Mass Loss and the Death of Low Mass Stars

JASON KALIRAI

(STScI)

Collaborators:

Carnegie	*Dan Kelson*
HIA/NRC	*Gregory G. Fahlman, Peter B. Stetson*
Pontificia U	*Marcio Catelan*
Swinburne	*Jarrod R. Hurley*
UBC	*Harvey Richer, Saul Davis*
UCLA	*Brad M. S. Hansen, R. Michael Rich, David B. Reitzel*
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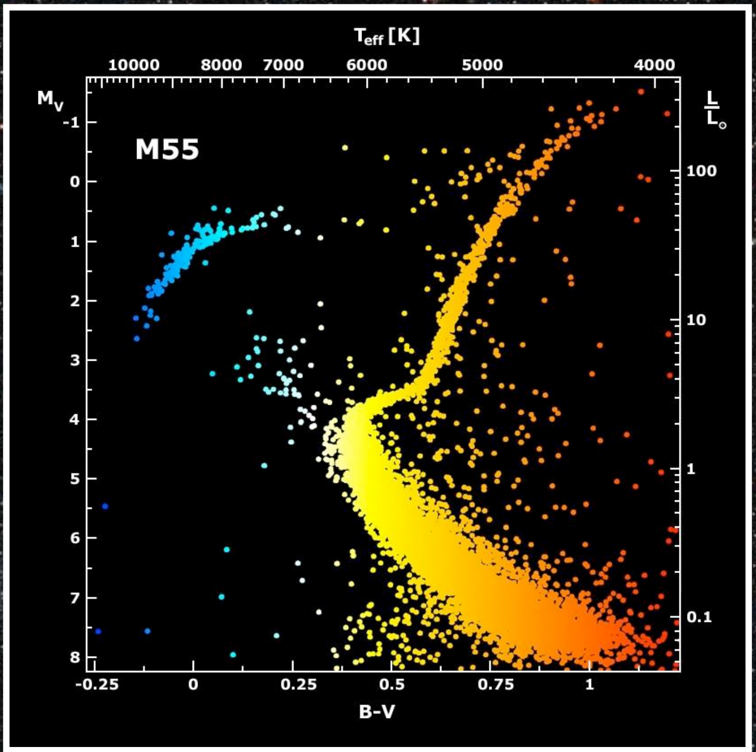
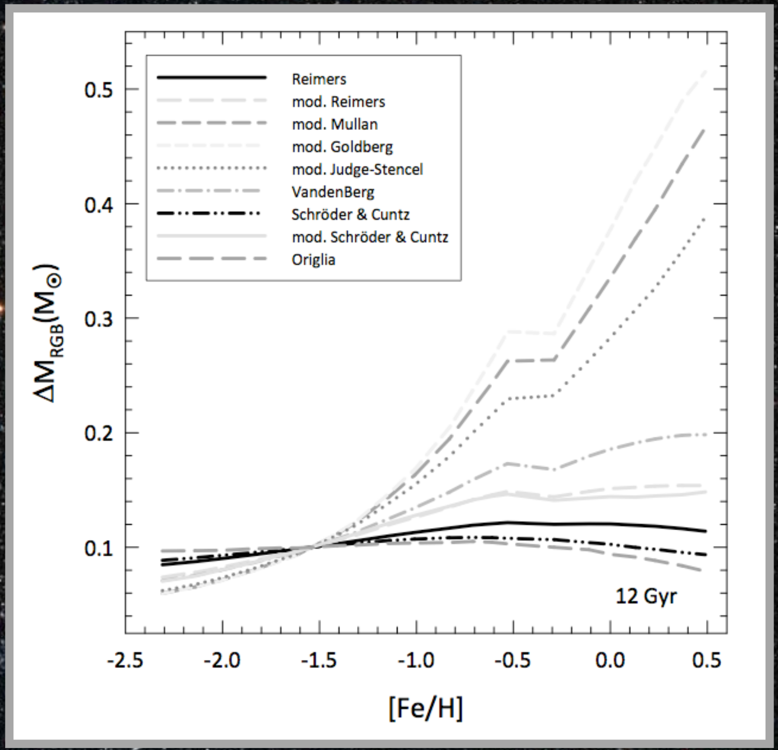
The Importance of Mass Loss in Low Mass Stars





Catelan (2000, ApJ, 531, 826)
Catelan (2009, IAU Symp 258, arXiv:0811.2947)

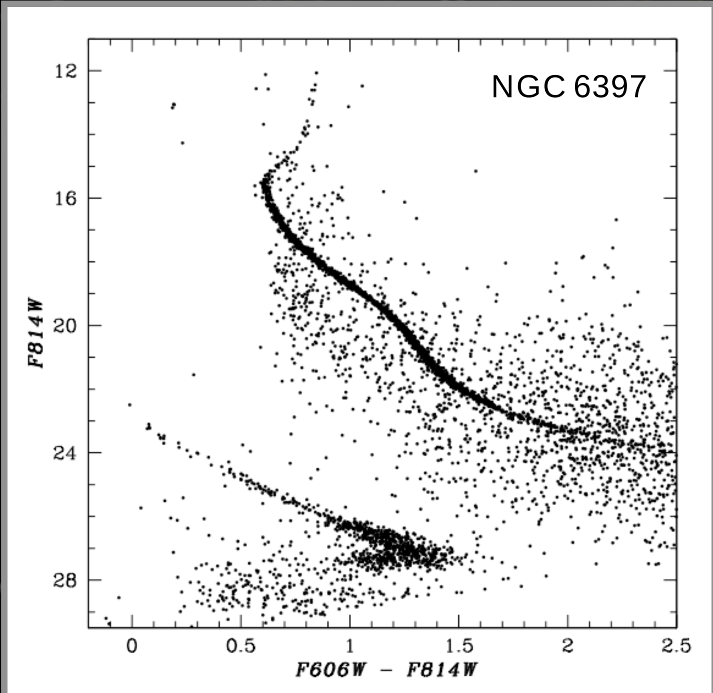
→ dM/dt on the first ascent RGB guides future evolution of star.

