The HMXB \( z-z \) connection

Connecting the metallicity dependence and redshift evolution of HMXBs

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Local $L_{\text{HMXB}}$-SFR correlation

Star-forming (high sSFR) galaxies

$s\text{SFR}=\text{SFR}/M_\star$

M101

HMXB dominated

NASA/CXC/JHU

Mino+2012

Chandra XX
The little \( z \): \( L_{\text{HMXB}}/\text{SFR} \) evolves with redshift.

Stacking galaxies in the Chandra Deep Field South:

- Best fit \( \beta \text{SFR}(1+z)^{\delta} \)
- Theoretical model (Fragos+2013)

Driven by metallicity dependence?

Lehmer+2016

Fragos+2013

Chandra XX
The big $Z$: The effect of metallicity on HMXB evolution

High-$Z$  

Low-$Z$
The big $Z$: The effect of metallicity on HMXB evolution

High-$Z$  

Low-$Z$
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High-$Z$

Low-$Z$
The big Z: The effect of metallicity on HMXB evolution

High-Z

Low-Z
Implications of $Z$-dependence

- In addition to providing insight into models of stellar evolution, HMXB $Z$-dependence can also constrain:
  - progenitor pathways of GW sources
  - contribution of HMXBs to the heating/reionization of IGM
  - contamination of HMXBs to low-$L_X$ AGN searches in dwarfs
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Mezcua+2016
Evidence of $\mathcal{Z}$-dependence

- Local galaxies exhibit $L_X$-SFR-$\mathcal{Z}$ correlation, but samples may be biased.
- Redshift evolution of HMXB relation could be effect of $\mathcal{Z}$-dependence or driven by other factors.

$log(L_X/SFR) = 12 + log(O/H)$

$\mathcal{Z}$ proxy for HMXBs

Brorby+2016
Is redshift evolution of HMXBs driven by metallicity?
The MOSDEF Survey

- Rest-frame optical spectra for ~1500 galaxies at z~2 in fields with deep X-ray data
Chandra extragalactic surveys

AEGIS-X
800 ks exposure

Deep Field North
2 Ms exposure

Deep Field South
7 Ms (80 day) exposure

Luo+2017
Alexander+2003

Nandra+2015

Chandra XX
Going deeper with existing data

Individual detections of small number of objects

Average X-ray properties for large sample of objects
The MOSDEF sample

- O3N2 $Z$ indicator
- Hα SFR
- Exclude X-ray, IR, and optical AGN
- *Chandra* PSF<3.5"
- 79 galaxies
- Stacked exposures: 20-50 Ms (200-600 days!)

Fornasini+2019
Redshift evolution consistent with previous studies

![Graph showing redshift evolution and X-ray luminosity evolution](image)
Redshift evolution consistent with previous studies

![Graph showing the evolution of log(L_X/SFR) with redshift (z) and 12+log(O/H) as axes. The graph includes data points for Total XRB, HMXB only, and different studies such as Lehmer et al. (2016), Aird et al. (2017), Lehmer et al. (2010), Mineo et al. (2012), This work: full sample, and This work: high sSFR.]
HMXBs exhibit $Z$-dependence at $z \sim 2$

- First evidence for $Z$-dependence at $z > 0$ (97% confidence)
- Likely driven by HMXBs rather than LMXBs

Fornasini+2019
The $Z$-$z$ connection

- HMXB-only normalization consistent with $z=0$ relation
Evidence favors $Z$-$z$ connection

• But is the local $L_x$-SFR-$Z$ relation biased?

• Can we improve measurements of this relation to provide better constraints for theoretical models?
Studying $z$ dependence at low $z$

COSMOS
160 ks exposure per pointing

Galaxy information from two spectroscopic surveys:
hCOSMOS ($z=0.1-0.4$)
zCOSMOS ($z=0.5-0.9$)
Studying $z$ dependence at low $z$

- **hCOSMOS sample:** 858 galaxies at $z=0.1-0.4$
- **$z$COSMOS sample:** 787 galaxies at $z=0.5-0.9$
- **R23 $z$ indicator**
- **SED (UV+IR) SFR**
- **Exclude X-ray, IR, and optical AGN**

![Graph](https://example.com/graph.png)
Different redshifts, same story

- Further support that z-evolution driven by metallicity
- Theoretical models with high L_x/SFR are in disagreement but SFR systematics are important
The \( z-z \) connection: summary & outlook

We have measured the HMXB \( z \)-dependence at \( z>0 \). \( z \)-dependence at different redshifts is consistent and accounts for the observed \( z \)-evolution of \( L_{\text{HMXB}}/\text{SFR} \).

- **hCOSMOS+ survey**
- **SDSS**
- **\( h \text{COSMOS+ survey} + \text{SDSS} \)**
- **Larger spectroscopic samples**
- **Improved SFR estimates**
- **Larger, deeper X-ray surveys**