Classification of Be/X-ray Binaries in the LMC

The Big Picture

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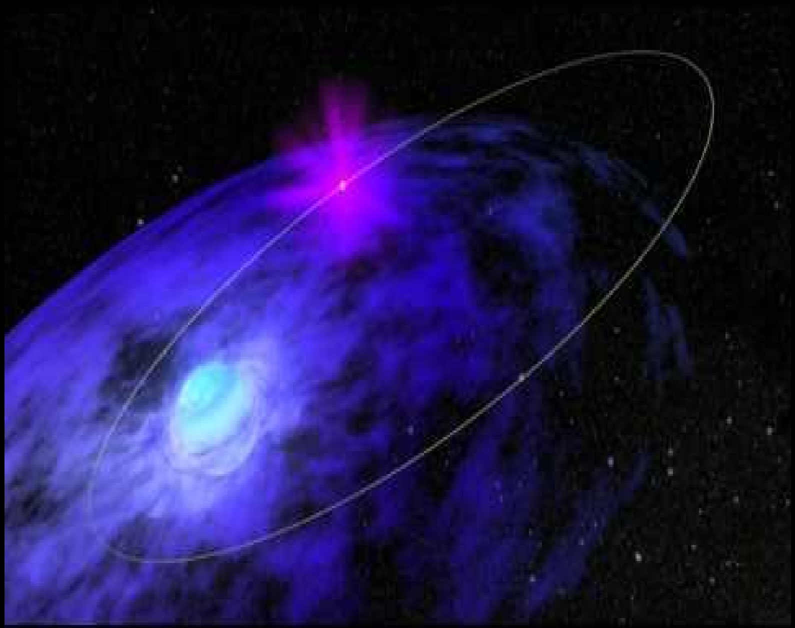
Before we start...

