Whispering in the dark: X-ray faint BHs around OB stars

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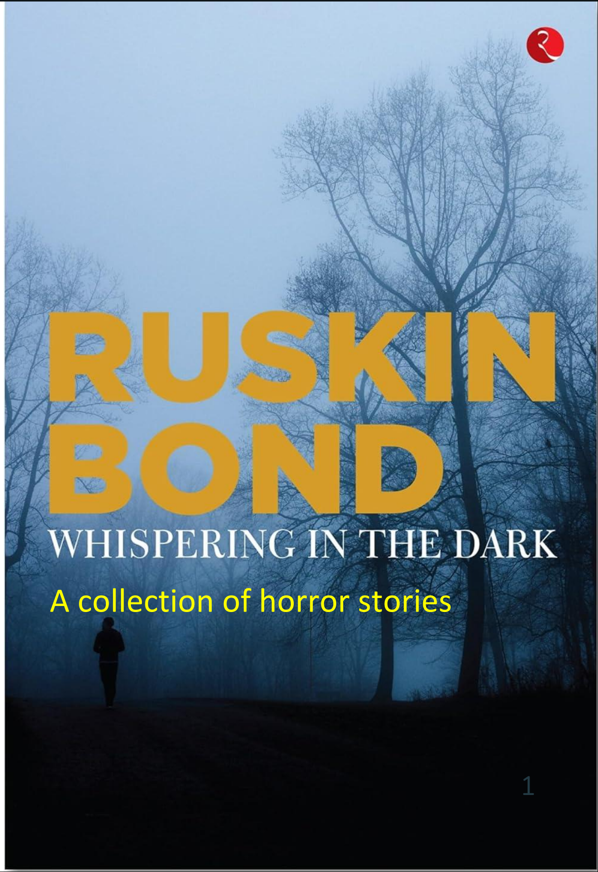

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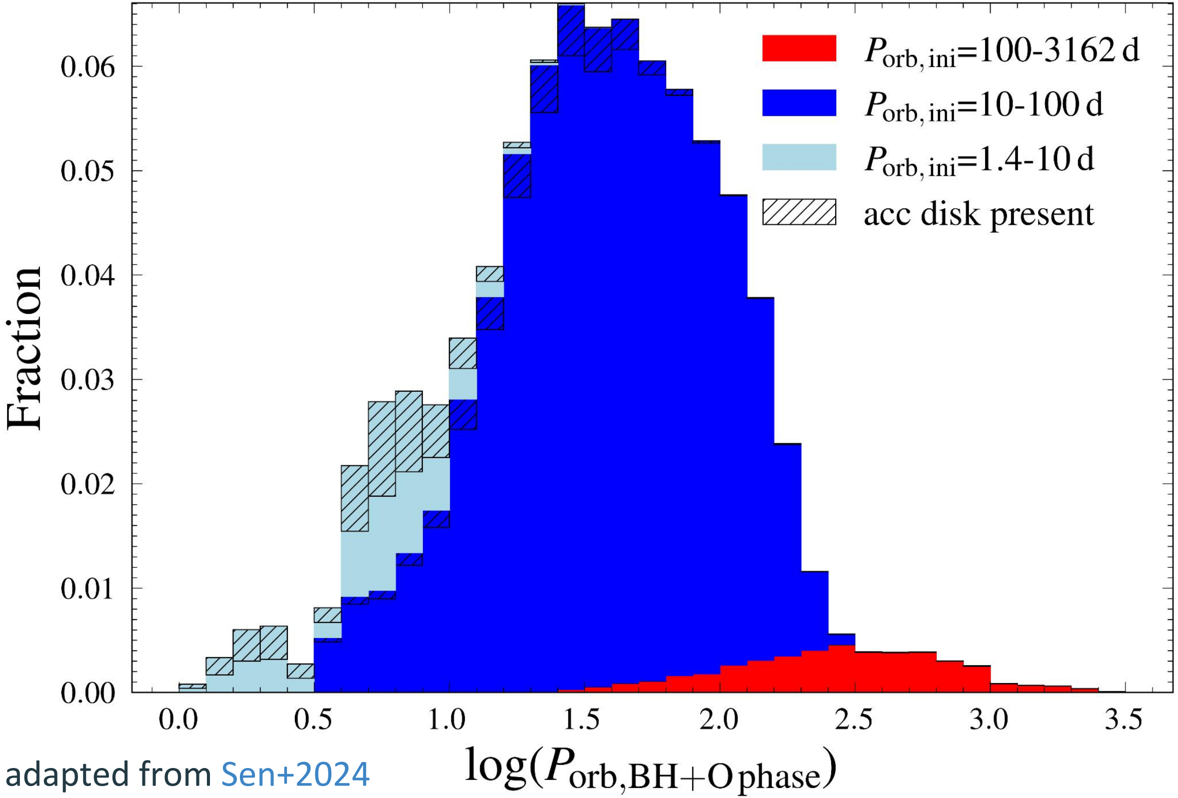
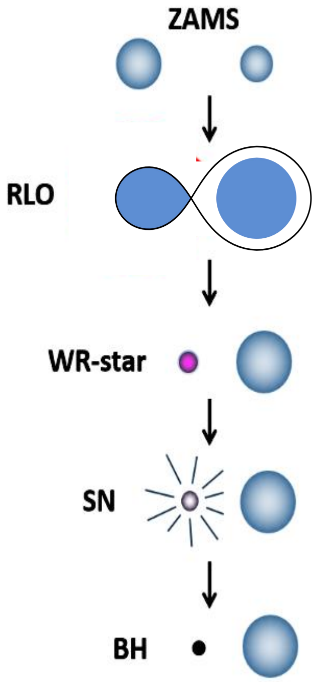
Black hole + OB star binaries



