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<b>Acceptance in OA</b>	2020-07-03T09:03:09Z
<b>Title</b>	Stellar models, globular and open clusters, satellite dwarfs: all are tracers of the chemical and dynamical evolution of the MW and LG galaxies
<b>Authors</b>	TOSI, Monica, BELLAZZINI, Michele, BRAGAGLIA, Angela, CARRETTA, Eugenio, CASSISI, Santi, Curir, A., LUCATELLO, Sara, MAGRINI, LAURA, RANDICH, Maria Sofia, ROMANO, Donatella, SPAGNA, Alessandro, VENTURA, Paolo, ANNIBALI, FRANCESCA, SOLLIMA, ANTONIO LUIGI, Re Fiorenti, P.
<b>Handle</b>	<a href="http://hdl.handle.net/20.500.12386/26303">http://hdl.handle.net/20.500.12386/26303</a>



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**Stellar models, globular and open clusters, satellite dwarfs: all are tracers of the chemical and dynamical evolution of the MW and LG galaxies.**

**Report from the INAF research unit**

**Monica Tosi**

**INAF – Osservatorio Astronomico di Bologna**

**Sexten, January 22<sup>nd</sup> 2015**



# INAF Unit

Distributed over 5 INAF institutes

M. Tosi (coordinator)  
M. Bellazzini  
A. Bragaglia ★  
E. Carretta  
S. Cassisi  
A. Curir  
S. Lucatello ★  
L. Magrini ★  
S. Randich  
D. Romano ★  
A. Spagna ★  
P. Ventura

} staff

F. Annibali  
A. Sollima  
P. Re Fiorentin

} postdocs

People labelled with ★ are speakers at this conference

To understand  
**galaxy evolution**

**theoretical models**

galaxy formation  
stellar evolution  
chemical evolution  
dynamical evolution  
...

**observational constraints**

chemical abundances  
gas/star/dark masses  
kinematics  
star formation history  
IMF  
...

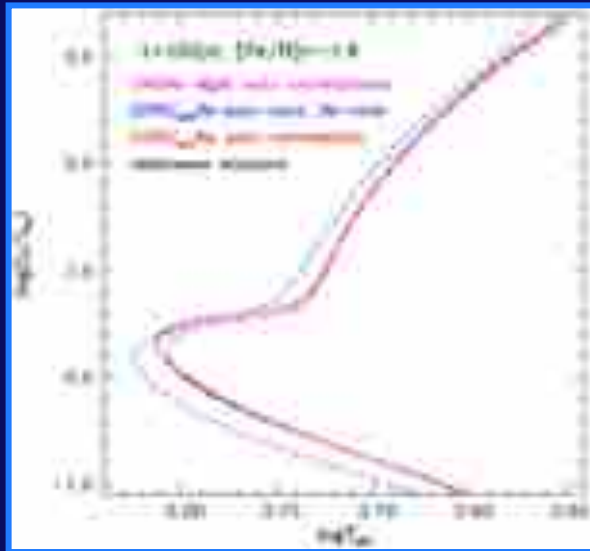
**In the INAF Unit we have addressed many of these items:  
Theoretical models, globular and open clusters in the MW  
and in nearby galaxies, structure and evolution of nearby  
dwarfs**

# Evolutionary Stellar Models for Multiple Population GCs

Santi Cassisi

(INAF-Astronomical Observatory Teramo)

It has been extensively investigated how the peculiar chemical patterns associated to the distinct sub-populations affect both the evolutionary properties and spectra of low-mass stars

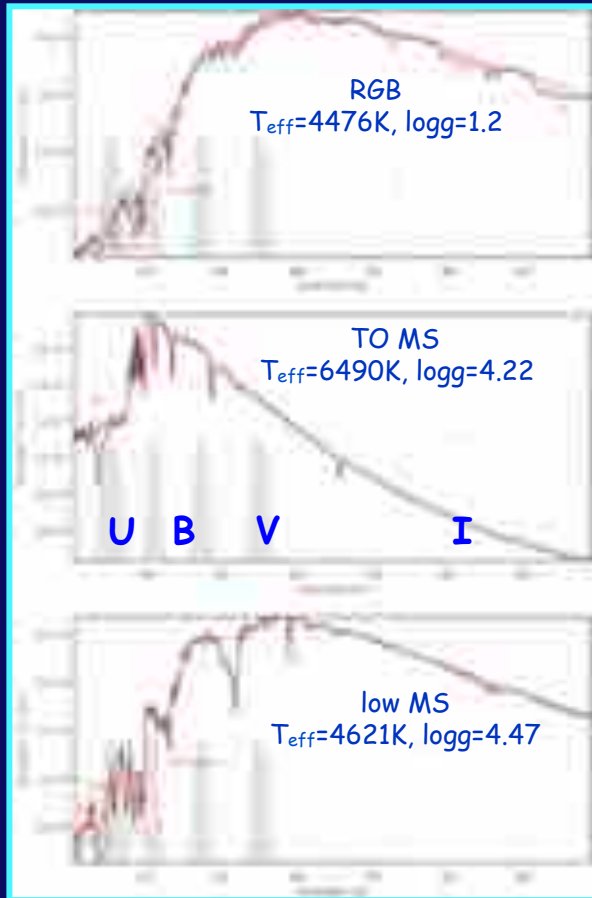


In the H-R diagram, at fixed  $[Fe/H]$ , a clear separation (split) of an evolutionary sequence can be obtained:

- for the MS, only as a consequence of a huge He-enhancement;
- for the SGB, only as a consequence of an increase of the (C+N+O) sum;
- in the case of the RGB, only as a consequence of an He increase;
- at constant C+N+O sum, light element (anti-)correlations such as Na-O and Mg-Al ones have no impact on the location of the various sequences in the H-R diagram;

...but multi-band observations suggest that the changes in the stellar Spectral Energy Distribution induced by these chemical patterns are important...;

# The impact of light-element anti-correlations on the SED



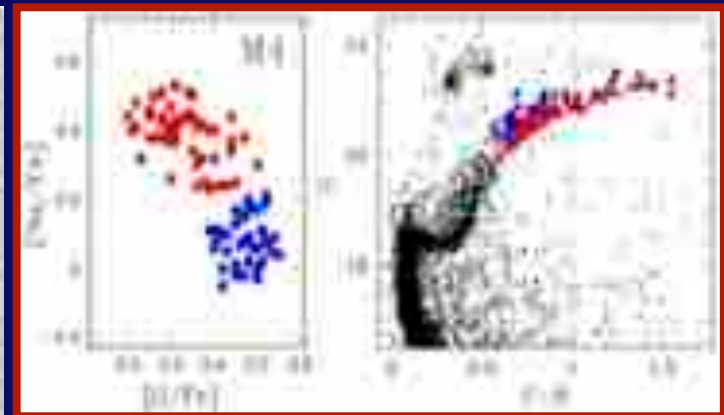
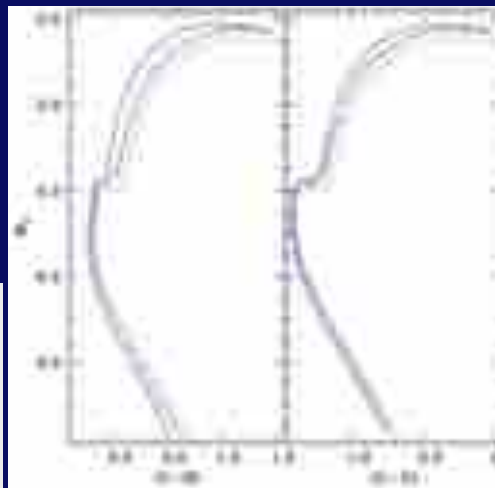
- black: reference  $\alpha$ -enhanced mixture
- red:  $(CNO)_{\text{ext}}\text{Na}$  anti-correlation

light-element changes affect mainly the portion of the spectra short of about 400 nm owing to the changes in molecular bands (...NH, CN, and OH in the fainter MS stars...)

Sbordone et al. (2011) - Cassisi et al. (2013)

## isochrones for multiple population: a self-consistent approach

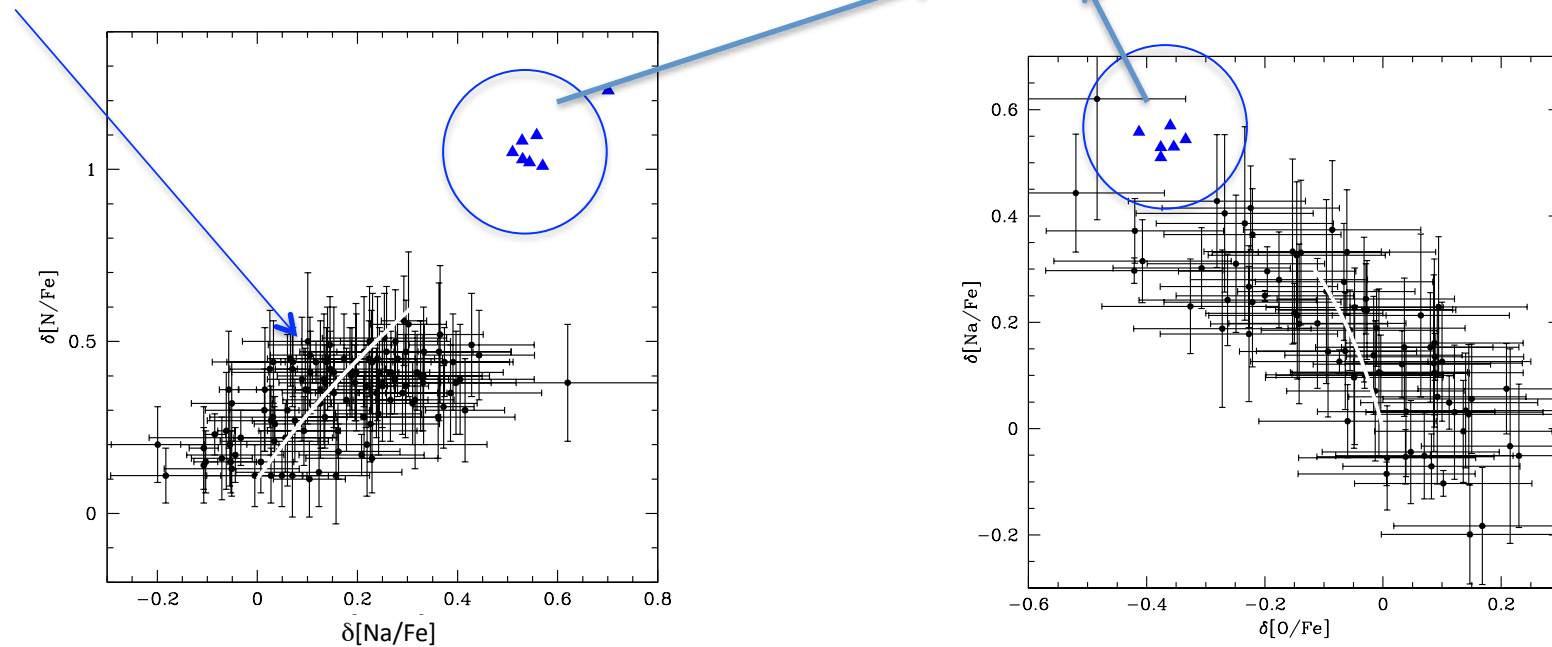
- blue solid: reference mixture
- red dash:  $CNO_{\text{Na}}$
- magenta dash:  $(CNO)_{\text{enh}}\text{Na}$  - normal He
- blue dot:  $(CNO)_{\text{enh}}\text{Na}$  -  $Y=0.40$



## The formation history of 47Tuc (Ventura et al. 2014, MNRAS, 437, 3274)

We reconstructed the formation history of the Globular Cluster 47Tuc in the framework of the self-enrichment scenario by massive AGB stars. To this scope, we calculated new yields from AGB models with the appropriate metallicity ( $[Fe/H]=-0.75$ ) and compared the chemistry of the ejecta with the spectroscopic analysis by Carretta et al. (2013).

Dilution curve

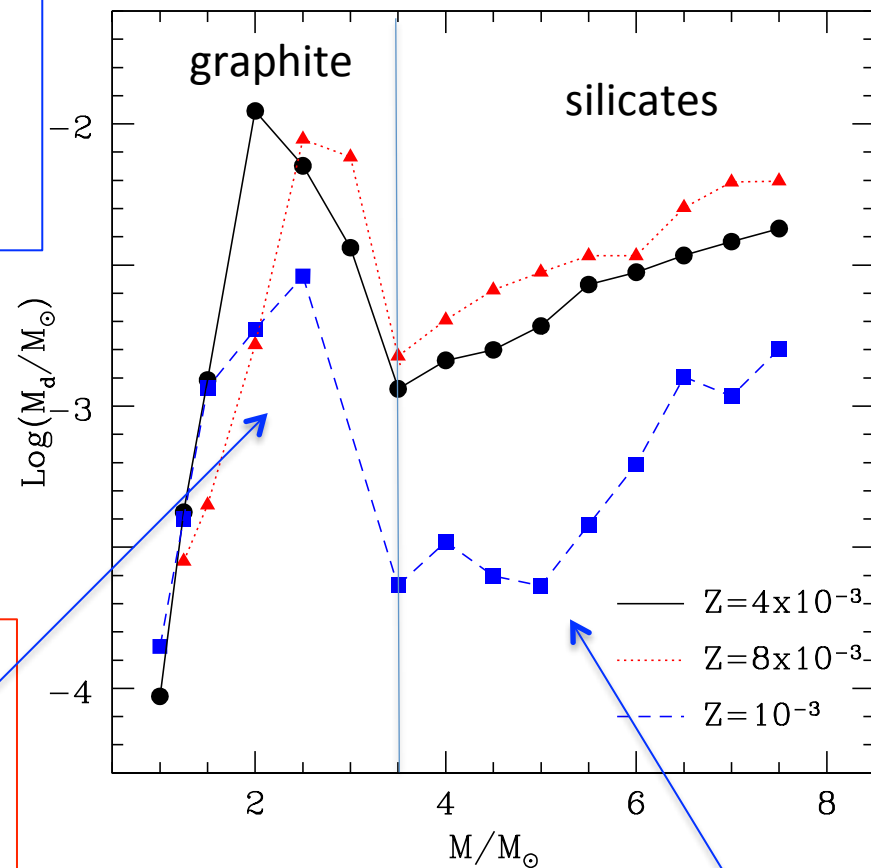


The pattern traced by the observed abundances can be reproduced by dilution of pristine gas in the cluster with the AGB ejecta, in relative fractions of, respectively, 65% and 35%. Dynamical arguments supports the conclusion that 47Tuc is the relic of a structure initially 7-8 times more massive than nowadays.

# Dust production from AGB stars (Ventura et al. 2014, MNRAS, 439, 977)

Low mass ( $M < 3M_{\text{sun}}$ ) AGBs experience many Third Dredge Up episodes and become carbon stars (C/O above unity)

The dust produced by low mass AGBs is under the form of solid carbon (graphite), with also traces of SiC



Massive AGBs ( $M > 3M_{\text{sun}}$ ) never become carbon stars, owing to the effects of Hot Bottom Burning, destroying the surface carbon

Massive AGBs produce silicate particles. Unlike low mass AGBs, in this case the quantity of dust produced scales with metallicity.

