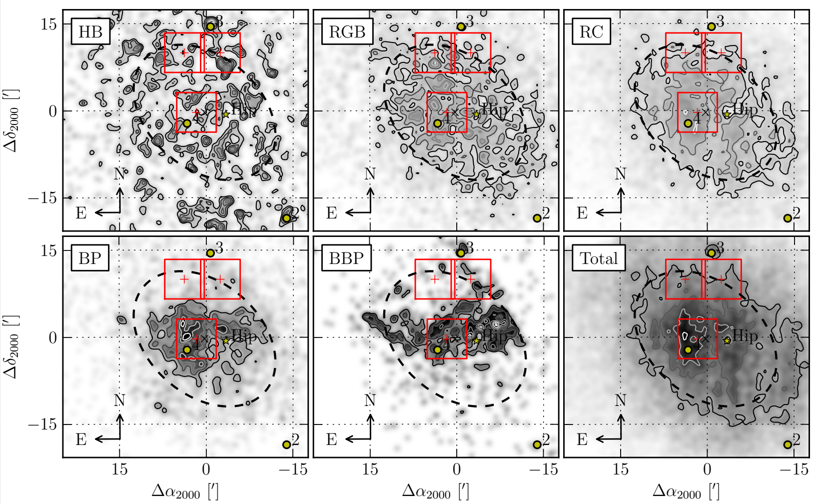
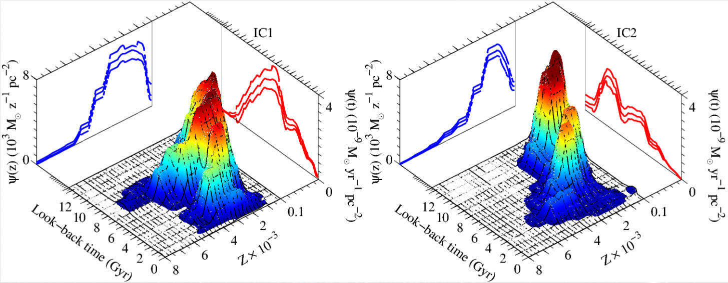
Spatial distribution
Strong differences between populations

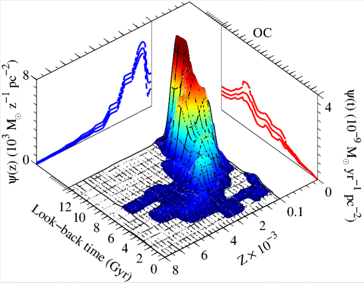


- Strong asymetries found in the young populations.
- Shell like structures of young stars ($\sim 2 - 3 Gyrs$).

The star formation history

General view





Summary

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- Narrower metallicity range in the outskirts.

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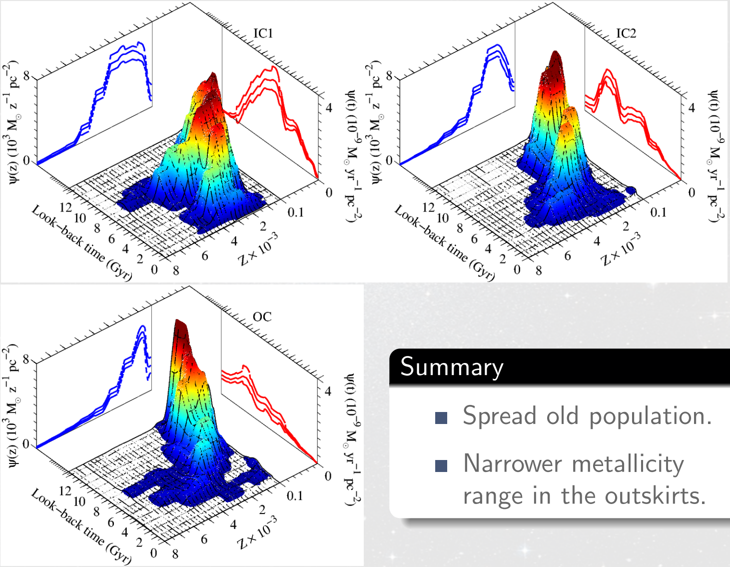

