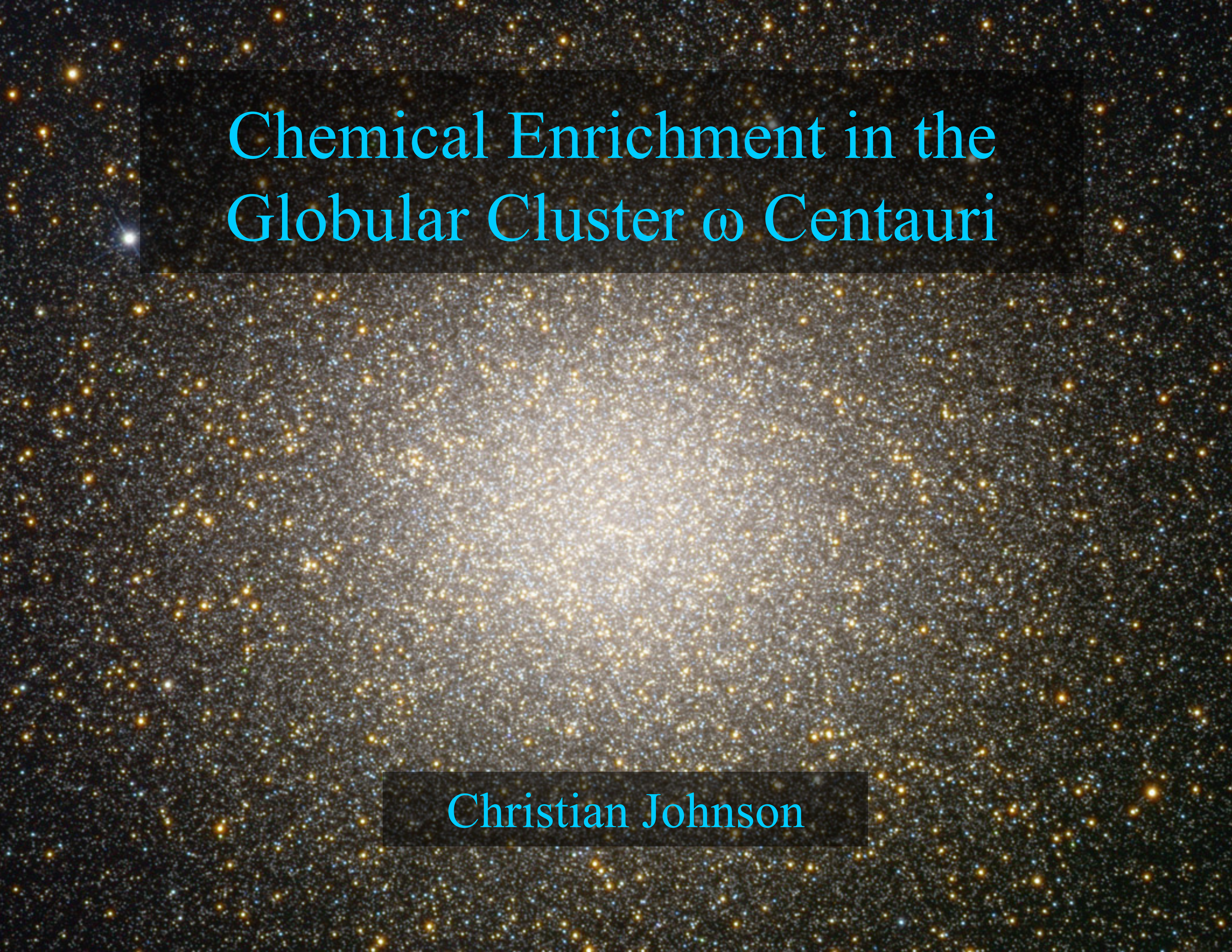
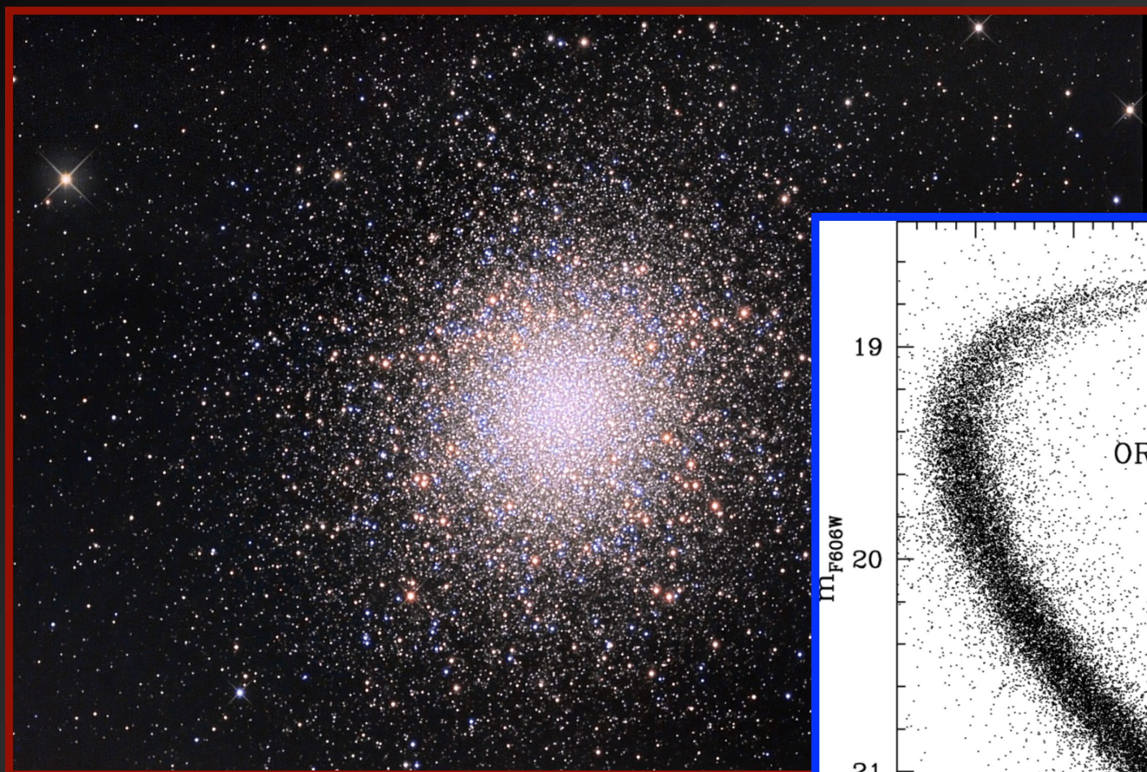
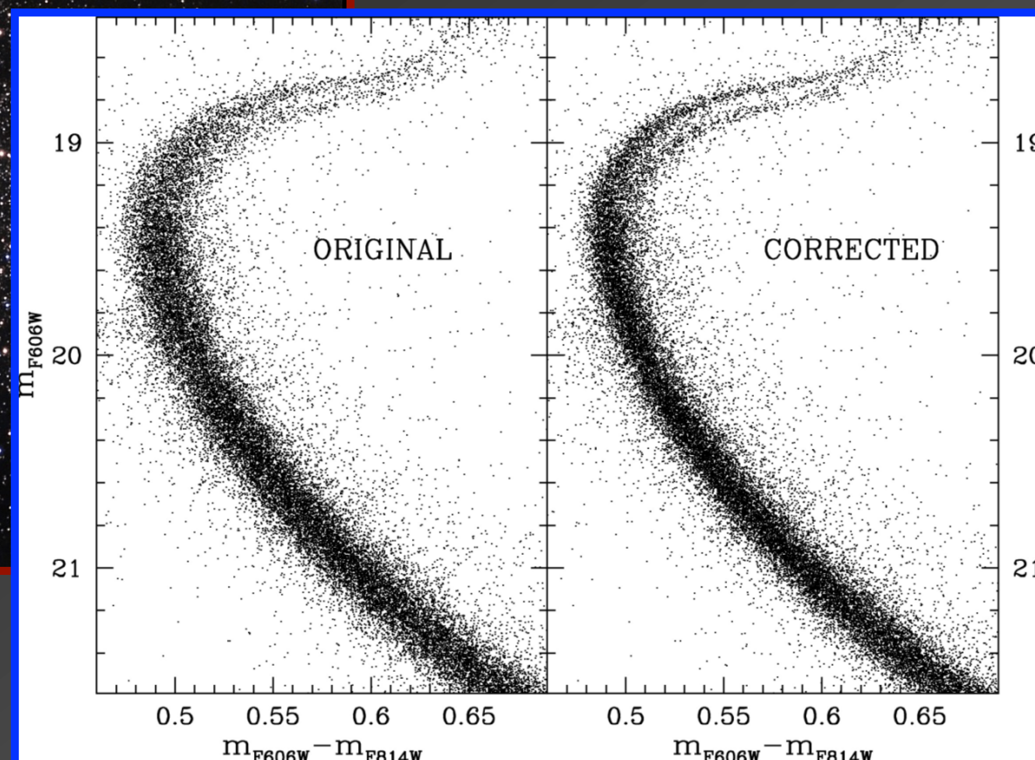
Chemical Enrichment in the Globular Cluster ω Centauri



