

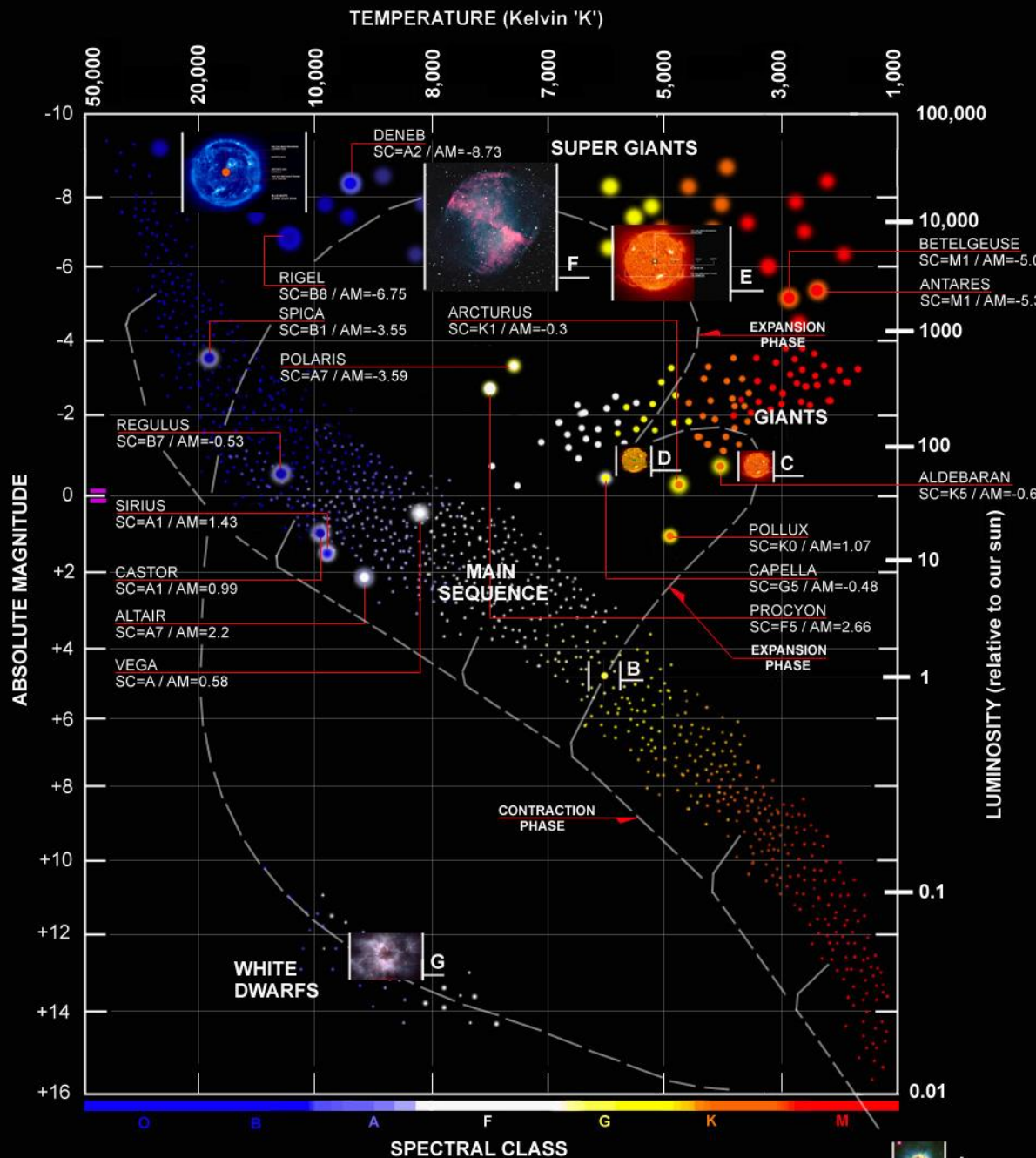
**THE LINK BETWEEN UNDERLUMINOUS
SUPERNOVAE EXPLOSIONS, GRAVITATIONAL
WAVES AND
EXTREMELY LOW MASS WHITE DWARFS**



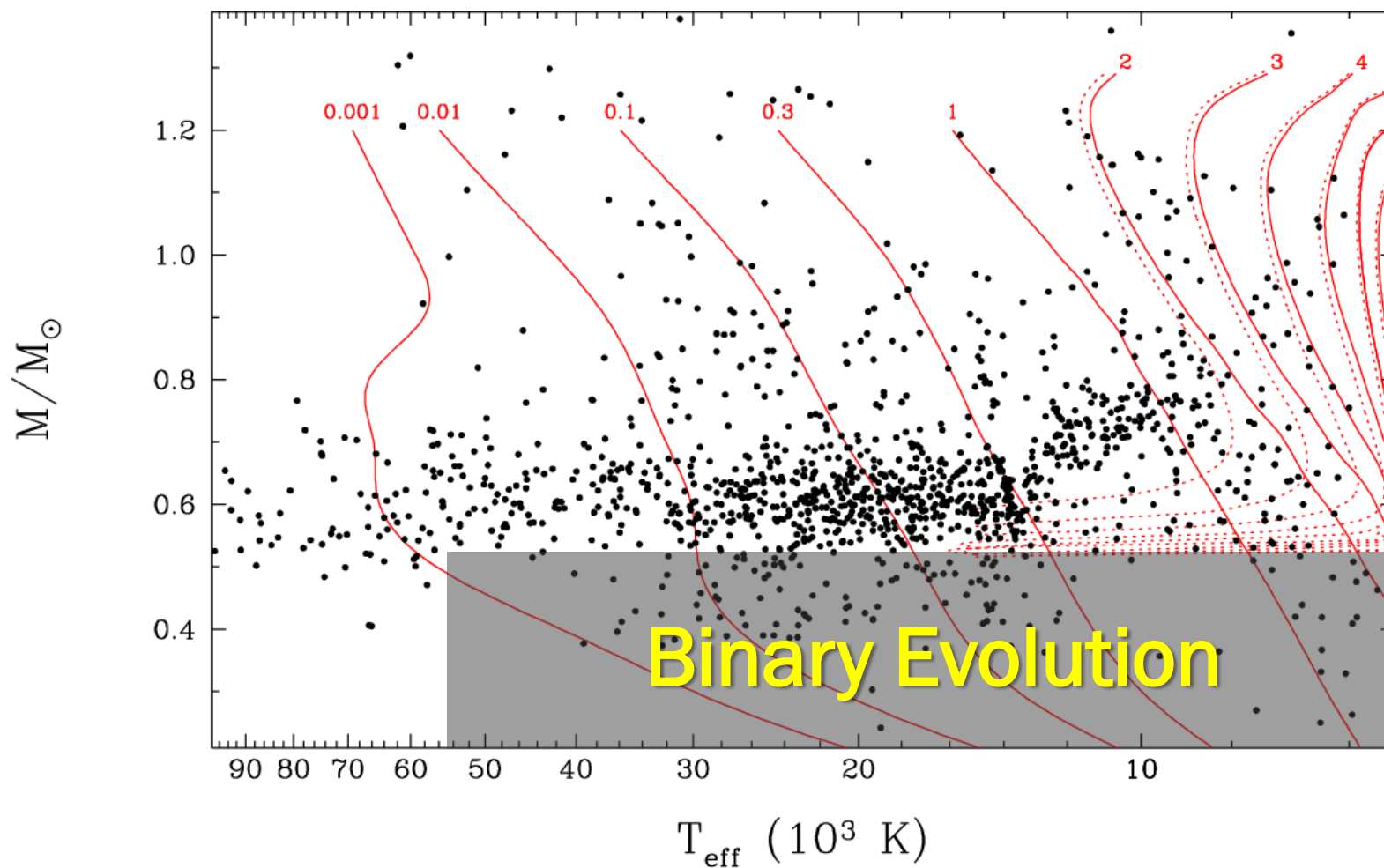
**Alex Gianninas
Mukremin Kilic, Warren Brown, & J.J. Hermes
December 9th, 2013
27th Texas Symposium**

