White Dwarf Binaries in Contact: Dynamical Stability at the Onset of Mass Transfer

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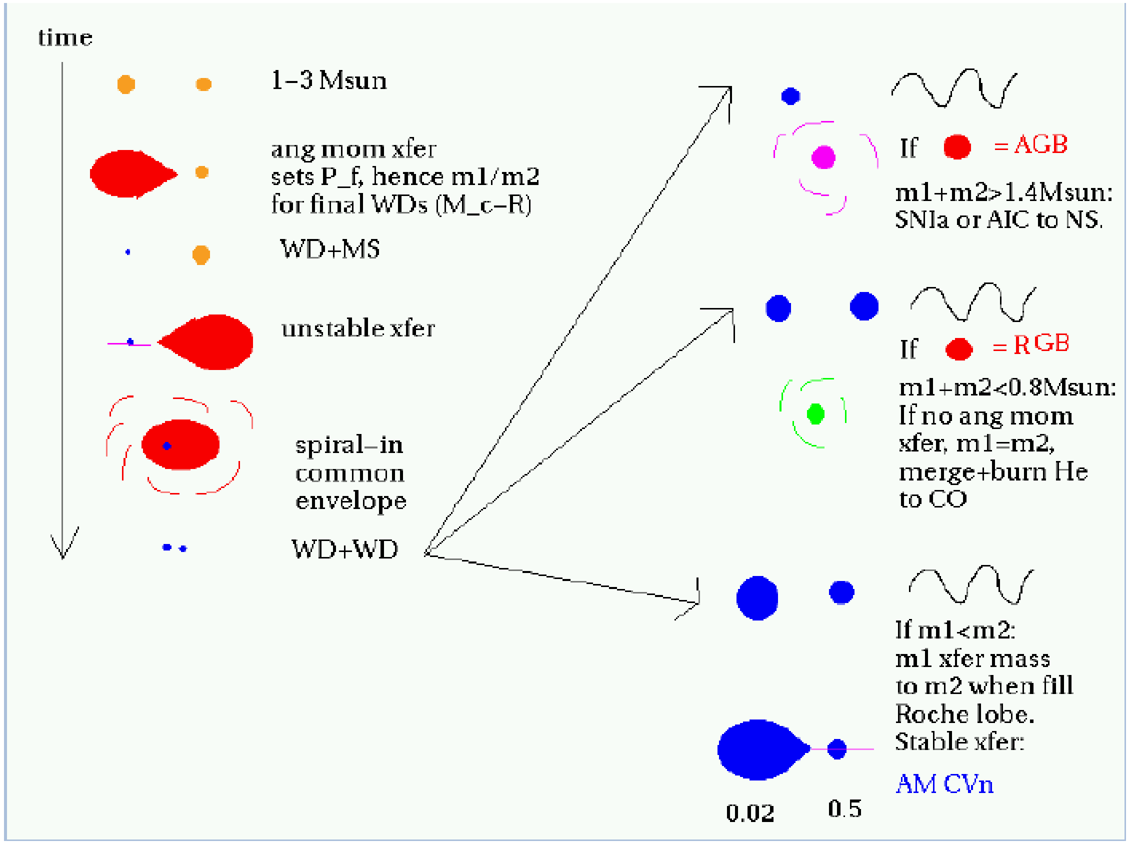
(*poor substitute for Danny Steeghs)

Outline

- Evolutionary and observational context
- Stability criteria
  - Importance of angular momentum transfer
  - Traditional: disk tide
- Direct impact (no disk) at short periods
  - Whither the angular momentum?
    - tidal coupling to stellar modes
    - mode dissipation/stellar tides