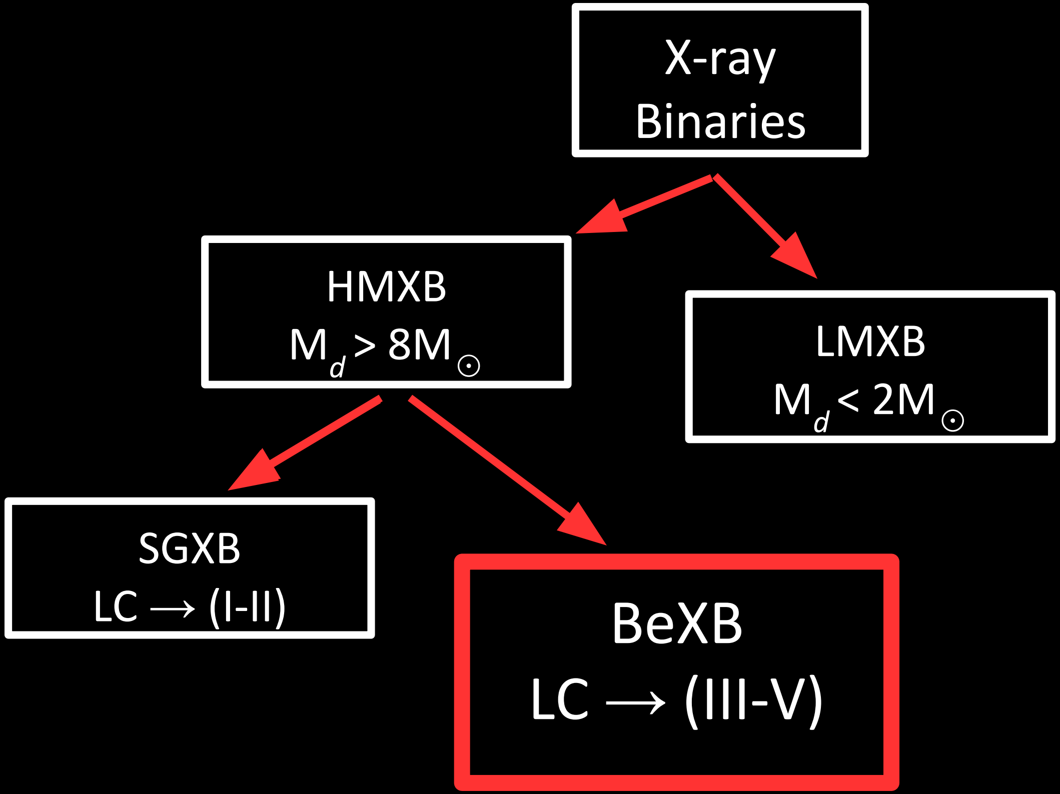
X-ray Binaries

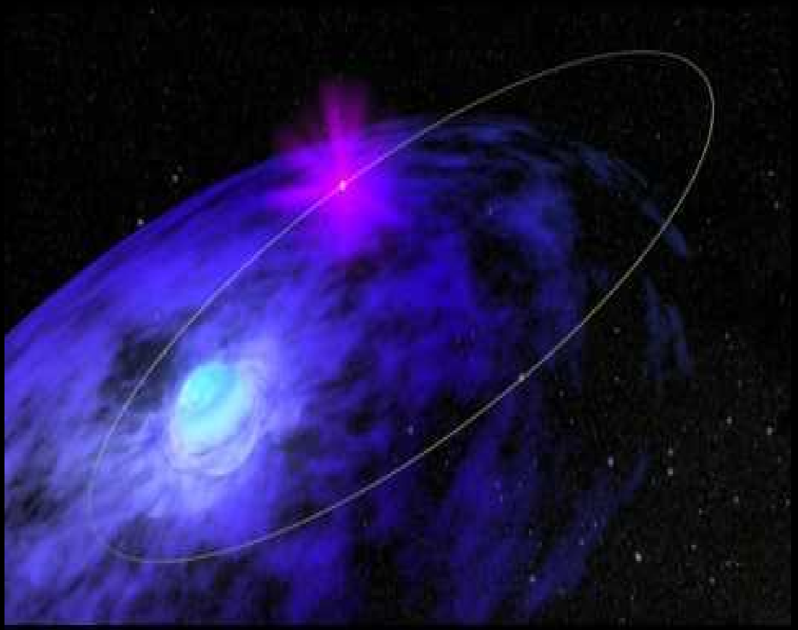
HMXB
$M_d > 8M_\odot$

LMXB
$M_d < 2M_\odot$



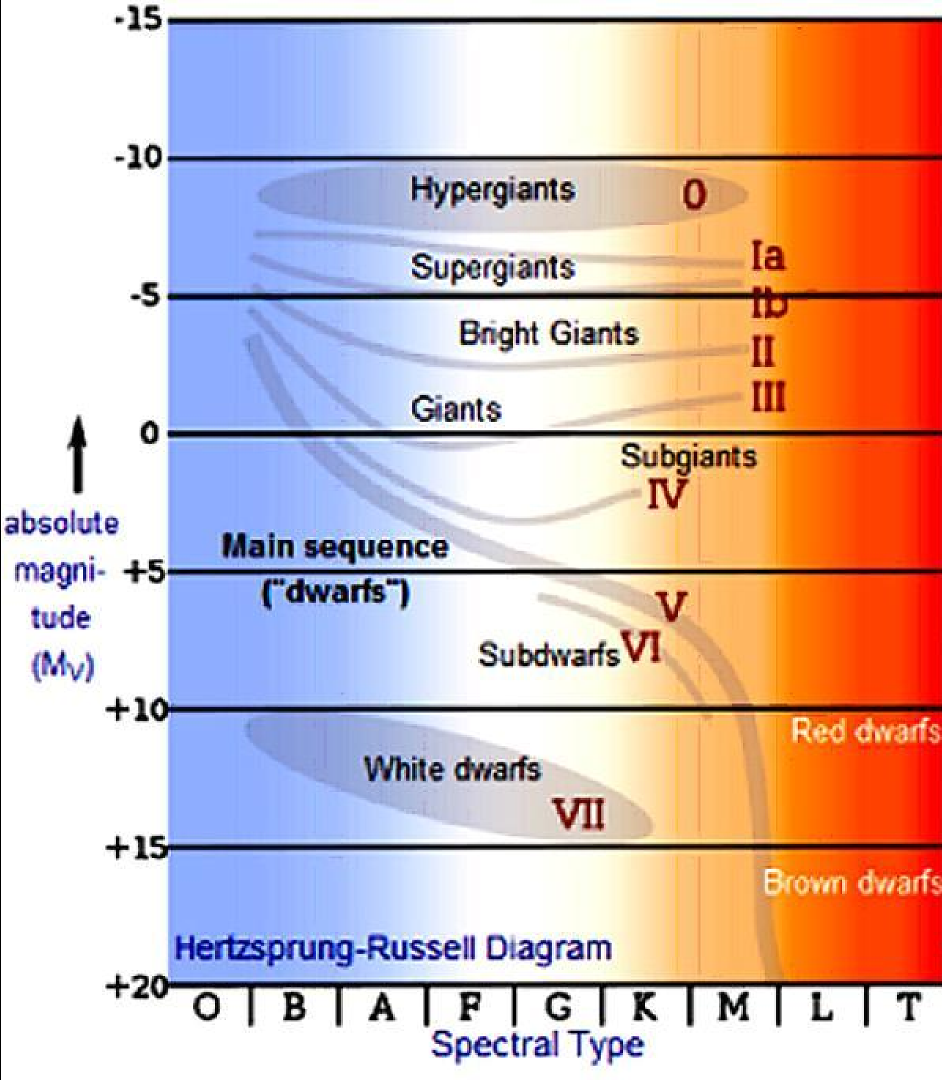
Before we start...





Be/X-ray Binaries

<u>OBe Star:</u>
→ Spectral type: late O or early B
→ Luminosity class: III-V



Be/X-ray Binaries

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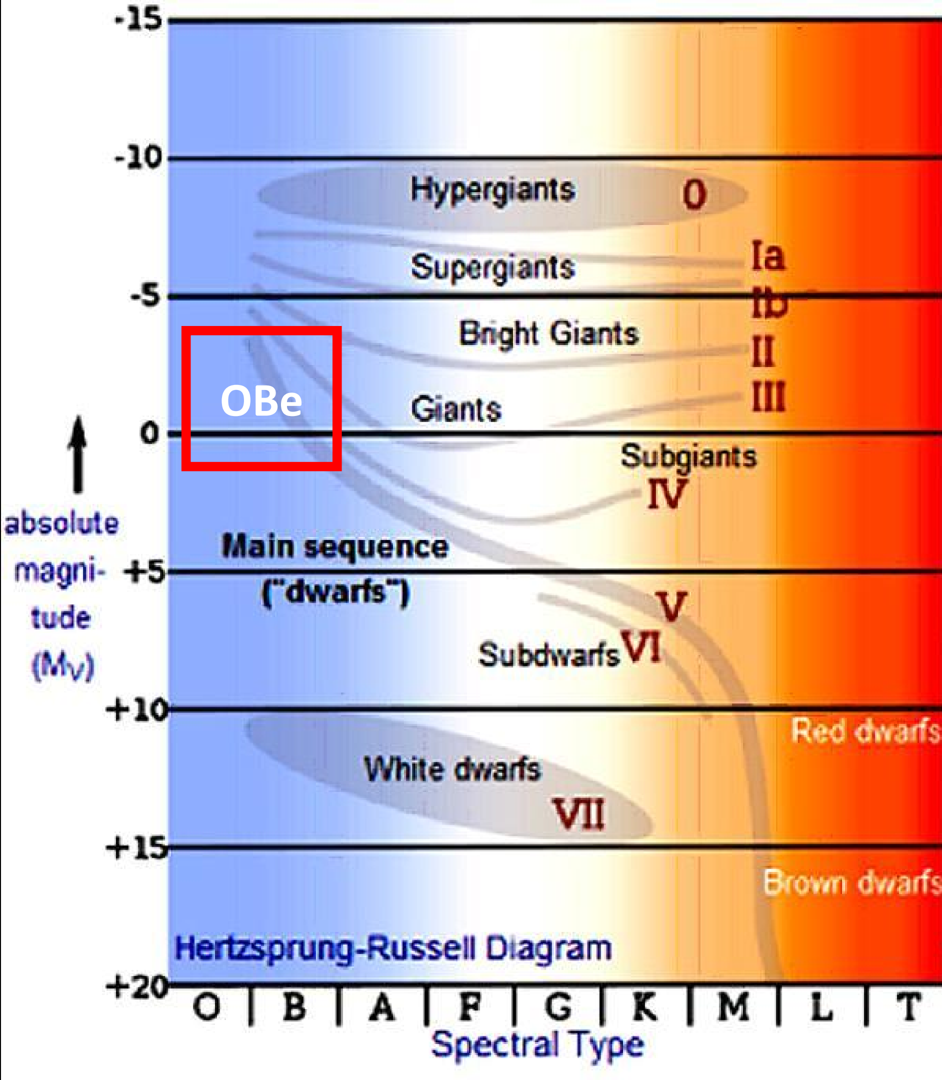
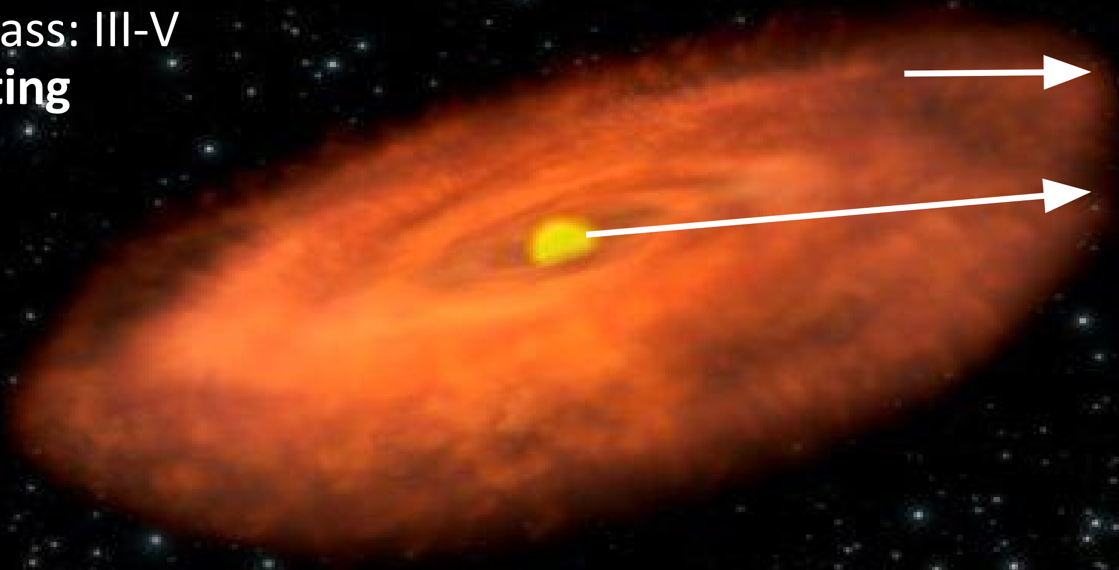
YOUNG STARS



