The Formation of Ultracompact Binaries

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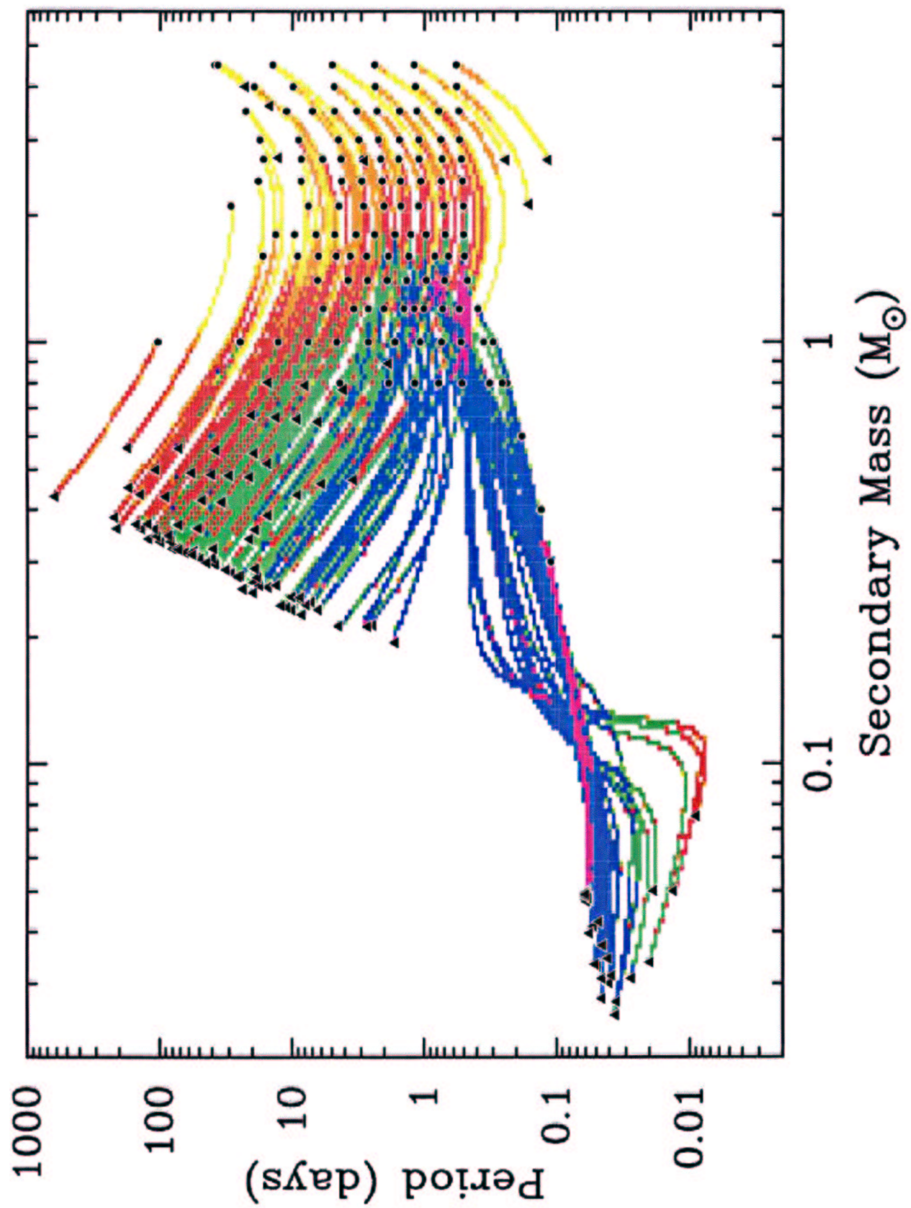
- **Ultracompact systems are systems with orbital periods** below the 'standard' period minimum (70 – 80 min) **with** neutron star (with periods as low as 11 min) **or** white dwarf (AM CVn binaries) **primaries**
- **Requires a low-mass** H-deficient **secondary** (at least partly degenerate/semi-degenerate)
- **Other models** (see Nelemans)
  - ▹ the double-degenerate model: **the secondary is a degenerate object** (i.e. He, HeCO white dwarf)
  - ▹ a helium-star model: **the secondary is a semi-degenerate helium star**
- Low-/Intermediate-mass X-ray binaries (L/IMXBs), cataclysmic variables (CVs) **with initially somewhat** evolved secondaries **become ultracompact systems with periods as short as** ~ 5 min (Tutukov et al. 1987; Fedorova & Ergma 1989; PRP 2002)



