Ultracompact X-ray Binaries in Globular Clusters

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Introduction

- Observationally known that Globular clusters (GCs) are very efficient at forming compact binaries in general – LMXBs alone are orders of magnitude over-abundant (per unit stellar mass) in GCs vs the field.
- In turn, compact binary population critical in stabilizing GC cores against collapse– binary binding energy is released via a variety of dynamical interactions.
- Some of the most exotic compact binaries also well-represented in GCs
  - until 2002 3/5 of ultracompact LMXBs hosted by GCs
  - representing ∼50% GC LMXBs with known/suspected binary periods

In this brief review, I will:

- present observational results on GC ultracompacts
- address question of their over-abundance
- outline some of the unique formation/evolutionary channels that might account for this

Observational Results

Field

4 well-determined:

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

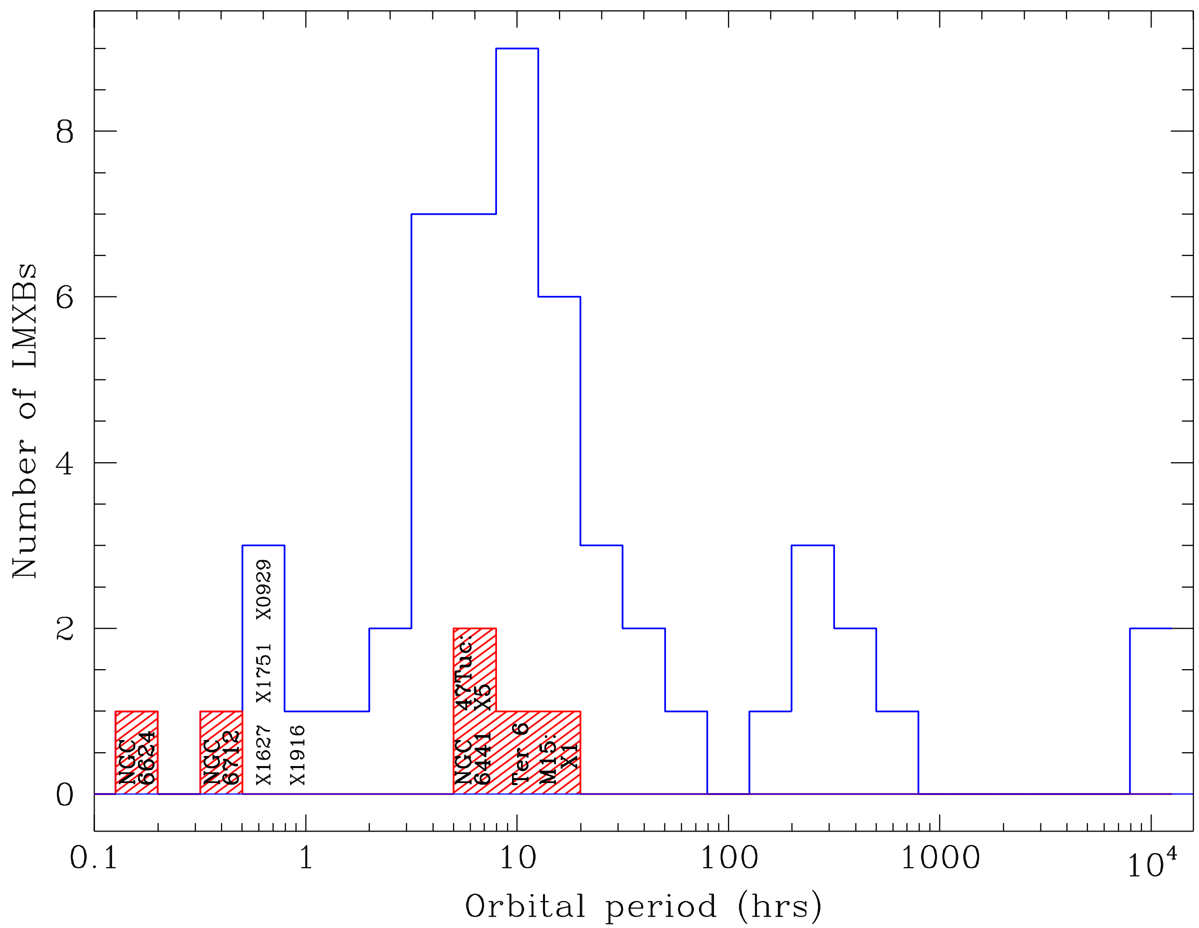
GCs

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:

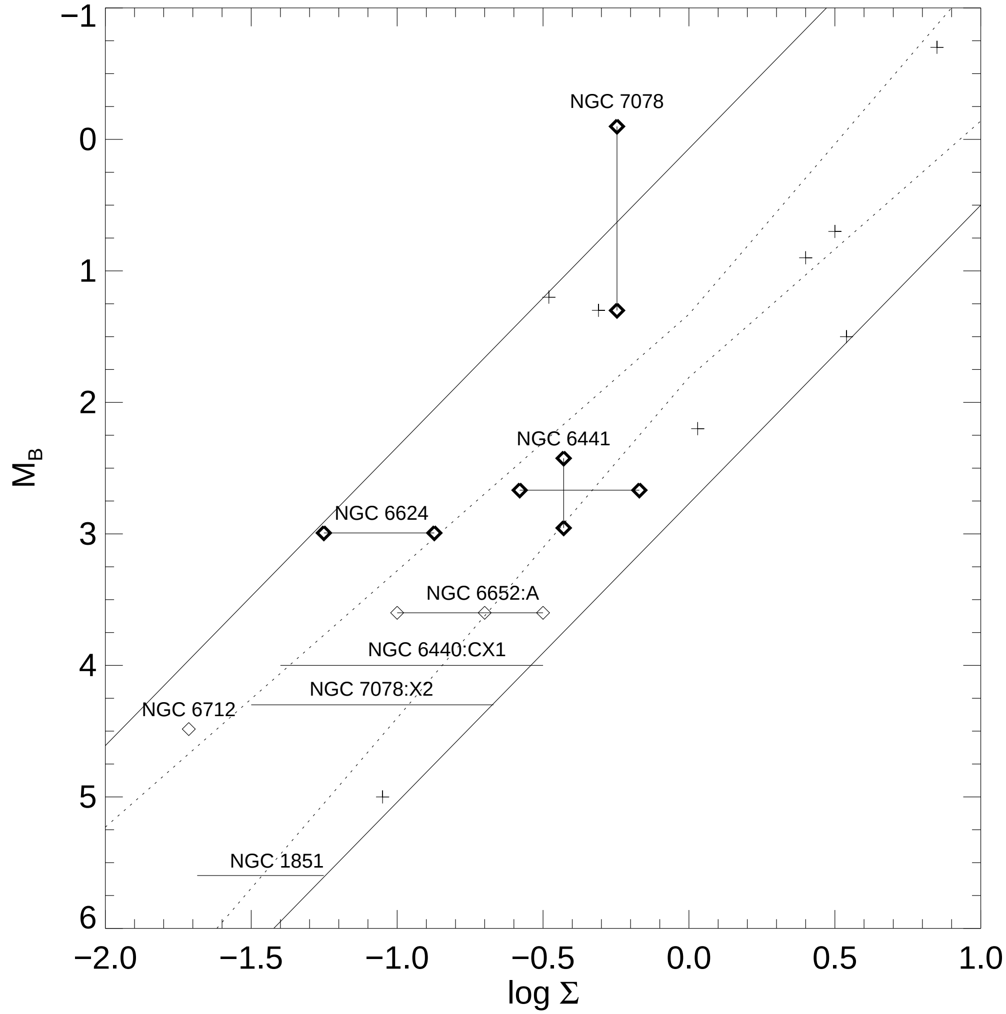
- NGC 1851: X0512–401 - *∼5min* (!), *≲85 min*

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 with possible measured ultrashort period:

- NGC 6652(A): X1832–330 - *50 min* (or 2.2/4.4 hr)



