Observations of Cataclysmic Variables and Non–flickerers in 47 Tucanae and NGC 6397

Peter Edmonds

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Cataclysmic variables (CVs)

Properties in field
- blue optical colors
- variable (flickering, outbursts, periodic variations)
- optical emission lines
- X–ray sources
- many CVs now seen in globulars thanks to HST & Chandra

Non–flickerers
- blue, non–variable stars in clusters, but not ‘normal’ CO WDs
- thought to be He WDs, low–mass WDs that did not undergo He burning
- these often found in binaries in field (e.g. WD and NS star companions)
- relatively few seen in globulars, but much work remains to be done

Motivation
- CVs in globulars almost certainly result from stellar interactions
- in solar neighborhood, ~0.01% of stars are CVs, in globulars, typically ≥0.1% of stars near core are CVs, (despite lower binary fractions than field)

Globular cluster CV formation mechanisms
- similar to neutron star systems (LMXBs)
- 3 or 4–body interactions
- tidal capture (?)

‘Normal’ WD formation
- any process that strips away giant envelope before He flash
- again, interactions are likely important

He WD formation

Why study these objects?
- CVs and He WDs good diagnostics of stellar interactions
- Compact binaries important for cluster evolution
- First known samples of these objects at same, well–determined distance
Outline
CVs and He WDs in core-collapsed NGC 6397
- HST photometry, time series and spectra
- ROSAT and Chandra observations

CVs and He WDs in un-collapsed 47 Tuc
- ROSAT and Chandra observations
- HST photometry and time series
- $F_X/F_{opt}$ for 47 Tuc CVs compared to field CVs

General questions/issues
- Are CVs in clusters magnetic?
- Comparisons between NGC 6397 and 47 Tuc

How to find CVs and He WDs in globular clusters?
(1) get deep HST imaging
(2) get deep Chandra imaging
(3) get deep radio data
(4) preferably all of above!
Time series photometry of stars in NGC 6397

CV 1  △  variable
CV 2  △  variable
CV 3  △  variable
CV 4  △  variable
NF 1  □
NF 2  □
NF 3  □
REF 1
REF 2
REF 3

Flux (10^{-17} ergs cm^{-2} s^{-1} Å^{-1})

CV optical spectra

(Grindlay et al. 1995)

NF optical spectrum

(Edmonds et al. 1999)

Cool et al. (1998)

(Edmonds et al. 1999)
Follow-up HST photometry

CVs

chromospherically active binaries (BY Dra)

(Grindlay et al. 2001b)

Chandra image of NGC 6397

(Taylor et al. 2001)

(Taylor et al. 2001)
Peter Edmonds (CFA) [KITP Globular Clusters 1-28-03] Observations of CVs and NFs in 47 Tuc and NGC 6397

ROSAT observation of NGC 6397

\[ \alpha - \alpha_c (') \]

\[ \delta - \delta_c (') \]

Verbunt and Johnston (2001)

NGC 6397
HST image from
Jan 1999

Green circles are blue stragglers

Chandra 3-\( \sigma \) positions

CVs = X-ray sources
He WDs ≠ X-ray sources

As predicted by prominent theoreticians
First X-ray ‘CMD’ for a globular cluster

HST finding charts for likely CVs (and a qLMXB) in 47 Tuc

CV

CV

CV

CV

CV

CV

CV

qLMXB

V1 (20σ)

V2 (20σ)

V3 (20σ)

W44 (10σ)

W15 (10σ)

X7 (20σ)
$F_X/F_{\text{opt}}$ as an accretion rate diagnostic: field CVs

- lower accretion rate
- higher $F_X/F_{\text{opt}}$

Richman (1996)

'nova-like' CVs (generally high accretion-rate systems)

field CVs projected at 47 Tuc distance

$L_X = 10^{30}$ erg/s

dwarf novae (generally low accretion-rate systems)

Edmonds et al. (2003); Verbunt et al. (1997)

$F_X/F_{\text{opt}}$ as an accretion rate diagnostic: 47 Tuc CVs

Edmonds et al. (2003)

47 Tuc

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- 47 Tuc CVs appear to have low accretion rates compared to field
- Is this a real effect?
- Caused by different formation?

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**Table 1**

<table>
<thead>
<tr>
<th>Source type</th>
<th>Number</th>
<th>$F_X/F_{\text{opt}}$ (median)</th>
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<tbody>
<tr>
<td>AMeers</td>
<td>29</td>
<td>0.0059</td>
</tr>
<tr>
<td>MSPs</td>
<td>4</td>
<td>0.46</td>
</tr>
<tr>
<td>CVs</td>
<td>17</td>
<td>1.18</td>
</tr>
<tr>
<td>47 Tuc CVs*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UX UMa</td>
<td>9</td>
<td>0.0072</td>
</tr>
<tr>
<td>2 UMa</td>
<td>9</td>
<td>0.043</td>
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<tr>
<td>AMeers</td>
<td>9</td>
<td>0.22</td>
</tr>
<tr>
<td>DQe Her</td>
<td>8</td>
<td>0.23</td>
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<tr>
<td>U Gem</td>
<td>13</td>
<td>0.99</td>
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<td>SU UMa</td>
<td>18</td>
<td>0.73</td>
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</table>

*CVs from the study of Verbunt et al. (1997)
Are a lot of globular cluster CVs magnetic?

Evidence for NGC 6397 CVs being magnetic

- 4 (previously reported) CVs detected in UV as blue & variable
- other CV candidates found but not (yet) detected in X-rays
- UV spectra also obtained

Evidence for 47 Tuc CVs being magnetic

- (Edmonds et al. 1999)
- (Grindlay et al. 2001a)
- (Knigge et al. 2000)
Comparison between 2 clusters

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Cluster $M_V$</th>
<th>Collision frequency</th>
<th>#CVs</th>
<th># He WDs</th>
<th>MS–binary fraction</th>
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</thead>
<tbody>
<tr>
<td>47 Tuc</td>
<td>-9.42</td>
<td>100</td>
<td>~30</td>
<td>1*</td>
<td>~14%</td>
</tr>
<tr>
<td>NGC 6397</td>
<td>-6.63</td>
<td>1</td>
<td>9</td>
<td>6</td>
<td>&lt; 5–7%</td>
</tr>
</tbody>
</table>

*No systematic search in optical

- 47 Tuc has more MS binaries, relatively fewer CVs
- NGC 6397 has apparently converted more of its primordial binaries into CVs (perhaps during core collapse)

Future observational work

- Search for faintest CVs, especially in 47 Tuc (less complete)
- Pulsation searches: optical and X-rays (magnetic CV search)
- Search for He WDs in 47 Tuc (have new HST/ACS data with $H\alpha$ imaging)
- More orbital periods needed for CVs
- Radial velocity studies needed for CVs and He WDs (challenging)
- More complete MSP searches in 6397 (NS number comparison)