Be/X-ray Binaries

<u>OBe Star:</u>

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



Be/X-ray Binaries

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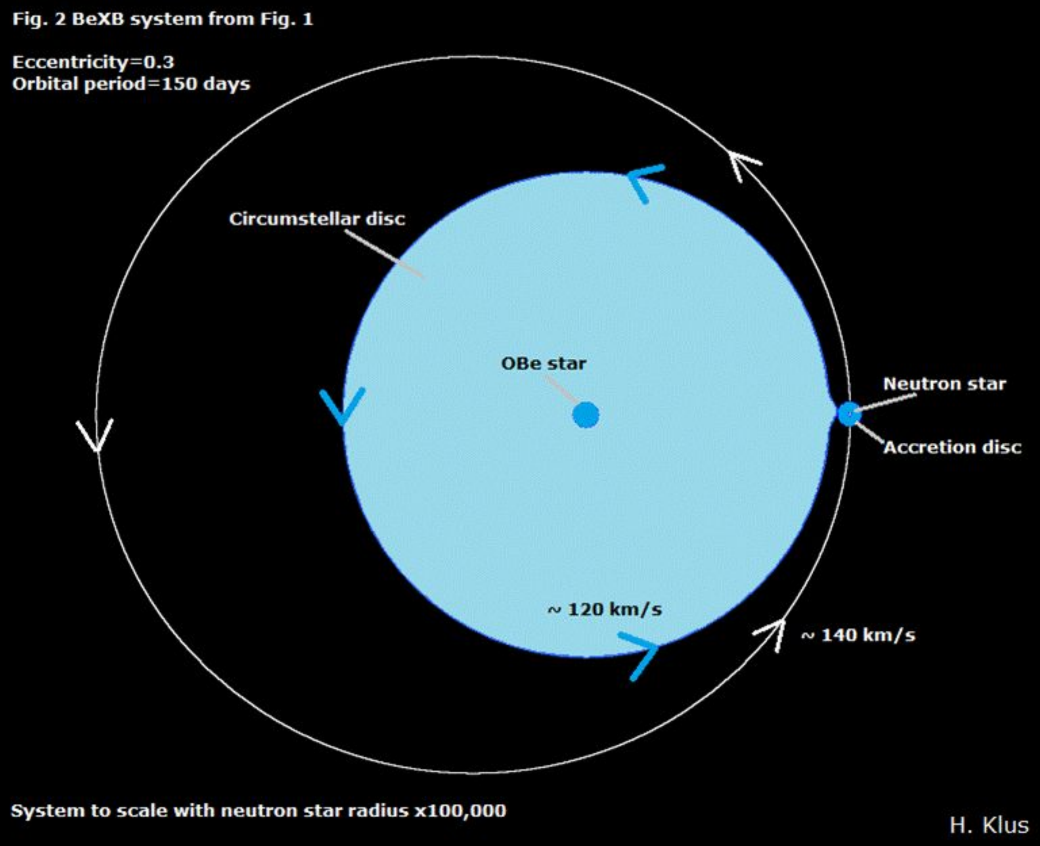
→ Rapidly rotating
→ $M_d > 8M_\odot$

Binary System:
→ **OBe star**
→ **Neutron star or black hole**



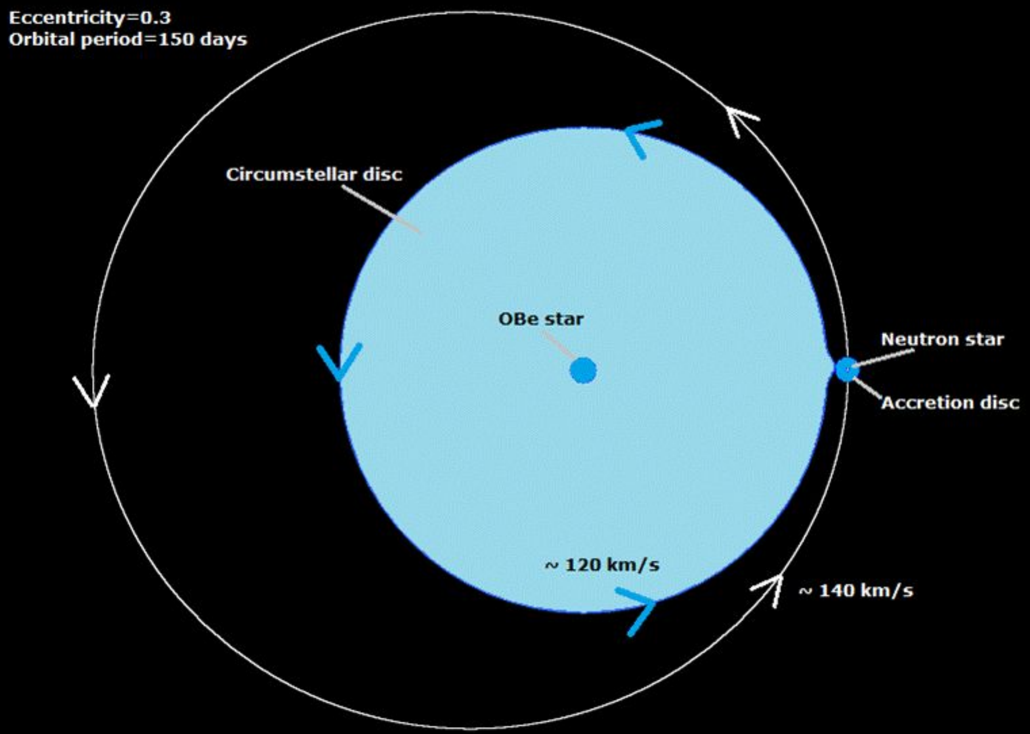
BeXBs Observationally

<u>Central star:</u>
→ Blue-end in optical

<u>Decretion disc:</u>
→ Red-end in optical
→ Near IR

<u>Neutron star:</u>
→ Hard X-rays

Fig. 2 BeXB system from Fig. 1



System to scale with neutron star radius x100,000

H. Klus

BeXBs Observationally

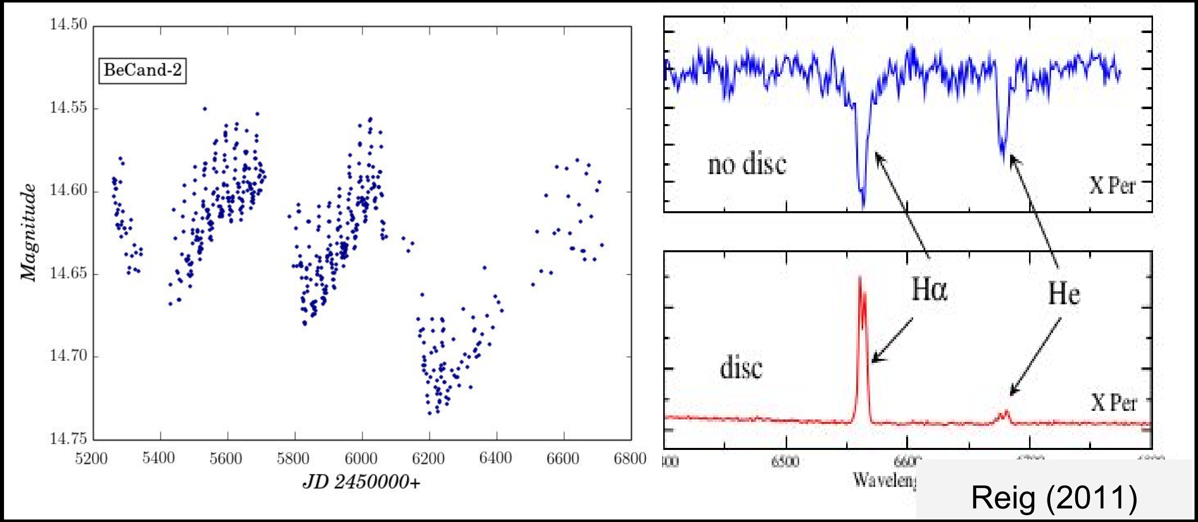
Central star:
→ Blue-end in optical

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

Neutron star:
→ Hard X-rays

Decretion Disc

NIR light curve | Emission lines



Reig (2011)

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

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SMC HMXB **+60**	**vs**	LMC HMXB **20**

