Stellar Systems with HST

(With European Impact)

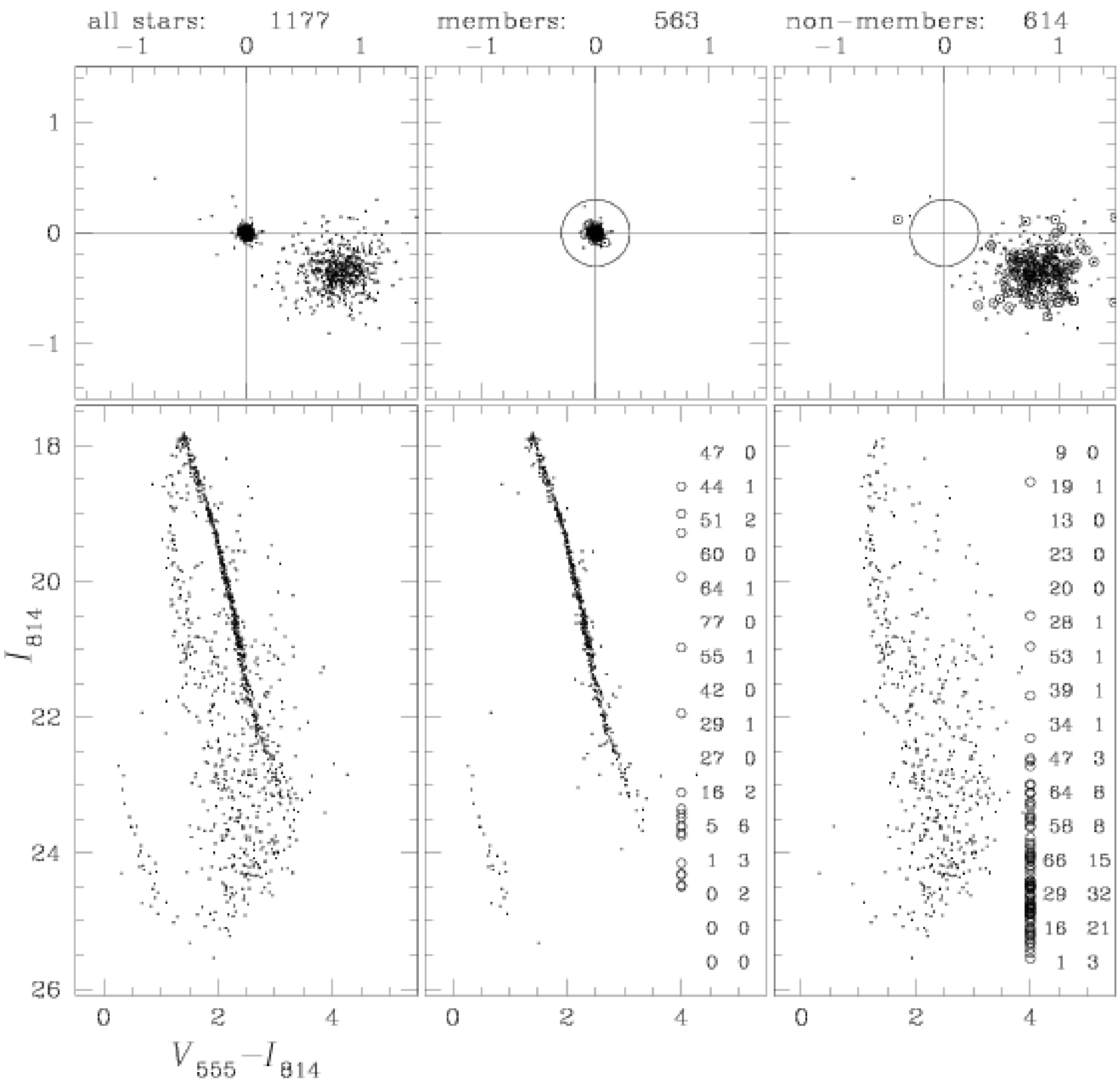
Topics:

- Surprizing Globular Clusters in the Milky Way
- The MW Bulge and its Globulars
- The Bulge, Halo, Stream and Disk of Andromeda
- Bulges at high redshifts

Emphasis on most recent results (>2000)

Alvio Renzini, ESLAB Synposium, Noordwijk, June 30, 2007

Globular Clusters in the MW
(a revolution with ACS)



Exquisitely "thin" CMDs of globular clusters with WFPC2 and ACS vindicate GCs as
Simple Stellar Population Templates
thanx to superior space resolution plus photometric and astrometric accuracy

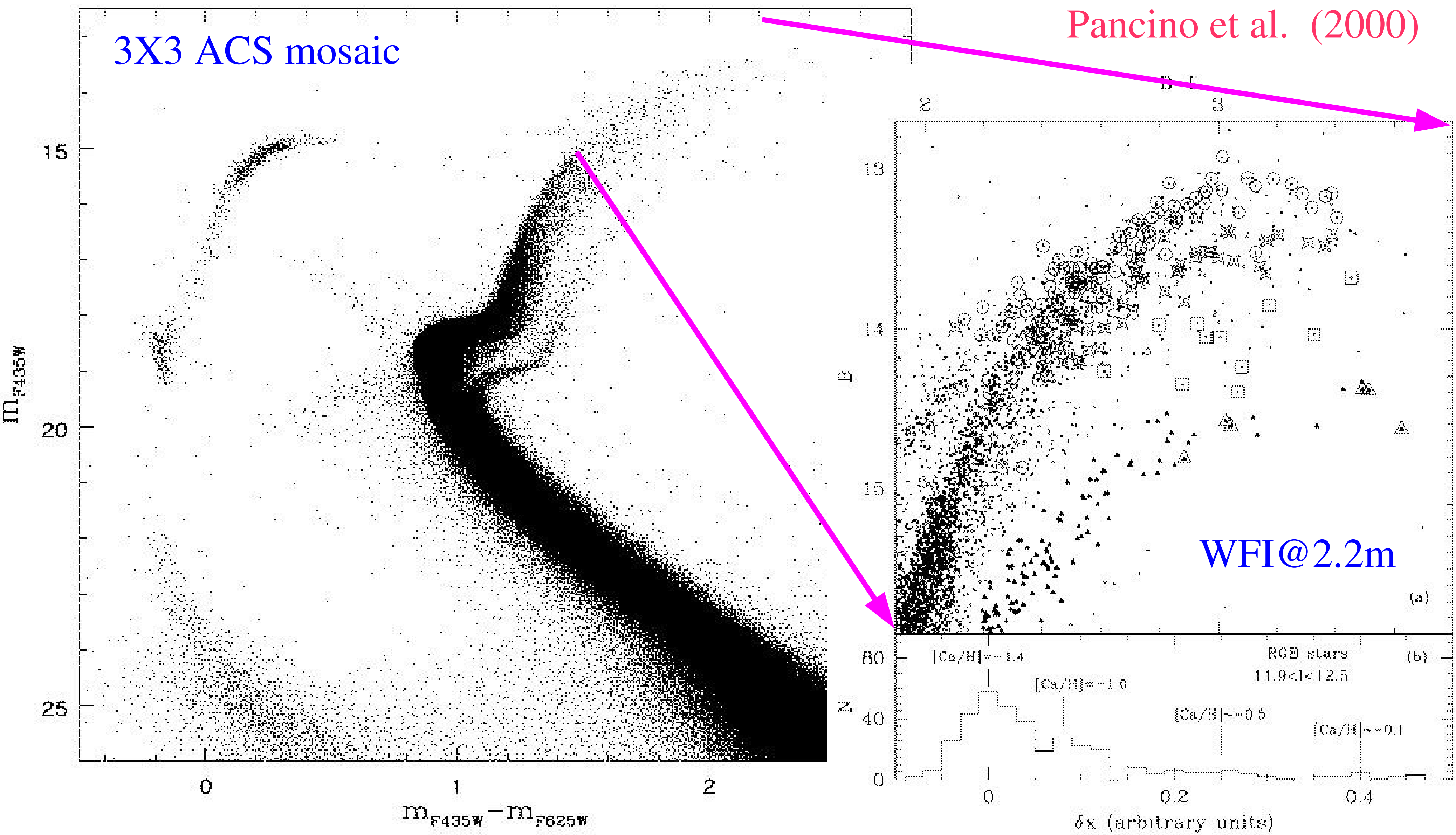
M4 from Bedin et al. (2004)

BUT ⇨

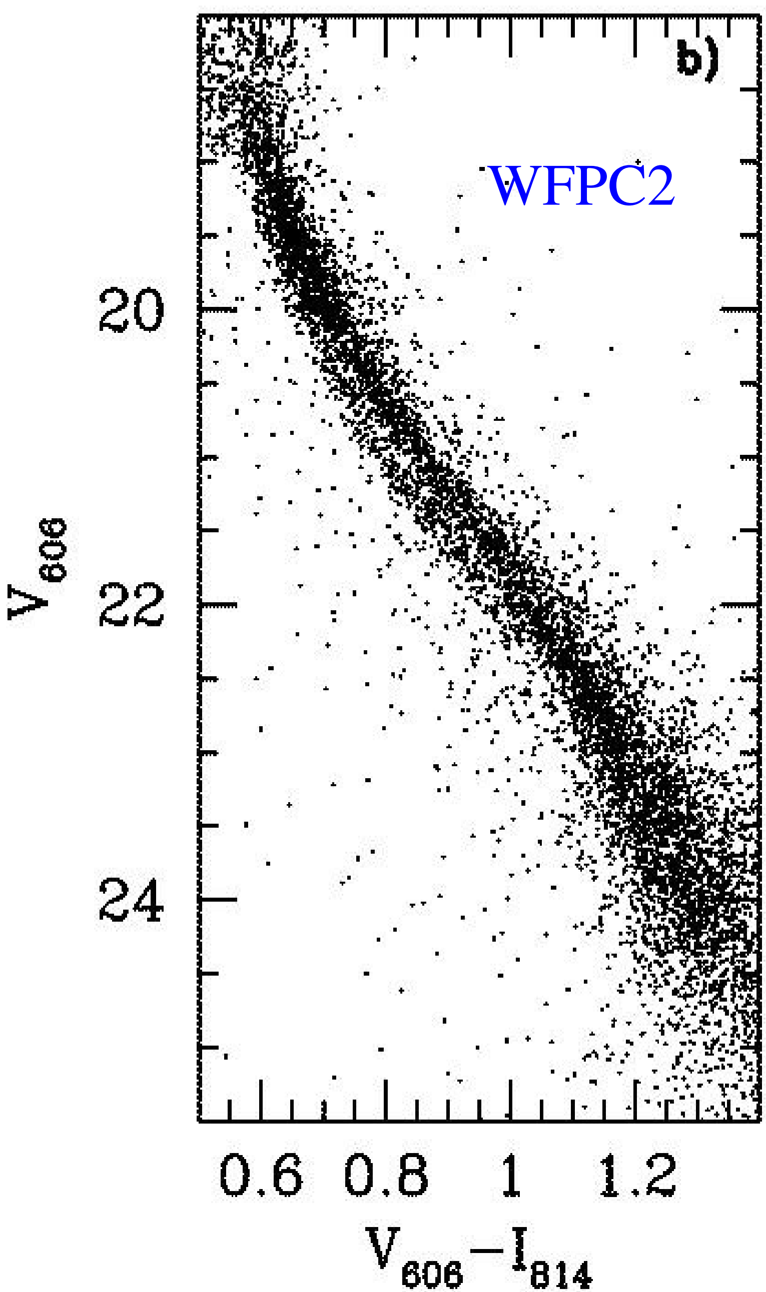
The astonishing case of ω Centauri

Villanova et al. (2007)

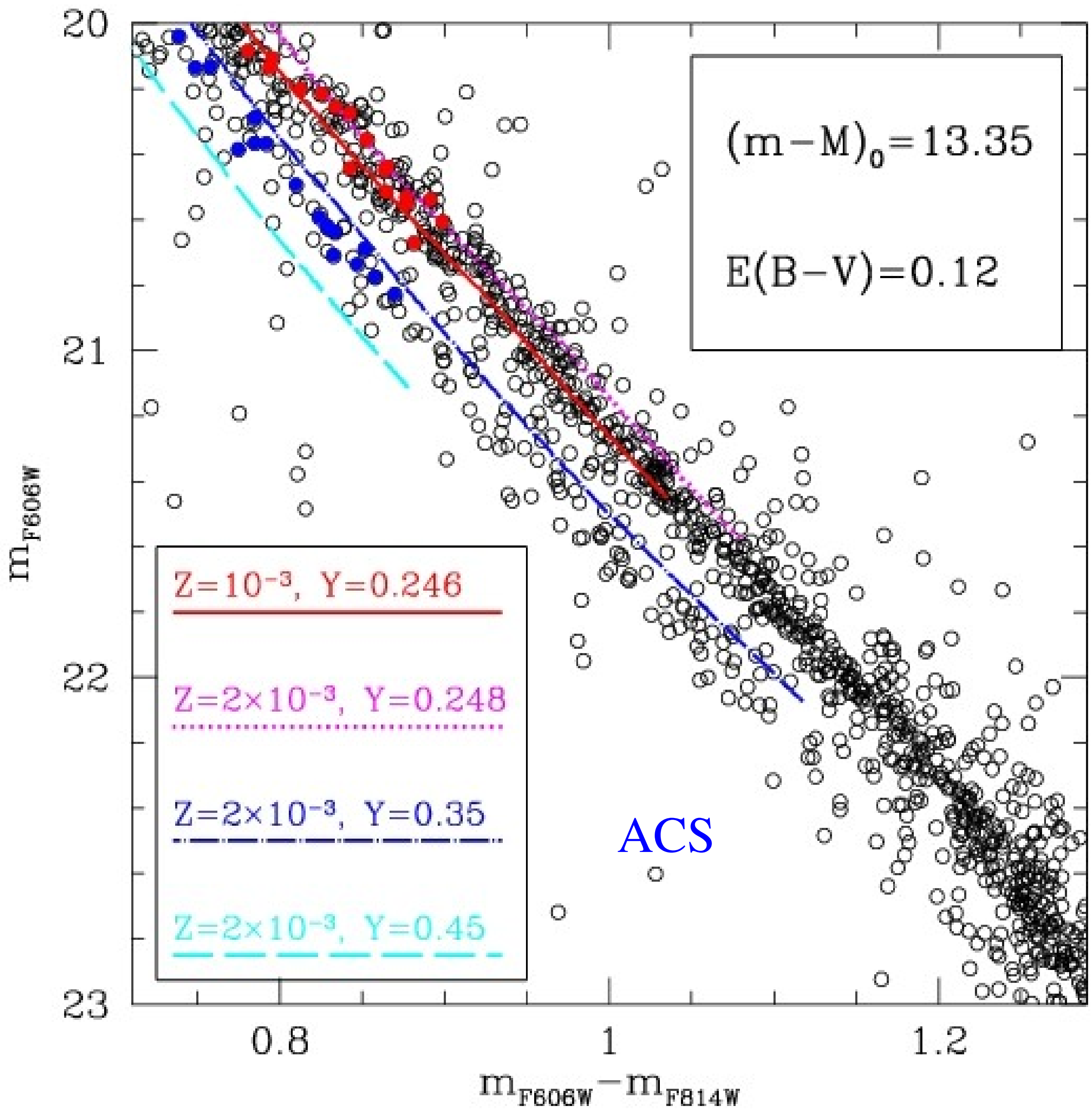
Pancino et al. (2000)



Bedin et al. (2004)

