

The ELM Survey: A Progress Report on the Search for the Most Extreme Binary White Dwarfs



*Alexandros Gianninas
University of Oklahoma*

*LISA Symposium XI
September 7, 2016*

Collaborators:

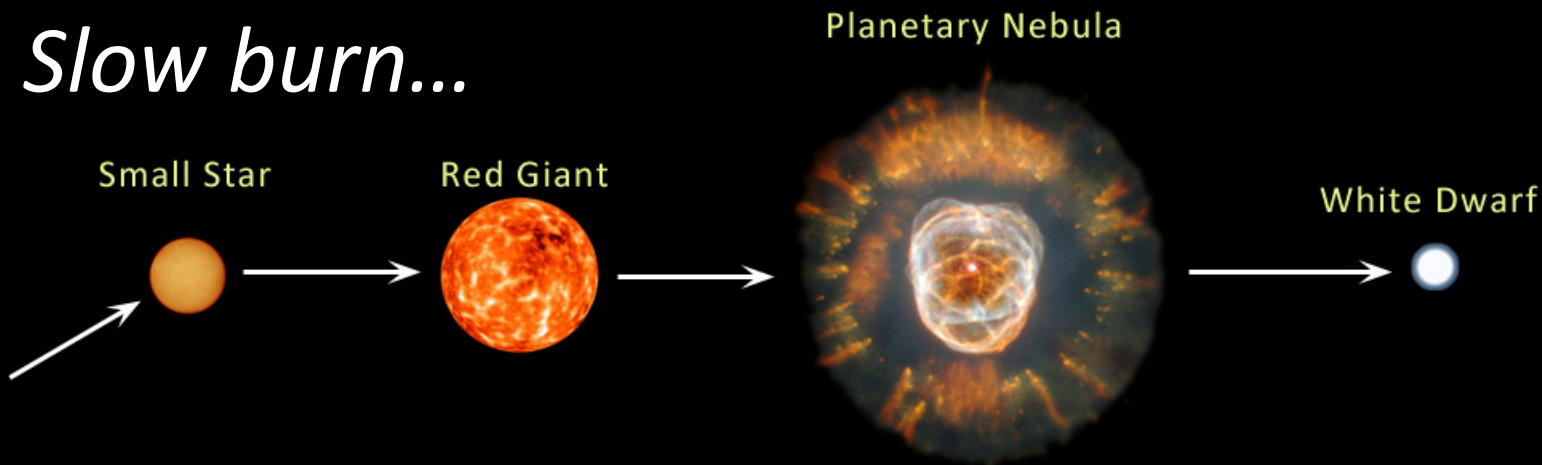
Mukremin Kilic (University of Oklahoma)

Warren R. Brown (Smithsonian Astrophysical Observatory)

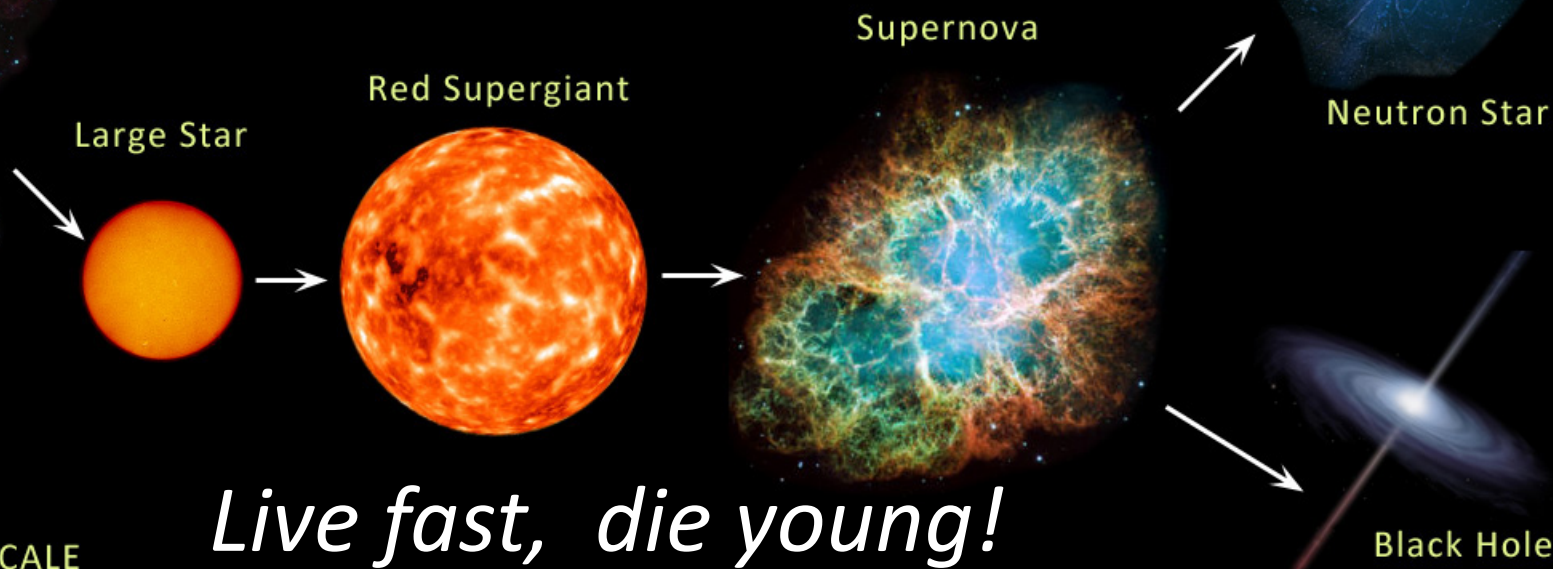
JJ Hermes (University of North Carolina)

EVOLUTION OF STARS

Slow burn...



But... over 50% of stars are in binary systems!

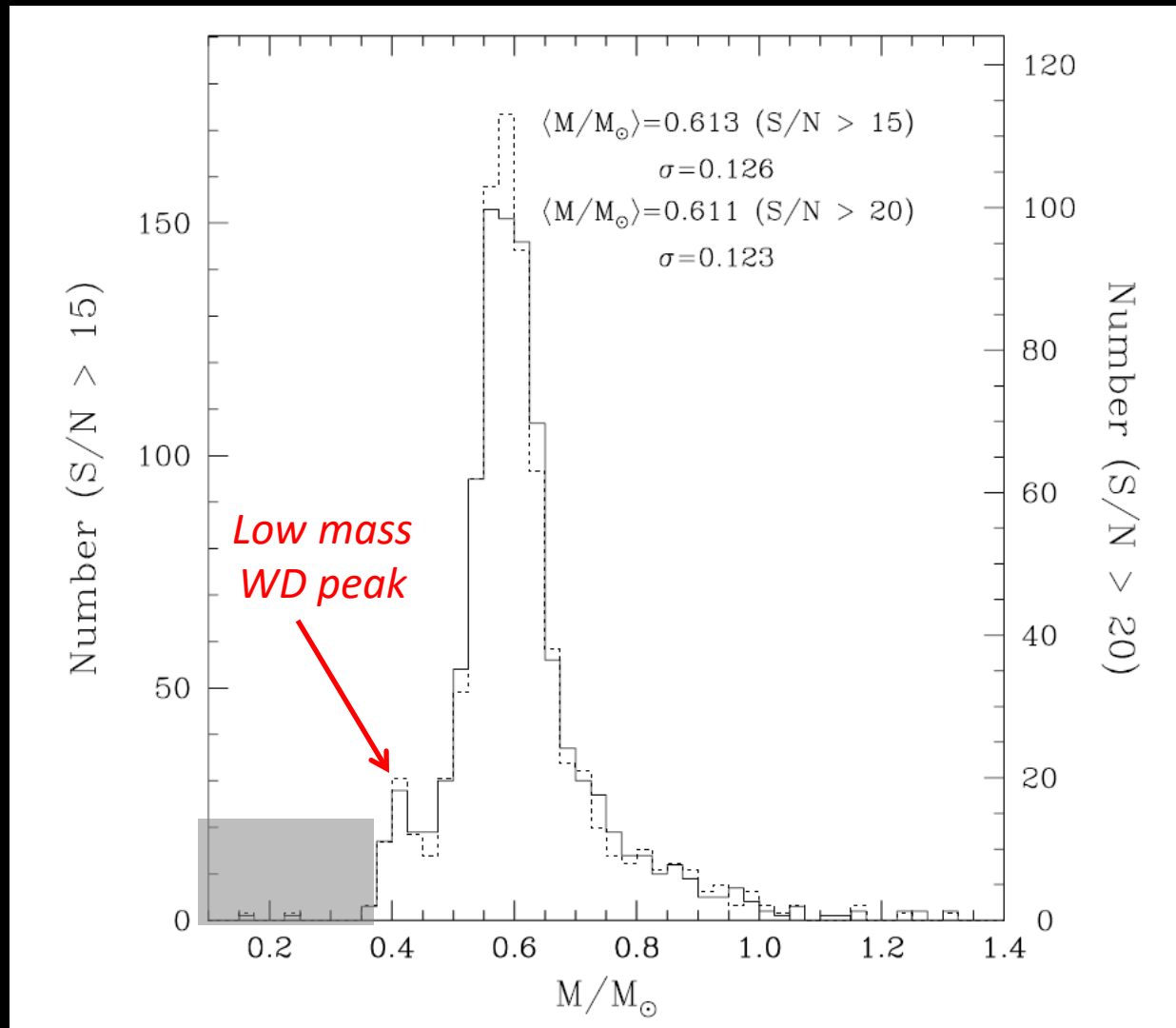


Live fast, die young!

