Emanuele Ripamonti

Universita' di Milano-Bicocca

Do Ultra-Luminous X-ray sources prefer metal-poor environments?

Collaborators: **M. Mapelli, L. Zampieri, A. Wolter, M. Colpi, G. Gavazzi, S. Mineo**

Outline

1. ULXs & Metallicity - Theory

2. ULX & Metallicity – Observational tests

2.1 Metallicities in the neighbourhood of ULXs

2.2 Association with star-forming regions

2.3 N_{ULX} predictions

2.4 Work in progress

Ultra-luminous X-ray sources (ULXs)

Non nuclear point-like X-ray sources with $L_X > 10^{39}$ erg/s

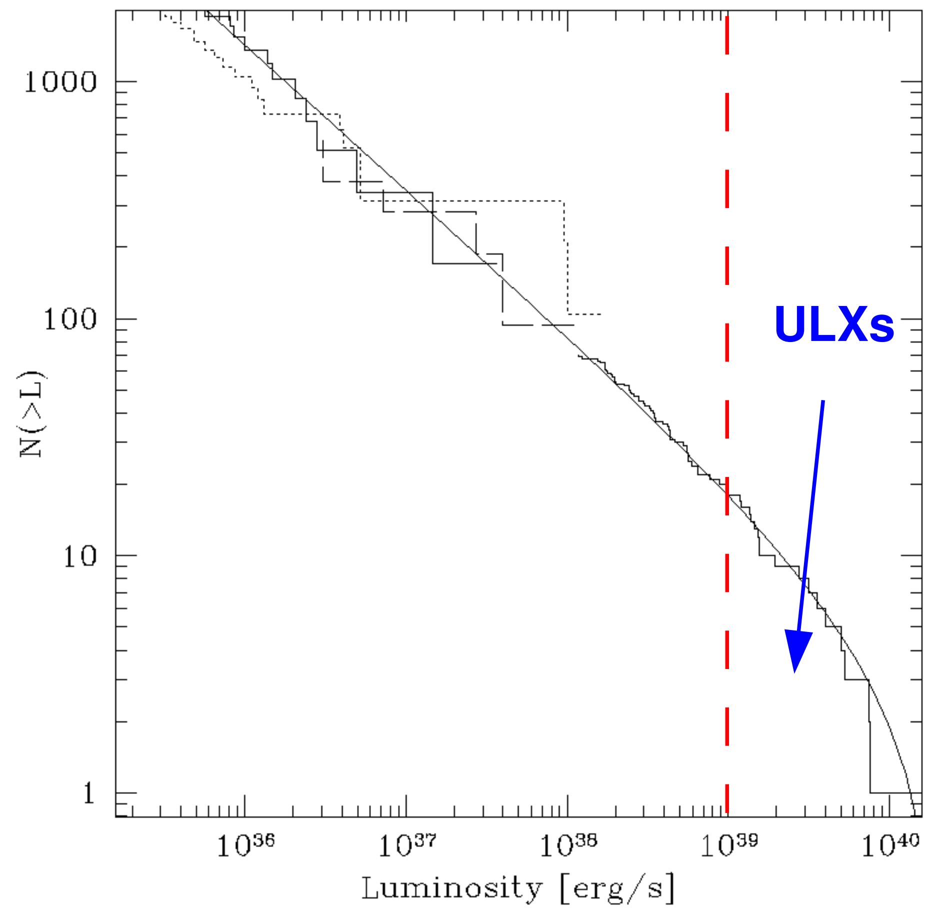
Non-nuclear → no AGN

$L_X > 10^{39}$ erg/s → over the Eddington limit for ~10 M_{sun} objects

Several hundreds sources;

most luminous have $L_X > 10^{41}$ erg/s

Grimm et al. 2003; see also Mineo et al. 2011



More common in late type galaxies (spirals, irregulars) than in early type galaxies (ellipticals, S0)

ULX models

Extension of High Mass X-Ray Binaries (HMXBs) on the luminosity function

→ same kind of objects (i.e. accreting BHs), only more massive?

- Intermediate-mass BHs → do they really exist? Are they so common?
- Stellar Black Holes → inconsistent with Eddington+maximum BH mass

ways around:

- non-isotropic emission (but "isotropic" nebulae have been detected)
- super-Eddington (how long? what Eddington ratio)

Supernovae → definitely there; but probably only ~10% of the ULXs&

Contamination (blended + background sources) → can be estimated (explain most ULXs in E & S0s)

All have some merit; but none can explain the bulk of the ULX population

Role of metallicity – stellar BHs at $Z \sim Z_{sun}$

Extension of High Mass X-Ray Binaries (HMXBs) on the luminosity function

→ same kind of objects (i.e. accreting BHs), only more massive?

