Insight from APOGEE Binaries with White Dwarf Companions

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CCAPP Fellows Symposium
Sept. 28, 2023

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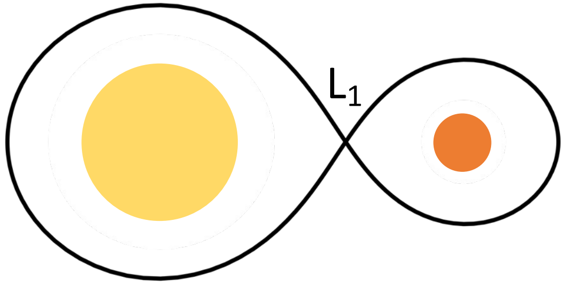
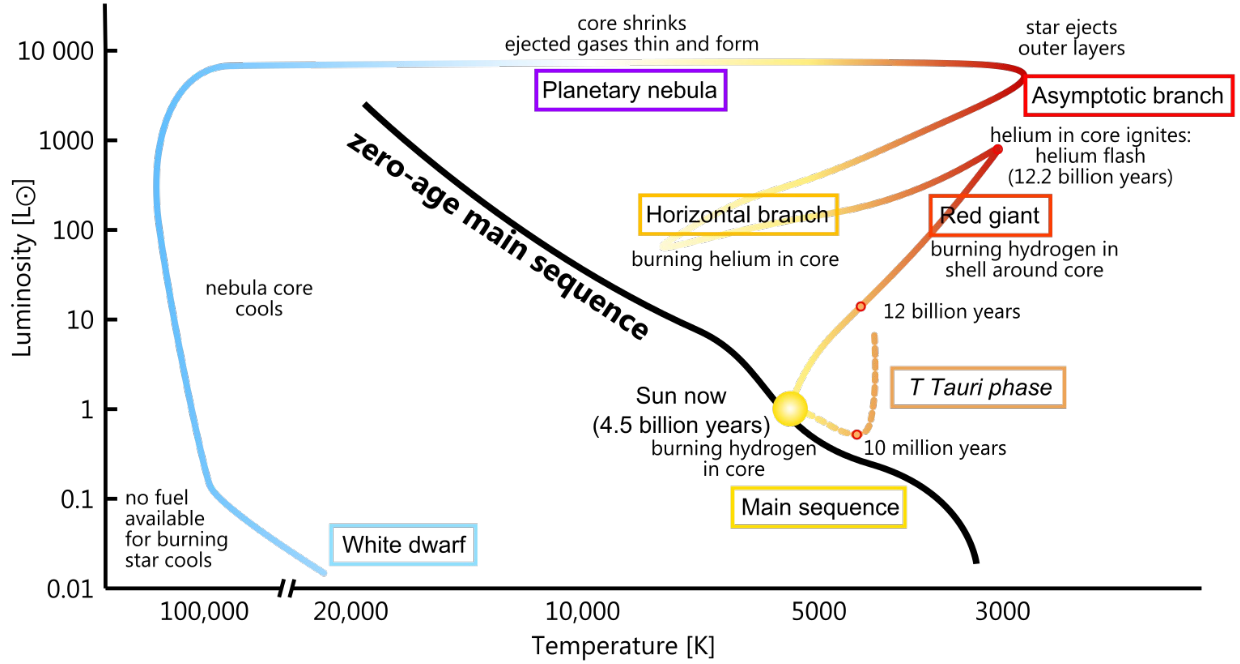
Mass Transfer: a feature of stellar evolution

Stars change their physical size by several orders of magnitude over their lifetimes.

But what happens to binary star systems?





Oftentimes, binaries are separated enough that they don't interact while on the MS.

