White Dwarfs: intrinsic properties and applications

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Discovery

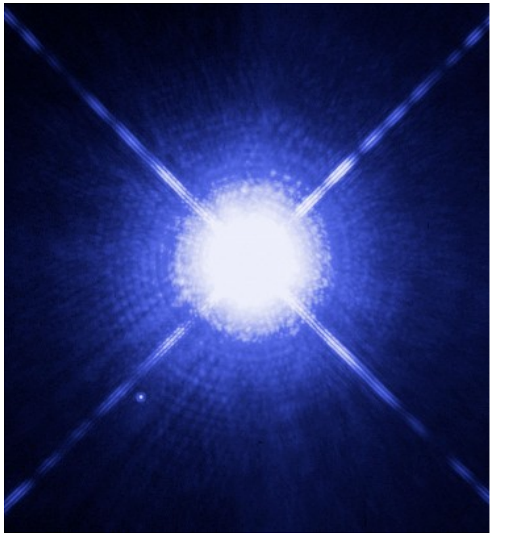
WDs were the first exotic objects discovered in the Universe

- *1783.* First WD discovered in the triple system 40 Eridani by William Hershel.

  (*1910.* Henry Norris Russell claims spectral type A despite being very dim star.)

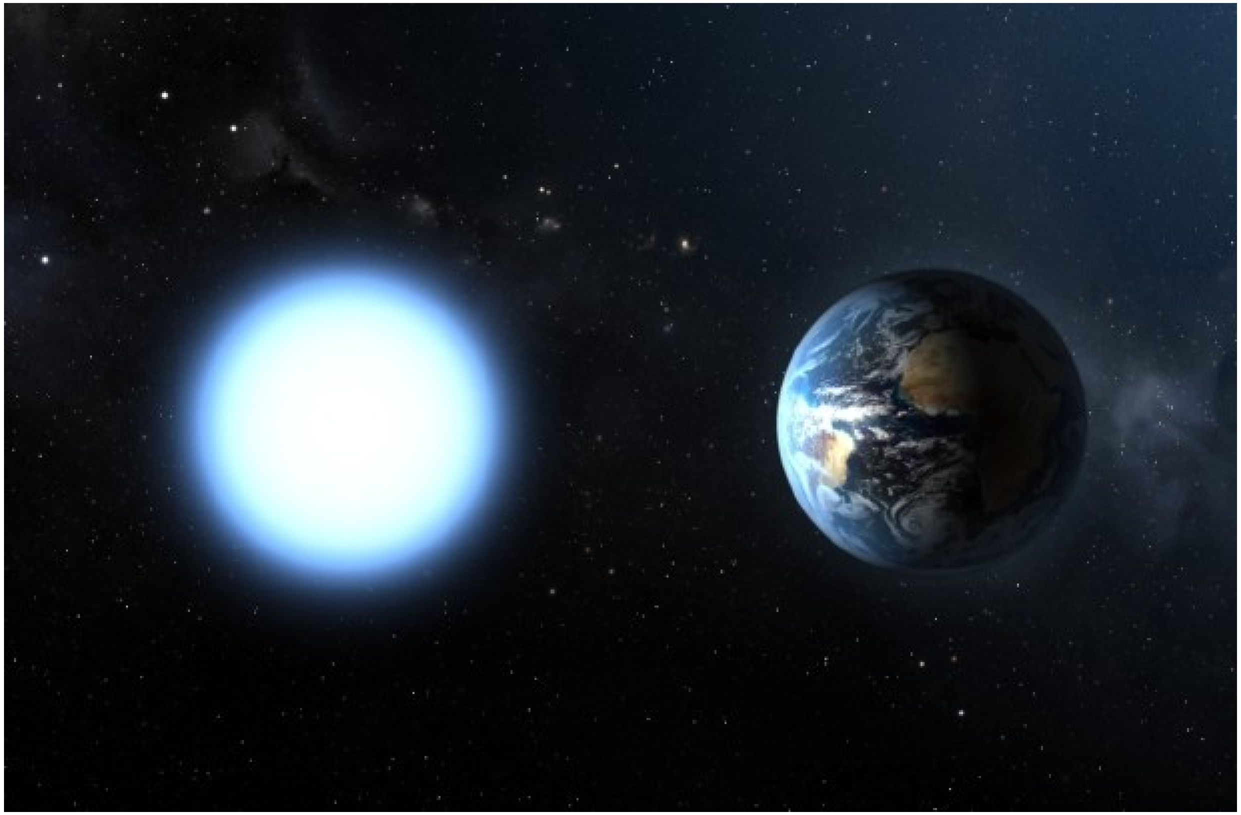
- *1862.* Second WD discovered as a companion of Sirius A.

  (*1915*. Walter Adams claims the spectra of Sirius A and B are very similar)



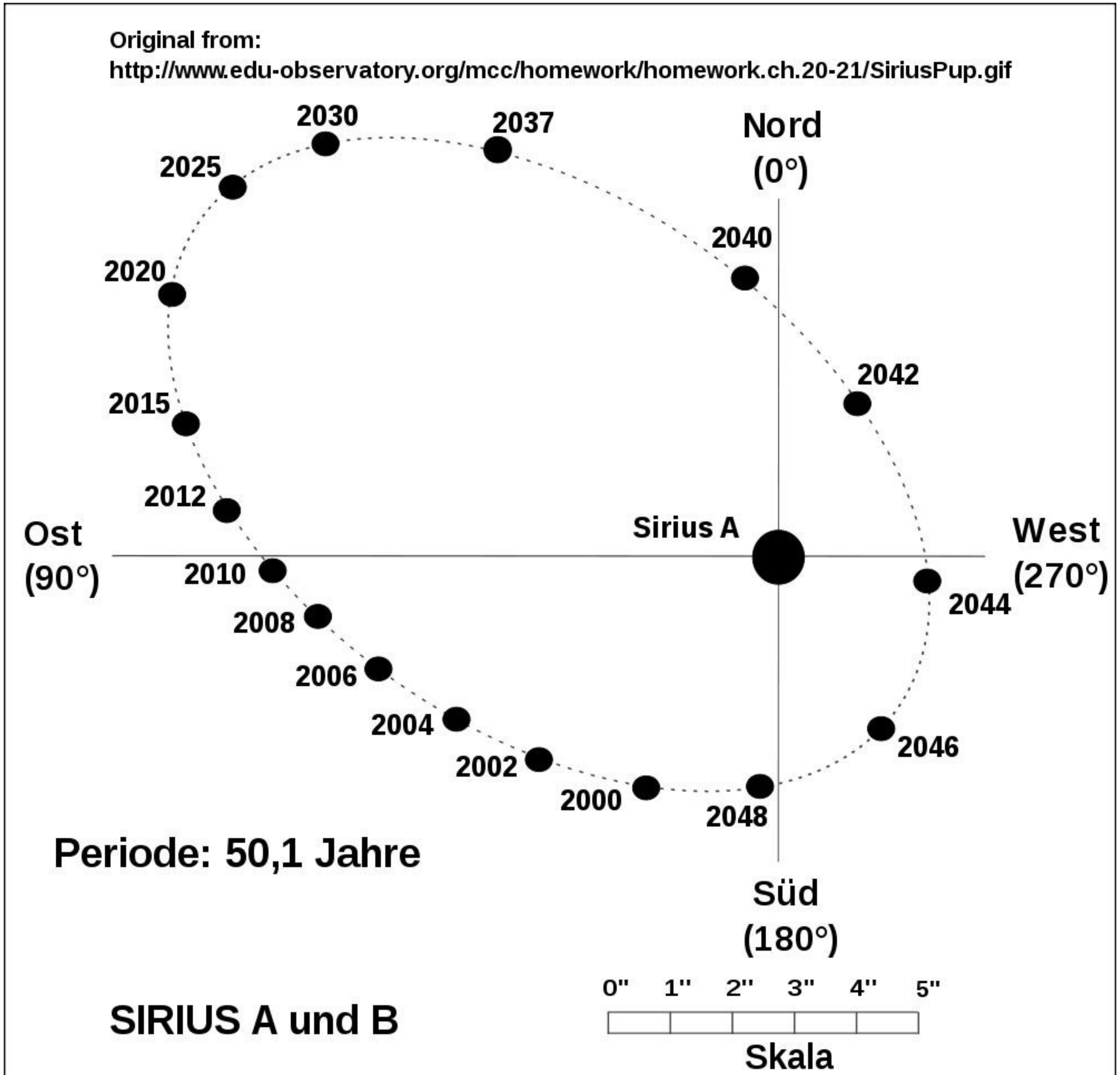
HST image

Discovery



Bluish and small Object → White Dwarf
(*1922.* Willem Luyten)

Discovery



Sirius B has a mass of ~1Msun!

But...

Colours are similar
Sp are similar
1/10 of the radius
10,000 fainter

Extremely dense!
Puzzling...

Properties

- WDs were not understood until *1926*.

  1) Quantum mechanics → at high density two e- cannot ocuppy the same state (Pauli's principle)