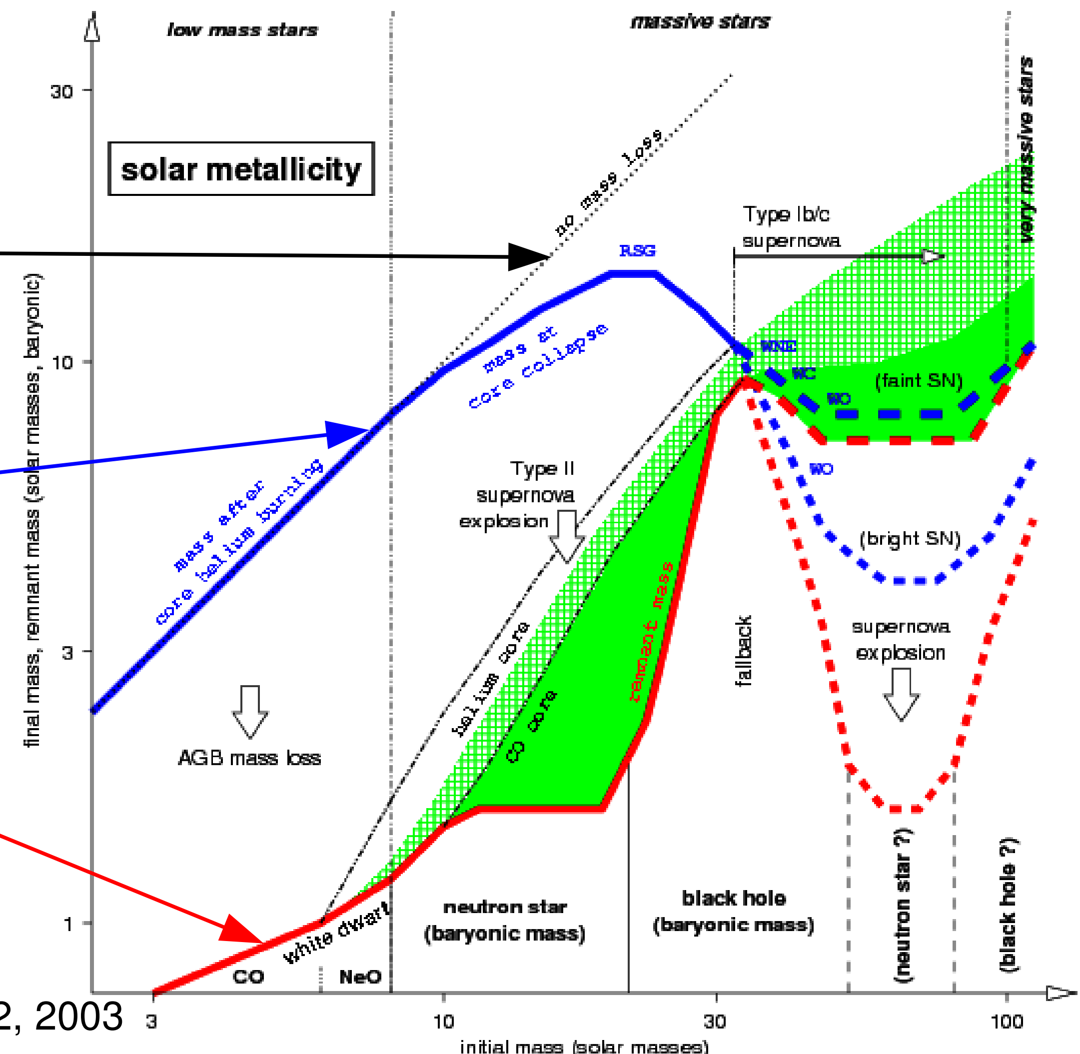
- Stellar Black Holes → inconsistent with Eddington + maximum BH mass

Massive stars reduce their mass through:
1) Mass-loss in stellar winds
2) Ejection in supernova explosions

Initial mass (no mass loss)

Final mass (mass just before transforming into a remnant)

Remnant mass



Heger et al. 2002, 2003

Role of metallicity – Massive stellar BHs at $Z \ll Z_{sun}$

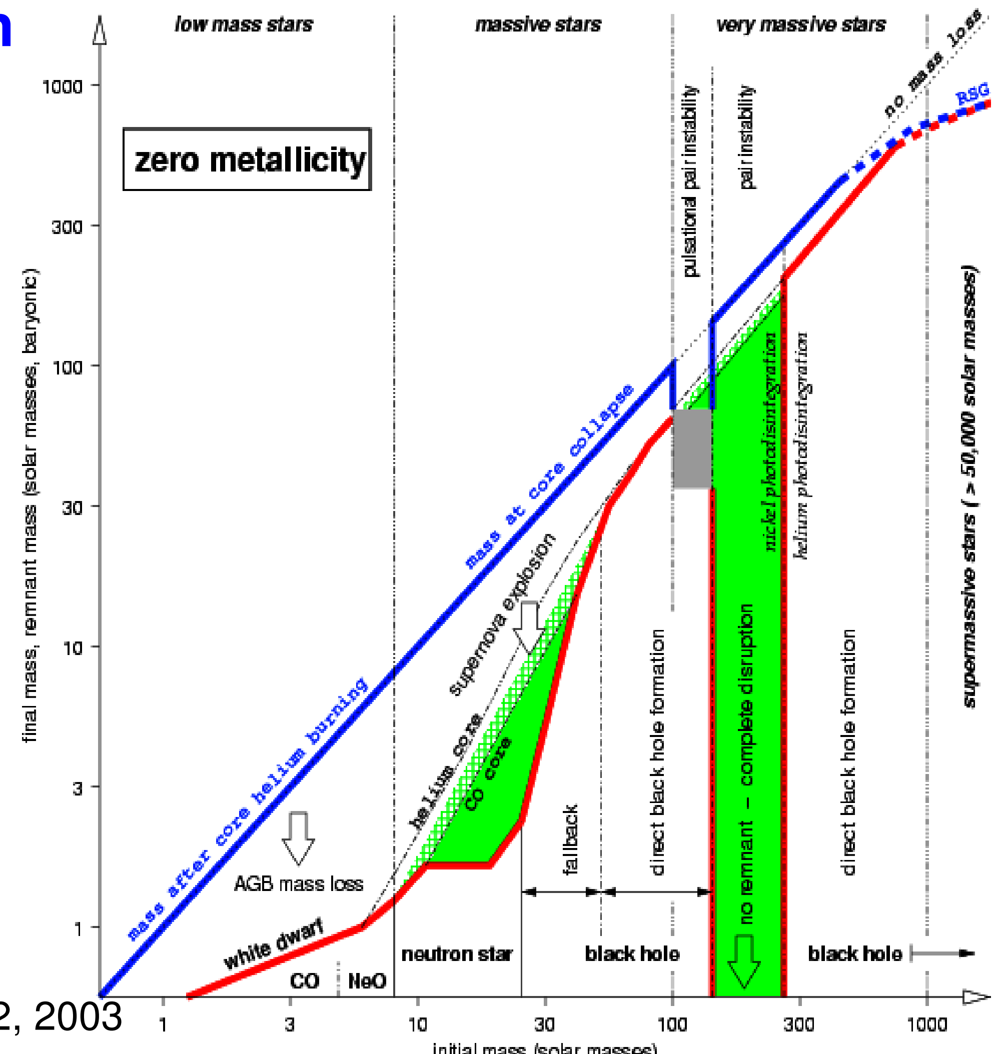
Extension of High Mass X-Ray Binaries (HMXBs) on the luminosity function
→ same kind of objects (i.e. accreting BHs), only more massive?
- Stellar Black Holes → inconsistent with Eddingtno + maximum BH mass

