The Globular Clusters-Field Stars Connection (in early type galaxies)

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A frequent statement:

"Globular clusters are powerful probes of the formation and evolution of galaxies"

Coined in the early 90's, according to M. Kissler Patig in "Globular Clusters: Guides to galaxies" , ESO Astroph. Symp. 2006.

However…,"important issues remain as open questions"

Can globular clusters be used as tracers of stellar populations in galaxies ?

- Probably NOT because:

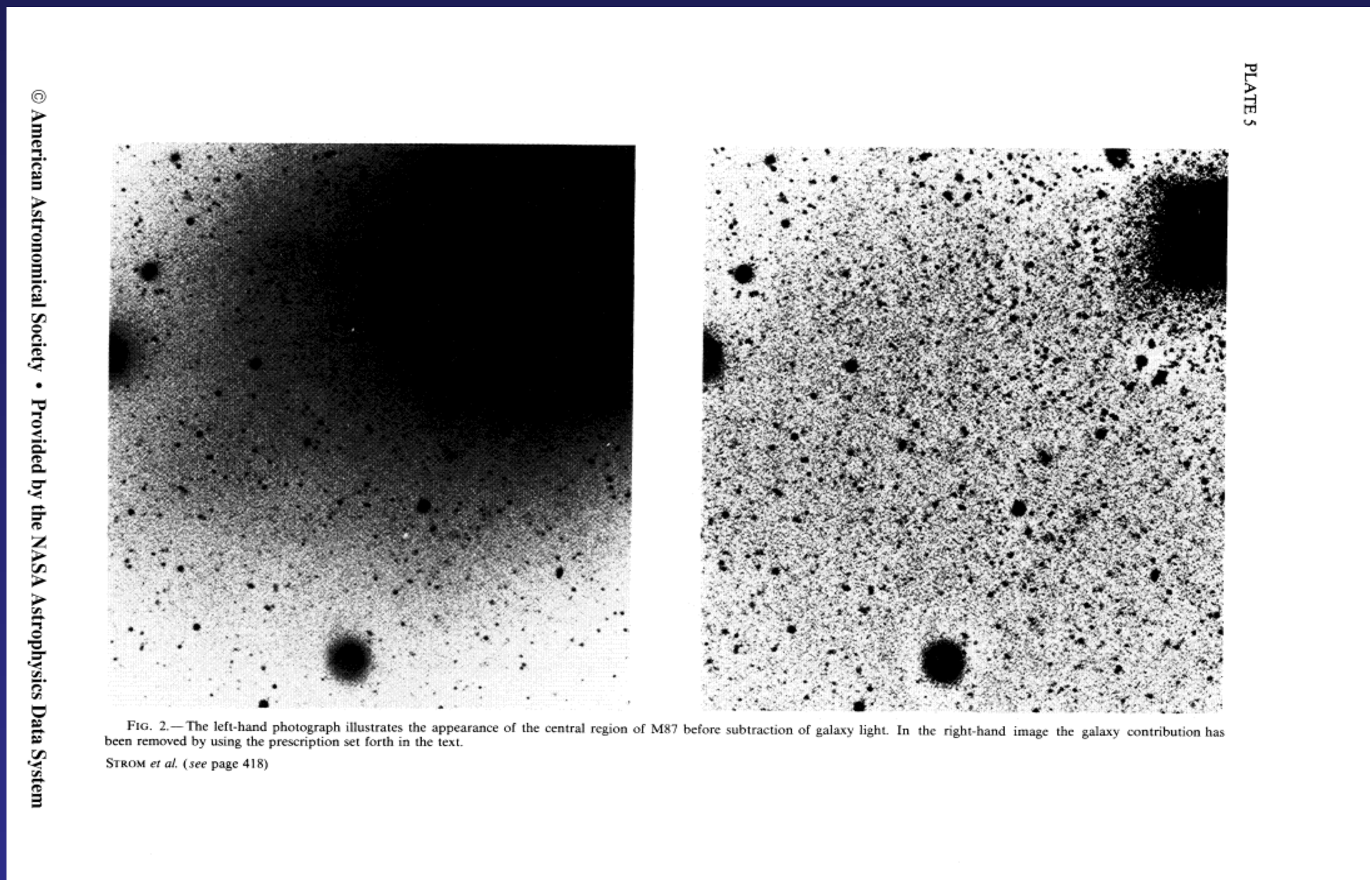
- GCs have more extendend spatial distributions than galaxy haloes (Racine 1978).

- GCs, as a whole, are bluer than the subjacent haloes (Forte et al. 1981, 1982).

- GCs exhibit colour gradients steeper than those of the haloes
  (e.g., Liu et al. 2011).

- GCs have bi-modal metallicity distributions while
  stars exhibit broad, unimodal and skewed distributions.

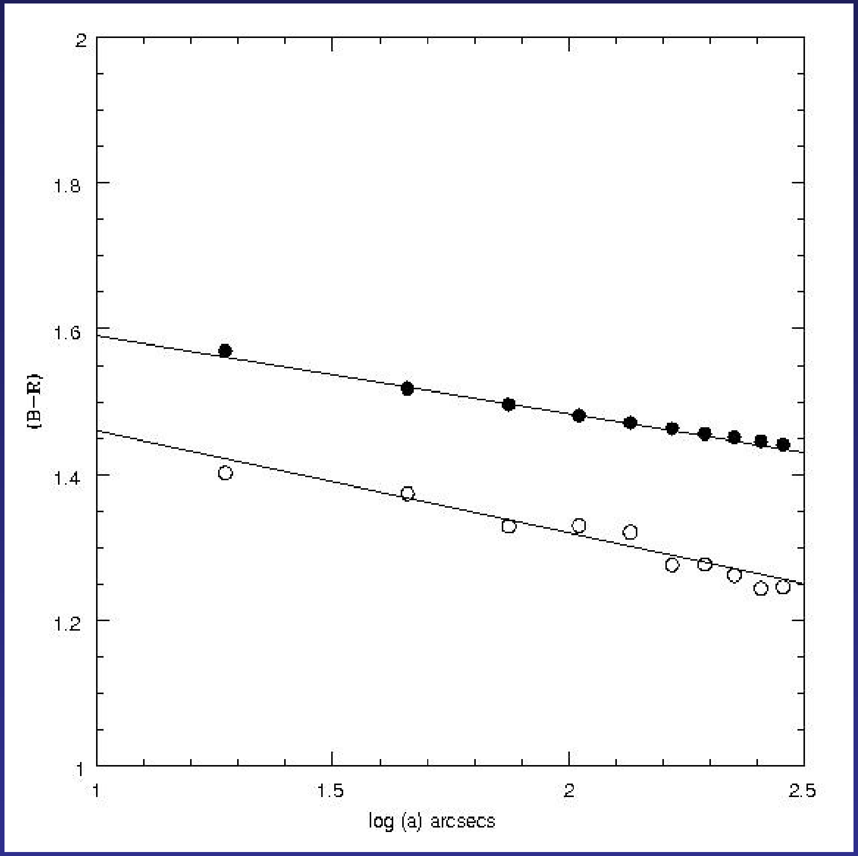
The GCs-stellar halo color offset in four Virgo galaxies:



GCs bluer than galaxy halo by 0.4 in (U-R)

Programs by Don Wells, circa 1980

GCs colour gradients are steeper than those of the galaxies: (the NGC 4486 case).



Galaxy

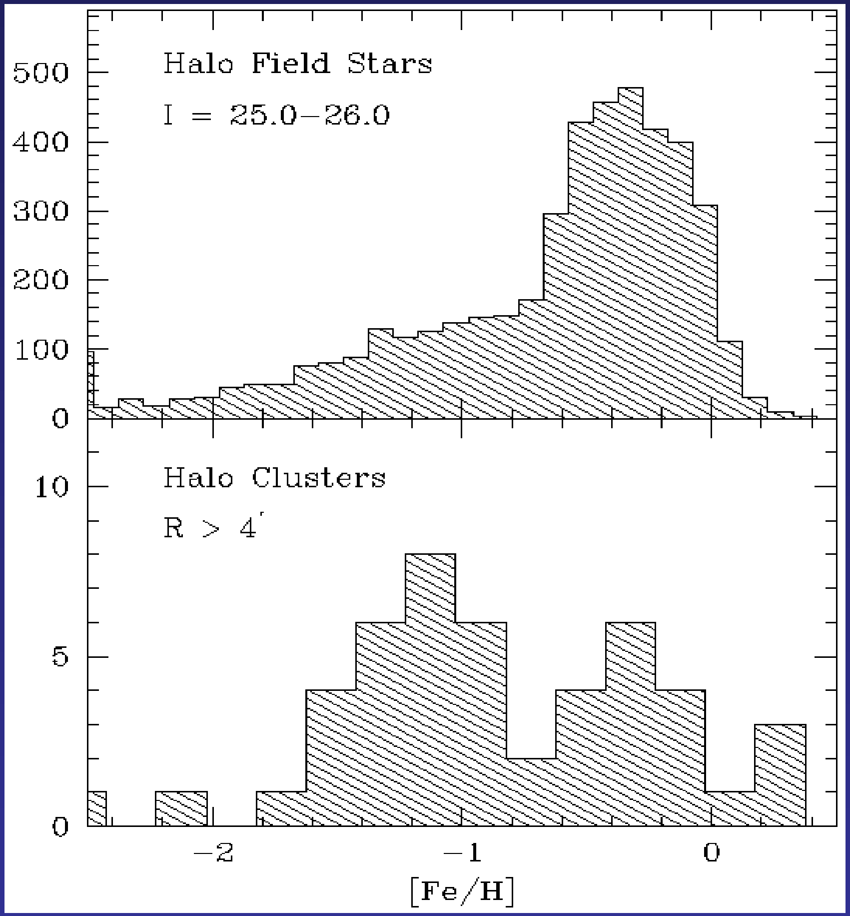
GCs

Michard, 2000

FFG, MNRAS 207

The field stars and GCs MDFs: NGC 5128

Rejkuba et al. 2007, 2010.



Resolved stars
(HST)

Globular clusters.

Moreover, there is a nice correlation between the number of GCs and that mass of central Black Holes….

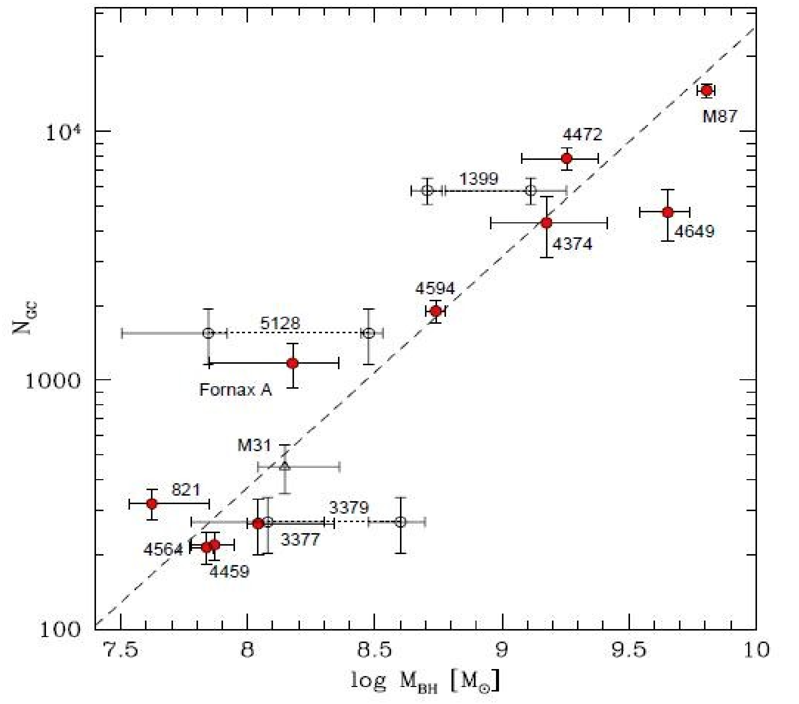


Fig. 1.— The number of globular clusters N_{GC} is shown as a function of SMBH mass M_{BH} for the 13 giant elliptical, lenticular and early-type spiral galaxies in Table 1. Open circles connected by dotted lines denote the galaxies NGC 1399, NGC 3379 and and NGC 5128 for which two estimates of the SMBH mass are given. The dashed curve shows the fit given by equation (2). The location of M31 is also plotted as an open triangle, but this galaxy does not contribute to the fit.

Burkert & Tremaine, 2010

Then, we´d better look for a GCs-BH connection rather than with stars !

However, these comparisons may NOT be as meaningful as they seem because:

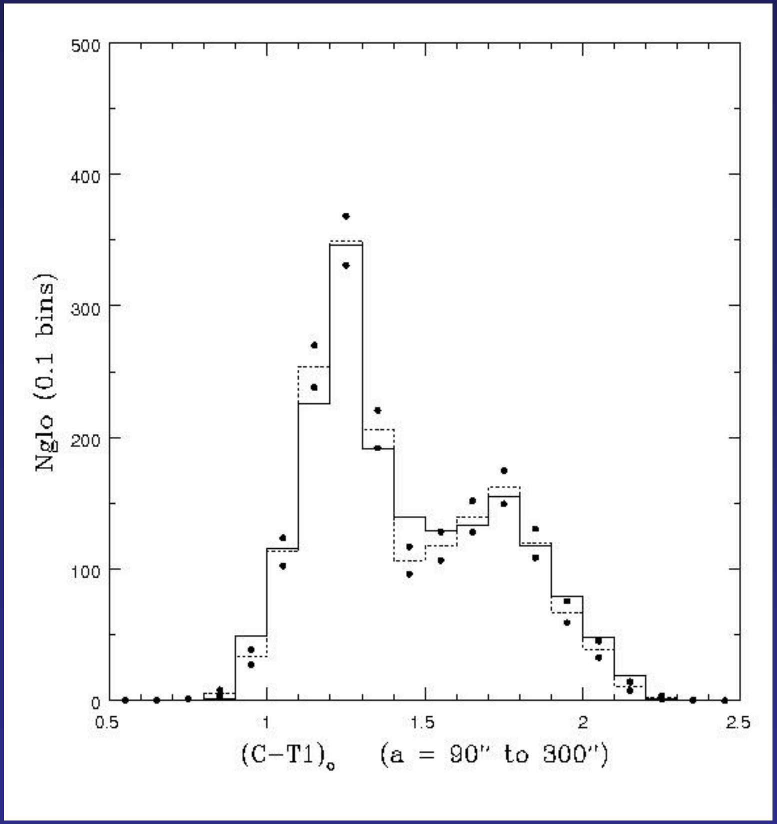
- GCs statistics are number weighted.
- Galaxy haloes properties come, naturally, in luminosity weighted format.
- The GCs-Black Hole relation is a secondary one (!)

Principal issues in this talk:

- I. GCs "Bi-modality".
- II. A possible quantitative link between GCs and field stars.
- III. Integrated properties of Virgo galaxies
- IV. Mapping NGC 4486.
- V. Large scale features, including dark matter distribution.

Globular clusters “Bi-modality”

Bimodality in NGC 4486 (M87): An example.



