Diamonds in the Rough: The Oldest Stars in the Galaxy

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Outline

→ Our Current Picture of Stellar Evolution
→ A Surprise in our Backyard: The First “Discovered” White Dwarf
→ Why Search for Dead Stars?
→ What 120 orbits of Hubble Space Telescope Time Gets You.
→ Summary and Future Outlook
An Interesting Correlation: The Hertzsprung-Russell Diagram

Parallax: Parallax angle = 1 / (distance to star)

Observation: 1.) Stars with the same parallax have different luminosities.

→ Giants vs Dwarfs! First luminosity classes created.

2.) Luminosities of some stars are correlated with their colors…
An Interesting Correlation: The Hertzsprung-Russell Diagram

Ejnar Hertzsprung

Henry Norris Russell
The Observatory, Vol: 36, 324, 1913
An Interesting Correlation: The Hertzsprung-Russell Diagram

“Zur Strahlung der Sterne” (On the Luminosity of the Stars)

“Giant and Dwarf Stars”
- Russell, H. N., The Observatory, Vol. 36, 324, 1913

“On the Probable Order of Stellar Evolution”

“...one corner of the diagram is vacant...There do not seem to be any faint white stars. All of the very faint stars are very red.”

“...the converse propositions are not true; there is no doubt at all that there exist many very bright red stars (such as Arcturus, Aldebaran, Antares, etc.).”

“There appears, from the rather scanty evidence at present available, to be some correlation between mass and luminosity.”
Two Key Properties

1.) Star formation produces predominantly low mass stars.
2.) Stellar evolution depends primarily on mass.
- Sirius: brightest star in the night sky ($V = -1.5$).
- 1840’s - exhibits irregular motions on the sky (Bessel 1844).
- Optical detection of companion by Alvan Clark in 1862.
50 year binary orbit $\rightarrow$ 1 $M_\text{sun}$ companion, but $M_\text{V} = 11.3 \times 0.003 L_\text{sun}!$

- Sirius A and B have similar colors $\rightarrow$ Radius of Sirius B = 1/100 Sirius A.
- Adams (1914, 1925): spectrum is white, gravitational redshift measured.
- White dwarf: very dense remnant of a hydrogen burning star (no fuel).
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**White Dwarf Fact Sheet**
Composition: Carbon core under extreme pressure….a diamond!

Golden Jubilee Diamond VS Average White Dwarf

- **Discovery:** 1985 VS 1862
- **Size:** 5 cm VS 1,000,000,000 cm
- **Mass:** 0.1 kg VS $1 \times 10^{30}$ kg
- **Density:** 5 g/cm³ VS 1,000,000 g/cm³
- **Value:** >10 million USD VS --------------
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White Dwarf Fact Sheet
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Golden Jubilee Diamond VS Average White Dwarf

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A Few Reasons to Study White Dwarfs

1.) Over 97% of all stars will eventually form white dwarfs. Unique link to the distribution of first generation stars in old stellar populations.

2.) White dwarfs cool predictably with time → use as chronometers.

3.) Upper mass limit to white dwarf production = lower limit to type II SNe.

4.) Constraining fundamental stellar evolution and stellar mass loss.

5.) Theoretical calibration of evolutionary models of AGB and PN phases.
How Do We Find These Gems?

- Should be faint and blue.
- Search rich stellar populations.

Stellar Associations (young and sparse) 10’s of stars
Open Star Clusters (Intermediate age) 1000’s of stars
Globular Star Clusters (old and rich) 100,000’s of stars
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White Dwarfs in Globular Clusters?

Ultra-deep HST Imaging of the Nearest Clusters

Measure the ages of nearby globular clusters using white dwarf cooling theory.

1st study - Messier 4 - 123 orbits of HST/WFPC2 awarded in Cycle 9.
2nd study - NGC 6397 - 126 orbits of HST/ACS awarded in Cycle 13.
3rd study - 47 Tuc - 121 orbits of HST/ACS and WFC3 to be executed in Cycle 17.
The Age of the MW Halo

NGC 6397
126 HST/ACS orbits

Richer et al. (2006, Science, 313, 936)
The Age of the MW Halo


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NGC 6397

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The Age of the MW Halo


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June 11th, 2009 - 16b
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The Age of the MW Halo


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Signature of a White Dwarf
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Signature of a White Dwarf

[Graph and diagrams showing spectral lines and star classification]
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**Signature of a White Dwarf**

- Richer et al. (2006, Science, 313, 936)
**Dating the Oldest Stars**

Conclusions: The Luminosity and Age of the Faintest White Dwarfs

1.) These white dwarfs are more than 1 billion times fainter than the faintest stars seen with the naked eye!

2.) The first stars formed in our Galaxy 12 Gyr ago, 1.7 Gyr after the Big Bang.

3.) The disk of our Galaxy formed much later, 8 Gyr ago.

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WDs in Globular Clusters: >400 HST orbits!

The End!
The Age of the MW Disk

White dwarf mass function: Liebert, Bergeron & Holberg (2005)
Summary of Globular Cluster Work:

- White dwarf cooling age of NGC 6397 = 11.5-12.0 Gyr (t = 10.1-12.5 for M4).
- NGC 6397: \( \mu_\alpha = +3.56 \pm 0.04 \) mas/yr, \( \mu_\delta = -17.34 \pm 0.04 \) mas/yr. Cluster orbit suggests frequent interactions with bulge/disk.
- Proper motion cleaned study of low mass cluster mass function.
- \( z = 0.1 \) extragalactic globular cluster system found.

...and Open Cluster Work:

- Age/distance/reddening/binary fraction/etc… measured for a large sample.
- \( M_{\text{final}} = (0.109 \pm 0.007)M_{\text{initial}} + (0.394 \pm 0.025)M_{\odot} \).
- Age of Galactic disk = 8 Gyr, Age of Galactic halo = 12 Gyr.
- Mass loss is more efficient in higher metallicity environments.
- NGC 6791 stars evolved along three channels…no age issue, 2nd peak.
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Some CFHT CMDs
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Weidemann + Reimers & Koester (1980’s)
Claver et al. (2001)
Dobbie et al. (2004, 2006)
Williams et al. (2004, 2007)
Kalirai et al. (2005)
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