The star formation history of the Fornax dwarf spheroidal

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and the HST-Fornax team:

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Science with the new HST after SM4, Bologna Jan.29, 2008

Why Fornax ?

- ✓ *Fornax is one of the most luminous dwarf spheroidal galaxies, unusual in many ways*
- ✓ *old stars along with young stars; 5 globular clusters of its own; faint sub-structures (related to interaction ?)*
- ✓ *we want to reconstruct its star-formation history as a test of our understanding of dwarf galaxy origin and evolution*

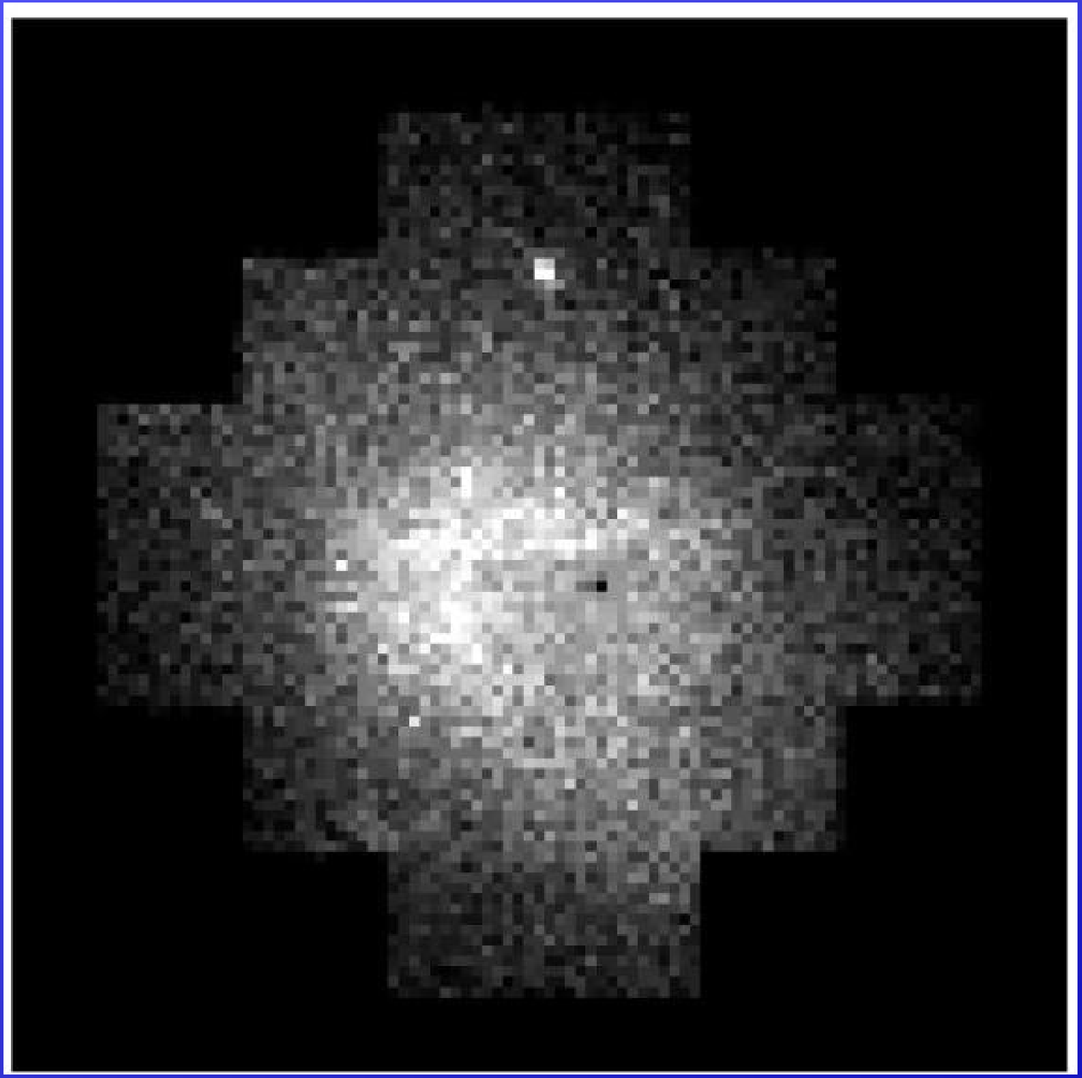
Open questions ...

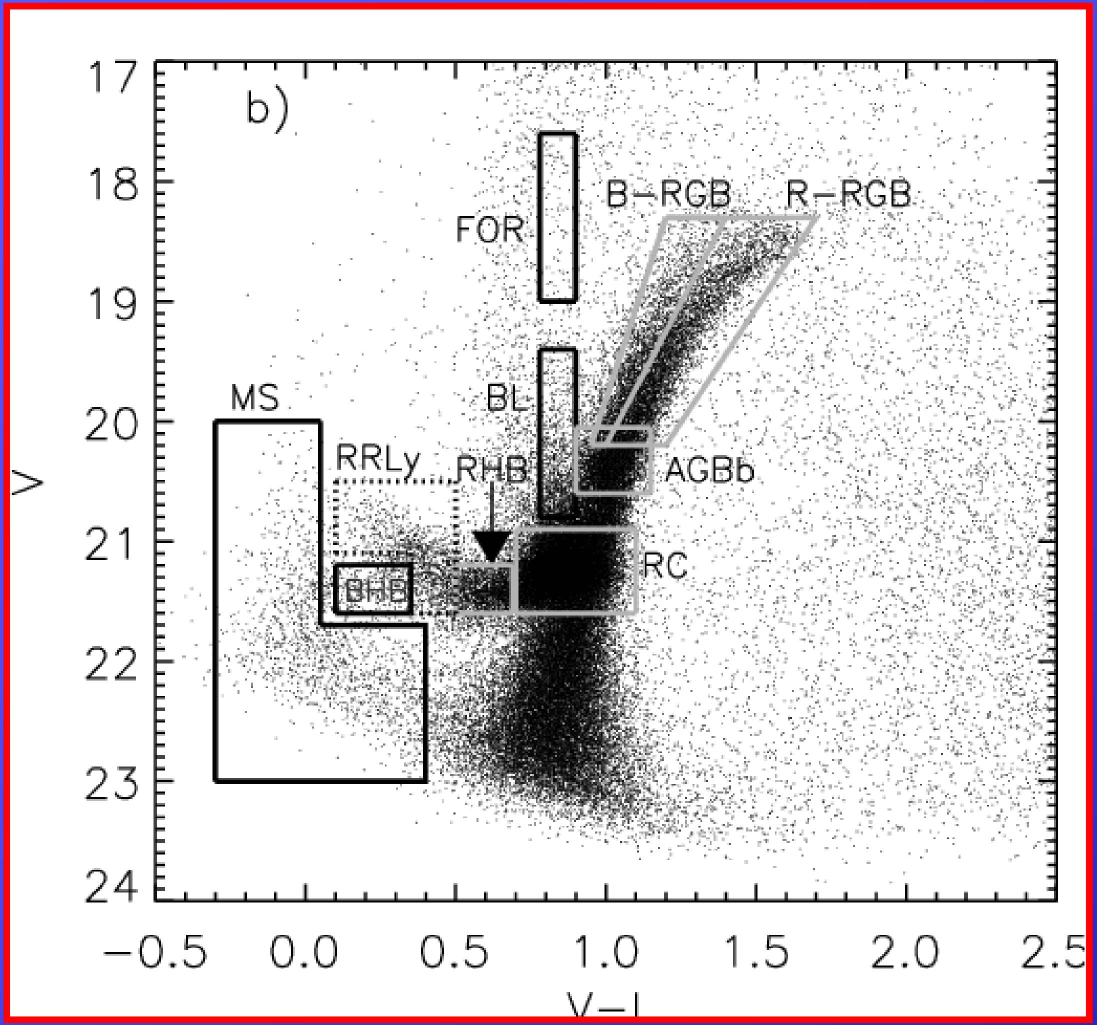
- *Is the old stellar population made up of stars formed in a very early burst, perhaps before the epoch of reionization, or the result of a more continuous star formation between 13 and 9 Gyr ago ?*

- *How quickly did Fornax increase its metallicity during its initial assembly and during subsequent episodes of star formation ?*