Stellar Cloud with Protostars

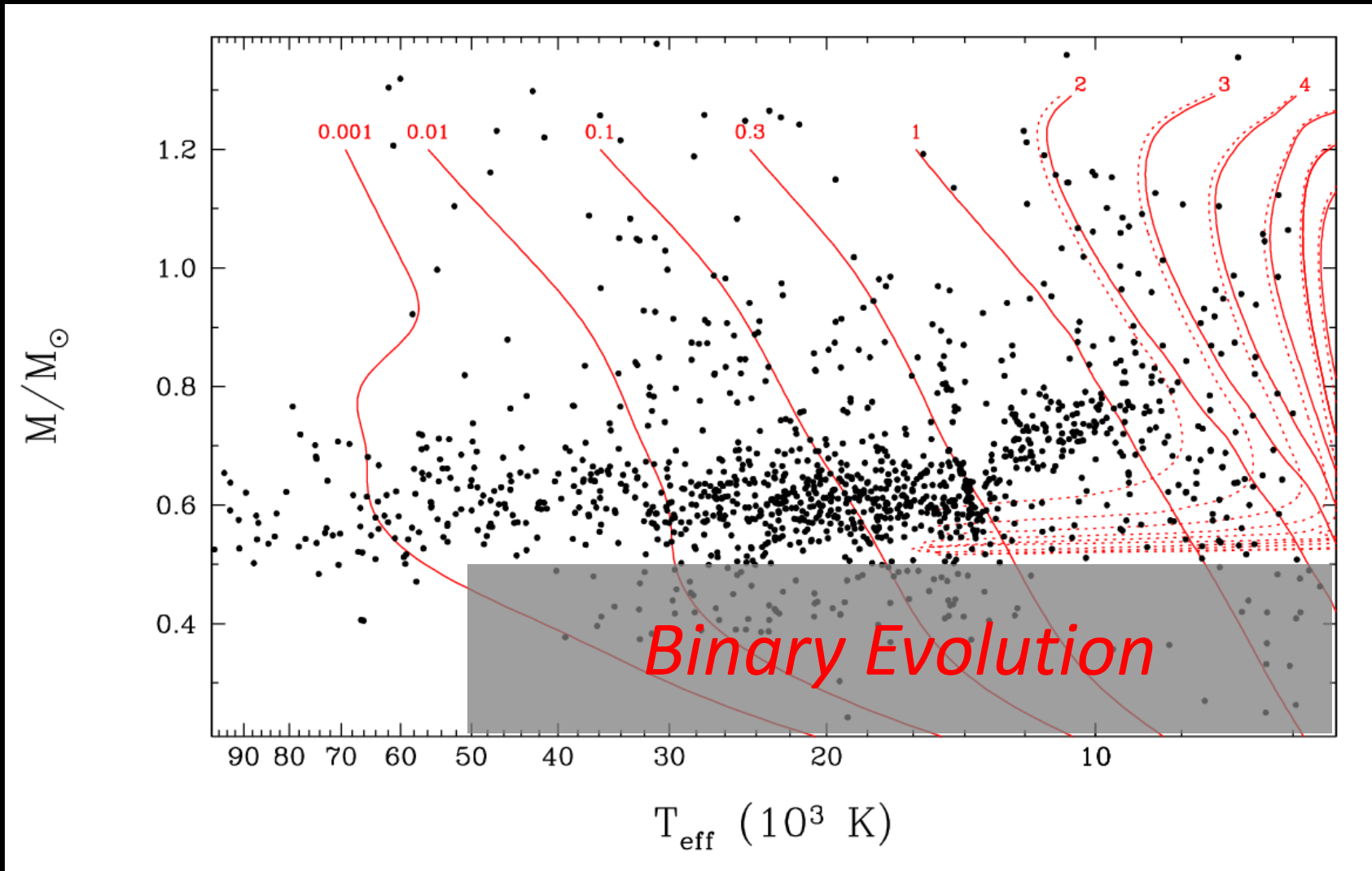
IMAGES NOT TO SCALE

Mass distribution of WDs from SDSS



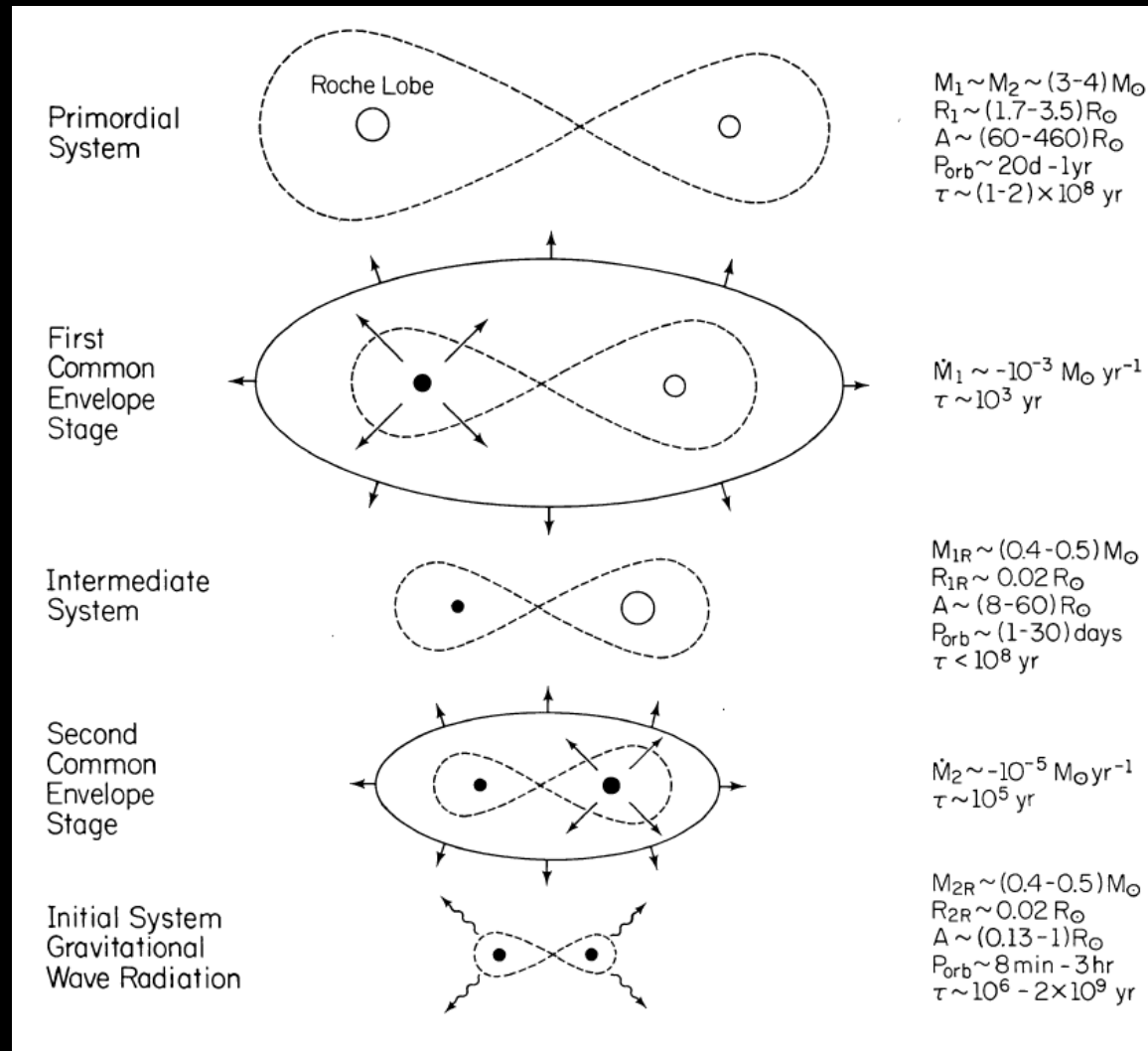
Tremblay et al. (2011, ApJ, 730, 128)

WD Mass Distribution as a Function of T_{eff}



Gianninas et al. (2011, ApJ, 743, 138)

Common Envelope Evolution



Iben & Tutukov (1984, *ApJ*, 54, 335)

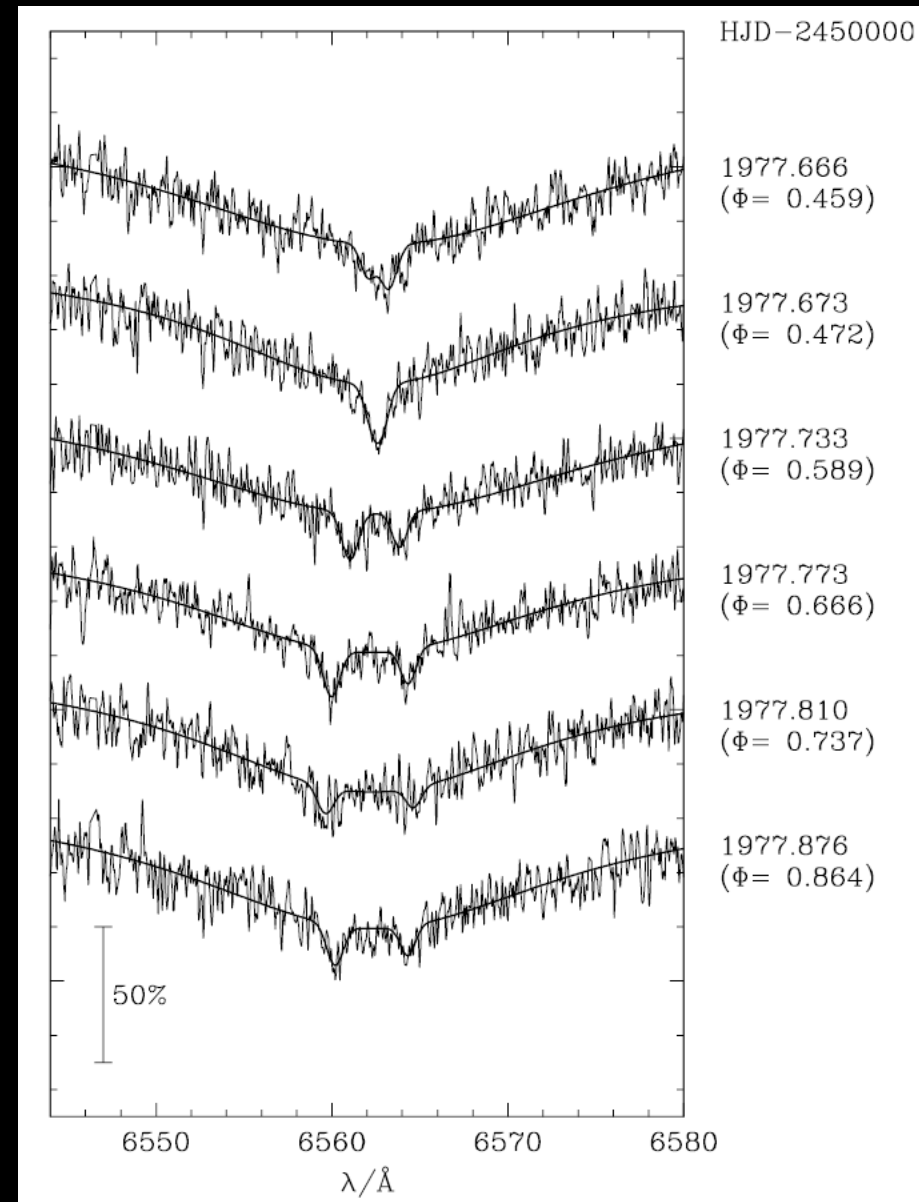
Before the ELM Survey...

- *Very few (18) double WD binaries were known and they had orbital periods from hours to several days*
- *Supernova Ia Progenitor Survey (SPY)*
 - *Radial velocity survey of ~1500 known WDs*
 - *Performed using UVES on the Very Large Telescope (VLT)*

