X-ray Spectral Modeling of Luminous Infrared Galaxies: Understanding Hot Gas and X-ray Binary Populations in the Most Active Local Starbursts

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Abstract

The established LX-SFR relation links X-ray luminosities (LX) to star-formation rates (SFRs) in star-forming galaxies. However, Luminous Infrared Galaxies (LIRGs) often appear under-luminous compared to predictions from this relation. Proposed explanations include significant intrinsic absorption, elevated metallicities, and young stellar populations. Using Chandra X-ray data and galaxy properties from the HECATE catalog, we analyze the X-ray spectra of 63 LIRGs to test these theories. Our study focuses on disentangling the contributions of hot gas and X-ray binaries (XRBs) to LIRG X-ray emission, through spectral modeling. We present refined LX estimates for both hot gas and XRBs, highlighting their correlations with galaxy properties. Our results provide new insights into the observed X-ray deficit in LIRGs and the role of hot gas and XRBs in shaping this phenomenon.

Motivation

The study of X-ray emission in galaxies offers **essential insights into both stellar evolution and galactic feedback processes**. X-ray emissions in galaxies arise primarily from two sources: **hot gas**, which traces supernova-driven feedback and stellar wings, and **XRBs**, which provide a window into the **lifecycle of compact objects in binary systems**. These emissions are closely linked to star formation and other host-galaxy properties, such as stellar mass and metallicity, with **hot gas emissions reflecting the energy input into the interstellar medium (ISM) and XRBs probing the population of neutron stars and black holes** in galaxies. **Studying these components and their scaling relations enhances our understanding of how galaxies evolve, regulate star formation, and distribute energy** within their environments.

While X-ray scaling relations have been well-studied in "normal" star-forming galaxies, there remains a gap in our understanding of these relationships in **extreme star-forming environments, such as LIRGs. LIRGs, defined by their high infrared luminosities** (greater than $10^{11} L_{\odot}$), are often the result of intense star-forming bursts triggered by **galaxy mergers or strong gravitational interactions**. These galaxies serve as **local analogs to the high-redshift starburst galaxies** that were prevalent during the **peak of cosmic star formation** ($z \sim 2$). **Studying LIRGs thus provides a critical opportunity to examine feedback processes and compact object evolution under conditions of extreme star formation**, offering insights relevant to understanding the properties of galaxies during this pivotal epoch in cosmic history.

However, past studies of LIRGs' X-ray properties have encountered significant limitations. Many studies have focused on **integrating X-ray properties without isolating the contributions from hot gas and XRBs**, potentially obscuring critical differences in scaling relations. Additionally, **LIRGs commonly exhibit high intrinsic absorption**, which can complicate X-ray observations and hinder direct comparisons to scaling relations observed in "normal" galaxies. **By leveraging the high spatial resolution of Chandra, this research overcomes these obstacles**, enabling the decomposition of X-ray emissions from hot gas and XRBs within a carefully selected sample of LIRGs.

Through this analysis, **we aim to construct new scaling relations for LIRGs** that reveal **how feedback processes and binary populations behave in extreme star-forming environments**. By comparing these scaling relations to those of less extreme star-forming galaxies, **our study provides a comprehensive view of the roles that hot gas and XRBs play in galaxy evolution across different environments**. Ultimately, this research enhances our understanding of the **interplay between star formation, feedback, and compact object populations**, contributing a **valuable local benchmark for interpreting the evolution of galaxies during the universe's peak star formation epoch**.

