Mass transfer in eccentric White Dwarf – Neutron Star binaries

Alexey Bobrick, Melvyn B. Davies, Ross P. Church

Lund University
Department of Astronomy and Theoretical Physics

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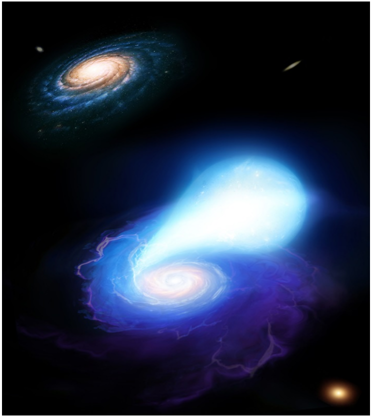
Introduction



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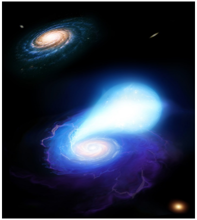
White Dwarf (WD) and a Neutron Star (NS)

Why are WD-NS systems interesting

- May power a special type of GRBs (King et al. 2007)
- Likely source of Ca-rich gap transients (Kasliwal 2012)
- Nuclear burning possibly important (Metzger 2012).
- Main UCXB progenitors (van Haaften et al. 2012).
- Good source for space-based GW missions (Antoniadis 2014).
- High mass loss – possible implications for galactic chemistry.
- Often contain millisecond pulsars (Wijnands 2010).
- Second largest fraction of doubly compact binaries (Nelemans et al. 2001).

Summary on WD-NS systems

- Form at a above $\sim R_\odot$
- Inspiral to contact due to GW emission
- Two possibilities after MT starts:
    - Low mass WD:
        - Stable MT on $\sim \tau_{GW}$
        - Seen as UCXB
        - Fade after a few Gyr
    - High mass WD:
        - Unstable MT on $\sim \tau_{dyn}$
        - Transient event

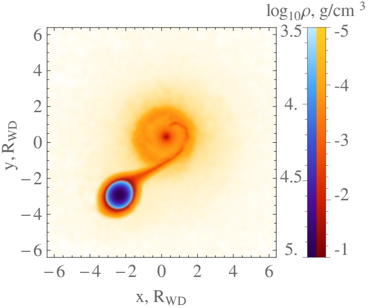


WD-NS observations

- Detached systems – binary pulsars (radio):
  - ~ 250 known (ATNF catalogue)
  - $2.2 \cdot 10^6$ expected in the Galaxy (Nelemans et al. 2001)
  - Merger rate of $1.4 \cdot 10^{-4}$ yr^{-1} per galaxy (Nelemans et al. 2001)
- Transferring systems (low mass WDs) – UCXBs (x-ray):
  - 13 confirmed (van Haaften et al. 2012)
  - ~ 500 expected with $P < 70$min (Belczynski & Taam 2004)
- Transients (high mass WDs):
  - ~ 10 gap transients seen, e.g. Kasliwal (2011)

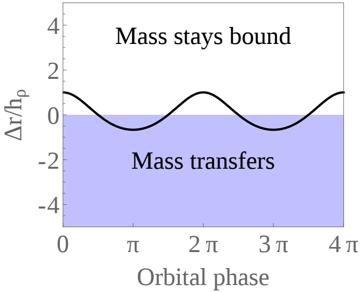
Our work

- Modified SPH simulations of mass transfer
- Which systems are stable? M_{crit} – ?
- How do they look like?
  - Extract non-conservative mass transfer parameters
  - Apply binary stellar evolution



Eccentricity importance

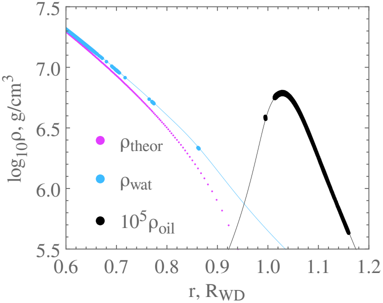
- Eccentric population with a heavy WD (Davies et al. 2002)
- At least ~ 0.1 of all WD-NS in the field (Nelemans et al. 2001)
- Contact e is $\sim 10^{-2.5}$ from GWs only
- WD atmospheres are thin: $h_\rho \sim 10^{-5} R_{WD}$
- MT turns on and off during the orbit
- UCXBs in GCs are often eccentric, e.g. 4U 1820-30, also Prodan & Murray (2015).

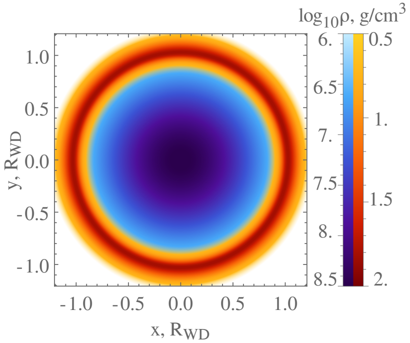


Stable mass transfer in SPH

- Hard to model in standard SPH
- Need $\sim 10^{12}$ particles
- Typical UCXBs transfer $\sim 10^{-12} M_{WD}$ per orbit
- Cannot use too different particle masses
- Oil on water approach (Church et al. 2009)
- Treat stellar body and atmosphere separately

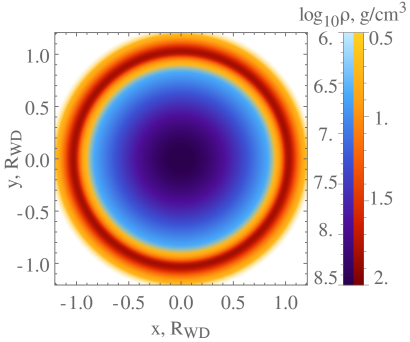
OW method scheme





Numerical method 1: Oil layer

- Has to be thick
- Support by artificial T (ideal gas, applies for $\dot{M} < 10^{-5} M_{\odot}/\mathrm{yr}$)
- No self-gravity: $\mathcal{O}(N_{oil})$ complexity
- Equations scale-free in m_{oil}



