WINGS: WIYN Indiana Northern Globular Cluster Survey

Identifying Multiple Stellar Populations with the CN Red System

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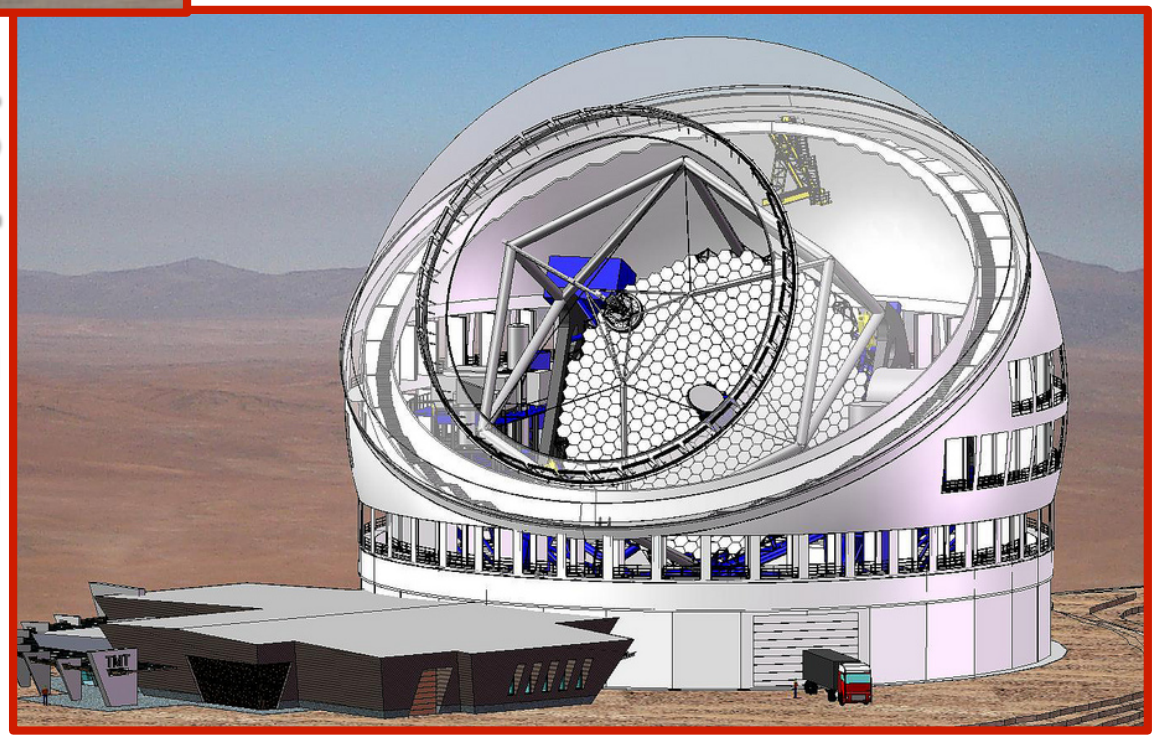
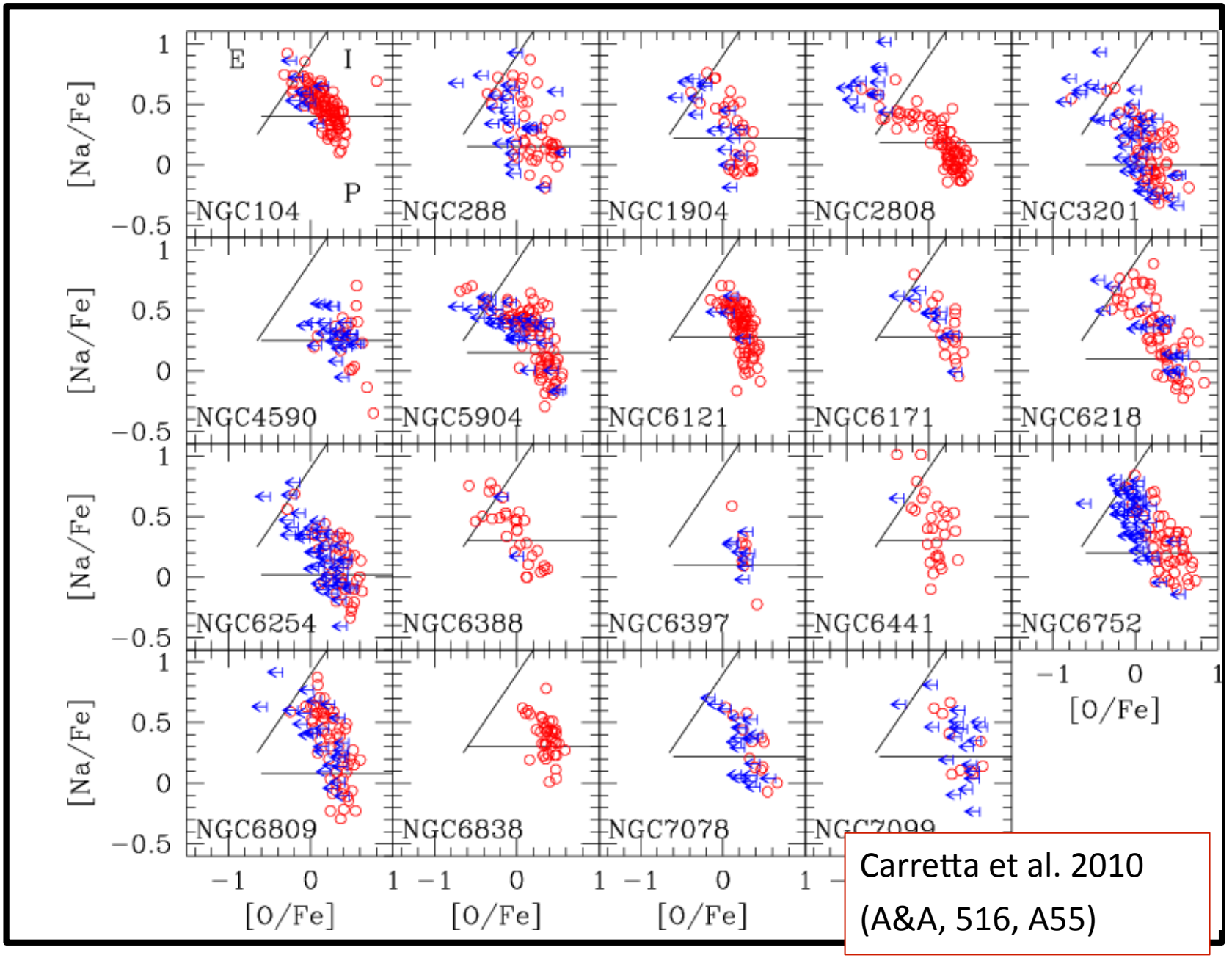


A COMMON PATTERN IN CLUSTERS

Na-O Anti-Correlation



Carretta et al. 2010
(A&A, 516, A55)