Metallicity can affect this conclusion

stellar winds are stronger in high-Z stars
→ mass loss depends on Z

BHs can form through
direct collapse (**no SN!**)
further reducing mass losses

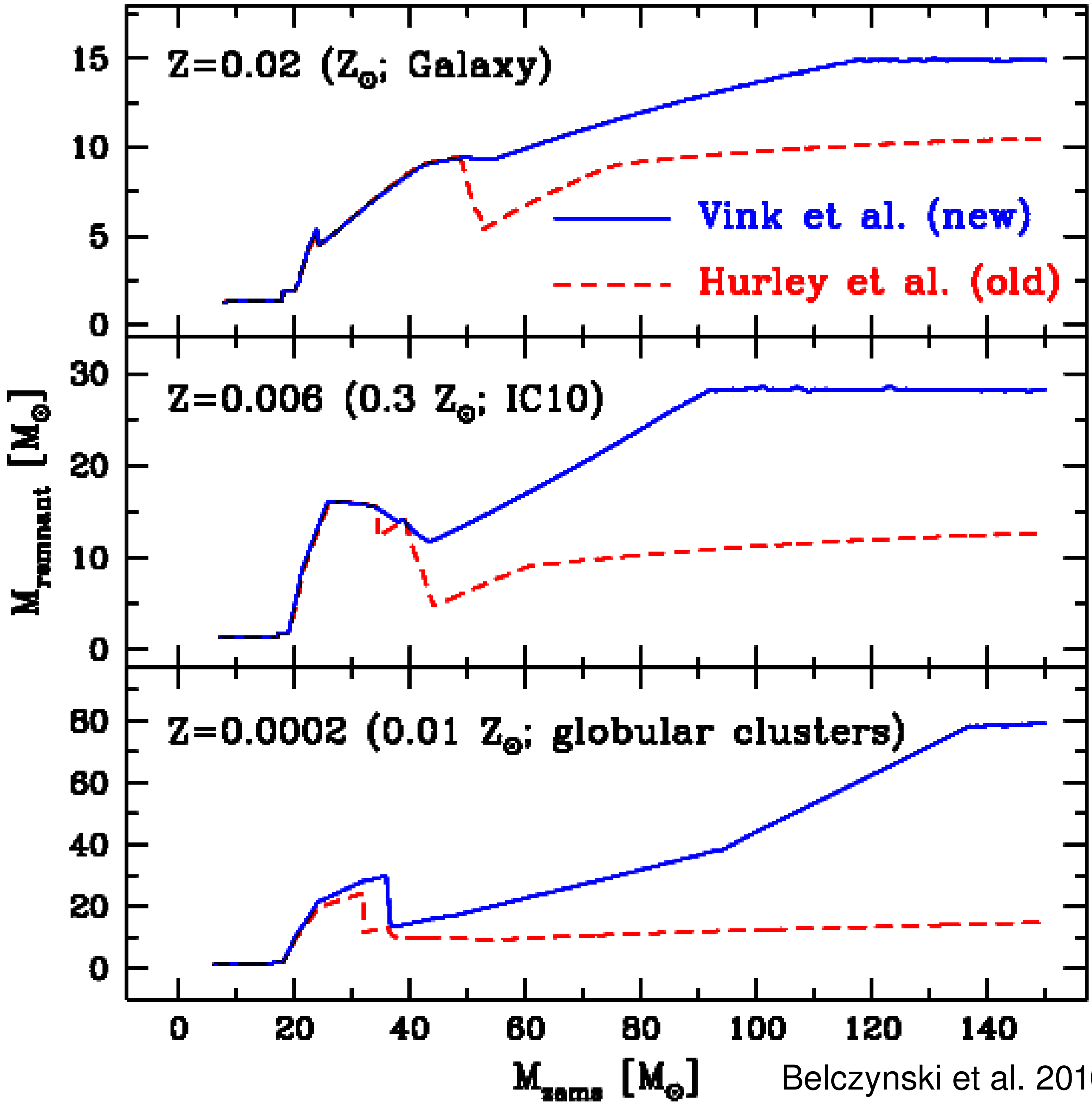
→ **remnant mass depends on Z!**



Heger et al. 2002, 2003

Role of metallicity – Massive stellar BHs at Z~0.01-0.3 Z_{sun}

30-80 M_{sun} BHs (MSBHs) can form at Z <~ 0.3 Z_{sun}



Belczynski et al. 2010

Outline

1. ULXs and Metallicity - Theory

2. Observational tests

2.1 Metallicities in the neighbourhood of ULXs

2.2 Association with star-forming regions

2.3 N_{ULX} predictions

2.4 Work in progress

MSBHs and ULXs:

Eddington limit for 40 M_{sun} MSBHs is $L_X \sim 5x10^{39}$ erg/s

Mild anisotropies/super-Eddington can reach the XRLF break ($\sim 2x10^{40}$ erg/s)

Need massive (> 10 M_{sun}) stellar companion to sustain accretion

(Roche-lobe overflow is required)

Observational tests :

