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Challenging Ultraluminous X-ray Sources

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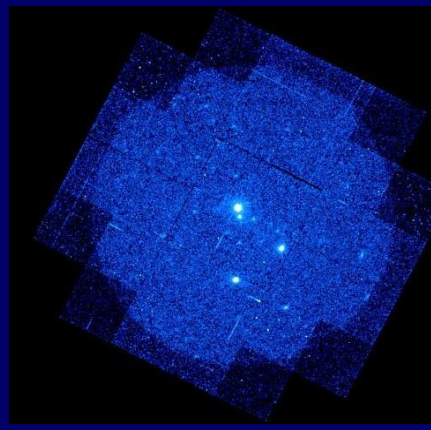
Outline

- Challenging ULXs
- ULXs and low metallicity environment
- Massive stellar BHs and HMXBs in low Z environment
- Dynamical kicks of massive stellar BHs and ULX displacements
- Conclusions

Challenging ULXs

- X-ray observations of nearby galaxies show a population of pointlike, off-nuclear sources with L >> Ledd for 1 Msun (L>1.0e39 erg/s) → UltraLuminous X-ray Sources (e.g. Fabbiano 2006)

- Likely the majority of these ULXs are accreting BHs in binaries (e.g. Zampieri & Roberts 2009)
  - Very high X-ray luminosity, X-ray spectra, short term variability
  - Often in young stellar environments, stellar optical counterparts
  - (Orbital) modulation in the X-ray (and possibly optical) flux, QPOs



- Challenging ULXs:

  → *what are the masses of the BHs powering these sources?* Possibility to probe existence of BHs in a mass range unexplored

  → *what are the properties of their donor stars? And those of their accretion flow? What is the relation with their environment*?

ULXs and low metallicity environments

(+) Specific ULX frequency decreases with increasing host galaxy mass indicating that smaller, lower metallicity systems have more ULXs per unit mass (Swartz et al. 08)

(+) Line intensities of HII regions in ULX host galaxies (e.g. Mapelli et al. 10, using Pilyugin et al. 04 calibration) → 0.1-0.5 Zsun for a sample of 52 ULX-hosting galaxies

(+) Measurement of the metallicity from the stellar environment (NGC 4559 X-7, Cropper et al. 04; NGC 1313 X-2, Grise' et al. 08) or from the optical spectrum of bubble nebulae (Ho II X-1, Pakull & Mirioni 02; NGC 1313 X-2, Ripamonti et al. 11) → subsolar abundance

(?) Oxygen abundance from K-shell photoionization edges of high S/N ratio *XMM* spectra of 14 ULXs → solar abundance (Winter et al. 07)

Pintore & Zampieri (11)

Anlysis repeated on two ULXs with higher counting statistics and with a different spectral model → ~0.5 Zsun (Pintore & Zampieri 11)

→ see Pintore's talk

ULXs and low metallicity environments

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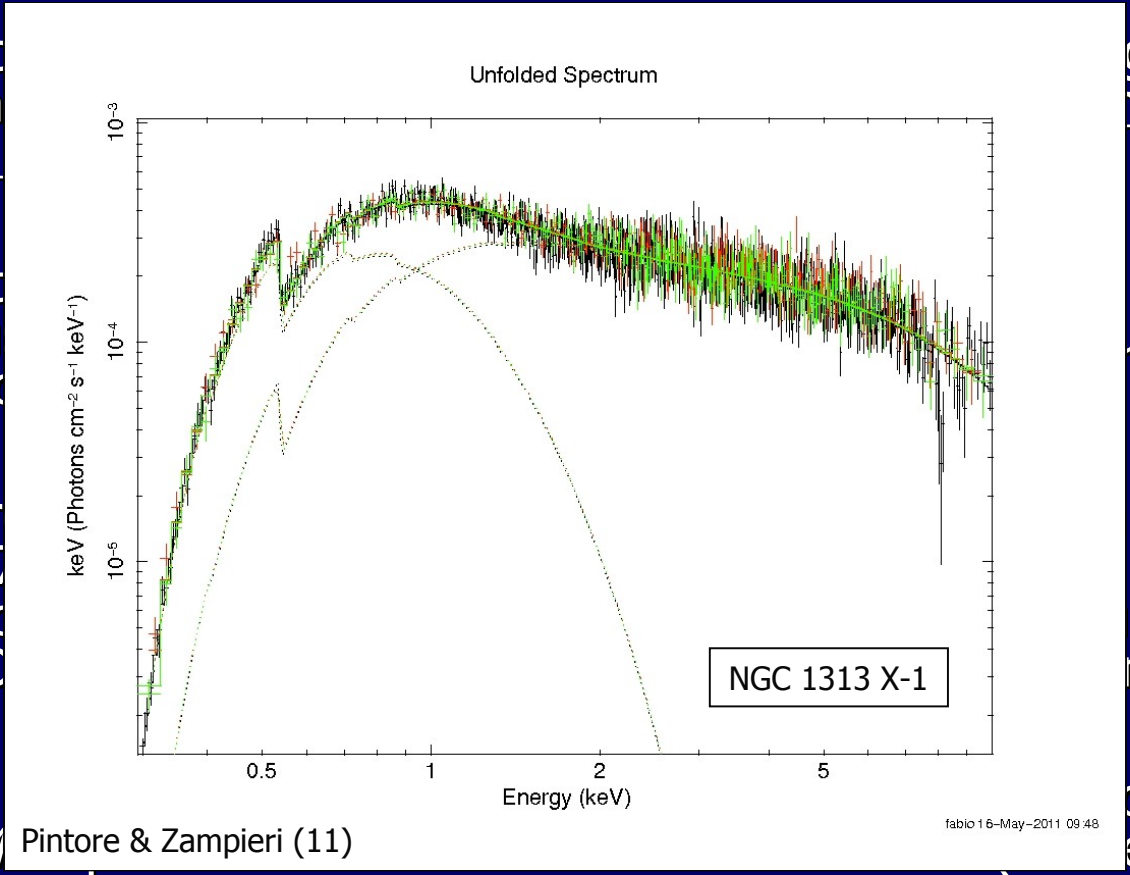

