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 22nd 2015

ISTITUTO NAZIONALE DI ASTROFISICA INAF

INAF Unit

Distributed over 5 INAF institutes

staff

- **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**

postdocs

- **F. Annibali**
- **A. Sollima**
- **P. Re Fiorentin**

People labelled with ★ are speakers at this conference

To understand

galaxy evolution

theoretical models

- galaxy formation
- stellar evolution
- chemical evolution
- dynamical evolution
- …

observational constraints

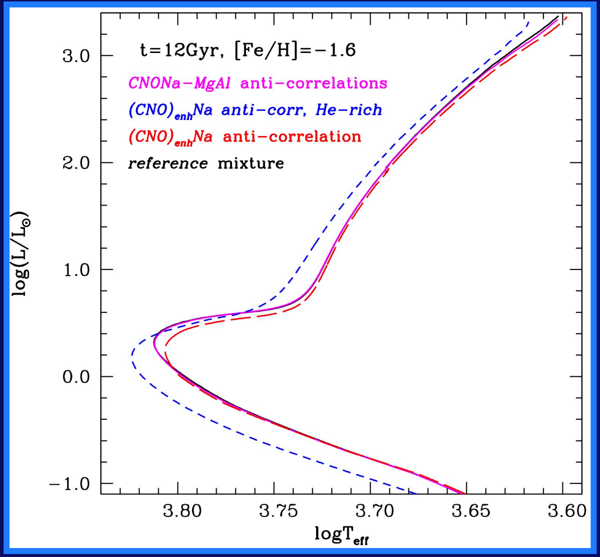
- chemical abundances
- gas/star/dark masses
- kinematics
- star formation history
- IMF
- …

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

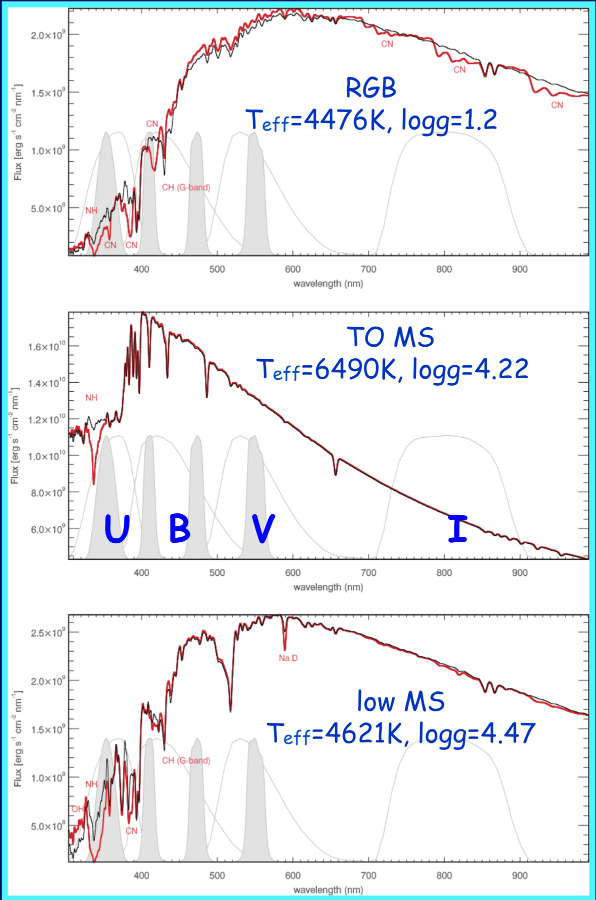


In the H-R diagram, at fixed [Fe/H], a clear separation (split) of an evolutionary sequence can be obtained:

- 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



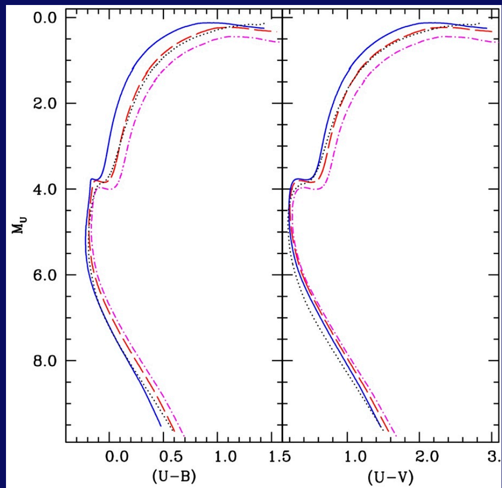
- black: reference α-enhanced mixture
- red: $(CNO)_{ext}$Na anti-correlation

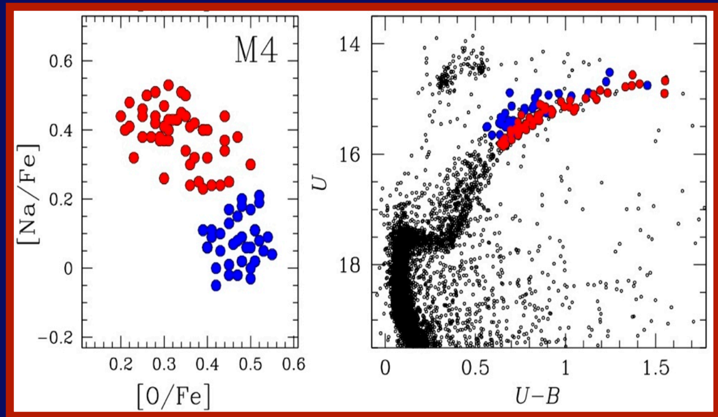
light-element changes affect mainly the portion of the spectra short of about 400 nm owing to the changes in molecular bands (...,NH, CN, and OH in the fainter MS stars...)

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

isochrones for multiple population: a self-consistent approach

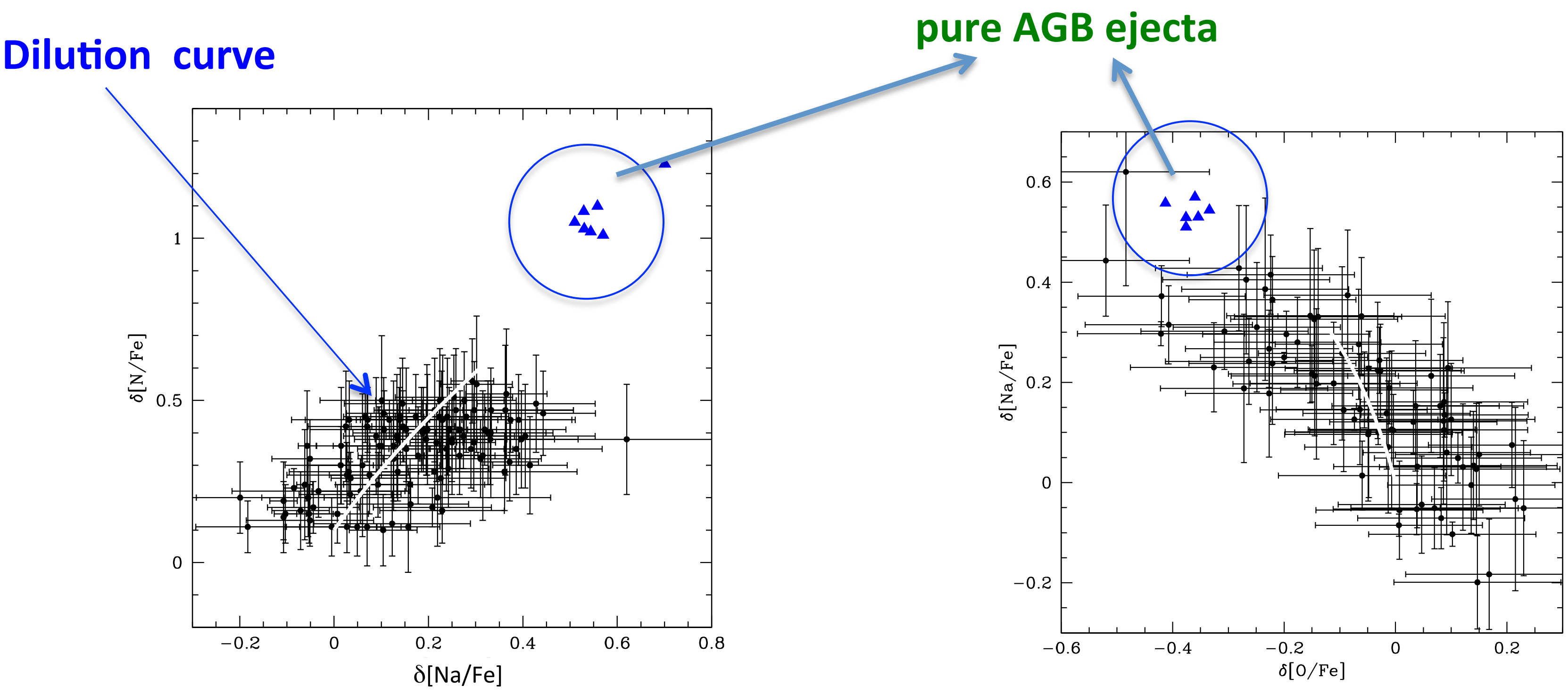
- blue solid: reference mixture
- red dash: CNONa
- magenta dash: $(CNO)_{enh}$Na - normal He
- blue dot: $(CNO)_{enh}$Na - Y=0.40





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

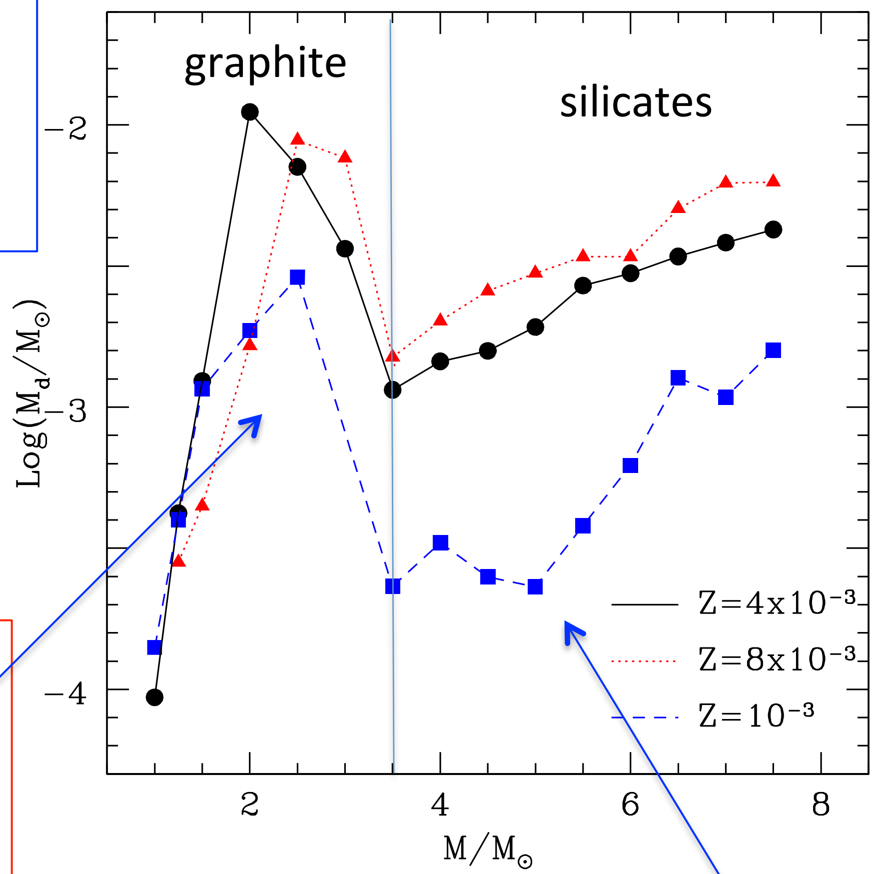
We reconstructed the formation hystory of the Globular Cluster 47Tuc in the framework of the self-enrichment scenario by massive AGB stars. To this scope, we calculated new yields from AGB models with the appropriate metallicity ([Fe/H]=-0.75) and compared the chemistry of the ejecta with the spectroscopic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



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



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

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

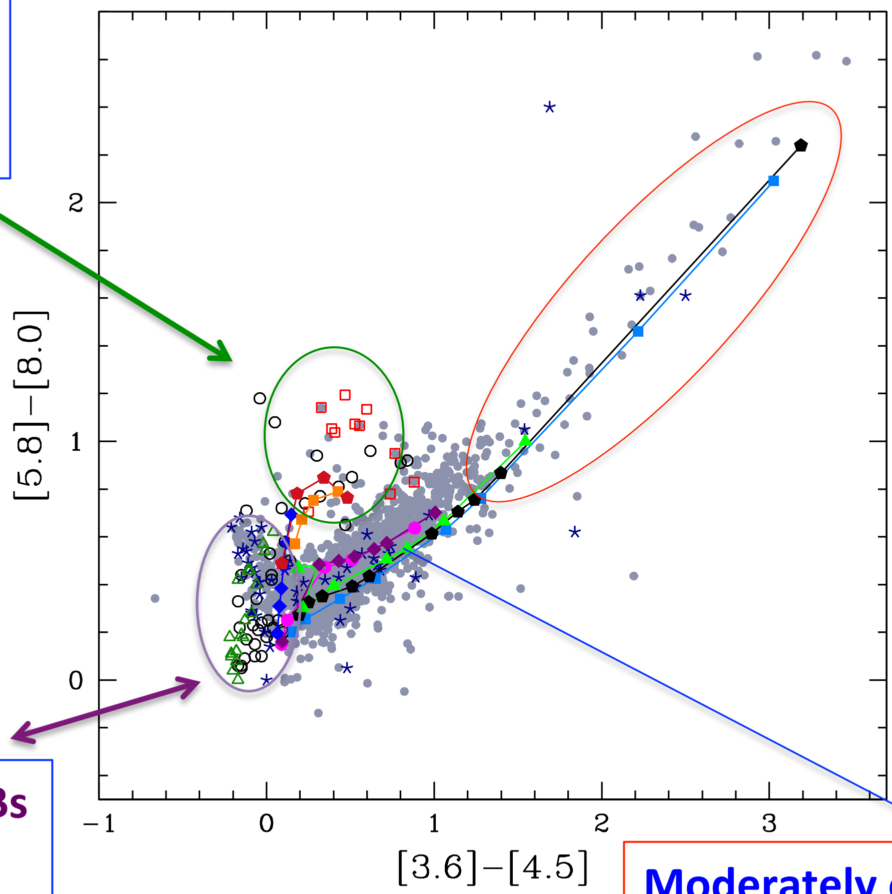
Massive AGBs produce silicate particles. Unlike low mass AGBs, in this case the quantity of dust produced scales with metallicity.