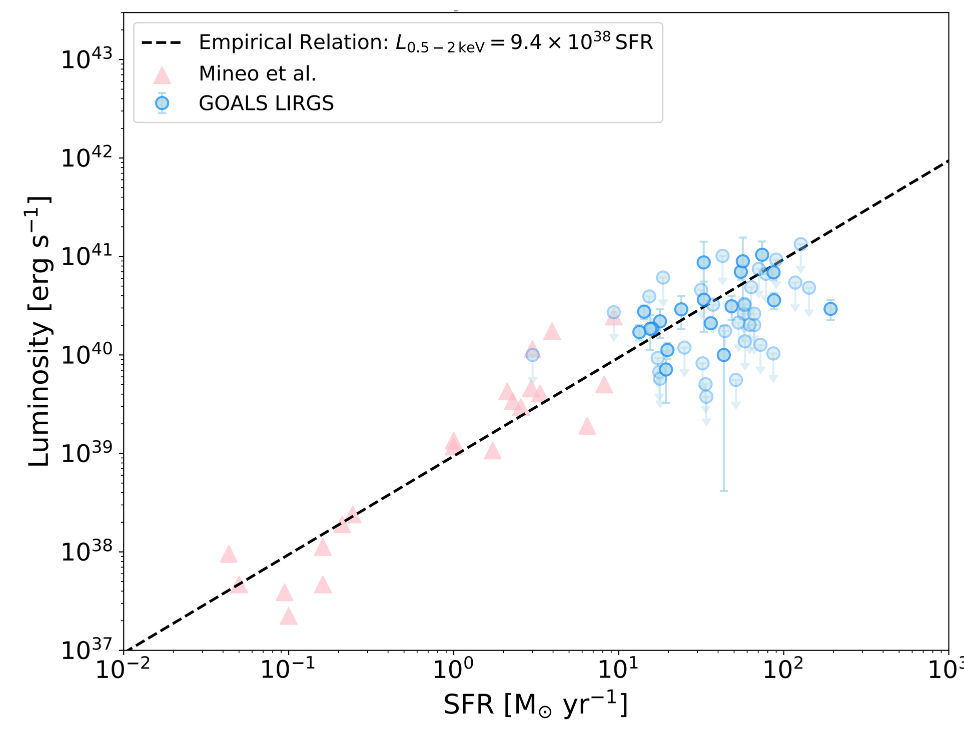

Figure 1: Luminosity of Hot Gas vs. SFR

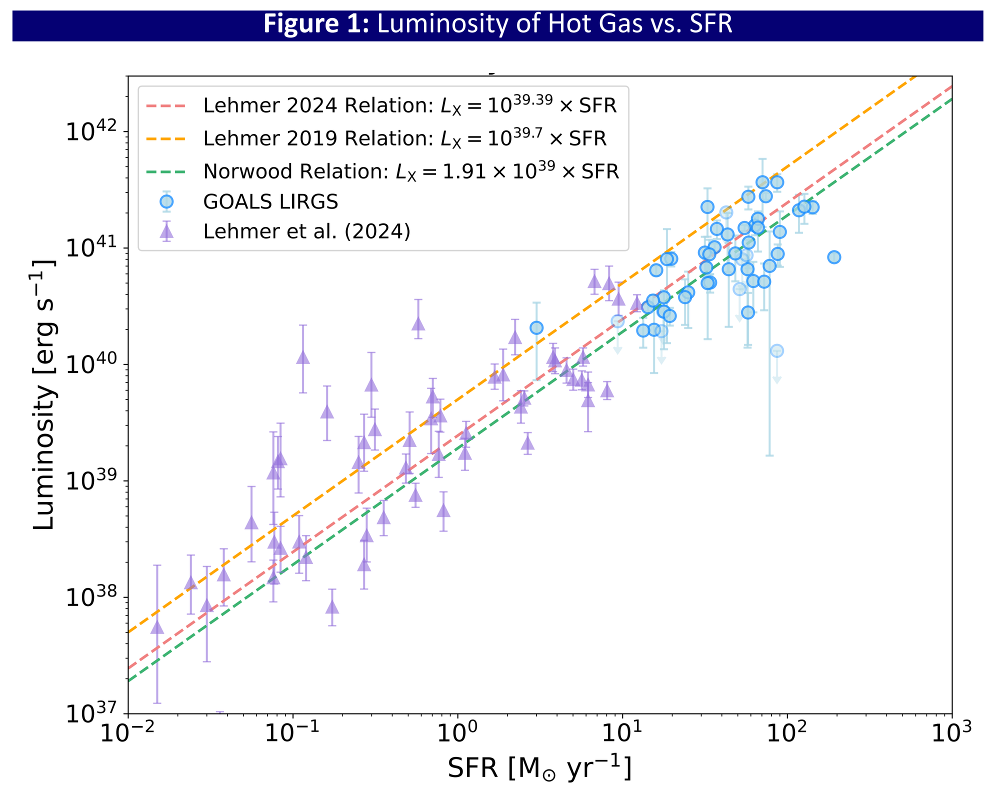

