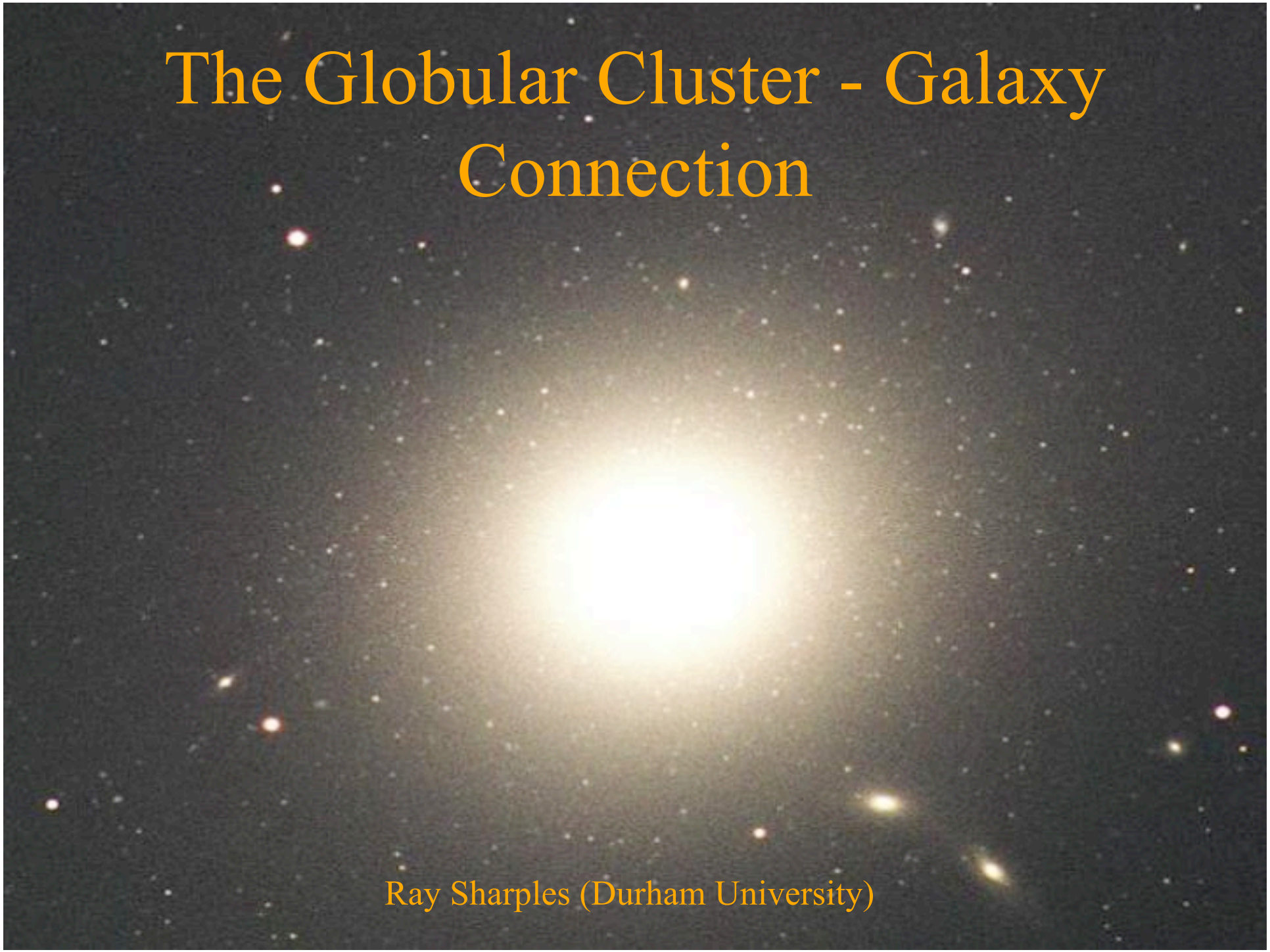


The Globular Cluster - Galaxy Connection

Ray Sharples (Durham University)

Outline of Talk

- Globular Clusters as Probes of the Formation Histories of Galaxies
- Open Questions in the Globular Cluster - Galaxy Connection
- What Can be Done with an 8m (+HST) ?
- What Could be Done with an E-ELT ?

Collaborators: Mark Norris (UNC), Steve Zepf (MSU), Terry Bridges (Queens), Harald Kuntschner (ESO), David Hanes (Queens), Duncan Forbes (Swinburne), Juan-Carlos Forte (La Plata), Markus Kissler-Patig (ESO), Karl Gebhardt (Texas) to name but a few …

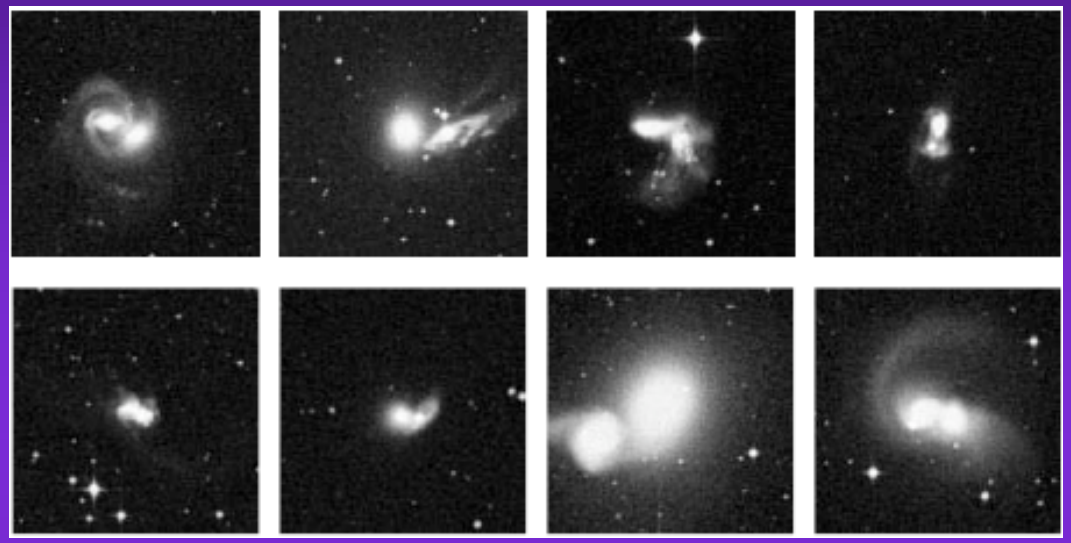
Why Globular Clusters ?