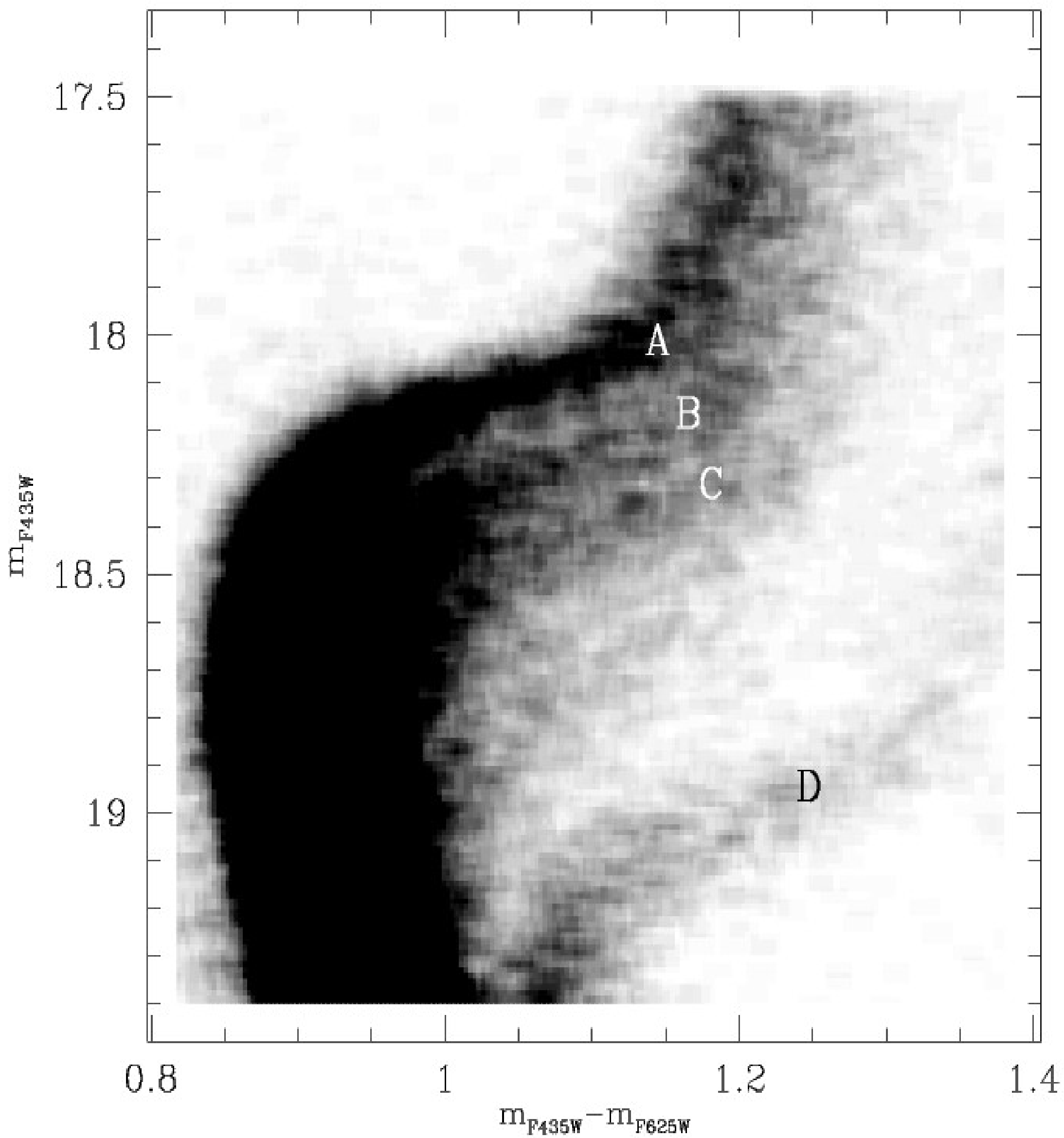


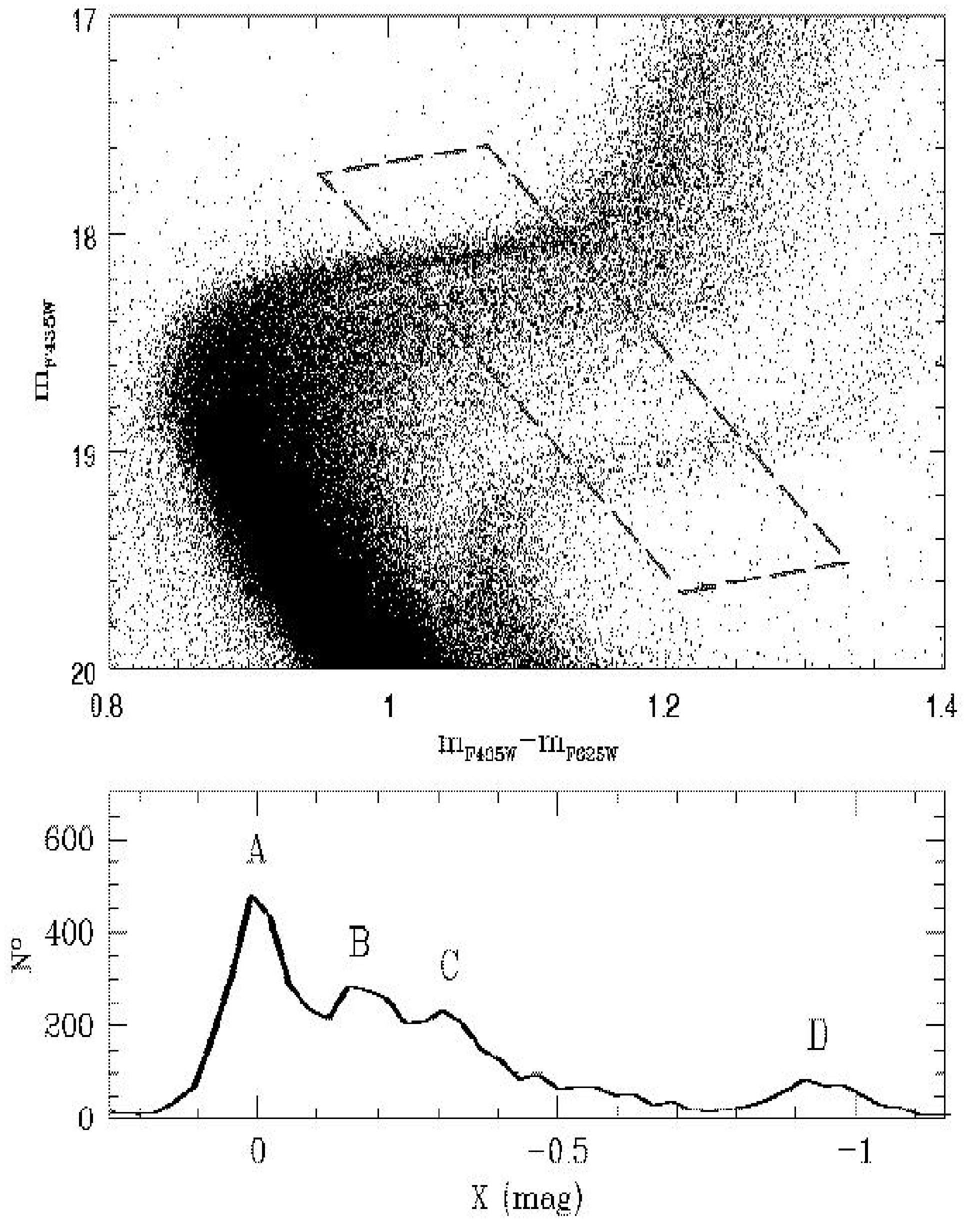
Piotto et al. (2005)



4 or 5 Multiple Subgiant Branches

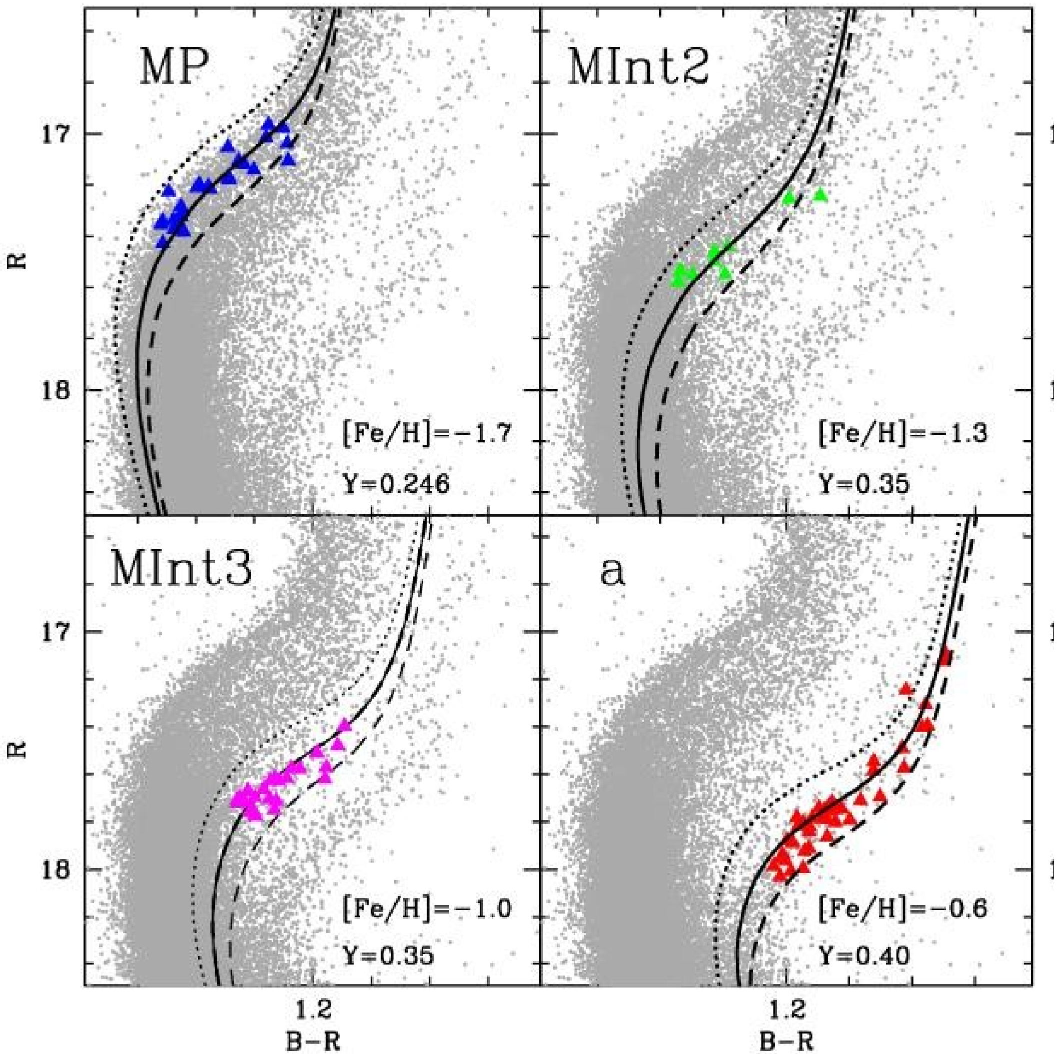
Villanova et al. (2007)



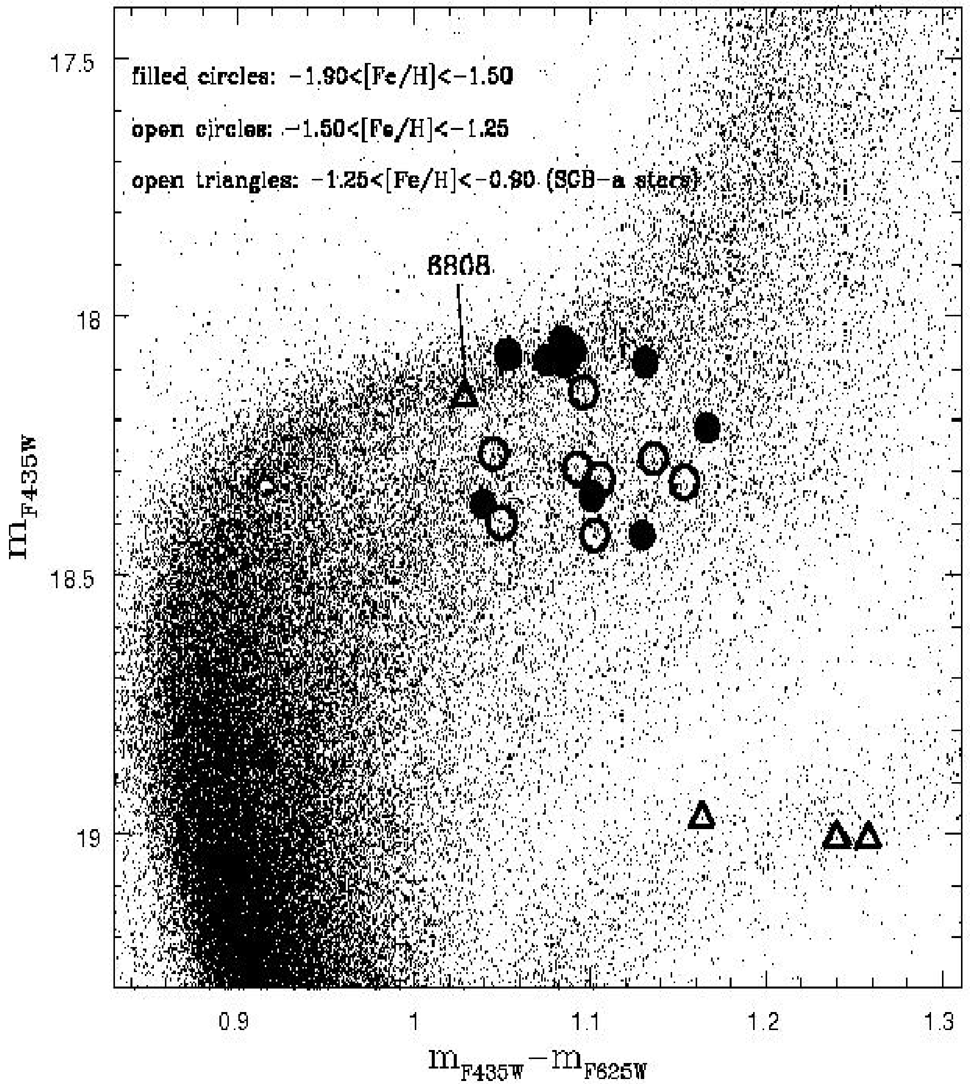


From HST to VLT/FLAMES

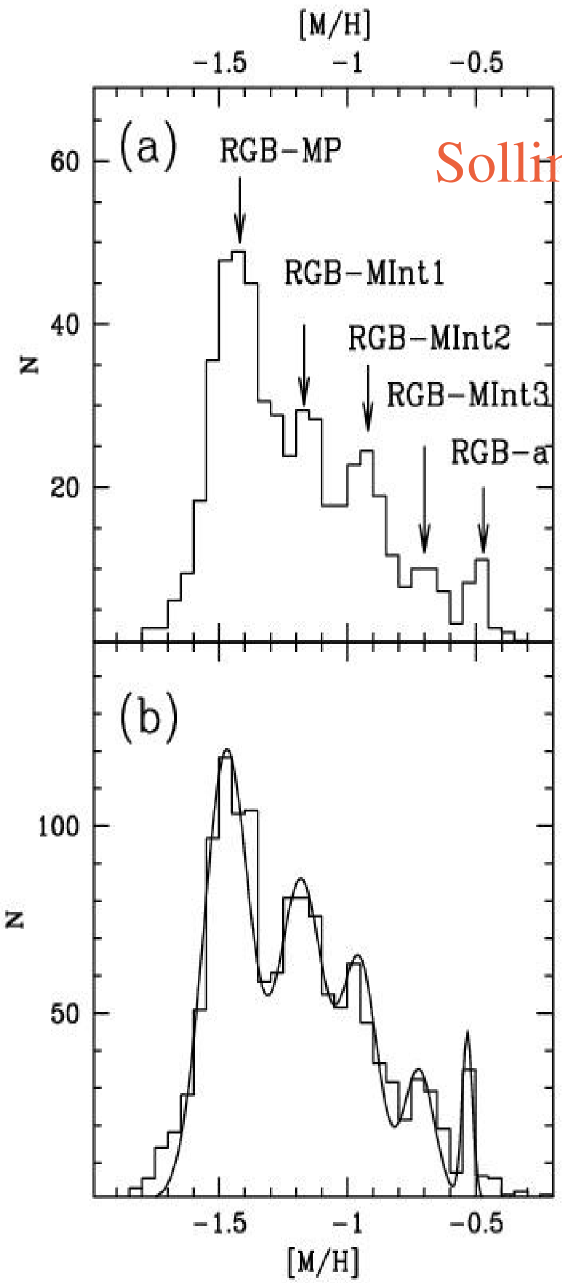
Sollima et al. (2005)



