Ultra-Luminous X-ray sources in the most metal poor galaxies

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With special thanks to Leigh Jenkins and Ann Hornschemeier

Ultra-Luminous X-ray Sources

Sources with $L_X > 10^{39} - 10^{41}$ ergs/s

- Stellar sources (not at the centers of galaxies)
- Eddington luminosity implies a mass > 10 $M_\odot$, maximum mass of a stellar BH
- Resolved to be single source (many variable)
- Clearly associated with star formation, => HMXB (some in older stellar population, not discussed here)
- Intermediate mass black holes? Possibly some (e.g. M82), consensus most are not.
  - Appear to be extension of HMXB population to high luminosities (Gilfanov and collaborators)
  - In starbursting ring galaxies -- e.g. the Cartwheel -- an infeasible amount of material would be required to make all the "dead" ULX.

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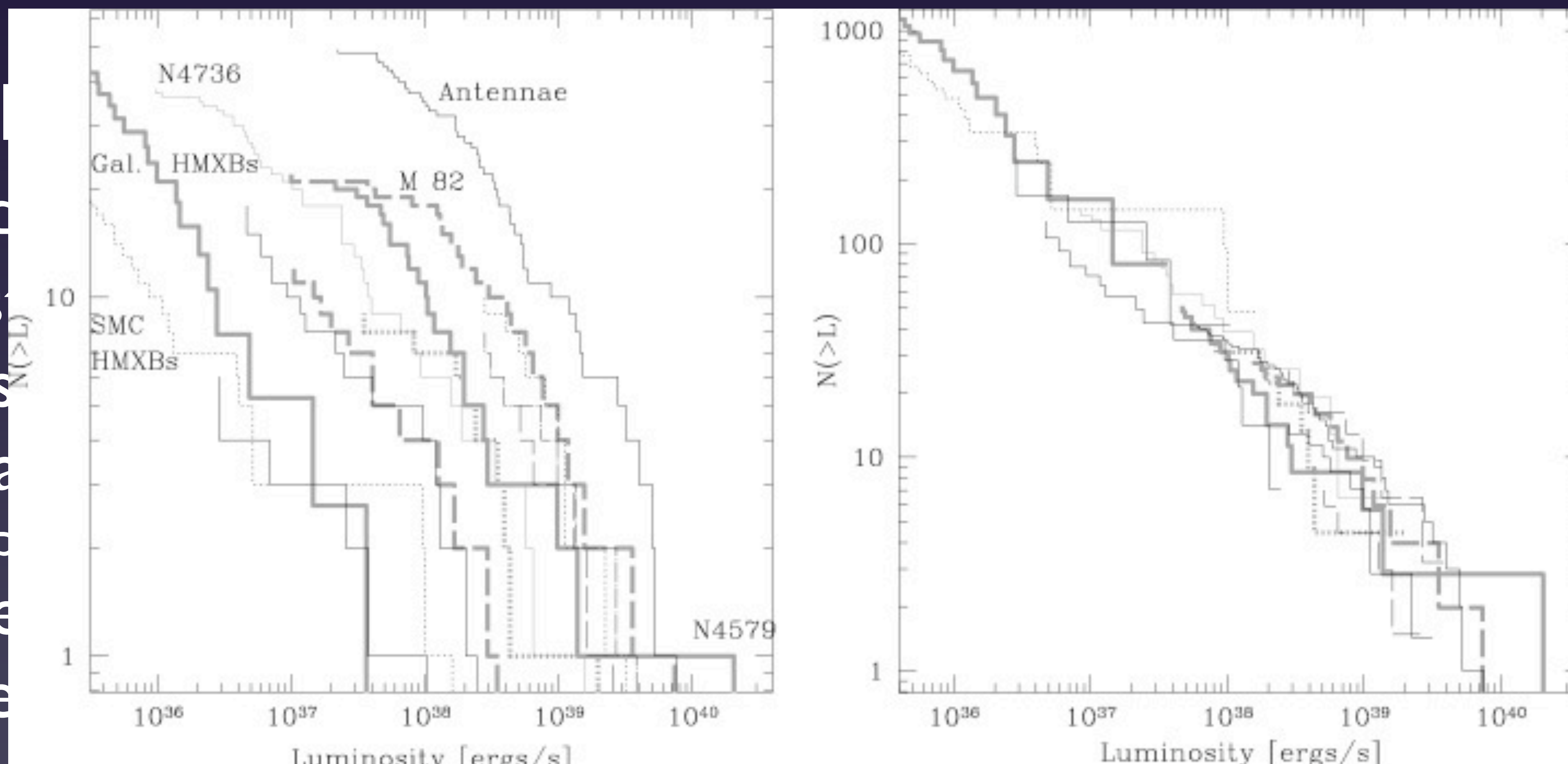