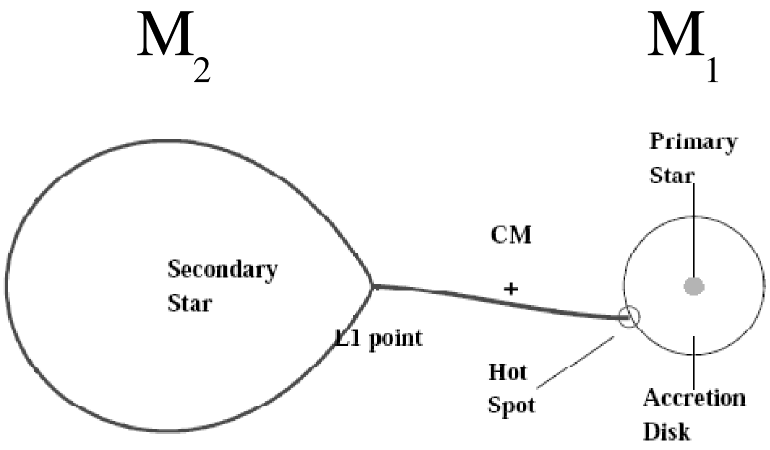
Evolutionary context



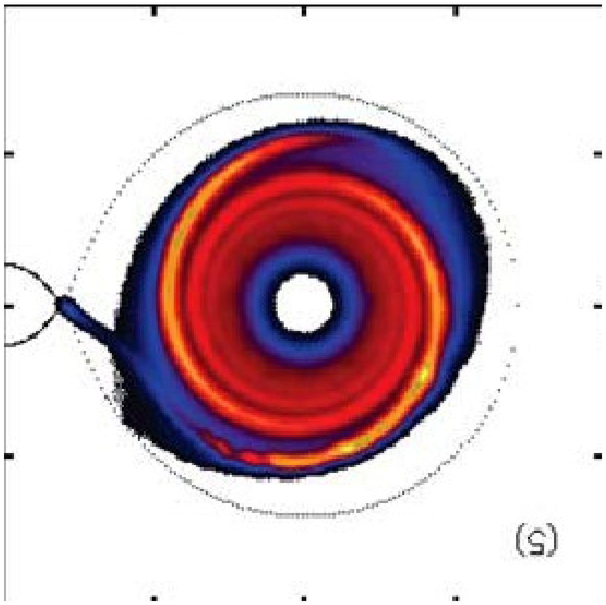
- Double degenerates
  - Stability of mass transfer depends on mass ratio.
  - donor << accretor: 'always' stable.
  - accretor << donor: 'always' unstable.
  - accretor ~ donor: it depends on details.

Largest birthrate for this case!

\`Standard' stable AM CVn story

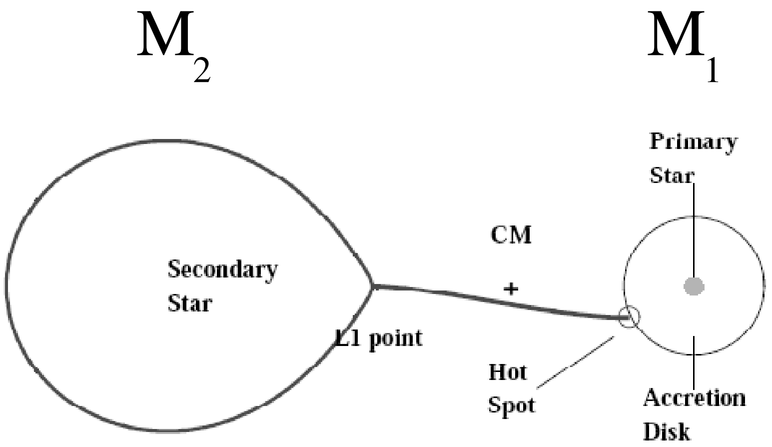


q=0.03
Truss 2007
3-D sph



- $M_2 << M_1$: stable transfer
- low mass degenerate donor $R \sim M_2^{-1/3}$.
- $R_{L2} \sim a M_2^{1/3}$
- So Roche lobe contact requires $a \sim M_2^{-2/3}$
- Orbital angular momentum $J \sim M_2 a^{1/2} \sim a^{-1}$.
- Gravitational radiation loss of J causes orbit expansion.

Unstable transfer



- $M_2 \sim M_1$: stable/unstable transition
- NB: losing orbital angular momentum to spin destabilizes. Putting it back helps stabilize.

- $M_2 \gg M_1$: unstable transfer
- Most orbital angular momentum is in M_1 : $J \sim M_1 a^{1/2}$, so if J fixed, $a \sim M_1^{-2}$
- $R_{L2} \sim a$
- So Roche lobe of massive donor 2 shrinks dramatically.
- For most stars (except some radiative zones), dynamically unstable.