  ↓

  e- are degenerate

  2) Compression increases number e- in a given volume

  ↓

  pressure (of degenerate e-) balances gravitational collapse

Properties

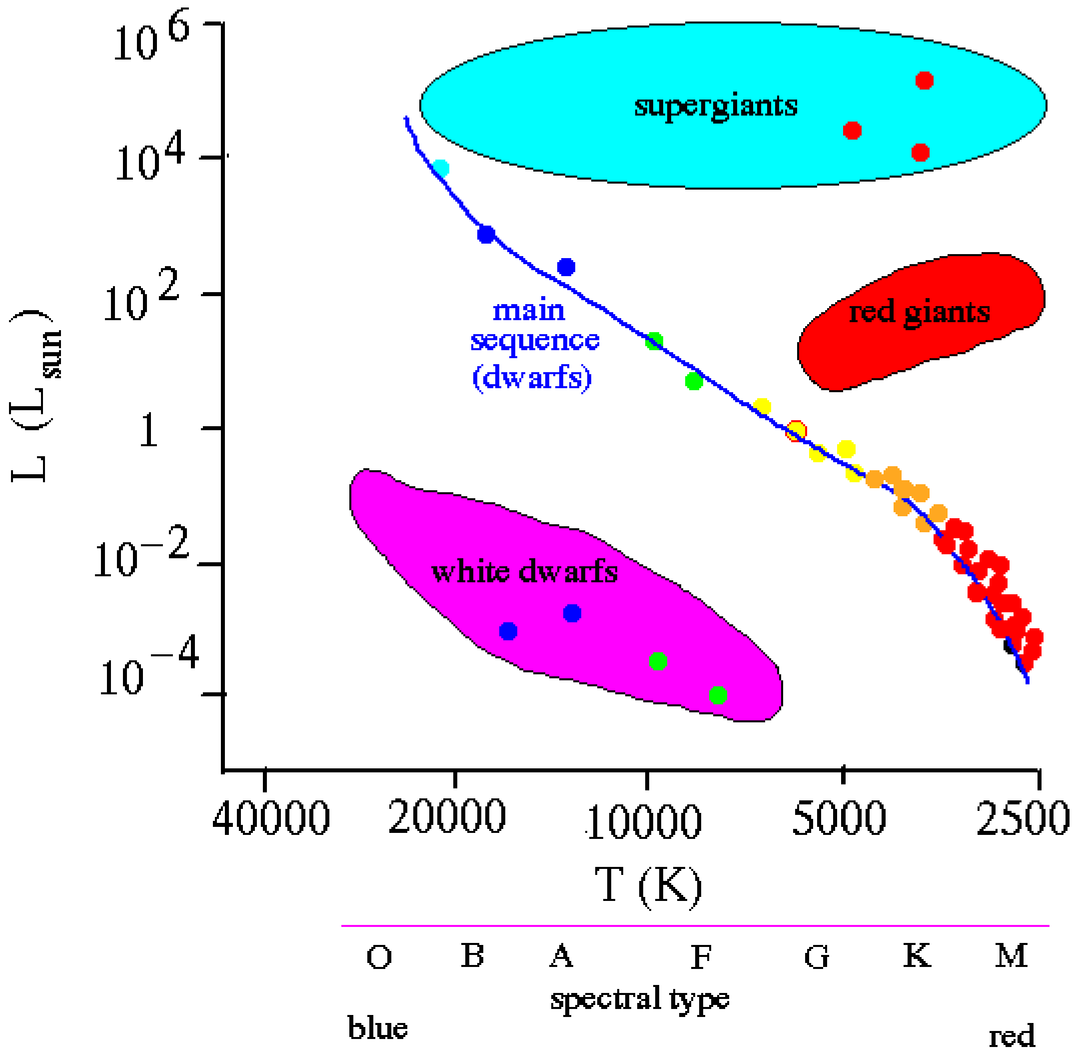
- WDs → electrons are degenerate:

  1) Gravitational collapse supported by the pressure of degenerate electrons

  2) Chandrasekhar mass limit → type Ia supernova

  3) Radius decreases with mass

But what are WDs really?



Giant's core → WD

↓

small → low L

but hot → Sp ~ A

Evolution driven by their cooling

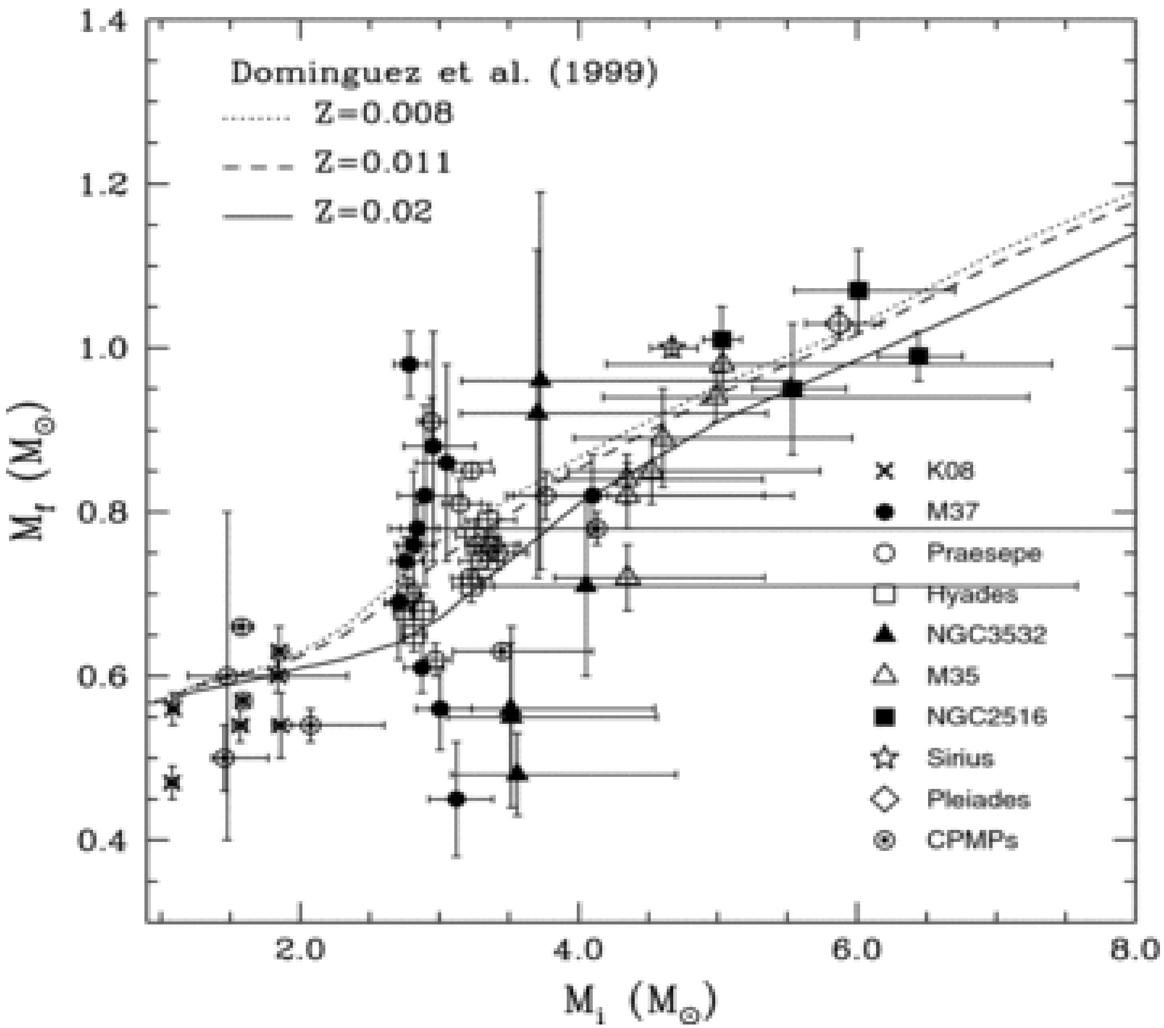
- WDs are stellar remnants → most common stars in the sky

Finding WDs

- Early proper motion searches → ~100 WDs by 1950
- McCook & Sion catalogue → ~600 WDs by 1977

  (spectroscopic observations by several 'active groups')
- First surveys (e.g. P. Green, KISO, Hamburg, Edinburgh, and many more) → ~2,200 WDs by 1999
- SDSS → ~30,000 WDs to date (DR10)
- LAMOST → ~1,000 currently identified (DR2)
- The ~40 pc local (unbiased) sample → ~500 WDs (~70% complete)
- Gaia → ~400,000