White Dwarf Properties

- $M \sim 0.6 M_{\odot}$
- $R \sim 0.01 R_{\odot} \sim 1 R_{\oplus}$
- $\rho \sim 10^6 \rho_{\odot}$
- $\log g \sim 8.0$
($\log g_{\odot} = 4.4$)
- $T_{\text{eff}} \sim 150,000 \rightarrow 3000 \text{ K}$
- No H burning \rightarrow WDs cool over several Gyrs



Gianninas et al. (2011)



Low-mass white dwarfs need friends: five new double-degenerate close binary stars

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- ◎ These “friends” are binary companions that stripped a significant amount of material from the progenitor, preventing the ignition of He burning, giving birth to an extremely low mass (ELM) WD
- ◎ ELM WDs are found almost exclusively in short-period binaries ($P < 1$ day)
- ◎ **Many will merge in less than a Hubble time!**

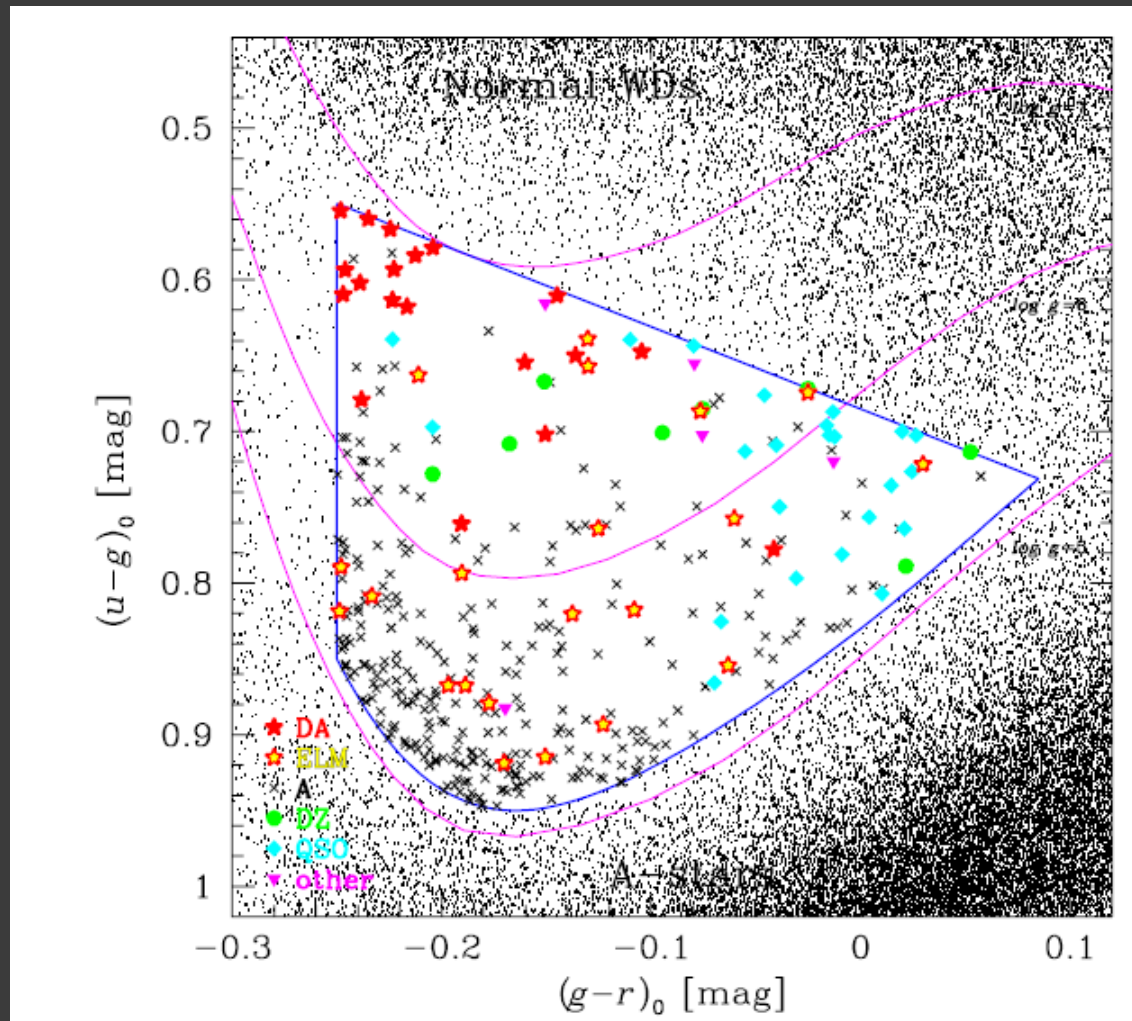
ELM Survey

- ⊙ Targeted search for Extremely Low Mass WDs
- ⊙ ELM WDs = $M < 0.25 M_{\odot}$
- ⊙ Motivation:
 - Progenitors of Type Ia supernovae (DD channel)
 - Progenitors of underluminous supernovae (.Ia SN; Bildsten et al. 2007)
 - Progenitors of AM CVn systems (Kilic et al., 2013)
 - Pulsar companions (e.g. PSR J1816+4510; Kaplan et al. 2013)
 - **Nearest systems are important sources of gravitational waves!**

