Compact binaries and gravitational waves

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Outline

Observed double white dwarfs

System	P_{orb} (d)	a_{orb} ($R_\odot$)	M_1 ($M_\odot$)	M_2 ($M_\odot$)	q_2 (M_2/M_1)	$\Delta\tau$ (Myr)
WD 0135–052	1.556	5.63	0.52 ± 0.05	0.47 ± 0.05	0.90 ± 0.04	350
WD 0136+768	1.407	4.99	0.37	0.47	1.26 ± 0.03	450
WD 0957–666	0.061	0.58	0.32	0.37	1.13 ± 0.02	325
WD 1101+364	0.145	0.99	0.33	0.29	0.87 ± 0.03	215
PG 1115+116	30.09	46.9	0.7	0.7	0.84 ± 0.21	160
WD 1204+450	1.603	5.74	0.52	0.46	0.87 ± 0.03	80
WD 1349+144	2.209	6.59	0.44	0.44	1.26 ± 0.05	—
HE 1414–0848	0.518	2.93	0.55 ± 0.03	0.71 ± 0.03	1.28 ± 0.03	200
WD 1704+481a	0.145	1.14	0.56 ± 0.07	0.39 ± 0.05	0.70 ± 0.03	-20[a]
HE 2209–1444	0.277	1.88	0.58 ± 0.08	0.58 ± 0.03	1.00 ± 0.12	500

[a] Unclear which white dwarf is older

See references in Maxted et al. (2002), Nelemans & Tout (2005) and MvdS et al. (2006)

- WD masses $\sim 0.3 - 0.7\ M_\odot$
- Orbital separations $\sim 0.5 - 6\ R_\odot$ ($+47\ R_\odot$)

Common Envelope and Envelope Ejection

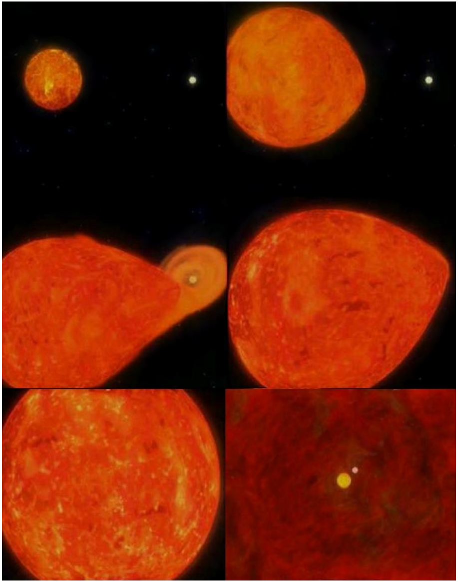
Properties of observed white dwarfs:

- Average orbital separation:
  - $7\,R_\odot$
- Typical progenitor system:
  - $M_c \gtrsim 0.3\,M_\odot$
  - $R_* \sim 100\,R_\odot$

Assumptions:

- Envelope ejection occurs much faster than nuclear evolution, hence:
  - core mass does not grow during envelope ejection
  - no accretion by companion during envelope ejection
- The timescale is not necessarily the dynamical timescale(!)

Envelope ejection



Classical α-common envelope (CE; spiral-in):

- orbital energy is used to expel envelope (Webbink, 1984):

$$E_{\mathrm{bind}} = \alpha_{\mathrm{CE}} \left[\frac{G\,M_{1\mathrm{f}}\,M_2}{2\,a_{\mathrm{f}}} - \frac{G\,M_{1\mathrm{i}}\,M_2}{2\,a_{\mathrm{i}}} \right]$$

- α_{CE} is the common-envelope efficiency parameter

γ-envelope ejection (EE; spiral-in not necessary):

- envelope ejection with angular-momentum balance (Nelemans et al., 2000):

$$\frac{J_{\mathrm{i}} - J_{\mathrm{f}}}{J_{\mathrm{i}}} = \gamma_{\mathrm{CE}} \frac{M_{1\mathrm{i}} - M_{1\mathrm{f}}}{M_{1\mathrm{i}} + M_2}$$

- $\gamma_{\mathrm{CE}} \approx 1.5$ is the efficiency parameter

Envelope structure parameter

- Detailed stellar model is needed to compute $E_{\rm bind}$
- Use $\lambda_{\rm env}$ to approximate $E_{\rm bind}$ from basic parameters (Webbink, 1984; De Kool et al., 1987)

$$\lambda_{\rm env} \equiv \frac{G\,M\,M_{\rm env}}{R\,E_{\rm bind,env}}$$

$$-\frac{G\,M\,M_{\rm env}}{R} = \alpha_{\rm CE}\,\lambda_{\rm env}\,\Delta E_{\rm orb}$$

- Smaller $\lambda_{\rm env}$ indicates more centrally concentrated envelope
- Often, a constant value for $\lambda_{\rm env}$ is assumed in population-synthesis codes:
  - $\lambda_{\rm env} = 0.5$ (*e.g.* De Kool 1987; Nelemans et al., 2000; Hurley et al., 2002)
  - $\alpha_{\rm CE}\lambda_{\rm env} = 0.5, 1.0$ (*e.g.* Belczynski et al., 2008)
- Value of $\lambda_{\rm env}$ is far from constant (*e.g.* Dewi & Tauris, 2000; MvdS et al., 2006)

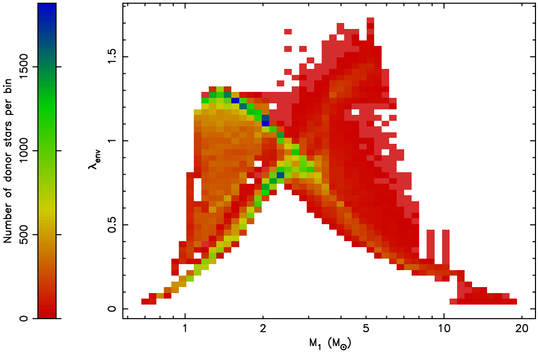
Determine typical values for $\lambda_{\rm env}$

- Grid of 116 detailed stellar-evolution models; 32 brown-dwarf models
- Generate 10^6 random ZAMS binaries; $M_* < 20\,M_\odot$; uniform $P(\log P_{\rm orb})$,$P(q)$; $M_{\rm c} \equiv M(X = 0.1)$
- Follow donor stars from ZAMS to CE; record properties at RLOF: 165,007 CEs