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 ofage, 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

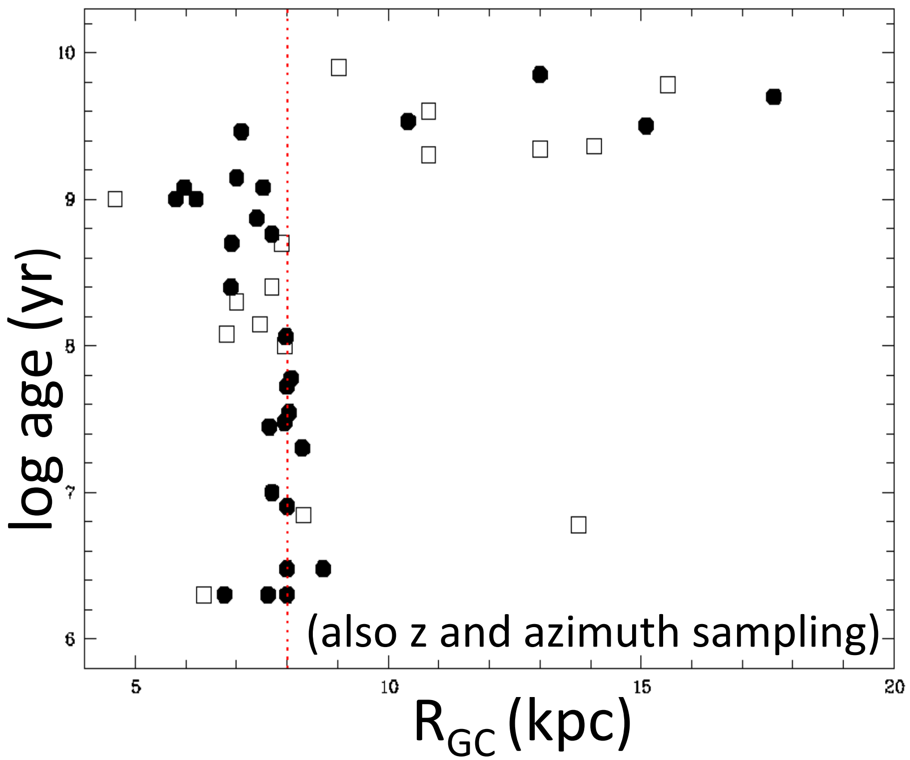
5 papers 2013-14 & more in preparation/to come

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



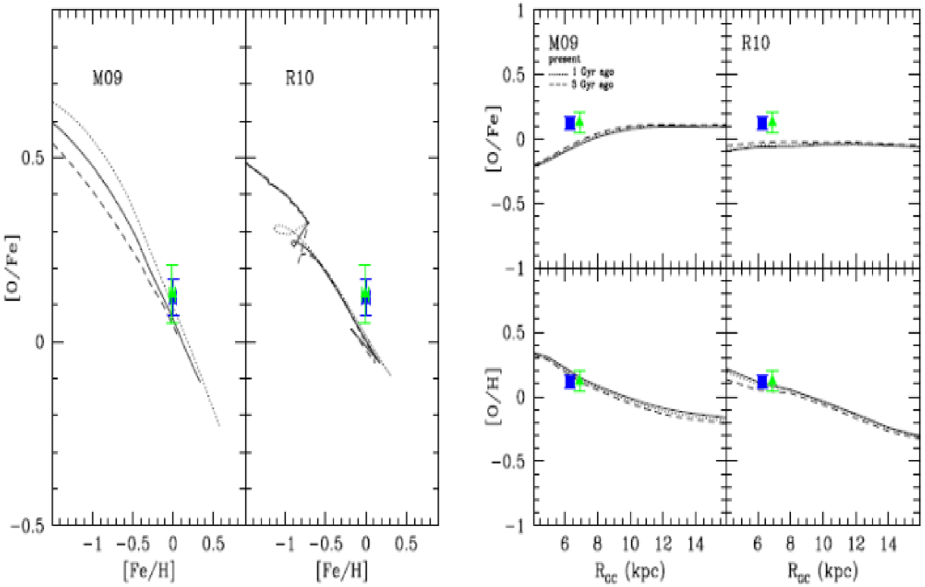
- Observations of 28 clusters completed
- ~25000 stars
- RVs, APs, [Fe/H], individual abundances
- 12 papers on OCs with PRIN participants as co-authors – see Magrini & Bragaglia's talks

● observed

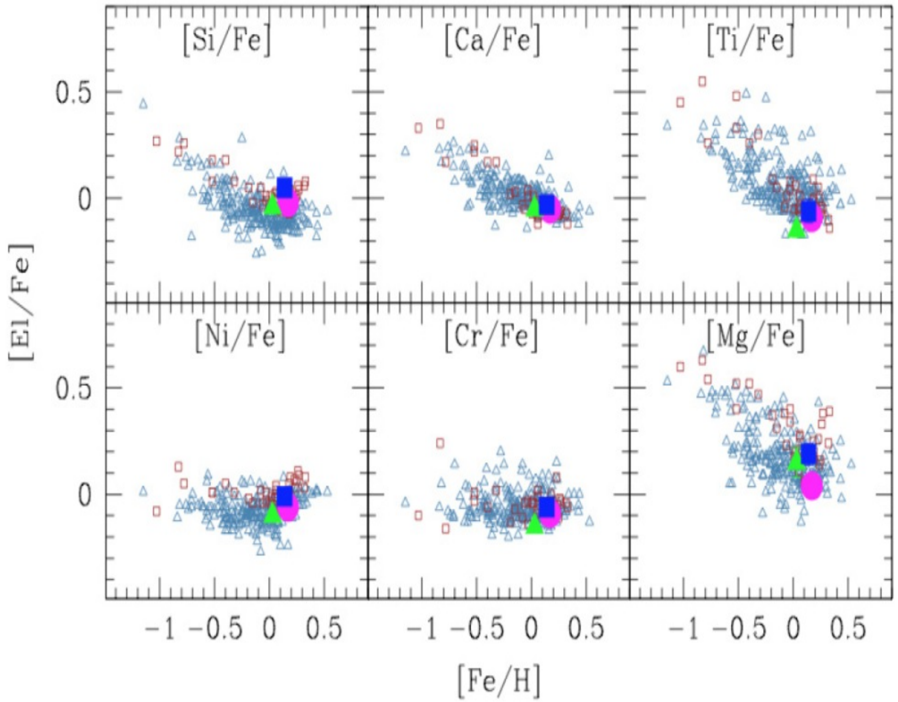
□ to be observed in the next months

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 - Tautvaišiene + (2015)



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

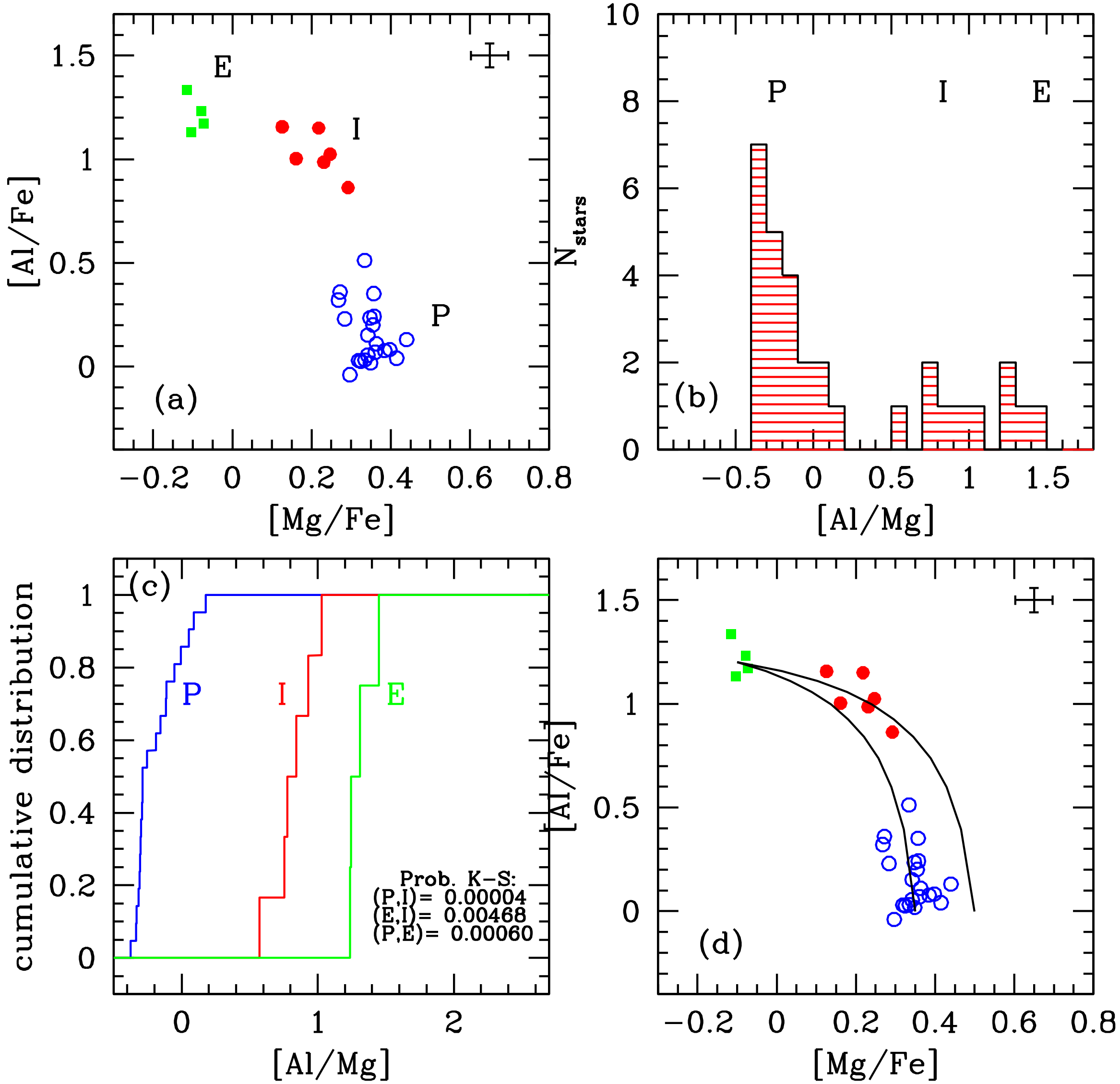


[Fe/H]

The radial metallicity gradient
see Laura Magrini's talk

R_{GC} (kpc)

Three discrete population of giants with distinct chemistry in NGC 2808



Carretta (2014, ApJ, 795,L28)

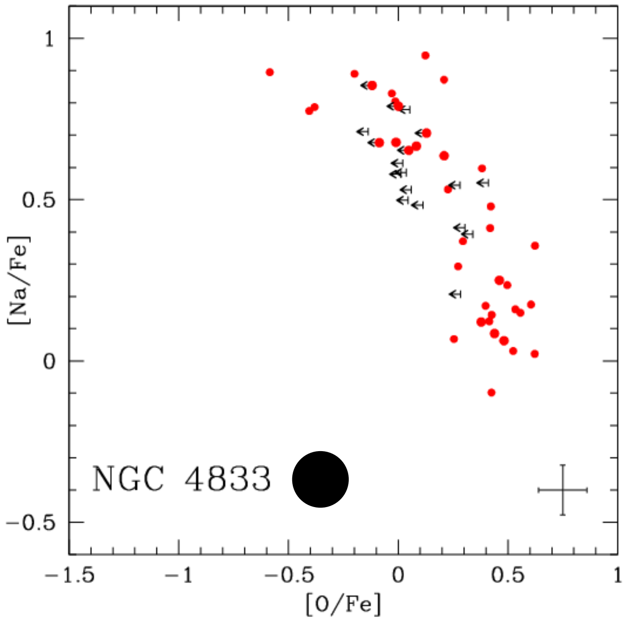
Mg-Al anticorrelation from 31 RGB stars (UVES spectra) in (a).
3 distinct groups (b), with different chemistry (c): primordial P composition, intermediate I and extremely E modified chemistry of 2nd generation.
No simple dilution model (d) is able to reproduce the I group by mixing P and E compositions

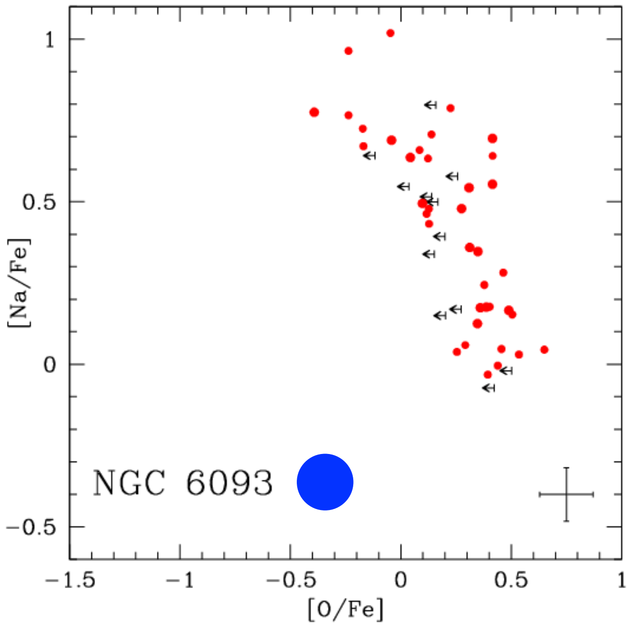
TWO classes of different polluters, as in NGC 6752 (Carretta et al. 2012,ApJ, 750,L14)