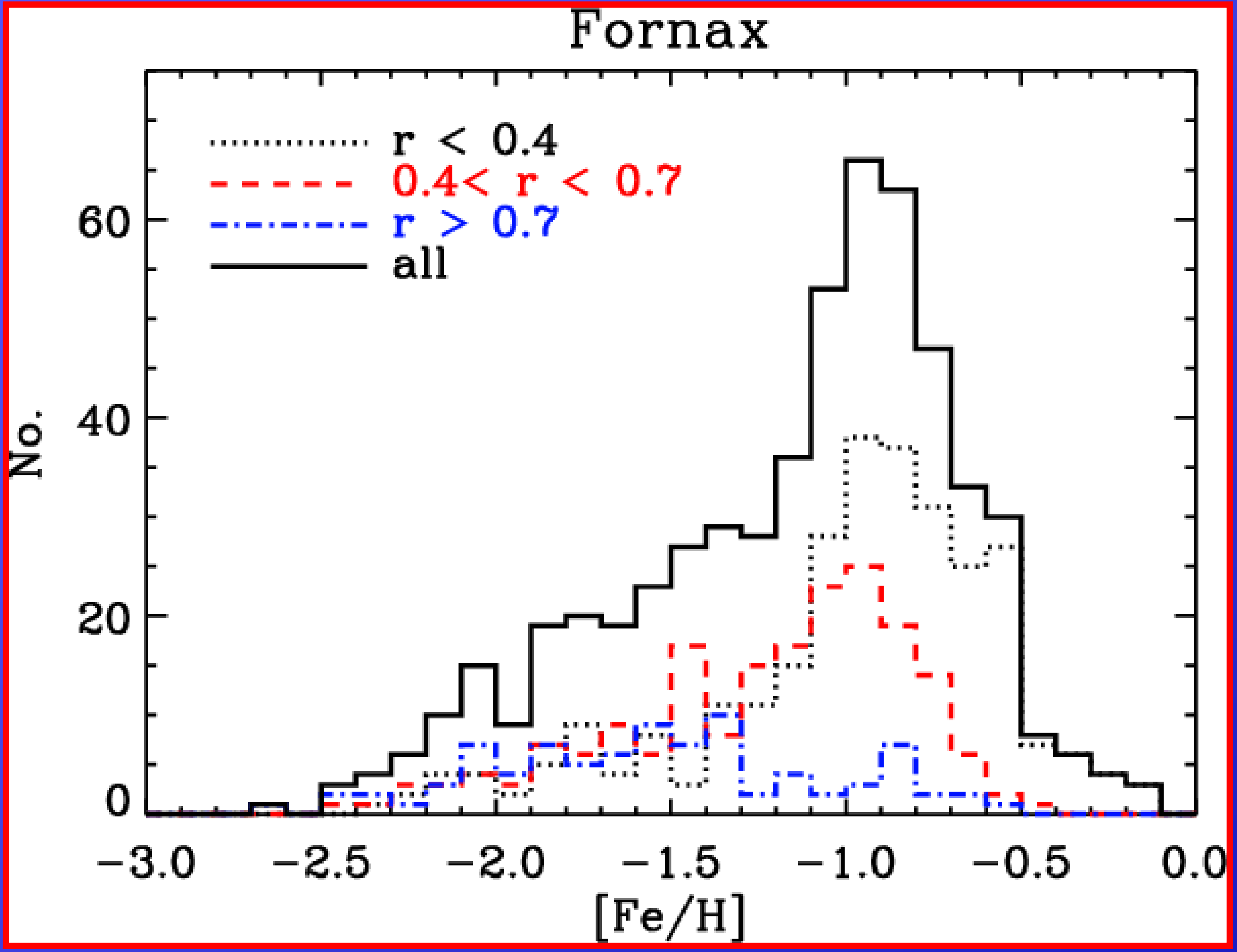
- *Are accretion episodes required to explain the age-metallicity history of Fornax ?*

❖ *A surface density map of stars brighter than V=23 (30” cells) show a “crescent shaped” stars’ distribution (Stetson et al. 1998)*

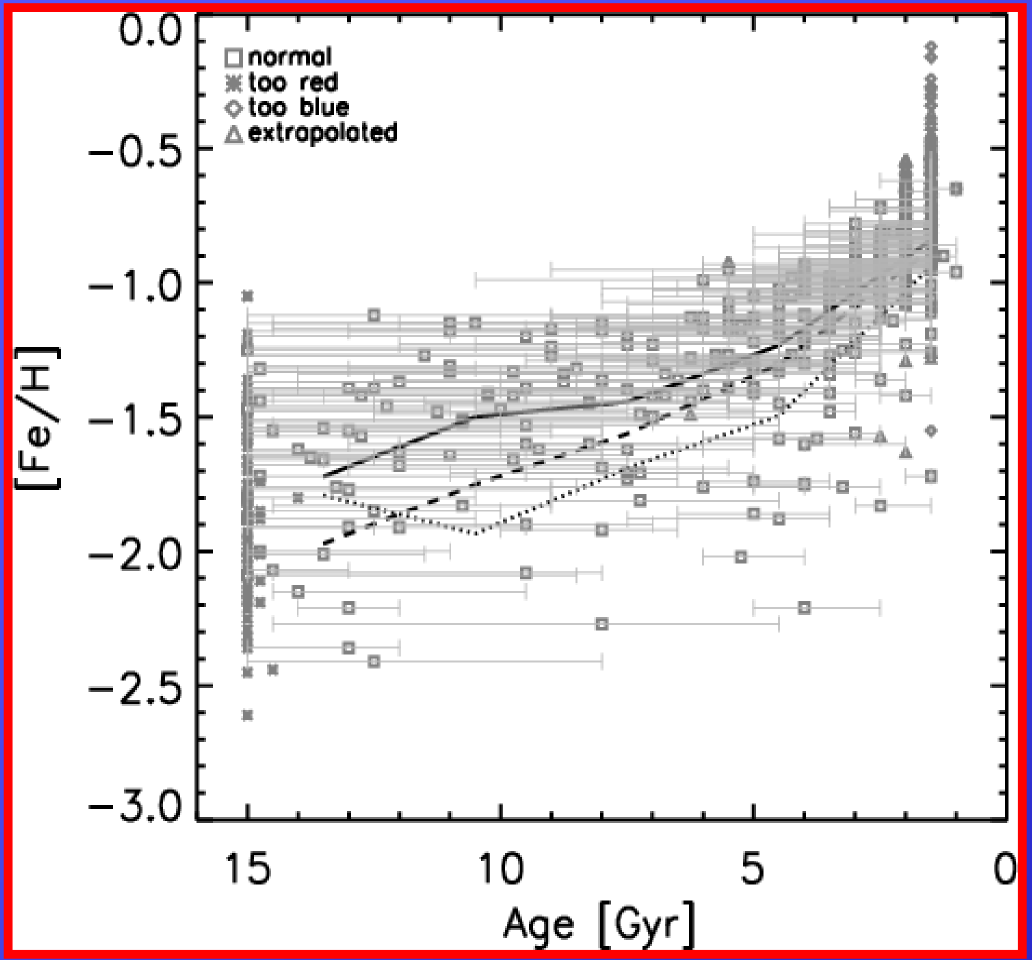




❖ *Fornax CMD from WFI observations (Battaglia et al. 2007; Rizzi et al. 2007). The main evolutionary phases reachable with ground-based observations are indicated. Note that RGB and He-b stars are well studied from the ground.*



- *CaT spectroscopy of <u>individual RGB stars</u> in Fornax (Pont et al. 2004; Battaglia et al. 2007) provided metallicity distributions at different distances from the galaxy center. A metallicity gradient is detected in Fornax red giants.*

