Mass transfer dynamics in white dwarf binary systems

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Numbers on Galactic WDs

- total number of WDs: 10^{10}

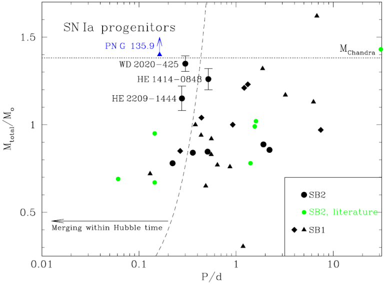
Napiwotzki (2009)

- 2.5×10^8 Double White Dwarfs:
    - 53% He-He DWDs
    - 25% CO-CO DWDs
    - 20% He-CO DWDs
    - 1% ONeMg-He/CO DWDs

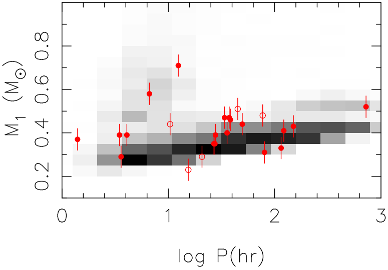
- ~50% contact DWDs within t_{Hubble}

- ~9% AM CVn

Nelemans et al. (2001)

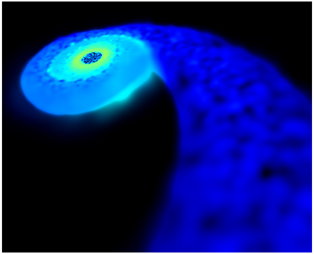


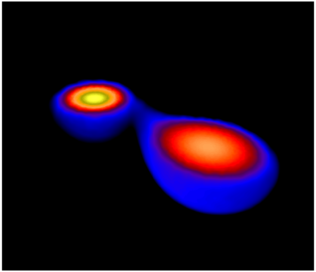
Napiwotzki et al. (2007)



Nelemans et al. (2005)

Mergers or semi-detached binary systems?

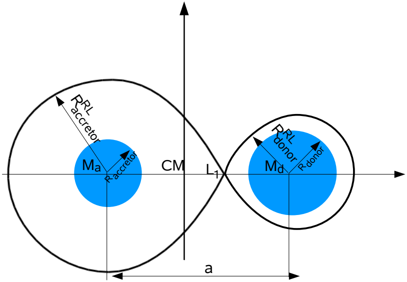




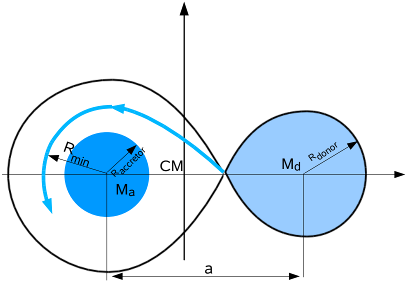
- Mergers
  - Type Ia supernova
  - Accretion induced collapse to a neutron star
  - Extreme He star, R Coronae Borealis (RCrB)
- Semi-detached binaries
  - AM Canum Venaticorum (AM CVn) stars

Mass transfer process

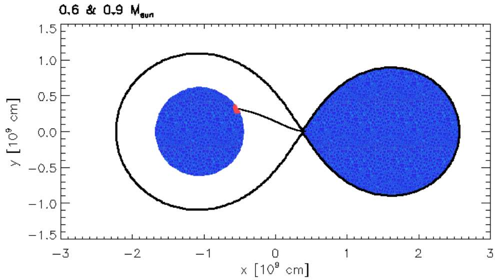
- $R_{\rm donor} = R^{\rm RL}_{\rm donor}$, mass transfer sets in



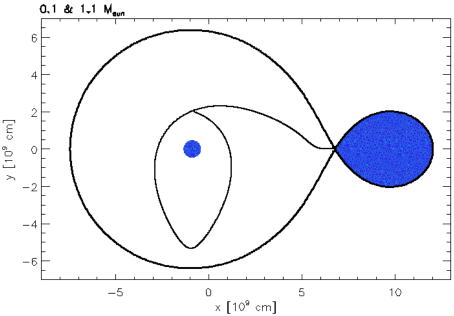
- $\dot{R}_{\rm donor} = \dot{R}^{\rm RL}_{\rm donor}$, mass transfer is dynamically stable



