Compact object population in ULXs

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No precise mass measurements

larger Eddington limit

vs.

super-Eddington accretion

Two main possibilities:

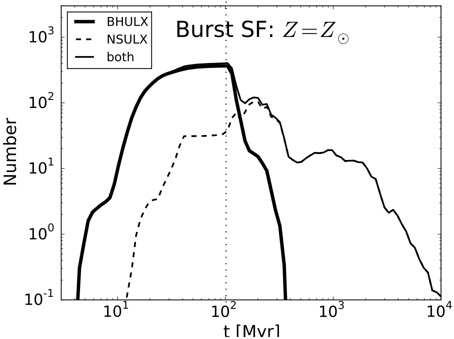
1. **intermediate-mass black holes** $(\sim 10^2 \div 10^5\, M_\odot)$
2. **stellar-mass accretors** $(\lesssim 10^2\, M_\odot)$
   - stellar-mass black holes (BH)
   - neutron stars (NS)

Wide picture

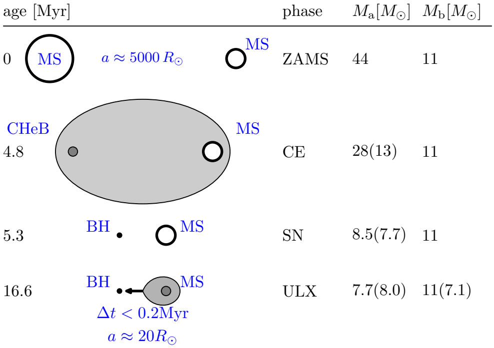
Population synthesis method

Use results of detailed evolutionary models to predict/explain observations

- large number of simulated systems ($N \sim 10^6$)
- variety of models tested



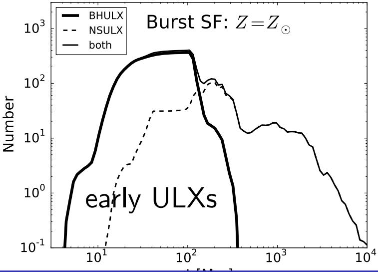
ULX formation sequence
ULXs in star-forming regions

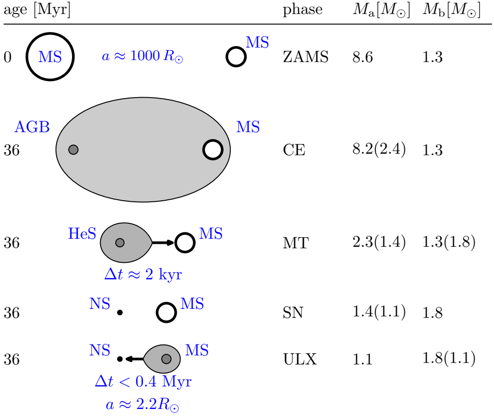


compare Rappaport et al. 2005

About 2/3 of ULX are found in star-forming regions

1. $t \approx 4-40\,\mathrm{Myr}$
   BH – MS ($5.6-11\,M_\odot$)
2. $t \approx 6-800\,\mathrm{Myr}$
   NS – MS ($0.9-1.5\,M_\odot$)





Fragos et al. 2015 → $M_{\rm don} > 5\,M_\odot$

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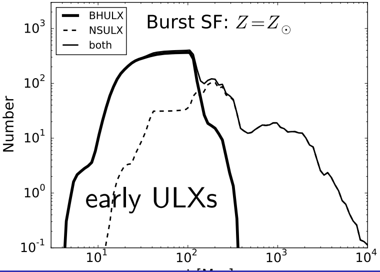
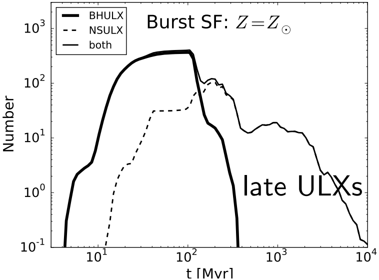


age [Myr]		phase	$M_{\rm a} [M_\odot]$	$M_{\rm b} [M_\odot]$
0	MS, $a \approx 1000\,R_\odot$, MS	ZAMS	7.6	1.3
46	AGB, MS	CE	7.3(1.3)	1.3
4200	WD, RG, $\Delta t \approx 10$ kyr	MT	1.3(1.4)	1.3
4200	NS, RG	ECS	1.4(1.3)	1.3
4200	NS, RG, $0.1 < \Delta t < 0.2$ Myr, $a \approx 23 R_\odot$	ULX	1.3	1.3(1.0)

3. $t \approx 430-1100\,\mathrm{Myr}$
   NS – HG ($0.6-1.0\,M_\odot$)
4. $t \approx 540-4400\,\mathrm{Myr}$
   NS – RG ($\sim 1.0\,M_\odot$)



Wiktorowicz et al. 2017

NS are expected to be present in all ULX population!

