Digging in the stellar graveyard with VST ATLAS

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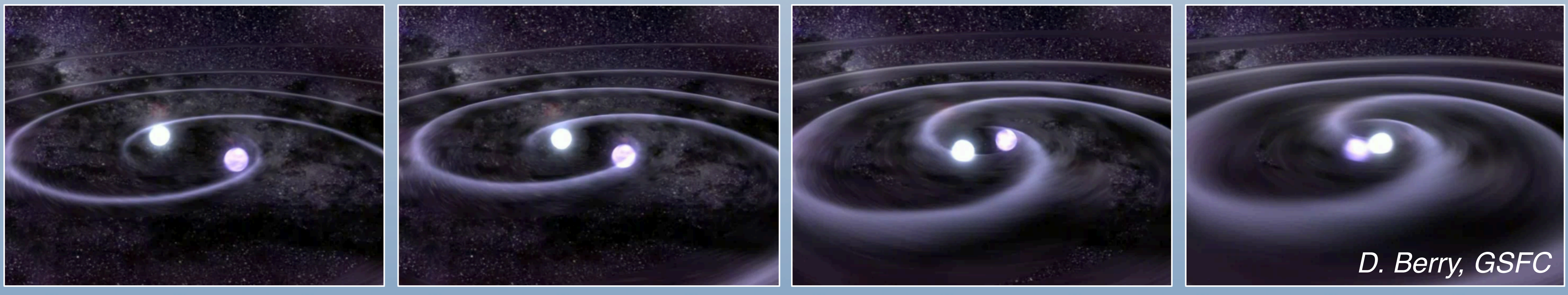
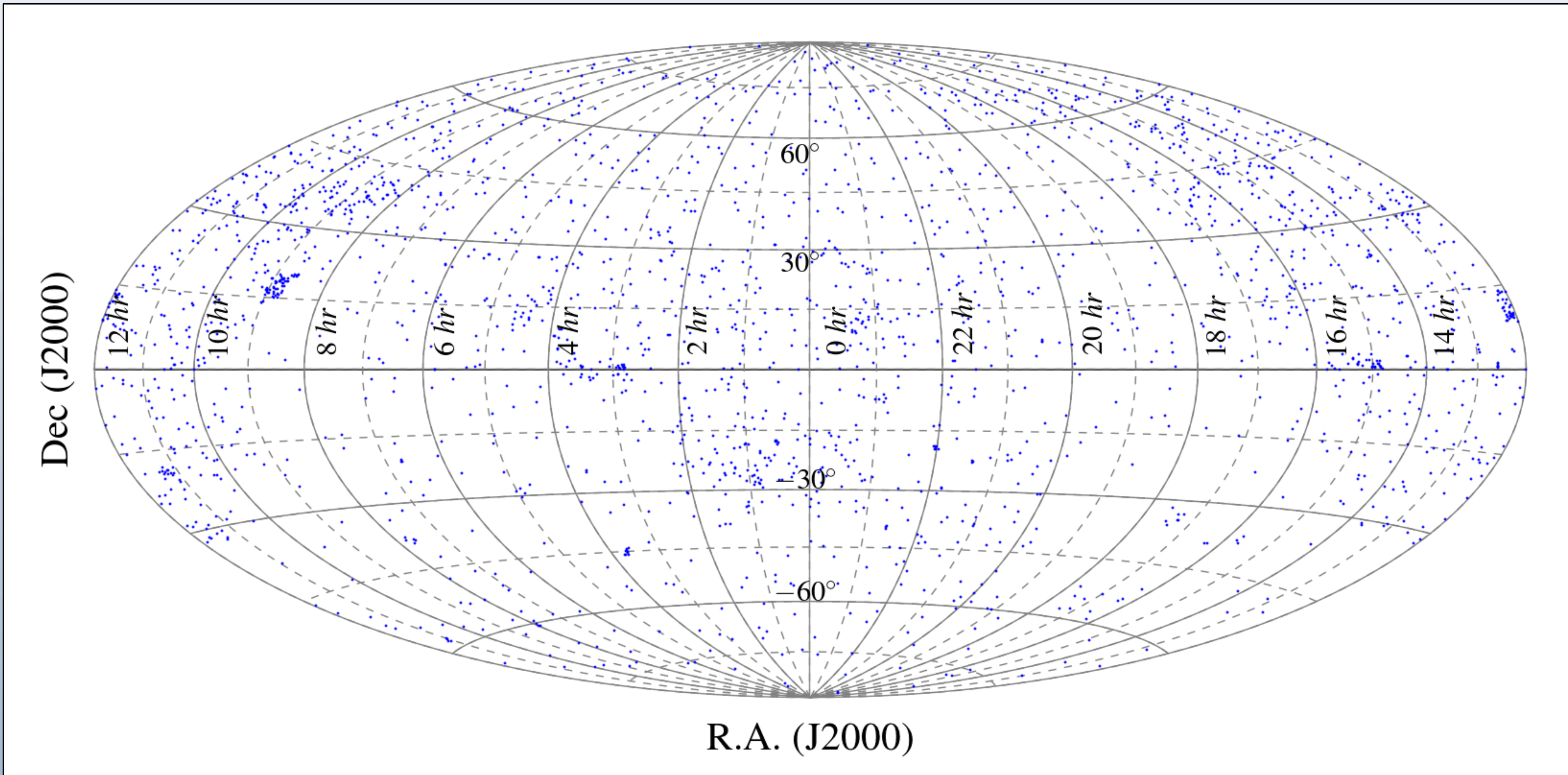
Motivation and Outline

- We are amidst exponential white dwarf discovery in the era of deep, large-area, multi-colour photometric surveys
- *WDs: The Endpoints of Single Stars*
  - Ultracool (<4000 K) WDs trace the Galactic star formation history
  - Pulsating WDs allow us to probe their degenerate interiors
  - Some WDs bear the signatures of evolved planetary systems
- *WDs: The Endpoints of Binary Systems*
  - WDs in binaries constrain both single-degenerate and double-degenerate Supernovae Ia progenitors
  - Explore post-common-envelope binary evolution
  - Ultracompact binaries rapidly merge due to gravitational radiation