Mass transfer process. Disc vs. direct impact accretion



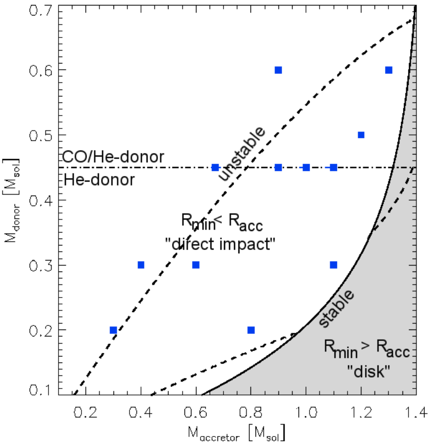
- $R_{\rm min} < R_{\rm accretor}$, direct impact accretion



- $R_{\rm min} > R_{\rm accretor}$, disk accretion

Analytical estimates. Marsh et al. (2004)

- $\dot{\mathrm{J}}_{\mathrm{orb}} = \dot{\mathrm{J}}_{\mathrm{GR}} + \dot{\mathrm{J}}_{\mathrm{MT}} + \dot{\mathrm{J}}_{\mathrm{tid.torque}}$
- Guaranteed stable and unstable mass transfer regimes
- disk accretion *stabilize* mass transfer
- direct impact accretion *destabilize* mass transfer
- If $\dot{\mathrm{M}} \gg \dot{\mathrm{M}}_{\mathrm{Edd}}$ *both stable and unstable binaries merge* (Han & Webbink (1999))



Reproduced after Marsh et al. (2004)

Numerical model

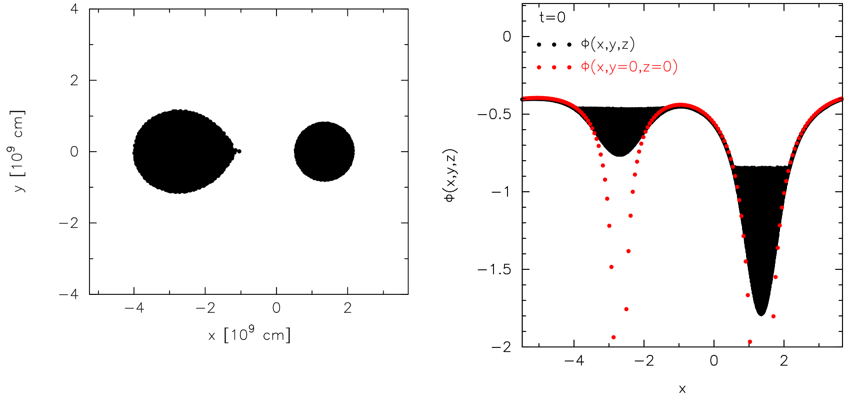
- 3D smoothed particle hydrodynamics (SPH) code (Rosswog et al. (2008))
- equation of state: HELMHOLTZ EOS (Center for Astrophysical Thermonuclear Flashes at the University of Chicago. (Timmes & Swesty (2000)))
- nuclear burning: QSE-reduced alpha network (Hix et al., 1998)
- gravitational forces: binary tree (Benz et al. (1990))

Numerical model. Initial conditions

- Numerically resolvable mass transfer:

$$\dot{M}_{\rm num.res.} \sim \frac{1 \text{ particle}}{\text{orbit}} \approx 1.2 \frac{M_\odot}{\rm yr} \left(\frac{10^6}{\rm npart}\right) \cdot \left(\frac{M_{\rm tot}}{1.5\ M_\odot}\right)^{3/2} \cdot \left(\frac{2\cdot 10^9\ {\rm cm}}{a_{\rm MT}}\right)^{3/2}$$