Newtonian particle trajectories

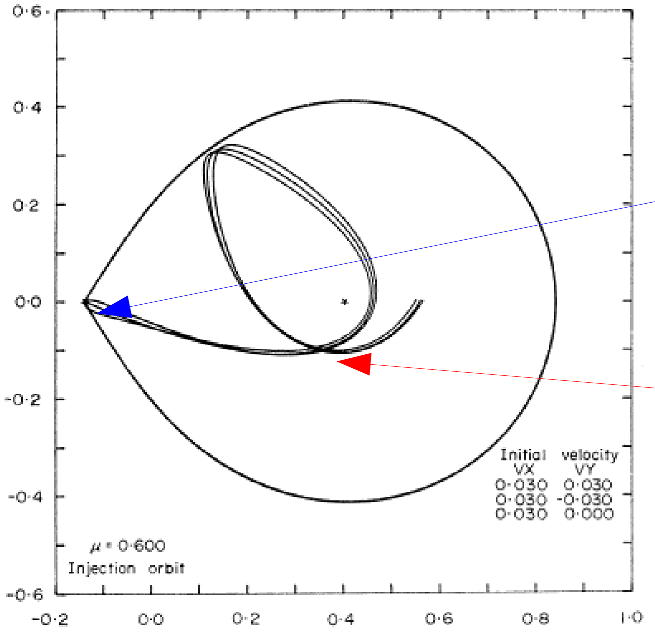
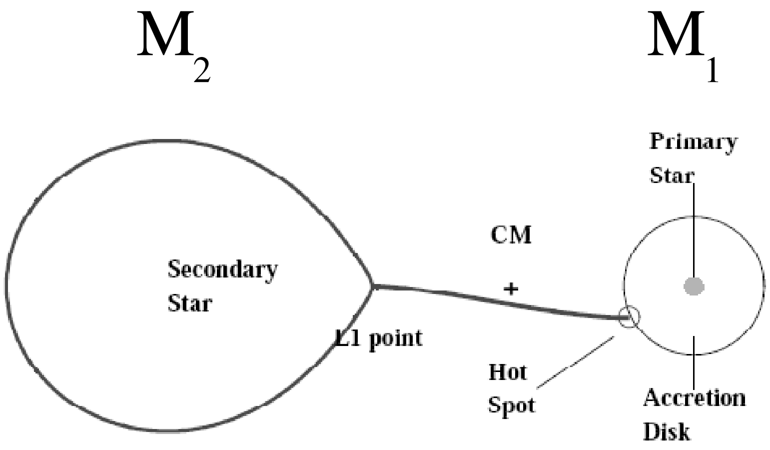


Fig. 4. *Particle trajectories in the orbital plane corresponding to thermal evaporation from the inner Lagrangian point for a mass fraction of 0·6. The bounding curve represents the Roche equipotential through L_1. Note that the trajectories cross before reaching the region of hot spot formation, which is $r_d = 0{\cdot}10$ for this mass fraction.*

Flannery 1975 MNRAS 170, 325

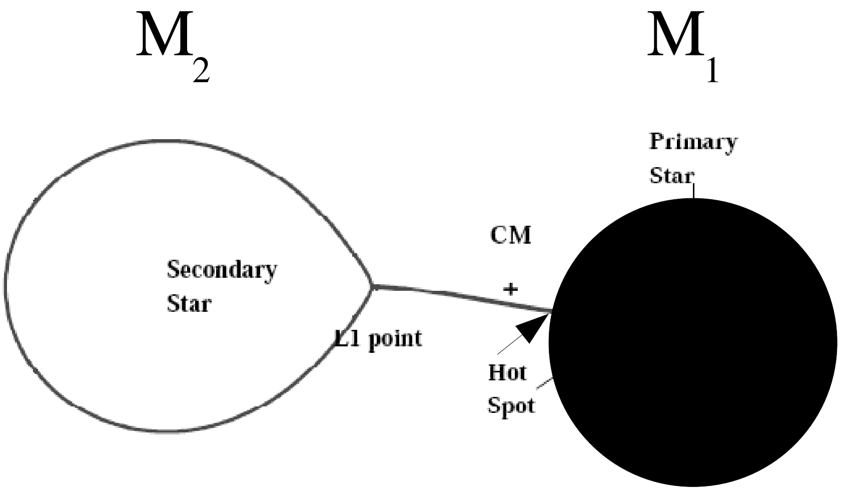
- No viscosity: material falling from L1 has specific angular momentum of ring with radius ~0.2 of Roche lobe radius.
- Small companion: gas stream intersects, forms accretion disk.
- Viscosity spreads disk: mass accretes, angular momentum given to outer parts, expanding until tidal coupling to donor gives angular momentum back to orbit,
- $R_{disk} \sim 0.9R_L$.
- (Priedhorsky & Verbunt 1988 ApJ 333, 895, Truss 2007 MNRAS 376, 89)