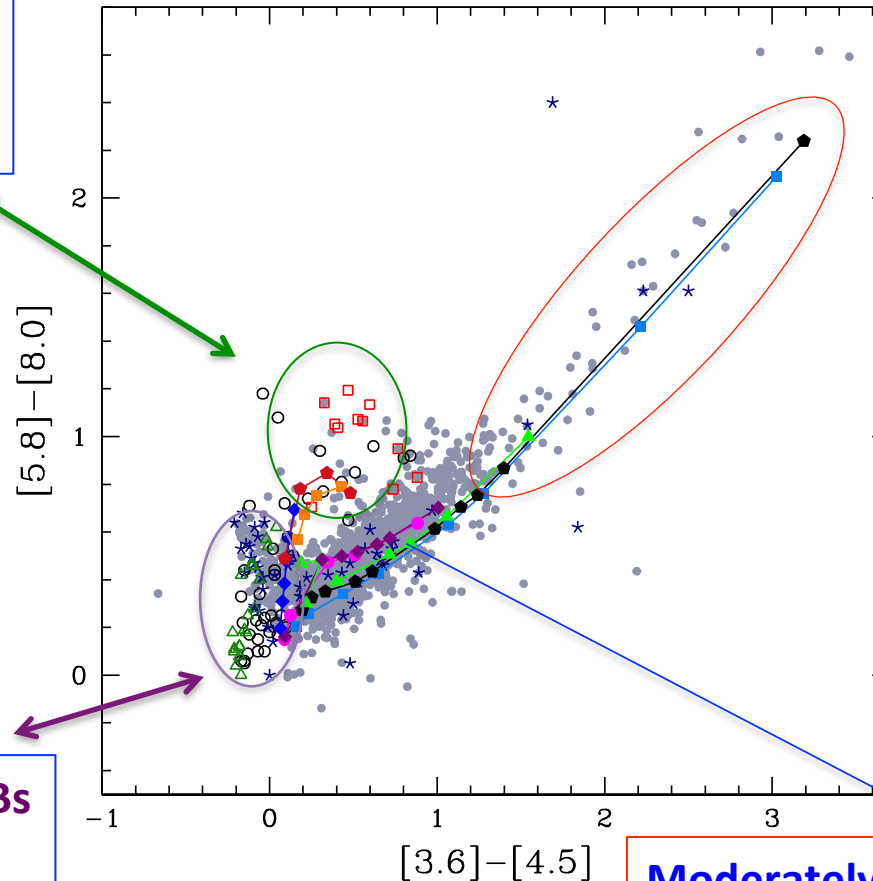
# The interpretation of Spitzer observations of AGB stars in the LMC

( Dell'Agli et al. 2014, MNRAS, 442, L38; Dell'Agli et al. 2015, MNRAS, in press)

Dust-surrounded stars in the LMC occupy distinct regions in the colour-colour plane, according to whether they are carbon stars or oxygen-rich . This allows a characterization of the AGB population of the LMC in terms of age, surface chemistry, dust properties

**Obscured M stars**  
Age: 100-200 Myr  
Progenitors: 5-6Msun

**Heavily obscured  
Carbon stars.**  
Age: 500 Myr  
Progenitors: 2-3Msun



**Scarcely obscured AGBs**  
Both C- and M-stars

**Moderately obscured carbon stars.**  
Age: 0.4-3 Gyr  
Progenitors: 1-3Msun

## INAF UdR: GGs Bologna/Padova - OCs Bologna/Arcetri

### Massive (globular) clusters

- study of the multiple populations using chemical tracers  
(He, Al-Mg, Na-O, Li, n-capture)
- definition of limit between open & globular clusters
- search for (young) GC counterparts  
10 papers 2012-14 & more in preparation/to come  
see talks A. Bragaglia, S. Lucatello  
E. Carretta, A. Sollima, M. Bellazzini : contributions here

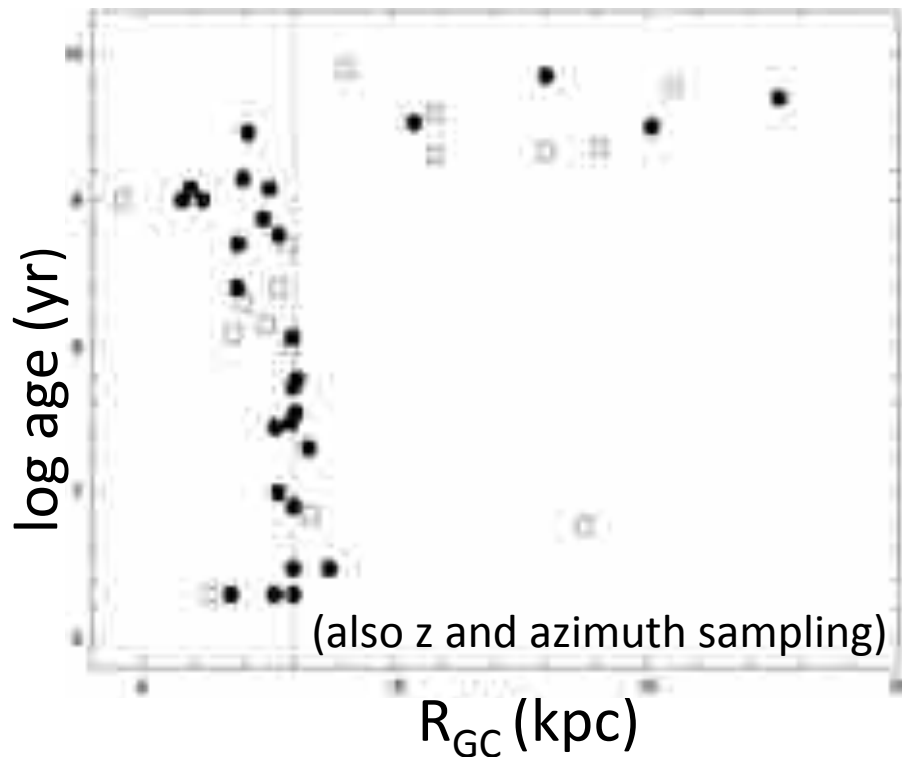
### Open Clusters

- the Gaia-ESO public spectroscopic survey & the MW disc  
5 papers 2013-14 & more in preparation/to come  
see talks A. Bragaglia, L. Magrini  
S. Randich, D. Romano : contributions here ; P. Donati (UdR UNIBO)



## The Gaia-ESO Survey in the context of the PRIN project: Open Clusters as tracers of the formation and evolution of the thin disc (1/2)

### The sample so far



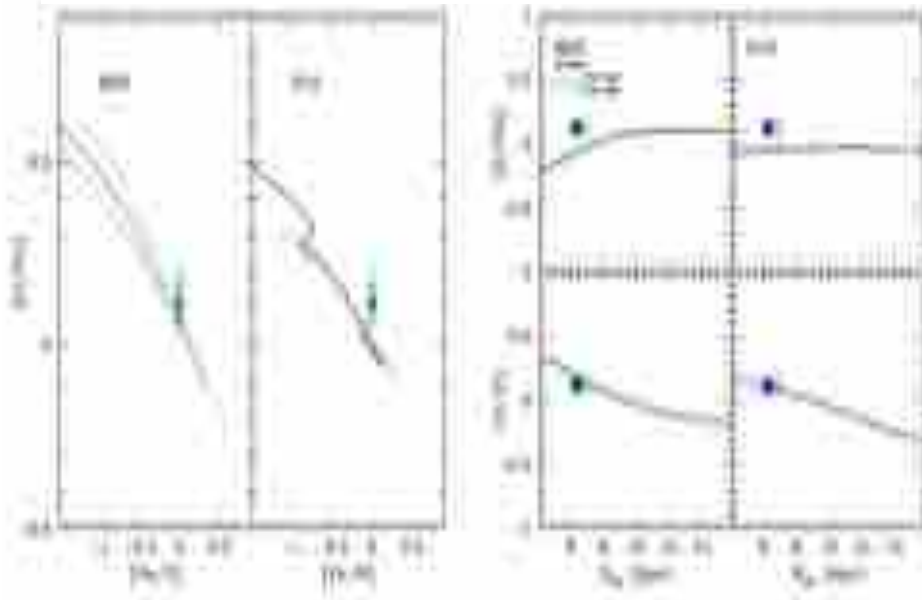
- Observations of 28 clusters completed
- ~25000 stars
- RVs, APs, [Fe/H], individual abundances
- 12 papers on OCs with PRIN participants as co-authors  
– see Magrini & Bragaglia's talks

- observed
- to be observed in the next months

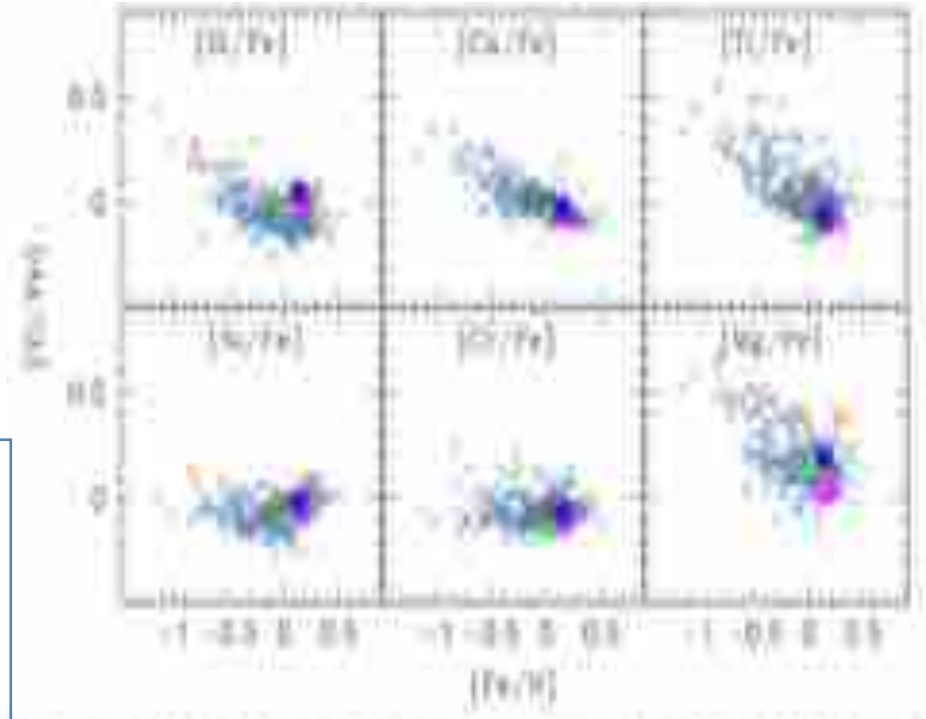


# The Gaia-ESO Survey in the context of the PRIN project: Open Clusters as tracers of the formation and evolution of the thin disc (2/2)

Oxygen evolution - Tautvaišienė + (2015)



Evolution of the inner disc – comparison  
of clusters and MW field - Magrini,  
Randich, + (2014)

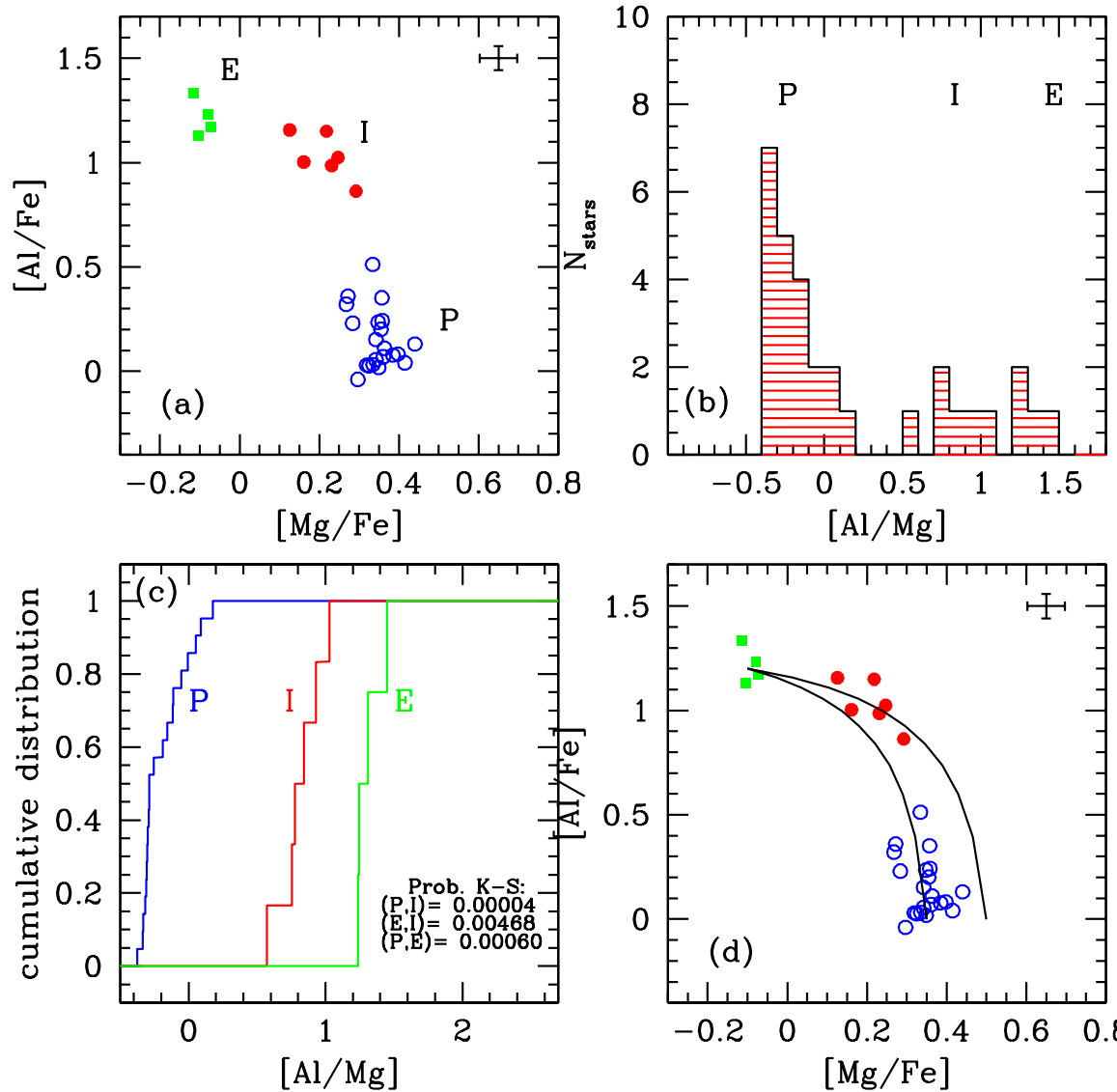


[Fe/H]

The radial metallicity gradient  
see Laura Magrini's talk

$R_{GC}$  (kpc)