1776 GCs candidates brighter than T1=23.2

(dots: counting uncertainties)

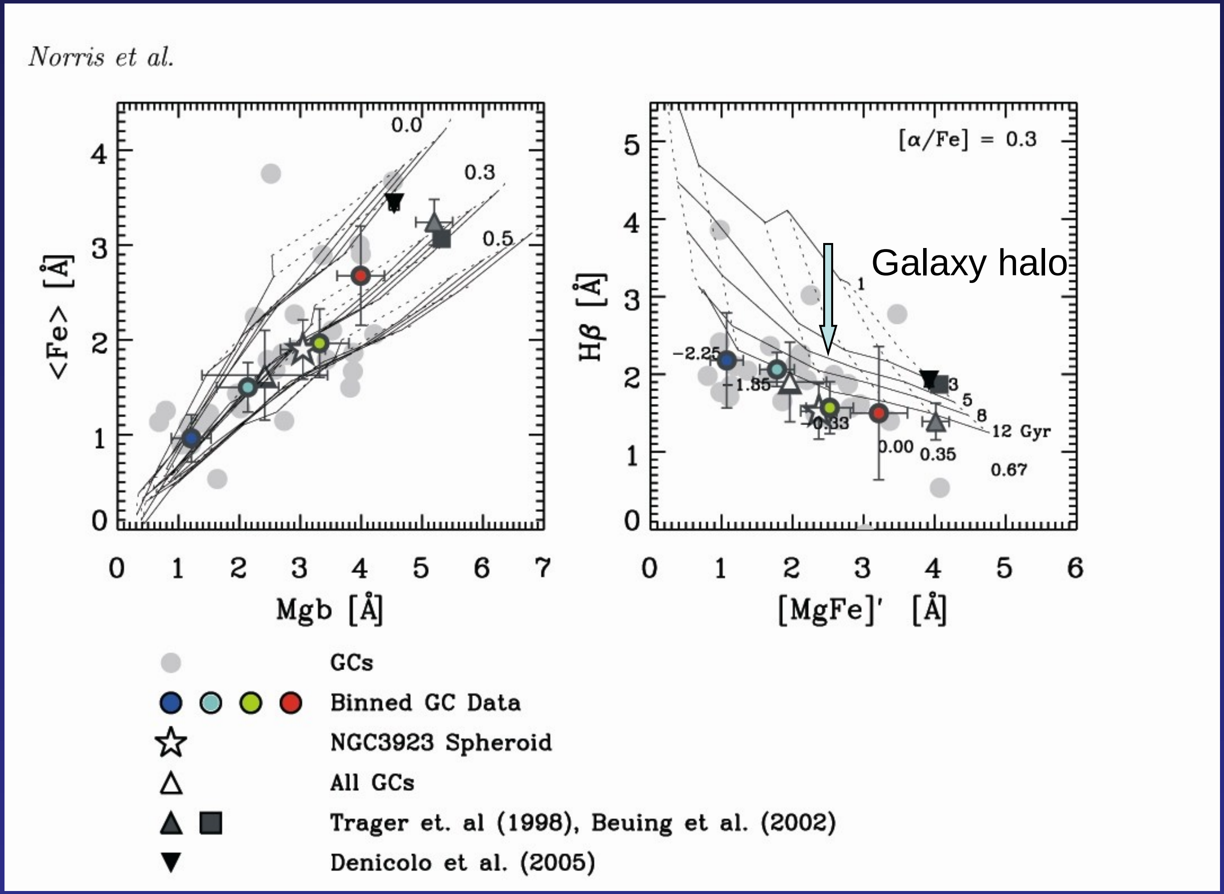
(C-T1)= 1.26 (g-z) +0.01

C & T1 from the Washington system

Ng(Z): From chemical abundance to colours.

- Colours depend on both age and chemical abundance.
- However, GCs and field stars in early type galaxies seem mostly coeval.
- We adopted an empirical connection between z and colours through an empirical relation.

Ages and metallicities from Lick indices:

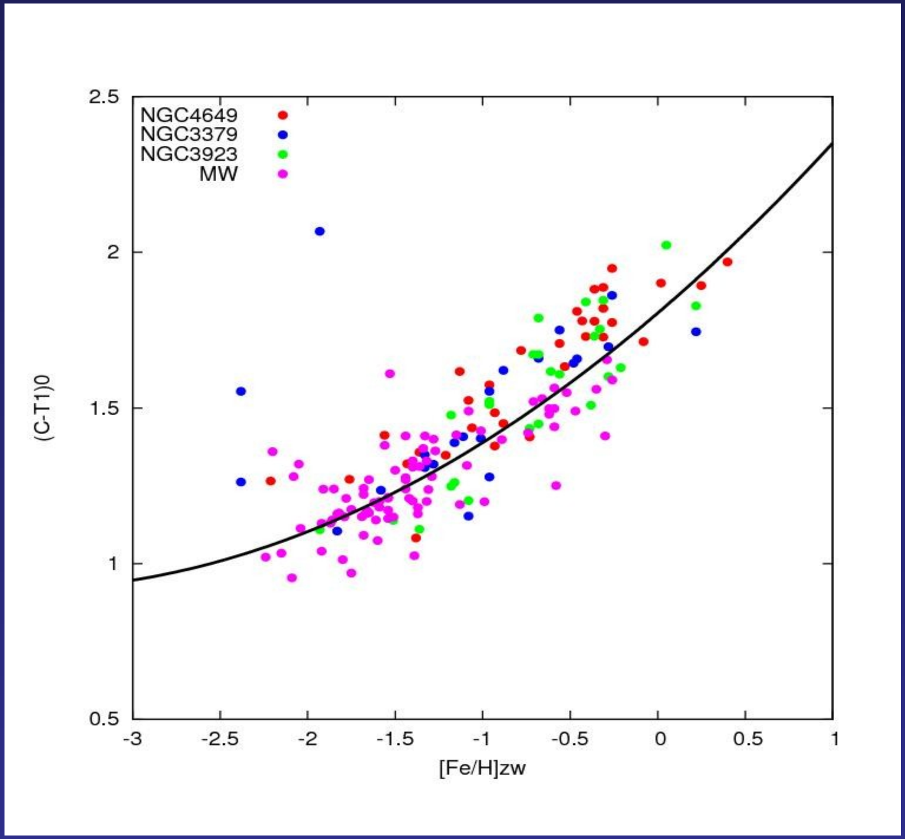


Bridges,T.
Faifer, F.
Forbes, D.
Forte, J.C.
Hanes, D.
Norris, M.
Pierce, M.
Sharples, R.
Zepf, S.

Norris et al. 2008

GCs and field stars look coeval.....

An empirical colour-metallicity relation (100 MW GCs plus 98 in other 3 galaxies).



Gemini North & South
(and MOS)

(C-T)=0.916+0.068([Fe/H]zw+3.75)**2

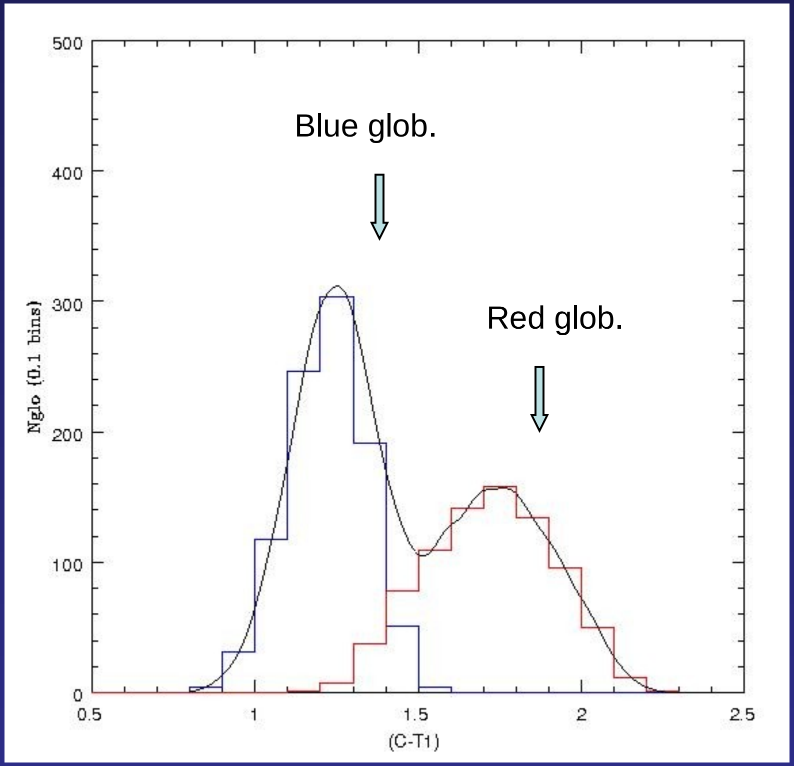
[Fe/H]zw: Zinn & West scale.

A “trial” function for the number of GCs with a given chemical abundance, Ng(z):

$$N_g(z) \approx e^{-\left(\frac{z - z_i}{z_s}\right)}$$

Zi= lowest abundance
Zs= Abundance scale parameter.

Bimodality fit: An example.



Nglo= 1776 clusters

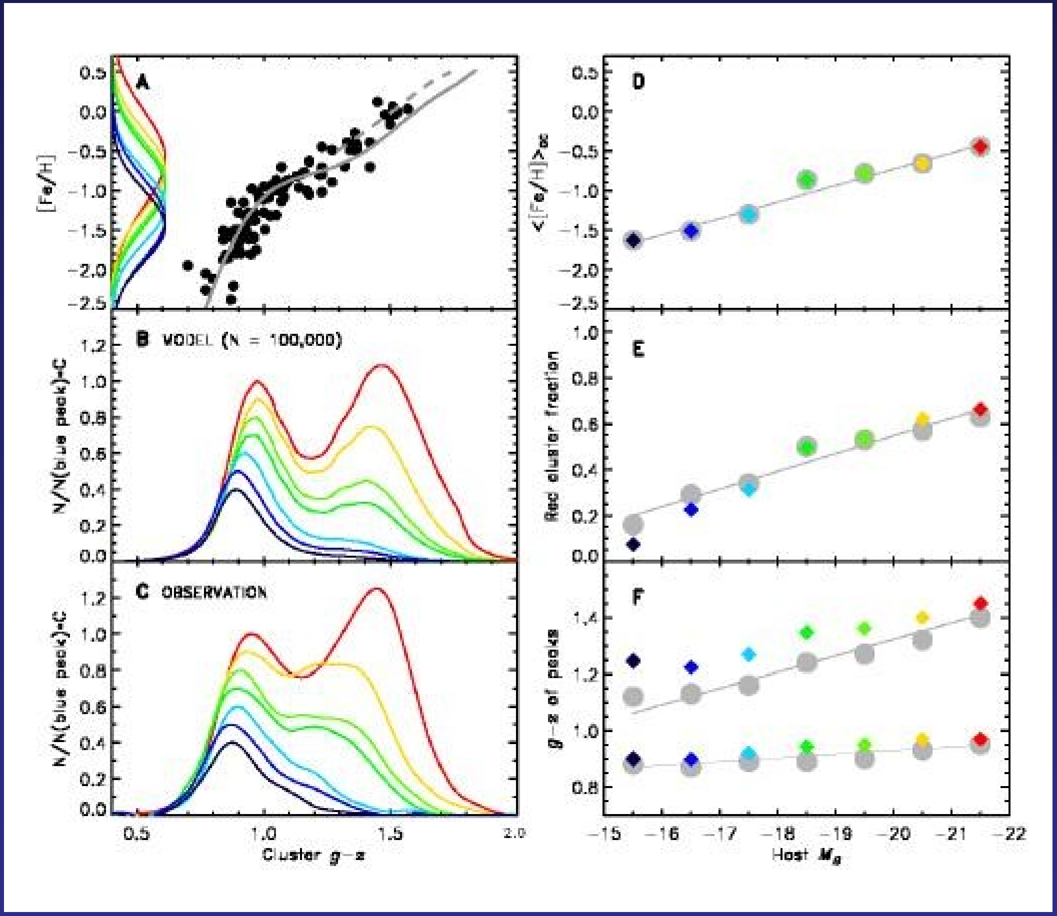
Nbg=950 Zsb=0.023 Zib=0.001+tilt

Nrg=826 Zsr=0.90 Zir=0.05

Widely different !

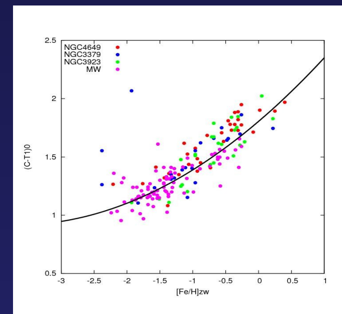
“blue” tilt: Dependence of abundance with cluster brightness.
About cero at T1=23.2 and 0.05 at T1=19.0

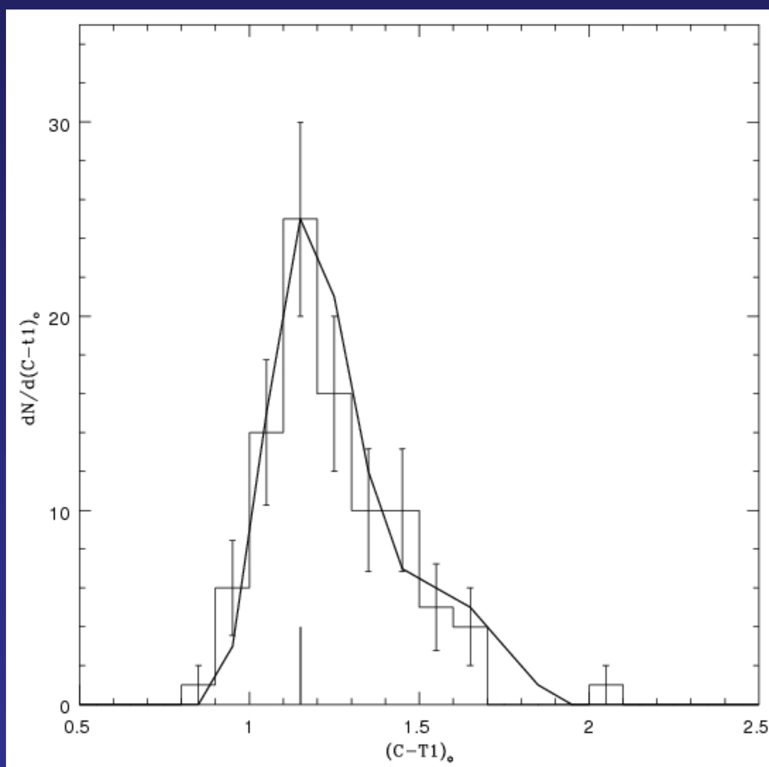
A different interpretation of bimodality (Yoon, 2006)



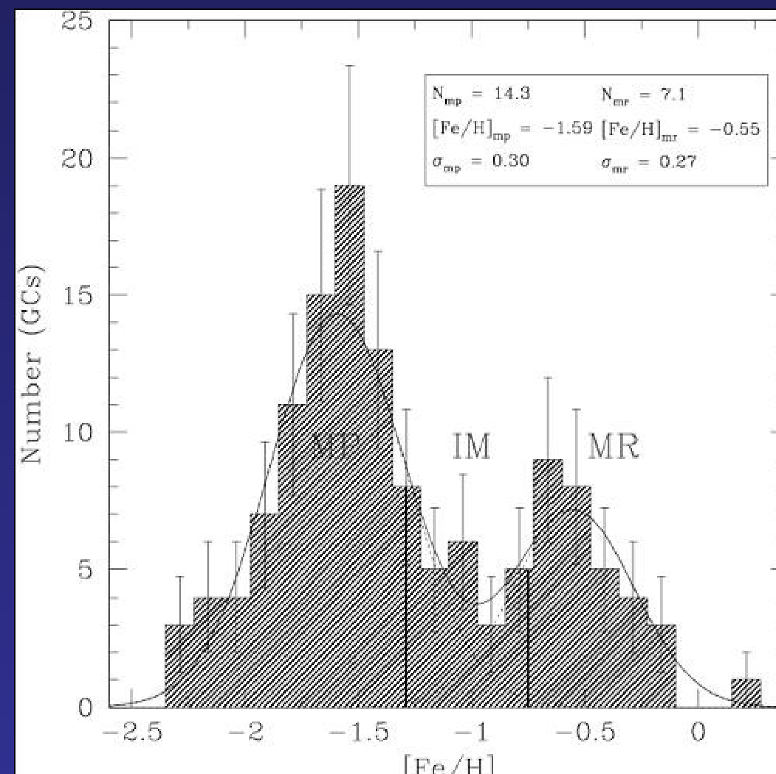
However....(a big one)

The case of the MW GCS





“Uni-modal”



“Bi-modal”

A possible approach:

The number of globular increases with M*: $\log N_{glo} \approx a \log M_* + b$

However, Nglo per unit M* decreases: $t = \frac{dN_{glo}}{dM_*}$ **(GCs efficiency)**