→ Effects the HB morphology, integrated colors of distant galaxies.

→ dM/dt is a function of *v*, L, dust composition, and Ψ.

Mass Loss and the Death of Low Mass Stars

How Can White Dwarf Stars Help?



Richer et al. (2006, Science, 313, 936)
Kalirai et al. (2007, ApJL, 657, 93)

Draft version August 14, 2009
Preprint typeset using LaTeX style emulateapj v. 12/14/05

THE MASSES OF POPULATION II WHITE DWARFS[1,2,3]

Jason S. Kalirai[4], D. Saul Davis[5], and Harvey B. Richer[5]
P. Bergeron[6], Marcio Catelan[7,8], Brad M. S. Hansen[9], and R. Michael Rich[9],

Draft version August 14, 2009

ABSTRACT

Globular star clusters are among the first stellar populations to have formed in the Milky Way, and thus only a small sliver of their initial spectrum of stellar types are still burning hydrogen on the main-sequence today. Almost all of the stars born with more mass than 0.8 $M_\odot$ have evolved to form the white dwarf cooling sequence of these systems, and the distribution and properties of these remnants uniquely holds clues related to the nature of the now evolved progenitor stars. With ultra-deep HST imaging observations, rich white dwarf populations of four nearby Milky Way globular clusters have recently been uncovered, and are found to extend an impressive 5 – 8 magnitudes in the faint-blue region of the H-R diagram. In this paper, we characterize the properties of these population II remnants by presenting the first direct mass measurements of individual white dwarfs near the tip of the cooling sequence in the nearest of the Milky Way globulars, M4. Based on Gemini/GMOS and Keck/LRIS multiobject spectroscopic observations, our results indicate that 0.8 $M_\odot$ population II main-sequence stars evolving today form 0.53 ± 0.01 $M_\odot$ white dwarfs. We discuss the implications of this result as it relates to our understanding of stellar structure and evolution of population II stars and for the age of the Galactic halo, as measured with white dwarf cooling theory.

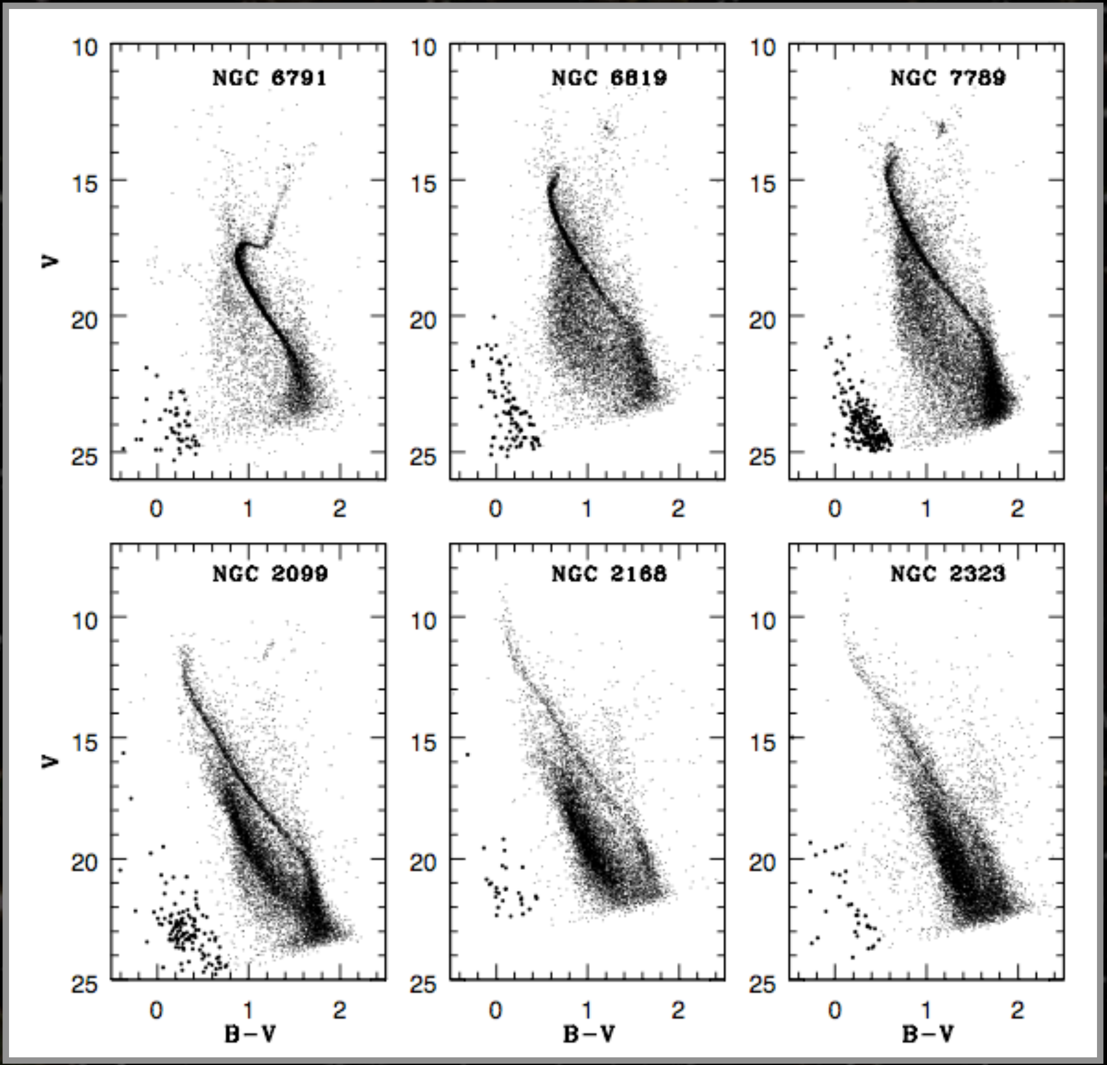
Subject headings: photometry — globular clusters: individual (M4) — methods: data analysis — stars: evolution — techniques: photometric, spectroscopic — white dwarfs