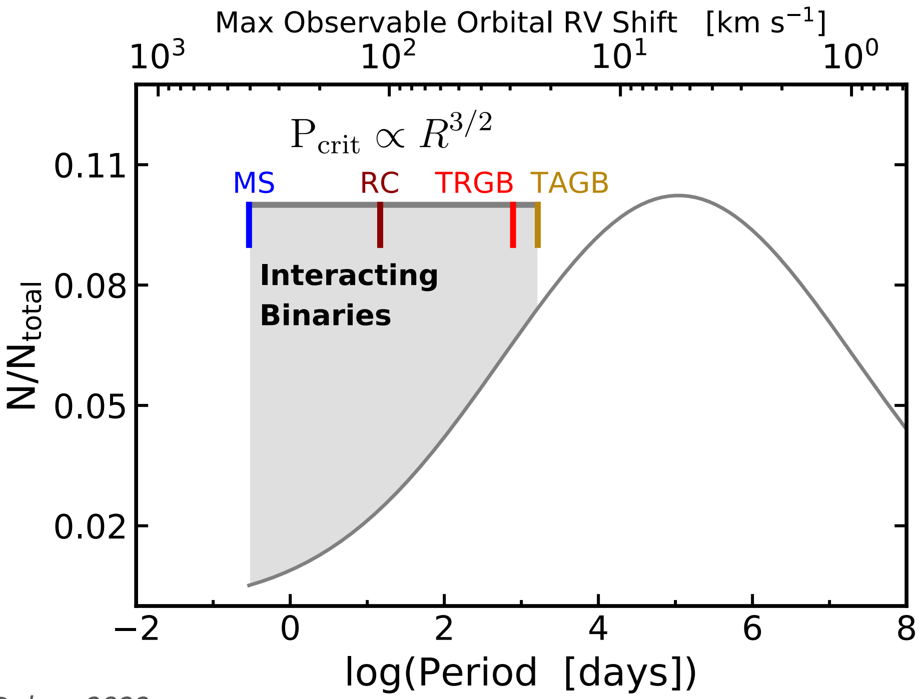
Once the primary begins to evolve, however, all bets are off!

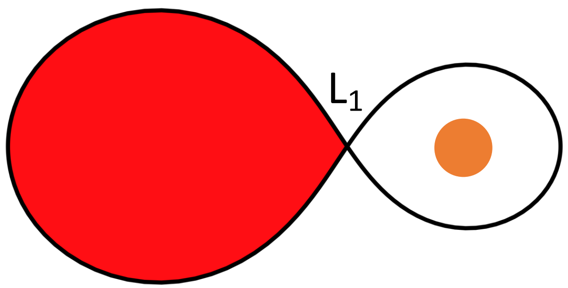
Credit: https://commons.wikimedia.org/wiki/File:Evolution_of_the_Sun_2_EN.svg#filelinks

Mass Transfer: a feature of stellar evolution

Mass transfer through L_1 begins once the system reaches the critical period for Roche Lobe Overflow (RLOF),