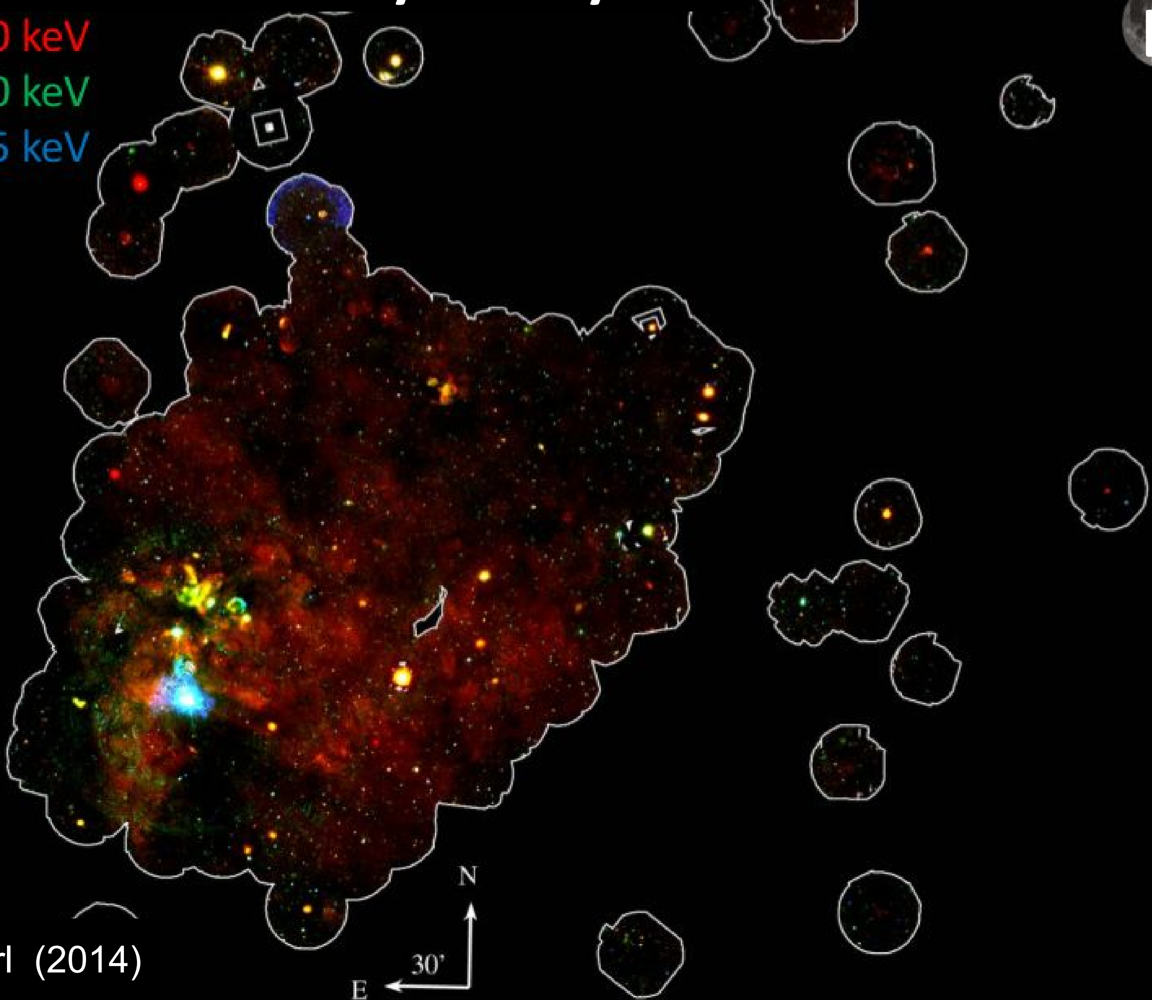
Antoniou et al. (2015)

Aim

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

Candidate Selection?

XMM-Newton X-ray Survey



Haberl (2014)

LMC Candidates

X-ray hardness ratios:

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

i	Energy band
1	(0.2 – 0.5) keV
2	(0.5 – 1.0) keV
3	(1.0 – 2.0) keV
4	(2.0 – 4.5) keV
5	(4.5 – 12.0) keV

