Probing the building blocks of galaxies: sub-galactic scaling relations between X-ray luminosity, SFR and stellar mass

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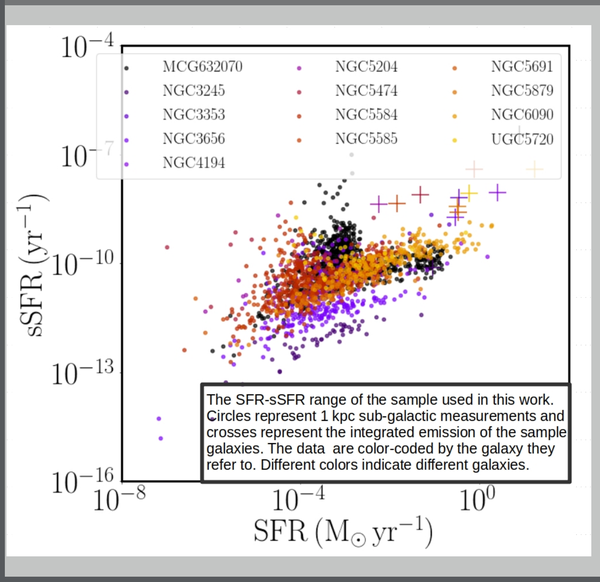
Abstract

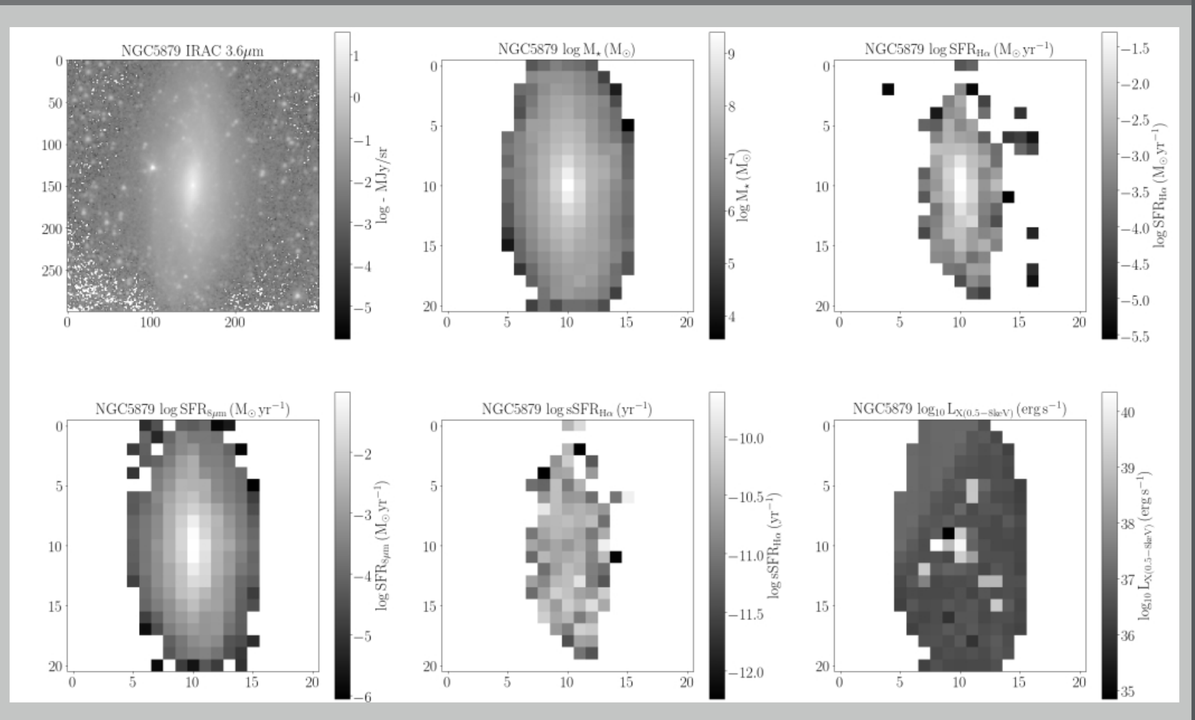
It is well known that X-ray luminosity ($\mathrm{L_X}$) originating from high mass X-ray binaries (HMXBs) is tightly correlated with the host galaxy's star formation rate (SFR). We explore this connection using a sample spanning ~ 4 dex in SFR and ~ 3 dex in specific SFR (sSFR) along with a comprehensive set of star-formation (24μm, 8μm, Hα), stellar mass (3.6μm) indicators, and *Chandra* observations. We investigate the $\mathrm{L_X - SFR}$ and $\mathrm{L_X}-$ stellar mass ($\mathrm{M_\star}$) scaling relations down to sub-galactic scales of $1\,\mathrm{kpc}^2$. This way we examine these correlations to extremely low SFR ($\sim 10^{-6}\mathrm{M_\odot \cdot yr^{-1}}$) and $\mathrm{M_\star}$ ($\sim 10^4\mathrm{M_\odot}$). We find good agreement with established relations down to $\mathrm{SFR} \sim 10^{-3}\mathrm{M_\odot \cdot yr^{-1}}$ and an excess of $\mathrm{L_X}$ for lower values. We finally show evidence that the excessive $\mathrm{L_X}$ is attributed to low mass X-ray binaries (LMXBs). We also find that the intrinsic scatter of the $\mathrm{L_X - SFR}$ relation is not correlated with SFR.