- Constructing accurate initial conditions



Performed simulations

Run No.	Masses $[\mathrm{M}_\odot]$	Composition	a_{MT} $[R_1 + R_2]$	T_{max} $[10^8\ \mathrm{K}]$	ρ_{max} $[10^7\ \mathrm{g\ cm}^{-3}]$	L_{lost} $[\%L_{\mathrm{tot}}]$	#Orbits	#Particles $[10^3]$
1	0.2 — 0.8	He-C/O	2.927	4.892	0.954	5.7	85	200
2	0.3 — 1.1	He-C/O	3.045	12.227	6.146	7.112	59	200
3	0.5 — 1.2	He-ONeMg	2.71	18.85	15.44	4.86	31	200
4	0.3 — 0.6	He-C/O	2.100	4.92	0.32	2.5	45	200
4	0.6 — 0.9	C/O-C/O	1.952	10.6	1.75	0.8	29	200
6	0.2 — 0.3	He-He	1.791	2.37	0.05	1.03	22	200
7	0.3 — 0.4	He-He	1.697	2.72	0.108	0.6	14	200
8	0.9 — 1.2	C/O-C/O	2.038	71.15	16.1	2.3	29	200
Lower number of particles								
9	0.45 — 1.1	He-C/O	2.222	13.3	5.79	3.7	28	100
10	0.45 — 1.0	He-C/O	2.152	21.1	2.83	3.5	30	100
11	0.45 — 0.9	He-C/O	1.992	16.11	1.59	2.2	30	100
12	0.45 — 0.67	He-C/O	1.882	12.3	0.48	0.55	21	100

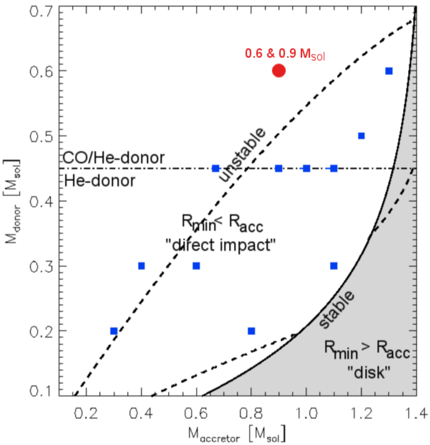
a_{MT} is the separation at the moment when the relaxation in the corotating frame ends

L_{lost} is the angular momentum lost from the system

#orbits $= t_{\mathrm{end}}/P_0$, where P_0 is the initial orbital period
at the onset of mass tranfer and t_{end} is the moment of disruption of the donor.

Numerical results: direct impact, unstable MT regime

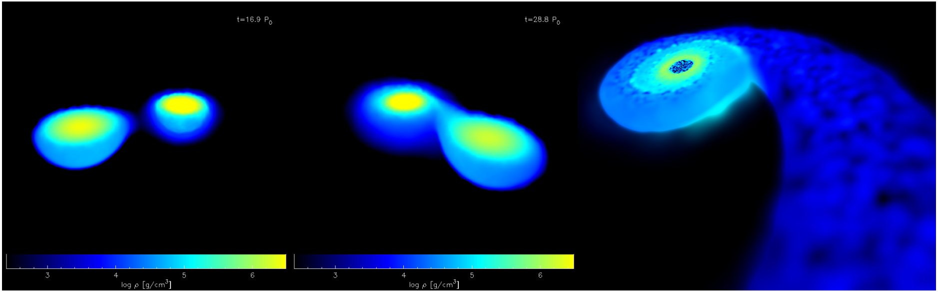
- $q = 0.66$ (0.6 & $0.9\mathrm{M}_\odot$), He/CO-CO merger.