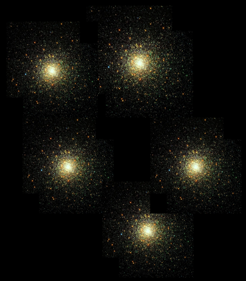
Both t and [z/H] follow power laws of M*:

$$\begin{cases} \log t \approx -c \log M_* + d \\ [z/H] \approx e \log M_* + f \end{cases}$$

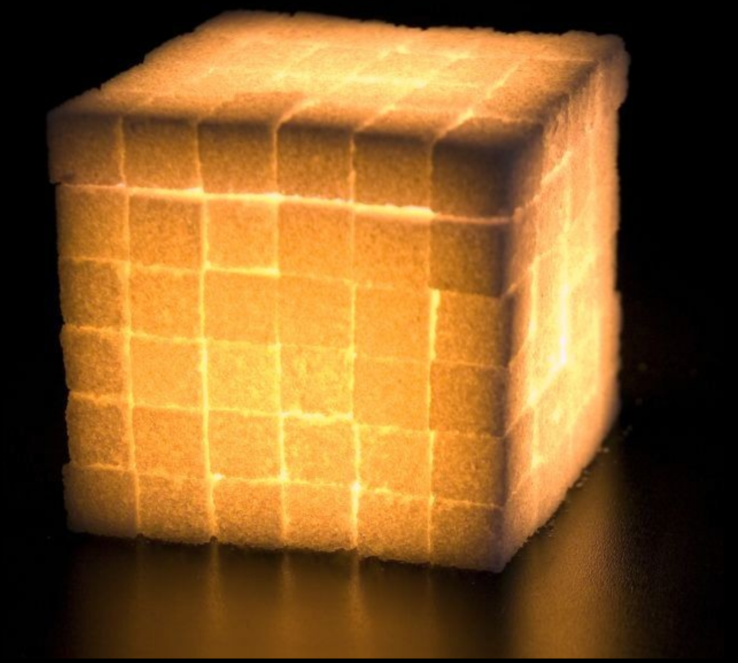
Then, at a given [z/H] ⟹

$$\frac{dN_{glo}}{dM_*} = \gamma\, e^{-\delta [z/H]}$$

dN(z) globular clusters



A “brick” of dM*(z) diffuse stellar mass



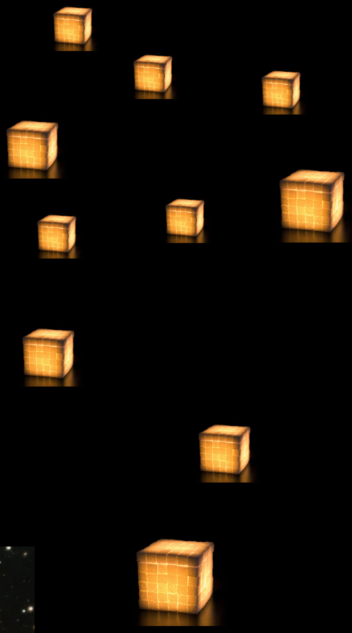
Trough Gamma & Delta

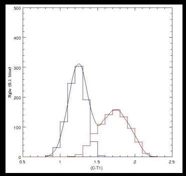
Blue and Red globs.
Characterized by their
N, Zs, Zi

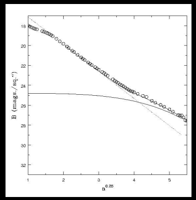
Stars that share:

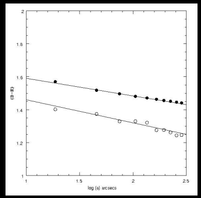
Age (or very similar)
Chemical abundance.
Colours.
(M/L) typified by z and age.
Spatial distribution

Many bricks are needed to form a galaxy









$$\frac{dN(z)}{dM_*(z)} = \gamma e^{-\delta[z/H]}$$

$$dM_*(z) = \frac{1}{\gamma} N_g(z)\, e^{\delta[z/H]}\, dz$$

$$M_* = \int_{z_{low}}^{z_{upp}} dM_*(z)$$

$$L_{*_\lambda} = \int_{z_{low}}^{z_{upp}} R_\lambda^{-1}\, dM_*(z)$$

(R is the stellar mass to luminosity ratio at a given photometric band)

$$z_* = \frac{\int dM(z) z}{M_*}$$

(Mass weighted chemical abundance)

For a given Ng(z)

- γ: Normalization Parameter
- δ: determines
  - Colours
  - Mean chemical Abundance
  - Stellar Mass to Luminosity Ratio at λ

e.g.

$$R_B = 3.70 + ([z/H] + 2.0)^{2.5}$$

(Age=12 gy, from Worthey 1995)

Brief outline:

- GCs with a given Z are generated through Monte Carlo and according to Zs and Zi (for ecah GCs sub-population).

- Z is transformed to [Fe/H]zw (Mendel et al. 2007).
  [Fe/H]zw = [Z/H] - 0.131.

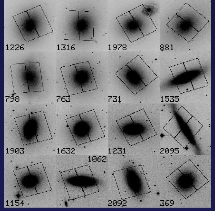
- (C-T1)o colours are derived from the empirical calibration.
  Interstellar reddening and errors are added in order to
  fit the GCs colour histogram.

- Integrated galaxy brightness and colours are fit trough Gamma and Delta (this imply a given M*(Z)).

Integrated properties of 60 galaxies in the Virgo ACS

Forte, Vega, Faifer 2009, 2011

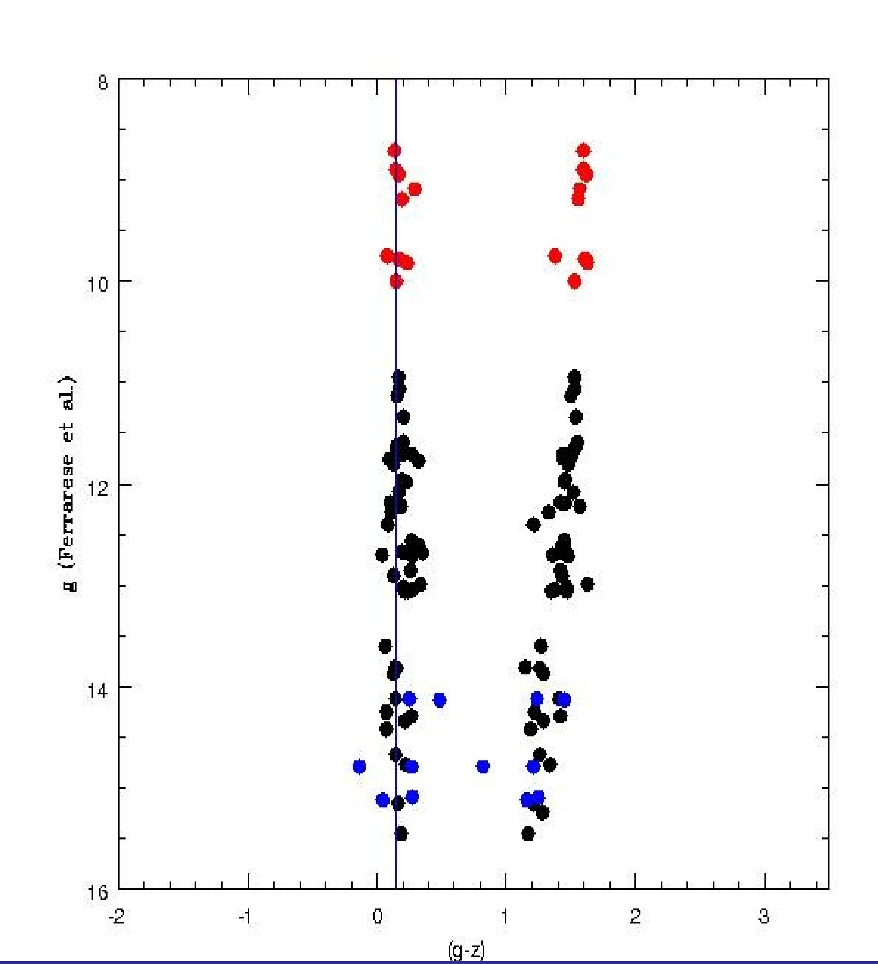
(Data from Cote et al. 2004, Ferrarese et al. 2007, Peng et al 2008,2009)



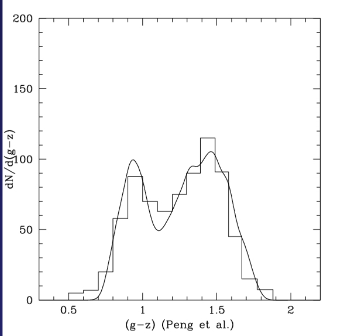
g vs. (g-z) diagram for 60 galaxies in Virgo

GCs colour distribution

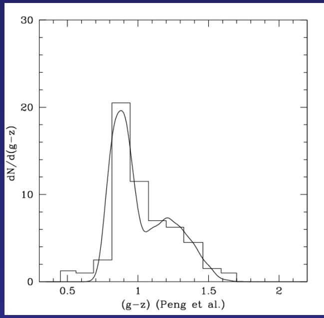
ACS



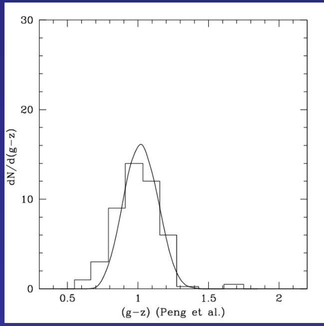
Forte, Vega & Faifer MNRAS 2009



Bimodals

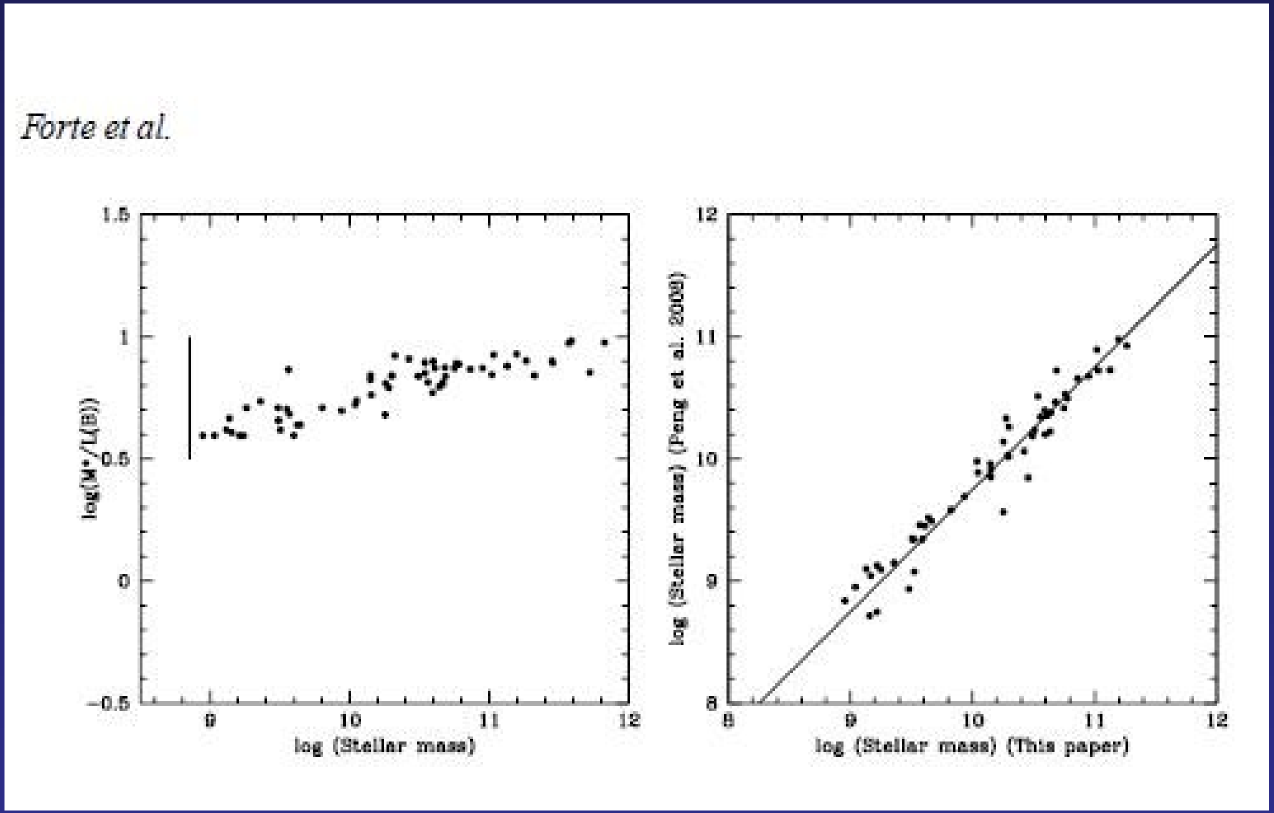


“Transition”



Unimodals

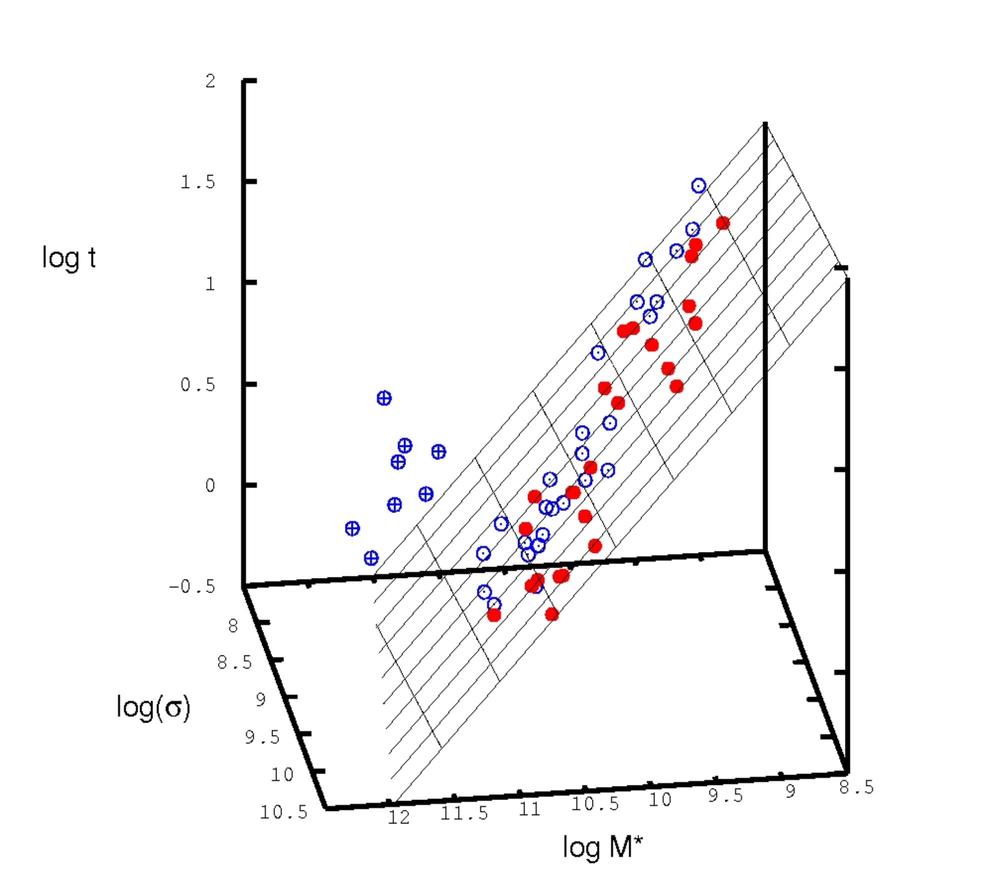
Stellar mass to Blue luminosity ratio (left) and a comparison of stellar masses (with Peng et al. 2008).



Slope=1

(M/L) range from Napolitano et al. 2007

The Efficiency-Mass-Mass density space



log(t)=-0.70*log(M*)+0.11*log(Sm)+6.78

Sm: projected mass density inside re

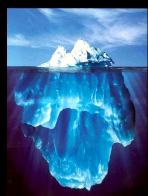
Mergers: ?