- Found ubiquitously around all galaxies
  - understanding of both spheroidal and disk galaxies
- Oldest stellar populations with reliable ages
  - probe earliest phases of galaxy assembly
- Scale approximately with host galaxy mass
  - intimate connection with galaxy formation
- Simple (?) stellar populations
  - easier age/metallicity determination

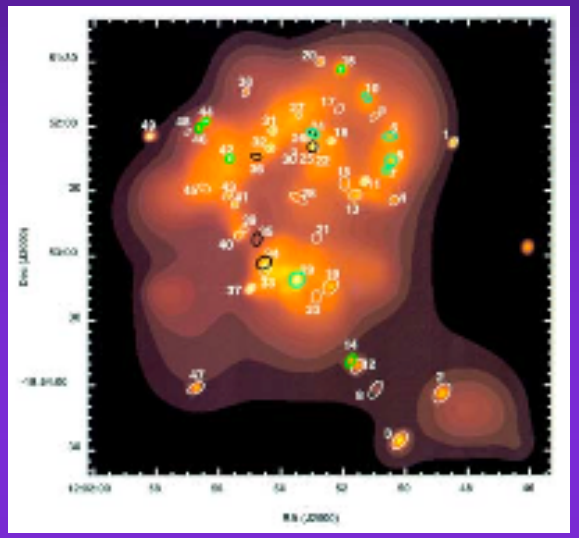
Key Questions

- How do we form GCs (ELT/ALMA) ?
- What parameters drive the luminosity (colour) & metallicity distributions of GCSs (8m/ELT) ?
- Are the ages & abundances of GCs in ellipticals similar to those in spirals (8m/ELT) ?
- What regulates the relative formation of stars vs clusters (ELT) ?
- What are the major sites of GC formation (primordial halos, protogalaxies, mergers) (8m/ELT/JWST) ?

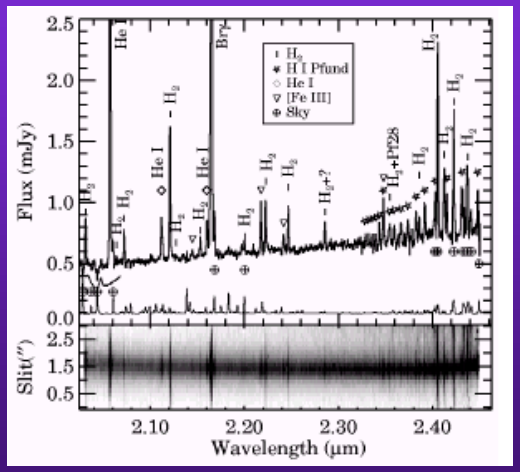
Star Clusters & Mergers



4’



NGC4038/39

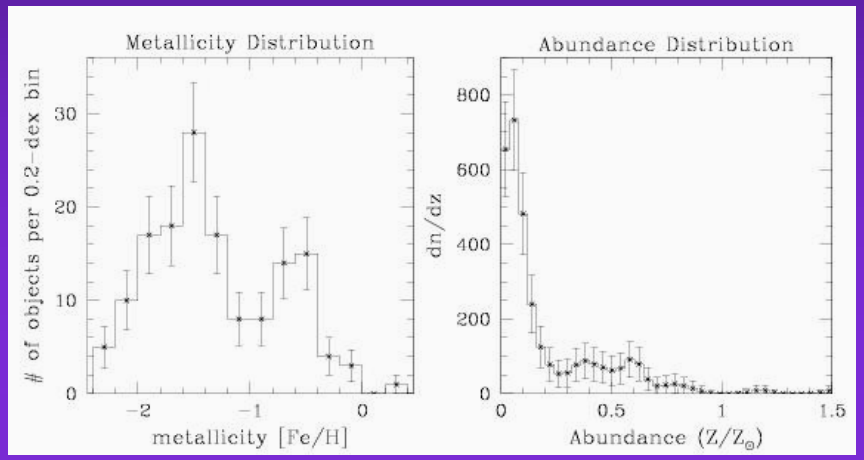


Gilbert et al (2001)

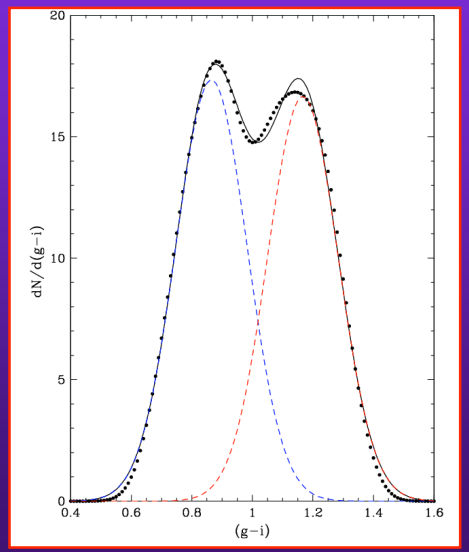
KMOS @ VLT
March 2011
0”.2 sampling

EAGLE @ ELT
March 2018
0”.075 sampling

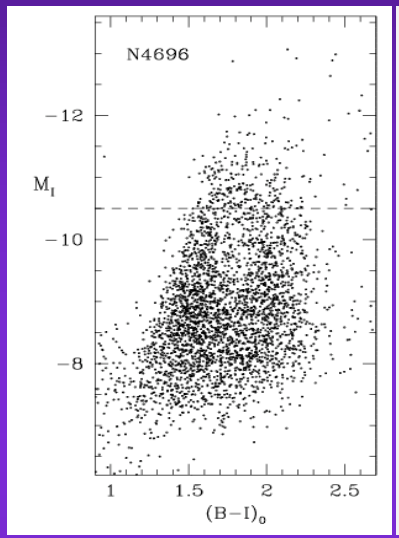
Bimodality and Mass-Metallicity Relations