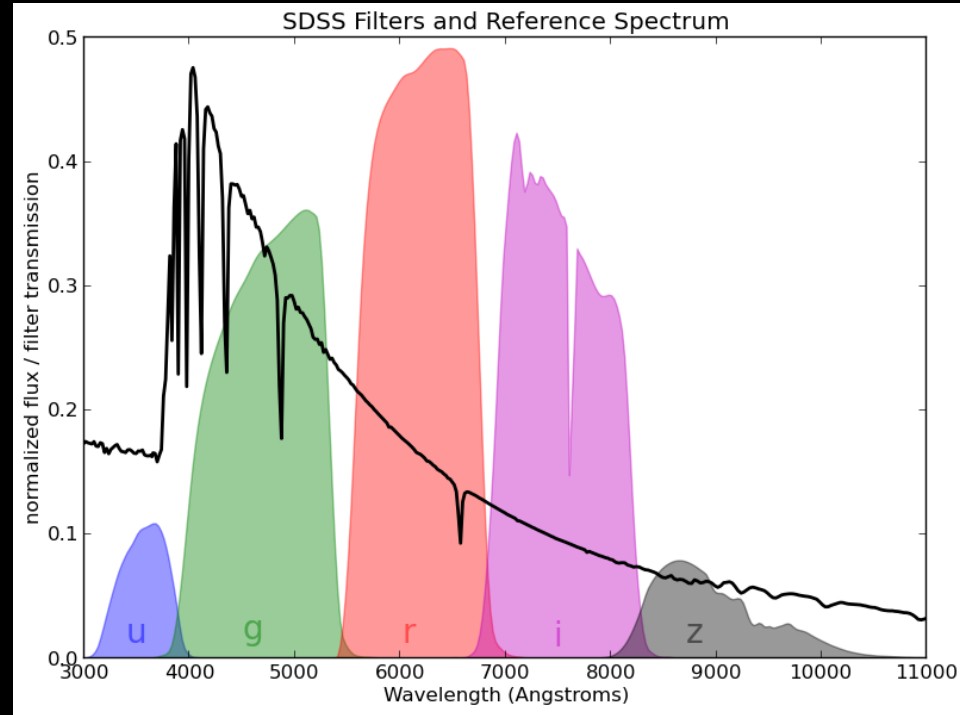


HE 1414-0848

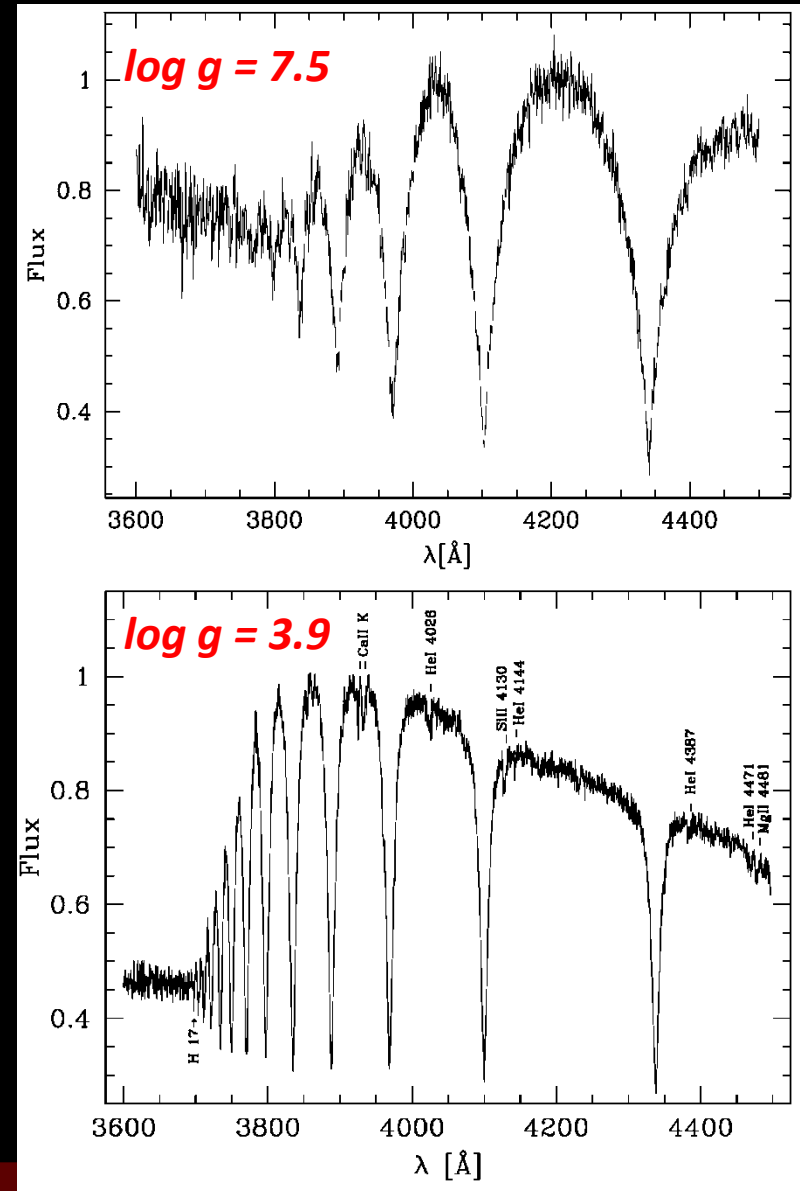
- $0.71 M_{\odot} + 0.52 M_{\odot}$
white dwarfs
- *Period = 0.518 days*
(12.43 hrs)
- *SPY:*
 - *~100 new binaries*
 - *A handful of merger systems*



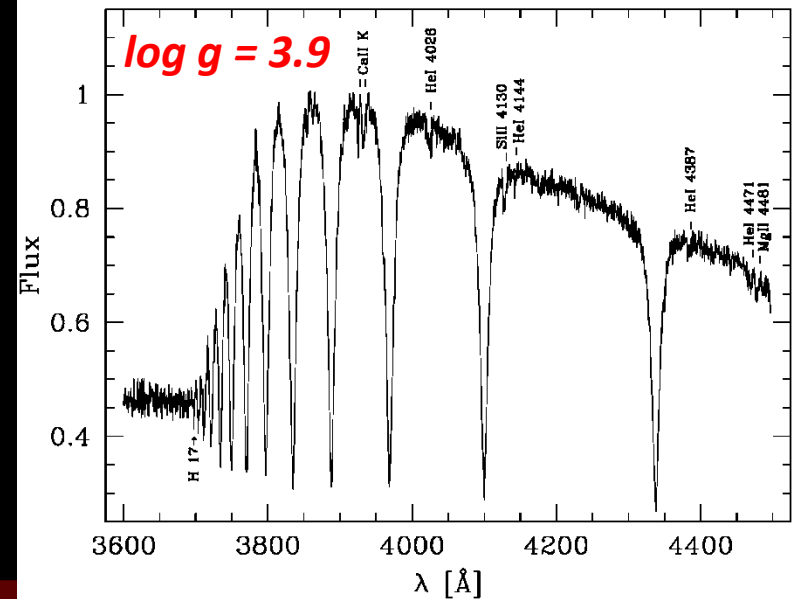
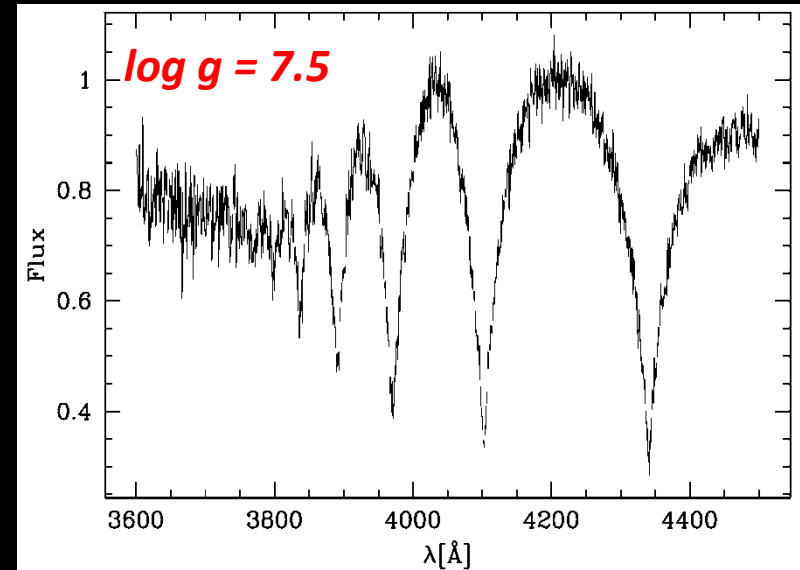
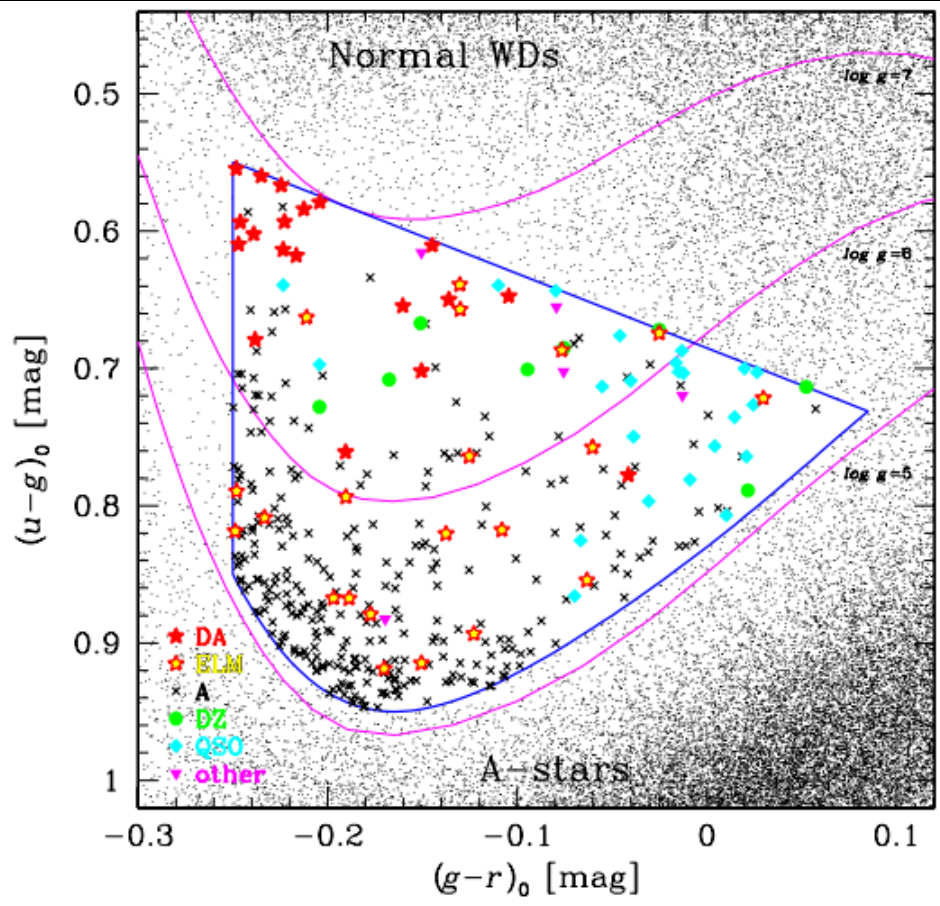
SDSS colors work well for choosing ELM WD candidates



