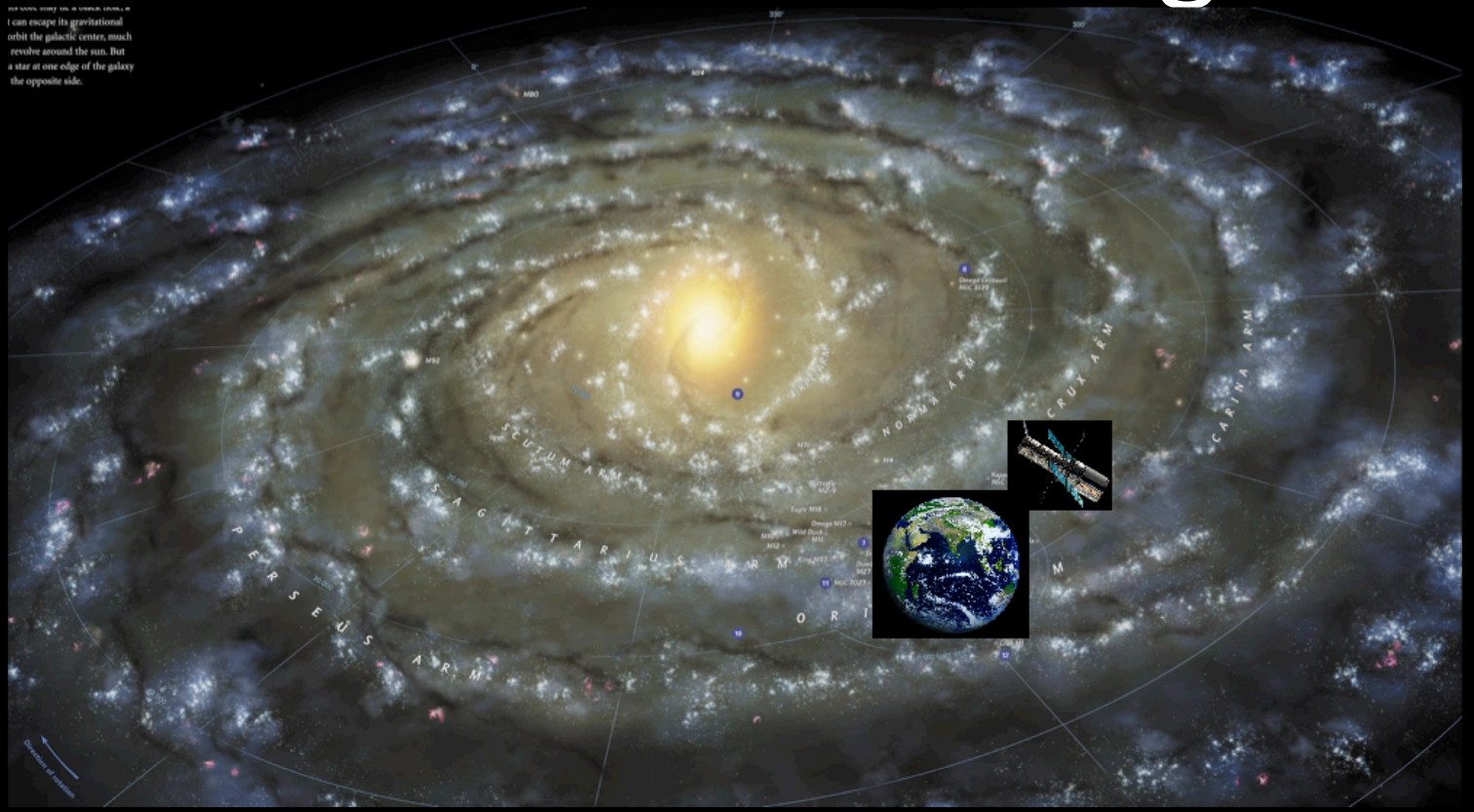
The Age and Helium Abundance of the Galactic Bulge

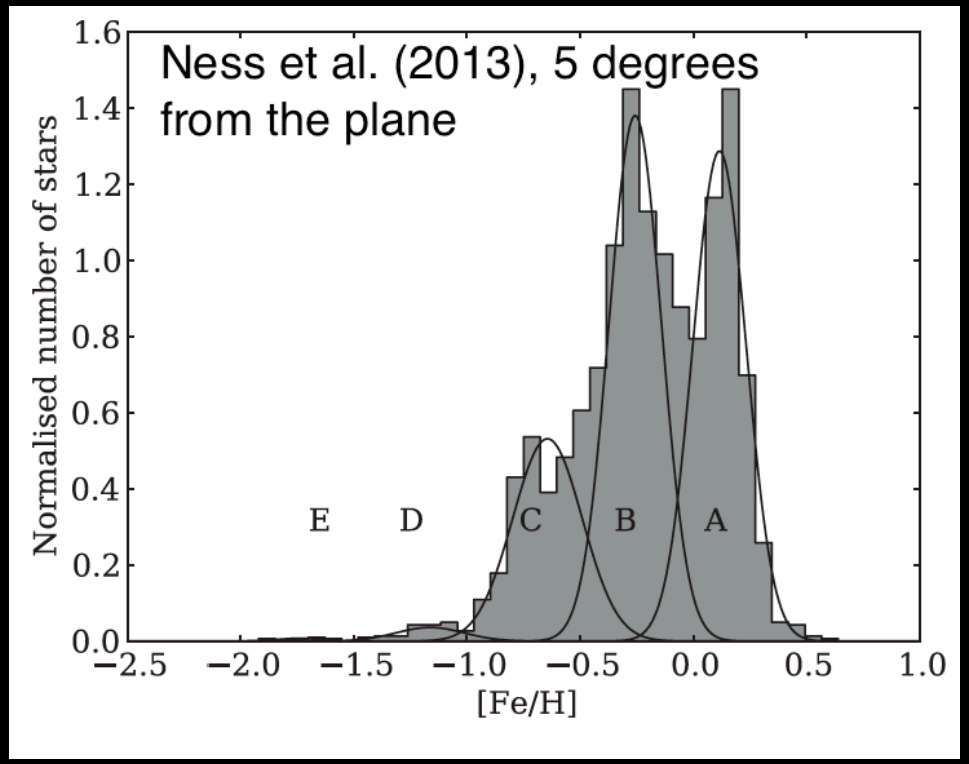


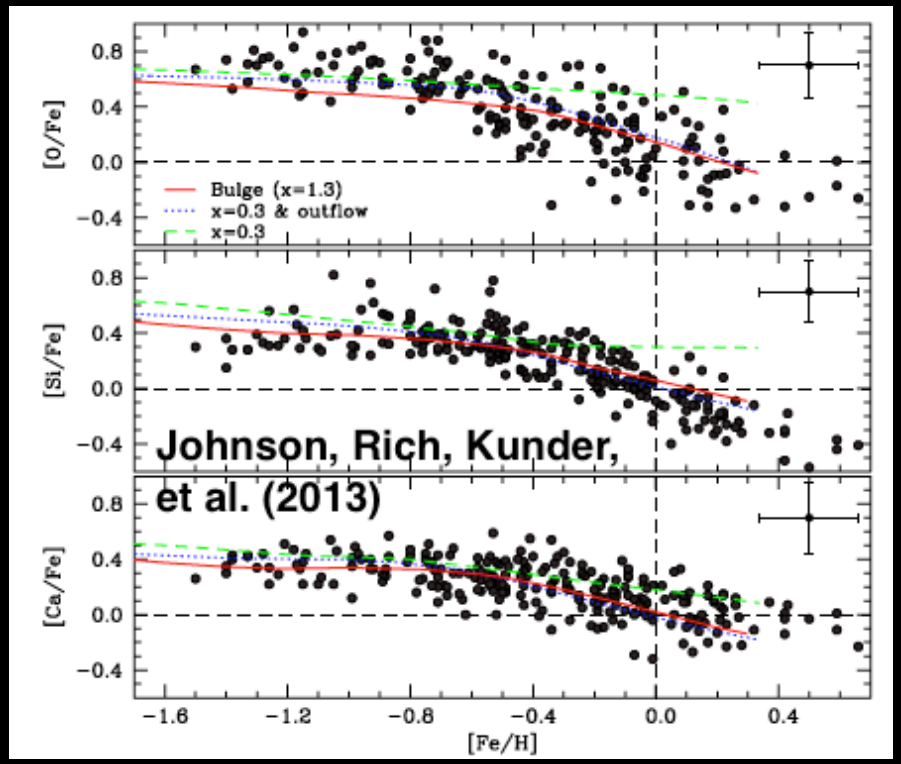
Credit: National Geographic

David Moïse Nataf

Australian National University

Bulge "Metals" Distribution: A Well-Known Galactic Parameter

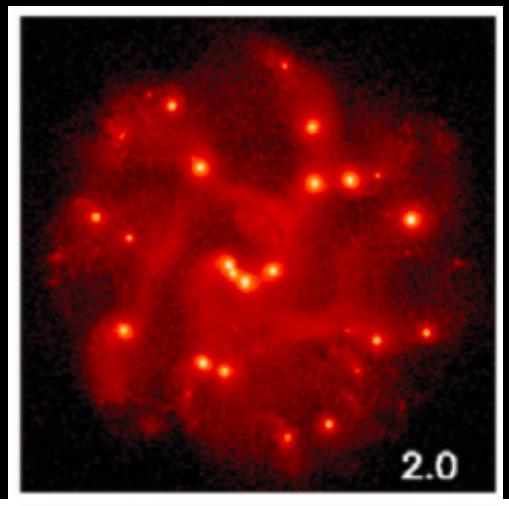


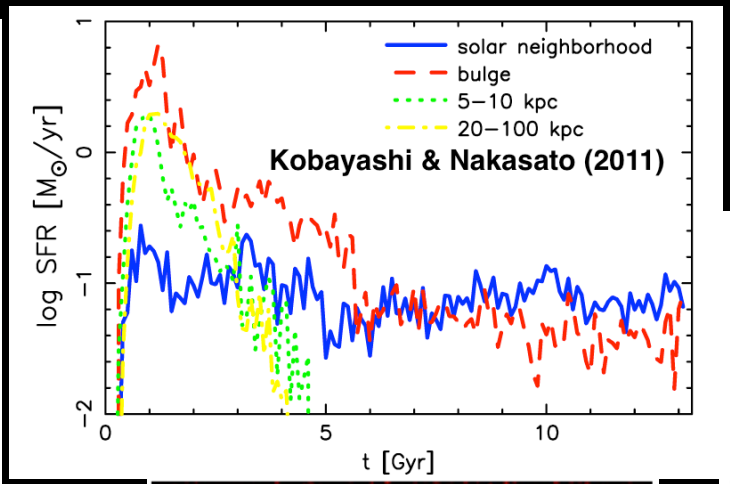


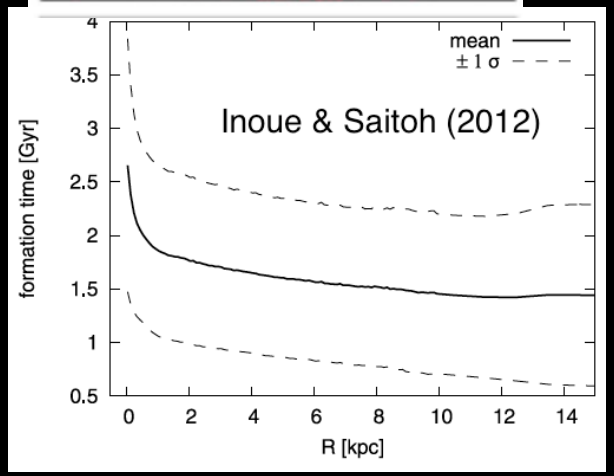
Bulge Age Distribution: A Once Well-Known Galactic Parameter

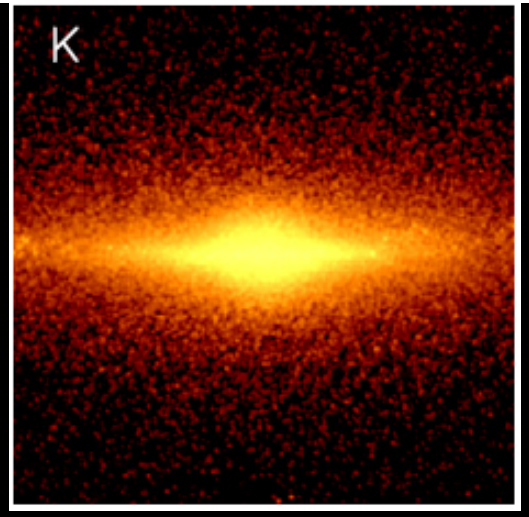
- "… the CMD of Baade's Window field indicate a uniformly old age for stars in the Galactic bulge, thus helping to settle the question of the formation of galactic bulges" – Renzini (1995).
- "… the bulge of our Galaxy formed at the same time and even faster than the inner Galactic halo." – Matteucci & Romano (1999).
- "The population with nondisk kinematics (which we conclude to be the bulge) has an old main-sequence turnoff point, similar to those found in old, metal-rich bulge globular clusters, " – Kuijken & Rich (2002).
- "… the bulge age, which we found to be as large as that of Galactic globular clusters, or >≈ 10 Gyr. No trace is found for any younger stellar population." – Zoccali et al. (2003).