Numerical results: direct impact, unstable MT regime

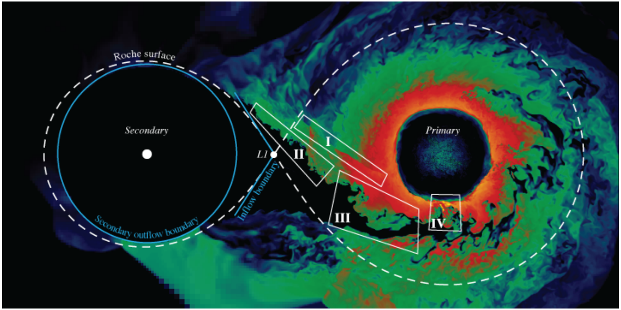
- $q = 0.66$ $\left\{ \begin{array}{l} - \text{WD masses: } 0.6 \ \& \ 0.9 \ \mathrm{M}_\odot \\ - \text{composition: He/CO-CO} \end{array} \right.$

The mass transfer is NOT over in 2 orbits, but on 29



Numerical results: surface detonation of sub-Chandrasekhar WDs

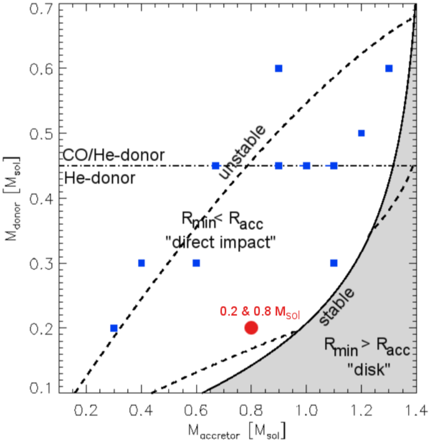
- What happens with the accreted Helium of the 0.6 & $0.9\mathrm{M}_\odot$ system?
  - Kelvin-Helmholtz instabilities trigger thermonuclear explosions of the He envelope



Guillochon, Dan, Ramirez-Ruiz & Rosswog, ApJL, 709, L64, 2010

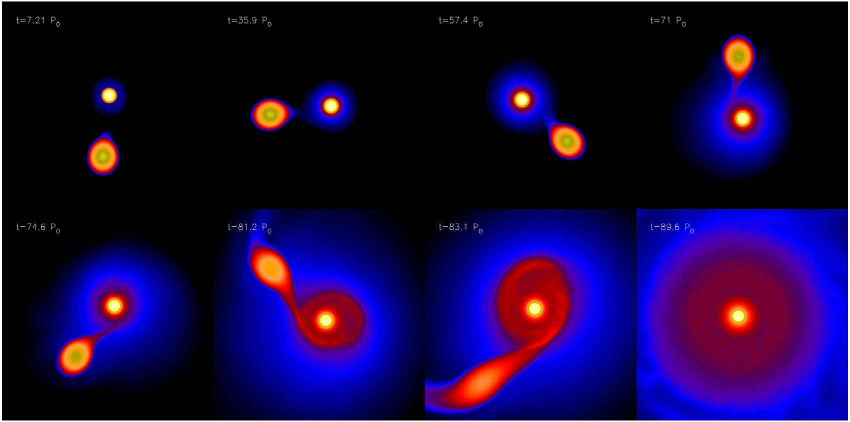
Numerical results. 0.2 & 0.8 $\mathrm{M}_\odot$: stable or unstable mass transfer?

- $q = 0.25$ (0.2 & $0.8\mathrm{M}_\odot$).



Numerical results. 0.2 & 0.8 $\mathrm{M}_\odot$: stable or unstable MT?

- $q = 0.25$
  - WD masses: 0.2 & 0.8 $\mathrm{M}_\odot$
  - composition: He-donor and a C/O accretor
  - no. of orbits: 85



Conclusions

- revision of earlier results (Benz et al. 1990):
  - (numerical) mass transfer is NOT over in two orbital periods; instead it continues for *several dozens of orbits*
  - unstable mass transfer of Helium can lead to surface detonations: Is this the ignition mechanism for a type Ia supernova?
- At $\dot{\mathrm{M}} \gg \dot{\mathrm{M}}_{\mathrm{Edd}}$ ALL close double white dwarfs with $0.25 \leq q \leq 1$ merge

Thank you!