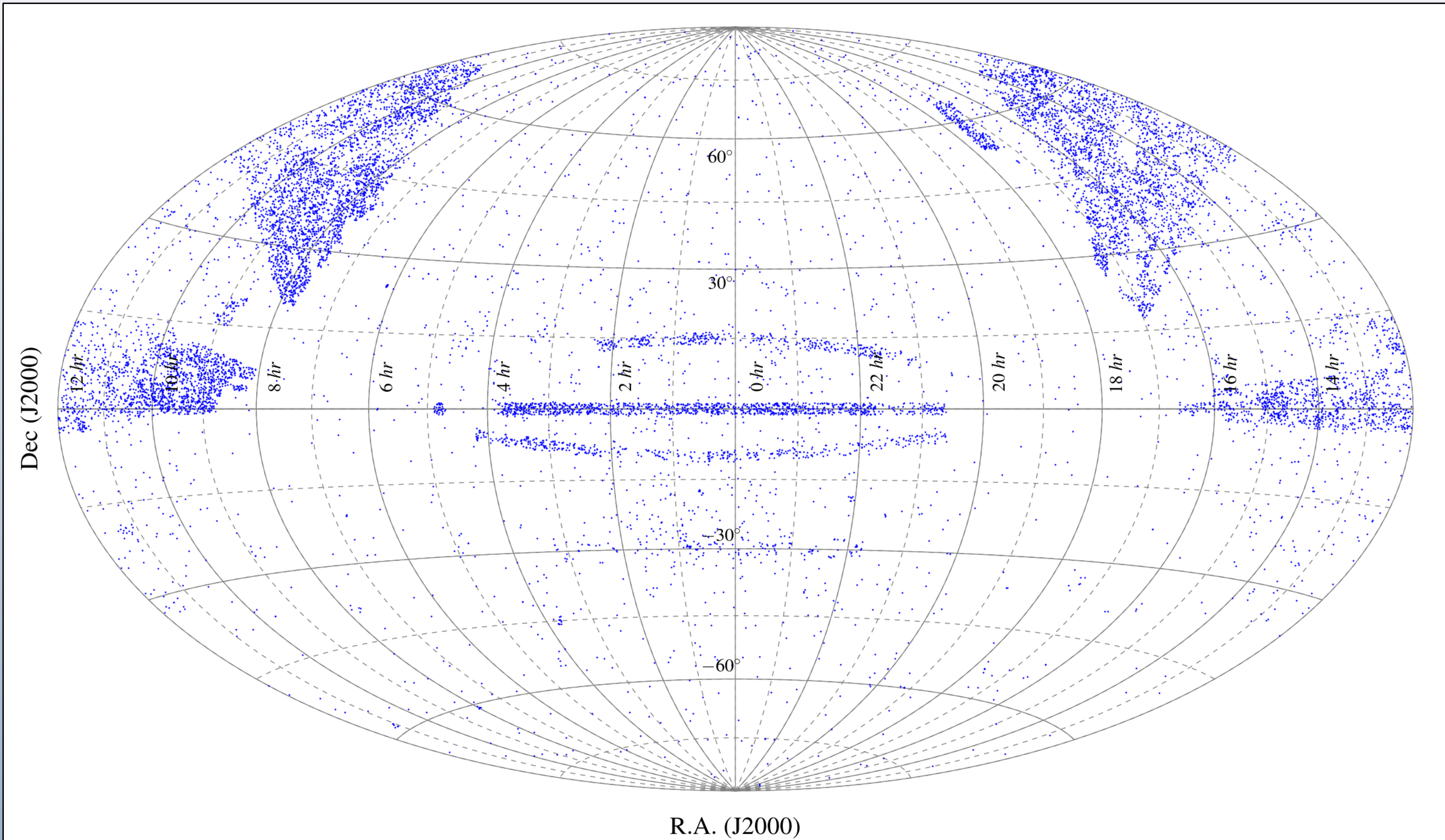
The White Dwarf Catalogue in 1999 April



Spectroscopically confirmed WDs

McCook & Sion 1999, ApJS, 121, 1

The White Dwarf Catalogue in 2013 January



Spectroscopically confirmed WDs

McCook & Sion 1999; Kleinman et al. 2013, ApJS, 204, 5

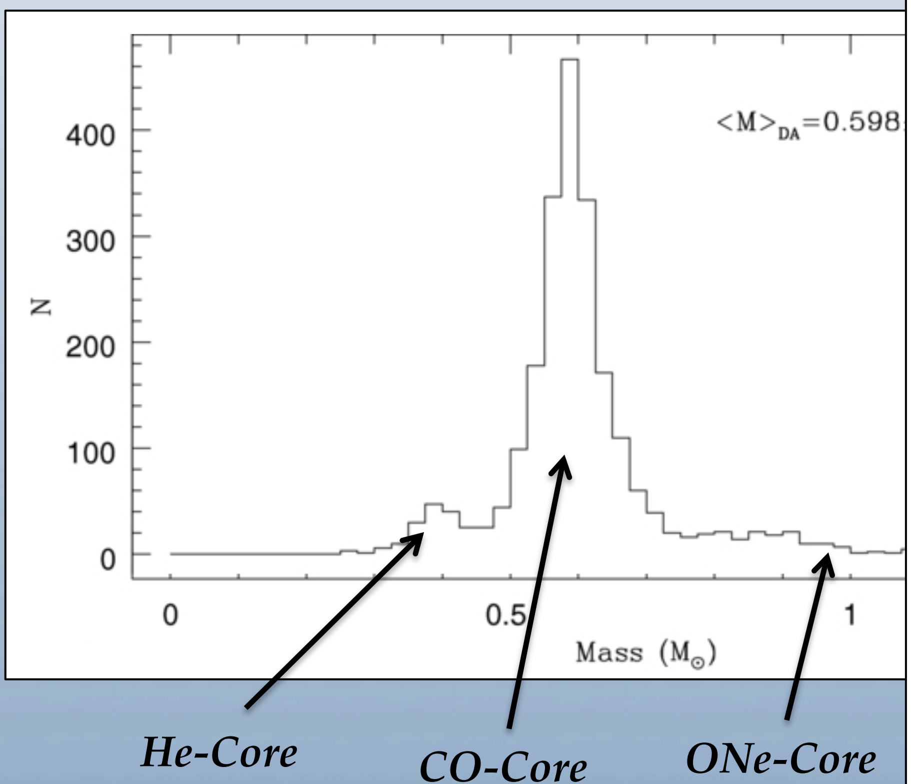
White Dwarfs, the Quantum Dots

- White Dwarfs (WDs) are the burnt-out cores of all low-mass stars with initial masses below ~8-10 $M_{\odot}$
- They are personal, since this is the future of our Sun

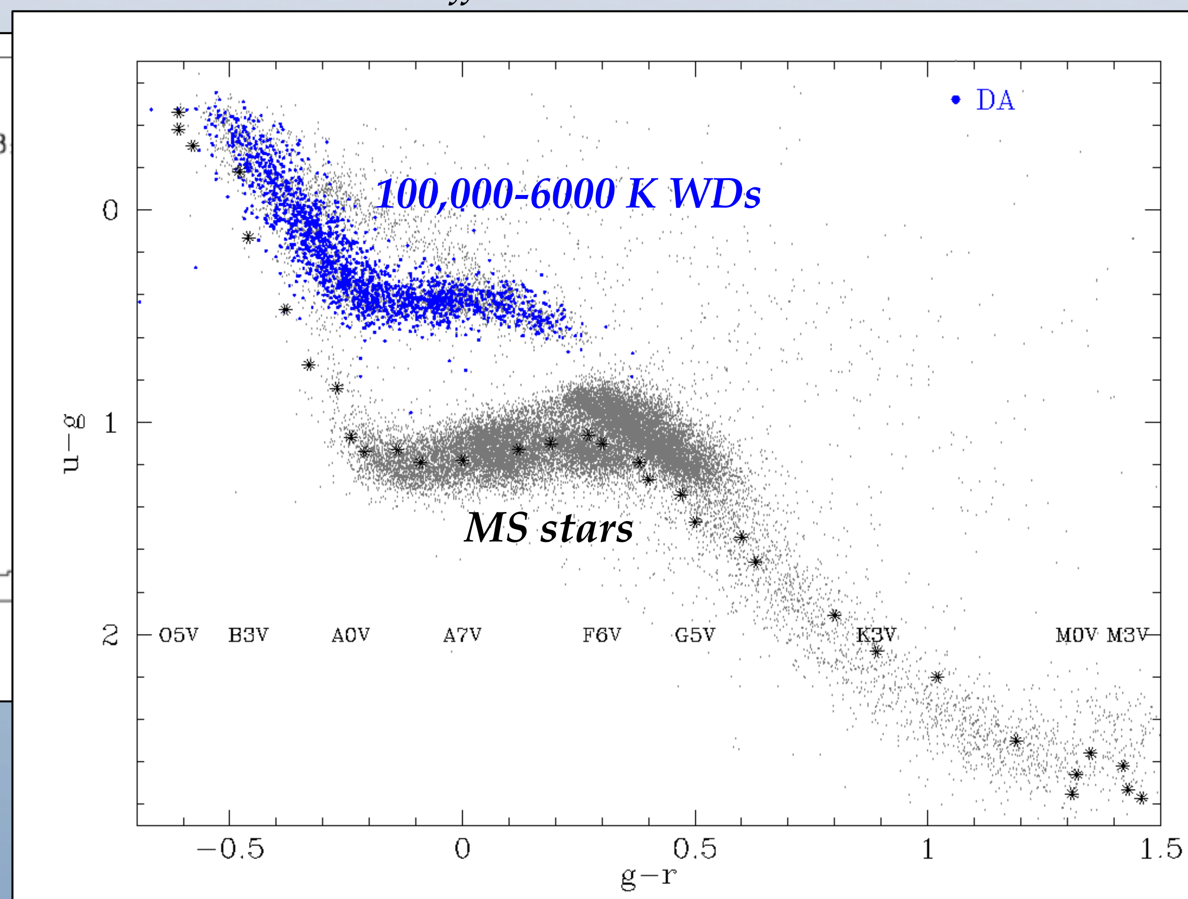
- WDs are blue and hot but very faint (roughly an Earth radius)
  - The brightest WD, Sirius B, is just 2.6 pc away and is still *V*=8.4 mag
- Thus, our knowledge of WDs is still fragmentary

Dwarfspotting.

- Local WD sample only complete out to ~13 pc
  - Likely still missing >50% of WDs within 25 pc
- Hydrogen-atmosphere (DA) WDs separate by *u-g*, *g-r* colours
- 80% of WDs are hydrogen-atmosphere (gravitational settling)
- Fit spectra to model atmospheres to get T_{eff}/log(*g*) → masses