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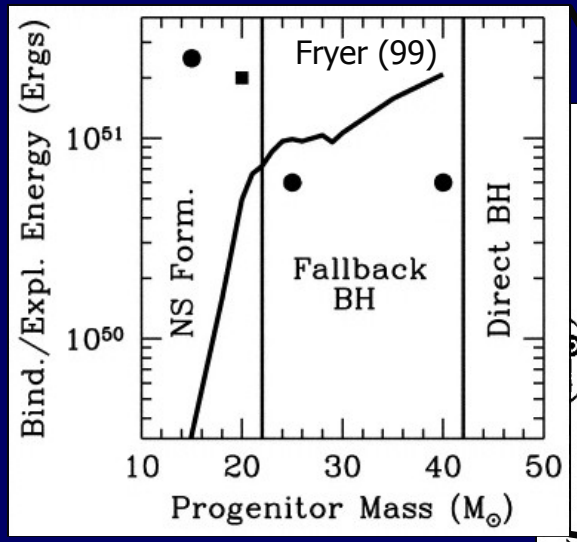
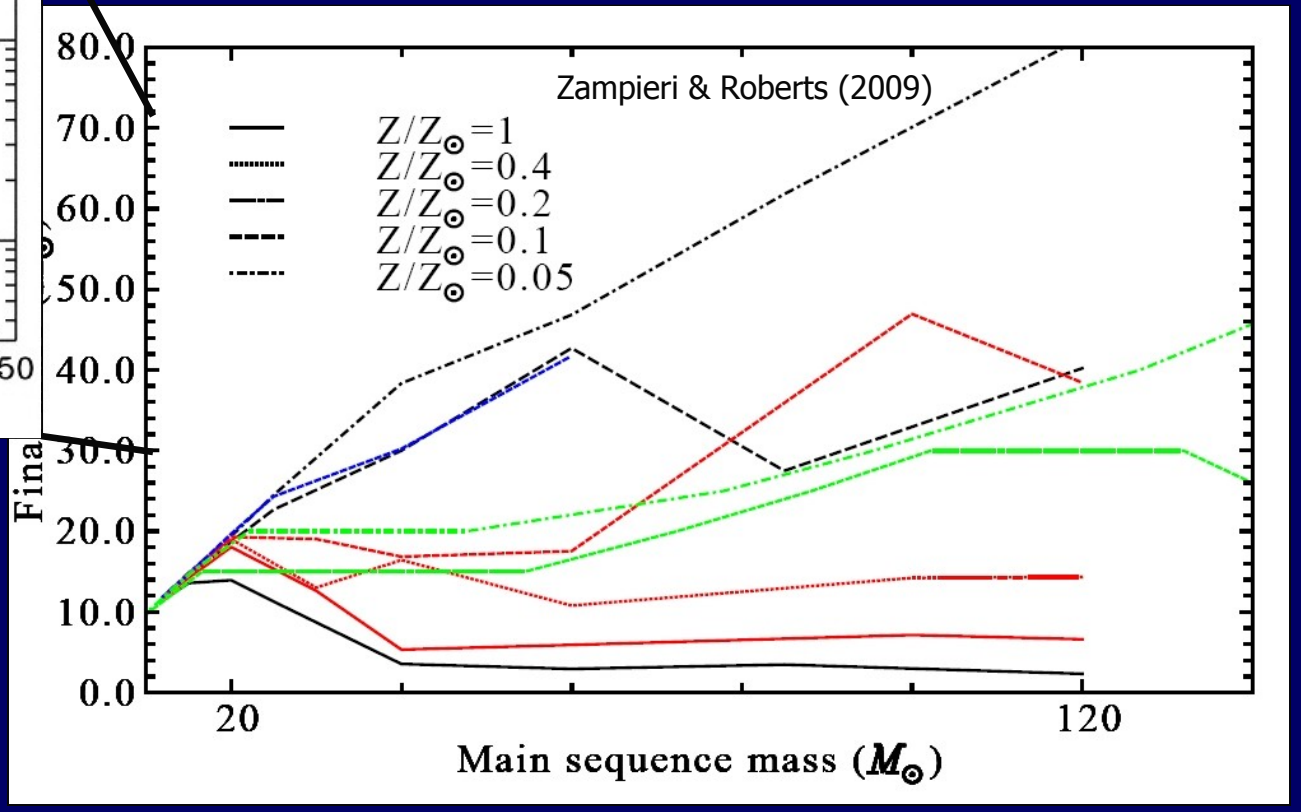
ULXs from massive low-Z stars

Massive BH formation through direct collapse of massive low-Z stars → Mbh~30-70 Msun