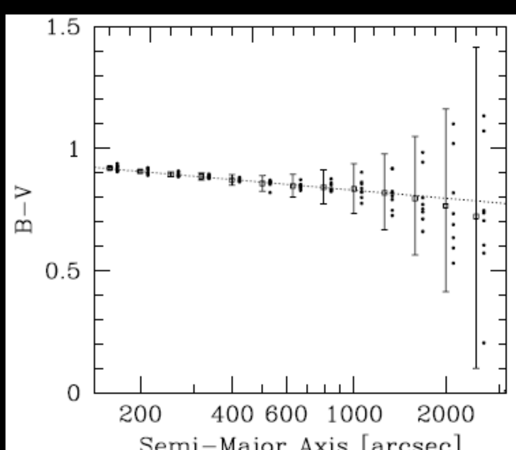
Mapping NGC 4486 trough its GC System

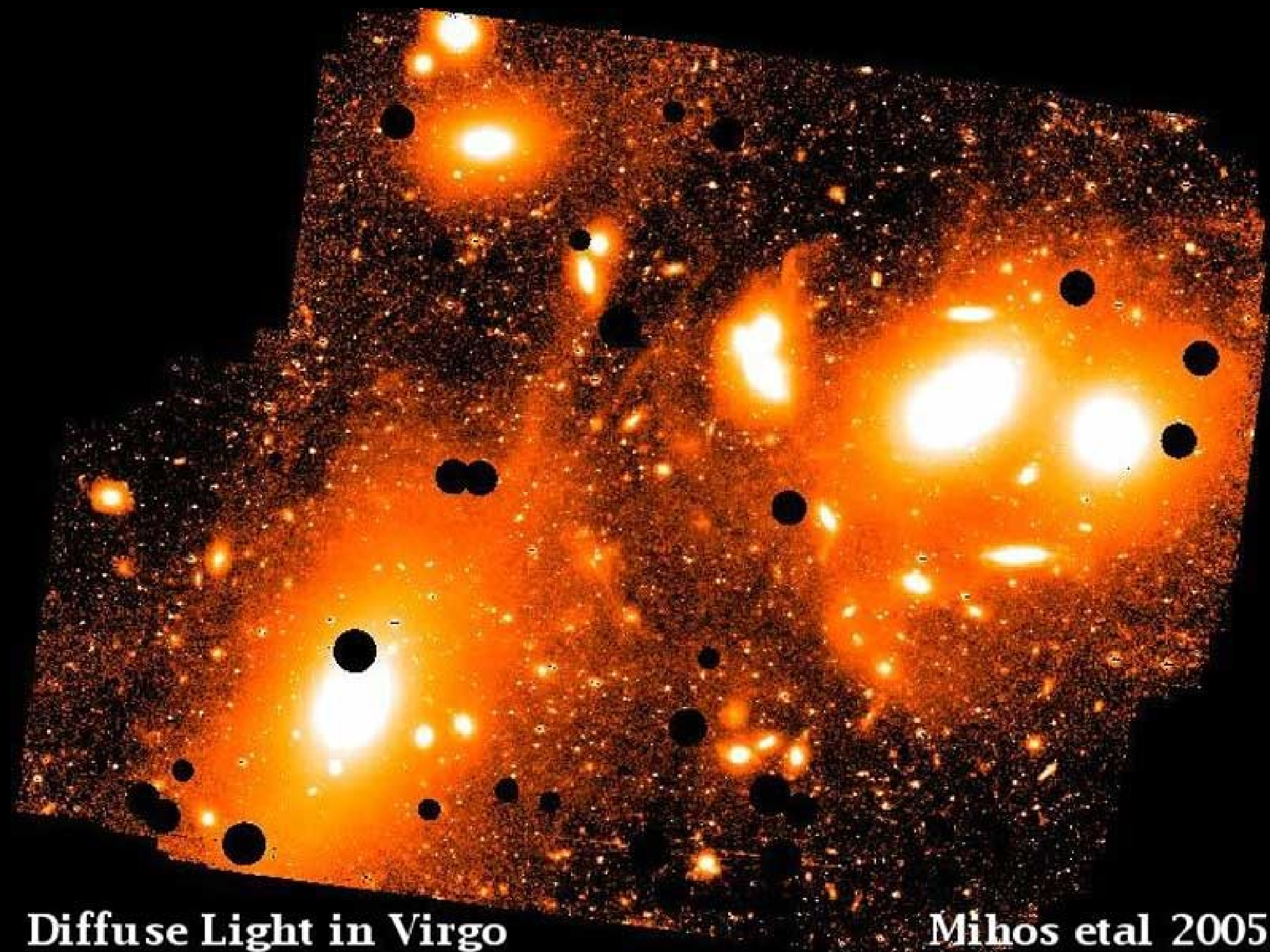
(Forte, Vega & Faifer, 2011)

NGC 4486 (M 87) in Virgo

N 4486 and its environment

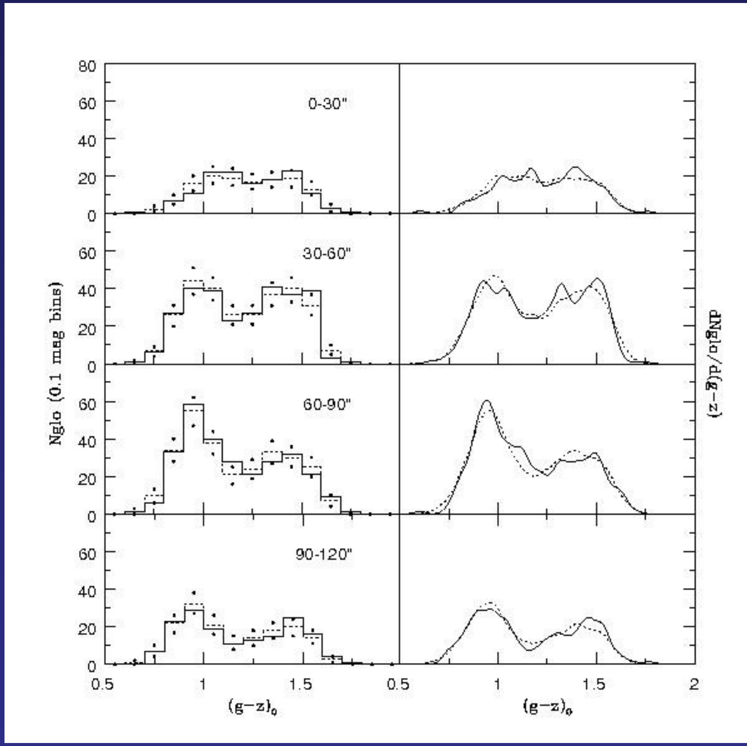




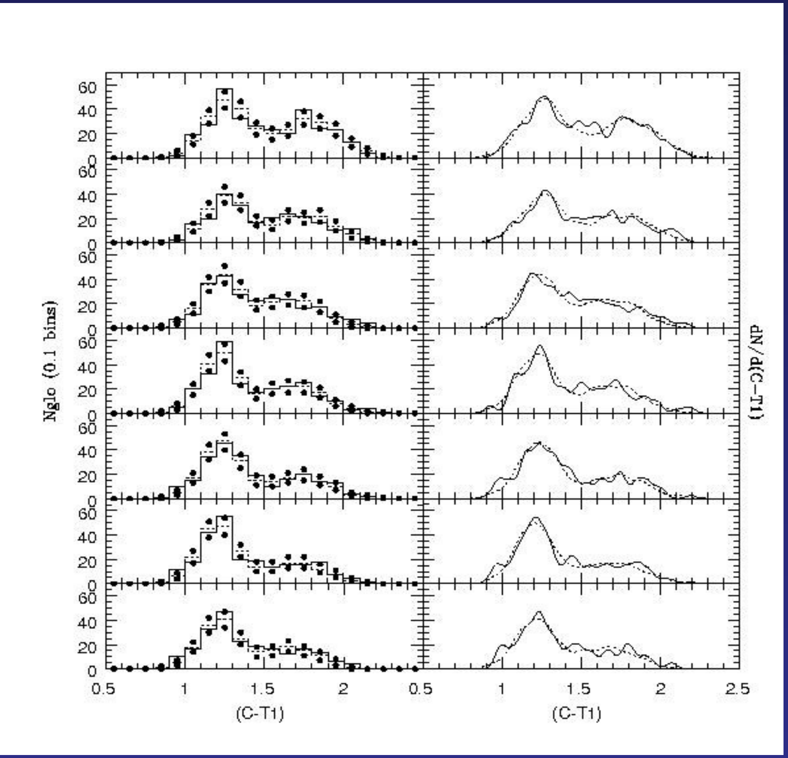


Ruddick et al. 2010.

Colour histograms for GCs between a= 0 and 120 " in NGC 4486.

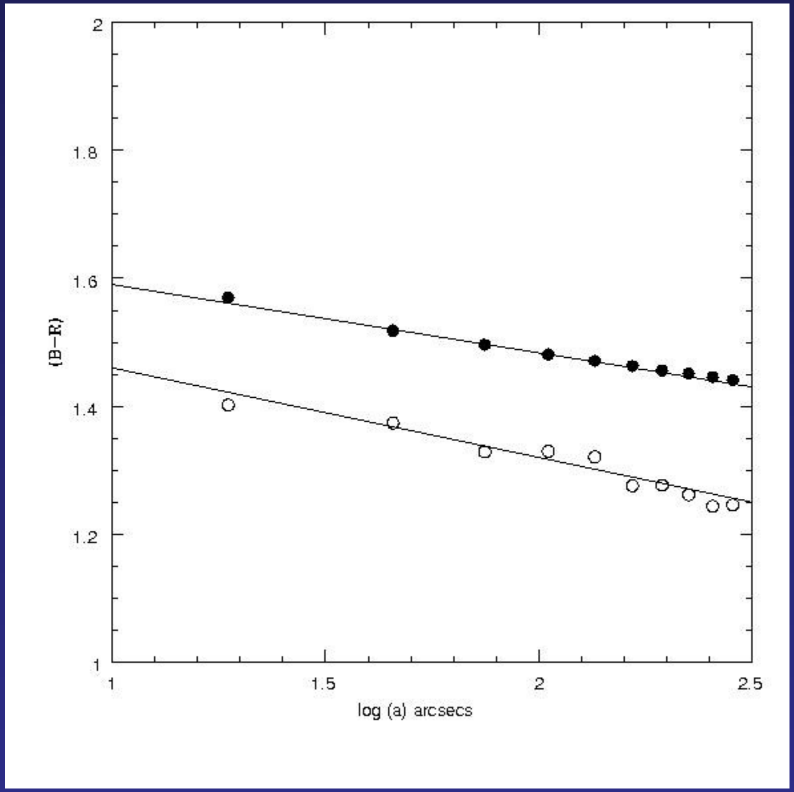


(g-z) HST photometry by Jordan et al. 2009.



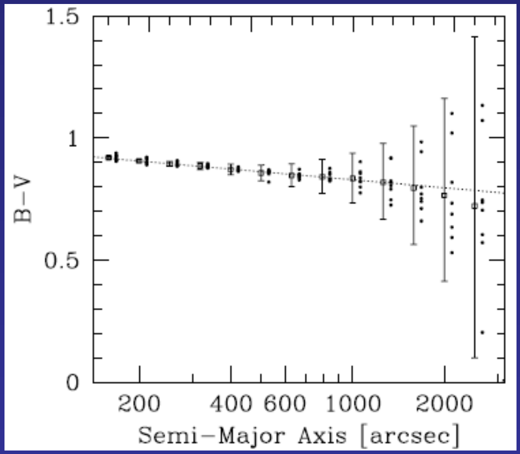
(C-T1) photometry from FFG07

Colour gradients for the galaxy and for the
GCs in NGC 4486

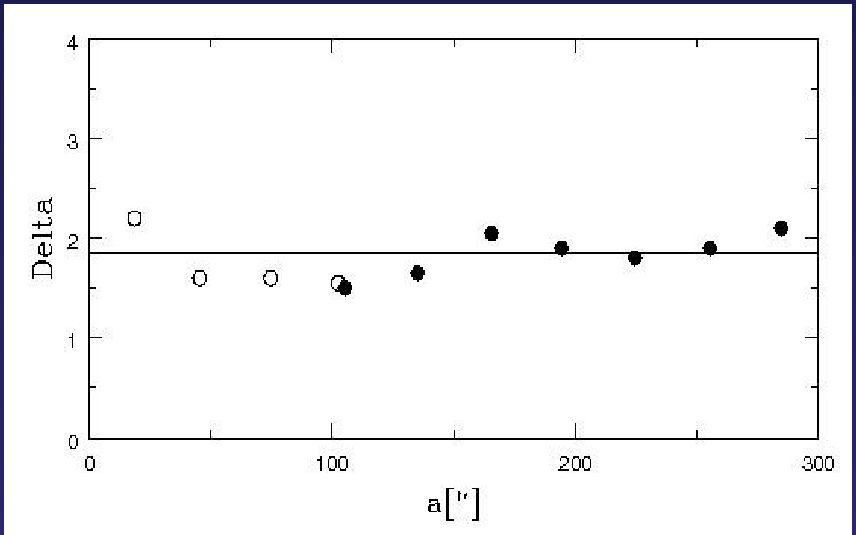


Gamma and Delta are derived within each of these 10 elliptical rings and following the galaxy ellipticity.

Ruddick et al. 2010



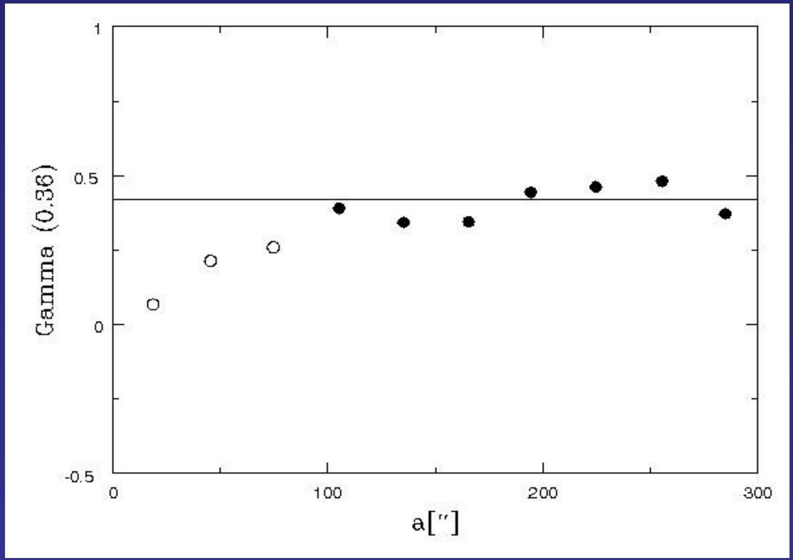
Fit parameters for NGC 4486



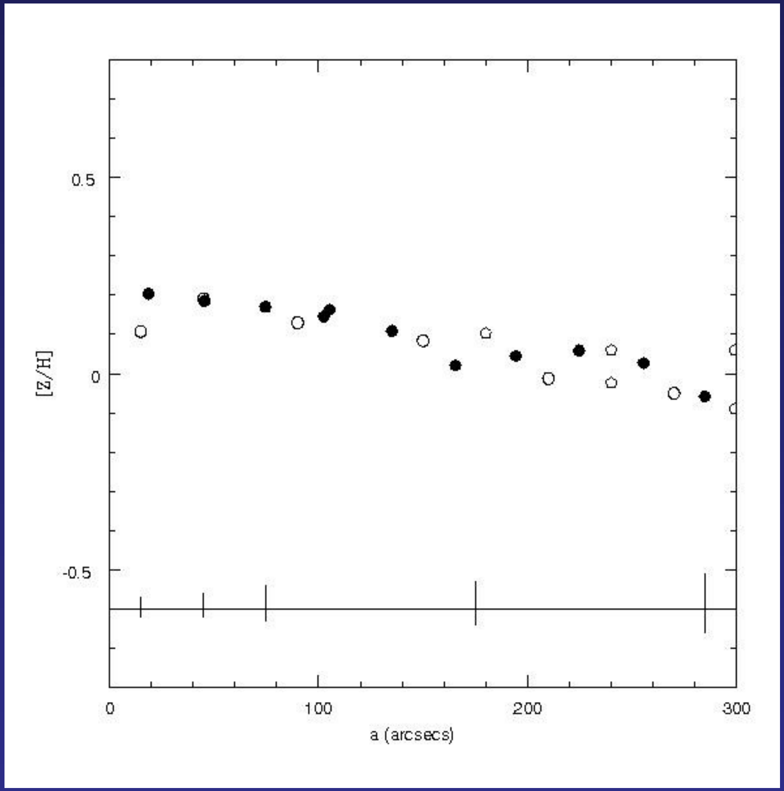
Delta

Gamma

10**(-8) units



Chemical abundance gradient (mass weighted):



Vertical lines: Age effect +/- 1.5 Gy.