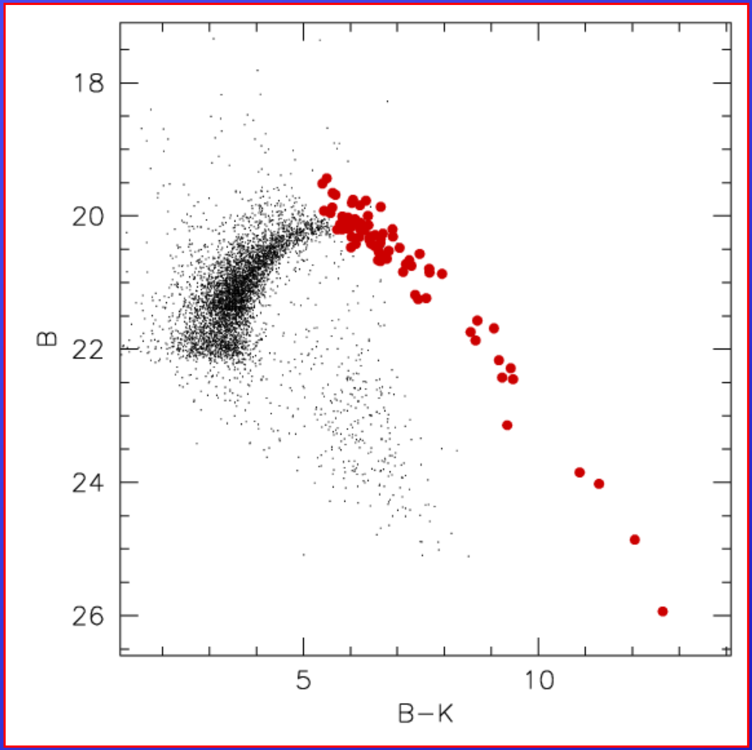


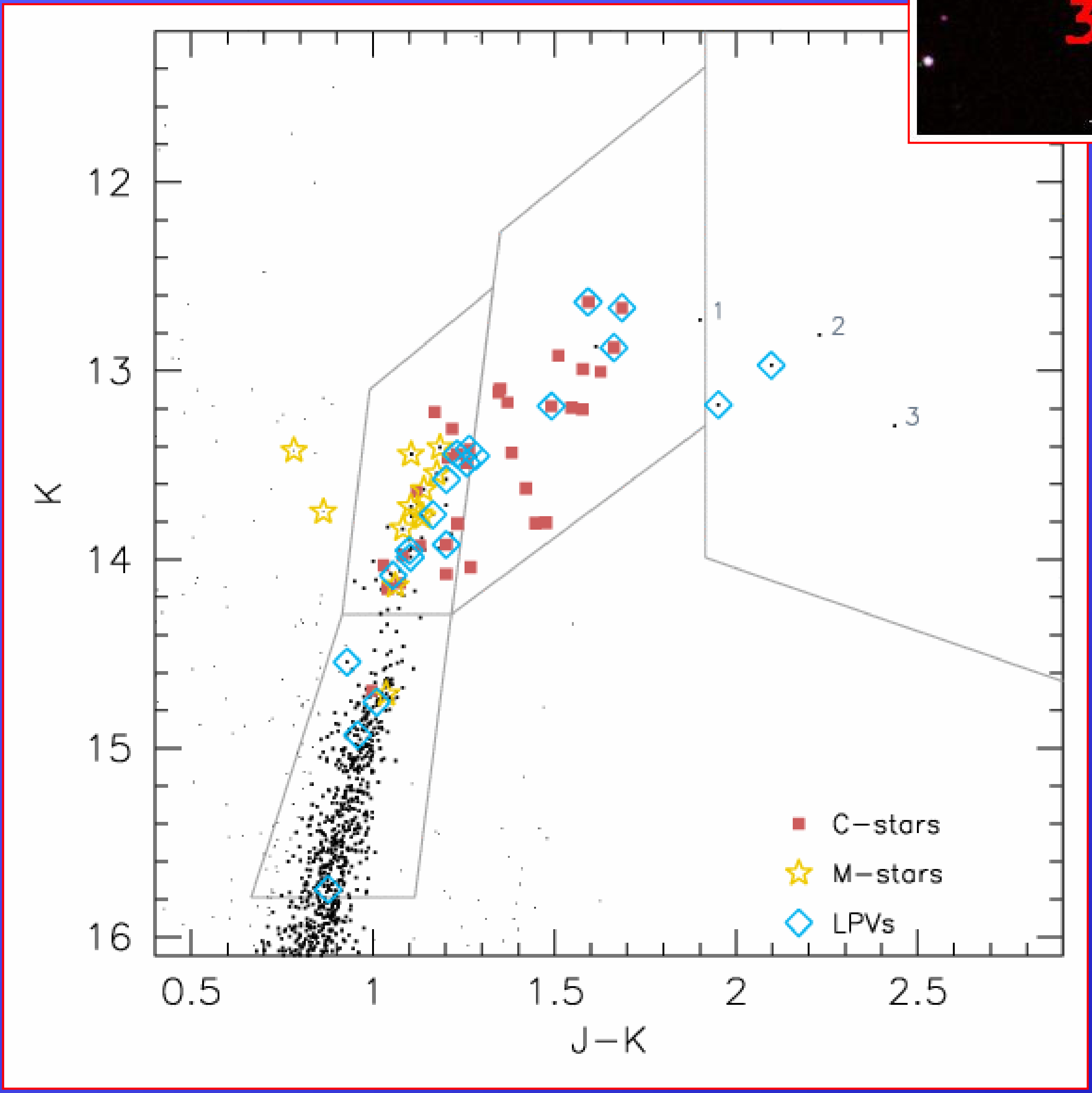
❖ *Low-resolution spectroscopy of RGB stars in Fornax (Pont et al. 2004; Battaglia et al. 2007), together with colors, has been used to infer an age-metallicity relation which suggests an increase in metallicity in the last few Gyr*

❖ *high-resolution spectroscopy has been used to study the internal kinematics of Fornax (e.g., Walker et al. 2006)*

❖ *The near- and mid-infrared spectral range provides the best information on the intermediate-age stars population the upper AGB. Oxygen- and carbon-rich stars can be discriminated and cross-identified with spectroscopic surveys.*

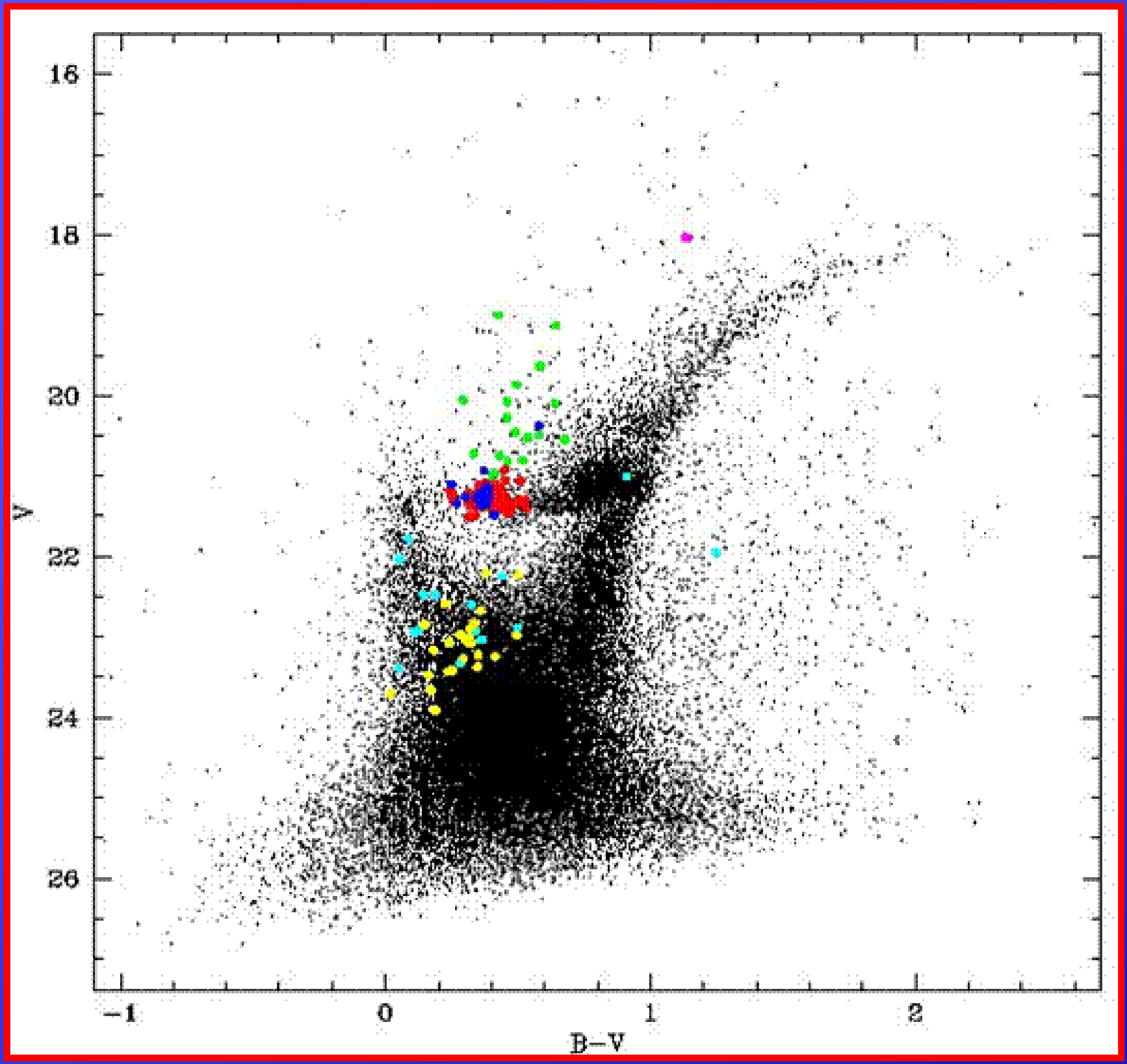
❖ *Mid-infrared follow-up using Spitzer and the VLT has recently allowed to study the mass-loss rate in some AGB stars of Fornax (Matsuura et al. 2007; Lagadec et al. 2008)*