SDSS colors work well for choosing ELM WD candidates

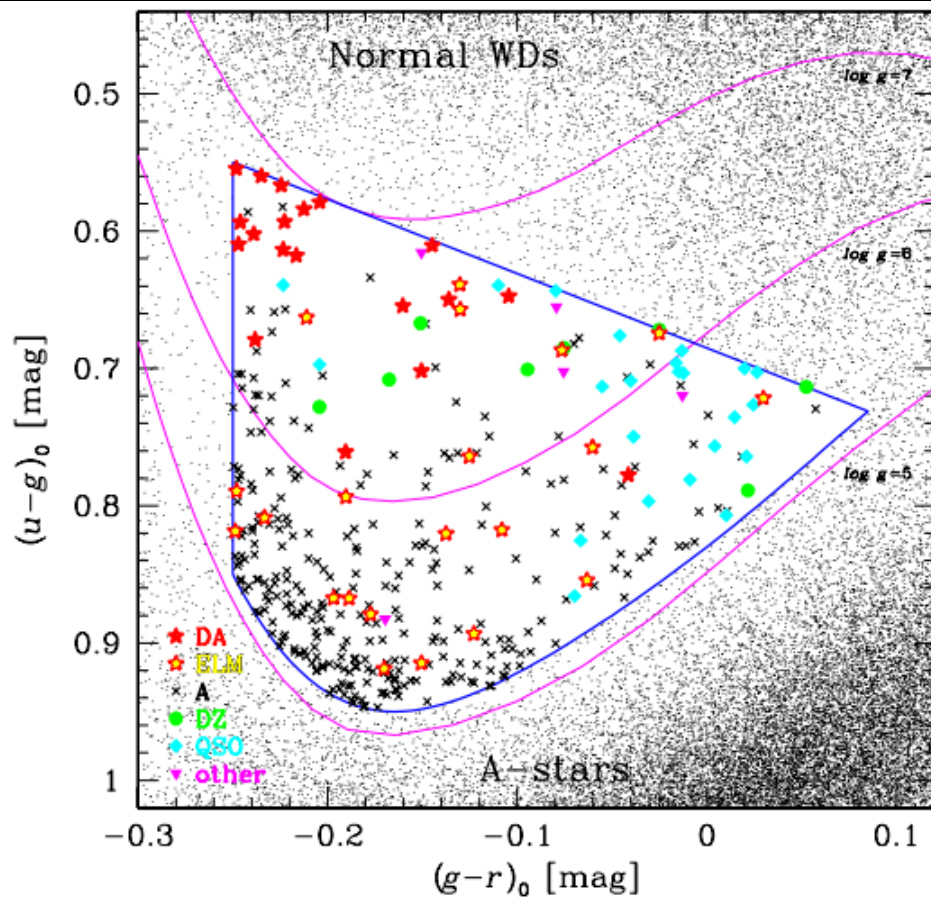


SDSS colors work well for choosing ELM WD candidates

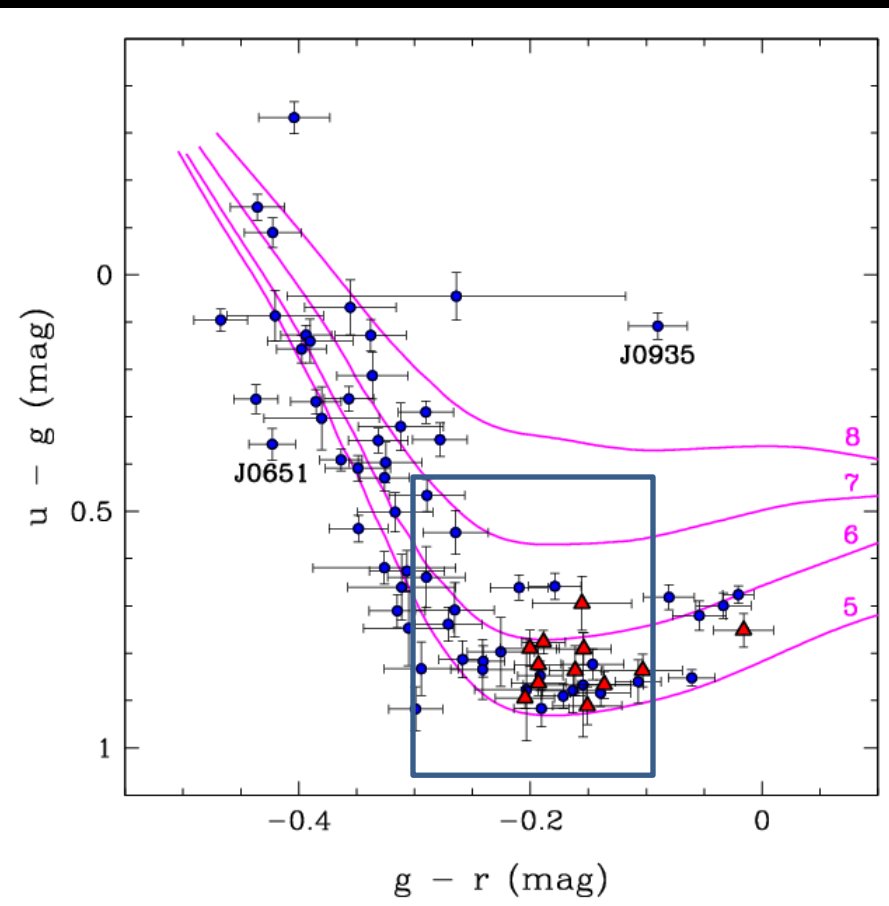


Brown et al. (2012, ApJ, 744, 142)

SDSS colors work well for choosing ELM WD candidates



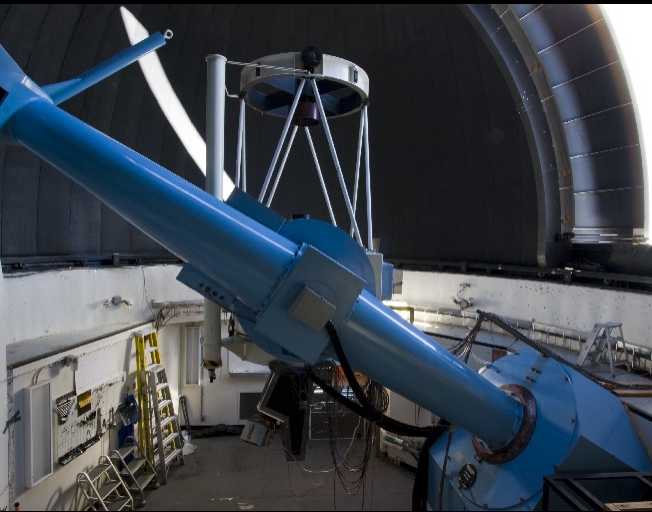
Brown et al. (2012, *ApJ*, 744, 142)



Gianninas et al. (2015, *ApJ*, 812, 167)

Radial Velocity Follow-Up

FLWO 1.5m



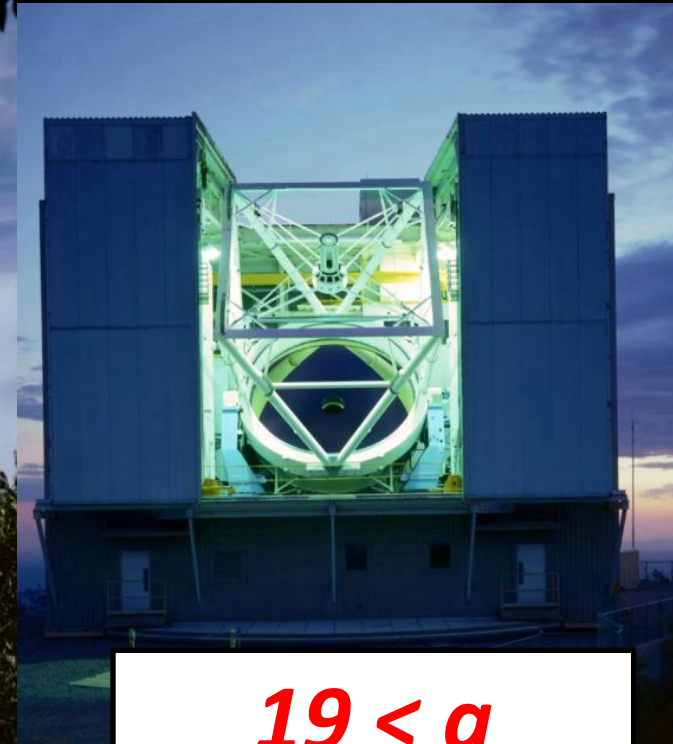
$g < 17$

KPNO 4m



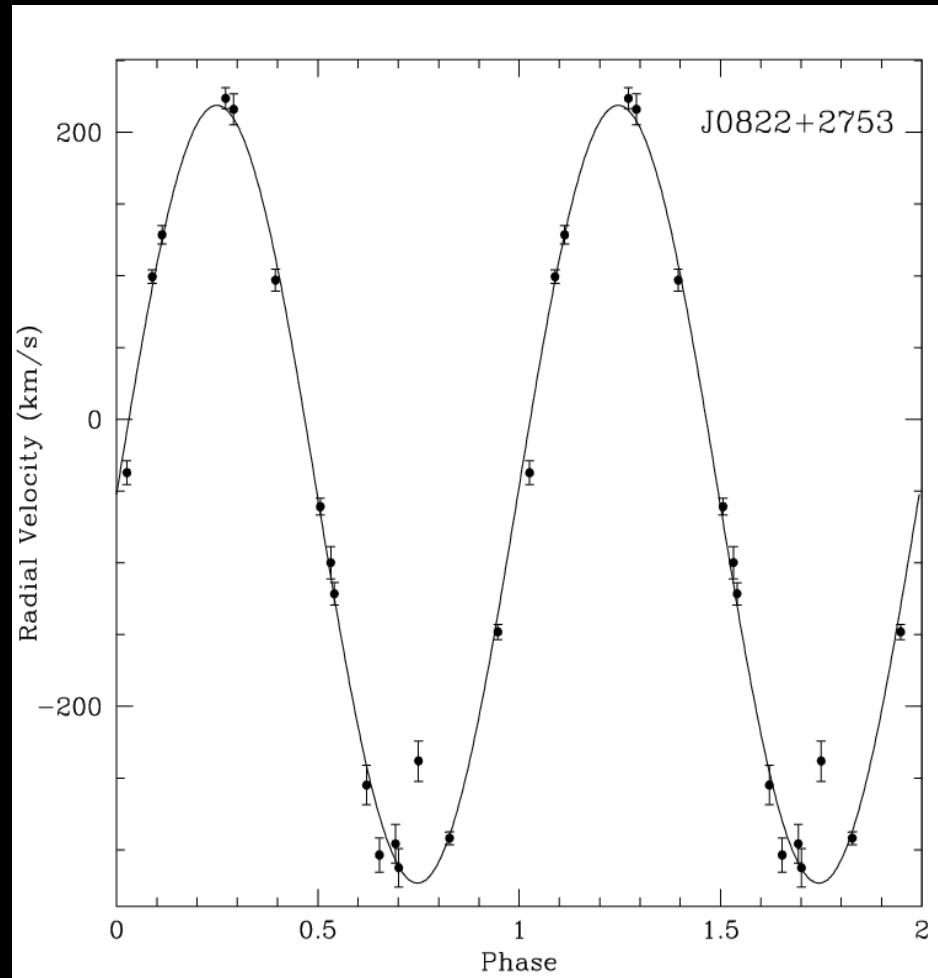
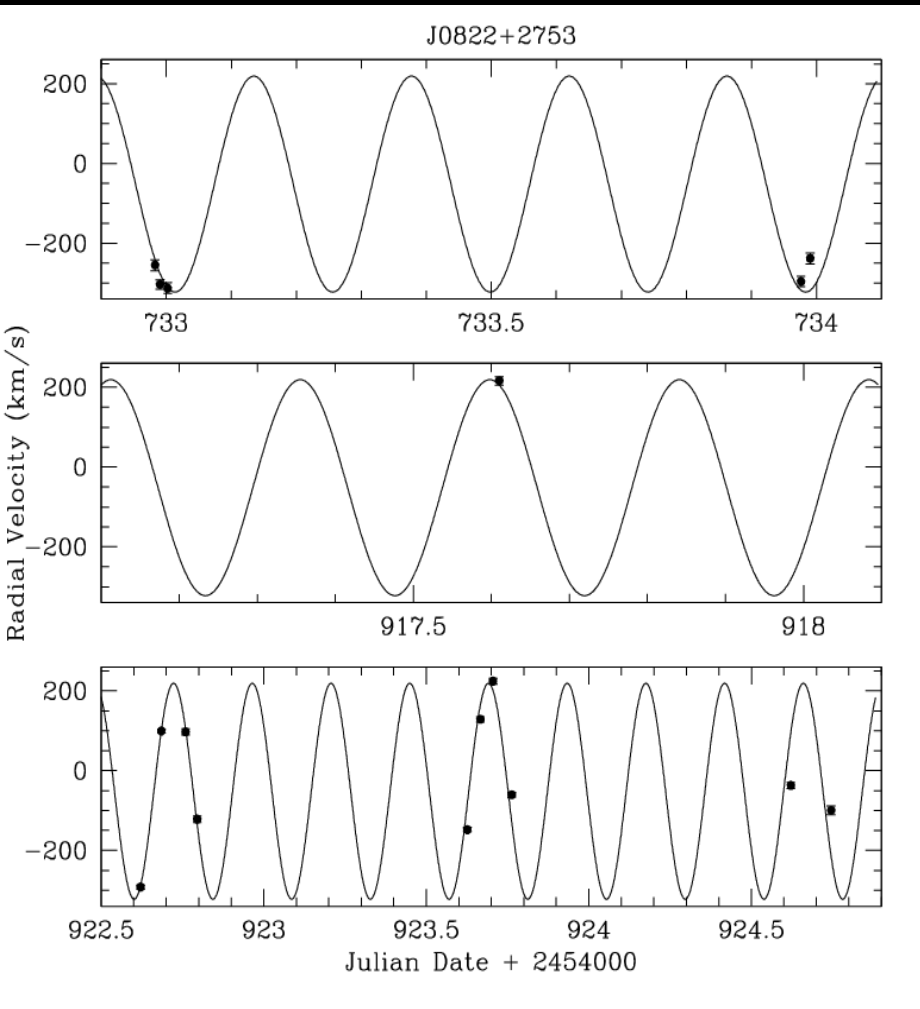
$17 < g < 19$