# Three discrete population of giants with distinct chemistry in NGC 2808



Mg-Al anticorrelation from 31 RGB stars (UVES spectra) in (a).  
 3 distinct groups (b), with different chemistry (c): primordial P composition, intermediate I and extremely E modified chemistry of 2<sup>nd</sup> generation.  
 No simple dilution model (d) is able to reproduce the I group by mixing P and E compositions



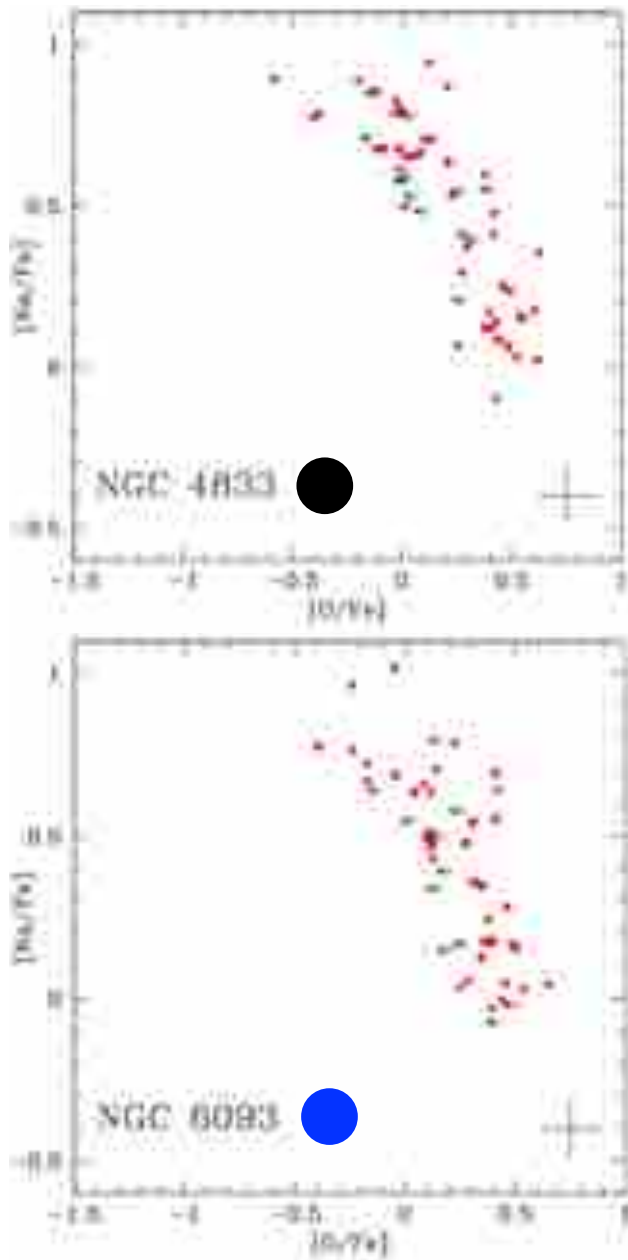
**TWO classes** of different polluters, as in NGC 6752 (Carretta et al. 2012,ApJ, 750,L14)

Number ratios:

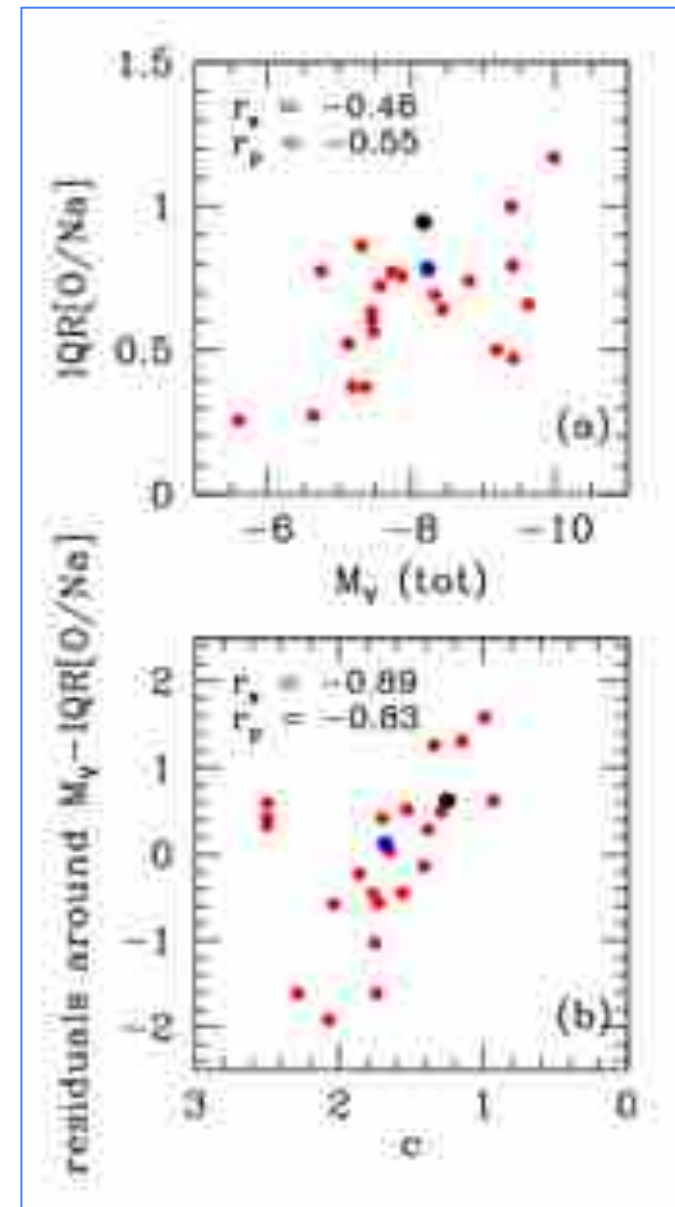
<b>P: 68±15%</b>	<b>rMS: 62±2%</b>
<b>I : 19± 8%</b>	<b>iMS: 24±2%</b>
<b>E: 13± 4%</b>	<b>bMS: 14±3%</b>
this work	Milone+2012

Carretta (2014, ApJ, 795,L28)

## Multiple populations in NGC4833 and NGC6093 (M80)



The amount of chemical modifications in 2<sup>nd</sup> generation stars (e.g. the interquartile range of the  $[O/Na]$  ratio) is primarily driven by the cluster total mass (a) and modulated by the cluster concentration (b)



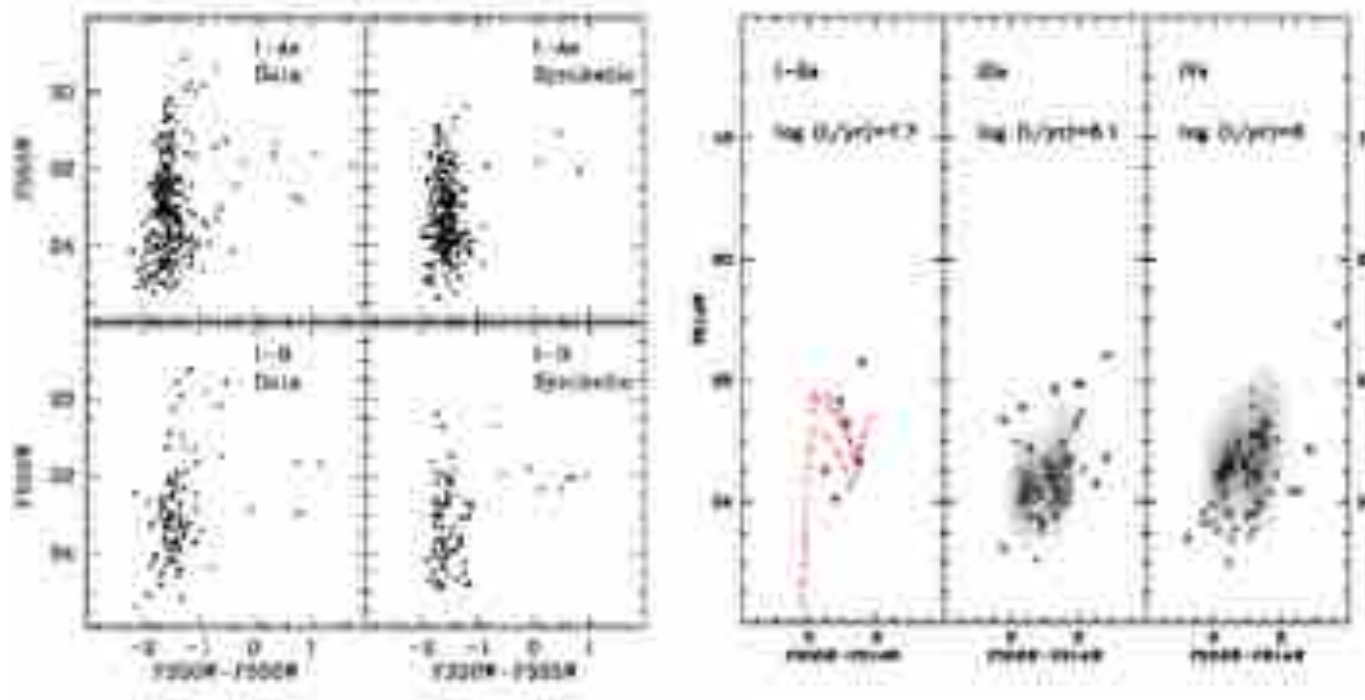
# Search of multiple stellar populations in YMCs of nearby galaxies

A. Sollima (OABO)

Explore the population YMCs in nearby starburst galaxies with the aim of detecting signatures of multiple stellar populations in systems which are expected to evolve towards a GC-like structure



NGC4214 YMCs reveals no  
ions in resolved clusters

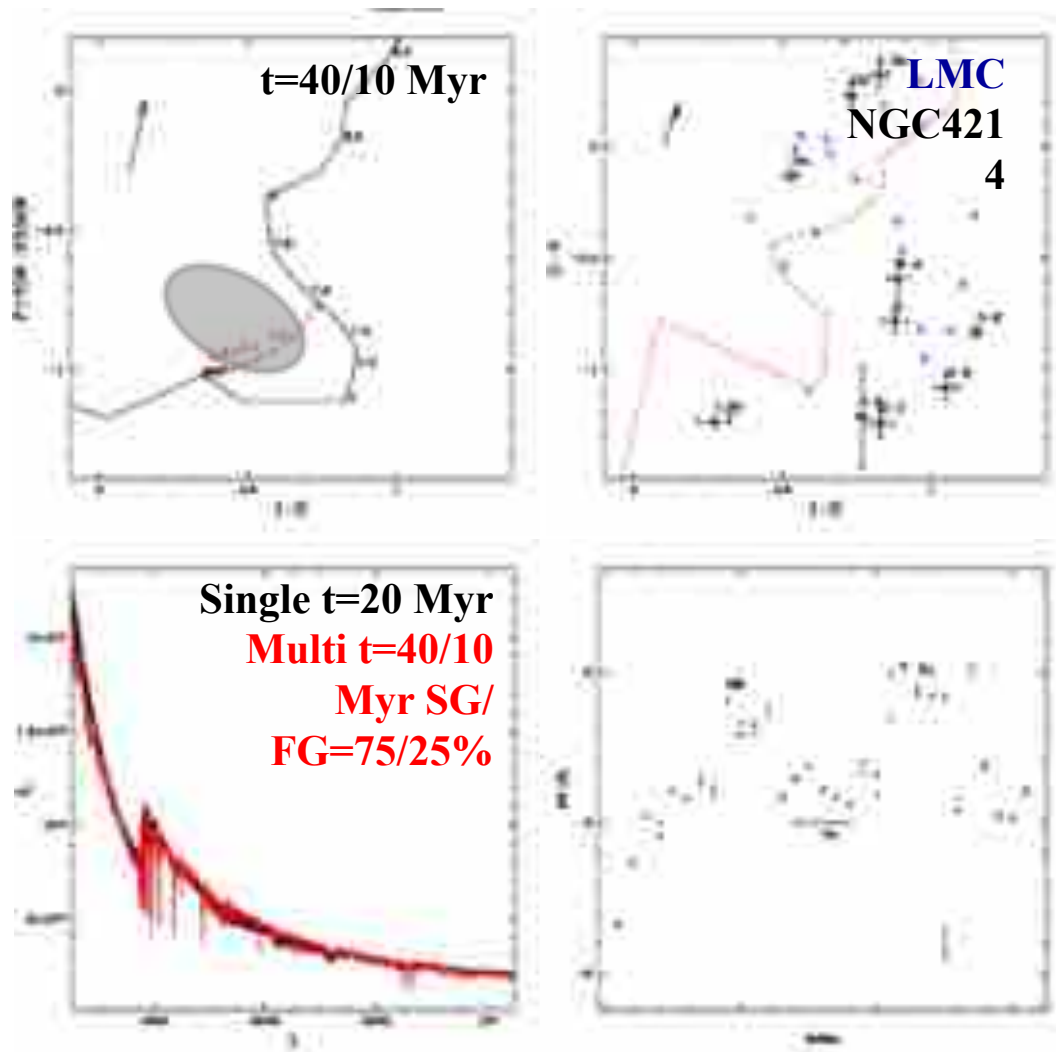


Sollima et al. (2014)

# Search of multiple stellar populations in YMCs of nearby galaxies

*A. Sollima (OABO)*

Estimate of the effect of multiple stellar populations in integrated colors and spectra of YMCs using stellar population synthesis



•YMCs with multiple population locates in the UV-IR color-color diagram in a region forbidden to single-population cluster

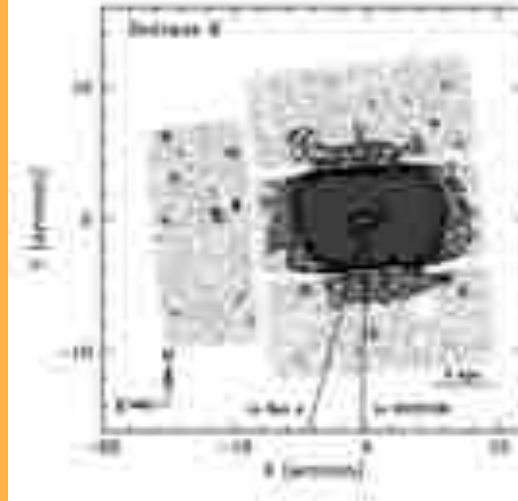
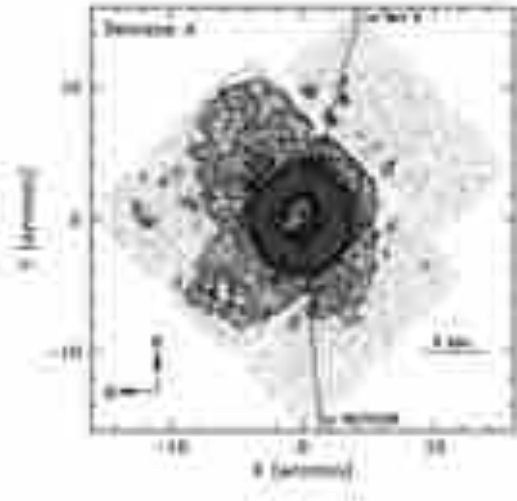
•Spectra of multiple- and single-population YMCs are almost indistinguishable