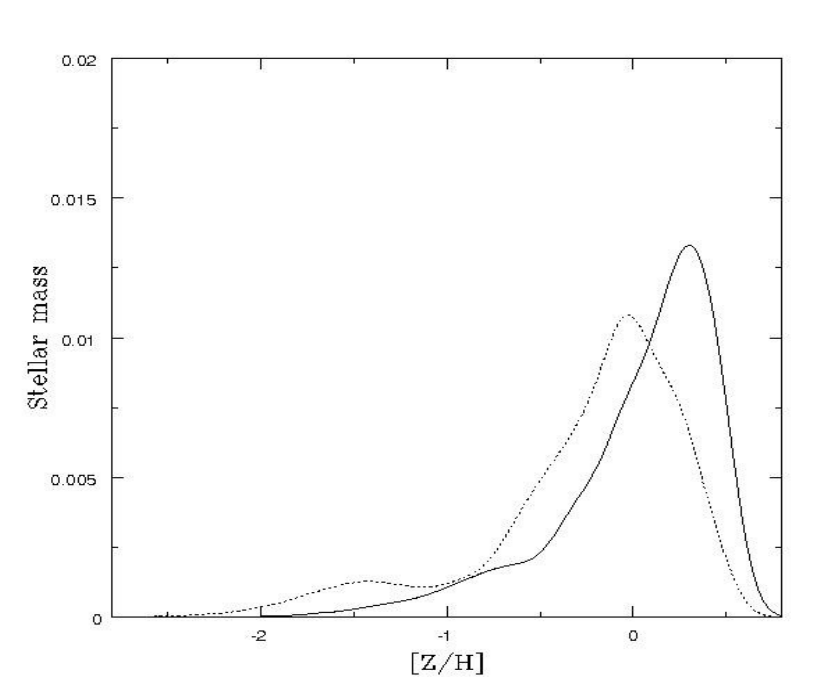
Filled dots: from GCs analysis.

Hot gas X ray obs.

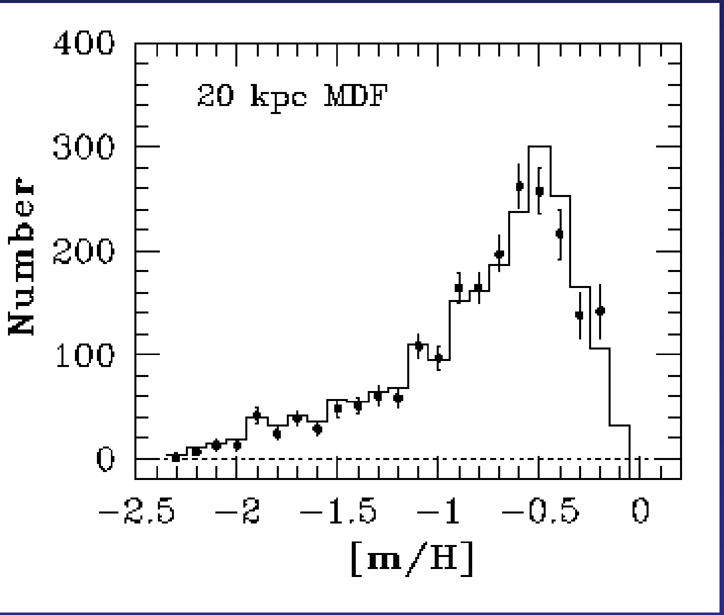
Open dots: Gastaldello and Molendi 2002.

Open pentagons: Simionescu et al. 2010.

Logarithmic chemical abundances for stars.

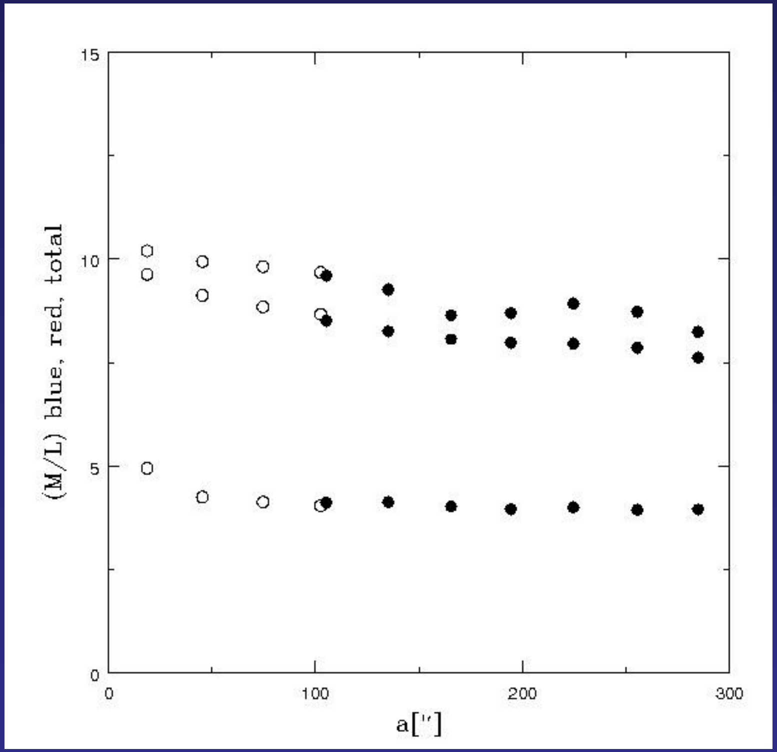


NGC 4486: inferred



NGC 5128: resolved stars

Mass to B luminosity ratio gradient:



Bulge

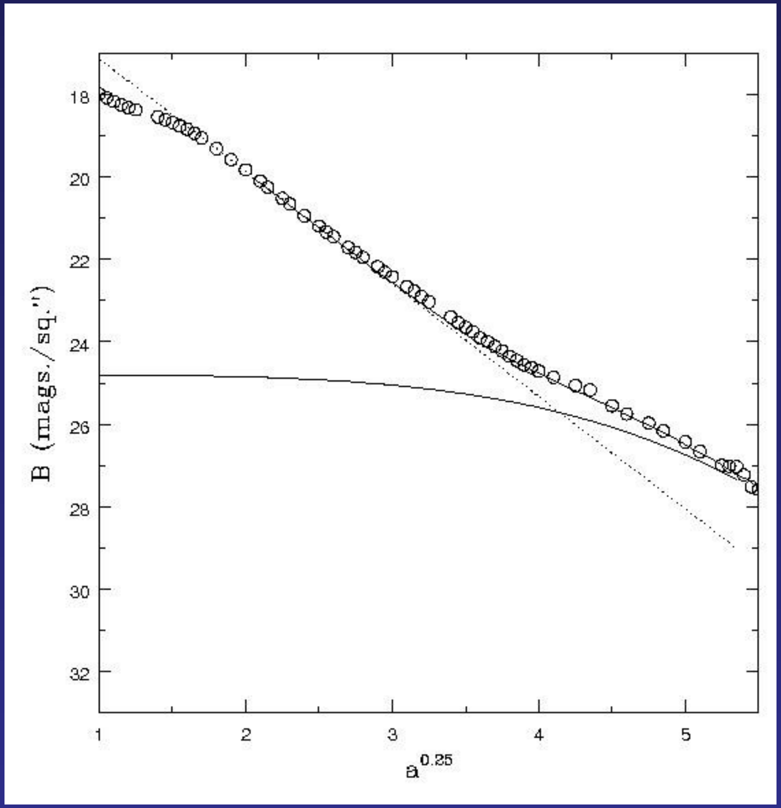
Composite ratio

Exponential halo

Large scale structure of NGC 4486:
(up to 1000 arcsecs = 80.5 Kpc)

$$\Sigma(r) = \Sigma_0 \exp\left\{-b_n \left[(r/r_e)^{1/n}\right]\right\}$$

Single and double Sérsic fits (with variable ellipticity):

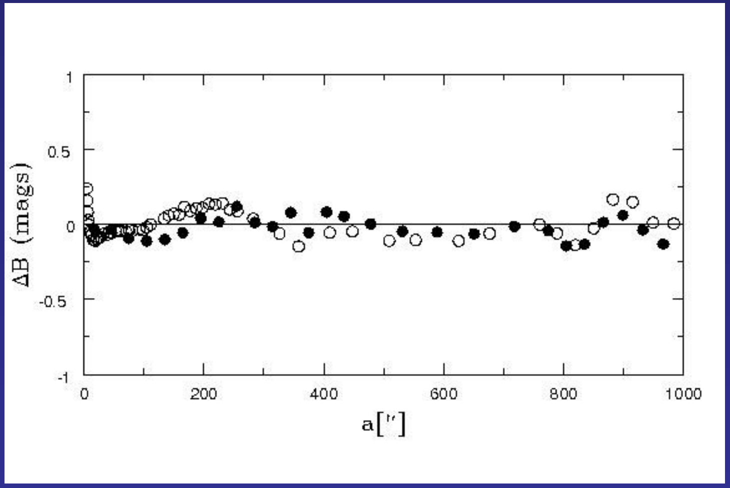


Single fit: n=7.5

Double fit:

n=4 rs=0.021

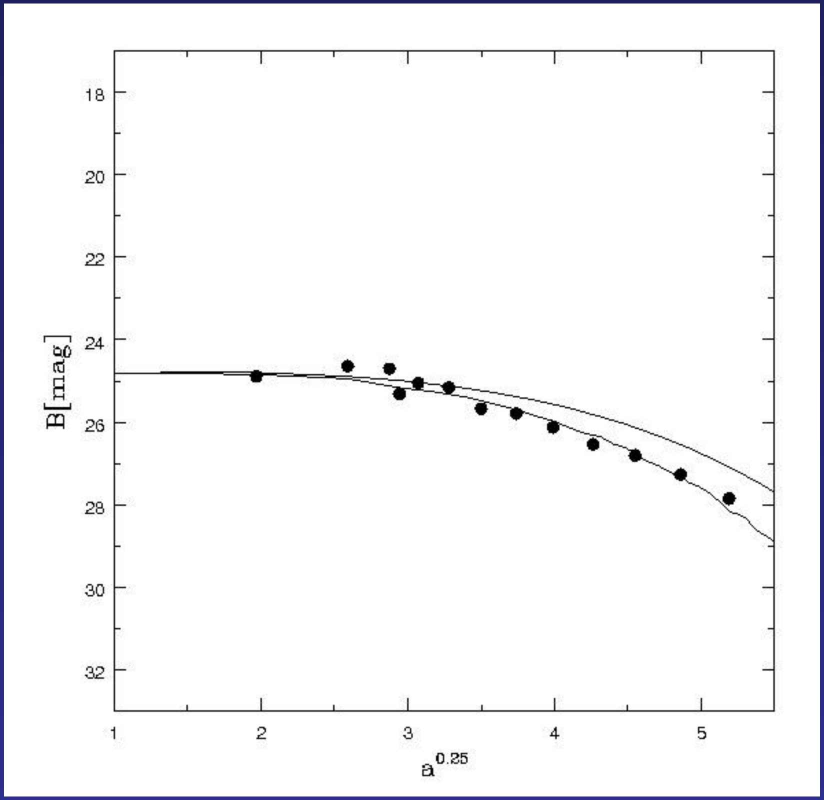
n= 1 rs=350 arcsecs



Photometry from Caon, Capaccioli & Rampazzo 1990.

Fit residuals (open=single; filled=double)

The exponential halo and the “blue” GCs

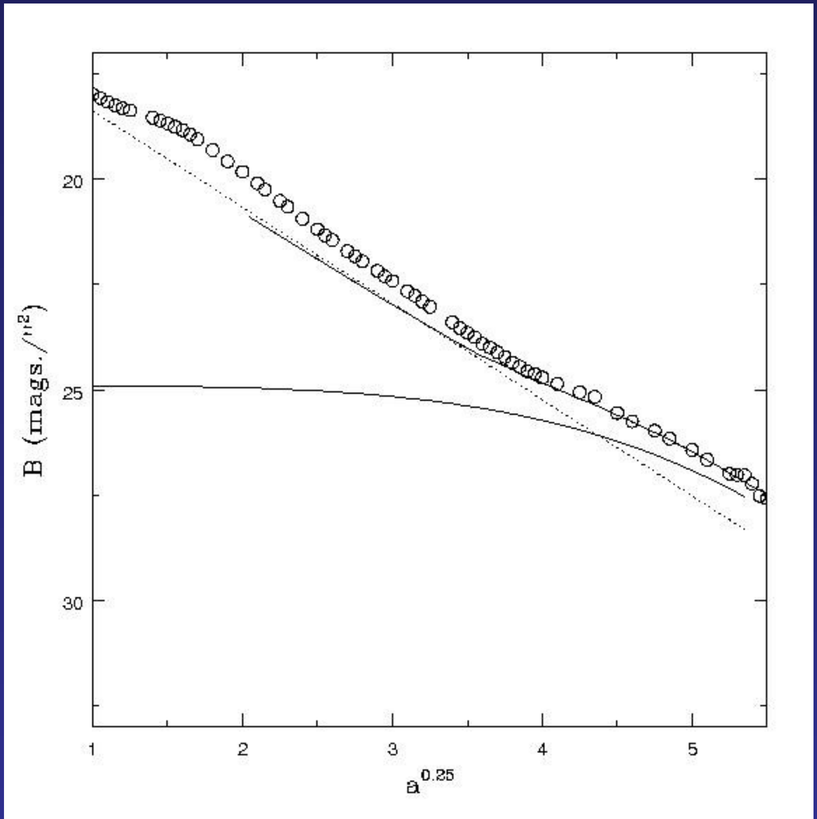


Halo
Ellipticity: 0.4

Blue globs.
Counts in circular annuli (Harris 2009)

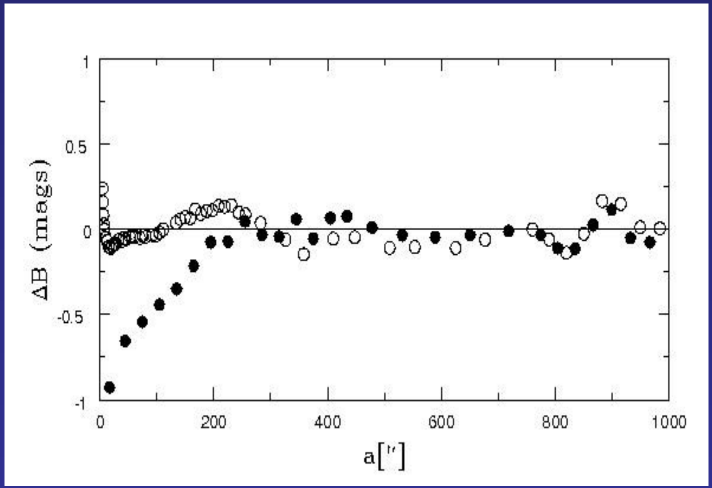
Galactocentric radius

Profile fit using GCs as luminosity tracers (with variable ellipticity):