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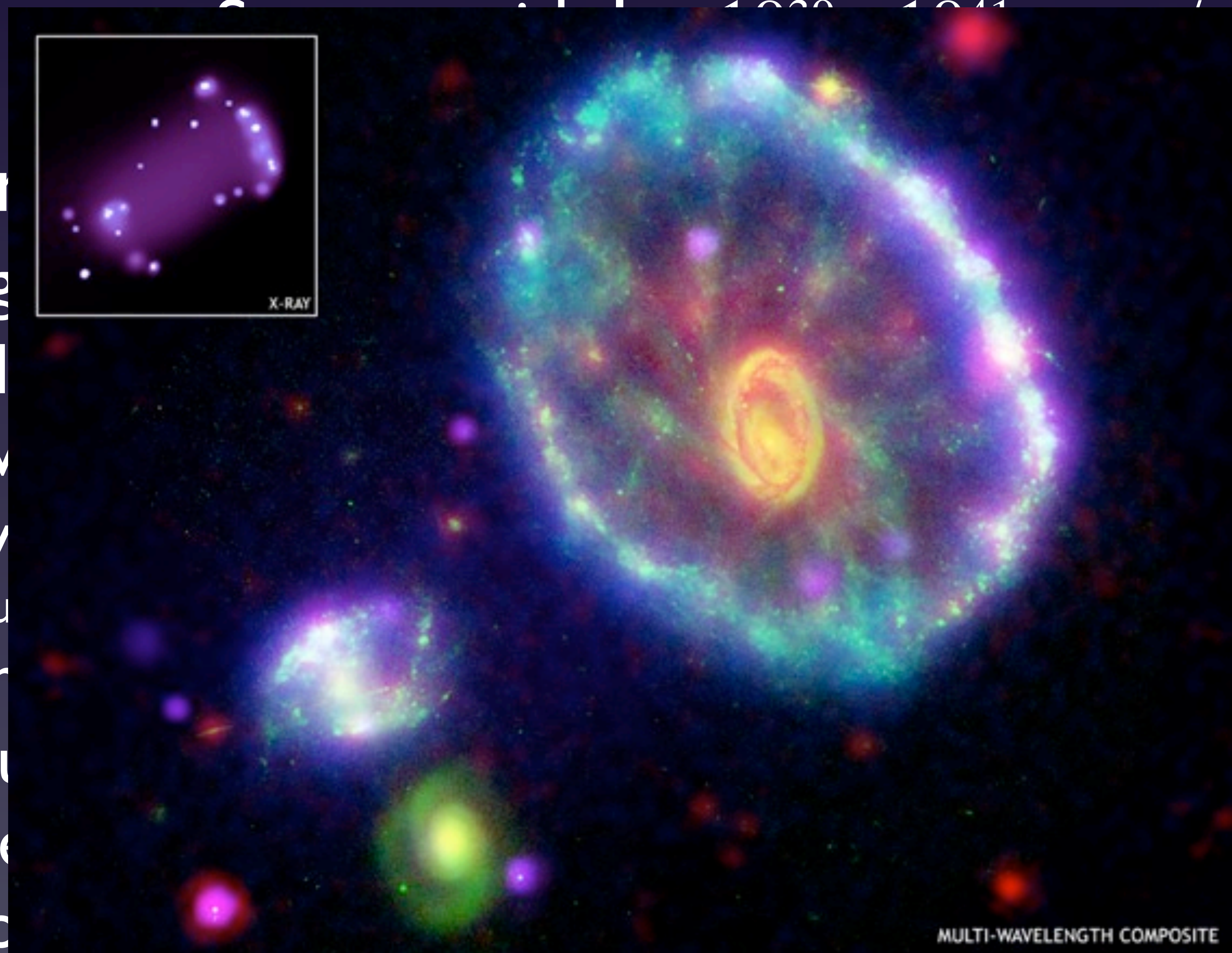

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ULX - Outstanding Questions

- What is the source of the high luminosity?
- Very high accretion rates? How is this stable?
- Somewhat higher compact object masses? 10 - 100 $M_\odot$
- What objects make up the bulk of the population?
- How do they form and evolve?
- Are a few of the most extreme examples IMBH?

Are ULX more common in Metal Poor Galaxies?

- Anecdotal evidence that ULX are found in metal poor environments:
  - An excess of ULX in dwarf galaxies -- metallicity the underlying correlation? (Swartz+ 2009)
  - Spectroscopy of nebulae surrounding individual ULX hints at low metallicity gas (Soria and collaborators)
  - "LOTS" of ULX in the Low Metallicity Cartwheel Galaxy (Gao + 2003, Wolter+ 2004)
  - More recently, possible anti-correlation of the number of ULX with metallicity (Mapelli+ 2010). However, scatter large.