Small (~0.5) beaming or L ~ 2-3 Ledd for bright (> 10^{40} erg/s) ULXs

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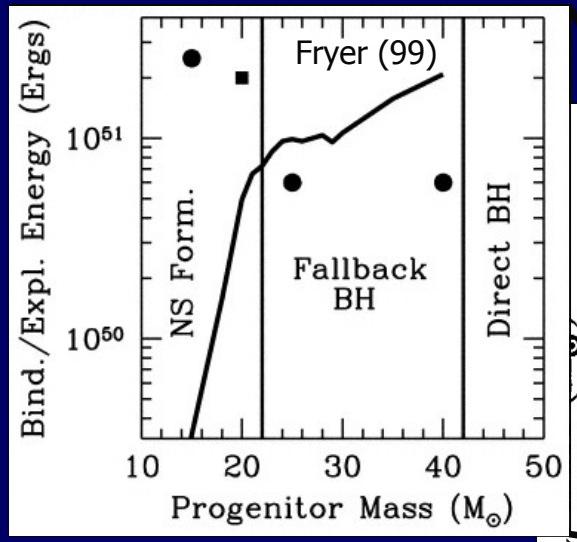

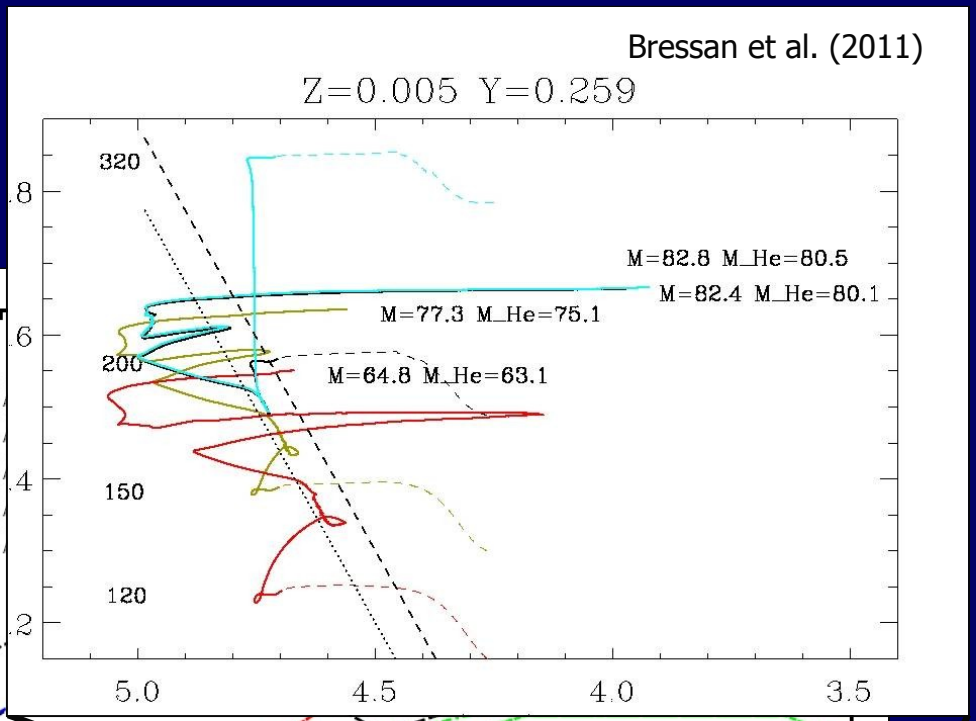

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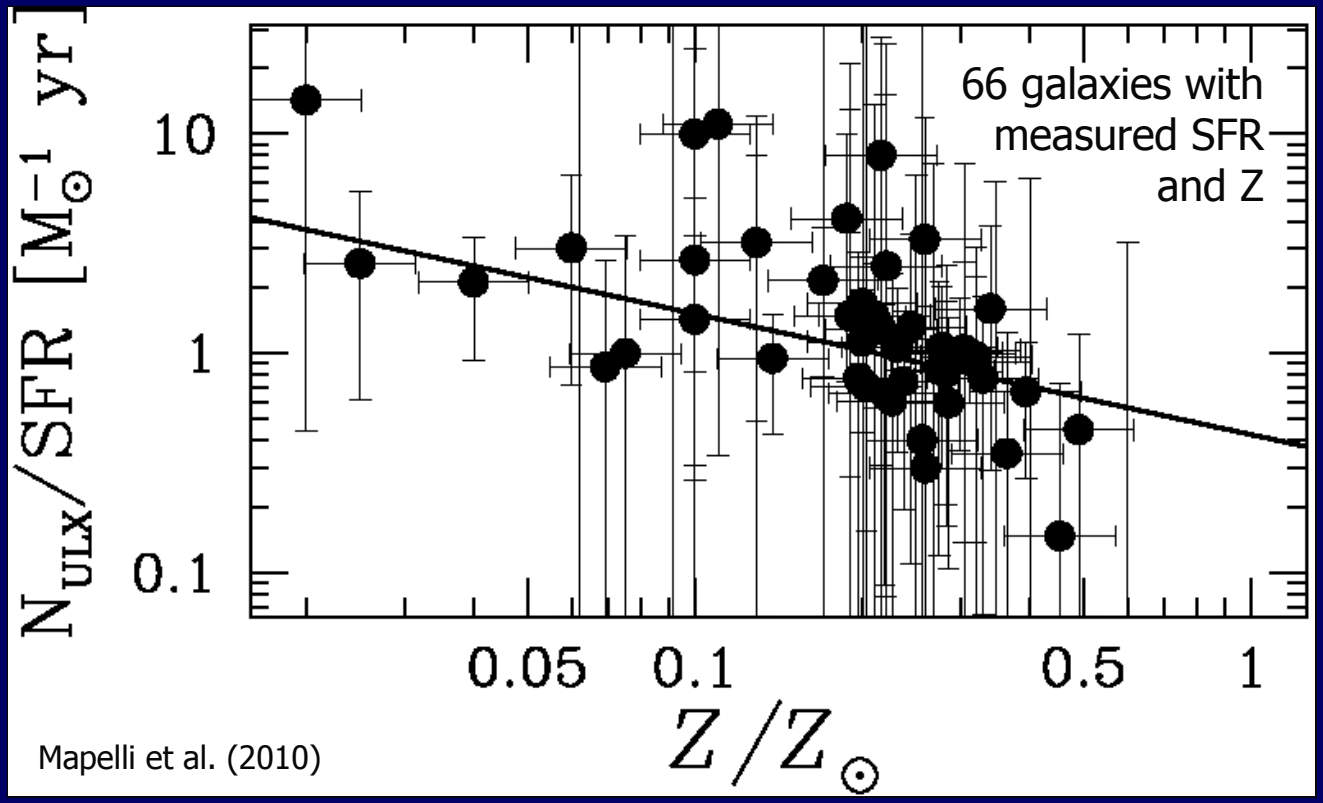
ULX population