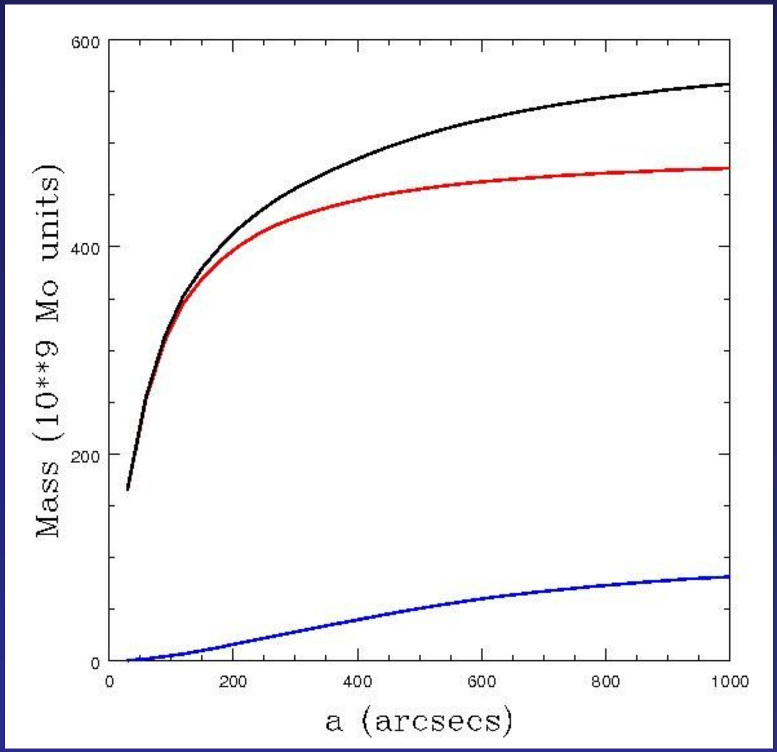
Bulge (Red globs.)
n= 4   rs=0.058

Halo (Blue globs.)
N=1   rs=335 arcsecs



Fit residuals (open=single; filled=double)

Cumulative stellar mass:

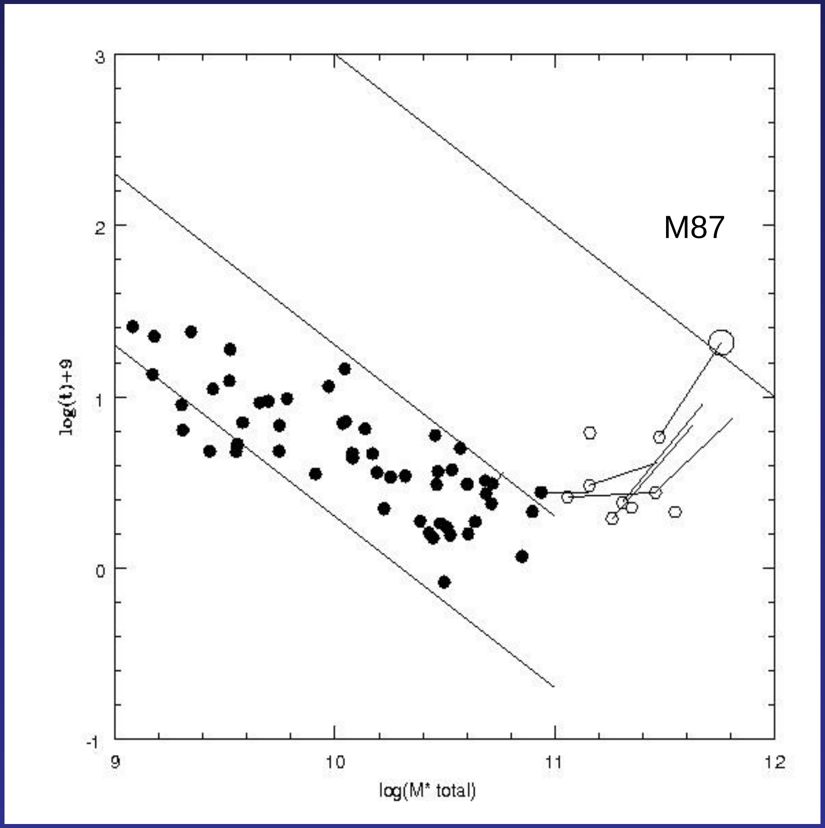


Total :5.5 x 10 **11 Mo

Bulge: 4.7 x 10**11 Mo

Halo: 0.85 x 10**11 Mo

GCs formation efficiency as a function of The galaxy stellar mass M*.

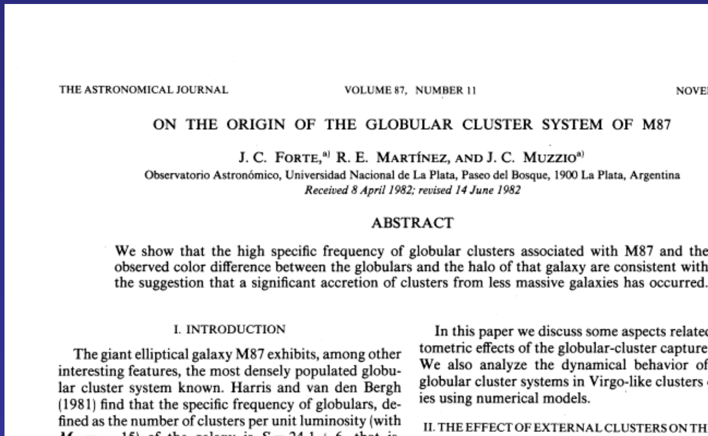


10**4 globs.

200 globs.

15 globs.

GCs accretion from other galaxies….



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ON THE ORIGIN OF THE GLOBULAR CLUSTER SYSTEM OF M87

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ABSTRACT

We show that the high specific frequency of globular clusters associated with M87 and the observed color difference between the globulars and the halo of that galaxy are consistent with the suggestion that a significant accretion of clusters from less massive galaxies has occurred.

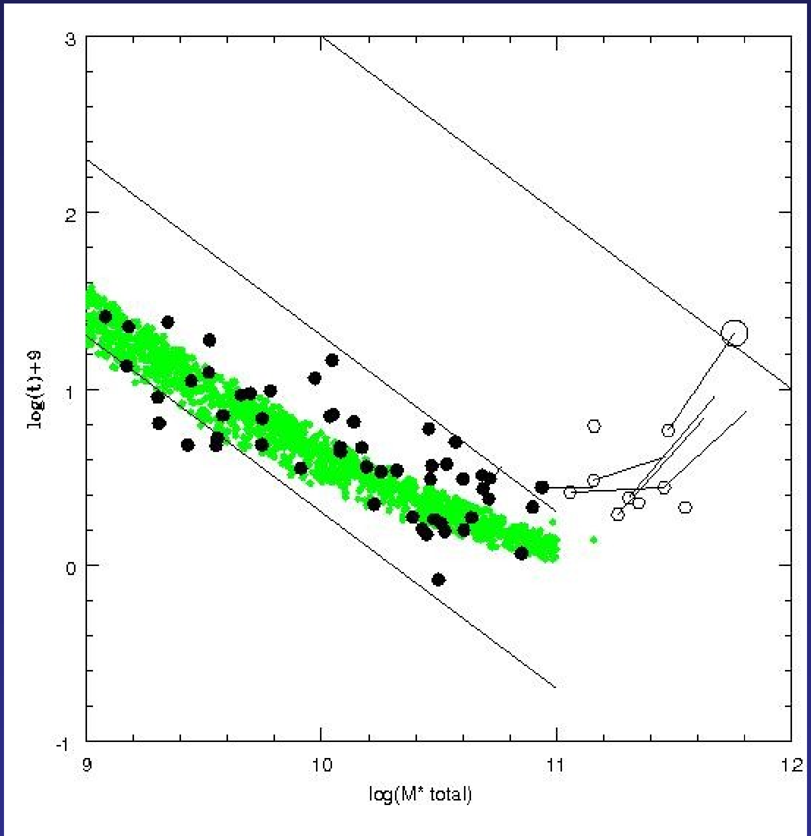
I. INTRODUCTION

The giant elliptical galaxy M87 exhibits, among other interesting features, the most densely populated globular cluster system known. Harris and van den Bergh (1981) find that the specific frequency of globulars, defined as the number of clusters per unit luminosity (with

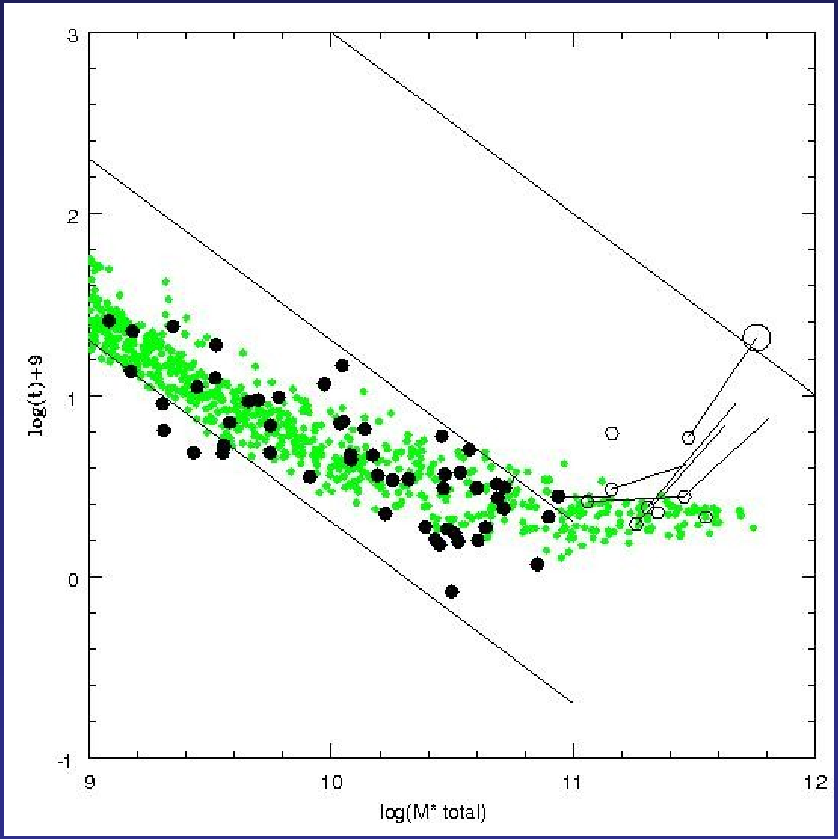
In this paper we discuss some aspects relate tometric effects of the globular-cluster capture We also analyze the dynamical behavior of globular cluster systems in Virgo-like clusters ies using numerical models.

II. THE EFFECT OF EXTERNAL CLUSTERS ON TH

Mergers: preliminary modeling for Virgo galaxies.

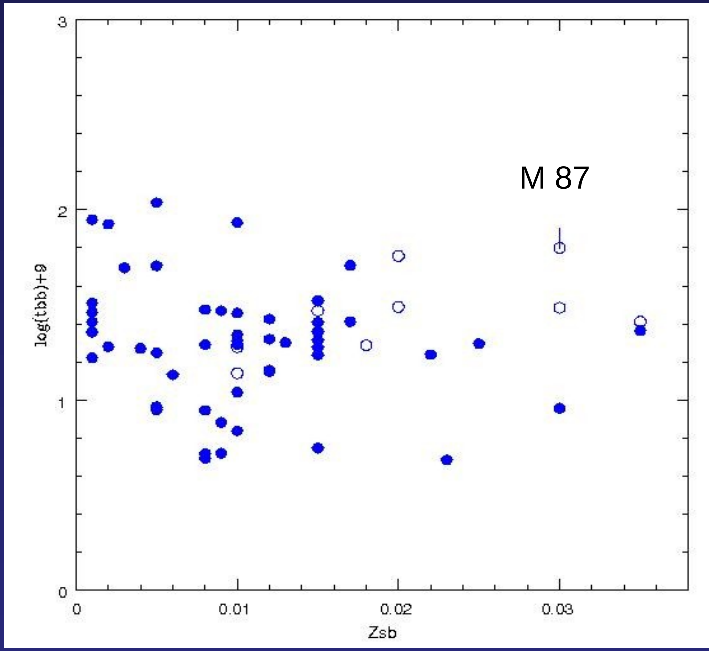


“Canonical galaxies” (green)



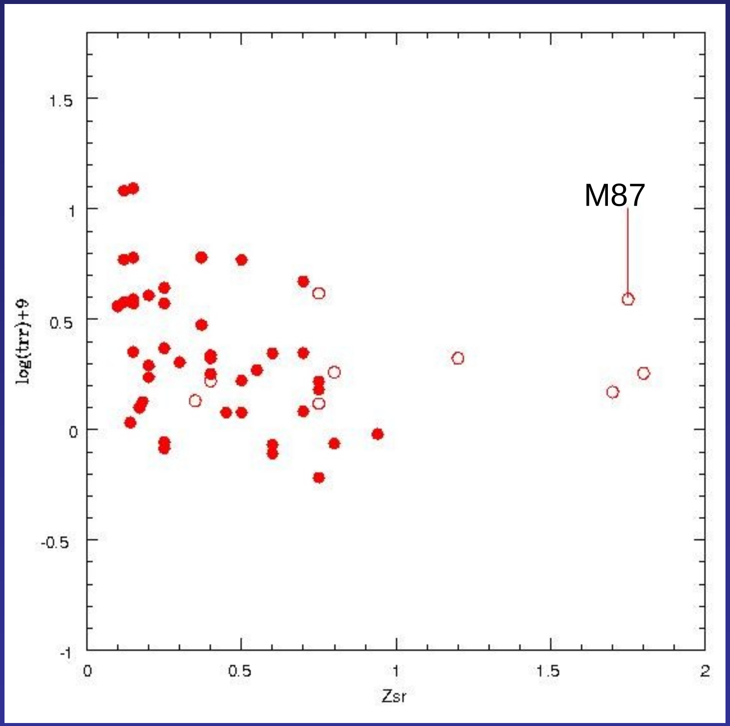
After “naive” dry merging

Halo and GCs similarities and differences…….



M87’s blue halo: NOT distinct from other Virgo galaxies

M87’s red bulge: VERY different from other Virgo galaxies



Dark matter
(An agnostic view)

Enclosed total mass profile for NGC 4486

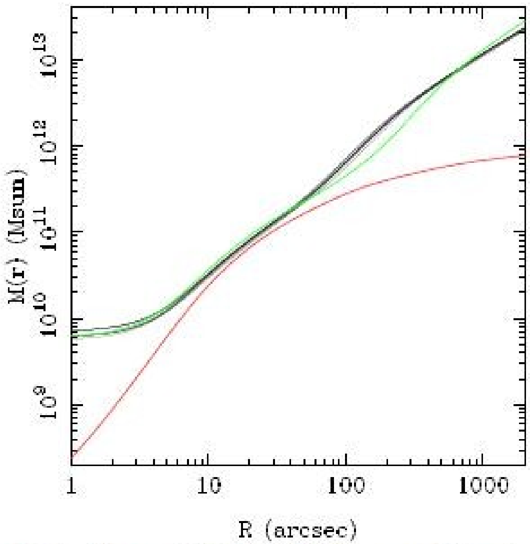


FIG. 7.— The mass profile for M87. The black lines represent the models that are within the 68% confidence band of the best fit (as in Figure 6). The green line is the mass profile derived from our representation of the X-ray gravitational potential (i.e., the green line in Figure 6). The red line is the average contribution from the stars, where we use the light profile in Figure 1 times 6.3 (the best-fitted M/L). The mass profiles for the dynamical model show a smooth transition from 30 to 1000″, whereas the X-ray profile shows a kink.

Gebhardt & Thomas, 2009.

