Lessons learned from Ultraluminous X-ray Source populations and their environment

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Introduction

Ultraluminous X-ray sources (ULXs; see [1]) are X-ray binaries with luminosity exceeding the Eddington limit for an accreting stellar black hole ($\sim 10^{39}\,\mathrm{erg\,s^{-1}}$), challenging our understanding of **binary evolution** and **accretion physics**.

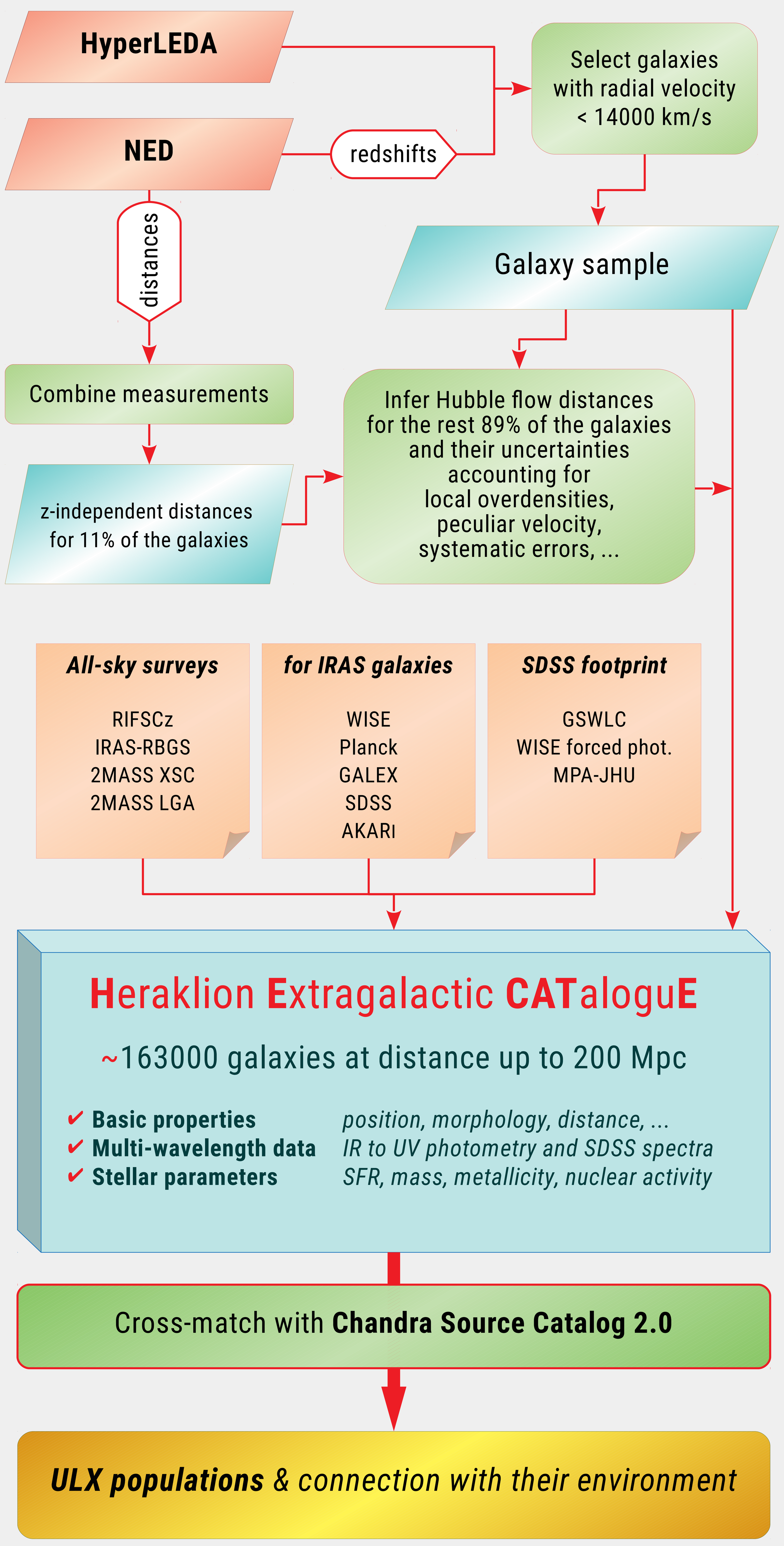
ULXs are of great importance to **gravitational wave** research (as progenitors of compact object mergers, [2]) and **cosmology** (pre-heating of the intergalactic medium [3]).