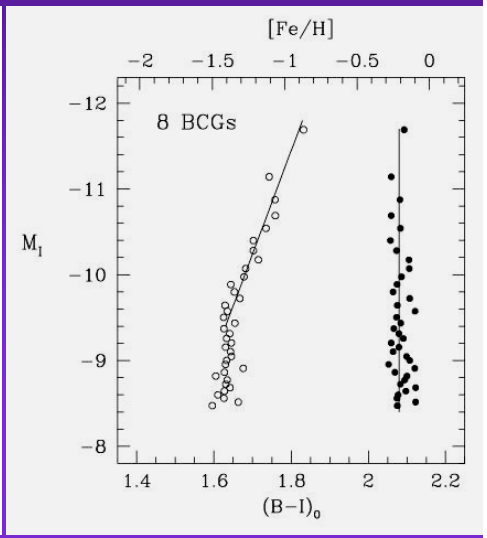


Milky Way (~150 GCs)



NGC4649 (Virgo)
Bridges et al

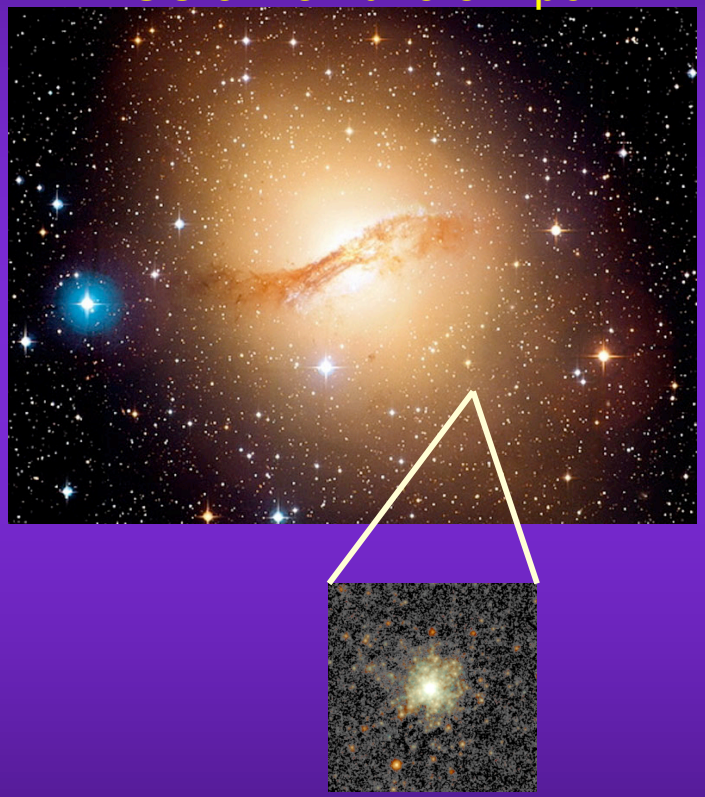




BCGs: $Z \sim M^{1/2}$ for M>10^6 Mo
(Harris 2009)

NGC5128: Resolved Halo Populations

NGC 5128: d=3.8 Mpc

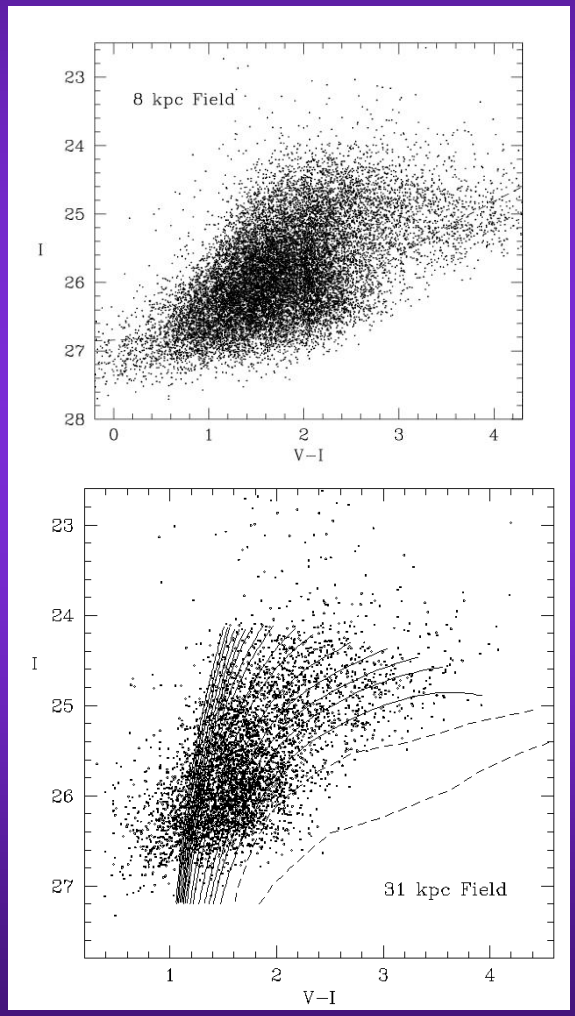


r_h ~ 1 – 5 parsecs (averages 3 pc)