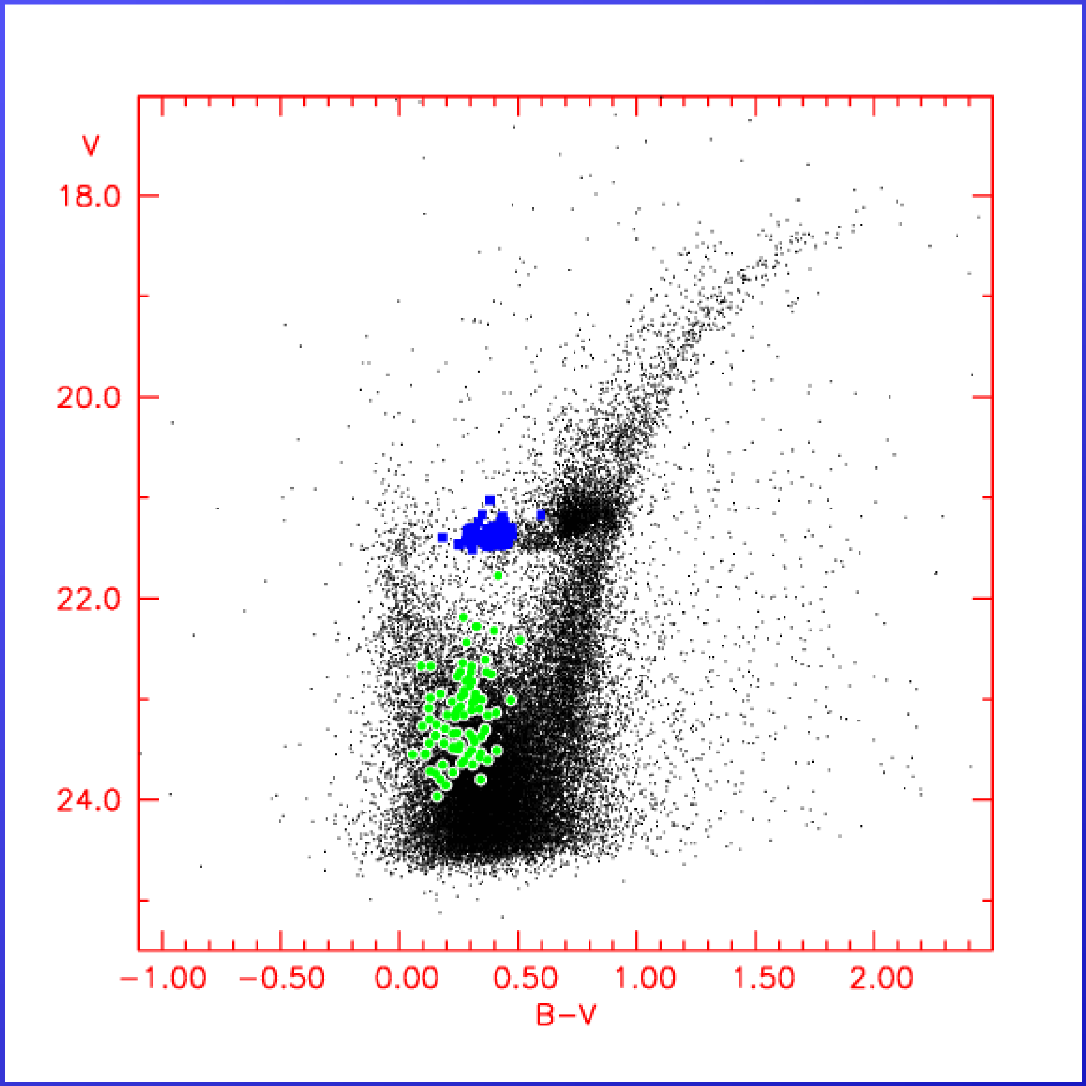


Gullieuszik et al. (2007), Held et al. (2008,in prep.)

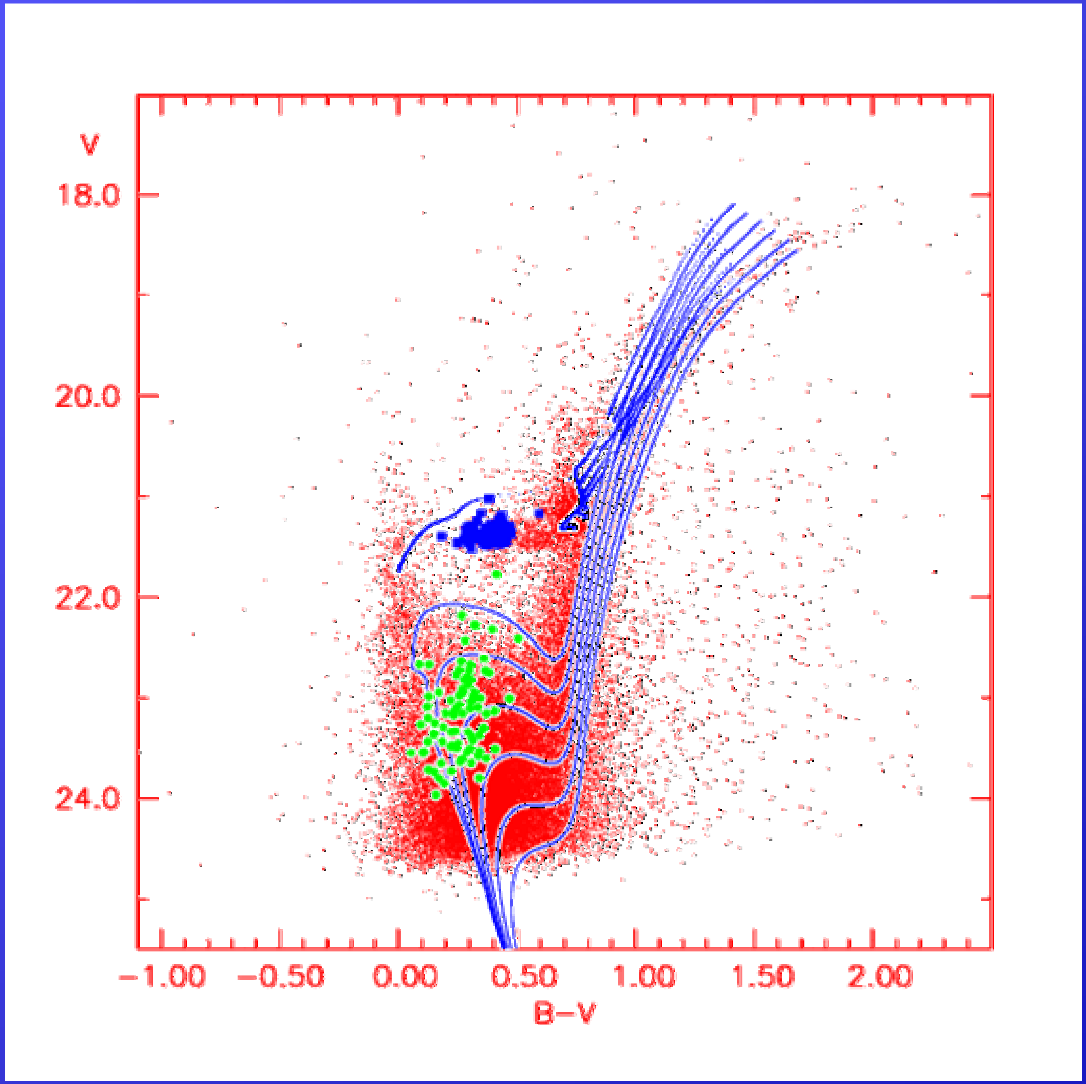
❖ *Variable stars have also been used as effective tracers of stellar populations in Fornax (e.g., Bersier & Wood 2002; Greco et al. 2005). Here is an example of the different types of variables found by our ongoing Fornax Project (Clementini, Poretti, Held, and coll.)*



- *1 CCD for clarity*
- *V error < 0.05 mag*



Poretti et al. (2008, to be submitted)



- *Canonical, scaled solar isochrones from Pietrinferni et al. (2004), Z=0.002*
- *ages 1.5, 2.25, 3.5, 5.5, 9, 14*

The Fornax HST project (GO 11129)

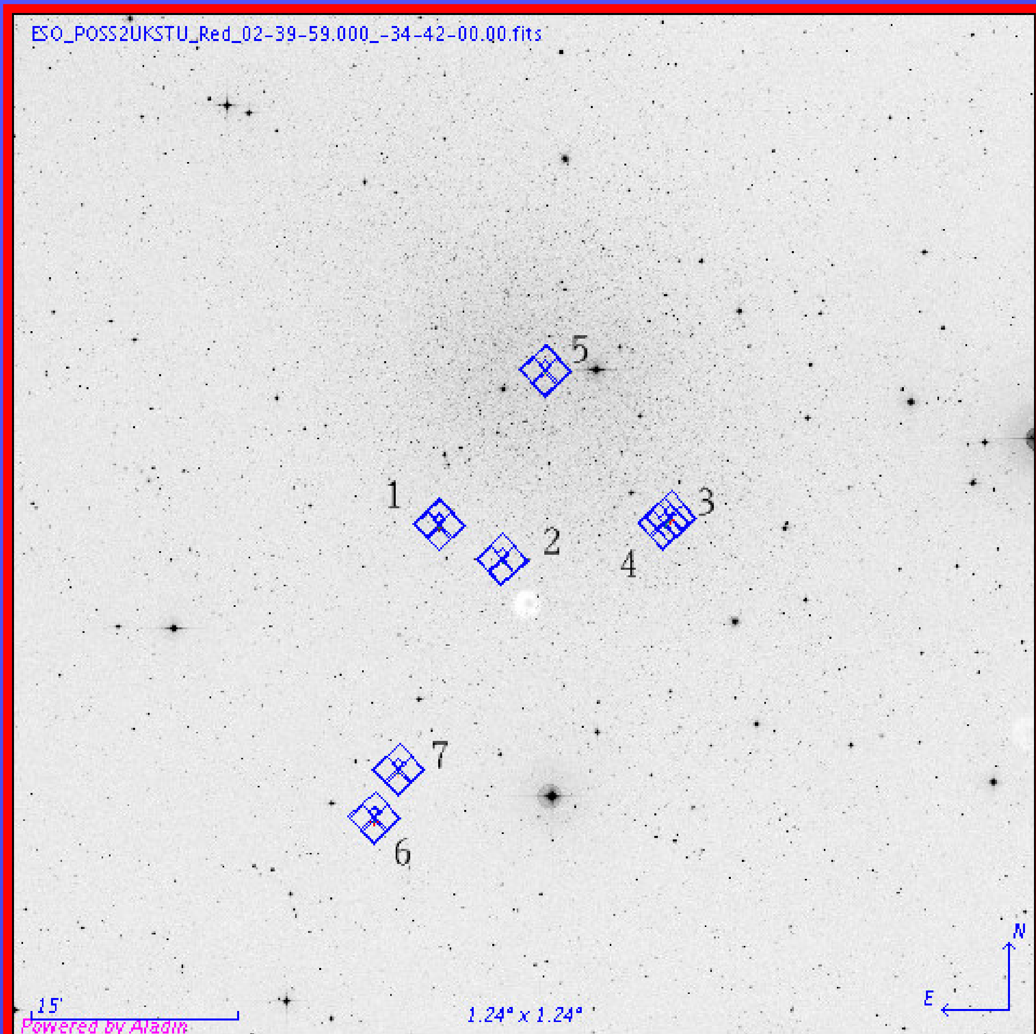
✓ *We need to study the global SFH of the Fornax field using deep data providing good age resolution, to measure the age mixture of the stellar populations and their spatial variations, as well as their metallicity variations*