•Photometric detection possible only in a narrow range of FG/SG mass ratio, age difference, metallicity, SG age

•Strong uncertainties in stellar evolution models and synthetic spectral libraries as well as reddening and photometric zero points

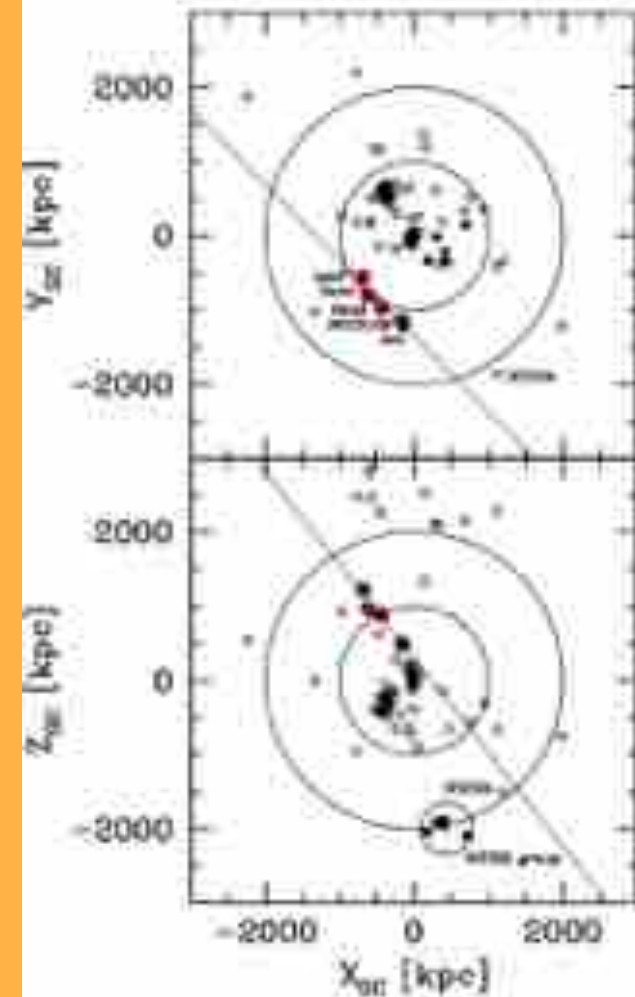
## The extended structure of isolated dwarf galaxies

Bellazzini et al. 2014, A&A, 566, A44



LBC and VIMOS deep ( $r \sim 26.5$ ) wide-field photometry to unveil the extended LSB stellar body of dwarfs presumably evolved in isolation. Published papers on: VV124, Sex A, Sex B, Sgr dIrr; data analysis ongoing for WLM and Tucana. In all the cases we were able to trace the surface density profile down to  $\sim 30$  mag/arcsec<sup>2</sup> **finding that the stellar body of the considered galaxies is >2 times more extended** than previously believed and has a scale comparable with the associated HI distribution.

We discovered that the dwarfs in the NGC3109 group + Leo P are tightly aligned in space and show a coherent pattern in  $V_r$ .



Bellazzini et al. 2013, A&A, 599, L11  
[17 citations in one year]

## The SECCO survey



Searching for stellar counterparts of compact High Velocity HI Clouds identified in ALFALFA (Adams et al. 2013) as candidate mini-halos in the Local Group and its surroundings. Very deep WF imaging of the 25 best candidates + Leo P, taken as a template.

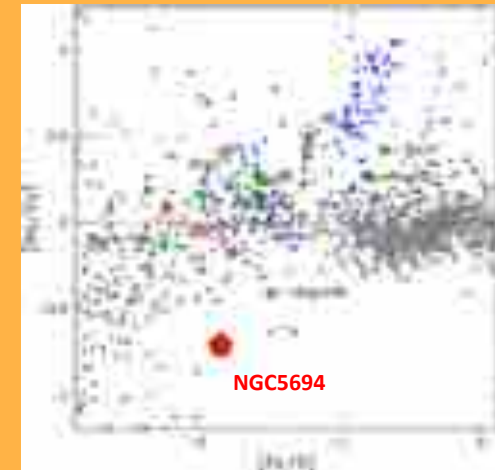
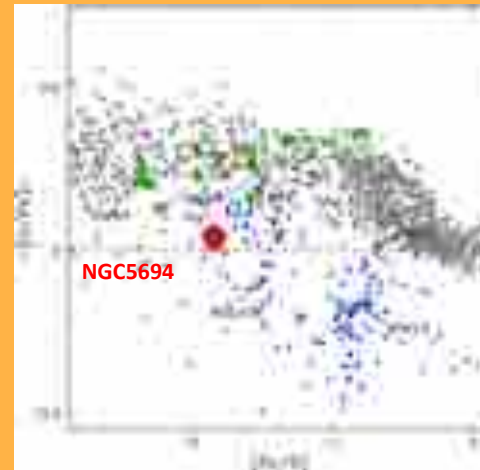
First paper published (Bellazzini et al. 2015, A&A, in press, [arXiv:1412.5857](https://arxiv.org/abs/1412.5857)); The second is submitted and several more are planned. Spectroscopic follow-ups ongoing.

See <http://www.bo.astro.it/secco/>

Michele Bellazzini (INAF-OABO)

## Anomalous/accreted globular clusters

Chemical, kinematical and photometric properties of Galactic globular clusters that are suspected to have an “extragalactic” origin [or that show some interesting anomaly].



For example we have performed full abundance analysis from UVES spectra of six stars in NGC5694 confirming that its abundance pattern is different from typical Galactic halo clusters and more similar to metal poor stars in dwarf spheroidals.

- NGC2419:** Beccari et al. 2013, MNRAS, 431, 1995
- NGC5694:** Mucciarelli et al. 2013, MNRAS, 435, 3667
- Ter 5 :** Massari et al. 2014, ApJ, 795, 22
- NGC6362:** Dalessandro et al. 2014, ApJ, 791, L4
- NGC5694:** Bellazzini et al. 2015, MNRAS, 446, 3130

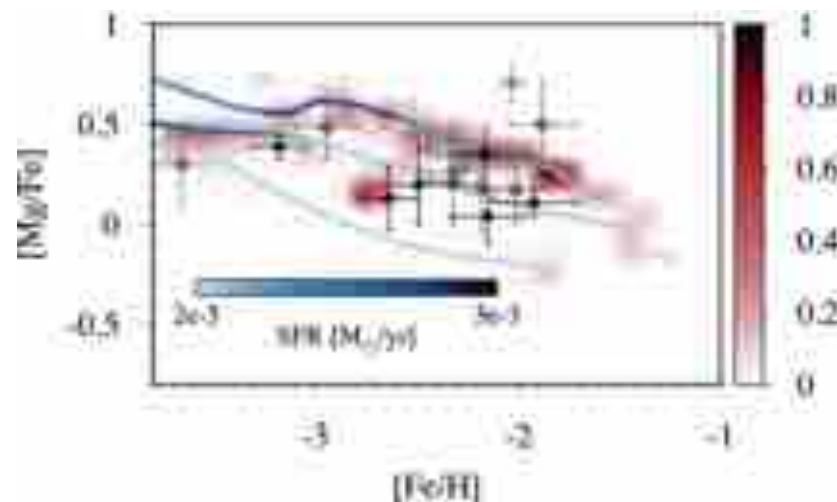
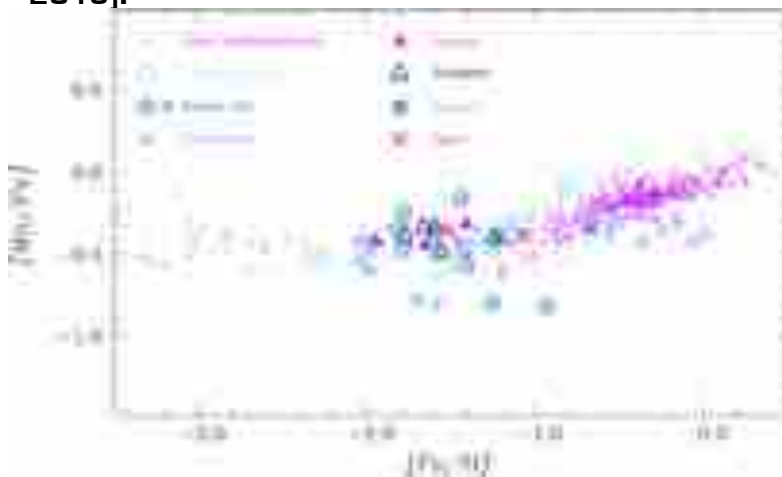
# UdR Bologna – Chemical evolution of galaxies

*Donatella Romano, MT*

★ **Astroarchaeology:** chemical abundances as tracers of the formation history of the Milky Way and Local Group galaxies. Participation in GES collaboration (Magrini, Randich, DR, et al. 2014; Mikolaitis et al. 2014; Tautvaišienė et al. 2015); abundances in RR Lyrae stars [Pancino, Britavskiy, DR, et al. 2015]; models of MW disks [Micali, Matteucci & DR 2013] and halo formation [Brusadin, Matteucci & DR 2013].

★ **Main interest: modelling.** Fundamental ingredients for models: stellar yields. How good are they? Role of binary systems. (Romano et al. 2010; Lagarde et al. 2012; Matteucci, DR, Arcones, et al. 2014)

★ **Cosmological context for assembly histories of galaxies** (Romano & Starkenburg 2013; Romano et al. 2015).



# UdR Bologna – Chemical evolution of galaxies

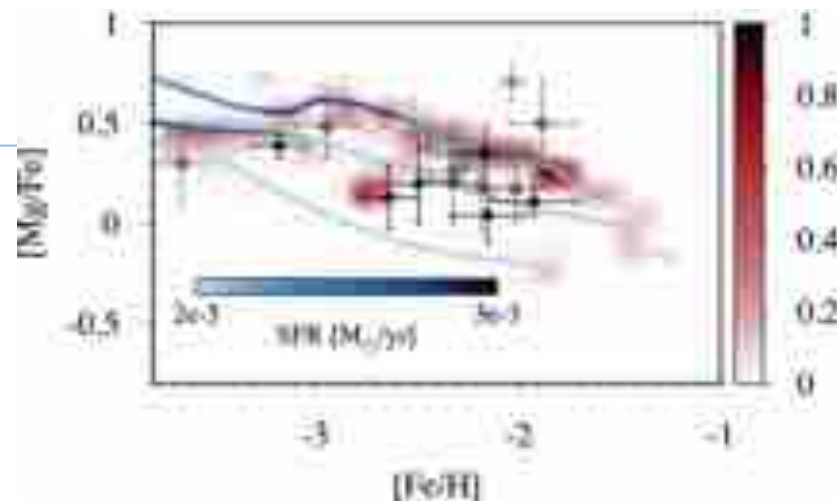
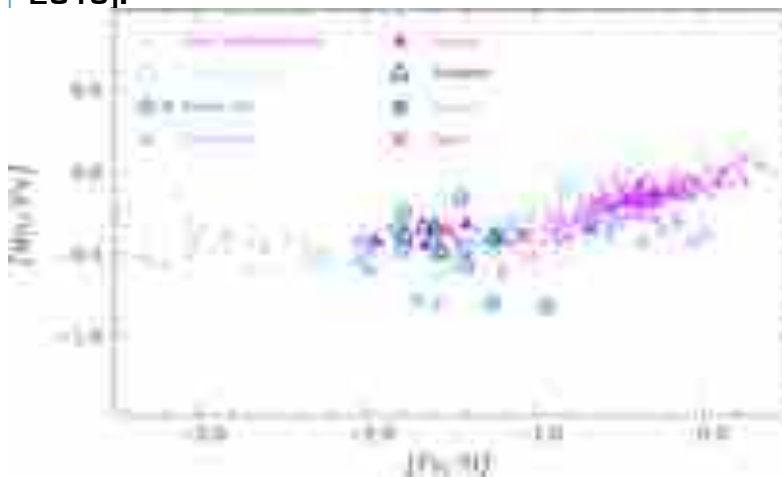
*Donatella Romano, MT*

★ **Astroarchaeology: chemical abundances as tracers of the formation history of the Milky Way and Local Group galaxies.** Participate **Angela's and Laura's talks** (Mikolaitis et al. 2014; DR, et al. 2014; Mikolaitis et al. 2014; Tautvaisiene et al. 2015); **abundances in RR Lyrae stars** [Pancino, Britavskiy, DR, et al. 2015]; **models of MW disks** [Micali, Matteucci & DR 2013] and **halo formation** [Brusadin, Matteucci & DR 2013].

★ **Main interest: modelling. Fundamental ingredients for models: stellar yields. How good are they? Role of binary systems.** (Romano et al. 2010; Lagarde, et al. 2012; Matteucci, DR, & Ariniello 2012)

Donatella's talk

★ **Cosmological context for assembly histories of galaxies** (Romano & Starkenburg 2013; Romano et al. 2015).



**Star formations histories from the CMDs  
of resolved stellar populations  
(Annibali, Tosi & collaborators):**

**the deeper, the tighter, the better**

(e.g. Tolstoy, Hill, Tosi 2009, ARAA, and many others)