Direct impact



- For short period systems, accretor larger than initial disk: direct impact of stream on star, disk does not form. Marsh & Steeghs 2002 MNRAS 331, L7

Direct impact



- For short period systems, accretor larger than initial disk: direct impact of stream on star, disk does not form. Marsh & Steeghs 2002 MNRAS 331, L7
- No emission (lines) from disk.
- X-ray emission from impact point modulated at orbital period.
- RXJ0806+1527 (P=321s)?
- RXJ1914_2546 (P=569s)?
- ES Cet (P=618s)

Direct impact

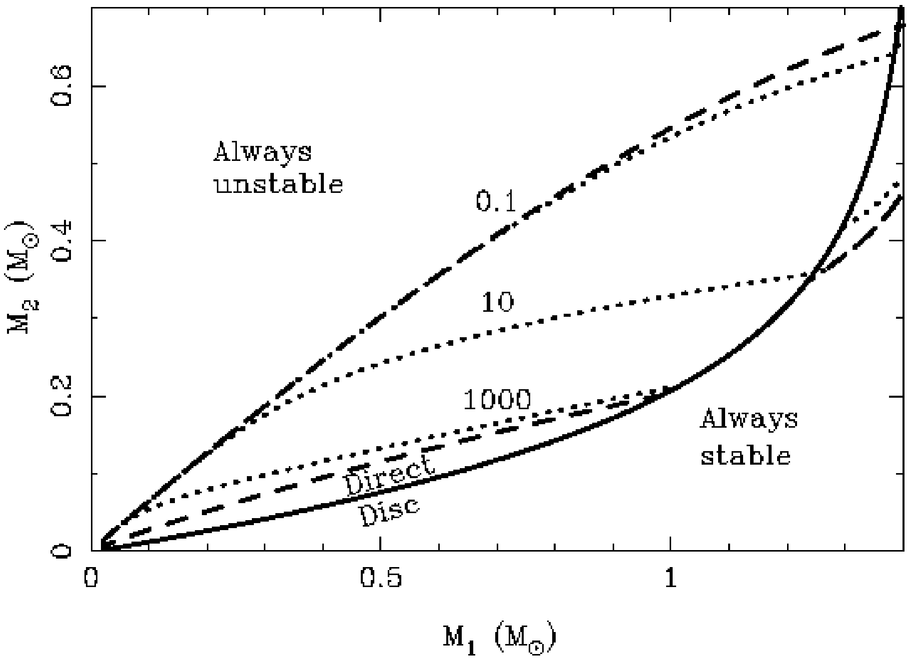


Figure 1. The upper dashed line shows the dynamical stability limit (equation 30), while the lower dashed line shows the stricter criterion of Nelemans et al. (2001) (equation 31), accounting for the switch between direct impact and disc accretion at $M_1 \approx 1\ \mathrm{M}_\odot$. The solid line shows the transition between disc and direct impact accretion. The three dotted lines show how the strict stability limit of Nelemans et al. (2001) is relaxed when dissipative torques feed angular momentum from the accretor back to the orbit (equation 32), once again accounting for both the direct impact and disc accretion cases. The three lines are labelled by the synchronization time-scale in yr.

10-100 yrs is GR inspiral time for near contact WDs.
Tidal coupling is subtle only if on this timescale.
Longer: irrelevant. Shorter: rigid lock.