$$P_{crit} \propto \sqrt{\frac{R^3}{GM}}$$



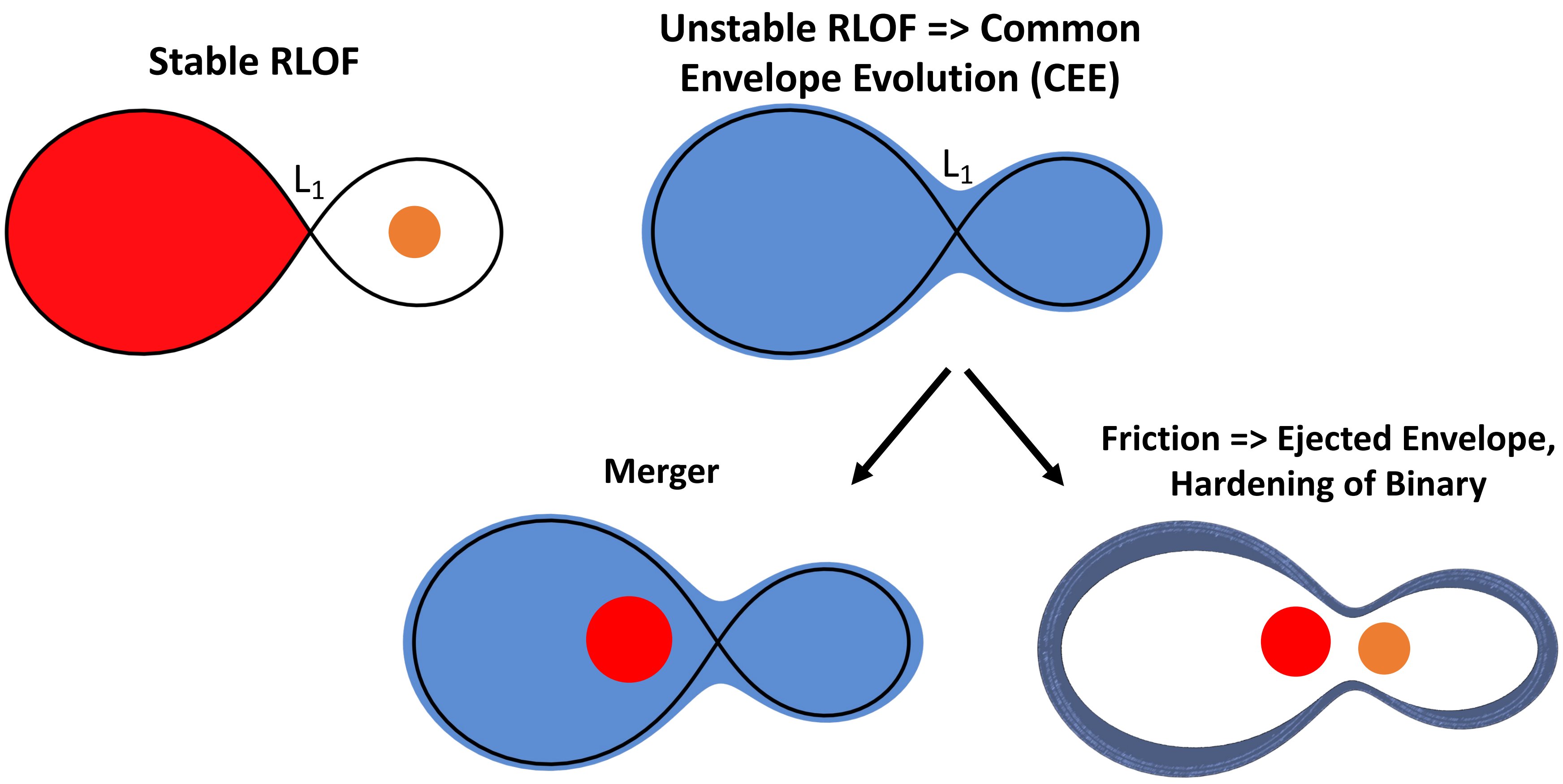


For close sun-like binaries, interactions are a normal part of their evolution!

Adapted from Daher+2022

Mass Transfer: the theoretical picture

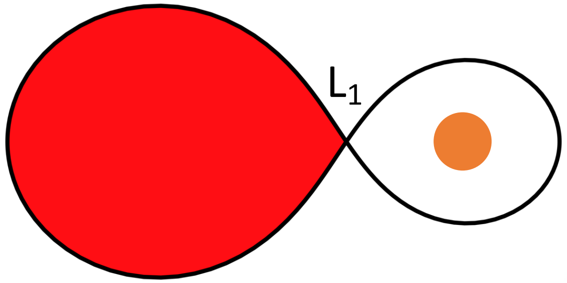
But what does MT look like?



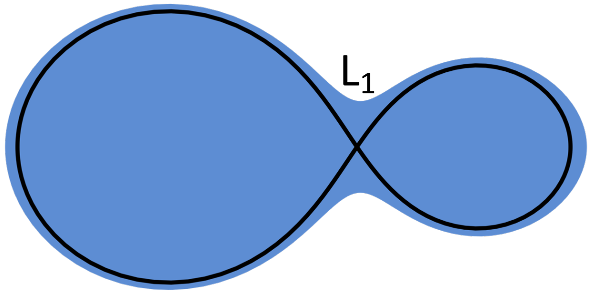
Mass Transfer: the theoretical picture

But what does MT look like?