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

Details on Individual Systems

X1820-303: Star K in NGC 6624

- P_{orb}=11.4 min, determined from X-ray lightcurve (*EXOSAT*, Stella, Priedhorsky & White 1987) $\rightarrow$ suggested nature of secondary ($\sim$0.1 $M_\odot$ He WD)
- UV and optical counterpart identified (King et al. 1993), placing system within 0.02pc of cluster centre
- Period confirmed in UV (Anderson et al. 1997) with 8% semi-amplitude $\rightarrow$ inclination$\sim$70°.
- Extensive X-ray observations (van der Klis et al 1993 and refs therein)$\rightarrow$ $\dot{P}/P = -5.3 \times 10^{-8}\mathrm{yr}^{-1}$ (or 0 if due to changes in disc rim structure)
- Either way contradicts $\dot{P}/P = +8.8 \times 10^{-8}\mathrm{yr}^{-1}$ for GR driven evolution of fully degenerate He secondary.
- But (i) other evolutionary models predict such a negative value (e.g. work of Podsiadlowski and co-workers), (ii) revised radial position means acceleration in cluster potential could reduce positive $\dot{P}$ to zero.

X1850-087: Star S in NGC 6712

- UV-bright counterpart identified in *Einstein* X-ray error circle: star S (Anderson, Margon & Deutsch 1997)
- 21 min U-band modulation revealed in *HST* photometry at single epoch (Homer et al. 1996)
- 4% semi-amplitude → inclination$\sim$30°
- No uncontaminated optical/UV spectra taken

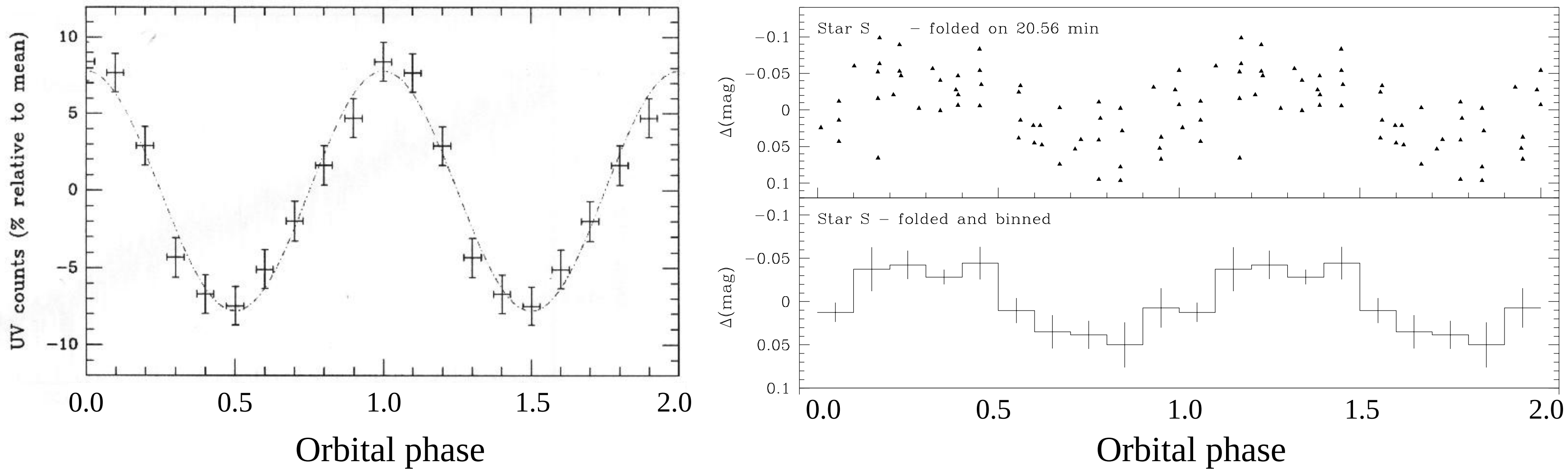
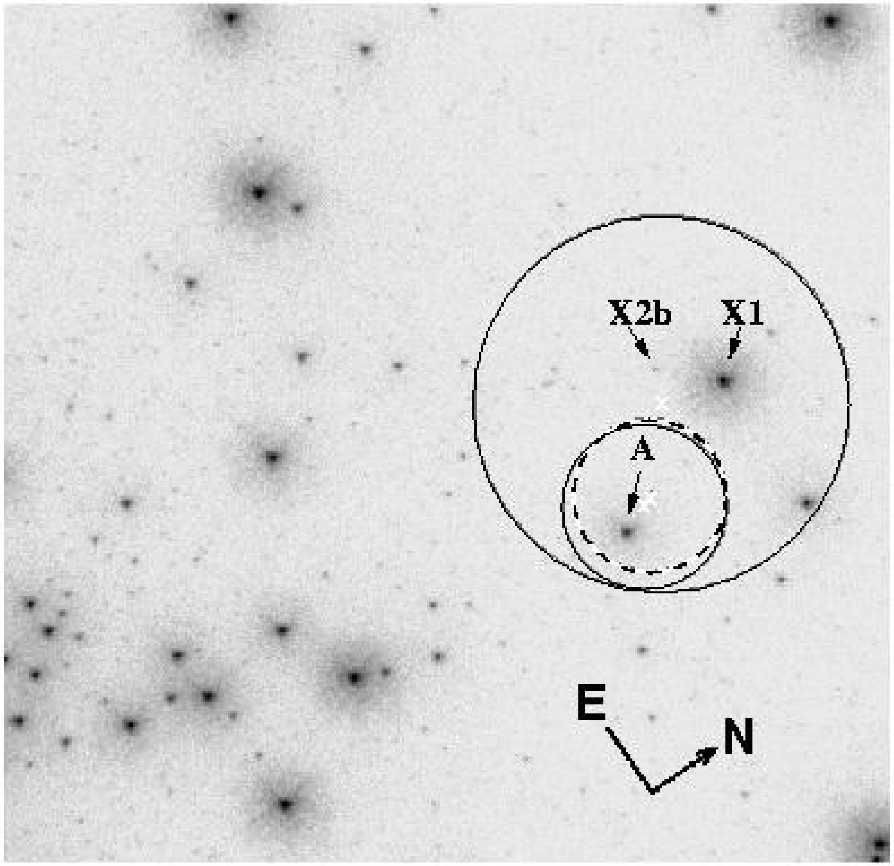


