The Age and Helium Abundance of the Galactic Bulge

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Credit: National Geographic
Bulge “Metals” Distribution: A Well-Known Galactic Parameter

Ness et al. (2013), 5 degrees from the plane

[Diagram showing metallicity distribution with peaks labeled A, B, C, D, E]


[Plot showing metallicity distribution with trends and error bars]

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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 \( \geq 10 \text{ Gyr} \). No trace is found for any younger stellar population.” – Zoccali et al. (2003).
Chemical Evolution Models Predict a (Nearly) Purely Old Bulge

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

Clarkson et al. (2011)
3% of bulge stars are younger than 5 Gyr

Bensby et al. (2013)
- 23% of bulge stars are younger than 5 Gyr.
Close Inspection of a young star in the Bensby et al. (2013) sample.

OGLE-2011-BLG-0950: 
$[\text{Fe}/\text{H}]=+0.33$, 
$T_{\text{eff}}=6130$ Kelvin 
(not 5500 Kelvin as per $t=11$ Gyr).

...Ergo, age $\approx 2.9$ Gyr.
Reviving a Forgotten Issue: The Age-Helium Degeneracy in the Galactic Bulge

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, effect of helium uncertainties on age determinations, microlensing selection effects from Galactic dynamics models, the mass of red giant stars, Terzan 5, planetary nebulae, and red giant temperatures.
The Red Giant Branch Bump: An Independent Probe of the Age-Helium-Metallicity Relation

$t_{\text{RGBB}} = 33.2$ Myr

YREC stellar track, Pinsonneault et al.

![Graph showing $t_{\text{RGBB}}$ as a function of age.]

- Milky Way Bulge
- $\omega$ Cen
- Galactic Globular Clusters
- Dwarf Spheroidals

Nataf, Udalski, Gould & Pinsonneault (2011)

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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 et al. (2010).

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

Bono, Cassisi, Zoccali, & Piotto (2001)

$t_{\text{RGBB}} = 33.2$ Myr
$[\text{M/H}] = +0.2$
$Y = 0.27$
$M = 1.08 \, M_\odot$

$t_{\text{RGBB}} = 20.2$ Myr
$[\text{M/H}] = +0.2$
$Y = 0.35$
$M = 0.90 \, M_\odot$

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The Challenge of Precisely Interpreting Galactic Bulge Color-Magnitude Diagrams

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

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

\[(l,b) = (0,-2)\]

\[\text{Photometry: Szymanski et al. (OGLE-III, 2011)}\]
\[\text{Analysis: Nataf et al. (2011)}\]
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:**
  \[ \Delta I \approx -1.08, \]
  \[ f \approx 5.5\%. \]

Photometry:
Piotto et al. (2002), Sarajedini et al. (2007), Dotter et al. (2011)

Analysis:
Nataf, Gould, Pinsonneault, & Udalski (2013)

Nataf, Gould, Pinsonneault, & Udalski (2013)
The Red Giant Branch Bump Also Traces Metallicity Differences Within and Between Bulges!

- At 6 degrees from the plane, $\Delta l \approx 0.58$ mag, $f \approx 18\%$, corresponding to $\Delta[M/H]$ of $\approx 0.19$ dex with 2 degrees from the plane.
- Monachesi et al. (2011) measure the parameters towards M32, suggested $\Delta[M/H] \approx 0.31$ dex.
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.

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Searching for Helium on the Main-Sequence and Subgiant Branch

NGC 2808
DY/DZ >>> 2.0
Piotto et al. (2007)

[NICHT GESAGT]

[BENSBY ET AL. (2013)]

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Age-Helium Degeneracy on the Main-Sequence Turnoff and Subgiant Branch: Underestimating Helium → Underestimated Ages
Signature of Enhanced Helium-Enrichment?

$Y_{\text{True}} - Y_{\text{Assumed}} = 0.098$

Bensby et al. (2013)

(a) $[\text{Fe/H}] \leq 0$

(b) $[\text{Fe/H}] > 0$

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Microlensing Selection Effects Must be Modelled As Well

• What if the helium-enrichment is exactly what the isochrones predict, and the age differences are just due to selection effects?
Modelling Selection Effects – Very Limited Disc Contamination

- Disc contamination is small (~8%), contributes only old, metal-poor thick disc stars
- Microlensed dwarfs are in the bulge, and primarily at the back of the bulge by ~0.13 mag offset.