Number ratios:

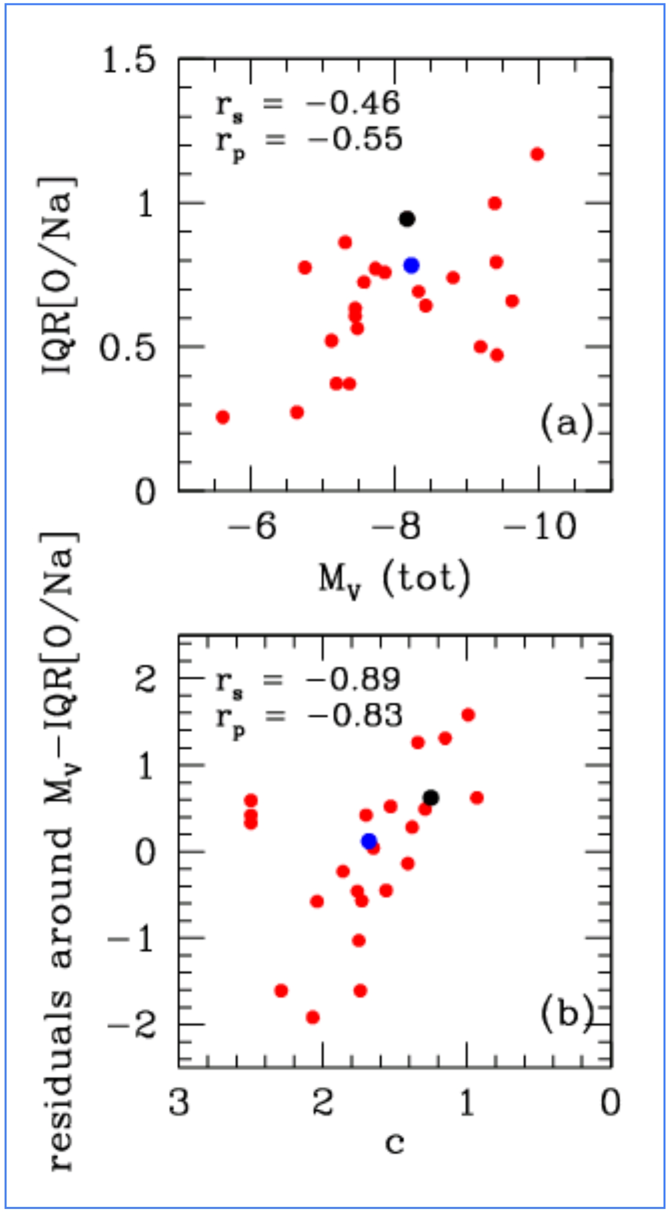
P: 68±15%	**rMS: 62±2%**
I : 19± 8%	**iMS: 24±2%**
E: 13± 4%	**bMS: 14±3%**
this work	Milone+2012

Multiple populations in NGC4833 and NGC6093 (M80)





The amount of chemical modifications in 2nd 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)



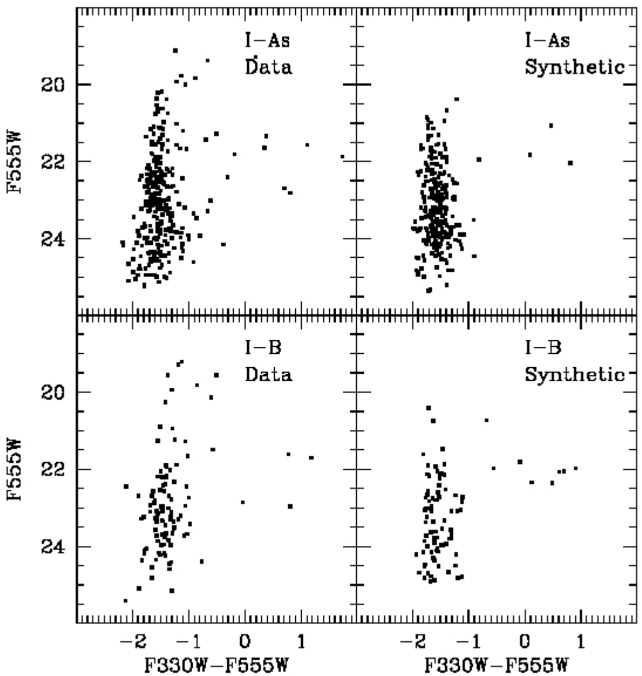
Carretta et al. (2014, A&A, 564,A60) and Carretta et al. (2015, in prep.)

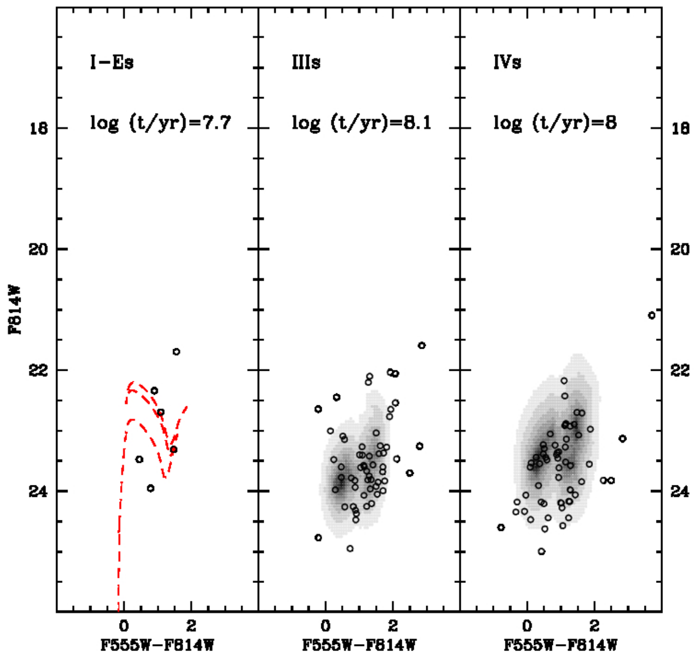
Search of multiple stellar populations in YMCs of nearby galaxies

A. Sollima (OABo)

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

NGC4214 YMCs reveals no ions in resolved clusters



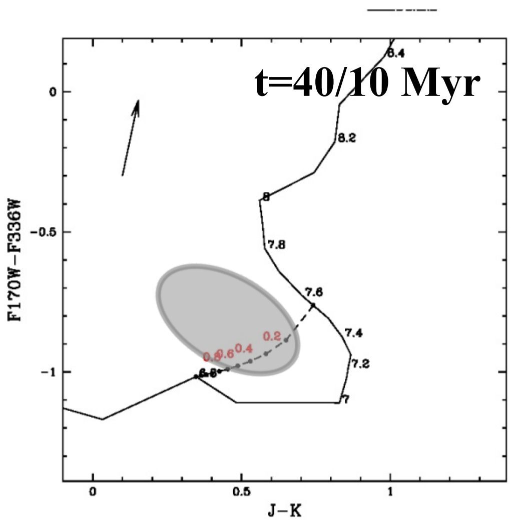


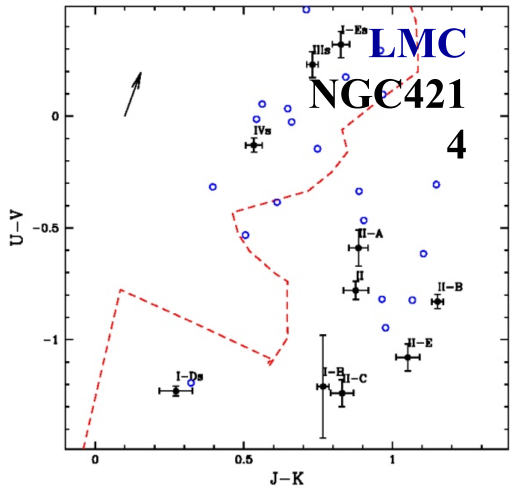
Sollima et al. (2014)

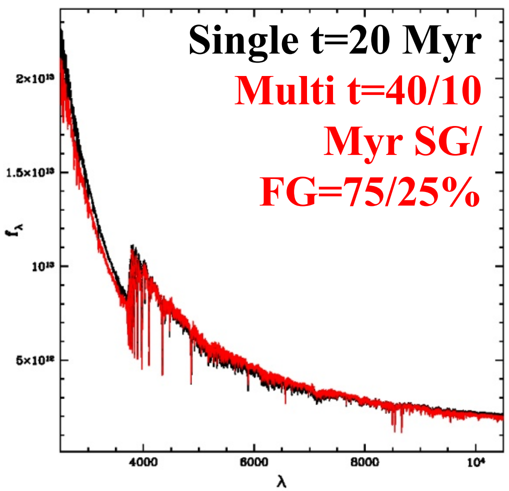
Search of multiple stellar populations in YMCs of nearby galaxies

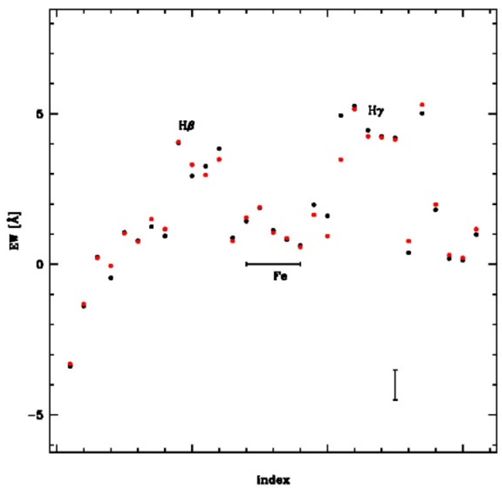
A. Sollima (OABo)

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

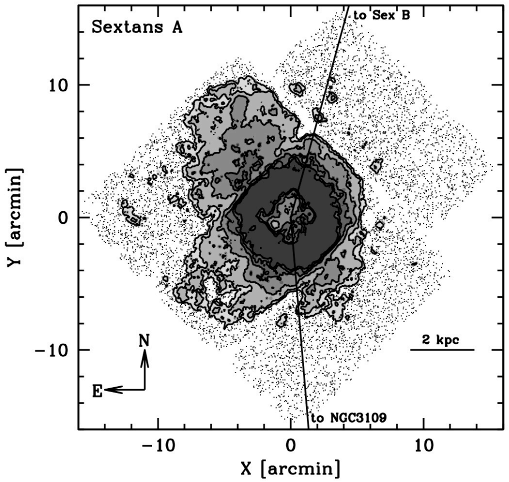
- Photometric detection possible only in a narrow range of FG/SG mass ratio, age difference, metallicity, SG age

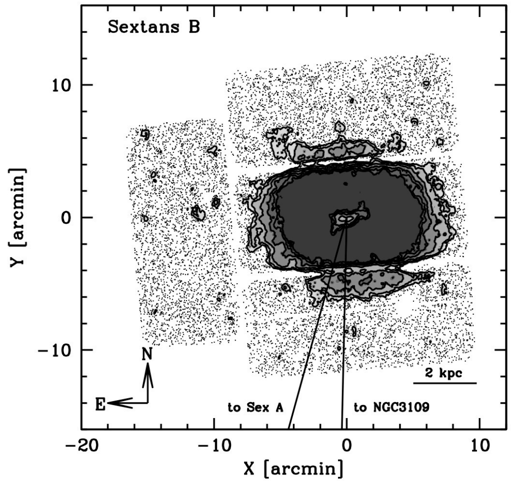
- Strong uncertainties in stellar evolution models and synthetic spectral libraries as well as reddening and photometric zero points

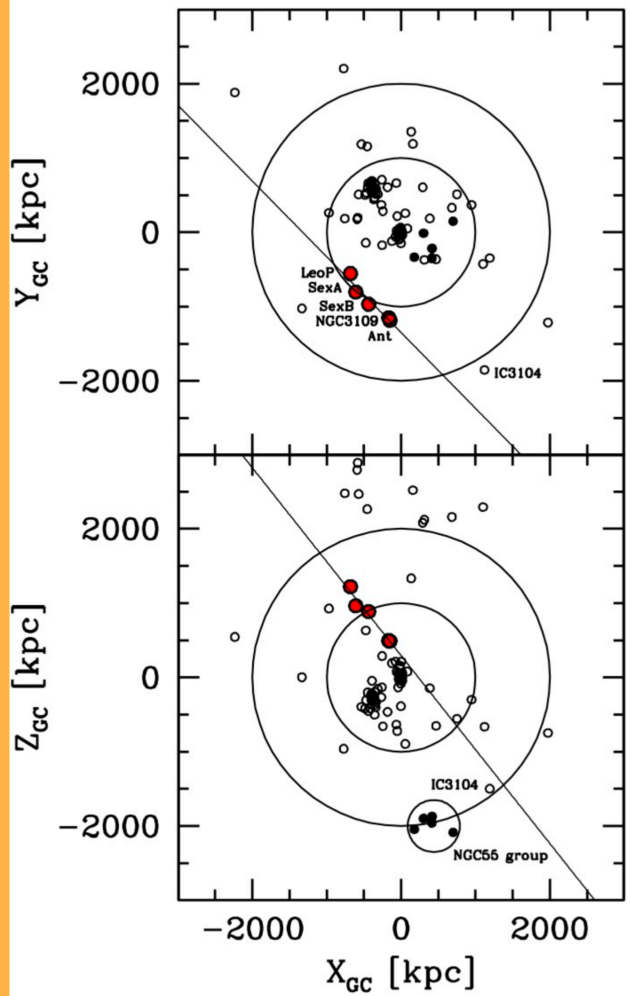
Michele Bellazzini (INAF-OABo)

The extended structure of isolated dwarf galaxies

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







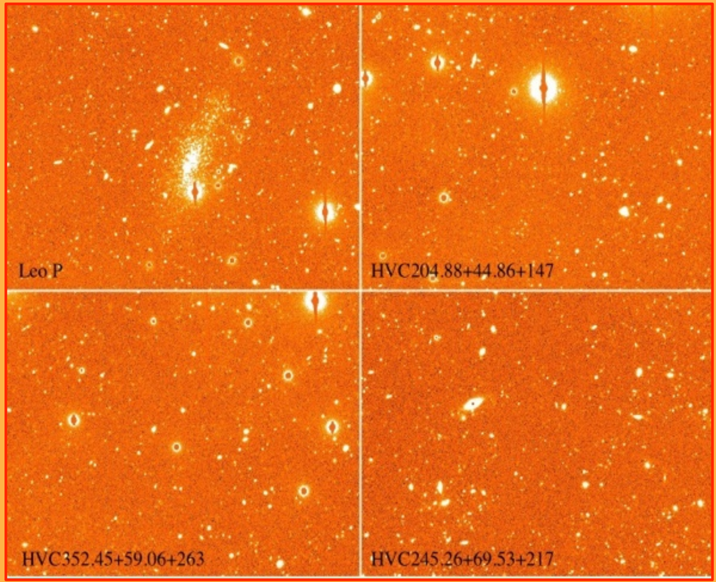
LBC and VIMOS deep (r~26.5) wide-field photometry to unveil the extended LSB stellar body of dwarfs presumably evolved in isolation. Published papers on: VV124, Sex A, Sex B, Sgr dIrr; data analysis ongoing for WLM and Tucana. In all the cases we were able to trace the surface density profile down to ~30 mag/arcsec^2 **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 Vr.