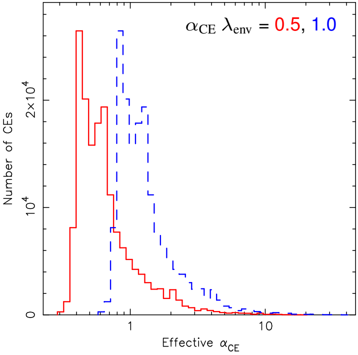
Envelope structure parameter

Properties of 165,007 CEs

	RGB	AGB	Total
Survivors	16.1%	31.8%	48.0%
Mergers	45.4%	6.6%	52.0%
Total	61.5%	38.5%	100.0%

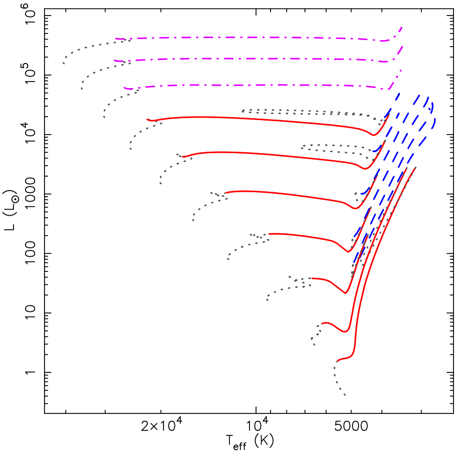


MvdS et al. (2010)



- Implicit $\alpha_{CE} > 1$ for 16% and 64% of CEs

Fits for the binding energy



low-mass RGB low-mass AGB high-mass GB

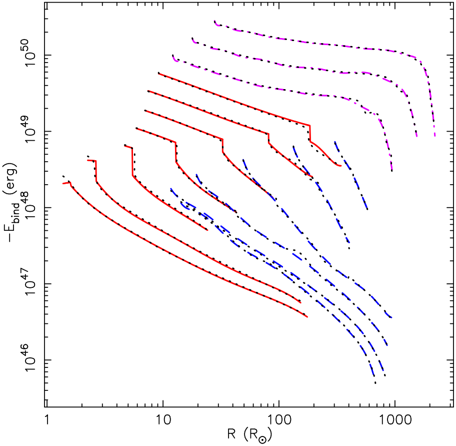
$$E_{\rm bind} = \int_{M_c}^{M_s} \left(E_{\rm int}(m) - \frac{Gm}{r(m)} \right) {\rm d}m$$

$$\log\left(\frac{-E_{\rm bind}}{\rm erg}\right) \approx E_0 + \Lambda(M_0, M) \times \sum_{m,r} \alpha_{m,r} \left[\log\left(\frac{M}{M_\odot}\right)\right]^m \left[\log\left(\frac{R}{R_\odot}\right)\right]^r$$

- 73 models, $0.8\,M_\odot \leq M \leq 100\,M_\odot$
- fit as a function of ZAMS mass, current mass and current radius
- 6 different metallicities ($Z = 10^{-4} - 0.03$)
- Λ correction factor for wind mass loss
- separate fits for recombination energy

Andrew Loveridge et al. (2011)

Fits for the binding energy



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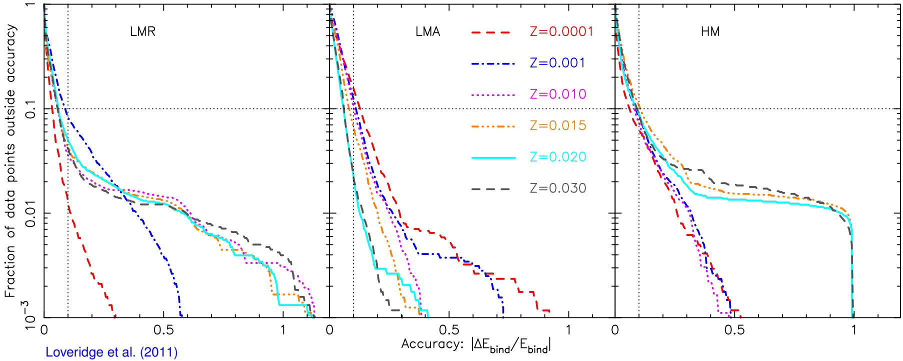
Accuracies of the fits

Z	group	$\Delta_{10\%}$ fit	$\Delta_{10\%}$ test	$\Delta_{15\%}$ fit	$\Delta_{15\%}$ test
10^{-4}	LMR	97.6%	97.7%	98.9%	99.1%
10^{-4}	LMA	86.6%	86.4%	94.8%	94.8%
10^{-4}	HM	94.8%	93.6%	96.4%	94.6%
10^{-3}	LMR	92.0%	90.4%	95.0%	93.6%
10^{-3}	LMA	85.3%	84.3%	95.2%	92.5%
10^{-3}	HM	91.1%	90.0%	95.5%	93.4%
0.02	LMR	94.3%	92.7%	96.4%	96.4%
0.02	LMA	97.1%	91.9%	99.3%	96.9%
0.02	HM	92.0%	91.7%	96.6%	96.1%



Loveridge et al. (2011)

Conclusions for the binding energies

Envelope binding energies:

- $\lambda_{\rm env}$ varies wildly as a function of stellar mass and evolutionary stage
- Simplified assumptions for $\lambda_{\rm env}$ may imply unphysical values for $\alpha_{\rm CE}$
- Loveridge et al. (2011) provide accurate fits for $E_{\rm bind}$
    - electronic data files and routines online
    - $\lambda_{\rm env}$ no longer needed

Population-synthesis codes:

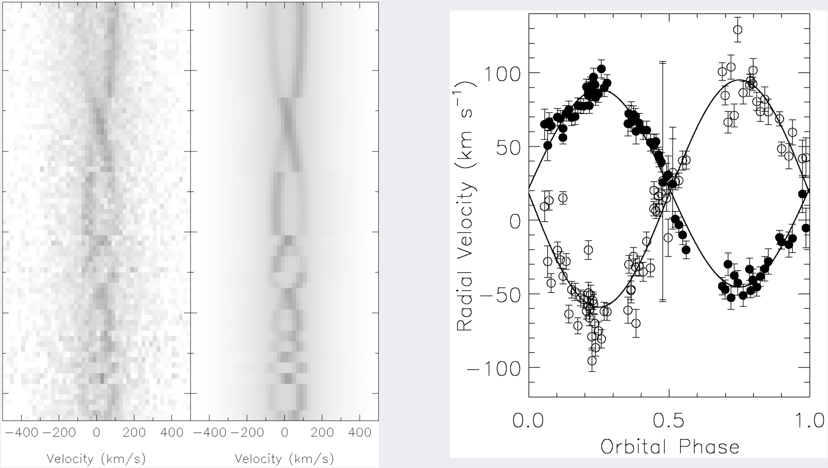
- Fits are (being) implemented in:
    - StarTrack (Belczynski et al.)
    - SeBa (Toonen?)
    - BSE (Hurley et al., Mónica Zorotovic)