Villanova et al. (2007)



Up on the RGB and Beyond: a puzzle

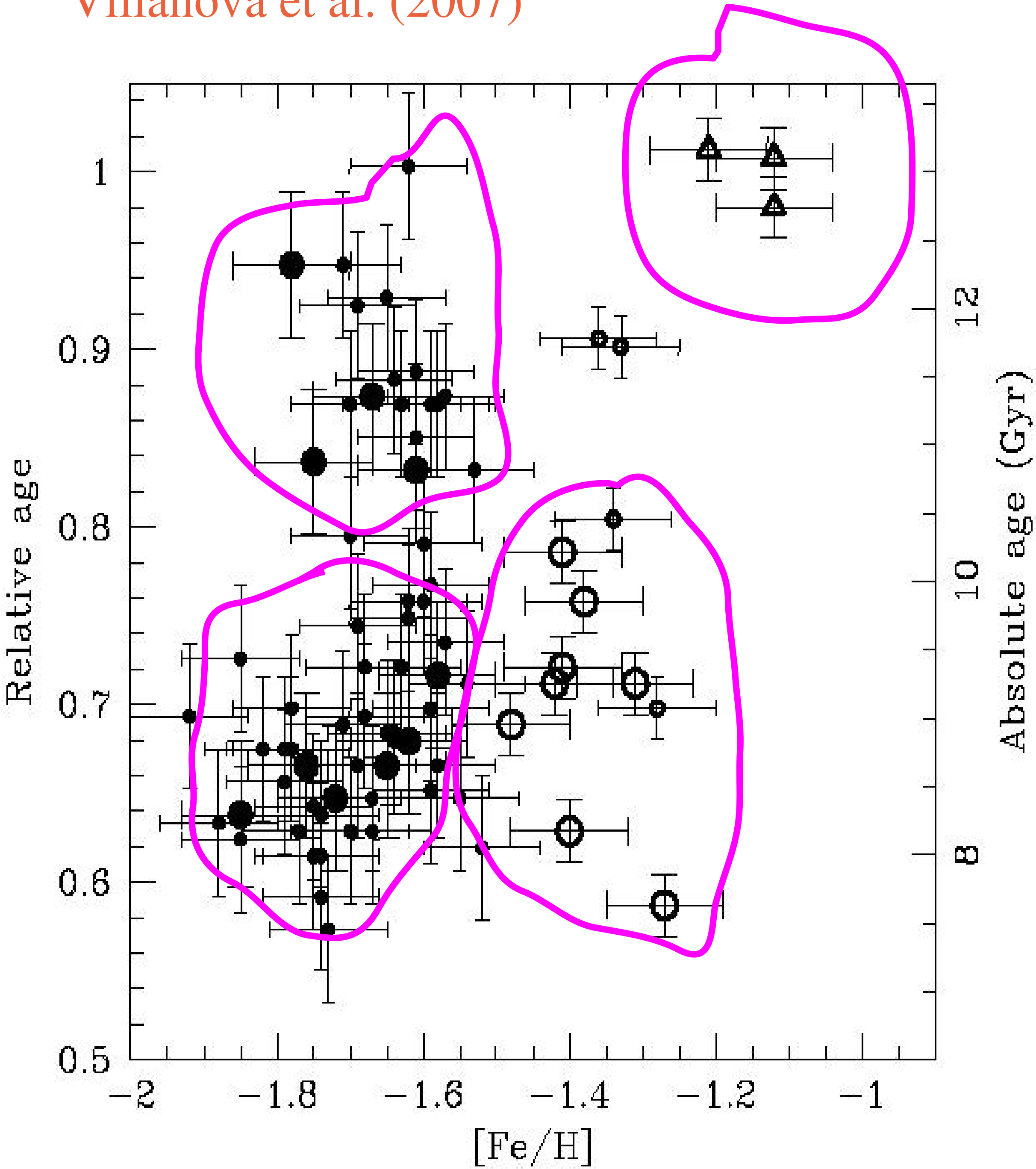


Sollima et al. (2004)

- At least 3 MSs
- 4-5 SGBs
- 5 RGBs
- A multimodal HB

- How to connect the various parts of the CMD?
- What are Age, Z, Y of each of the 5 populations?

Villanova et al. (2007)

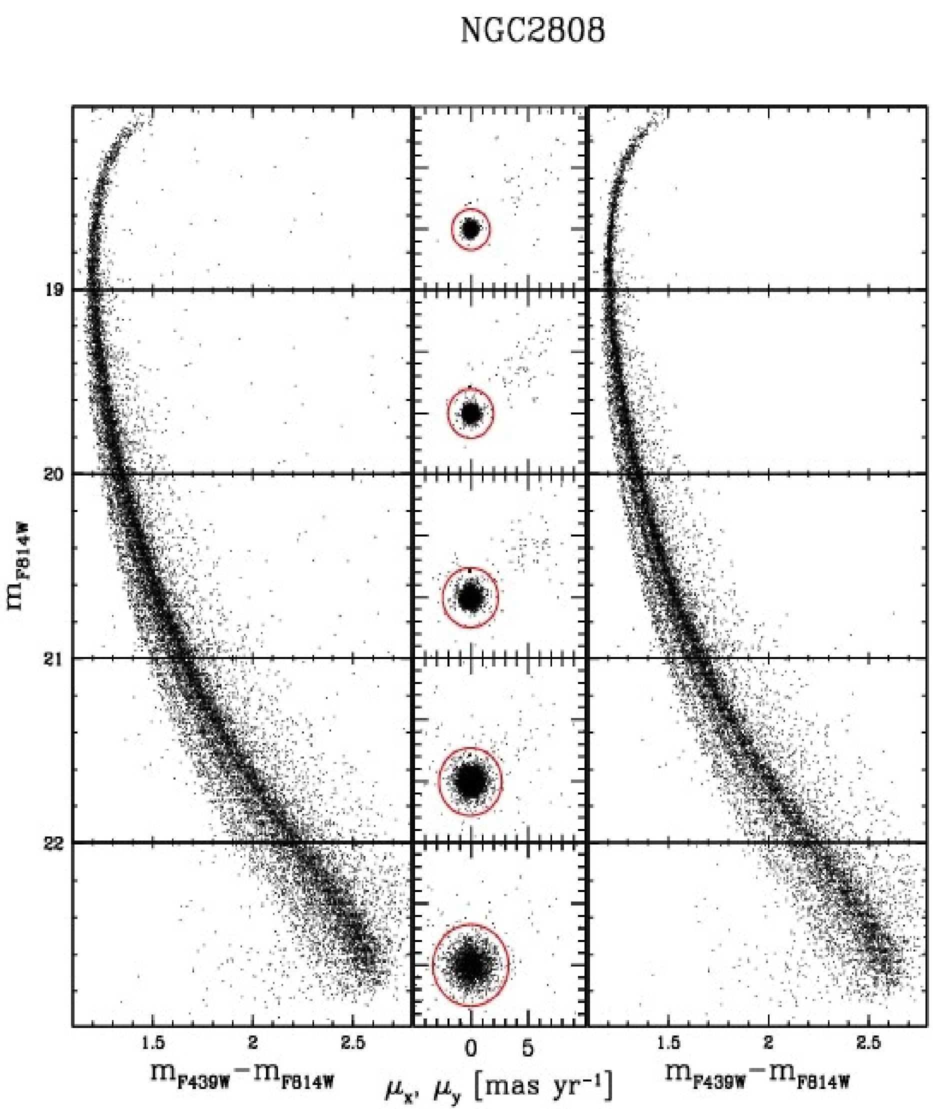


Four main age-metallicity groups. Assuming only 2 values of helium.

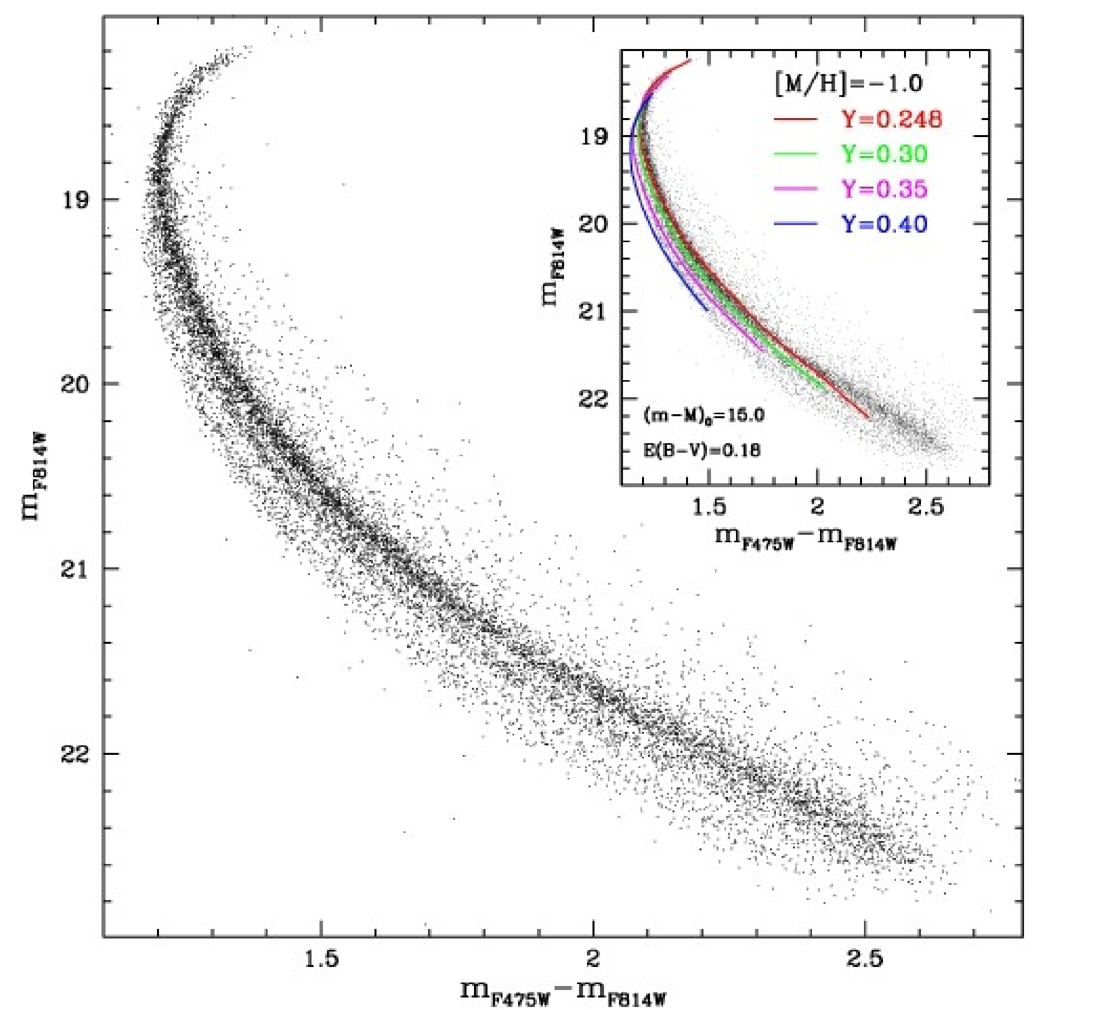
But Sollima et al. (2005) assume 3 values of helium, and find all populations to be nearly coeval, within the uncertainties.

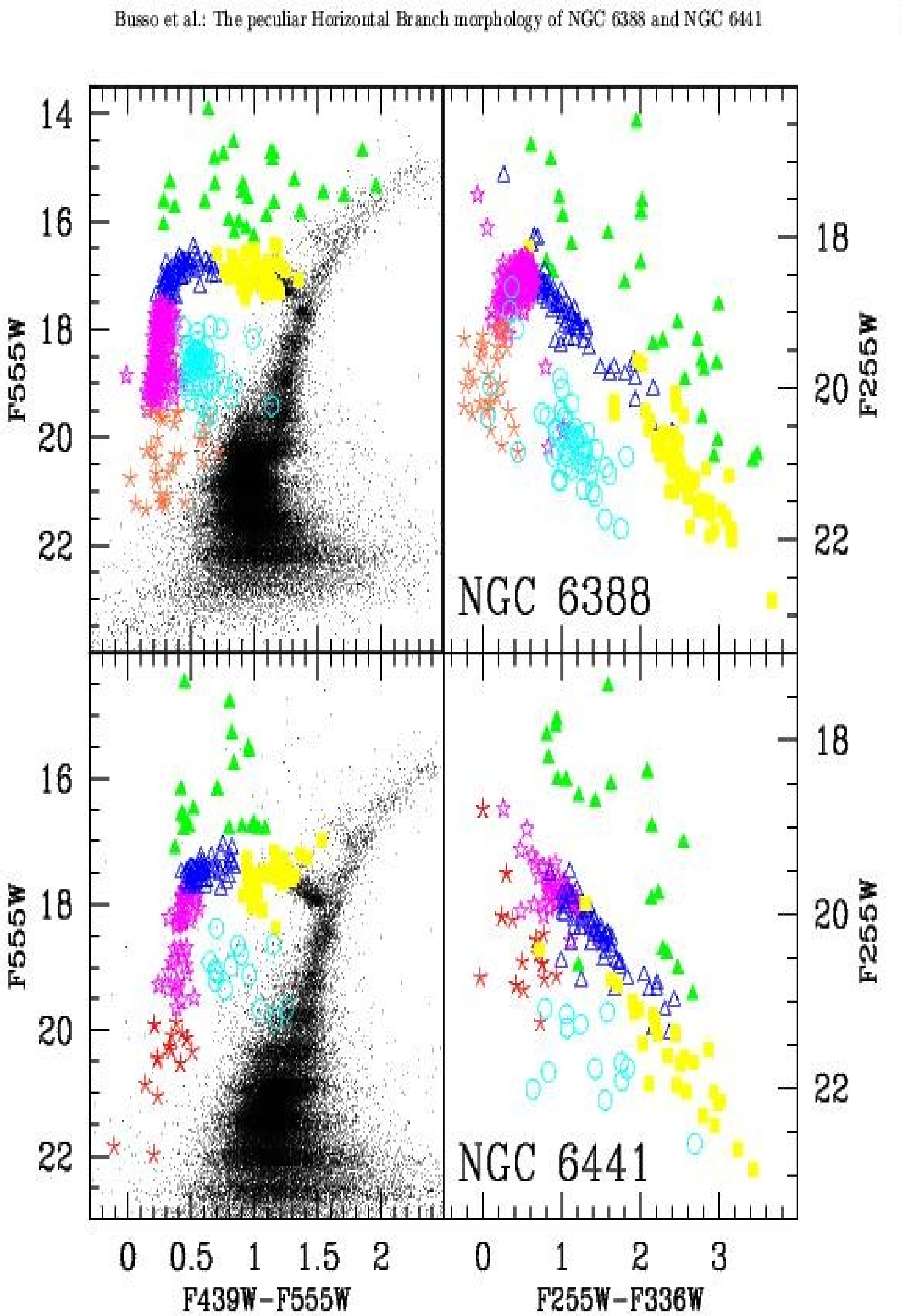
The three Main Sequences of NGC 2808

Three wildly different heliums (Y=0.25. 0.30. 0.35) with the same metallicity!!!