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Modelling Selection Effects – Small Bias For Younger Stars

• If there are “young” stars ($\tau \leq 5$ Gyr), their numbers will be overestimated by $\sim 40\%$.

• Reduces the fraction of young stars to $\sim 15\%$, still controversial.
Modelling Selection Effects in Detail: Create Synthetic Stellar Populations, Compare to Hubble CMDs

- Ages: Grieco et al. (2012).
- Isochrones: Dotter et al. (2008).
Option #3: Let’s Measure the Mass of Red Giant Stars with 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.
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

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A Time-Variable, Double-Lined Calcium Triplet
More on Terzan 5

- Complex metallicity distribution function with peaks at $[\text{Fe/H}] = -0.79$, -0.25, +0.27, +0.75, or $Z = 0.0025$ to 0.090 (Massari et al. 2014).
- Metal-poor peak outnumber metal-rich peak by 4:1 ratio (Tuesday talk by Livia Origlia).

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Terzan 5 Thus a Testbed for Bulge Chemical Evolution, But Needs a Better Reddening Map

Wein Lau, David Nataf, Antonino Milone, & Martin Asplund (2014, in prep)

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Terzan 5 Thus a Testbed for Bulge Chemical Evolution, Continued

• 2:1 ratio for faint versus bright red clump, compared to 4:1 ratio in red giant spectroscopy;
• 21% bump to clump ratio;
• Both results suggest younger age or enhanced helium or both;

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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 $[\text{Fe/H}]=0$, ages below 5 Gyr.
Indication of an Age/Helium Surprise from the ARGOS (Ness et al. 2013) Survey?
Indication of an Age/Helium Surprise from the ARGOS (Ness et al. 2013) Survey?
Confirmation of the Red Giant Temperature Offset / Narrow Subgiant Branch Detected by Ness et al. (2013)

Choices:
1. Bulge has a younger component;
2. Bulge has a helium-enriched component;
3. Isochrones don’t work;
4. Combination of #1, 2, and 3;
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.
Scientific Wishlist From a Friendly Postdoc

- Uniform metallicity scale for Galactic bulge and Galactic globular clusters;
- Better CMDs (in 3+ bandpasses) and spectroscopic metallicities for bulge globular clusters;
- More measurements of microlensed dwarfs;
- Spectra of red giant eclipsing binaries;

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Bulge Star Formation History Matters, Part 1

- ~10% of the Milky Way’s mass, with a bias to the oldest and most metal-rich stars. Must be matched by any realistic Galaxy formation model.

- Λ-CDM simulations fail at reproducing observed bulge distribution (Kormendy et al. 2010, Kunder et al. 2012).
Bulge Star Formation History Matters, Part 2

- Only spheroidal for which we can conceivably measure all six kinematic components and detailed chemical abundances of individual stars, as well as the integrated luminosity luminosity function.
Bulge Morphology – A Well-Known Galactic Parameter

Cao et al. (2013, MNRAS) fit various triaxial models to the bar:
- Measure an orientation angle of 29 degrees between the bar’s major axis and the sun-Galactic center line of sight;
- Best-fit axis ratios are 1:0.43:0.40;
- The number density function is close to exponential, with a scale length of 0.67 kpc.

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Bulge Extinction – A Well-Measured Galactic Parameter

Nataf et al. (2013b) combined OGLE-III photometry in the optical (Landolt VI) to measure the reddening, $E(V-I)$ ranges from 0.5 to 3.0 in the regions of interest. Reddening measured on 4’ scales toward 90 deg² of the inner Galaxy.

Combined analysis with VVV reddening maps from Gonzalez et al. (2012) of $E(J-K_s)$ demonstrates a mean $E(J-K_s)/E(V-I) \approx 0.33$, compared to 0.41 for a canonical $R_v=3.1$ extinction curve.

Results consistent with an $R_v \approx 2.5$ extinction curve. Similarly, $AI/E(V-I) \approx 1.22$. 

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Musings on Milky Way Assembly

Are globular clusters the stellar building blocks of the Galaxy?
11,000 eclipsing binaries toward the bulge -> ≈250 detached red giant eclipsing binary twins
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.

Graczyk et al. (2012) 
P=371.6 Days
Galactic Archeology and the Challenge of Age Dating

- Historical archeology has been revolutionized by carbon-dating methods.
- No such luck for Galactic archeology, so we’re not as successful, at least not so far.