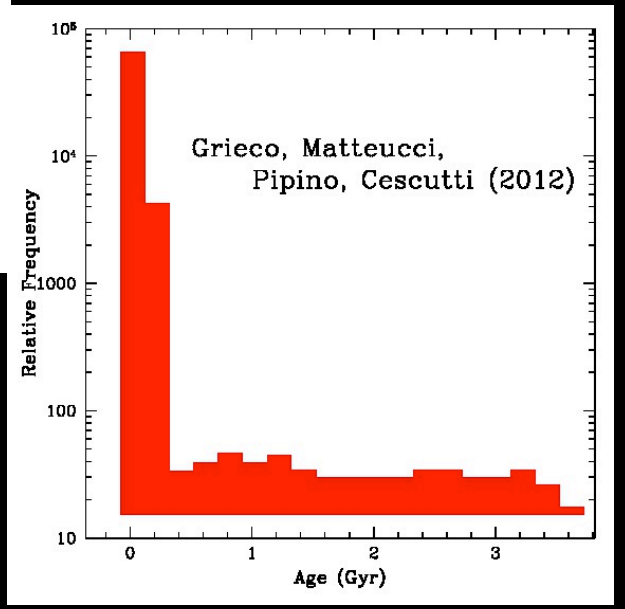
Chemical Evolution Models Predict a (Nearly) Purely Old Bulge



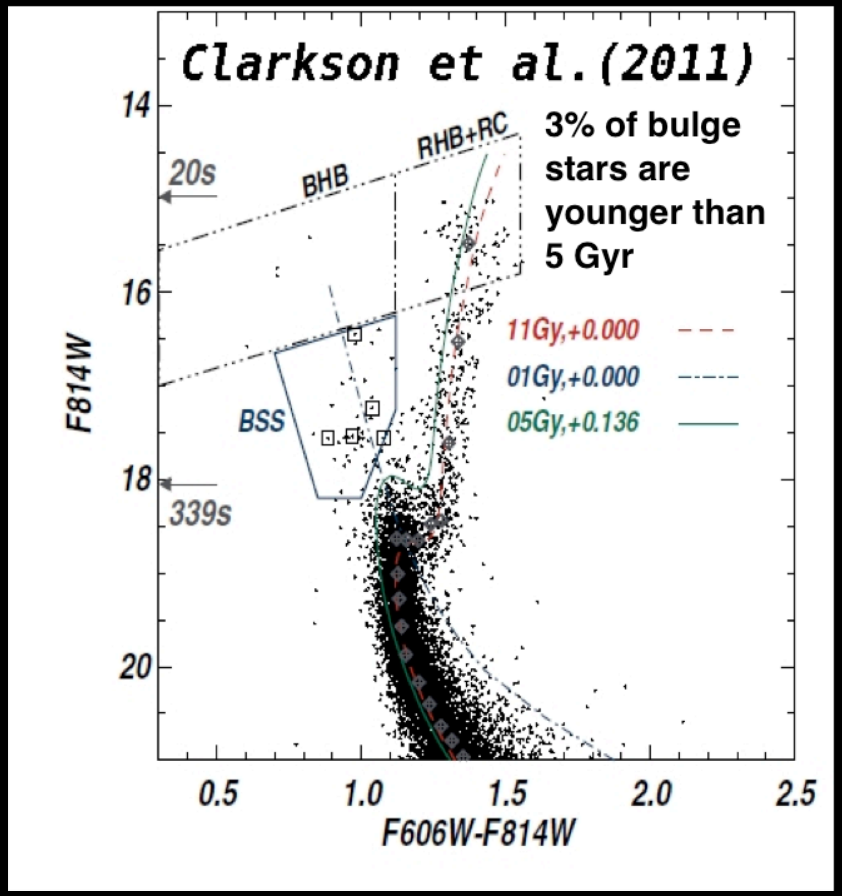


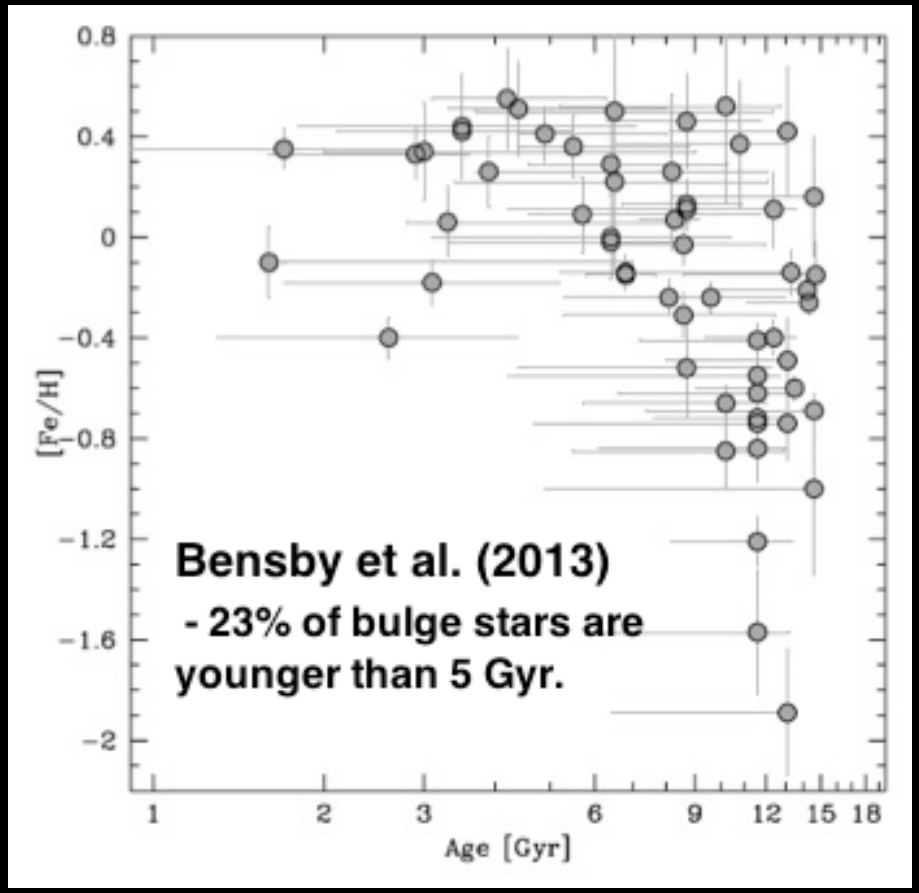






Galactic Bulge Stellar History: Age Distribution a Matter of Renewed Controversy





Close Inspection of a young star in the Bensby et al. (2013) sample.

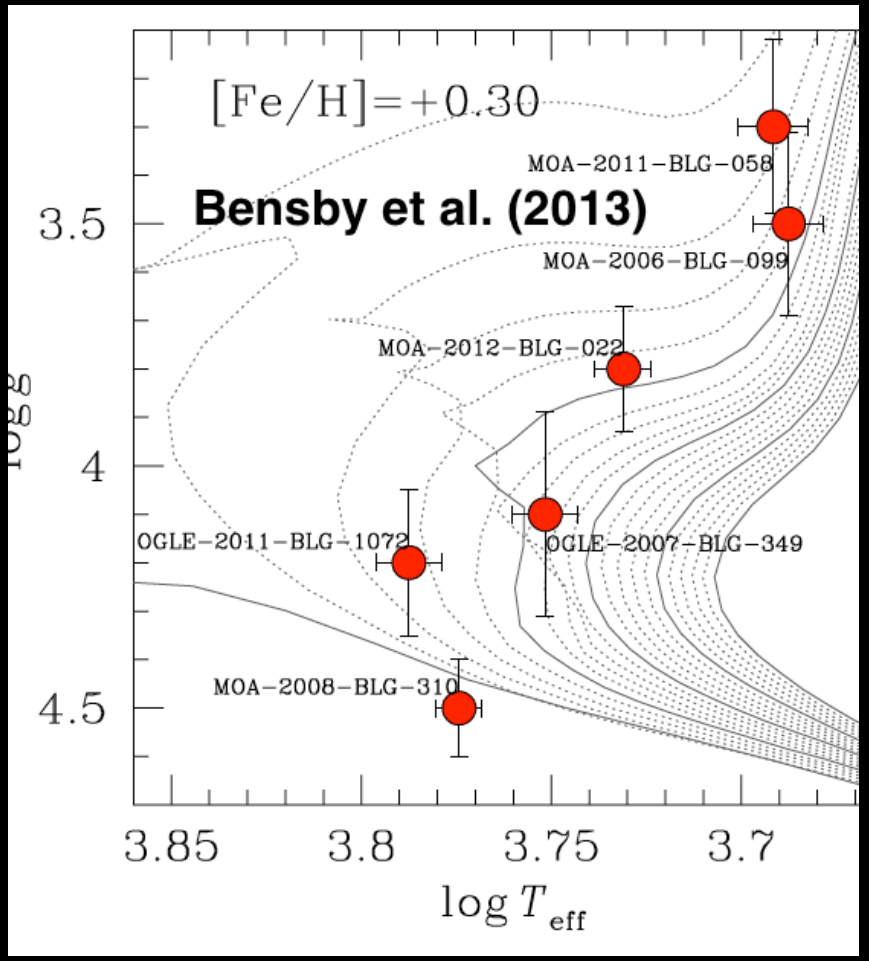
OGLE-2011-BLG-0950:

[Fe/H]=+0.33,

$T_{\rm eff}$ = 6130 Kelvin

(not 5500 Kelvin as per t=11 Gyr).

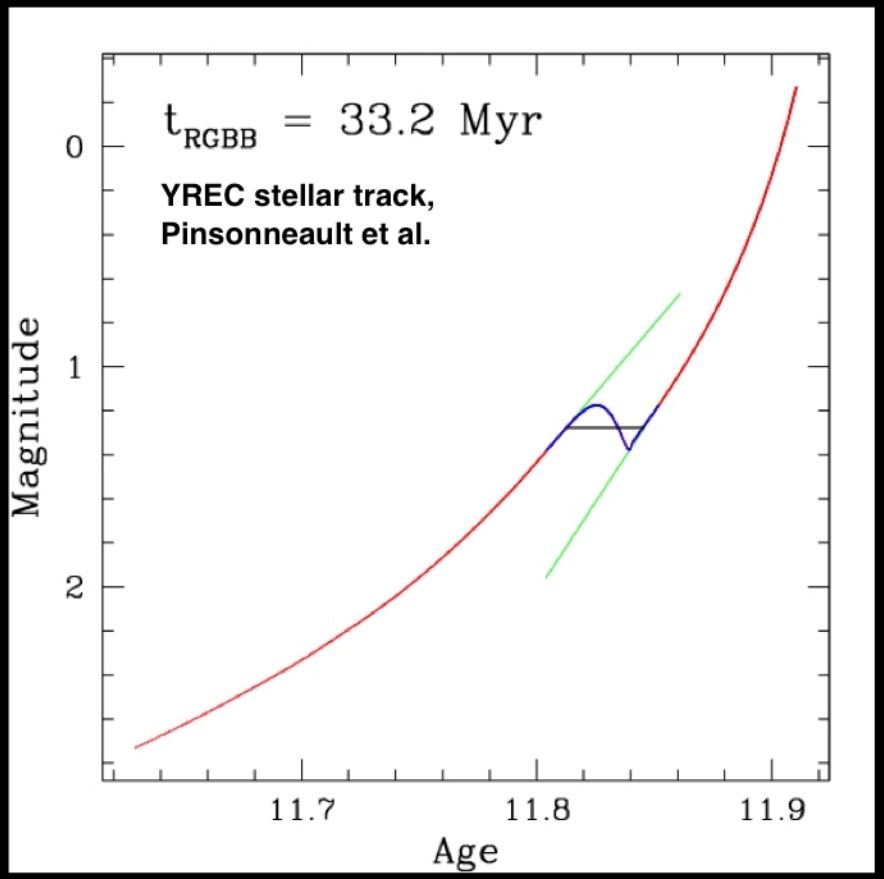
…Ergo, age ≈ 2.9 Gyr.

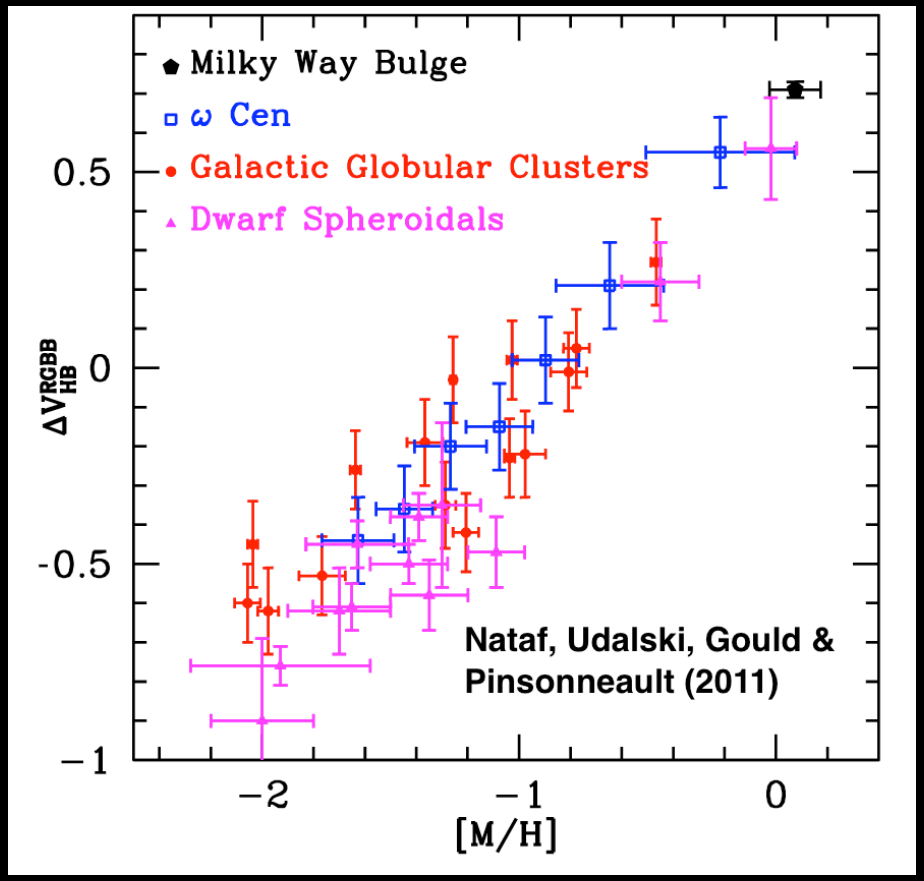


Reconciling the Galactic Bulge Turnoff Age Discrepancy

- Hypothesis: Turnoff age discrepancy due to a combination of non-standard helium-enrichment and selection effects.
- Will explore these issues by looking at the red giant branch bump, microlensing selection effects from Galactic dynamics models, and the mass of red giant stars in the Galactic bulge.