Piotto et al. (2007)





Two weard GCs in the Bulge:

* High metallicity ([Fe/H]~-0.5)

* but with very extended, blue HB

* Oosterhoff Type III, <P_{ab}> = $0^d.75$, Unique as such in the Galaxy!!!

* Most likely require high helium sub-populations

Busso et al. (2007, submitted)

Multiple stellar populatins only in heavyweight GCs?

The 11 Clusters More massive than 1 million suns in the MW:

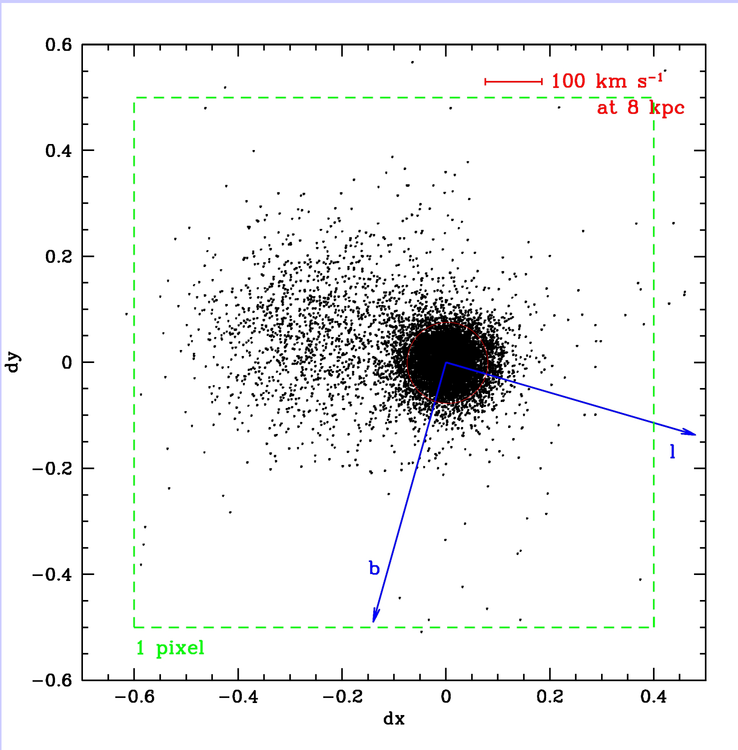
	Multiple Stellar Pops?
47 Tuc	NO
NGC 1851	Yes (Piotto et al. 2007 in prep.)
NGC 2808	Yes
NGC 5139	Yes
NGC 5824	?
NGC 6093	Observed in Cycle 16 (PI Piotto)
NGC 6388	Yes, Obser. in Cycle 16 (PI Piotto)
NGC 6441	Yes
NGC 6715	Observed in Cycle 15 (PI Piotto)
NGC 7078	Observed in Cycle 16 (PI Piotto)
NGC 7089	Observed in Cycle 16 (PI Piotto)

More questions than answers:

- How did the most massive GCs manage to form/accrete their multiple stellar populations?
- Where is the huge amount of helium coming from? From 3-8 $M_\odot$ AGB stars? Or where else?
- Is ω Cen the remnant core of a tidally disrupted galaxy?
- And if so, what about the other heavyweight GCs?

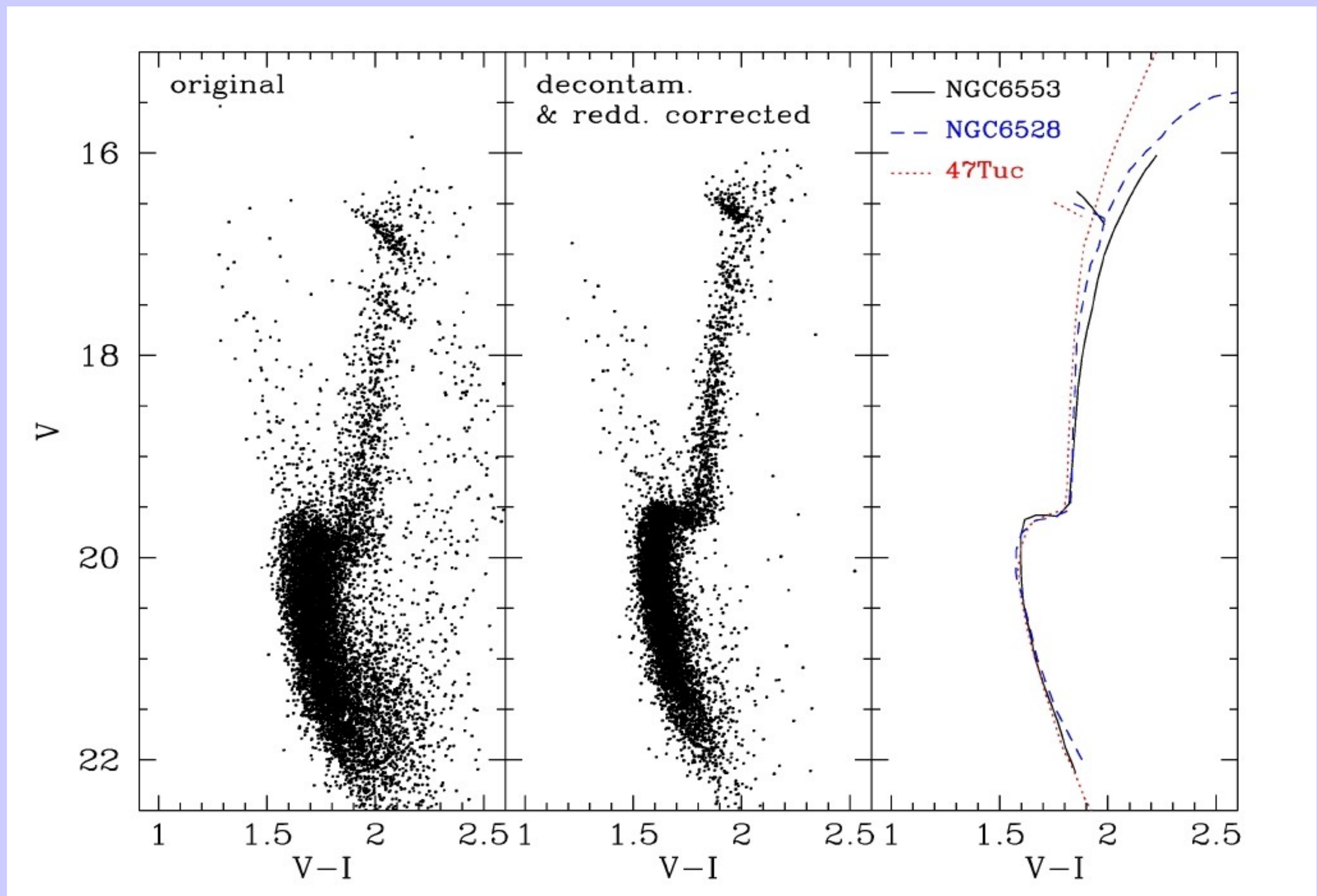
NGC6553 & Bulge Proper Motions

(Zoccali et al. 2001)



Age of Bulge GCs = Age of 47Tuc

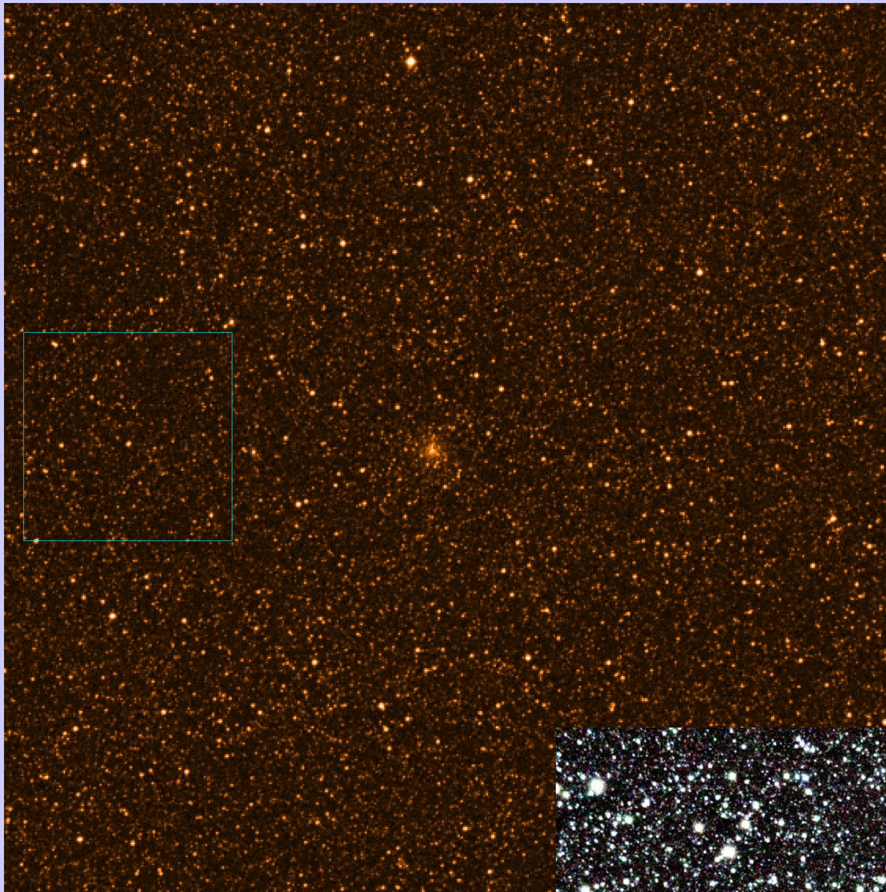
Age of 47Tuc ~ Age of Halo Clusters

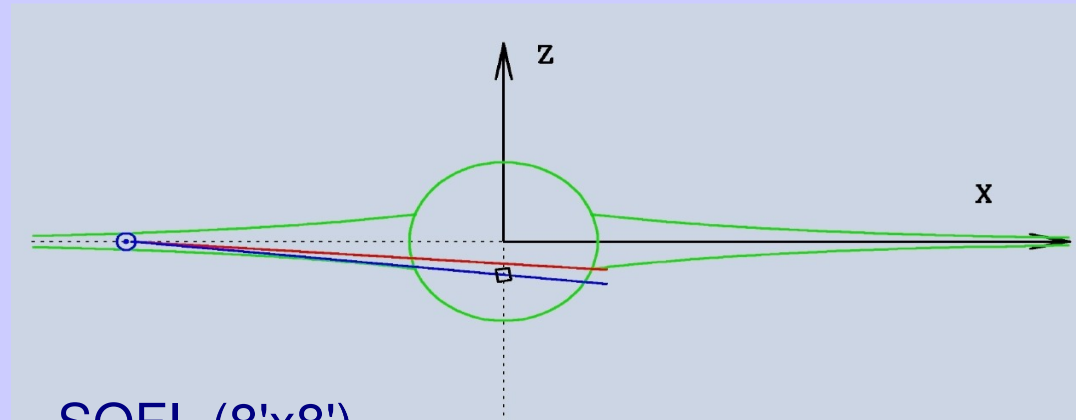


The same for the twin Bulge globular NGC 6528 by Feltzing & Johnson (2002)

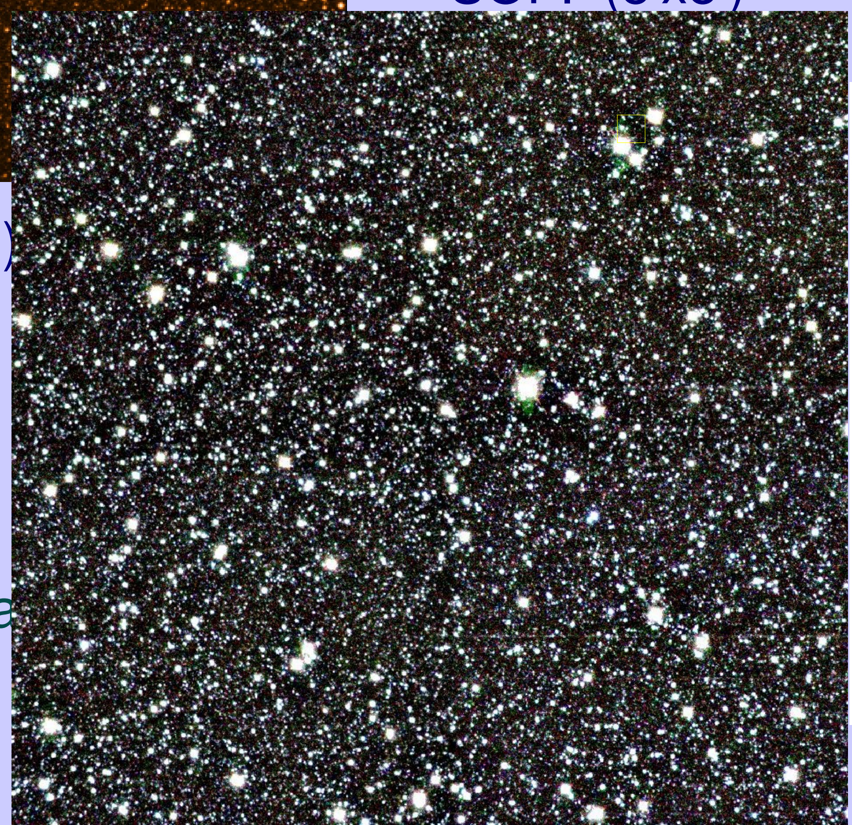
A Bulge Window

at (l,b=0,-6)





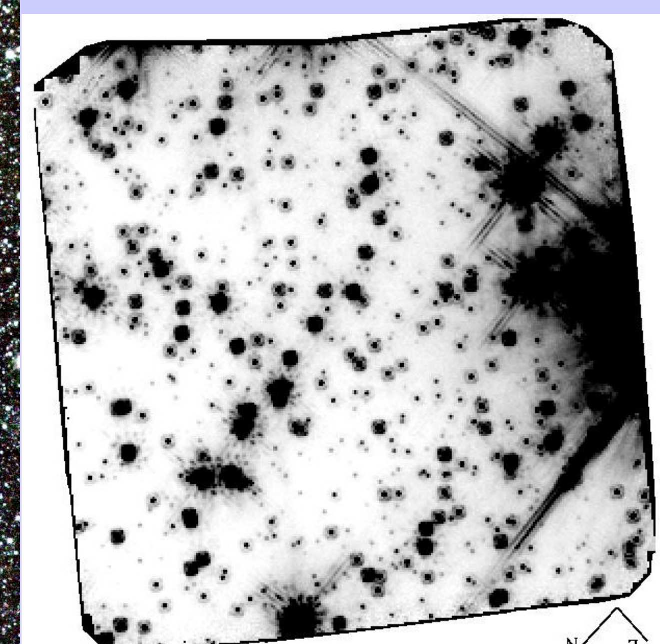
SOFI (8'x8')