Christian Johnson

Globular Clusters as (not so) Simple Stellar Populations: The New Paradigm

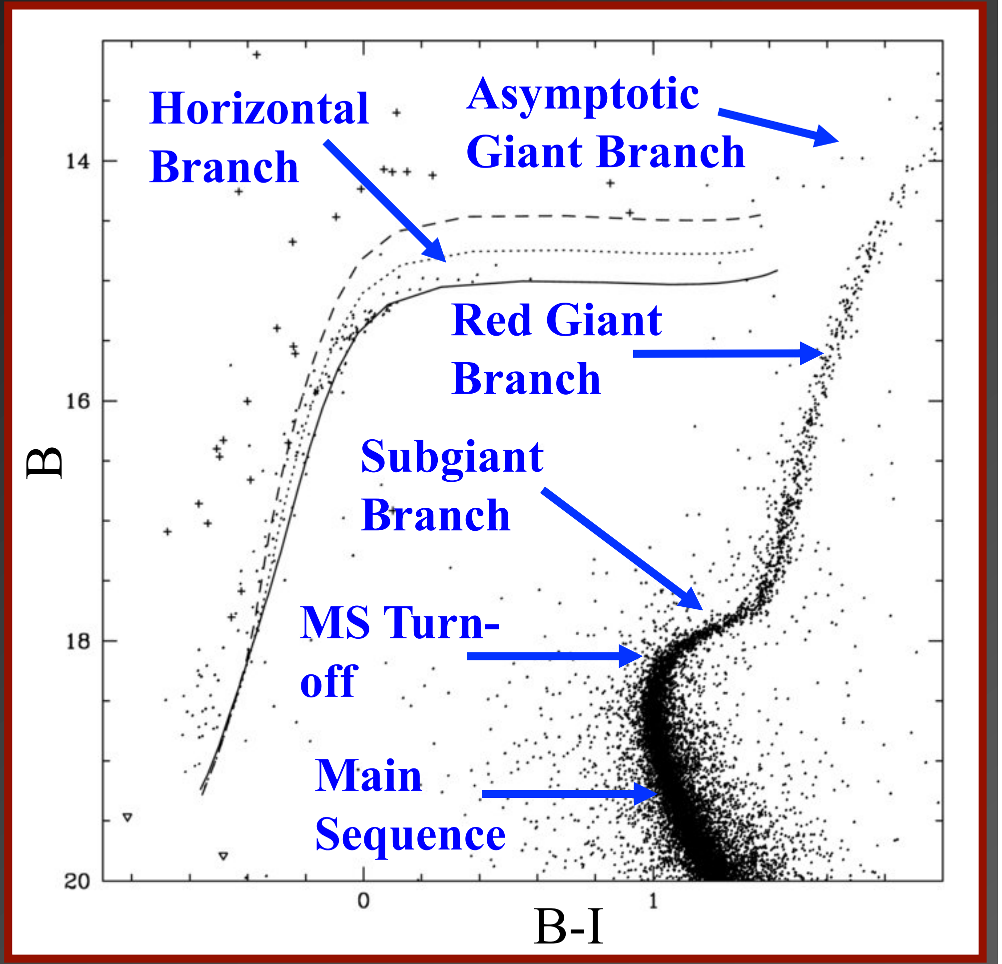




Globular Clusters as Simple Stellar Populations

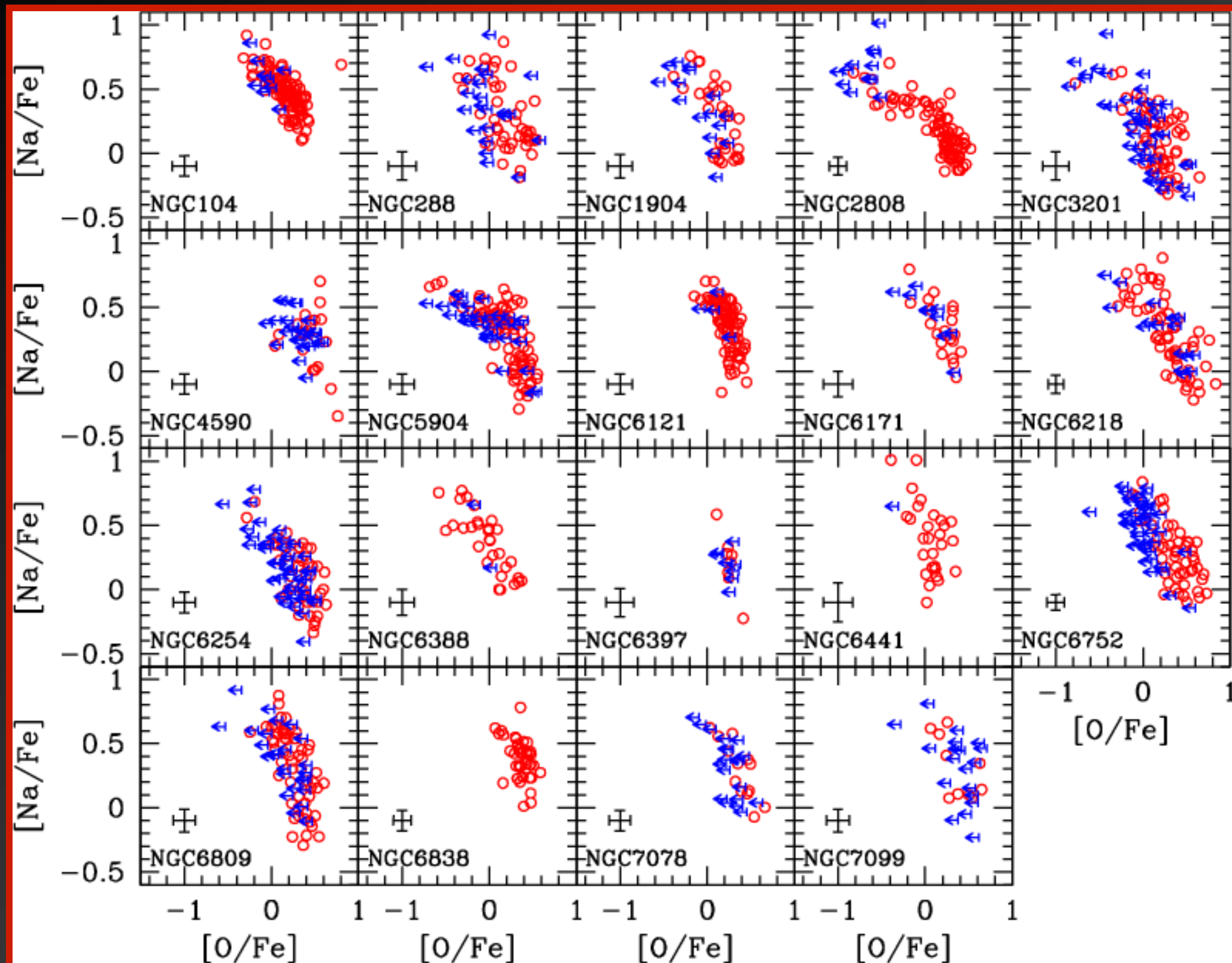
- ❖ Stars exhibit small or negligible age spread
- ❖ Very small (<0.1 dex) metallicity dispersion
- ❖ Old population; no gas/SF
- ❖ Enhanced "alpha" elements and small star-to-star abundance dispersion
- ❖ Heavy element pattern follows solar-scaled r-process
- ❖ Rapid enrichment timescale

Sandquist et al. (2010)



Globular Cluster M13

Are Globular Clusters Actually "Simple?"

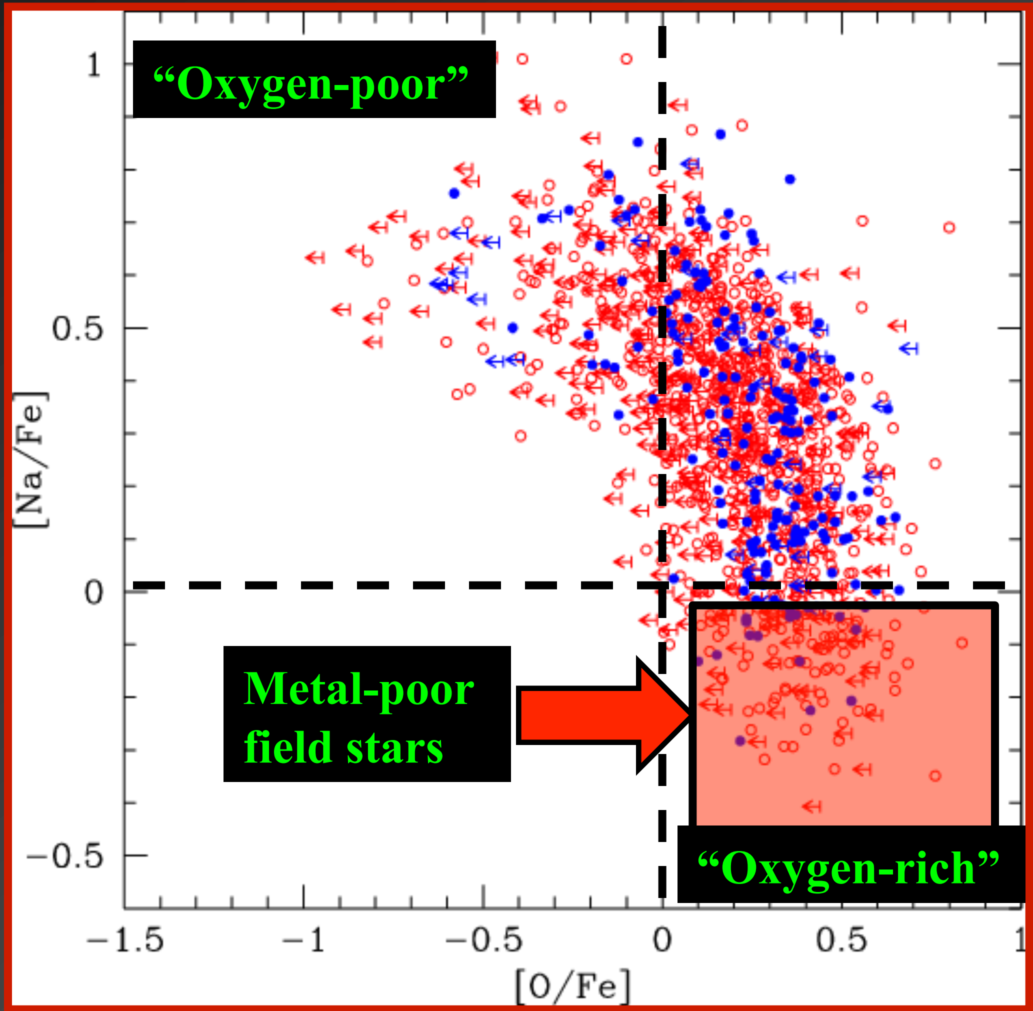


Carretta et al. (2009)

Are Globular Clusters Actually "Simple?"

- ❖ Large star-to-star abundance dispersions for "light" elements C-Al (and Si?)
- ❖ C-N, O-Na, Mg-Al, O-F anti-correlated and Na-Al correlated
- ❖>0.1 dex variations in neutron-capture elements
- ❖ Globular clusters are ***<u>NOT</u>*** chemically homogeneous

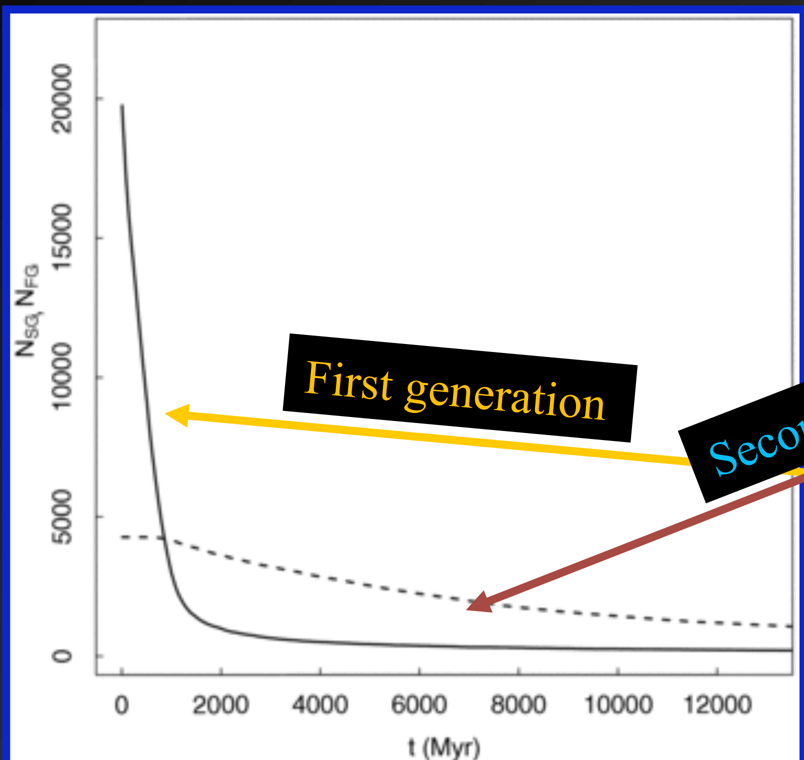
Carretta et al. (2009)