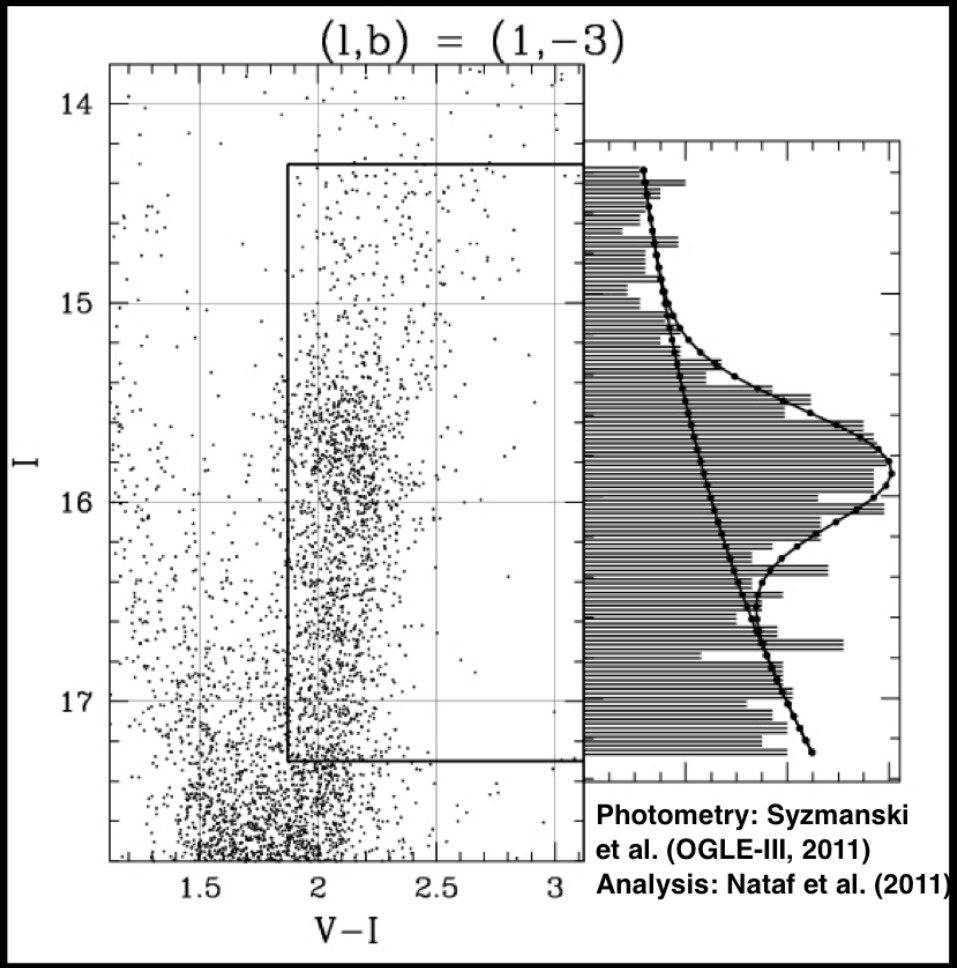
The Red Giant Branch Bump: An Independent Probe of the Age-Helium-Metallicity Relation



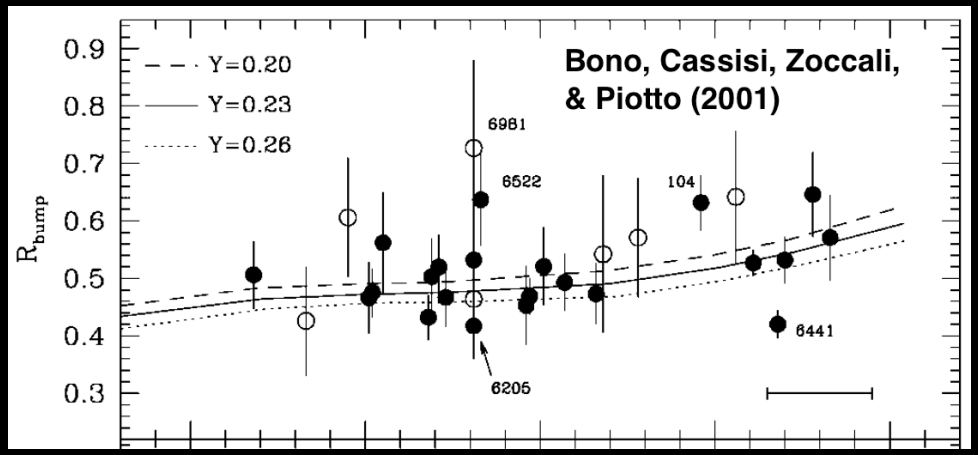


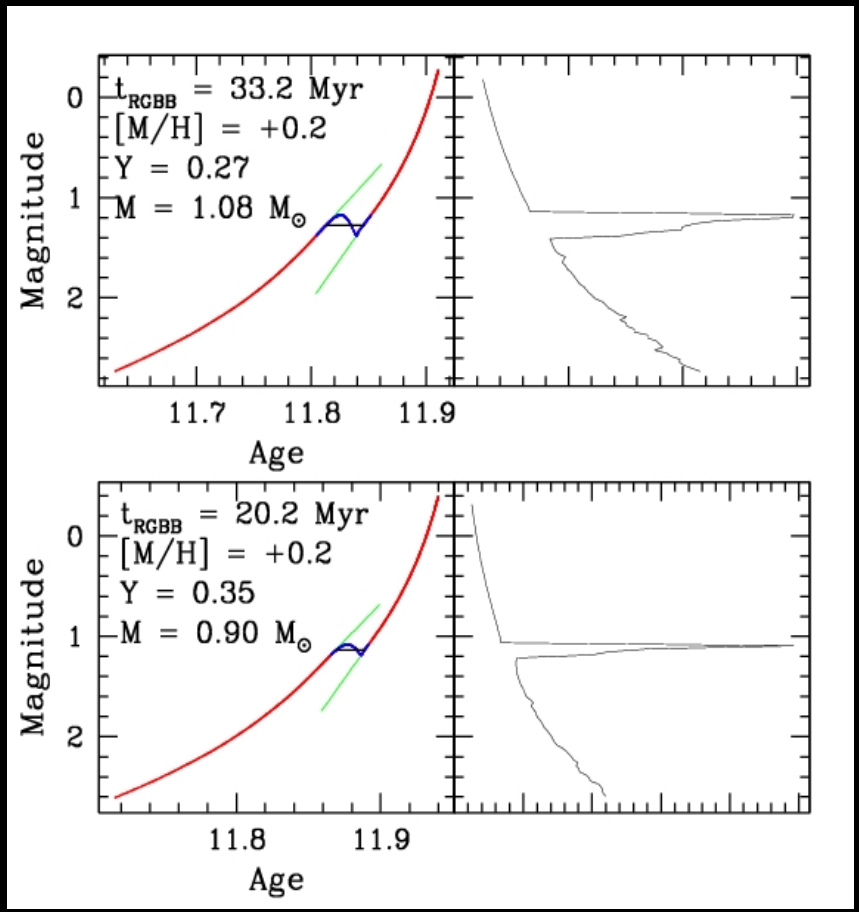
Galactic Bulge Color Magnitude Diagram: No Prominent Red Giant Branch Bump In Spite of Expectations

- "[The bump is harder to measure in] metal-poor clusters, where the bump moves toward brighter magnitudes and therefore less populated RGB regions." - Zoccali et al. (1999).
- "identification of the RGB bump in metal-poor GCs is more difficult since it is brighter than the HB, where evolution along the RGB becomes faster and the stellar sample, consequently, becomes smaller." - Di Cecco, Bono, et al. (2010).

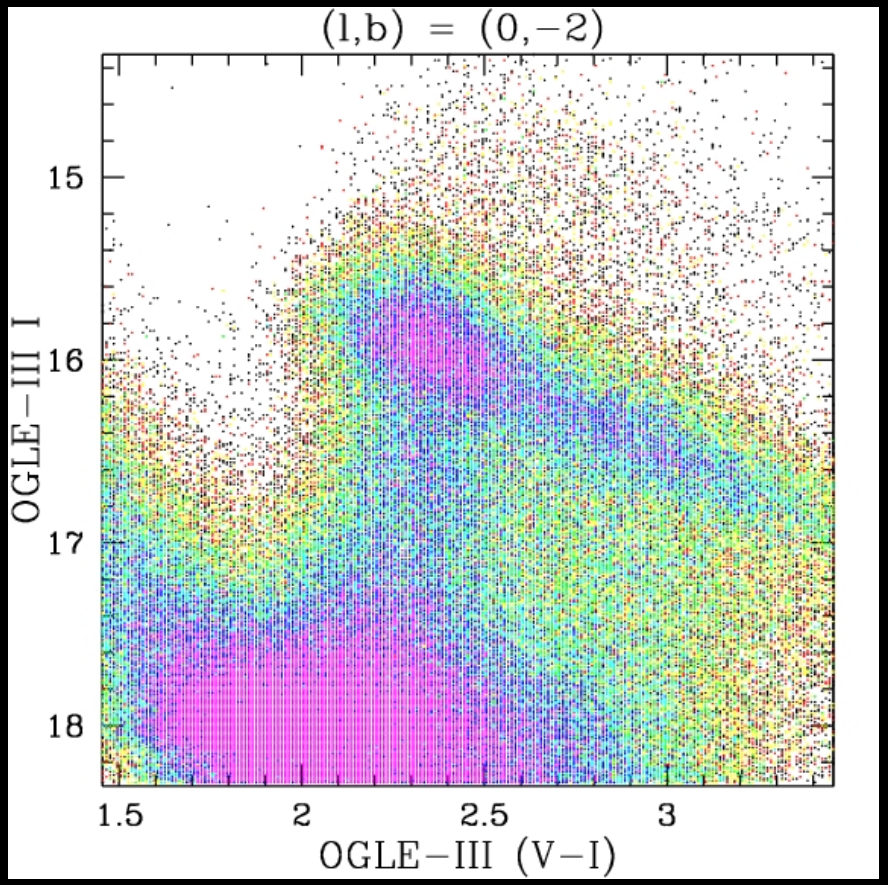


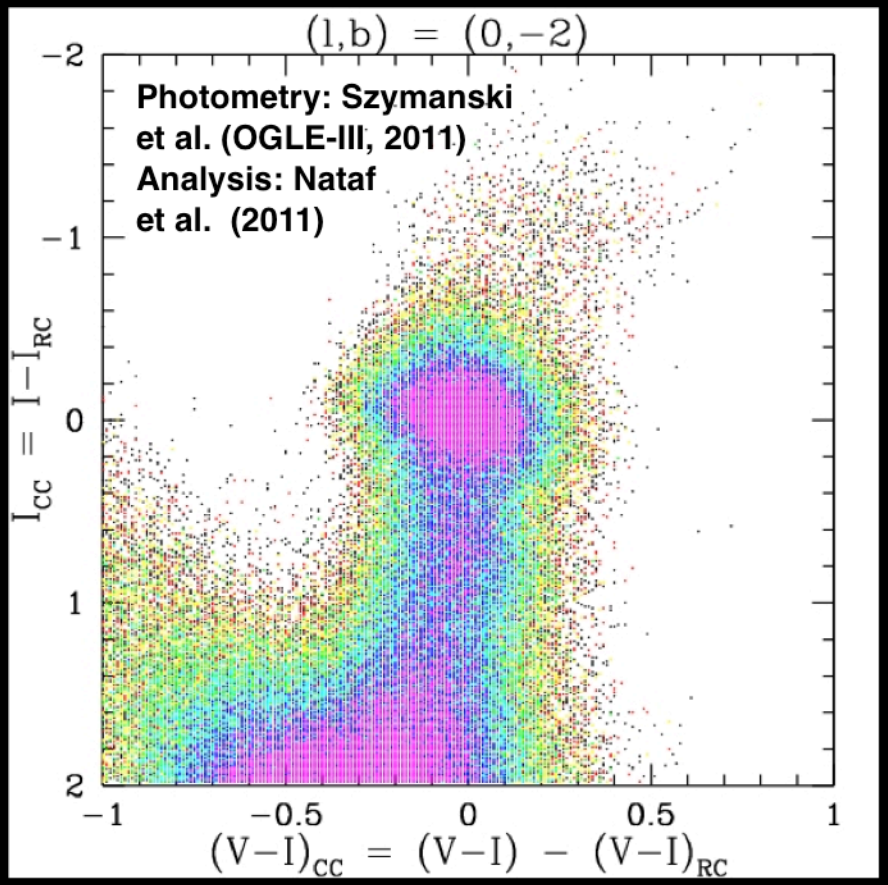
How to Hide the Red Giant Branch Bump: Enhanced Helium Enrichment





Precision Investigation of Bulge Reddening using Red Clump Method to Elucidate Luminosity Function





Probing Additional Post-Main-Sequence Evolutionary Features

- **Red Giant Branch Bump**:

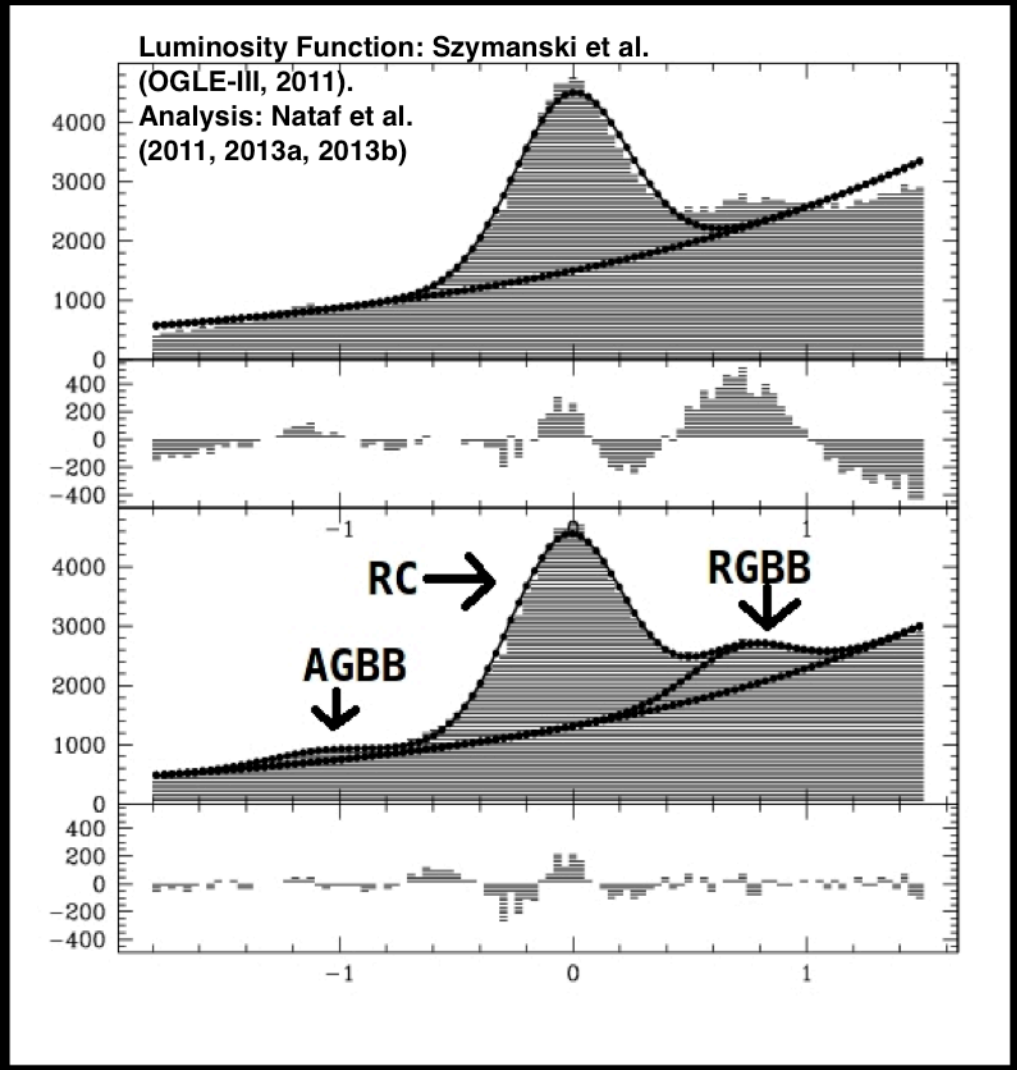
$\Delta I = 0.74 \pm 0.01$,

$f = 20 \pm 1\%$.

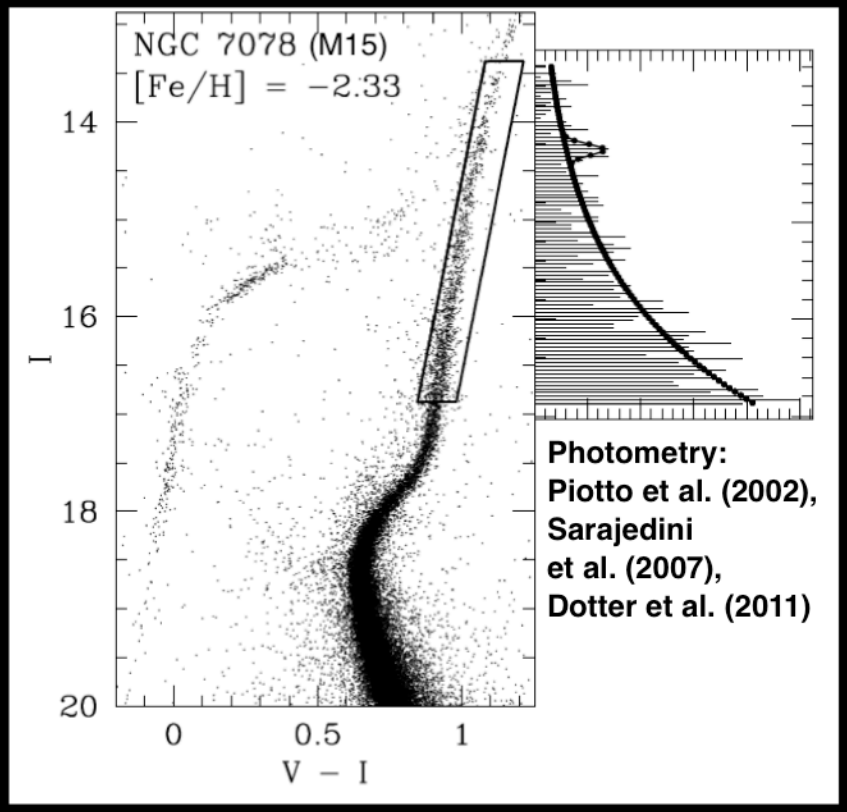
- **Asymptotic Giant Branch Bump**:

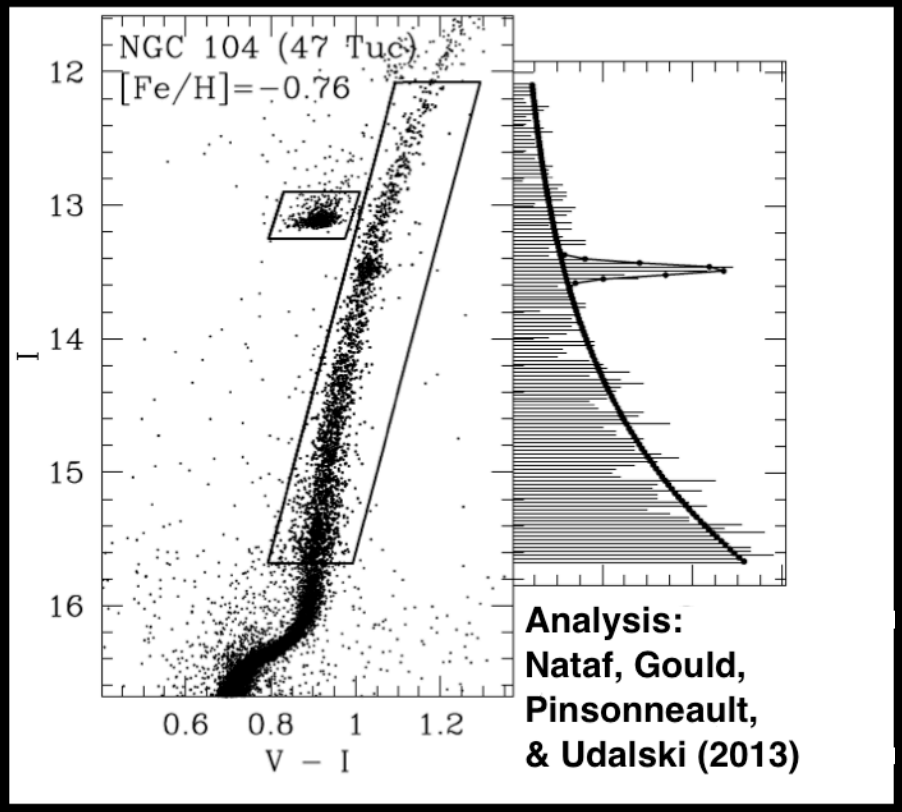
$\Delta I \approx -1.08$,

$f \approx 5.5\%$.



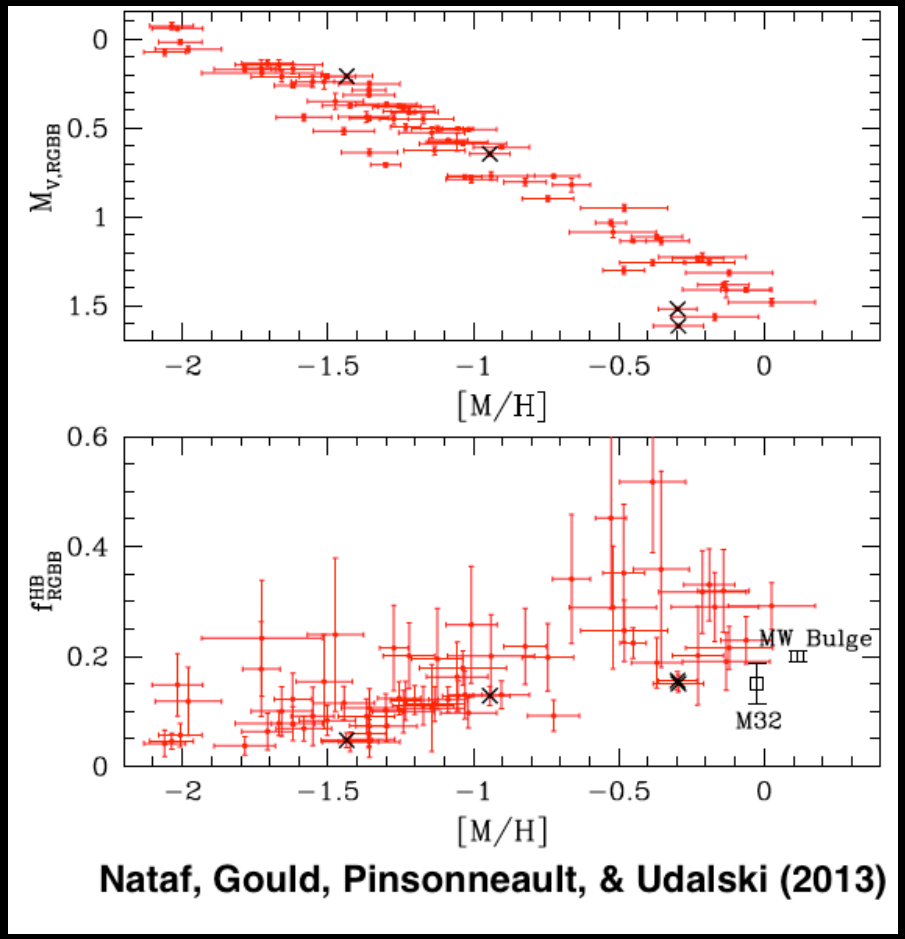
Comparing Galactic Bulge Red Giant Branch Bump Properties to Predictions – Empirical Globular Cluster Calibrations

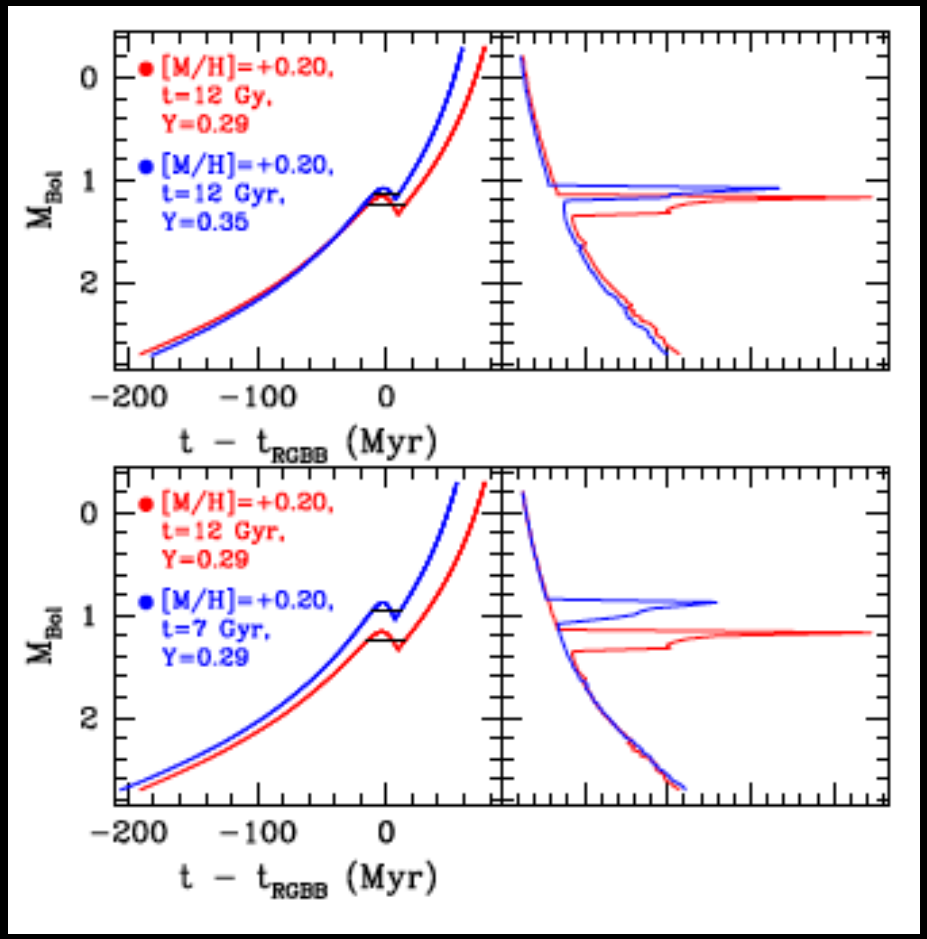




Nota Bene: See also Cohen et al. (2013, in preparation).