Big Picture Science: nature of ULX,
black hole formation in the early universe,
objects that create GRBs

A Chandra/HST Survey of Extremely Metal Poor Star Forming Galaxies

If ULX favor metal-poor environments, search in the most metal poor galaxies known!

- Extremely Metal Poor Galaxies:
  - (O/H)+12 < 7.65, or < 5% solar
  - Mainly Blue Compact Dwarfs, dominated by star formation
  - Extremely rare: < 1% of dwarf galaxies are XMPG. Most famous example is IZw18. Many have been discovered recently in SDSS survey
  - Are XMPG experiencing their first episode of star formation? Probably not, but the best nearby proxies to star formation in the early universe that we have

A Chandra/HST Survey of Extremely Metal Poor Star forming Galaxies

- Chandra Large Project in Cycle 11 joint with HST
- Chandra snapshots of 25 XMPG
  - Completeness limit $L_X=7\times10^{38}$ ergs/s
- Hubble/WFC3 images in F435W, F606W, F818W to detect star clusters and derive cluster ages
- Science goals:
  - Are ULX preferentially formed in XMPG?
  - Obtain sample of XMPG ULX with well determined star formation rates AND a comparison sample of ULX of "normal" metallicity galaxies
  - Assuming ULX were formed in the same star formation event as surrounding star clusters, use clusters to obtain ULX ages
  - Compare results with theoretical models - e.g. *StarTrack* and models by Mapelli and collaborators
- Chandra survey complete, HST ongoing.

Star formation Rates and Comparison Sample

- Number ULX known to scale with star formation rate, very careful determination of SFR required. Two methods:
  - Infrared luminosity: UV photons from young stars re-radiated by dust. Spitzer 24 micron emission arises from single photon emission from small grains. Use formula derived by Calzetti+ 2007 by calibrating HII regions in nearby galaxies
  - GALEX FUV luminosity: directly measure UV emission from stars. Use formula derived by Hunter+ 2010 for dwarf/low metallicity galaxies
- GALEX SFRs systematically higher than Spitzer! Understood because XMPG dust deficient compared to “normal” galaxies

Star formation Rates and Comparison Sample

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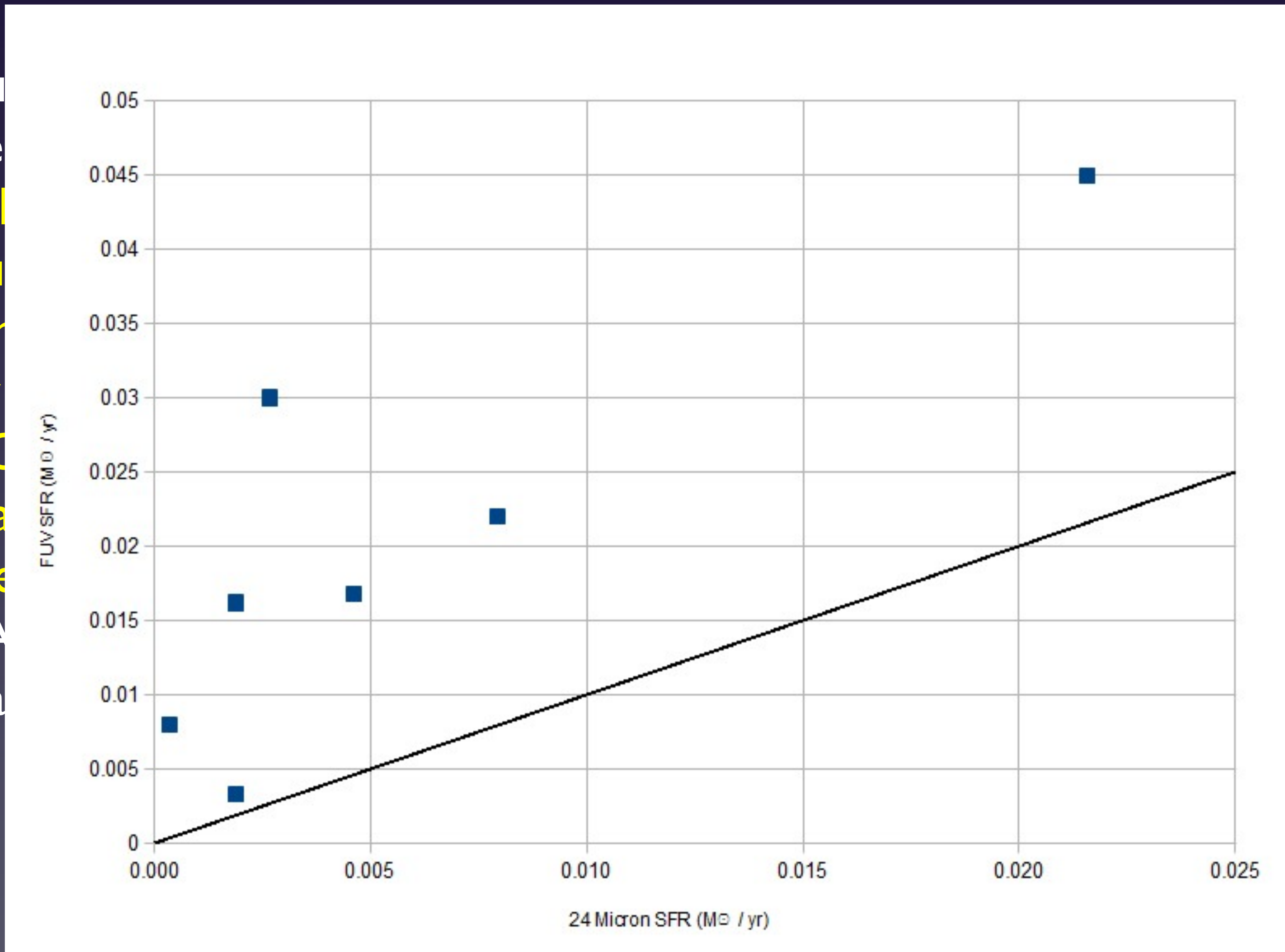