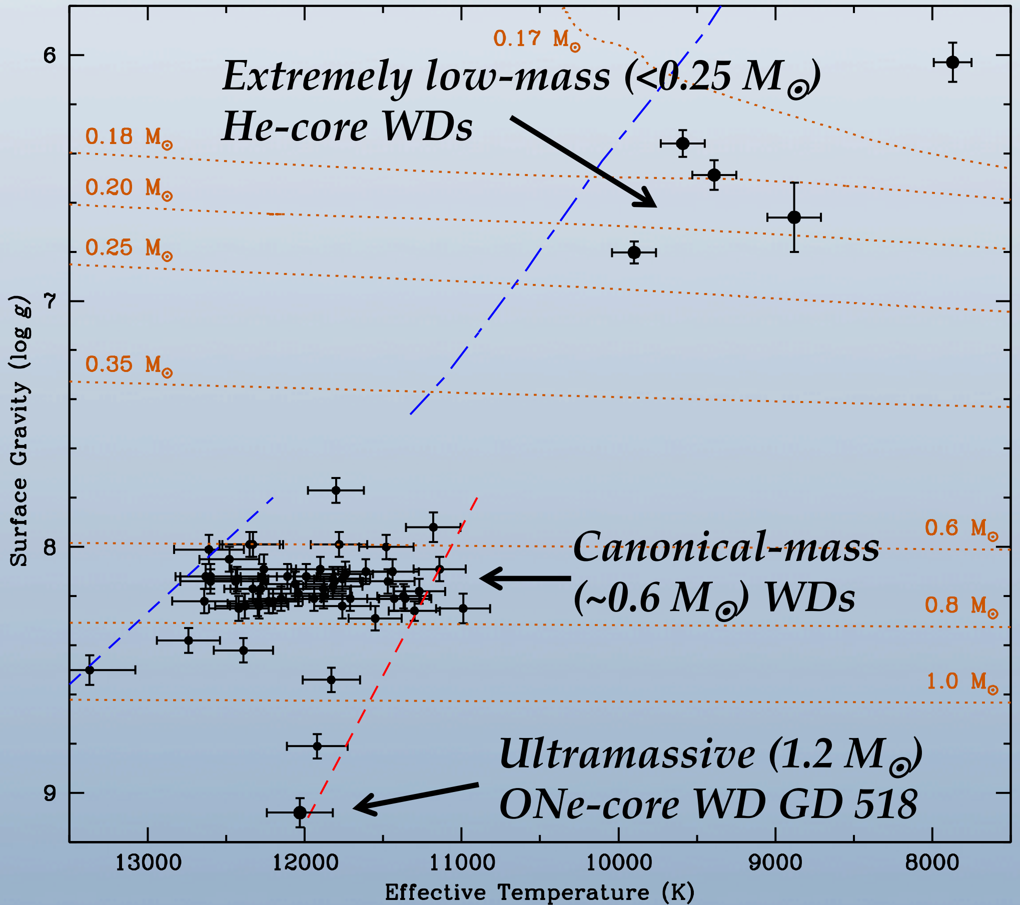


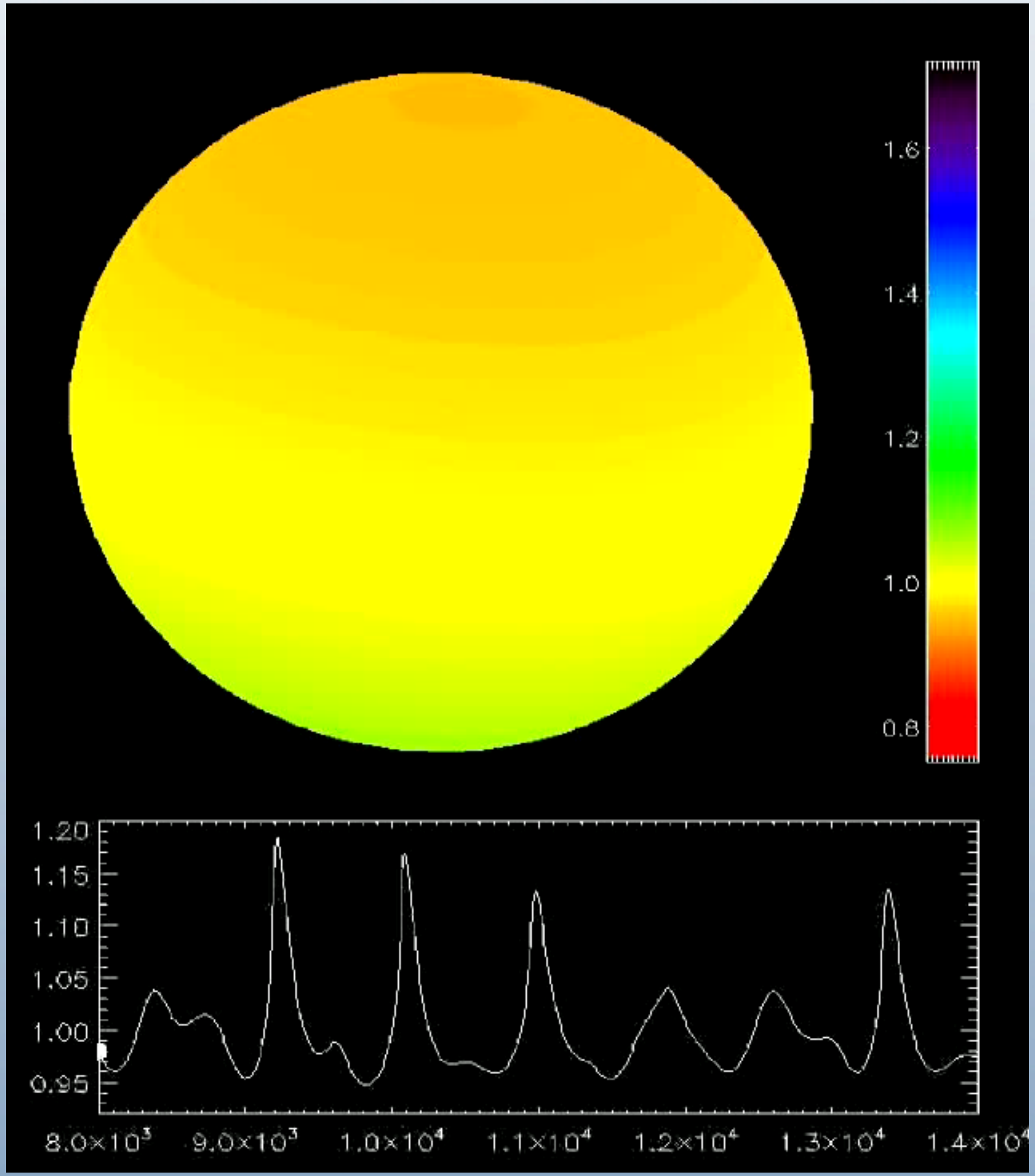
Kleinman et al. 2013, ApJS, 204, 5



Pulsating WDs Probe Degenerate Interiors

- Pulsations driven by H partial-ionization zone (12,500—11,200 K)
- Easy to select by temperature
- Pulsations probe **entire** WD