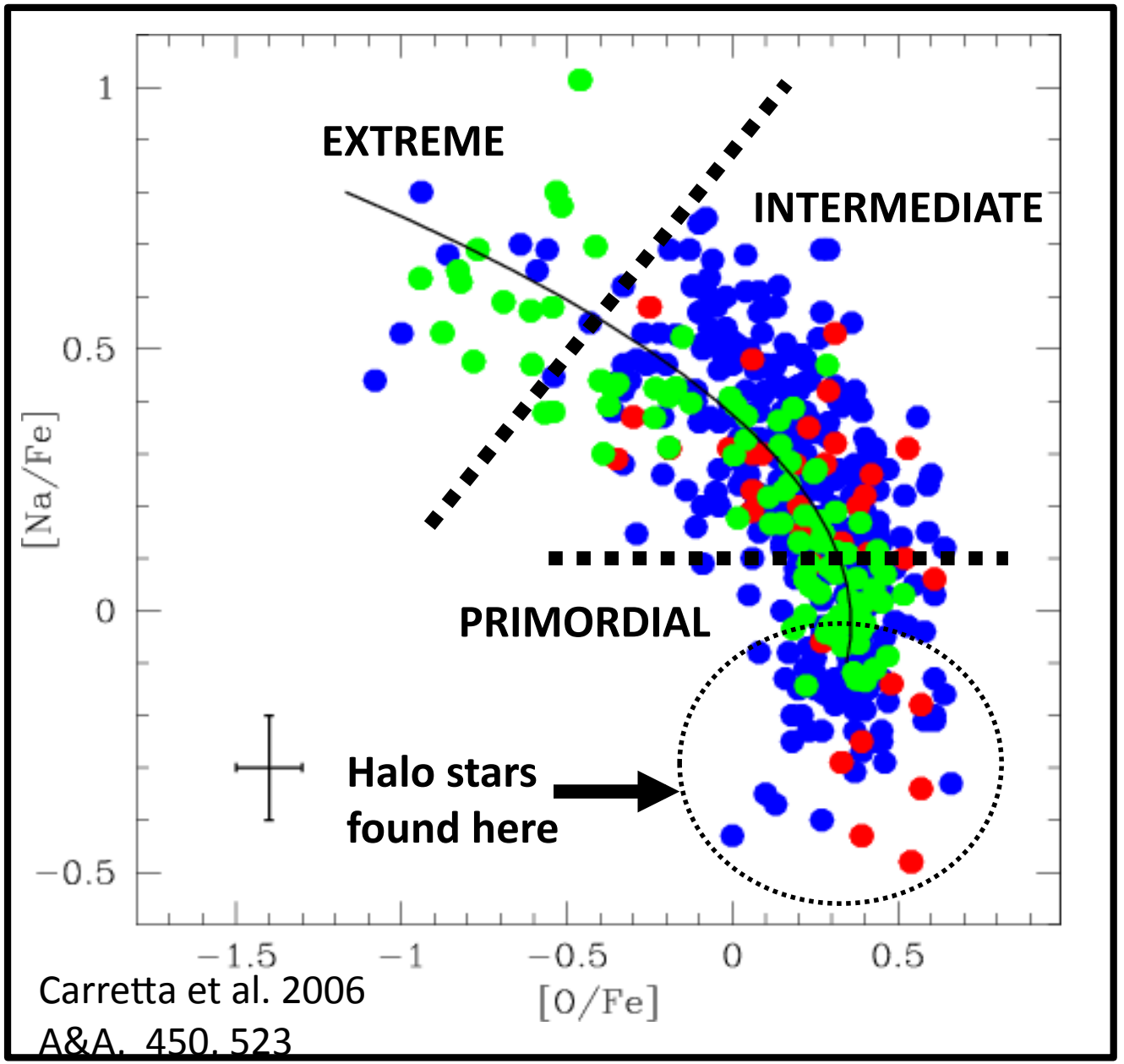
Sodium–Oxygen Anti-Correlation

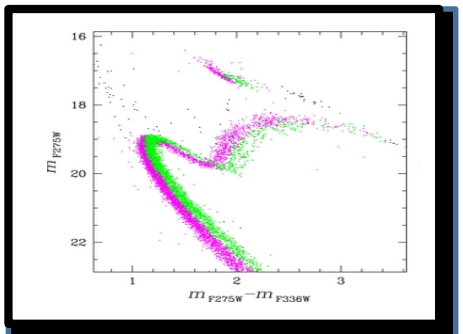
Carretta et al. (2009) define 3 groups

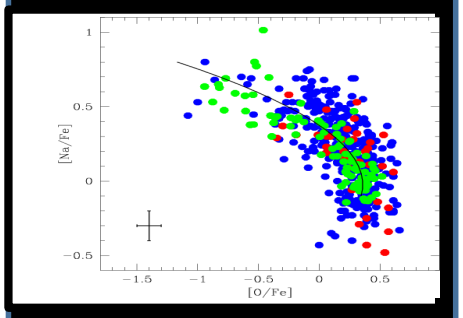
- Primordial
- Intermediate
- Extreme

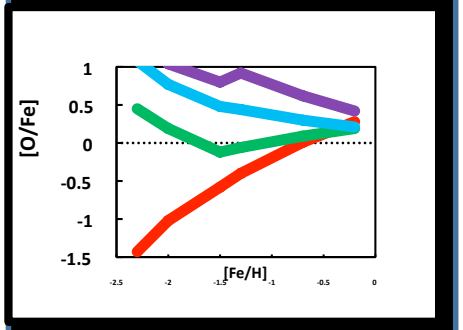
based on sodium and oxygen abundances

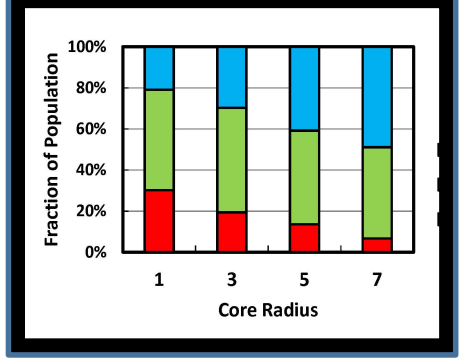
(Data for NGC 2808; colors are different samples. Solid line is mean of 20 clusters)







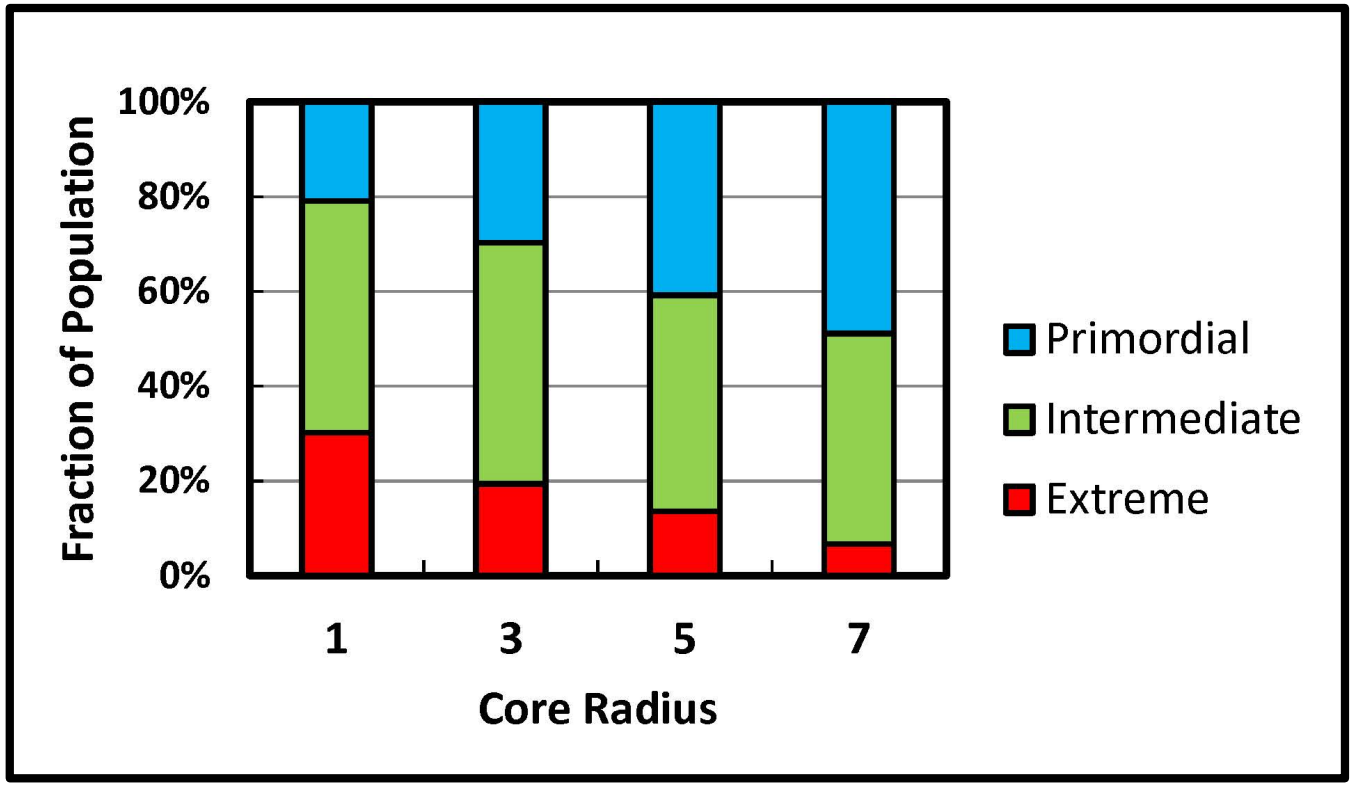




NOT SINGLE STELLAR POPS

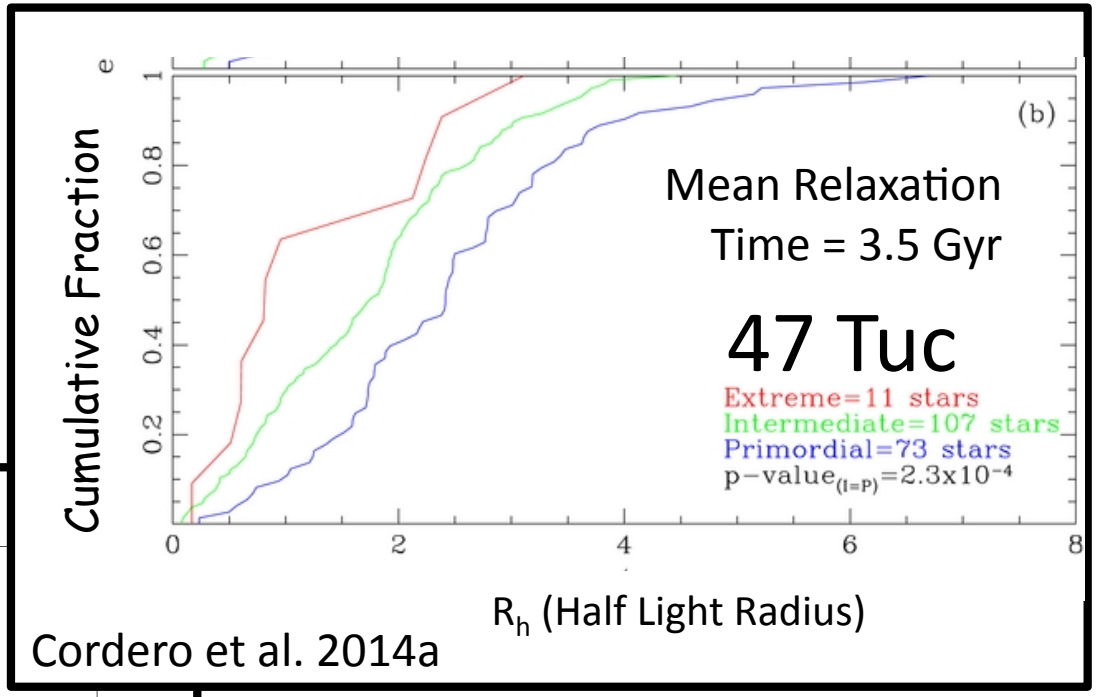
- Globular clusters contain multiple, discrete stellar populations identified in CMDs
- Populations are distinguished by different light element abundances
  - Primordial stars show normal "halo" abundances
  - Intermediate and extreme populations show products of proton-capture nucleosynthesis (He, O, Na, Al) & CN
- Later generation stars are usually centrally concentrated