20 Candidates

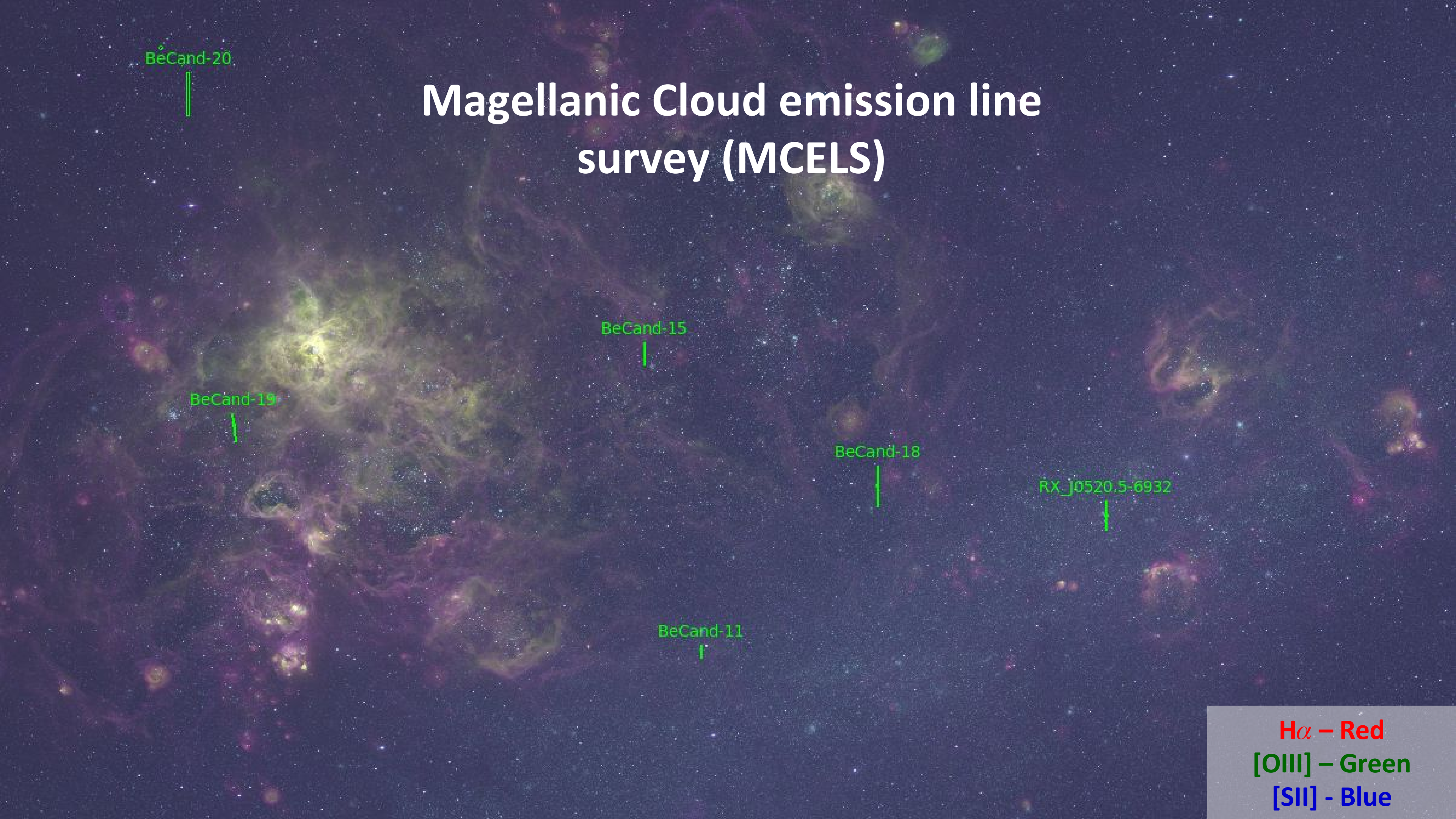
Aim

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

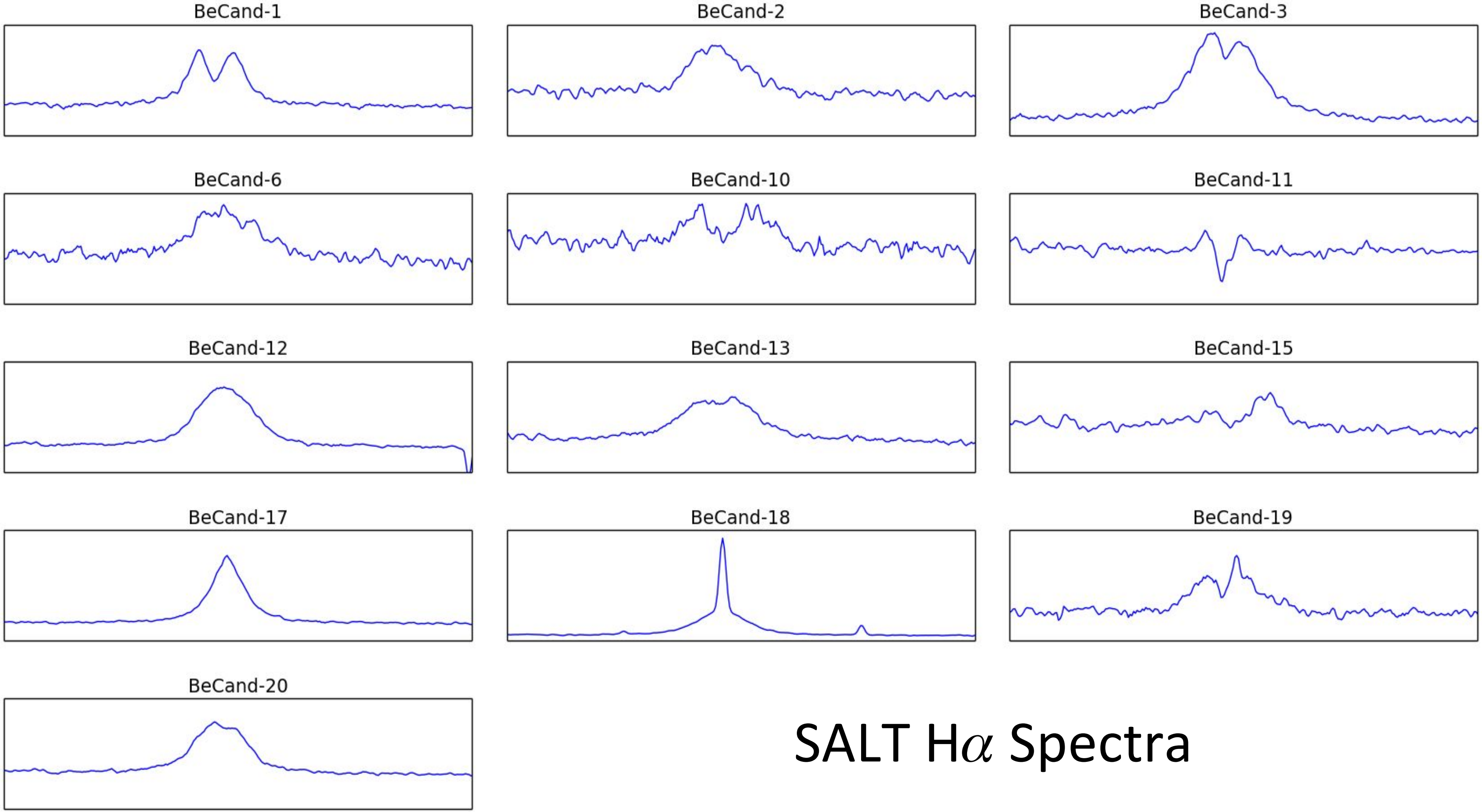
How?

- **Halpha emission – decretion disc**
- OGLE light curves – variability
- Blue spectra - spectral classification

Magellanic Cloud emission line survey (MCELS)

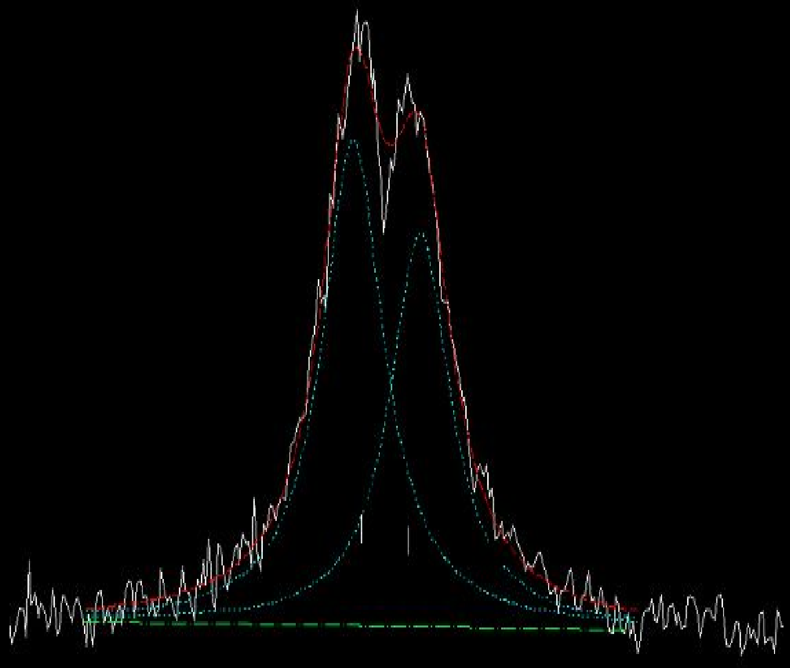


Hα – Red
[OIII] – Green
[SII] - Blue



SALT Hα Spectra

SALT Hα Spectra



<u>What can you learn from Hα profiles?</u>

→ Presence of Hα confirms disc

→ Profile Fitting:

Measurement	Implication
Equivalent Width	Extent of decretion disc
FWHM	Rotational velocity
V/R (double peaks)	Overdensity in disc

Aim

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

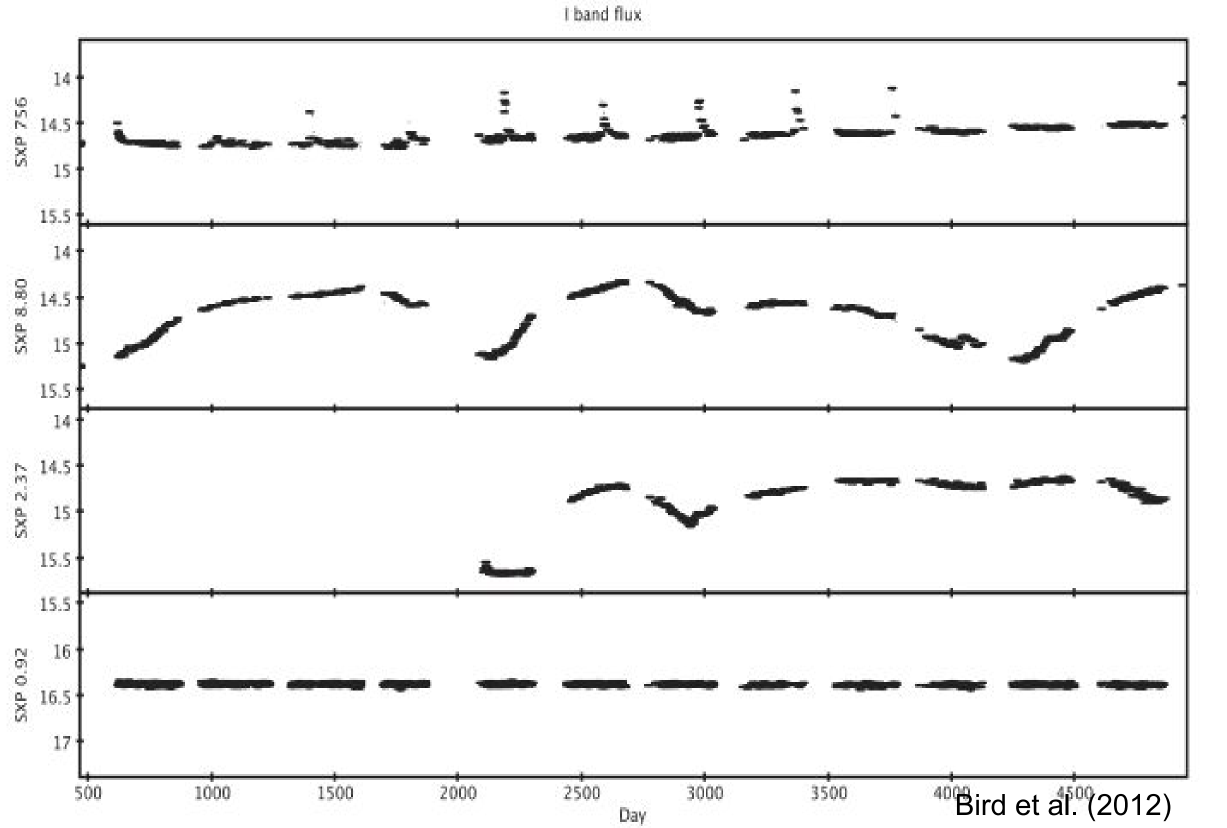
How?

