The nature of
Extreme Ultraluminous X-ray Sources

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In this proof-of-concept study we demonstrate that in a binary system mass can be easily delivered toward an accreting compact object at extremely high rates. If the transferred mass is efficiently converted to X-ray luminosity (without disregard of the classical Eddington limit) then binaries can form extreme ULX sources with the X-ray luminosity of $L_X \geq 10^{42}\,\mathrm{erg\,s^{-1}}$. Observations of HLX-1 in ESO 243-49 with X-ray luminosity of $1.1 \times 10^{42}\,\mathrm{erg\,s^{-1}}$ encouraged us to look into the problem.

Results

- **We find several evolutionary channels that lead to *phases of an extreme mass transfer rate*. These evolutionary phases are extremely short, but they appear in lifetimes of $\sim 0.1\%$ X-ray binaries.**

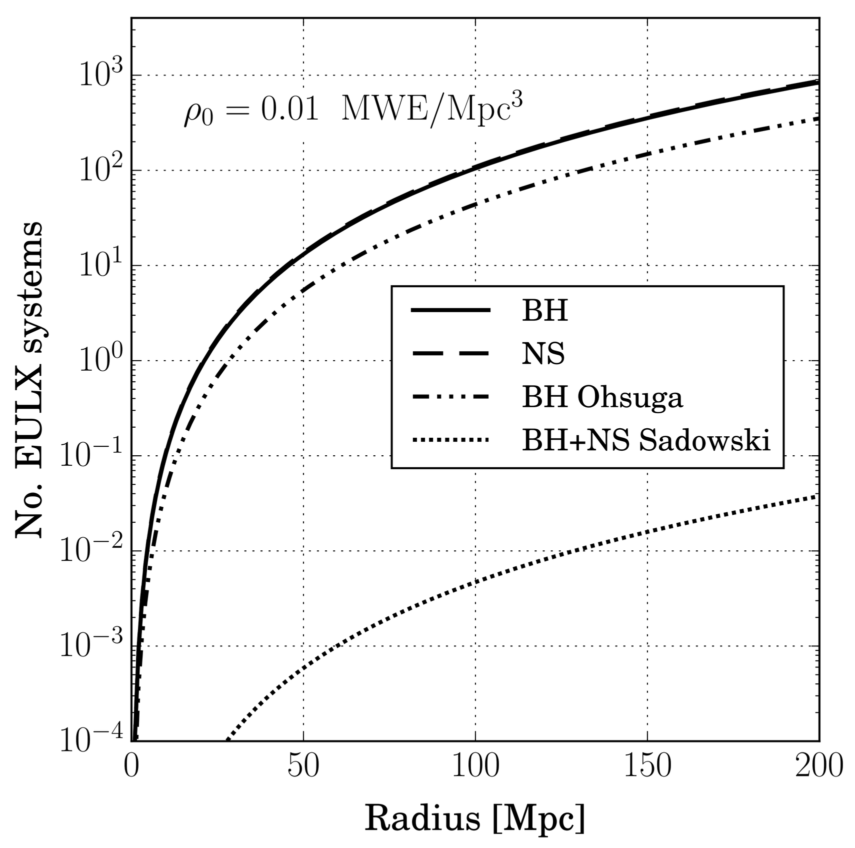


Figure 1: Upper limits on the number of EULXs within the sphere of radius R (solid for BH systems, dashed for NS systems). The dot-dashed and dotted lines correspond to the limited accretion scenarios, with L_X constrained following models of O07 and S15, respectively.