Sodium – Oxygen Anticorrelation

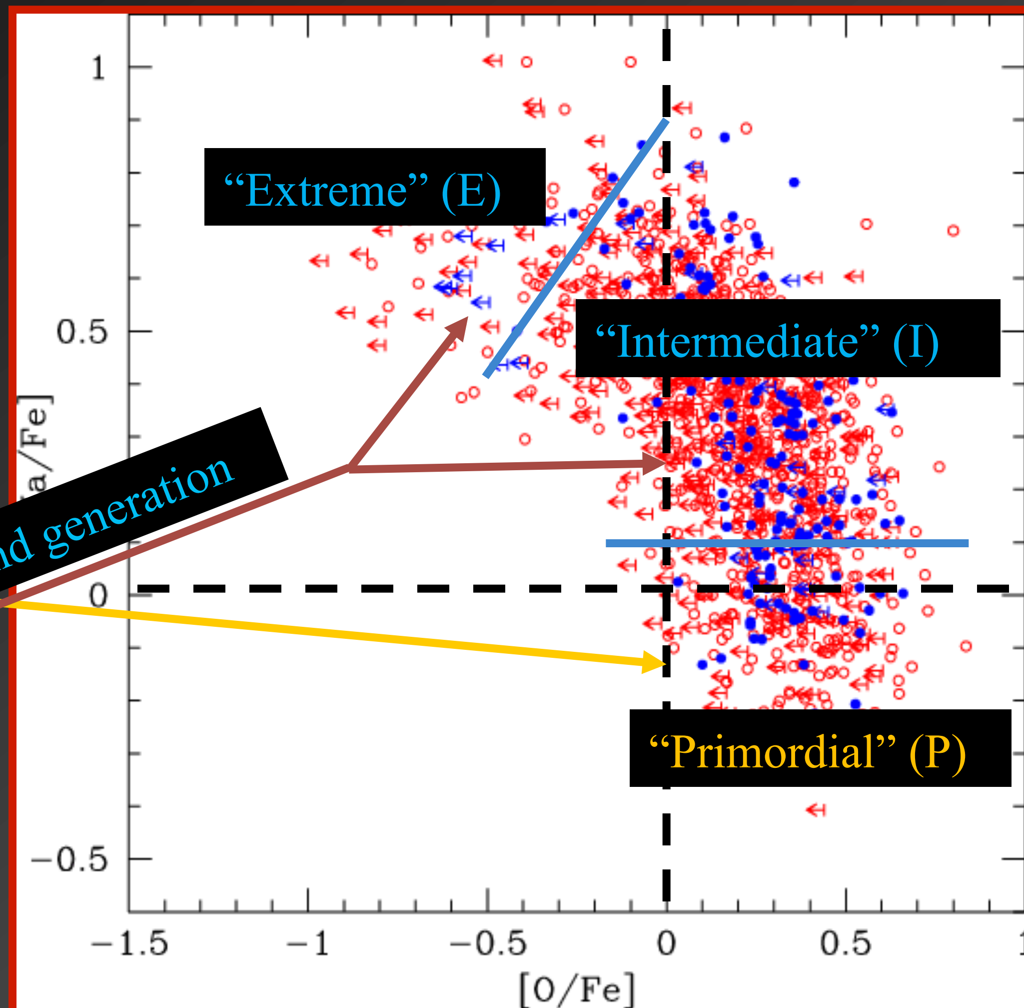
Are Globular Clusters Actually "Simple?"

D'Ercole et al. (2008)



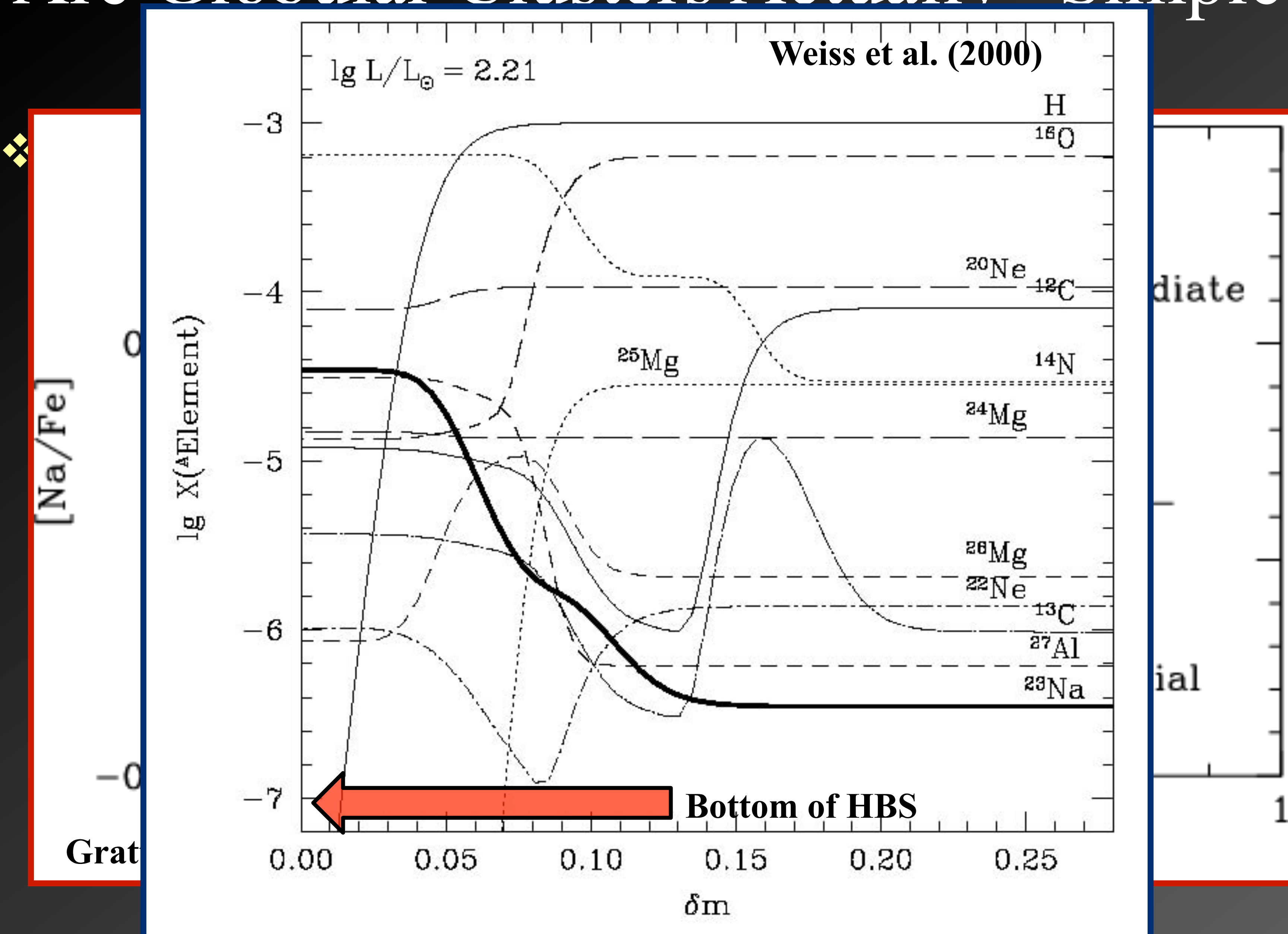
First Generation Loss

Carretta et al. (2009)



Sodium – Oxygen Anticorrelation

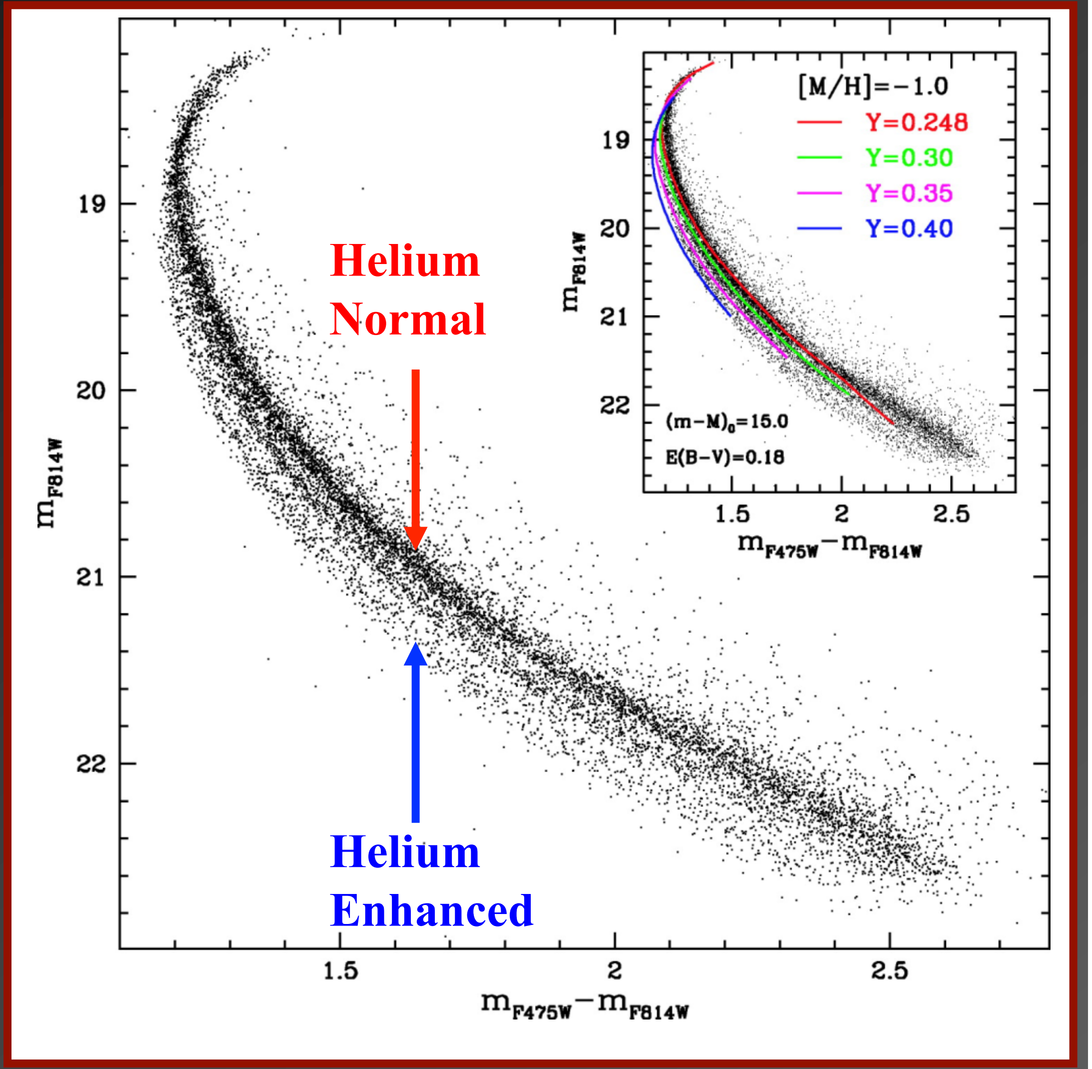
Are Globular Clusters Actually "Simple?"