Figure 2: Luminosity of XRBs vs. SFR

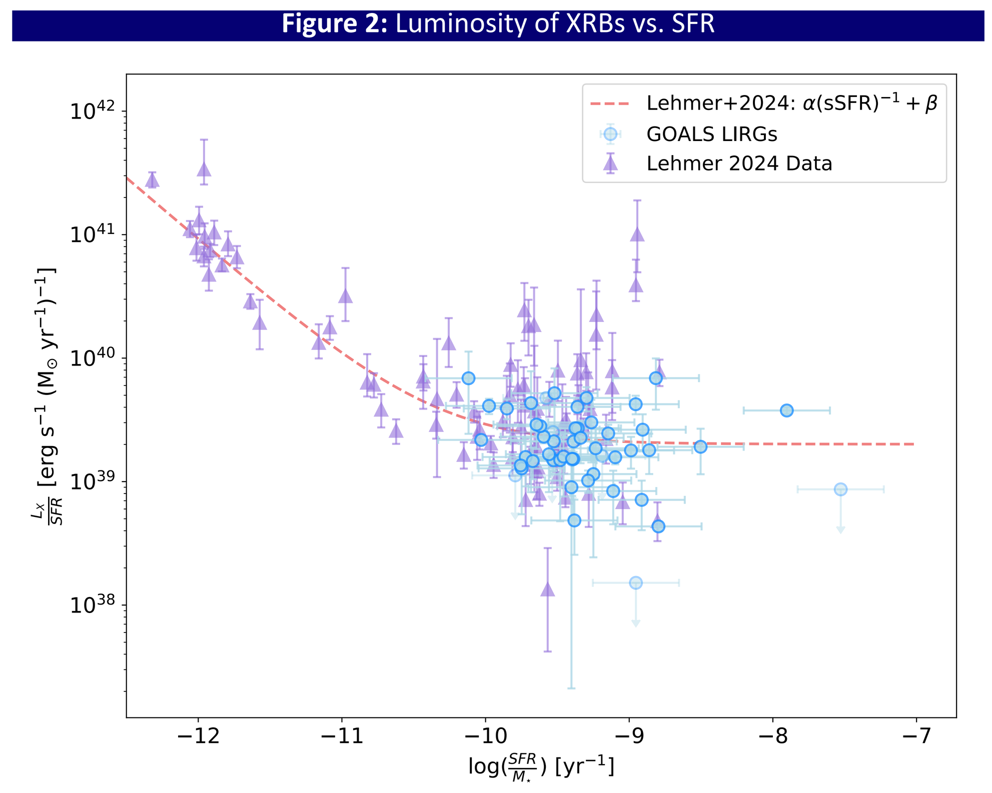

Figure 3: Luminosity per Unit SFR vs. SFR per Unit Stellar Mass (XRB)