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Star formation Rates and Comparison Sample

- Comparison sample - 32 SINGS (Spitzer Infrared Nearby Galaxies Survey) galaxies studied in detail by Calzetti+ 2007
  - SFR and metallicities determined in a consistent way, distances well determined
  - All have Chandra data

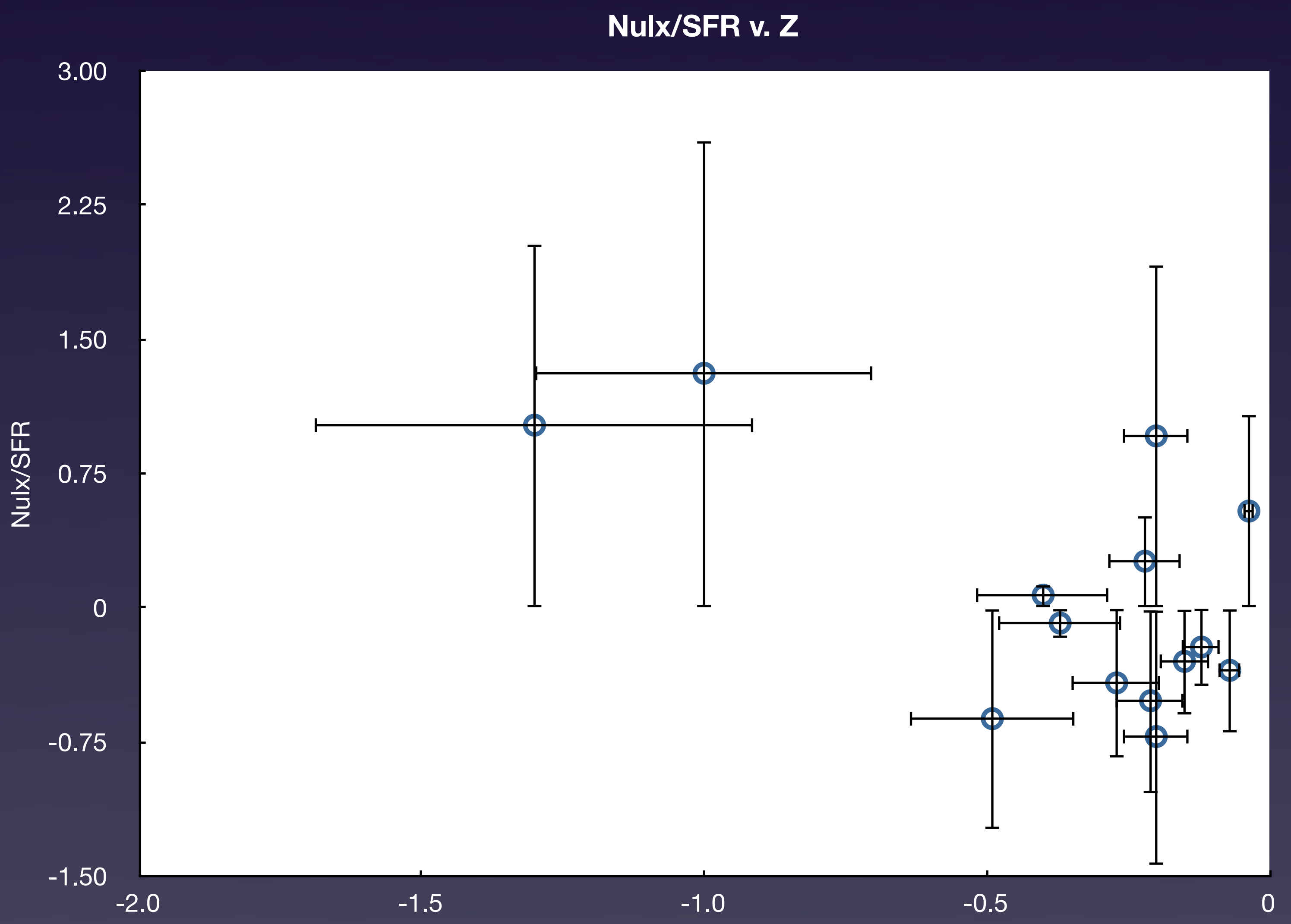
Galaxy Class	Number	Metallicity	∑SFR $M_\odot$/year
High	22	>0.3 solar	112.3
Intermediate	5	0.1-0.3 solar	0.631
Low	5	<0.1 solar	0.123