ELM Survey: Target Selection

- Hypervelocity Survey (Warren Brown, SAO): search for B type stars leaving the Galaxy, colors similar to ELM WDs → 15% of targets are in fact ELM WDs
- Spectroscopy from the Sloan Digital Sky Survey (SDSS)
- SDSS colors (u-g, g-r)

ELM Survey: Target Selection



Brown et al. (2012)

ELM Survey: Follow-up

- ⦿ MMT (6.5m), FLWO (1.5m), KPNO 4m
- ⦿ Radial velocity follow-up to confirm the binary nature of each candidate
- ⦿ Once confirmed, we seek to improve our orbital solution by better sampling all phases of the orbit

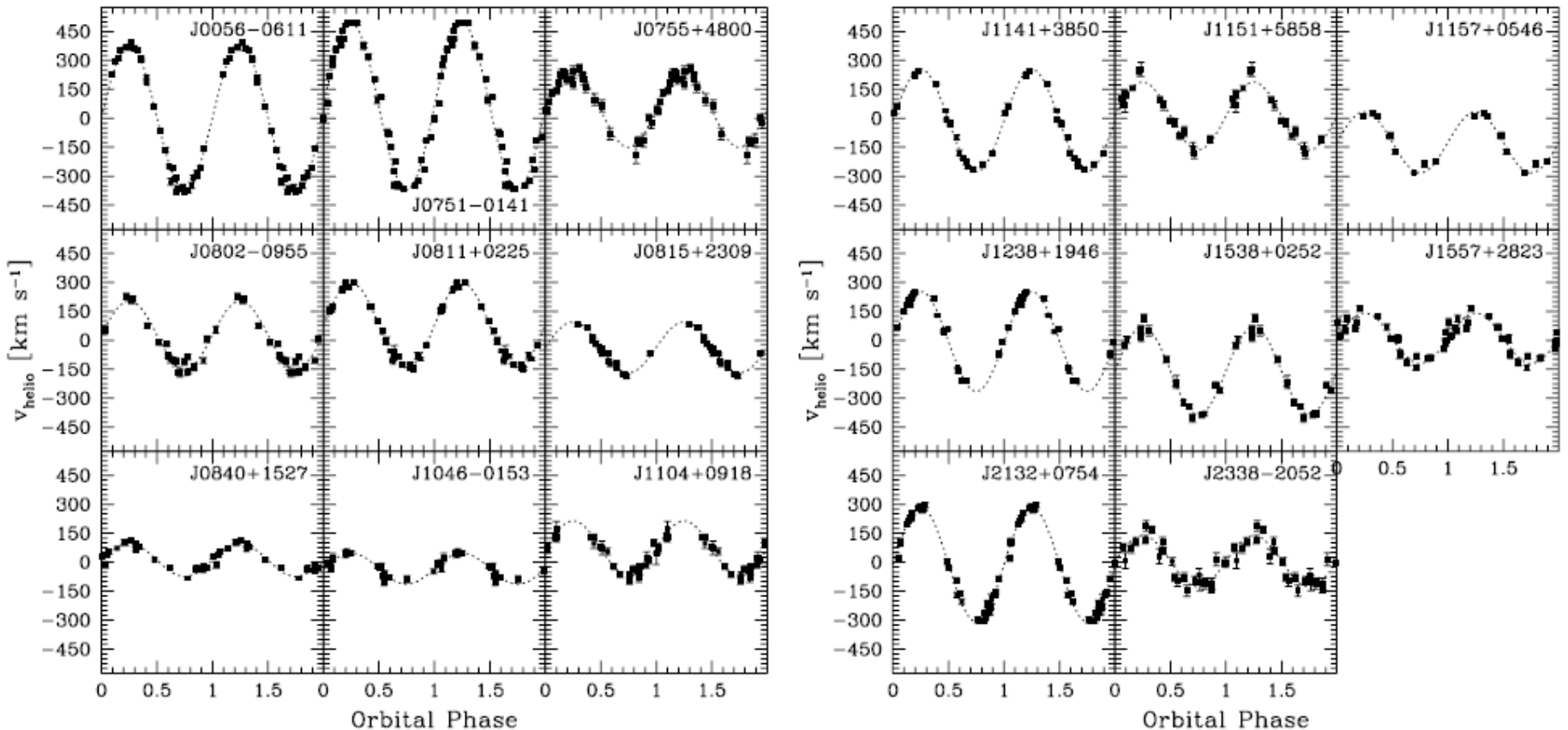


ELM Survey: Success Rate

	Paper	ELM WD	Merger Systems
Brown et al. (2010)	I	12	6
Kilic et al. (2011)	II	4	2
Brown et al. (2012)	III	7	6
Kilic et al. (2012)	IV	7	5
Brown et al. (2013)	V	17	6

- **Before ELM Survey:**
 - Only 6 known merger systems (SPY)
 - Shortest known period is $P = 1.5$ hr
- ELM Survey has found 8 systems with $P < 1.5$ hr and 3 with $P < 1$ hr