1) Look at the metallicity around ULXs

2) Check whether ULXs are associated to star-forming regions

3) Compare N_{ULX} to model predictions

Outline

1. ULXs & Metallicity - Theory

2. Observational tests

2.1 Metallicities in the neighbourhood of ULXs

2.2 Association with star-forming regions

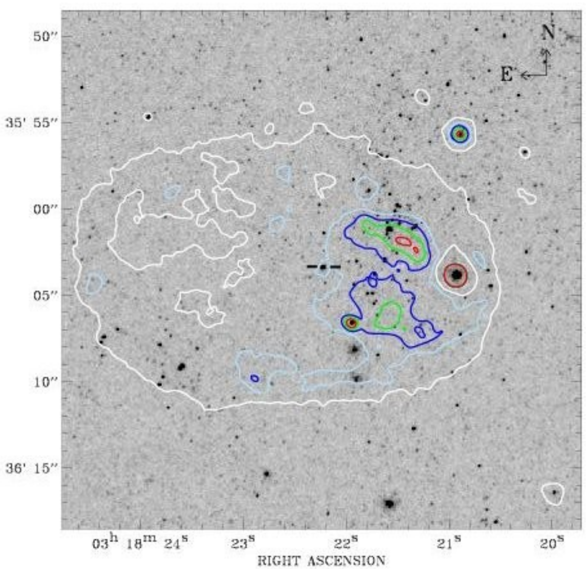
2.3 N_{ULX} predictions

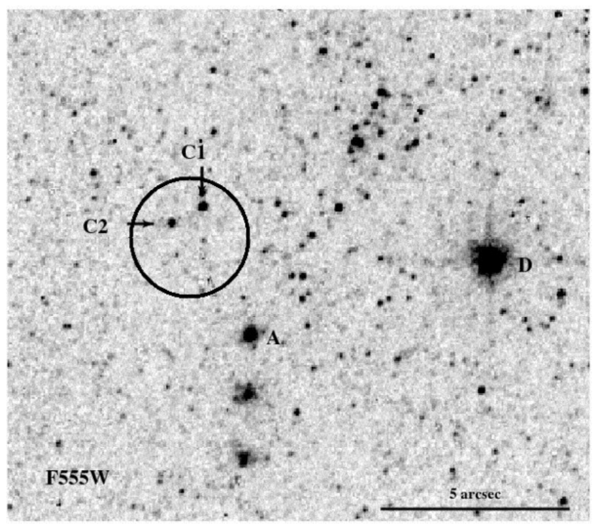
2.4 Work in progress

Metallicity in ULX neighbourhoods

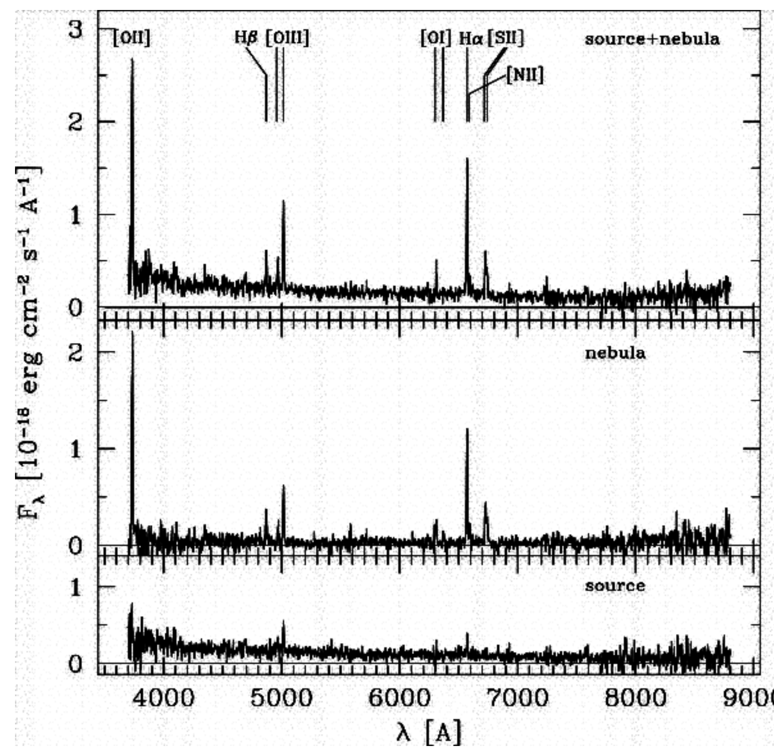
If ULXs are associated with MSBHs, $Z_{ULX} < 0.4\ Z_{sun}$

Possible only for a handful of objects; NGC1313 X-2 has the best data and appears to have **$Z \sim 0.2\ Z_{sun}$** [ER et al., in prep.]





Grise' et al. 2008



Mucciarelli et al. 2005, 2007

Outline

1. ULXs & Metallicity – Theory

2. Observational tests

2.1 Metallicities in the neighbourhood of ULXs

2.2 Association with star-forming regions

2.3 N_{ULX} predictions

2.4 Work in progress

Are ULXs in star-forming regions?

Observational answer: **close, but not inside**: median distance from ULX to closest SF region is ~100 pc [Berghea PhD thesis]