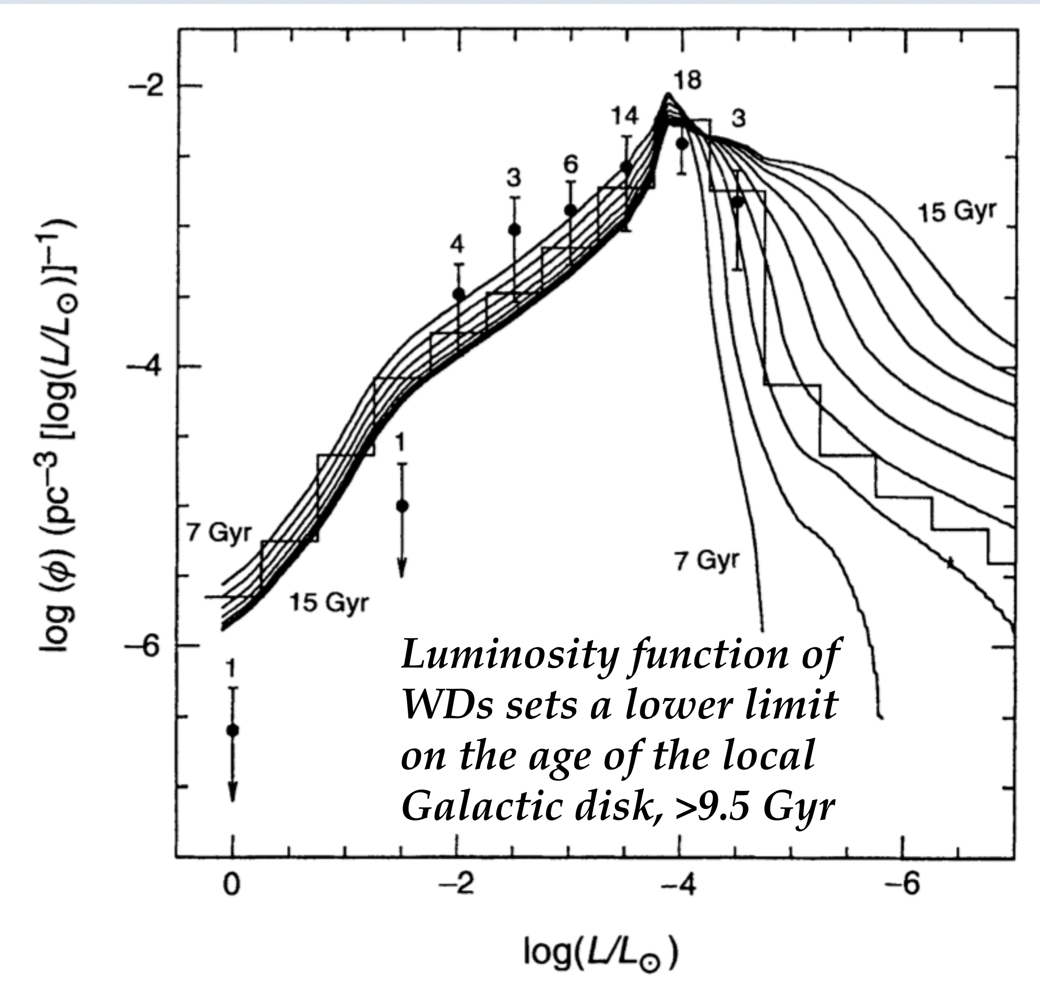




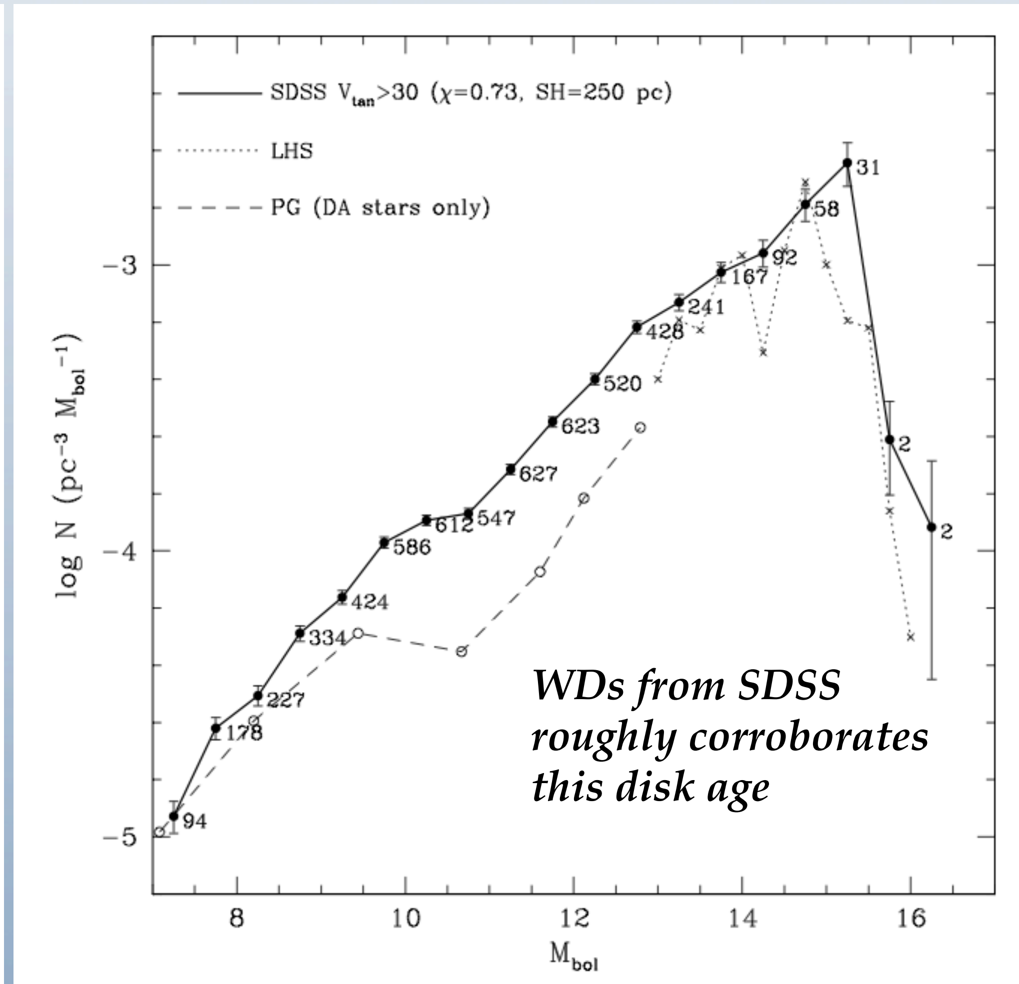
He-Core: Hermes et al. 2013, MNRAS, 436, 3573
ONe-Core: Hermes et al. 2013, ApJ, 771, L2

Cool WDs Trace Galactic Star-Formation History

- Ultracool WDs: T_{eff} <4000 K, can be proper-motion/colour selected
- Insight into the oldest stellar populations (cooling ages >8 Gyr)
- ATLAS can firm ages by finding more cool and ultracool WDs



Luminosity function of WDs sets a lower limit on the age of the local Galactic disk, >9.5 Gyr



WDs from SDSS roughly corroborates this disk age

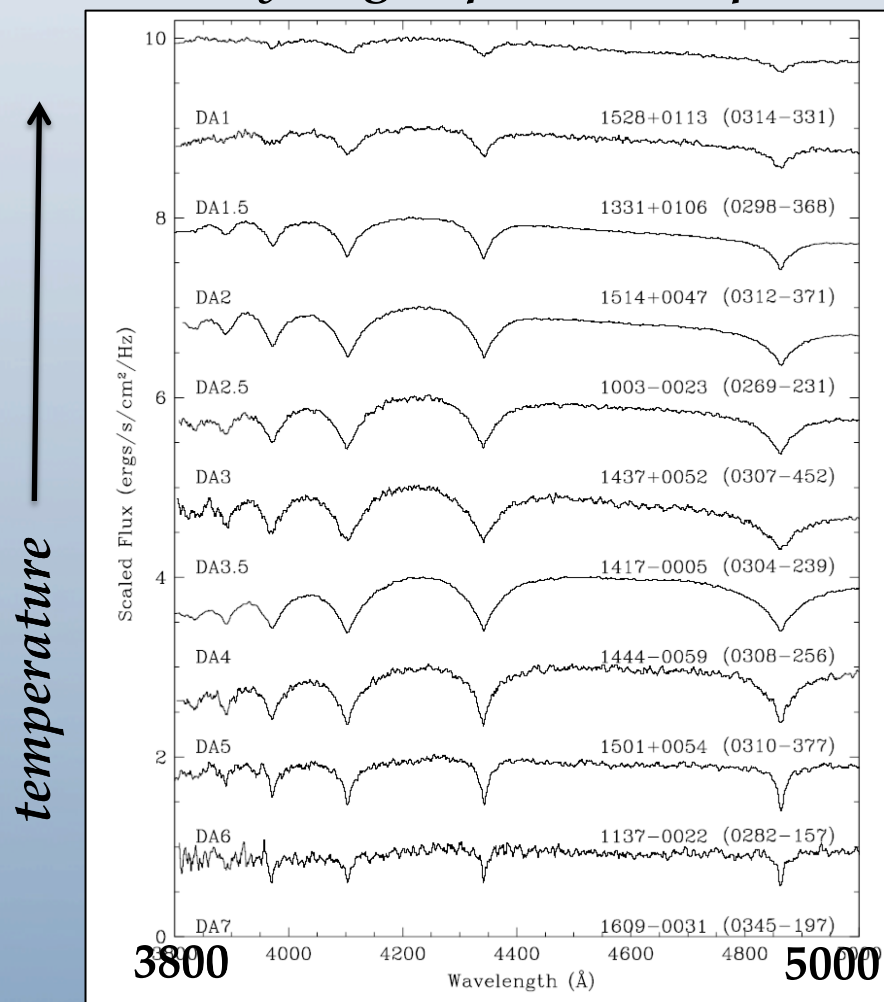
Oswalt et al. 1996, Nature, 382, 692

Harris et al. 2006, AJ, 131, 571

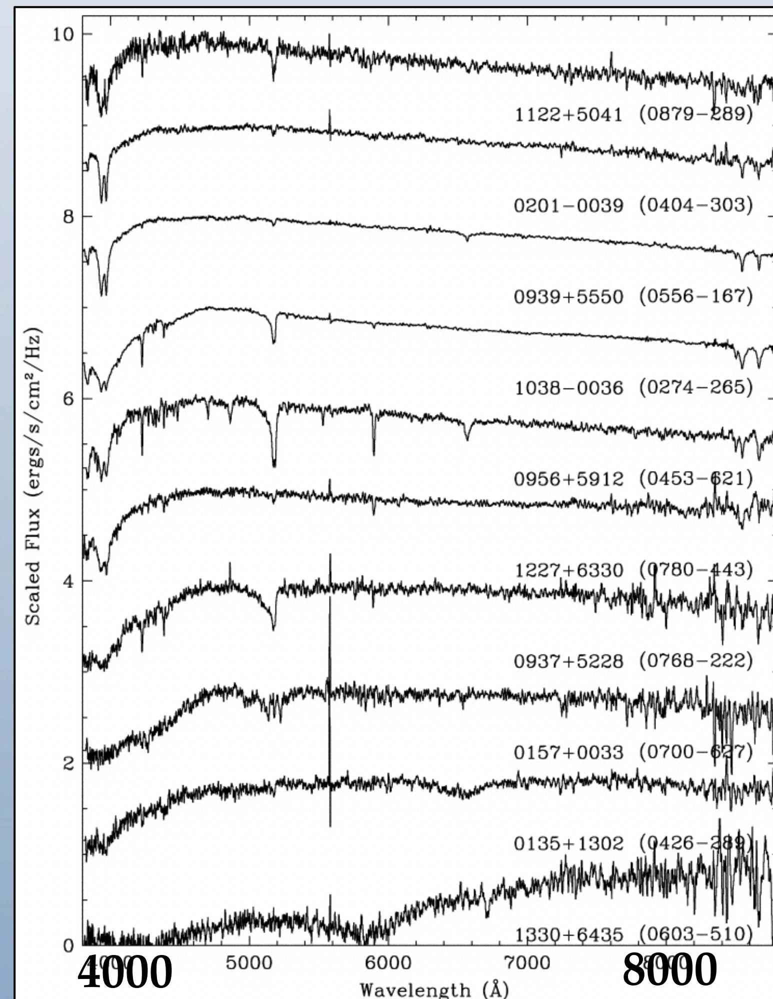
Not All WDs Have Chemically Pure Atmospheres

- Not all WDs have simply hydrogen- or helium-only atmospheres
- Roughly 30-50% of all cool WDs show some metal pollution
- These metals sink out of WD photosphere in days to years

DA (hydrogen-pure atmosphere)



DZ (atmospheric metals)



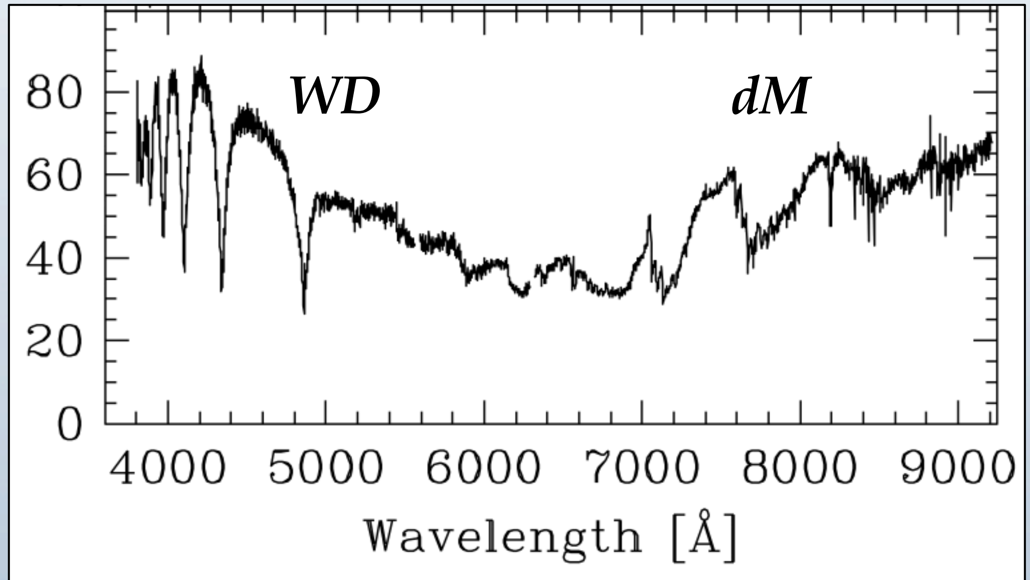
The Scars of Tidally Disrupted Planetary Material

