Catching a glimpse of the X-ray emission from galaxies in the early Universe by studying nearby low-metallicity galaxies

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Based on X-ray studies of HMXBs of High-z Galaxies and Local Analogs, LOWER metallicities Drive HIGHER X-ray luminosities

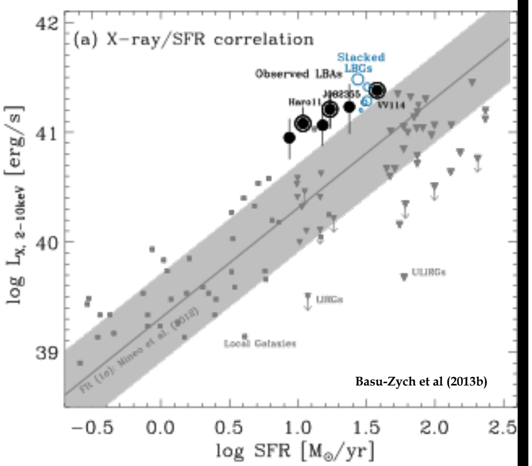


Figure (above): Lyman break galaxies (shown as blue circles) and their low redshift (z~0.1) analogs (**LBAs**, shown as **black circles**) have elevated 2-10 keV X-ray luminosities, given their SFRs, compared to other local star forming galaxies (gray).

Sample: Low redshift (*z~0.1*) **Lyman break analogs (LBAs)**

- are selected by UV luminosity and surface brightness,
- screened against AGN, using optical emission lines.
- have high specific SFRs (SFR/M_*), therefore are expected to have X-ray binary populations dominated by high mass X-ray binaries (HMXBs).

Observation: We compare stacked X-ray observations of Lyman break galaxies **(shown in** blue) at different redshifts with **LBAs (black points)** and find that UV-selected galaxies have elevated X-ray/SFR compared to local star-forming galaxies. (*Basu-Zych+2013a, b*)

Theory: Based on X-ray binary population synthesis models, HMXBS that form in low-metallicity environments are more numerous and more luminous (see **black solid line** on figure at *right; Linden+2010; Fragos+2013a, b*).

Since low-metallicity galaxies produce different populations of HMXBs, resulting in higher X-ray luminosities we must study low-metallicity local galaxies to understand the X-ray emission from high-redshift galaxies in the early Universe. *(Kaaret+2011; Prestwich+2013; Brorby+2014; Basu-Zych+2015-submitted)*

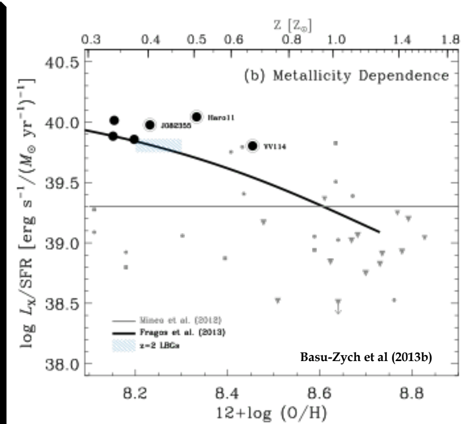


Figure (above): Galaxies with lower metallicities are theoretically predicted to have higher Lx/SFR (**black solid line;** *Fragos +2013*) than local star-forming galaxies (gray solid line; *Mineo+2012*), based on X-ray binary population synthesis models. The LBAs **(black points)** and *z~2* stacked LBGs (blue hashed region) have consistently lower metallicities and elevated X-ray luminosities per SFR.