If MSBHs form through direct collapse (no SN kick) this might be a problem

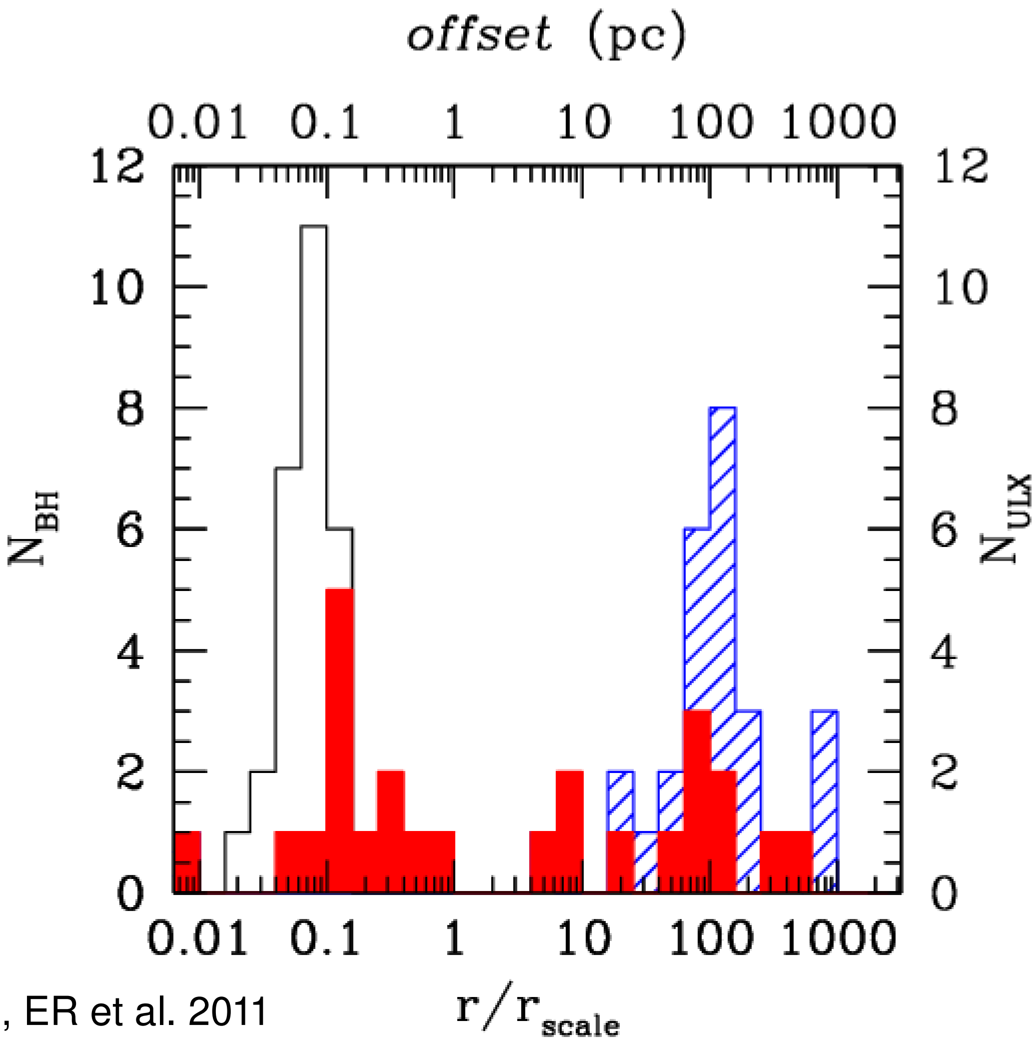
Are ULXs in star-forming regions?

Observational answer: **close, but not inside**: median distance from ULX to closest SF region is ~100 pc
[Berghea PhD thesis]

If MSBHs form through direct collapse (no SN kick) this might be a problem

However, **dynamical kicks** can do the trick and even more: expelled MSBH are in closer binaries than MSBHs in cluster

Blue (dashed): observations
Black (empty): model, t=0
Red (filled): model, t=10 Myr



Mapelli, ER et al. 2011

Outline

1. ULXs & Metallicity - Theory

2. Observational tests

   2.1 Metallicities in the neighbourhood of ULXs

   2.2 Association with star-forming regions

   2.3 N_{ULX} predictions

   2.4 Work in progress

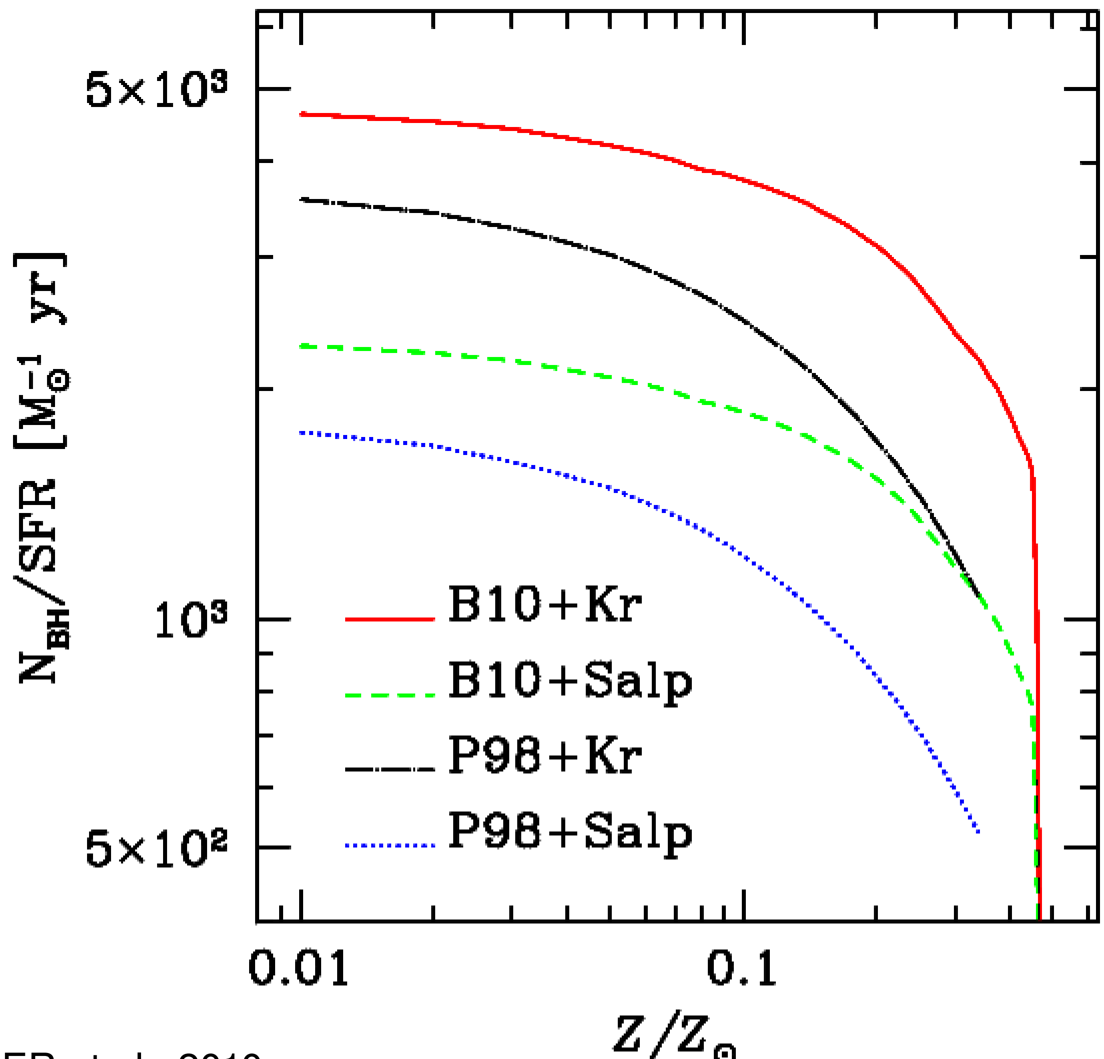
MSBHs as a function of Z - predictions

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

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

α ~ 2.35 (e.g. Salpeter)