Do ULX prefer metal poor environments?

Galaxy Class	N_{gal}	N_{ulx}	$\sum N_{ulx} / \sum SFR$
High	22	28	0.24
Intermediate	5	0	0
Low	5	2	6.4
XMPG	25	6	6.9

Nulx/SFR v. Z

Do ULX prefer metal poor environments?



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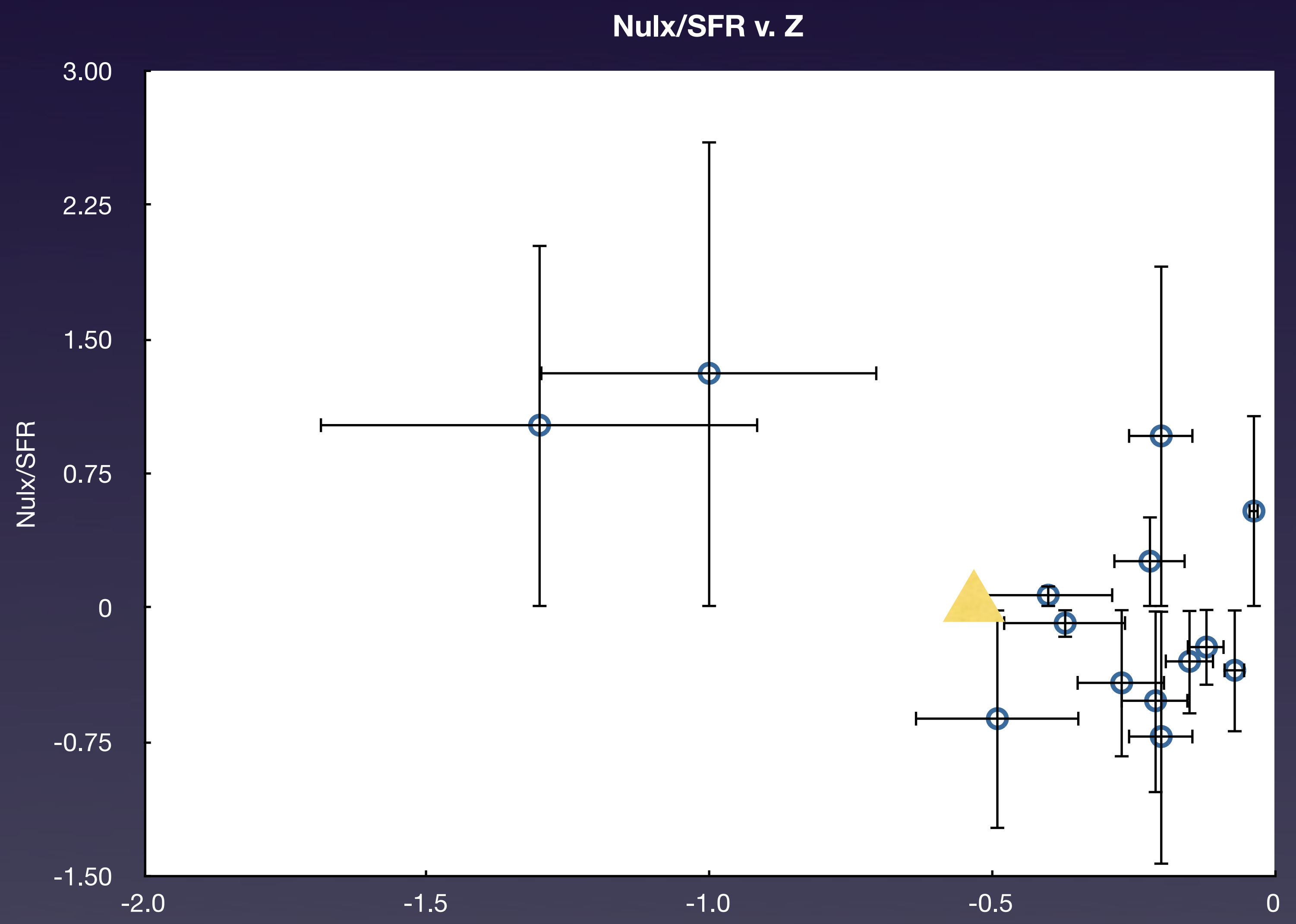

