Can XRBs in M83 be the progenitors of gravitational waves sources for LVK?

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INTRODUCTION

The X-ray binaries (XRBs) are considered as promising progenitors of the merging double compact objects (DCOs) such as double black holes (BH-BH), double neutron stars (NS-NS) and BH-NS which are the sources of gravitational waves detectable by LIGO/VIRGO/Kagra (LVK).

M83

- it has one of the highest number of detected X-ray point sources : **363** (Lehmer et al. 2019)
- the X-ray point sources population was cleared out of supernova remnants and background AGNs leaving only XRBs confirmed through the optical observations (Hunt et al. 2021)

XRBs

XRBs are close binary systems where X-ray emission is powered by accretion of the mass transferred from the donor star onto the compact object (NS or BH).

Types of XRBs

- **LMXBs** (low-mass X-ray binaries): $M_2 < 3.0\ M_\odot$. They can be further divided into:
  - transient LMXBs (T-LMXBs) which cycle between short period of outbursts ($L_x \sim 10^{36} - 10^{39}$ erg/s) and long periods of quiescence ($L_x < 10^{33}$ erg/s)
  - persistent LMXBs (P-LMXBs) which stay permanently in the luminous state
- IMXBs (intermediate-mass X-ray binaries): $3.0\ M_\odot < M_2 < 8.0\ M_\odot$
- HMXBs (high-mass X-ray binaries): $8.0\ M_\odot < M_2$

where M_2 is the donor mass.

XRBs in M83

There are **214 XRBs** identified on basis of X-ray (Lehmer et al. 2019) and optical (Hunt et al. 2021) observations. Among them:

- **30 LMXBs**
- **64 IMXBs**
- **120 HMXBs**

Methodology

1. To generate the intrinsic population of XRBs in M83 we use the population synthesis code **StarTrack** (Belczynski et al. 2002, 2008).

2. To obtain the population of XRBs that can be compared to the observations we need post-processing steps:
   - only the sources with $L_x \geq 10^{35}$ erg/s
   - we account for the difference between X-ray and optical coverage of M83
   - we distinguish between T-LMXBs and P-LMXBs following the criteria of the disk instability model (Lasota et al. 2008). We adopt the value of the duty cycle (the fraction of a system lifetime that a transient LMXB spends in the outburst) to be 0.025 following Yan&Yu 2015

Those steps result in the reduction of the intrinsic number of synthetic XRBs.

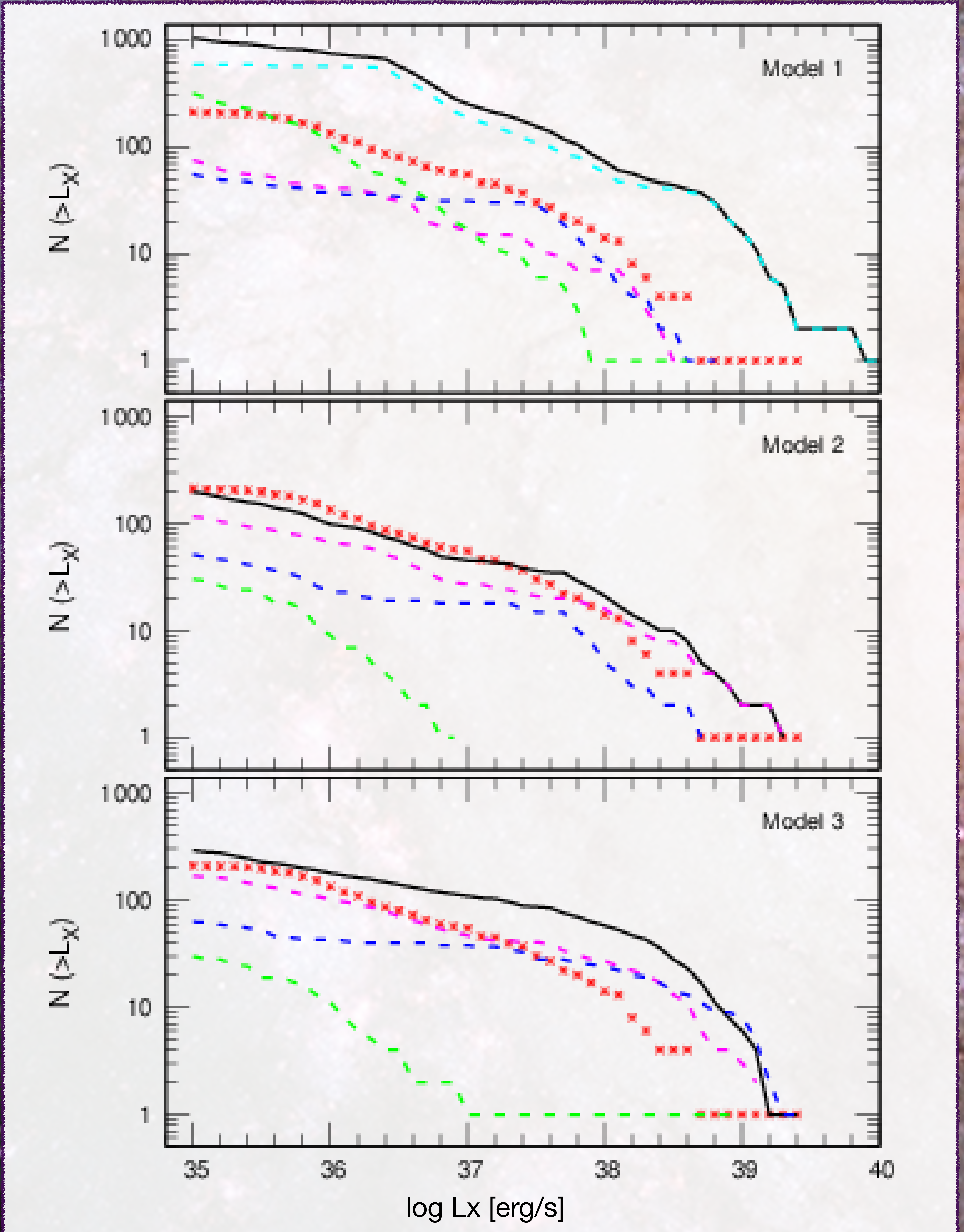
From all models that we calculated we choose 3 based on the criteria:

1. the XLF shape
2. the total number of XRBs
3. the numbers of XRBs in the subgroups: LMXBs, IMXBs, HMXBs

Model 1 : in which we get the reduced XRBs population due to post-processing. It is the reference model to Model 2

Model 2 : the most satisfying model considering our criteria

Model 3 : with parameters like in Model 2 but with the alternative CE development criteria



X-ray Luminosity Function

- ★ observations
- all XRBs
- HMXBs
- IMXBs
- T-LMXBs
- P-LMXBs

Model 1: standard CE, $M_2 < 3.0\ M_\odot$ for LMXBs,
SFR=2.5 $M_\odot\ yr^{-1}$, all LMXBs

Model 2: standard CE, $M_2 < 3.5\ M_\odot$ for LMXBs,
SFR=3.5 $M_\odot\ yr^{-1}$, 30 LMXBs

Model 3: stable RLOF, $M_2 < 3.5\ M_\odot$ for LMXBs,
SFR=3.5 $M_\odot\ yr^{-1}$, 30 LMXBs

All: Z=0.01

XRBs type	Number of systems			
	Observed	Model		
		1	2	3
LMXBs	30	689 (0.7)	**30 (0.03)**	30 (0.03)
P-LMXBs	?	441	**0**	2
T-LMXBs	?	248	**30**	28
IMXBs	64	55 (0.7)	**51 (0.8)**	64 (1.5)
HMXBs	120	75 (0.3)	**116 (1.2)**	169 (4.7)
Total	214	819 (1.7)	**197 (2.0)**	263 (6.2)

Numbers in parenthesis are the estimated number of XRBs which are predicted to end up as merging DCOs (NS-NS/BH-NS/BH-BH).

Model 2 is a good approximation of observations in terms of the total number XRBs as well as their observed subclasses.
Model 3 is closer to observations in LMXBs and IMBXs numbers than Model 2 but is not our model of choice due to high number of HMXBs.