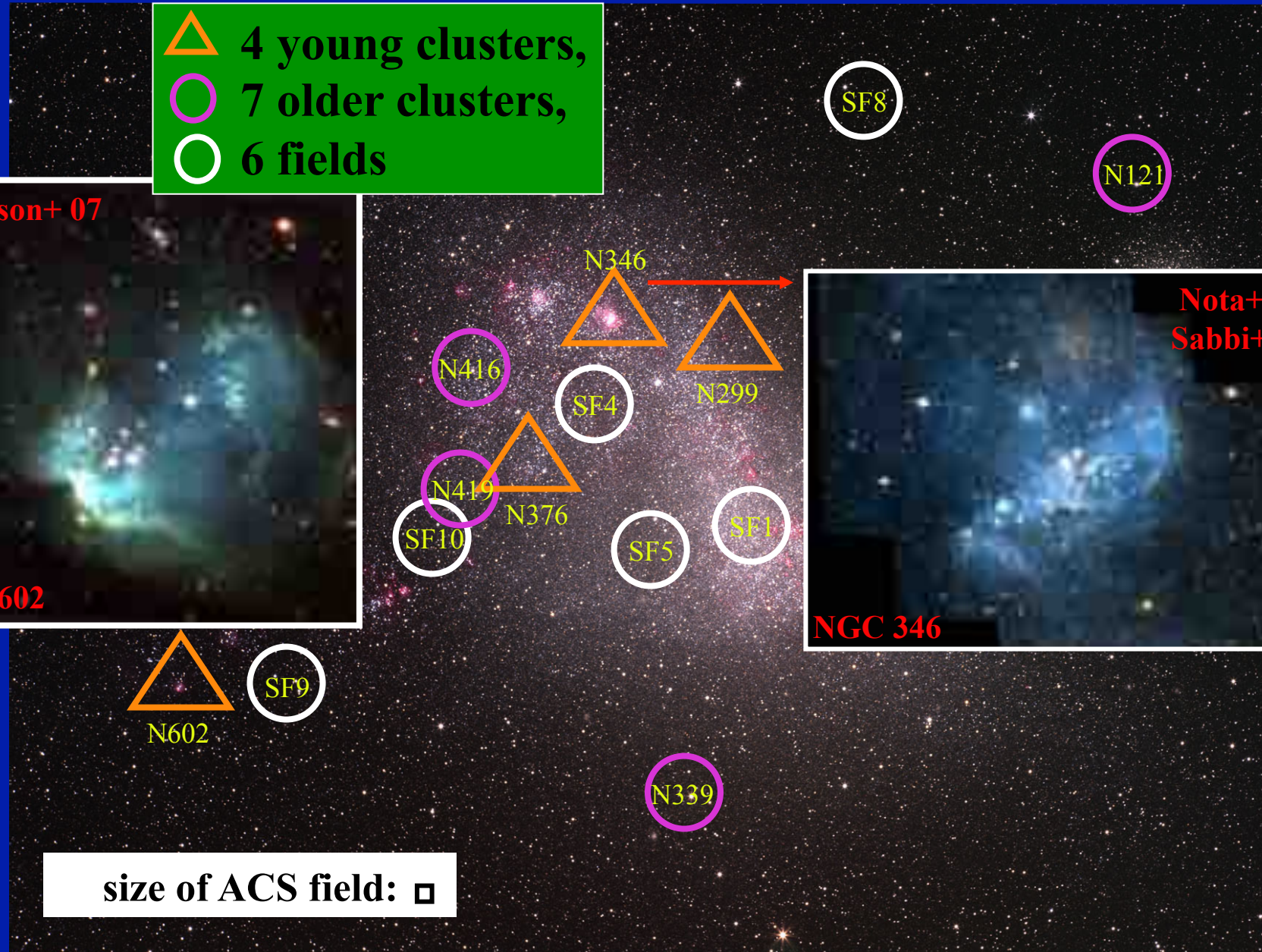
**The SMC is the closest dIrr**



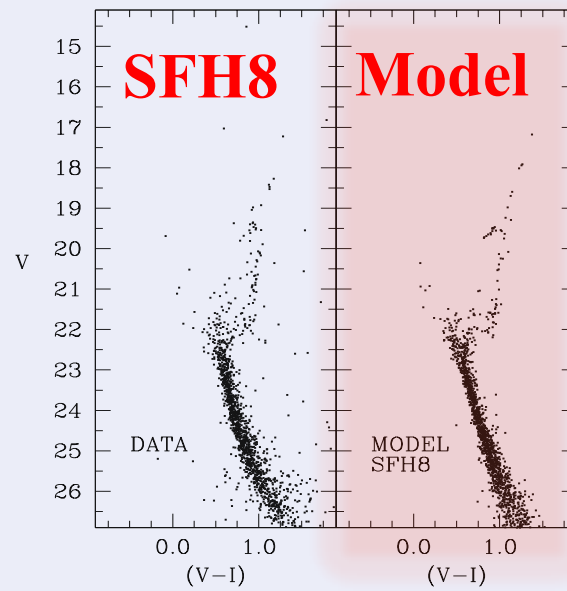
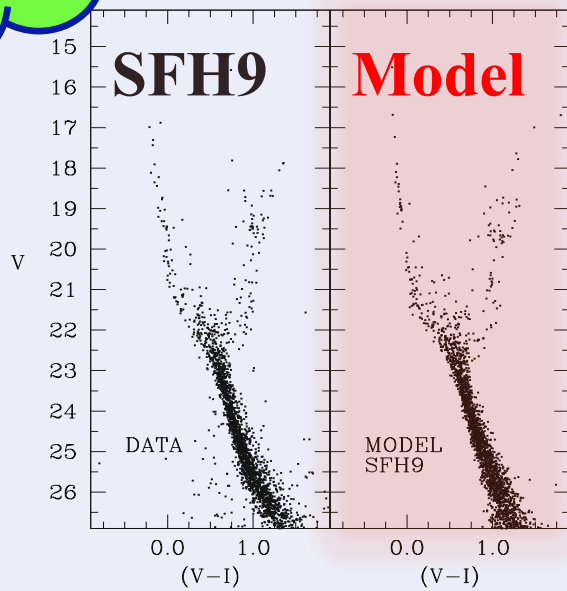
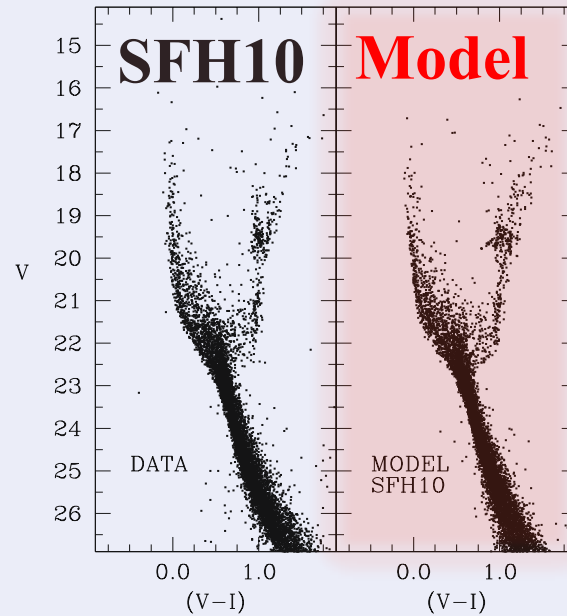
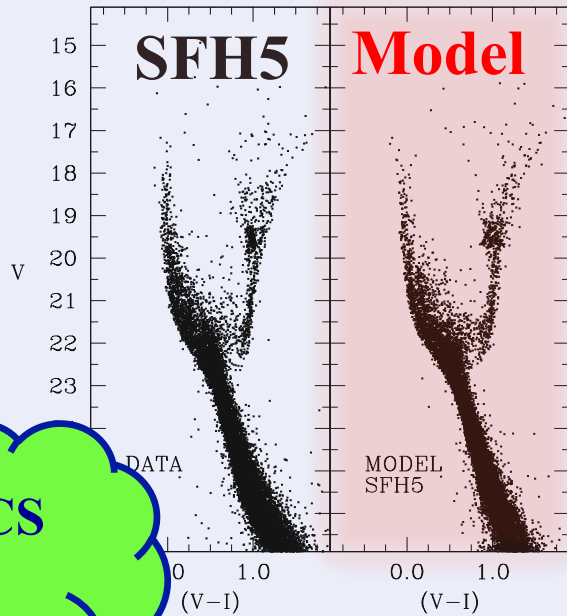
**the best target for SFHs of late-type dwarfs**

# The SMC is the closest dIrr => best benchmark

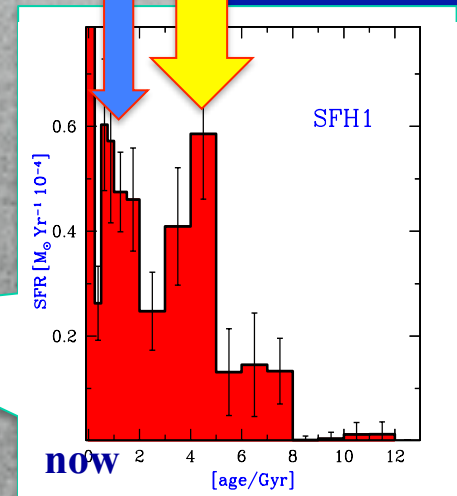
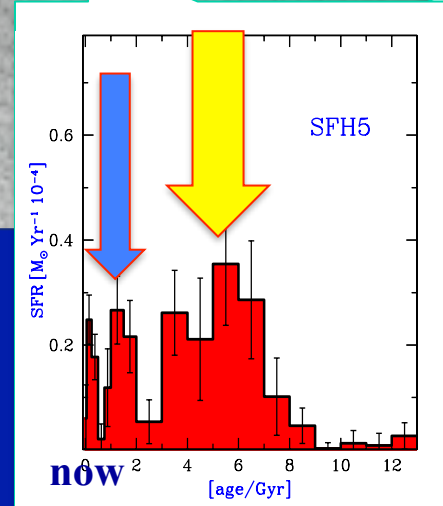
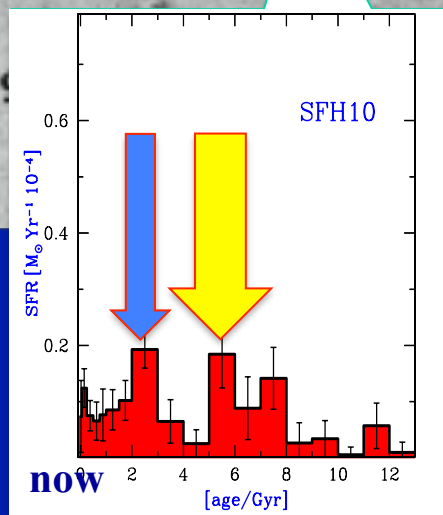
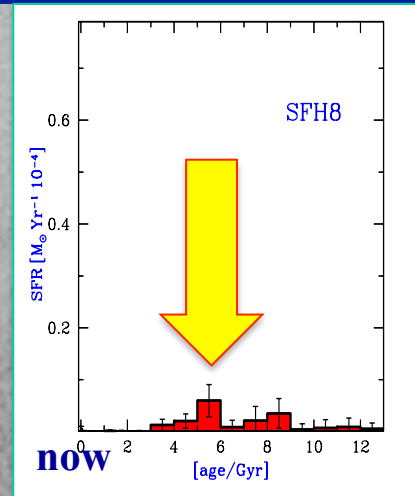
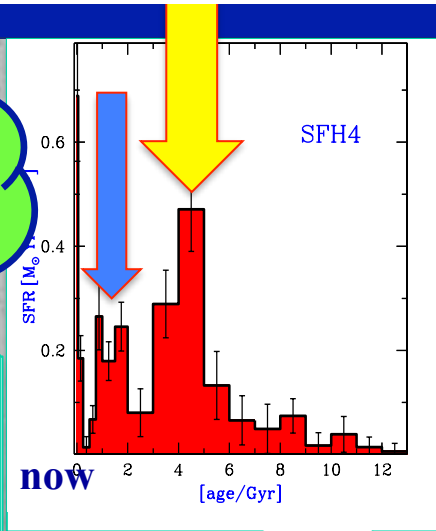
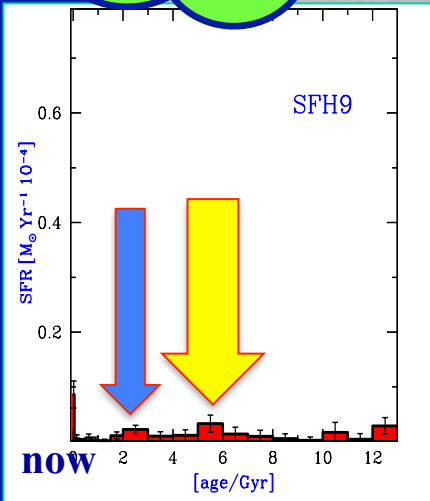
△ 4 young clusters,  
○ 7 older clusters,  
○ 6 fields