To do:

- Massive stars:
    - uncertainty in core-envelope boundary
    - deviations due to strong stellar winds

Observed double white dwarfs

WD 0316+768



Adapted from Maxted et al. (2002)

- well determined: P_{orb}, q
- model-dependent: M_1, M_2, τ_{cool}

Observed double white dwarfs

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Galactic double white dwarfs for cLISA

Types and formation channels:

	ν	N	$N/N_{\rm gal}$	$N_{\rm Resolved}$	%
Types of WD binaries:					
He+He	1.34×10^{-2}	1.06×10^{8}	38.41%	19 936	59.21%
CO+He	5.07×10^{-3}	4.11×10^{7}	14.89%	12 852	38.17%
CO+CO	1.15×10^{-2}	1.08×10^{8}	39.13%	586	1.74%
ONeMg	2.13×10^{-3}	2.09×10^{7}	7.57%	296	0.88%
Formation channels:					
RLOF+CE	9.86×10^{-3}	8.27×10^{7}	29.96%	1061	3.15%
CE+CE	2.12×10^{-2}	1.84×10^{8}	66.67%	32 609	96.85%
other channels	1.04×10^{-3}	9.3×10^{6}	3.37%	0	0
Total	3.21×10^{-2}	2.76×10^{8}		33 670	

Yu & Jeffery (2010)

- Most Galactic DWDs form a noise *foreground*
- Resolved systems appear between $f \sim 1.4$ and $5.0\,$mHz ($P_{\rm orb} \sim 24 - 7\,$min)

Formation scenarios

Stable + unstable MT

MS + MS

↓ Stable M.T. (cons./part.cons.) ↓

WD + MS

↓ Unstable M.T. (α-CE) ↓

WD + WD

Unstable + unstable MT

MS + MS

↓ Unstable M.T. (γ-EE) ↓

WD + MS

↓ Unstable M.T. (α-CE, γ-EE) ↓

WD + WD

Envelope ejection with angular-momentum conservation

- Average specific angular momentum of the system:

$$\frac{J_{\rm i} - J_{\rm f}}{J_{\rm i}} = \gamma_{\rm s} \frac{M_{\rm 1i} - M_{\rm 1f}}{M_{\rm tot,i}} \qquad (\gamma_{\rm s} \sim 1.5)$$

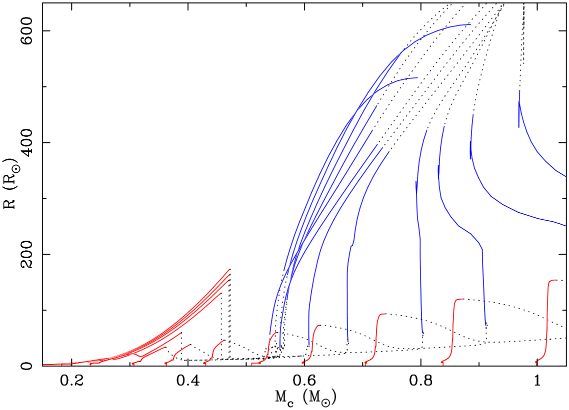
- Specific angular momentum of the donor:

$$\frac{J_{\rm i} - J_{\rm f}}{J_{\rm i}} = \gamma_{\rm d} \frac{M_{\rm 1i} - M_{\rm 1f}}{M_{\rm tot,f}} \frac{M_{\rm 2i}}{M_{\rm 1i}} \qquad (\gamma_{\rm d} \sim 1.0)$$

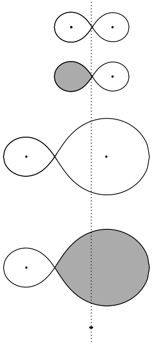
- Specific angular momentum of the accretor:

$$\frac{J_{\rm i} - J_{\rm f}}{J_{\rm i}} = \gamma_{\rm a} \left[1 - \frac{M_{\rm tot,i}}{M_{\rm tot,f}} \exp\left(\frac{M_{\rm 1f} - M_{\rm 1i}}{M_2}\right)\right] \qquad (\gamma_{\rm a} \sim 1.0)$$

Formation models: reconstruction



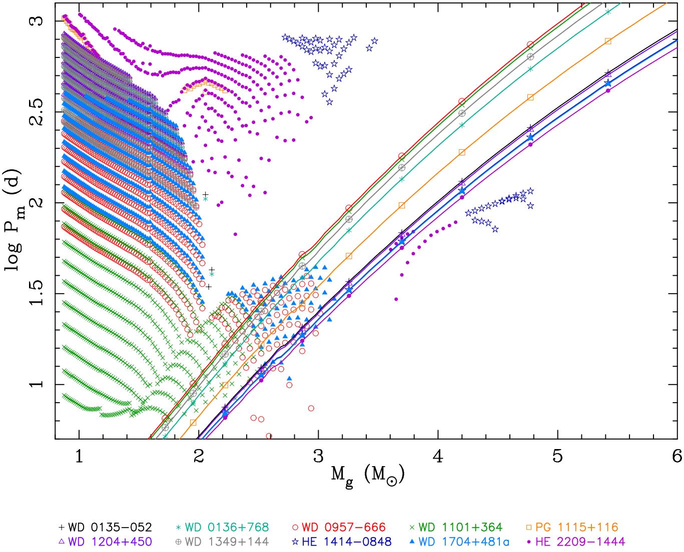
- 199 single-star models
- 0.8–10.0 $M_\odot$
- CEs at RGB or AGB
- $M_c = M_{WD}$
- $R_* = R_{RLOF} \rightarrow P_{orb}$



Reconstructing the second mass-transfer phase: CE

- White-dwarf mass sets core mass (evolutionary state) of progenitor
- Giant radius determines orbital period of progenitor
- Envelope binding energy dictates what α_{CE} is needed for ΔP_{orb}
- **Unknown:** progenitor mass $\rightarrow$ parametrise