Orbital Solutions

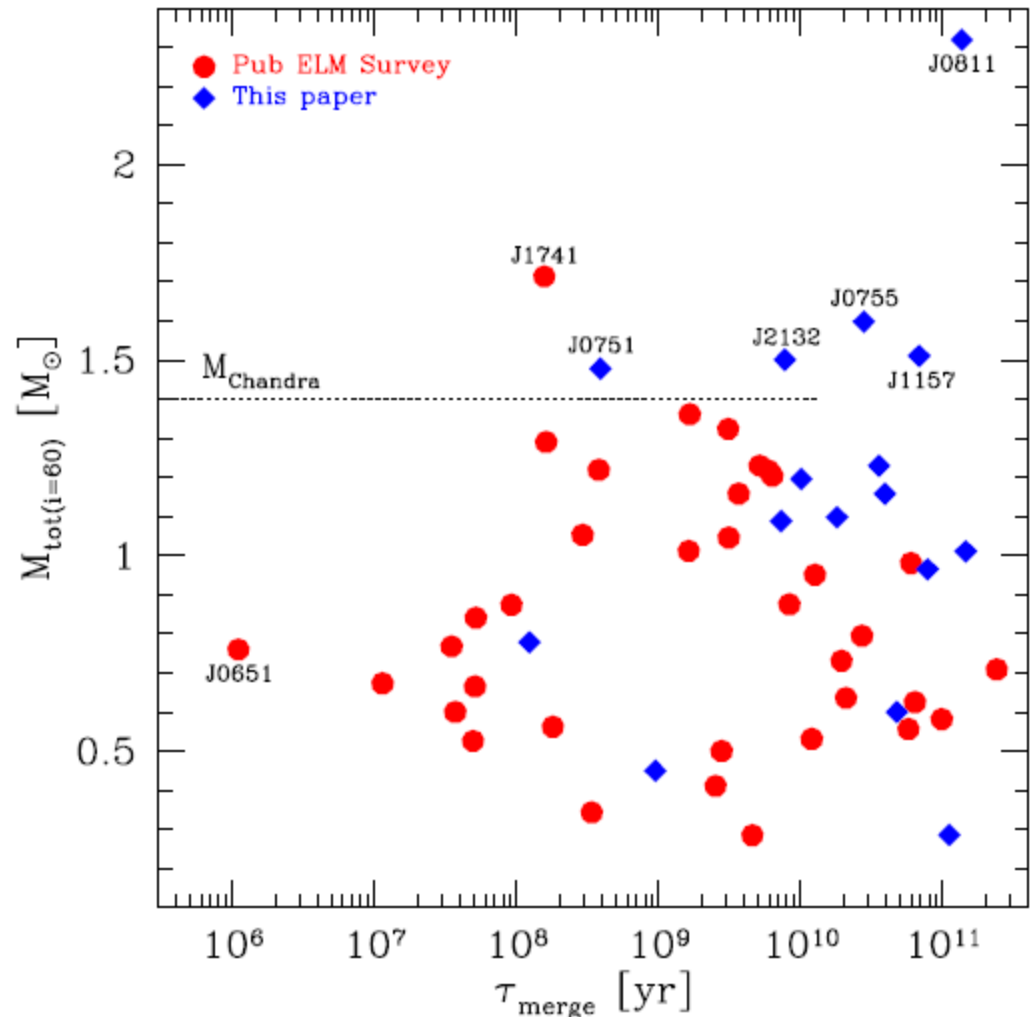


Orbital solutions provide period (P) and velocity semi-amplitude (K)

Brown et al. (2013)

ELM Survey: Results

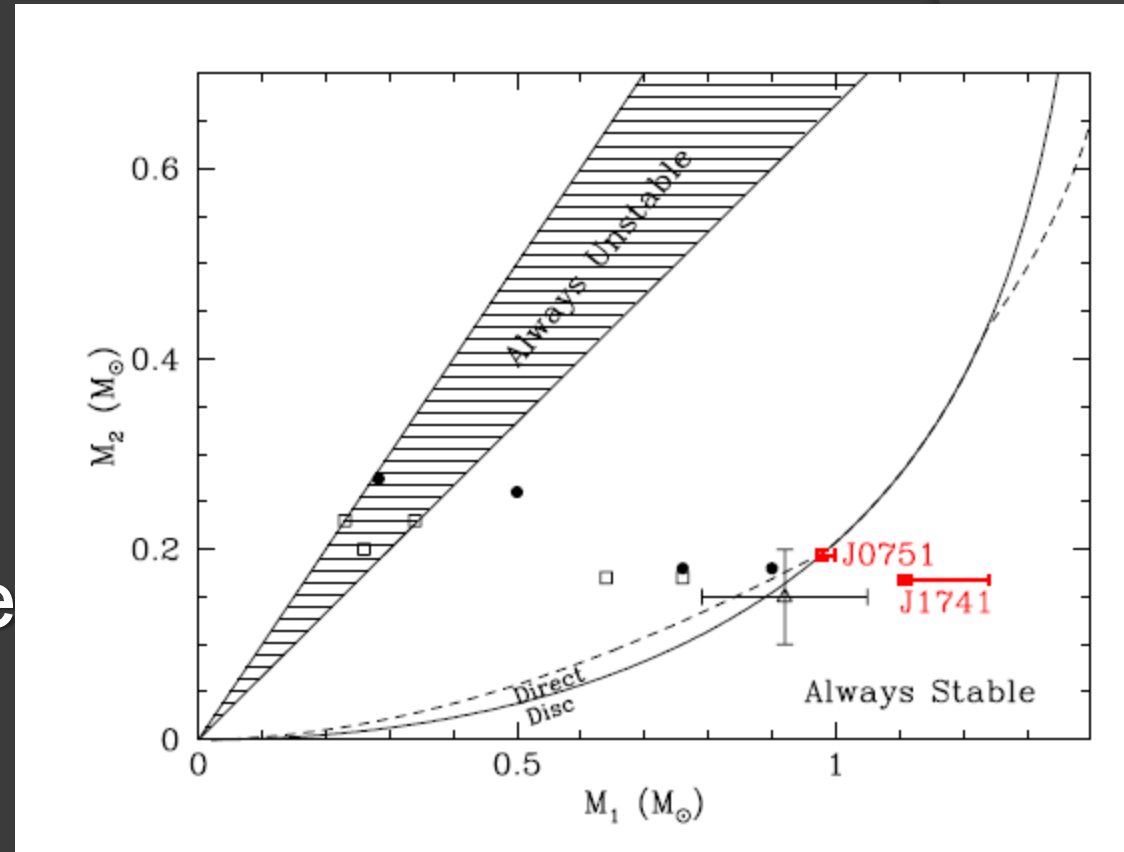
- Super-Chandrasekhar mass systems not necessarily Type Ia progenitors
- Mass ratio is important
- 0.2 + 1.2 M systems → Stable mass transfer system (AM CVn, .Ia SN)
- Can be WD+NS binaries



Brown et al. (2013)

Progenitors of AM CVn (cataclysmic variables, novae)

- Massive Companion
- Pulsars? No detections with Chandra
- Will undergo stable mass transfer
- Result: AM CVn