Globular Clusters: Multiple Populations

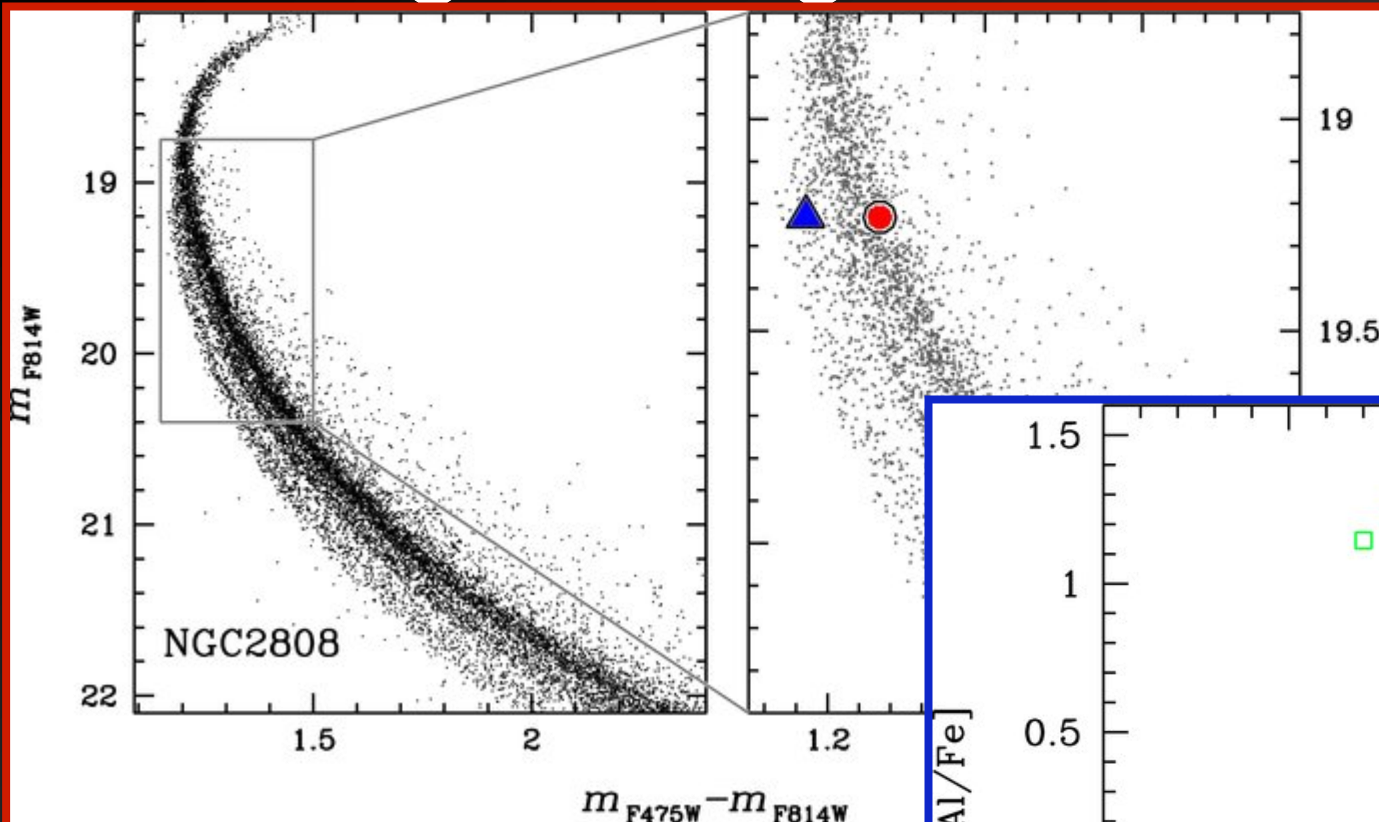
- ~10 globular clusters (so far) known to contain multiple MS, SGB, and/or RGB populations
- Massive clusters
- Almost always *discrete* populations
- Populations may be tied to He content
- Former dwarf galaxies?

Piotto et al. (2007)