Radial Distribution in Omega Cen

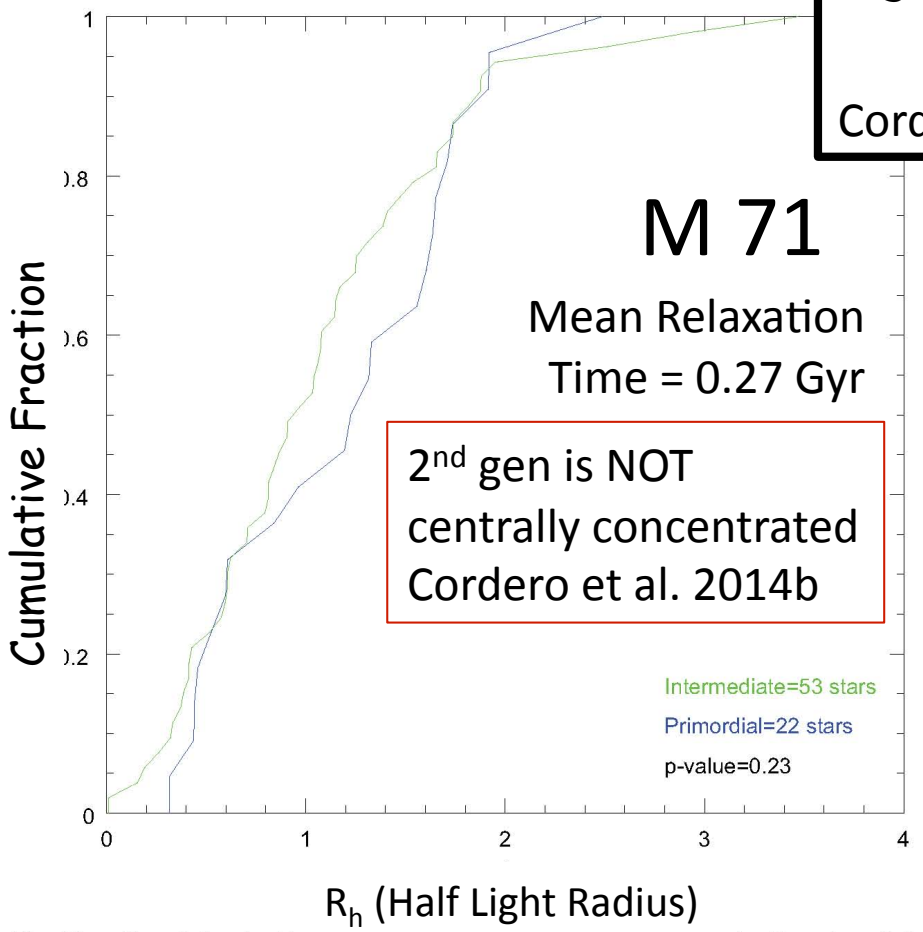


- Oxygen-poor, “extreme” stars reside near the cluster center
- Similar fractions of “intermediate” stars are found at all radii
- Oxygen-rich, “primordial” stars are not centrally concentrated

Centrally Concentrated 2nd Generation



Cordero et al. 2014a

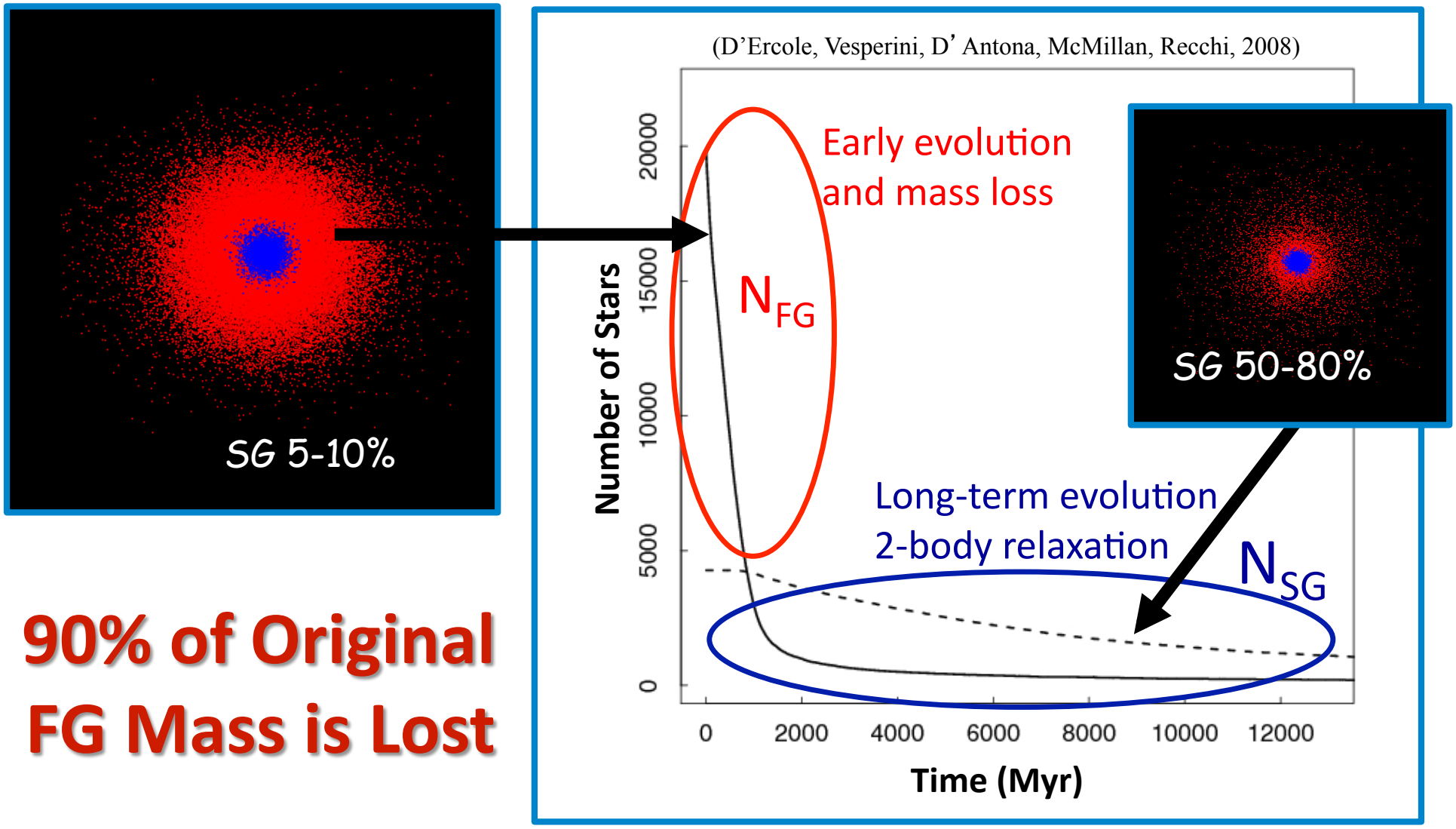


Populations become well mixed after several relaxation times

- 47 Tuc is dynamically young
- M71 is dynamically old

See also

- M 2, M 3, M 5, M 13, M 15, M 92 and M 53 (Lardo et al. 2011)
- NGC 3202 (Carretta et al. 2010)
- M13 (Johnson & Pilachowski 2012)