Empirical Brightness and Number Counts Calibration –The Red Giant Branch Bump of the Galactic Bulge is Slightly Overluminous, Very Underpopulated (Nataf et al. 2011, 2013)



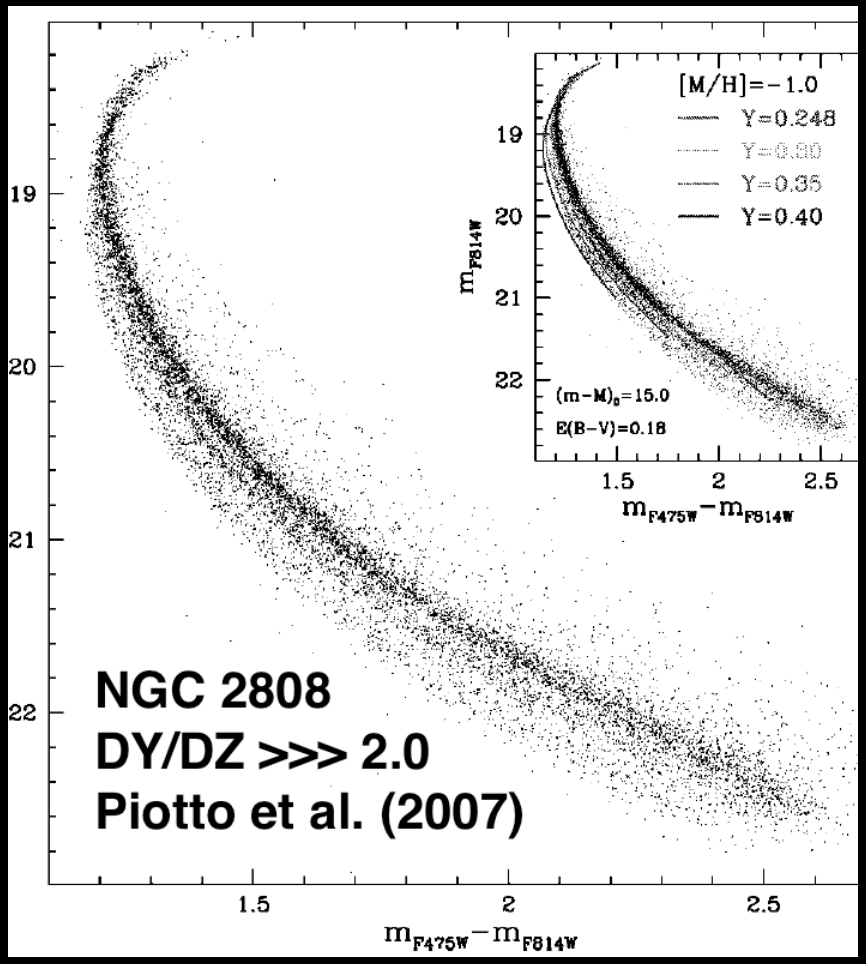


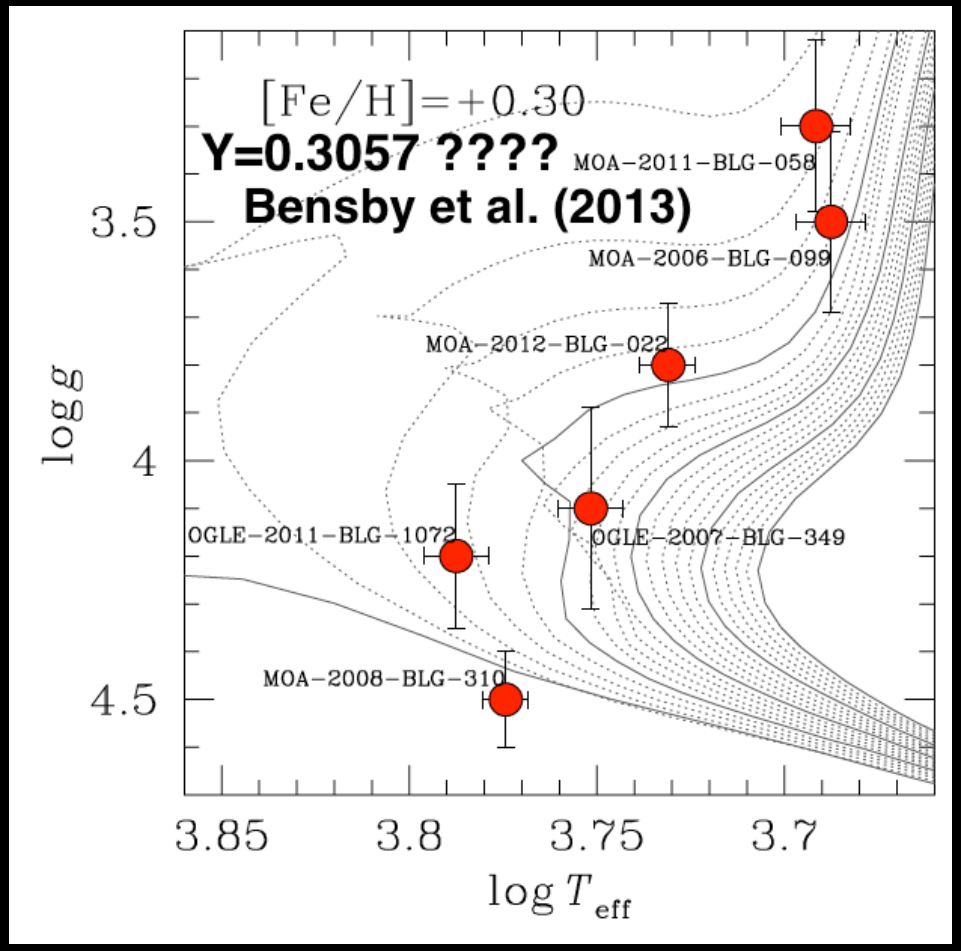
How to Understand if Galactic Bulge Stars Are Helium-Enhanced? Young? Both?

1. Ever more precise and more detailed investigations of the red giant branch bump.
2. Searching for clues to age and helium by other means.

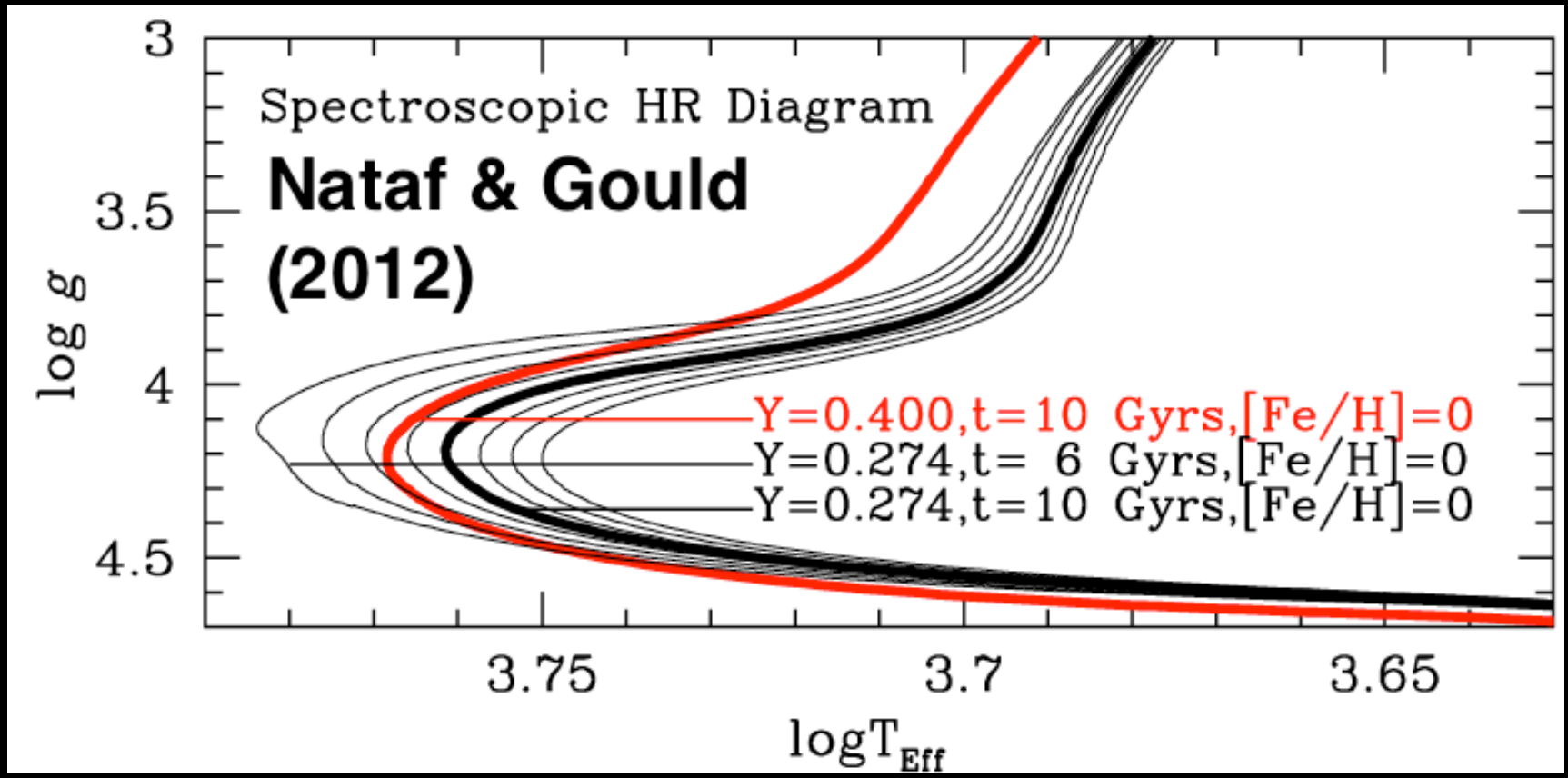
Adventure Moving Forward: Searching for Signs of Helium and Youth by Other Means.

Searching for Helium on the Main-Sequence and Subgiant Branch

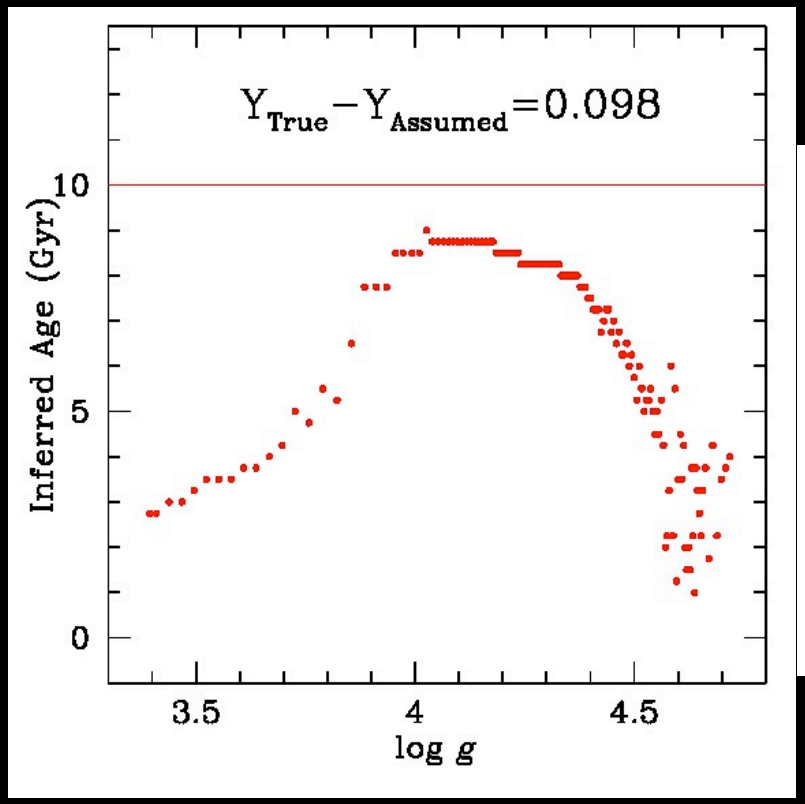


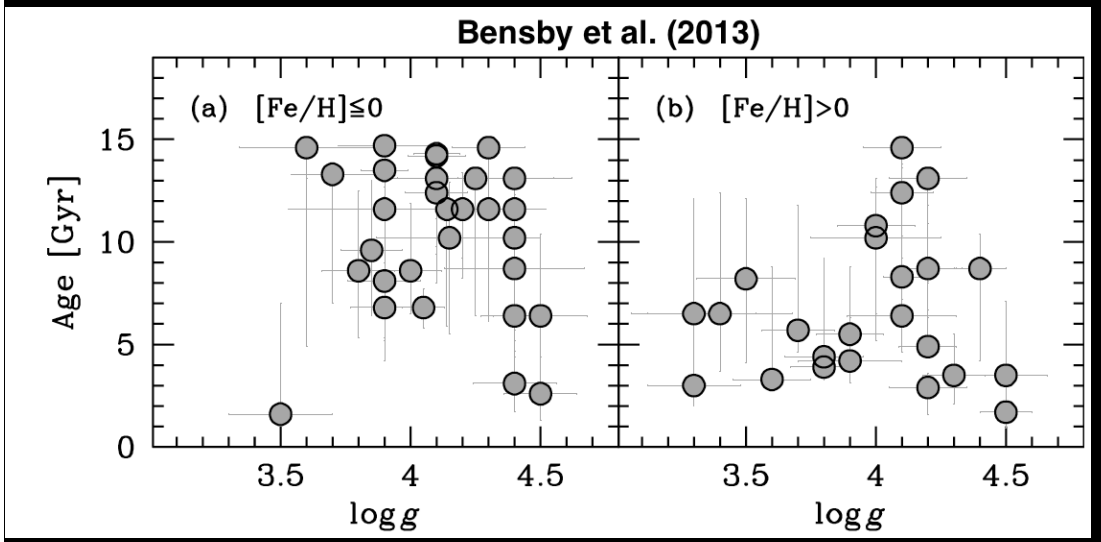


Age-Helium Degeneracy on the Main-Sequence Turnoff and Subgiant Branch: Underestimating Helium → Underestimated Ages



Signature of Enhanced Helium-Enrichment?