Sample



The sample used for this work consists of 13 star-forming (non-AGN)Star-Formation Reference Survey (SFRS, [1]) galaxies that have *Chandra* data of adequate quality to study the X-ray emission down to 1 kpc^2 scales. The integrated emission of the sample galaxies spans ~ 4 dex in the SFR and ~ 3 dex in sSFR. In sub-galactic scales these ranges become ~ 6 dex and ~ 5 dex in SFR and sSFR respectively.

Base of analysis



In order to probe the correlations between SFR, stellar mass and the X-ray emission in sub-galactic scales we create grids of different physical scales ($1, 2, 3,$ and $4\,\mathrm{kpc}^2$). Then we apply the same grids on the IRAC 3.6 μm data (used to measure the stellar mass), the Hα, IRAC 8μm, and MIPS 24μm data (used to measure the SFR), and the *Chandra* data in the soft ($0.5-2.0\mathrm{keV}$), hard ($2.0-8.0\mathrm{keV}$), and total ($0.5-8.0\mathrm{keV}$) bands. From these grids we generate stellar mass, SFR, sSFR, and $\mathrm{L_X}$ maps which we use to correlate these parameters in each sub-galactic region. Here as an example we see the IRAC 3.6μm data and the $1\,\mathrm{kpc}^2$ $\mathrm{M_\star}$, Hα based SFR, 8μm based SFR, specific SFR, and the total$\mathrm{L_X}$ maps of the galaxy NGC5879.

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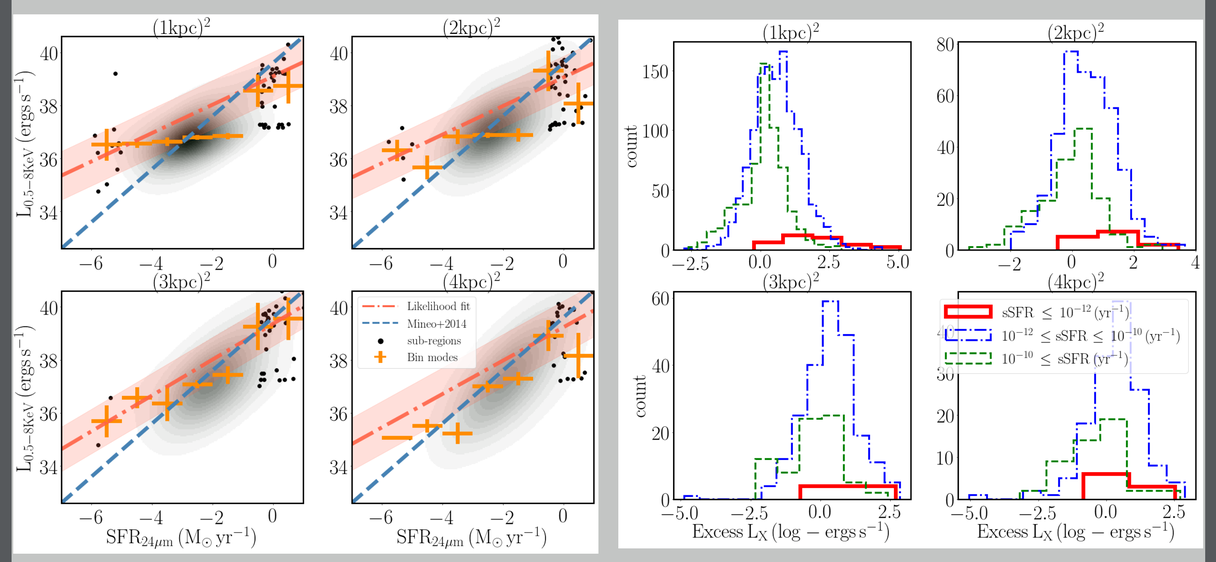
Results: Max. likelihood fits & X-ray luminosity excess in low SFR