adapted from Sen+2024

Isolated binary evolution



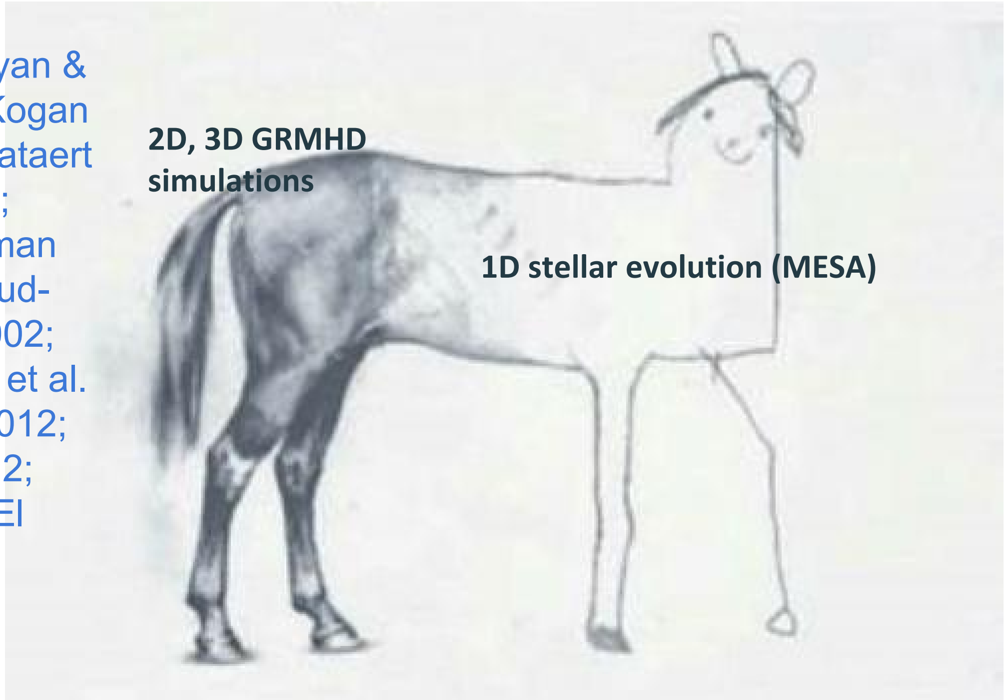
adapted from Kruckow+2018

Searching techniques for BH+OB binaries

- strong X-ray emission (e.g. Walter et al. 2015; Motta et al. 2021).
- astrometric variations (e.g Breivik et al. 2017; Mashian & Loeb 2017; Yamaguchi et al. 2018; Andrews et al. 2019).
- photometric variability (Zucker et al. 2007; Masuda & Hotokezaka 2019).
- spectroscopic monitoring (e.g. Geisers et al. 2018, Thompson et al. 2019, Mahy et al. 2022, Shenar et al. 2022).

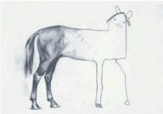
Modelling accretion in BH+OB binaries

Ichimaru 1977; Narayan & Yi 1994; Bisnovatyi-Kogan & Lovelace 1997; Quataert & Narayan 1999; Blandford & Begelman 1999; Yuan 2001; ud-Doula & Owocki 2002; Sharma+2007; Yuan et al. 2012; Xie & Yuan 2012; Cunningham+2012; Cangemi+2021; El Mellah+2022