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

PRIN MIUR: "The Chemical and Dynamical Evolution of the Milky Way and Local Group Galaxies",
PI: Francesca Matteucci [prot. 2010LY5N2T].

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.

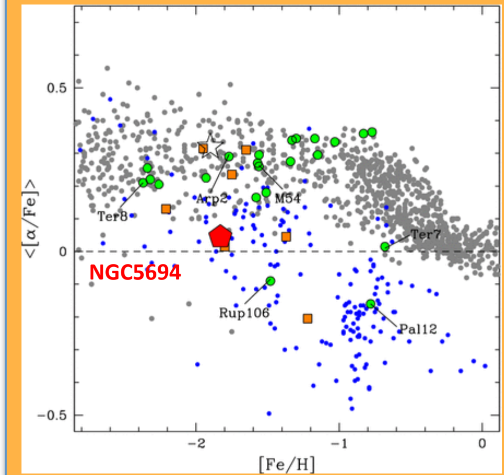
First paper published (Bellazzini et al. 2015, A&A, in press, arXiv:1412.5857); The second is submitted and several more are planned. Spectroscopic follow-ups ongoing.

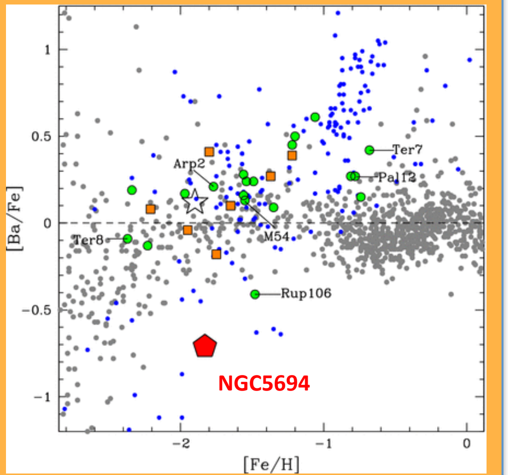
See http://www.bo.astro.it/secco/

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

PRIN MIUR: "The Chemical and Dynamical Evolution of the Milky Way and Local Group Galaxies", PI: Francesca Matteucci [prot. 2010LY5N2T].

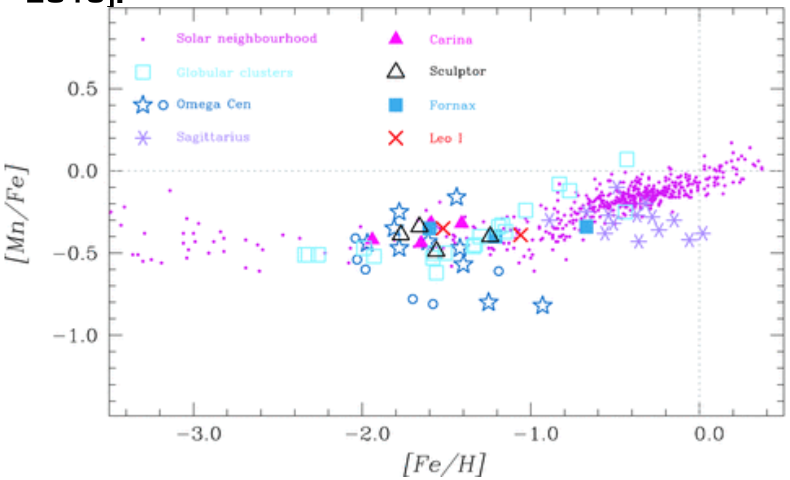
UdR Bologna – Chemical evolution of galaxies

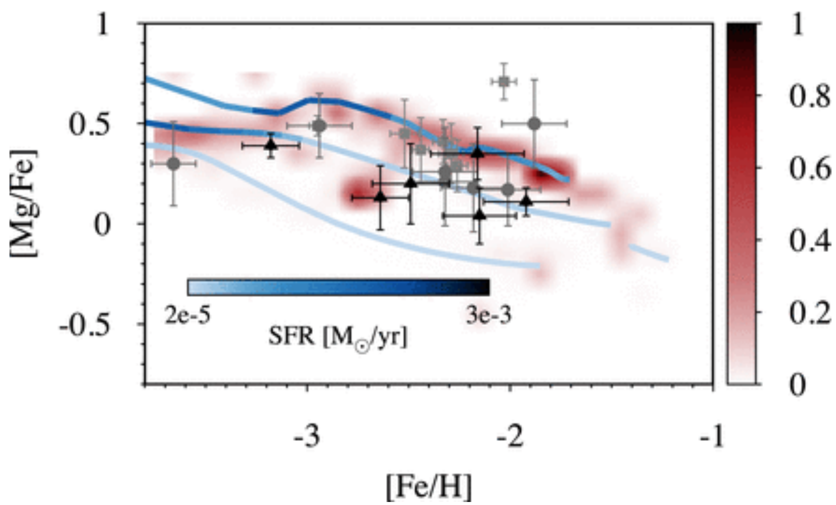
Donatella Romano, MT

★ 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; 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, Arcones, et al. 2014)

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





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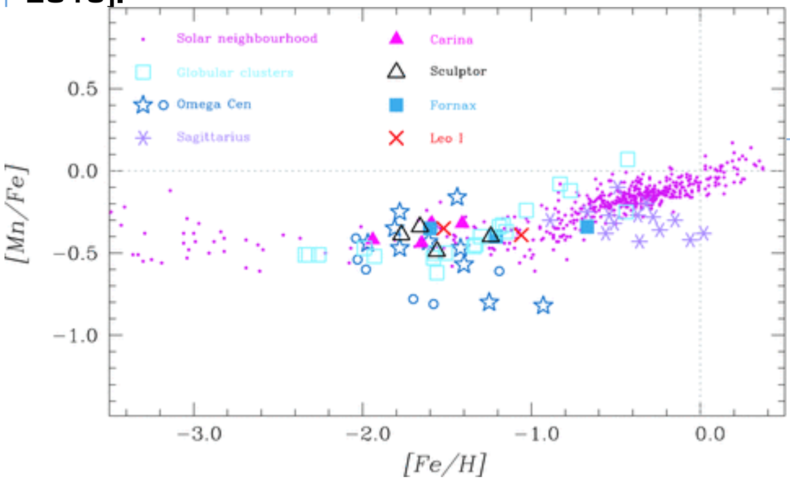
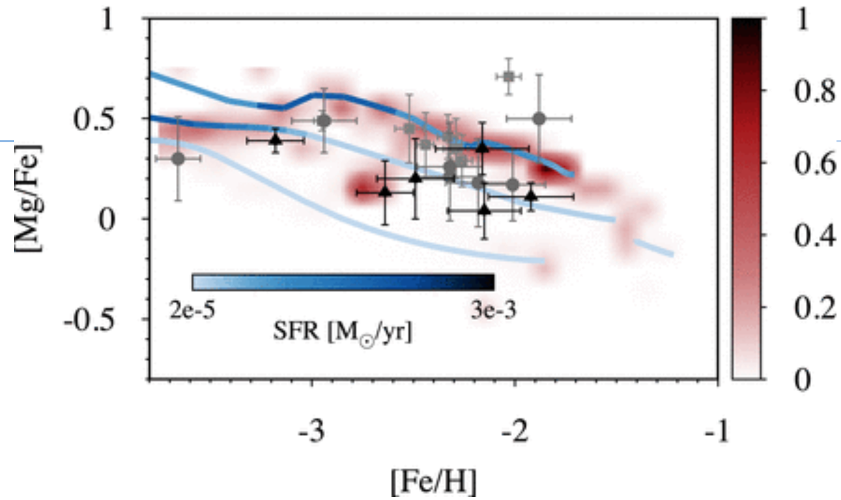




Star formations histories from the CMDs of resolved stellar populations
(Annibali, Tosi & collaborators):

the deeper, the tighter, the better
(e.g. Tolstoy, Hill, Tosi 2009, ARAA, and many others)