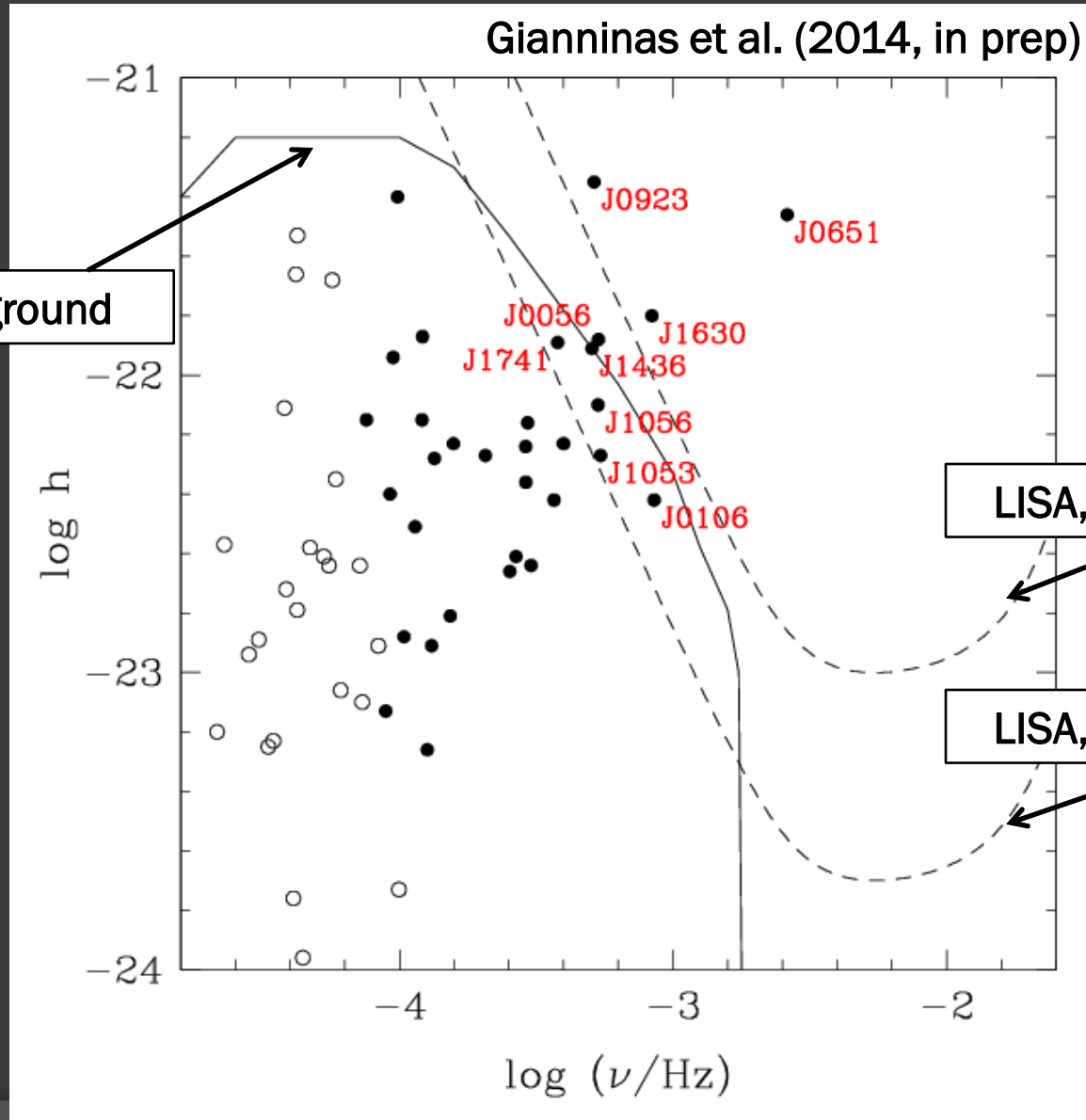


Kilic et al. (2013)

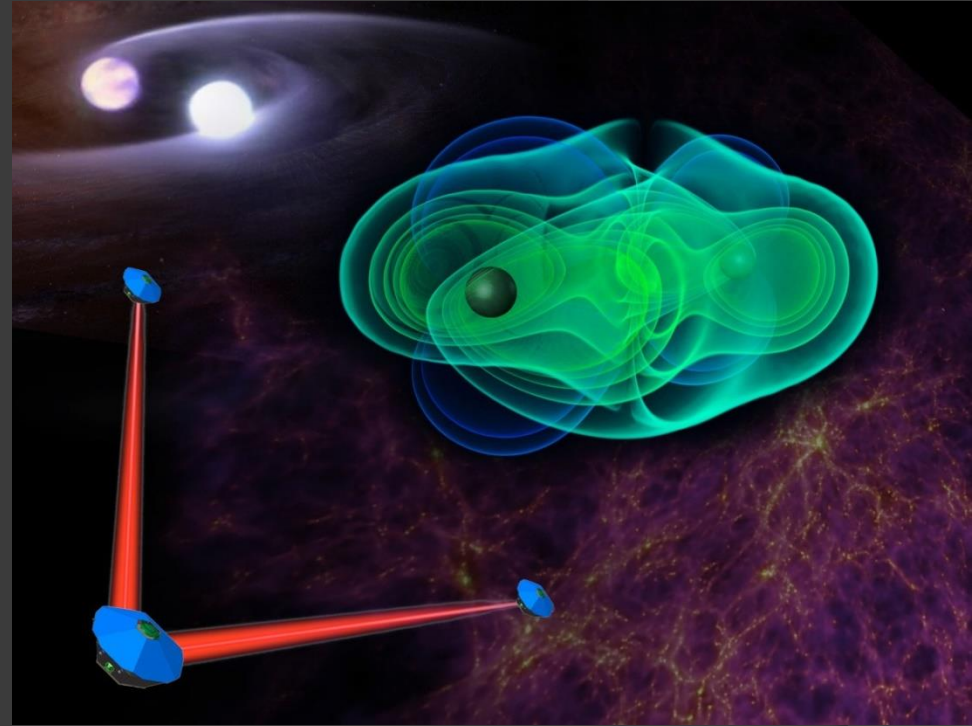
Masses & Radii

- ⦿ Model dependent and model independent measurements
- ⦿ Model independent:
 - Eclipses
 - Ellipsoidal variations (tidal distortion)
- ⦿ Model dependent: two ingredients
 - Precise measurements of the atmospheric parameters (T_{eff} and $\log g$)
 - Evolutionary models (Althaus et al., 2013)