First mass-transfer phase: stable, conservative MT

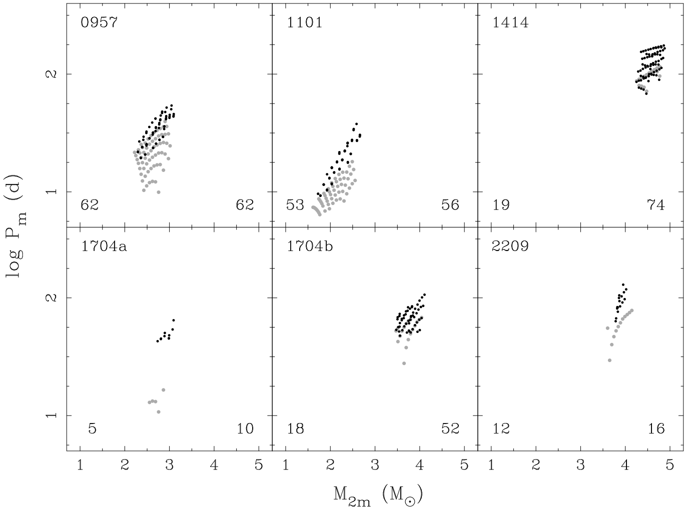


Stable MT: $R_* < R_{\mathrm{BGB}}$
or $q < q_{\mathrm{crit}}$
(Hurley et al., 2002)

Maximum P_{orb} after stable mass transfer with
$q_{\mathrm{i}} = 0.62$
(Nelemans et al., 2000)

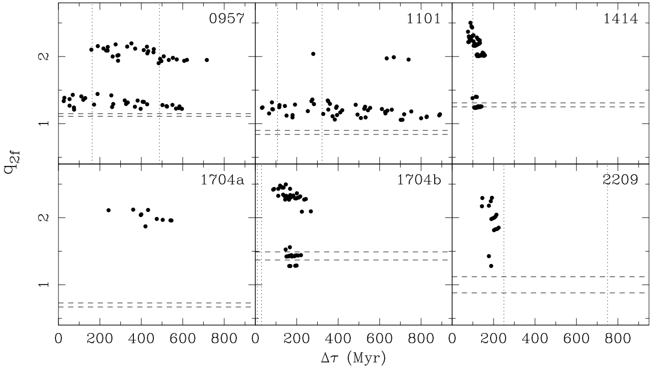
Only 5 systems have CE solutions with
$P_{\mathrm{orb}} < P_{\mathrm{max}}$

Conservative mass transfer: masses and periods



- 570 detailed binary-evolution models, computed to match pre-CE systems
- 270 result in DWDs
- spiral-in
- **stable**

Conservative mass transfer: mass ratios and cooling-age differences



- **1414** fits
- **0957, 1101, 1704b** and **2209** nearly fit

- Out of ten systems, 1 can be explained, 4 are close

Models for unstable MT + unstable MT

Number of progenitor models:

- 10+1 observed systems
- 199 progenitor models in our grid
- 11 variations in observed mass: $-0.05, -0.04, \ldots, +0.05\ M_\odot$
- Total: $11 \times 11 \times \sum_{n=1}^{198} n \quad \approx \quad$ 2.4 million

Filters:

- Unstable MT: $\quad R_* > R_\mathrm{BGB} \quad$ and $\quad q > q_\mathrm{crit}$
  - $q_\mathrm{crit} \approx 0.64 + 0.94 \left(\frac{M_\mathrm{c}}{M_*}\right)^5 (Z = 0.02)$ (Hurley et al., 2002)
- Age: $\quad \tau_1 < \tau_2 < 13\,\mathrm{Gyr}$
- EE-parameter: $\quad 0.1 < \alpha_\mathrm{CE}, \gamma_\mathrm{s,d,a} < 10$

Result:

- Candidate progenitors left: $\quad \sim 204\,000$

Unstable MT results: overview

Select systems with:

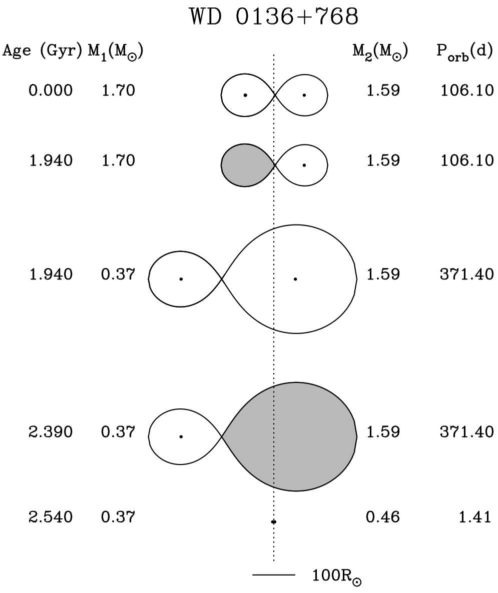
- $0.8 < \alpha_{\rm CE} < 1.2$
- $1.46 < \gamma_{\rm s} < 1.79$
- $0.9 < \gamma_{\rm a,d} < 1.1$

System	1: $\gamma_{\rm s}\alpha_{\rm CE}$	2: $\gamma_{\rm s}\gamma_{\rm s}$	3: $\gamma_{\rm a}\alpha_{\rm CE}$	4: $\gamma_{\rm a}\gamma_{\rm a}$	5: $\gamma_{\rm d}\alpha_{\rm CE}$	6: $\gamma_{\rm d}\gamma_{\rm a}$	Best:
0135	$-/-$	$+/\sim$	$+/\sim$	$-/-$	$+/\sim$	$+/\sim$	2,3,5,6
0136	$+/+$	$+/+$	$+/\sim$	$+/\sim$	$+/+$	$+/+$	1,2,5,6
0957	$+/+$	$+/+$	$-/-$	$+/-$	$+/+$	$+/+$	1,2,5,6
1101	$+/\sim$	$+/-$	$+/-$	$-/-$	$+/\sim$	$+/\sim$	1,5,6
1115	$+/\sim$	$+/+$	$+/\sim$	$+/\sim$	$+/+$	$+/+$	2,5,6
1204	$-/-$	$+/-$	$+/-$	$+/-$	$+/-$	$+/+$	6
1349	$+/+$	$+/+$	$+/+$	$+/+$	$+/+$	$+/+$	1–6
1414	$-/-$	$+/+$	$-/-$	$+/+$	$-/-$	$+/+$	2,4,6
1704a	$+/-$	$+/-$	$-/-$	$-/-$	$-/-$	$-/-$	1,2
1704b	$+/-$	$+/-$	$-/-$	$+/-$	$+/-$	$+/-$	1,2,4,5,6
2209	$+/+$	$+/+$	$-/-$	$-/-$	$+/\sim$	$+/+$	1,2,6
Best	7×	9×	2×	3×	7×	10×	

