Fitting Scaling Relations with Low S/N Data

INSTITUTE OF ASTROPHYSICS

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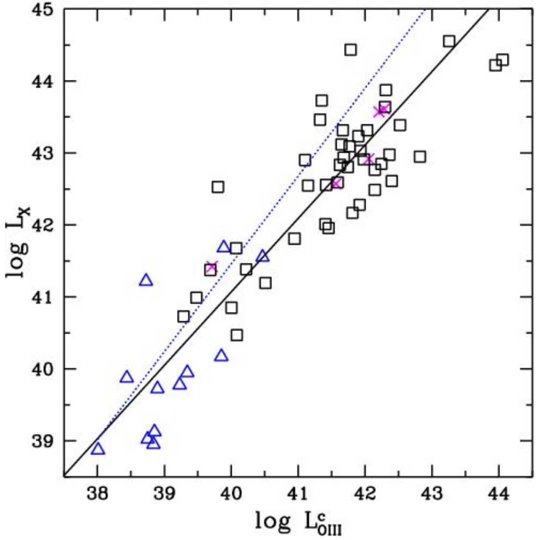
INTRODUCTION

Scaling relations can shed light on the connection between the observables and the physical parameters of galaxies.

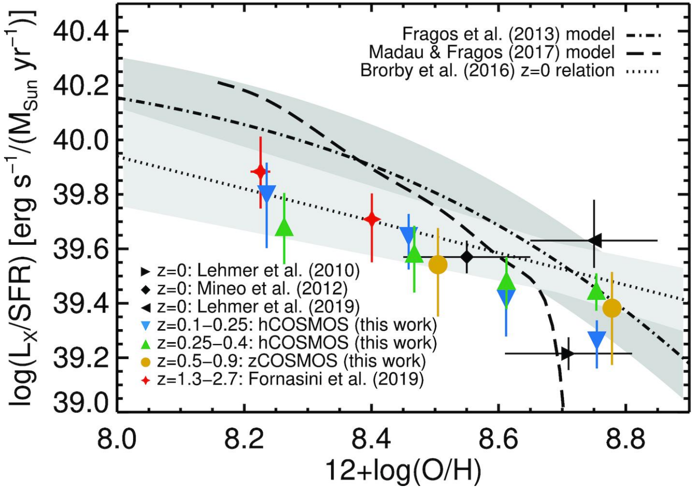
Useful to understand the evolution of the galaxies.

L_x - O_{III}



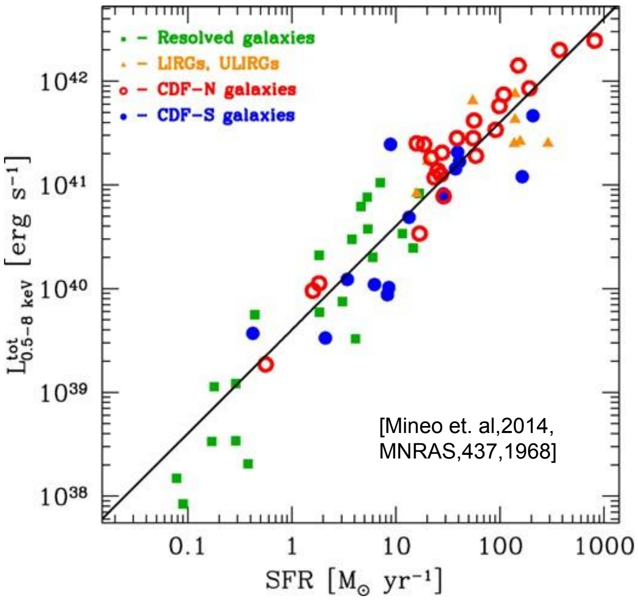
[Lamastra et al. 2009, A&A,504,73]

L_x - SFR-Metallicity



[Fornasini et al. 2020, MNRAS,495,771]