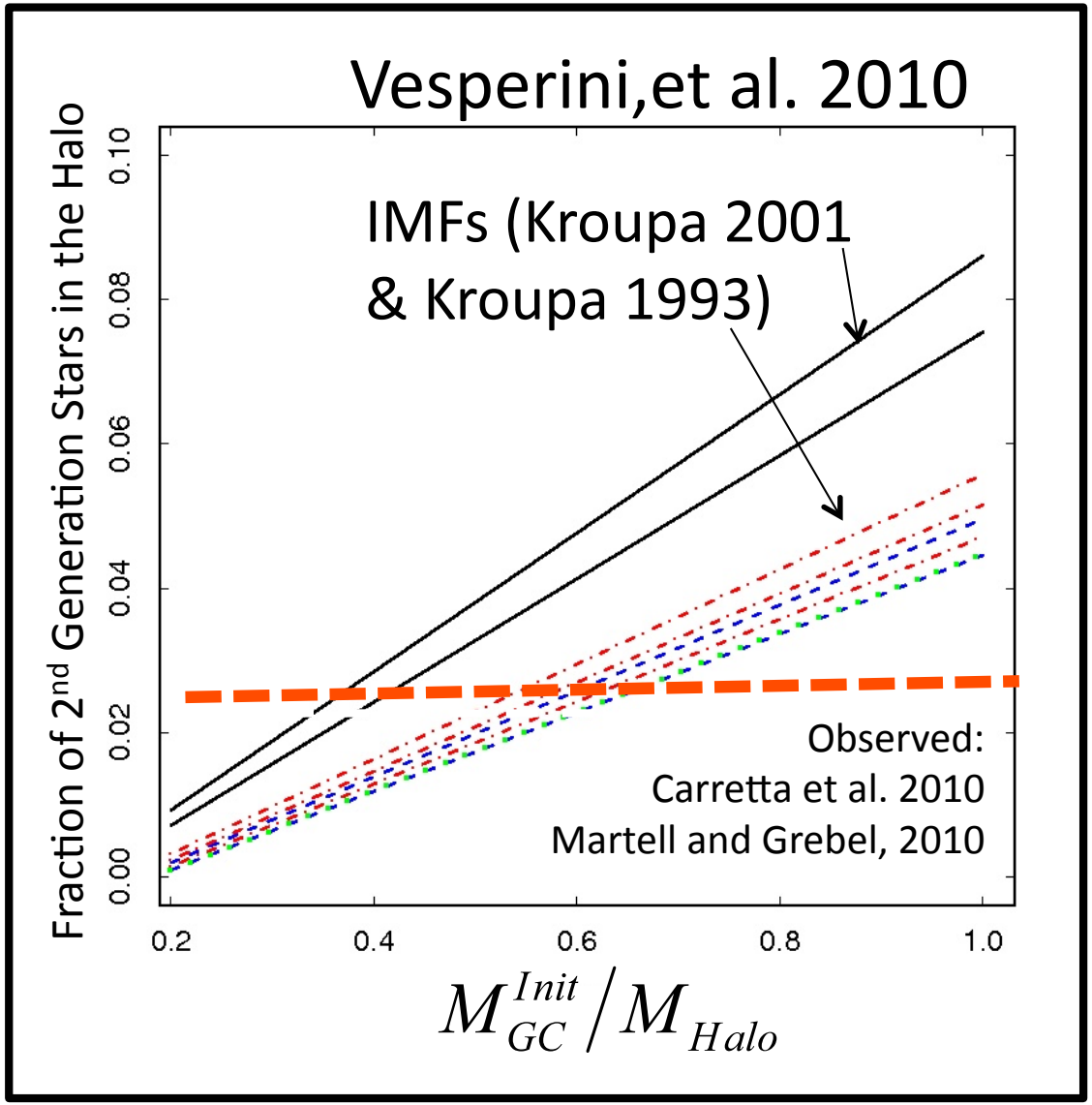


90% of Original FG Mass is Lost

- Outer, 1st generation stars stripped off
- 2nd generation stars become dominant

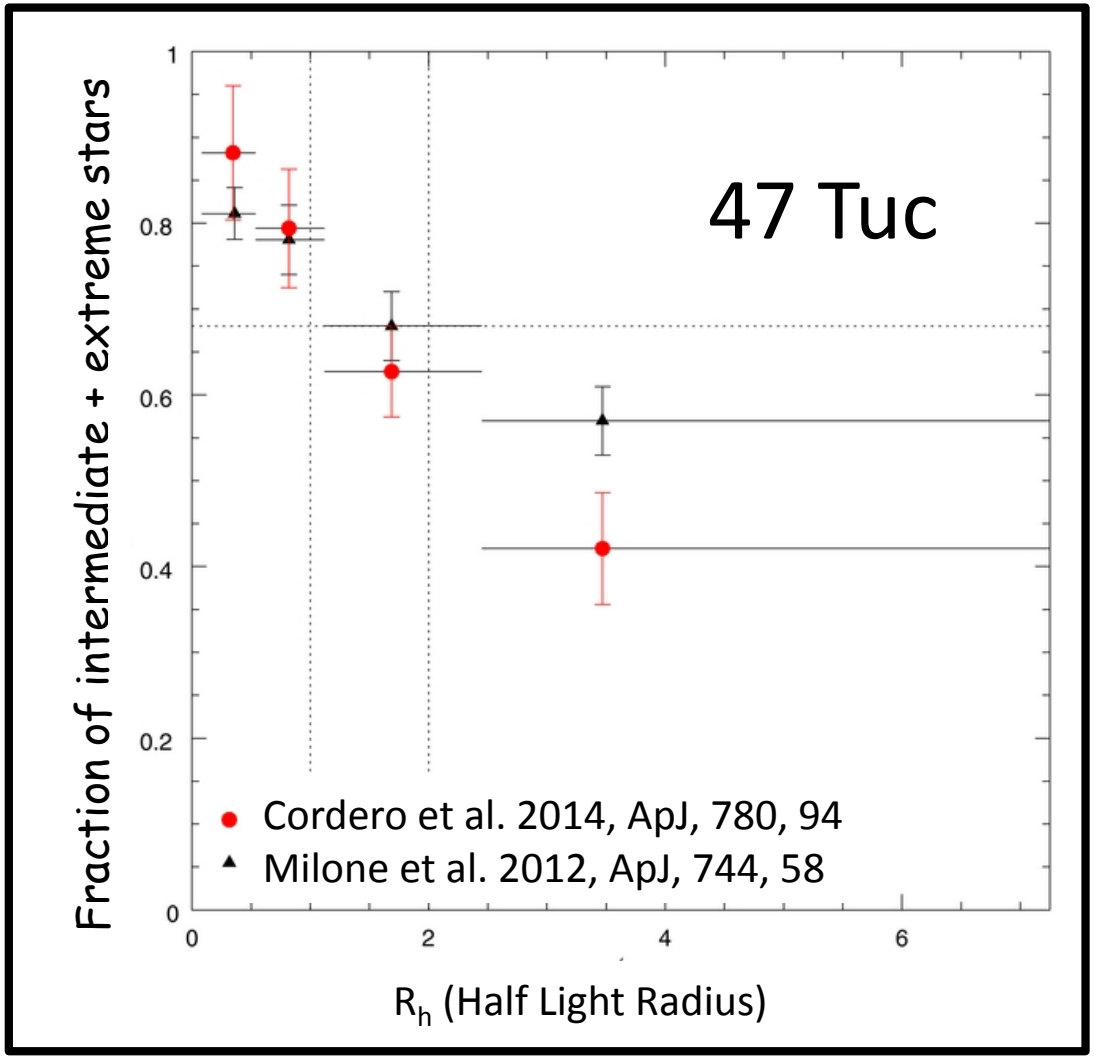
Implications for Galactic Halos

- Halo field stars mostly resemble primordial (1st gen) GC stars
- A few (2.5%) of halo field stars show 2nd gen characteristics
- **Lost 1st gen stars contribute 30-40% of halo field stars** (Vesperini et al. 2010)



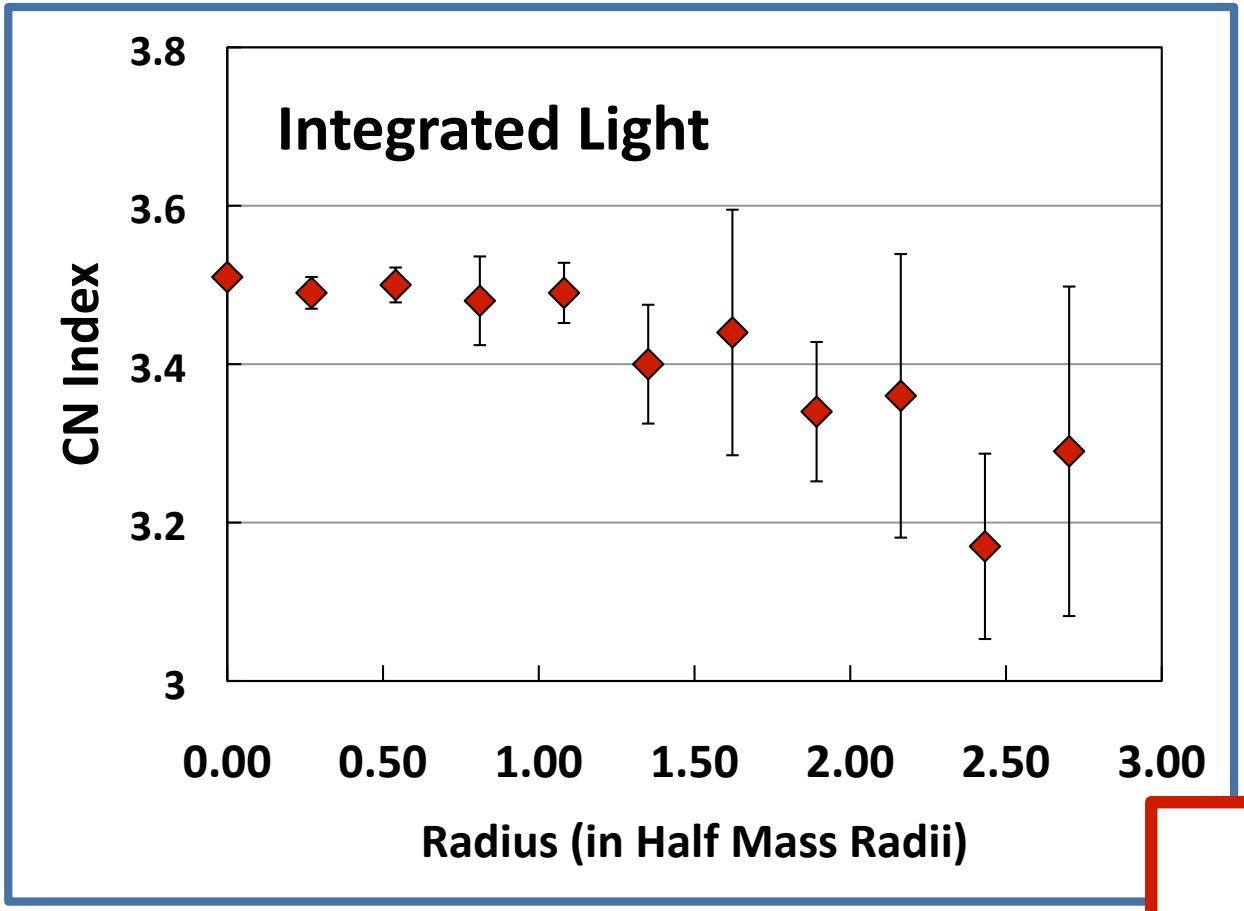
Do Globular Clusters Populate Galaxy Halos?