Column 1: $+$: α, γ within range, $-$: α, γ outside range

Column 2: $+$: $\Delta(\Delta t) < 50\%$, $\sim$: $50\% < \Delta(\Delta t) < 500\%$, $-$: $\Delta(\Delta t) > 500\%$

Results: example solution



$\gamma_d = 0.96 \rightarrow$

$\gamma_a = 1.05 \rightarrow$

$\Delta\tau = 450\,\mathrm{Myr} \rightarrow$

DWD conclusions so far

Stable, conservative mass transfer:

- Follow-up study of Nelemans et al. (2000)
- More accurate models give qualitatively same results
- We can reproduce perhaps 1–4 out of 10 systems, all with $\alpha_{\rm CE} > 1.6$
- **Conservative mass transfer cannot explain the observed double white dwarfs**

Unstable mass transfer:

- Unstable envelope ejection can explain the observed double white dwarfs
- Several EE descriptions can reconstruct observed masses and periods
- In addition, $\gamma_{\rm s}\gamma_{\rm s}$ and $\gamma_{\rm d}\gamma_{\rm a}$ can explain most observed cooling-age differences

But:

- What do $\gamma_{\rm s,d,a}$ mean?
- Is $q_{\rm crit}$ a good condition for stabilty of MT?
- What about stable, *non-conservative* MT?
- Do stellar winds have any influence?

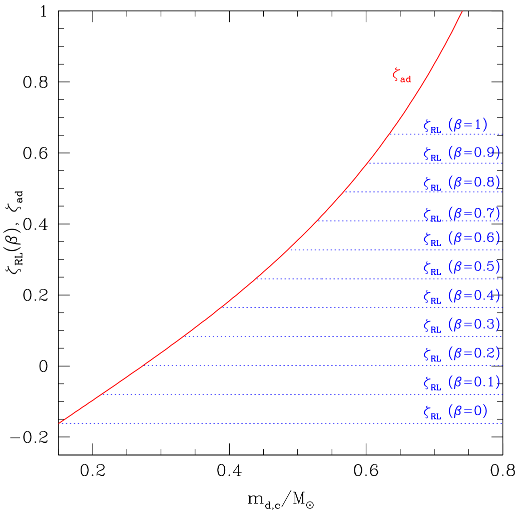
Stability of and conservation factor during mass transfer

Response of donor star and Roche lobe to mass loss:

$$\zeta_{\rm ad} \equiv \left(\frac{d\log R_*}{d\log M_*}\right)_{\rm ad} = f\left(\frac{M_{\rm c}}{M_*}\right)$$

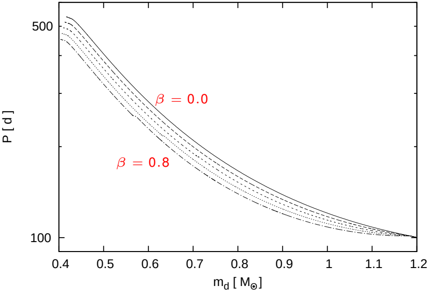
$$\zeta_{\rm Rl} \equiv \frac{d\log R_{\rm Rl}}{d\log M_*} = f(q,\beta)$$

- If $\zeta_{\rm ad} \gtrsim \zeta_{\rm Rl}$ (*i.e.*, $\dot{R}_* \lesssim \dot{R}_{\rm Rl}$), mass transfer is dynamically stable (Hjellming & Webbink, 1987)
- β: mass-conservation factor; $\dot{M}_2 = -\beta\dot{M}_1$



Tyrone Woods et al., 2012

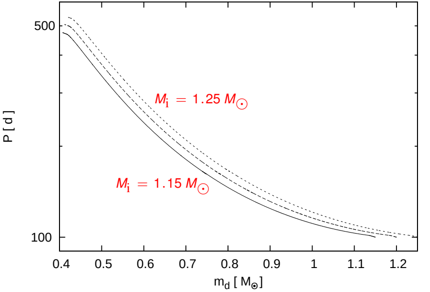
Dependence on binary parameters

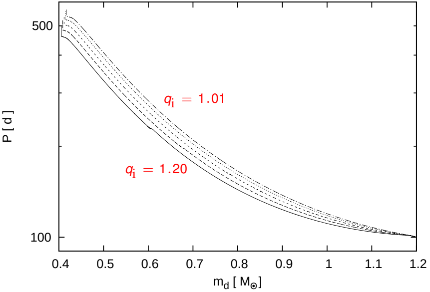


Default system:

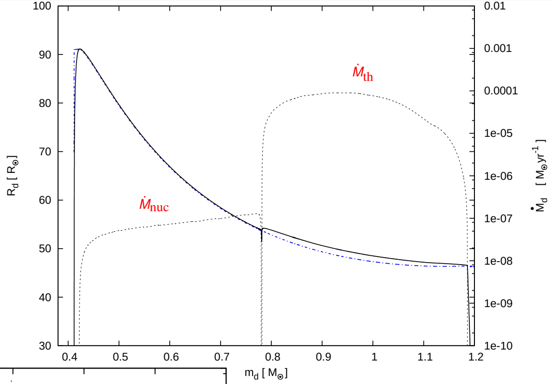
- $M_{1,\mathrm{i}} = 1.2\,M_\odot$
- $q_\mathrm{i} = 1.09$ ($M_{2,\mathrm{i}} = 1.1\,M_\odot$)
- $P_\mathrm{i} = 100\,\mathrm{d}$
- $\beta = 0.3$

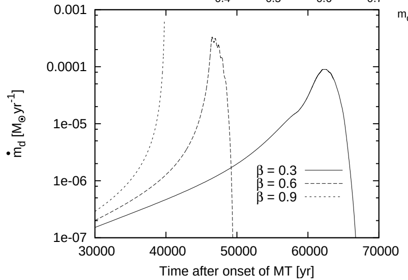
Woods et al., 2012





Thermal and nuclear mass transfer



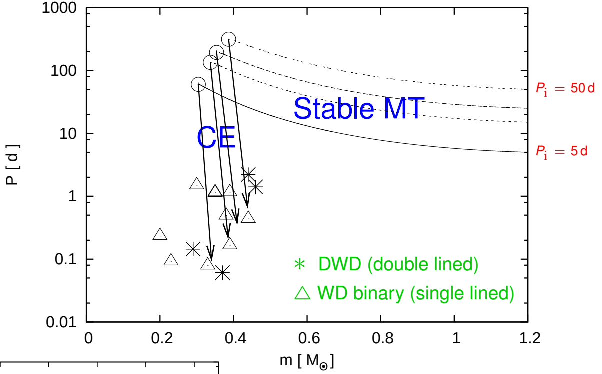


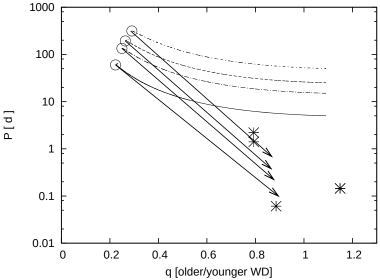
Default system:

- $M_i = 1.2 + 1.1\,M_\odot \quad (q_i \approx 1.09)$
- $P_i = 100\,\mathrm{d} \quad (M_{c,1} \approx 0.35\,M_\odot)$
- $\beta = 0.3$

Woods et al., 2012

Formation of low-mass DWDs through stable mass transfer





Initial systems:

- $M_i = 1.2 + 1.1\, M_\odot \quad (q_i \approx 1.09)$
- $P_i = 5, 15, 25, 50$ d
- $\beta = 0.3$

Woods et al., 2012

DWD conclusions

Stable, conservative mass transfer

- Cannot explain the 10 observed DWDs
- Best try: 1–4 systems, with $\alpha_{\mathrm{CE}} \gtrsim 1.6$

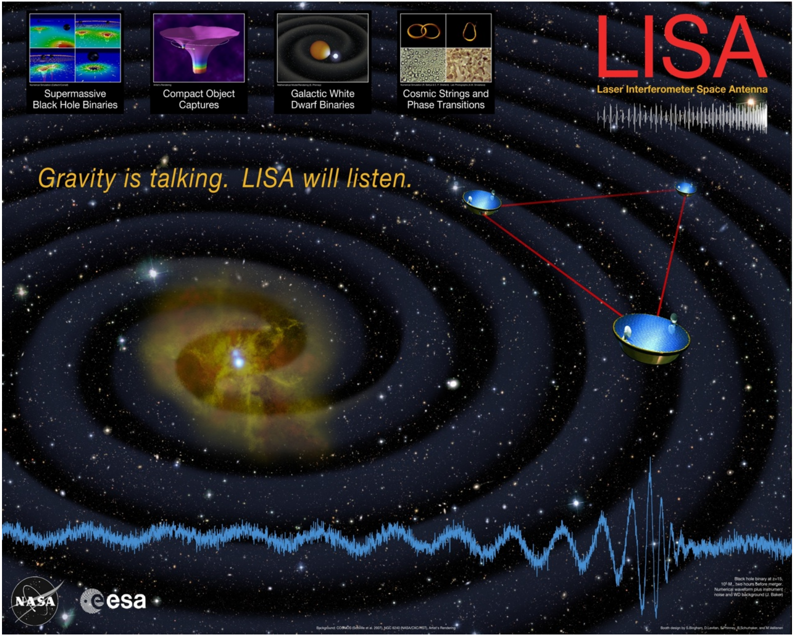
Unstable envelope ejection (α, γ)

- Explains 9–10 out of 10 of them reasonably
- Explains 8–9 systems when cooling age is taken into account
- Physics is (somewhat) poor for (some) γs

Stable, non-conservative mass transfer

- Explains DWDs comparable to 3 out of 10 observed systems
- Only works for systems with $M \lesssim 0.47\,M_{\odot}$, $q \lesssim 1$ — or does it?
- Cooling ages not taken into account in Woods et al. (2012)

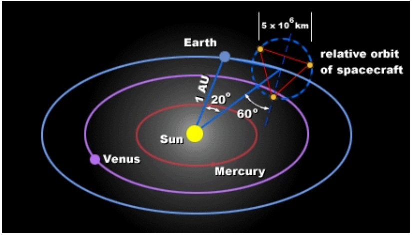
European Laser Interferometer Space Antenna (eLISA)



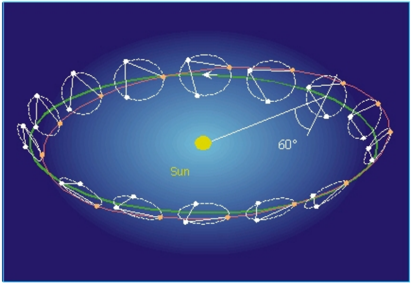
European Laser Interferometer Space Antenna (eLISA)

Mission:

- 3 spacecraft, 4 test masses
- Triangular configuration, arm length $\sim 2 \times 10^6$ km
- Detector is in solar orbit, trailing the Earth by 20°, in a plane inclined by 60°
- 1 Watt laser beams between spacecraft
- Low-frequency sensitivity: 0.1 mHz – 0.1 Hz ($P_{\rm orb} \sim 20\,$s – 5 h)



- Mission length $\geq 5\,$yr
- Final decision April 2012
- LISA Pathfinder must test technology ($\sim$ 2012?)
- Launch $\gtrsim$ 2020 – 2025?



eLISA: Galactic binaries

Detached binaries:

- Double white dwarfs:
  - abundant; most common endpoint of evolution: $\sim 3 \times 10^8$, $\sim 3 \times 10^4$ resolved (Yu & Jeffery, 2010)
  - several tens discovered (*e.g.* Saffer 1988, Marsh 1995)
  - so far, only few in the eLISA band
- White-dwarf–neutron-star binaries:
  - typically WD + pulsar
  - long periods
  - no systems in eLISA band found, several expected
- Double neutron stars:
  - earliest discovered (Hulse & Taylor 1975)
  - 8 known
  - PSR J0737–3039 has $P = 2.4\,\mathrm{h}$ ($f = 2.3 \times 10^{-4}\,\mathrm{Hz}$)

Interacting binaries:

- AM CVn stars:
  - white dwarf accretes He-rich material from a compact donor (*e.g.* Warner 1995)
  - periods 5.4 – 65 min
- Ultracompact X-ray binaries:
  - $\sim$ 27 known, 8 with known periods 11–50 min
  - donor typically He rich, sometimes CO rich
  - up to half of the 14 observed LMXBs in GCs is ultracompact

(Nelemans, 2009)

