Supersoft Be X-ray binaries in the Magellanic Clouds

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Be stars

- Rapidly rotating B stars forming a decretion (also excretion) Keplerian emission line disk
- Equivalent width of Hα from some Å to some tens of Å
- Emission line variability on time scale of years
- Emission line profile variability
- Excess of near infrared emission
A (HR 5223)
B (μ Cen)
C (HR 4823)
D (o Aqr)

Hα

Hβ

Fe II λ 5169

(Rivinius+ 2013)
SuperSoft Be X-ray binaries

– 30% of Be are binary systems (Oudmaijer & Parr, 2010)

– thin viscous truncated Keplerian disk of gas in the equatorial plane of the B star

– higher density disk than in isolated Be (Reig+ 2016)

– variability of emission lines (H, He, Fe) on shorter time scales (1-5 yrs, Reig 2011) than isolated Be (2-11 yrs, Okazaki 1997)

– double spiral arms caused by the binarity (Panoglou+ 2016, 2018)
SuperSoft Be X-ray binaries

- very soft X-ray spectrum $L_{sx} \sim 10^{35} - 10^{38}$ erg s$^{-1}$ (and negligible emission above 1 keV)

- SS flare hypothesis: short thermonuclear flash caused by ignition of hydrogen from the Be disk through the CNO cycle onto a WD

- Be/WD binaries in MW are expected to be frequent (~70%, Raguzova 2001),

- Be/X-ray binaries in MCs are mostly Be/NS, very few examples of Be/WD have been discovered

- It is extremely difficult to detect the WD presence

- Be+WD binaries are expected to host a massive WD and, if the WD accretes from the Be excretion disk, they are candidate SNe Ia progenitors through a new channel
LMCV 2135

SSS

$L_{sx} = 5.5 \times 10^{36} \text{ erg s}^{-1}$

$V = 14.80 \pm 0.02$
$B-V = -0.03 \pm 0.03$

SpType = B0-3e

WD Be/X-ray binary
7-15 $M_\odot + 0.9-1.0 \ M_\odot$

$\text{EW}(H\alpha) = 32 - 37 \ \text{Å}$
$V_{\text{rad}}(H\alpha) = 6 - 430 \ \text{km s}^{-1}$

(Kahabka+ 2006)
**XMMU-J010147.5-715550**

AzV281
Recurrent SSS

$L_{\text{SX}} = 7.3 \times 10^{37} \text{ erg s}^{-1}$

$V = 14.47\pm0.04$

SpType = O7IIIe – B0Ie
NIR excess and variability
WD Be/X-ray binary
(Sturm+ 2012)

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**Suzaku J0105-72**

1E0102.2-7219 (Takei+ 2008)
2dFS 2064 (Evans+ 2004)

Transient SSS in a SNR

$L_{\text{SX}} = 2 \times 10^{37} \text{ erg s}^{-1}$

$V = 14.64$ (Evans+ 2004)

SpType = B0 IV (Evans+ 2004)
O9.3 III/Ve (Lamb+ 2016)
MAXI J0158-744

Transient SSS

$L_{0.2-2 \text{ keV}} \sim 2 \times 10^{37} \text{ erg s}^{-1}$

$L_{2-4 \text{ keV}} \sim 1.6 \times 10^{39} \text{ erg s}^{-1}$

$I = 14.82$

SpType = B1/2 IIIe

WD Be/X-ray binary

Nova explosion event

(Li+ 2012)
Robert Stobie Spectrograph (RSS)
Long-slit mode
PG900 (R=1100), PG2300 (R=2900)

XMMU J05  3 epochs  2016
XMMU J01  2 epochs  2016
Suzaku J01  2 epochs  2016
MAXI J0158  2 epochs  2016
<table>
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<tr>
<th>Object</th>
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<td>2017</td>
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<tr>
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XMMU-J052016.0-692505

Suzaku J0105-72

MAXI J0158-744

(Cracco et al. 2018)
Results

– blue continuum with Hα, Hβ, Hγ, He I 5876,6678,7065, Fe II 4523,5018,5317

– no He II 4686 (= no accretion disk)

– no one is a shell Be

– double peaked Hβ with V/R changing from 0.5 to 1.5 in few days

– Δv(Hβ) ~ 130 – 220 km s⁻¹

– complex Hα profiles with multiple peaks or wine-bottle shape

– Δv(Hα) ~ 120 – 200 km s⁻¹

– small disk radii (~ 10 R_★ vs. ~ 14-22 R_★, Reig+2016)

Since V/R variations could indicate disk perturbations induced by the binary system, time series of profiles may allow to constrain the physical properties of binaries (Panoglou+2018)
High Resolution Spectrograph (HRS)
Dual-beam fiber-fed echelle
Low Resolution  R=15000

XMMU J05  10 epochs  2018
XMMU J01  11 epochs  2018
Work in progress

• Equivalent width

• Radial velocity \( \lambda_0 = \frac{\int \lambda f_\lambda d\lambda}{\int f_\lambda d\lambda} \) First Moment (Peterson+ 2004)

• \( \text{V sin } i \) Fast Fourier Transform (Gray 1973, Simon-Diaz+ 2006, Dufton+ 2006, Dufton+ 2011)

• Asymmetry \( A = \frac{a - b}{a + b} \)

Equivalent Width

\[ P(\text{H}\beta) = 670 \text{ days (fap = 0.02\%)} \]

\[ P(\text{H}\alpha) = 640 \text{ days (fap = 0\%)} \]
Heliocentric velocity

\[ P(H\alpha) = 640 \text{ days (fap = 3\%)} \]
Average spectrum

Normalized flux

Wavelength (Å)

3950 4000 4050 4100 4150 4200 4250 4300 4350 4400 4450 4500 4550

4550 4600 4650 4700 4750 4800 4850 4900 4950 5000 5050 5100 5150

- He
- HeI 4026
- Hδ
- HeI 4144
- Hγ
- HeI 4388
- HeI 4471
- HeI 4686
- HeII 4686
- Hβ
- HeI 4921
- HeI 5047
- HeII 5047
$V \sin i = \frac{c}{\lambda} \frac{f(\epsilon)}{\sigma} \approx 200 \text{ km s}^{-1}$
Asymmetry

P(Hβ) = 668 days  (fap = 0.02%)
P(Hα) = 640 days  (fap = 0.13%)
Equivalent Width

\[ P = 1264 \pm 2 \text{ days} \]  (Sturm+ 2012)
Heliocentric velocity

![Graph showing heliocentric velocity over time. The graph includes different symbols and lines representing different periods.](image-url)
Average spectrum

Normalized flux vs. Wavelength (Å)

- He
- HeI 4026
- HeI 4144
- Hδ
- HeI 4388
- HeI 4471
- Hβ
- HeI 4686
- HeI 4921
\[ V \sin i = \frac{c}{\lambda} \frac{f(\epsilon)}{\sigma} \approx 350 \text{ km s}^{-1} \]
Asymmetry

$P(\text{H}\beta) = 1198$ days  (fap = 24%)
To be continued…. 