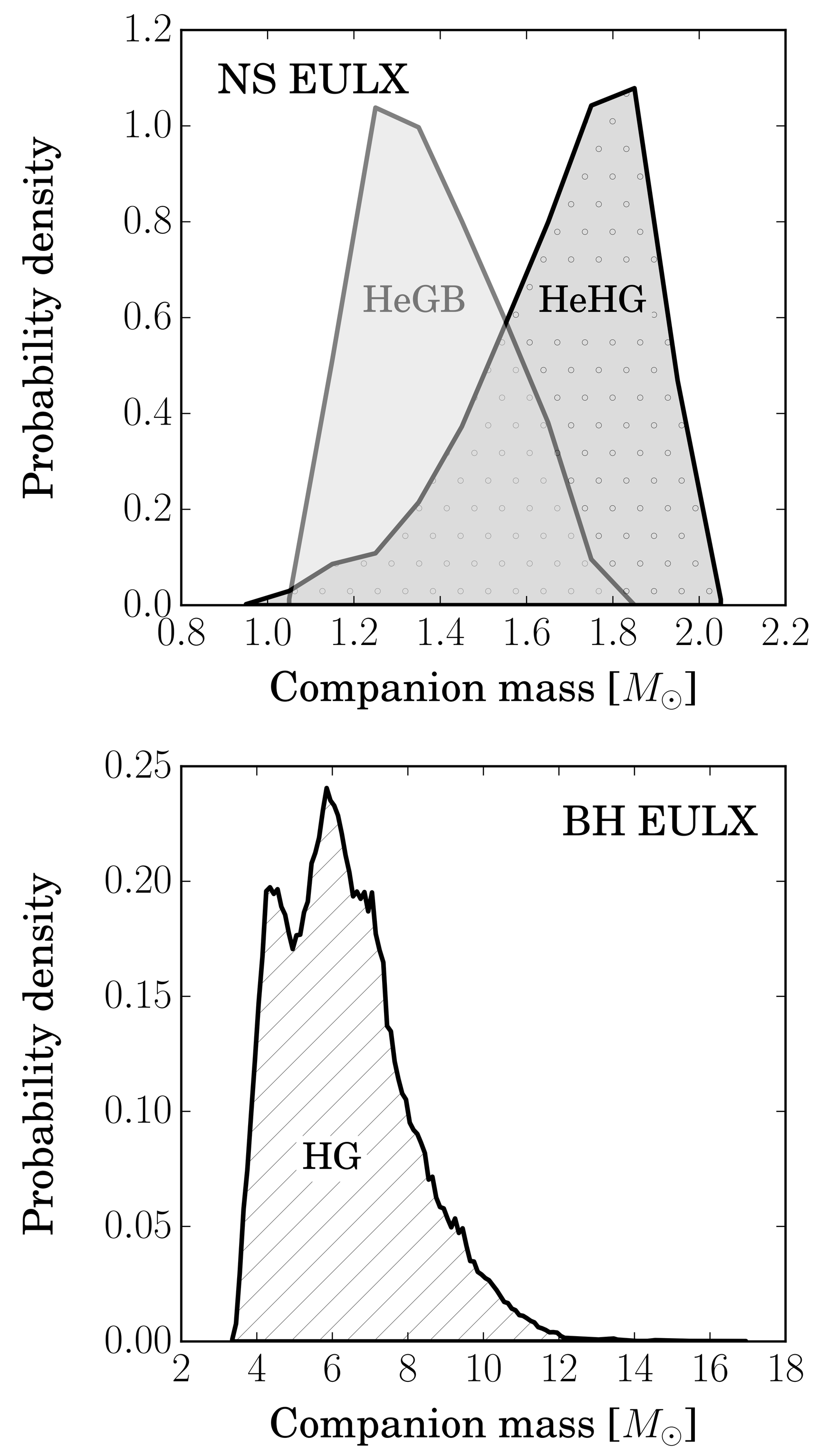


Figure 2: Mass distribution of the most common companions in NS (top) and BH (bottom) systems during the EULX phase in our reference model.

- **We found that EULXs may host also NS accretors.**
- **Even if strong outflows from the accretion disk were present (models S15 and O07), we were able to obtain EULXs.**

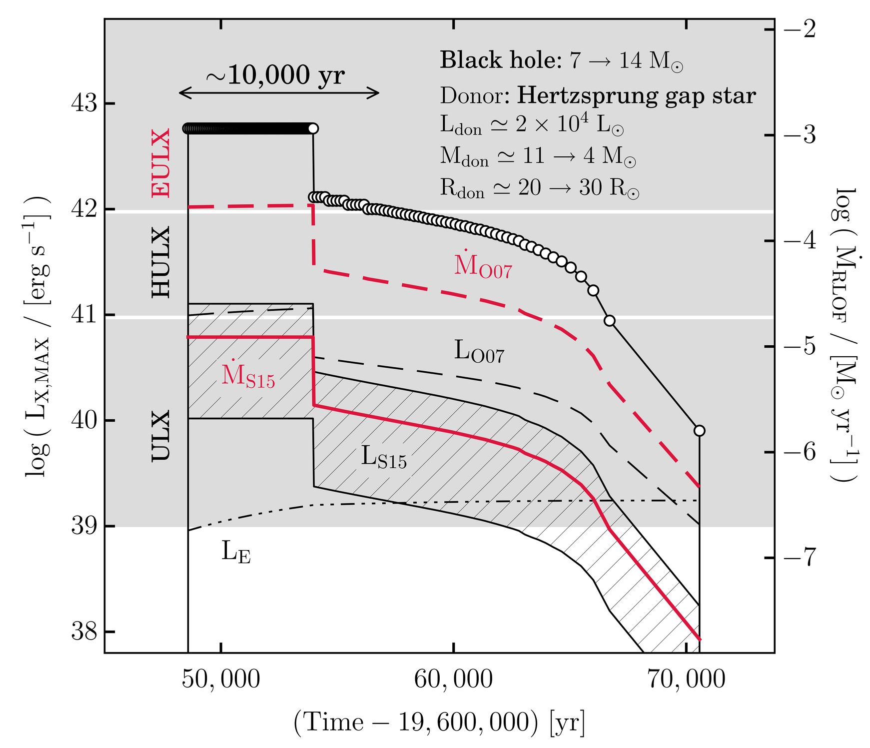


Figure 3: Typical evolution through Roche lobe overflow for a potential BH EULX binary in our reference model The thick/red solid line and the hatched area represent luminosities obtained for S15 model. Similarly, the thick/red dashed line and thin/black dashed line show the mass accretion rate and luminosity derived with the O07 model.