While studies of individual ULXs provide input for accretion physics, **statistical studies of ULX populations** in the context of stellar population parameters of their **host galaxies** probe their formation and evolution. The results of statistical studies constrain **binary population synthesis** models [4].

Objectives

1. Compile the *Heraklion Extragalactic CATalogueE* (**HECATE**), a catalog of all known galaxies in the local Universe ($D \lesssim 200\,\mathrm{Mpc}$) with distances, stellar population parameters, and AGN content where available.
2. Construct the most up-to-date **census of ULXs** by cross-matching *HECATE* with **Chandra Source Catalog 2.0**
3. Study the **rate of ULXs** as function of the host galaxy's star formation rate (SFR), stellar mass ($M_\star$) and metallicity.
4. Study the high end of the luminosity function (LF) of High Mass X-ray Binaries (HMXBs).

Creating the galaxy & ULX catalogs



Results

1. Donors of ULXs can be either HMXBs traced by star formation rate (SFR), or Low Mass X-ray binaries (LMXBs) and thus traced by staller mass ($M_\star$). The number of ULXs per galaxy in bins of the $M_\star$-SFR plane is shown in **Fig. 1**.

   We fit for the scaling of the number of ULXs with both stellar population parameters in late-type galaxies:

   $$N_{\mathrm{obs}} = \alpha \times \mathrm{SFR} + \beta \times \mathrm{M}_\star + N_{\mathrm{bkg}}$$

   where N_{obs} is the number of observed sources above $10^{39}\,\mathrm{erg\,s^{-1}}$, N_{bkg} is the expected number of interlopers. α and β are the scaling factors for SFR and $M_\star$ respectively. For all late-type galaxies (LTGs) we find (black in **Fig. 2**):

   $$\alpha = 0.55\,\mathrm{M_\odot^{-1}\,yr}$$

   in good agreement with the HMXB LF of [5] ($\sim$0.56 HMXBs above $10^{39}\,\mathrm{erg\,s^{-1}}$ per $\mathrm{M_\odot\,yr^{-1}}$ star formation rate), and

   $$\beta = 3.5 \times 10^{-12}\,\mathrm{M_\odot^{-1}}$$

   in agreement with the LMXB LF of [7] ($\sim$4 LMXBs above $10^{39}\,\mathrm{erg\,s^{-1}}$ per $10^{12}\,\mathrm{M_\odot}$ stellar mass.)

   As illustrated in the same figure, we systematically find evidence for higher α as we go from early spirals (red) to late spiral and irregular galaxies (blue).

2. We find $\sim$**1.7 ULXs** per $10^{11}\,\mathrm{M_\odot}$ stellar mass in early-type galaxies, with elliptical galaxies hosting ~3 times as many ULXs as lenticular galaxies, supporting the findings of [6].

3. Irregular galaxies contain more ULXs per star formation rate ($\sim 1.8\,\mathrm{M_\odot^{-1}\,yr}$) than Sa-Sb spirals ($\sim 0.3\,\mathrm{M_\odot^{-1}\,yr}$) and Sc-Sd spirals ($\sim 0.7\,\mathrm{M_\odot^{-1}\,yr}$). We find that the excess is negatively correlated with the host's metallicity in agreement with [8]. In addition we find an excess of ULXs in low mass galaxies (**Fig. 3**) with respect to the average relation of ULXs and SFR, $M_\star$.