Stellar mass=6 x 10**11 Mo (within 1000 arcsecs)

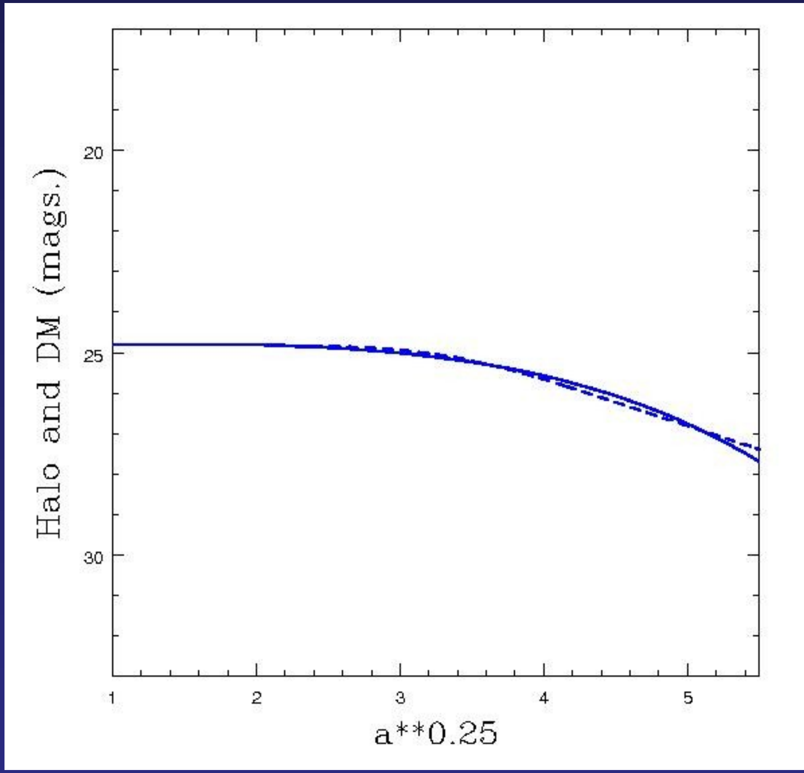
Black hole= 6.4 x 10 **9 Mo

Dark mater halo (logarithmic pot.)

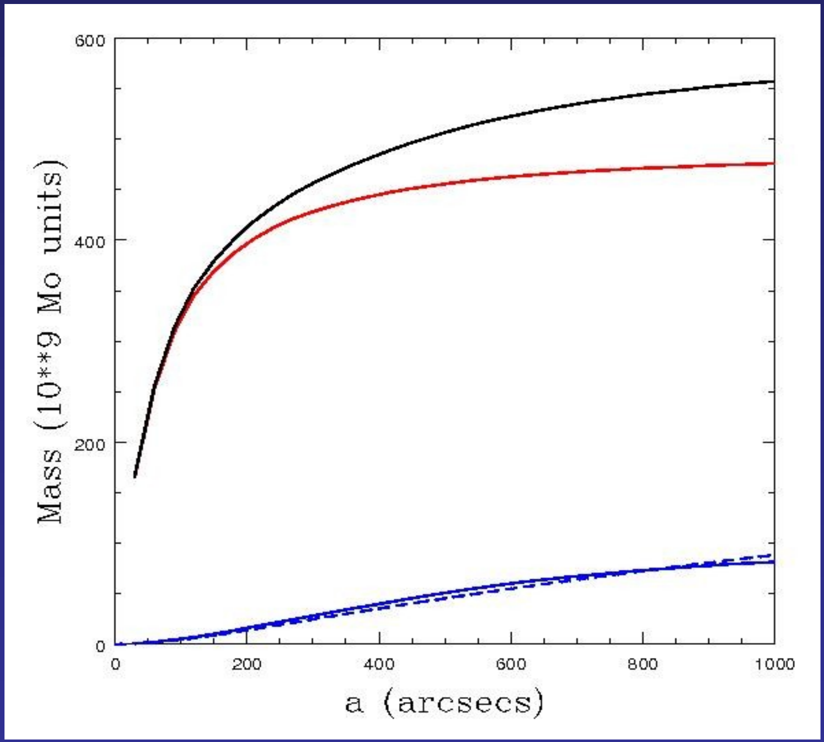
Vc= 715 km/s rc= 196 arcsecs

DM vol. density= (Vc**2)*(3rc**2+r**2)/(rc**2+r**2)**2

Projected Stellar halo and Dark Matter (dashed)



Cumulative stellar and dark masses.



The case of NGC 1399 (Forte, Faifer, Geisler 2005)

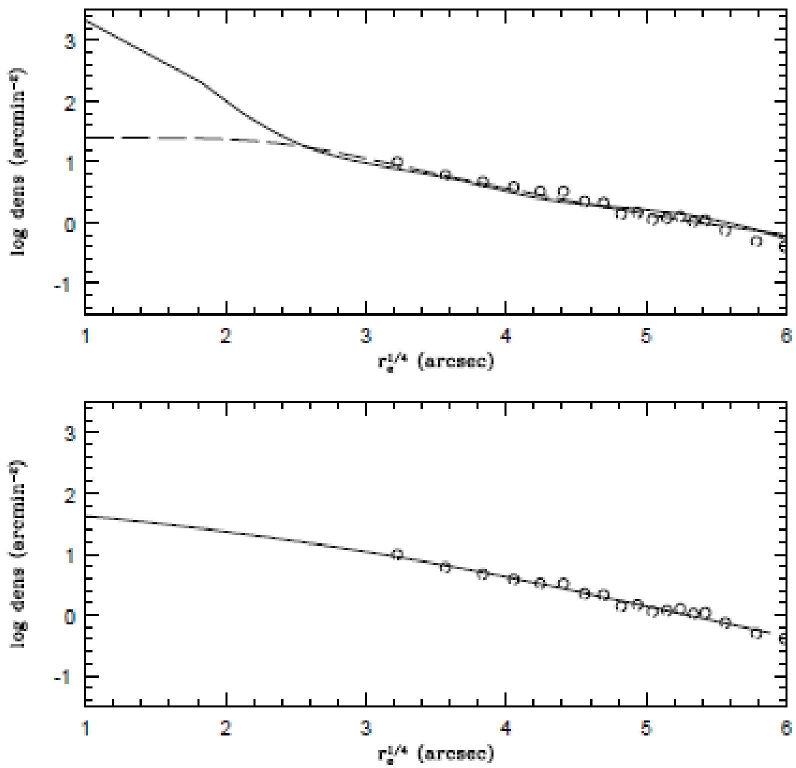


Figure 13. Upper panel: The NGC 1399 blue globular clusters density profile (open circles) compared with that of the hot X ray emitting gas (continuous line: from Paolillo et al. 2002; dahed line: from Jones et al. 1997 . Lower panel: blue GC compared with the (projected) dark matter profile obtained by R2004 using GC kinematics.

Hot gas & Blue globs.

Dark mater & Blue globs.

A comparison: N1399 N4486

a) Very similar baryonic mass.
b) Very similar number of bulge (“red”) clusters (4000).
c) M 87 has 2 to 2.5 more halo (“blue”) clusters (7500).
d) M87 has a 2.5 to 4 more massive dark matter halo.

Dark matter
(changing sides....)

Conclusions:

- Globular clusters can trace both **global** and **local** properties of galaxy haloes.

- **GCs bimodality just reflects the bulge-halo nature** of the structure of galaxies and the transition from **pure halo** to **bulge dominated** galaxies as stellar mass increases.

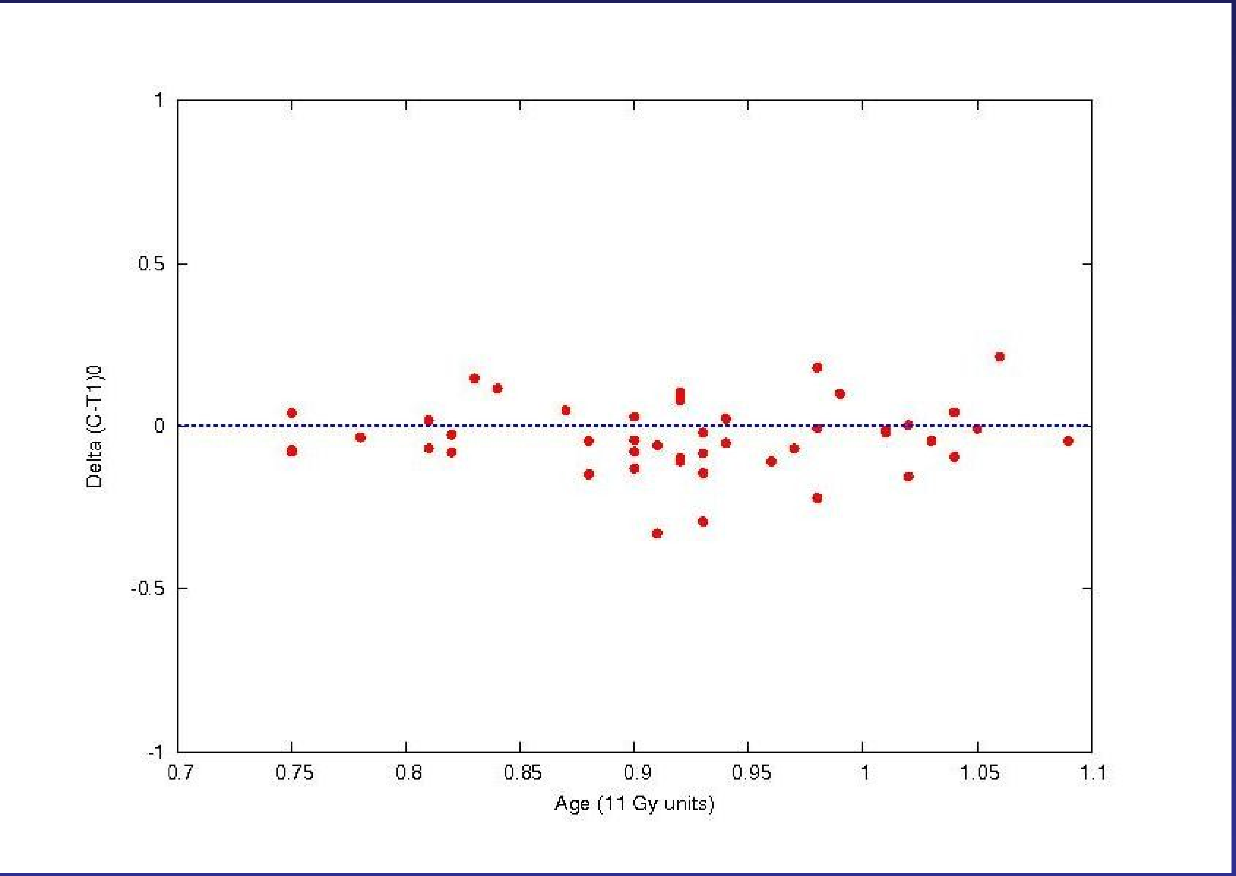
- The relation between the number of GCs and diffuse stellar mass at a given Z **reconciles** seemingly distinct features of these systems.

- It is not clear yet if Z is the driver of this relation **or** just a “clock”.

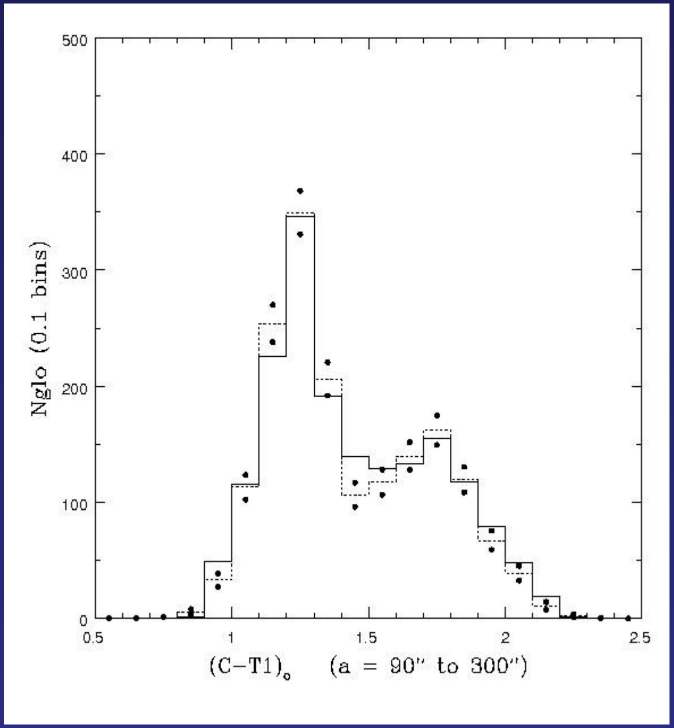
- Extendend stellar haloes seem **remarkably similar** to projected dark matter haloes.

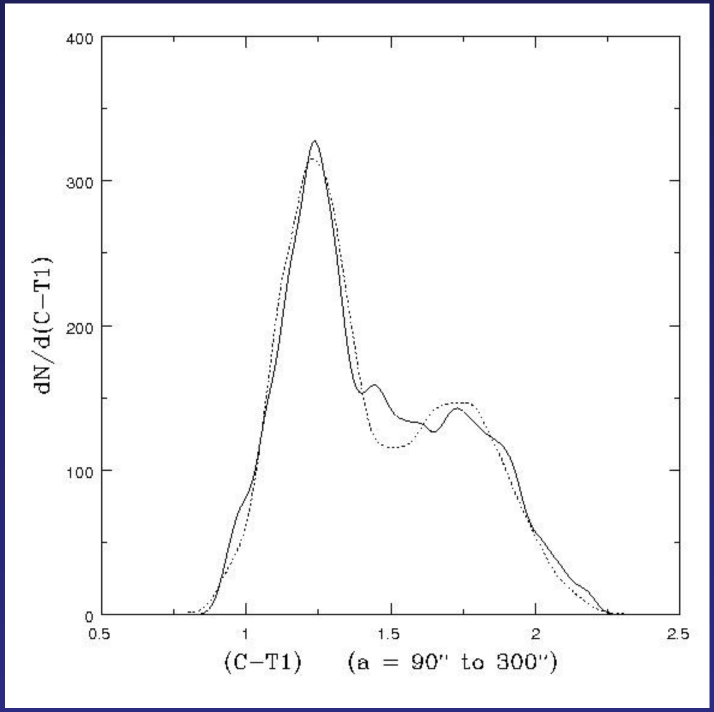
Appendix

Colour residuals as a function of relative T.O. ages for MW globulars.



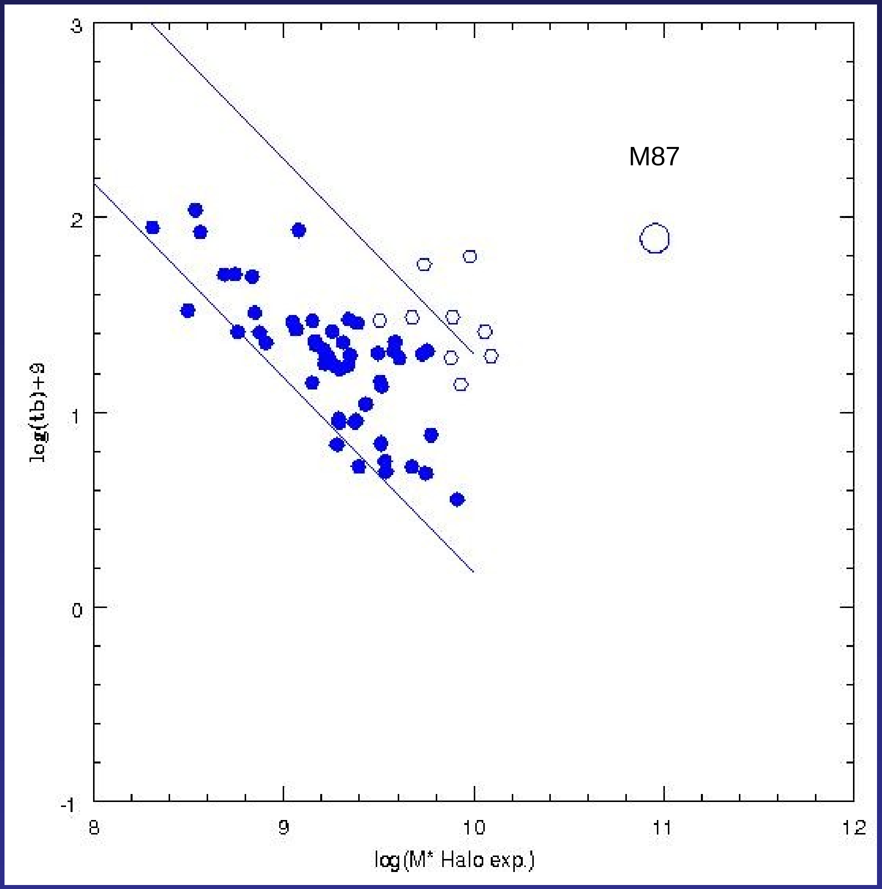
Bimodality in NGC 4486 (M87): An example.