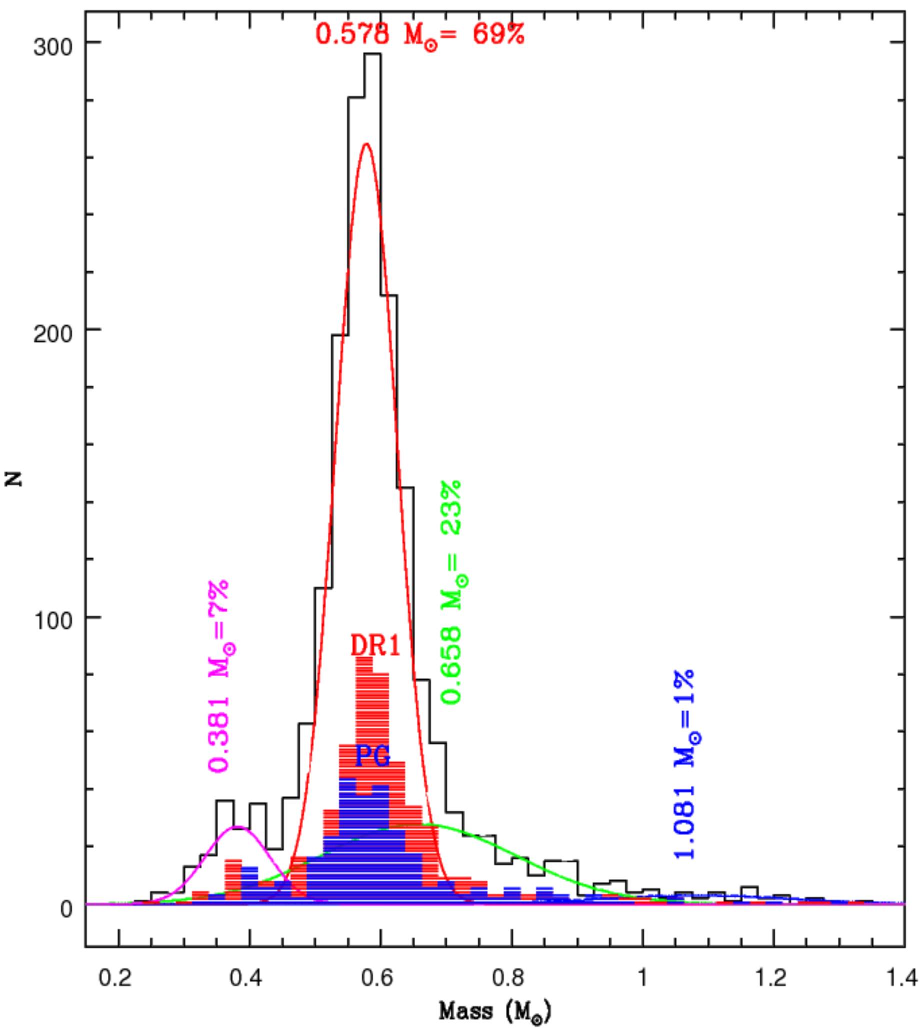
The WD mass distribution



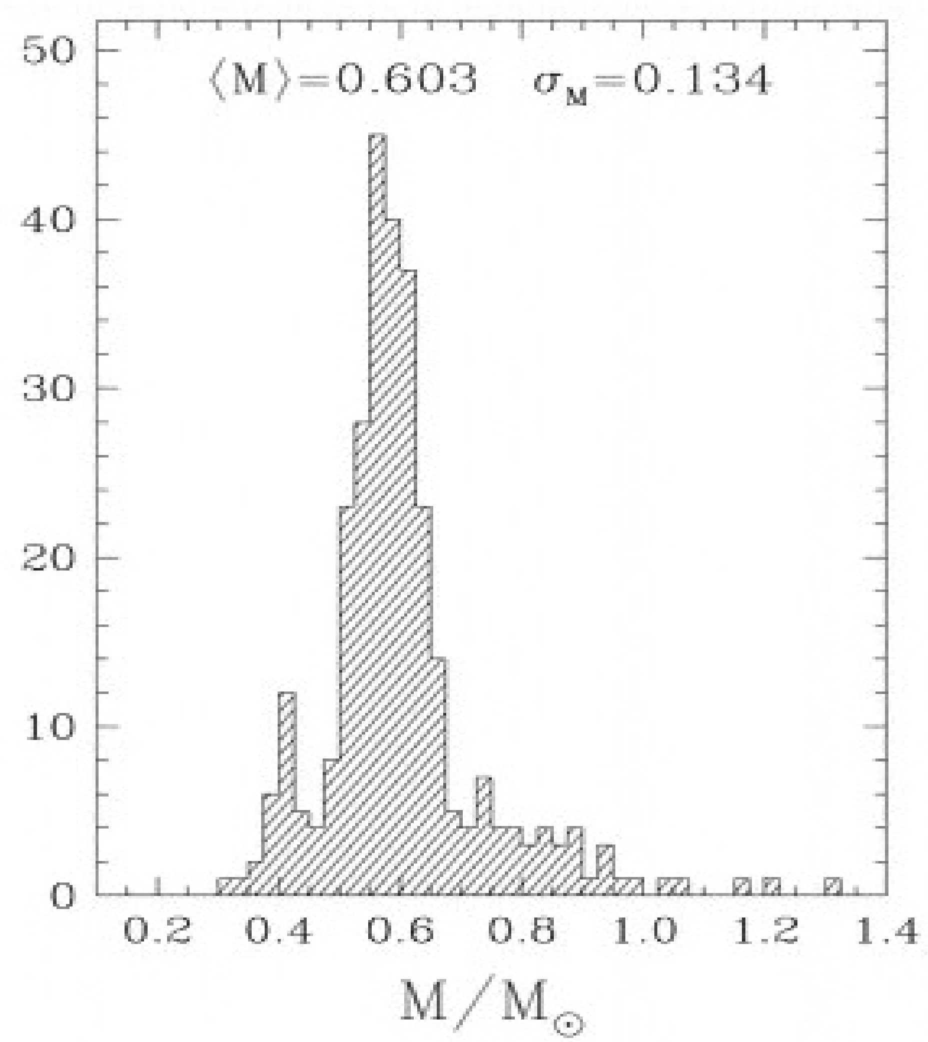
IFMR
Catalan et al. (2008)

G | F | A | B

The WD mass distribution

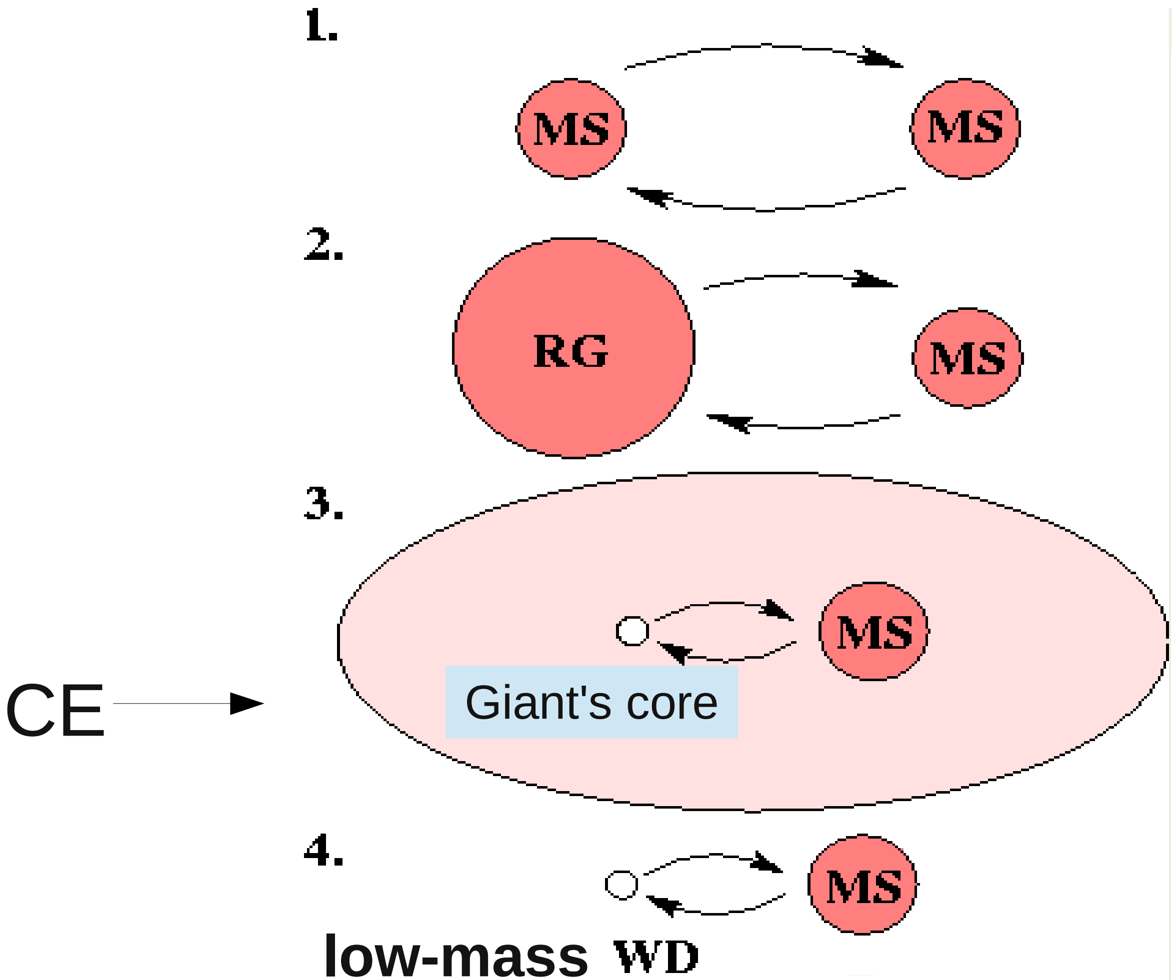


Kepler et al. (2007) for ~1,900 SDSS DR4 WDs



Liebert et al. (2005) for ~300 PG WDs

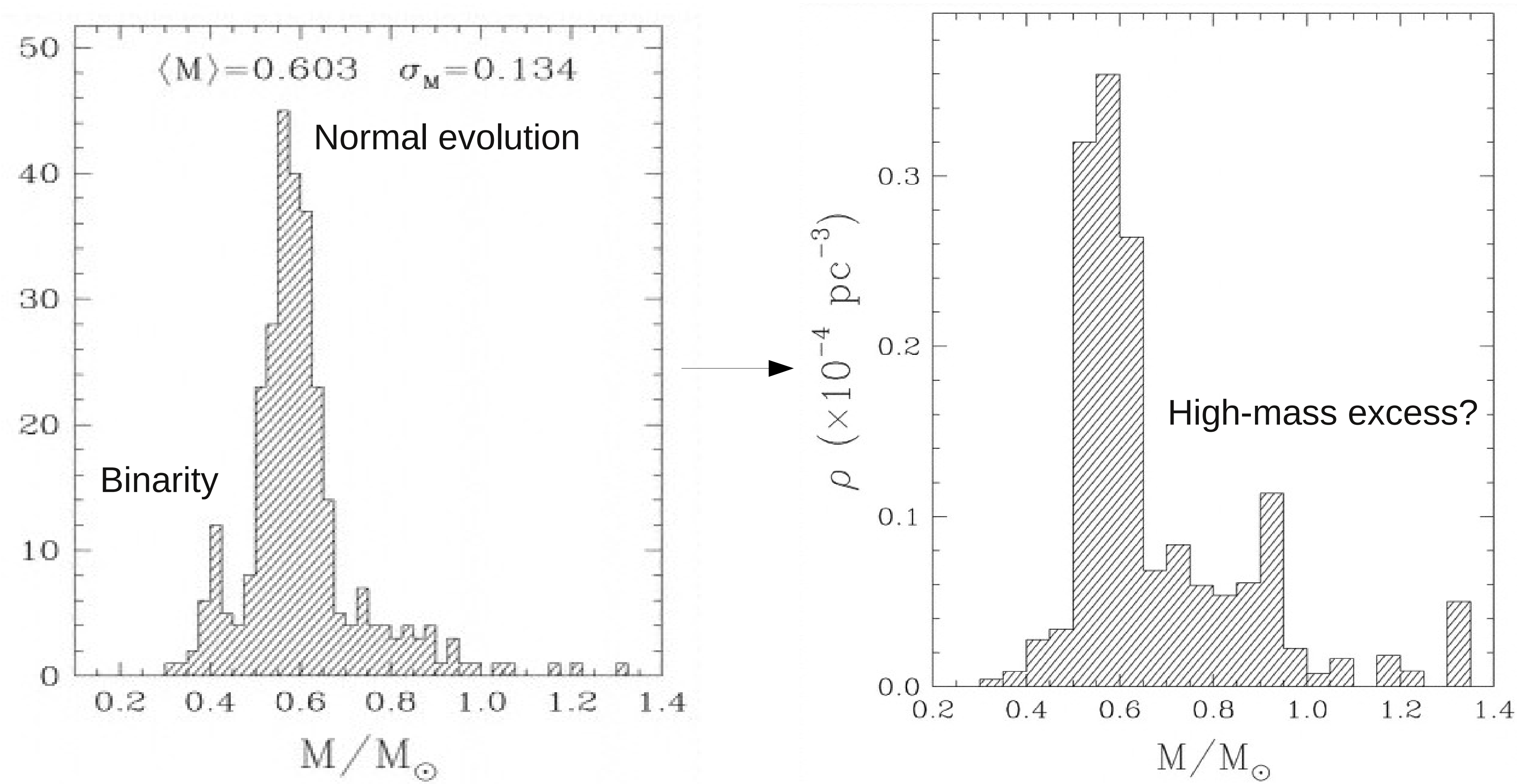
(The origin of low-mass WDs)



Marsh et al (1995), Maxted et al. (2001), Reb-Mans et al (2011), Kilic et al. (2012)