Central concentration of 2nd gen stars suggests composition gradients in integrated light



Stars within two half light radii show stronger CN, Na features

CN Strength Gradient in 47 Tuc Detected by Chun & Freeman (1979)



CN is stronger in the central region

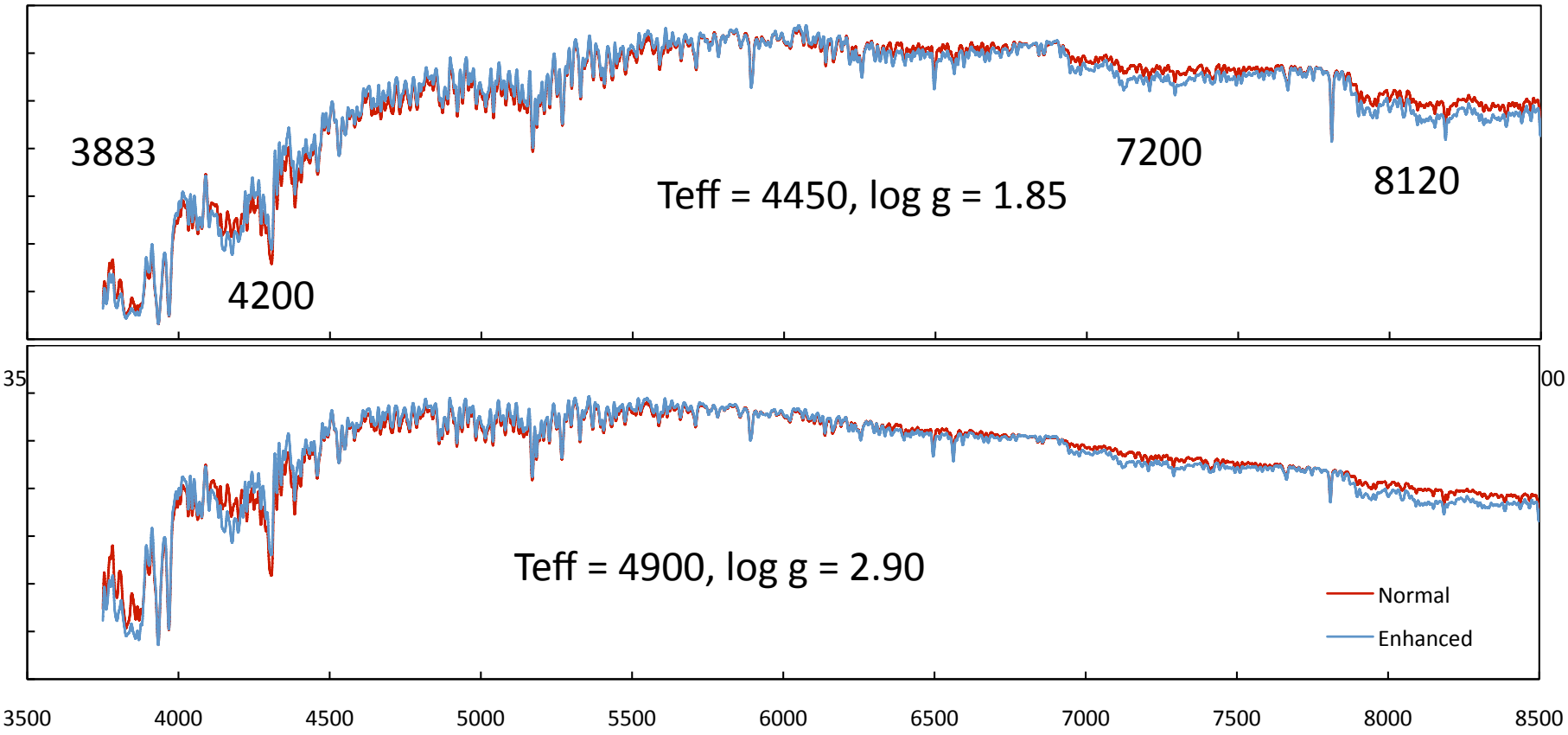
Color gradients have been known for a while, but have been difficult to explain

Chun & Freeman 1979, ApJ, 227, 93

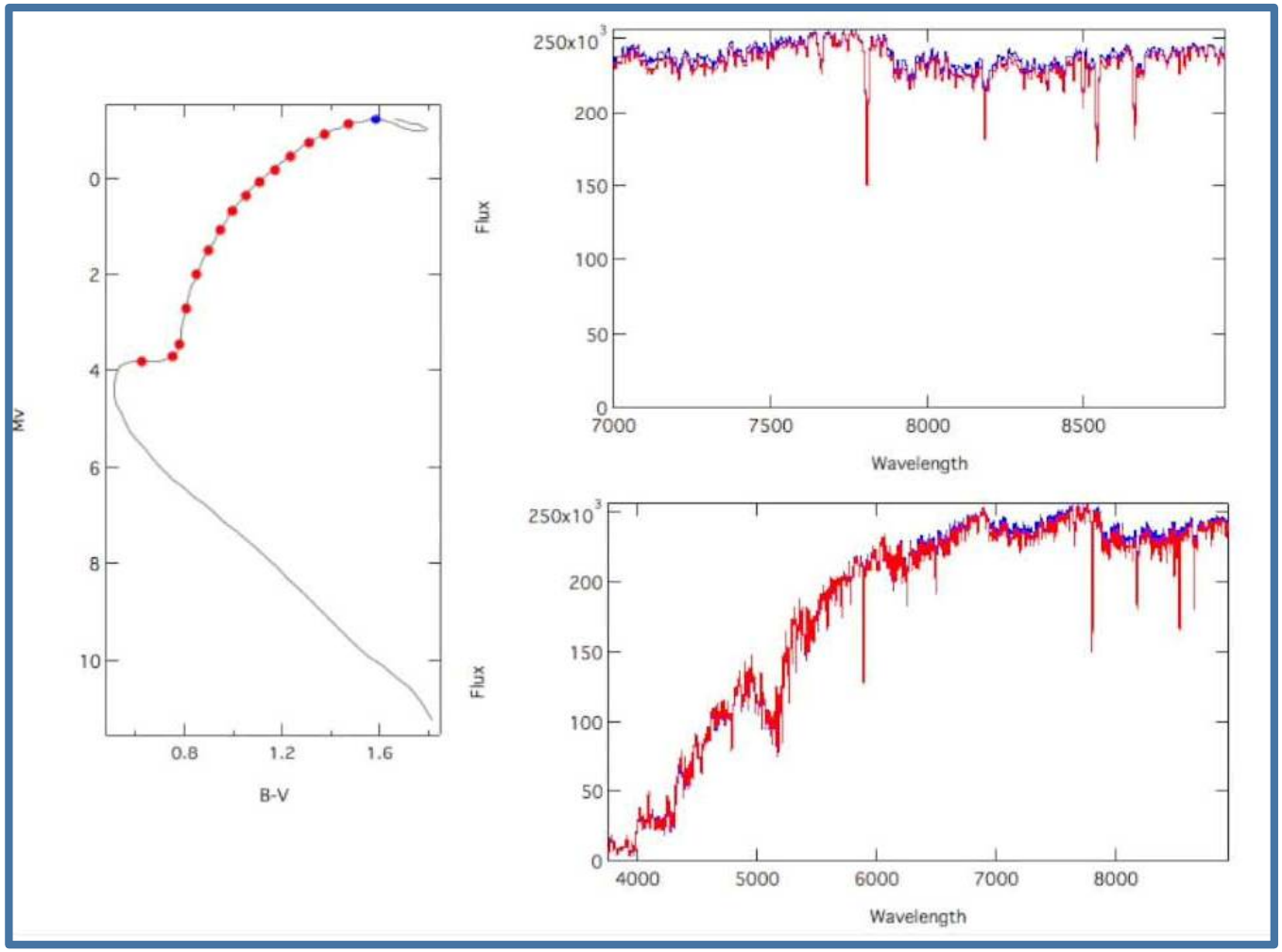
Detecting Multiple Pops in Integrated Light: The CN Red System

Why use the CN red system?