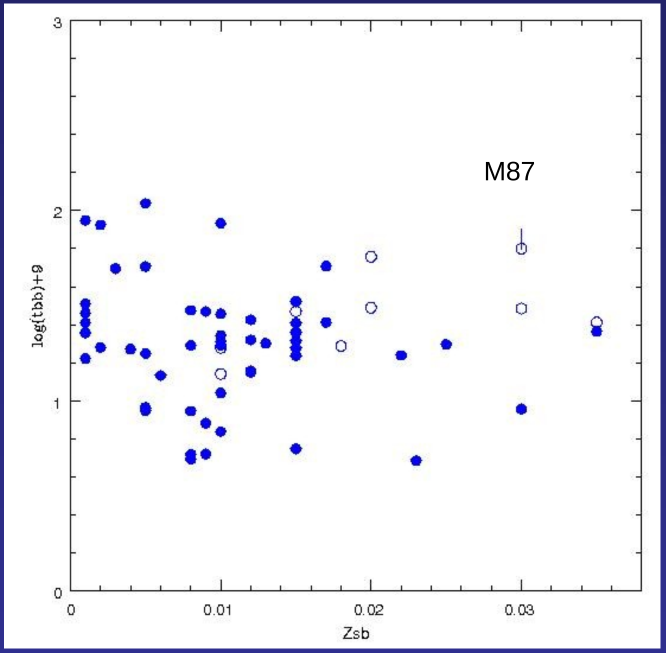


Some 1700
GCs.

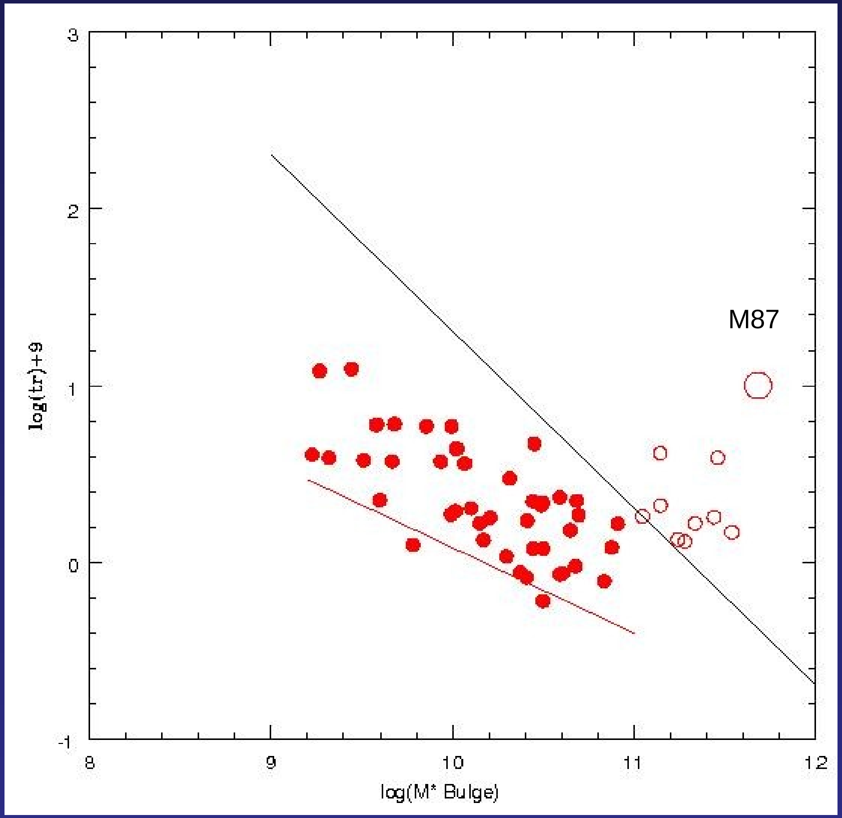
Blue GCs efficiency vs. Halo Mass



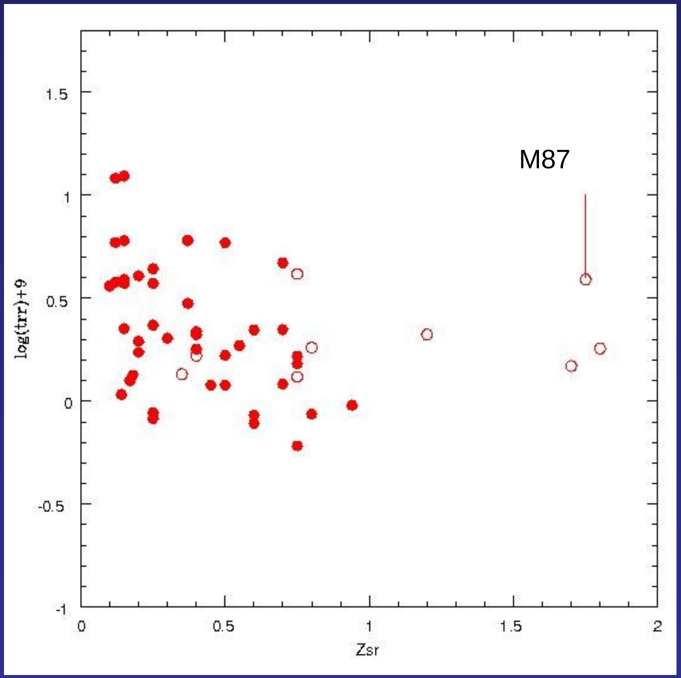
Blue GCs efficiency vs Chemical scale lenght

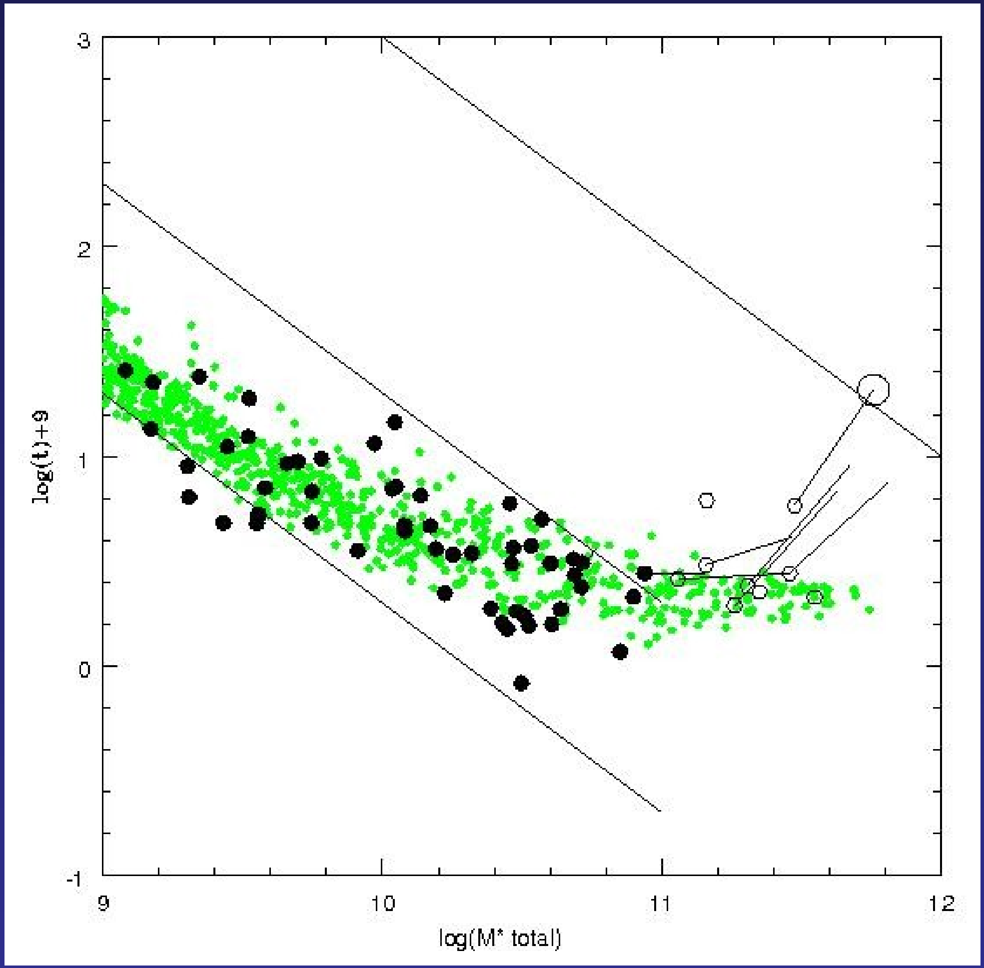


Red GCs eficiency vs Bulge Mass

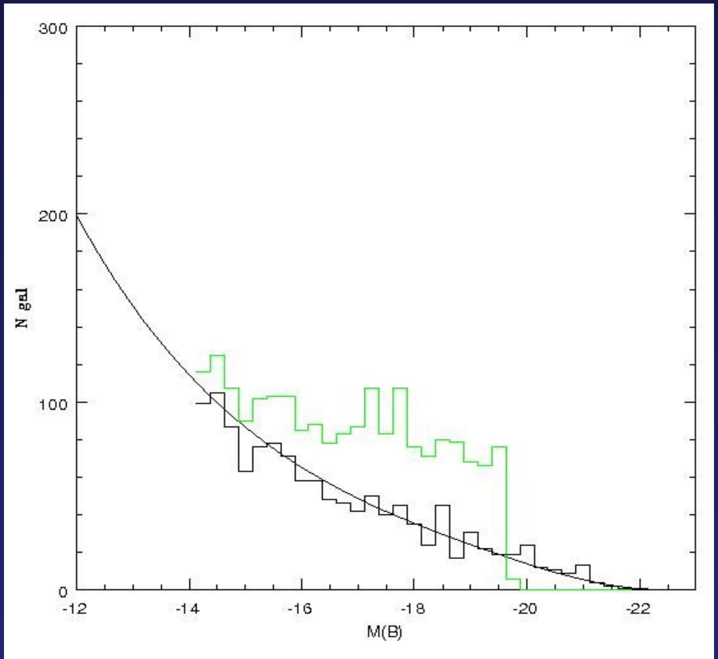


Red GCs efficiency vs Chemical scale lenght

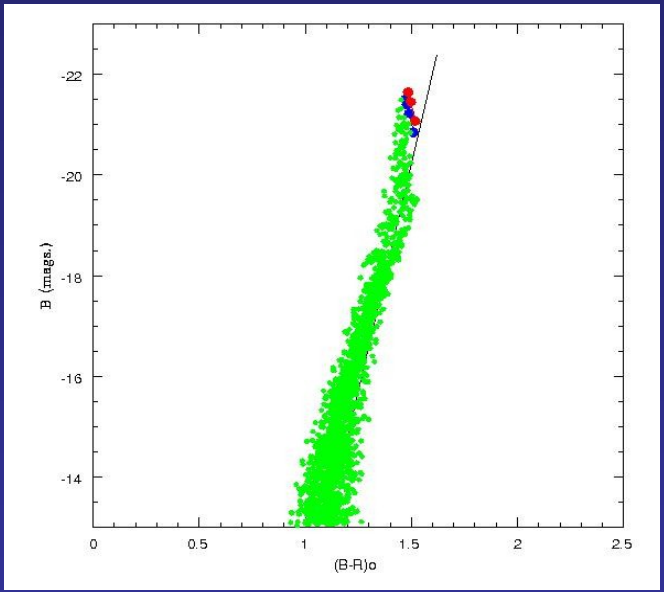




log(t)+9
log(M* total)

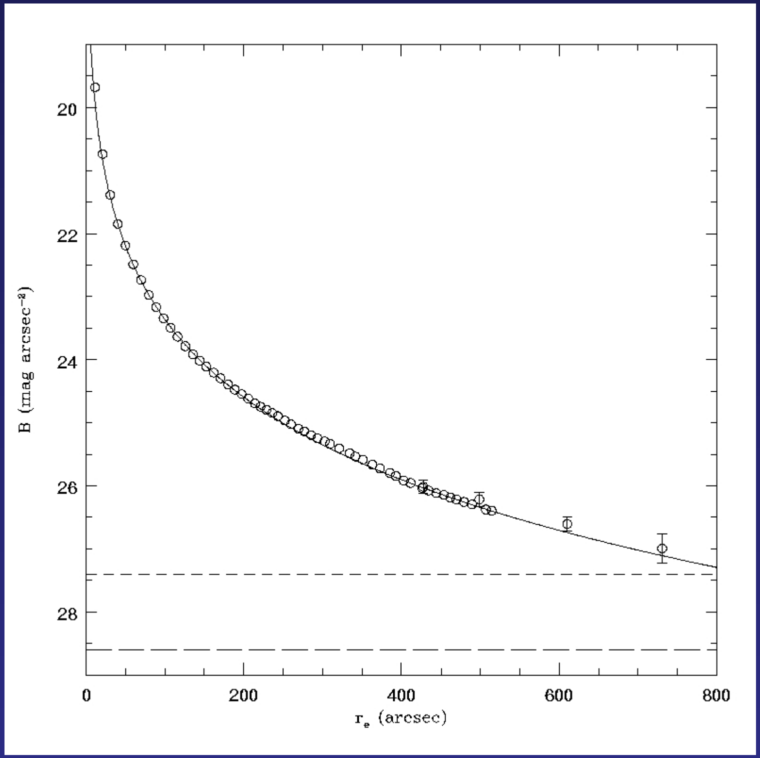


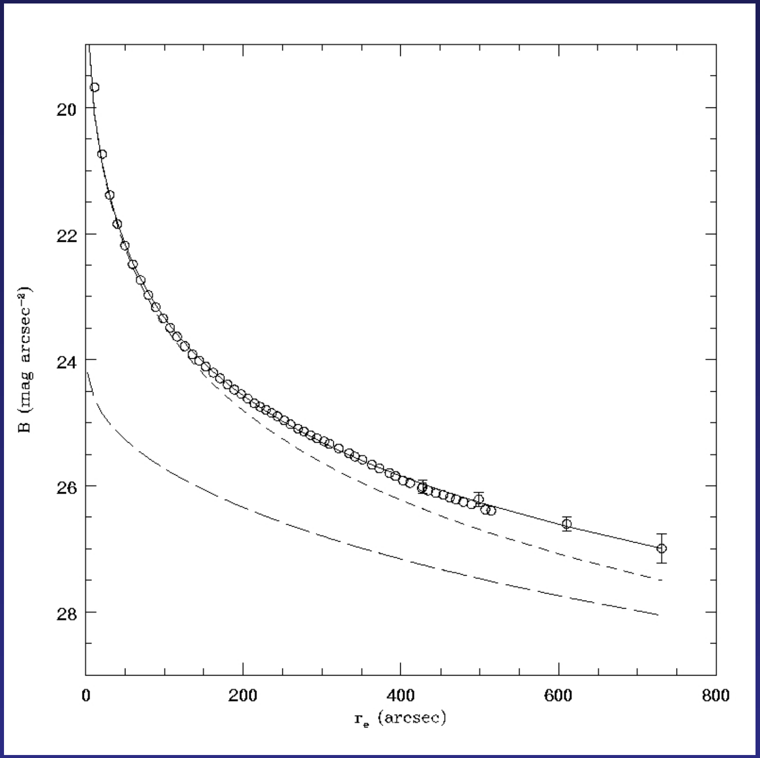
N gal
M(B)



B (mags.)
(B-R)o

The case of NGC 1399 (Forte Faifer Geisler, 2005)





Sersic profile fit.

Using GCs as tracers.

GCs and the Rosetta Stone