- Matters for double degenerate formation scenario for AM CVn: most come into contact with mass ratios near `standard' J-conserving q=2/3 stability limit. If angular momentum stored on accreting star, most would be dynamically unstable. Marsh, Nelemans & Steeghs 2004 MNRAS 350, 113.
- Less of an issue for semi-degenerate scenarios (cf Deloye & Bildsten 2005 ApJ 624, 934)

Orbital evolution

$$\dot{J}_{\rm GW} = -\frac{32}{5}\frac{G^3}{c^5}\frac{M_1 M_2 M}{a^4}J_{\rm orb}$$

$$\dot{J}_{\rm orb} = \dot{J}_{\rm GW} + \dot{J}_{\rm acc} + \dot{J}_{\rm tidal,diss} - m_\alpha b_\alpha \frac{d}{dt}|c_\alpha|^2,$$

$$\sqrt{GM_1R_{\rm h}}\dot{M}_2$$

destabilizing: reduces maximum *q* for dynamical stability (Marsh et al 2004)

$$\mathcal{T}_{\rm diss} = \frac{1}{\tau_S} I(\Omega - \omega_{\rm orb}),$$

Tidal coupling from star spinning faster than orbit is stabilizing

- modal tidal coupling (angular momentum in tidally excited growing stellar modes near resonance).
- Racine, Phinney & Arras 2007 MNRAS in press. (astro-ph/0610692) [r-modes, rotating star], can lock spin.
- Rathore, Blandford & Broderick 2005 MNRAS 357, 834. [f,g-modes, non-rotating star]. Might lock orbit.

Modal excitation can matter

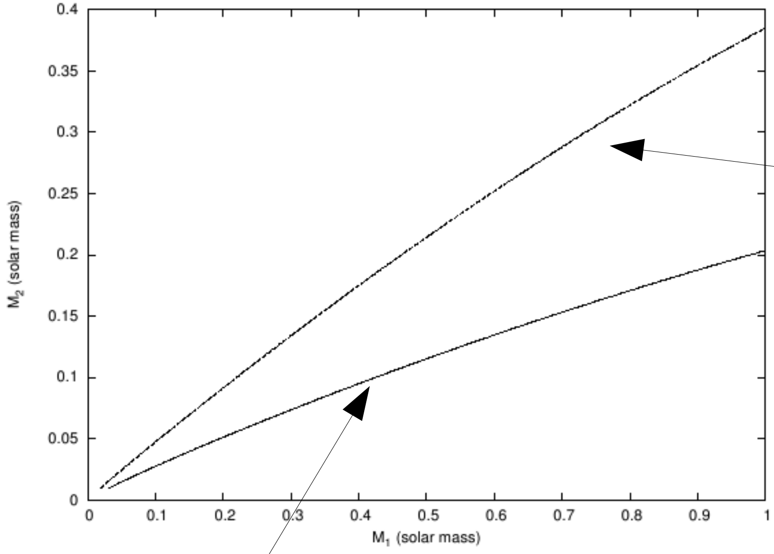


Figure 1. This figure shows the boundary of the regimes of guaranteed stability in two cases: (solid line) when no modes are driven, which is the criterion of Marsh, Nelemans and Steeghs (2004), and (dashed line) during resonance locking, which is Eq.(22) with $x_\alpha = 0.5$. The binary is stable to mass transfer in the region of the graph below the line corresponding to the appropriate regime. Clearly resonance locking increases significantly the parameter space over which the binary can undergo stable equilibrium mass transfer.

- mass transfer stabilized during resonance locking by growing r-mode. (Racine, Phinney & Arras 2007)
- To have tidal torque on accretor balance accretion torque requires $Q<10^9$. (cf Jupiter-Io $Q=10^6$): large internal heating due to need to stay synchronised as orbit evolves. Depth of heating depends on which modes.