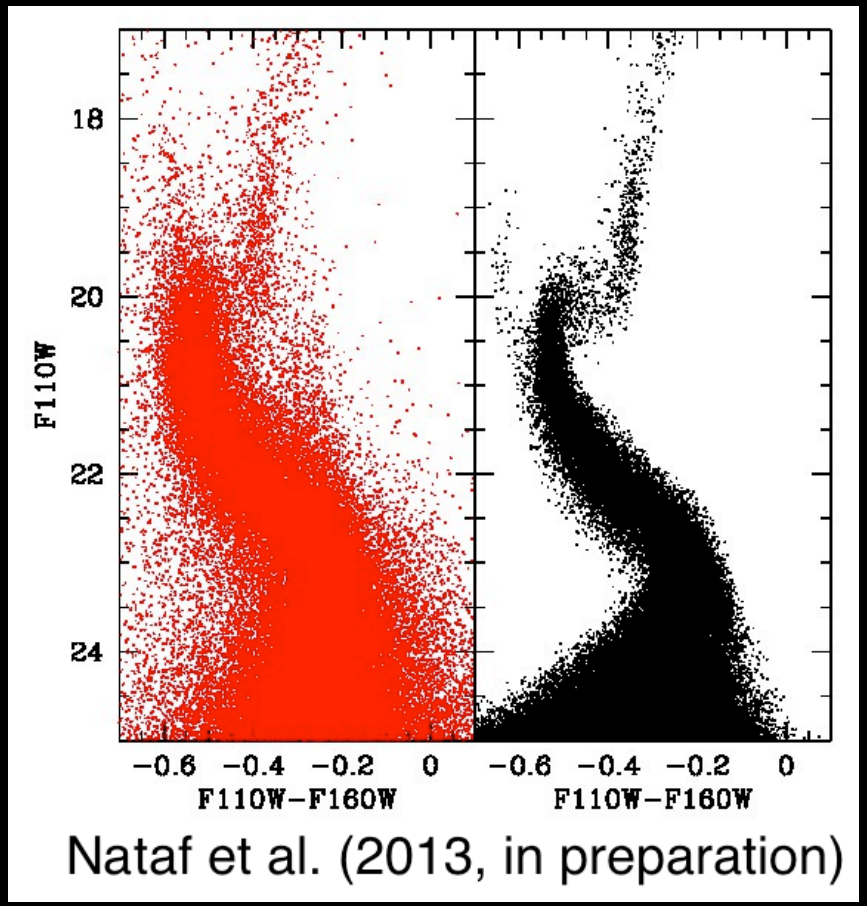
Microlensing Selection Effects Must be Modelled

- There Can Be No Age Determinations Without Helium Determinations. What can be due to helium can also be due to age, and vice versa.
- Age variations, age-helium correlation and dispersions must be explored as well.
- Selection effects likely to be important, need modelling based on Galactic dynamics.

Collaborators: Matthew Penny, Calen Henderson, Jennifer Johnson, Valentina Grieco, Francesca Matteucci, Martin Asplund, Maria Bergemann, Aaron Dotter, Thomas Brown, Mario Gennaro

Modelling Selection Effects Step 1: Create Synthetic Stellar Populations, Compare to Hubble CMDs

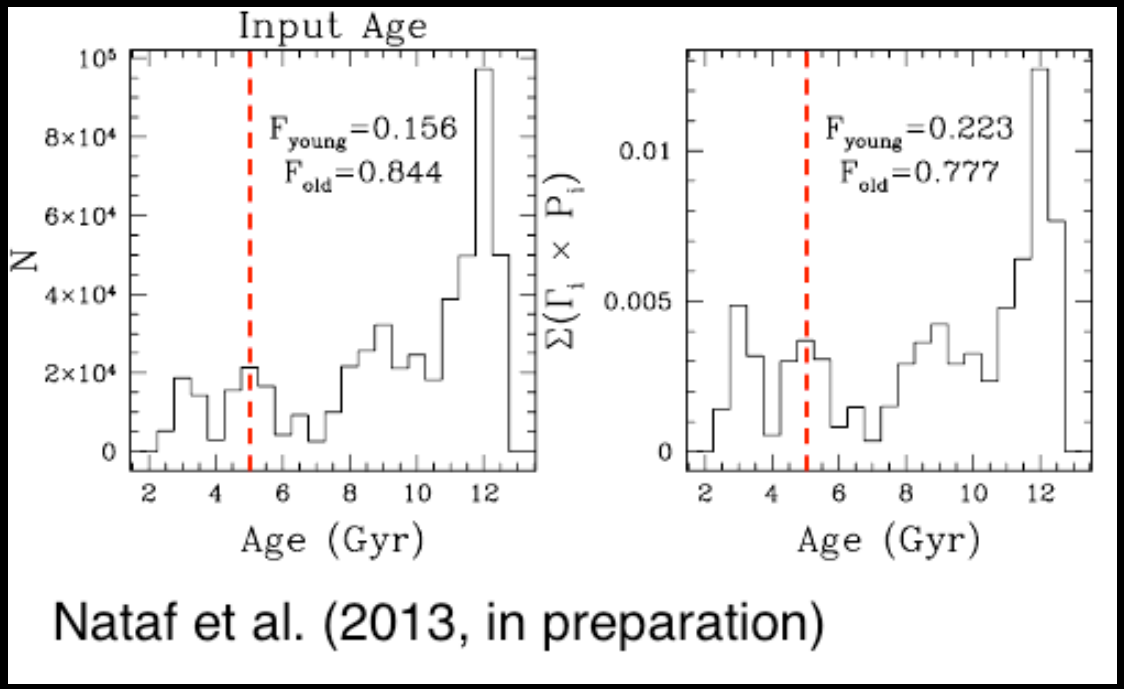
- Galactic model: Han & Gould (2003).
- Metallicities: Hill et al. (2011).
- Ages: Grieco et al. (2012).
- Reddening, differential reddening, reddening curve, distance, distance dispersion: Nataf et al. (2013).
- Isochrones: Dotter et al. (2008).
- Difficult task, see talk by Mario Gennaro.



Nataf et al. (2013, in preparation)

Modelling Selection Effects – Small Bias For Younger Stars

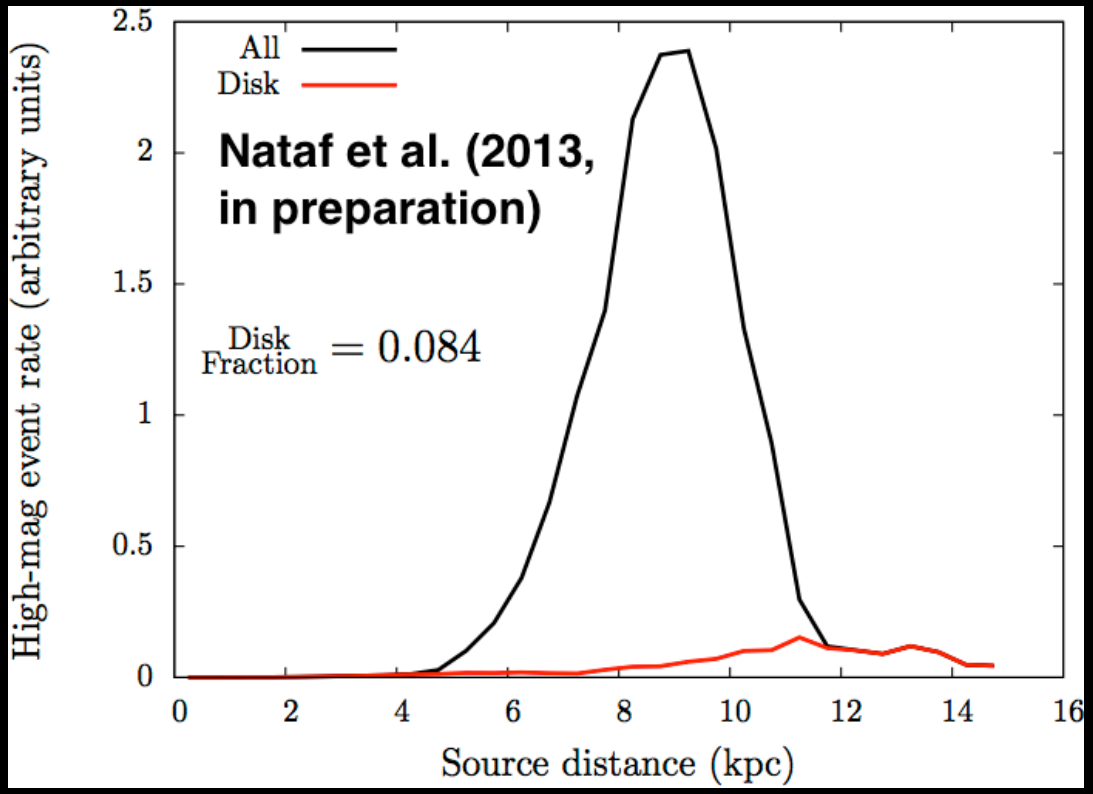
- If there are "young" stars ($\tau \leq$ 5 Gyr), their numbers will be overestimated by ~40%.
- Reduces the fraction of young stars to ~15%, still controversial.



Nataf et al. (2013, in preparation)

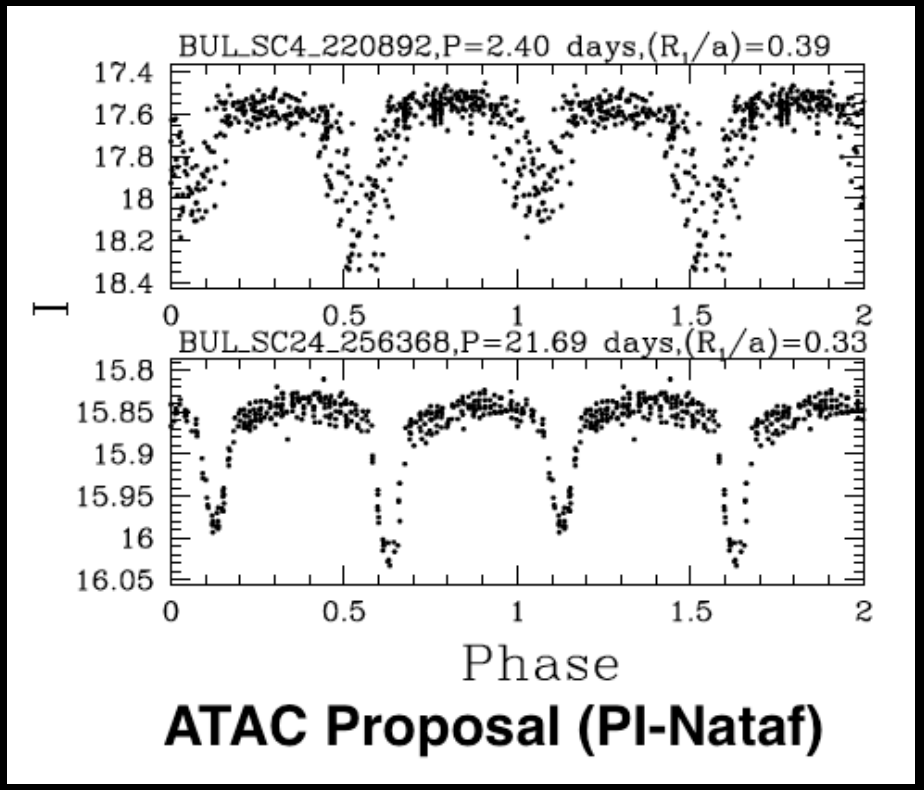
Modelling Selection Effects – Very Limited Disc Contamination

- Disc contamination is small (~8%)… and it contributes only thick disc stars, 600+ pc from the Galactic plane.

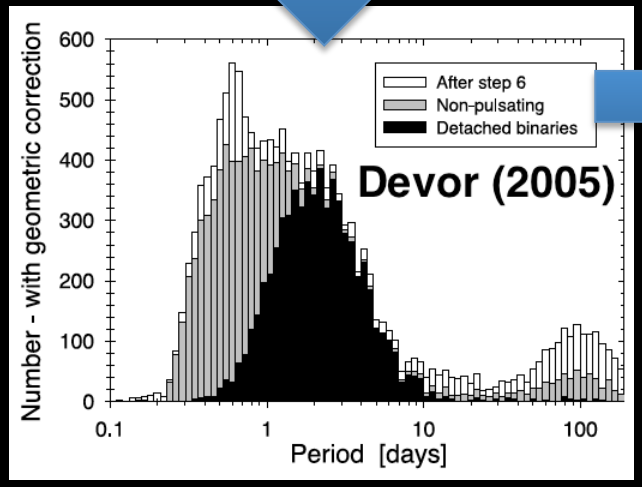


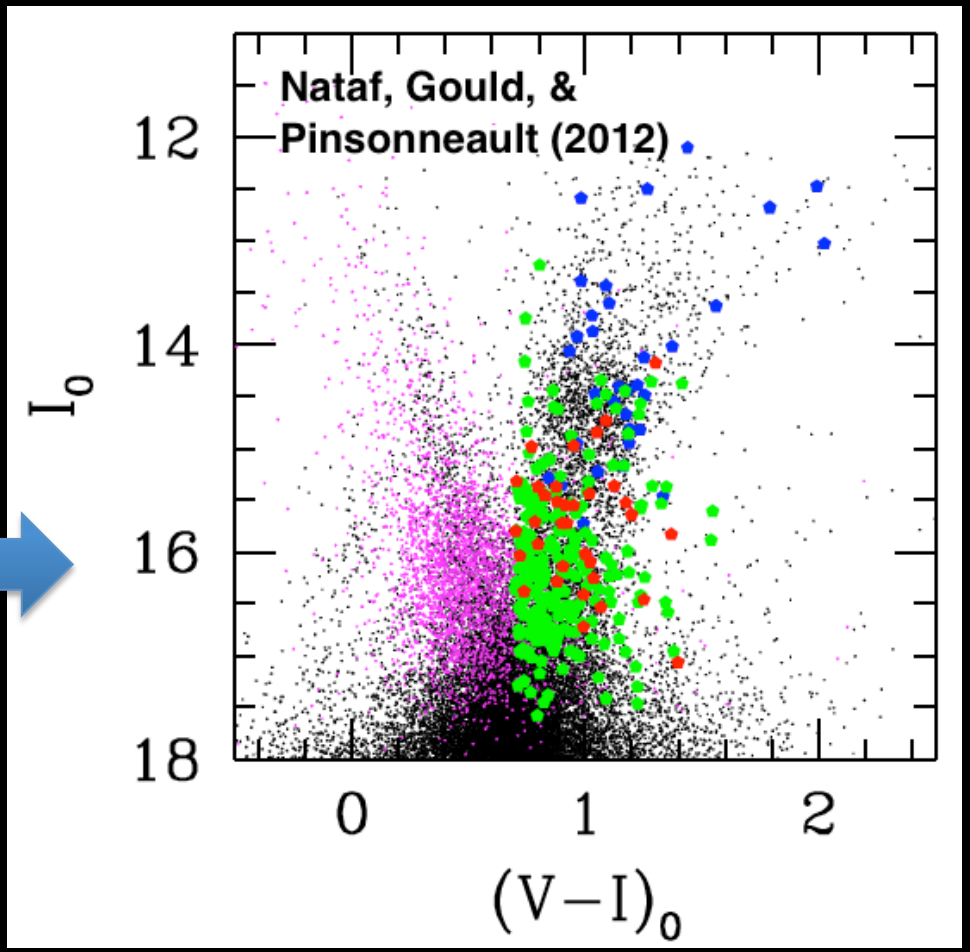
There Can be No Age Determinations Without Helium Determinations: Let's Measure the Mass of Red Giant Stars with Detached Red Giant Eclipsing Binary Twins.