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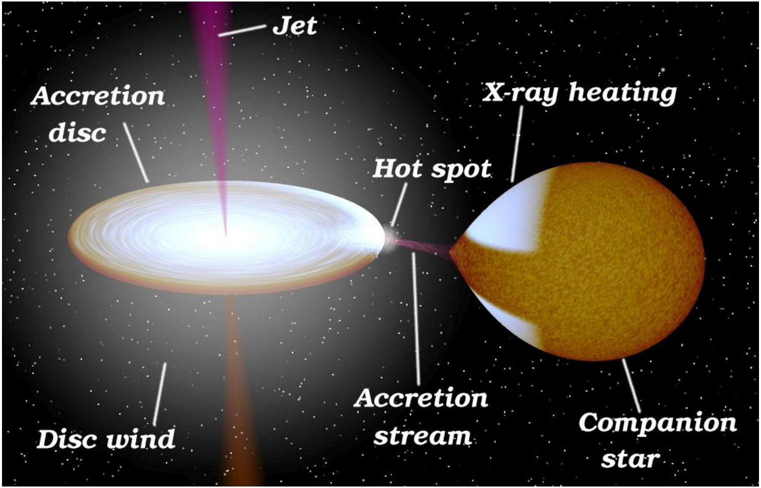
Cataclysmic variables, AM CVn systems, low-mass X-ray binaries

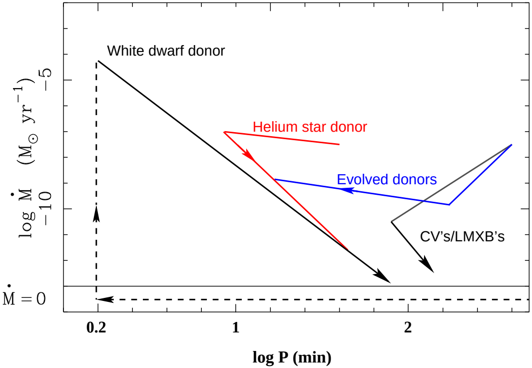
BinSim,
R. Hynes



- WD/NS accretor
- Optical emission comes from *hot spot*
- Accretion speed, hence luminosity, varies, sometimes dramatically

AM CVn systems

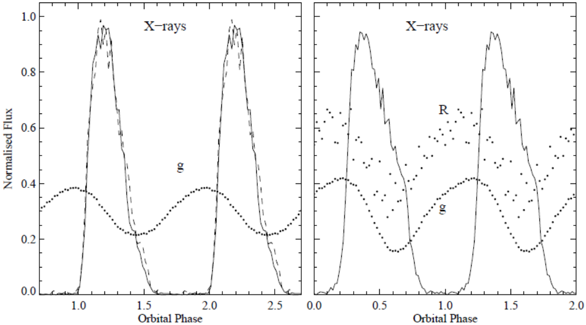
- $\sim$ 30 known
- He-dominated spectra:
  - CVs without H signature
  - H/He $\lesssim 10^{-5}$
  - H-poor donor fits in tighter orbit
- Short orbital periods: $\sim$ 5–65 min
- Main guaranteed LISA sources
- Possible donors:
  - He/hybrid He-CO white dwarf
  - helium star
  - evolved main-sequence star



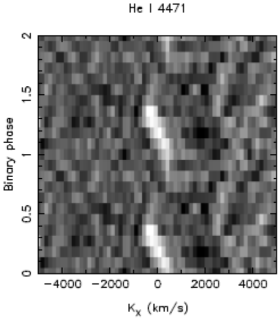
(Nelemans et al. 2010)

First ultracompact systems

V 407 Vul HM Cnc



HM Cnc

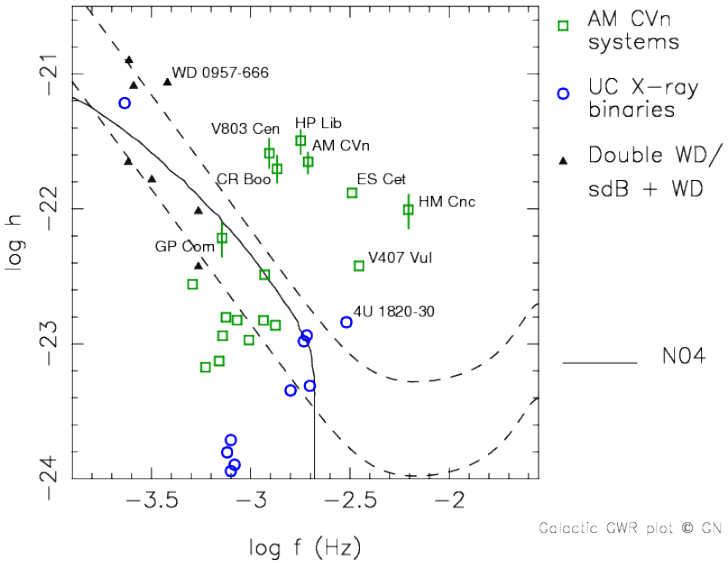


(Motch et al. 1996; Israel et al., 1999; Burwitz & Reinsch 2001)

(Roelofs et al. 2010)

- Two systems previously known from X-ray emission
- Ultrashort periods now confirmed using 10 m Keck-telescope:
  - HM Cnc: shortest known period: 5.4 min

cLISA: verification binaries



Nelemans, 2009; Roelofs et al., 2007, 2010

Mock LISA data challenges (MLDCs)

Round 1 (2006):

1. Single galactic binaries / verification binaries / resolvable binaries
2. Massive black-hole binaries
3. EMRIs

Round 2 (2007):

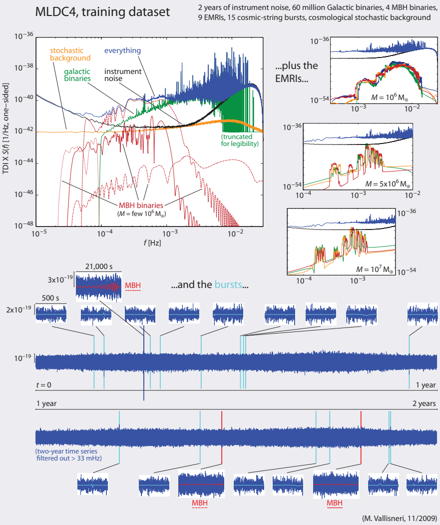
1. Galactic foreground: 30M monochromatic galactic binaries + 25 verification binaries
2. The Whole Enchilada: (1) + 4–6 BH binaries + 5 EMRIs

Round 3 (2008):