Ultracompact Binaries

- evolved secondaries that start mass transfer near the end of the main sequence and below the bifurcation period ($\sim 18\,$hr; depends on magnetic braking law!) become ultracompact systems
- systems with H-exhausted cores transform themselves into degenerate helium stars (white dwarfs)
- shortest period: $\sim 5\,$min
- systems pass through periods of observed systems twice, before the period minimum when the orbital period decreases and after the orbital period minimum when the orbital period increases
- observational tests:

  decreasing orbital period:

  ▷ amount of hydrogen in the secondary (spectral lines, properties of X-ray bursts)

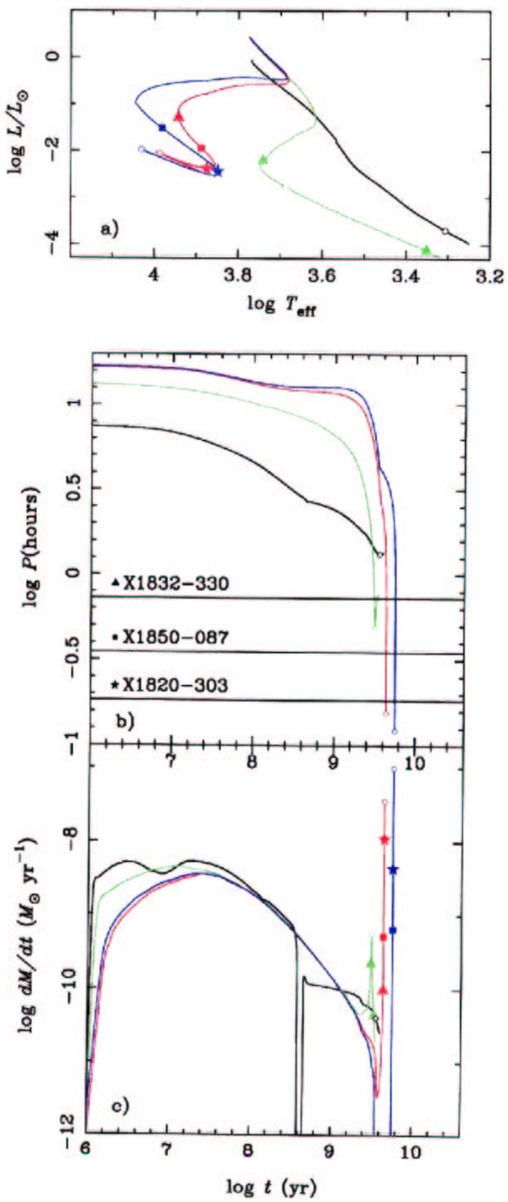
  ▷ negative $\dot{\mathrm{P}}$ (e.g. 4U 1820-303)

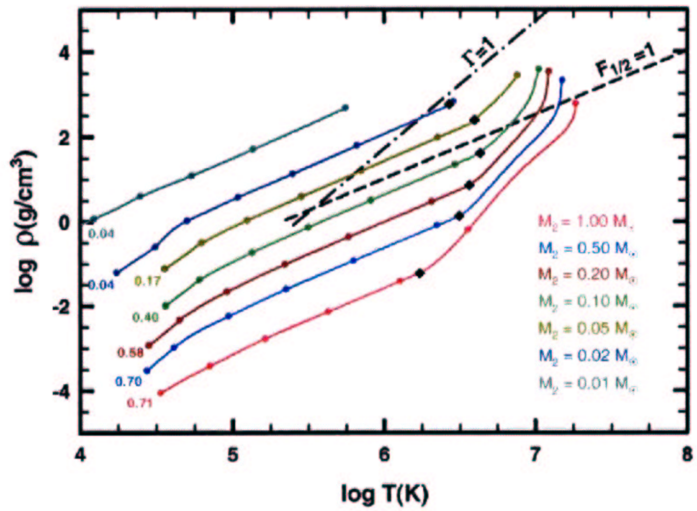
  increasing orbital period:

  ▷ no, little hydrogen

  ▷ positive $\dot{\mathrm{P}}$

Note: because of possible variations in the secondary structure (degree of degeneracy, size of H-rich/H-burning shell/core), $\dot{\mathrm{P}}, \dot{\mathrm{M}}$ can vary significantly and cannot generally be determined from simple analytic prescriptions.





Nelson & Rappaport (2003)

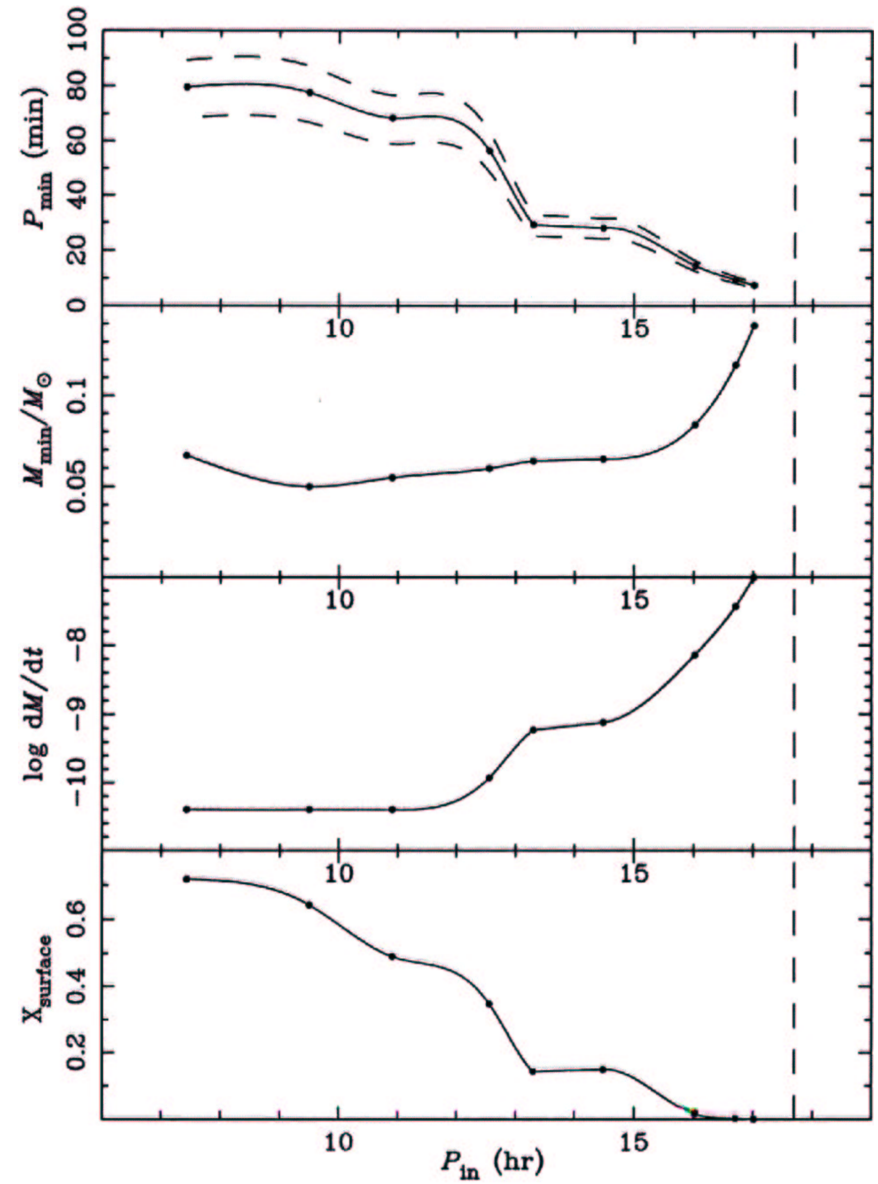


TABLE 1

X-Ray Binaries in Globular Clusters

Name	Globular Cluster	Observed Parameters: P_{orb} (hr)	L_X[1] ($\times 10^{36}$ erg s^{-1})	$(P/\dot{P})_{obs}$ (yr)	Model Parameters: $\dot{M}$ ($M_\odot$ yr^{-1})	$(P/\dot{P})$ (yr)	M_2 $M_\odot$	$X_{surface}$	model[a]
X2127+119	NGC 7078	17.10[2]	3.5	…	$10^{-10} - 4\times10^{-9}$	…	…	…	
X1747−313	Terzan 6	12.36[3]	3.4	…	$10^{-10} - 4\times10^{-9}$	…	…	…	
X1746−370	NGC 6441	5.70[4]	7.6	…	$10^{-10} - 4\times10^{-9}$	…	…	…	
X1832−330	NGC 6652	0.73[1]	2.2	…	2.2×10^{-10}	-7.2×10^{8}	0.094	0.28	b
					4.5×10^{-11}	$+5.4\times10^{9}$	0.026	0.05	b
					9.8×10^{-11}	-3.3×10^{8}	0.140	0.35	c
					1.7×10^{-11}	$+5.2\times10^{8}$	0.018	0.00	GR