4. The median distance of the ULXs from the center of the host galaxy increases going from early- to late-type galaxies.

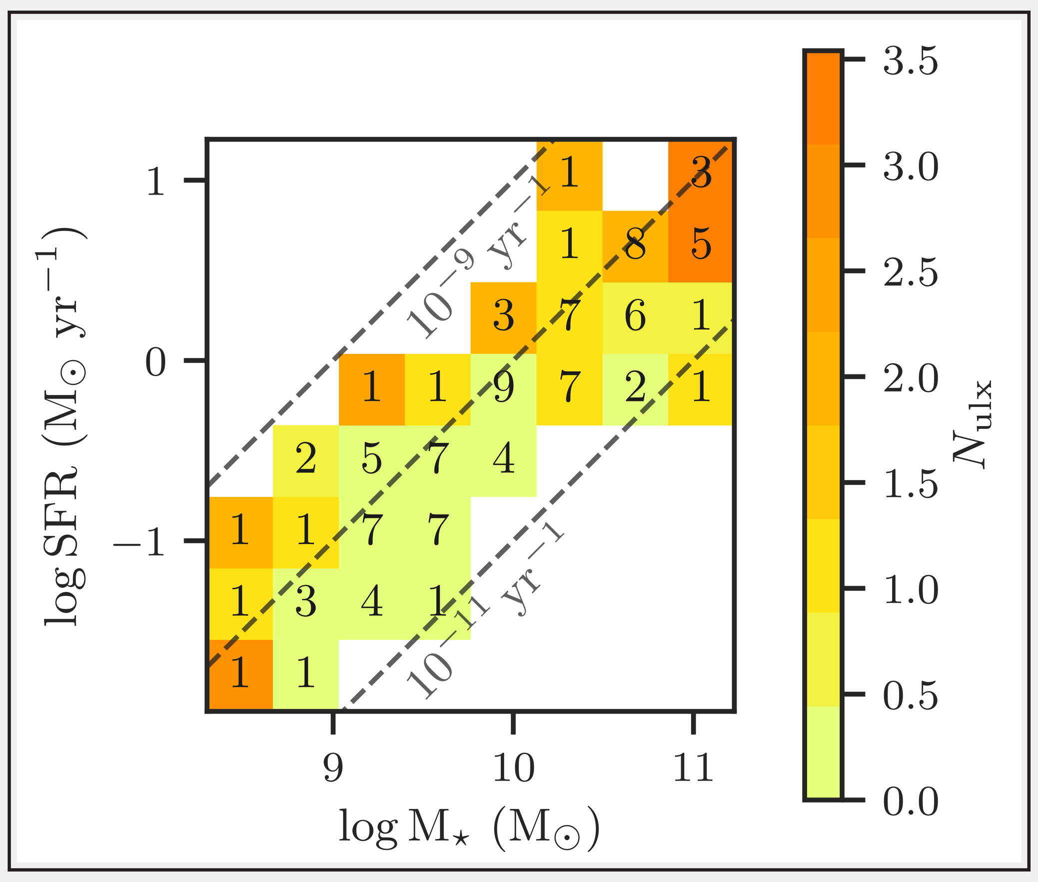


Fig. 1: Average number of ULXs per galaxy binned by SFR and stellar mass. Diagonal lines indicate the specific SFR. The number of galaxies in each bin is given in the center of the bins.