MMT 6.5m



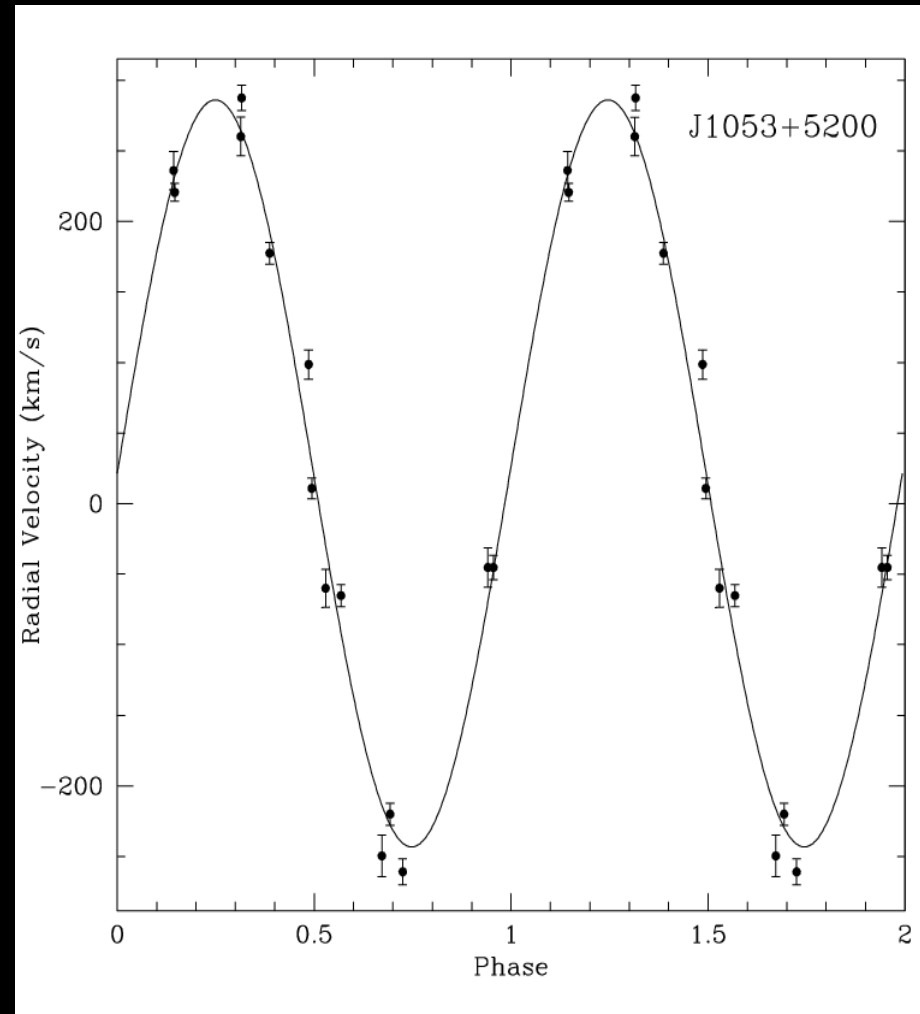
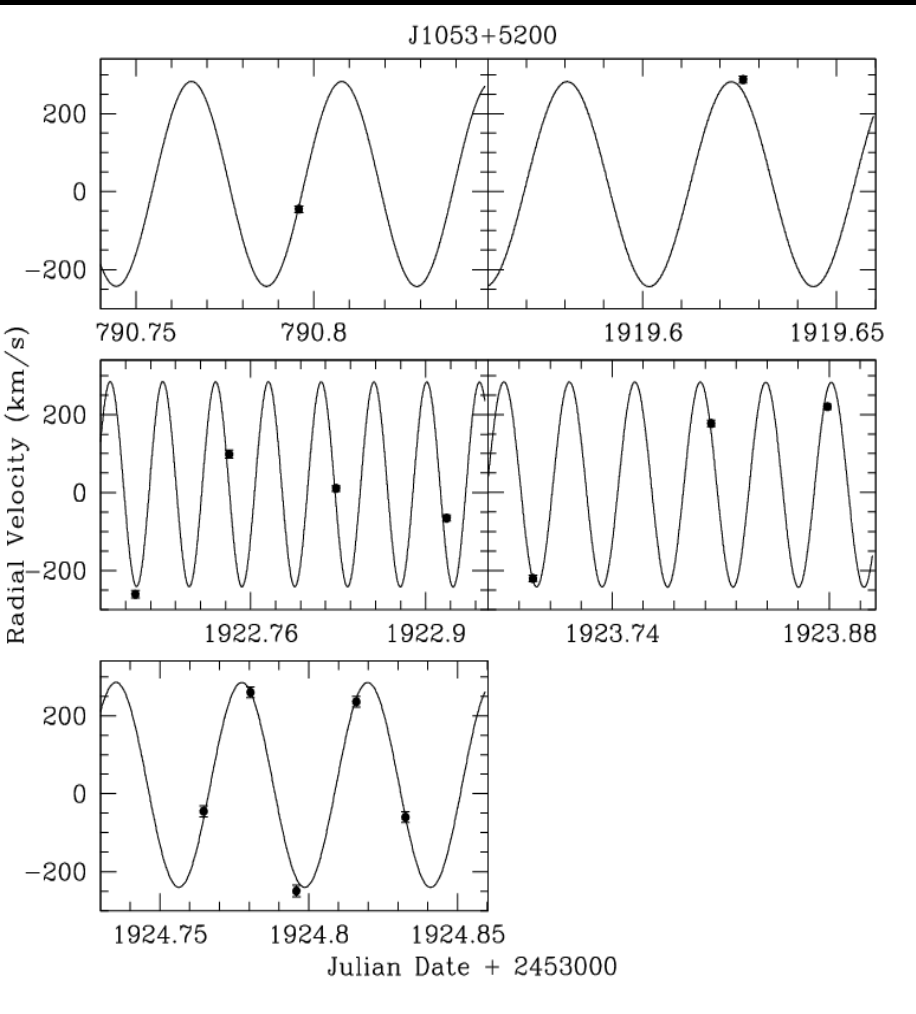
$19 < g$

$P = 5.9$ hr binary



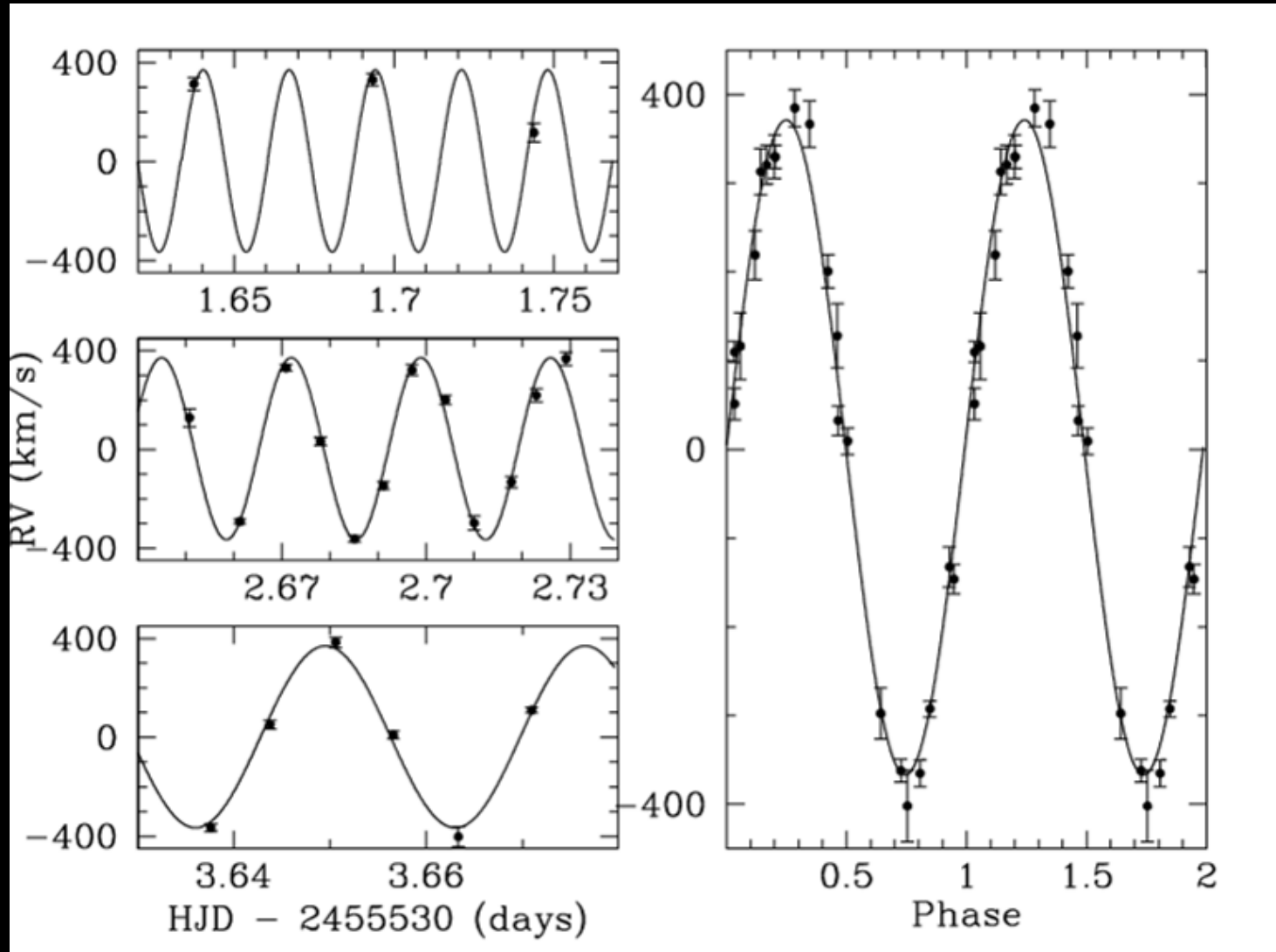
Kilic et al. (2010, ApJ, 716, 122)

$P = 1.0$ hr binary



Kilic et al. (2010, ApJ, 716, 122)

J0106-1000: $P = 39$ min binary!