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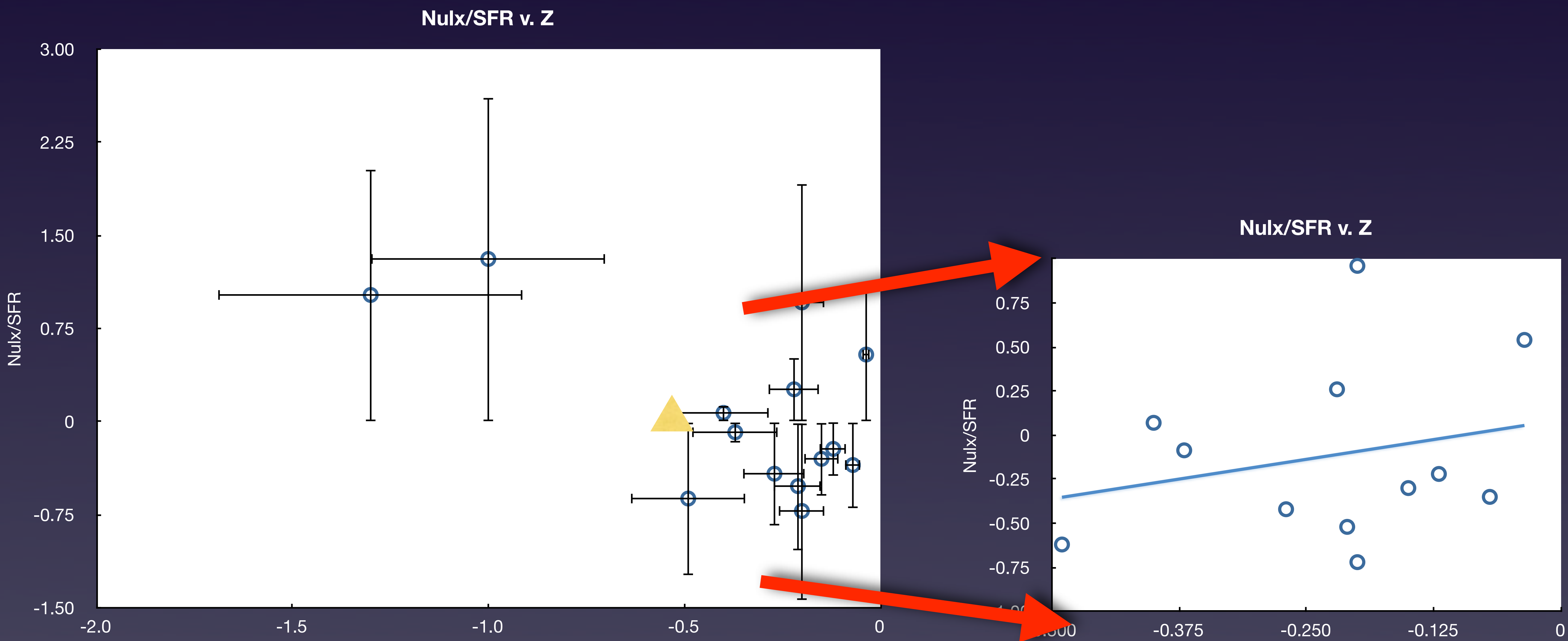