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

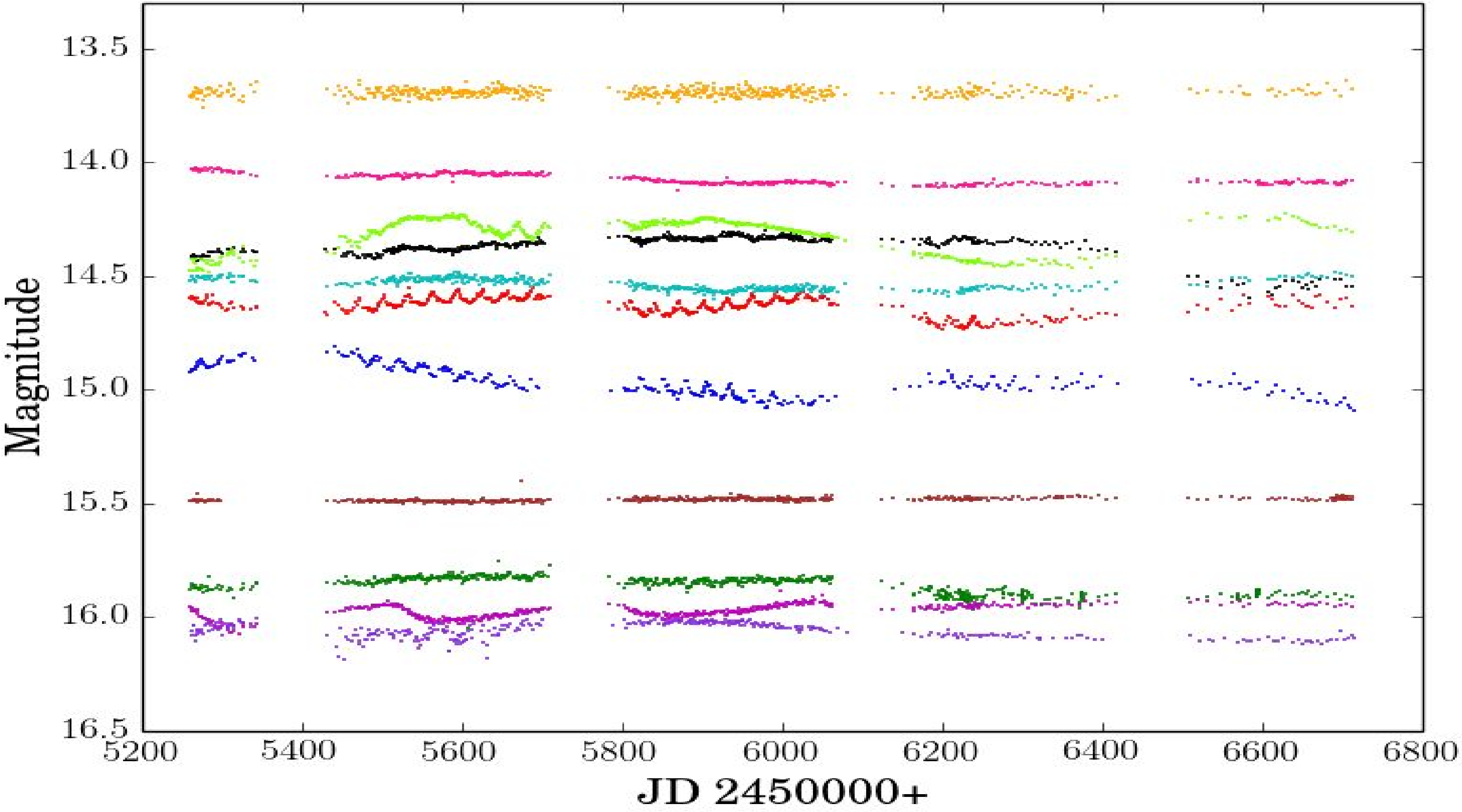
OGLE Light Curves

→ OGLE III & IV fields
→ I band

AIM:
→ Variability*
→ Orbital periods



Bird et al. (2012)


13.5
14.0
14.5
15.0
15.5
16.0
16.5
Magnitude
5200
5400
5600
5800
6000
6200
6400
6600
6800
JD 2450000+

Light Curve Analysis

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

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

Light Curve Analysis

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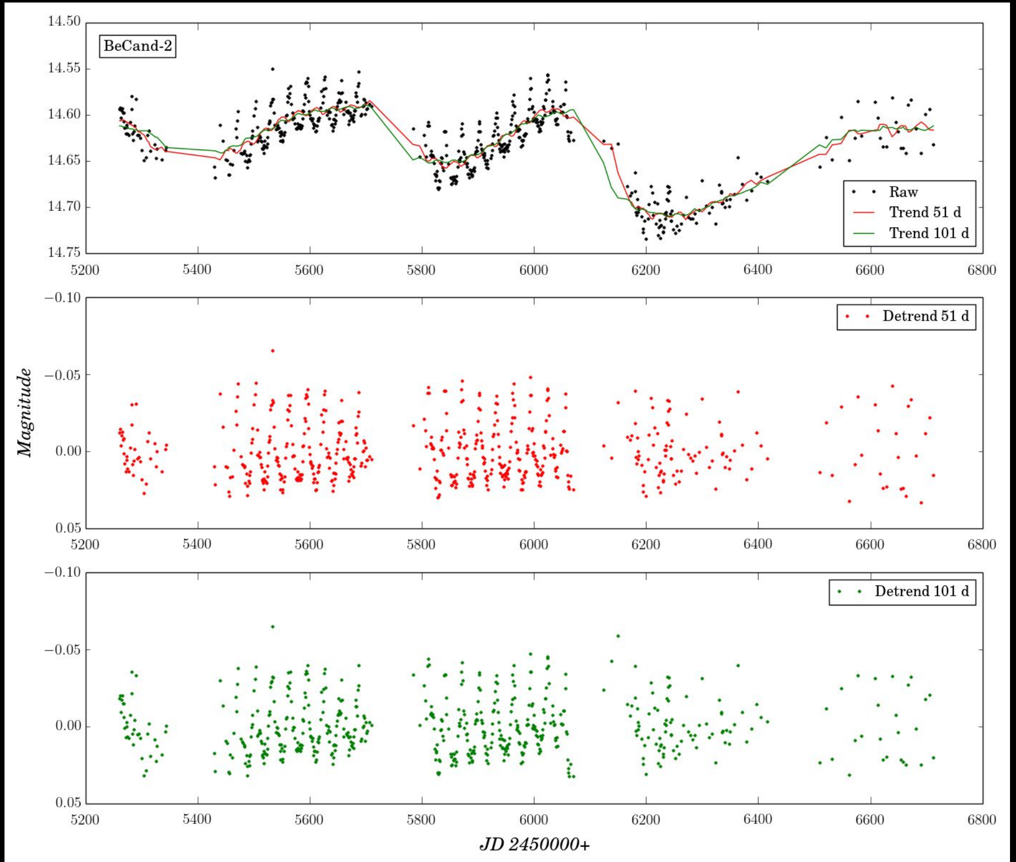