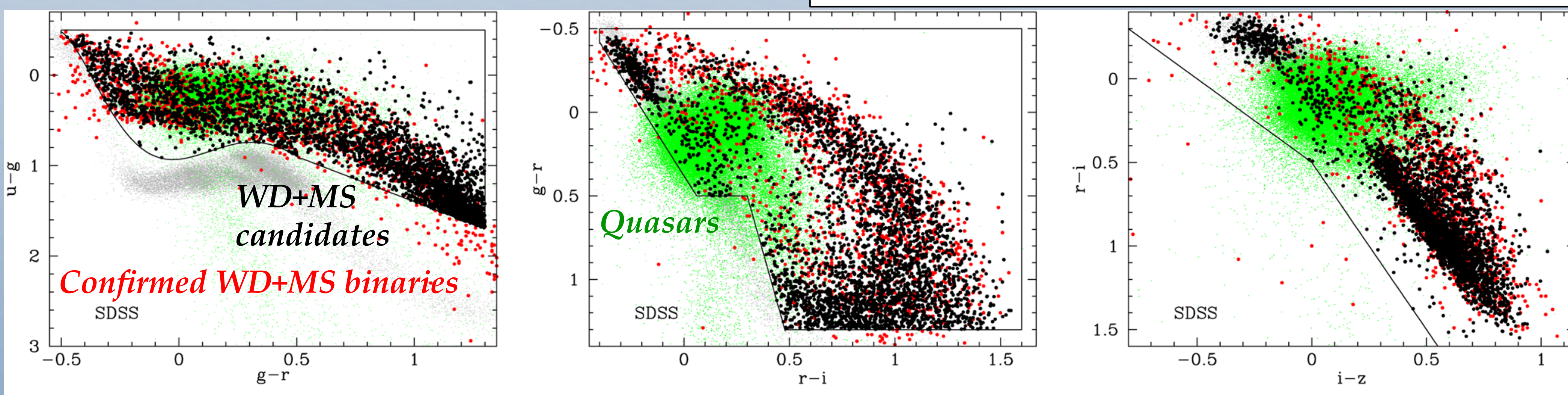
- Metal-polluted WDs reveal the chemical composition of rocky exoplanetary debris (comets, asteroids, planetessimals, etc.)
- Abundance analyses show that this exo-terrestrial debris is rocky; chemically diverse, like meteorites (Gänsicke+ 2012)
- Strong evidence that some debris is rocky & water-rich (Farihi et al. 2013)
- Many have infrared excesses from debris disks (ATLAS+VHS)

Gänsicke et al. 2012, MNRAS, 424, 333
Farihi et al. 2013, Science, 342, 218
Koester et al. 2014, arXiv: 1404.2617

Dwarfspotting.

- The number of identified WD+MS binaries went from a few dozen before SDSS to more than 2,200 in 2013
- Many of these systems have evolved through a common-envelope phase and are close, detached WD+dM
- These are the progenitors of cataclysmic variables (CVs)

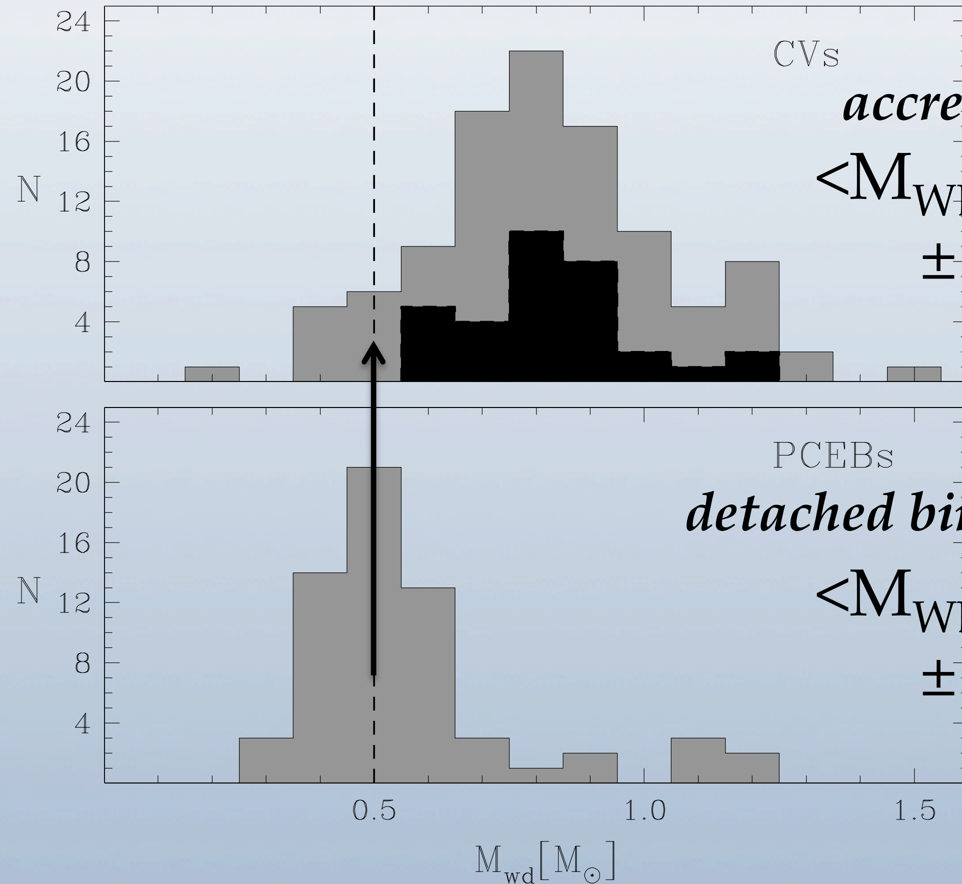




Rebassa-Mansergas et al. 2013, MNRAS, 433, 3398

Do Dwarf Novae Actually Grow in Mass?

- Theoretical predictions: dwarf novae eject more mass than they accrete
- Mean mass of CVs (0.83 $M_\odot$) is significantly higher than the mean mass of isolated WDs (0.6 $M_\odot$) or WDs in post-common-envelope binaries (0.58 $M_\odot$)
- PCEBs will evolve into CVs
- ATLAS can help select many more systems, to firm up these statistics



accreting WDs:

$\langle M_{WD} \rangle = 0.83 \pm 0.23\ M_\odot$

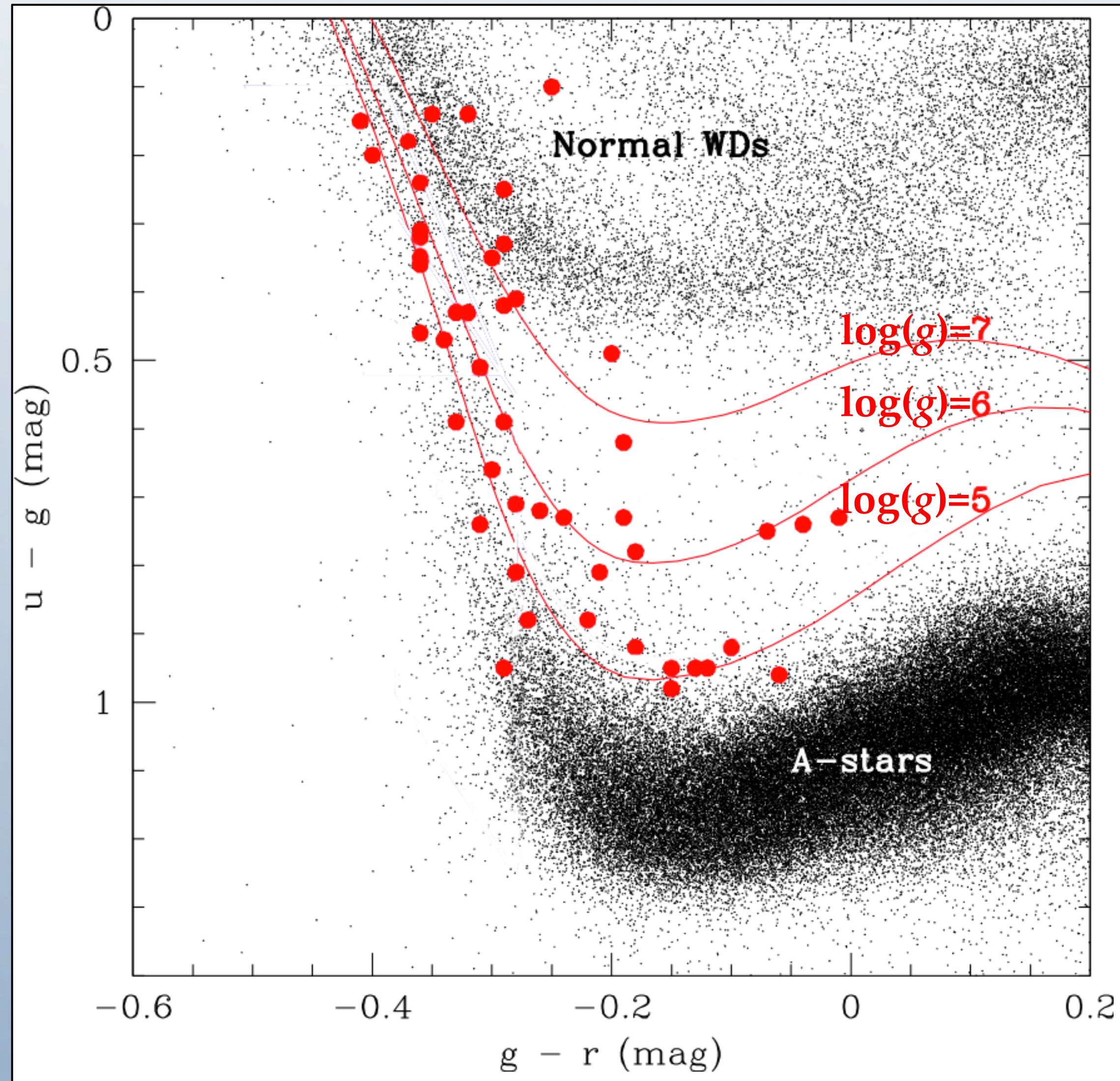
detached binary WDs:

$\langle M_{WD} \rangle = 0.58 \pm 0.20\ M_\odot$

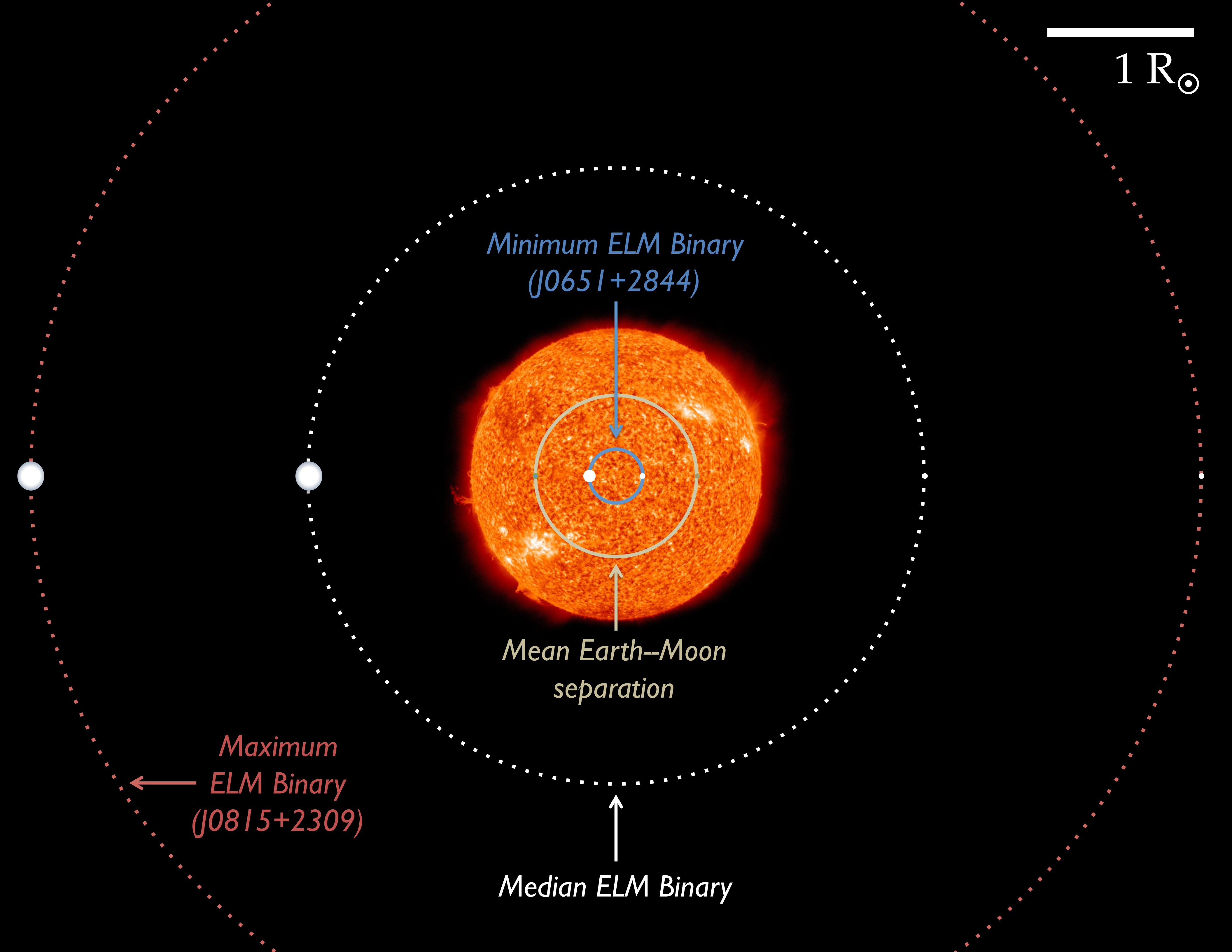
Zorotovic et al. 2011, A&A, 536, 42

Dwarfspotting.

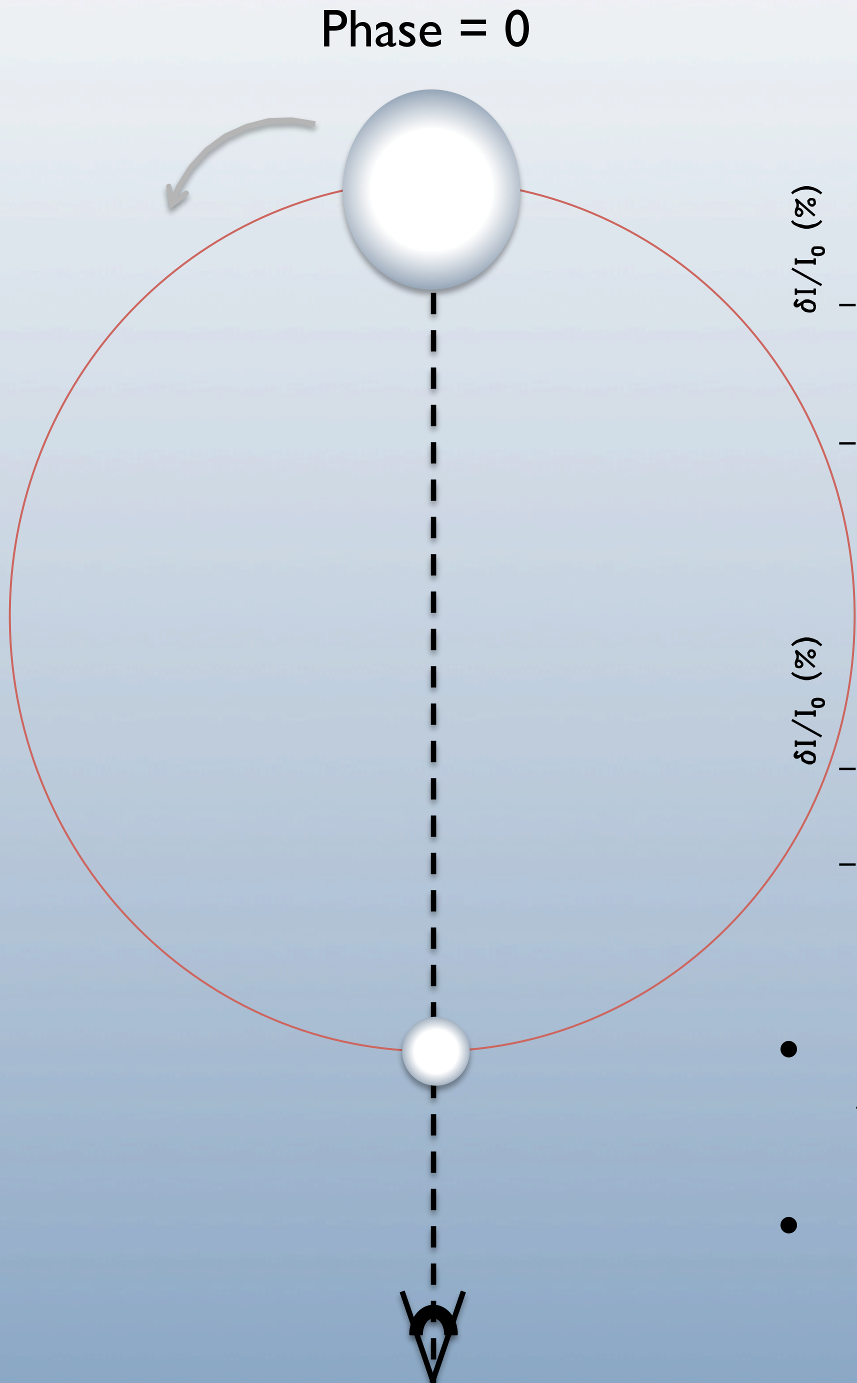
- Another recent boon from SDSS: Extremely low-mass (<0.3 Msun) ELM WDs
- Bridge the *u-g*, *g-r* gap between WDs (logg=8) and MS stars
- These WDs are by necessity the products of close binary evolution, and many are found in ultracompact binaries
- Excellent gravitational wave sources!