- Statistical analysis of a sample of galaxies hosting ULXs plus a number of galaxies of the Local Group (excluding ellipticals)



Mapelli et al. (2010)

- Strong correlation between Nulx and SFR (Grimm et al. 03; Mineo et al. 10)

  Nulx ~ A*SFR

  A=1.20+/-0.2

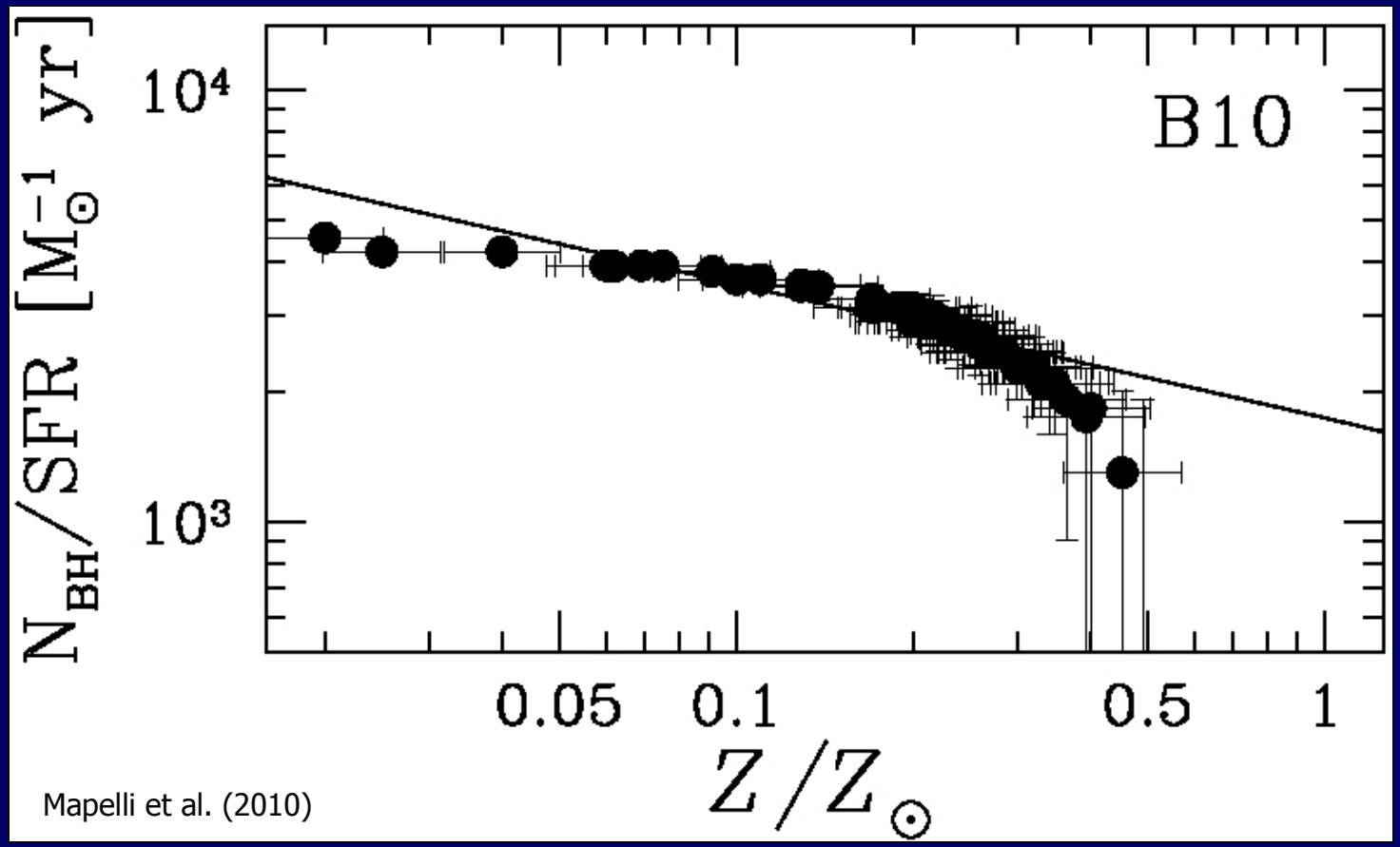
- Fit of Nulx/SFR vs Z using a power-law wrt a fit with a constant: improvement significant at the 96% conf. level