- ✓ Better CCD QE
- ✓ More flux
- ✓ Better angular resolution & AO
- ✓ OH “hole”



Synthesis of the CN Red System

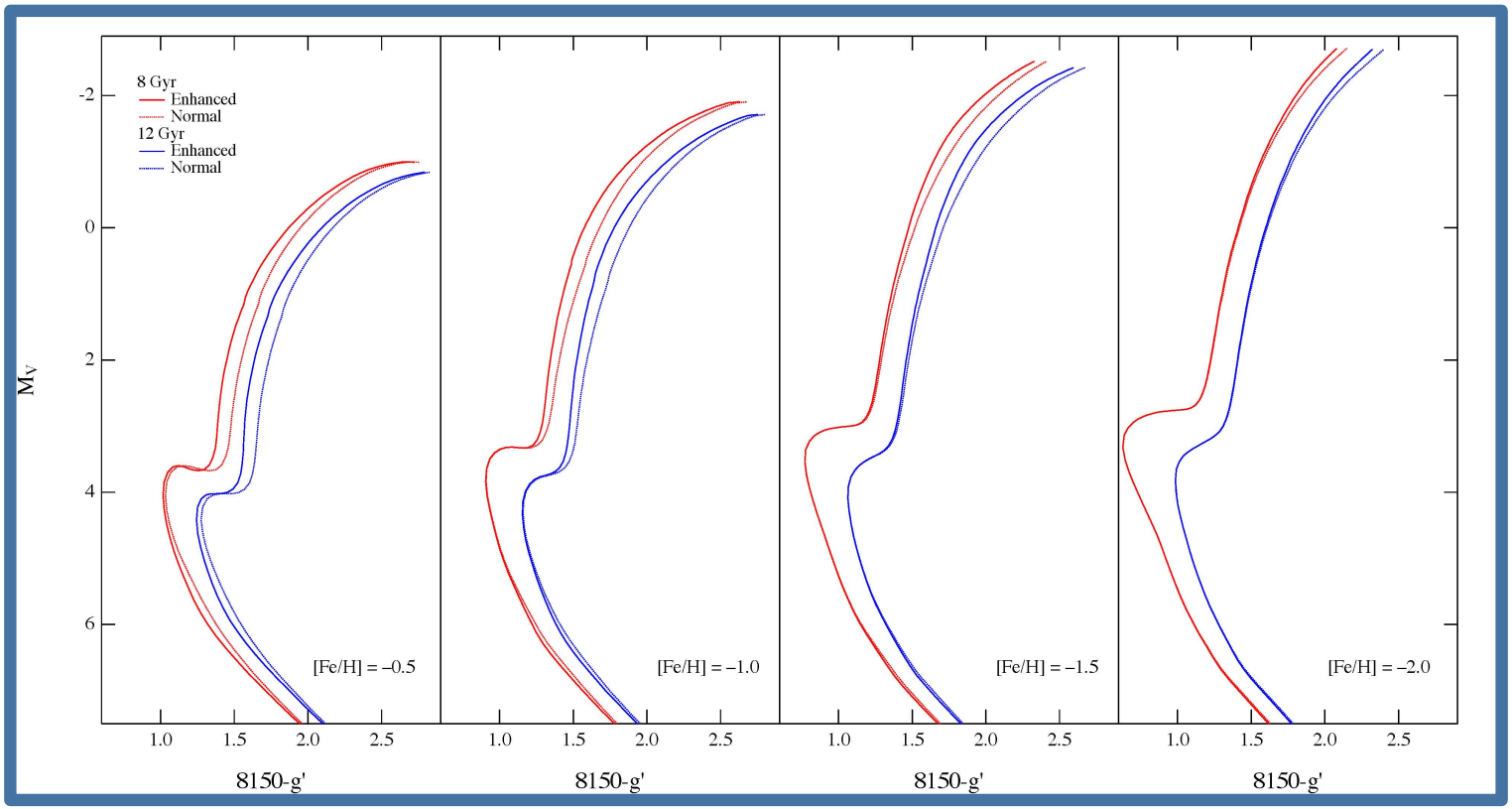


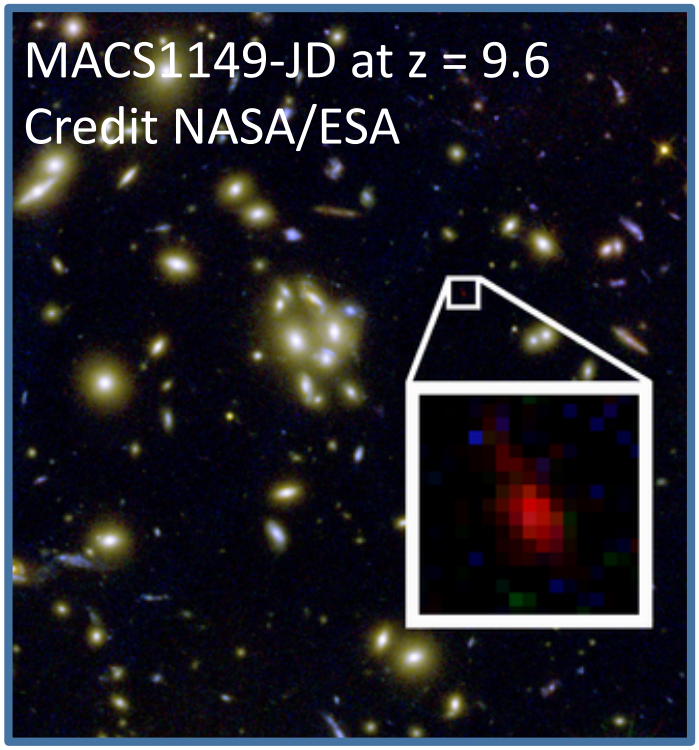
Thanks to Mike Briley!

CN (8150 – g') vs. Metallicity

- ✓ In metal rich clusters, CN is saturated at the tip
- ✓ In metal poor clusters, CN is too weak on the lower RGB

More thanks to Mike Briley!





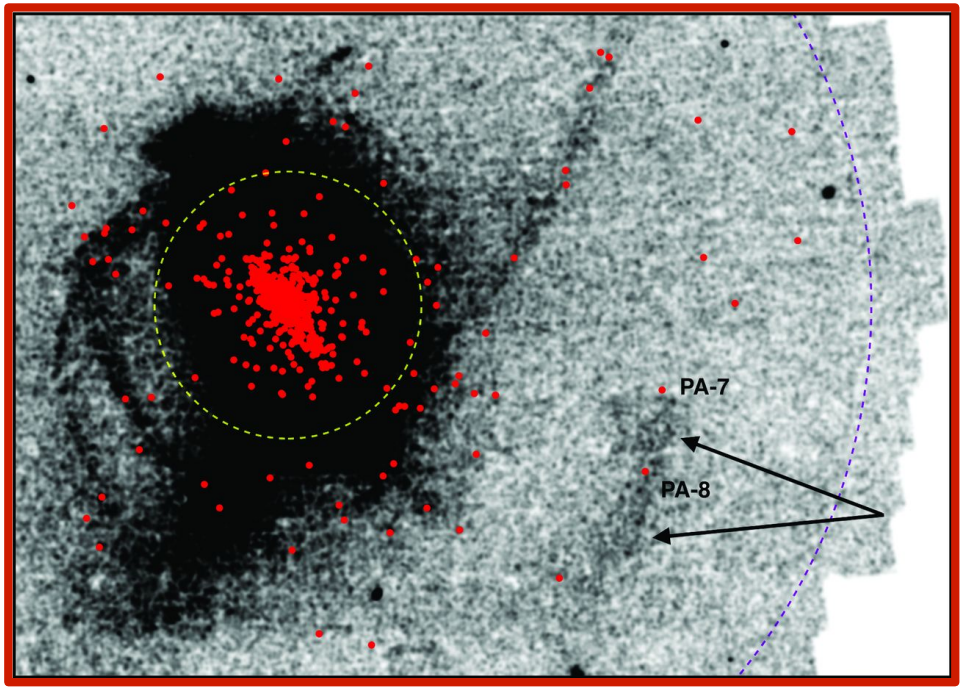
Why Should You Care?

✓ Understanding GC formation is key to understanding star formation in the early universe

✓ Multiple populations may relate to the interpretation of red/blue GC systems in external galaxies

✓ GC systems in external galaxies provide large samples in different environments against which we can test cluster evolution models against various parameters (mass, age, metallicity, concentration, He abundance, orbit…)

What's Possible Now?