MESA

Paxton+2011,2013, 2015,2018,2019; Jermyn+2023



Revisiting accretion onto stellar mass BHs

figure not to scale

Matter is accreted from the stellar wind (v_{wind}) of the O star

$$v_{\rm wind} = 2.6\, v_{\rm esc}\, (1 - R_{\rm O}/a)$$

$$v_{\rm esc} = \sqrt{2GM_{\rm O}/R_{\rm O}}$$

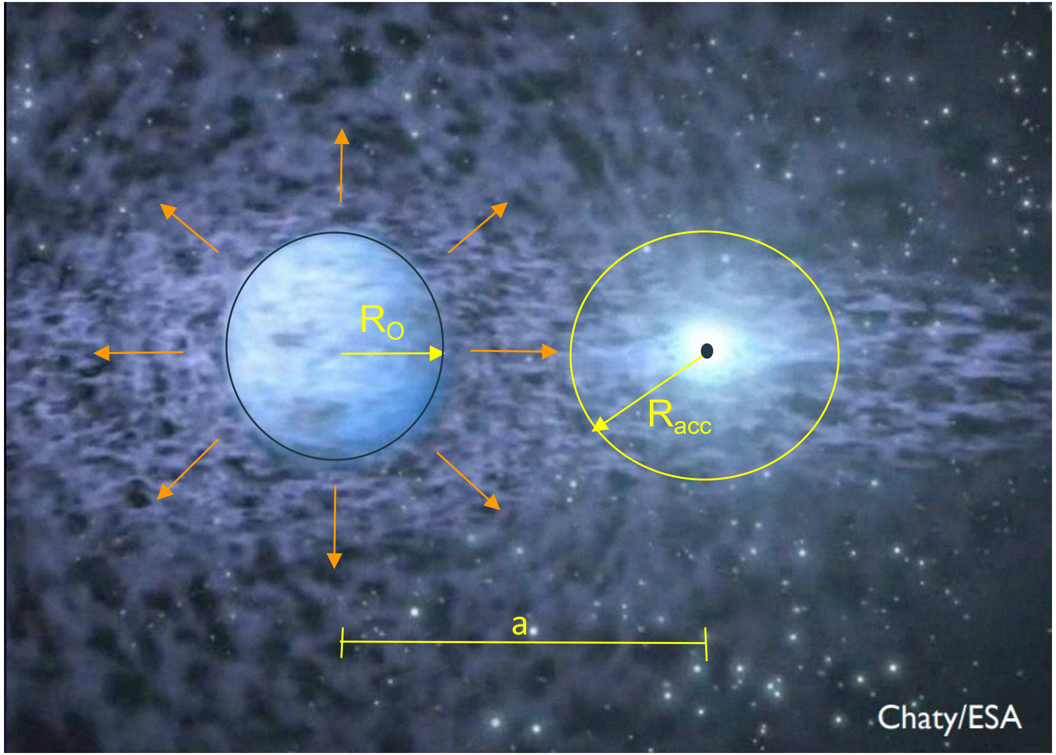
Accretion radius of the compact object (Davidson+1973)

$$R_{\rm acc} = \frac{2GM_{\rm BH}}{v_{\rm rel}^2}$$

$$v_{\rm rel} = \sqrt{v_{\rm wind}^2 + v_{\rm orb}^2}$$

Bondi-Hoyle mass accretion rate (Bondi+1944)

$$\frac{\dot{M}_{\rm acc}}{\dot{M}_{\rm w}} = \frac{\pi R_{\rm acc}^2}{4\pi a^2} \frac{v_{\rm rel}}{v_{\rm w}}$$



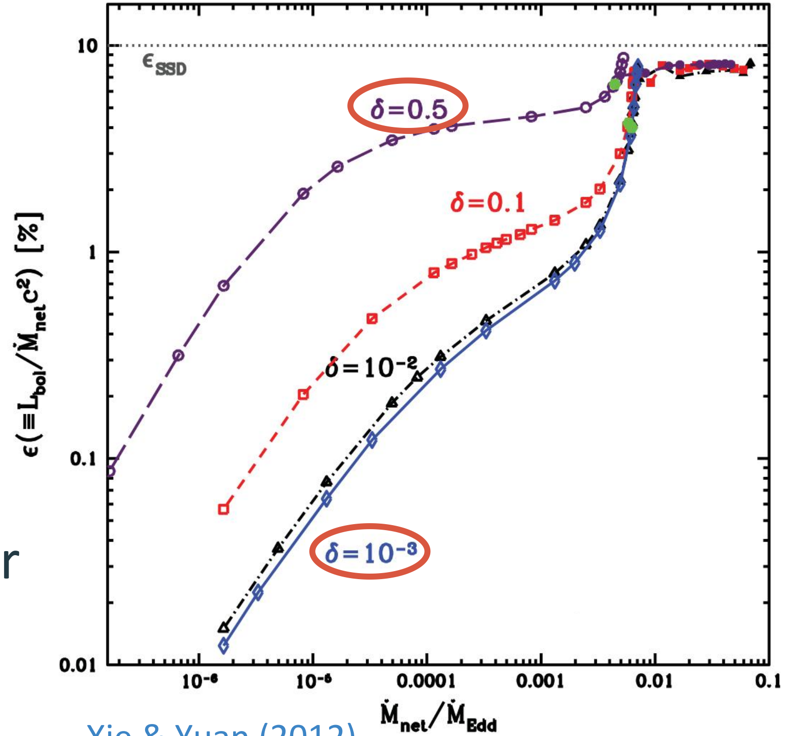
Radiative efficiency of BHs w/o disks (ADAF)

