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

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Live fast, die young!

Slow burn...

But... over 50% of stars are in binary systems!
Mass distribution of WDs from SDSS

\[ \langle M/M_\odot \rangle = 0.613 \text{ (S/N > 15)} \]
\[ \sigma = 0.126 \]
\[ \langle M/M_\odot \rangle = 0.611 \text{ (S/N > 20)} \]
\[ \sigma = 0.123 \]

Low mass WD peak

WD Mass Distribution as a Function of $T_{\text{eff}}$

Common Envelope Evolution

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
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\[ \log g = 7.5 \]

\[ \log g = 3.9 \]
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$P = 5.9$ hr binary

$P = 1.0 \text{ hr binary}$

J0106-1000: $P = 39 \text{ min binary!}$

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!

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- 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**  

8m Gemini data shows the dM is a background object

Time resolved spectroscopy from Gemini North with GMOS

Na I doublet  Hα

**J0651: the poster child for ELM WDs**

- **Shortest period ELM WD binary**: $P = 12.75$ min!
- **During my talk > 2 orbits!**
- **Eclipsing!**

Primary and secondary eclipses clearly detected + ellipsoidal variations

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

- Observed \( \frac{dP}{dt} = -0.2891 \pm 0.0028 \text{ ms/yr} \)
- Predicted \( \frac{dP}{dt} \) from only GR = \( -0.26 \pm 0.05 \text{ ms/yr} \)
- System will merge \( \approx 1 \text{ Myr} \)

\[ \text{Res.} = 0.0 \pm 0.0 \]

\( \text{Day (BJD}_{\text{TPB}} - 2455652) \)
PSR B1913+16: The Hulse-Taylor pulsar

- Orbital decay of a binary pulsar system (PSR +NS)
- First evidence of GW
- Merger time $\approx 300$ 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

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

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