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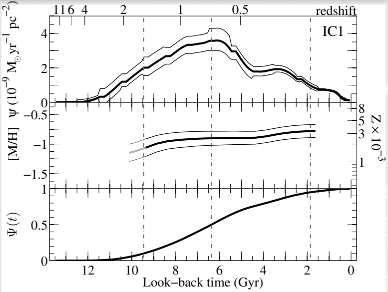
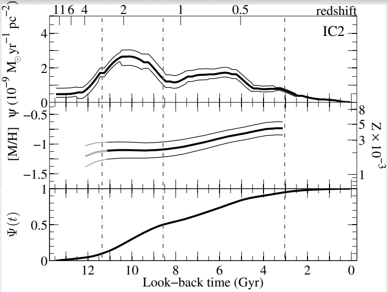
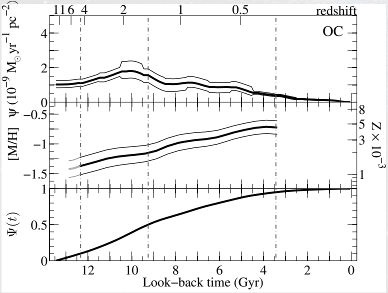
Detailed view



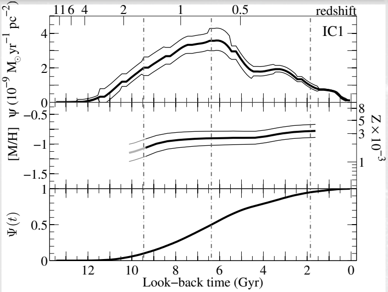


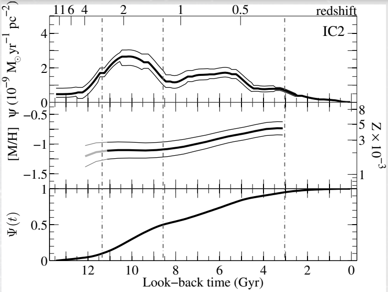


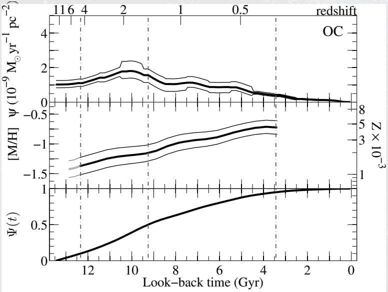
Differences between regions

- Last burst located in the core.
- Small differences in the AMR.
- SF ends before as we move outwards.

The star formation history
Detailed view







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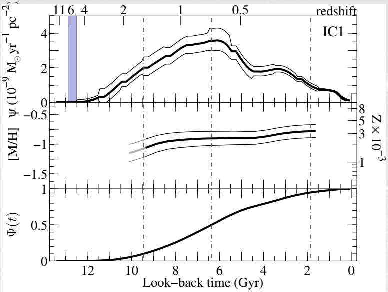
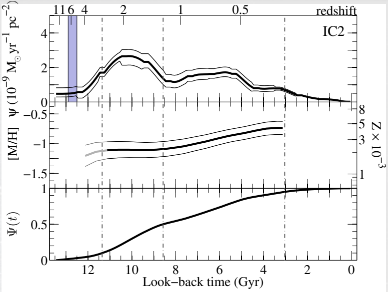
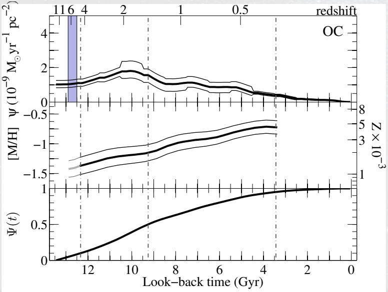
The star formation history
Global and cosmological evolution