Stable RLOF



Unstable RLOF => Common Envelope Evolution (CEE)



Mass Transfer: the theoretical picture

Classic reference text: Paczynski (1976)

Over the years, the prescriptions have grown ever more complicated to better address the complex, poorly-constrained underlying physics …

- $\boldsymbol{\alpha}$: efficiency of dissipating orbital energy into the CE, governing envelope ejection [Livio & Soker 1988]
- $\boldsymbol{\lambda}$: fudge factor in E_{bind} for variation in donor's envelope structure [de Kool 1990]
- $\boldsymbol{\gamma}$: change in angular momentum, needed to explain double WD binaries [Nelemans+2000]

Theoretical tools needed to explore RLOF/CEE:

- Radiative transfer/stellar atmospheres
- Stellar evolution codes
- 1D/3D hydrodynamic simulations
- Binary Population Synthesis (BPS)

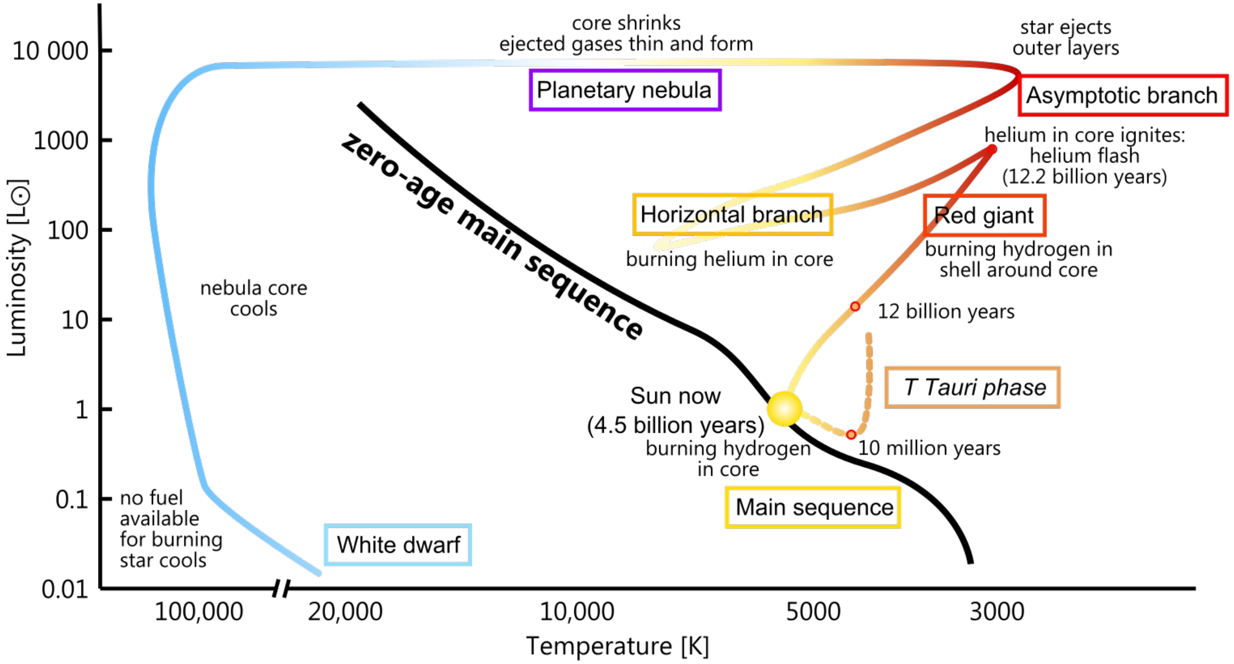
Ten years ago, Ivanova+2013 reviewed the field:

"Despite the importance of CEE, it is essentially unsolved."

An opportunity in white dwarf binaries

RLOF/CEE end quickly relative to evolutionary timescales, so actually observing them is very difficult. We instead rely on suspected post-CE systems…like WD binaries!