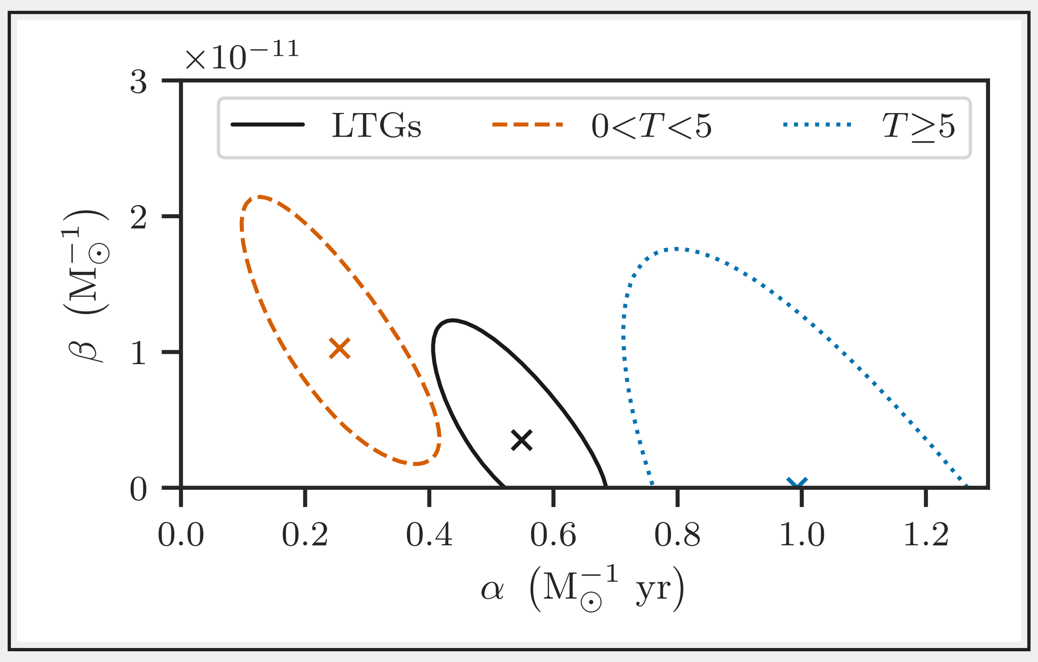


Fig. 2: Best fit values and 68% confidence regions for the scaling factors *a* and *b* (see Results 1) for all late-type galaxies within 40 Mpc (black) and separately for early spirals (red) and late-spirals/irregulars (blue). While in early spirals, the correlation with $M_\star$ is required to explain the number of ULXs, in late spirals the SFR scaling alone can explain the population of ULXs.

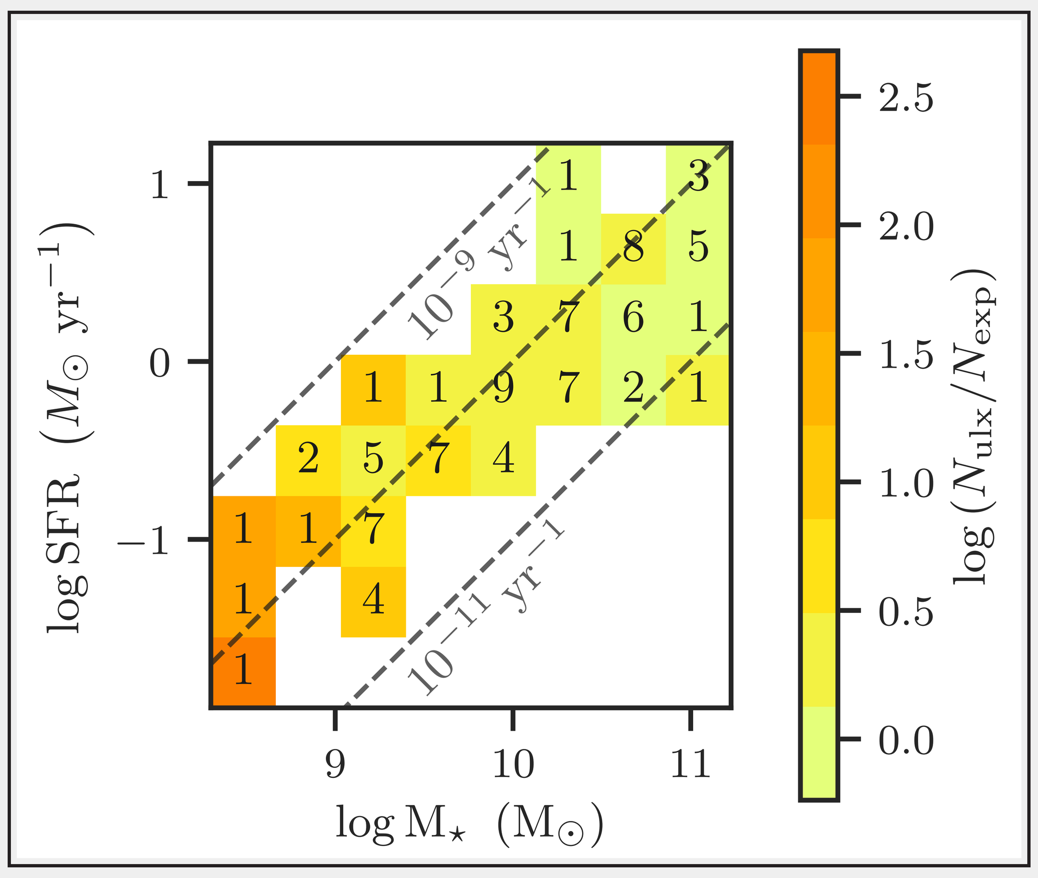


Fig. 3: Same as Fig. 1 but now the colors indicate the excess of ULXs with respect to the average relation for late-type galaxies (Results 1.)

References

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