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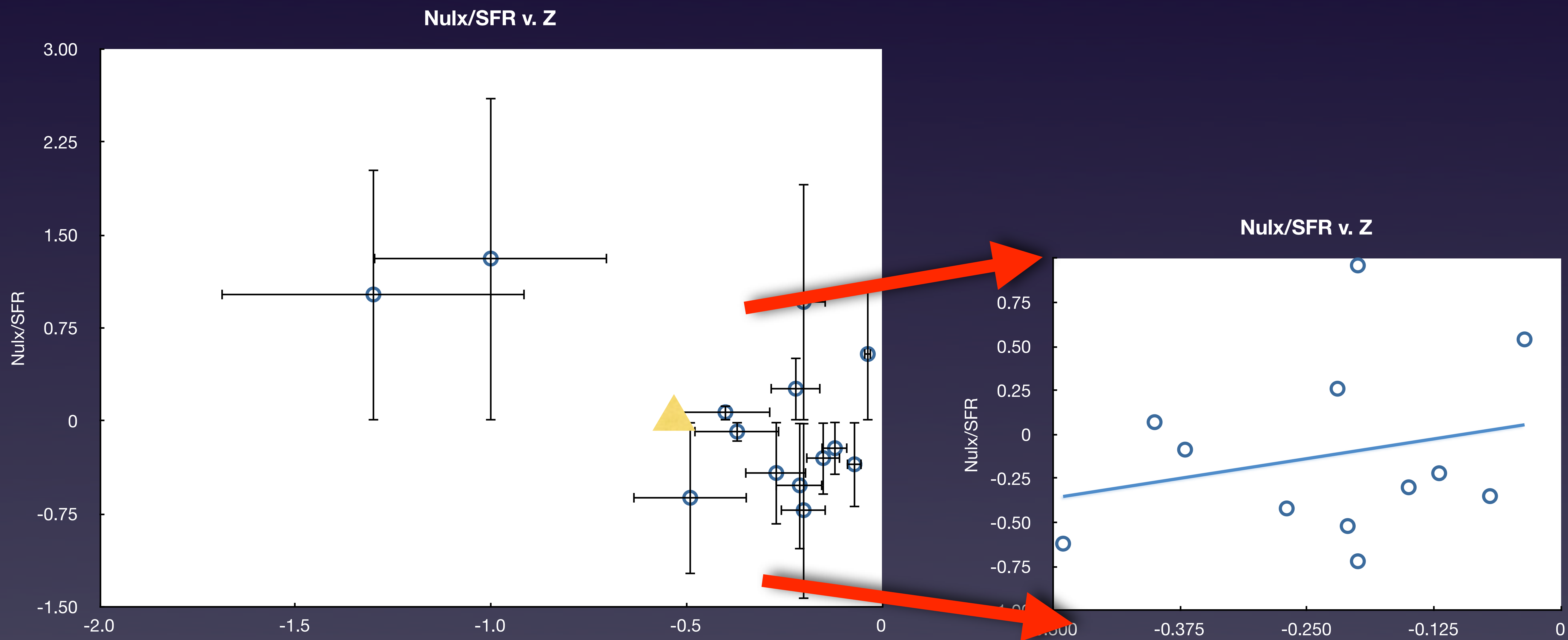
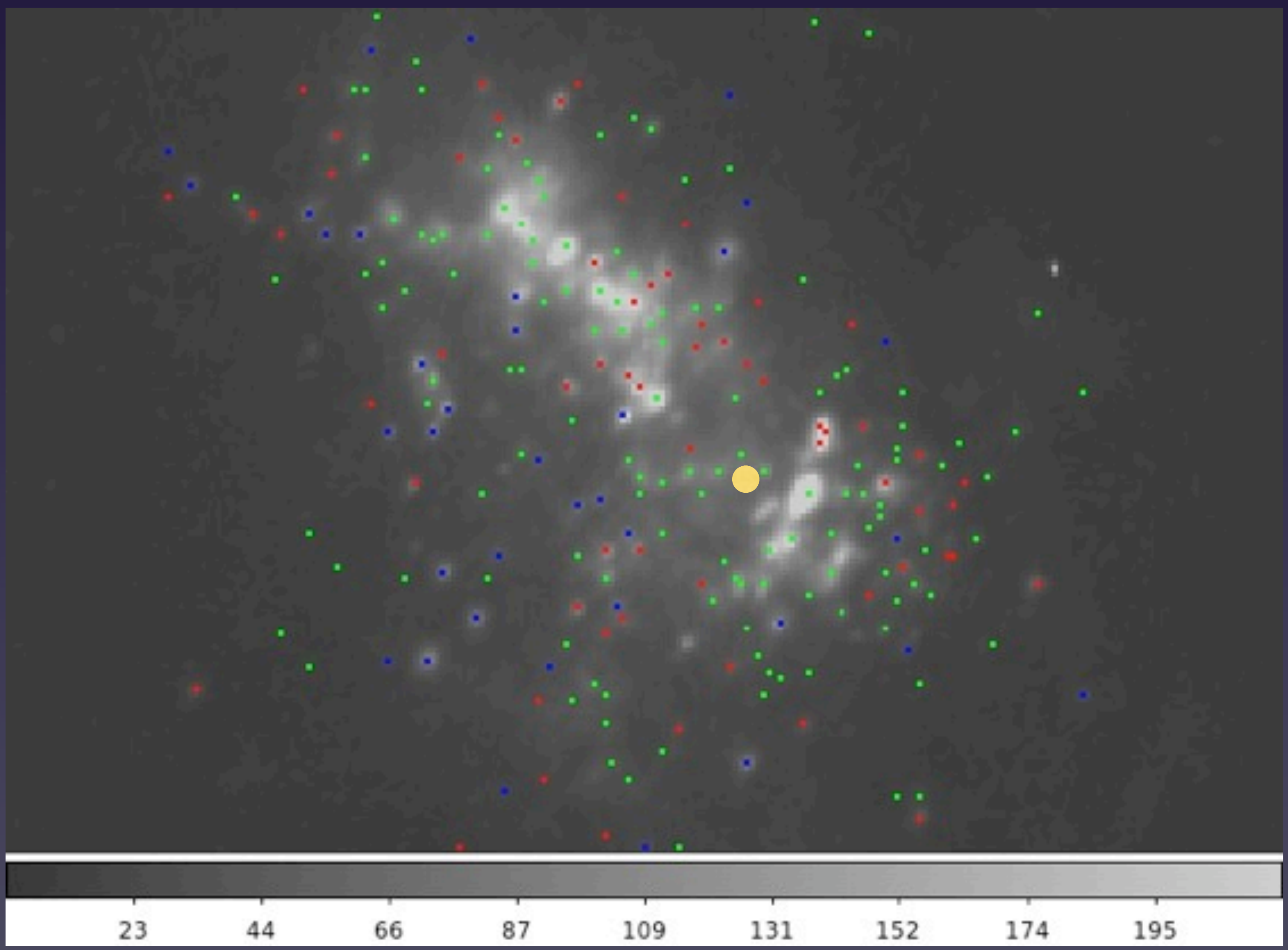