Kalirai et al. (2009, ApJ, in press)

- → WDs are the end products of this (mass loss) evolution.
- → Final remnant masses are easy to measure.
- → Linking to initial masses is possible in star clusters.

Mass Loss and the Death of Low Mass Stars

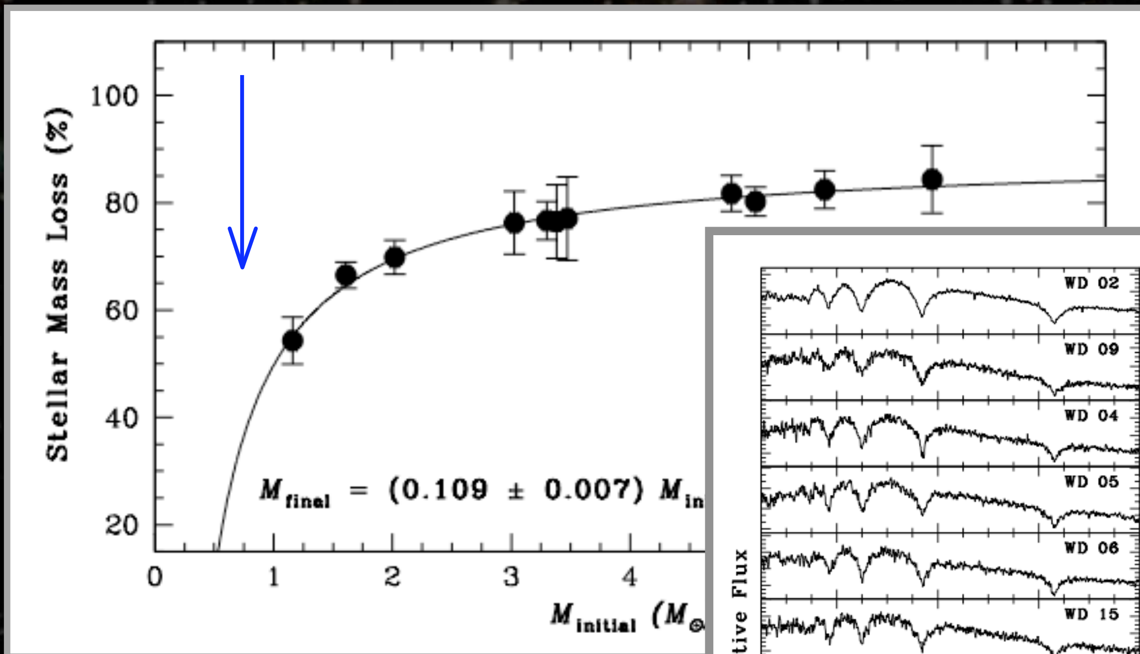
How Can White Dwarf Stars Help?



Kalirai et al. (2001, AJ, 122, 257) + others

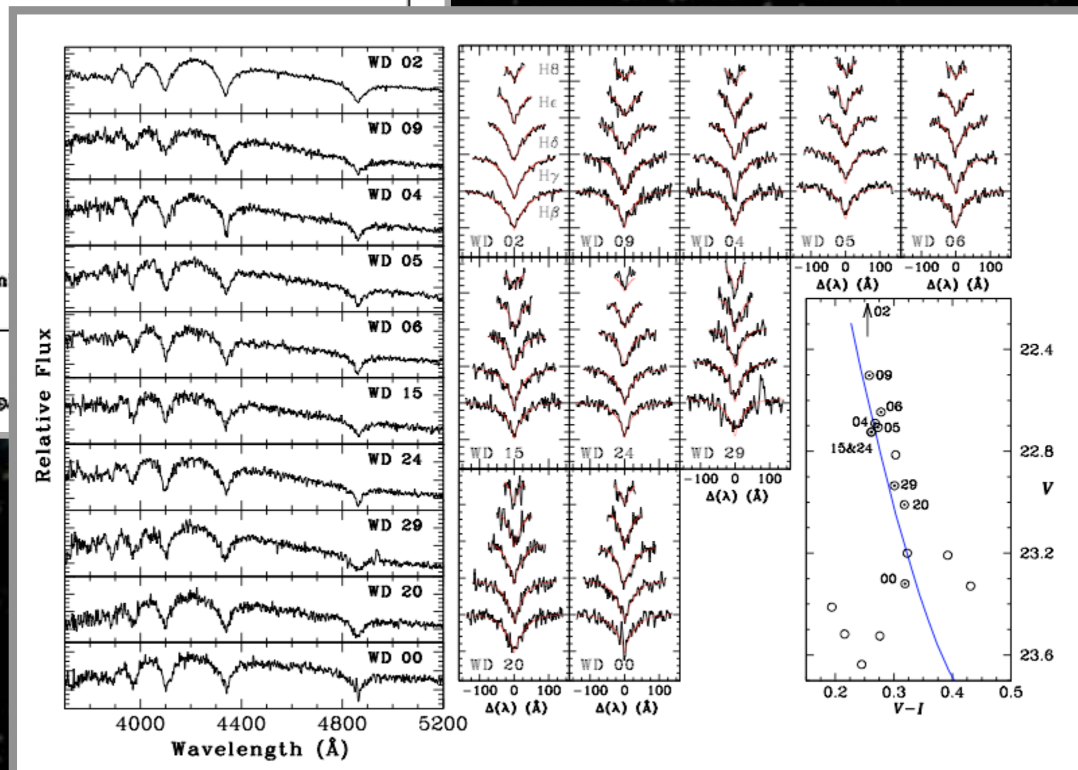
Mass Loss and the Death of Low Mass Stars