→ 0.3” at d=3.8 Mpc

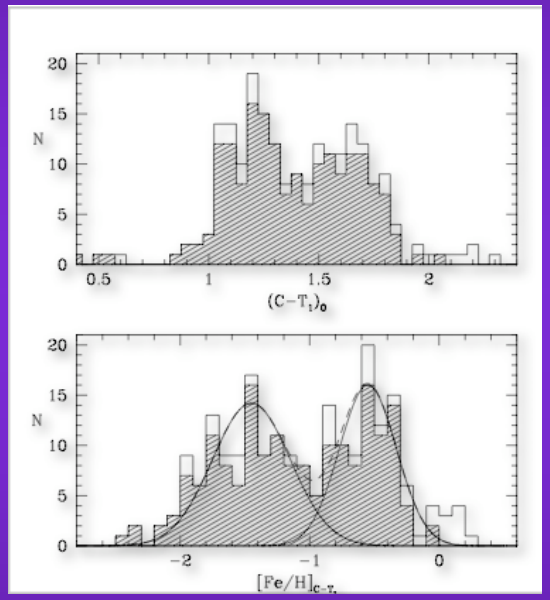
→ 0.1” at d=10 Mpc

→ 0.06” at d=15 Mpc

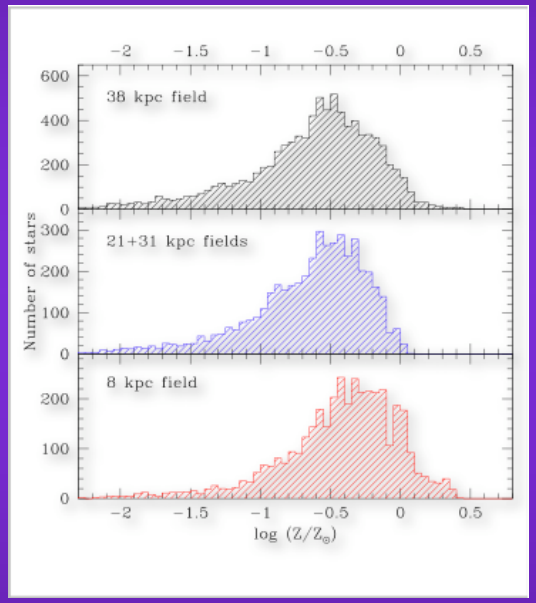


NGC5128 (Harris et al)

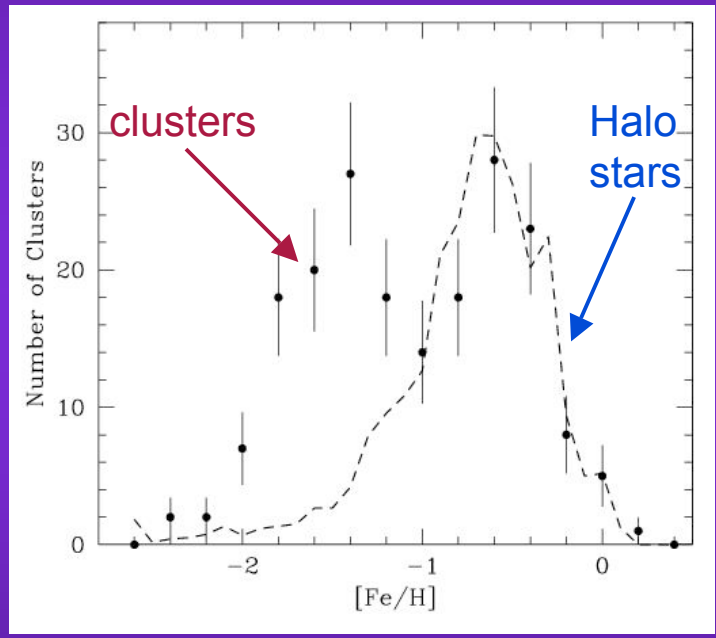
Metallicity Distribution Functions



Globular clusters
(Harris et al 2004)



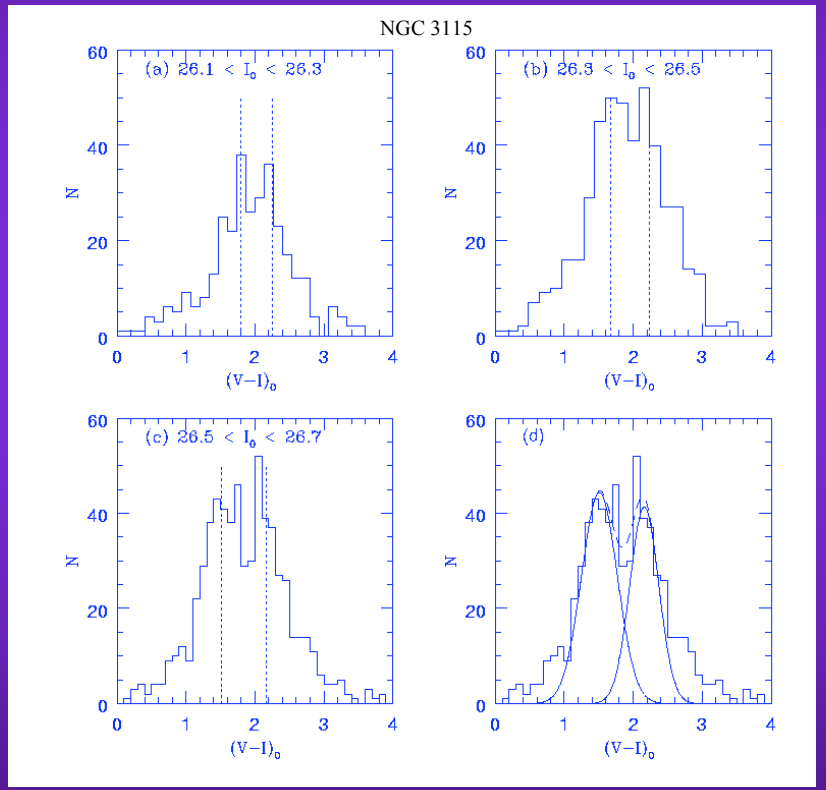
Field stars
(Rejkuba et al 2005)



