# Ultracompact X-ray Binaries in Globular Clusters

Lee Homer, University of Washington

# Outline

- *Introduction:* what is an ultracompact X-ray binary?
- *Observational results* to date: are ultracompacts over-abundant in globular clusters (GCs) relative to the field?
- *Formation and evolution* scenarios in GC environments
- *Future* prospects
- *Conclusions*

## What is an ultracompact X-ray binary?

- interacting binary with a neutron star accretor (for purposes of this talk at least)
- so compact that Roche-lobe filling star cannot be lower main-sequence H-burning $\equiv P_{orb} < 80\mathrm{min}$, $a \lesssim 0.6\, R_\odot$
- donor must be at least partially degenerate and in part H-depleted
- best studied case, field LMXB pulsar X1627–673, appears to have $0.02\, M_\odot$ C-O or O-Ne-Mg white dwarf- the fractionated core of a formally more massive WD.
- relevance to GCs? – possible over-abundance, relating to unique formation channels

# Observational Results

**Field**

4 well-determined:

- X1627–673 - *41 min*
- XTE J1751–305 - *42 min*
- XTE J0929–314 - *44 min*
- X1916–053 - *50 min*

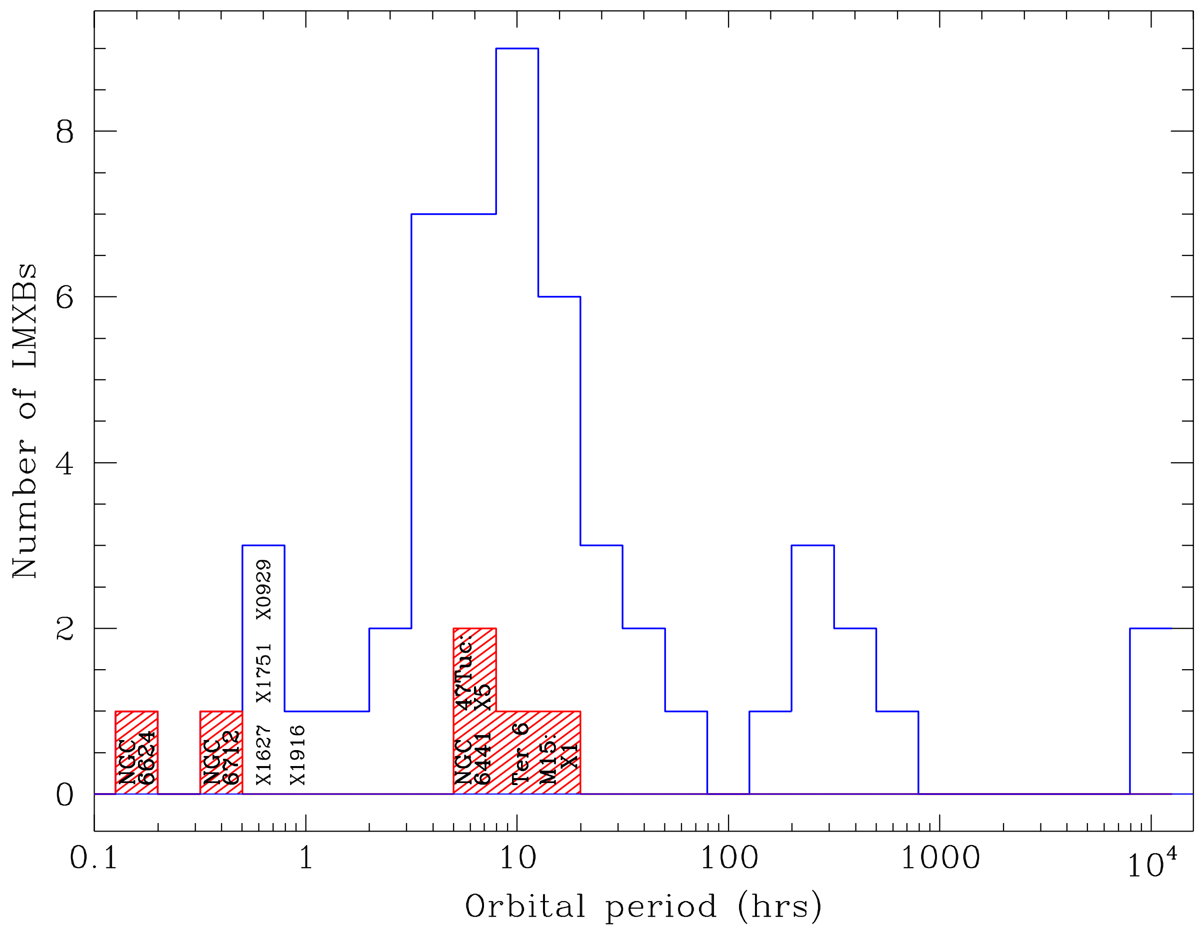
**GCs**

1 well-determined:

- NGC 6624: X1820–303 - *11 min*

1 to be confirmed:

- NGC 6712: X1850–087 - *21 min*



Consideration of relation between $L_X/L_{opt}$ and system size, as parameterized by van Paradijs & McClintock (1994) enables prediction of nominal period and upper limits.

1 probable:

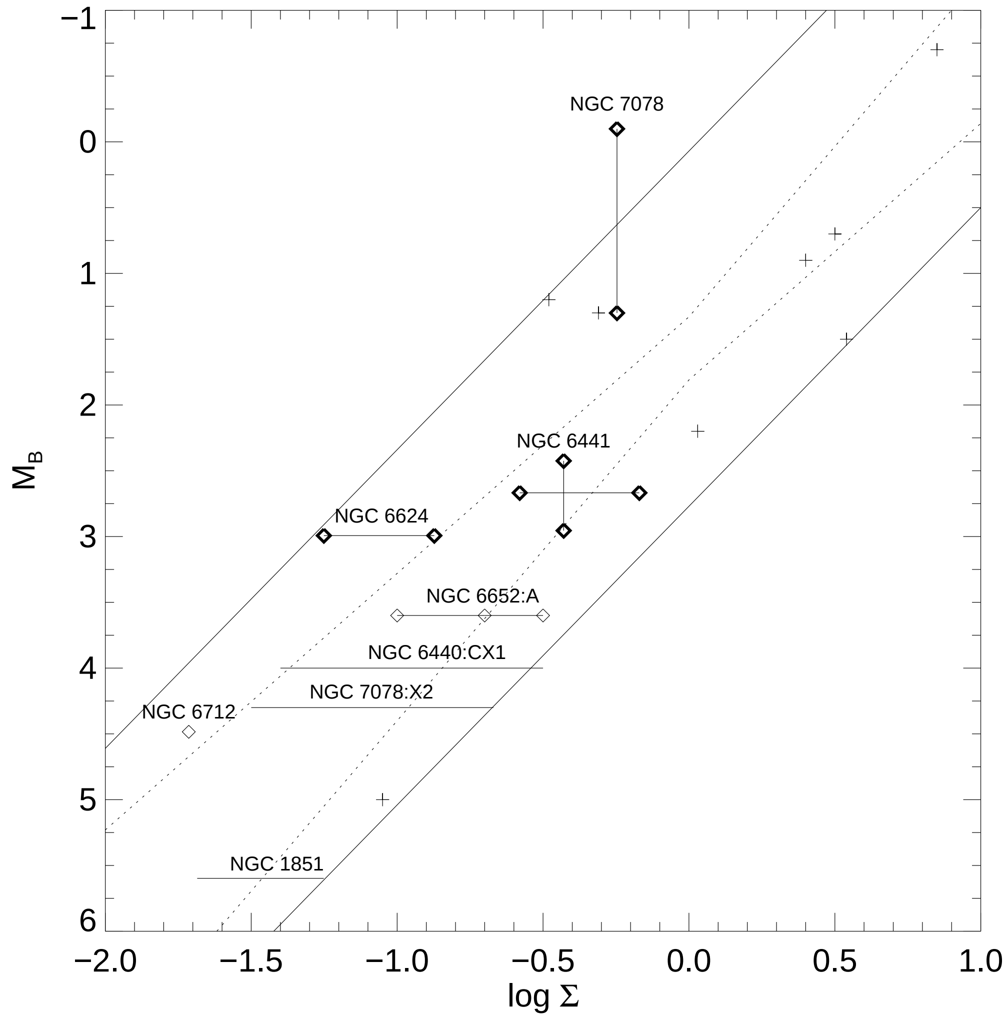
- NGC 1851: X0512–401 - *∼5min* (!), *≲85 min*

2 potential:

- NGC 7078(X2): CXOU J212958.1–121002 - *∼46 min* (≲4.7 hr)
- NGC 6440(CX1): CXOU J174852.1–202132 - *∼60 min* (≲5.8 hr)

another 2 possible (measured)

- NGC 6652(A): X1832–330 - *50 min* (or 2.2/4.4 hr)
- NGC 6652(B): CXOGLB J183544.5–325939 - *45 min ??*




Absolute magnitude of LMXBs versus $\Sigma = (L_X/L_{Edd})^{1/2}(P/1\mathrm{hr})^{2/3}$. Field LMXBs from van Paradijs & McClintock (1994) are marked by "+" symbols. Adapted from Deutsch (1998).

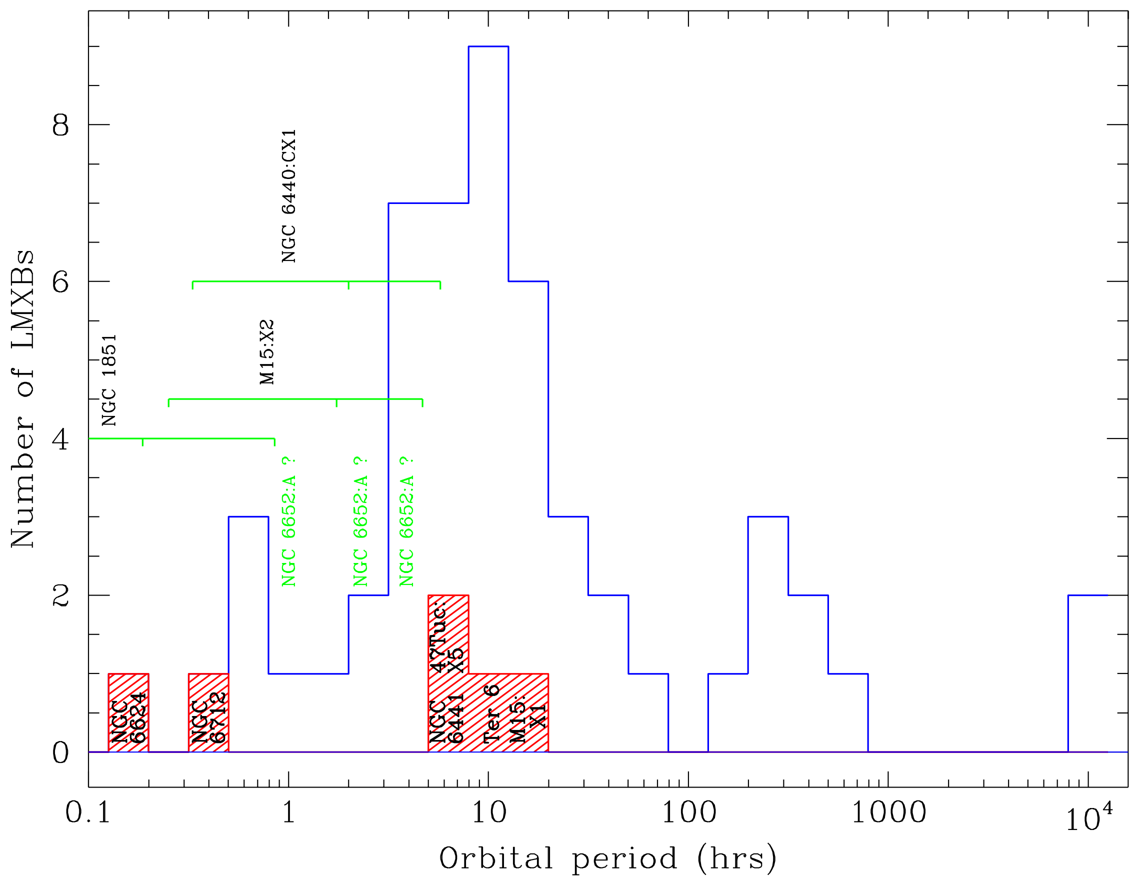
# Comparison of period distributions

*Note:* Further 2 field LMXBs (X0918-549 and X1543-624) have very high $L_X/L_{opt}$ *and* show excess Ne absorption in X-ray spectra similar to the known ultracompact X1627-673 (Juett et al. 2002) → candidate ultracompacts.