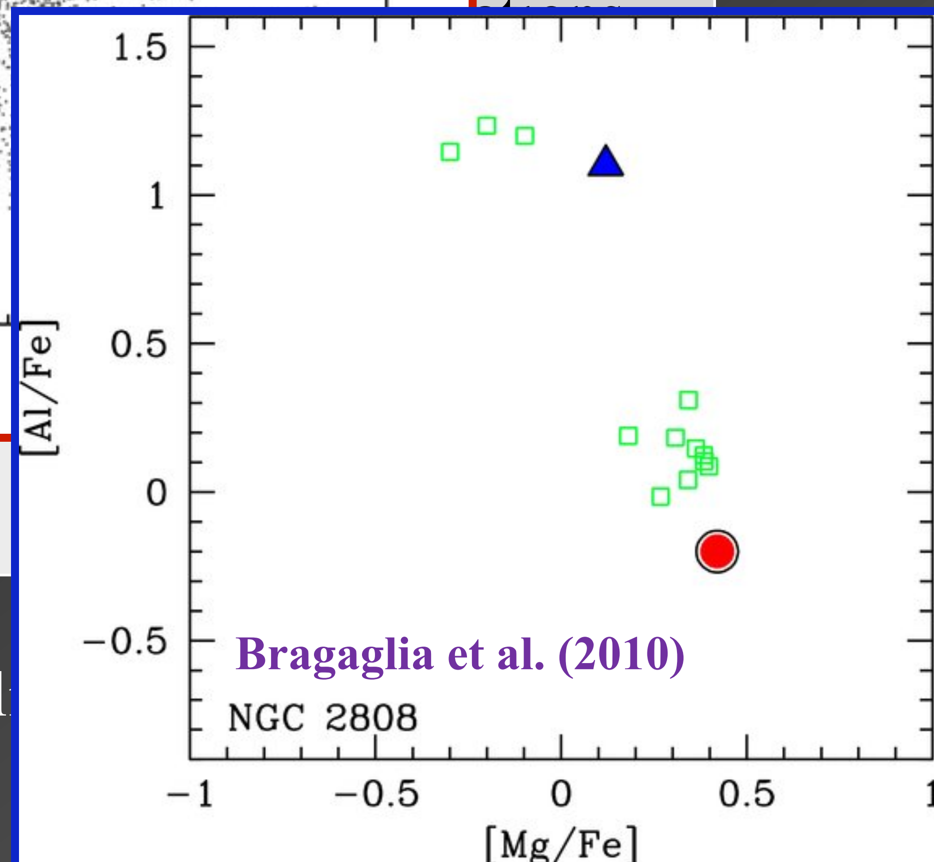
Triple Main Sequence: NGC 2808

Origin of High He Abundances



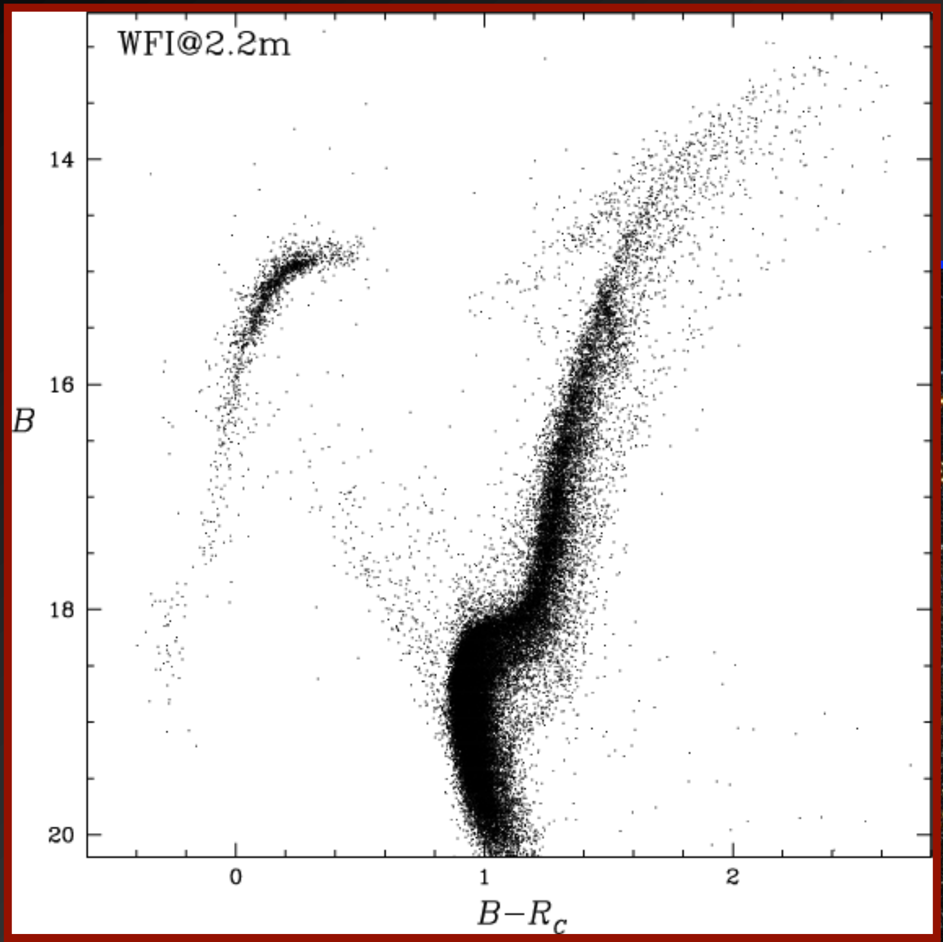
ould be
rming

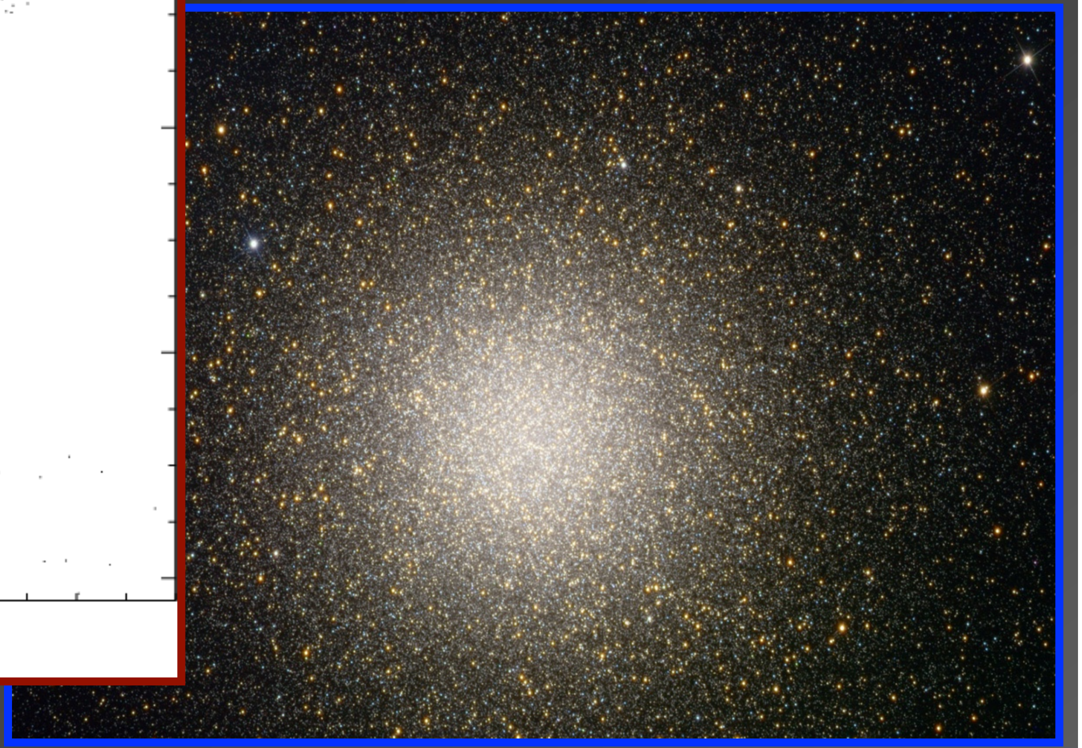
<2 $M_\odot$ RGB Stars



May be a connection to l

Omega Centauri: The Extreme Example

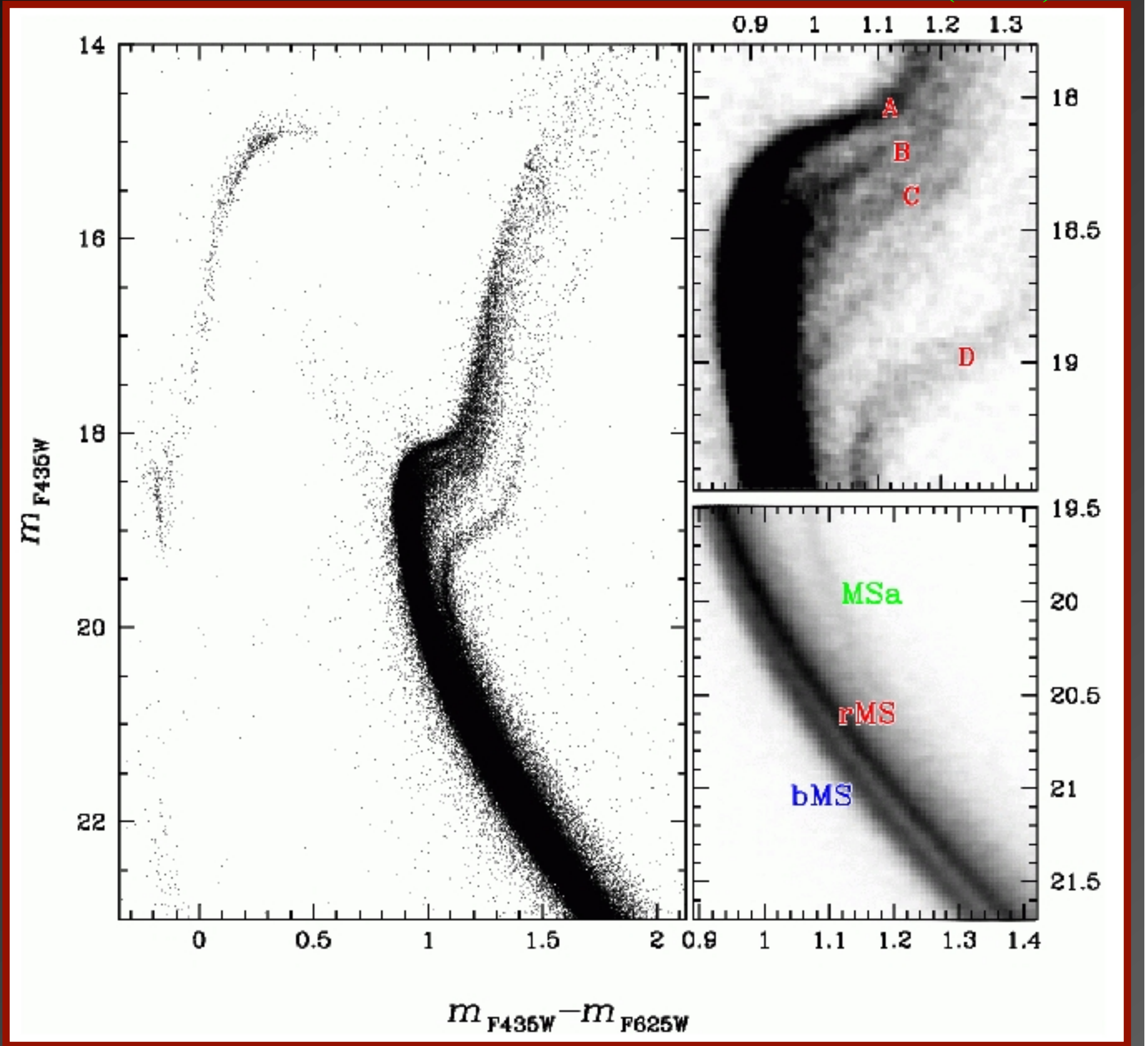




Omega Centauri: The Extreme Example

- Several discrete populations
- Multiple MS, MSTO, SGB, and RGB
- Large abundance spread for *all* elements
- Blue MS *more metal-rich* than red MS
- Blue MS best fit with Y~0.38
- 0-6 Gyr age spread?
- Half-light two-body relaxation time: 12 Gyr

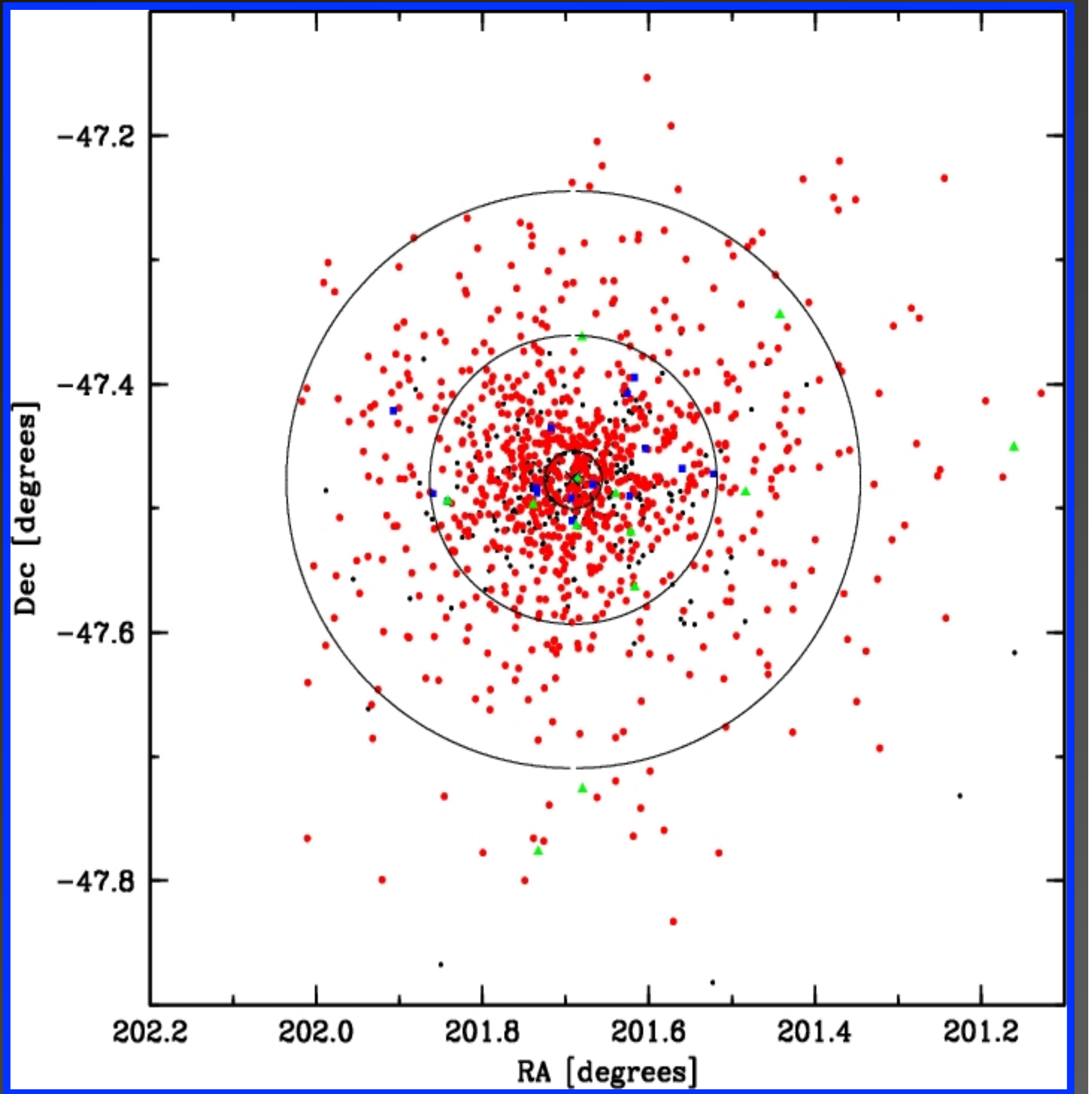
Bellini et al. (2010)



ω Cen CMD

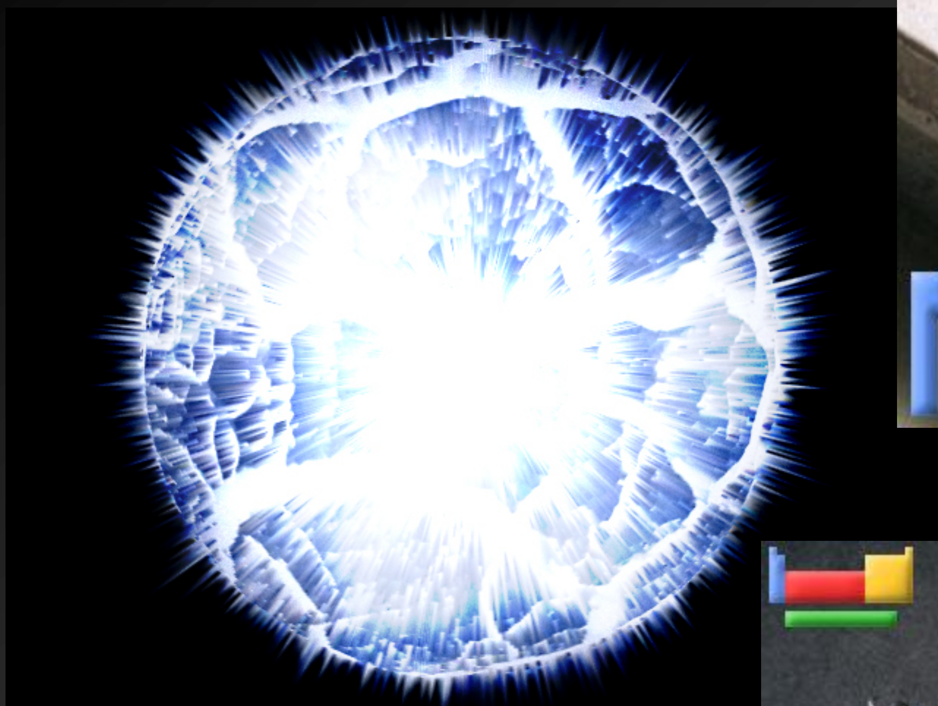
Omega Centauri: Observations

- >850 RGB stars
- Mag. limited at V=13.5; >90% completeness
- Spans the full cluster metallicity range
- R(λ/Δλ) ≈ 18,000
- S/N > 100
- Only 2 spectroscopic binaries
- EW and synthesis analysis with MOOG