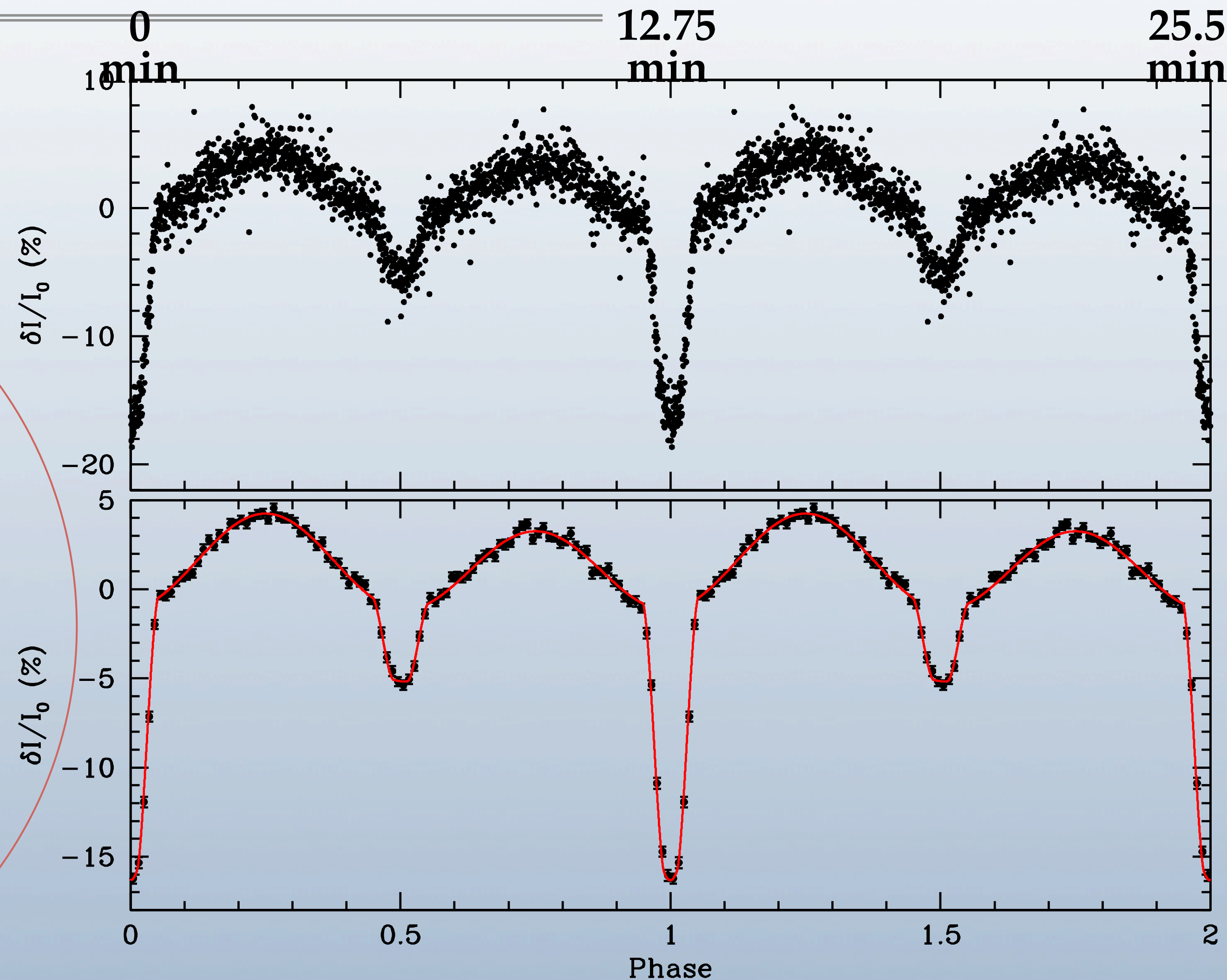


Latest ELM Survey release: Brown et al. 2013, ApJ, 769, 66


1 R$_\odot$
Minimum ELM Binary
(J0651+2844)
Mean Earth--Moon
separation
Maximum
ELM Binary
(J0815+2309)
Median ELM Binary

SDSS J0651+2844: A 12.75-min WD+WD Binary

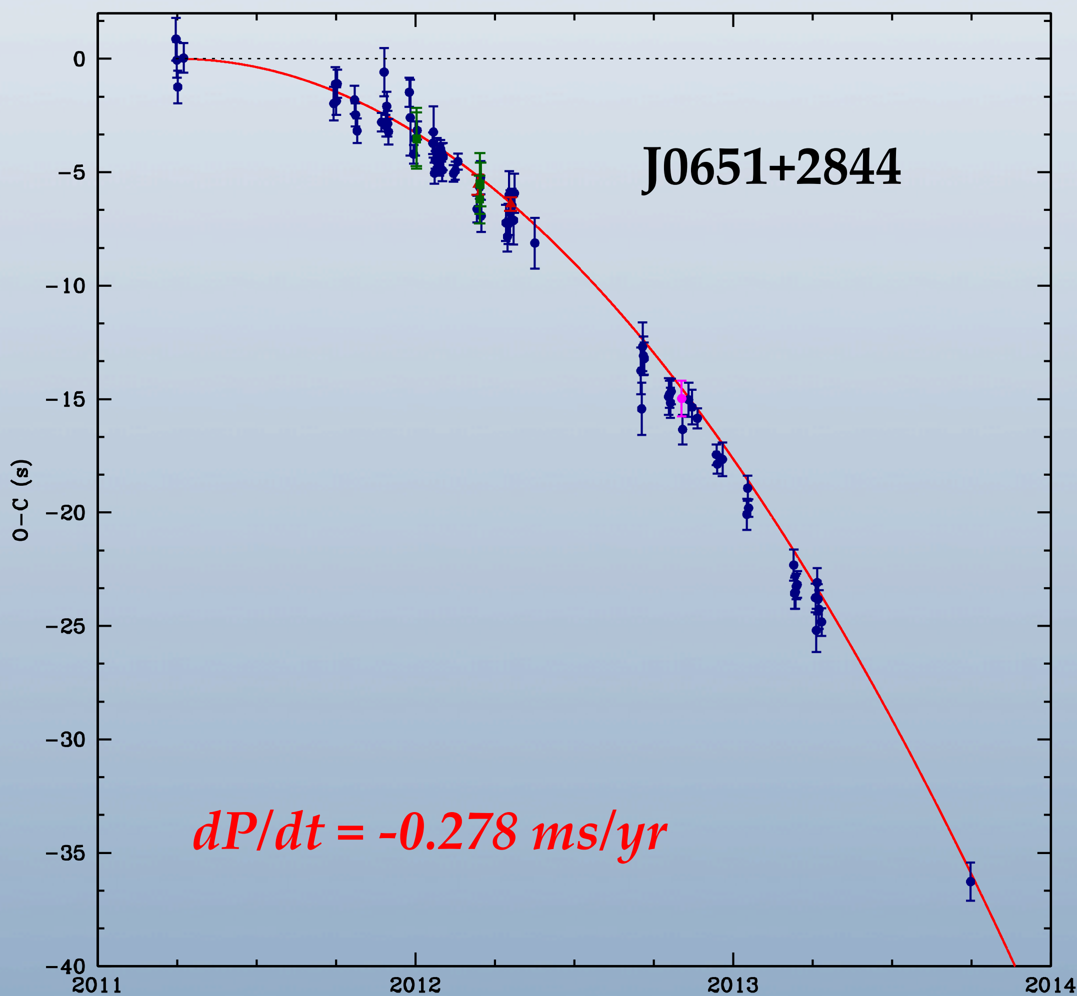




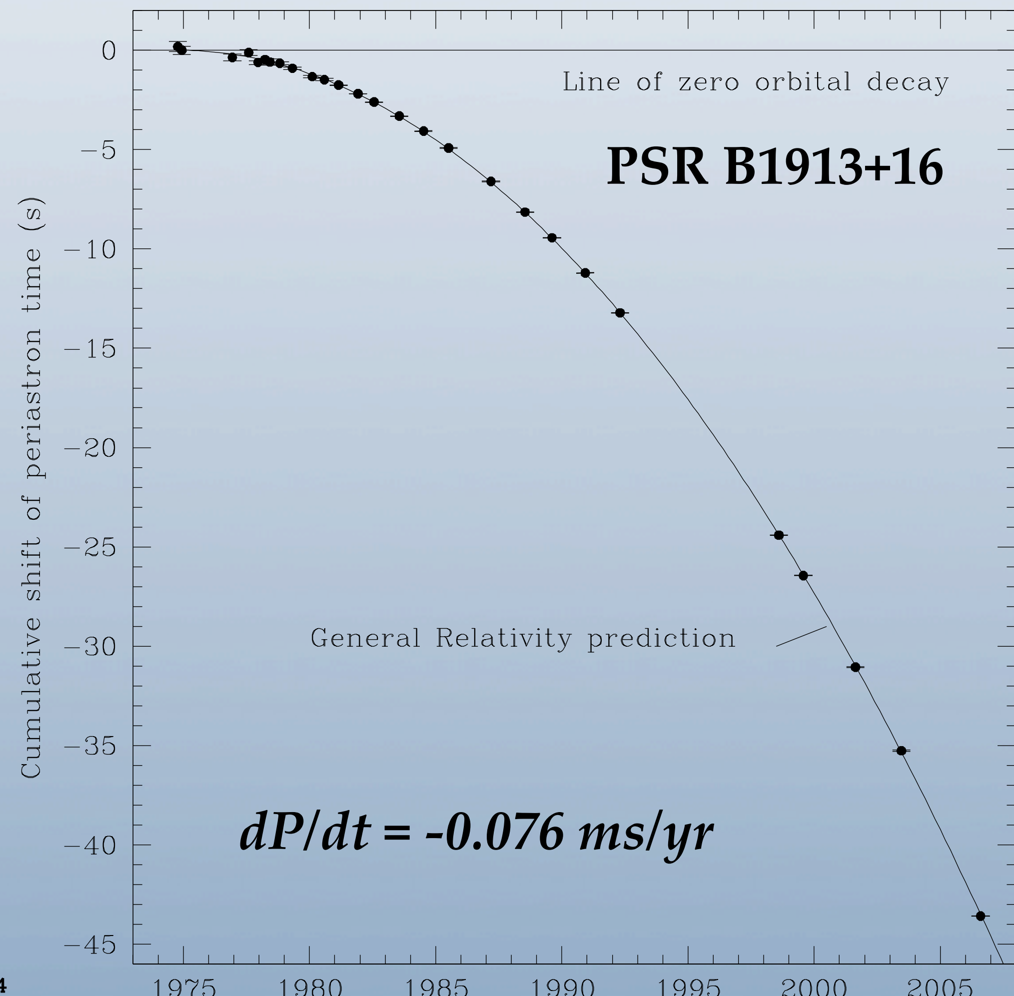
- This is the most compact detached binary system currently known
- It will come into contact in <1 Myr due to emission of gravitational radiation