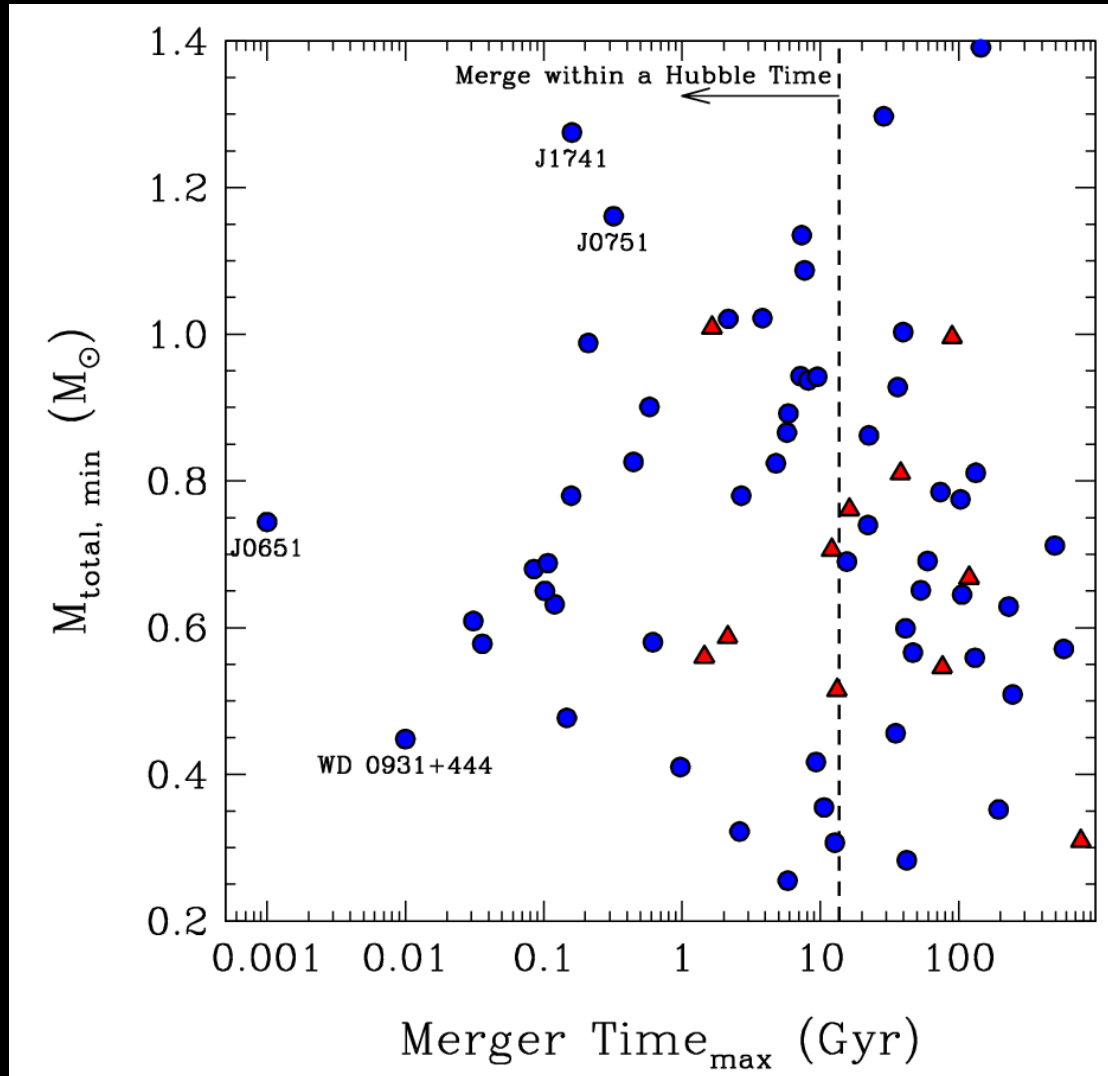


Kilic et al. (2011, MNRAS, 413, L101)

ELM Survey so far...

- *88 new ELM WDs of which 76 are in compact binaries with Periods < 1 day*
- *40 systems that will merge within a Hubble*

Lots of new merger systems!



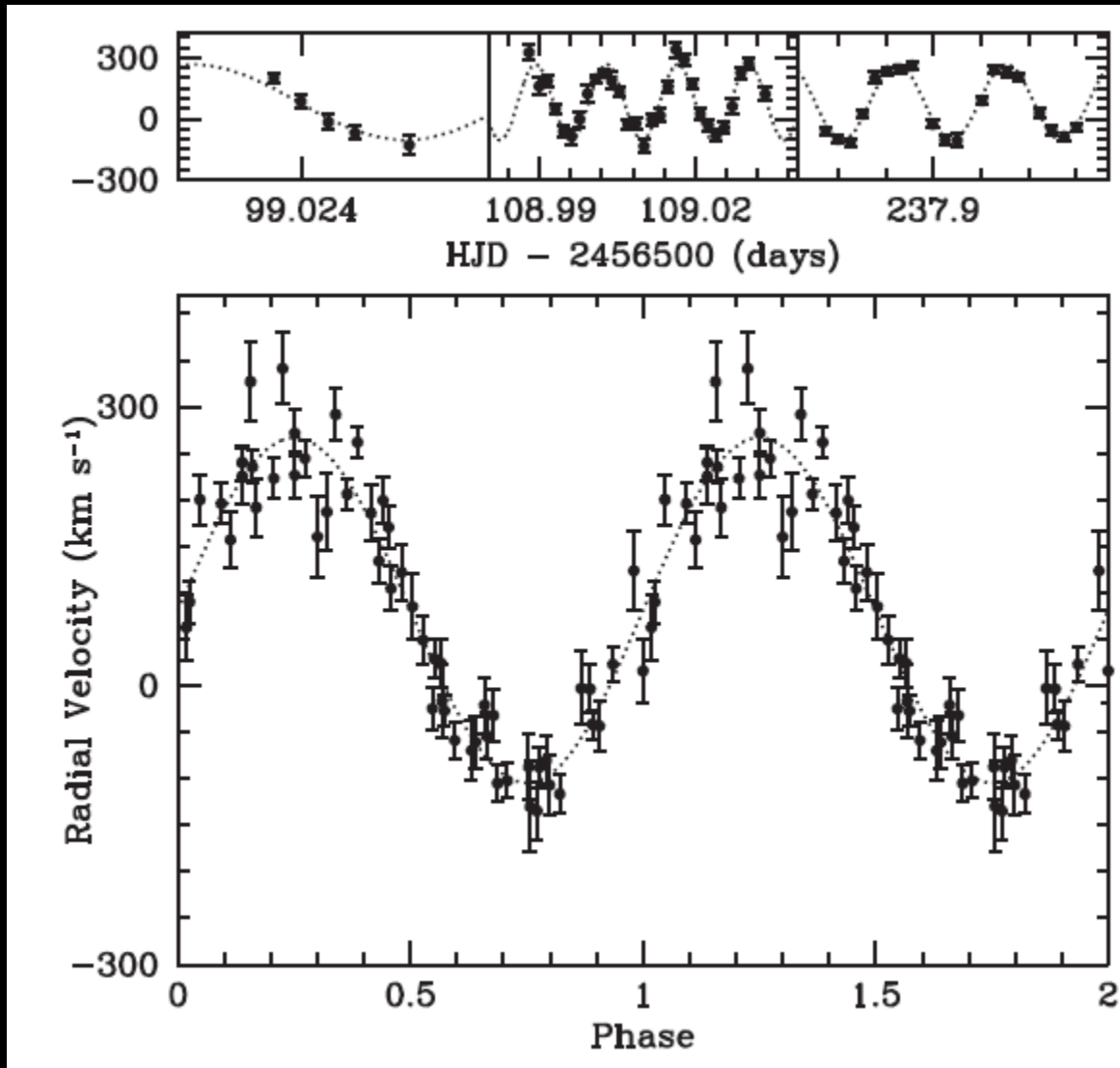
Gianninas et al. (2015, ApJ, 812, 167)

ELM Survey so far...

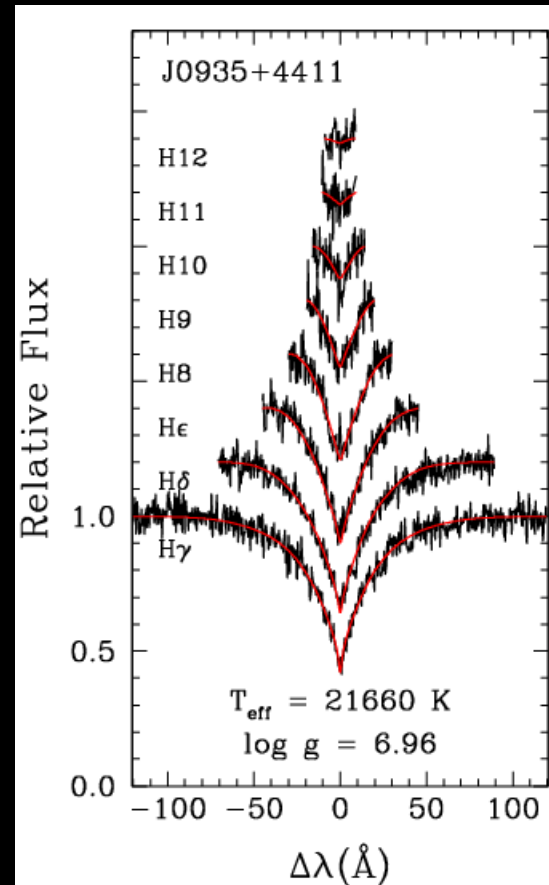
- *88 new ELM WDs of which 76 are in compact binaries with Periods < 1 day*
- *40 systems that will merge within a Hubble*
- *Estimated merger rate of $3 \times 10^{-3} \text{ yr}^{-1}$ (Brown et al., 2016, ApJ, 824, 46)*
 - *40x formation rate of AM CVn (cataclysmic variables)*
 - *6-30x rate of Underluminous SN*
 - *\approx formation rate of R Cor Bor stars (unusual carbon-rich supergiants)*

WD 0931+444: a new 20-min ELM WD!

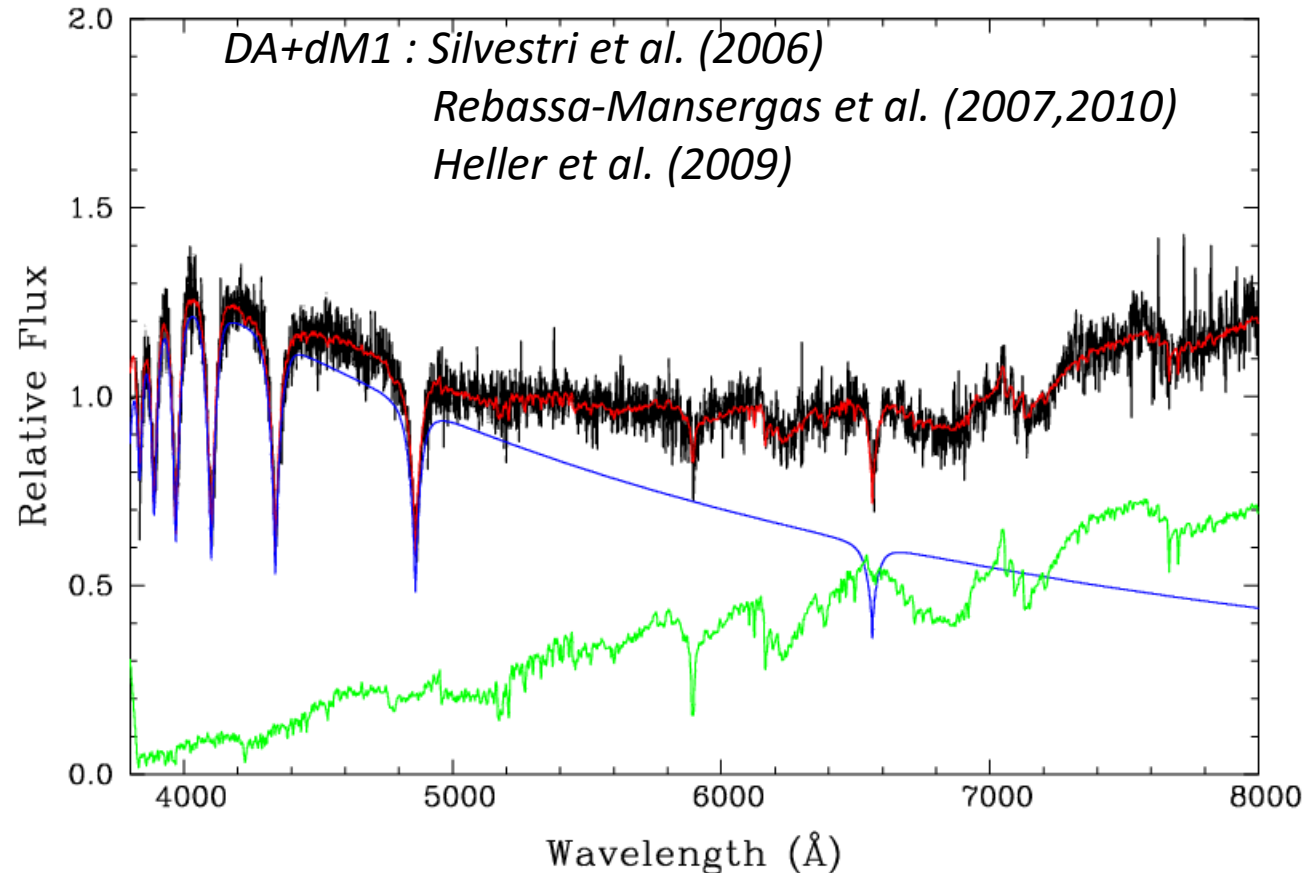
- Chosen from a preliminary selection of SDSS DR10 candidates
- The system will merge in less than 9 Myr



WD 0931+444 looks like a DA+dM...