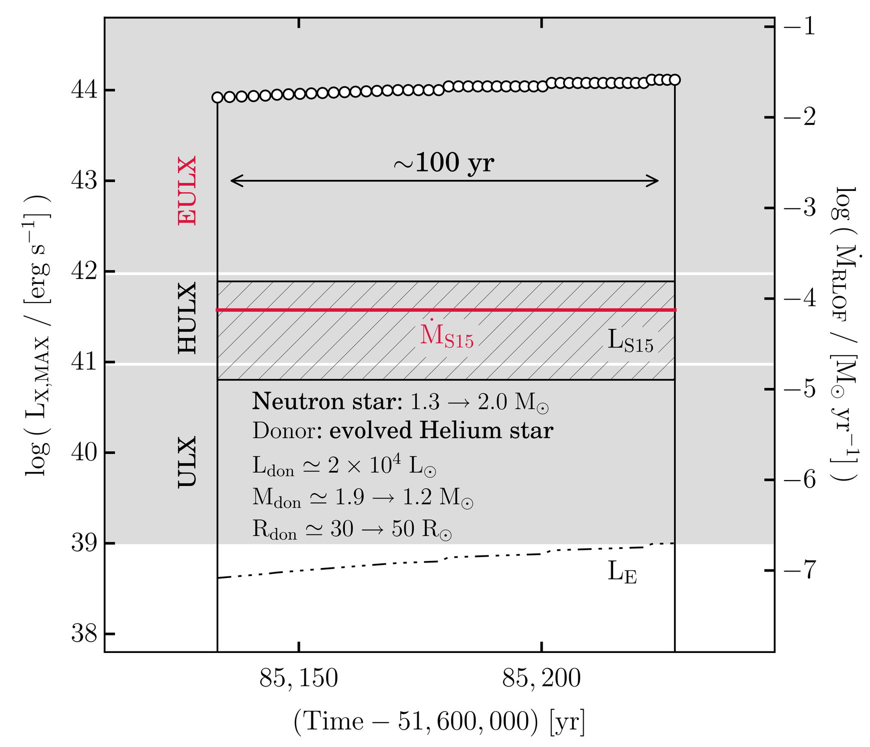
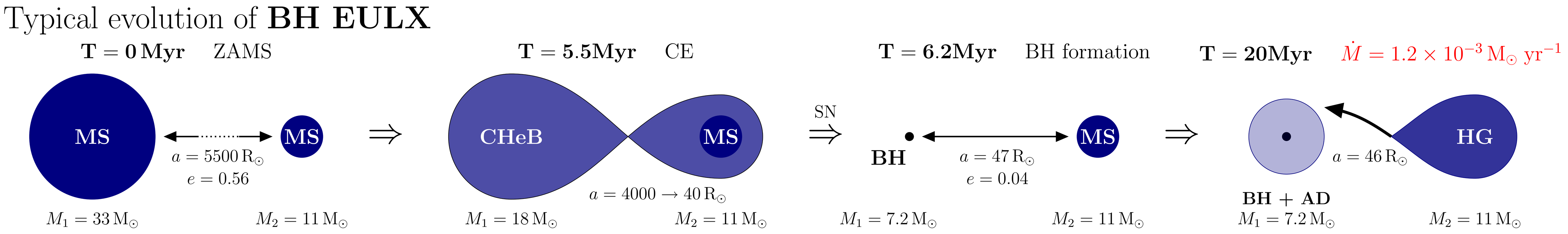
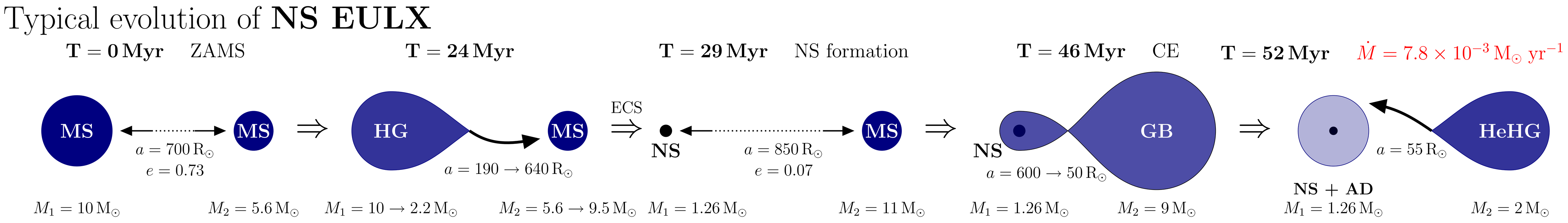


Figure 4: Typical evolution through Roche lobe overflow for a potential NS EULX binary system in our models. Lines similarly like in Figure 3.