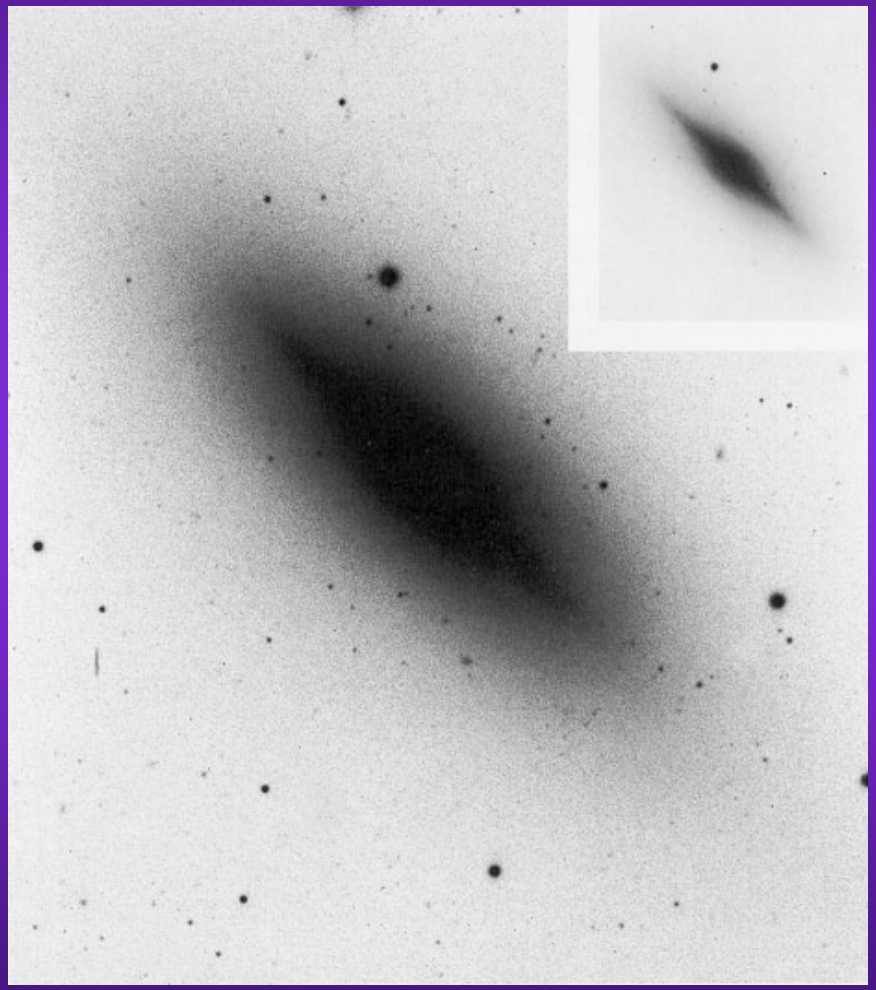
Harris et al

The Galaxy Halo – Globular Cluster Connection

- Critical test of models is to compare metallicity distribution functions of GC with underlying spheroid
- Resolved C-M diagrams for red giant branches in nearest spheroidal galaxies.
- Determine metallicity distribution functions and specific frequency as function [Fe/H].
- WFPC2/ACS observations of NGC3115 (D=10Mpc). Comparison with VLT spectra of GCs.

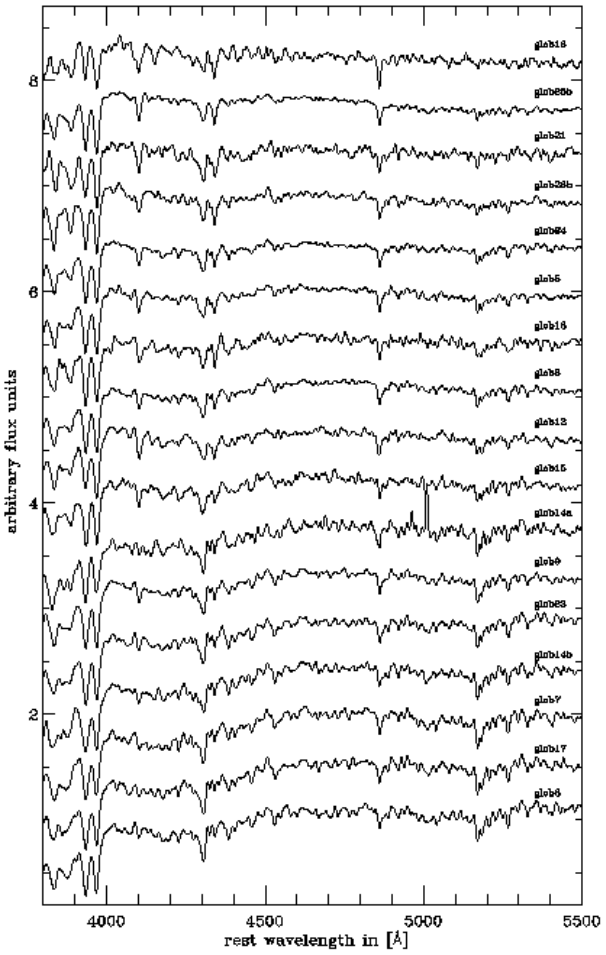


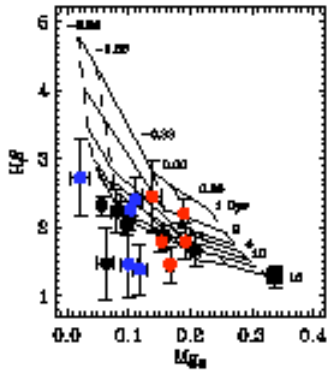
NGC3115

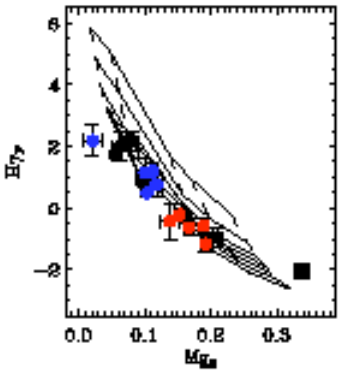


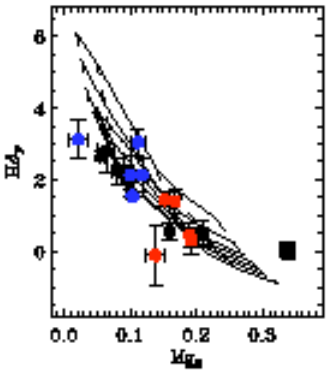
- Bright (M_B=-20.1) S0 in Leo Spur
- D=10 Mpc
- Test case for formation of field S0's
- VLT/FORS2 spectra of 17 clusters
- GMOS long-slit data