Diverse, statistical samples of WD binaries can shed light on the physics of MT!



Credit: https://commons.wikimedia.org/wiki/File:Evolution_of_the_Sun_2_EN.svg#filelinks

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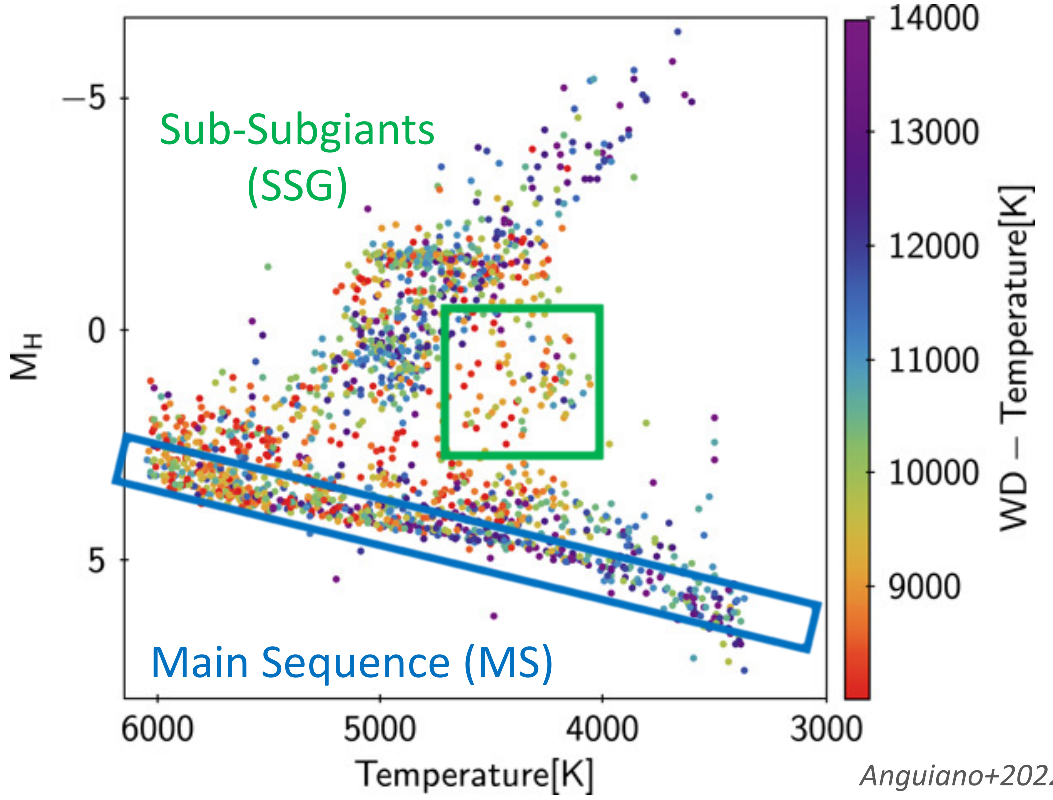