WFI+2MASS (32'x32')

EIS

2nd public relea

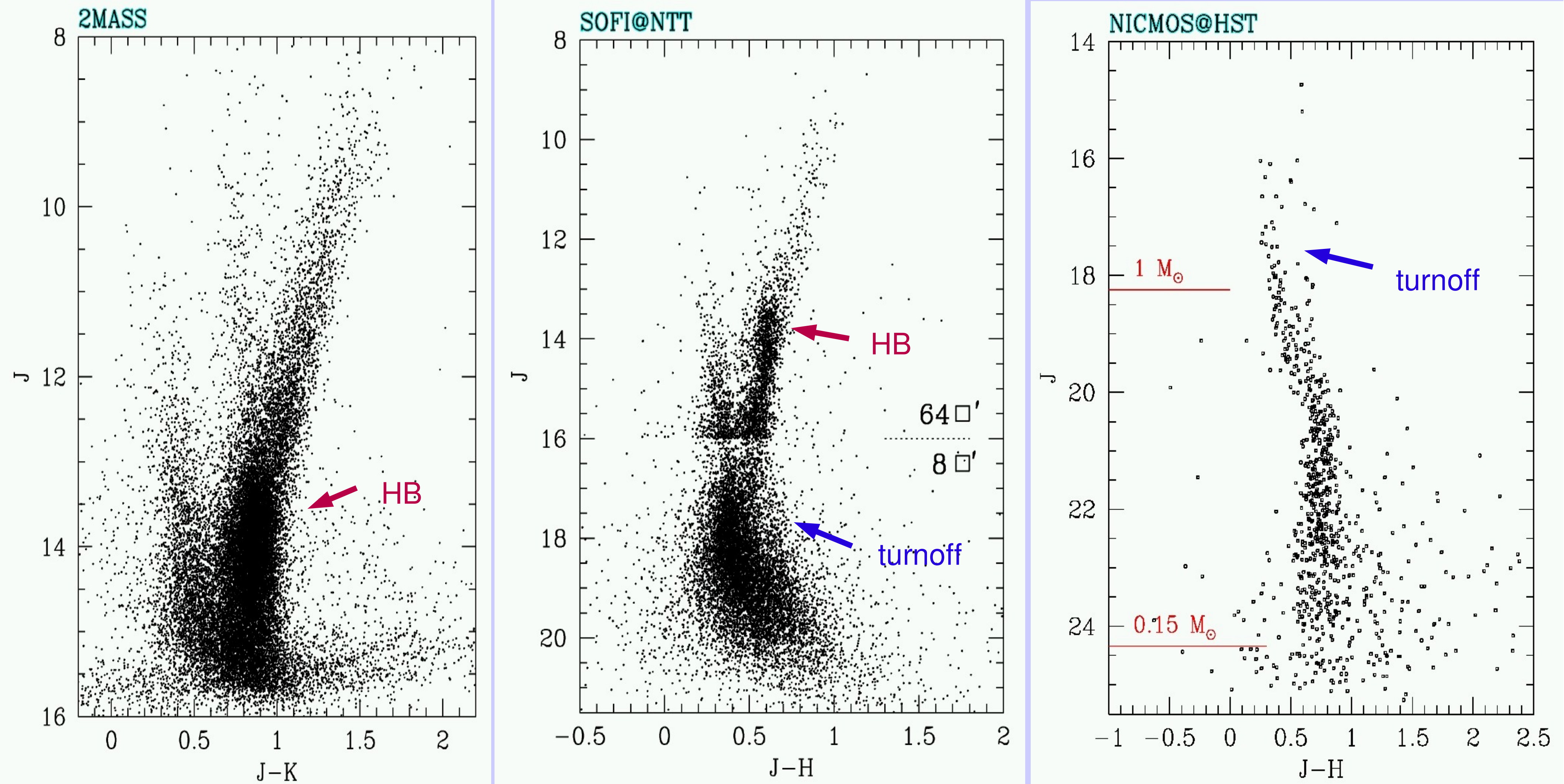


NICMOS (21"x21")

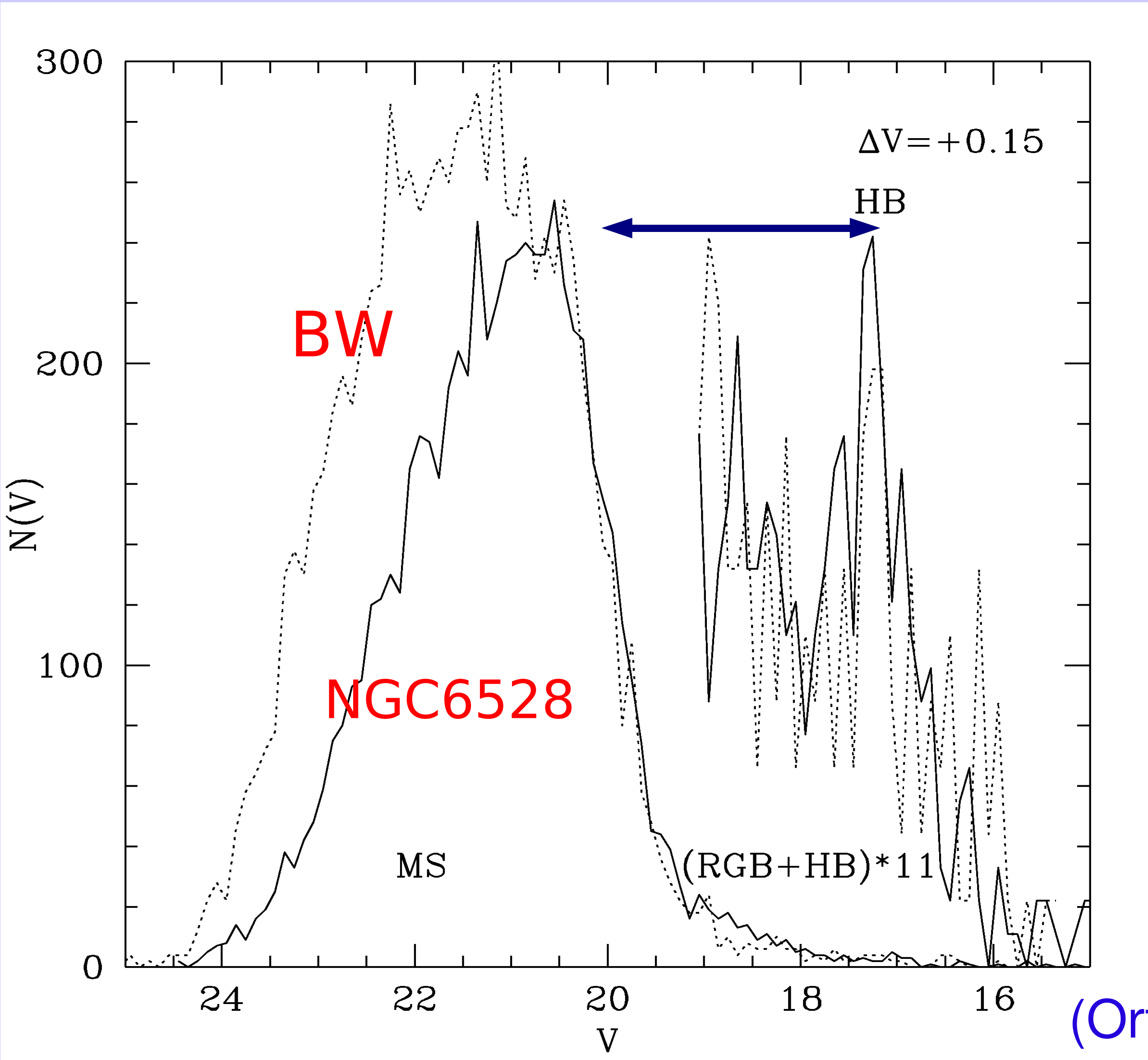
The near-IR CMD from Top to Bottom

Zoccali et al. (2003)

upper RGB | turnoff region | main sequence



The Bulge Age relative to the Bulge Metal Rich Globular Clusters



Bulge LF in Baade's Window (dotted) compared with the LF of NGC 6528 (solid)

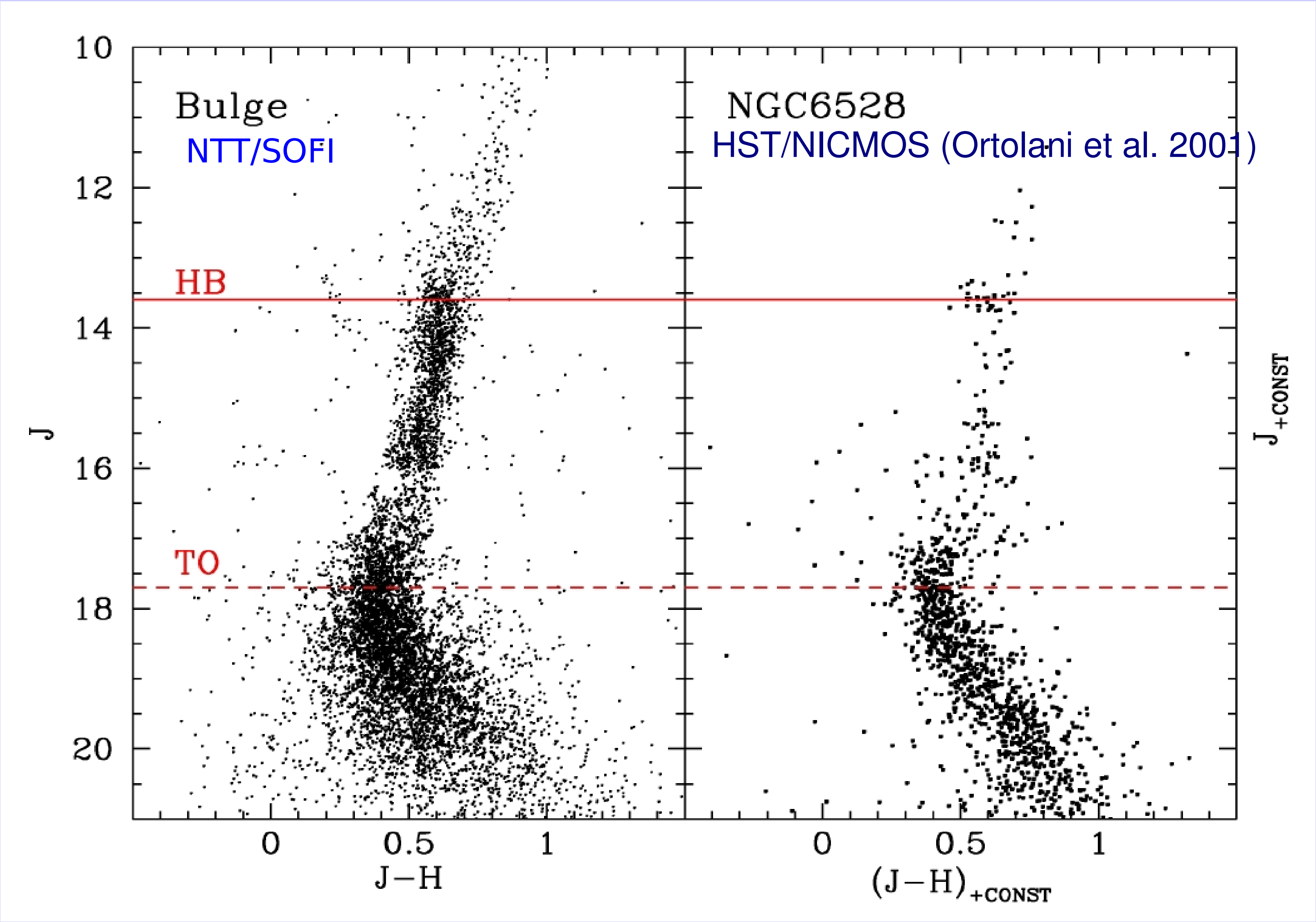
ΔΔV(HB-TO) in BW is the same as in NGC 6528,

thus cluster and bulge are coeval, and old (~12 Gyr)

(Ortolani et al. 1995)

The Bulge Age

Relative to Globular Clusters



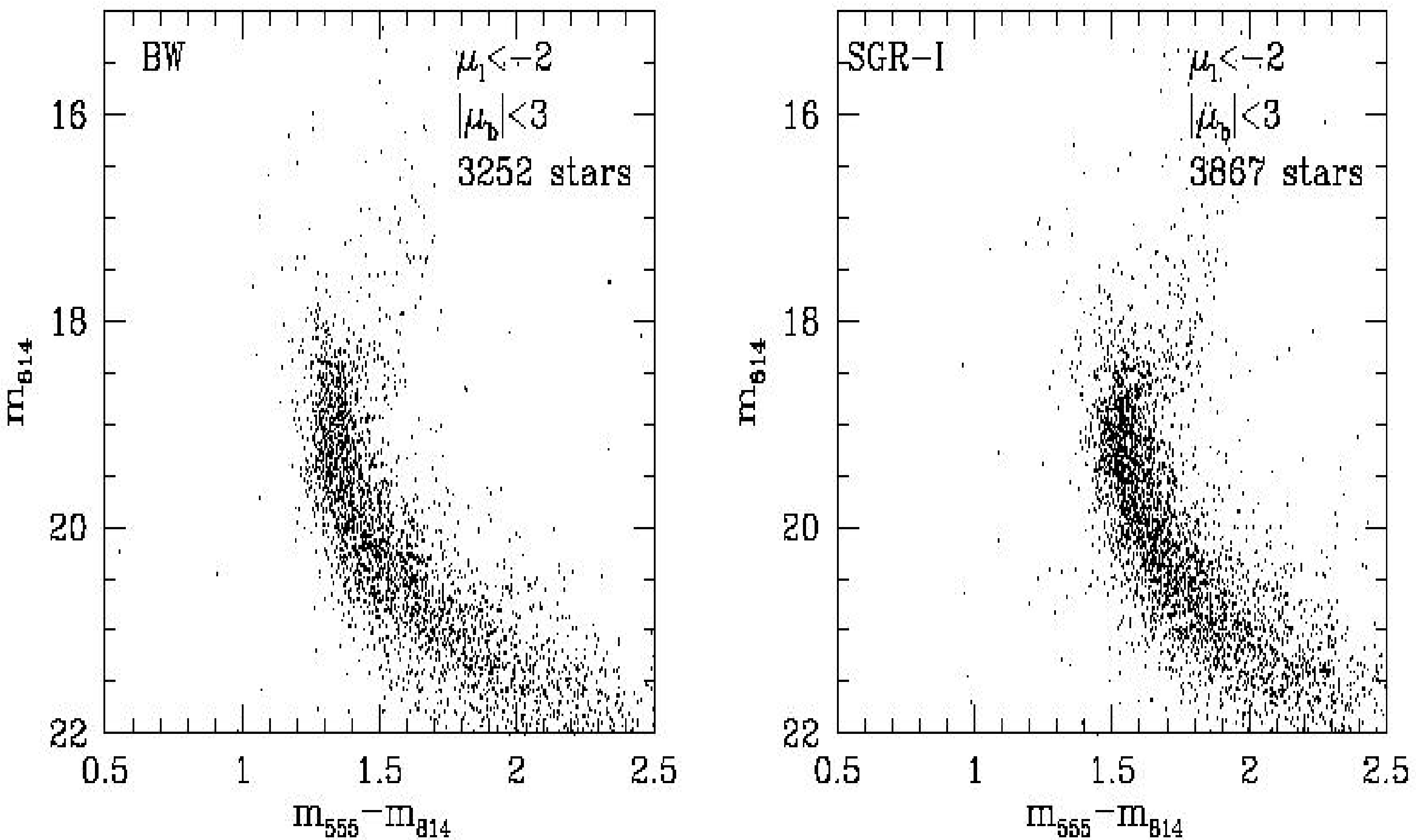
Age of the Bulge = Age of Bulge GCs

within ±2.5 Gyr

WFPC2 proper motion cleaning of CMDs from disk contaminants over BW & SGR-I

Kuijken & Rich (2002)