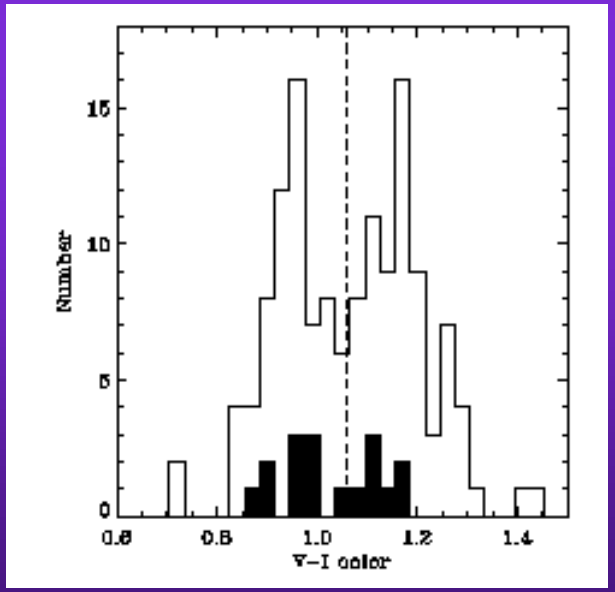
NGC3115





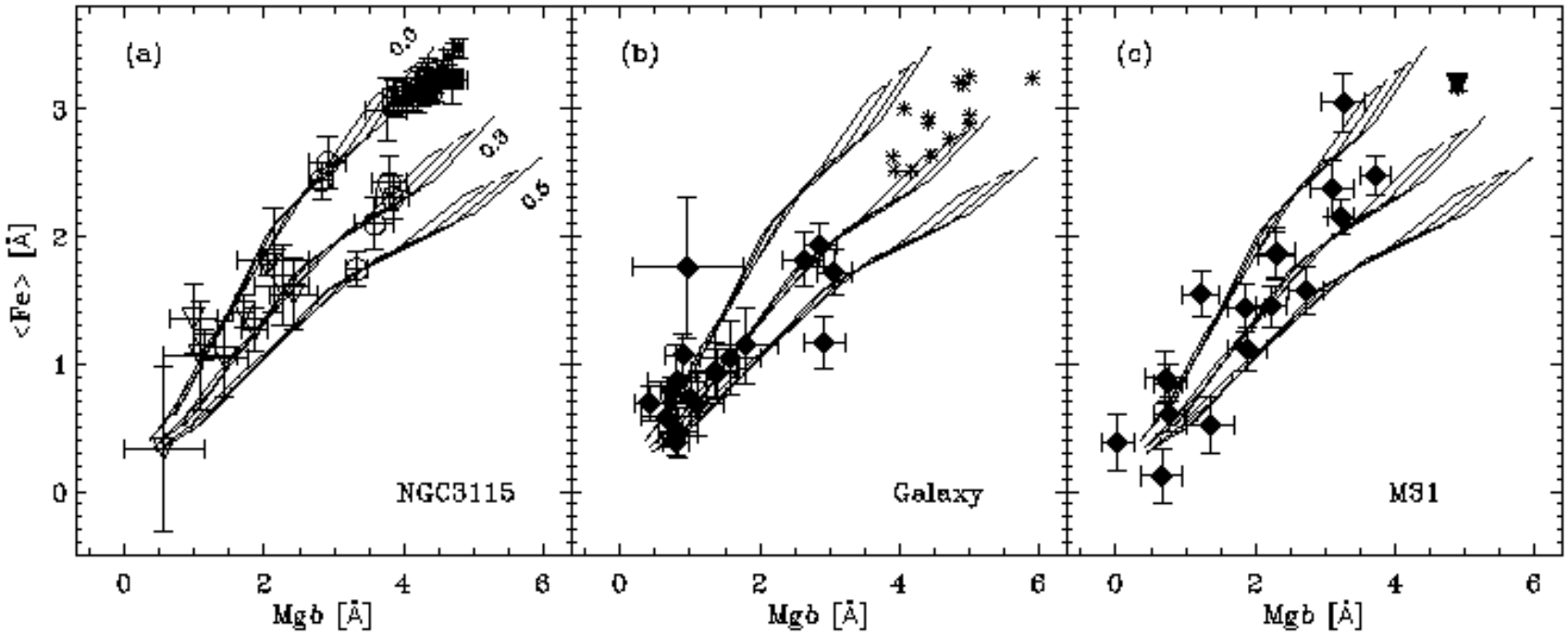






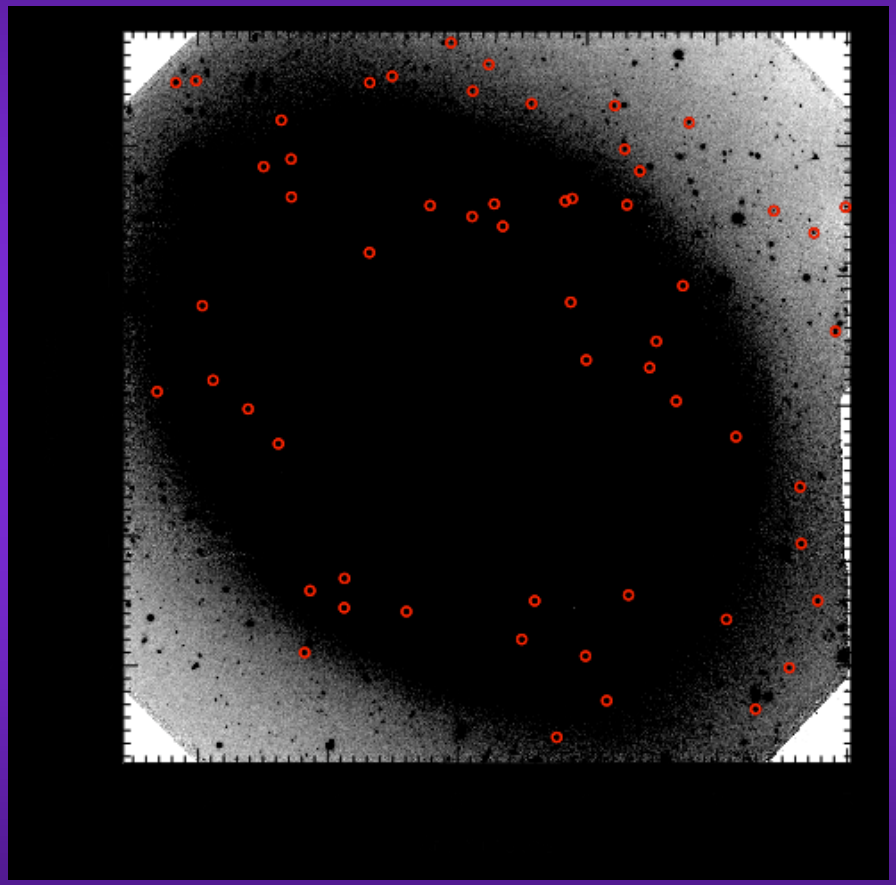
- **Two distinct (metallicity) populations of GCs**
- **Both populations formed at early (12 Gyr) times**