Typical evolution of **BH EULX**



Typical evolution of **NS EULX**



Glossary

AD - Accretion disk
BH - Black Hole
CE - Common Envelope
CHeB - Core Helium Burning
ULX - UltraLuminous X-ray source
ECS - Electron Capture SN
EULX - Extreme ULX
GB - Giant Branch star
HeGB - Helium Giant Branch star
HeHG - Helium Hertzsprung Gap star
HG - Hertzsprung Gap star
MS - Main Sequence
NS - Neutron Star
SN - SuperNova
ZAMS - Zero Age Main Sequence

Ultraluminous X-ray Source

- point-like
- off-nuclear
- $L_X > 10^{39}\,\mathrm{erg\,s^{-1}}$

($\approx L_{Edd}$ for $10\,M_\odot$ BH)

More than **470** identified sources (Walton et al., 2011)

Nature still unknown:

1. **IMBH** (e.g., Colbert & Mushotzky, 1999)
2. **super-Eddington accretion** (e.g., Motch et al., 2014)

Extreme Ultraluminous X-ray Source

- ULX with $L_X > 10^{42}\,\mathrm{erg\,s^{-1}}$
- To date only one EULX. HLX-1 located in ESO 243-49 with $L_X \approx 1.1 \times 10^{42}\,\mathrm{erg\,s^{-1}}$

Methodology

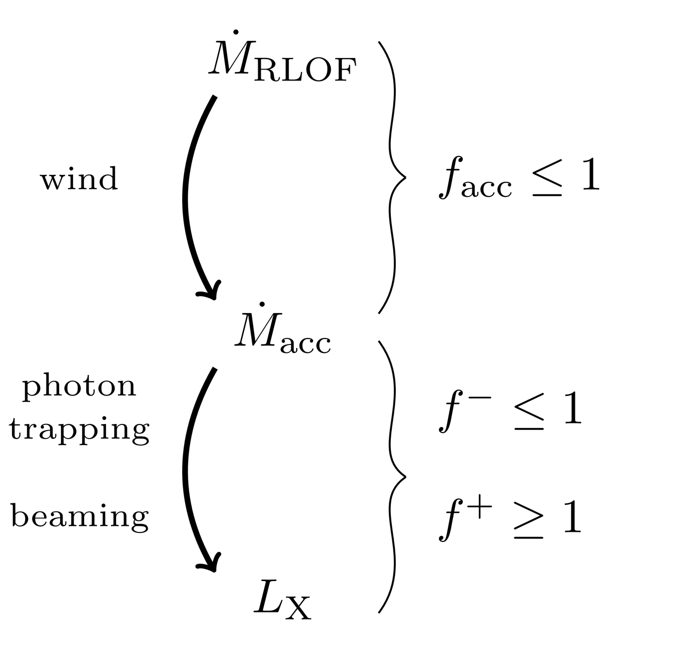


Figure 5: Most important processes affecting the final outcome of transferred mass conversion into X-ray luminosity (left), their input and output parameters (middle) and our parametrisation of these processes (right).

We utilised the StarTrack population synthesis code to perform the massive simulations of binaries' evolution in Milky-Way-type galaxy. We use the **BOINC** platform for volunteer computing in our program ***Universe@home*** (http://universeathome.pl). We analysed systems whose L_X exceeded $10^{42}\,\mathrm{erg\,s^{-1}}$.

Models tested:

- The reference model ($f_{acc} = f^+ = f^- = 1$)

$$L_X = f^- f^+ \frac{\epsilon G M_{acc} f_{acc} \dot{M}_{RLOF}}{R_{acc}} = \eta \dot{M}_{RLOF} c^2$$

- The Sądowski model ($f_{acc} = 0.01$, $f^+ \approx 8$) (**S15**; Sądowski et al., 2015)
- The Ohsuga model ($f_{acc} = 0.15$-0.36, $f^+ \approx 66$) (**O07**; Ohsuga, 2007)

Forthcoming Research

Our next goal will be to investigate the population of all ULXs. Our new source of huge computational power (the Universe@home project) will make it possible to calculate a vast grid of models and to perform thorough analysis.

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