X1850−087	NGC 6712	0.34[5]	0.8	…	5.2×10^{-10}	-4.6×10^{7}	0.136	0.31	c
					6.4×10^{-10}	-5.0×10^{7}	0.155	0.40	d
					5.6×10^{-10}	$+3.3\times10^{7}$	0.037	0.00	GR
X1820−303	NGC 6624	0.19[6]	40.6	-1.1×10^{7} (7)	1.1×10^{-8}	-1.2×10^{7}	0.129	0.18	c
					4.3×10^{-9}	-6.5×10^{6}	0.153	0.35	d
					8.8×10^{-9}	$+3.8\times10^{6}$	0.068	0.00	GR

NOTE.—Observed parameters: P_{orb}: orbital period; L_X: X-ray luminosity; $(P/\dot{P})_{obs}$: orbital spin-up time scale. Model parameters: $\dot{M}$: mass-transfer rate; $(P/\dot{P})$: orbital spin-up time scale; M_2: secondary mass; $X_{surface}$: surface hydrogen abundance. [a] The theoretical model from which the parameters were taken: either one of the sequences in Fig. 14 (a−d) or a fully degenerate model including only gravitational radiation (GR).

REFERENCES.—(1) Deutsch, Margon & Anderson 2000; (2) Ilovaisky et al. 1993; (3) in't Zand et al. 2000; (4) Sansom et al. 1993; (5) Homer et al. 1996; (6) Stella et al. 1987; (7) van der Klis et al. 1993.

44 min

Binary Population Synthesis (BPS)