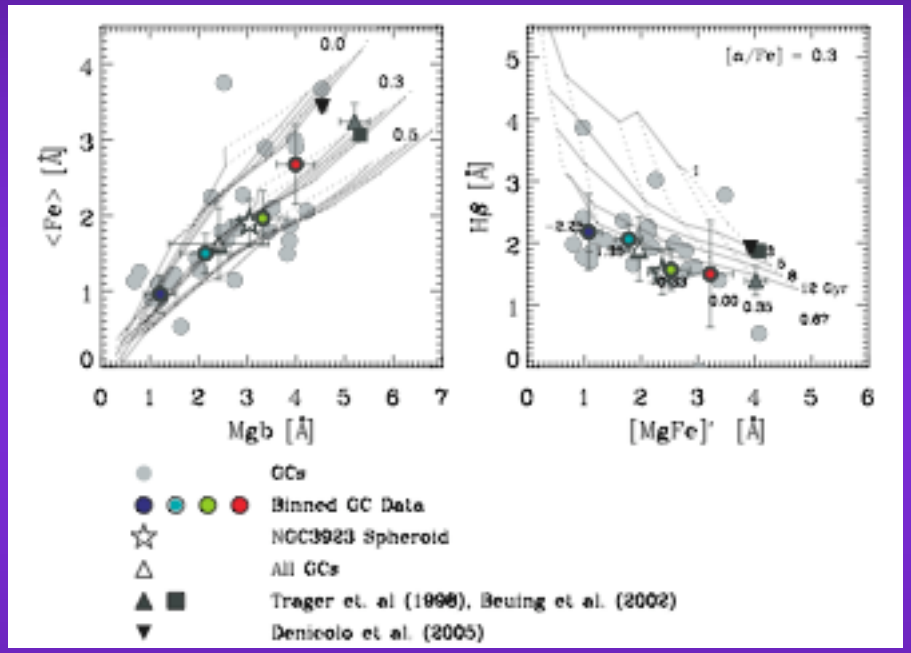
NGC3115



- Spread in abundance ratios from [Mg/Fe]=0.0 to +0.3
- Range of formation timescales (similar to M31 GC)
- Spheroid major axis has [Mg/Fe]=0.0

NGC 3923

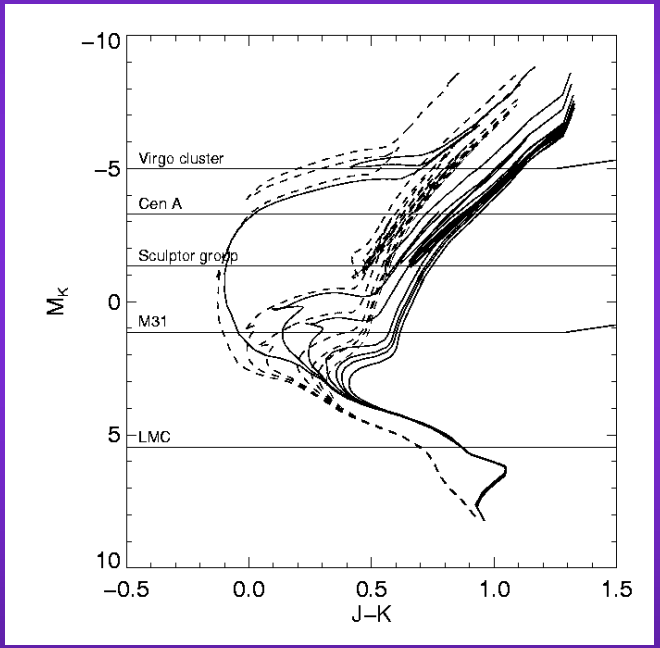




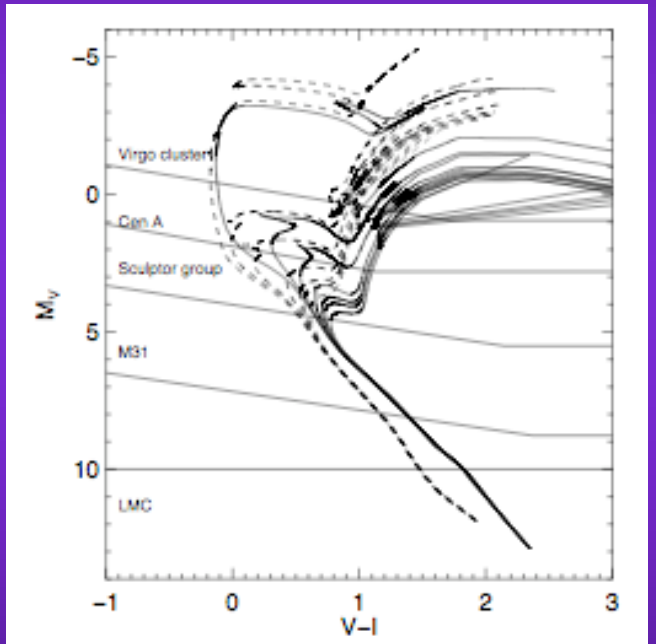
Norris et al (2008)

