Classification of Be/X-ray Binaries in the LMC
The Big Picture

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Before we start...

- X-ray Binaries
  - HMXB $M_d > 8M_{\odot}$
  - LMXB $M_d < 2M_{\odot}$
Before we start...

- **X-ray Binaries**
  - **HMXB**
    - \( M_d > 8M_\odot \)
  - **LMXB**
    - \( M_d < 2M_\odot \)
- **SGXB**
  - \( LC \rightarrow (I-II) \)
- **BeXB**
  - \( LC \rightarrow (III-V) \)
Be/X-ray Binaries

OBe Star:
→ Spectral type: late O or early B
→ Luminosity class: III-V
Be/X-ray Binaries

OBe Star:
→ Spectral type: late O or early B
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YOUNG STARS
Be/X-ray Binaries

**OBe Star:**
- Spectral type: late O or early B
- Luminosity class: III-V
- Rapidly rotating
- $M_d > 8M_\odot$

Decretion disc
Central star
Be/X-ray Binaries

OBe Star:
→ Spectral type: late O or early B
→ Luminosity class: III-V
→ Rapidly rotating
→ $M_d > 8M_\odot$

Binary System:
→ OBe star
→ Neutron star or black hole
BeXBs Observationally

Central star:
→ Blue-end in optical

Decretion disc:
→ Red-end in optical
→ Near IR

Neutron star:
→ Hard X-rays
BeXBs Observationally

Central star:
→ Blue-end in optical

Decretion disc:
→ Red-end in optical
→ Near IR

Neutron star:
→ Hard X-rays
Why Be/X-ray Binaries?

- HMXBs trace star formation
- Magellanic Clouds: direct measurement of HMXB production rate
- Complete sample of HMXB population:
  - SFR locally
  - Extend to more distant galaxies
  - Metallicity
Why Be/X-ray Binaries?

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  - Extend to more distant galaxies
  - Metallicity

SMC HMXB +60

VS

LMC HMXB 20

Antoniou et al. (2015)
Aim

→ **Characterise** BeXB candidates to determine their **nature**
→ **Identify** new BeXBs

Candidate Selection?
XMM-Newton X-ray Survey

0.2-1.0 keV
1.0-2.0 keV
2.0-4.5 keV

LMC Candidates

X-ray hardness ratios:

$$HR_i = \frac{R_{i+1} - R_i}{R_{i+1} + R_i}$$

<table>
<thead>
<tr>
<th>$i$</th>
<th>Energy band</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(0.2 – 0.5) keV</td>
</tr>
<tr>
<td>2</td>
<td>(0.5 – 1.0) keV</td>
</tr>
<tr>
<td>3</td>
<td>(1.0 – 2.0) keV</td>
</tr>
<tr>
<td>4</td>
<td>(2.0 – 4.5) keV</td>
</tr>
<tr>
<td>5</td>
<td>(4.5 – 12.0) keV</td>
</tr>
</tbody>
</table>

20 Candidates
Aim

→ **Characterise** candidates to determine their **nature**
→ **Identify** new BeXBs

**How?**

✚ **Halp**ha emission – decretion disc
✚ OGLE light curves – variability
✚ Blue spectra - spectral classification
Magellanic Cloud emission line survey (MCELS)
SALT Hα Spectra

What can you learn from Hα profiles?
→ Presence of Hα confirms disc
→ Profile Fitting:

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Implication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent Width</td>
<td>Extent of decretion disc</td>
</tr>
<tr>
<td>FWHM</td>
<td>Rotational velocity</td>
</tr>
<tr>
<td>V/R (double peaks)</td>
<td>Overdensity in disc</td>
</tr>
</tbody>
</table>
Aim

→ **Characterise** candidates to determine their **nature**
→ **Identify** new BeXBs

**How?**

✓ Halpha emission – decretion disc
✚ OGLE light curves – variability
✚ Blue spectra – Spectral classification
OGLE Light Curves

→ OGLE III & IV fields
→ I band

AIM:
→ Variability*
→ Orbital periods
Based on Bird et al. (2012) analysis of SMC Be/X-ray binaries