$$L_X = \epsilon \dot{M}_{net} c^2$$

ϵ = radiative efficiency

$\epsilon = \epsilon\ (\dot{M}_{net}, \delta)$

δ = electron heating parameter



Xie & Yuan (2012)

Grid of binary evolution models

$M_{donor,i}$ = 10 - 90 M_{sun}

$q_i = M_{accretor,i}/M_{donor,i}$ = 0.25 - 0.95

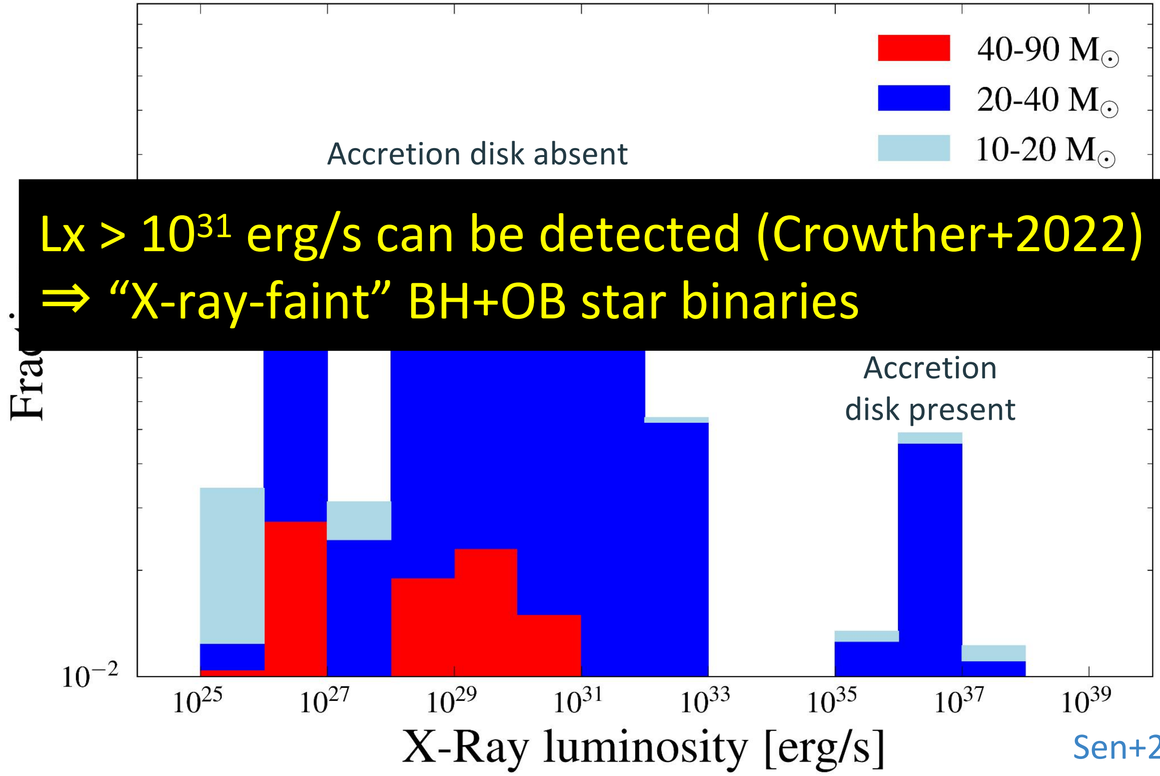
$P_{orb,i}$ ~ 1 - 3162 days

Population syn* of BH+OB binaries

*weighted by the Salpeter IMF, initial binary distribution functions, and the time spent in the BH+OB phase

adapted from Kruckow+2018

X-ray luminosity of BH+OB star binaries



Lx > 10^{31} erg/s can be detected (Crowther+2022)

⇒ "X-ray-faint" BH+OB star binaries

Sen+2024

X-ray luminosity of BH+OB star binaries

Source of δ = 0.5:

↓

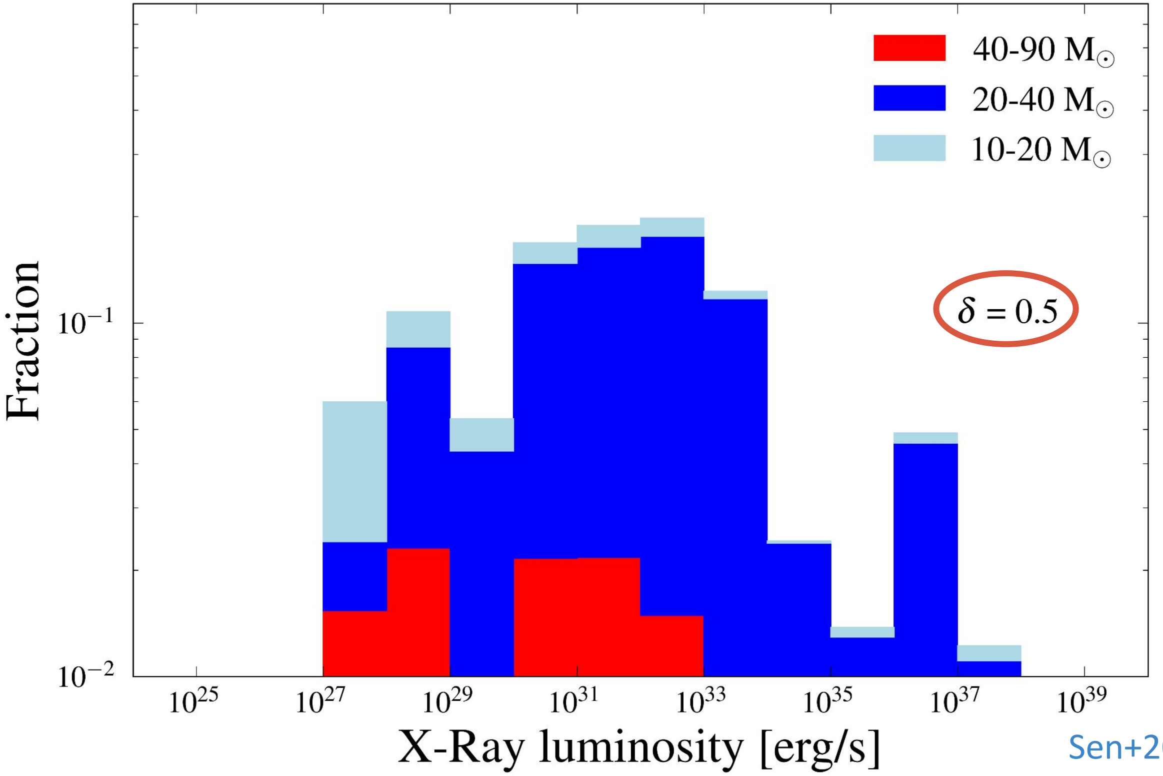
particle acceleration through magnetic reconnection (Quataert & Gruzinov 1999)

↓

σ of 10^2-10^5 possible for an OB star with B = 10 G

↓

Non-thermal synchrotron emission from the BH corona (Sen+2024)



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A smoking gun: HD 96670

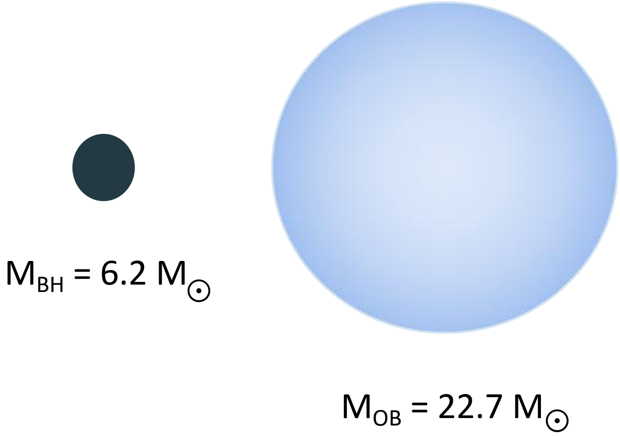
M_{BH} = 6.2 Msun, M_{OB} = 22.7 Msun

P_{orb} = 5.28 d, R_{OB} = 17.1 Rsun

Teff = 38000 K (Hohle+2010)

Observed Lx = 2.2e32 erg/s (NuSTAR, Gomez+2021) to 2.4e34 erg/s (XMM-Newton, Saxton+2008)