✓ *Our HST project (GO 11129) aims at obtaining very deep images in several fields across the Fornax dSph galaxy, to reach the oldest subgiant branch and main-sequence turnoffs and measure the SFH over different regions with distinct kinematics and metallicity, from first stars coeval with the Milky Way halo to the youngest populations ~200 Myr ago.*

✓ *The CMD analysis with WFPC2 will be combined with the large amount of ground-based data collected by our team. Information on age, metallicity, and kinematics will allow us to trace out the early phases of the evolution of Fornax.*

Observing strategy

- ✓ *7 WFPC2 fields at different distances from the center (originally, 10 ACS pointings)*
- ✓ *5 orbits/field, filters F555W (4x1100 s) and F814W (4x1100 s + 1600 s); WFPC2-BOX standard 4-point dithering for CR/Hot Pixels rejection. Our goal: 0.2 mag I error at I=24.5*
- ✓ *Short V,I 120 s exposure to obtain photometry of bright (V=18) stars*
- ✓ *fields 3,4 are shifted by ½ CCD to assess our ability to properly correct for CTE effects*



Our fields will sample:

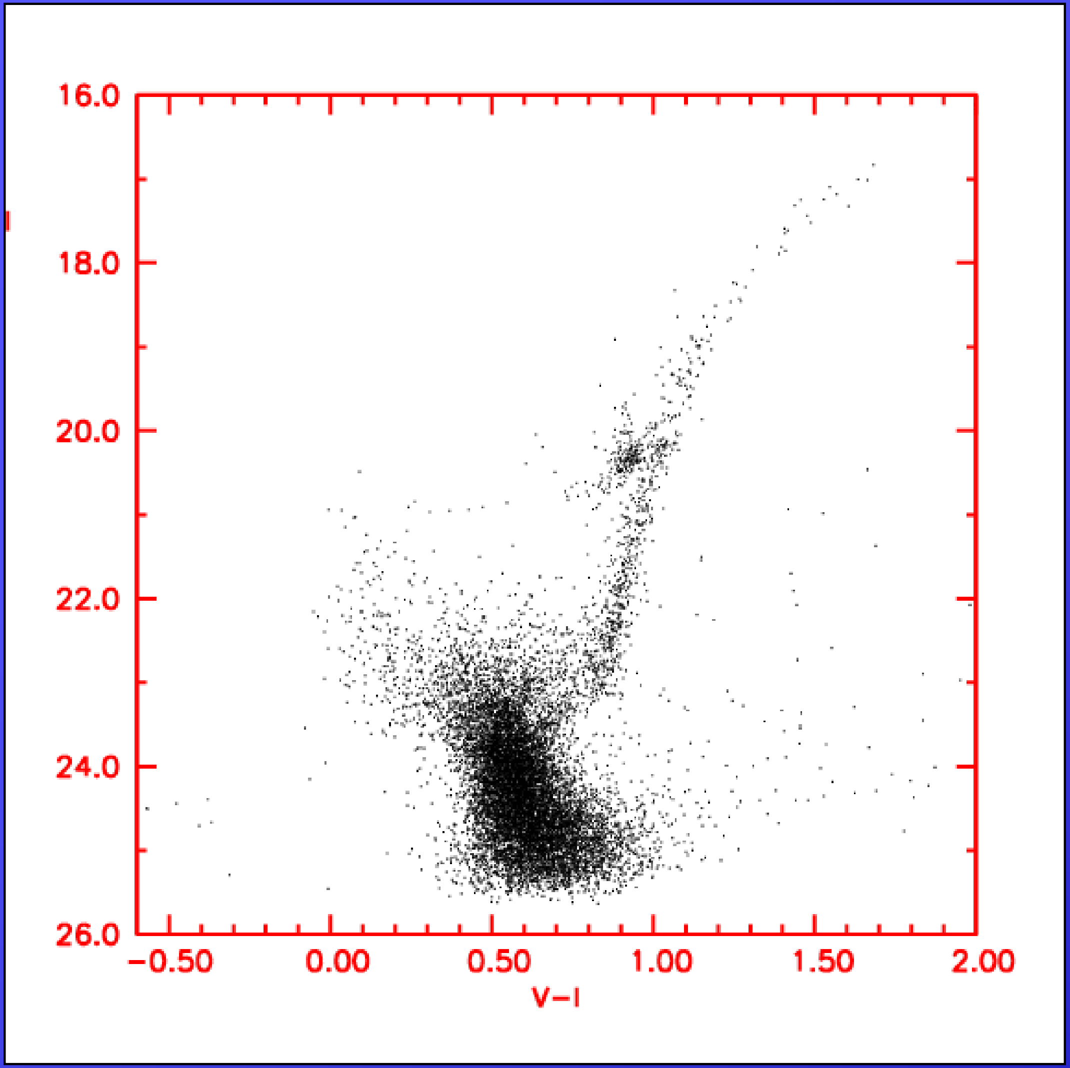
- *the youngest stars [5]*
- *young He-b stars [3,4]*
- *the "inner clump" (Olszewski et al .2006) [1] and surrounding field [2]*
- *the old, metal-poor populations [6,7]*

Reduction

- ✓ *Standard pipeline reduction with on-the-fly recalibration;*
- ✓ *PSF fitting photometry using HSTPHOT (Dolphin) with the most recent CTE corrections;*
- ✓ *V, I magnitudes on the standard system;*
- ✓ *artificial star experiments done, and used to provide input completeness and errors for CMD simulations*

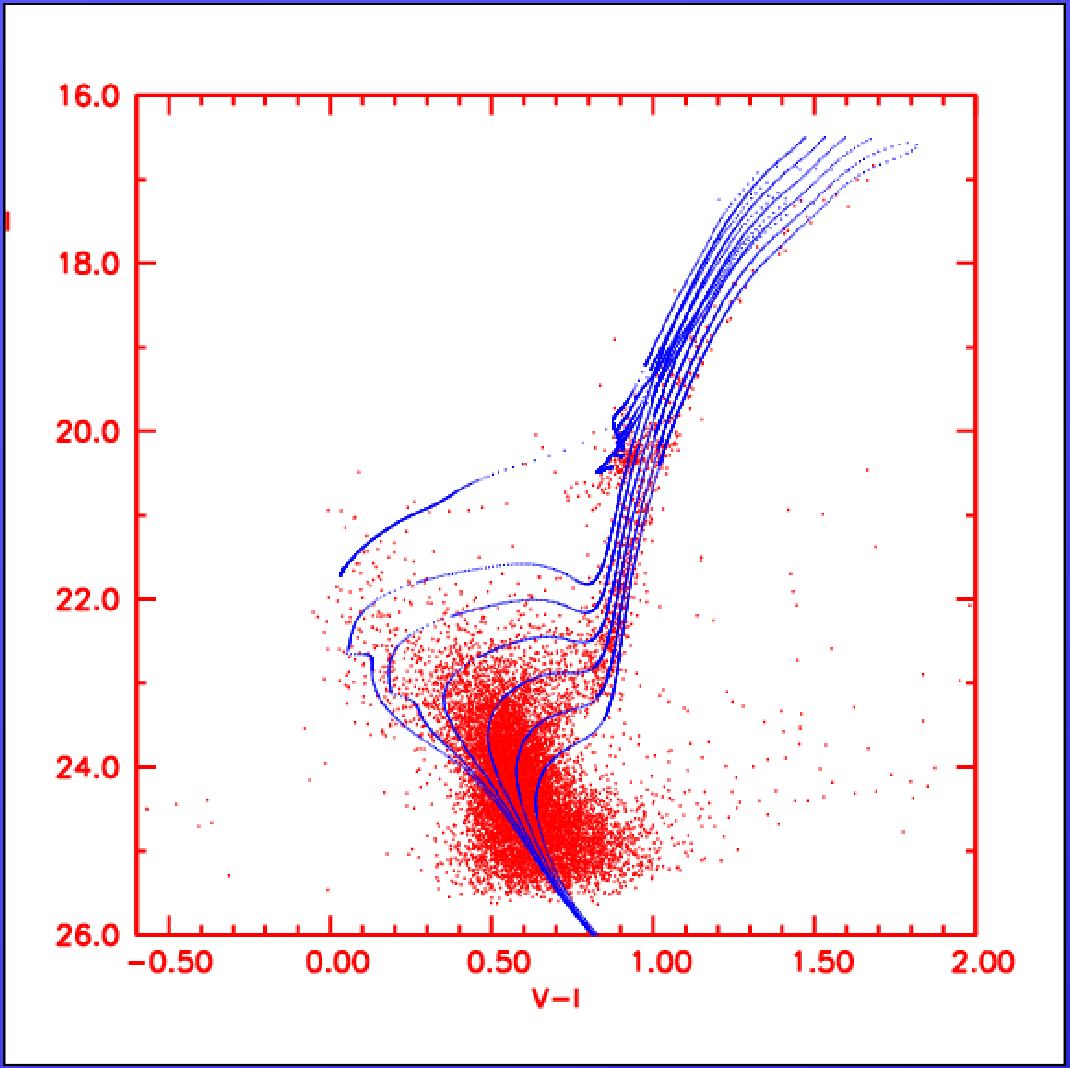
Early imaging: first results

- ✓ *The present results have been made possible by early acquisition of two fields: “field5” (central) and “field6” (outer);*
- ✓ *the remaining 5 fields are scheduled between May-Aug. 2008, just before SM4;*
- ✓ *one field may have to be postponed and taken with WFC3 … depending on SM4*