New observations for this project

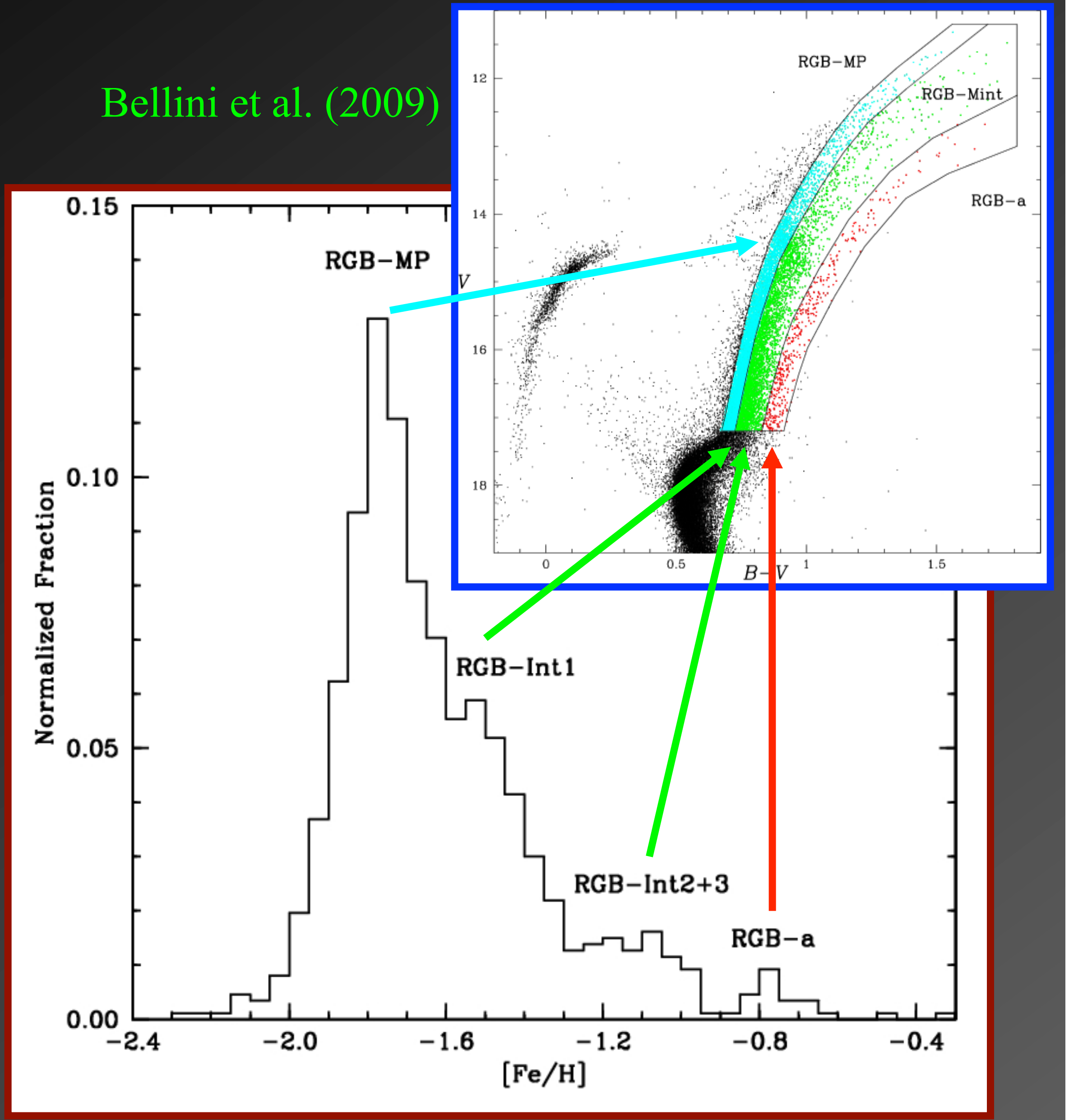
ω Cen: Chemical Self-Enrichment



Metallicity Distribution Function

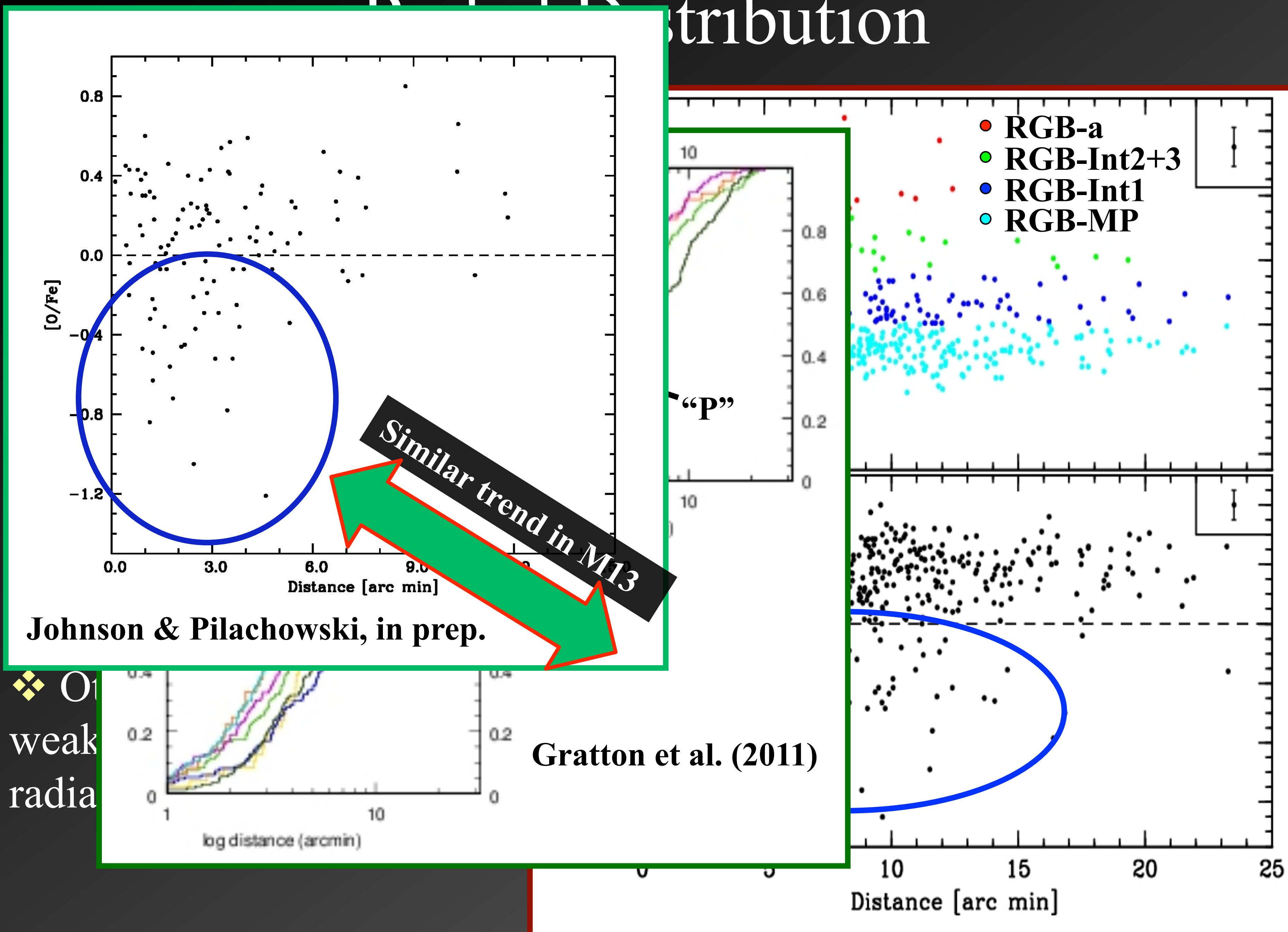
- ❖ Confirm 4-5 MDF peaks
  - ❖ RGB-MP (61%)
  - ❖ RGB-Int1 (27%)
  - ❖ RGB-Int2+3 (10%)
  - ❖ RGB-a (2%)
- ❖ Spectroscopic estimate agrees with photometric number counts
- ❖ MDF similar for RGB, SGB, and MS stars

Bellini et al. (2009)