t_{co} = lifetime of the (>10 M_{sun}) companions ~ 10 Myr



Mapelli, ER et al., 2010

Literature sample

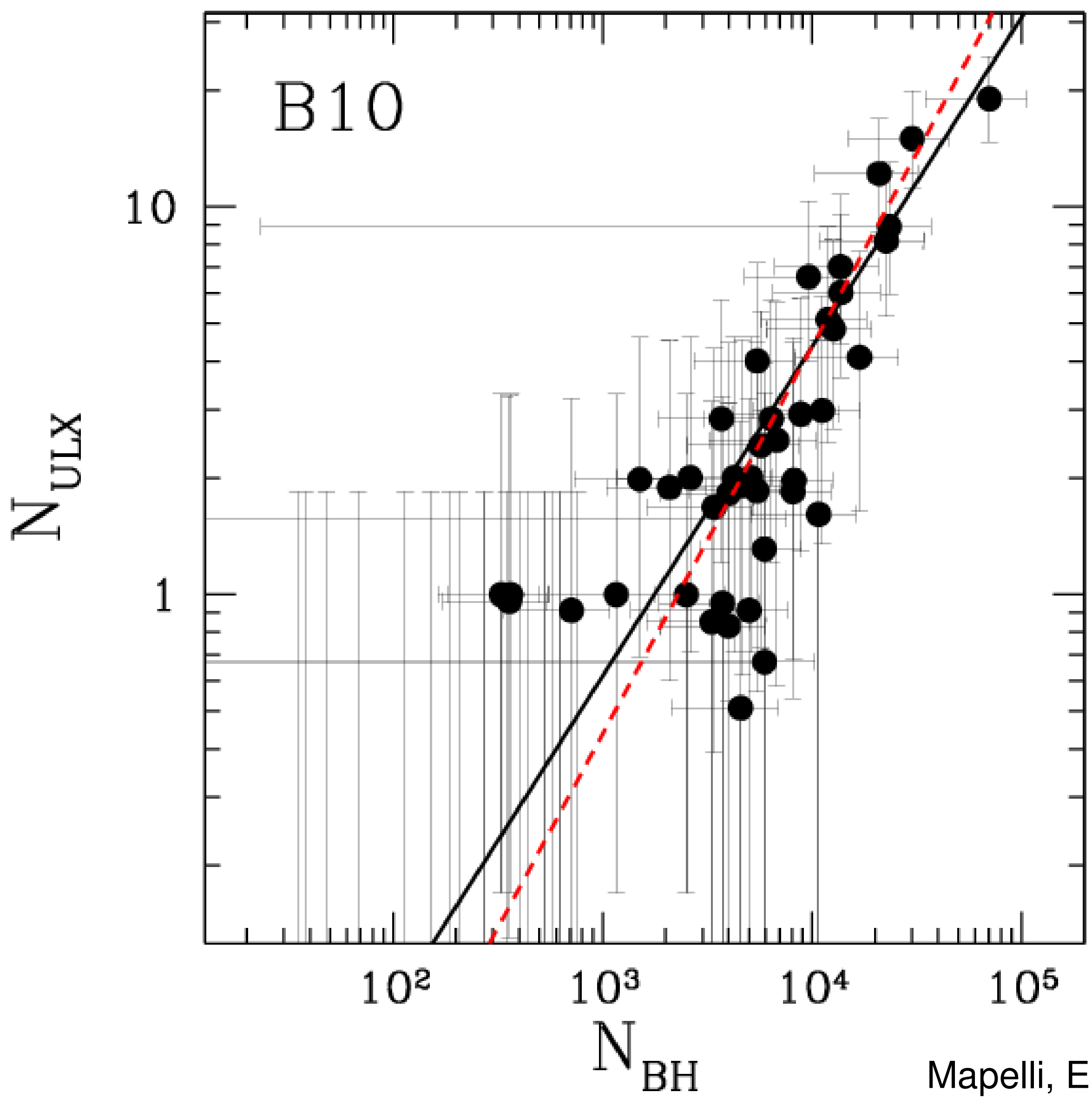
The model needs **Z** and **SFR**; results must be compared with the observed $\mathbf{N_{ULX}}$

Searched the literature for galaxies with
- X-ray data
- SFR (from Halpha, radio, IR/FIR, UV)
- metallicity (from emission line spectra)

Excluded E and S0s because of high contamination from background sources

Sample of 63 galaxies with reasonably uniform (e.g., rescaled to the same calibrations) measurements of Z, SFR, N_{ULX}