Gravitational Wave Strain

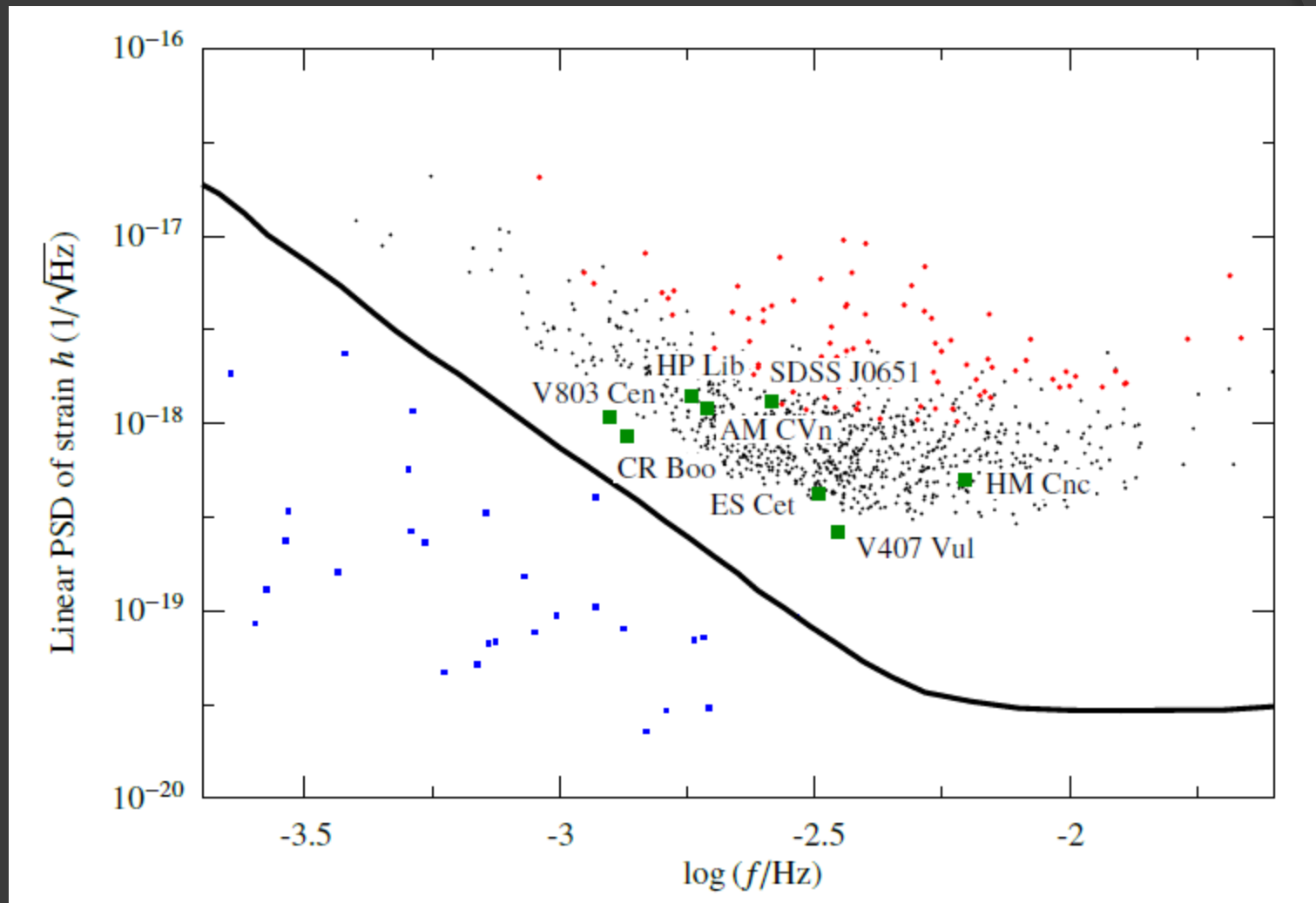


eLISA



- ⊙ Replaces LISA
 - **Two** beams instead of three
 - Reduced sensitivity
 - Frequency range spans four decades (~ 0.1 mHz – ~ 1 Hz)
- ⊙ “The Gravitational Universe” approved as science theme for ESA L3 project (launch in ~ 2034)

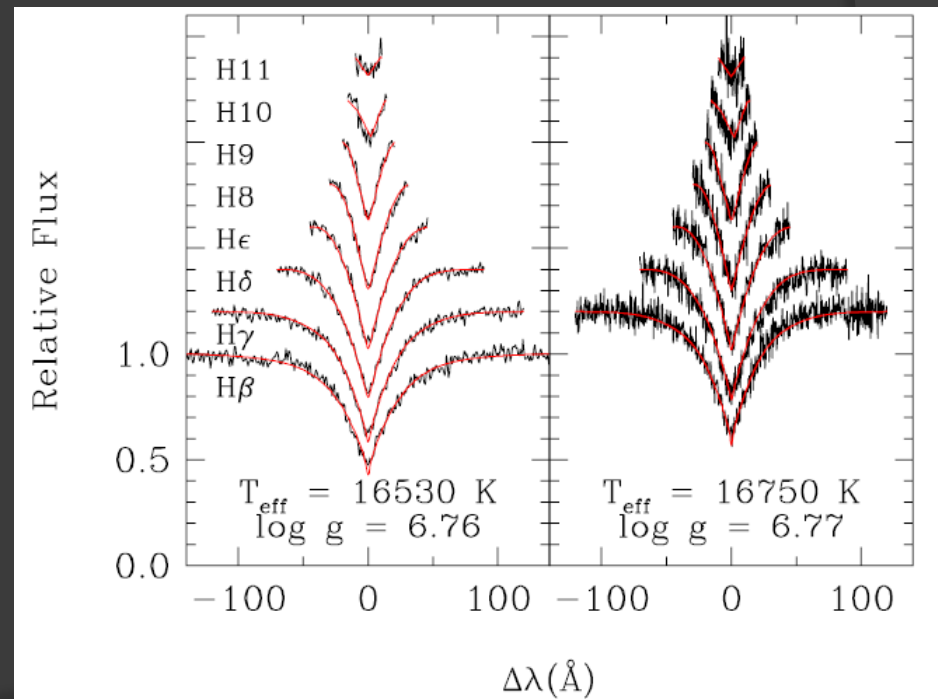
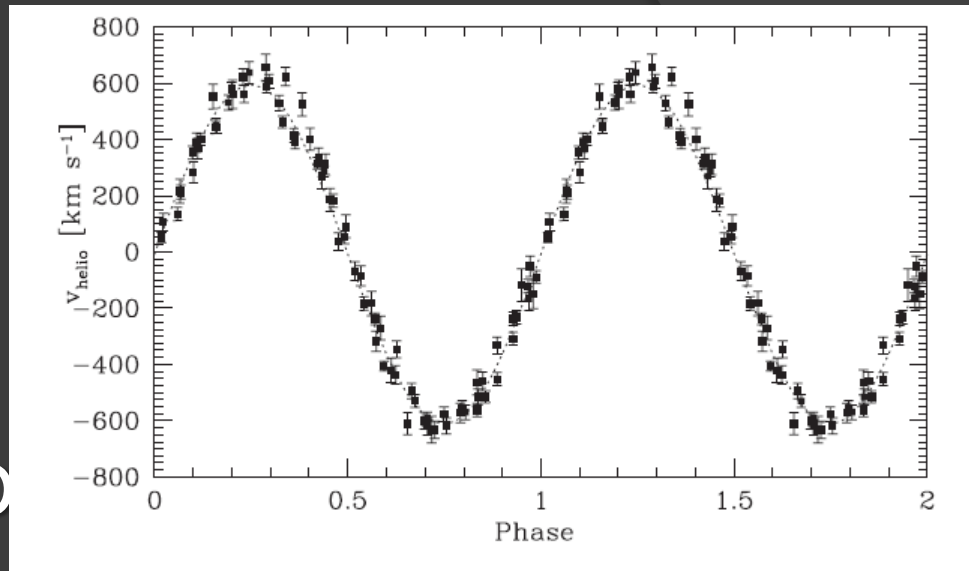
eLISA Verification Sources