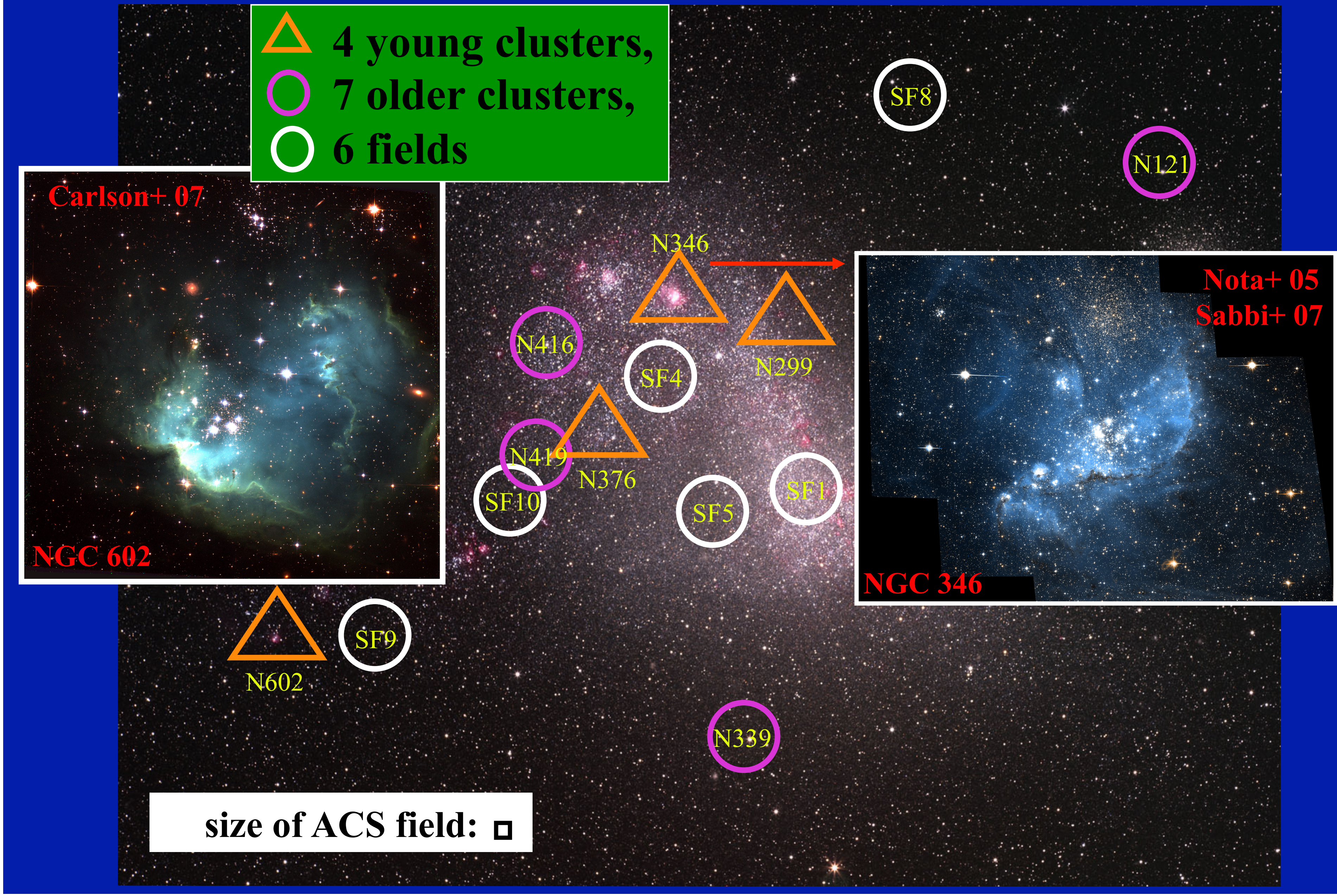
↓

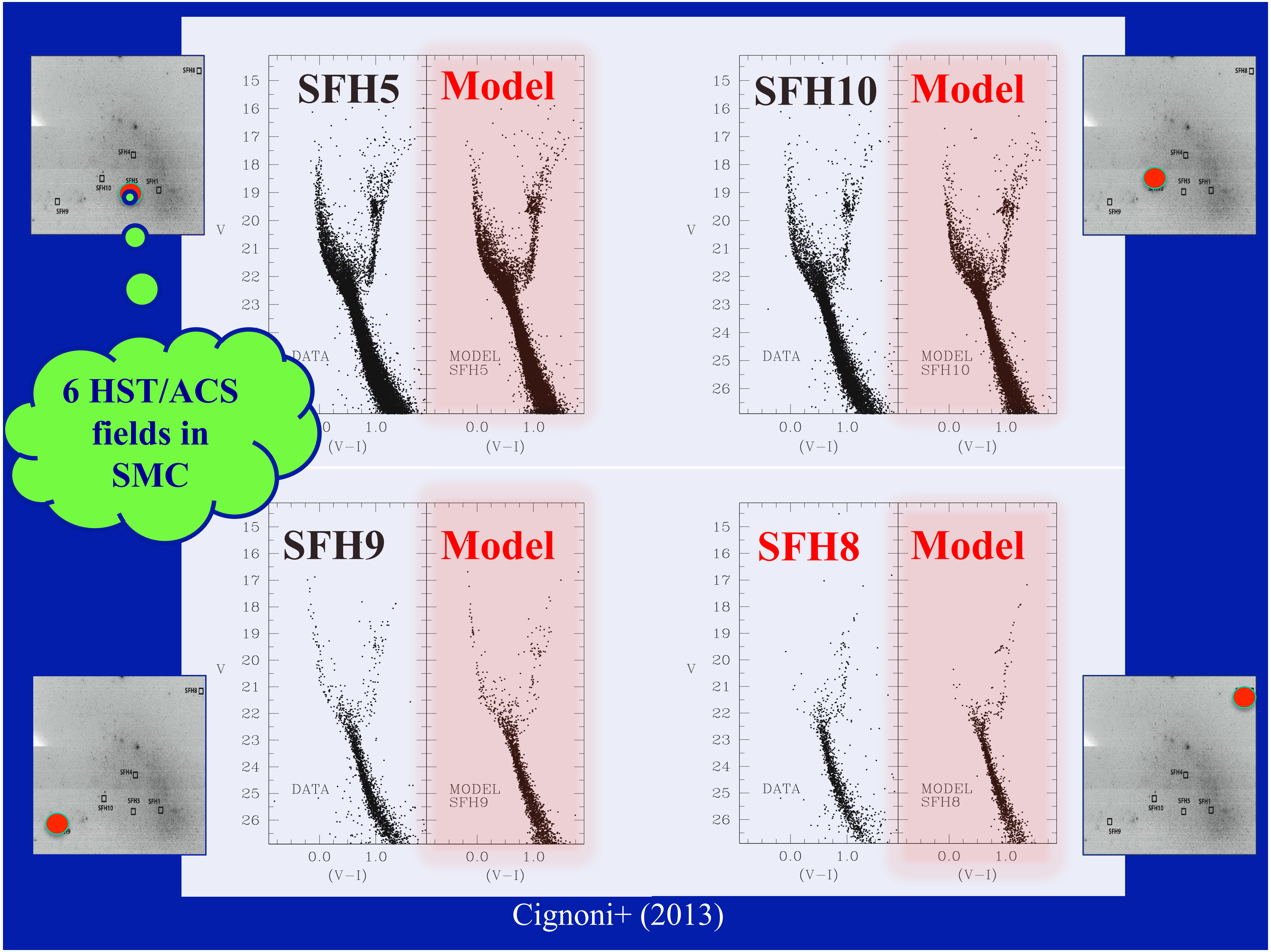
The SMC is the closest dIrr

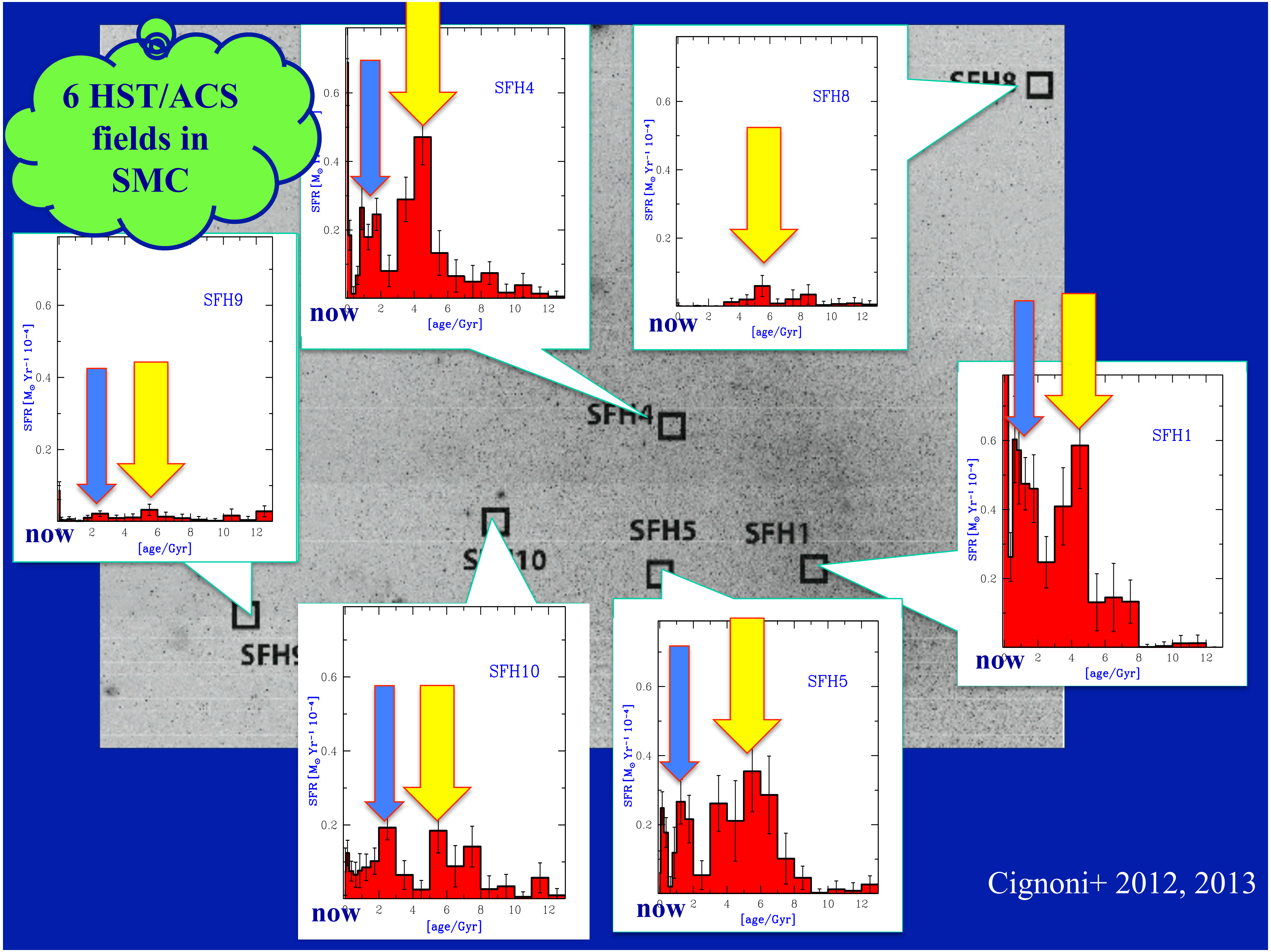
↓

the best target for SFHs of late-type dwarfs

The SMC is the closest dIrr => best benchmark




6 HST/ACS fields in SMC
SFH5
Model
DATA
MODEL SFH5
SFH10
Model
DATA
MODEL SFH10
SFH9
Model
DATA
MODEL SFH9
SFH8
Model
DATA
MODEL SFH8
V
(V−I)
Cignoni+ (2013)



6 HST/ACS fields in SMC
SFH4
SFH8
SFH9
SFH10
SFH5
SFH1
now
[age/Gyr]
SFR [M⊙ Yr⁻¹ 10⁻⁴]
Cignoni+ 2012, 2013

Completion Status

Deep: To be completed in P93 or following

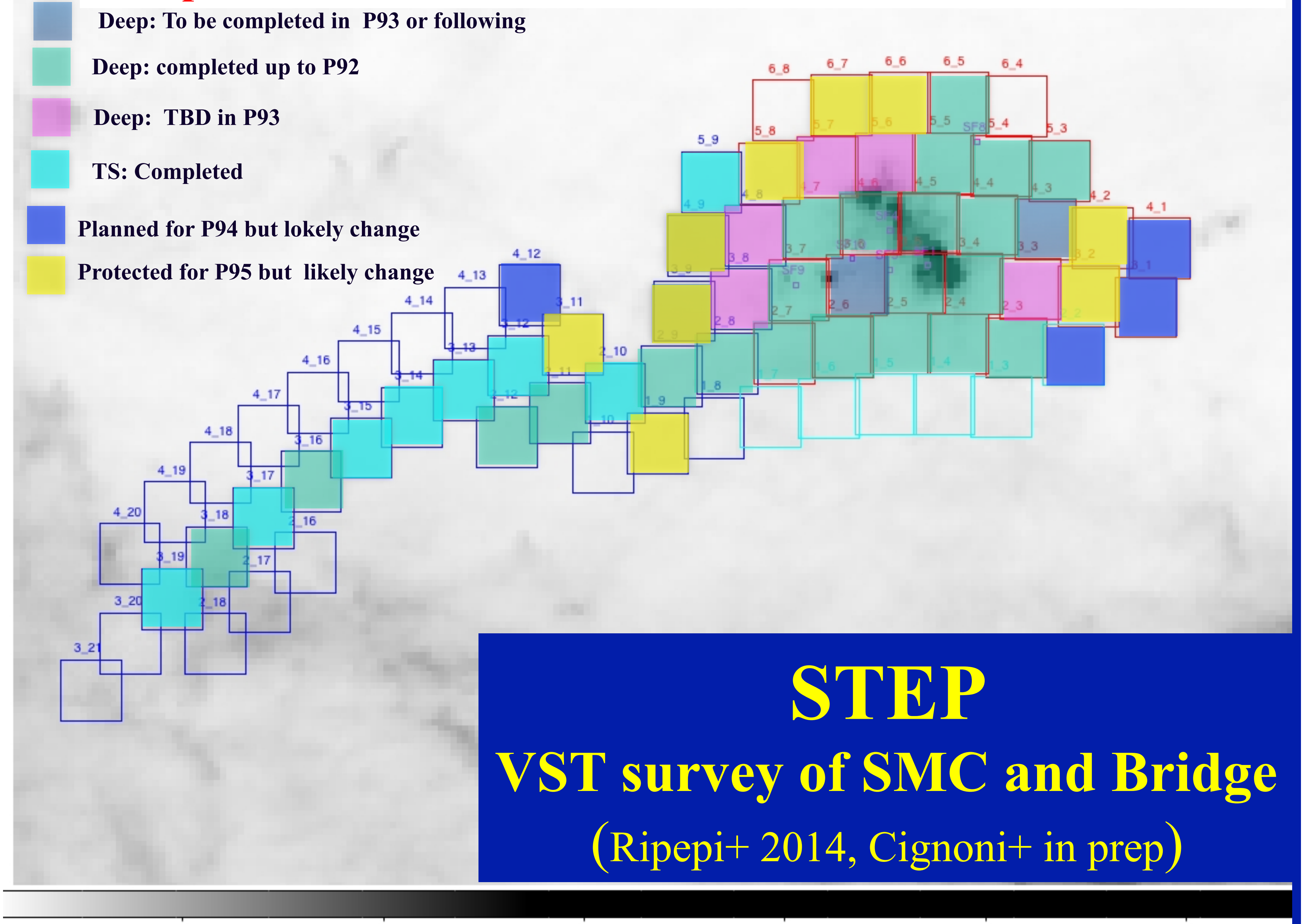
Deep: completed up to P92

Deep: TBD in P93

TS: Completed

Planned for P94 but lokely change

Protected for P95 but likely change

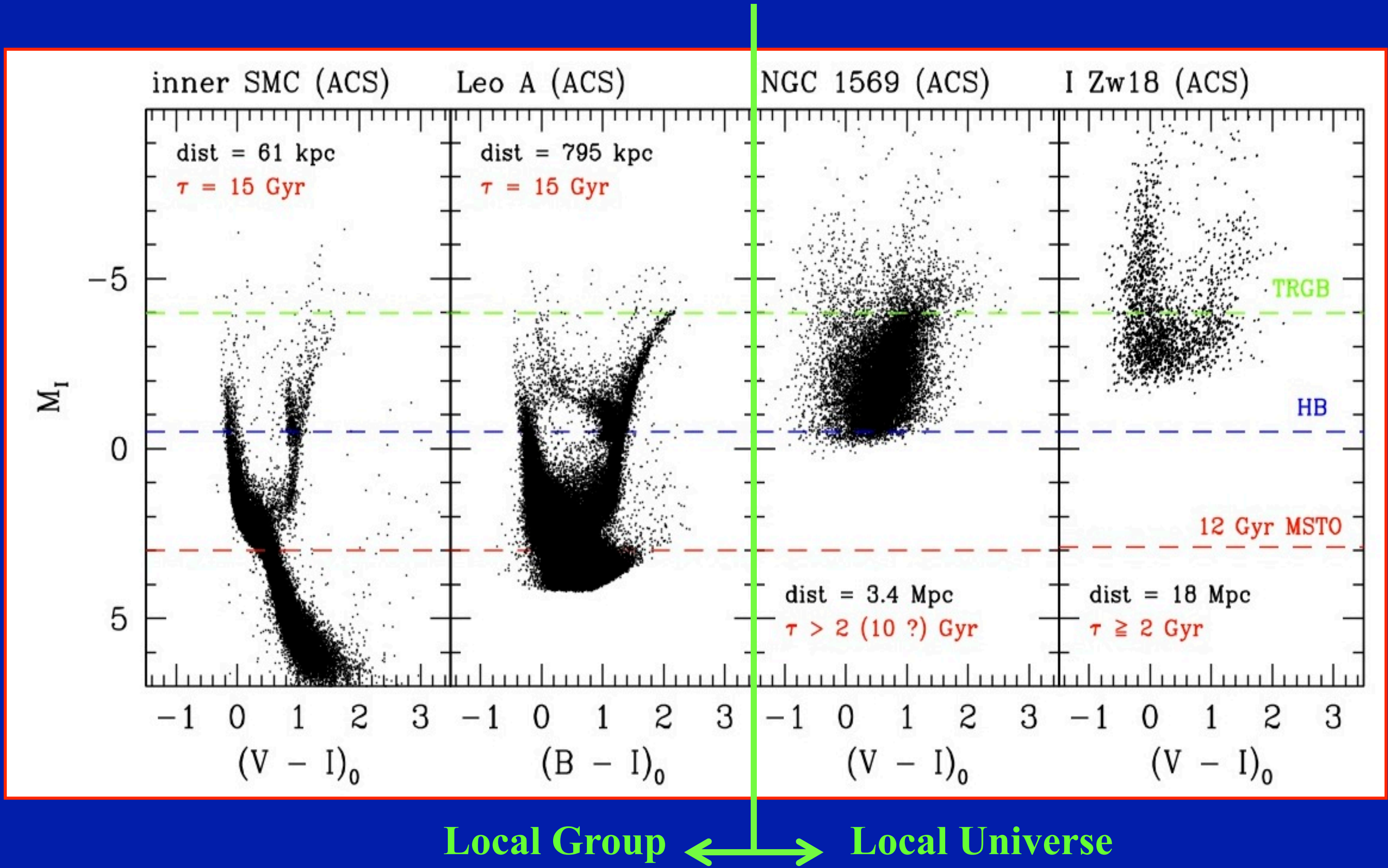


STEP

VST survey of SMC and Bridge

(Ripepi+ 2014, Cignoni+ in prep)

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



the Local Group and beyond

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

⇓

SFHs must be studied also outside the LG

ACS :
VI H_α

DDO 68

12 Mpc ?

Very metal poor, streams ?