Results – NULX vs. NBH

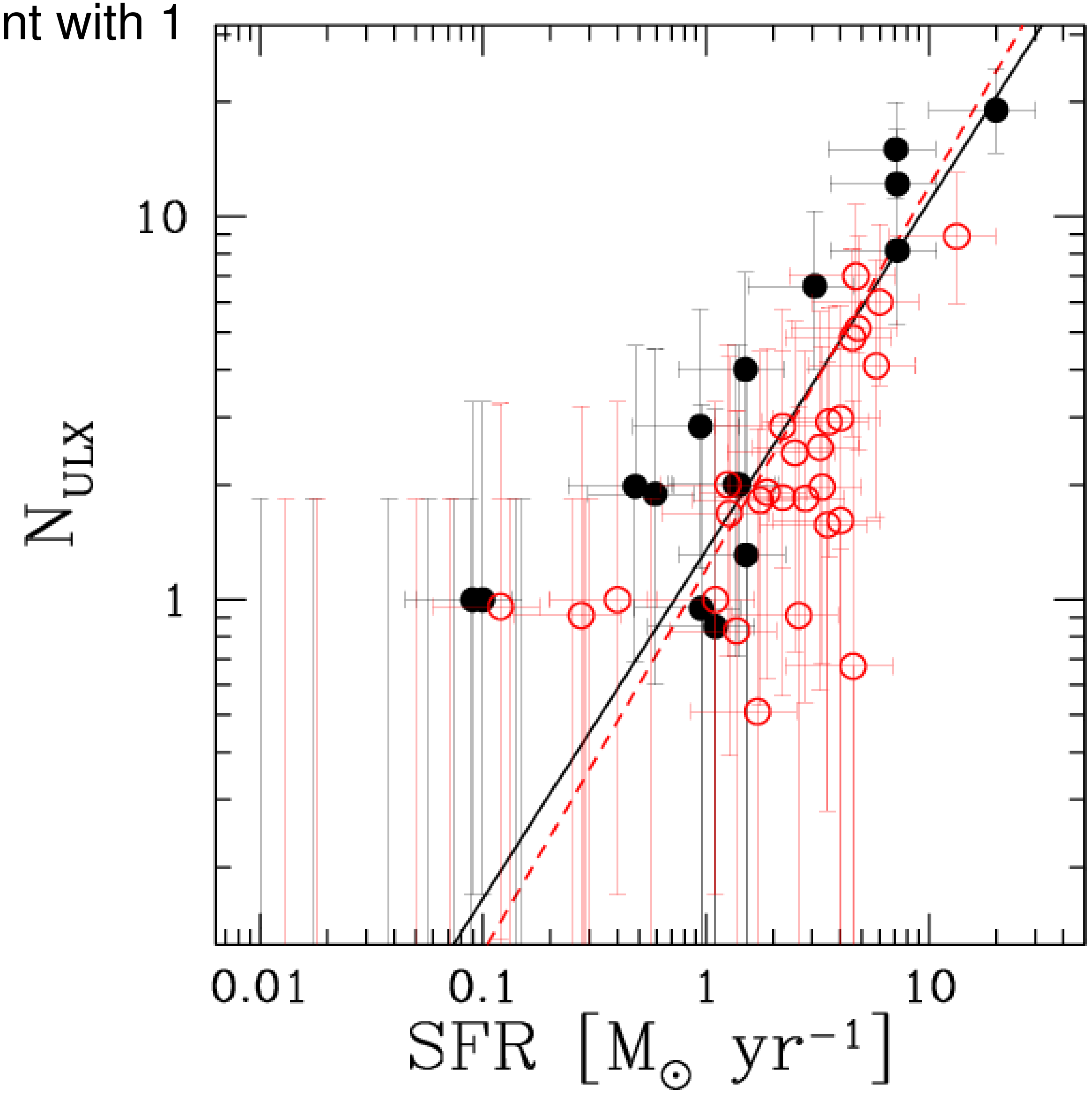


Mapelli, ER et al., 2010

Results – NULX vs. SFR

The model predicts a linear relation between SFR and N_{ULX}

Power-law fit gives a slope consistent with 1
Normalization consistent with the
SFR-HMXBs relation
[e.g. Grimm, Gilfanov & Sunyaev 2003]



Dispersion is larger than in the previous plot

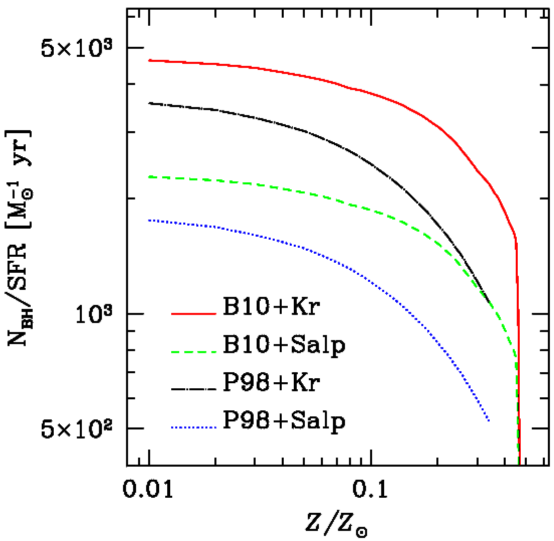
Black (filled): $Z<0.2\ Z_{sun}$ galaxies
Red (empty): $Z>0.2\ Z_{sun}$ galaxies