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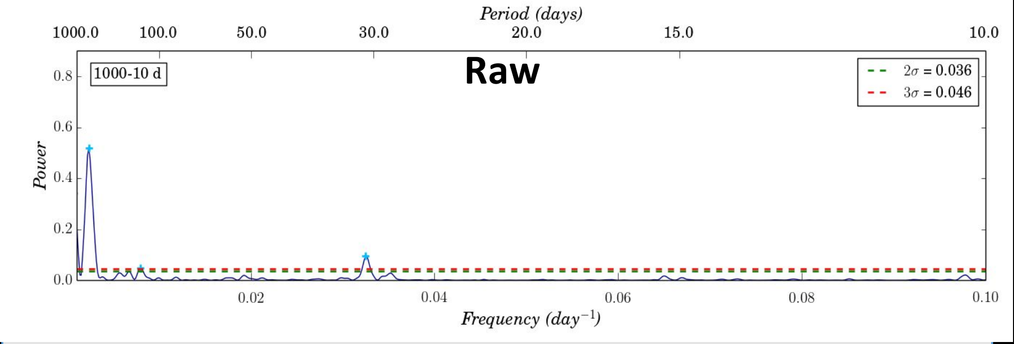

- Determine significance levels
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- Lomb-Scargle Periodogram (LS)
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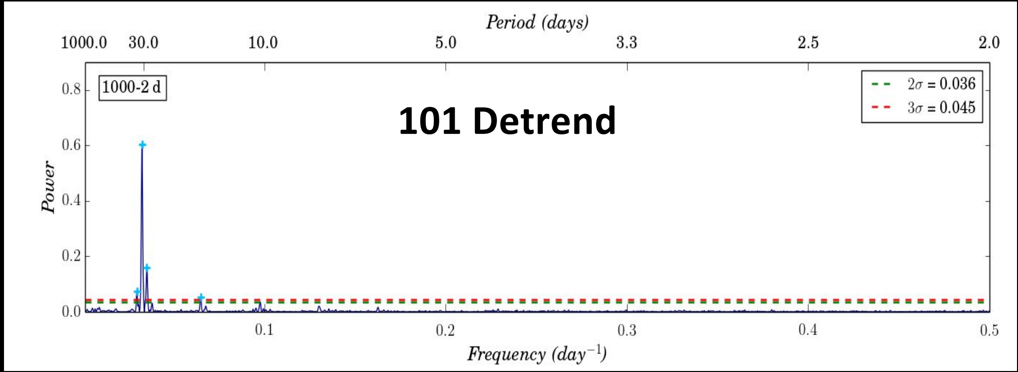

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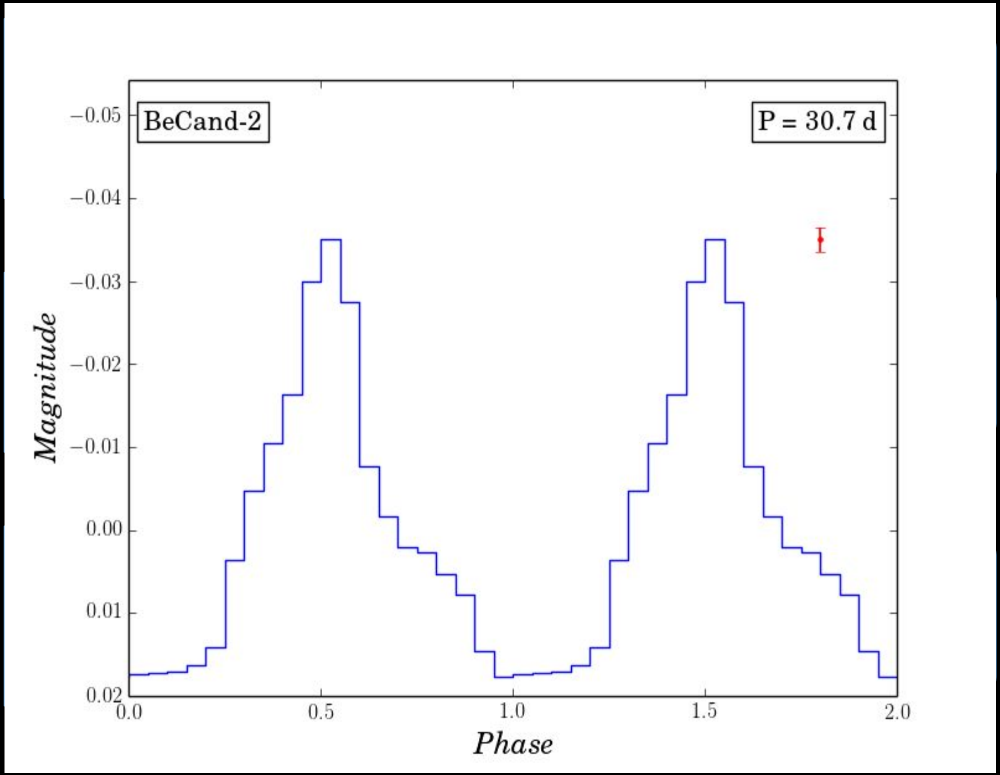
Based on Bird et al. (2012) analysis of SMC Be/X-ray binaries

- Detrend
- Monte Carlo Simulation
- Comparison
- Phase



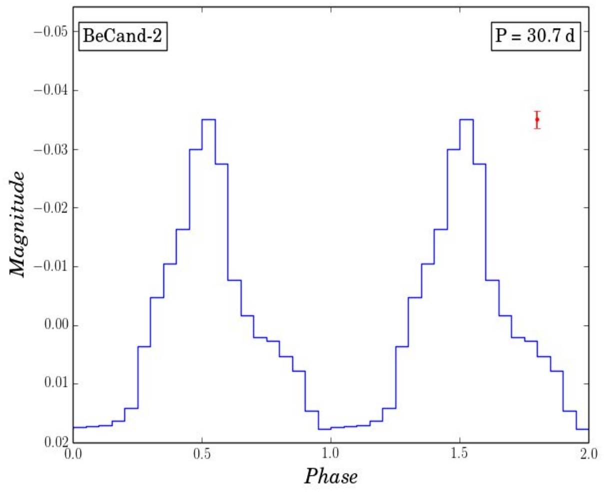
- Histogram phased light curve
- Determine bin errors

Real Orbital Periods?

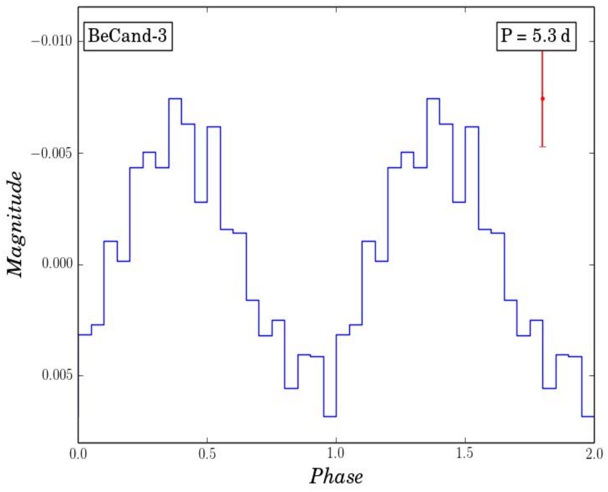
<u>Problem:</u>

Distinguish between real orbital periods and aliased pulsations.