MMT 6.5m



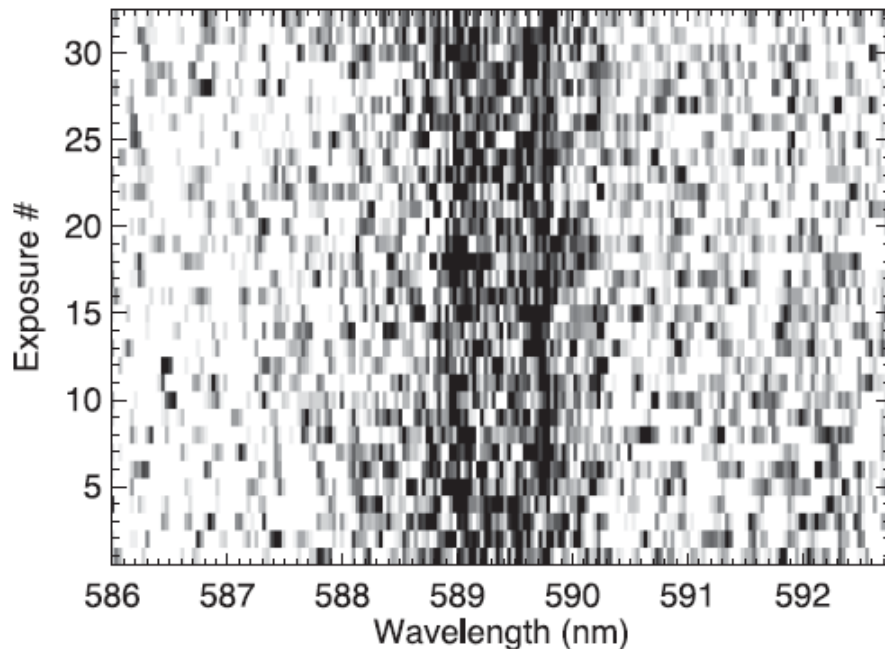
SDSS

Kilic et al. (2014, MNRAS, 441, L1)

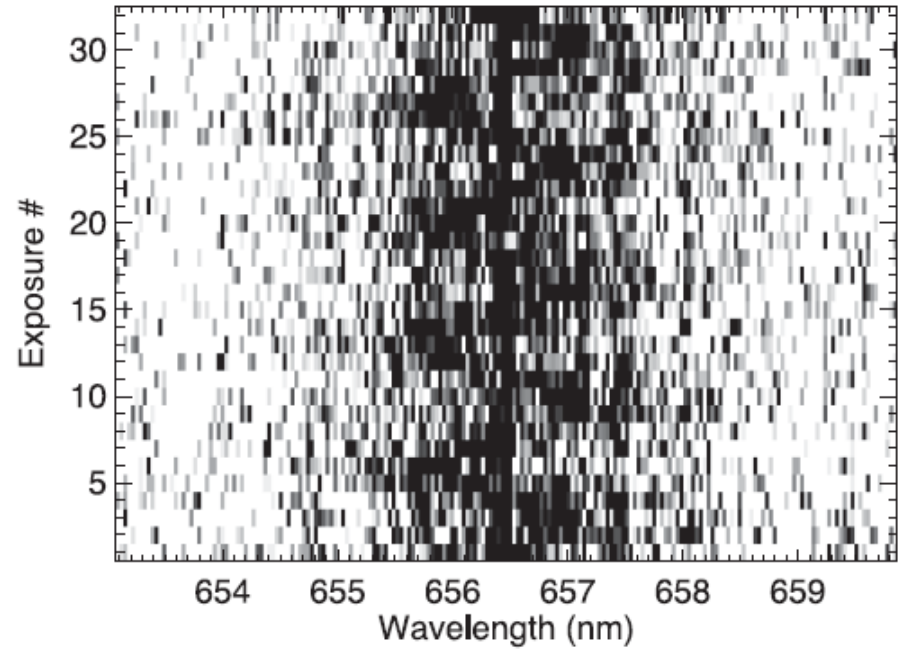
8m Gemini data shows the dM is a background object



Time resolved spectroscopy from Gemini North with GMOS



Na I doublet

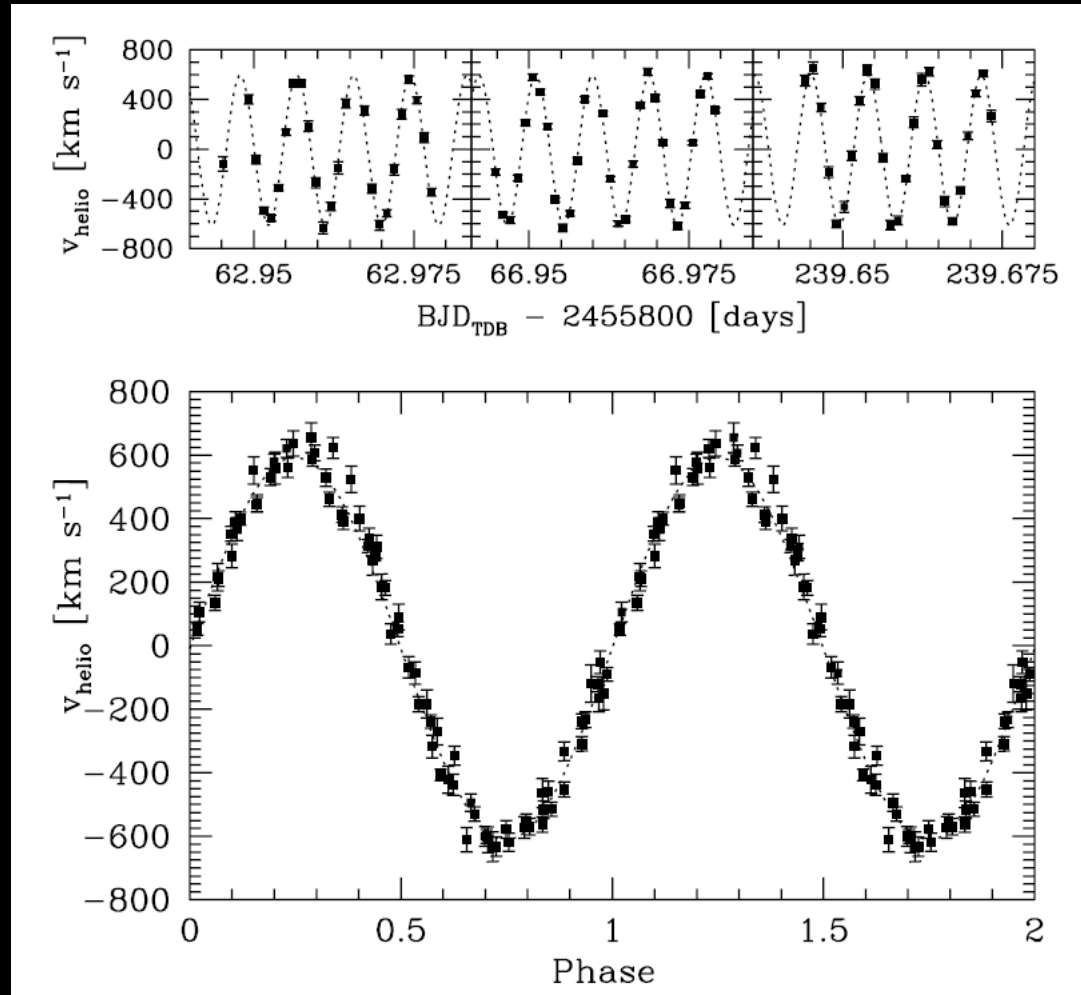


H α

Kilic et al. (2014, MNRAS, 441, L1)

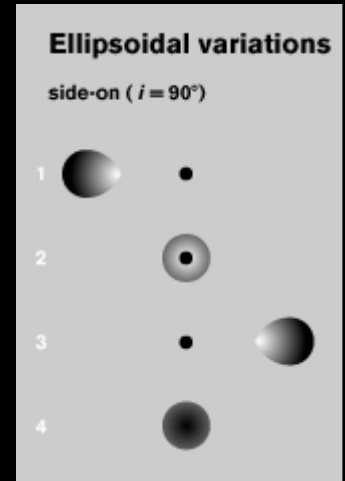
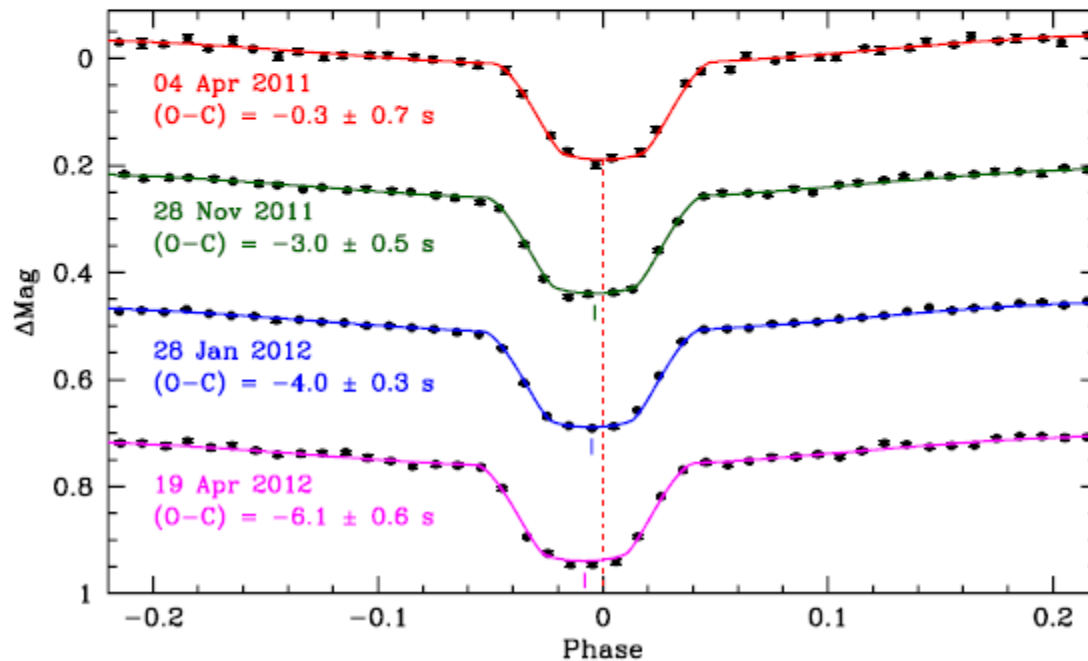
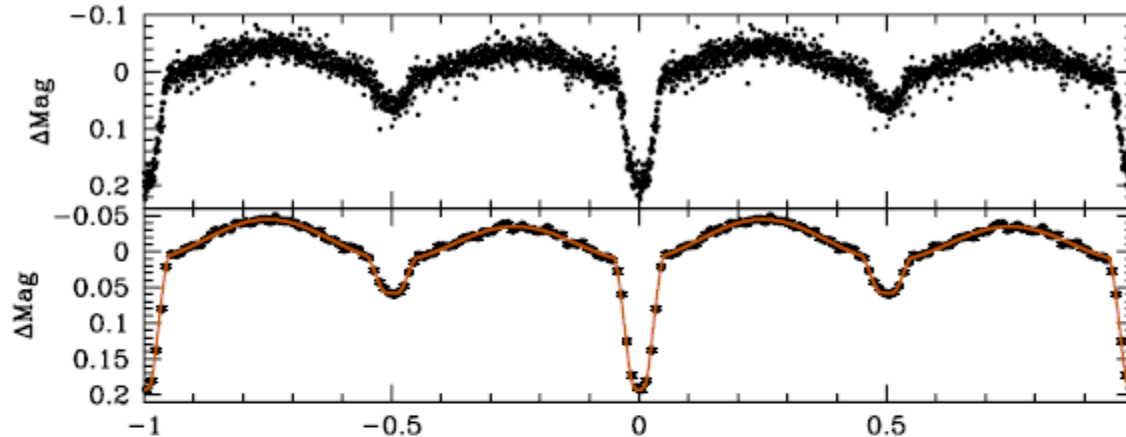
J0651: the poster child for ELM WDs

