Young and Exciting: An Investigation of the energetic processes from stellar populations and X-ray binaries

Antara Basu-Zych[1,2]; Kristen Garofali[3]; Panayiotis Tzanavaris[1,2]; Mihoko Yukita[1,3]; Ann Hornschemeier[1]; Edmund Hodges-Kluck[1]; Bret Lehmer[4]; Andrew Ptak[1]; Neven Vulic[5]; Chris Richardson[6]

antara.r.basu-zych@nasa.gov

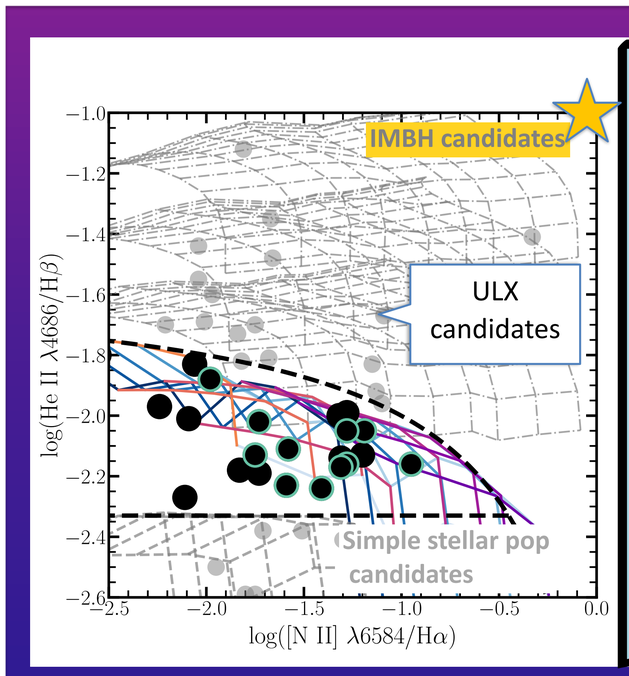
[1]NASA/Goddard Space Flight Center; [2]UMBC; [3]Johns Hopkins University; [4]Univeristy of Arkansas; [5]Eureka; [6]Elon University

Background:

Spectroscopic observations of high-redshift galaxies and their nearby analogs have uncovered puzzling **nebular emission line features**, indicative of excitation by a source of very **high-energy photons**. The low metallicities and bursty star formation histories of such galaxies are conducive to the **efficient formation of ultra-luminous X-ray sources (ULXs)**, which has led to a surge of interest in whether ULXs are an important excitation mechanism in high redshift galaxies and their analogs. Yet the age-dependence for forming ULXs also impacts their ionizing potential.

Driving Motivation:

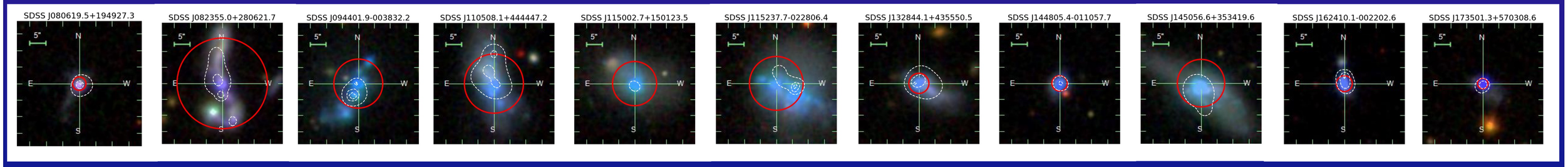
Can ULXs power the high ionization emission observed in high redshift galaxies and their analogs?



Sample Selection:

Based on updated emission line diagnostics that include the modeling of stellar populations, **ULXs (see Garofali et al.2024)**, and **IMBHs (Richardson et al. 2022)** we separate the sample of HeII-selected galaxies by the likely HeII excitation origin. Here, we focus on the **ULX candidates (black points)**

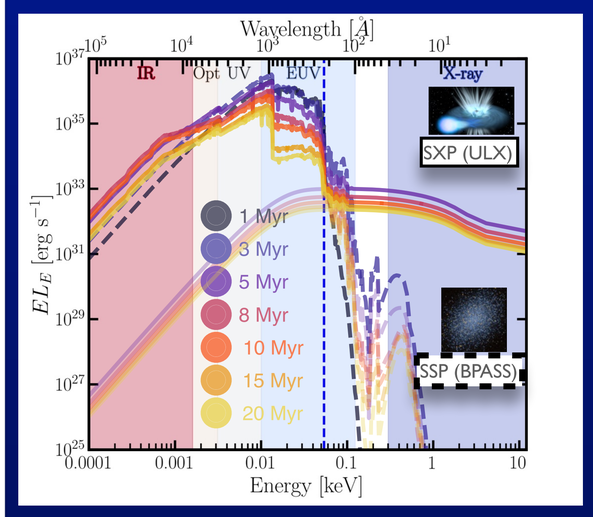
Those with cyan outlines have significant Chandra X-ray detections.