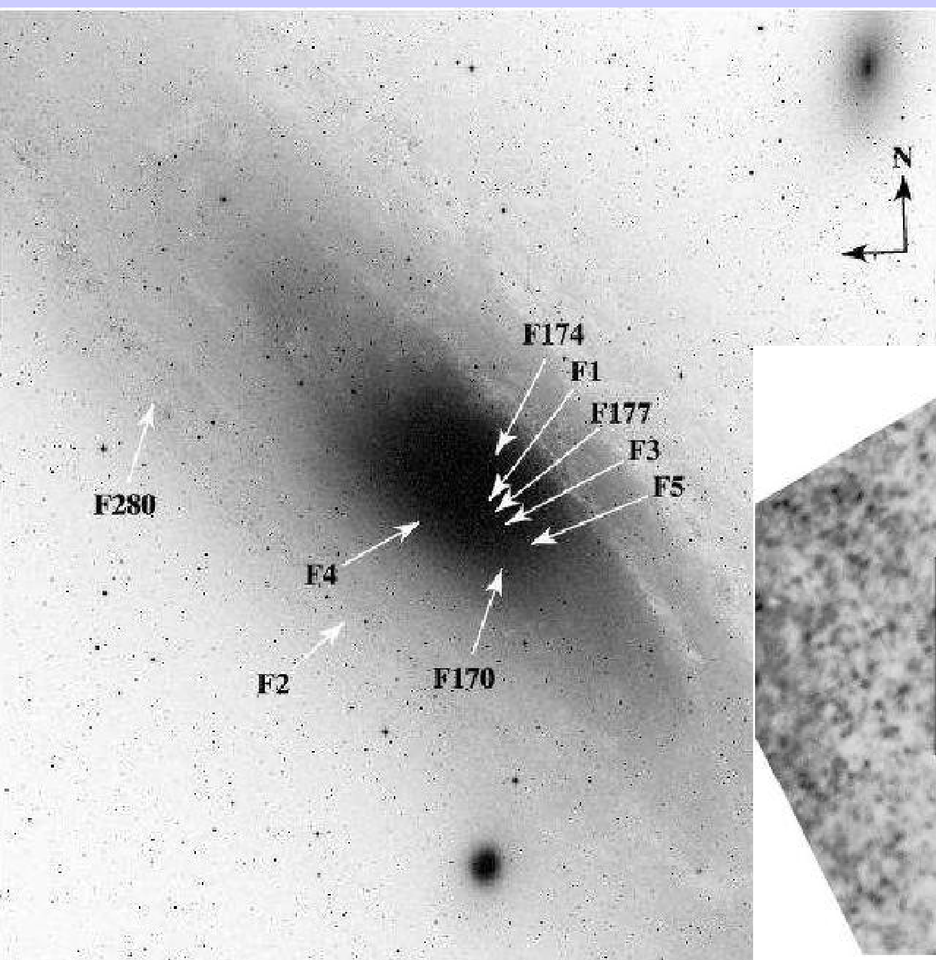
Note: Very clean Tornoff, no evidence for anything younger than the dominant population



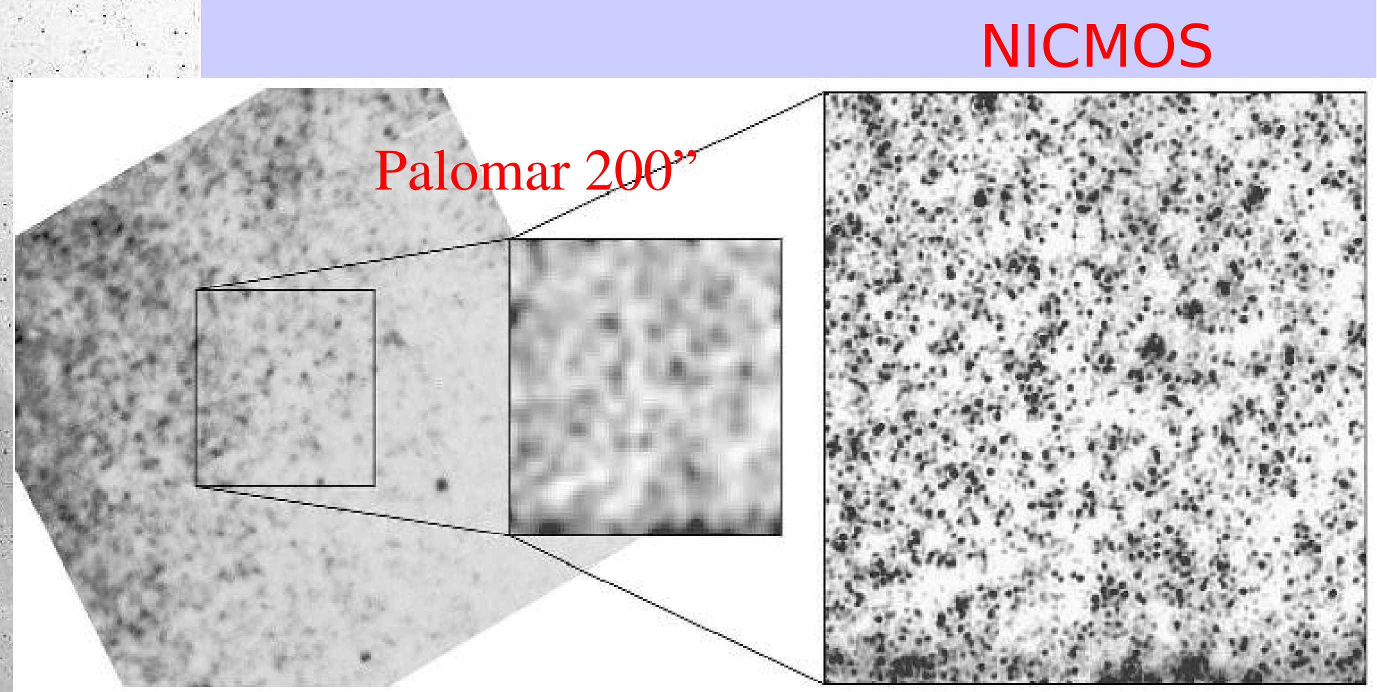
HST/NICMOS Observations in the Bulge of M31

Stephens et al. (2003)

Observed Fields



HST resolution helps deblending stellar groups that others interpreted as individual, Bright AGB stars and concluded that the bulge of M31 is young ....



The Luminosity Function of the M31 Bulge

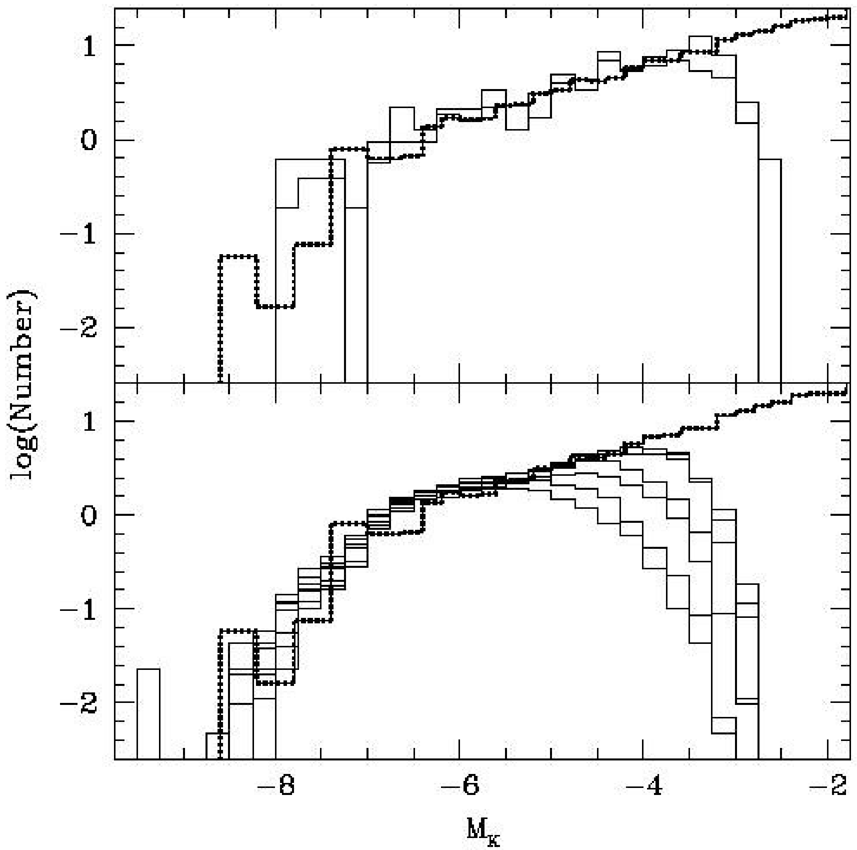


FIG. 10.—Comparison of M31 luminosity functions with that of Baade's window (BW). *Top*, M31 disk (F2 and F280) LFs (*solid line*) compared with the BW LF (*beaded line*); *bottom*, M31 bulge LFs (*solid line*) overplotted on the BW LF (*beaded line*). All LFs have been normalized in the range $-7 < M_K < -5.5$. The BW LF is a composite of measurements made by Frogel & Whitford (1987) and DePoy et al. (1993). Note that the M31 disk LFs extend more than 0.5 mag brighter than the cutoff at $M_K \sim -7.4$ seen in BW, while the M31 bulge LFs are in good agreement with the observations of BW.

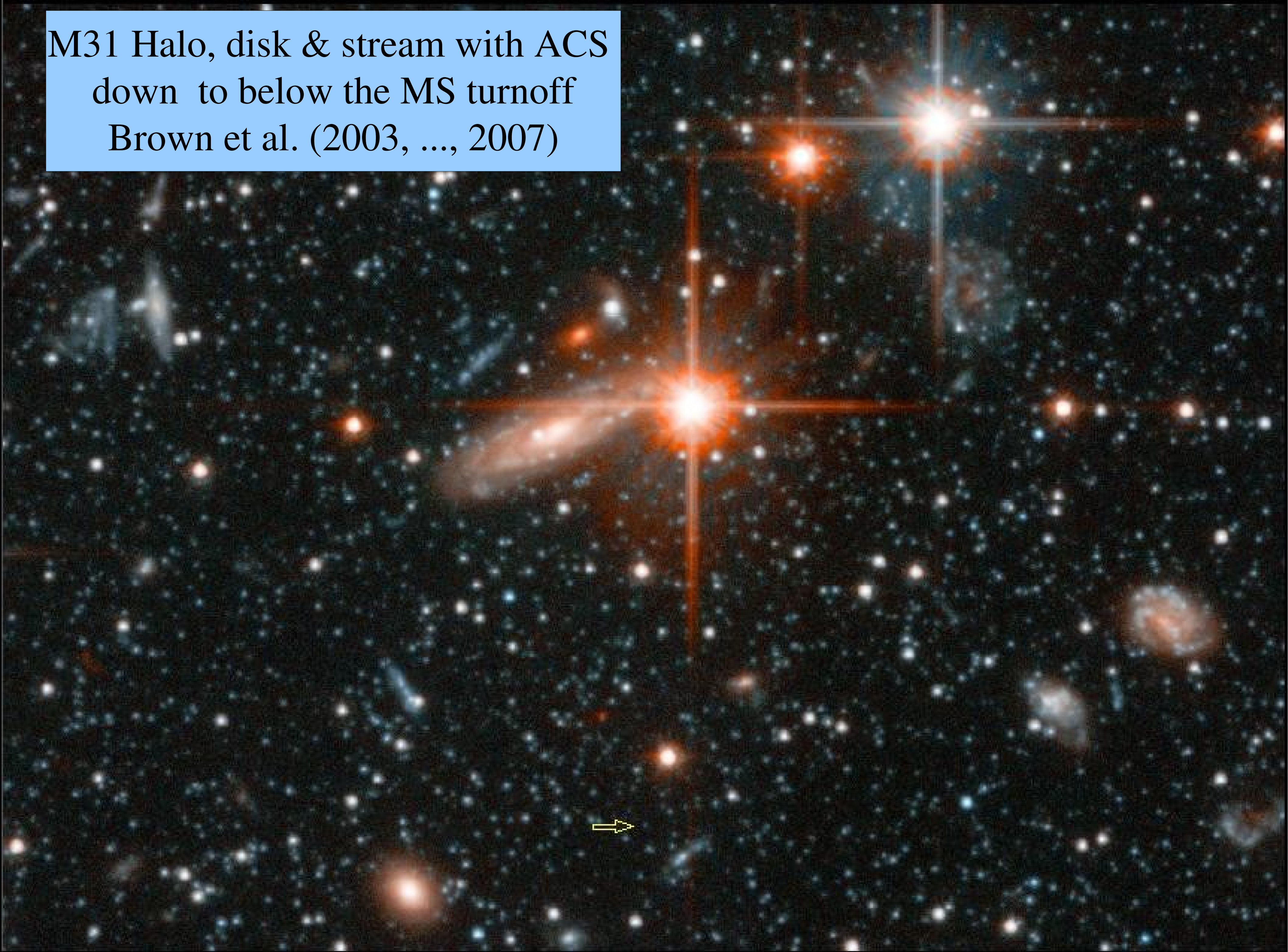
The K-band Luminosity Function of the bulge of M31 is indistinguishable from theat of the MW Bulge.

The MW Bulge is old ⇨ so is that of M31

Summary:
In the MW Bulge we see the MS turnoff which gives an age of ~12 Gyr

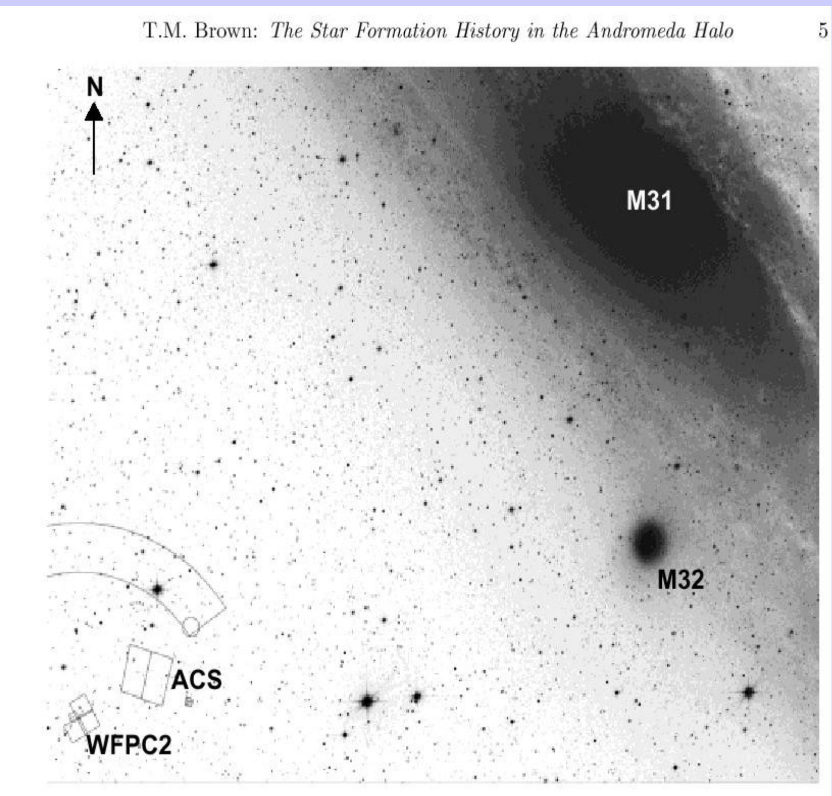
In M31 bulge we don't see the turnoff, but we measure the LF, which is the same ....