Results:

- $\mathrm{L_X}$ against $8\,\mu$m-based SFR for ($1, 2^2, 3^2,$ and $4^2\,\mathrm{kpc}^2$) sub-galactic regions (all regions in all 13 galaxies are included in the density plot). The points with errobars represent the $\mathrm{L_X}$ distribution of the regions in 1 dex SFR bins. The red line show a max. likelihood fit to the $\log\mathrm{L_X} = \alpha\log\mathrm{SFR} + \beta$ relation, which is flatter than the [4] relation ($\alpha = 1$). The red shaded areas represent the 67.8 percentile of the calculated scatter.
- Excess of $\mathrm{L_X}$ with respect to the [4] relation. The histograms show the distribution of $\mathrm{L_X}$ excess for sub-galactic regions of 1, 2^2, 3^2, and $4^2\,\mathrm{kpc}^2$ grouped according to their sSFR.
- We find dependence of α and β on the SFR indicator, with $\mathrm{H_\alpha}$ being closer to linear slope. This can be attributed to the fact that $\mathrm{H_\alpha}$ is tracing younger stellar populations, similar to the HMXBs formation time-scales [2].
- We fit $\log\mathrm{L_X} = \alpha\log\mathrm{SFR} + \beta + \sigma$ in order to quantify the scatter in the relation, where $\sigma = \sigma_1 + \sigma_2\mathrm{SFR}$. We find no significant dependence of σ on SFR ($\sigma_2 \simeq 0$).
- We fit an $\mathrm{L_X} = 10^\alpha\mathrm{SFR} + 10^\beta\mathrm{M_\star}$ model to our data in order to quantify the dependence of $\mathrm{L_X}$ on SFR and $\mathrm{M_\star}$. We find varying results depending on the SFR indicator and physical scale of the analysis, with the larger scales converging to the integrated-galaxy relations.

Conclusion

- We extend the $\mathrm{L_X - SFR}$ correlation down to extremely low SFR ($\mathrm{SFR} \sim 10^{-6}\,\mathrm{M_\odot\,yr^{-1}}$), relevant also for dwarf galaxies.
- We find a shallower slope in the $\mathrm{L_X - SFR}$ correlation in all sub-galactic scales (1, 2^2, 3^2, and $4^2\,\mathrm{kpc}^2$) and by all the SFR indicators (Hα, 8μm, 24μm) used in this project.
- This shallower slope is driven by an excess of $\mathrm{L_X}$ in the extremely low SFR regime ($\mathrm{SFR} \leq 10^{-2}\,\mathrm{M_\odot\,yr^{-1}}$).
- The excess of $\mathrm{L_X}$ in the low SFR regime can be attributed to underlying emission of LMXBs.
- There is a systematic difference in the $\mathrm{L_X - SFR}$ correlation between the the different SFR indicators. This can be attributed to the fact that the different indicators have varying sensitivity to stellar populations of different age [3], with $\mathrm{H_\alpha}$ being closer to linear slope.
- We show that the intrinsic scatter of the $\mathrm{L_X - SFR}$ correlation is not correlated with SFR.

References

[1] Ashby, M. L. N., Mahajan, S., Smith, H. A., Willner, S. P., Fazio, G. G., Raychaudhury, S., Zezas, A., Barmby, P., Bonfini, P., Cao, C., González-Alfonso, E., Ishihara, D., Kaneda, H., Lyttle, V., Madden, S., Papovich, C., Sturm, E., Surace, J., Wu, H., and Zhu, Y.-N. (2011). The Star Formation Reference Survey. I. Survey Description and Basic Data. *PASP*, 123:1011.

[2] Fragos, T., Lehmer, B., Tremmel, M., Tzanavaris, P., Basu-Zych, A., Belczynski, K., Hornschemeier, A., Jenkins, L., Kalogera, V., Ptak, A., and Zezas, A. (2013). X-Ray Binary Evolution Across Cosmic Time. *ApJ*, 764:41.

[3] Kennicutt, R. C. and Evans, N. J. (2012). Star Formation in the Milky Way and Nearby Galaxies. *ARA&A*, 50:531–608.

[4] Mineo, S., Gilfanov, M., Lehmer, B. D., Morrison, G. E., and Sunyaev, R. (2014). X-ray emission from star-forming galaxies - III. Calibration of the $\mathrm{L_X}$-SFR relation up to redshift z $\approx$ 1.3. *MNRAS*, 437:1698–1707.

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