FIRST RESULTS



Kalirai et al. (2008, ApJ, 676, 594)

→ Z = Zsun, dM/dt = 36%



Kalirai et al. (2009, ApJ, in press)

**All results account for latest Stark broadening calculations: See Tremblay & Bergeron (2009)

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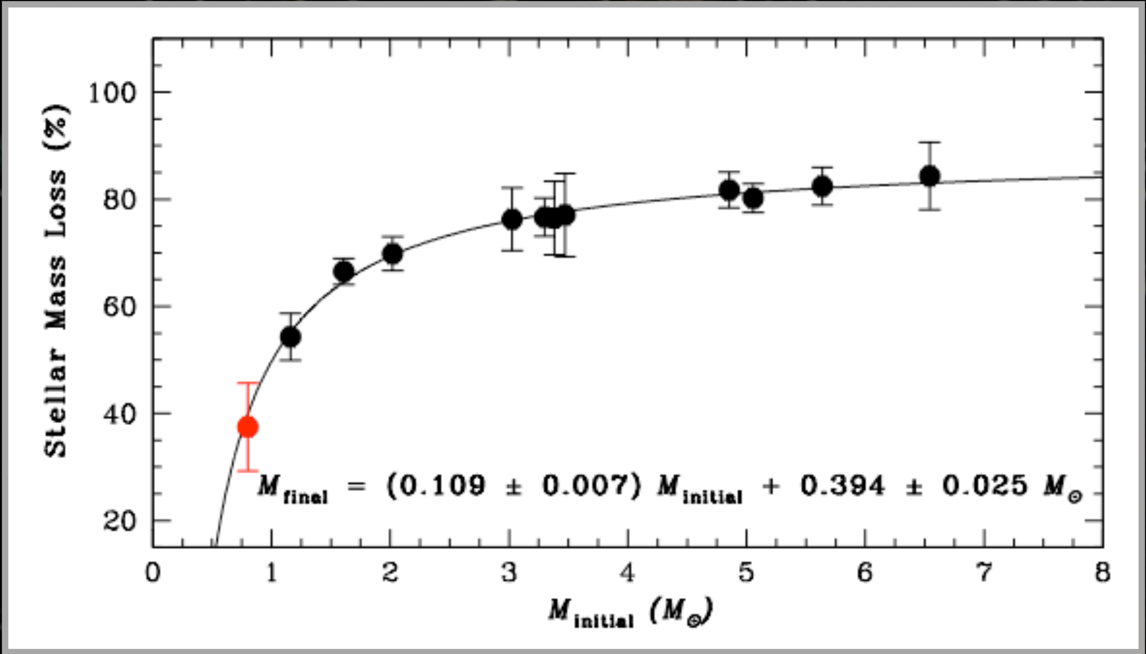
FIRST RESULTS