Notwithstanding the small number statistics-
Ratio of systems with $P_{orb} < 80$ min to those with $P_{orb} < 1000$ hr:

- Field- 4-9%
- GCs- 30-60%

→ Suggests possible over-abundance of ultracompact LMXBs in GCs



## Formation & Evolution Scenarios in GCs

At least four scenarios have been put forward:

1. *Direct collision of neutron star (NS) with red giant (RG)* → spiral-in of NS and loss of giant's envelope → NS-WD (former core of RG) binary. Eventually brought into contact by gravitational radiation (GR) angular momentum (AM) loss – Verbunt (1987).
   Problem: probable complete disruption of RG before spiral in – Rasio & Shapiro (1991), Bailyn (1988).

2. *Tidal capture of MS star by NS* → MS-NS binary. Donor only fills Roche lobe when evolves off MS, then mass transfer unstable → formation of common envelope (CE) → spiral-in and then as for (1) – Bailyn & Grindlay (1987).

3. *Exchange encounter of NS into primordial binary* → MS-NS binary then as for (2) – Rasio, Pfahl & Rappaport (2000, RPR00)

4. *Tidal capture of low-mass MS star by NS* → short period ($\lesssim$ 18 hr) MS-NS binary → mass transfer starts near or at point of central H exhaustion → degenerate He star donor → stable mass transfer with decreasing $P_{orb}$ continues – Fedorova & Ergma (1989), Podsiadlowski, Rappaport & Pfahl (2002, PRP02)

# Case 3: further details

As a step en route to forming the short-period millisecond pulsars observed in GCs (e.g. >20 in 47 Tuc) RPR00 examined ways to produce NS-WD binaries with ultrashort periods:

- started out with population of primordial binaries and NSs → migrate to core due to mass segregation
- interact together– too hard → ejection, too soft → disruption, remainder form NS-MS binary via exchange interaction (Note: MS star has 1–3 $M_\odot$ typically, as earlier in life of cluster)
- with expansion as secondary evolves off MS → 1/2 of systems enter CE phase → formation of close NS-WD binary.
- if $P_{orb} \lesssim$ 8hr GR AM losses → contact and Roche-lobe overflow
- short-lived ($10^6 - 10^7$ yr) X-ray bright phase, as ultracompact like X1820–303

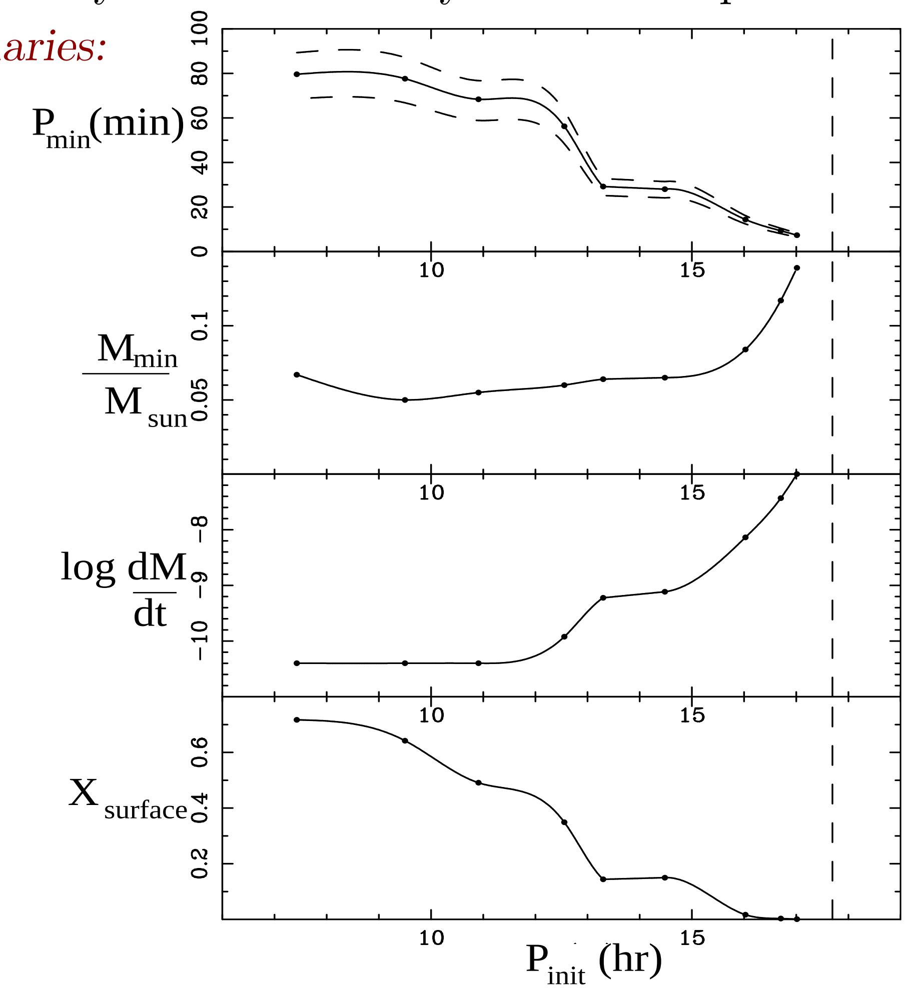
Problems:

- Mostly robust, but details of CE phase still very uncertain

# Case 4: further details

PRP02 undertook a systematic study of evolution of LMXBs and IMXBs, determining 100 binary evolution sequences, spanning full range of likely initial secondary masses and periods → *confirmed formation path for ultracompact binaries:*

- If initial binary period (at which mass transfer comences) below bifurcation value (~18 hr), systems evolve to shorter periods
- For $P_{init} \gtrsim 5$ hr, minimum period within the range of ultracompact
- With mass transfer onset around time of end of core H-burning → donor becomes degenerate He star → $P_{orb}$ as short as ~5 min
- One particular binary sequence able to account for periods of most of GC LMXBs– from AC211 with 17.1 hr to X1820-303 with 11 min




Formation of ultracompact LMXBs; all calculations start with 1.4 $M_\odot$ NS and 1 $M_\odot$ donor. Dashed curves represent limits of fully conservative (upper) or nonconservative mass transfer (lower). Reproduced from PRP02.

*Of special note:*

- initial period range ∼10–18 hrs preferentially attained following tidal capture of MS star by NS → could account for the (possible) over-abundance of ultracompacts in GCs
- exchange interactions *do not* generally lead to such initial conditions

Caveats:

- during tidal capture, total energy to be dissipated in MS star ∼its binding energy → disruption?
- hence range of possible initial MS-NS periods may well be further constrained
- value of bifurcation period strongly dependent on magnetic braking, e.g. change of efficiency by factor of 5 leads to values of ∼20 hr and ∼5 hr instead

# Future Prospects

## Observationally

*Determining the period distribution:*

- Confirm/determine X1850-087 and NGC 6652:A & B periods with further *HST* (or ground-based+ AO?) time-series photometry
- For known optical counterparts (NGC 6440:CX1, M15: X-2) attempt time-series photometry
- Via colour (*HST*) photometry seek identifications of *all* LMXBs – extremely difficult for either remaining persistent sources in highly reddened clusters or the new quiescent LMXBs being uncovered by *Chandra*

*Nature of secondaries:*

- High-resolution X-ray (with *Chandra* or *XMM*) spectroscopy may well provide more detailed information on elemental abundances of transferred material, c.f X1627-673, X0918-549 and X1543-624 (in the field)
- Multi-epoch orbital determinations to measure $\dot{P}$.
- Taken together these may be used to test formation/evolutionary channels, and/or constrain current phase of given system. e.g. by comparison with the predictions of $\dot{P}$ and abundances in the sequences of PRP02.

## In theoretical modelling: deriving predicted period distribution

- General progress in modelling of GC stellar dynamics and evolution → improved understanding of relative importance of exchange encounters versus tidal capture
- Specific constraints on the nature of the resulting stellar systems, together with a full binary population synthesis studies→ prediction of period distribution for GC LMXBs
- Improvements still needed in understanding processes of tidal capture and CE evolution– indeed comparisons of observational and theoretical period results may provide useful constraints.

# In Conclusion

1. Observational work in recent years, especially using *HST* in the UV/optical indicates a possible prevalence for ultracompacts amongst the GC population of LMXBs.

2. A number of formation/evolution channels have been proposed. Both those involving exchange collisions and tidal capture are naturally enhanced in the dense stellar environments of GC cores.

3. Much remains to be done

   - to confirm difference between period distributions of field and GC LMXBs
   - to take into account full effects of stellar dynamics together with evolution and its effects on the proposed formation scenarios