FRED



Sinusoidal



Candidate	Period (days)
BeCand-1	78.5
BeCand-2	427.0
	30.7
BeCand-3	40.2
	5.3
BeCand-6	27.5
BeCand-12	73.2
BeCand-13	290.7
BeCand-15	Variability
BeCand-17	Variability
BeCand-18	None
BeCand-19	Variability
BeCand-20	~30 d

Real Orbital Periods?

Problem:

Distinguish between real orbital periods and aliased pulsations.

Solution:

Metrics from folded light curves:

1. Phase Span (PS): FWHM
   - Sinusoidal ~ 0.5
   - FRED < 0.5

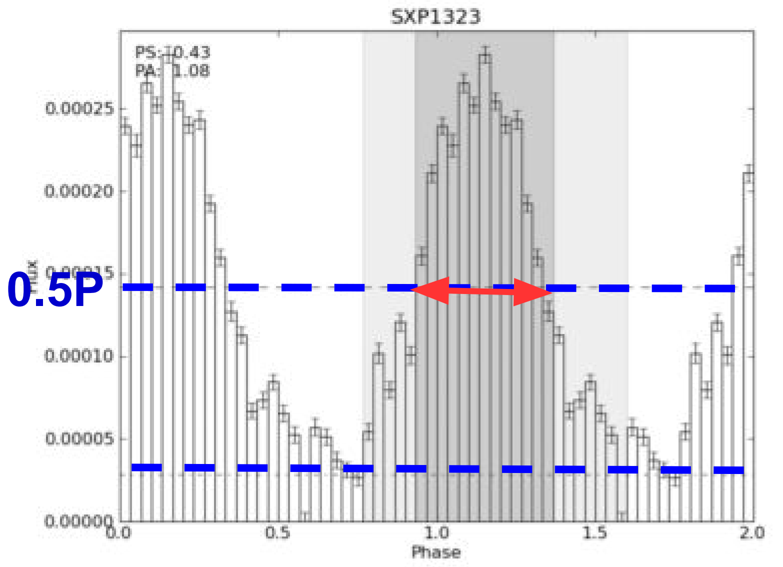


Figure 7. Folded light-curve analysis for SXP1323 (folded on the 26.17 d period). The dashed horizontal lines indicate 10 and 50 per cent of the maximum value, where the PS (darker shaded region) and PA (lighter shaded region) are evaluated.

Bird et al. (2012)

Real Orbital Periods?

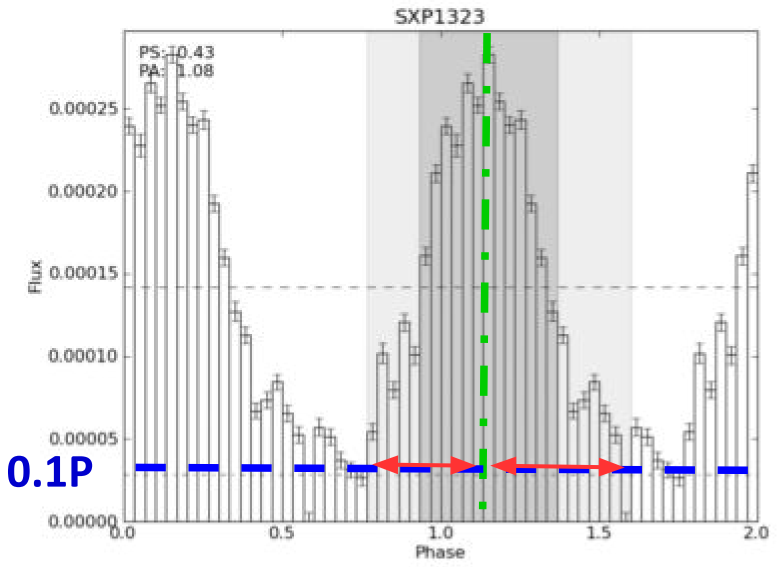
Problem:

Distinguish between real orbital periods and aliased pulsations.

Solution:

Metrics from folded light curves:

1. Phase Span (PS):
   - Sinusoidal ~ 0.5
   - FRED < 0.5
2. Phase Asymmetry (PA):
   - Sinusoidal ~ 1
   - FRED > 1



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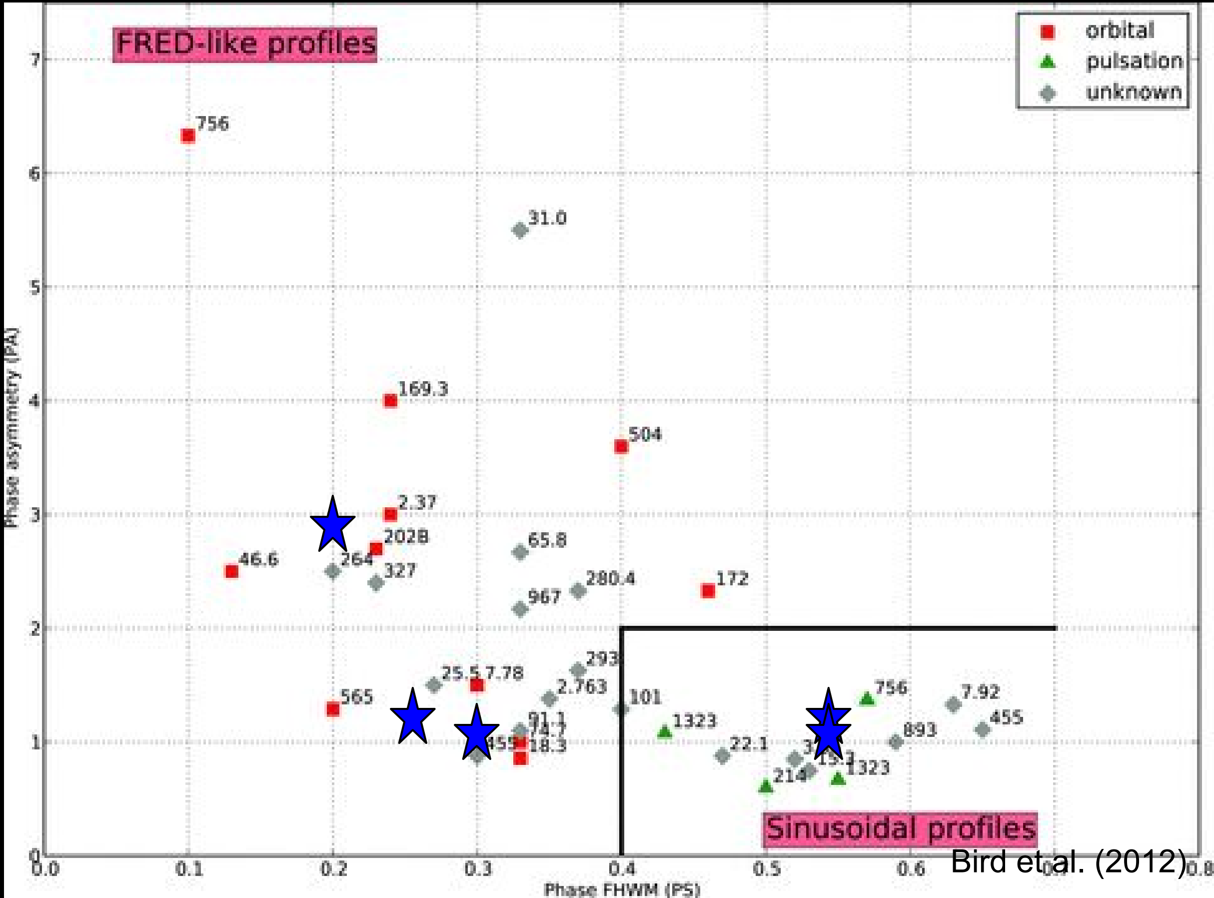
Real Orbital Periods?

Sinusoidal → Aliased pulsation

FRED → Orbital period

★ -- **XMM candidates**

Candidate	Period (days)
BeCand-2	30.7
BeCand-6	27.5
BeCand-12	73.2



Bird et al. (2012)

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**