Amaro-Seoane et al. (2013)

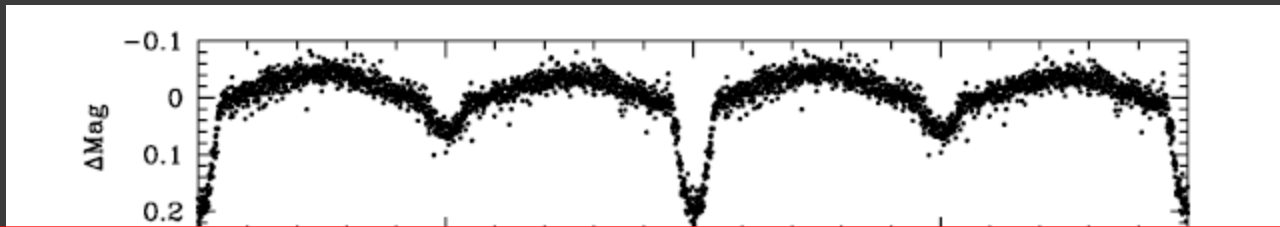
J0651

- “Poster child” for ELM WDs
- Shortest period ELM WD binary $\rightarrow P = 12.75$ min!
- Eclipsing!
- After initial discovery, photometric follow-up at McDonald, APO, Gemini North and GTC

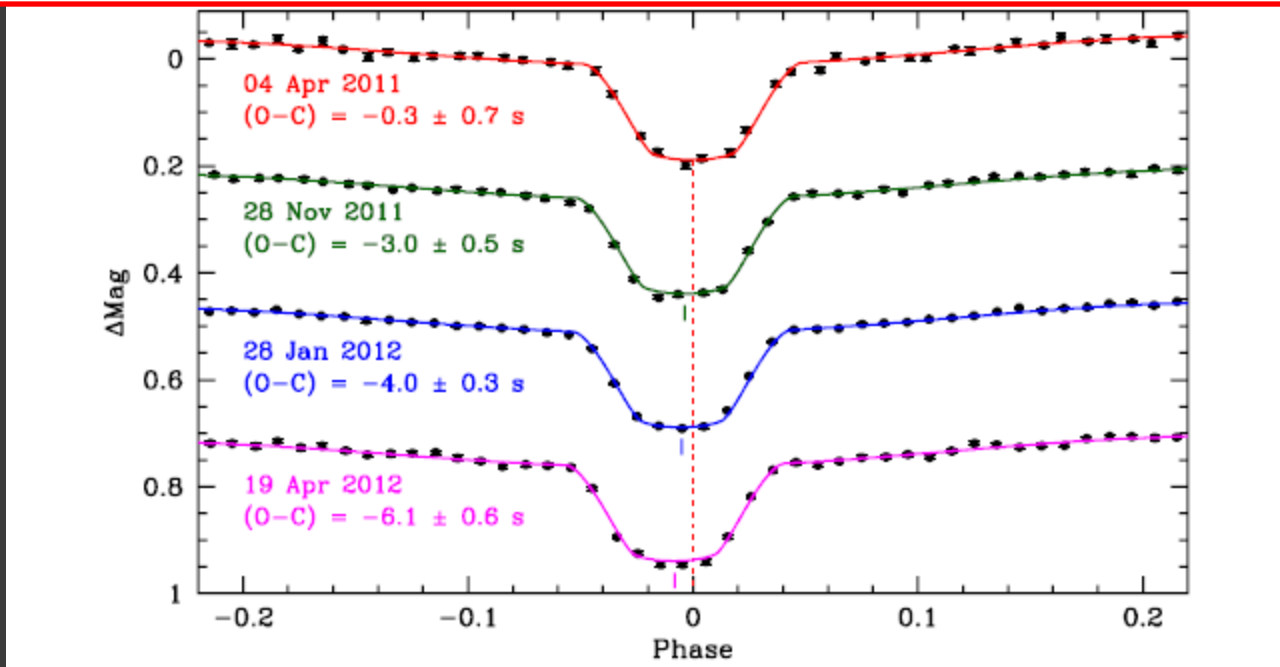


Hermes et al. (2013)