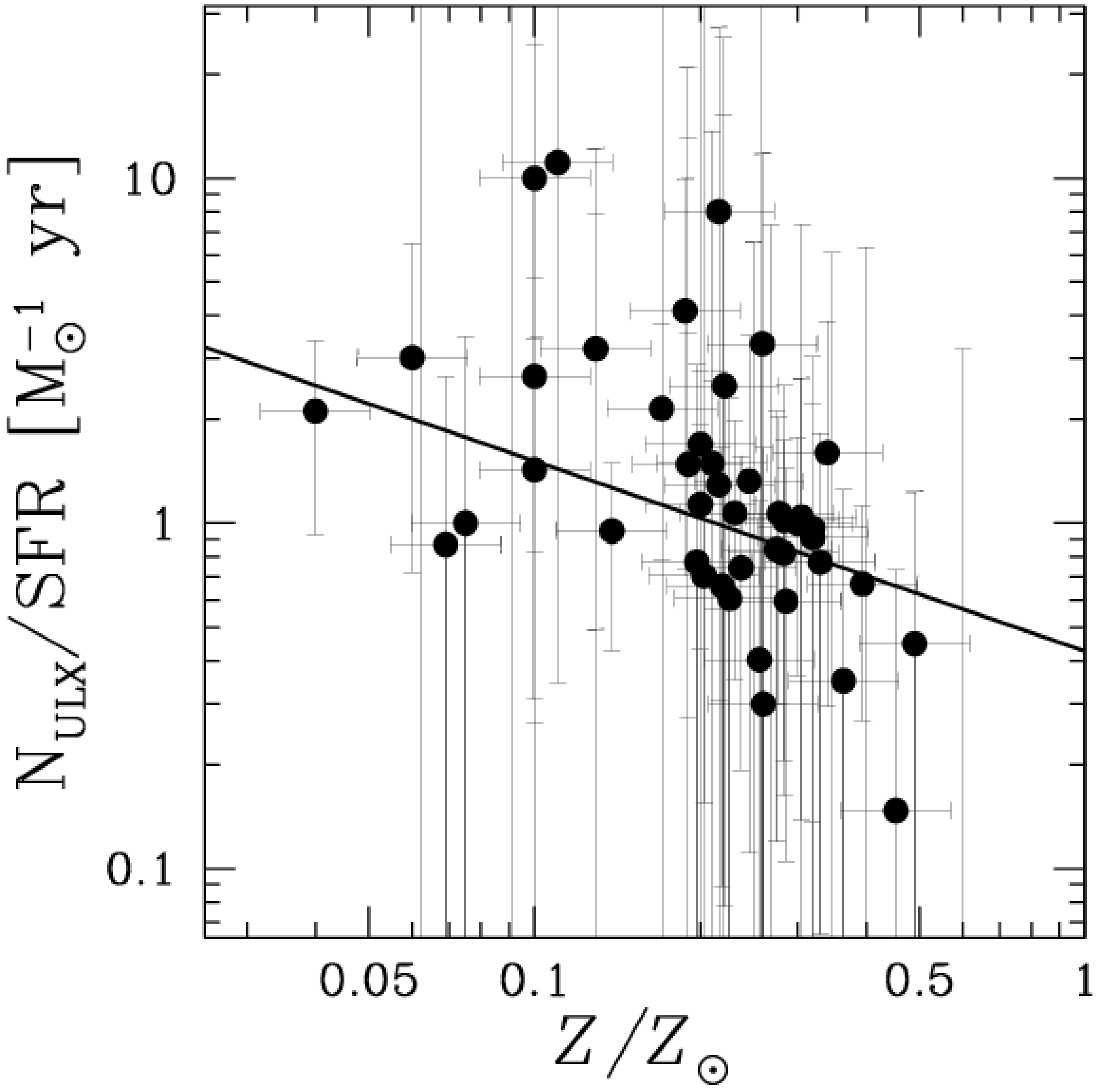
Results – NULX/SFR vs. Z

We use N_{ULX}/SFR to remove the effects of the SFR

The predicted anti-correlation appears to be there

However significance is low (~ 2 sigma)





Outline

1. ULXs & Metallicity - Theory

2. Observational tests

2.1 Metallicities in the neighbourhood of ULXs

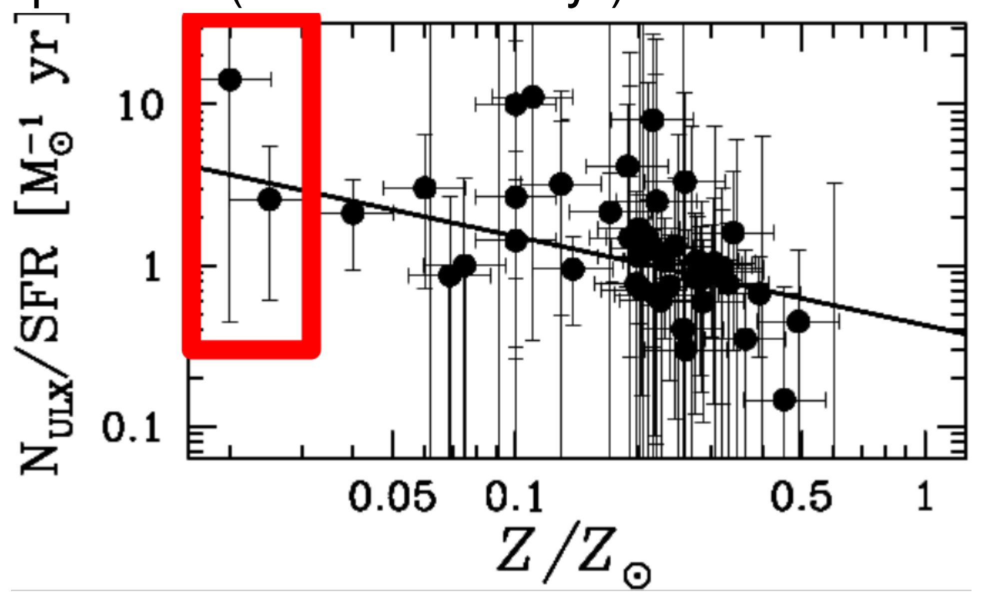
2.2 Association with star-forming regions

2.3 N_{ULX} predictions

2.4 Work in progress

Extend the sample – Extremely metal-deficient galaxies

The two most metal-poor galaxy known host 3 ULXs
(1 in I Zw 18, 2 in SBS0335+53) despite low (0.1-0.5 Msun/yr) SFRs



22 eXtremely Metal Deficient galaxies (Z<0.05 Zsun)
observed by Chandra in 2010-2011 - Total (combined) SFRs >~ 0.5 Msun/yr

Got Hα oservations to complete the SFR coverage

How many ULXs?

No Z dependency → 1 ULX in the whole sample.

Z dependency I Zw 18-like → >3 ULXs

Extend/improve the sample – spiral and ring galaxies

Extend

Many galaxies have X-ray and SFR data, but lack Z measurements

Extending the sample with new observations by us [~20 objects] and better literature search (~ 15 objects) [Still reducing/analyzing data :-( ]

Improve

Poissonian “noise” is inevitable

However, consistency is important: try to use the SAME metallicity estimator and the SAME value for solar metallicity (!!!)

Additional problem for large galaxies: metallicity gradients. Try to use a “representative” radius for ULXs

[For example, in NGC 922 Z~0.7-1 Zsun at the centre, but Z~0.2-0.3 Zsun on the ring (were ULXs are located!)]

Conclusions

MSBHs appear to provide a viable explanation for the bulk of ULXs

However, more data are needed to test the model.

In particular, we wish to:

1) Enlarge the sample
   eXtremely Metal-Deficient (XMDs) are very interesting, since they populate the left part of the previous diagram
   [I'm actually here to measure the SFR of a sample of XMDs]
   Ring galaxies and LIRGs/ULIRGs are other interesting classes of galaxies

2) Use only galaxies with high-quality X-ray and SFR data (e.g. the 29 galaxies selected by Mineo et al. 2011)
   [we are measuring the metallicities of several of them]