Figure 3: Left– *X1820-303*: UV lightcurve (Anderson et al. 1997) folded and plotted against orbital phase ($P_{orb} = 11.4$min).
Right– *X1850-087:* U-band lightcurve, folded and binned on $P_{orb} = 20.6$min.

X0512–401: Star A in NGC 1851

- UV-bright candidate identified in *Einstein* X-ray error circle, but 5% chance of coincidence: star A (Deutsch et al. 1998)
- Much more precise *Chandra* position confirmed ID (leaving only $\lesssim 1\%$ chance).
- No modulation detected in STIS FUV lightcurve, with 5% semi-amplitude upper-limit $\rightarrow$ inclination $\lesssim 30°$



Deep HST/STIS FUV (∼1400–1700 Å) image of the core of NGC1851. The large error circle (3″radius) is that of the *Einstein*/HRI X-ray position. The two smaller circles ($\simeq$ 1.2″) indicate the major refinement afforded by *Chandra*/HRC-S. (note: all 90% error radii)

Comparison of observational results

Table 1: Basic observational parameters

Source	Cluster	P_{orb} (min)	M_B	$L_X(10^{36})$erg s^{-1} [2-10 keV]
X1820-303	NGC6224	11.4	2.99	41.2
X0512-401	NGC1851	$\lesssim 85$	5.60	2.0
X1850-087	NGC6712	21.4	4.48	0.8

Broad band X-ray spectra: (*BeppoSAX* data, Sidoli et al 2001)

- Analysis of uniform set of spectra (0.1–100 keV) for most of the bright GC LMXBs
- Fitting 2 component models: high energy Comptonization emission + soft disc-blackbody.
- Spectral properties divide clearly into *2 groups:*

1. Sources in NGC 1851, NGC 6712 and NGC 6624 → physically reasonable disc-blackbody parameters, with inner disc temperatures (kT_{in}) and radii consistent with that needed for the Comptonization seed photons
2. Sources in M15 (NGC7078), NGC 6440, NGC 6441, Terzan 2, Terzan 6 and Liller 1→ Comptonization seed photons temperatures $kT_0 << kT_{in}$, since kT_{in} unreasonably high, disc inner radii also too small.