M31 Halo, disk & stream with ACS down to below the MS turnoff
Brown et al. (2003, ..., 2007)

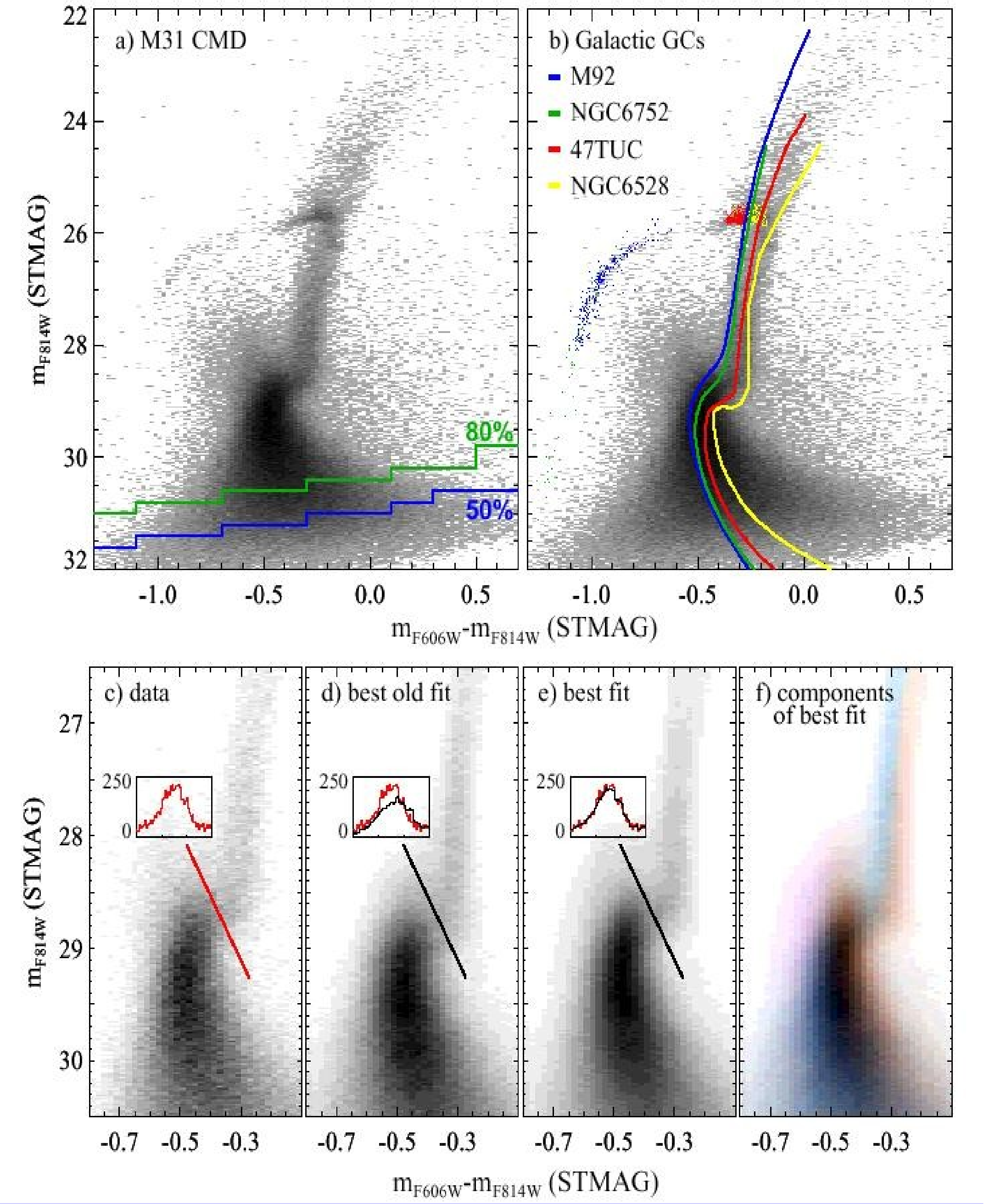


The M31 Bulge is old, but the Halo is young! (ironically)

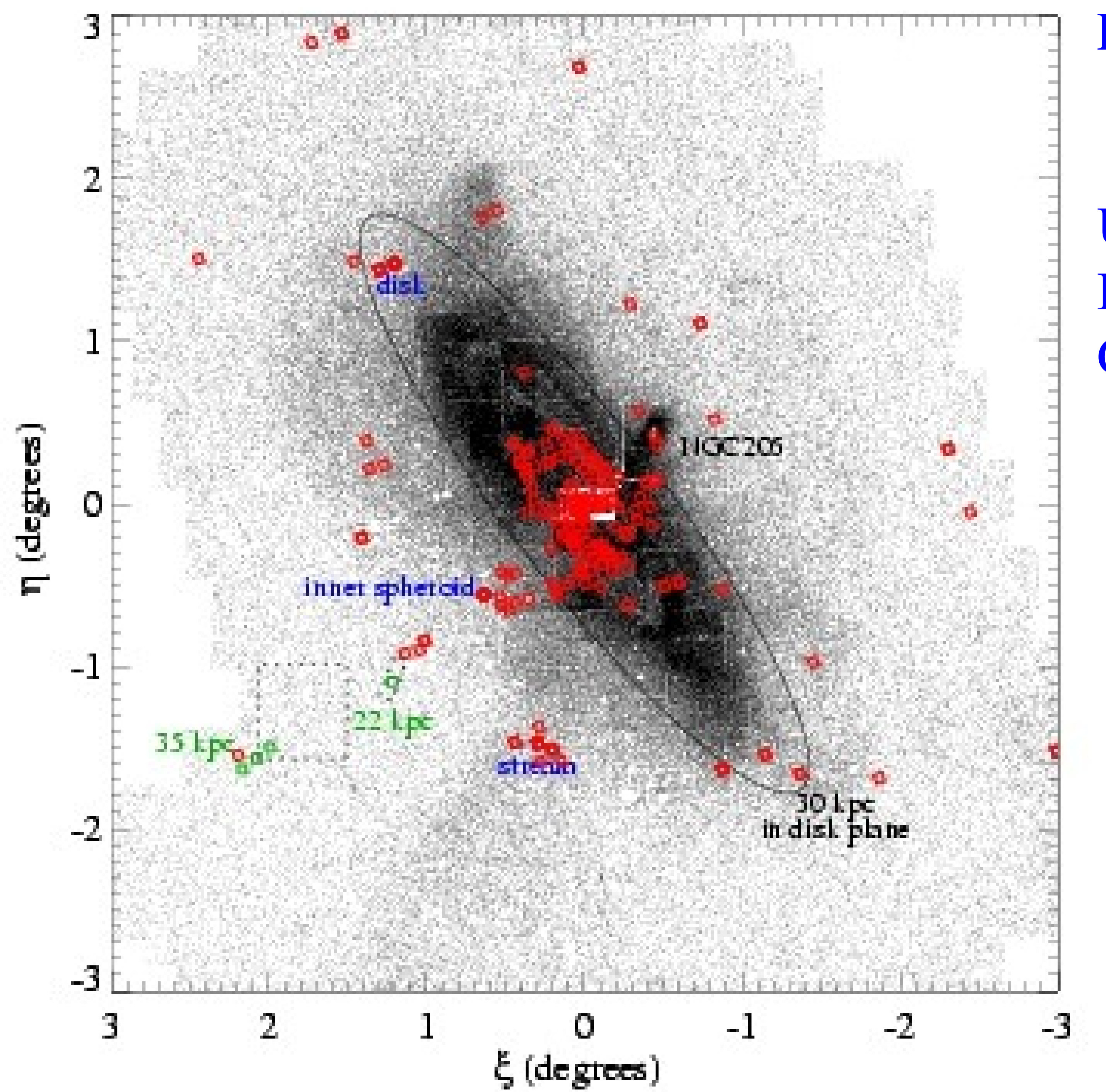
Brown et al. 2003, ApJ, 592, L17:
11 kpc from the center the halo of M31 is made ~40% by 6-8 Gyr old, solar metallicity stars, and ~60% by ~12-13 Gyrold metal poor stars. Disk debris from an earlier merger and/or due to major disk damage 6-8 Gyr ago?