Massive BHs in low metallicity environments

$$N_{\rm BH}({\rm SFR},\ Z) = A({\rm SFR}) \int_{m_{\rm prog}(Z)}^{m_{\rm max}} m^{-\alpha}\,{\rm d}m$$

$$A({\rm SFR}) = \frac{{\rm SFR}\ \ t_{\rm co}}{\int_{m_{\rm min}}^{m_{\rm max}} m^{1-\alpha}\,{\rm d}m}$$

Linear fit statistically consistent with the observed correlation



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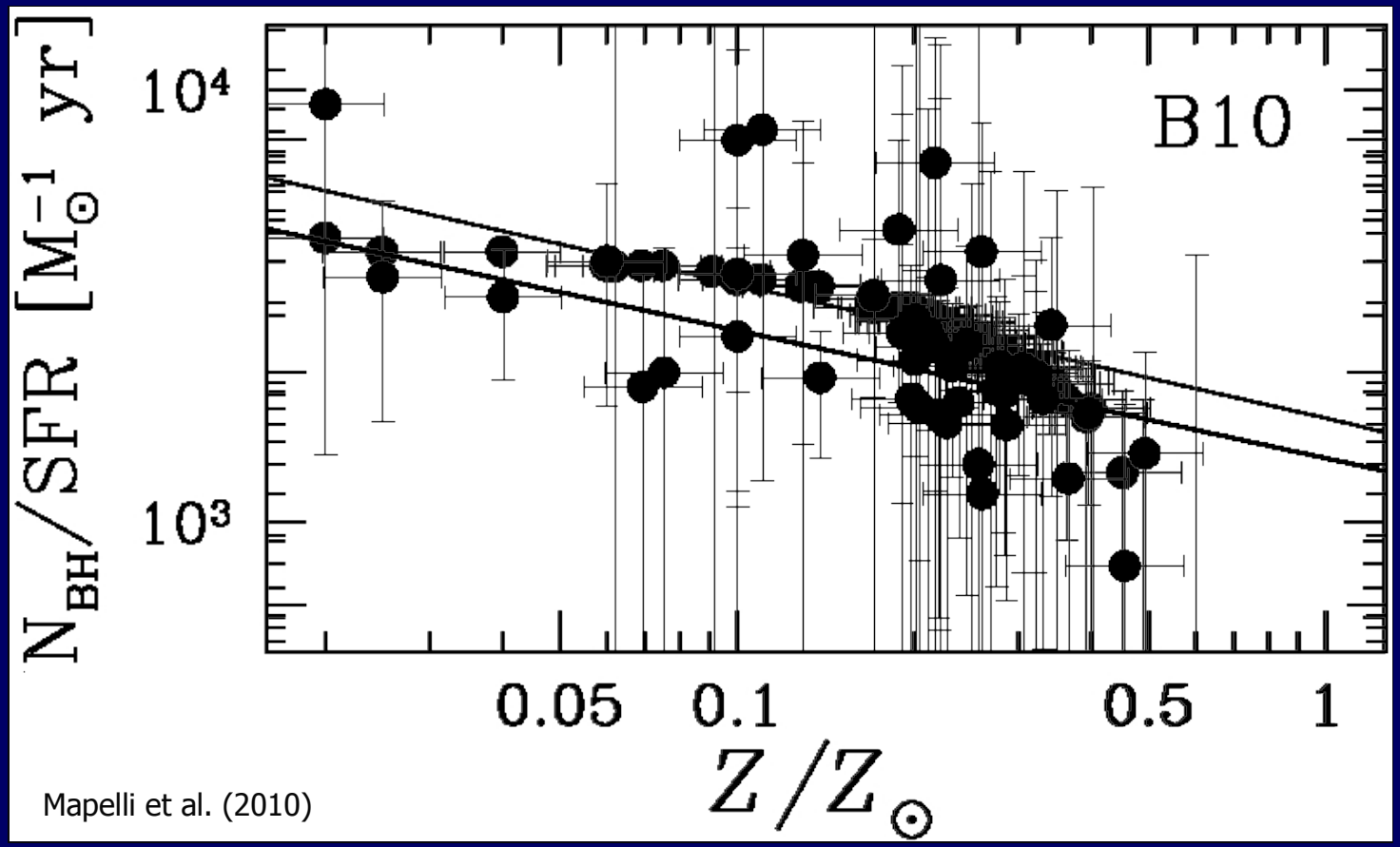