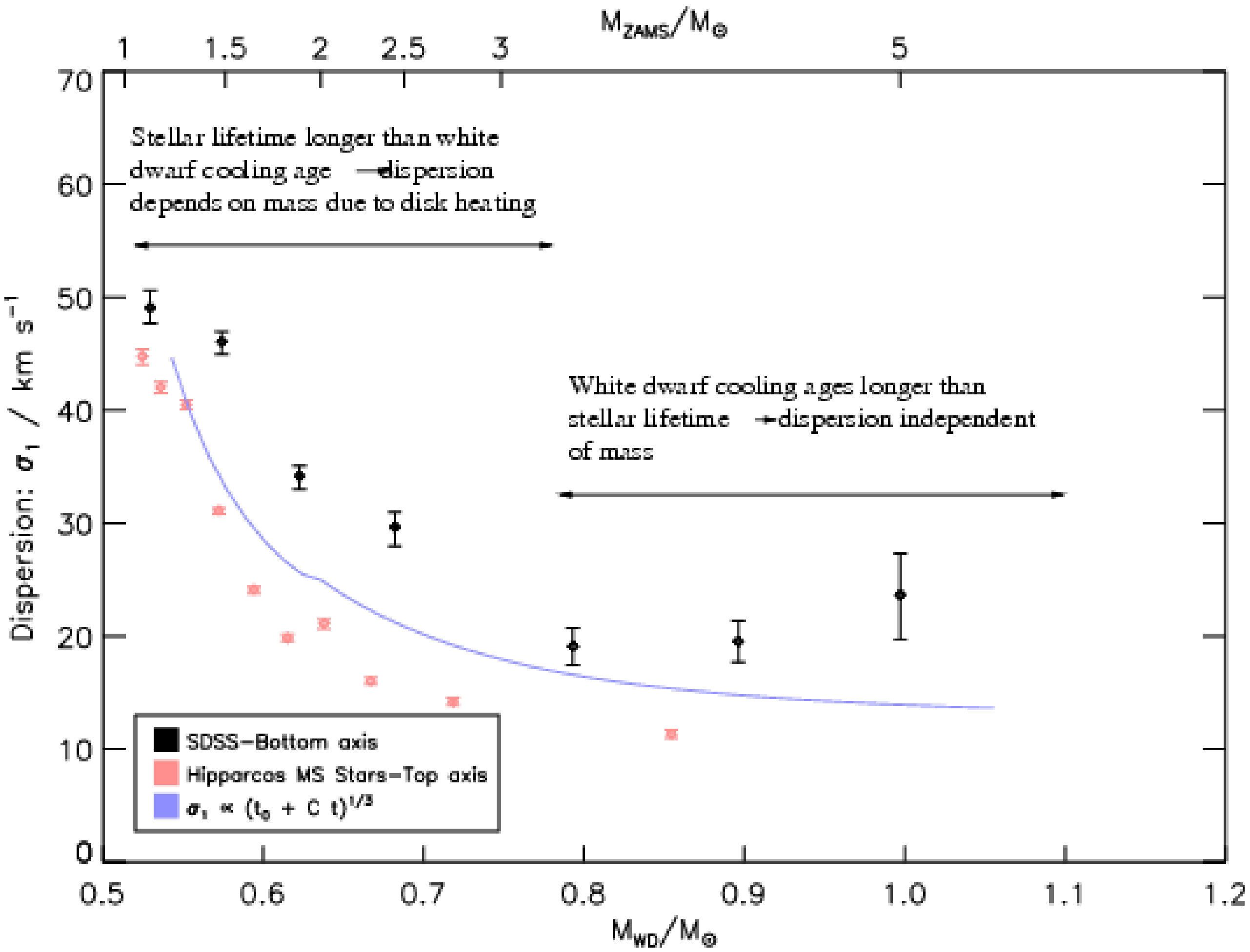
Status of the candidates

- RXJ0806+1527, RXJ1914+2456 both observed to have decreasing periods.
- Standard lobe-filling conservative transfer predicts increasing periods!
- Early mass transfer (before full lobe filling)?
  - Atmosphere inside Roche lobe -Willems & Kalogera 2005: unlikely -lasts only ~ years, while observed >10 years!
  - Photosphere outside Roche lobe -Deloye & Taam 2006: radiative layer, so shrinks on mass loss. Can last 10^3-10^6y.
- Still no definite confirmation that periods are orbital.