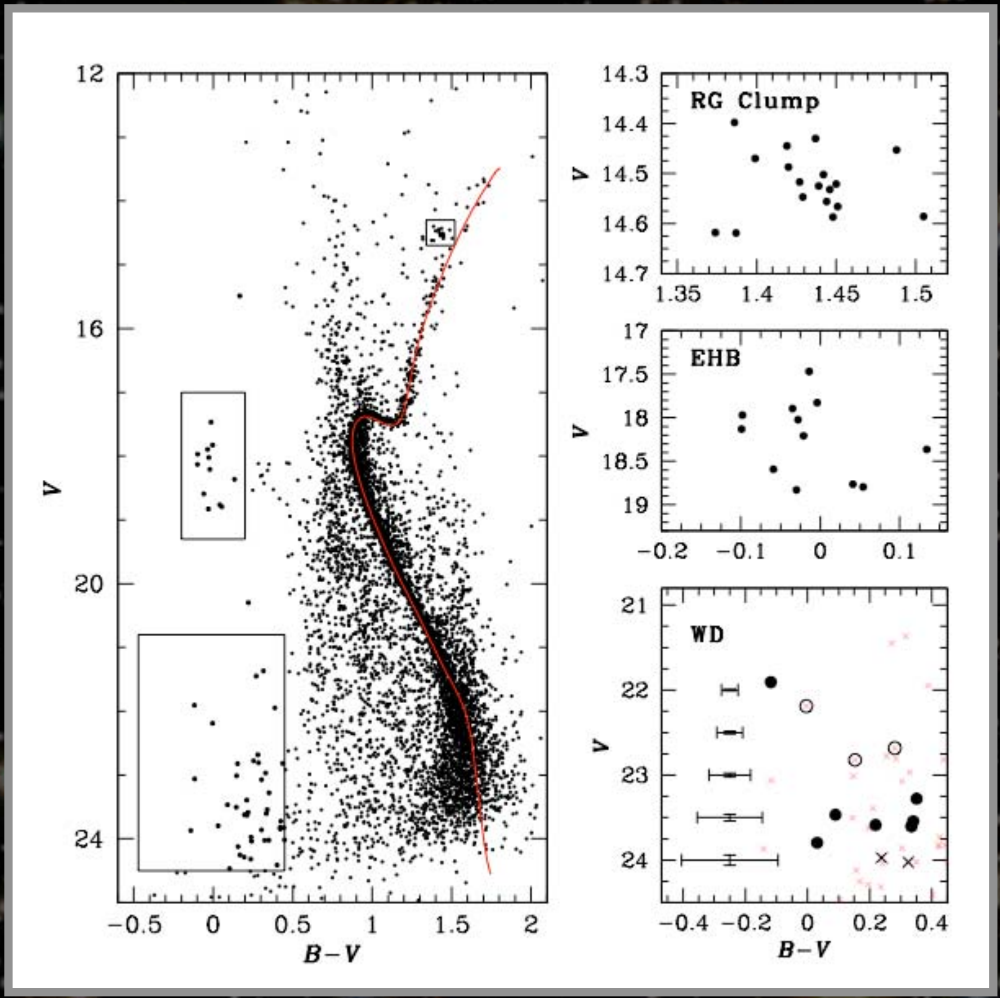
→ Z = Zsun, dM/dt = 36%

WDs in M4: $M_{final} = 0.53 +/- 0.01\ M_{sun}$ → Z = 0.001, dM/dt = 33%

Kalirai et al. (2009, ApJ, in press)

Mass Loss and the Death of Low Mass Stars

The Opposite Extreme: Stellar Evolution at High Metallicity



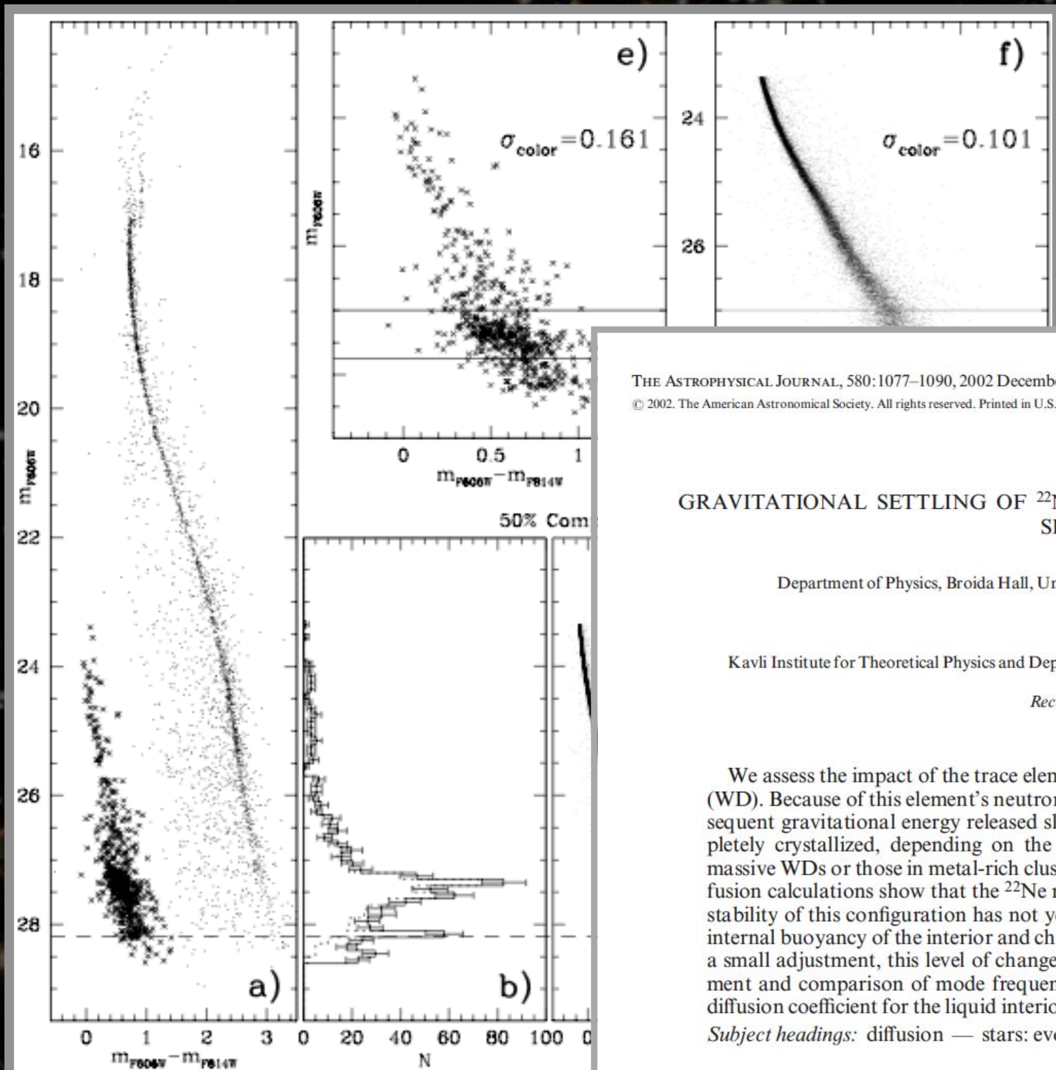
Kalirai et al. (2007, ApJ, 671, 748)

A Strange Cluster (N6791):

Age = 8 -10 Gyrs *but…*

[Fe/H] = +0.4

Mass Loss and the Death of Low Mass Stars



MS turnoff age = 8 Gyrs

WD cooling age = 2.4 Gyrs?