❖ *The innermost field shows a clear division between the brighter and fainter subgiant branch (see also Buonanno et al. 1999)*

All CCDs, error < 0.10 in both V and I

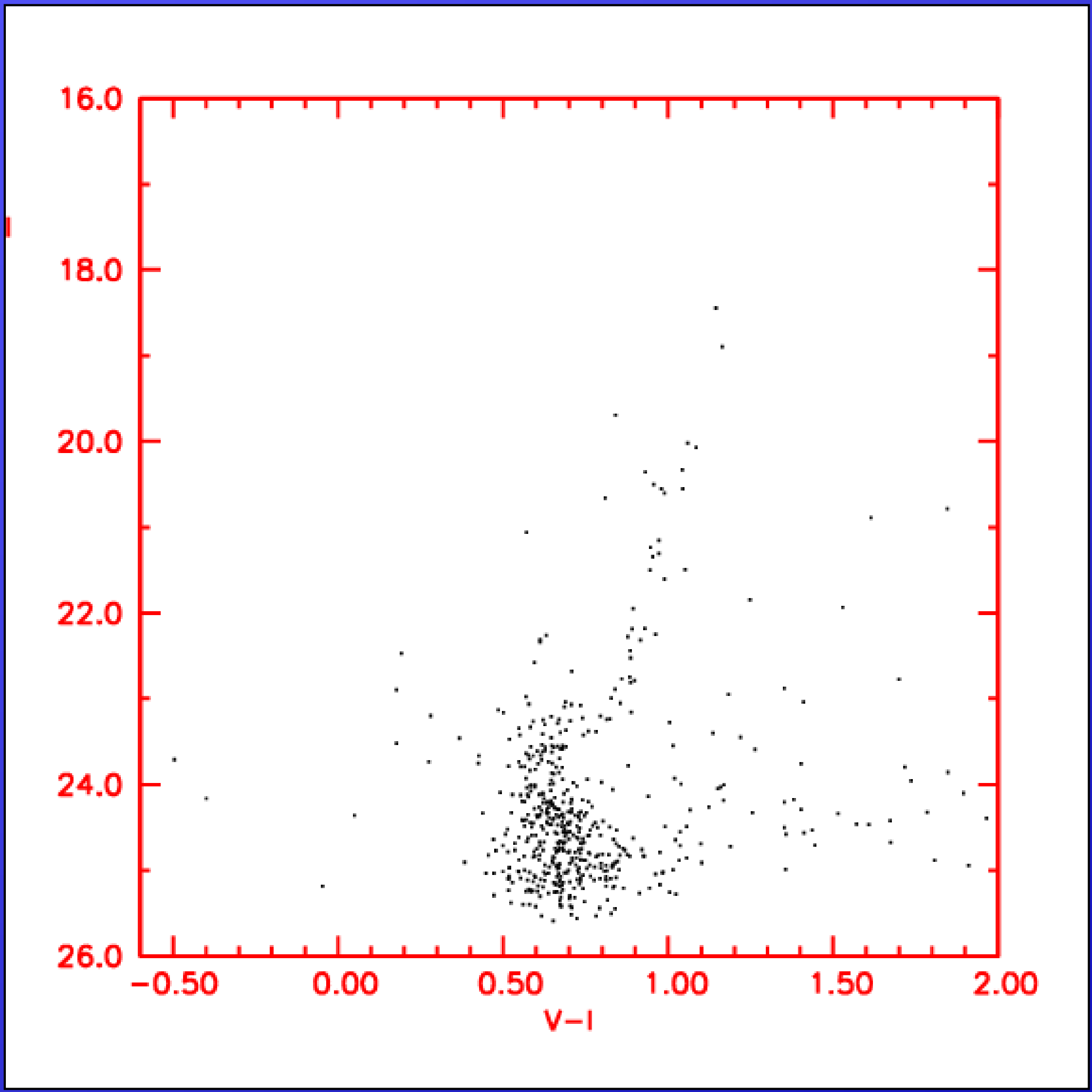


- *According to Z=0.002 Teramo isochrones, most of the stars formed between 9 and 3.5 Gyr ago; the two SGBs correspond to approximately 7 and 5 Gyr*
- *residual SF in the last Gyr*

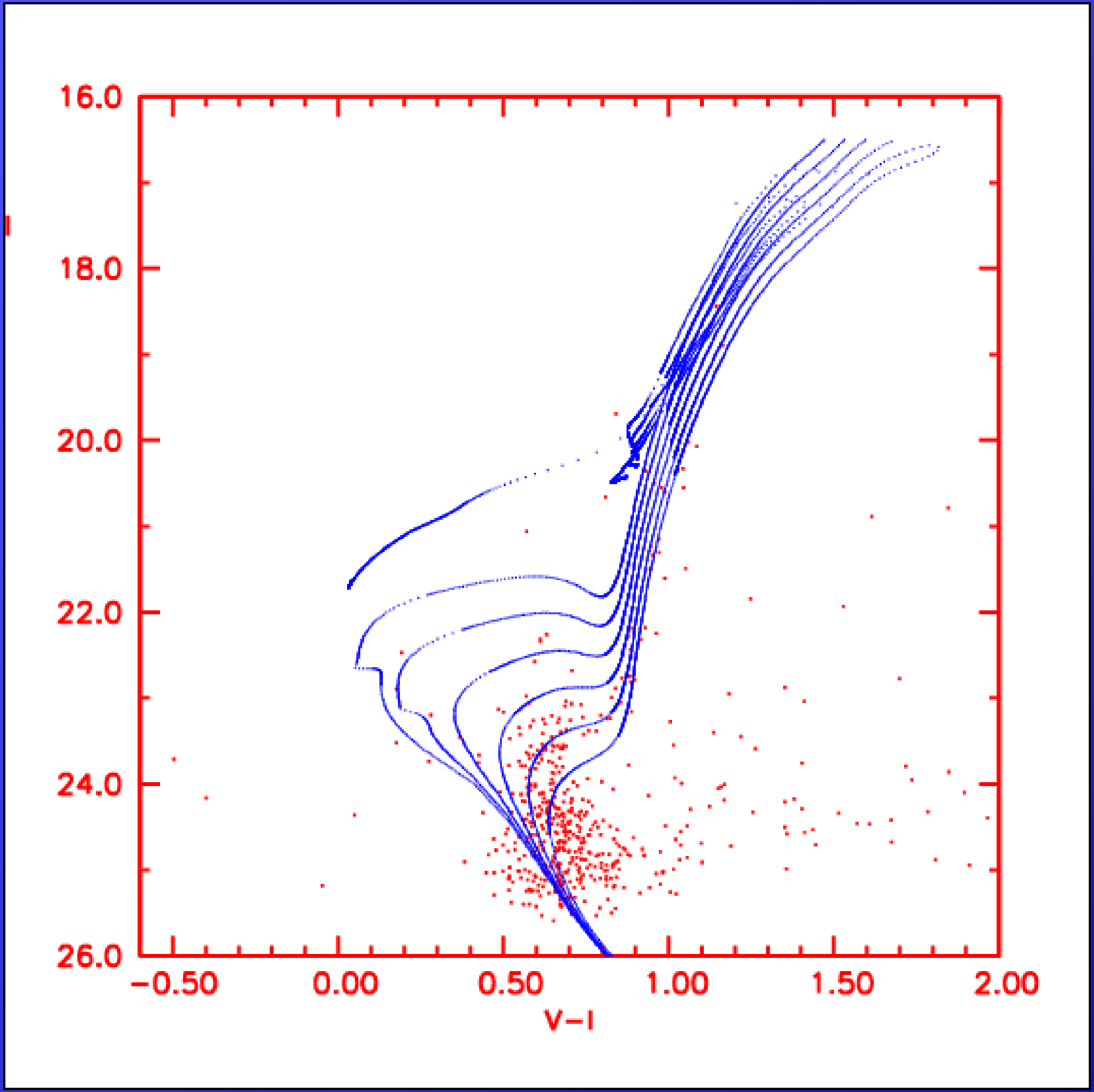
Canonical, scaled solar isochrones from Pietrinferni et al. (2004), Z=0.002 ;

ages 1.5, 2.25, 3.5, 5.5, 9, 14

❖ *Very few stars in the outer field ! However, a limited age range is apparent in the morphology of the SGB*