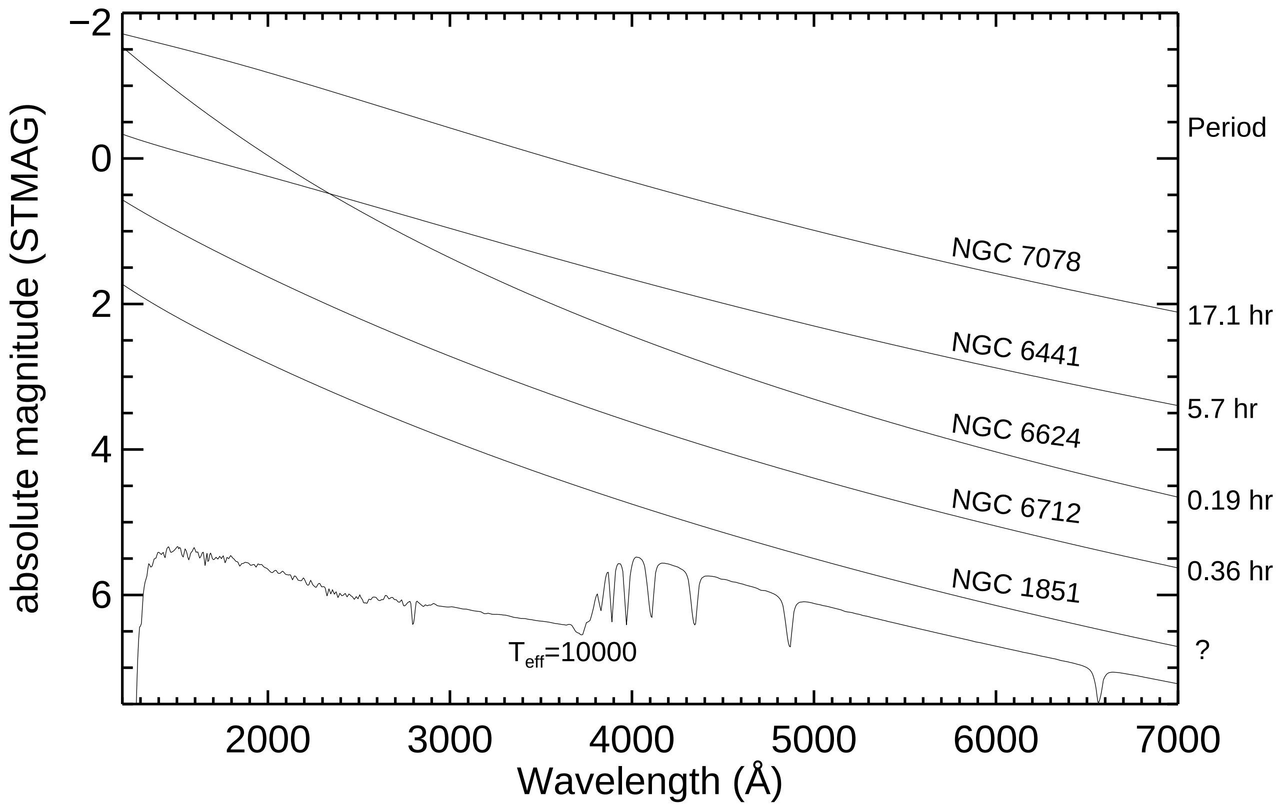
Moderate–high resolution X-ray spectra:

- *ASCA* moderate resolution spectrum of X1850-087 modelled by excess Ne absorption (similar to X1627–673, Juett et al 2001)
- *Chandra* high resolution spectra: X1850–087- ACIS/LETG=53 ks
X1820–303- ACIS/HETG=20 ks, HRC/LETG=15 ks
X0512–401- HRC/LETG=12 ks.

Optical-UV spectral energy distributions:

- Deutsch (1998) applied accretion disc models to broadband SEDs from *HST* (combining spectra and photometric data points)

- Again yields *2 groups:*
  1. two longer period systems have flatter SEDs, consistent with larger accretion disk with cooler outer regions (∼11000 K) emitting greater proportion of reprocessed X-rays in the optical
  2. the three ultracompacts have steeply rising spectra into the UV; here the discs are small, and coolest parts are still at $\gtrsim$ 15000 K



Best fit accretion disc models for each of the 5 GC sources studied by Deutsch (1998); these have been corrected for distance and reddening. At bottom a $T_{eff} = 10000$ K Kurucz model is plotted for comparison.