- Conclude:
- Some evidence for ULX enhancement at $Z<0.1Z_\odot$
- Formal significance is low (1.8 σ)
- Supports conclusions by Mapelli+ 2010 that ULX form preferentially at low metallicity
- Unlike Mapelli+, no "trend"

Nulx/SFR v. Z

XMPG Cluster Ages and ULX - Very Preliminary!

A1116+51



Clusters

Red < 10 Myr
Green < 10-100 Myr
Blue 100 Myr -1 Gyr

- A1116+51 ~10Myr old from clusters within the “kick radius”
- Other galaxies
  - NGC 5548 ~10Myr
  - Ho II ~100Myr

Comparison with Models

Comparison with Models

Kalogera and collaborators

- *StarTrack* : population synthesis code. Predicts two ULX pathways
- Roche Lobe Overflow (RLO) HMXB: mass ratio near unity, accretion stable via RLO, short orbital periods (~1 day). Numbers peak at 10 Myr
- Supergiant (SG) HMXB pathway: accretion via a strong wind, periods ~1000 days. Expected to be young, numbers peak 6Myr.

RLO-HMXBs dominate at $Z<0.1Z_{\odot}$ after 5-10 Myr (Linden et al 2010)

Mapelli and collaborators (Zampieri, Colpi, Roberts)

- Massive 25-80 $M_{\odot}$ black holes form from direct collapse of most massive stars. Lack of metals => lower opacity => smaller mass loss via stellar winds

Comparison with Models

- *StarTrack* predictions
- Increase in N_{ulx}/SFR at $Z<0.1Z_\odot$
- Abundant ULX associated with older (> 10Myr) stars
- short orbital periods
- Significant displacement from parent cluster due to SN kick
- Absolute numbers of ULX OK

- Massive black holes predictions
- Trend for anti-correlation in N_{ulx}/SFR with metallicity
- Most ULX should be very young (< 10Myr)
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(In the high metallicity Antennae ~30% of ULX associated with < 6 Myr clusters - poster 410.15, B. Rangelov, Thursday)

Summary and Conclusions

- Chandra/HST survey of 25 Extremely Metal Poor Galaxies
- When compared to a well defined comparison sample (SINGS)
- N_{ulx}/SFR for XMPG is x30 higher than for normal galaxies
- Increase appears to be important < 0.1 $Z_{\odot}$
- Formal significance is low due to small number statistics
- Models
- StarTrack predicts copious ULX ~10 Myr after start of starburst in XMPG due to RLO-HMXB sources
- Mapelli+ postulate population massive (30-80$M_{\odot}$) direct collapse black holes. These objects are young (<10Myr)
- From an observational perspective, both models are viable
- Star clusters can be used to infer the ages of ULX and distinguish between the two possibilities

Stay Tuned!