❖ *According to Z=0.002 Teramo isochrones, most of the stars formed ~ 9 Gyr ago (older if we adopt more metal-poor isochrones)*



SFH recipe 1 (Cole)

- ✓ *Latest Padova isochrones from Marigo et al. (2007); fixed distance and reddening;*

- ✓ *metallicity allowed to take any value between 0.0001 and 0.008 (no AMR was assumed);*

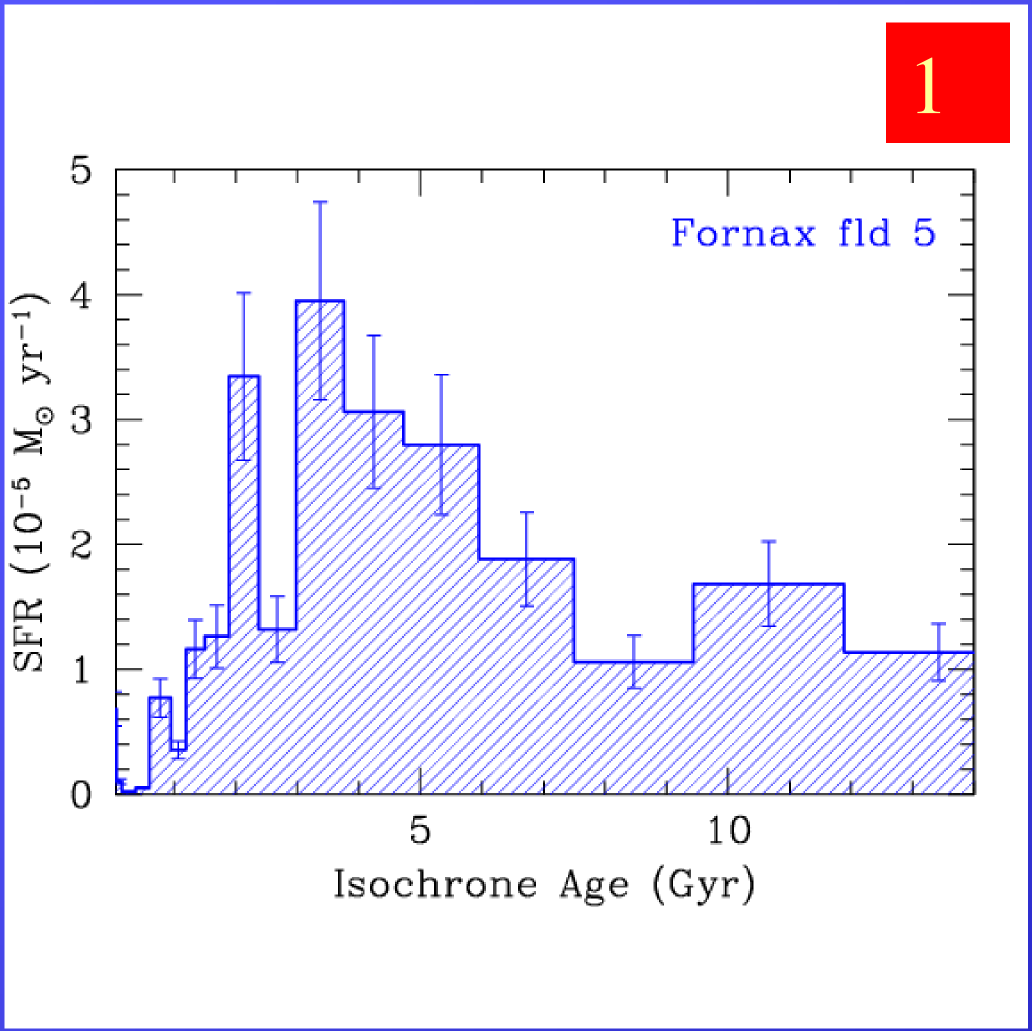
- ✓ *age bins 0.10 wide in log(age) for t>1 Gyr, 0.2 dex wide for 0.1-1 Gyr, and 0.4 dex wide for <0.1 Gyr*

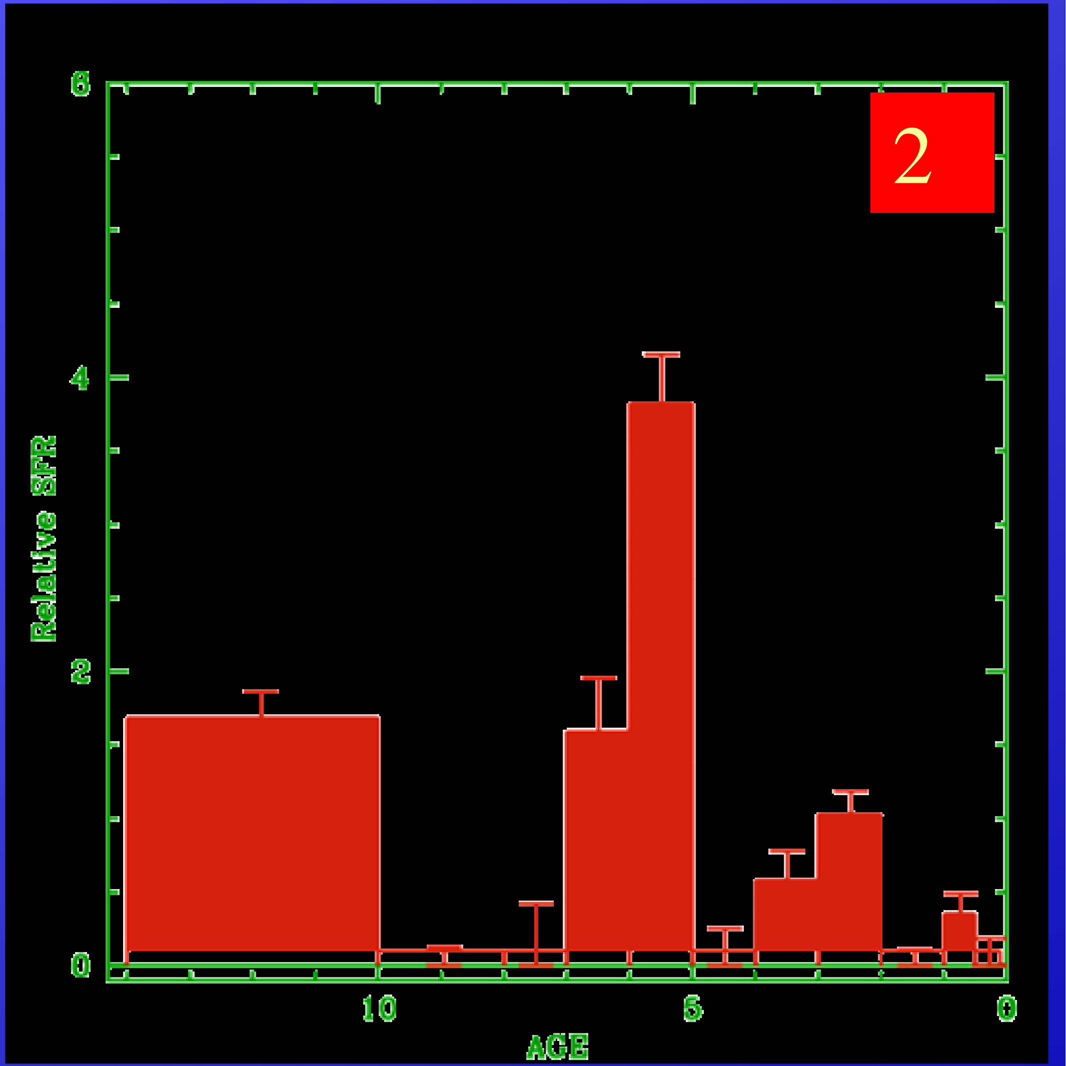
- ✓ *simulated annealing approach to find the best combination of CMDs that reproduce the data, as measured by log-likelihood (see Cole et al. (2007; and 2008, in prep.)*

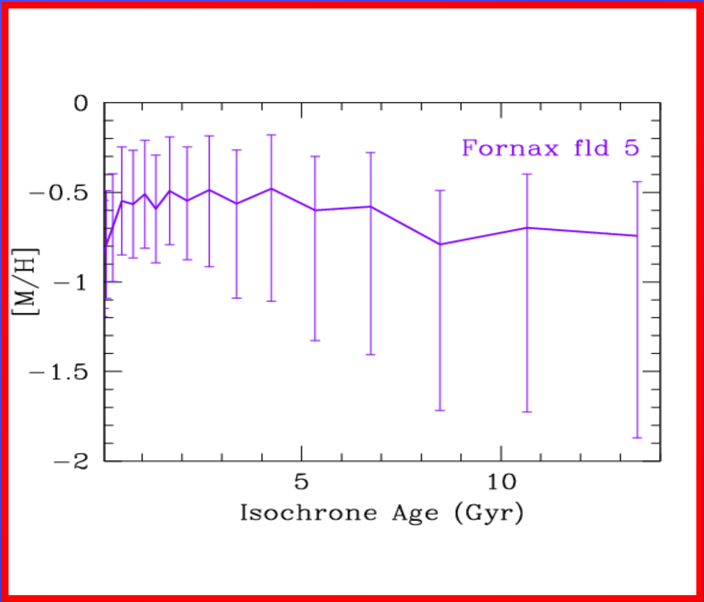
SFH recipe 2 (Rizzi+H.)