- Lower age implies a higher mass for red giant stars, higher helium implies a lower mass.
- **<u>Collaborators:</u>** Martin Asplund, Melissa Ness, Ken Freeman, Aaron Dotter, Frank Fekel, Alan Alves-Brito, Kenji Bekki, Kris Helminiak, Stefan Uttenthaler, Jonathan Devor.

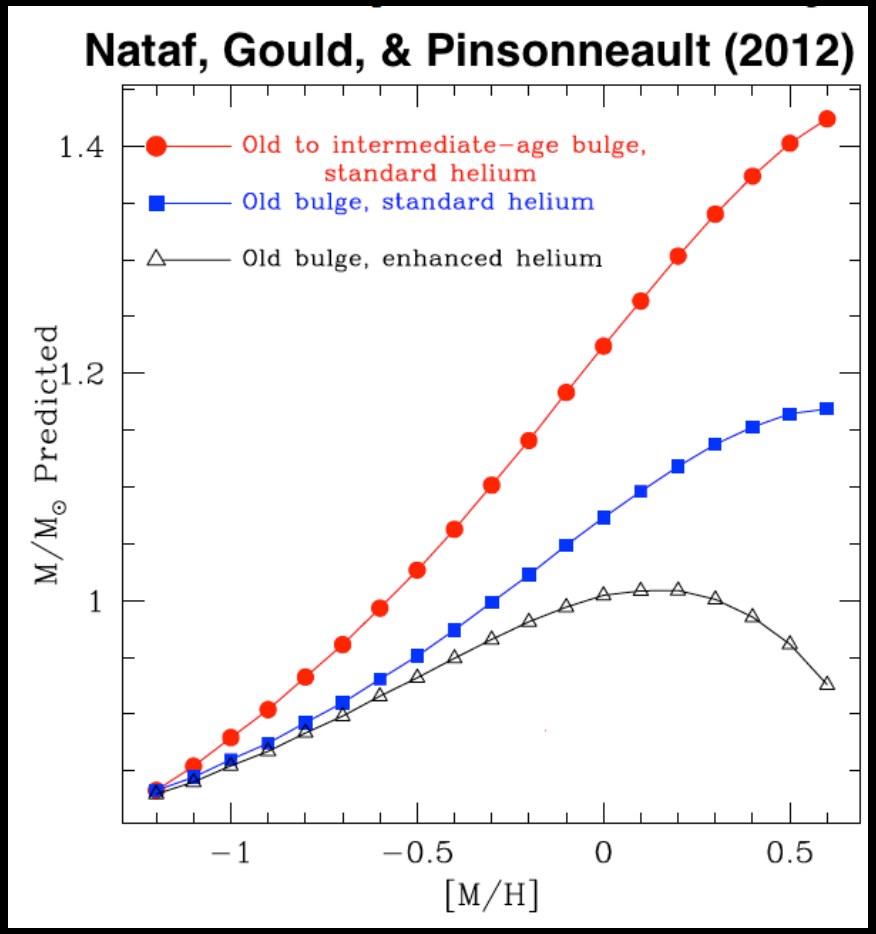


OGLE time-series photometry -> Eclipsing Binaries -> Red Giant Eclipsing Binary Twins

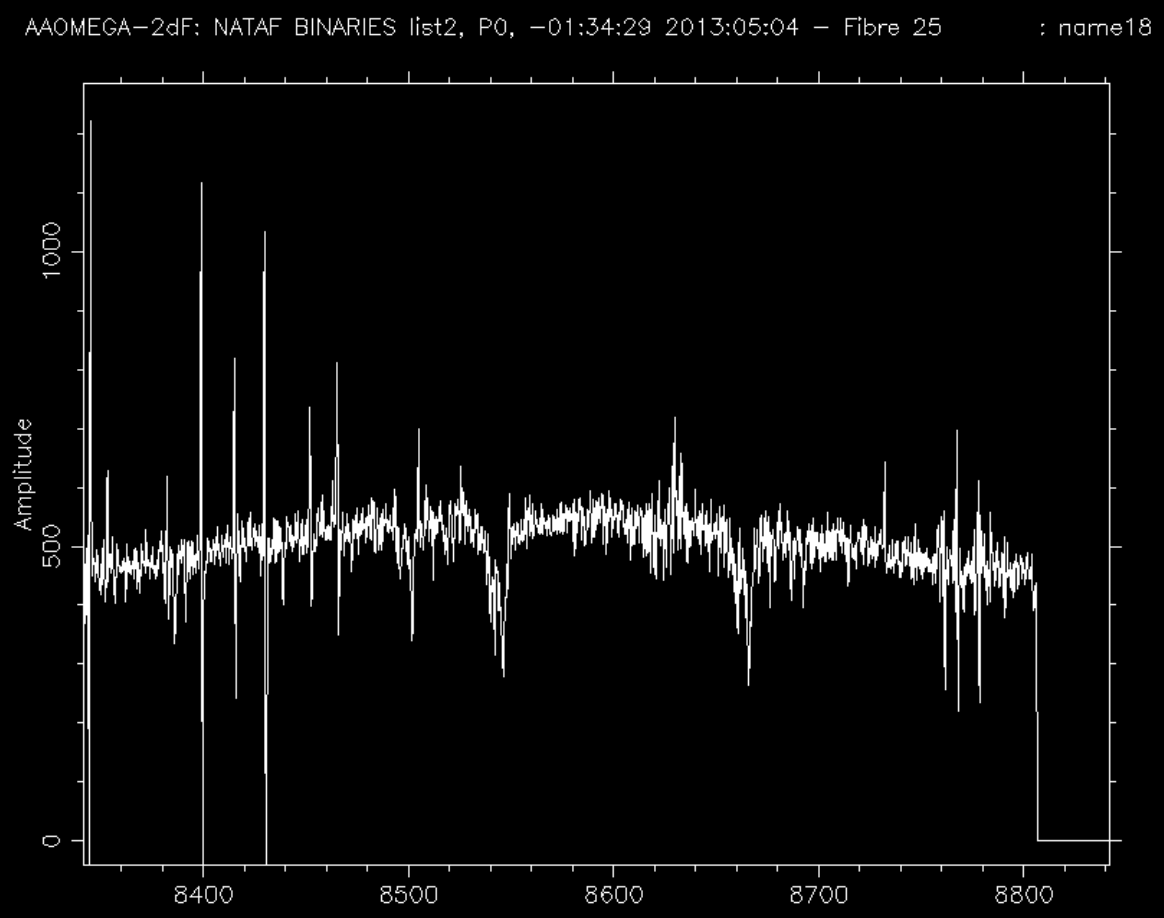




Constraints on Age and Helium Abundance of the Galactic Bulge from the Mass-Metallicity Relation Red Giant Stars

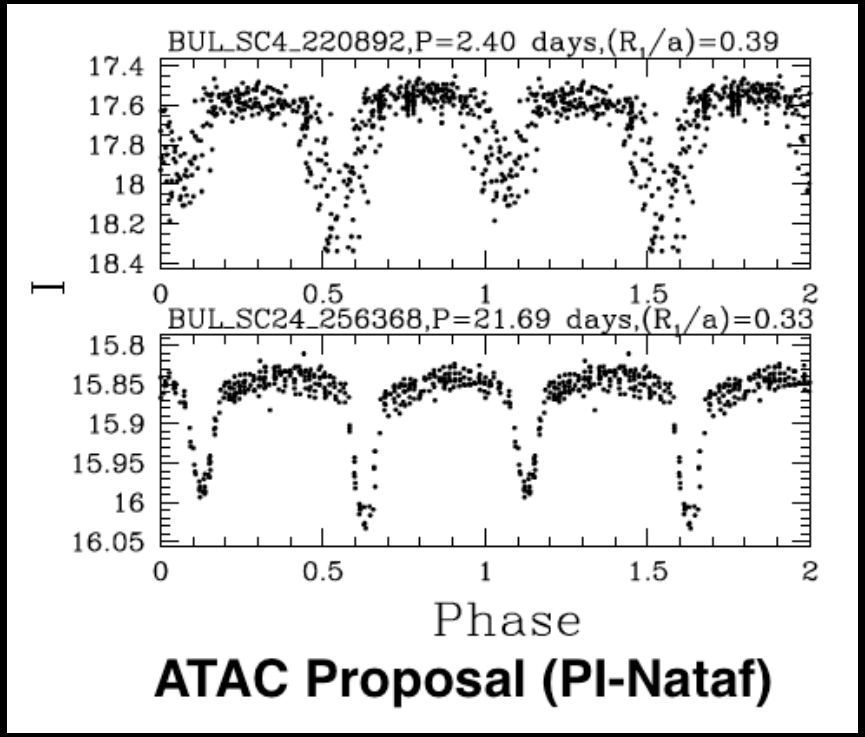


A Double-Lined Calcium Triplet



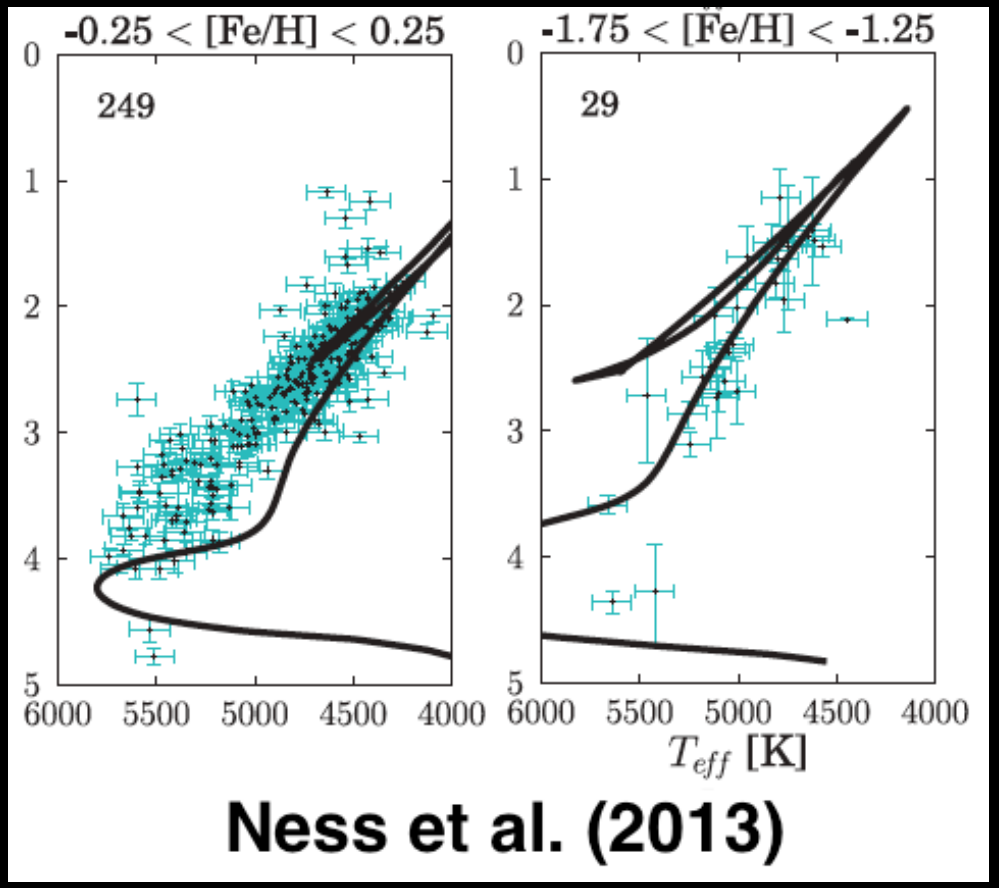
11,000 eclipsing binaries toward the bulge -> ≈250 detached red giant eclipsing binary twins

- Two variables shown: clearly detached, clearly eclipsing, clearly similar surface brightness, stars with 4% and 0.08% of the solar density.
- Clearly detached red giant eclipsing binary twins.



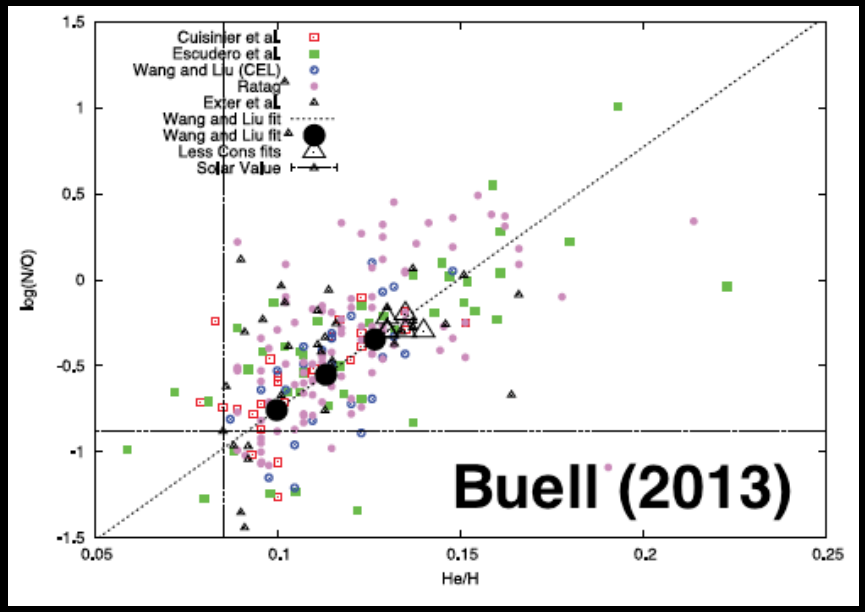
Indication of an Age/Helium Surprise from the ARGOS Survey?