- *Shortest period ELM WD binary*
→ $P = 12.75 \text{ min!}$
- *During my talk > 2 orbits!*
- *Eclipsing!*



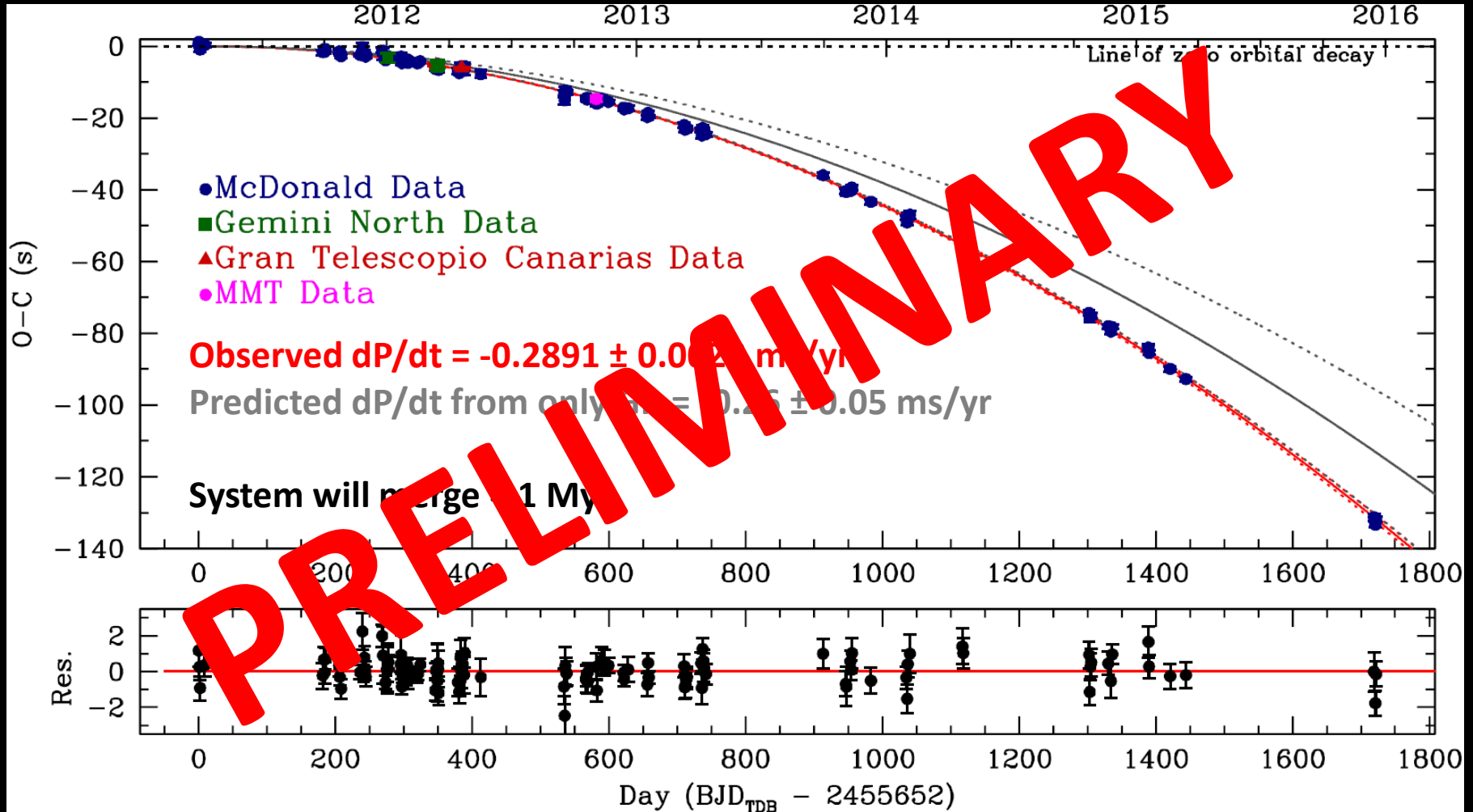
Hermes et al. (2012, ApJ, 757, 21)

Primary and secondary eclipses clearly detected + ellipsoidal variations



Hermes et al. (2012, ApJ, 757, 21)

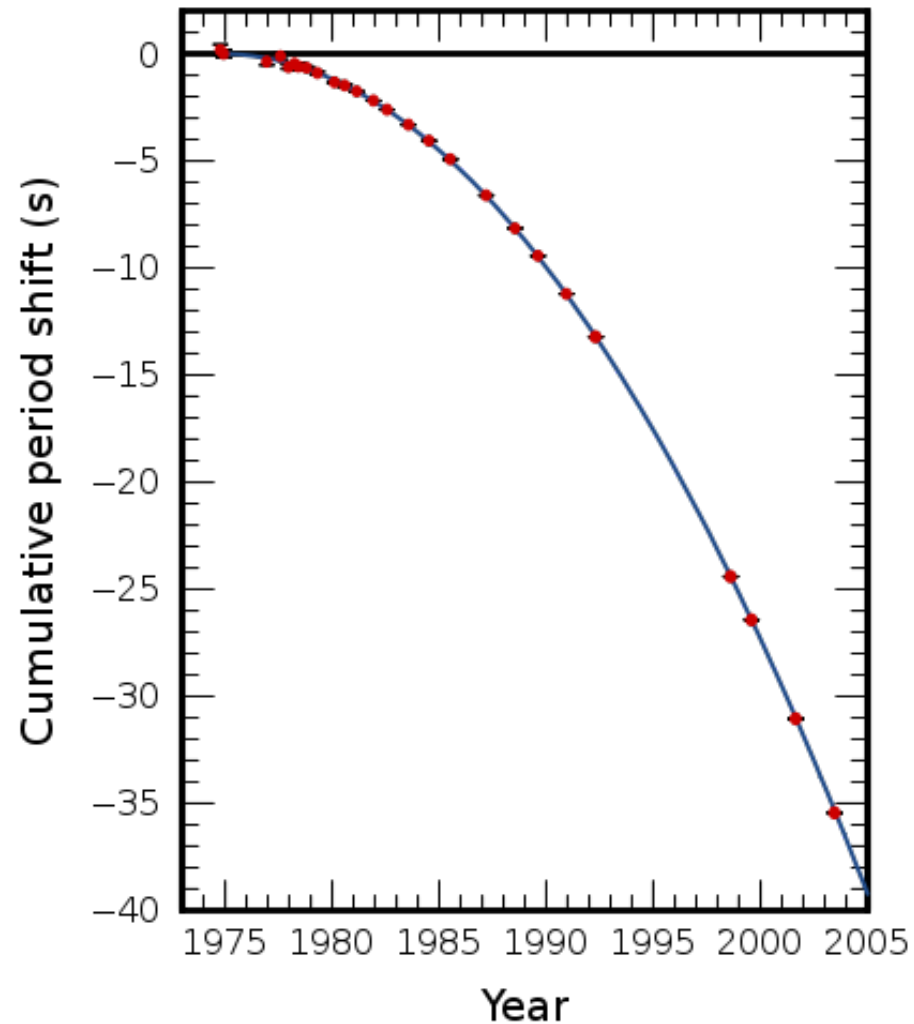
The rate of decay agrees with the prediction of General Relativity!



JJ Hermes (2016, private communication)

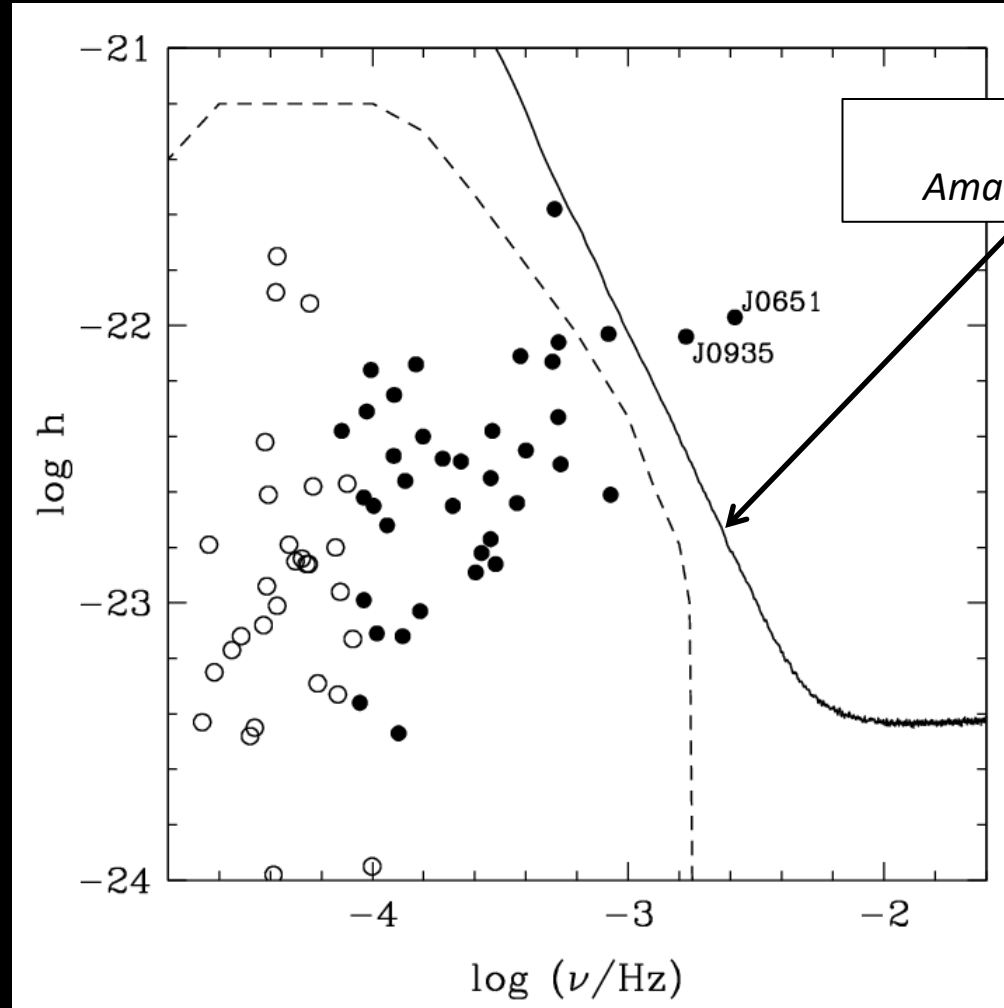
PSR B1913+16: The Hulse-Taylor pulsar

- *Orbital decay of a binary pulsar system (PSR + NS)*
- *First evidence of GW*
- *Merger time ≈ 300 Myr*
- *1993 Nobel Prize in Physics*
- *It took 30 years to display the same period shift as J0651 did in 2 years!*



Weisberg & Taylor (2005, ASPC, 328, 25)

ELM WDs are among the loudest gravitational wave verification sources for eLISA/LISA



eLISA after 2 years
Amaro-Seoane et al. (2013)

Kilic et al. (2015, ASSP, 40, 167)

Conclusions & Outlook

- *The ELM Survey has greatly increased the number of known ELM WD binaries and WD merger systems*
- *The two shortest period systems, J0651 and WD 0931+444, are among the loudest gravitational wave verification sources for LISA*
- *The ELM Survey continues...*
 - *~100-150 candidates in various stages of follow-up*
 - *Looking to expand the survey to the southern hemisphere... LSST will be very helpful!*
 - *GAIA*