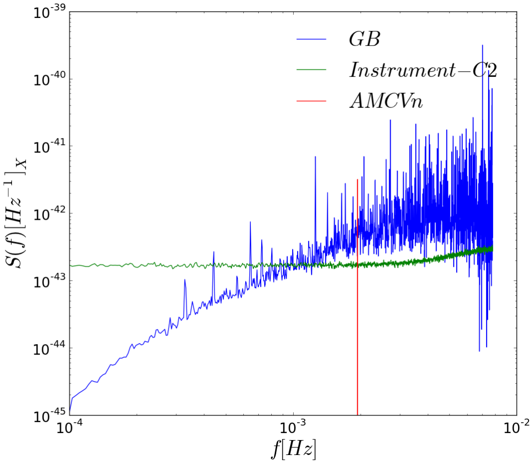
1. Galaxy with 60M chirping binaries
2. MBH binary over galactic confusion
3. EMRIs
4. Cosmic string bursts
5. Stochastic backgrounds

Round 4 (2011):

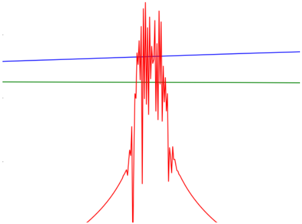
- Round 3, all in one data set:



Properties of AM CVn and SDSS J 0651+2844



Sweta Shah et al., in preparation



	AM CVn	J 0651
A (10^{-22})	1.494	1.670
f (mHz)	1.944	2.61
$\iota(^\circ)$	43	89.6
$\lambda(^\circ)$	170.1	101.4
$\beta(^\circ)$	37.2	5.7
$M_1(M_\odot)$	0.71	0.55
$M_2(M_\odot)$	0.13	0.25
d (kpc)	0.606	0.1
P (min)	17.1	12.8

Accuracies and correlations from GW data analysis

AM CVn, SNR $\approx$ 11.5, $\iota \approx 43^\circ$

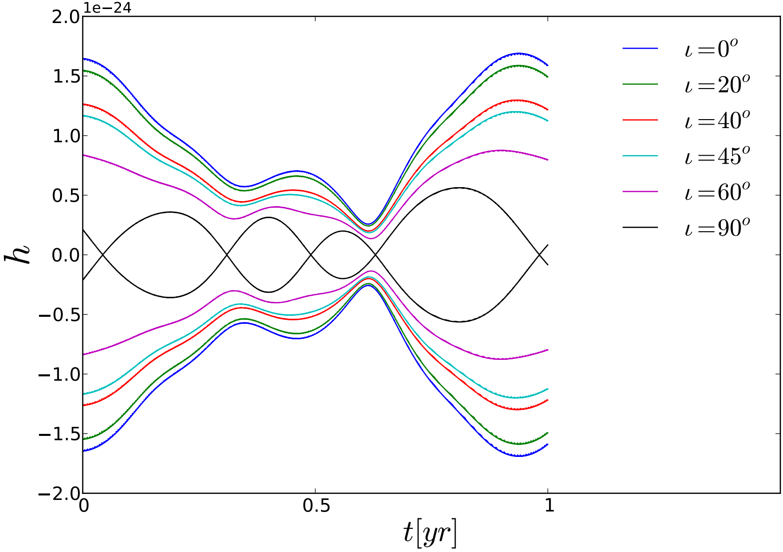
	$\mathcal{A}$	ϕ_0	$\cos\iota$	f	ψ	$\sin\beta$	λ
	1.49×10^{-22}	π	0.73	1.944×10^{-3}	$\pi/2$	0.61	2.97
$\mathcal{A}$	1.08×10^{-22}	0.29	−0.99	−0.06	−0.30	−0.03	−0.60
ϕ_0		3.22	−0.27	−0.03	−0.99	0.26	−0.44
$\cos\iota$			0.58	0.06	0.28	0.04	0.60
f				6.8×10^{-10}	−0.03	−0.11	−0.19
ψ					1.17	−0.27	0.03
$\sin\beta$						0.03	0.03
λ							0.04

J 0651, SNR $\approx$ 10.7, $\iota \approx 89.6^\circ$

	$\mathcal{A}$	ϕ_0	$\cos\iota$	f	ψ	$\sin\beta$	λ
	1.67×10^{-22}	π	0.01	1.944×10^{-3}	$\pi/2$	0.10	1.77
$\mathcal{A}$	1.56×10^{-23}	0.01	−0.05	−0.02	0.02	0.03	−0.08
ϕ_0		0.21	−0.01	−0.89	−0.02	0.13	−0.13
$\cos\iota$			0.04	0.01	0.02	−0.06	0.34
f				8.4×10^{-10}	0.01	−0.17	0.16
ψ					0.04	−0.03	0.09
$\sin\beta$						0.07	0.09
λ							0.02

Shah et al., in preparation

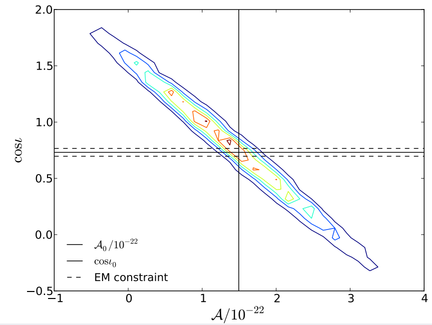
Signal envelopes for AM CVn



Shah et al., in preparation

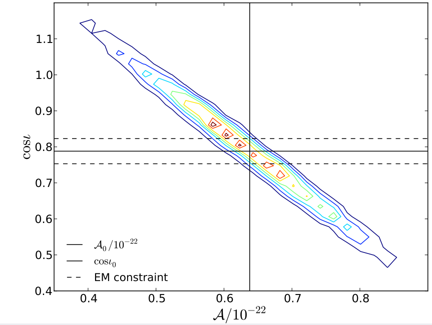
Improvement in amplitude uncertainties

AM CVn



Improvement in $\sigma_{\mathcal{A}}$: $\sim 5\times$

HM Cnc



Improvement in $\sigma_{\mathcal{A}}$: $\sim 4\times$

Shah et al., in preparation

Conclusions for LISA

For binaries with an inclination below 45°

- Amplitude and inclination are degenerate, hence ill-determined
- A strong correlation between these two parameters helps constrain $\mathcal{A}$ when ι is known
- A correlation between ϕ_0 and ψ is astrophysically uninteresting

For binaries with an inclination above 45°

- Amplitude and inclination are non-degenerate and well-determined
- A correlation between ϕ_0 and f is astrophysically uninteresting

Future work

- Determine the influence of sky position
- Develop strategic plans for EM follow-up

End...