Mackey et al. 2013, MNRAS, 429, 281
Huxor et al. 2014, MNRAS, 442, 2165

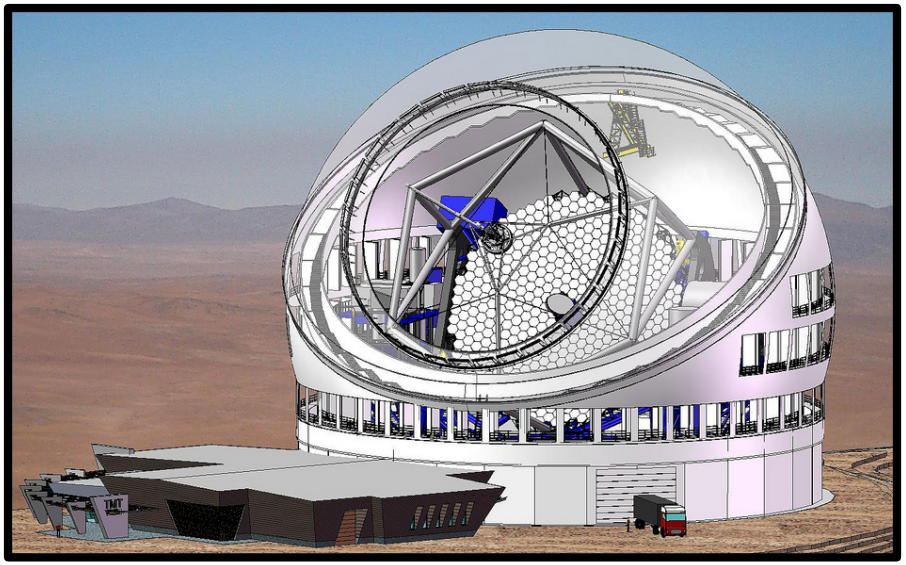
PAndAS Catalog

- 11 globulars with $R_h > 5''$
- 16 globulars with $3'' < R_h < 5''$
- 70 globulars with $R_h < 3''$
- Magnitude: $16 < m_i < 22$

WINGS will detect and measure population gradients in globular clusters in M31 (and other Local Group galaxies) in integrated light

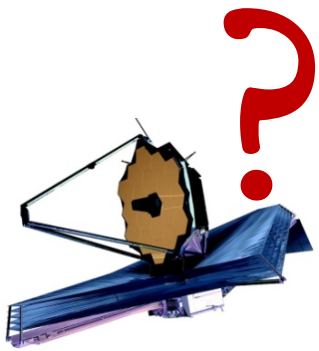
- HST: slit spectroscopy
- Ground-based: narrow band filters (8150-g')

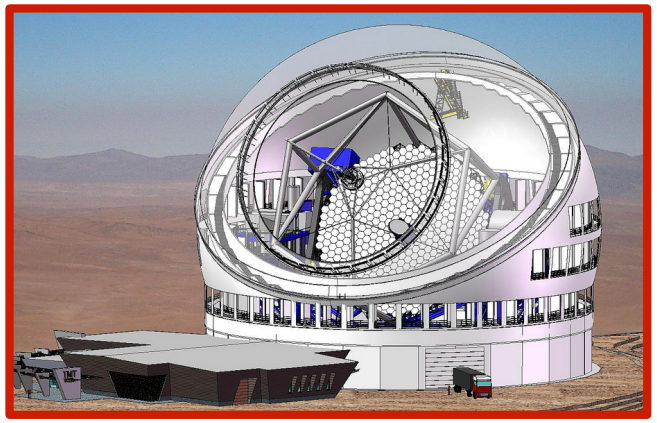
What's Possible with TMT?



- R_h at Virgo typically < 0.2"
- Magnitude of Virgo GCs: $22 < m_i < 26$

Imaging and spectroscopy with IRIS & AO at 0.8 microns will enable characterization of population gradients within globular clusters at the distance of the Virgo cluster.





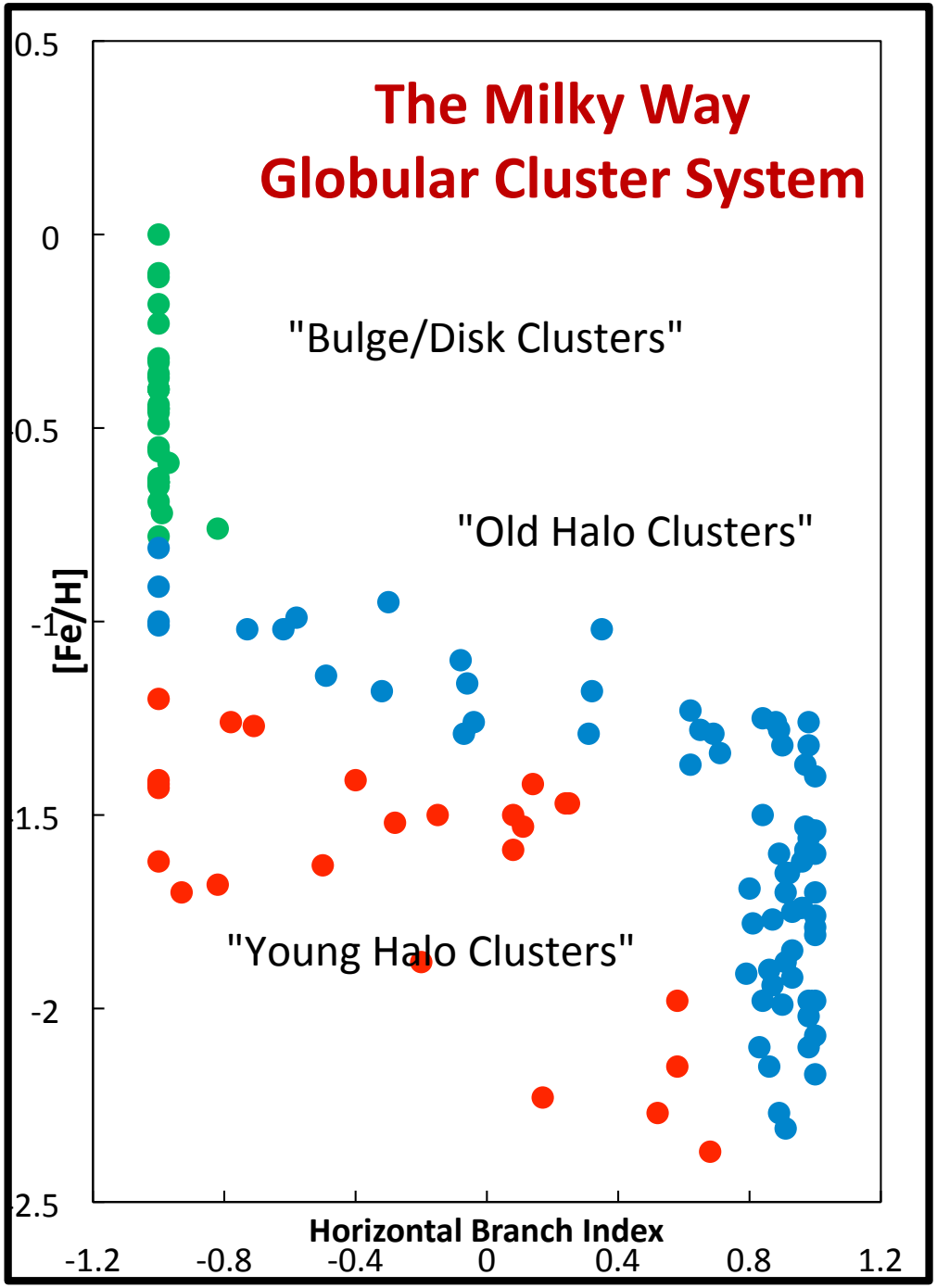
Summary

- ✓ Multiple populations in globular clusters are evident in integrated light
- ✓ We can study multiple populations in Local Group globular clusters with current facilities
- ✓ With TMT we can detect and study multiple populations as far as Virgo (and beyond?)