THE ASTROPHYSICAL JOURNAL, 580:1077–1090, 2002 December 1

GRAVITATIONAL SETTLING OF ^{22}Ne IN LIQUID WHITE DWARF INTERIORS: COOLING AND SEISMOLOGICAL EFFECTS

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Received 2002 June 26; accepted 2002 July 30

ABSTRACT

We assess the impact of the trace element ^{22}Ne on the cooling and seismology of a liquid C/O white dwarf (WD). Because of this element's neutron excess, it sinks toward the interior as the liquid WD cools. The subsequent gravitational energy released slows the cooling of the WD by 0.25–1.6 Gyr by the time it has completely crystallized, depending on the WD mass and the adopted sedimentation rate. The effects make massive WDs or those in metal-rich clusters (such as NGC 6791) appear younger than their true age. Our diffusion calculations show that the ^{22}Ne mass fraction in the crystallized core actually increases outward. The stability of this configuration has not yet been determined. In the liquid state, the settled ^{22}Ne enhances the internal buoyancy of the interior and changes the periods of the high radial order *g*-modes by ≈1%. Although a small adjustment, this level of change far exceeds the accuracy of the period measurements. A full assessment and comparison of mode frequencies for specific WDs should help constrain the still uncertain ^{22}Ne diffusion coefficient for the liquid interior.

Subject headings: diffusion — stars: evolution — stars: interiors — stars: oscillations — white dwarfs

Bedin et al. (2005, ApJL, 624, 45)

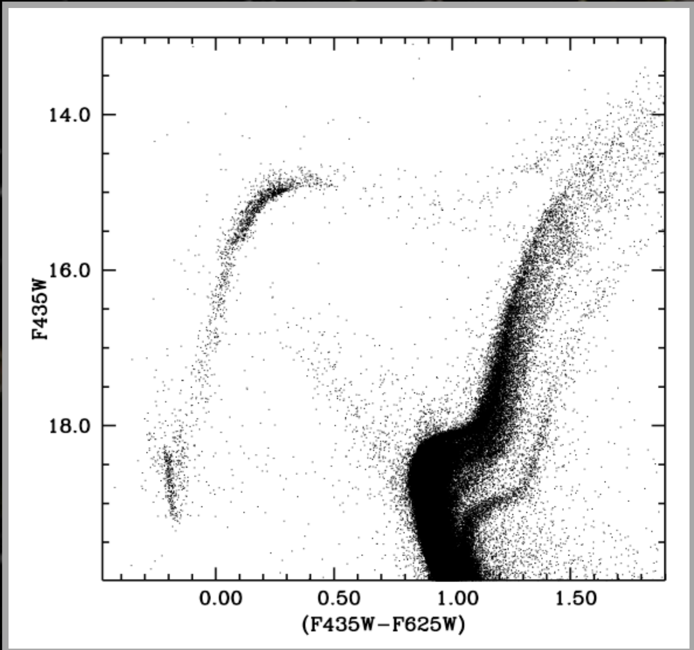
Deloye & Bildsten (2002, ApJ, 580, 1077)

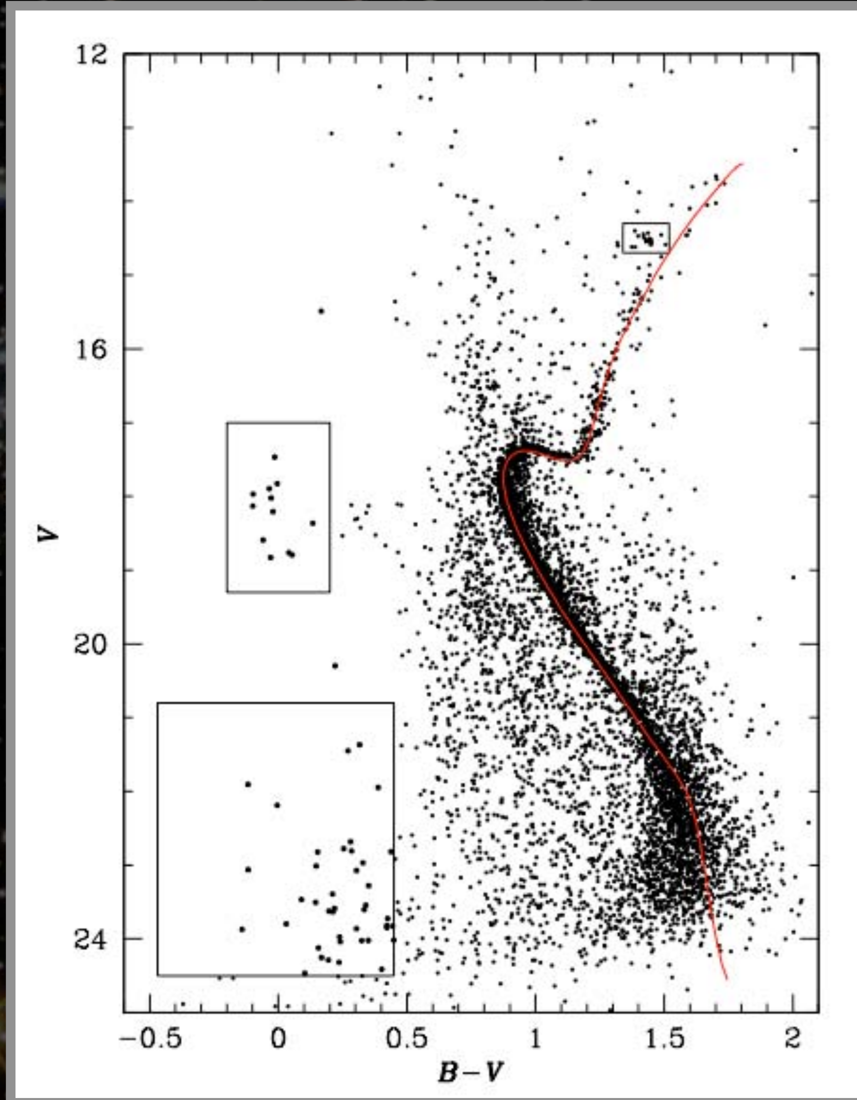
Mass Loss and the Death of Low Mass Stars