Predicted Lx = 8e33 erg/s



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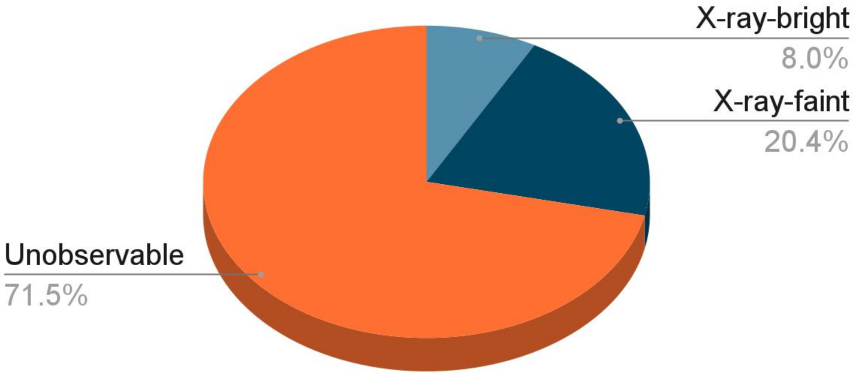
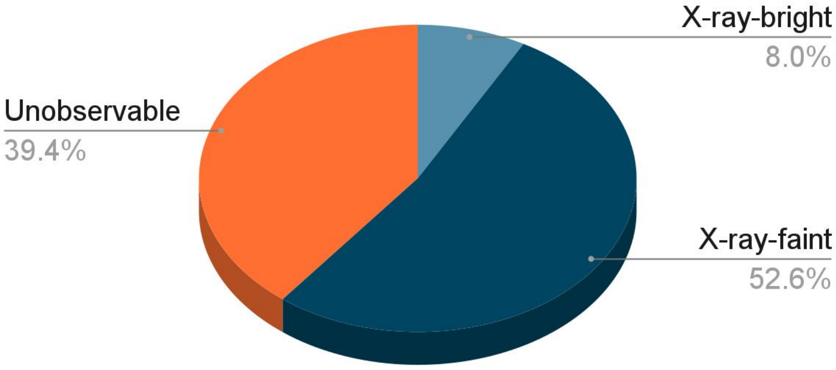
Number predictions for the LMC

Percentage of BH+OB star binaries (δ = 0.001)



≅ 28 X-ray-faint systems in the LMC

Percentage of BH+OB star binaries (δ = 0.5)



≅ 72 X-ray-faint systems in the LMC

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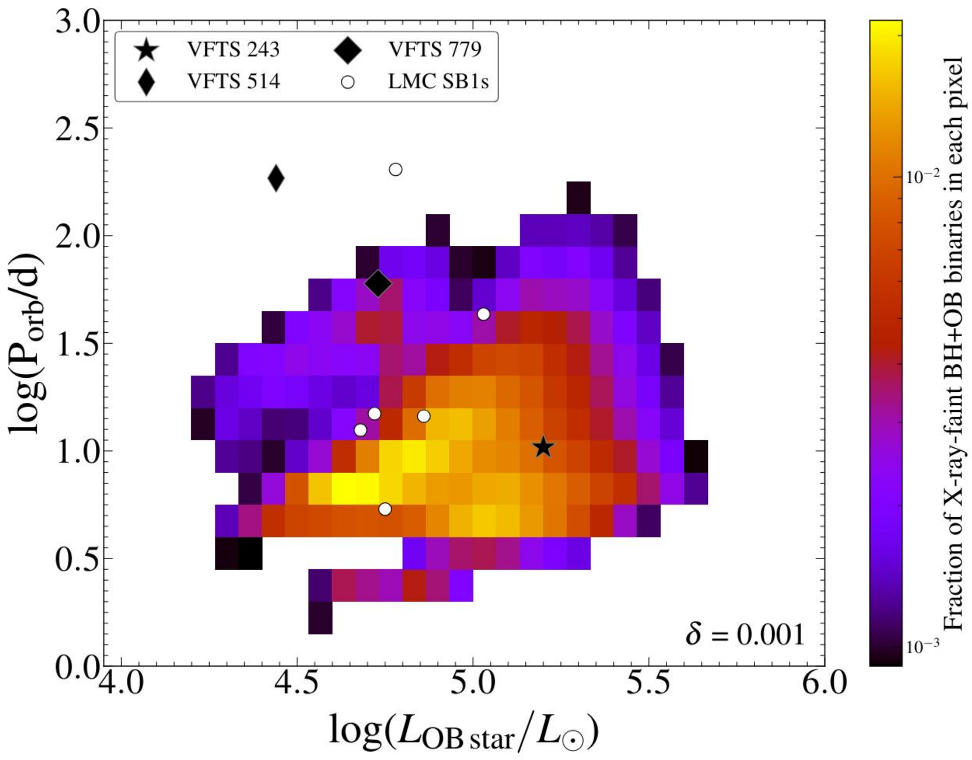
Observable properties of X-ray-faint systems



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Future directions (Wish list)

Identify X-ray candidates in the luminosity range 10^{31} - 10^{35} erg/s.