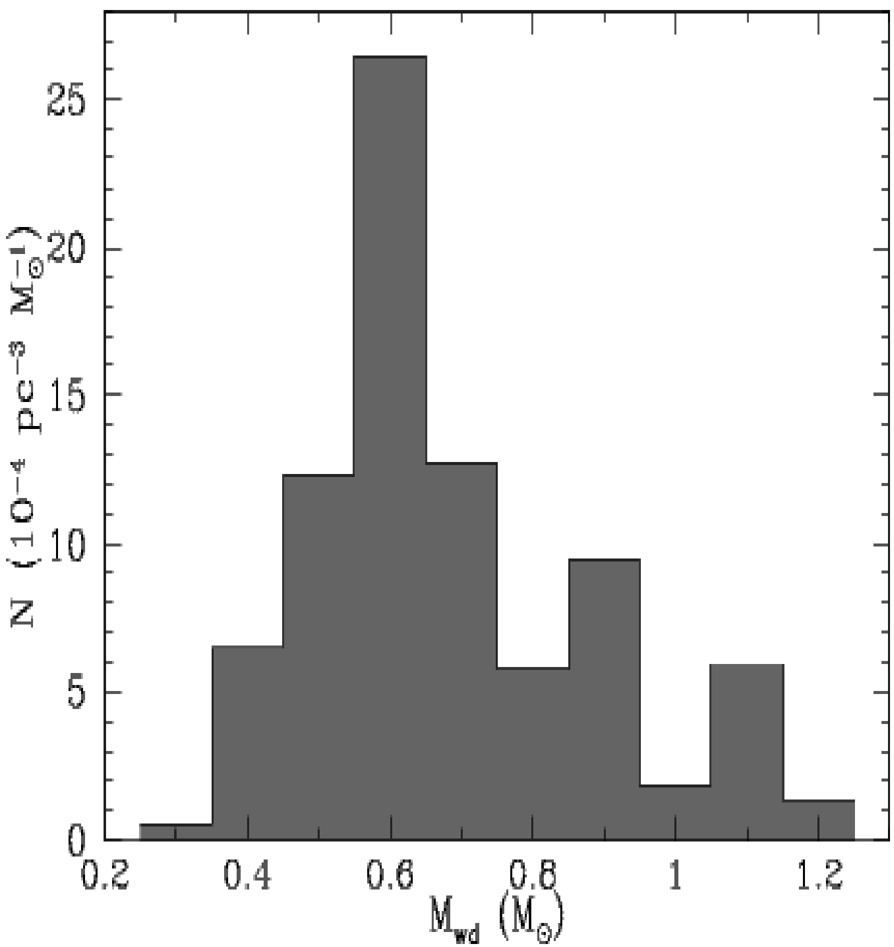
~90% of all low-mass WDs are formed in binaries

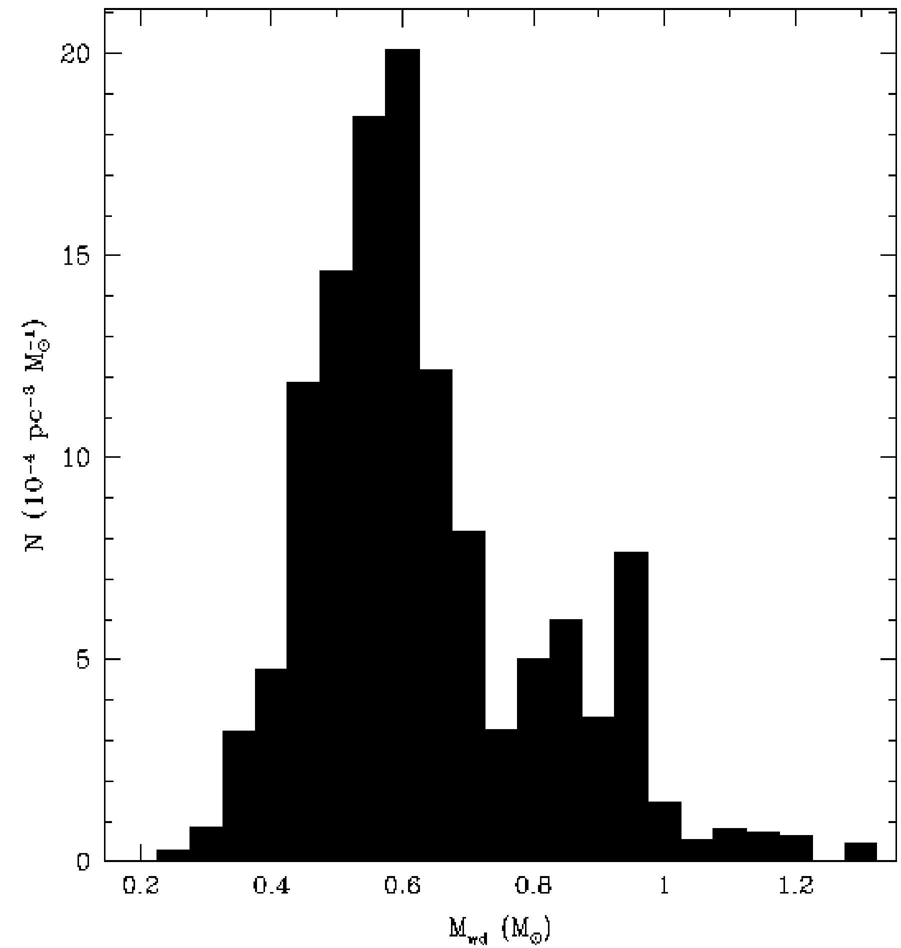
The WD mass function



Liebert et al. (2005) for PG WDs

Is the high-mass excess real?

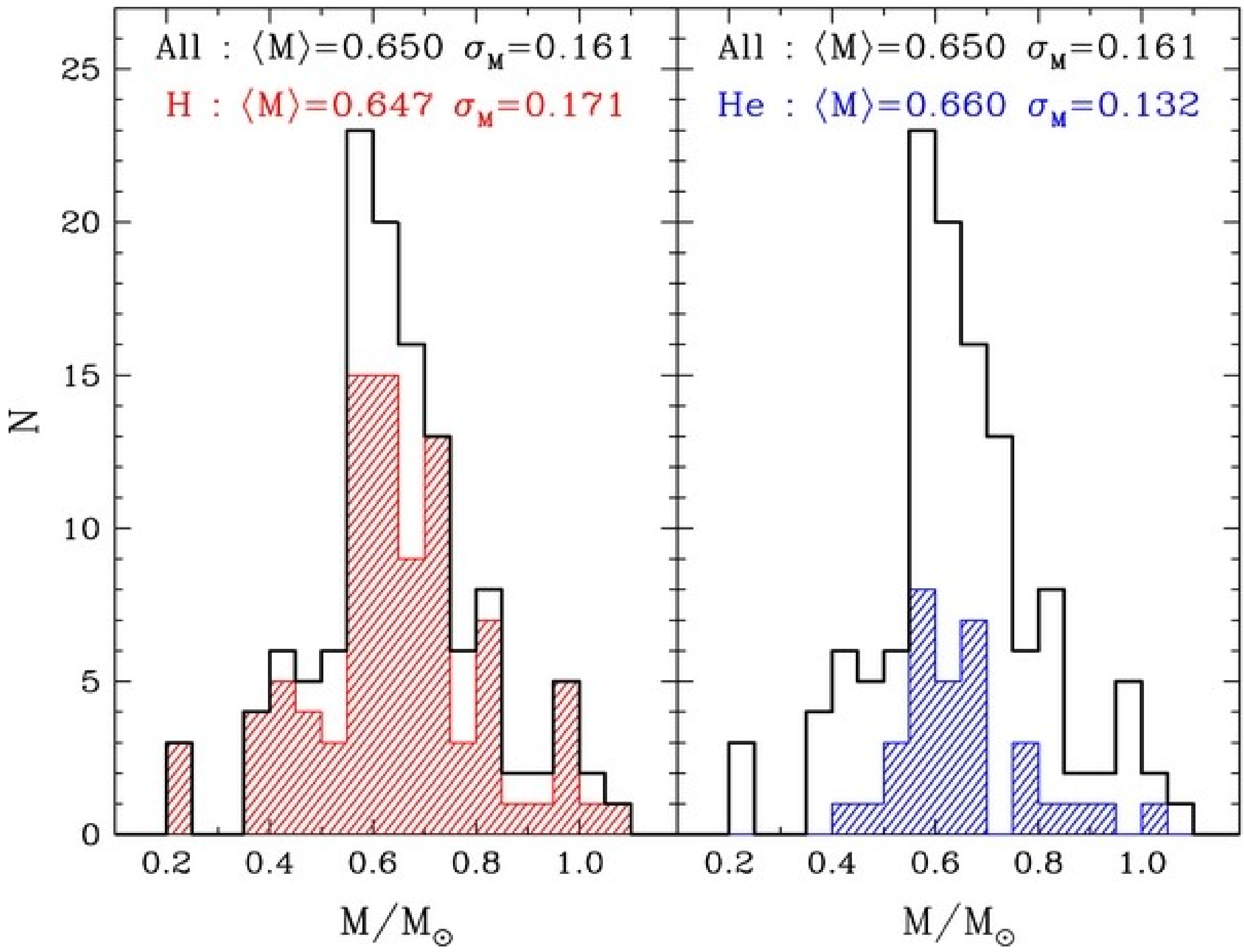




Reb-Mans et al. (2015a) for ~80 LSS-GAC DR1 WDs

Reb-Mans (2015b) sub. for ~5000 SDSS DR 10 WDs

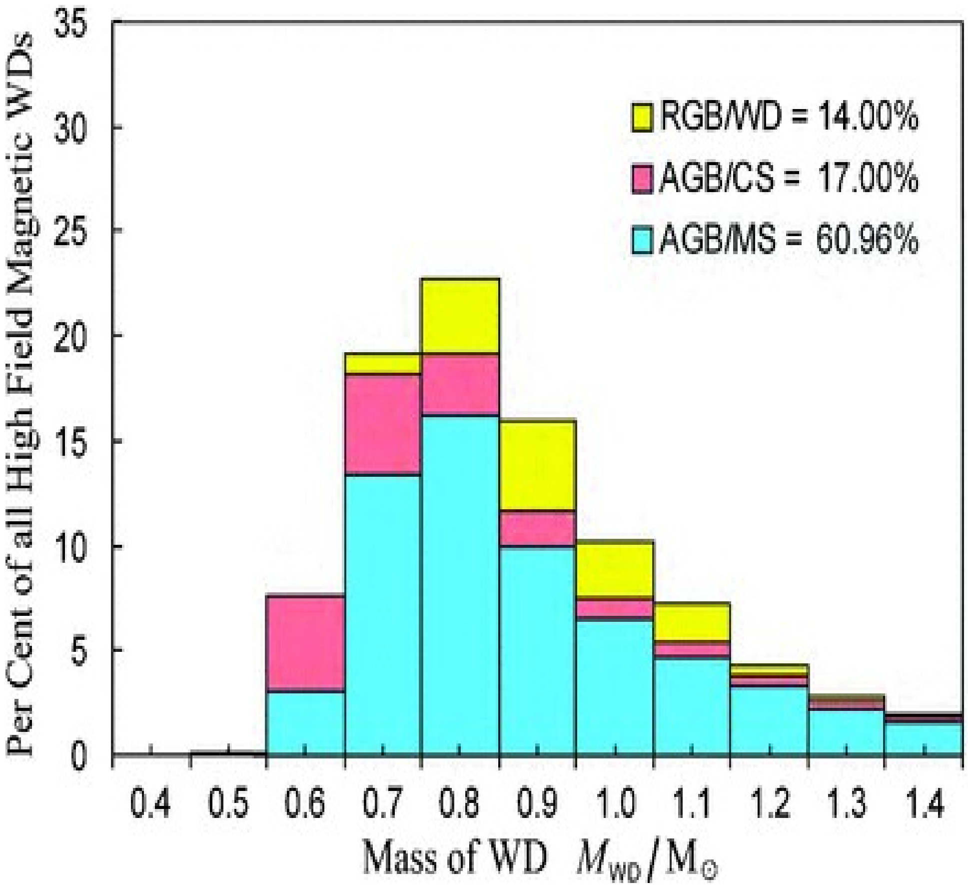
Is the high-mass excess real?