Totally unrelated:

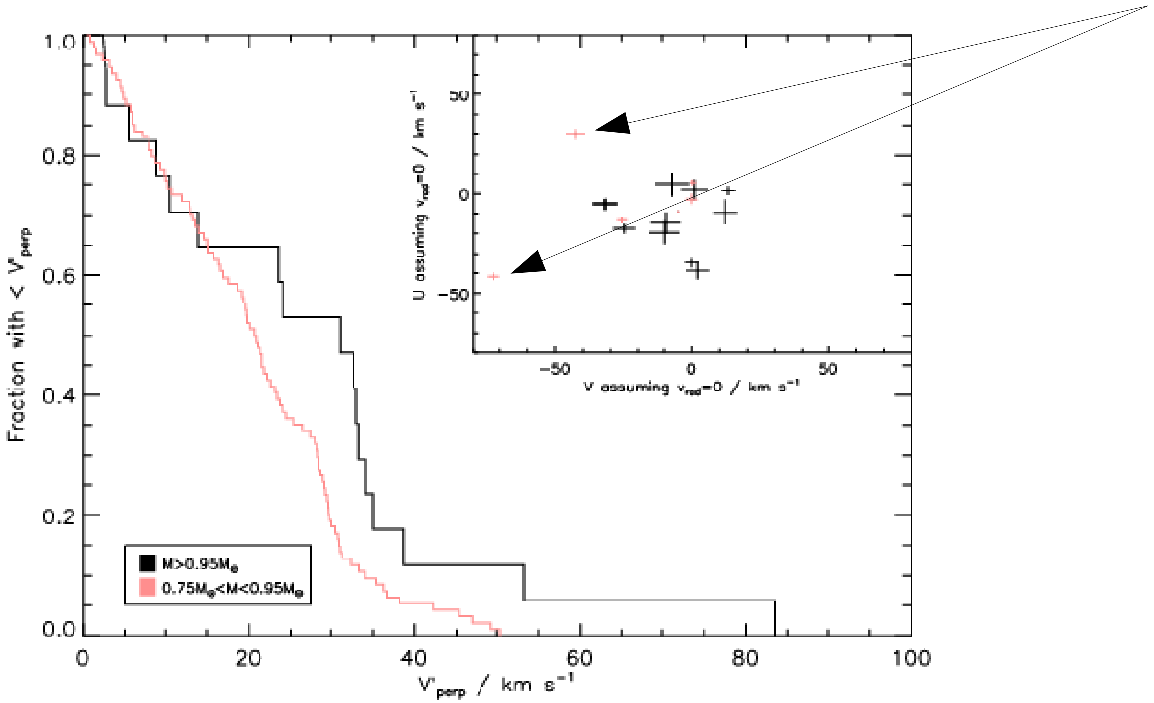
- Velocity dispersion vs white dwarf mass
  - Expect: born with dispersion of initial mass progenitor. Since then increased by encounters with density inhomogenities in disk.
  - Wegg & Phinney 2007 in prep
- PG and SDSS DR4 sample, T>12,000K, cooling age >300Myr, spectra, with adequate g, T (Wood models). Photometric distances.
  - sample of 1,971 WDs
  - proper motions from USNO-B, SDSS, POSS measurements.
- Velocity ellipsoids using method of Dehnen & Binney (assumes distribution is position-independent; adopt usual Schwarzschild axis ratios)

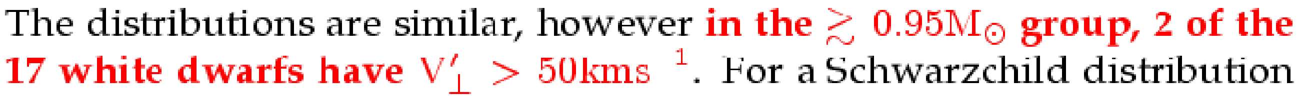
WD velocity dispersion vs mass



- Overall, a bit high, but generally in line with expectations,
- except for >0.95 solar mass WDs...

Velocities of >0.95Msun WDs





The distributions are similar, however **in the $\gtrsim 0.95 M_\odot$ group, 2 of the 17 white dwarfs have $V'_\perp > 50 \mathrm{kms}^{-1}$**. For a Schwarzchild distribution

- 2/17 high mass WDs have anomalous transverse v>50km/s
- Not consistent with early B runaway numbers.
- About 10x rate expected for WD-WD mergers