Cross-match with OB star catalogues (e.g. Antoniou+2019).

Get multi-epoch optical spectra of promising candidates (e.g. ESO/UVES).

Get X-ray spectra e.g. from XRISM.

Characterise the stellar and binary properties of BH+OB binaries

Summary

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e in the L … e surveys.
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X-ray-quiet

X-ray-faint

X-ray-bright

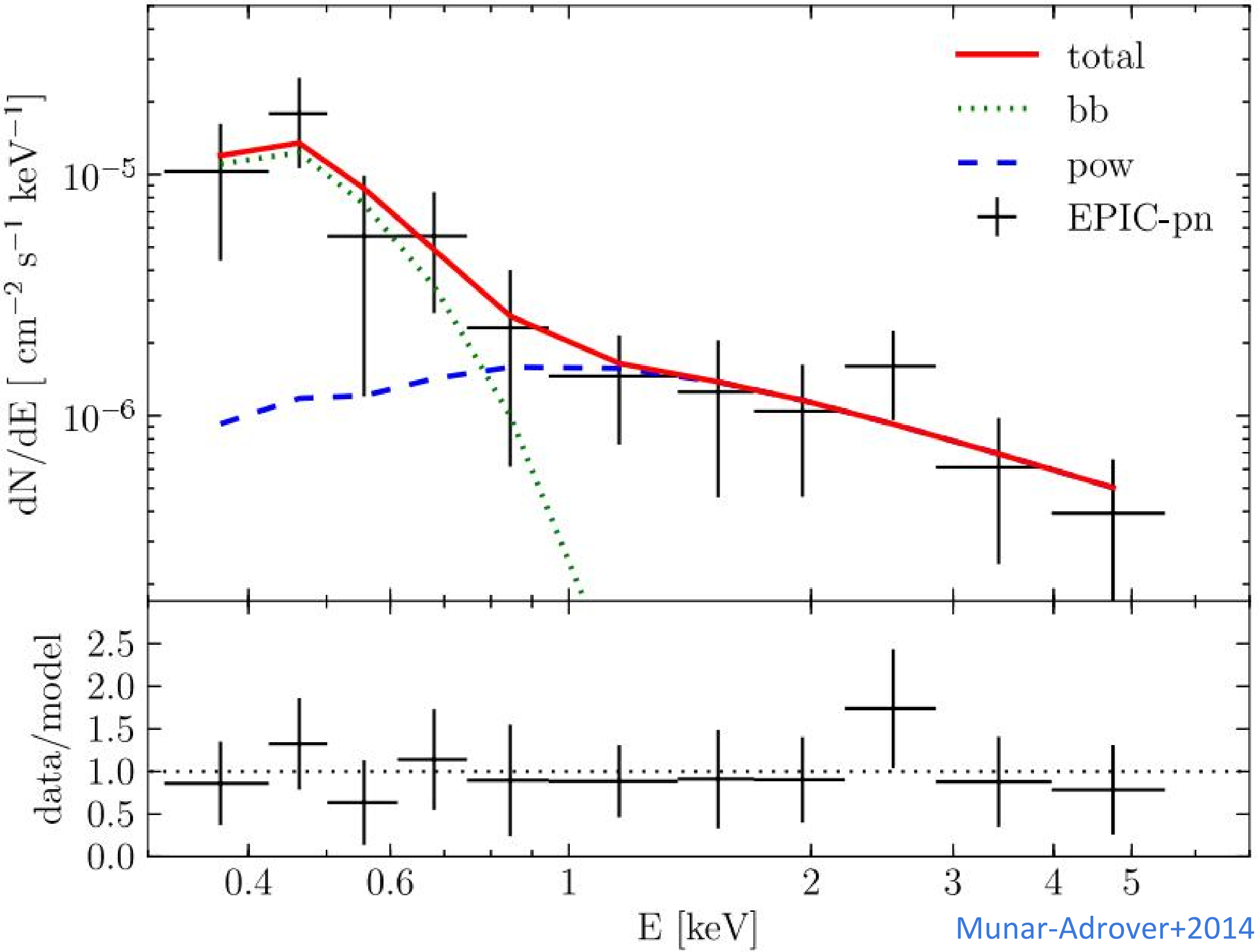
Backup slides

MWC 656

XMM-Newton; for 14 ks

$$L_{\rm bb} = (2.1^{+2.8}_{-1.5}) \times 10^{31}\ {\rm erg\ s^{-1}}$$

$$L_{\rm pow} = (1.6^{+1.0}_{-0.9}) \times 10^{31}\ {\rm erg\ s^{-1}}$$

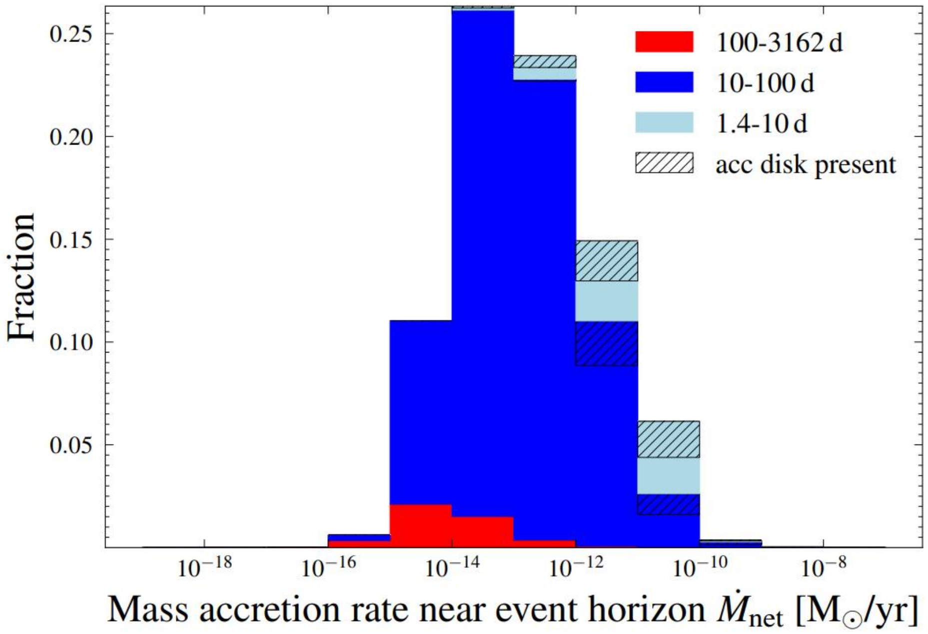


Munar-Adrover+2014

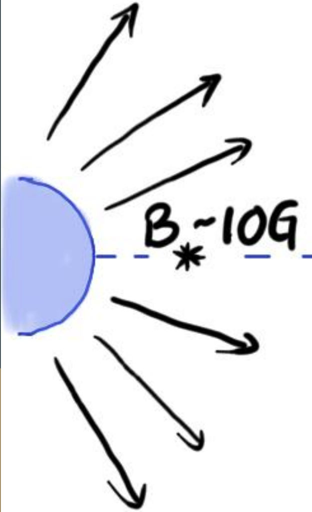
Mass accretion rate

For comparison, the Eddington accretion rate is

$$\dot{M}_{\rm Edd} = \frac{L_{\rm Edd}}{\epsilon c^2} \sim 2.19 \times 10^{-7} \left(\frac{M_{\rm BH}}{10 {\rm M}_\odot} \right) {\rm M}_\odot\,{\rm yr}^{-1}$$



