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  
  - $\sim5\text{min}$ (!), $\lesssim85\text{ min}$

2 potential:

- NGC 7078(X2): CXOU J212958.1–121002 - $\sim46\text{ min}$ ($\lesssim4.7\text{ hr}$)
- NGC 6440(CX1): CXOU J174852.1–202132 - $\sim60\text{ min}$ ($\lesssim5.8\text{ hr}$)

another with possible measured ultrashort period:

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

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**

- $P_{\text{orb}}=11.4$ min, determined from X-ray lightcurve (*EXOSAT*, Stella, Priedhorsky & White 1987) → suggested nature of secondary ($\sim0.1 M_\odot$ 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 → inclination $\sim70^\circ$.

- Extensive X-ray observations (van der Klis et al 1993 and refs therein) → $\dot{P}/P = -5.3 \times 10^{-8}\text{yr}^{-1}$ (or 0 if due to changes in disc rim structure)

- Either way contradicts $\dot{P}/P = +8.8 \times 10^{-8}\text{yr}^{-1}$ 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 $\rightarrow$ inclination$\sim30^\circ$

- 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 $\lesssim 30^\circ$

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

Table 1: Basic observational parameters

<table>
<thead>
<tr>
<th>Source</th>
<th>Cluster</th>
<th>$P_{\text{orb}}$ (min)</th>
<th>$M_B$</th>
<th>$L_X (10^{36})\text{erg s}^{-1}$ [2-10 keV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1820-303</td>
<td>NGC6224</td>
<td>11.4</td>
<td>2.99</td>
<td>41.2</td>
</tr>
<tr>
<td>X0512-401</td>
<td>NGC1851</td>
<td>$\lessapprox$ 85</td>
<td>5.60</td>
<td>2.0</td>
</tr>
<tr>
<td>X1850-087</td>
<td>NGC6712</td>
<td>21.4</td>
<td>4.48</td>
<td>0.8</td>
</tr>
</tbody>
</table>

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 ($kT_{\text{in}}$) 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 $kT_0 << kT_{\text{in}}$, since $kT_{\text{in}}$ 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 ($\sim$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:


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) – Davies & Hansen (1998), Rasio, Pfahl & Rappaport (2000)

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 $P_{\text{orb}}$ 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 → 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.