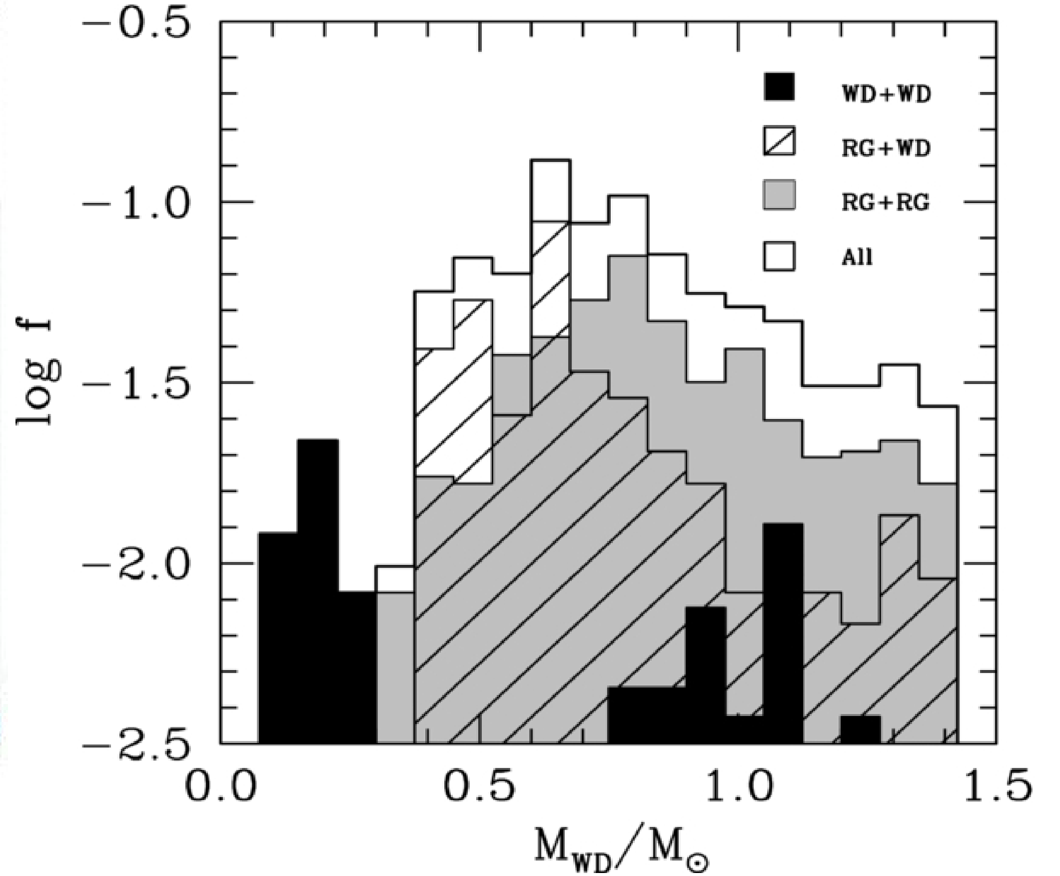
WD+WD
Mergers?

Giammichele et al. (2012) for the ~20 pc local volume-limited sample

The origin of the high-mass excess



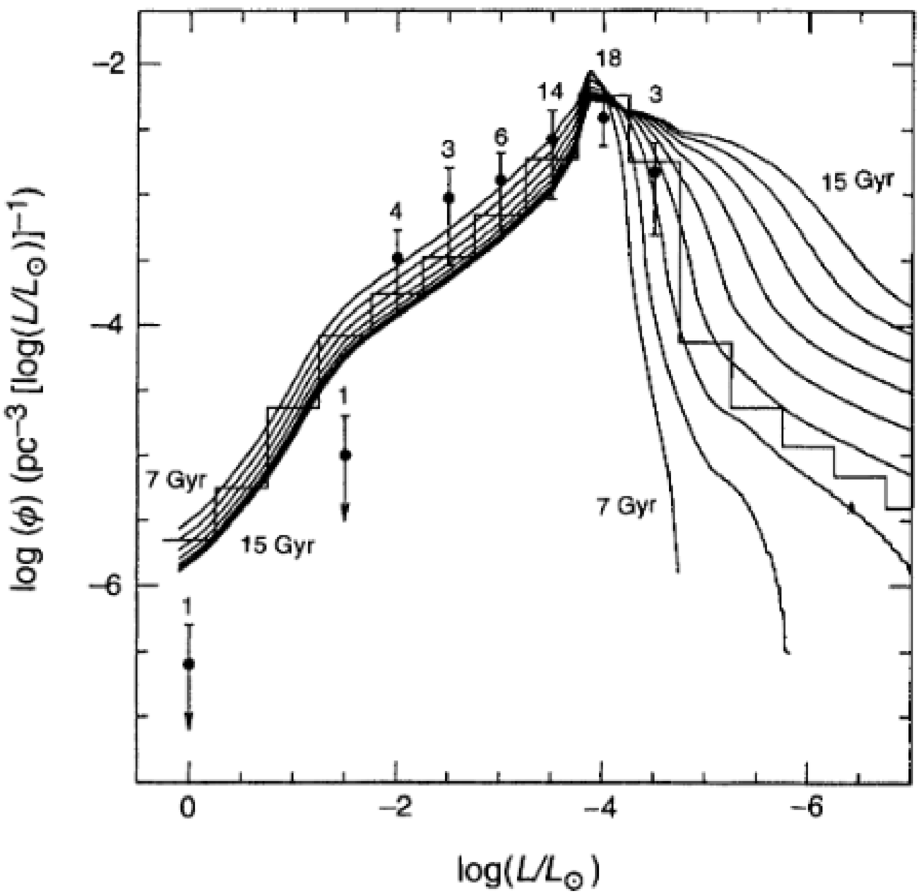
Briggs et al. (2015)

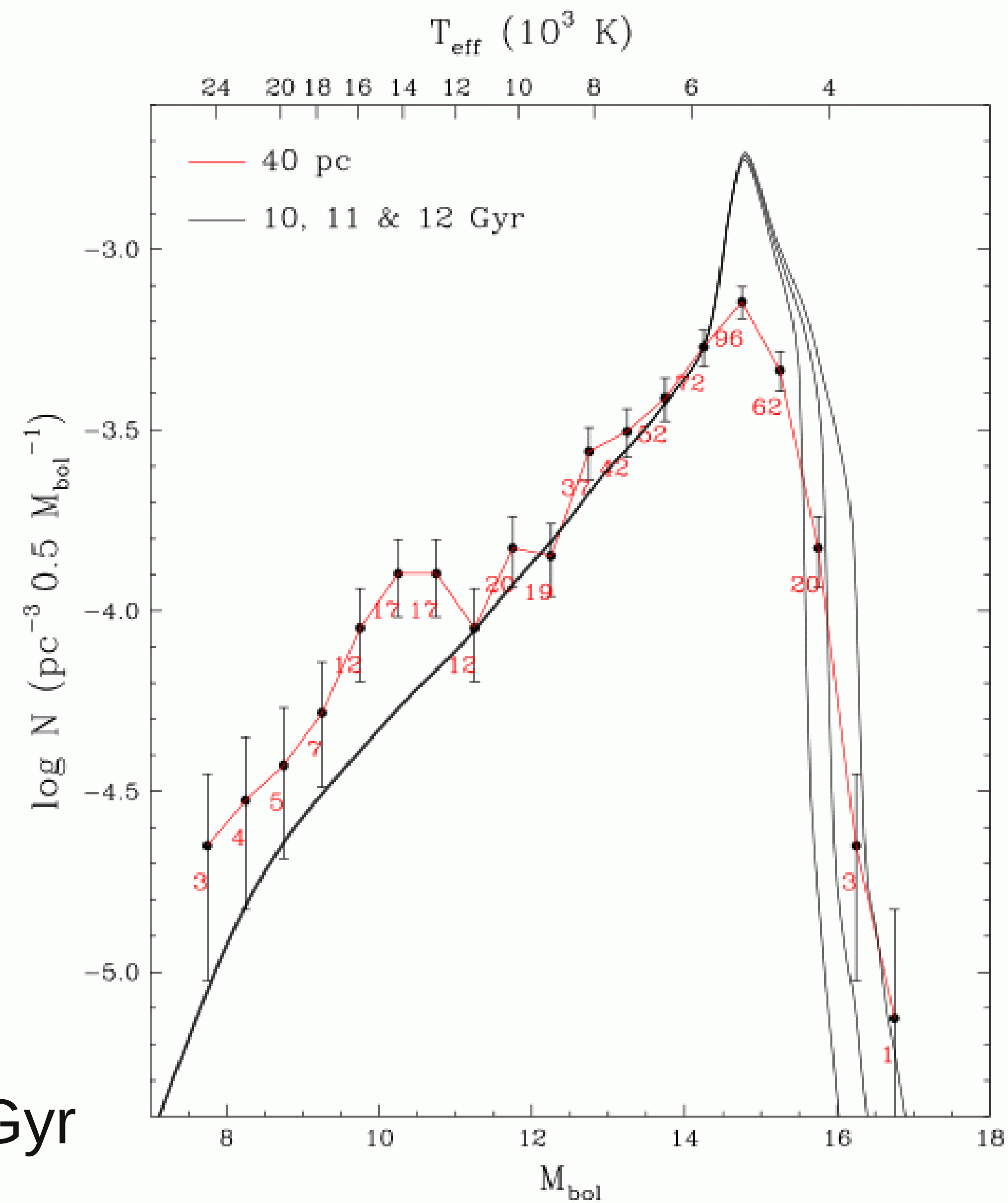


Garcia-Berro et al. (2012)