Characteristics of the synthetic XRBs population

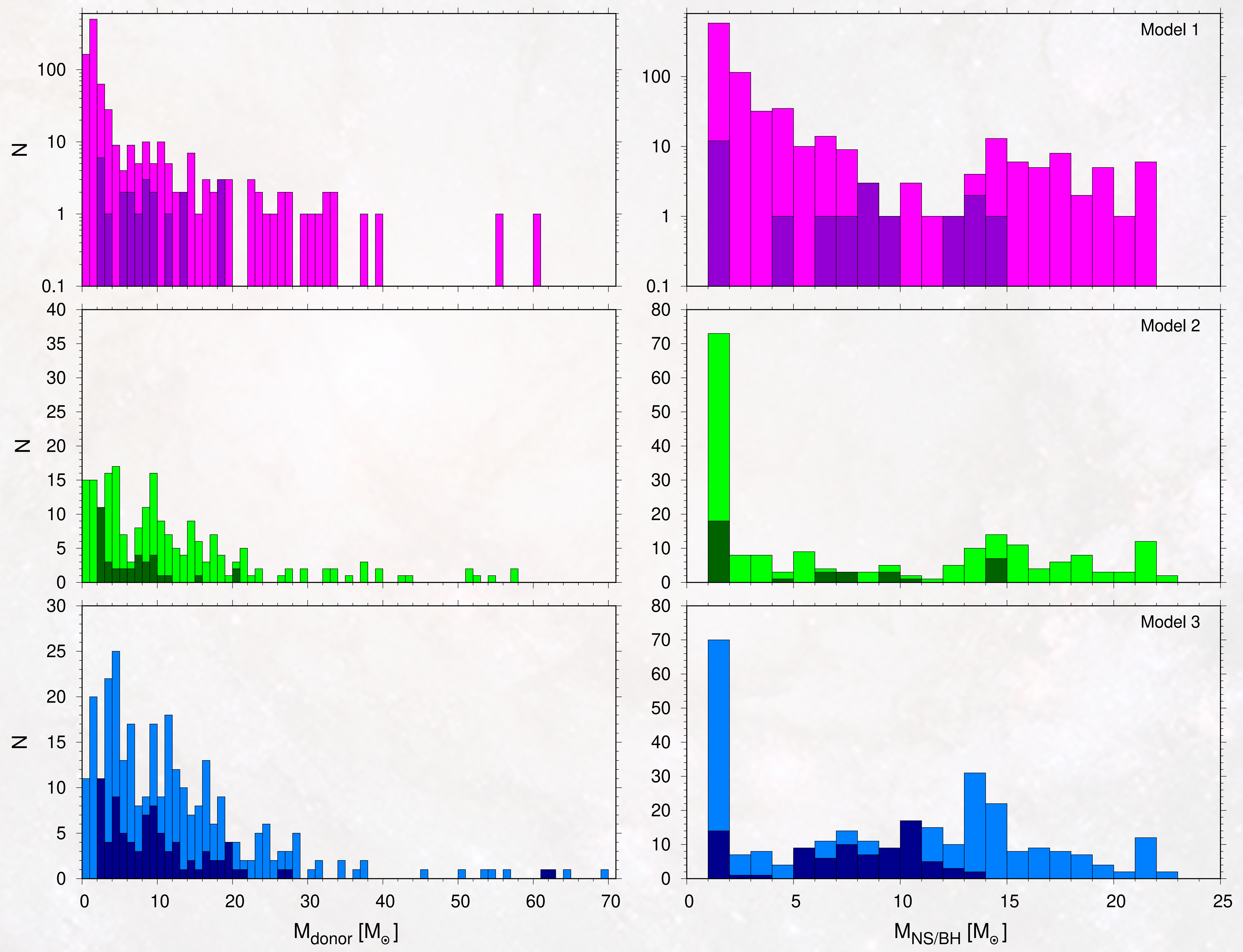
CO type

Model 1: 73% NSs

Model 2: 40% NSs

60% BHs

Model 3 : 70% BHs



Merging DCOs

1. Dominant type of the merging DCOs:
   - Model 1: NS-NS
   - Model 2: BH-NS
   - Model 3: BH-BH
2. The most probable progenitors of the merging DCOs:
   - Model 1: LMXBs (!) / IMXBs
   - Model 2: HMXBs
   - Model 3: HMXBs
3. What happens with all others XRBs?
   - HMXBs/IMXBs : disrupted in 2^{nd} SN, very wide BH/NS-COs, merge during 2^{nd} CE episode
   - LMXBs : wide NS-NS/WD-NS

Conclusions

1. We can match :
   - the shape of the observed XLF
   - the number of XRBs
   - the number of the specific XRBs subcategories: HMXBs ans IMXBs

   for the evolutionary channel that allows for effective formation of DCOs through CE evolution (Model 2).

2. The match of LMXBs number can be obtained only with artificial reduction of LMXBs in the synthetic population - the physics of LMXBs formation requires deeper investigation.

3. The model in which the majority of merging DCOs form via stable RLOF does not provide good match to the observed XLF shape.

4. Independent of our adopted evolutionary scenario only **1-2% of M83 XRBs will form merging DCOs.**

70
60
50
40
30
20
10
0
M_{donor} [M_{Sun}]
10^{-2}
10^{0}
10^{2}
10^{4}
10^{6}
P_{orb} [d]
1
0.8
0.6
0.4
0.2
0
e
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}