Anguiano+2022

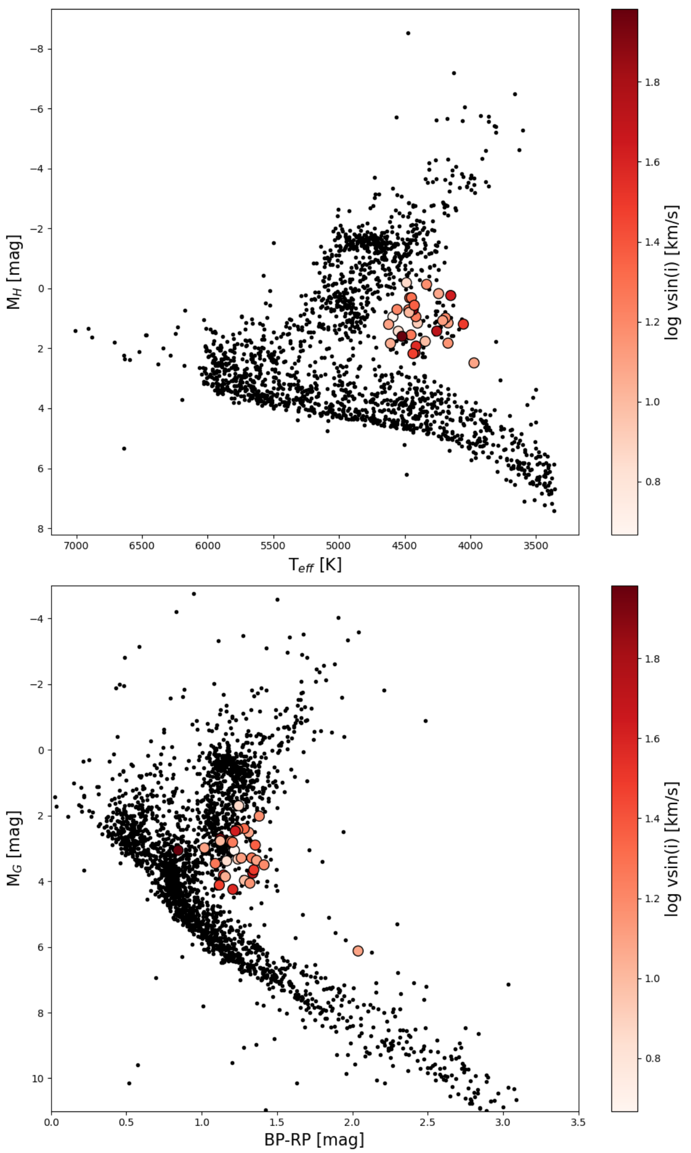
Thus was born, the AGGC with ~2000 WD binaries [Anguiano+22]

- **A**POGEE (SDSS-IV): high-res IR spectra, radial velocities (RVs)
- **G**ALEX: UV photometry
- ***G**aia*: astrometry, photometry, RV proxies, astrometric binary orbits
- TESS: lightcurves for P_{rot}, eclipses, variability

Case Study: SSG-WD binaries at LCO/NRES

What is a sub-subgiant?

- Red-ward of the subgiant branch
- Rapidly rotating, close binaries
- Frequently X-ray sources



Leiner+2017 proposed a few formation channels:

1) Strong magnetic fields => large starspots that suppress convection => lower luminosities and cooler temperatures
   - No reason *per se* for a WD companion

2) MT or stripped outer envelope
   - A WD companion is a natural product of the original donor!

Don Dixon, private communication

Case Study: SSG-WD binaries at LCO/NRES

This fall, we have a sample of 32 SSG-WD binaries from the AGGC that we're getting additional RV data from LCO/NRES.

Planning to jointly analyze:

- **Orbital information**
  P_{orb} ecc f(M)
- **APOGEE spectroscopic parameters**
  T_{eff} log(g) *v*sin*i* chemical abundances
- **UV colors**
  WD T_{eff} cooling ages
- **TESS light curves**
  P_{rot} eclipses activity and variability

Case Study: MS-WD binaries at WIYN/NEID

For BPS to simulate >10^6 systems, RLOF/CEE is implemented as a plug-n-play collection of the simplified parametrizations.*

*side effects may include violating energy or momentum conservation 🙂

Even still, predictions for individual systems vary dramatically!

Distributions of P_{orb} can reveal the relative contributions of unstable RLOF/CEE (blue lines) versus stable RLOF (orange lines).

To explore this, we're aiming to get RV orbital solutions for ~100 MS-WD binaries using WIYN/NEID, starting with the most obvious short-period systems.