- Spectroscopic gravities at the base of the red giant branch measured by Ness, Freeman, et al. (2013) are systematically lower than isochrone predictions at higher metallicities.



What Planetary Nebulae Tell us About Helium and CNO Elements in Galactic Bulge Stars

- Buell (2013) analyzed literature measurements of PNe toward the bulge.
- Analysis suggests $Y_{ZAMS} \approx 0.32$ at [Fe/H]=0, ages below 5 Gyr.

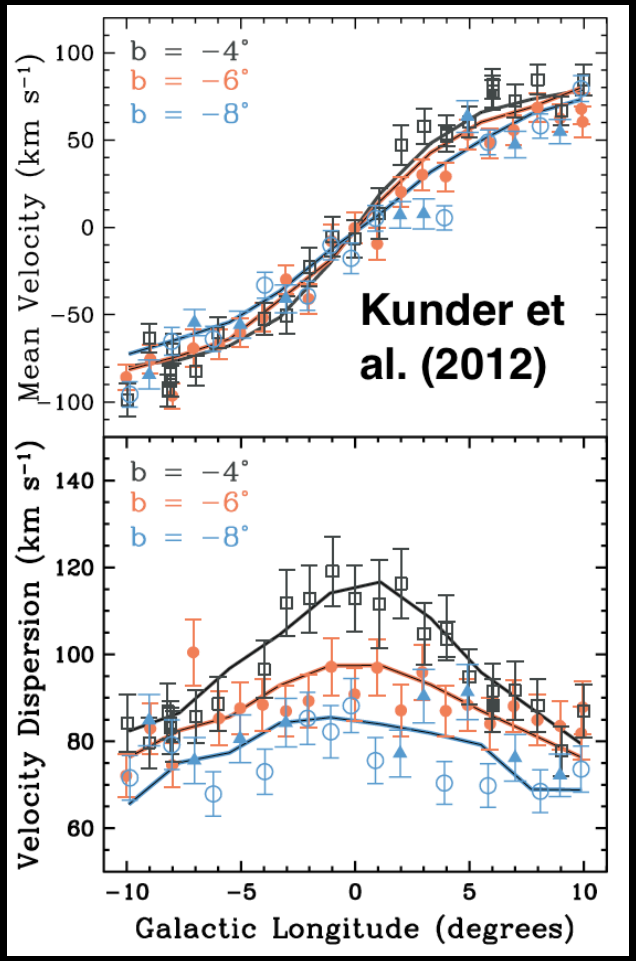


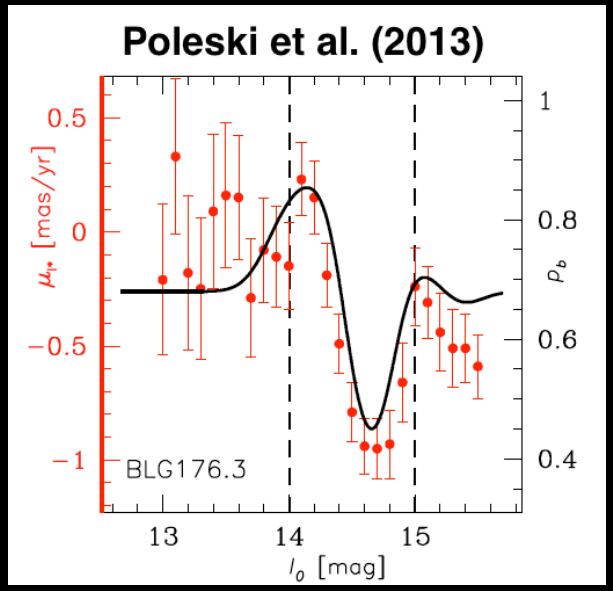
Conclusions

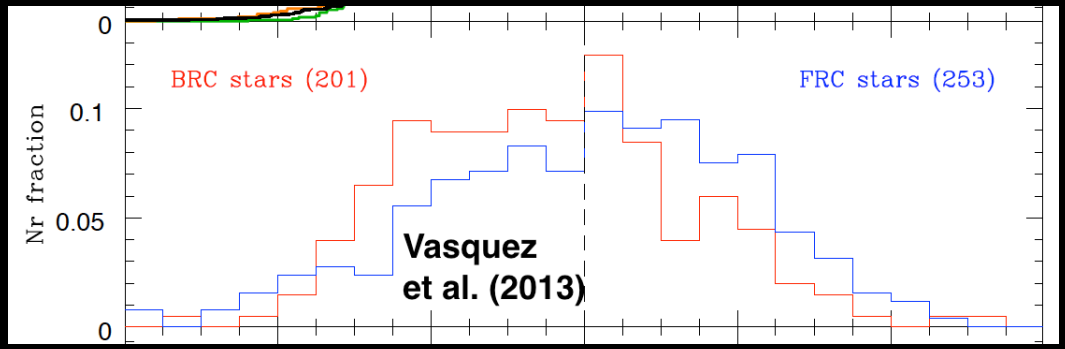
- There can be no age determinations without helium determinations, and vice versa.
- Problem is tractable, with precision spectroscopic studies of turnoff stars, and mass measurements of red giant stars.
- Evidence for both younger ($\tau \leq 5$ Gyr) and helium-enriched populations.
- We may need to rethink Galaxy formation and Galactic chemical evolution models.

Extra Slides

Dynamical Failure Mode to Chemical Evolution Models?

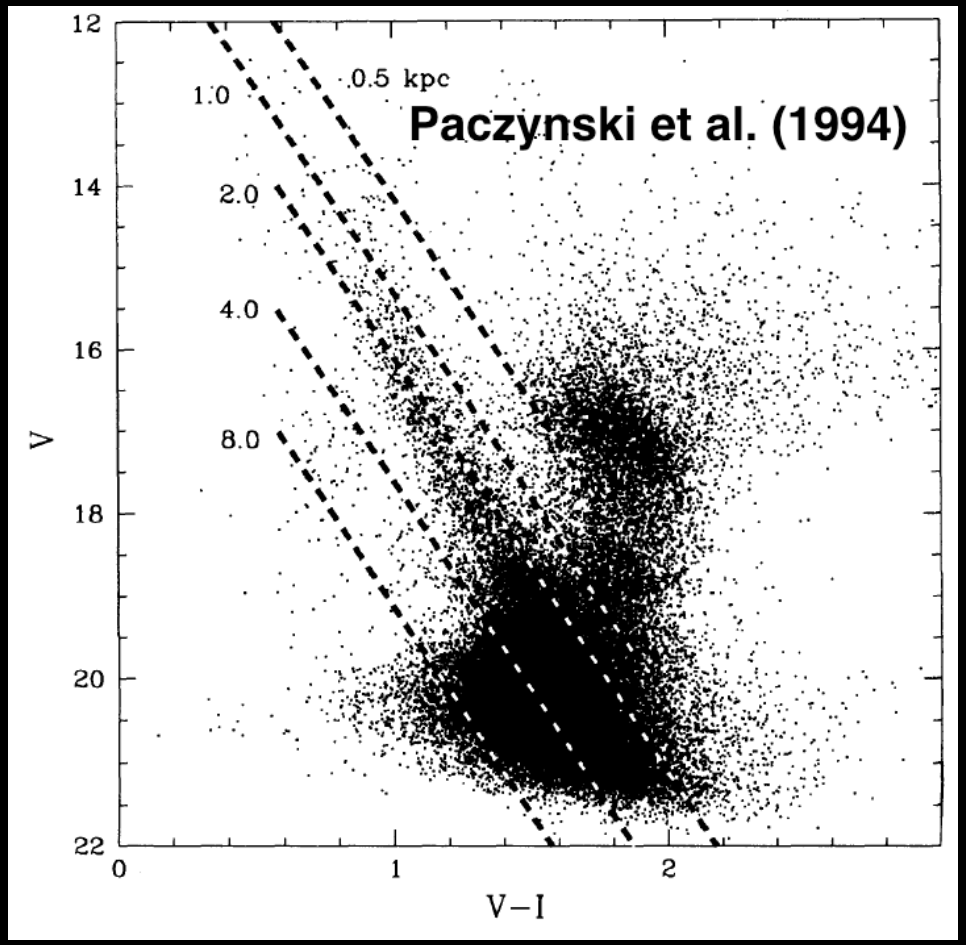




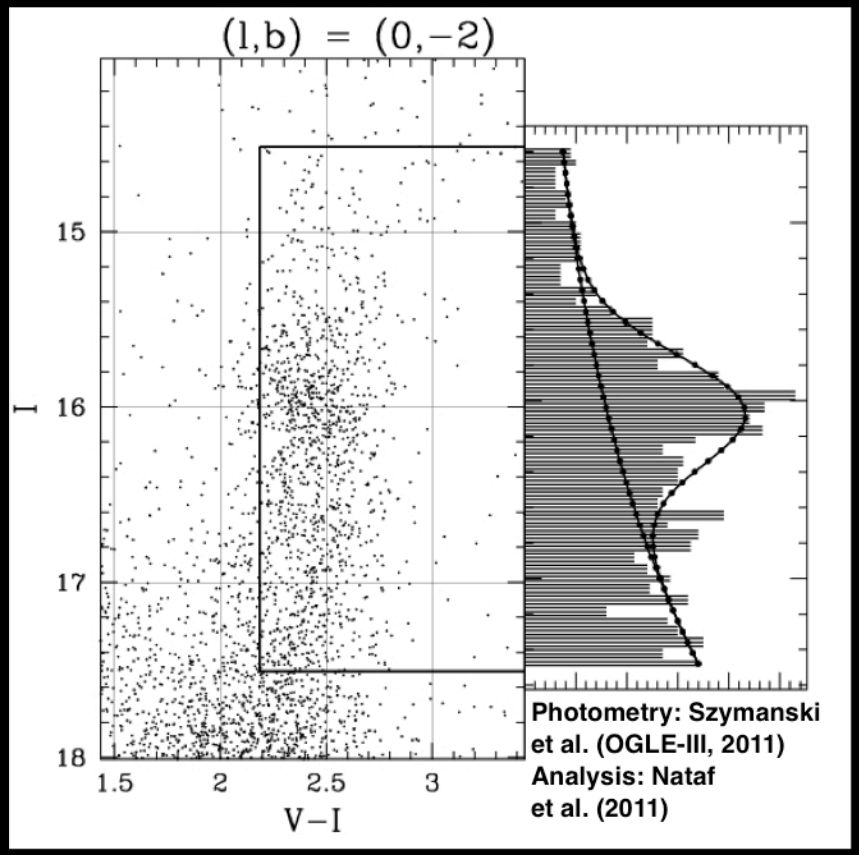


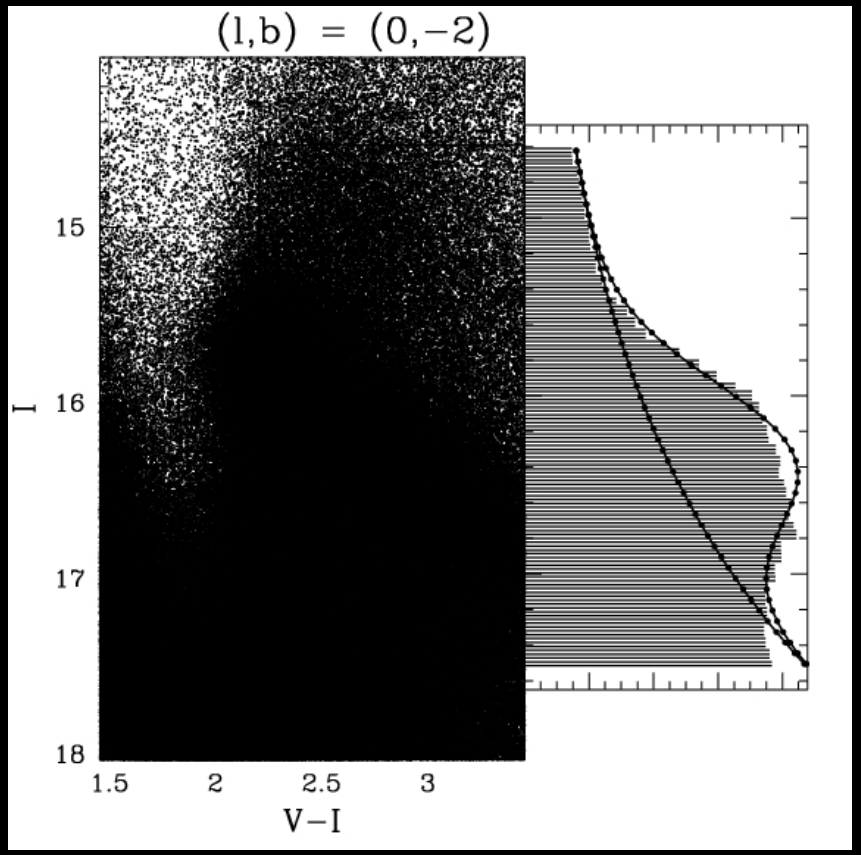
Reviving a Forgotten Issue: The Age-Helium Degeneracy in the Galactic Bulge

- Terndrup (1988), Renzini (1994), Paczynski et al. (1994), Minniti (1995), and Tiede et al. (1997) debated the age-helium degeneracy with respect to interpretations of horizontal branch star counts.
- There can be no age determinations without helium determinations.



The Challenge of Precisely Interpreting Galactic Bulge Color-Magnitude Diagrams





Too few stars (small radius)... or too much differential reddening (large radius).

Detached Red Giant Eclipsing Binary Twins Certainly Exist

- Graczyk, Pietrzynski, Gieren, Udalski, Minniti et al. (2012) measured distances (to the SMC) to 3% precision, masses to 1% precision, radii to 2% precision.