High-mass excess likely due to megers of giant star +WD or MS

The age of the Galactic disc

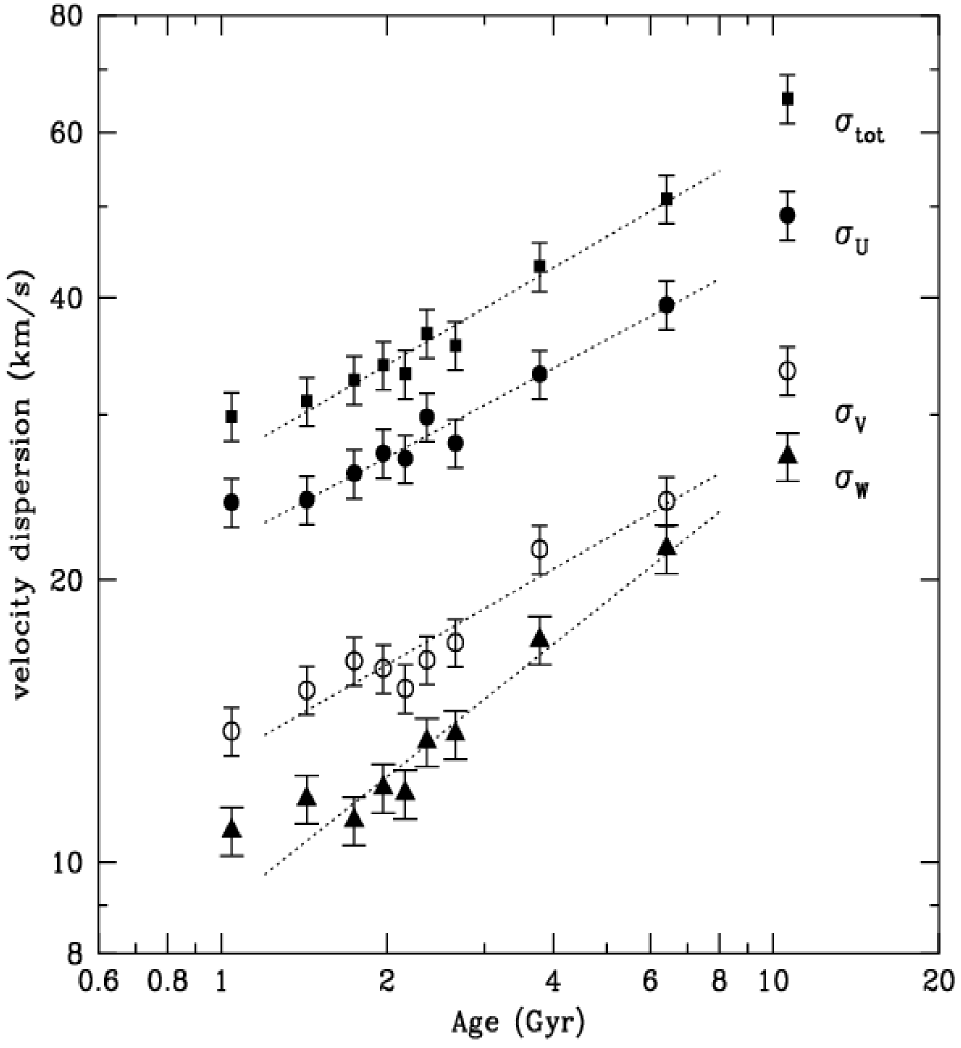




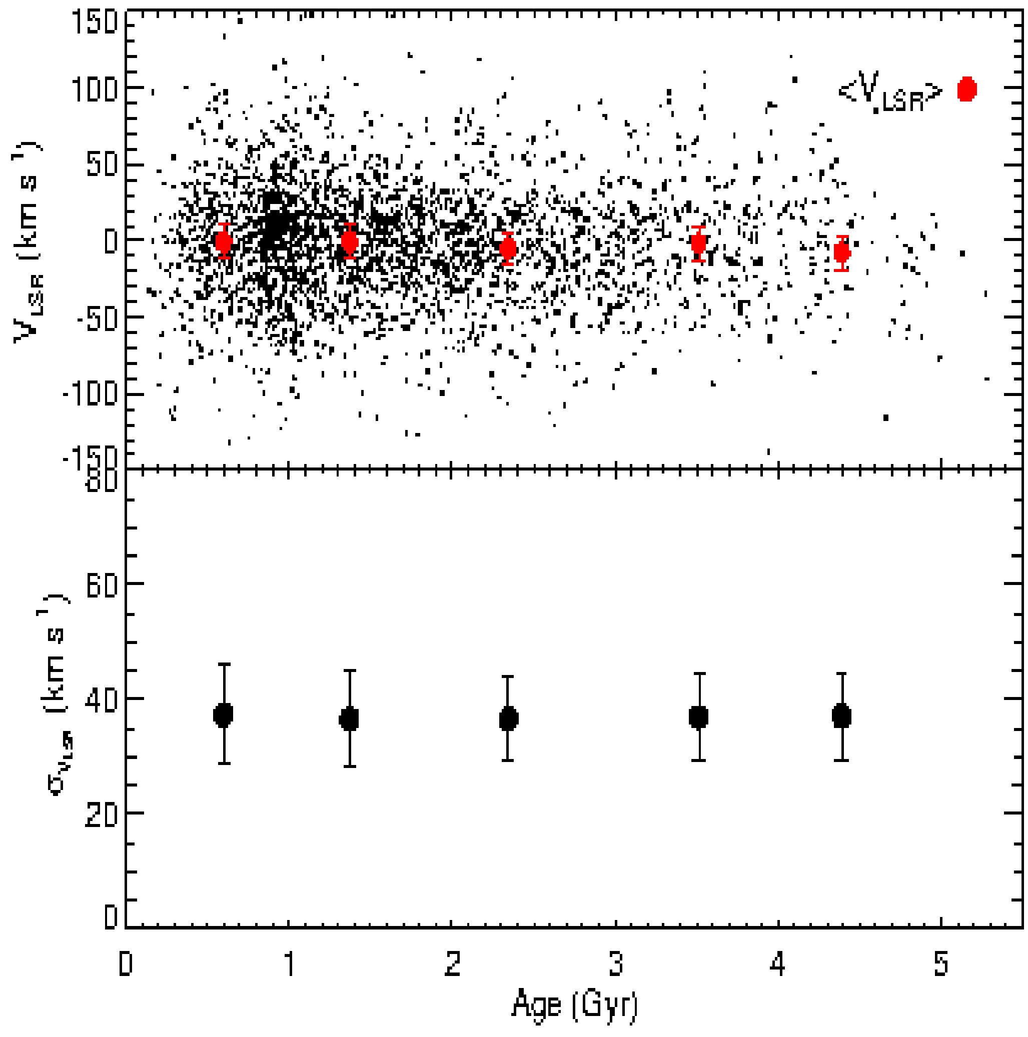
Oswalt et al (1996) → >9.5 Gyr

Limoges et al (2015) → 10-12 Gyr

The Age-σ vel relation

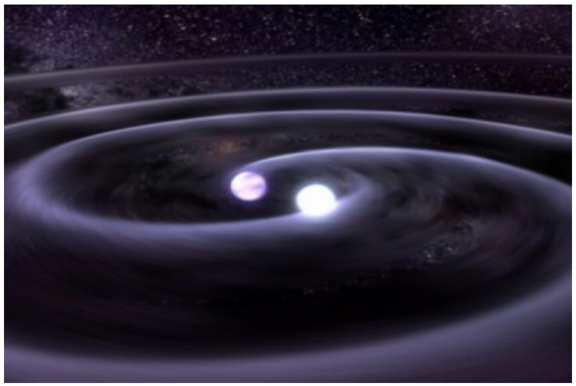


Nordstrom et al. (2004)