121 Orbits with ACS in V&I

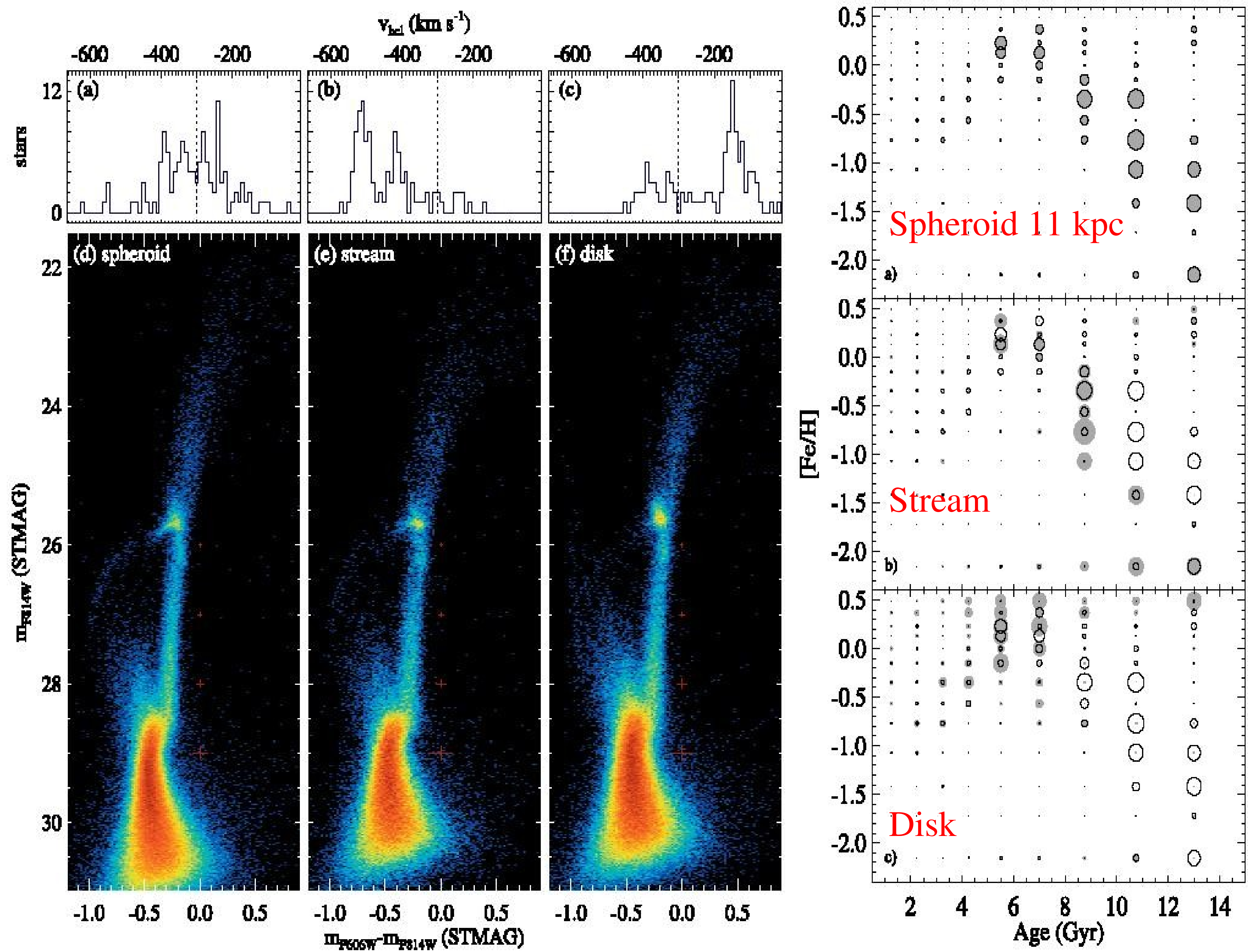


More Ultradeep ACS fields over M31

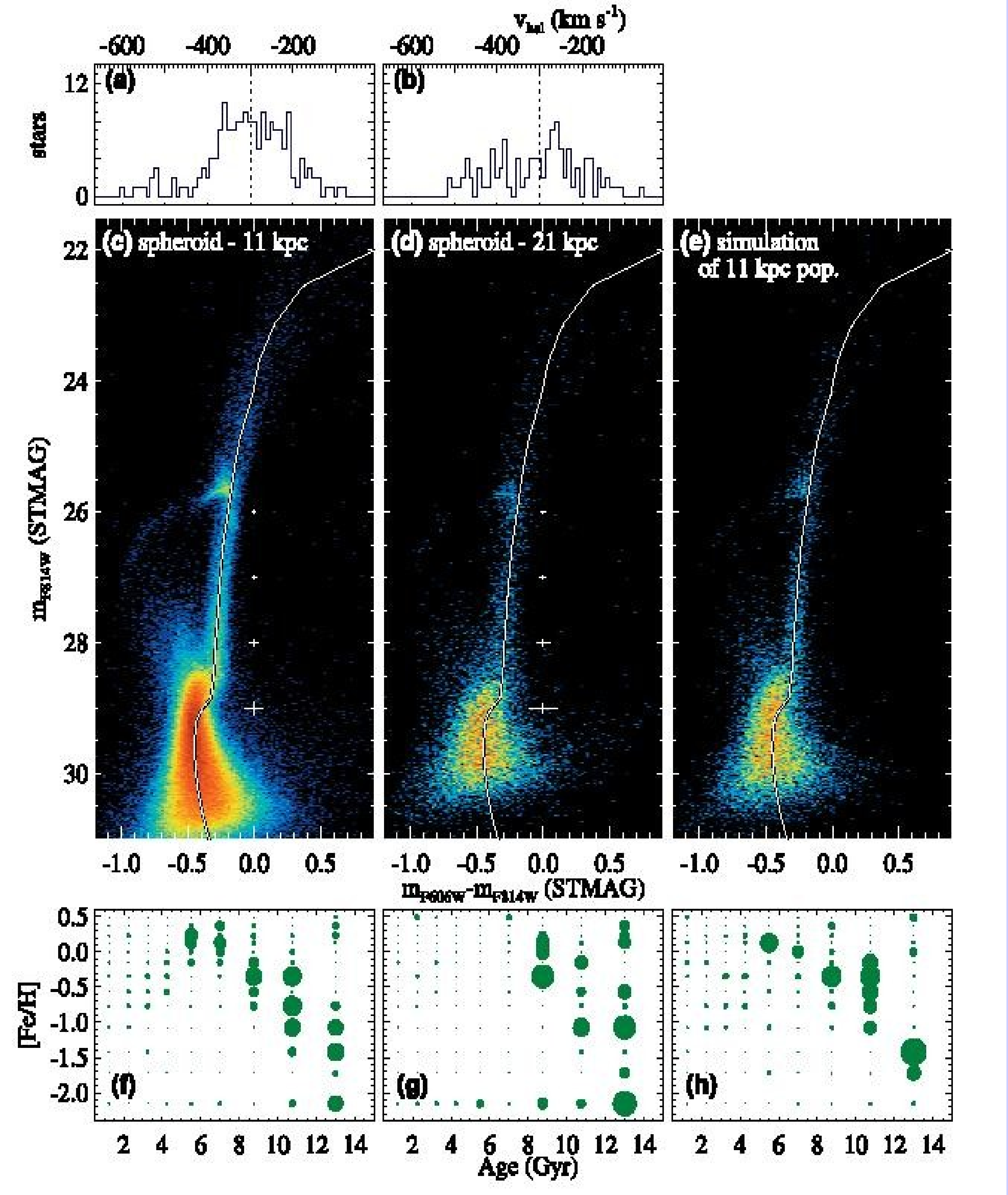


Ferguson et al (2005) INT map

Ultradeep ACS pointings by Brown et al. Are in Blue and Green



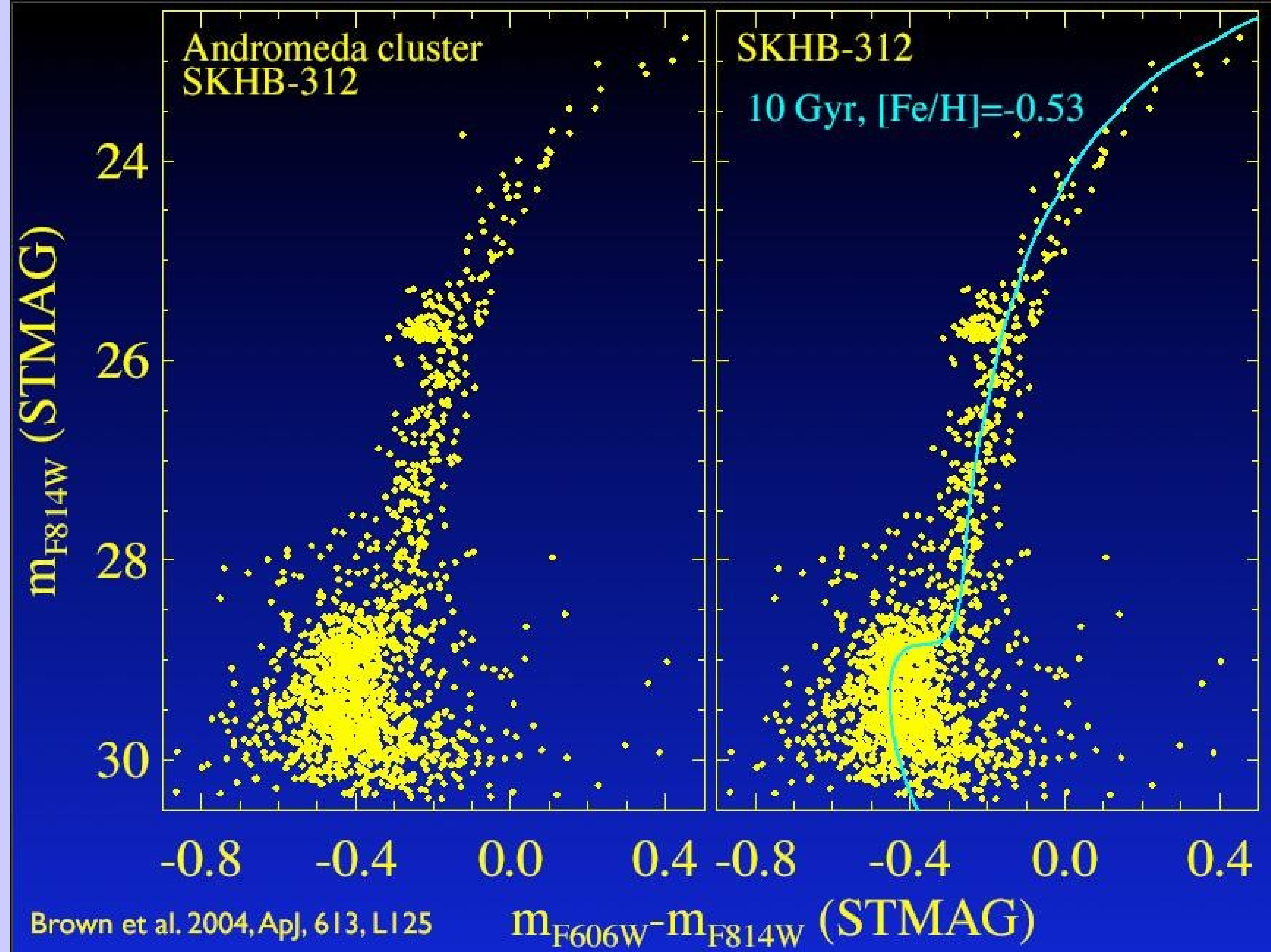
v_hel (km s^-1)
stars
(a)
(b)
(c)
(d) spheroid
(e) stream
(f) disk
m_F814W (STMAG)
m_F606W-m_F814W (STMAG)
Spheroid 11 kpc
Stream
Disk
[Fe/H]
Age (Gyr)
a)
b)
c)



M31 Spheroid along the minor axis at 11 and 21 kpc

One more Brown et al. Collaboration (2007)


Andromeda cluster SKHB-312



Andromeda cluster
SKHB-312
SKHB-312
10 Gyr, [Fe/H]=-0.53
24
26
28
30
m_F814W (STMAG)
-0.8
-0.4
0.0
0.4
-0.8
-0.4
0.0
0.4
m_F606W-m_F814W (STMAG)
Brown et al. 2004, ApJ, 613, L125

M31 vs MW

- The two bulges look coeval
- The two halos are very different, with ~7 Gyr, metal rich stars in M31 which are absent in the MW
- M31 disk more warped/damaged than that of the MW
- Giant stream(s) in M31 vs just Sagittarius in the MW
- Where did the metal rich stars in M31 halo form?

  In an accreted satellite?

  Or in the M31 disk that was badly damaged by it?

  Or in both?

Back to Bulges

As both MW and M31 Bulges are older than ~10 Gyr, they had to form at z~2 or beyond.

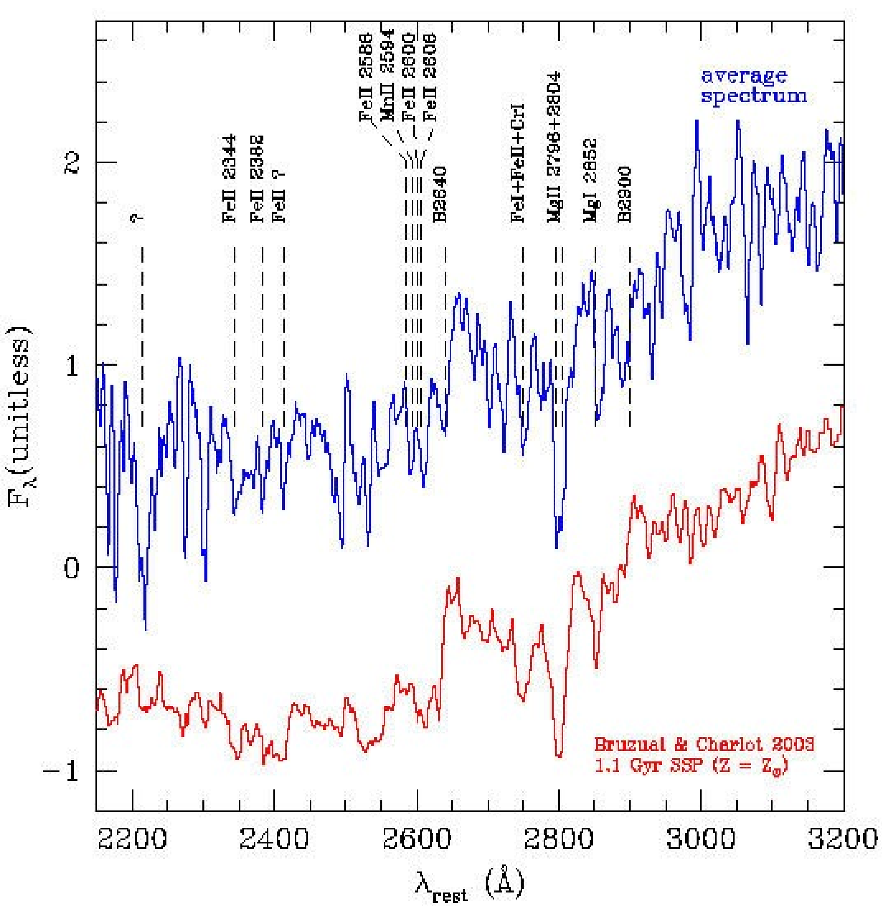
Q.: Do we see their peers at such high redshifts?

A.: Yes, we do ....

Old Bulges at z~1.6

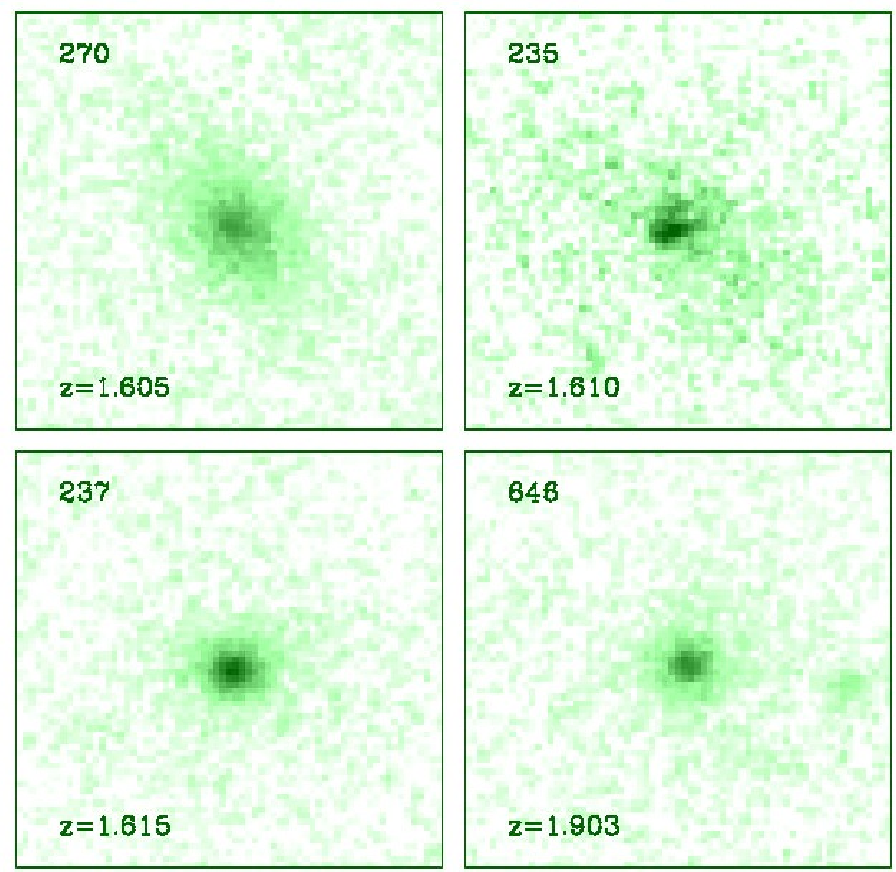
From Cimatti et al. (2004)

Coadded FORS2 spectrum vs. a 1.1 Gyr template

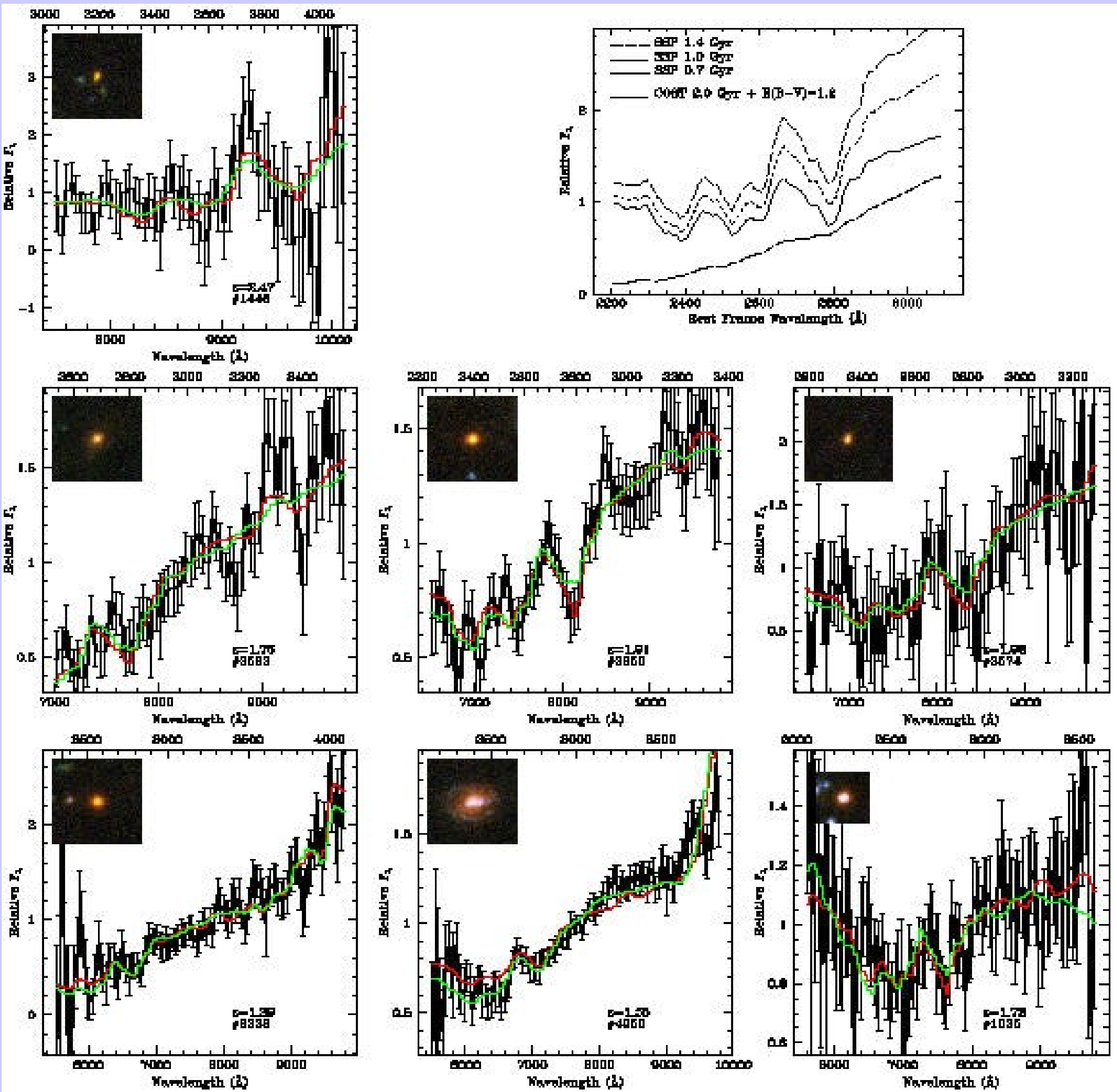


Deep HST/ACS z-band images (from GOODS)

2” = 17 kpc



UDF/ACS Cutouts & ACS/GRISM Spectra



← The Mg_{UV} Feature as a function of SSP age and for Continous SF + E(B-V)=1.2

Redshifts identified by the Mg_{UV} Feature agree with photo-z's

Daddi et al. (2005)

In Summary ....

There has been a very strong and successful use of HST by European astronomers, in the field of resolved stellar populations (globular clusters, MW & M31 Bulges and more, and high redshift galaxies).

HST+VLT Synergy has been very effectively exploited.

Much more to come in the final years of HST 2008-2014, with a more than ever powerful telescope (WFC3/COS/ACS/STIS/NICMOS/FGS)