The Theory:

- Mass Loss on the RGB (Faulkner 1972; Sweigart 1987, Castellani & Castellani 1993; Hansen 2005).

Omega Cen: Cassisi et al. (2009, ApJ, in press, arXiv:0907.3550)

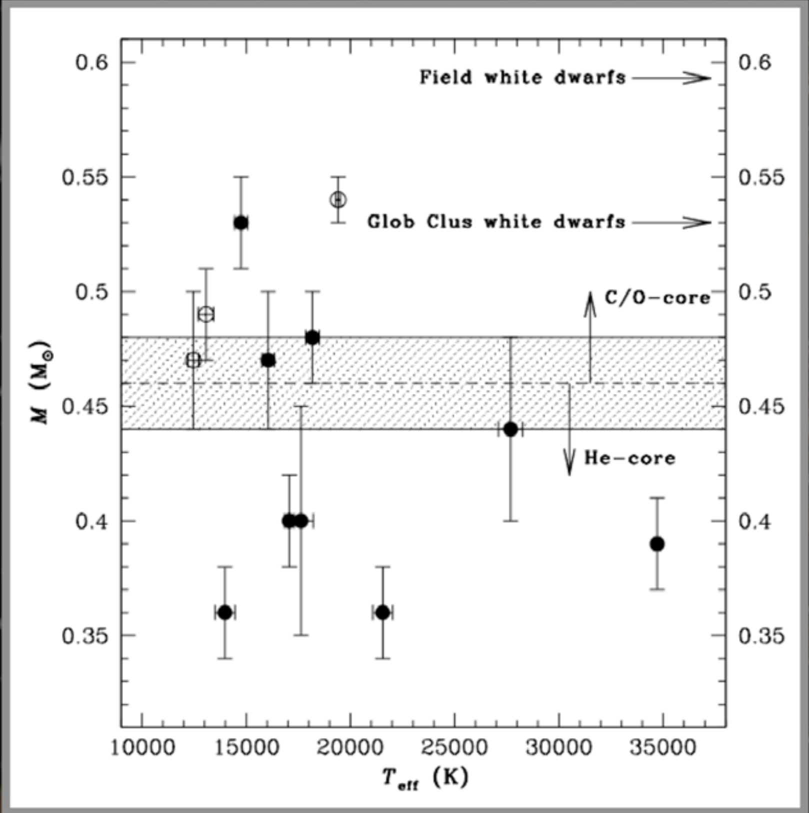




Kalirai et al. (2007, ApJ, 671, 748)

Mass Loss and the Death of Low Mass Stars

Forming He-core White Dwarfs



Kalirai et al. (2007, ApJ, 671, 748)

→ Z = 2.5Zsun, dM/dt = 55%

1.) He core WDs cool 3X slower than C/O core WDs.

2.) Stars currently on the HB will form C/O core WDs.

"Future observations of NGC 6791 may be able to confirm our picture. A deeper study of the cluster white dwarfs should also be undertaken with HST. Such observations should unveil a second peak in the white dwarf luminosity function resulting from the cooling of canonical carbon-oxygen core white dwarfs."