Cosmological Implications: Heating and Chemical Enrichment of the Intergalactic medium at early epochs

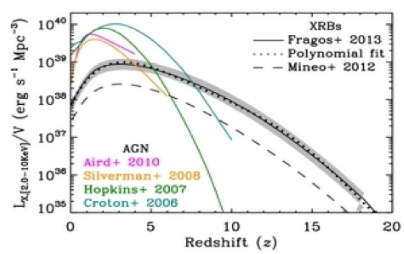


Figure (Left): HMXBs are potentially more relevant than AGN in heating the early Universe (z>6-8; see below: Fragos+2013 *and also Mesinger 2013+; Pacucci+2013; Kaaret +2014; Pobel+2015)*

Motivating Questions:

- ***How much energy and matter escapes from a starburst galaxy?***
- ***By what mechanism does this occur (i.e., leaking photons, supernova-driven winds, outflows)?***
- ***What galaxy properties drive these processes (SFR, M_*, surface brightness)?***
- ***What impact do these processes have on feedback for galaxy evolution over cosmic time?***

What Might Athena Reveal?

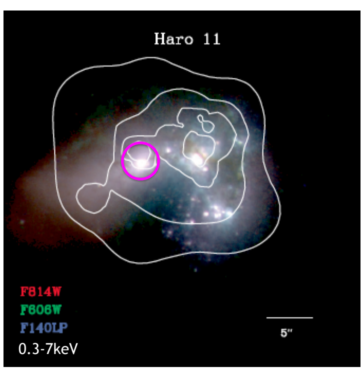
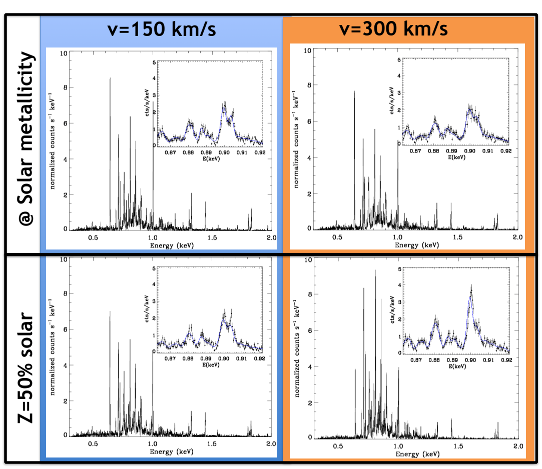
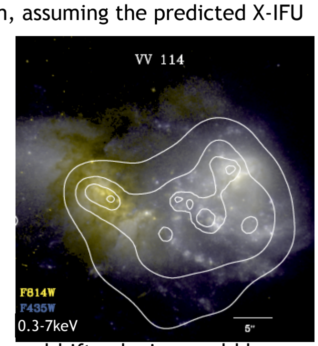


Figure (Above): Haro 11 is a low-metallicity starburst galaxy that is one of the closest Lyman break analogs This galaxy hosts 2 ULXs, and "Knot C" (marked by magenta circle) is associated with Ly alpha emission, signaling the leaking of Lyman alpha photons, potentially because of ULX-driven winds or outflows (see Östlin +2009; Prestwich+2015).

- **Haro 11** (optical image with Chandra 0.3-7keV contours shown *on left*) is one of the closest Lyman break analogs (D= 88 Mpc). Based on 75ks exposure times, we expect to detect individual emission lines or line triplets within 5 sigma for a soft thermal plasma for the 1.4 m² mirror. We use SIMX to simulate the Athena X-IFU spectrum, assuming the predicted X-IFU background model, for different outflow velocities and abundances (shown *below)*.



- **VV114** is another Lyman break analog (D= 86 Mpc; *shown on right*). Together these cases give detailed views of the X-ray energetics within analogs of high-redshift galaxies.



- Other LBAs (*z=0.1-0.3*) and higher redshift galaxies would be spatially unresolved and take prohibitively long exposure times to observe (> 1Ms). However, comparing VV114 and Haro11 with other local starburst galaxies (e.g., Ptak et al., Strickland+ 2010 white paper, etc.) we can investigate how galaxy properties relate to outflows of metals and energy into the circumgalactic medium to better constrain the effects of starbursts in the early Universe.