- ✓ *using ZVAR (Bertelli) with Padova evolutionary tracks*
- ✓ *Input metal enrichment law: linearly increasing from [Fe/H]= -2.1 at t=14 Gyr to [Fe/H]= -1.0 at t=0*
- ✓ *age bins 1 Gyr for t = 1-10 Gyr, 0.5 Gyr for t<1 Gyr, one large bin for t=10-14 Gyr*
- ✓ *best fit to the observed CMD by visual first guess refined by downhill simplex minimization*
- ✓ *16 regions (boxes) in the CMD used to count stars in specific evolutionary phases: subgiant branch, core He-burning stages, young main sequence*

SFH reconstruction: first results


1
Fornax fld 5
SFR (10^{-5} $M_\odot$ yr^{-1})
Isochrone Age (Gyr)
0
1
2
3
4
5
5
10


2
Relative SFR
AGE
0
2
4
6
10
5
0

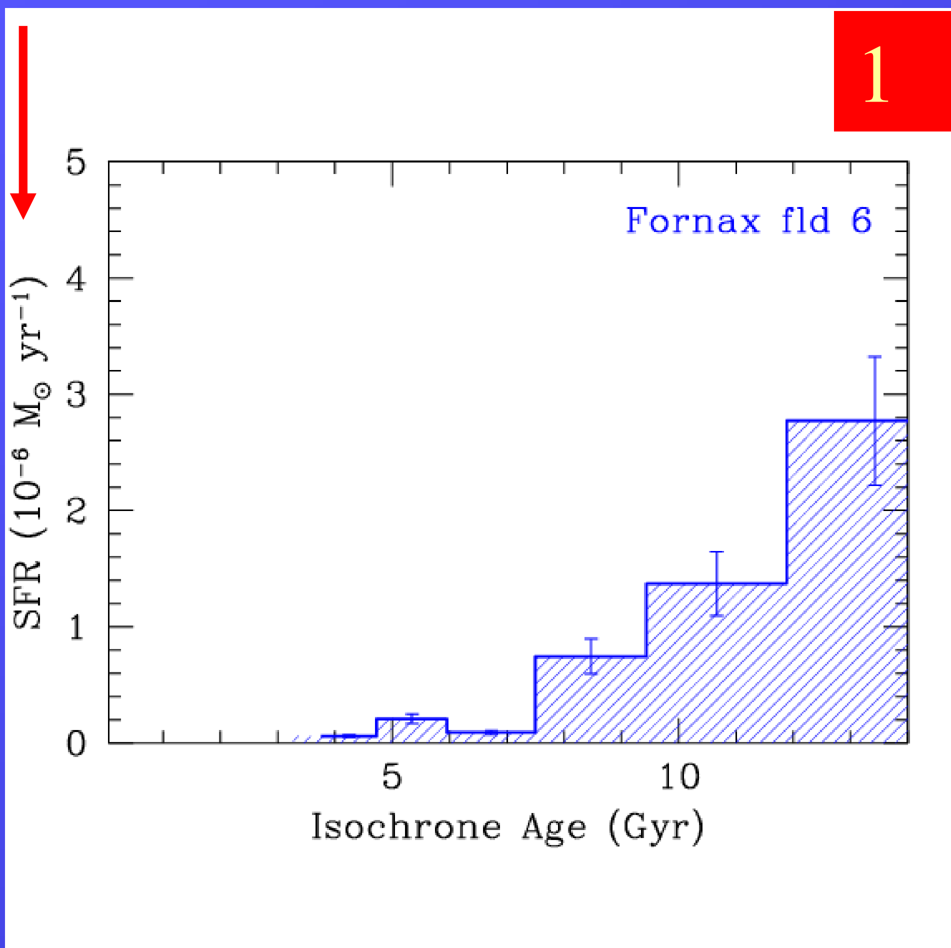


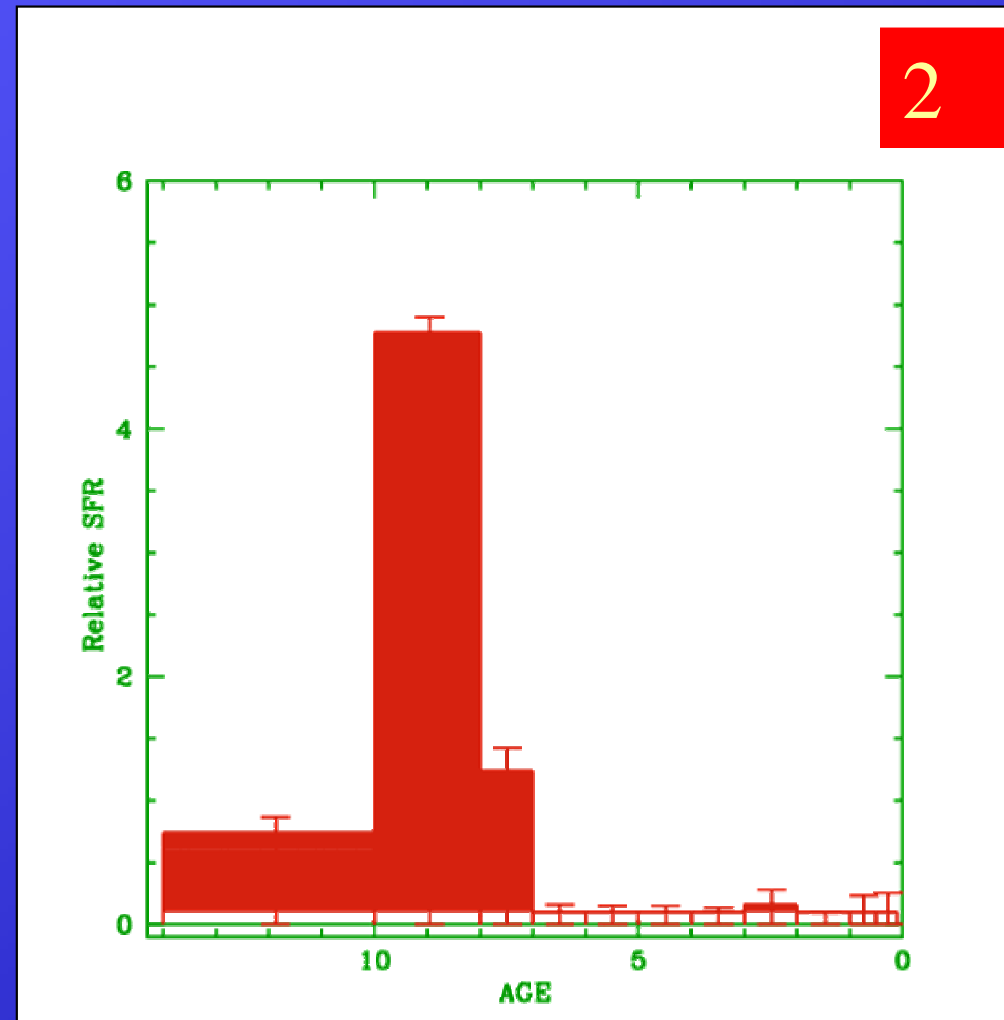
✓ *main star formation episode between 2-7 Gyr ago, possibly in distinct episodes (are gaps real ?)*

✓ *significant star formation at old ages, up to 14 Gyr*

✓ *the current (very approximate !) solution has the <u>average</u> metallicity increasing from Z = 0.002 at the oldest ages to Z = 0.007 at the youngest, with most of the stars in the 3-5 Gyr "peak" having Z ~ 0.005 (Cole's reconstruction)*

✓ *both <u>metal-rich</u> and metal-poor stars needed at old ages*


1
Fornax fld 6
SFR (10⁻⁶ M☉ yr⁻¹)
0
1
2
3
4
5
5
10
Isochrone Age (Gyr)


2
Relative SFR
0
2
4
6
10
5
0
AGE

- *As expected, only stars older than about 8 Gyr are found in the outer region (strong stellar population gradient)*

- *the detailed age distribution of old stars is a function of the adopted metal enrichment*

- *in reconstruction 1, the <10 Gyr age bin would disappear if the code is forced to exclude Z=0.004 isochrones*

Summary (so far ...)

- ✓ *Dramatic differences are found in the star formation histories of the inner and outer region of Fornax*
- ✓ *In the inner region sampled by WFPC2 “field5”, most of the stars formed between 3 and 7 Gyr ago, possibly in two distinct episodes*
- ✓ *Fornax started forming more than 10 Gyr ago even in the innermost region, in agreement with the presence of RR Lyrae stars. The old population is the only one present in the outer WFPC2 “field6” region.*

WFC3

✓ *most LG galaxies are more distant, up to 4 mag in distance modulus; many have been observed with ACS*

✓ *WFC3 opens up the possibility to efficiently survey the populations of young, hot stars …*

✓ *…and to observe the evolved stellar population (luminous intermediate-age AGB stars) in the near-infrared, in the Local Group and beyond (e.g., WFC E.R.)*