Aloisi+ in preparation

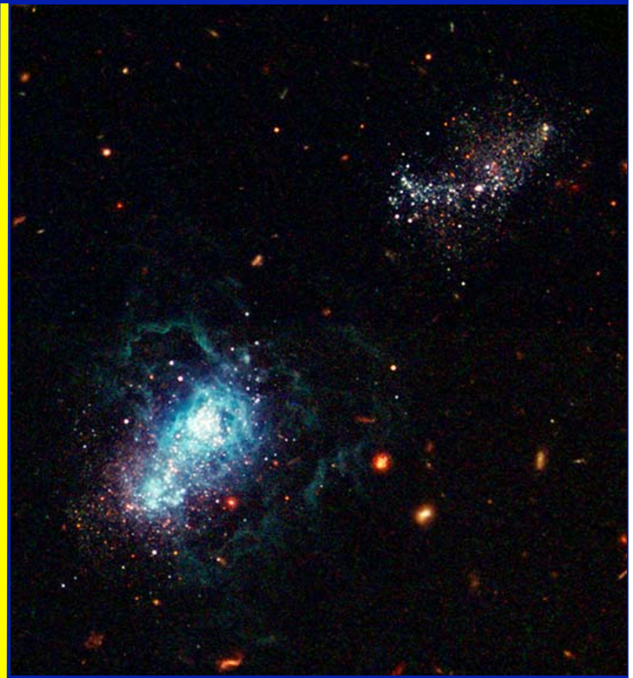
WFPC2 + NICMOS + ACS + WFC3 : UBVIJH

NGC 1705

5 Mpc

Strong starburst BCD, evidence of galactic winds

Annibali+ 03, 09



WFPC2 + ACS :
BVI

IZw18

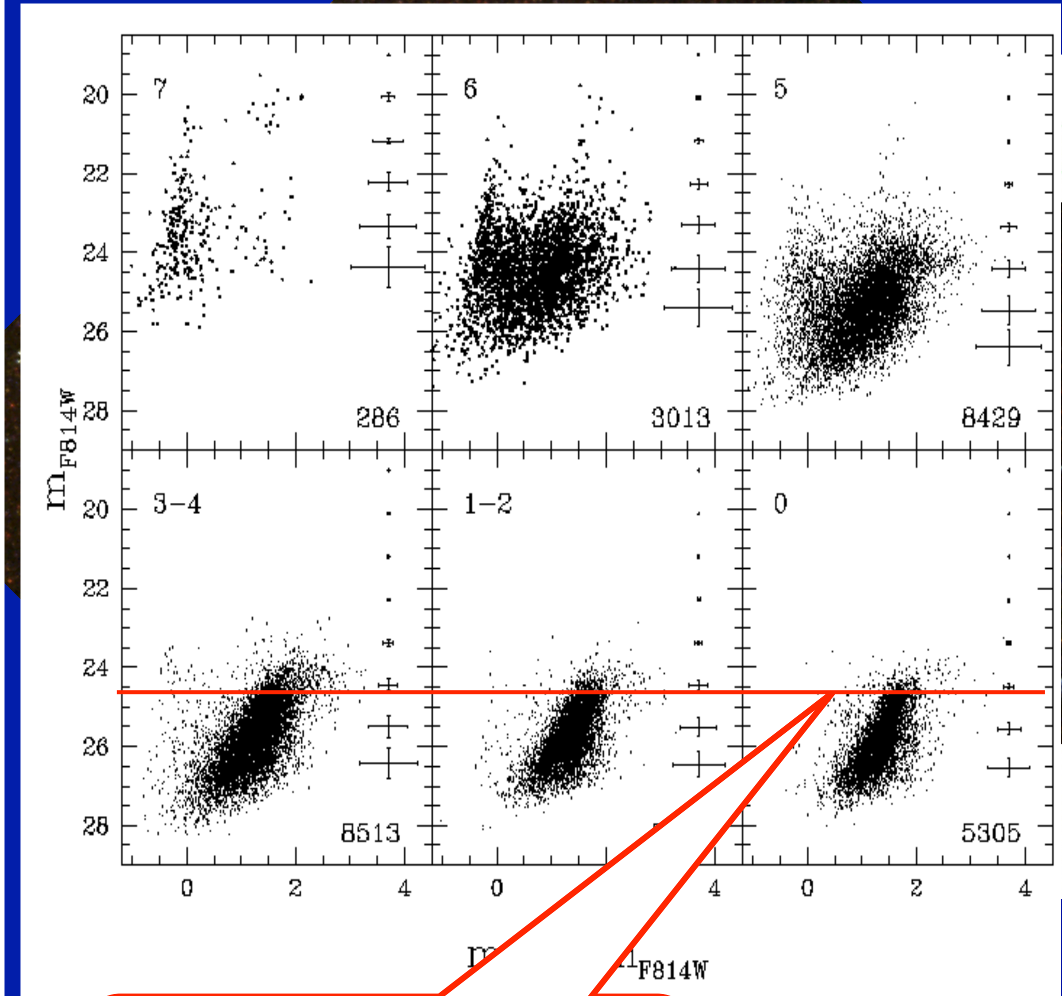
18 Mpc

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

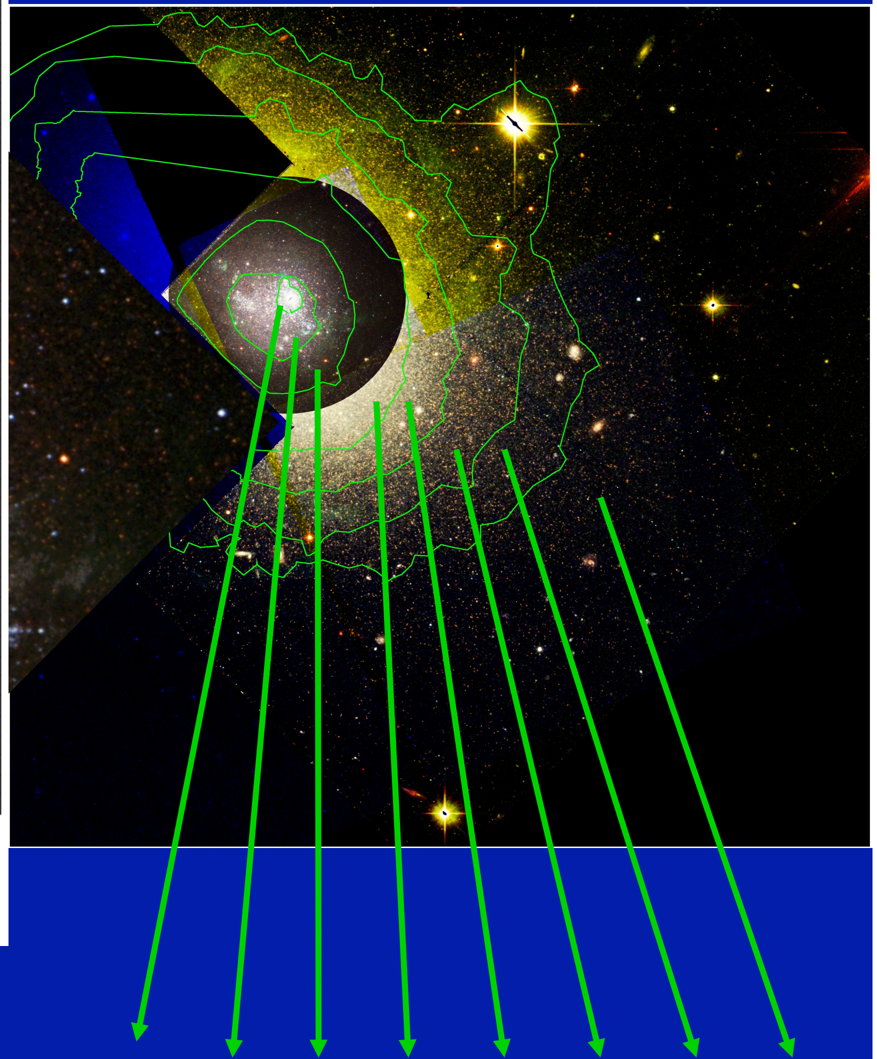
Annibali+ 13

Different regions in BCD NGC 1705: "old" results

Tosi+ 01



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

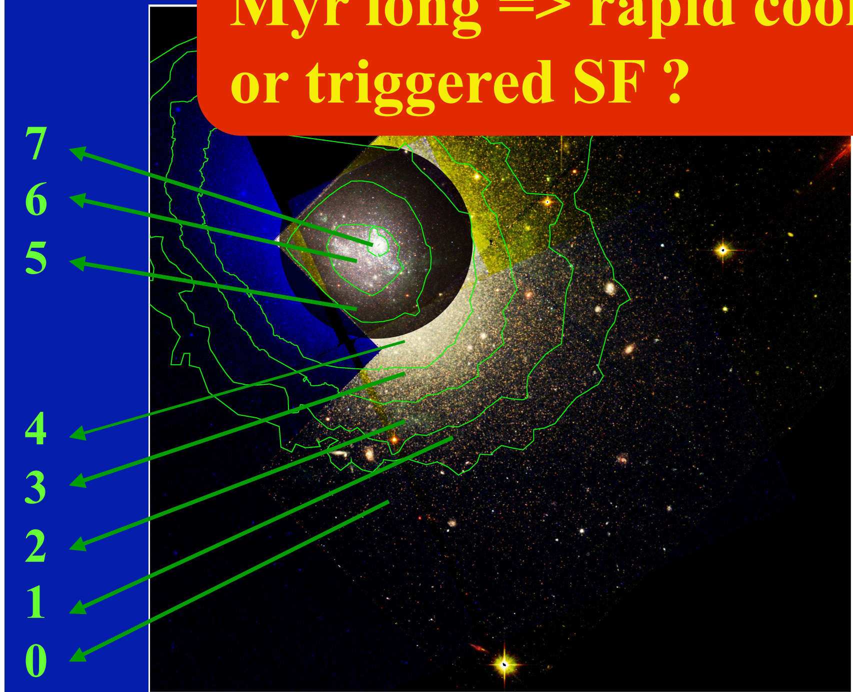


7 6 5 4 3 2 1 0

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

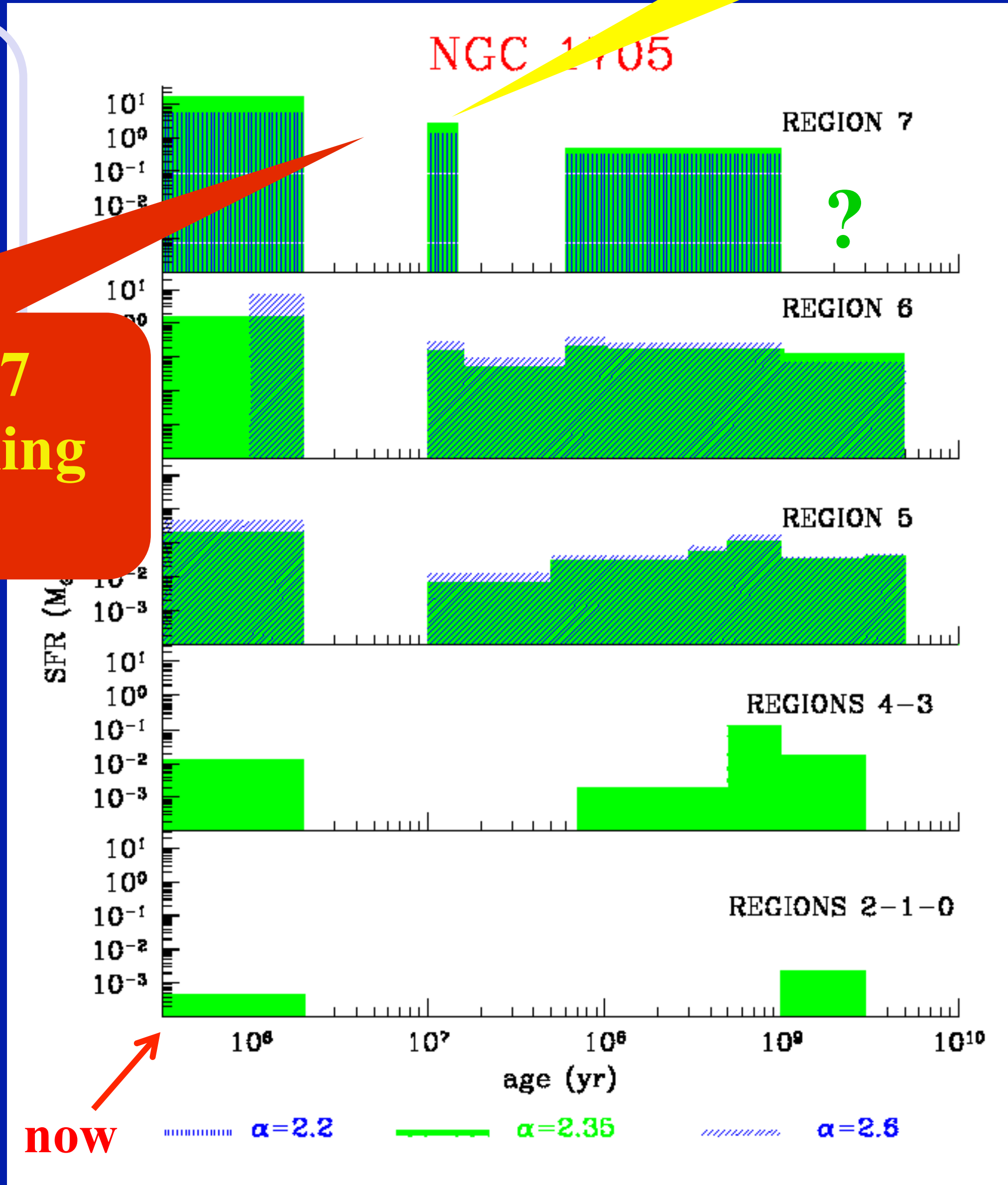
1) Some SF 5 - 1 Gyr ago
2) Some SF 1 - 0.02 Gyr ago
3) Strong central SF 17 - 10 Myr ago
4) No SF anywhere 10 - 3 Myr ago
5) Strong SF everywhere 3-0 M