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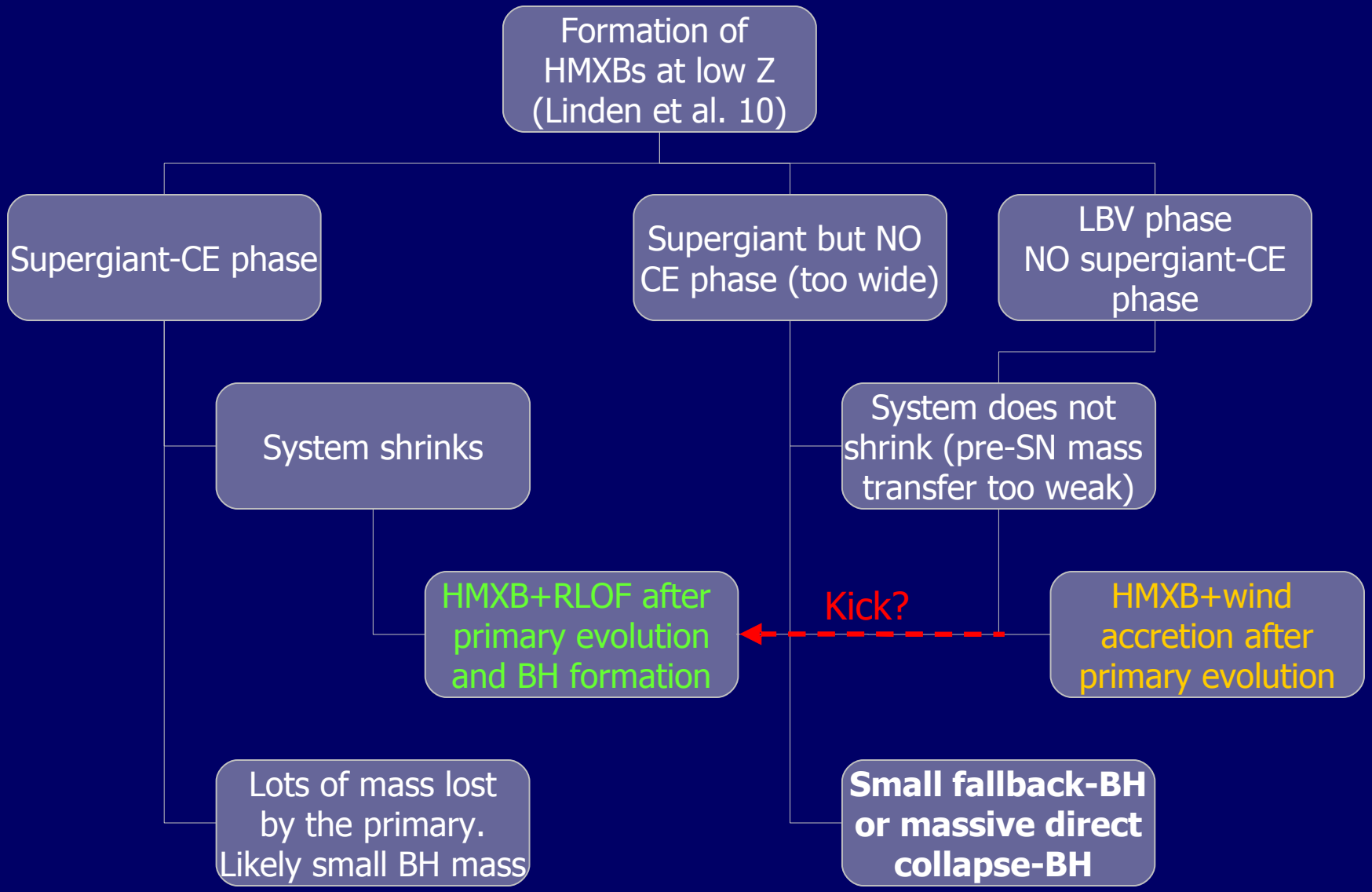
HMXBs in low metallicity environments

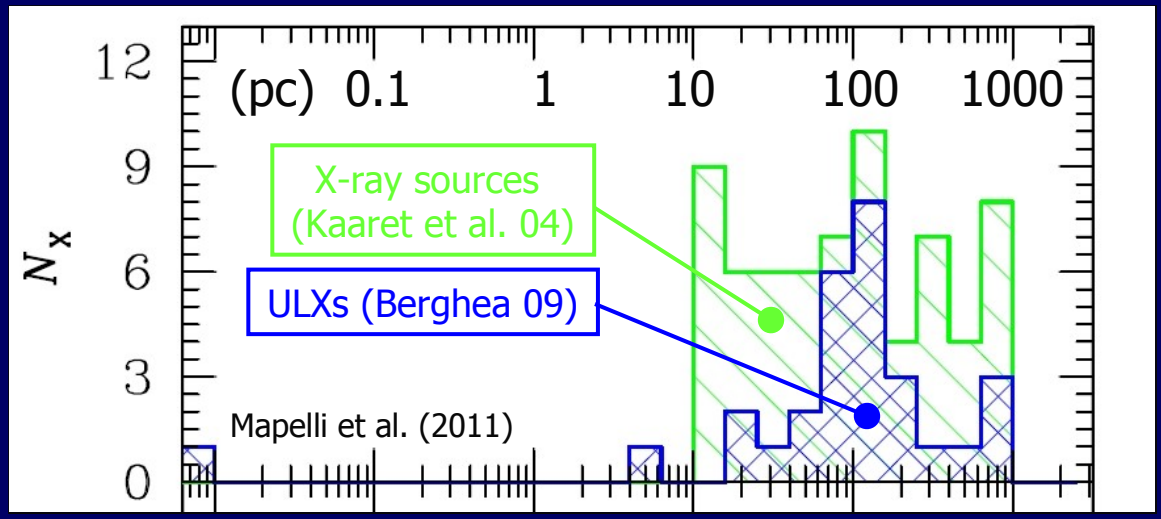


Dynamics of MSBHs and ULX displacements (1)