Pulses

Not all NS ULXs pulsate

- Magnetic fields
- pulses in ULP turn on and off (e.g. Bachetti et al. 2014)

Not always pulses will be visible

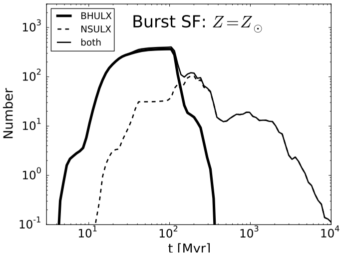
- below detectable limit
- observer needs to be located in the cone of the emission (Motch's talk)

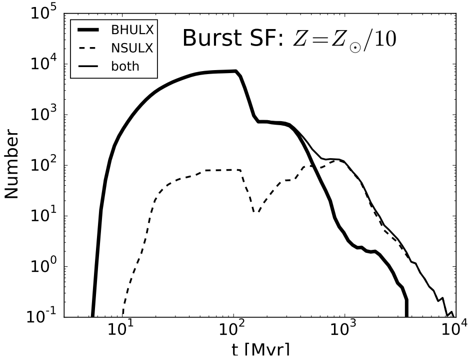
"A tip of the iceberg"

(King & Lasota 2016)

Neutron stars in ULXs
Role of metallicity

- number of NS ULXs in nearly unaffected by metallicity, but
- number of BH ULXs grows, so
- relative nubmer of NS ULXs is **lower** for low-Z environments





Higher accretor mass ($\sim 10^2 \div 10^5\, M_\odot$)

$\Rightarrow$

Higher Eddington limit ($\sim 10^{40} \div 10^{43}\,\mathrm{erg\,s^{-1}}$)

But...

- no dynamically confirmed IMBHs
- Formation scenario still unclear:
  - population III stars (Madau & Rees 2001),
  - repeated mergers in stellar clusters (Portegies Zwart & McMillan 2002),
  - runaway mergers (Portegies Zwart et al. 2004)
- problematic to produce sufficient number (King et al. 2004, Madhusudhan et al. 2006)

Intermediate mass black holes

Hyper-luminous X-ray sourses (HLX)

Most luminous ULXs ($L_X > 10^{41}\,\mathrm{erg\,s^{-1}}$) stand out from the majority of ULXs.

Examples are ESO 243 HLX-1 and M82 X-1

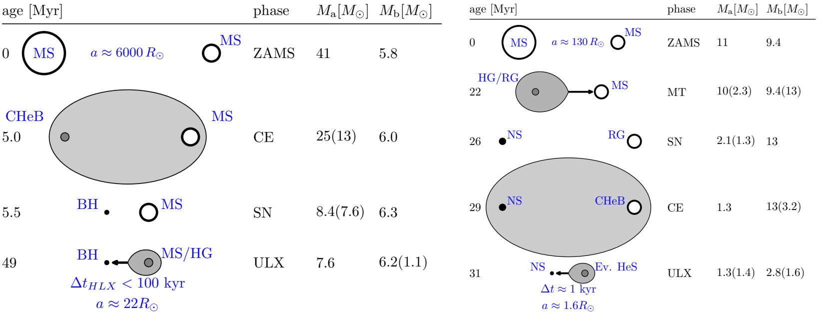
Best IMBH candidates!

- spectral states and transition unobserved in other ULXs, but similar to Galactic BH XRBs
- luminosity well beyond the XLF downturn at $\sim 2 \times 10^{40}\,\mathrm{erg\,s^{-1}}$
- but problems still remains (e.g. Lasota et al. 2011)

Part of the ULX population may harbour IMBHs!

Summary

- NS may be ubiquitous in ULXs
  (mainly $\sim 1\,M_\odot$ companions)
  ULP $\rightarrow$ *"A tip of the iceberg"*
- However, BHs seem to dominate
  in star forming regions (esp. in low-Z)
- IMBHs are still best candidates for HLX
  ($L_{\rm X} > 10^{41}\,{\rm erg\,s^{-1}}$)
  and HLX are the best candidates for IMBHs!



- Luminosities above $10^{41}\,\mathrm{erg\,s^{-1}}$
- Formed within $< 100\,\mathrm{Myr}$ after burst

Wiktorowicz et al. 2015