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



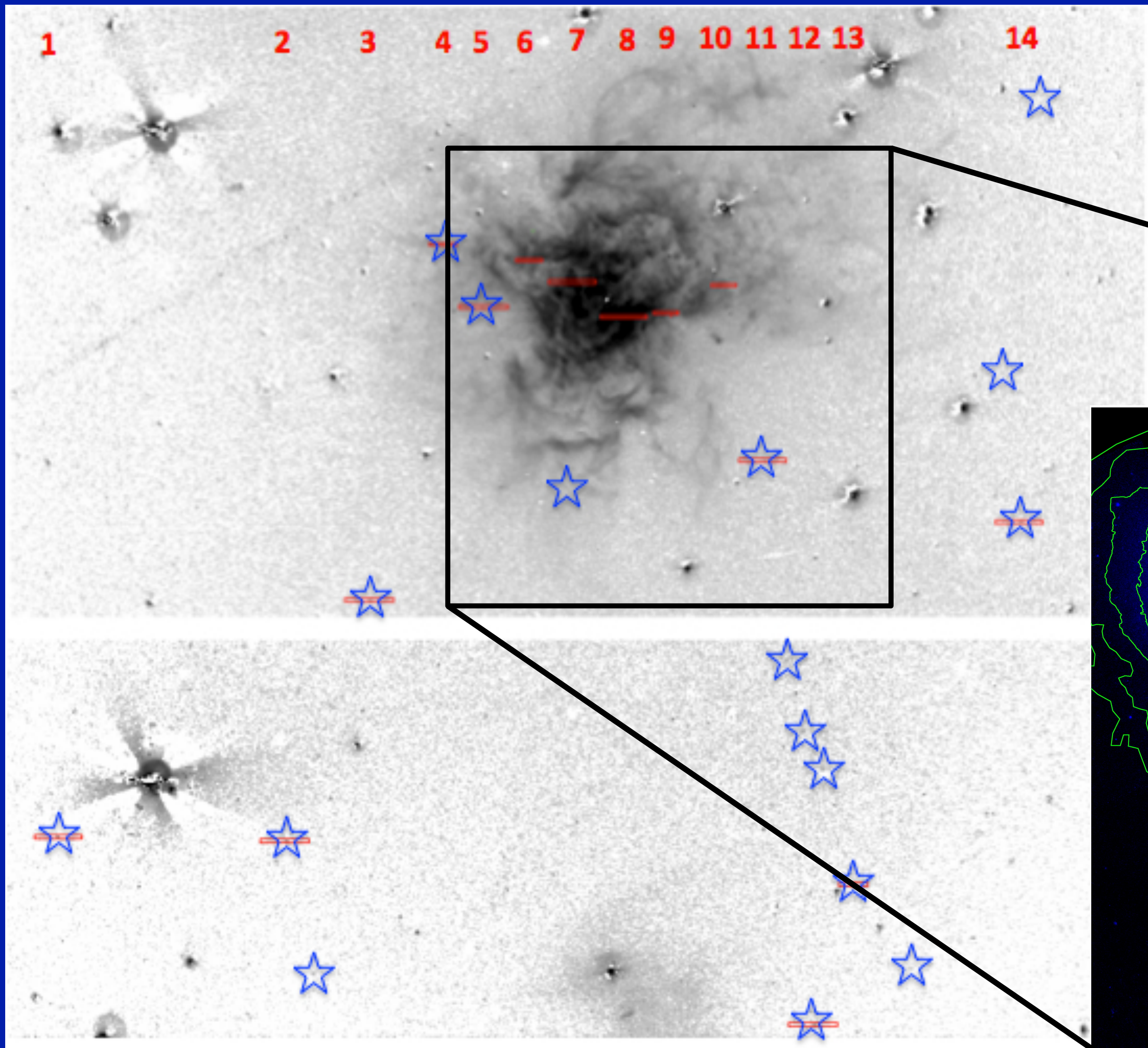
Annibali+ 03 and 09

wind source



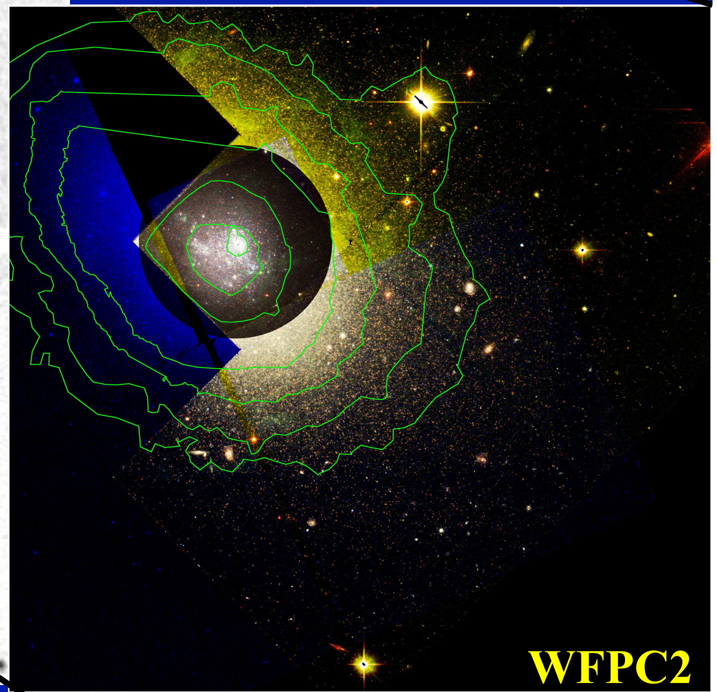
VLT FORS2 to study PNe and H II regions in NGC1705 (work in progress)

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 philaments)

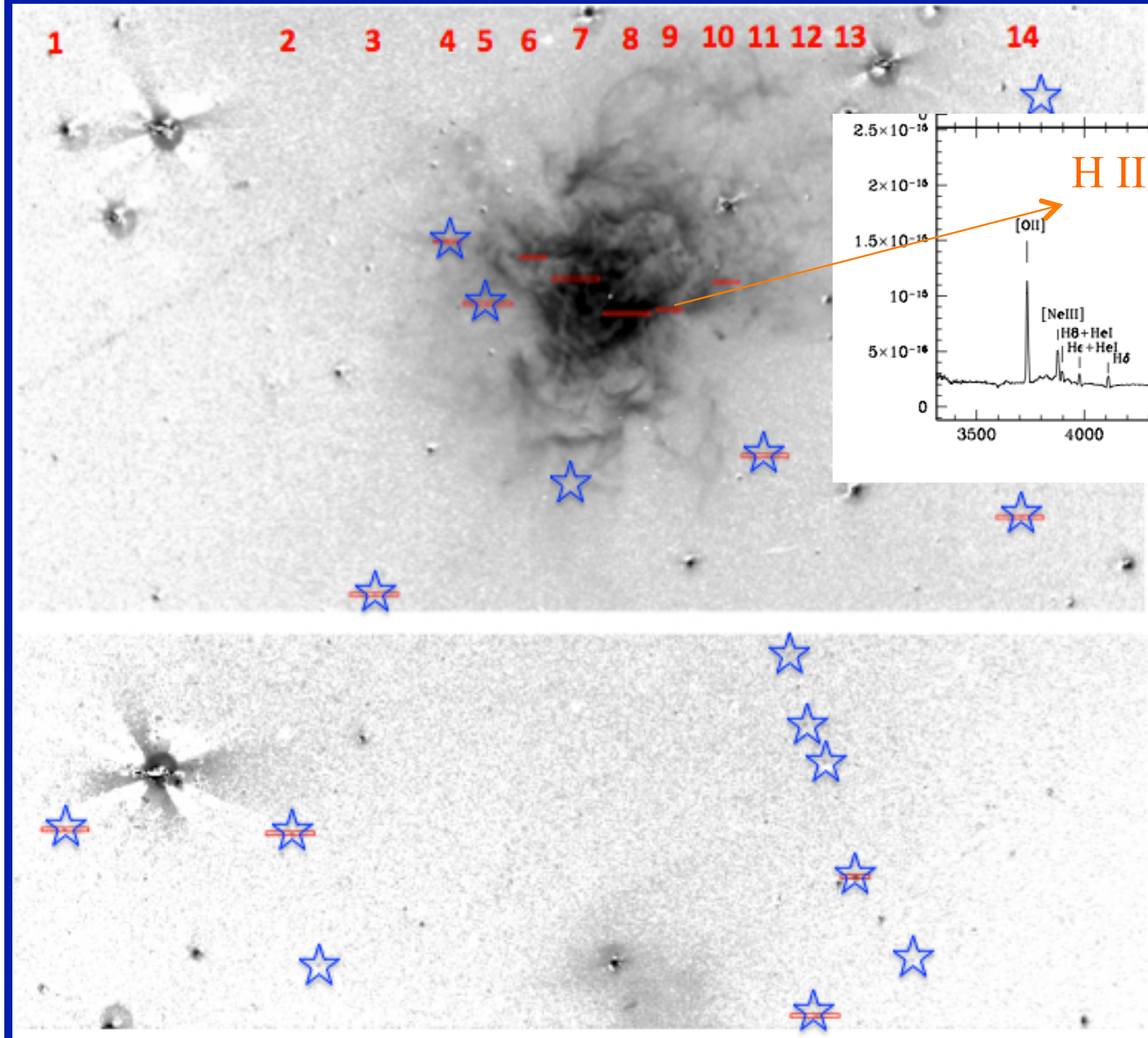


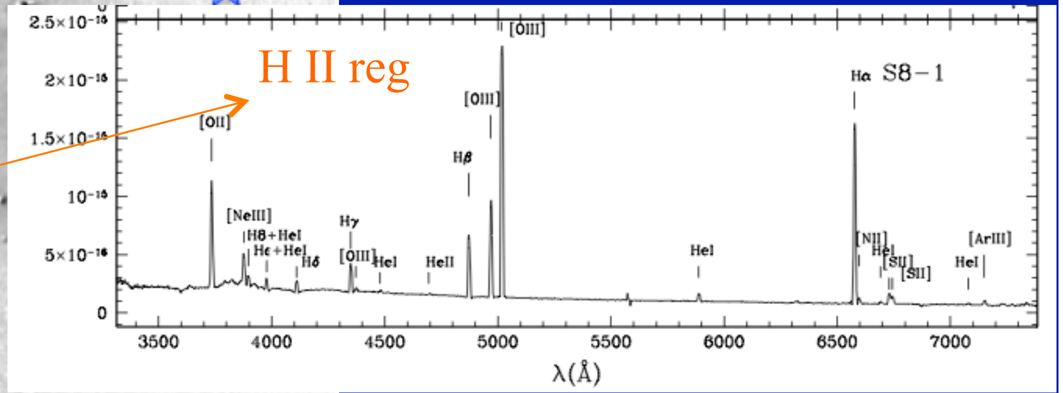
Chemical abundances in NGC 1705 from VLT/FORS2 data

(Annibali +, in preparation)

☆ PN candidates (17)

▭ MXU slits (PNe & H II)





Continuum-subtracted [OIII] image

RESULTS:

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

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

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

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

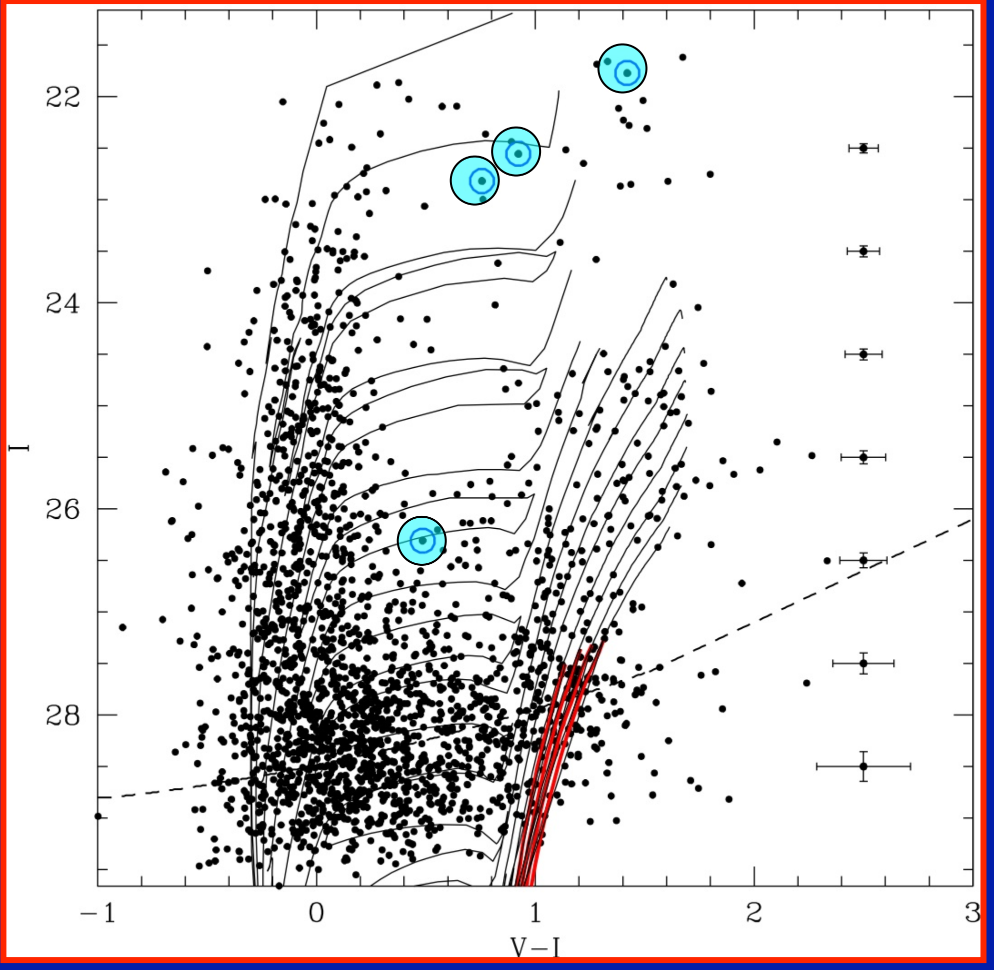
$\langle 12 + \log(S/H) \rangle = 6.42$

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

Oxygen lower than literature values

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

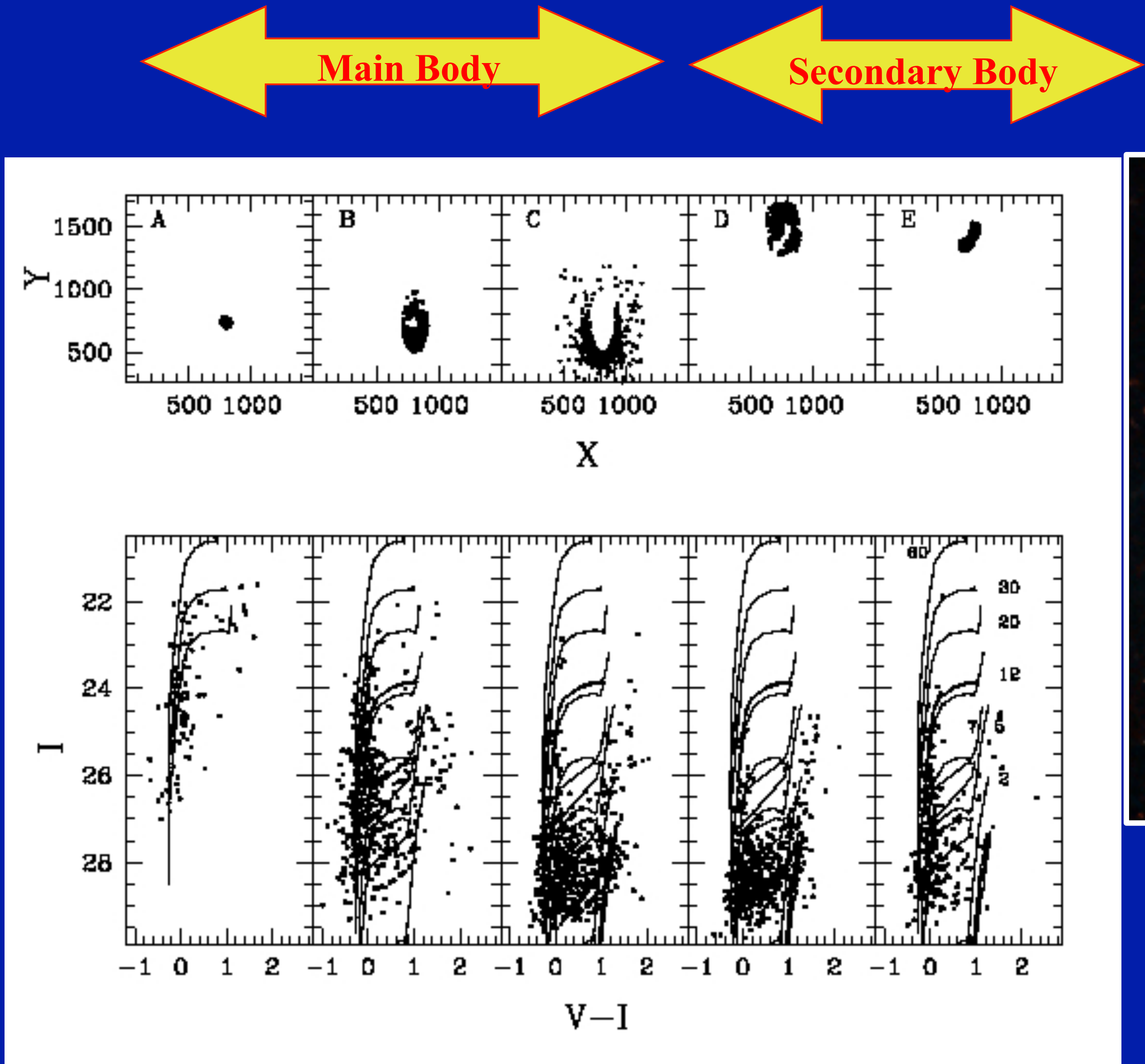
RGB identified
=> stars older than 1-2 Gyr
(possibly much older)
present



Distance from RGB Tip: $(m\text{-}M)_0 = 31.3 \pm 0.2$ => 18.3 ± 1.5 Mpc
Distance from Cepheids: $(m\text{-}M)_0 = 31.4 \pm 0.3$ => perfect agreement

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

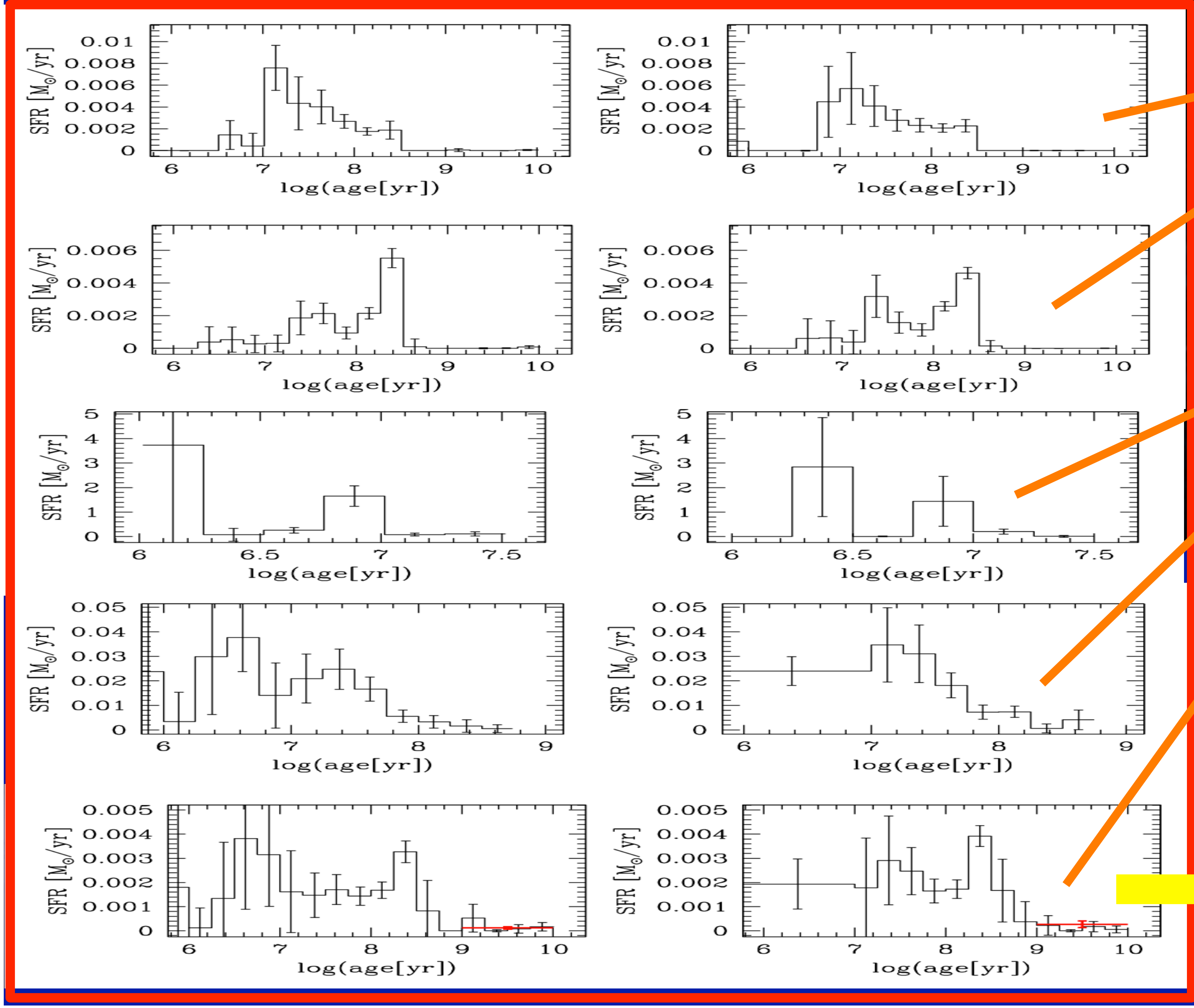
SFH of IZw18

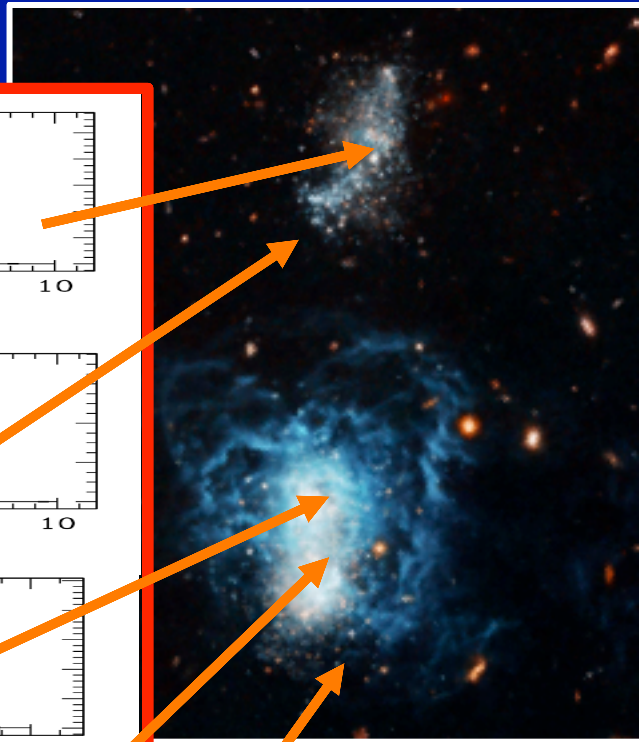


Annibali et al. 2013

SFH of IZw18

Baltimore code | **Bologna code**





Annibali et al. 2013

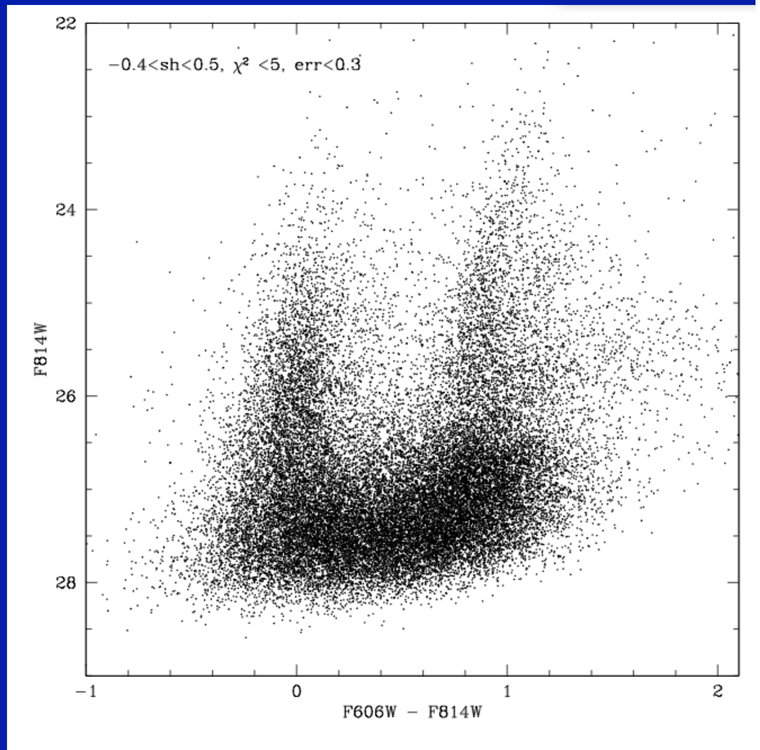
Mass(>1 Gyr)= $1.1 \pm 0.4 \times 10^{6}\ M_{\odot}$

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, Hα 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