6 HST/ACS  
fields in  
SMC

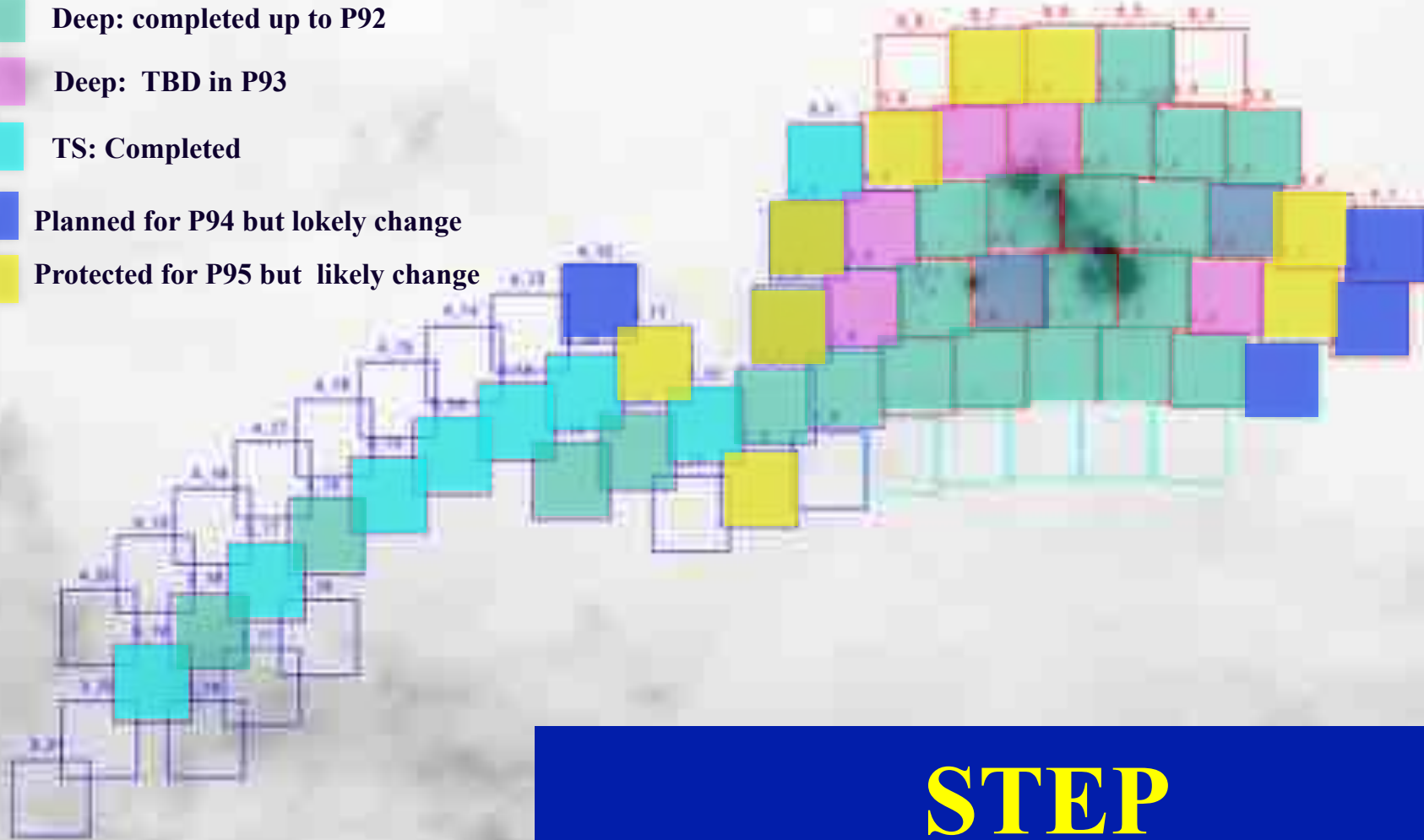


6 HST/ACS fields in SMC



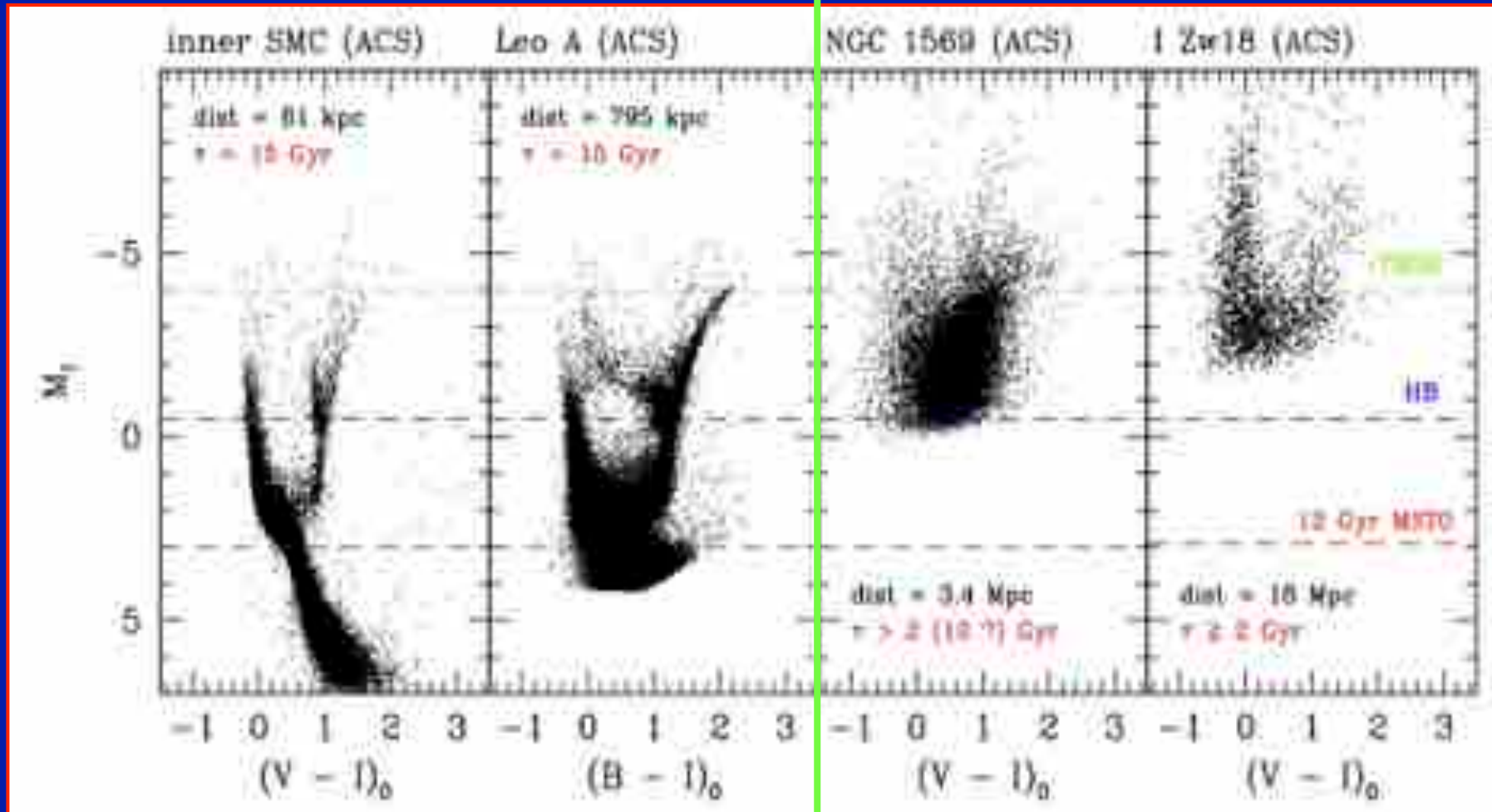
# Completion Status

- Deep: To be completed in P93 or following
- Deep: completed up to P92
- Deep: TBD in P93
- TS: Completed
- Planned for P94 but lokely change
- Protected for P95 but likely change



**STEP**  
**VST survey of SMC and Bridge**  
(Ripepi+ 2014, Cignoni+ in prep)

**Effect of distance on star resolution**  
→ **on reachable lookback times / stellar ages**



Local Group ← → Local Universe

## the Local Group and beyond

LG galaxies are not representative of all existing types: ellipticals and BCDs (i.e. the most and the least evolved ones) are not present here



**SFHs must be studied also outside the LG**



ACS :  
VI H<sub>α</sub>

**DDO 68**

12 Mpc ?

Very metal poor,  
streams ?

Aloisi+ in preparation



WFPC2 + NICMOS +  
ACS + WFC3 : UBVIJH

**NGC 1705**

5 Mpc

Strong starburst BCD,  
evidence of galactic  
winds

Annibali+ 03, 09



WFPC2 + ACS :  
BVI

**IZw18**

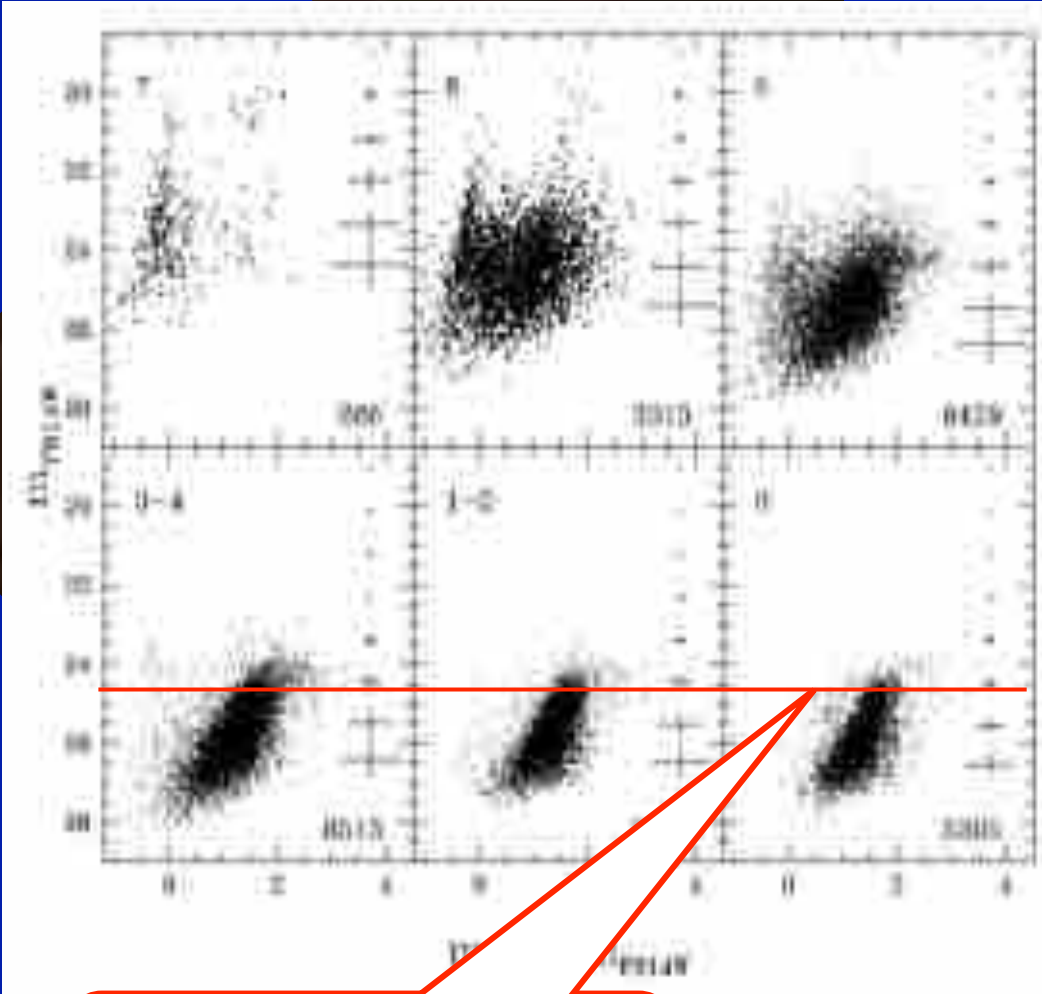
18 Mpc

Most metal poor BCD,  
winds ? satellite or gas  
accretion ?

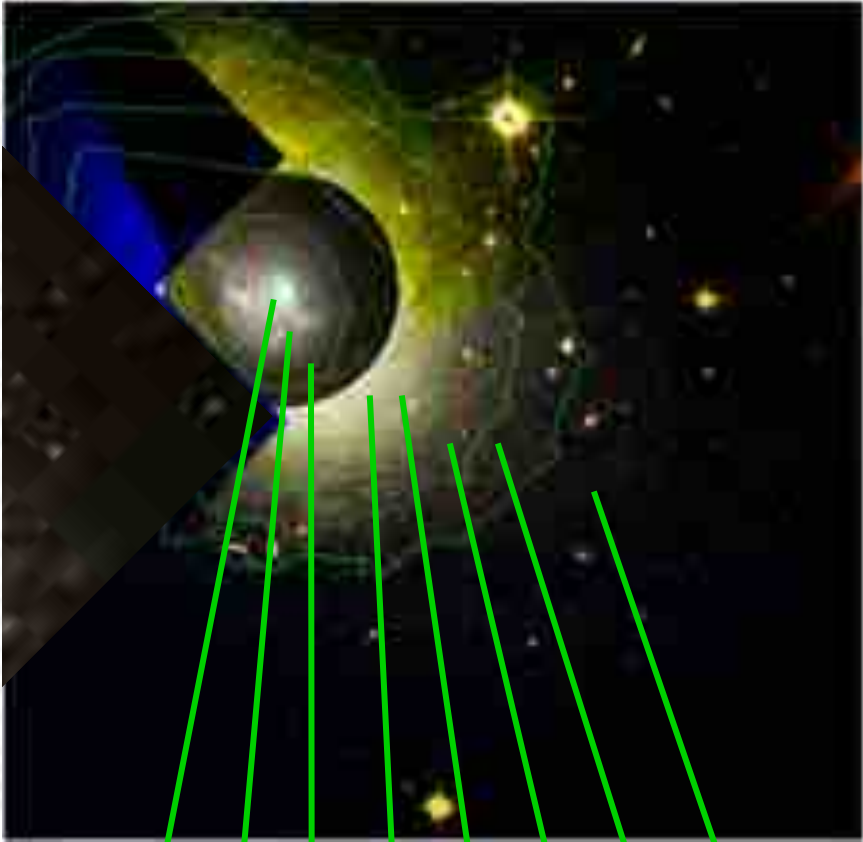
Annibali+ 13

# Different regions in BCD NGC 1705: “old” results

Tosi+ 01



**T-RGB very well defined**  
**=>  $(m-M)_0 = 28.54 \pm 0.26$**   
**=>  $D = 5.1 \pm 0.6$  Mpc**



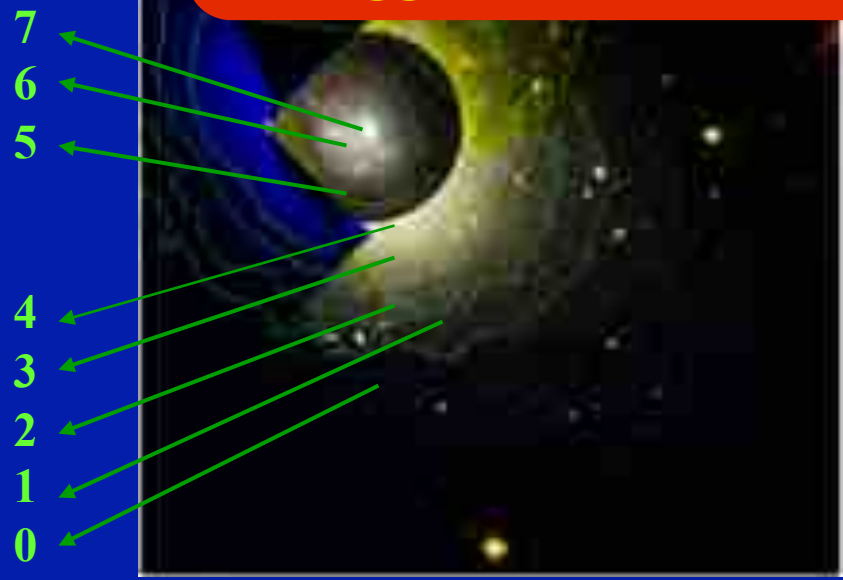
7 6 5 4 3 2 1 0

# NGC1705: a post-starburst BCD already back to SF activity; gasps and not bursts

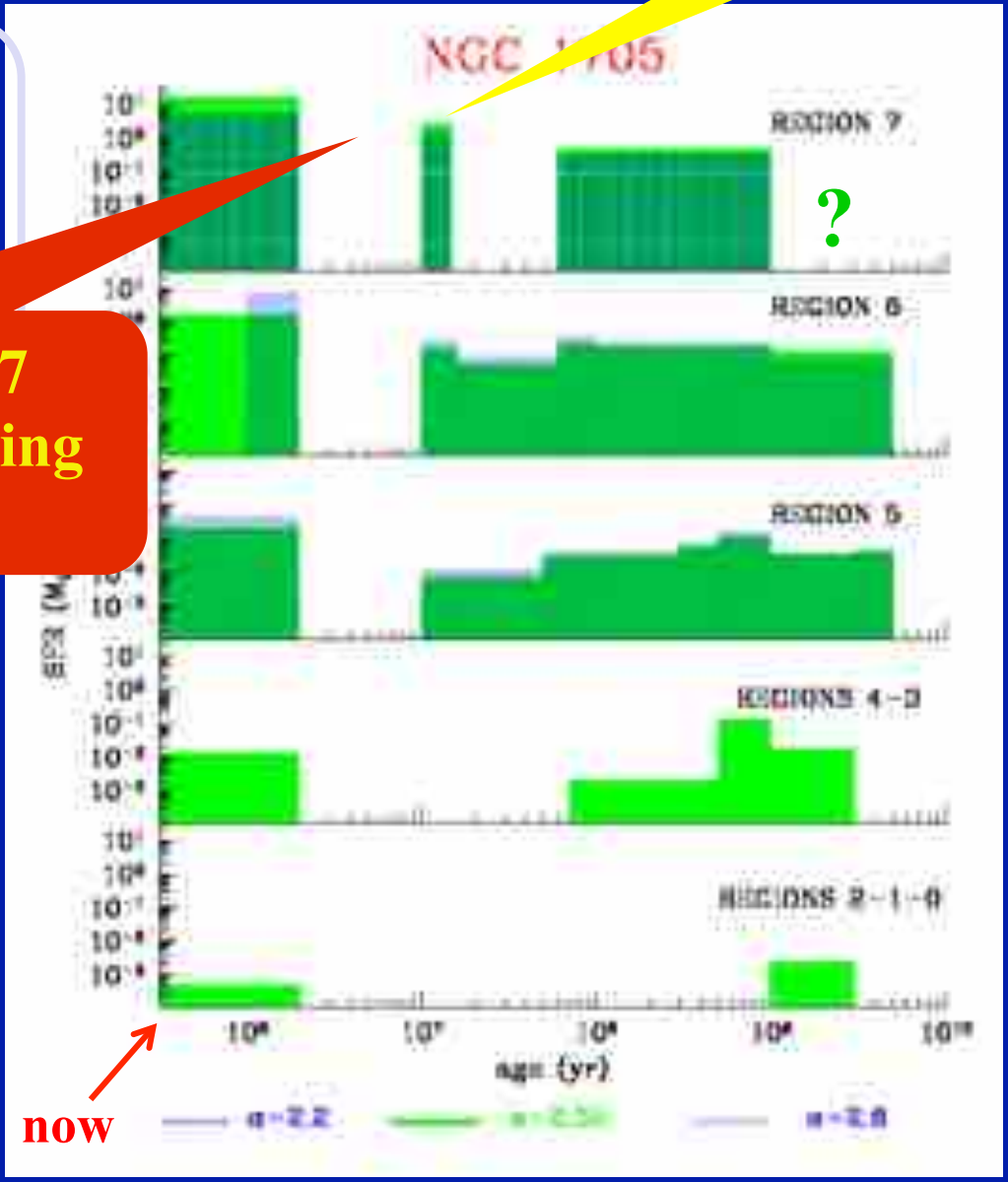
wind source

- 1) Some SF 5 - 1 Gyr ago
- 2) Some SF 1 - 0.02 Gyr ago
- 3) Strong central SF 17 - 10 Myr ago
- 4) No SF anywhere 10 - 3 Myr ago
- 5) Strong SF everywhere 3-0 Myr ago

quiescent phase only 6-7 Myr long => rapid cooling or triggered SF ?