ω Cen MDF

Radial Distribution



❖ O…

weak…

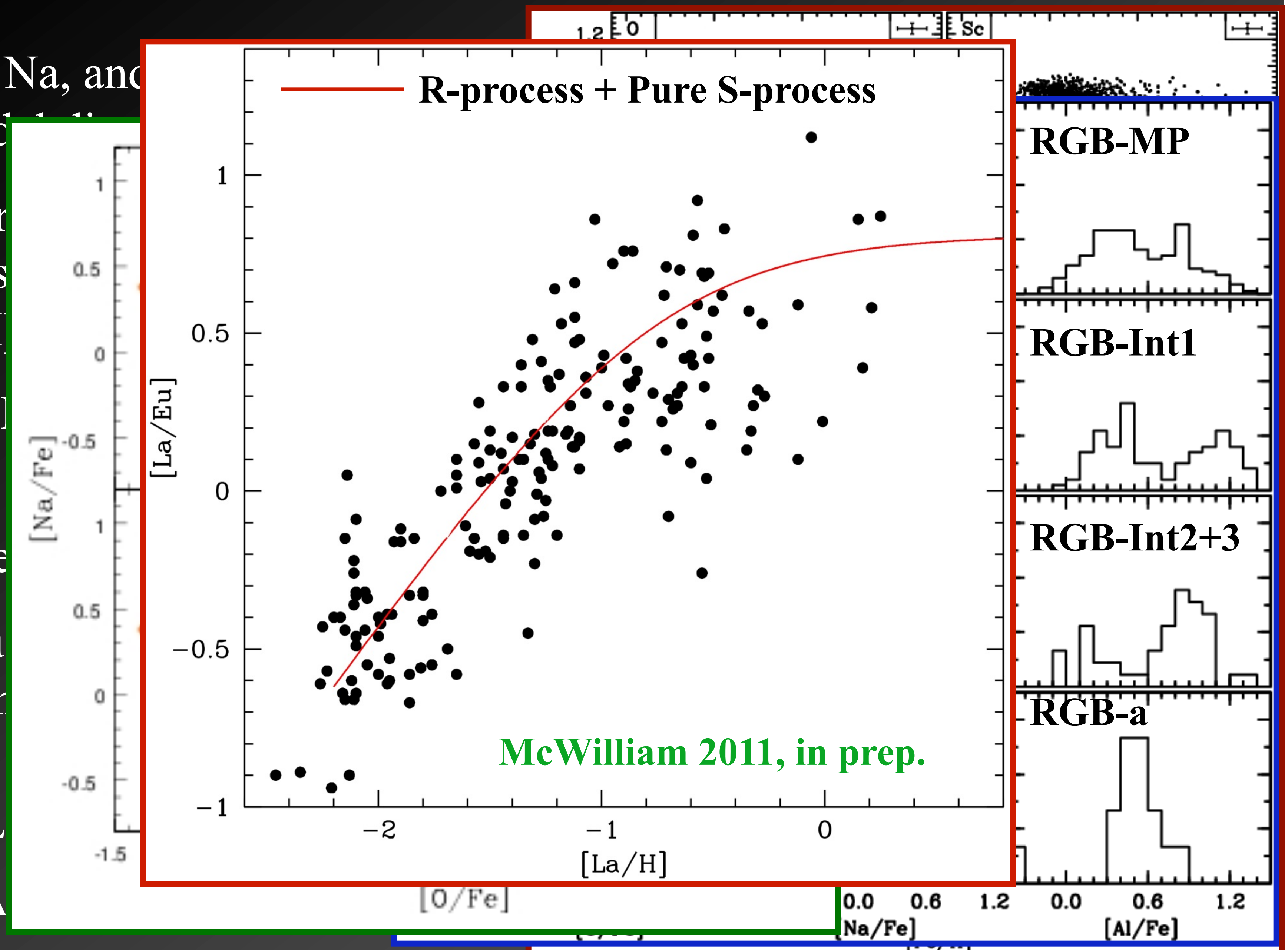
radia…

Chemical Abundance Results

- O, Na, anc
  bimod
- Per
  poor s
  [Fe/H]
- [α/
- >1
  light e
- Hu
  interm

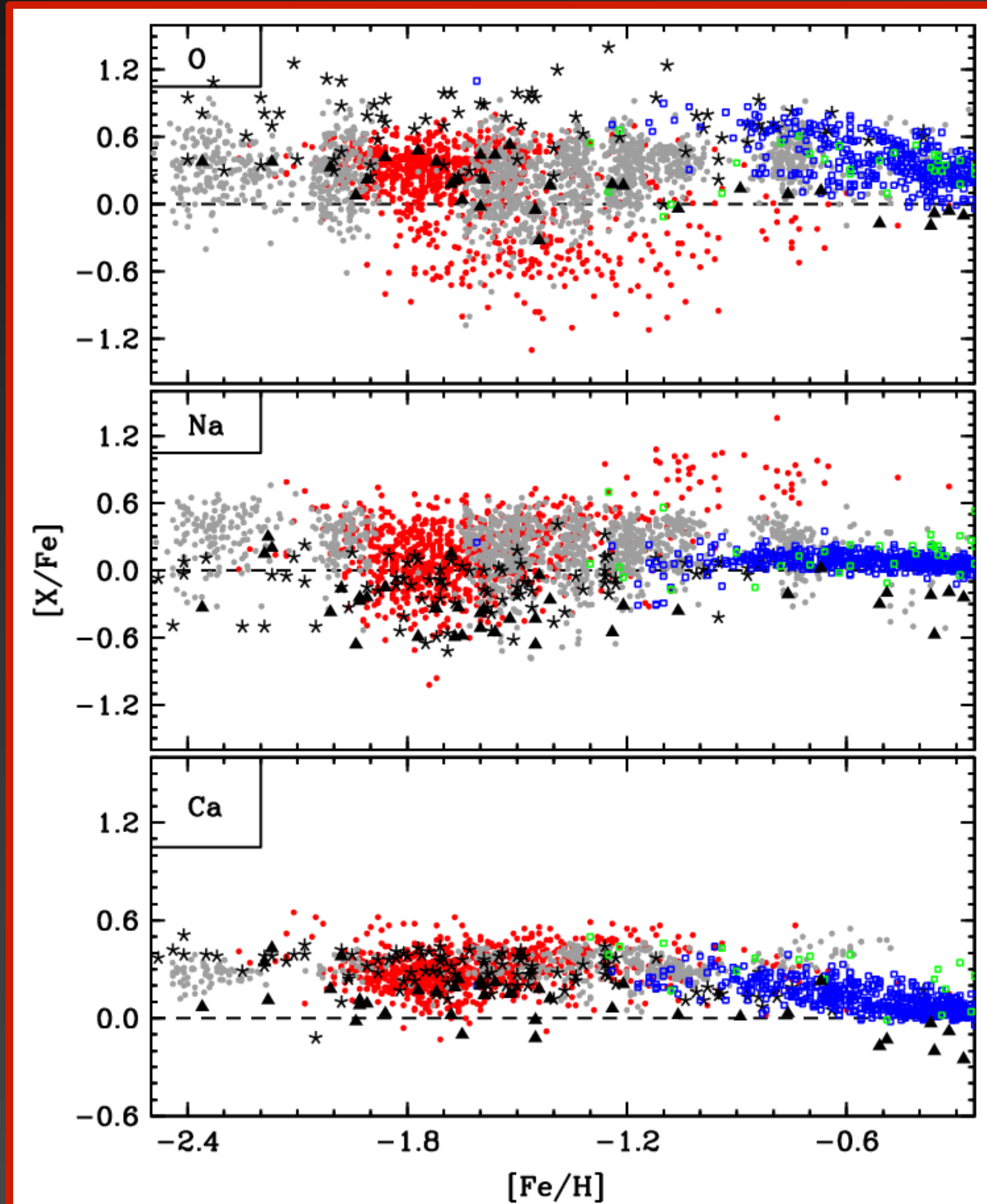
L

A



ω Cen: A Unique Composition

- ~25-50% of ω Cen stars similar to halo composition
- Remaining stars are O-poor, Na/Al-rich
- Light elements more similar to individual globular clusters
- Additional processes required to explain O, Na, & Al

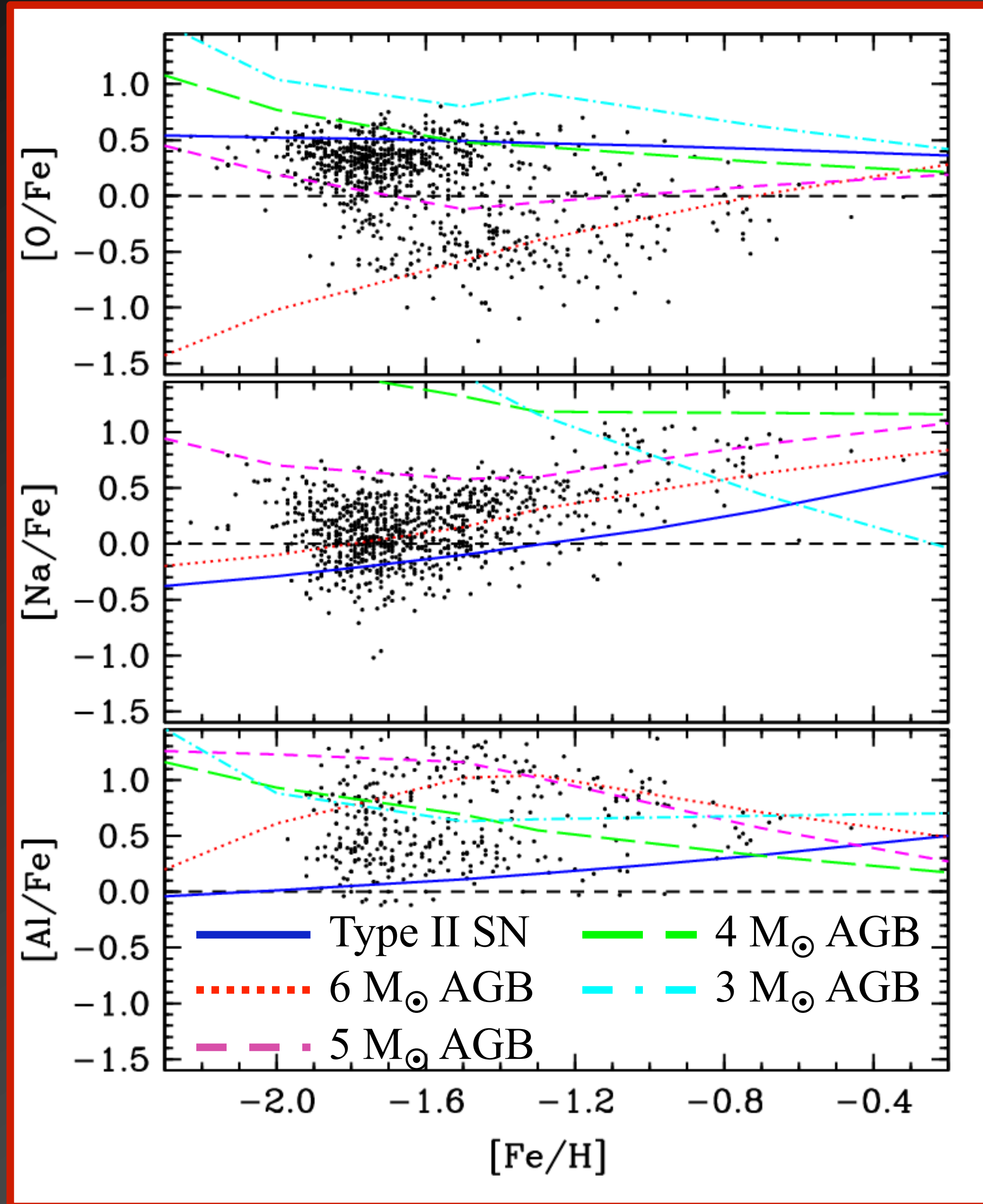


● ω Cen
● GGCs
□ Thin/thick Disk
□ Bulge
▲ Dwarf Galaxies
✱ Halo

Contributions from AGB Stars

- >3 $M_\odot$ AGB stars + Type II SNe reproduce observed Na and Al
- However, no reason to believe only ~3-6 $M_\odot$ AGB stars contributed
- Only *low metallicity*, >5 $M_\odot$ AGB stars eject O-poor material

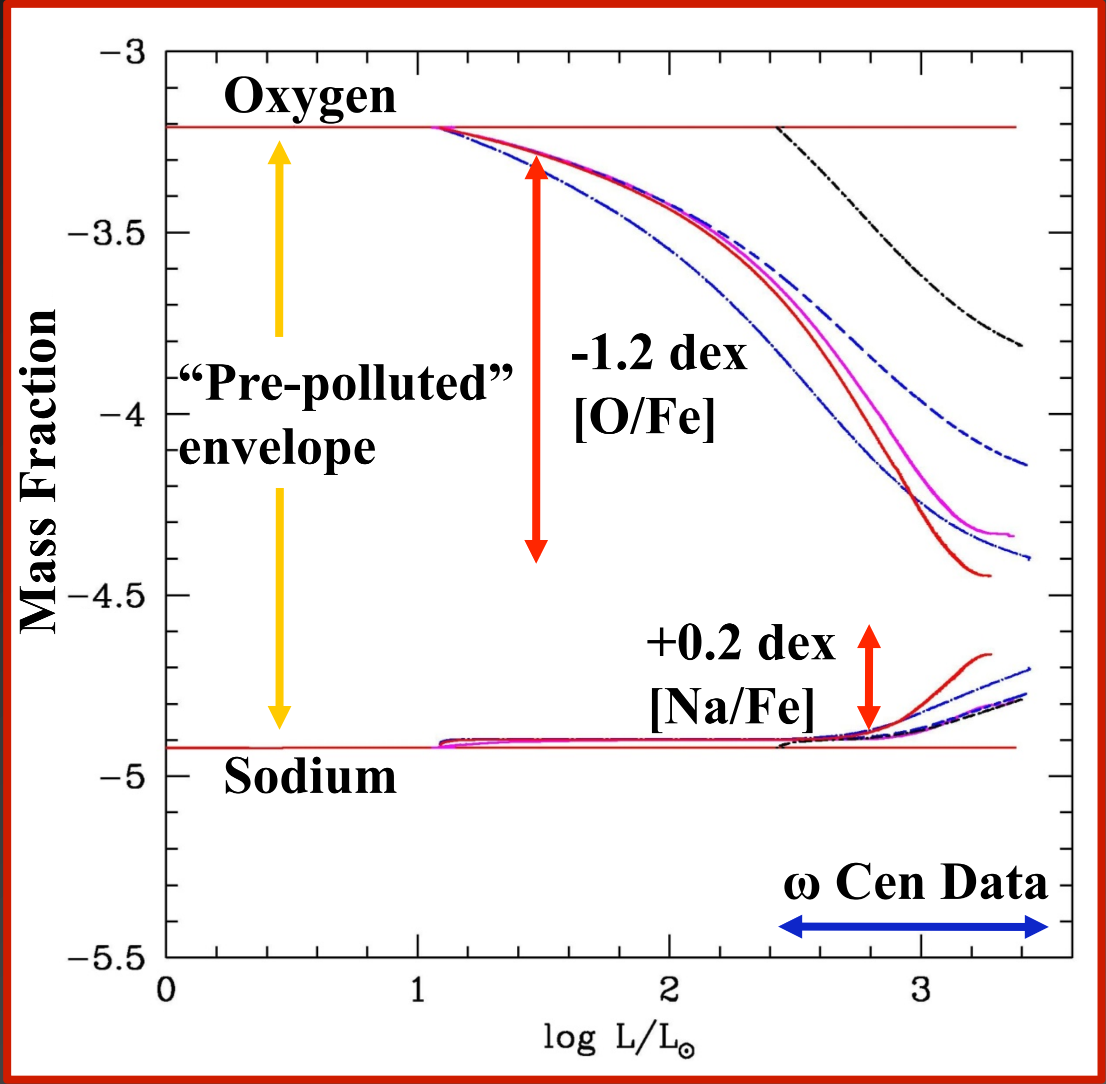
Creating a large population of O-poor stars requires that only a small AGB mass range polluted ω Cen



