The Bulge

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The Bulge is a **massive** and **old** component of the Milky Way.

**DISK MASS:** $\sim 6 \times 10^{10}$ solar masses

**BULGE MASS:** $\sim 10^{10}$ solar masses

**HALO MASS:** $\sim 10^{9}$ solar masses
The color-magnitude diagram of the Bulge is heavily contaminated by disk stars. The contamination significantly affects the MS turn off.
The CMD of Bulge stars can be statistically decontaminated from disk stars.
CMD and age of the Bulge

Valenti et al. (2013)
CMD, proper motions and age of the Bulge

Clarkson et al. (2008)
CMD, proper motions and age of the Bulge

Clarkson et al. (2008)

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Stars younger than \sim 5 Gyr, if present, comprise less than \sim 5% of the total number of Bulge stars.
The age of the Galactic Bulge: Arguments for an **old** Bulge

Conclusion from chemical evolution models

*The Bulge formed at the same time and even faster than the Galactic halo*

*e.g. Matteucci & Romano 1999*

Conclusion from the CMD

*The Bulge is as old as Globular clusters, (age>~10 Gyr) with no trace for any young stellar population*

*e.g. Zoccali et al. 2003*
The color-magnitude diagram of the Galactic Bulge:

Photometry of Bulge stars typically suffer for low-scale differential reddening.

Moreover, we deal with many Galactic components in the same field of view.

Lagioia et al. (2014):

CMD of stars in the Baade Window in the field of the Globular Cluster NGC6528

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http://progetti.dfa.unipd.it/GALFOR
The color-magnitude diagram of the Galactic Bulge:

Relative HST proper motions of stars in the field of view of the Baade window around the Globular cluster NGC6528 allow to identify bulge, disk, and cluster stars.

Lagioia et al. (2014)
Proper motions are used to separate the members of NGC6528 from Bulge and disk stars.

CMD and Vector points diagrams of proper motions for NGC6528 cluster members.

Lagioia et al. (2014)
The color-magnitude diagram of the Galactic Bulge

Cluster members are used to derive a high-resolution reddening map in the Baade Window (direction of NGC6528)

Lagioia et al. (2014)
The color-magnitude diagram of the Galactic Bulge

Lagioia et al. (2014)

The reddening map is then used to correct the (proper motion selected) CMD of Bulge stars for differential reddening.

We detect broadened MSs and RGB.
The age of the Galactic Bulge

The bulk of Bulge stars belong to old population with ages of \( \sim 10-12 \) Gyr.

This work suggests a rapid star-formation for the Bulge

Lagioia et al. (2014)
Star-formation in the Galactic Bulge

Bulge stars have high $[\alpha/Fe]$ ratio, implying rapid star formation.

Bulge and thick disk stars $[\alpha/Fe]$ in the common $[Fe/H]$ range.
The age of the Galactic Bulge

A new method to infer ages for Bulge stars is based on five-band HST photometry in five fields.

Proper motions are used to separate Bulge members from the bulk of disk stars.

Renzini et al. (2018)
The age of the Galactic Bulge

Reddening-free diagrams from multi-band photometry

Renzini et al. (2018)
Reddening-free diagrams from multi-band photometry are used to identify stellar populations with different metallicity.

Renzini et al. (2018)
The age of the Galactic Bulge

The bulk of Bulge stars are \(~10\) Gyr old and only \(~3\)% of stars are younger than \(~5\) Gyr

Renzini et al. (2018)
Age-metallicity relation of the Galactic Bulge

During **microlensing events** faint Bulge stars can brighten by several magnitudes
Age-metallicity relation of the Galactic Bulge

Bensby et al. (2013) get high-resolution spectra of dwarf stars in the Bulge when they are microlensed.

From the spectra they infer gravity, temperature and metallicity.
These stars are close to the MS turn off.

Ages are derived from the comparison of observations and isochrones in the $\log(g)$ vs. $\log(T_{\text{eff}})$ plane.

Bensby et al. (2013)

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Age-metallicity relation of the Galactic Bulge

~30% of the microlensed dwarfs are younger than ~7 Gyr. A few stars have ages of ~1.5 Gyr.

Bensby et al. (2013)
Stars with $[\text{Fe/H}] < \sim -0.4$ are **old**, with ages of **10-12 Gyr**
Stars with $[\text{Fe/H}] > \sim 0.4$ span a **wide range of ages**

Evidence for a **two-component Bulge?**
Age-metallicity relation of the Galactic Bulge

Results for 90 microlensed dwarfs confirm the discrepancy between ages inferred from spectroscopy and from HST photometry.

Bensby et al. (2017)