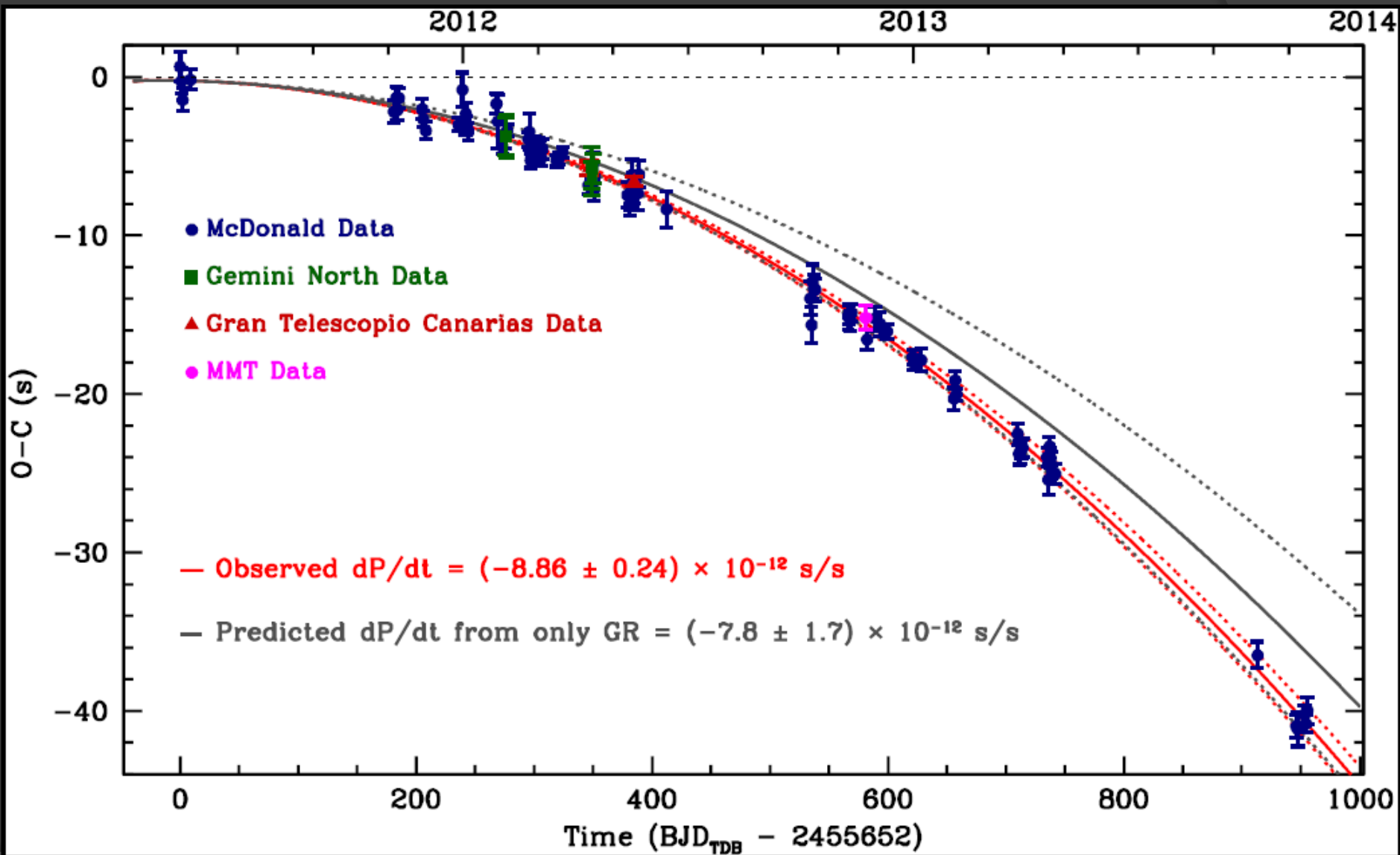
Light Curves for J0651



Direct detection of orbital decay!



O-C Diagram for J0651

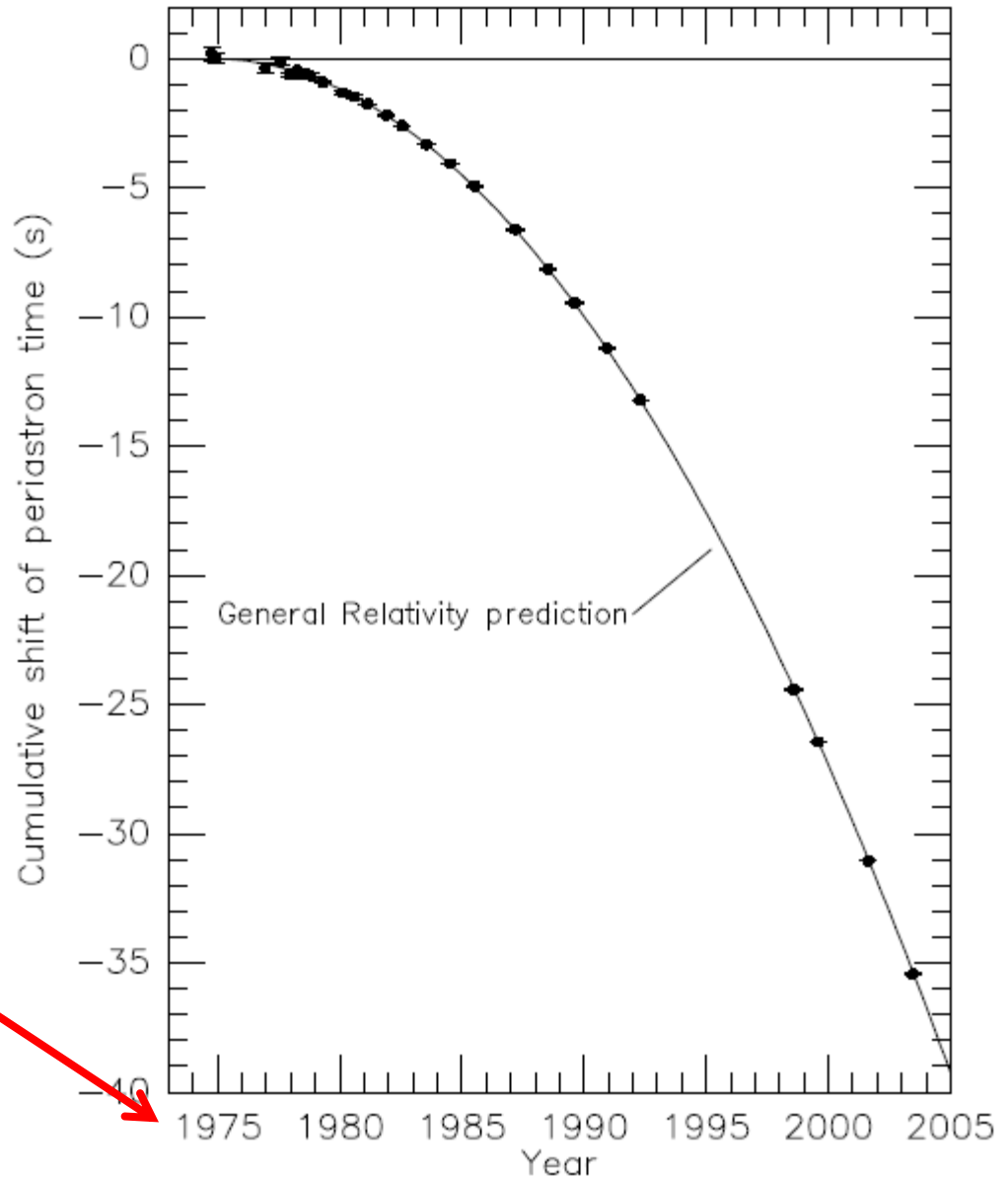


Hulse-Taylor Pulsar

PSR B1913+16

30 YEARS!

Weisberg & Taylor (2005)



Conclusions

- ⦿ ELM Survey: targeted search for extremely low-mass WDs
- ⦿ Success: ~60 systems with $P < 1$ day
- ⦿ J0651
 - Rate of orbital decay agrees with GR
 - Only takes a few years to detect
 - Verification source for eLISA

More to come...

◎ ELM Survey

- Ongoing: upcoming observing runs on MMT and KPNO 4m
- Expand to Southern Hemisphere
- **NEW!** : 20-min system discovered!

◎ J0651

- Continued monitoring