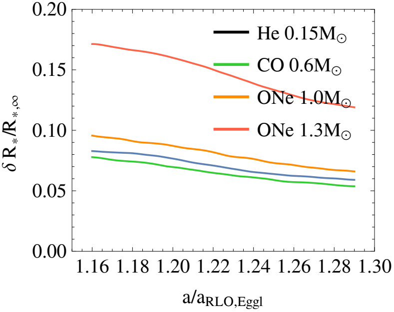
Numerical method 2: The binary

- Quadrupole interactions important
- Keplerian φ causes effective $e \sim 0.01$
- $\dot{M}$ swing of ~ 0.5 dex, e.g. Dan et al. (2011)

$M_{WD}, M_\odot$	0.15	0.6	1.0	1.3
δe_{quadr}	$4.0 \cdot 10^{-3}$	$7.0 \cdot 10^{-3}$	$6.8 \cdot 10^{-3}$	$7.0 \cdot 10^{-3}$

Numerical method 3: $R_\star(a)$ dependence

- $R_\star$ changes with a
- Indirectly observed by Dan et al. (2011)
- Typical change $\sim 5\%$
- Important for constructing waveforms



Simulations: what do we see

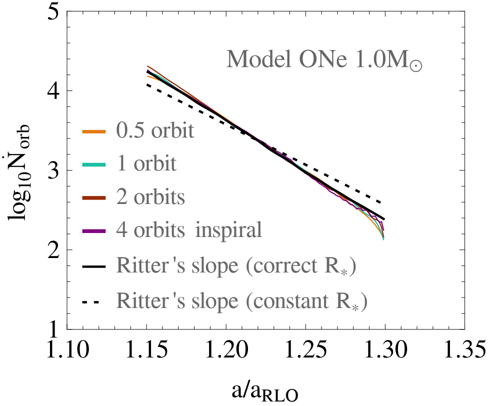
Video slide

Mapping SPH to the general model

- Atmosphere:
  - Artificially thick
  - Measure everything in h_ρ
- Timescales:
  - Real systems evolve over $10^2 - 10^6$ orbits
  - SPH: Represents continuum of stages
  - Scale-free, quasi-steady
- Mass flows:
  - Split the simulation into regions

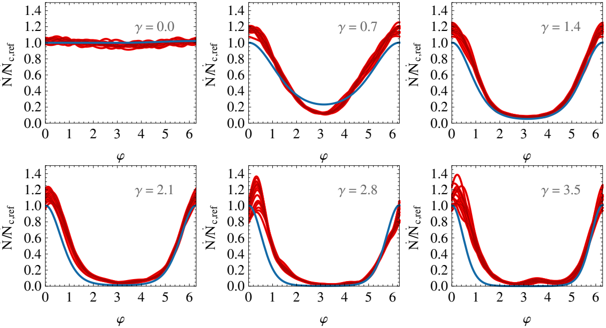
Instantaneous $\dot{M}_{circ}$

- $\dot{M}$ at given a
- Expect Ritter's formula (Ritter 1988): $\dot{M} \sim \exp \dfrac{R_\star - R_{RL}}{h_\rho}$
- Observed:



Instantaneous $\dot{M}_{ecc}$

- Eccentric $\dot{M}$: instantaneous response model
- $\dot{M}_{orb}(a, e) = \dot{M}_{circ}(a) f(\frac{Re}{h_\rho})$

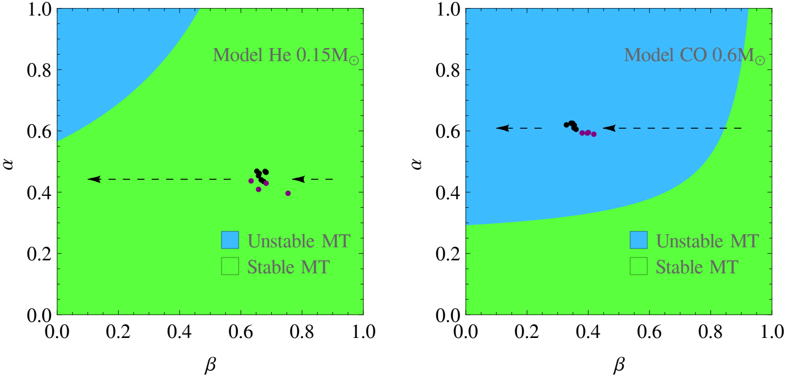


Parameters we extract

- Long term evolution: importance of mass loss
- Measure parameters (Rappaport 1982):
  - How much mass is lost: $\beta \equiv -\dot{M}_1/\dot{M}_2$
  - How much of J_z is lost: $\alpha \equiv \frac{\dot{J}_{loss}}{\dot{m}_{loss}} / \frac{J_{12}}{\mu}$
  - How much does the envelope affect a: $\alpha_{CE} \equiv \dot{E}_{orb}/\dot{E}_{ej}$

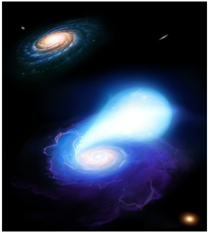
Further results

- Boundary masses $\sim 0.2 M_\odot$ for disc wind model
- Constant e does not affect long-term $\dot{M}$
- Varying e may drive $\dot{M}$
- Observations affected by: CE, rad. feedback, the jet



Conclusions

- WD-NS systems are:
    - Sources for UCXBs
    - Likely to produce transients
    - Often eccentric
- We model them using a modified SPH scheme
- And link the results to a binary evolution model



Thank you!