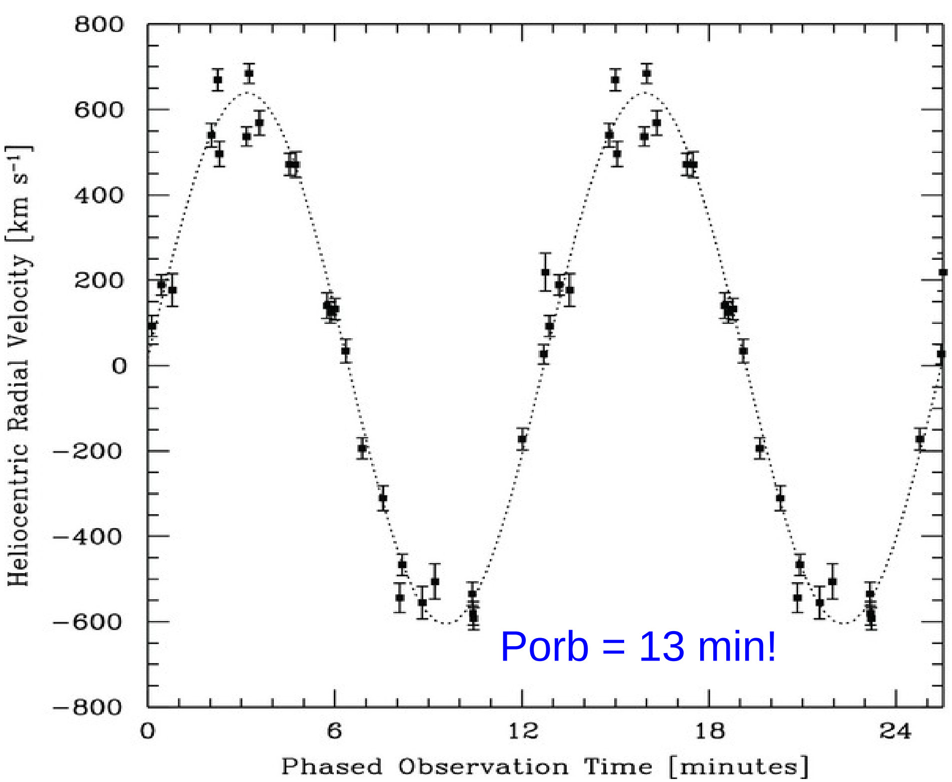
~2000 SDSS WDs

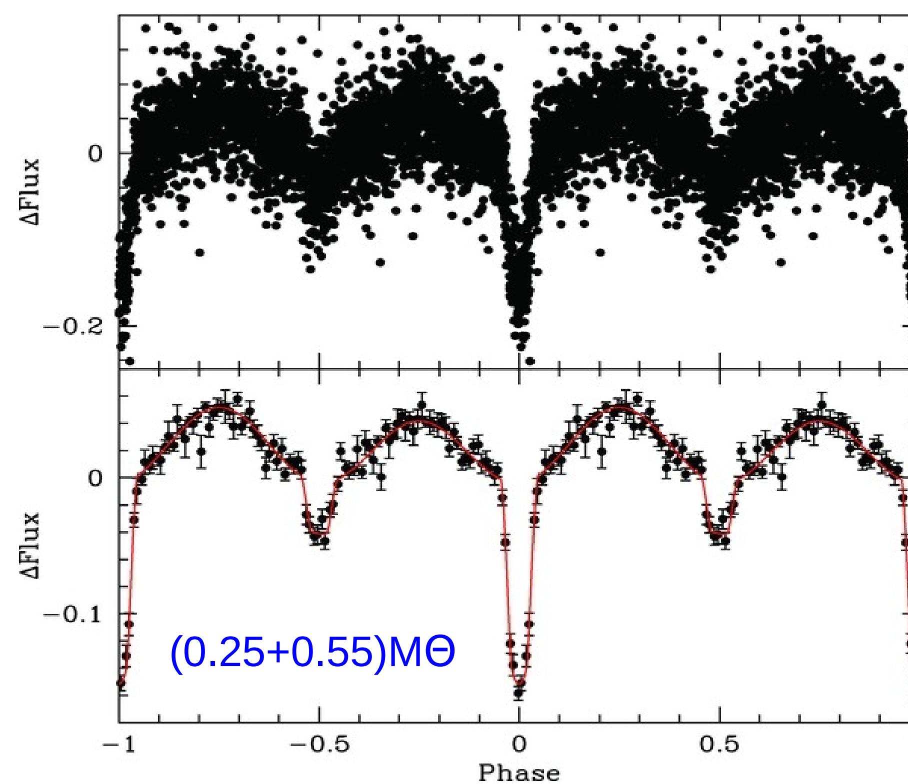
Gravitational Waves



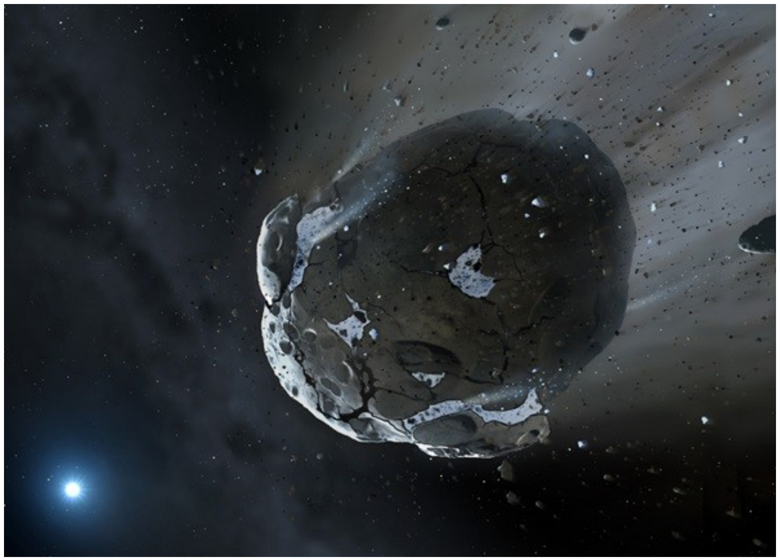
Merge in 0.9 Myr
Cleanest GW source
Change in Porb → Test General Relativity

Brown et al. (2011)



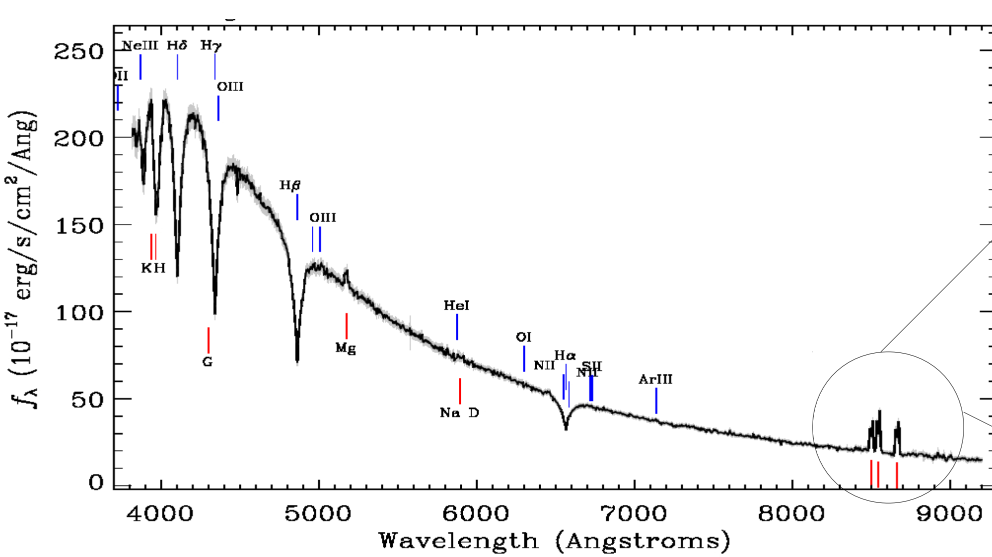


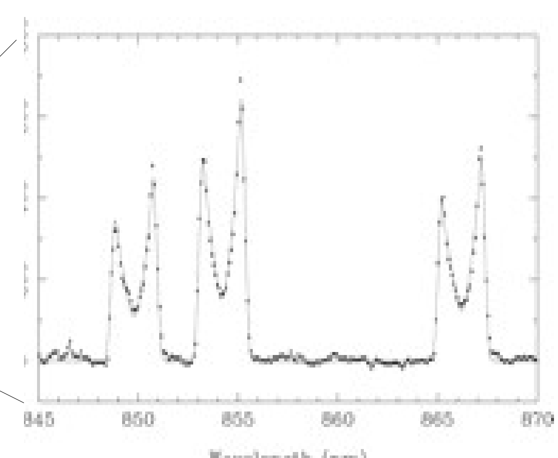
Debris Disks



Disrupted → Planetesimals

Zuckermann & Becklin (1987)

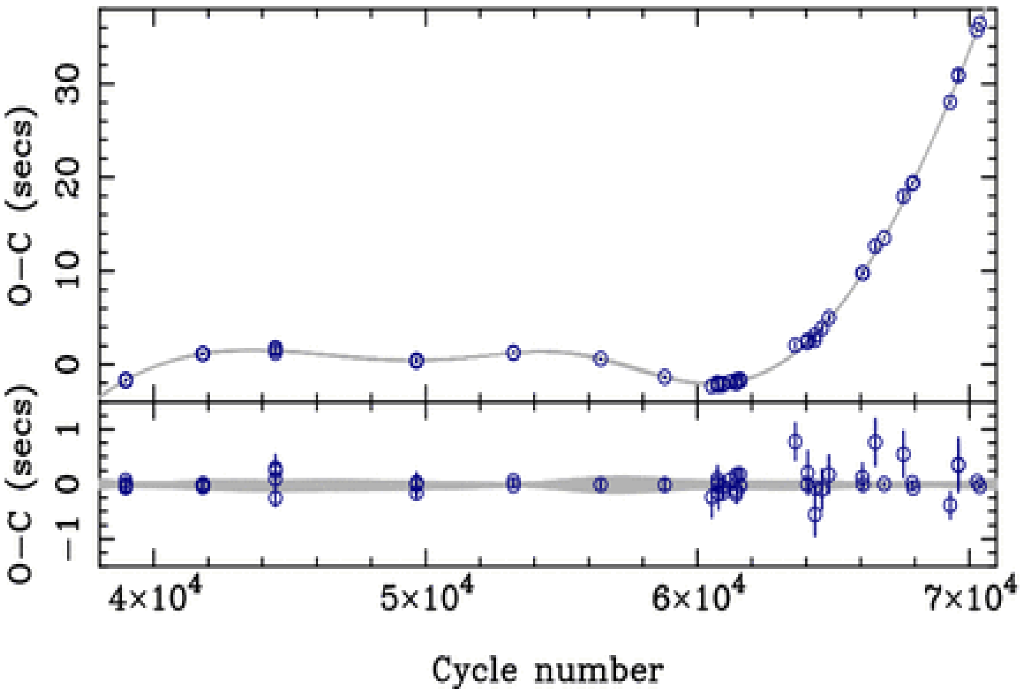




Rotating Gaseous disk

Gaensicke et al. (2006)

Planets around PCEBs

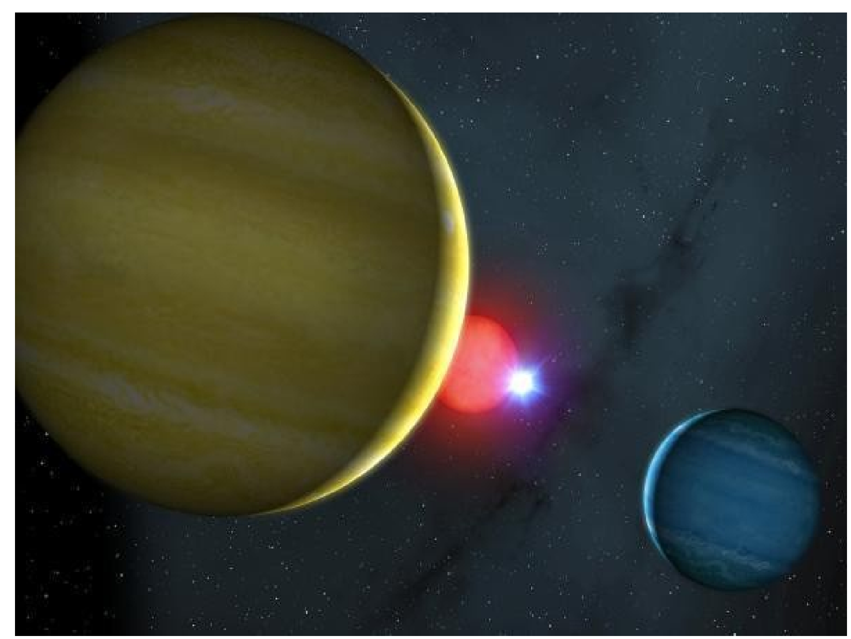


Beuermann et al. (2010)
Marsh et al. (2014)

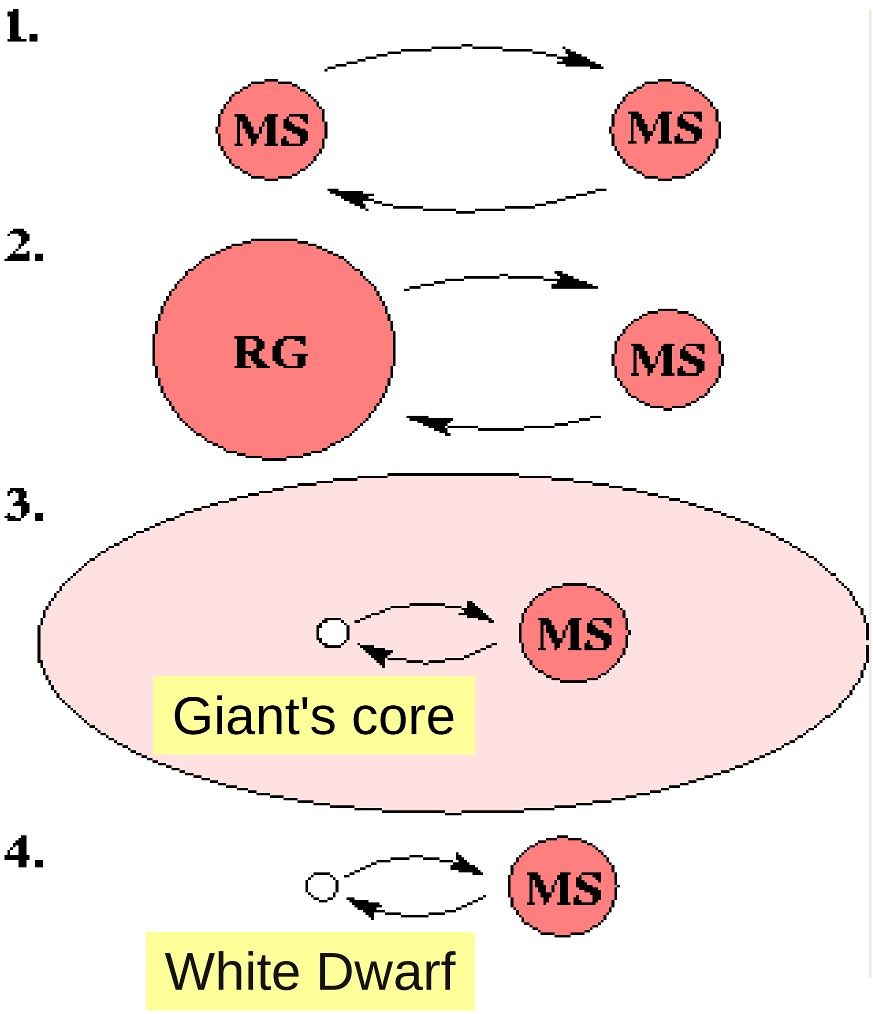
NN Serpentis
WD+MS + 2 circumbinary giant planets

Survived common envelope phase?
Second generation planets?