X-ray detected ULX candidates: SDSS optical images with Chandra 0.5-8 keV contours (dashed white) and extraction apertures (red) overlaid.

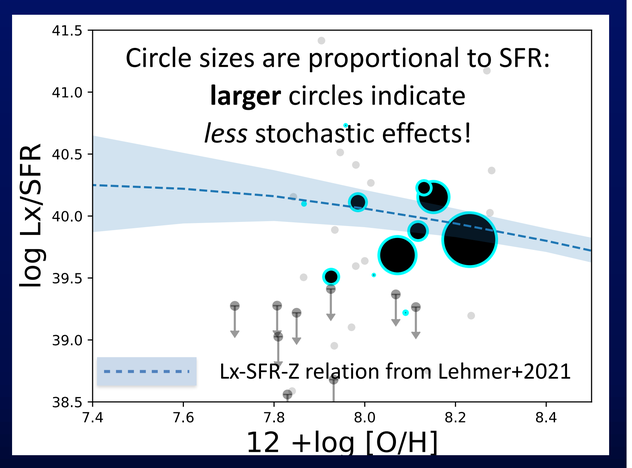
Chandra's superb spatial resolution allows us to verify that the region corresponding to SDSS fiber measurement coincides with a bona fide X-ray source (i.e. X-ray emission, SFRs and nebular emission measurements are compared from consistent regions)!

Results based on preliminary investigation of the X-ray emission



Left: The ULX model SED models (see Garofali+2024) are normalized based on theoretical Lx-Z scalings as a function of stellar age, and then coupled with stellar populations of the corresponding age and metallicity. These age and metallicity dependent composite SEDs are then used to produce the nebular emission line ratios shown in the grids above (sample selection figure). Therefore, the ULX candidates we have selected based on these grids are expected to have Lx/SFR ~ 10^{40} erg/s/($M_\odot$/yr), based on their Z.

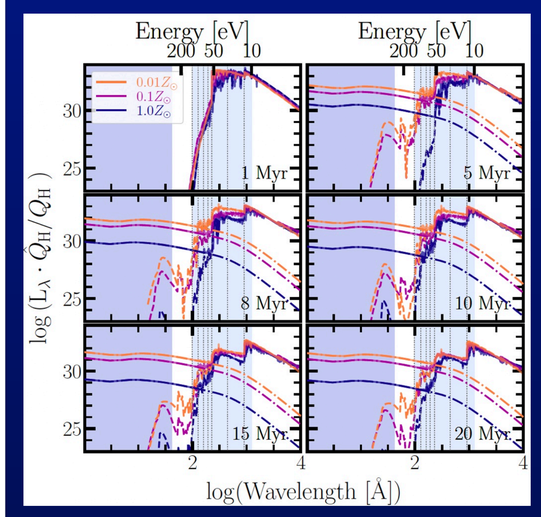
Right: We find that indeed the X-ray luminosities for the ULX candidates are consistent with the empirical Lx-SFR-Z, and therefore should be consistent with the ULX parameter space in the grid (modulo SFH and metallicity - see Next Steps). The symbol sizes, which scale with the SFR, show that stochasticity is a relevant factor to interpreting the overall results.



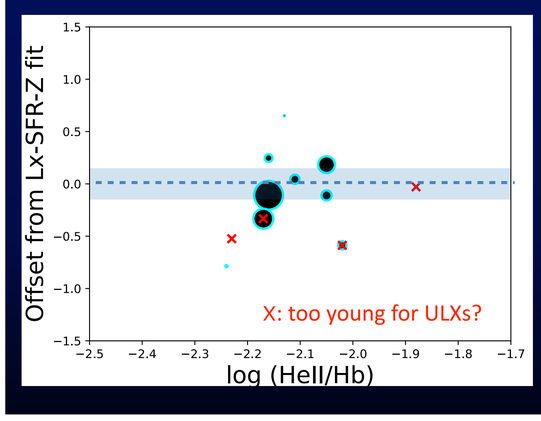
Therefore: YES! According to the measured 0.5-8keV luminosities, the nebular emission lines in these HeII sources are likely powered by ULXs!

The Next Steps:

Leveraging the combined power of Chandra X-ray with the multi wavelength spectro+photometric data, we will measure star formation histories to further test the models and learn what emission mechanisms power the nebular emission in these galaxies.



Top: The ULX modeling in Garofali+2024 self-consistently includes both stellar (dashed) and ULX(dash-dotted) components, taking into account both age- and metallicity-dependence in modeling the nebular emission lines from these sources.



Bottom: Using the Hβ equivalent width, EW(Hβ), as a proxy for stellar (and ULX formation) age, we show the offset from Lx-SFR-Z relation as a function of log (HeII/Hβ). The red X's mark sources with EW(Hβ) > 120, suggesting these may be too young for ULXs alone to account for the observed high HeII/Hβ ratios.

Next, **we will use the stars + ULX models to fit the full suite of multi wavelength (spectro-photometric) data to measure star formation histories and determine the energetic source(s) responsible for producing the nebular emission.**