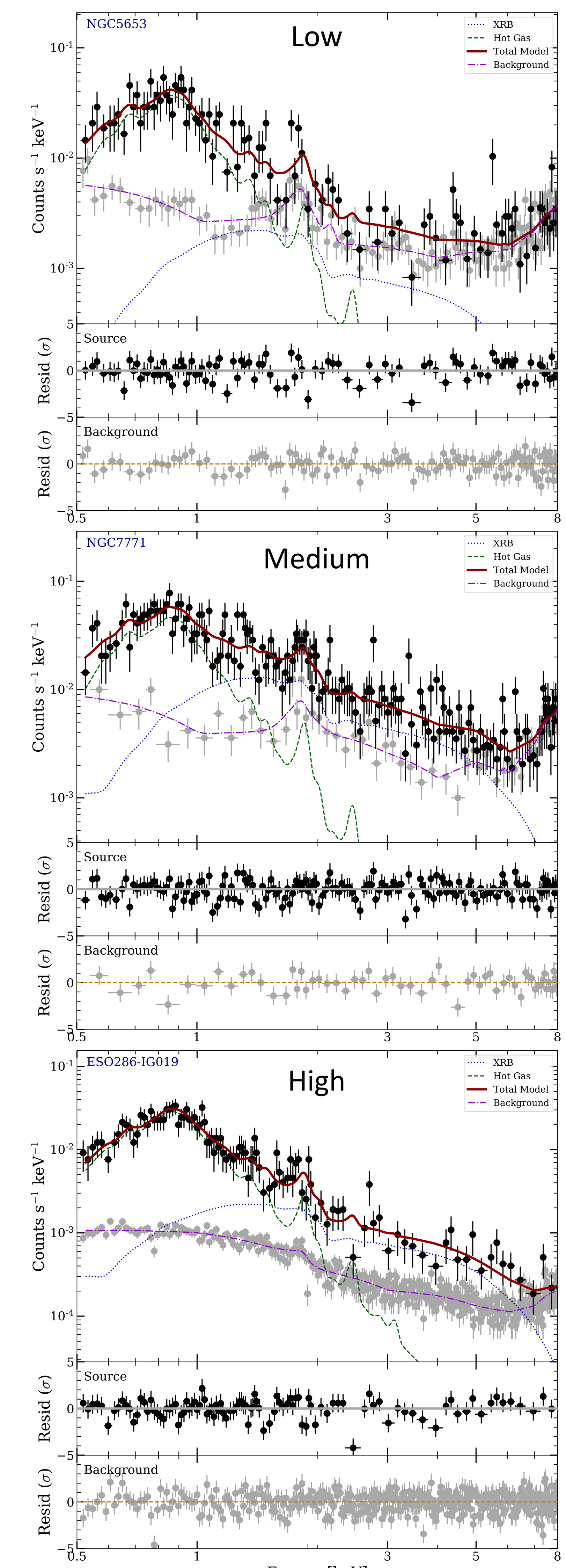

Figure 4: XRB spectral models for LIRGs classified by low, medium, and high SFR.

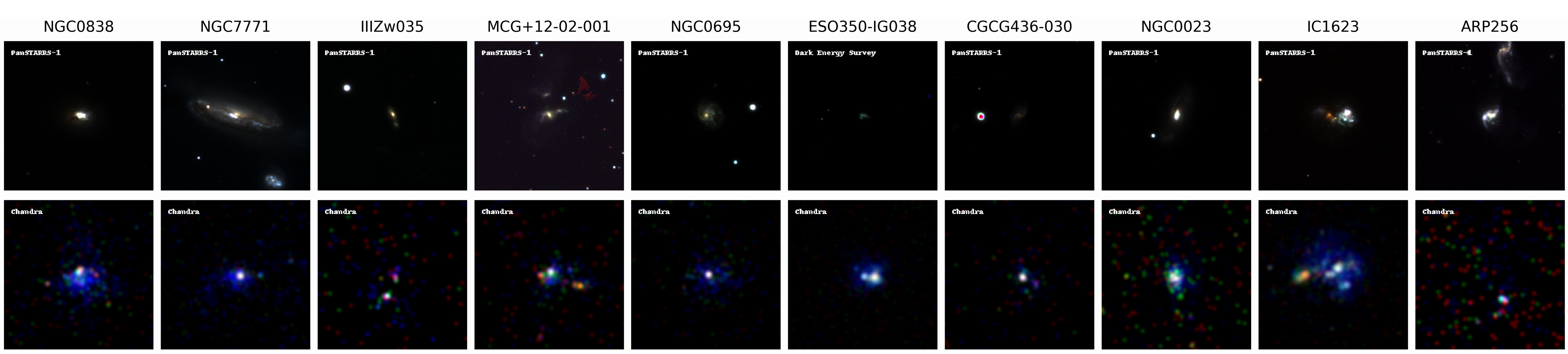

Figure 5: Postage stamp images showcasing multiwavelength observations of selected galaxies. The top panels display optical images from PanSTARRS/DES, and the bottom panels show corresponding X-ray images from Chandra

Key Results

- Both hot gas and XRB components are systematically underluminous compared to established LX-SFR scaling relations for normal star-forming galaxies.
- The X-ray deficit becomes more pronounced in higher SFR environments.
- New scaling relations specific to LIRGs provide improved predictions of X-ray luminosities by accounting for deviations caused by their extreme star-forming environments.
- L_X/SFR decreases with increasing sSFR $=$ SFR/M_*, emphasizing the importance of specific SFR in determining XRB luminosity efficiency.
- This relationship reflects the impact of younger stellar populations and higher metallicities in LIRGs.
- The new fitting method effectively separates X-ray contributions from hot gas and XRBs, yielding accurate models across low, medium, and high-SFR galaxies.
- The findings underscore how extreme star-forming conditions in LIRGs influence feedback processes and compact object populations.

Future Work

- Create a specific relation for L_X/SFR vs. SFR/M_* to better characterize LIRGs.
- Develop a global, automated code for spectral models.
- Analyze outliers in spectral models to identify potential drivers (e.g., young stellar populations, metallicity variations).
- Quantify the role of absorption in obscuring X-ray emissions and its impact on scaling relations.
- Finalize and publish the first paper based on this research.

Sources:

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