Mass Loss and the Death of Low Mass Stars

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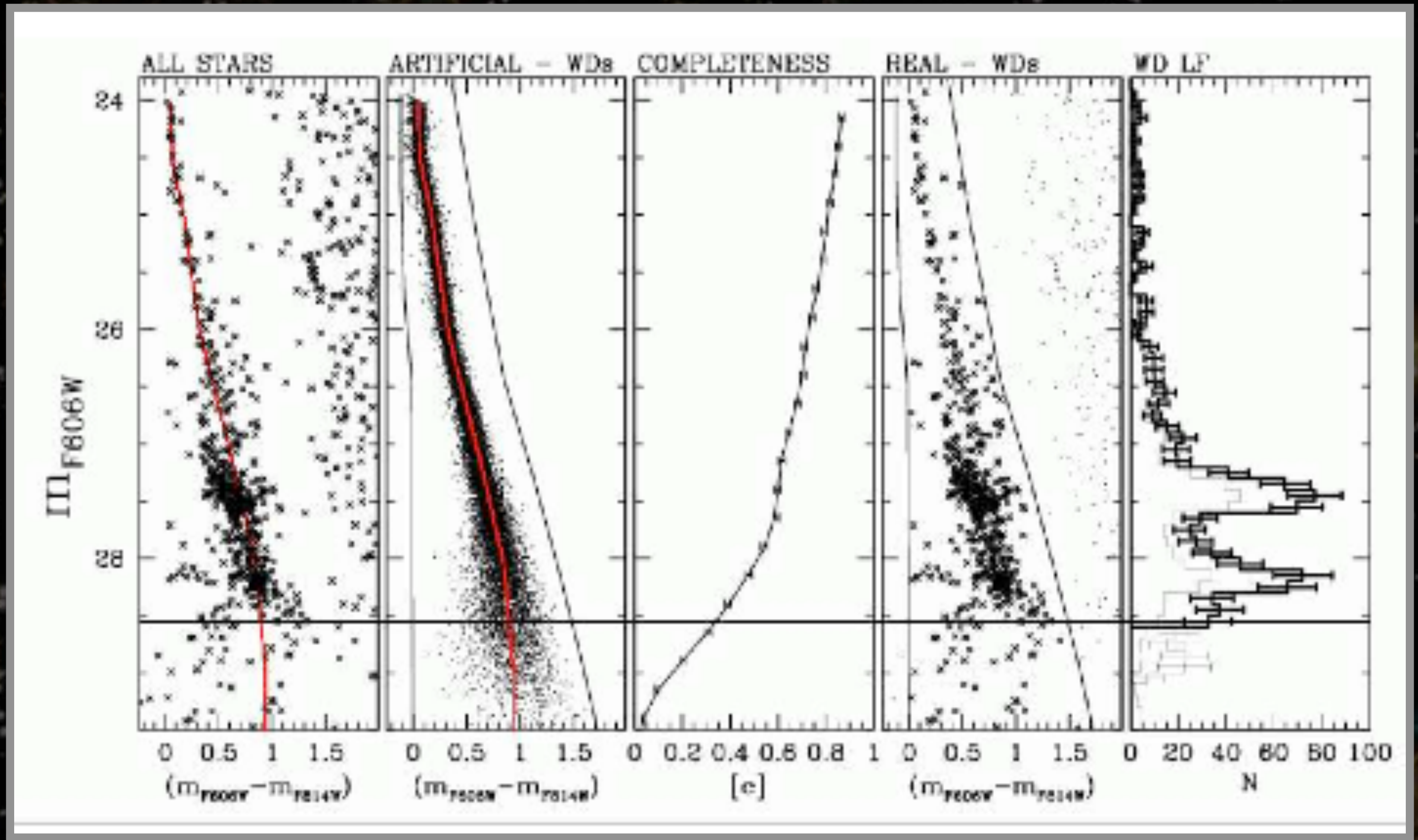

Bedin et al. (2008, ApJ, 678, 1279)

Astrophysical Implications

→ Light from distant galaxies: EHB stars as sources of the UV upturn.
  -- variable excess among galaxies.
  -- correlation with metallicity?

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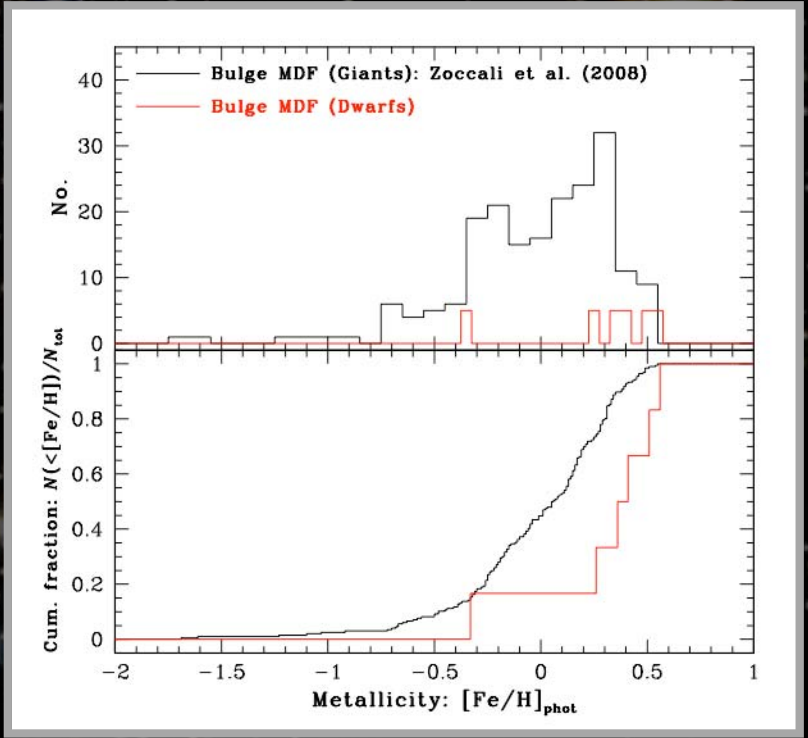
→ Milky Way Formation: Metallicity of Bulge Stars (Cohen et al. 2008; Johnson et al. 2008 + recent).



Astrophysical Implications

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→ Planets.
- currently no known planets around WDs.
- Fischer & Valenti (2005) - 25% MS stars with planets have [Fe/H] > +0.3
- 3% of MS stars with planets have -0.5 < [Fe/H] < 0.0