SDSS J0651+2844: A 12.75-min WD+WD Binary

- This 12.75-min WD+WD binary is decaying > 3.5 times faster than the 7.75-hr Hulse-Taylor binary pulsar, which was the first indirect detection of gravitational radiation (1993 Nobel prize in physics)



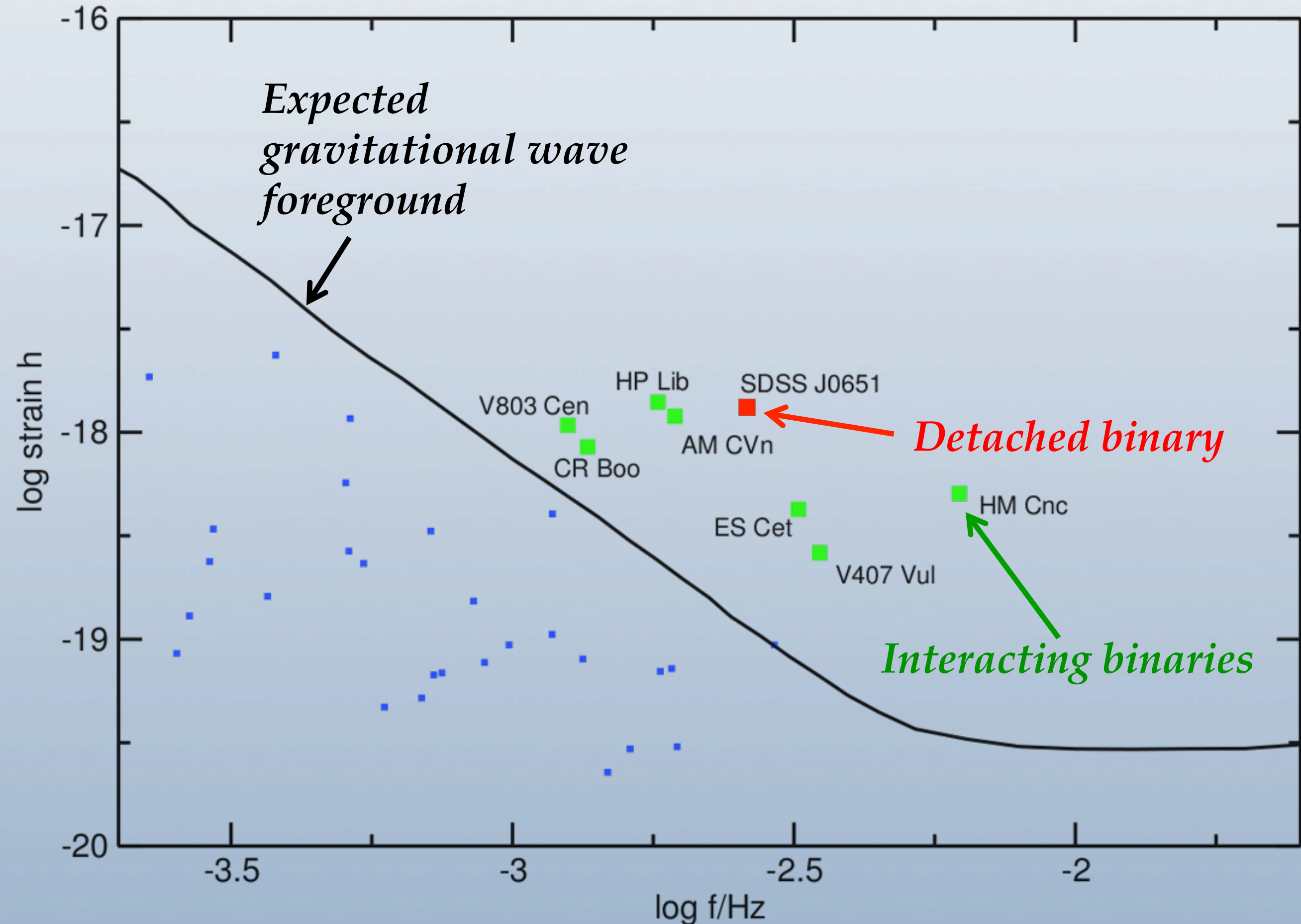
Hermes et al. 2012, ApJ, 757, L21



Weisberg et al. 2010, ApJ, 722, 1030

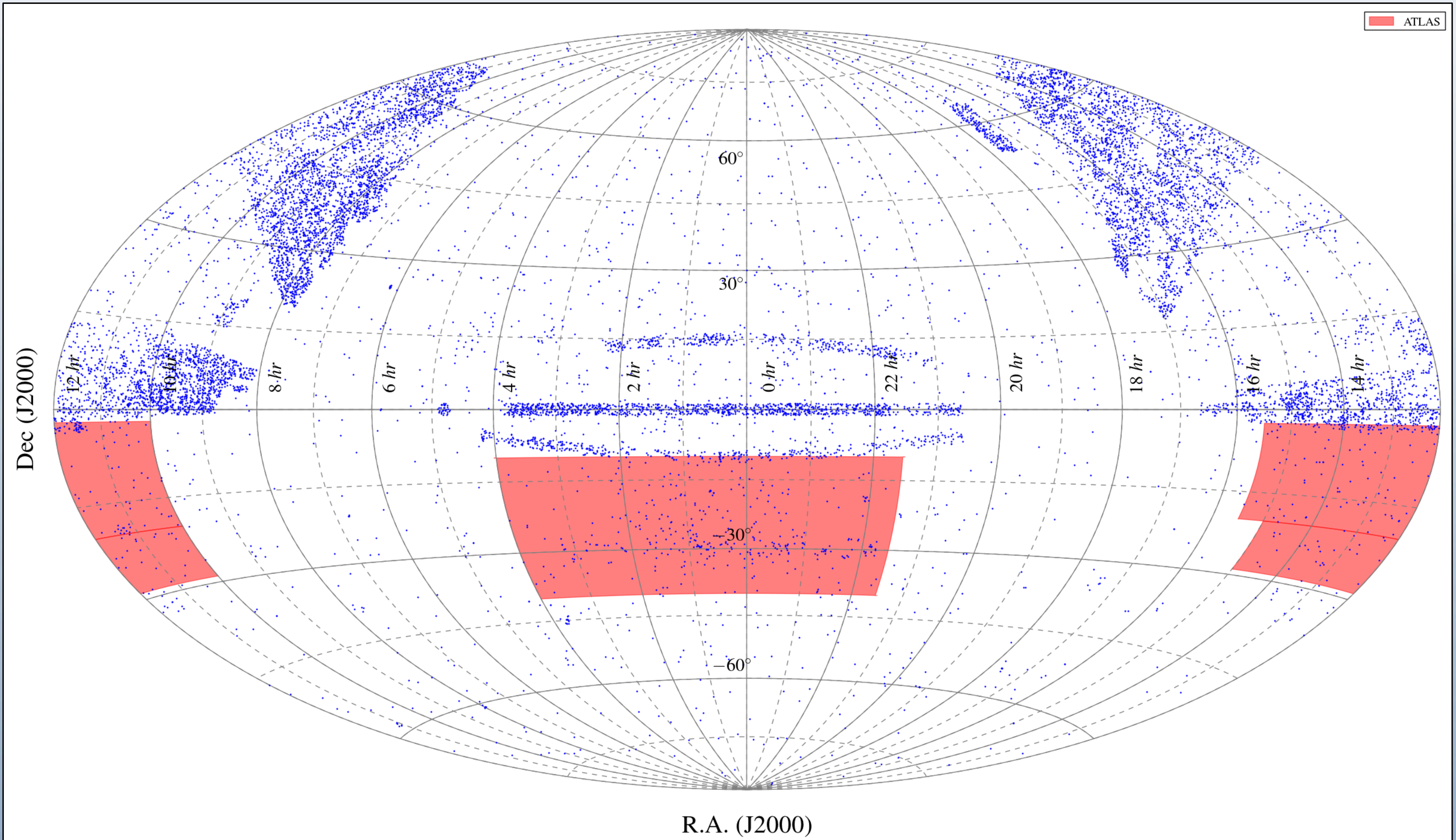
ELM WDs are Excellent *eLISA* Verification Sources

- J0651, an excellent verification source: f_{orb} = 1.30683671(9) mHz
- J0651+2844 should be detectable by *eLISA* with S/N > 3 within its first week of operation!
- Finding more ELM WDs in ATLAS will allow us to find more verification sources



Kilic, Brown & Hermes 2013, ASP Conference Series, 467, 47

VST ATLAS and WDs in the South



Digging in the Stellar Graveyard with VST ATLAS

- Finding WDs is trivial with well-calibrated *u* photometry and proper motions (PPMXL)
- VST ATLAS can find thousands of new WDs in the south
  - 10,000+ new individual WDs (many in clusters)
  - 100+ pulsating WDs
  - 50+ WDs with debris disks
  - 1000+ WD+MS binaries
  - 100+ extremely low-mass, compact WD+WD binaries
- Don't forget the stars!