for weak $\vec{B}$, the field lines are radial (ud-Doula & Owocki 2002)



$B \propto \frac{1}{r^2}$

$\rho \propto r^{-1.1}$

$B \propto r^{-2}$

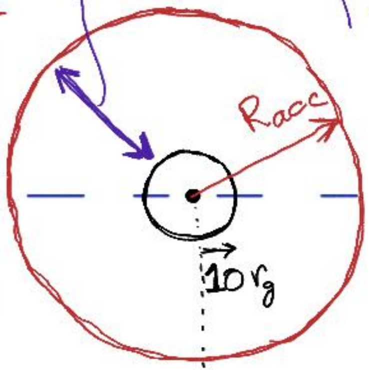
(Cunningham+2012)

$B_{10r_g} = B_{R_{acc}} \left(\frac{R_{acc}}{10r_g}\right)^2$

$\rho_{10r_g} = \rho_{R_{acc}} \left(\frac{R_{acc}}{10r_g}\right)^{1.1}$

$B_{R_{acc}} = B_* \left(\frac{R_*}{a}\right)^2$

$\rho_{R_{acc}} = \frac{\dot{M}_w}{4\pi a^2 v_w}$



$B_{10r_g} \sim 2\times10^6$ G

(Cangemi et al 2021)

cold magnetisation parameter (Kagan+2015)

$\sigma = \frac{B^2}{4\pi n m_e c^2}$

$\sigma_{10r_g} > 100$ for $B_* = 10$ G, $a = 100 R_*$

$\Rightarrow$ efficient particle acceleration $\Rightarrow$ synchrotron emission

$$R_{\rm acc} = \frac{2GM_{\rm BH}}{v_{\rm w}^2}$$

$$r_g = GM_{\rm BH}/c^2$$

Fraction of BH+OB vs NS+OB (BeXRBs) binaries