- Natal kick for direct collapse very uncertain, but likely smaller than in supernovae (Fryer & Kalogera 01)

- *What about kicks from (3-body) encounters of binaries with massive stellar BHs (MSBHs) with stars in their parent cluster?* If important, MSBHs may:
  → enter active ULX phase under the HMXB+RLOF channel
  → be ejected from their parent cluster (runaway binaries; Kaaret et al. 04, Sepinsky et al. 05)

- ULXs preferentially found close to star forming regions or young star clusters, but often displaced (Zezas et al. 02; Swartz et al. 09)



Dynamics of MSBHs and ULX displacements (2)

Simulations of 25 realizations of isolated star clusters hosting MSBH binaries with massive donors

Starlab code (Portegies Zwart et al. 2001)

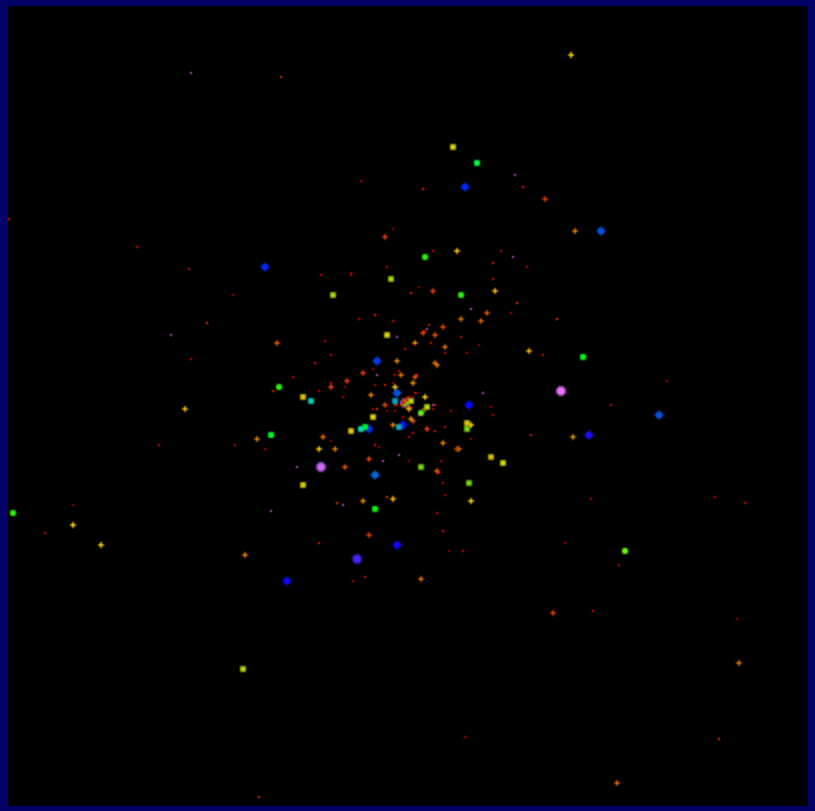
Nstars=5000, Mstars=4000 Msun, initial binary fraction=0.1, Salpeter IMF (0.08-120 Msun)

Stellar and binary evolution not considered (work in progress)

1 MSBH in each cluster (as expected at Z=0.1 Zsun; Mapelli et al. 10) **with Mbh=50 Msun**

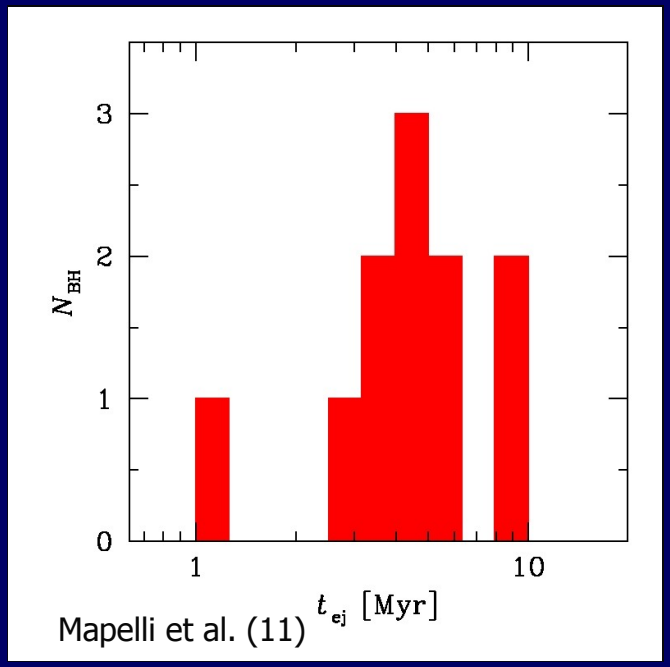
Donor masses uniformly distributed between 10 Msun (young systems) and 50 Msun (stable mass transfer)