Helium Enhancement and *In Situ* Mixing

- ❖ *In Situ* mixing relaxes narrow AGB mass range
- ❖ Can strongly deplete O with only a modest increase in Na and Al
- ❖ Can occur if a star is already moderately O-poor, Na/Al-rich, *and* He-rich
- ❖ "He-normal" stars have a steeper μ-barrier that may prevent deep(er) mixing
- ❖ *Are the O-poor ω Cen giants He-rich?*

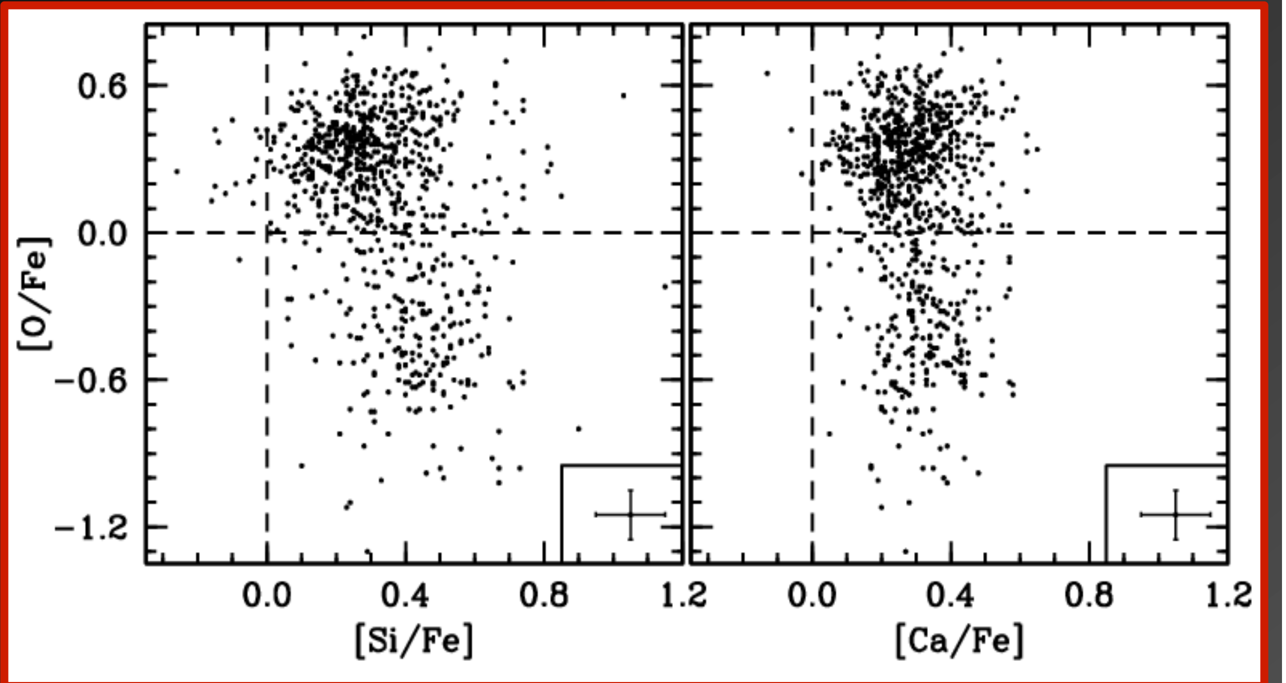
D'Antona & Ventura (2007)

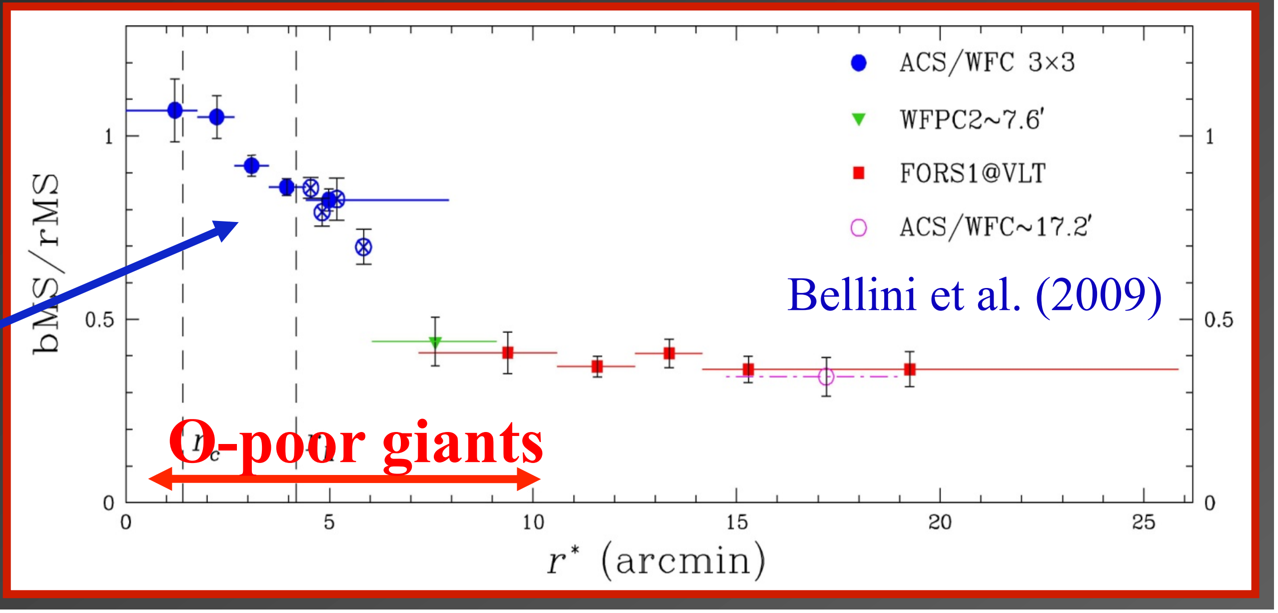


O and Na in a He-rich giant

Indirect Evidence for He-rich Giants

- No direct measurement of He in these cool giants
- Many sources that produce high He should process material at > 65x10^6 K
- Leakage from MgAl cycle should produce some Si
- Majority of blue main sequence stars inside 10 arc min

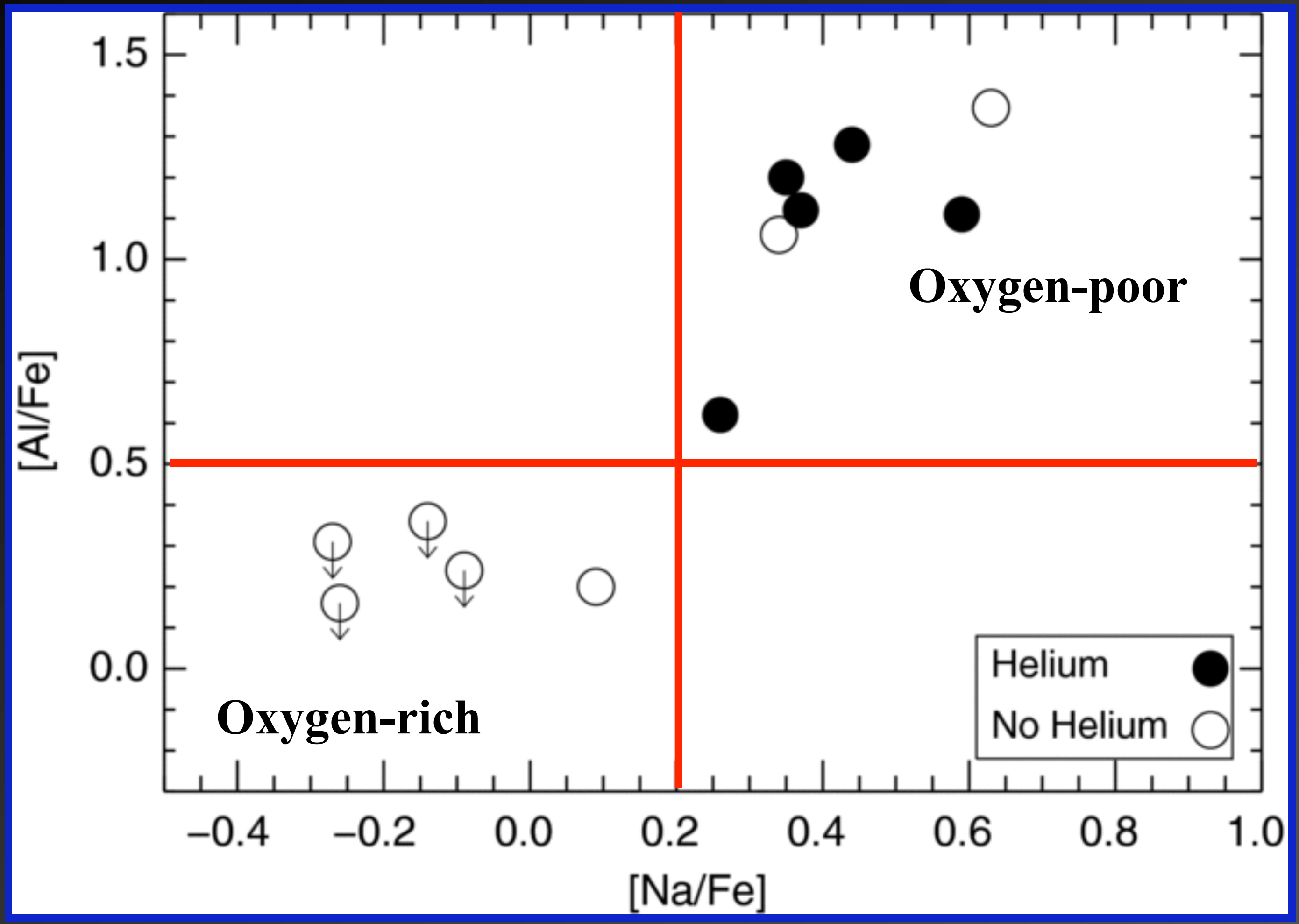




Blue MS → O-poor RGB

Blue Main Sequence	**O-poor Giants**
Located inside ~7-10’	91% inside 10’
25-35% of MS	27% of RGB
Intermediate [Fe/H]	Intermediate [Fe/H]
Y ~ 0.38	Y = 0.38?

Direct He Detection!



Dupree et al. (2011)

Assembling the Pieces…

TIME

PHASE I: Formation of the RGB-MP population – **similar composition to metal-poor halo/GC**

PHASE II: Enrichment of cluster ISM by large population of RGB-MP stars – **large increase in s-process**

PHASE III: Intermediate metallicity populations form – **complex, highly polluted populations; enriched in He, p-capture, and s-process products**

Formation of blue main sequence → O-poor giants

PHASE IV: Formation of most metal-rich population – **unusual composition, very high [Na/Fe], O-Na corr.**

PHASE V: Chemical enrichment ceases; minimal TYPE Ia; **no stars with [Fe/H] > -0.5 & no strong decrease in [α/Fe]**

Summary

❖ Confirmation of a large [Fe/H] spread with multiple peaks in the MDF mirroring the CMD population distributions

❖ Stars with [Fe/H] > -1.2 concentrated near the cluster core

❖ [α/Fe] ratios suggest minimal Type Ia SN contributions

❖ Light element correlations similar to those found in other globular clusters

❖ O-poor RGB stars linked to the blue main sequence, He-rich stars

❖ Huge increase in s-process elements in the more metal-rich populations; essentially follows a pure s-process pattern