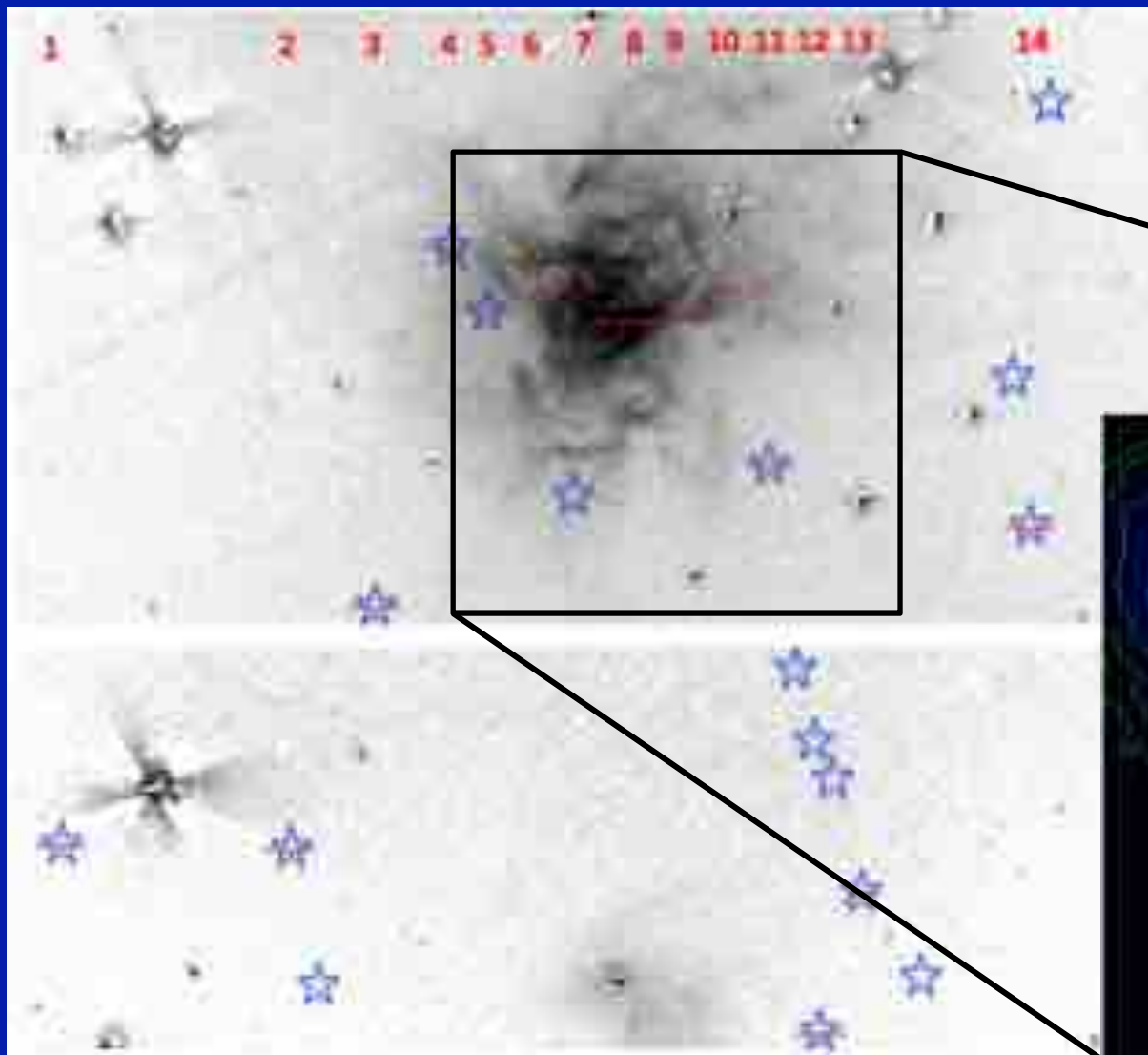


Annibali+ 03 and 09



# VLT FORS2 to study PNe and H II regions in NGC1705 (work in progress)

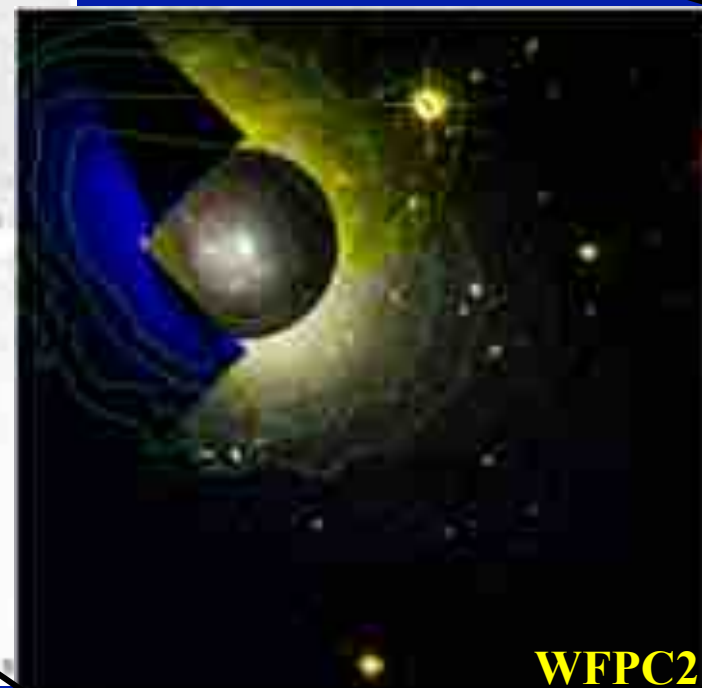
Continuum-subtracted [OIII] image of NGC 1705 (FOV ~ 6.5' x 5.8')



PN candidates (17)



MXU slits  
(9 PN cand + H II reg  
+ gas filaments)



# Chemical abundances in NGC 1705 from VLT/FORS2 data

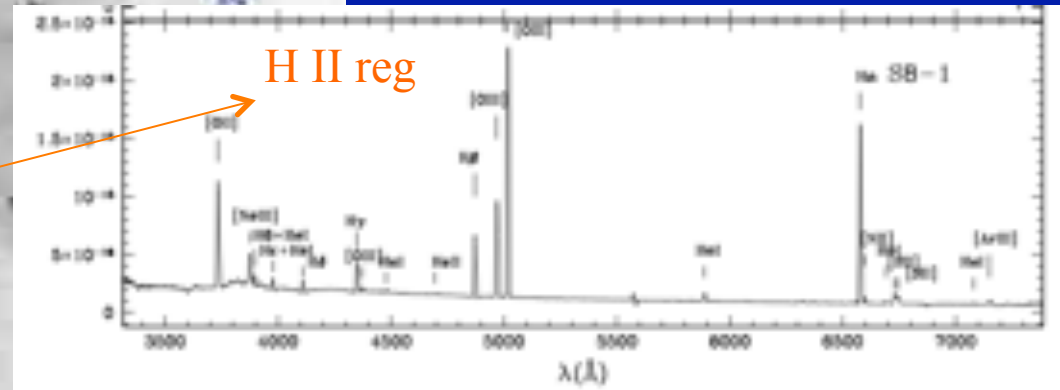
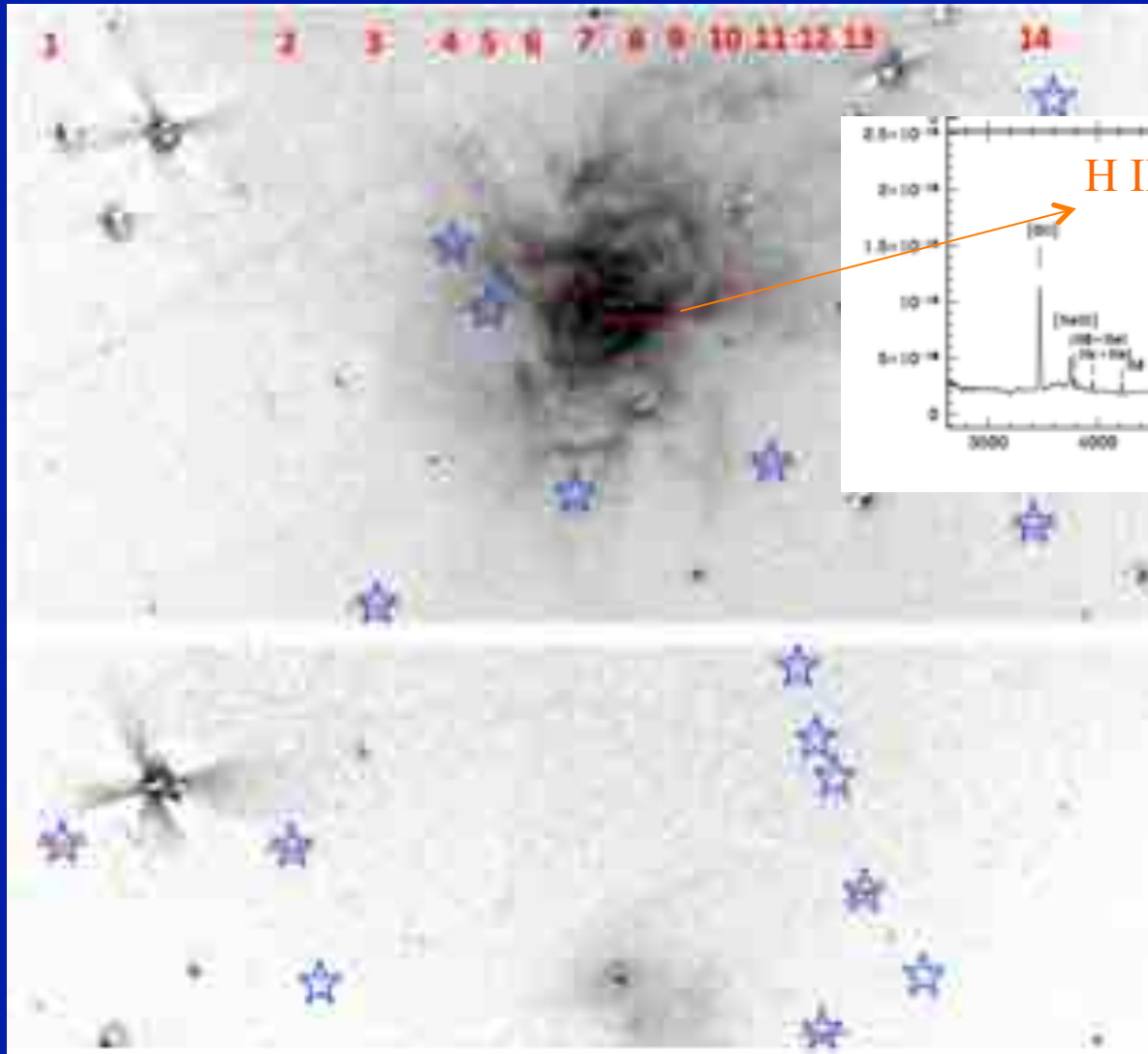
(Annibali +, in preparation)



PN candidates (17)



MXU slits (PNe & H II)



## RESULTS:

- Very low densities ( $n_e \sim 10 \text{ cm}^{-3}$ ) in most regions
- Abundances derived for N, O, Ne, S, Ar:

$$\langle 12 + \log(\text{N}/\text{H}) \rangle = 6.71$$

$$\langle 12 + \log(\text{O}/\text{H}) \rangle = 8.00$$

$$\langle 12 + \log(\text{Ne}/\text{H}) \rangle = 7.47$$

$$\langle 12 + \log(\text{S}/\text{H}) \rangle = 6.42$$

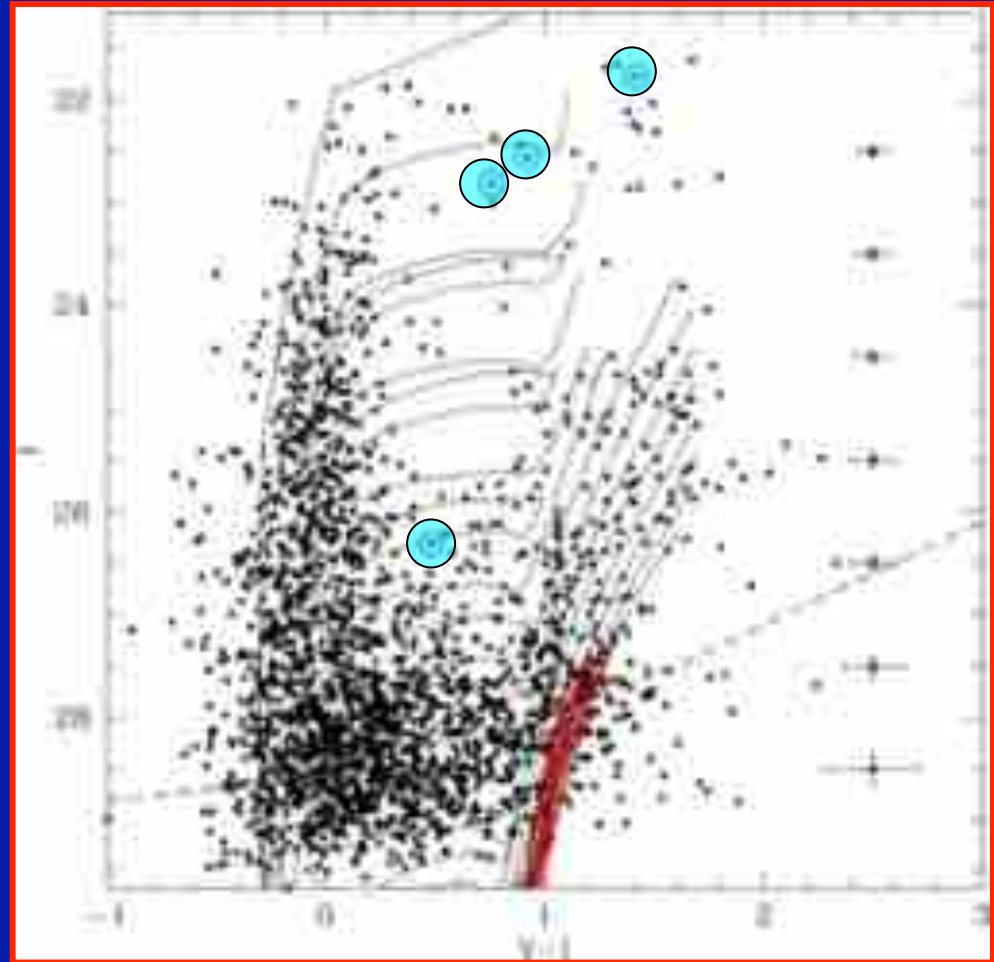
$$\langle 12 + \log(\text{Ar}/\text{H}) \rangle = 5.80$$