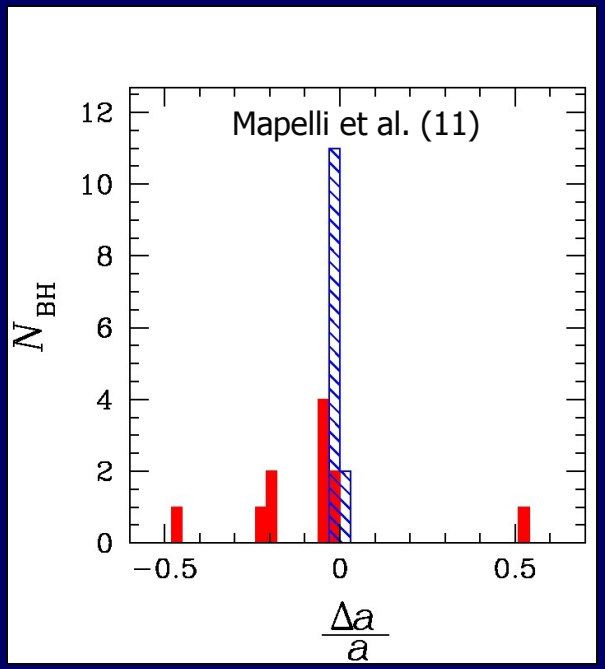
a>0.1 AU (to avoid merger) and a<10 AU (only hard binaries)



Snapshot of a Starlab simulation (256-body, W0=12 King model, Salpeter mass function)

Dynamics of MSBHs and ULX displacements (3)





Evolution after 10 Myr

- 14/25 (56%) MSBHs bound to the cluster, 70% of them in dynamically unstable triple systems
- 11/25 (44%) MSBHs ejected, 80% of them in binary systems (30% exchanged companion)
- Most ejections between 2.5 and 6.5 Myr (companion on the MS)
- Kicks smaller than assumed natal kicks of stellar-mass BHs (Linden et al. 10), but significant for direct-collapse BHs
- Fractional decrease of a and remarkable agreement with observed offset of ULXs

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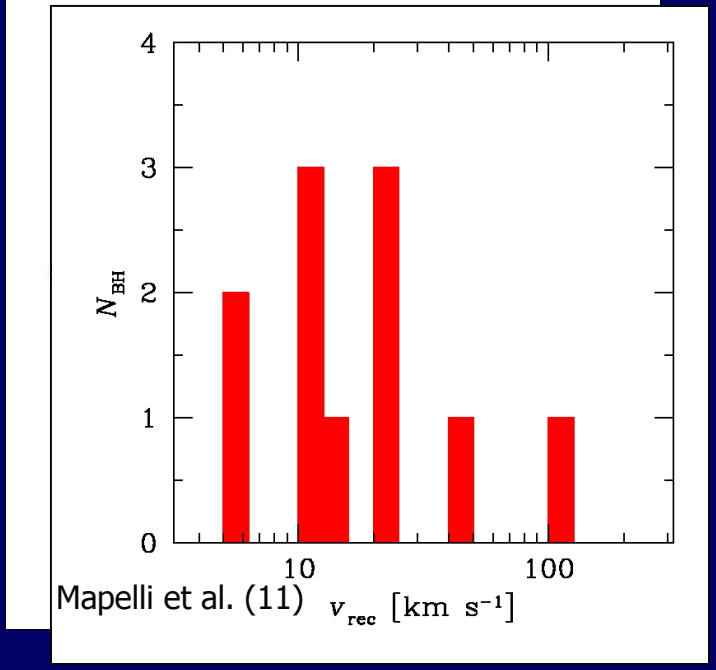

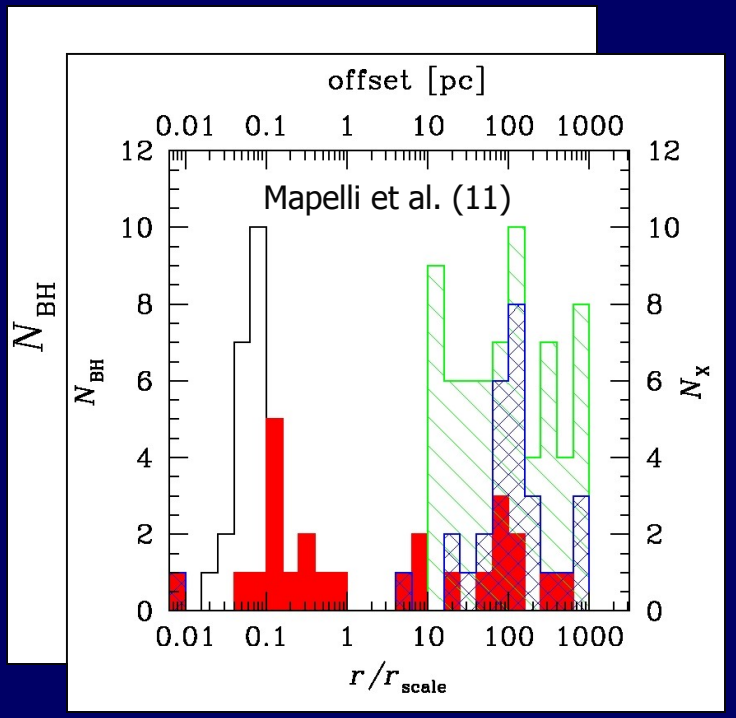

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Conclusions and perspectives

- ULXs preferentially found in low Z environments
- Marginal evidence of dependence of the number of ULXs/SFR on Z
  → More, and more accurate measurements needed
- Direct collapse of massive stars formed in low-metallicity environments produce MSBHs (30-70 Msun) that may power a fraction of ULXs
- Simulations of various realizations of young star clusters hosting MSBH binaries with massive donors: significant dynamical kicks leading to RLOF and causing offset wrt parent cluster in agreement with observations
  → Where are the MSBHs that remain bound?
  → Calculation with stellar and binary evolution, and including soft MSBH binaries under way