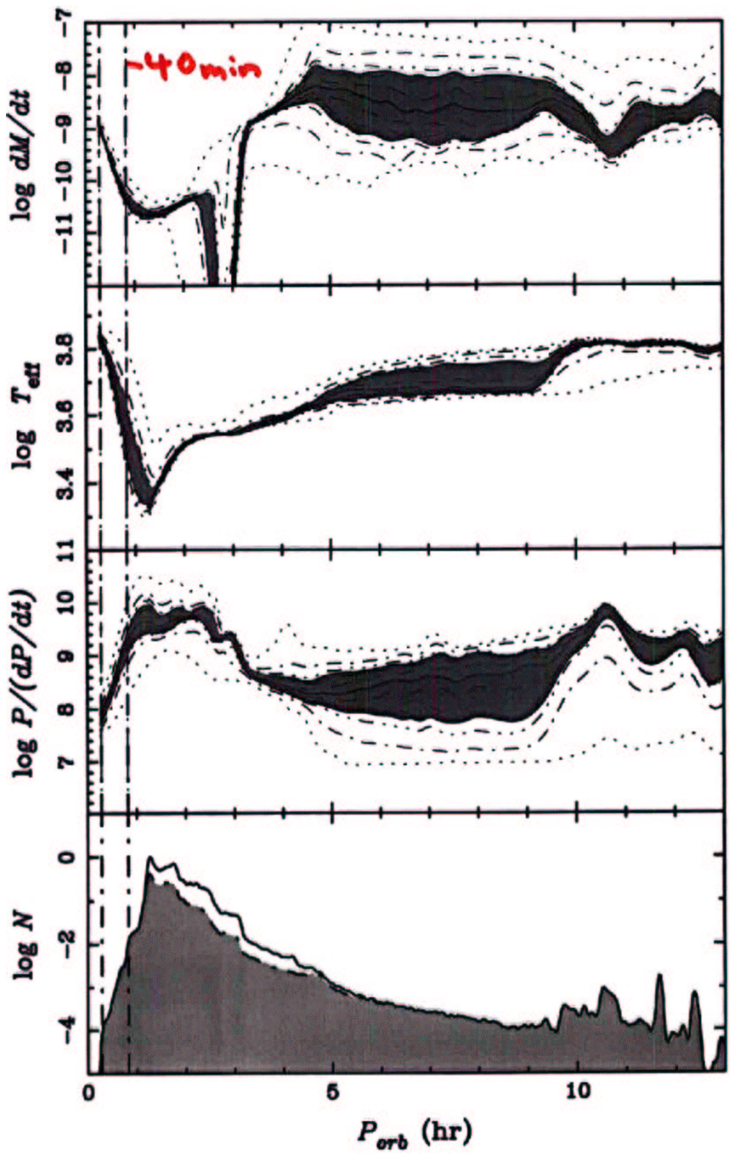
- simulate populations of binary systems
- combine standard BPS techniques with realistic binary evolution sequences instead of simple prescriptions

Ultracompact neutron-star binaries
(Pfahl, Rappaport, Podsiadlowski 2003)

- the X-ray binary population is dominated by IMXBs not LMXBs (by a factor of 5 to 20)
- ultracompact systems
  - ▹ ***Periods less than 90 min:*** $\sim 20\,\%$
  - ▹ ***Periods less than 50 min:*** up to a few %

AM CVn binaries (i.e. with white dwarfs)
(Podsiadlowski, Han, Rappaport 2002)

- ***Galactic formation rate:*** $\sim 10^{-3}\,\mathrm{yr}^{-1}$



X-ray binaries in globular clusters (GCs)

Observed Periods: 11 min (X1820-303), 21 min (X1850-087), 44 min (X1832-330), 5.7 hr (X1746-370), 12.4 hr (X1747-313), 17.1 hr (X2127+119)

- a large fraction of GC systems are ultracompact
- systems with periods from several hours to 1 d cannot be formed by 3 or 4-body interactions, but are expected from 2-body tidal captures

The tidal-capture problem

- the tidal-capture rate: 3- and 4-body interactions may dominate 2-body captures (?). What is the outcome of 3-/4-body interactions?
- the survival problem: do tidal-capture systems survive or merge either dynamically or because of the secondary's swelling due to tidal heating?
- binary sequences with tidal heating:
- *low-mass systems* ($\sim 1\,M_\odot$)
  - ▹ experience high mass-transfer rates (due to tidal heating),
  - ▹ but do not experience a mass-transfer run-away → survival?
- *intermediate-mass systems*
  - ▹ do not swell significantly (easier survival)
  - ▹ tidal heating is less important, different envelope structure, wind-like mass ejection (?)
  - ▹ transformation of an IMXB into a LMXB with a delay of 10^{10} yr