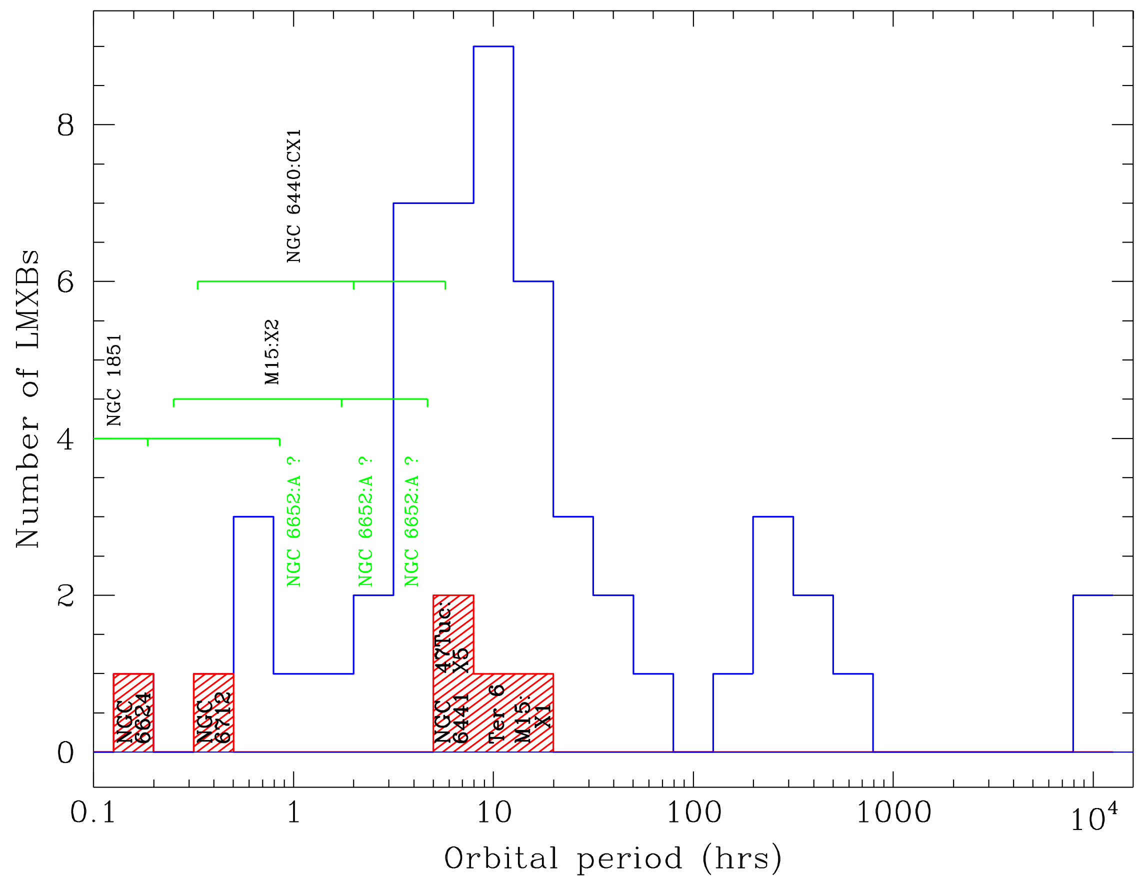
Field vs GC period distributions

Note: Further 3 field LMXBs (X0614+091, 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 (Paerels et al. 2001; 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

Four scenarios have been put forward:

1. *Direct collision of neutron star (NS) with red giant (RG)* $\rightarrow$ spiral-in of NS and loss of giant's envelope $\rightarrow$ NS-WD (former core of RG) binary. Eventually brought into contact by gravitational radiation angular momentum (AM) loss – Verbunt (1987), Davies et al. (1992).

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

3. *Exchange encounter of NS into primordial binary* $\rightarrow$ MS-NS binary then as for (2) – Davies & Hansen (1998), Rasio, Pfahl & Rappaport (2000)

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

Conclusions & Future Work

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.

   But still need to:

   - confirm difference between period distributions of field and GC LMXBs
   - determine key parameters such as abundances of transferred material $\rightarrow$ more detailed understanding of current evolutionary state

2. *Theoretically* 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.