Oxygen lower than literature values

Continuum-subtracted [OIII] image

# CMD and Cepheids of IZw18, the most metal poor SF galaxy, at 18 Mpc

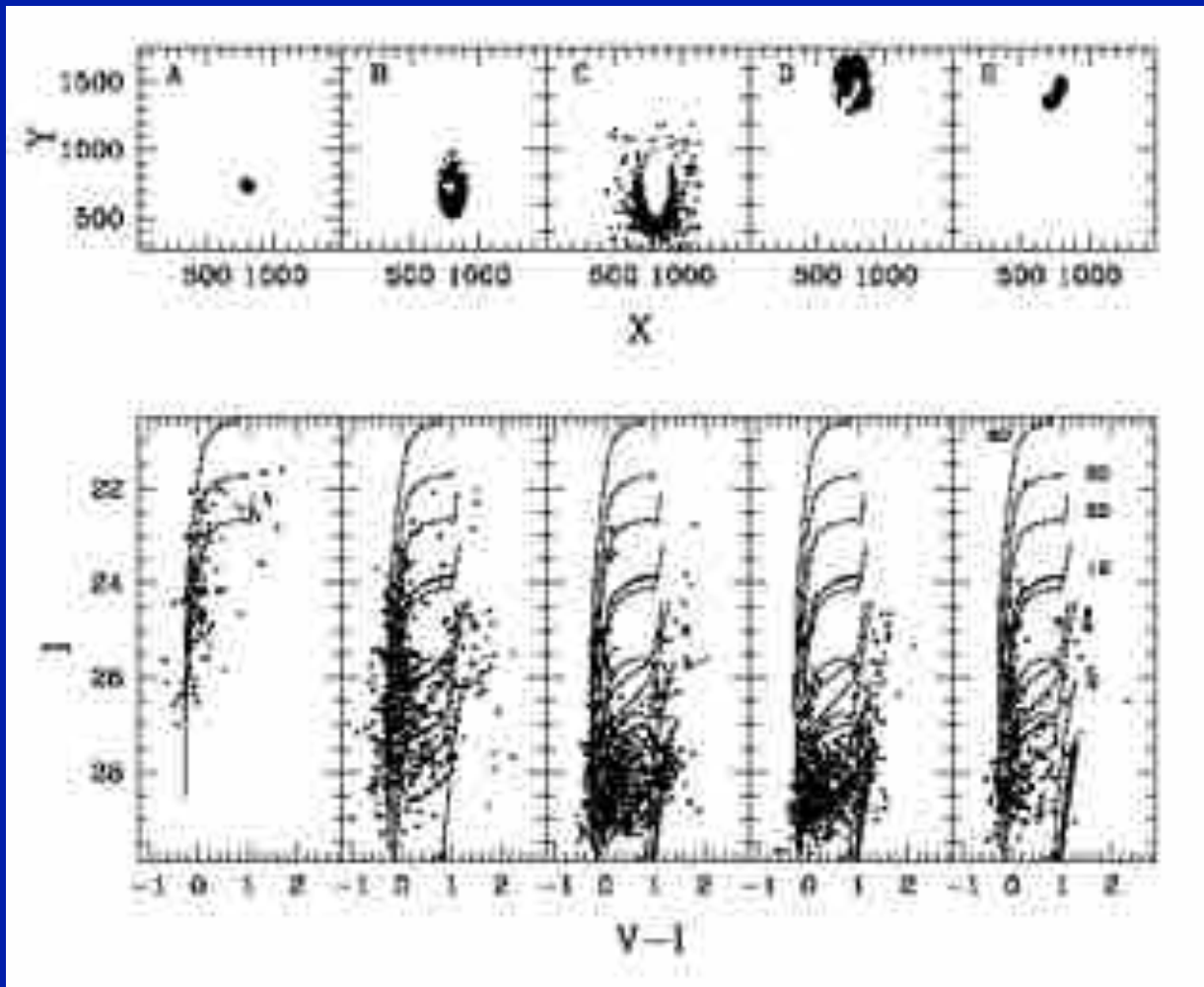
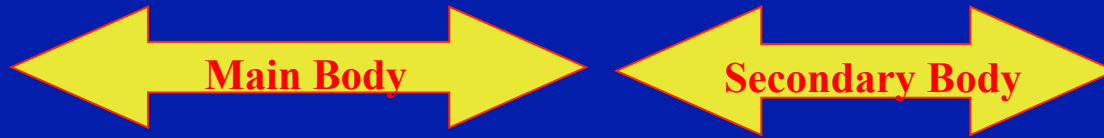
**RGB identified  
=> stars older than 1-2 Gyr  
(possibly much older)  
present**



**Distance from RGB Tip:  $(m-M)_0 = 31.3 \pm 0.2 \Rightarrow 18.3 \pm 1.5$  Mpc  
Distance from Cepheids:  $(m-M)_0 = 31.4 \pm 0.3 \Rightarrow$  perfect agreement**

Aloisi+ (2007), Fiorentino+ (2010), Contreras+ (2011), Annibali+ (2013)

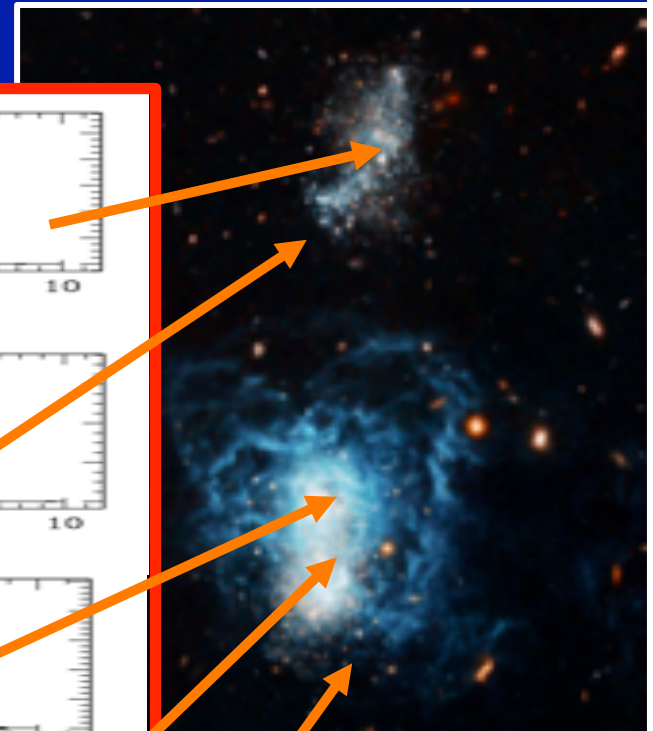
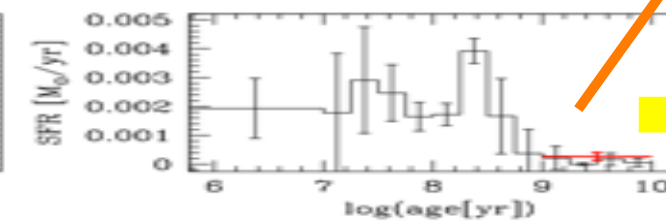
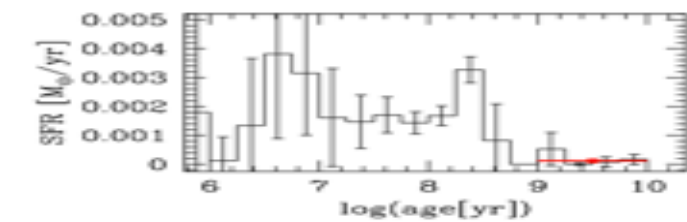
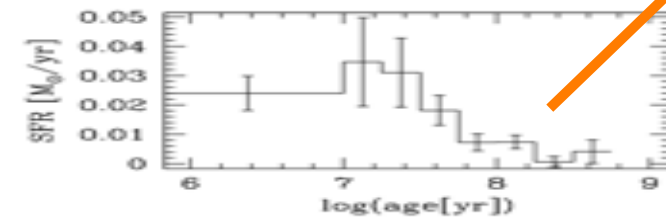
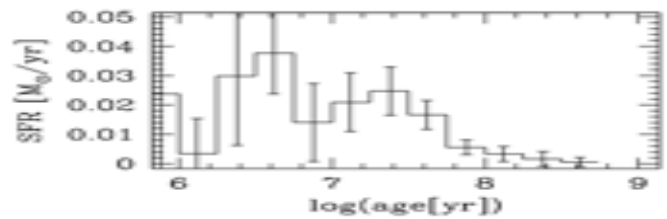
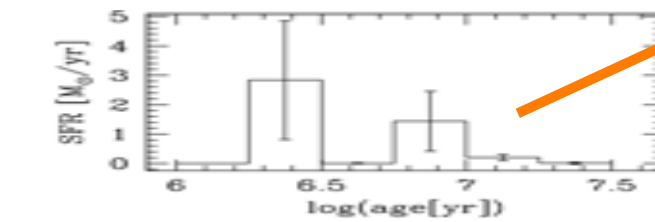
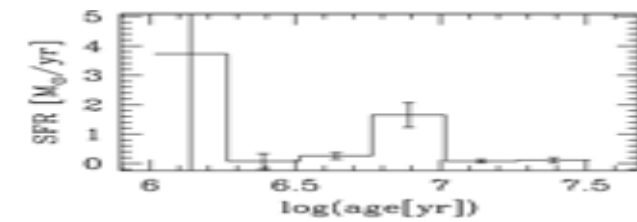
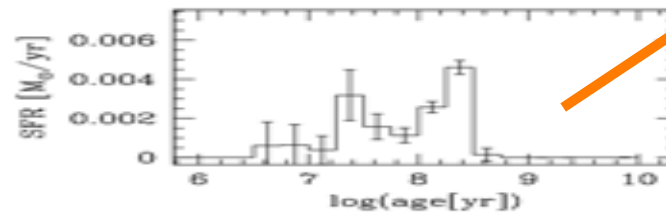
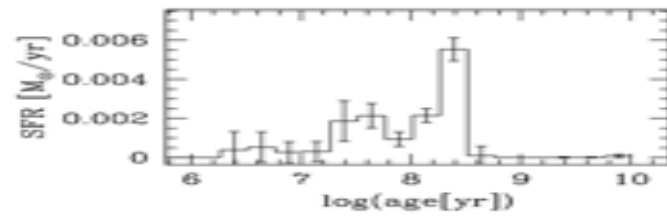
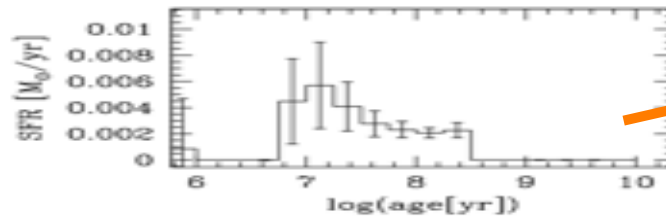
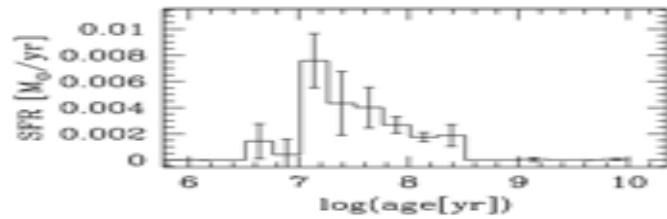
# SFH of IZw18



# SFH of IZw18

Baltimore code

Bologna code



Annibali et al. 2013

**Mass(>1 Gyr)=  
 $1.1 \pm 0.4 \times 10^6 M_{\odot}$**

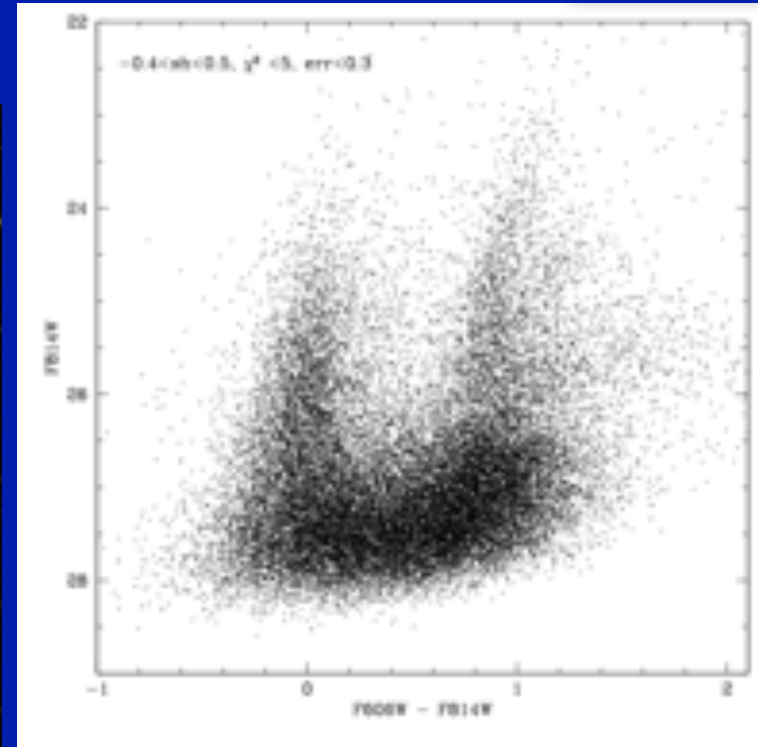
# The SFH of the BCD DDO 68 from HST/ACS data

(Aloisi, Annibali, Cignoni, Grocholski, James, Mack, Sacchi, Sirianni, Sohn, Tosi, van der Marel)

**DDO 68** holds the same record-low metallicity as I Zw 18, but it is located much closer (12 Mpc vs 18 Mpc)



V, I, H $\alpha$  ACS/WFC image



I, V-I CMD

*Aloisi et al. in prep.*  
*Sacchi et al. in prep.*

## General results on SFH from CMDs

No evidence of long interruptions in SF activity,  
except in early-types

Gasping rather than bursting SF regime in late-type galaxies  
(both in Local Group and beyond)

No galaxy currently at first SF episode  
(all examined ones already active at reached lookback time;  
ages old in all dwarfs)

No significant difference between SFHs of BCDs and dIrrs,  
except for current SFR

**Thank you**