Resolved Stellar Populations in Galaxy Spheroids

30 m



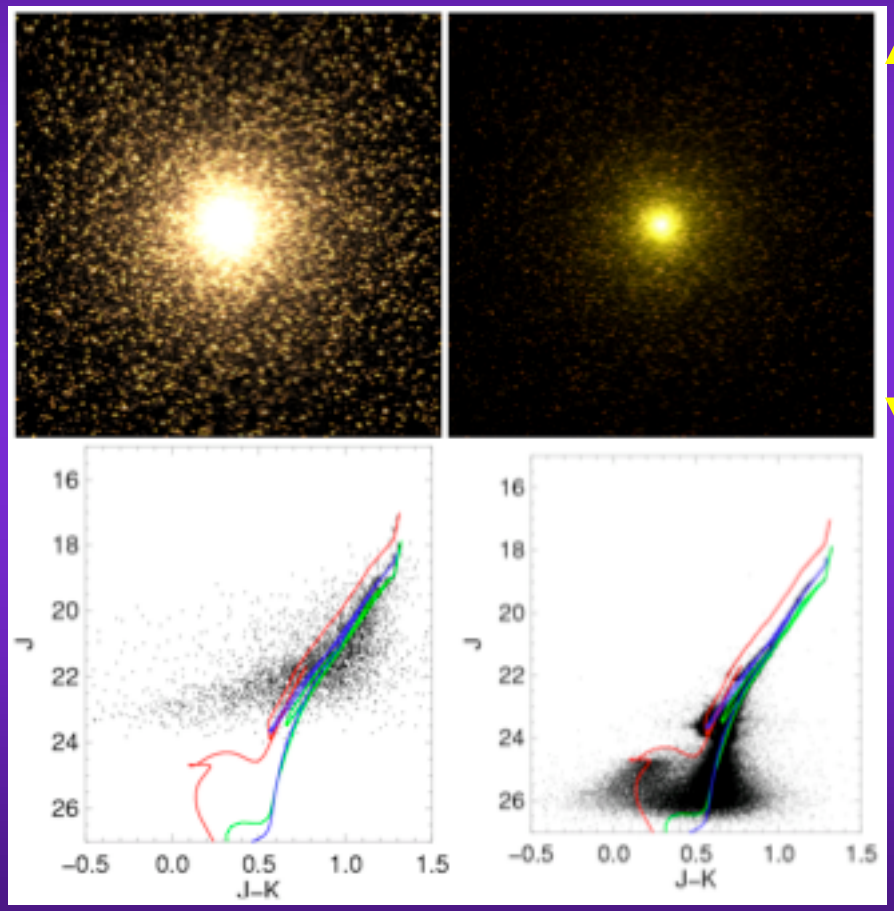
30 m



Magnitudes at which 10% photometry is possible in regions of surface brightness Σ_V=22, Σ_K=19 for galaxies at the indicated distances (Olsen, Blum & Rigaut 2003).

JWST vs ELT

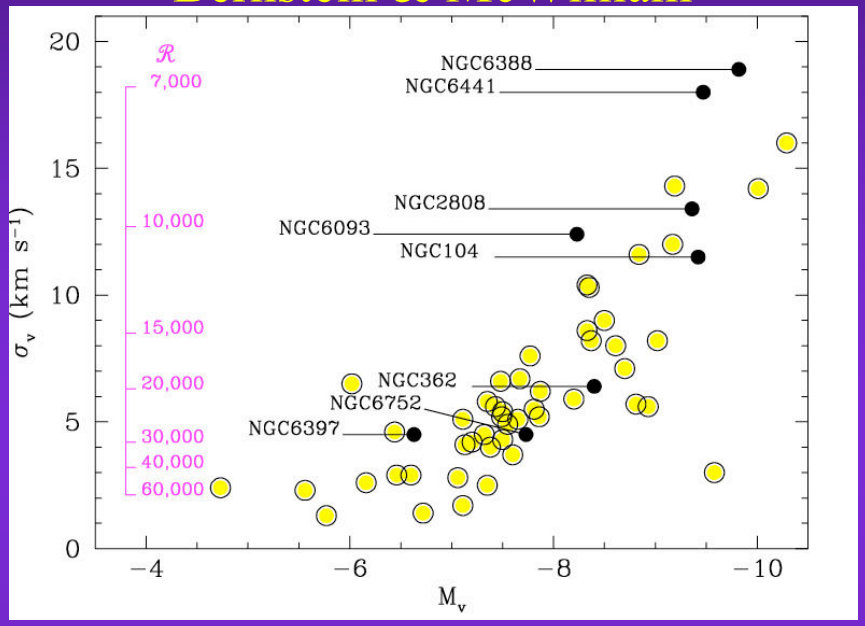
Simulated composite CMD of M32 (D=760 kpc)

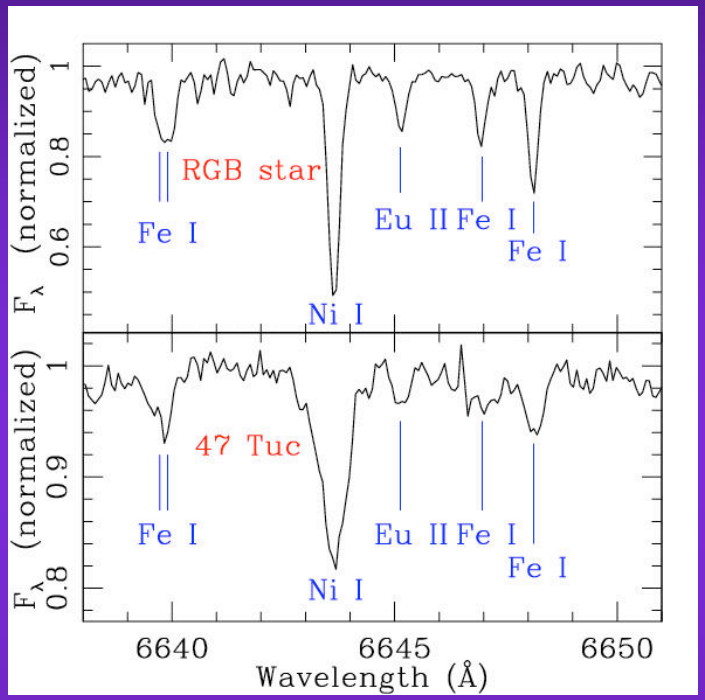


Olsen et al 2009

Detailed Chemical Abundances

Bernstein & McWilliam





[α/Fe] vs [Fe/H] : formation timescale

[Eu/Fe] : r-process (SNII)
IMF, nucleosynthesis

[Ba/Fe] : s-process (SNI, low-m),
IMF, nucleosynthesis

NGC 104 (47Tuc):
[Fe/H] = -0.76
σ_v = 12 km/s
M_V = -9 M_K = - 11
Eu: EW= 16 mÅ

→ need R>10000, multiplex>10, λ<1μm

Some Perspectives

- The local universe is not isotropic (site)
- Majority of abundance work is at optical (λ <1μm) wavelengths (instruments)
- Can we find suitable empirical substitutes for near-IR bands ?
- Can we develop the theoretical model atmospheres ?

Conclusions

- Globular clusters contain a fossil relic of the formation history of their parent galaxies.
- Key diagnostic will be to determine ages & metallicities for GC populations in range of environments and to compare the cluster age/metallicity distributions with those of the resolved spheroids in the nearest galaxies.
- Combination of integrated light spectroscopy (8m) and resolved stellar populations (ELT) can help to constrain the models effectively.