Zorotovic et al. (2013)
Bear+Soker (2014)



Close Compact Binaries + SN Ia progenitors



Common Envelope Efficiency

$$Eenv = \alpha \Delta Egr$$

Packzynski (1976), Webbink (2008)

Common Envelope:

- Not well understood
- Lacks observational constraints

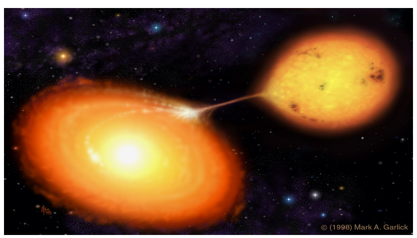
PCEB = close WD + MS

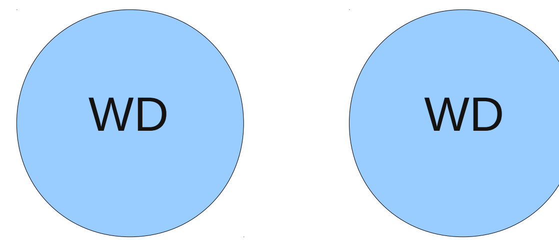
Close Compact Binaries + SN Ia progenitors

PCEB

Angular momentum loss

Second common envelope





CV
SSS

DD

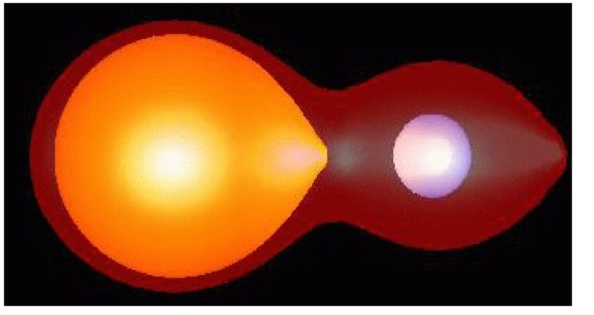
Single-degenerate channel

Double-degenerate channel

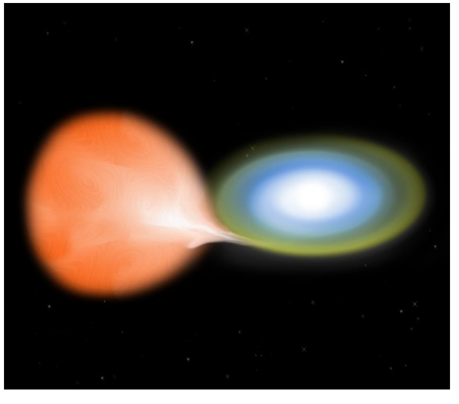
SN Ia
Progenitors??

Close Compact Binaries + SN Ia progenitors

Long-term observational campaign targeting LAMOST F, G, K stars displaying significant UV excess

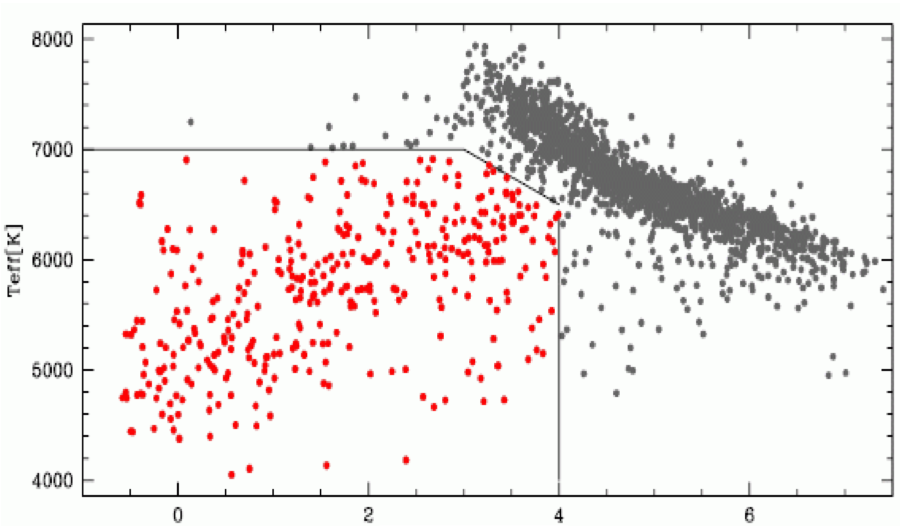


- Past evolution: constrain CE efficiency
- Future evolution: test single degenerate channel for SN Ia

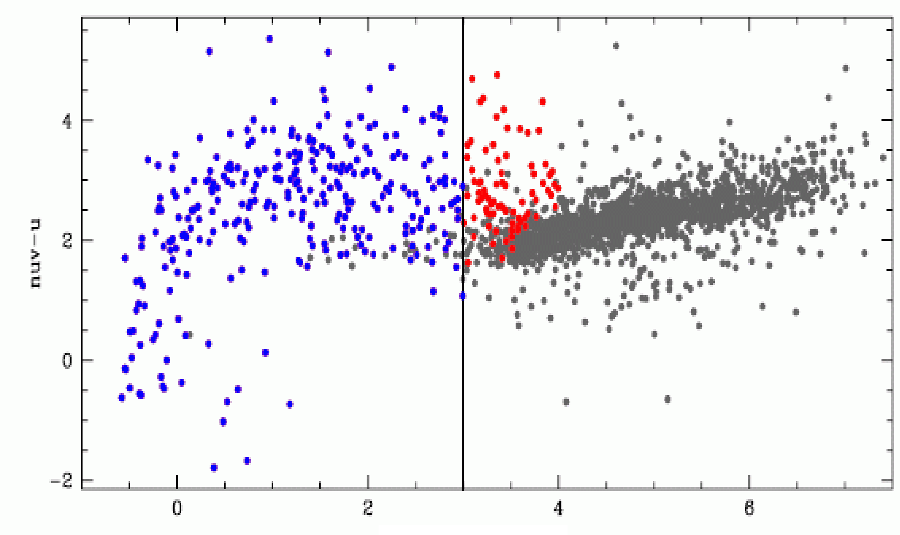


Close Compact Binaries + SN Ia progenitors

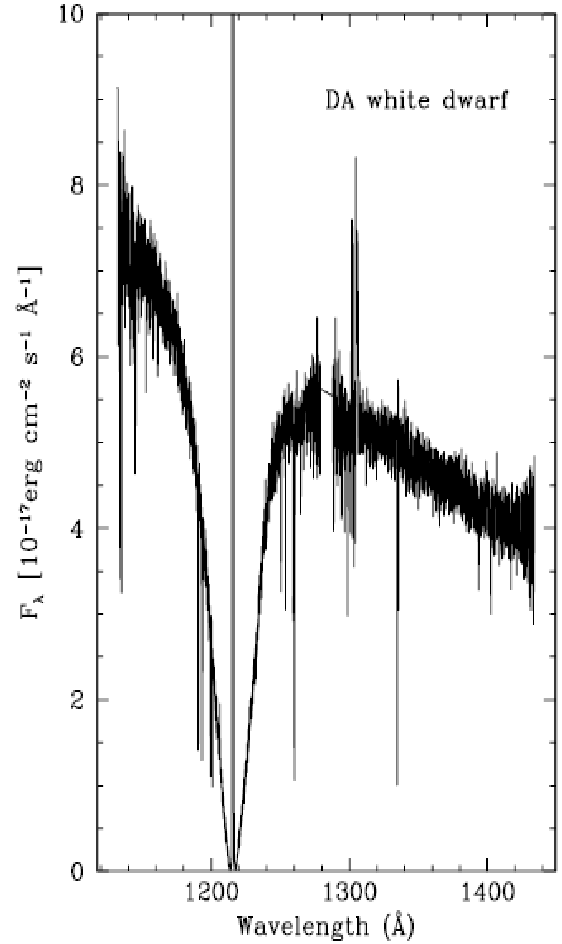
Teff



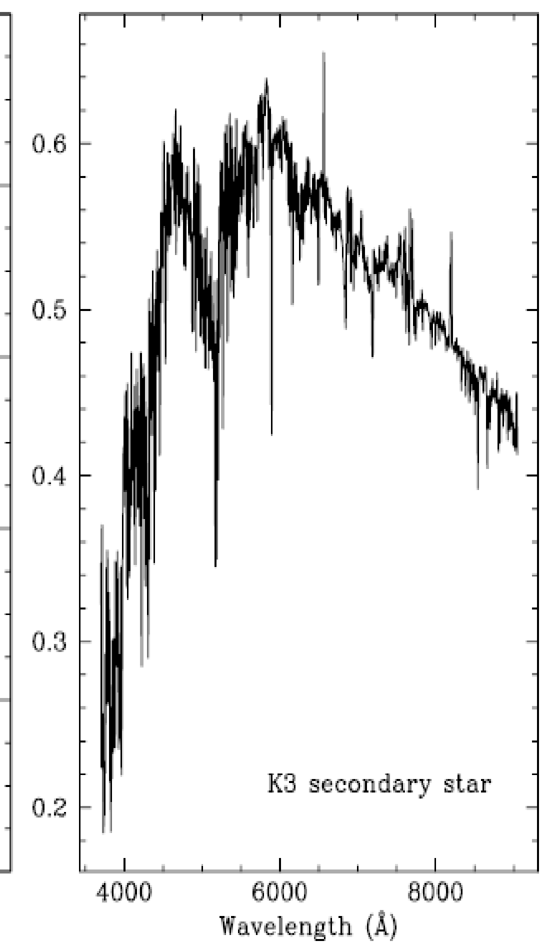
nuv-u



GALEX fuv-nuv



HST



LAMOST

Conclusions

- White dwarfs (and white dwarf binaries) are fascinating objects that allow us to study several different open problems in astrophysics