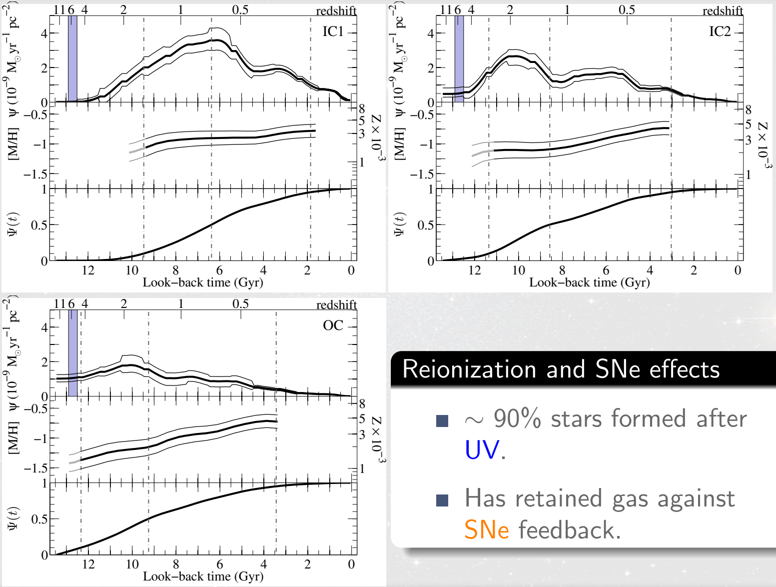


Reionization and SNe effects

- $\sim$ 90% stars formed after UV.
- Has retained gas against SNe feedback.

The star formation history

Global and cosmological evolution



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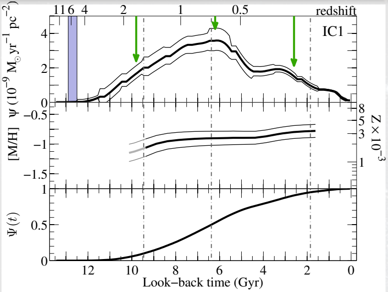
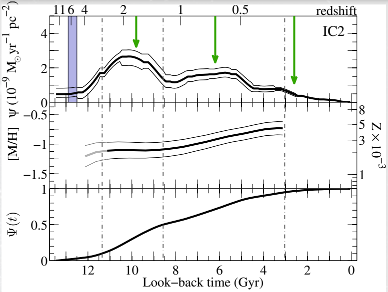
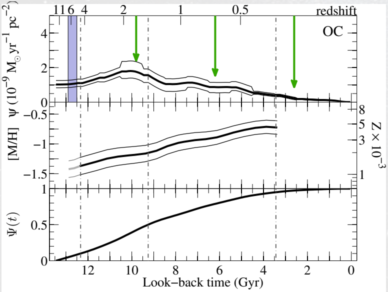
The star formation history

Possible tidal interactions







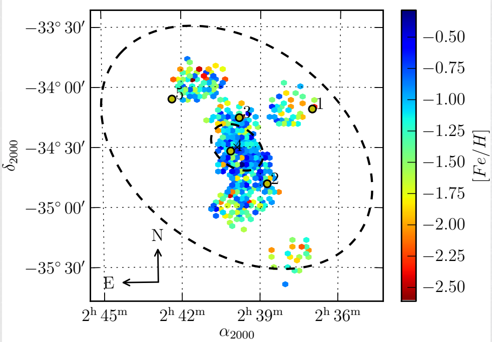
Tidal interaction with the MW?

- 118 kpc of perigalacticon.
- 152 kpc apogalacticon.
- 3.2 Gyr of orbital period.

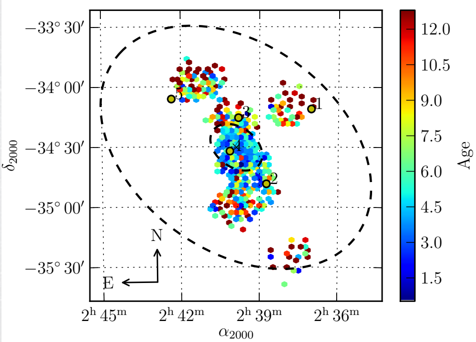
(Piatek *et al.* 2007)

CaT spectroscopy
Metallicity and Age map

Metallicity map:

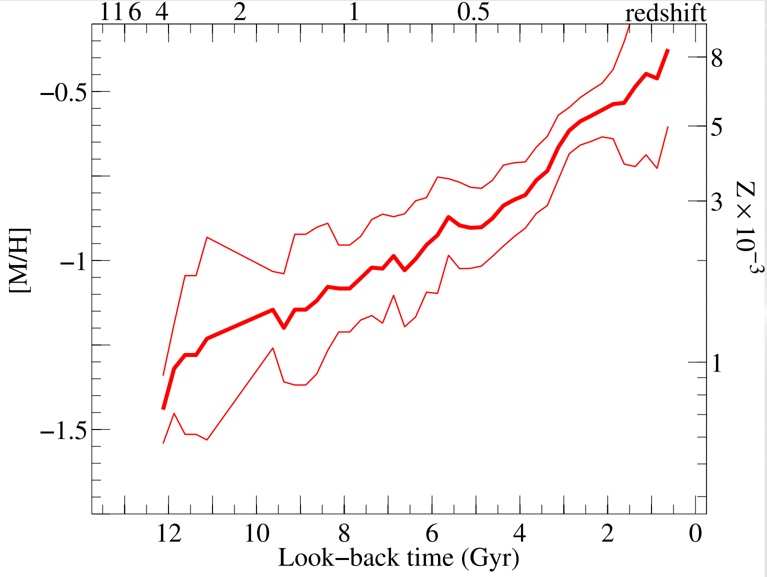


Age map:

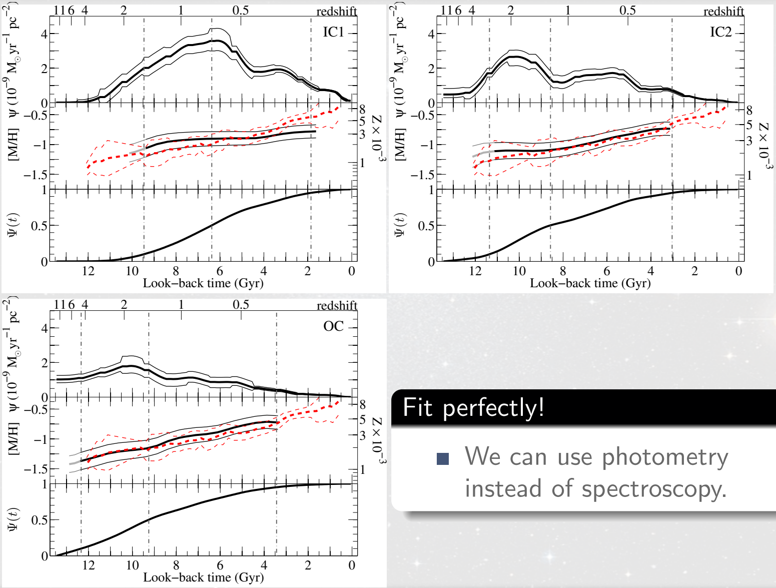


- Metallicity and age distributions do not follow optical shape.

CaT spectroscopy
The AMR



CaT spectroscopy
Comparison between results



Fit perfectly!

- We can use photometry instead of spectroscopy.

Outline

Global and local considerations

Reionization and SNe effects on Fornax

- $\sim 90\%$ stars formed after UV.
- Has retained gas against SNe feedback.

} $M \gtrsim 10^8 - 10^9 M_\odot$ (Self-Shielding effect)

Possible tidal interactions

- Our results favored an interaction with a smaller system (~ 3 Gyrs ago)
  - Strong asymetries found in the young populations.
  - Shell like structures of young stars ($\sim 2 - 3 Gyrs$).
  - $Z = 0.004$ for Clump stars (Olszewski *et al.* 2006).
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Conclusions

- Fornax has been forming stars continiously up to less than 1 Gyr.
- There exist strong differences as a function of the position.
  - Last burst located mostly at the center ($\lesssim$ 4 Gyrs).
  - Old population uniformly distributed well beyond the core ($\gtrsim$ 11 Gyrs, $z \lesssim 0.002$).
  - Mean metallicity higher in the innermost regions.
- Both, reionization and SNe feedback do not show decisive effects.
- Our results favored an interaction with a smaller system ($\sim$ 3 Gyrs ago), and do not discard a tidal interaction with the MW.

And...

Thank you!