**Light Curve Analysis**

**Detrend**
- Long period filter
- 51 & 101 day

**Monte Carlo Simulation**
- Determine significance levels
- 10 000 iterations

**Comparison**
- Lomb-Scargle Periodogram (LS)
- Determine significant periods
- Determine period error

**Phase**
- Histogram phased light curve
- Determine bin errors
Based on Bird et al. (2012) analysis of SMC Be/X-ray binaries

- Long period filter
- 51 & 101 day
Based on Bird et al. (2012) analysis of SMC Be/X-ray binaries

**Light Curve Analysis**

- **Detrend**
- **Monte Carlo Simulation**
- **Comparison**
- **Phase**

- Determine significance levels
- 10,000 iterations

- Lomb-Scargle Periodogram (LS)
- Determine significant periods
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Light Curve Analysis

Based on Bird et al. (2012) analysis of SMC Be/X-ray binaries

- Histogram phased light curve
- Determine bin errors
Real Orbital Periods?

**Problem:**
Distinguish between real orbital periods and aliased pulsations.

### FRED

![FRED Graphs]

- BeCand-2: $P = 30.7$ d

### Sinusoidal

![Sinusoidal Graphs]

- BeCand-3: $P = 5.3$ d

<table>
<thead>
<tr>
<th>Candidate</th>
<th>Period (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BeCand-1</td>
<td>78.5</td>
</tr>
<tr>
<td>BeCand-2</td>
<td>427.0</td>
</tr>
<tr>
<td>BeCand-3</td>
<td>30.7</td>
</tr>
<tr>
<td>BeCand-4</td>
<td>40.2</td>
</tr>
<tr>
<td>BeCand-5</td>
<td>5.3</td>
</tr>
<tr>
<td>BeCand-6</td>
<td>27.5</td>
</tr>
<tr>
<td>BeCand-12</td>
<td>73.2</td>
</tr>
<tr>
<td>BeCand-13</td>
<td>290.7</td>
</tr>
<tr>
<td>BeCand-15</td>
<td>Variability</td>
</tr>
<tr>
<td>BeCand-17</td>
<td>Variability</td>
</tr>
<tr>
<td>BeCand-18</td>
<td>None</td>
</tr>
<tr>
<td>BeCand-19</td>
<td>Variability</td>
</tr>
<tr>
<td>BeCand-20</td>
<td>~30 d</td>
</tr>
</tbody>
</table>
Real Orbital Periods?

**Problem:**
Distinguish between real orbital periods and aliased pulsations.

**Solution:**
Metrics from folded light curves:

1. Phase Span (PS): FWHM
   - Sinusoidal $\sim 0.5$
   - FRED $< 0.5$

*Figure 7.* Folded light-curve analysis for SXP1323 (folded on the 26.17 d period). The dashed horizontal lines indicate 10 and 50 per cent of the maximum value, where the PS (darker shaded region) and PA (lighter shaded region) are evaluated.

Bird et al. (2012)
Real Orbital Periods?

**Problem:**
Distinguish between real orbital periods and aliased pulsations.

**Solution:**
Metrics from folded light curves:

1. Phase Span (PS):
   - Sinusoidal \( \sim 0.5 \)
   - FRED \(< 0.5 \)

2. Phase Asymmetry (PA):
   - Sinusoidal \( \sim 1 \)
   - FRED \( > 1 \)

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*Figure 7. Folded light-curve analysis for SXP1323 (folded on the 26.17 d period). The dashed horizontal lines indicate 10 and 50 per cent of the maximum value, where the PS (darker shaded region) and PA (lighter shaded region) are evaluated.*

Bird et al. (2012)
Real Orbital Periods?

Sinusoidal $\rightarrow$ Aliased pulsation
FRED $\rightarrow$ Orbital period

-- XMM candidates

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<tr>
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<td>30.7</td>
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<tr>
<td>BeCand-6</td>
<td>27.5</td>
</tr>
<tr>
<td>BeCand-12</td>
<td>73.2</td>
</tr>
</tbody>
</table>
Summary

→ **Identify** new BeXBs

Successful???

→ Currently, 16 confirmed BeXB in LMC
→ XMM candidates, 3 very likely BeXB candidates

**Increase the BeXB population of the LMC by at least 20%!**
Future work

Aim:

→ **Characterise** candidates to determine their **nature**
→ **Identify** new BeXBs

**How?**

✓ Halpha emission – decretion disc
✓ OGLE light curves – variability
✚ Blue spectra – Spectral classification
✚ Paper