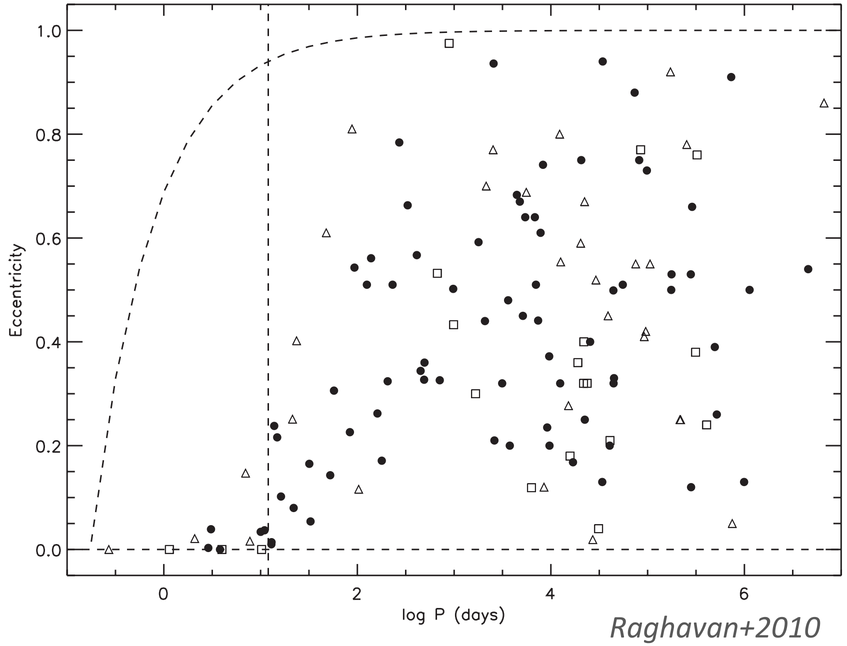
Katie Breivik, private communication

Case Study: MS-WD binaries at WIYN/NEID

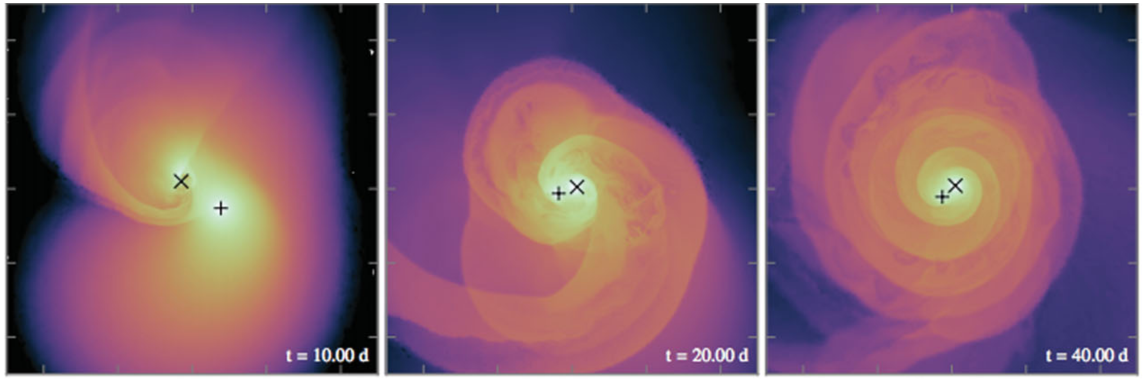
Potentially even more interesting is the combination of P_{orb} and eccentricity.

Tidal interactions pre-CEE are expected to circularize the orbit (vertical line), but spiral-in likely undoes this work.

- Does that eccentricity remain post-CEE?
- Could close circumbinary disks excite eccentricity?
- Could the few prior eccentric detections be driven by Kozai-Lidov oscillations?



Raghavan+2010



Ohlmann+2016

Summary

- MT/CEE is one of the most outstanding unsolved problems in astrophysics.
- Catching systems in the act of CEE or merging [V838 Mon, V1309 Sco] is very, very unlikely, so we generally study suspected post-CEE systems…such as WD binaries, or planetary nebulae!
- Ongoing observational campaigns at LCO/NRES and WIYN/NEID will use AGGC WD binaries to investigate
  1) the formation mechanisms of SSG-WD binaries
  2) the past experiences of RLOF/CEE of MS-WD