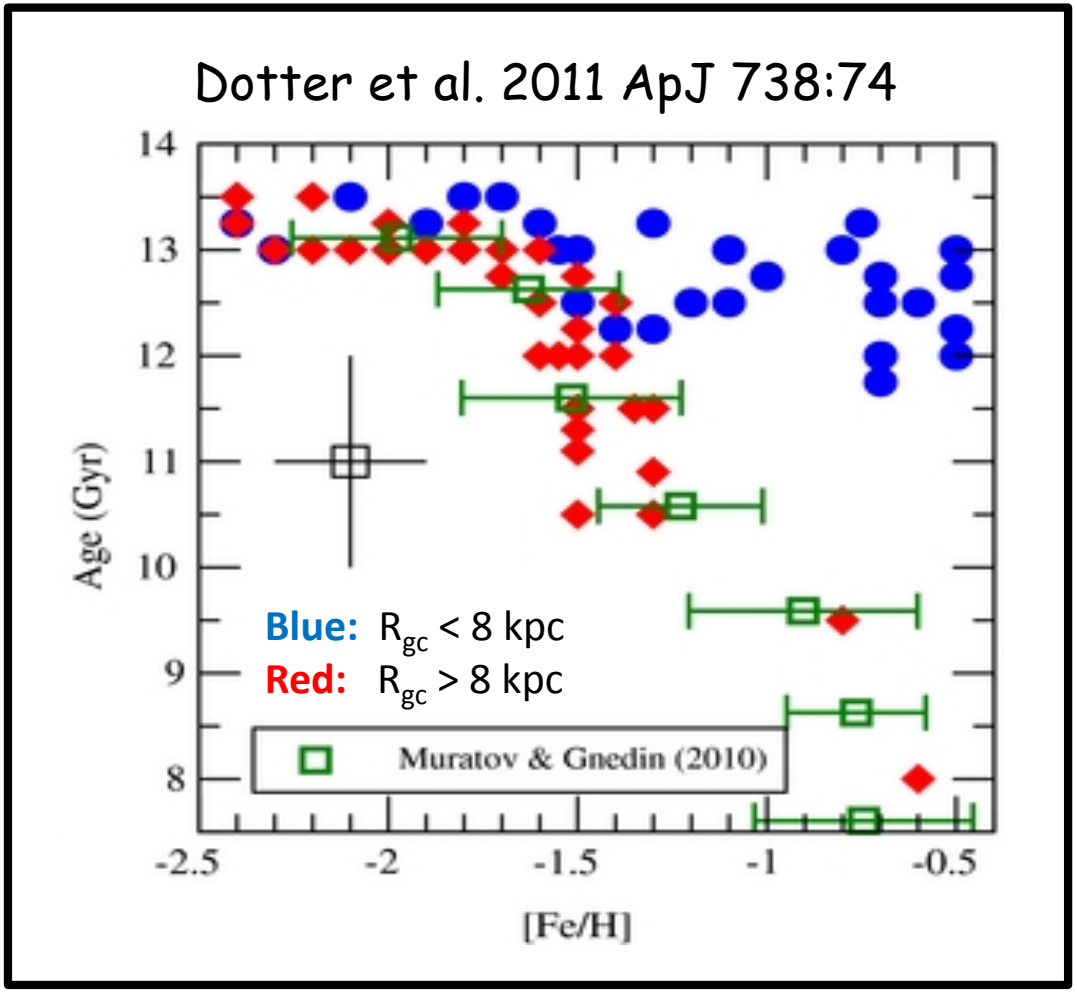
Extra Slides

Galaxy Halos Are Not Simple Stellar Pops

- The MW halo includes 3 cluster subsystems distinguished by metallicity, age, HB type, & kinematics (see Mackey & Gilmore 2004 for a full discussion)
- Halos built through globular (and smaller) cluster disruption, mergers, & other processes



Implications for GC System Formation



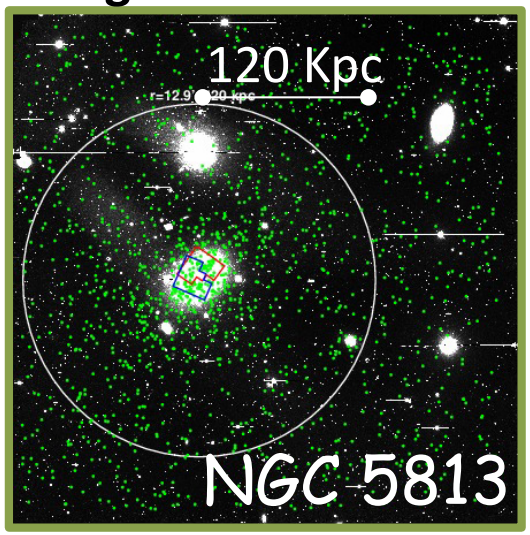
- **MW GCs with R_{gc} < 8 kpc (blue)** formed during rapid chemical enrichment in the inner galaxy
- **Some/most MW Red GCs with R_{gc} > 8 kpc** formed in dwarfs and were later accreted

Extragalactic GC Systems Also Provide Clues

See poster 214.10 by Jessica Windschitl et al. Tuesday

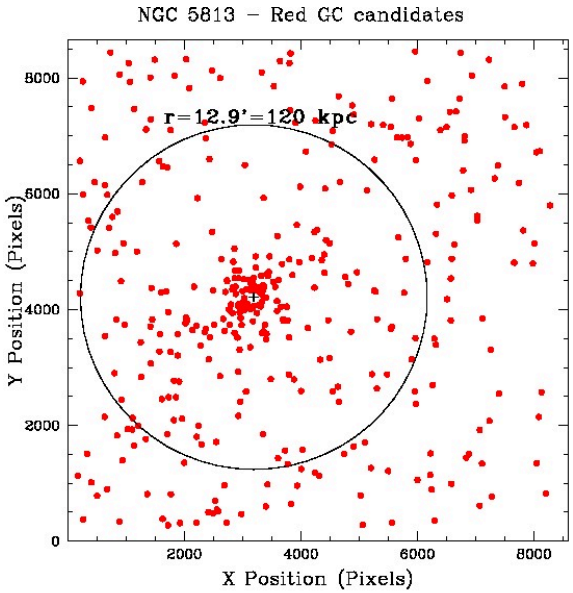
- Bimodal color/metallicity distributions
- Radial distributions differ
  - Red GCs: metal-rich, centrally concentrated
  - Blue GCs: metal poor, less concentrated

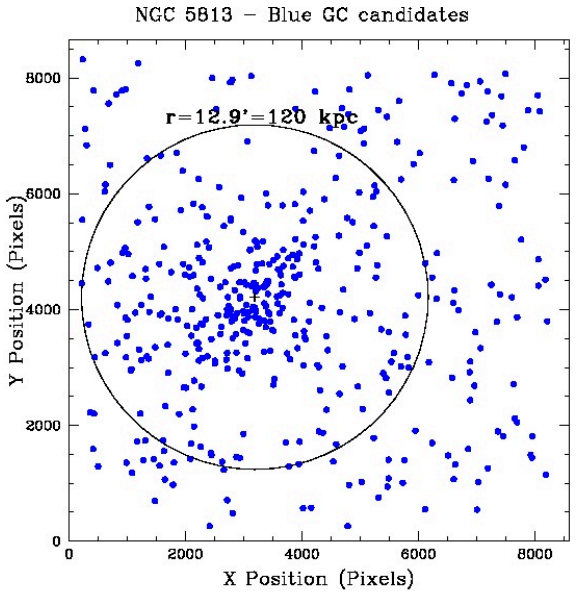
Hargis & Rhode 2012



Mayall 4-m

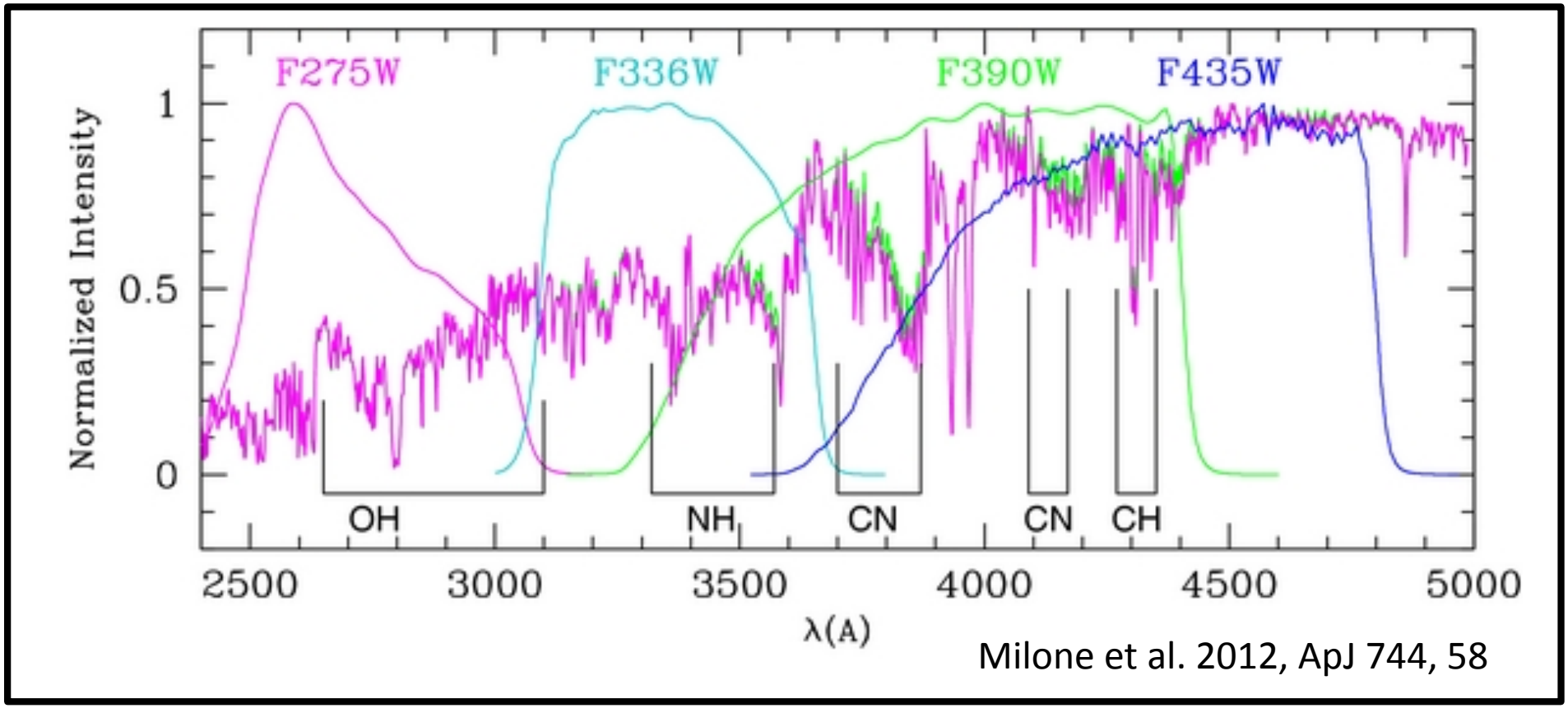
Green = GC candidates





Multiple Pops are COMMON in Globular Clusters

(If you know how to look for them)



Milone et al. 2012, ApJ 744, 58