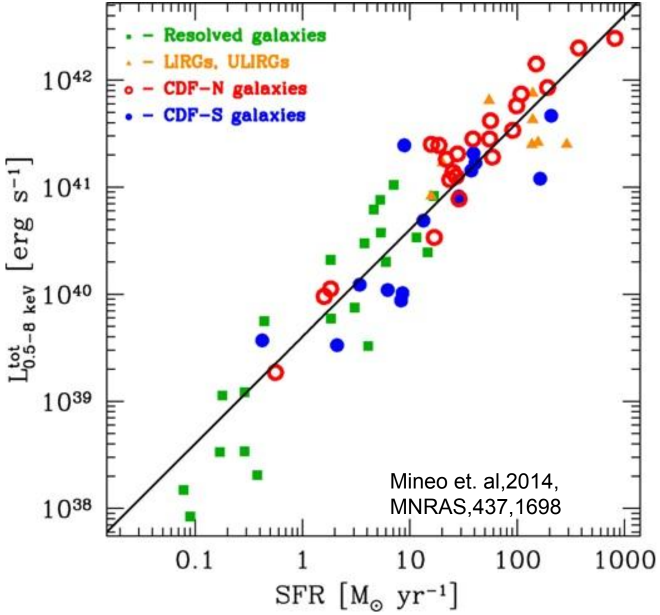
L_x - SFR



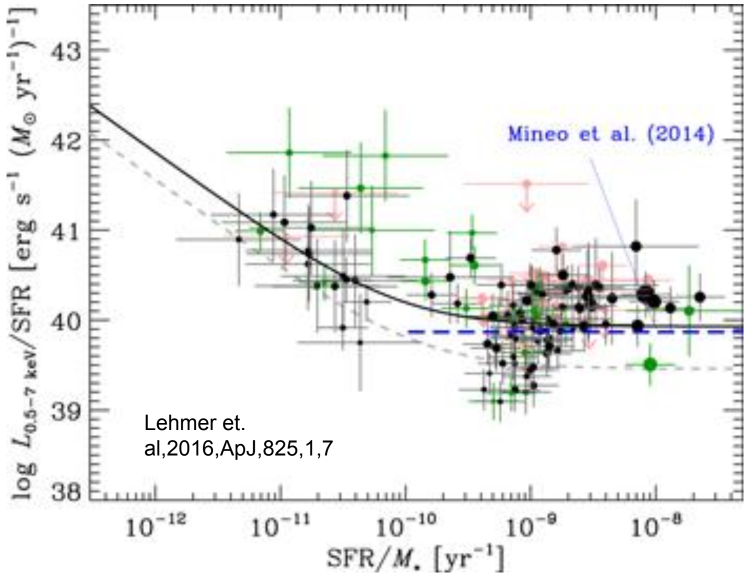
THE PROBLEM

Traditionally the fitting of the models is performed only on the detections (high S/N data).

L_x - SFR



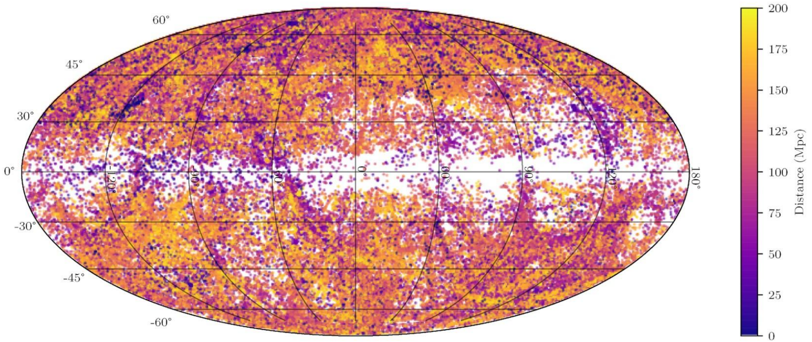
L_x - SFR - $M_\star$

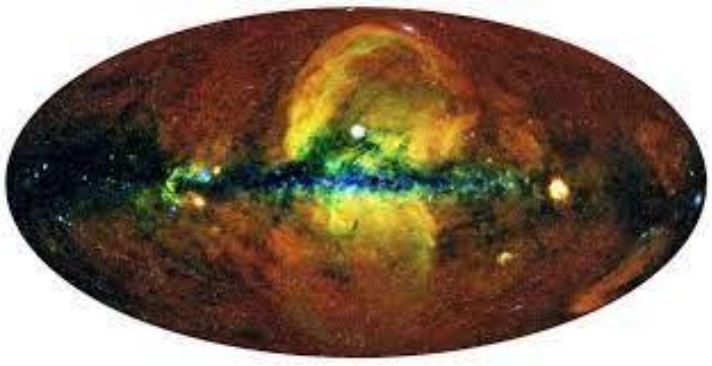


Not accounting for Upper-Limits (low S/N data) results to biased scaling relations.

Data sets provided by all-sky blind surveys, most likely will comprise Upper Limits, that must be considered for the calculation of unbiased scaling-relations.

THE PROJECT





An unbiased sample

HECATE catalog: ~200.000 galaxies
Kovlakas et al.,2021, 506,1896

An all-sky blind X-ray survey

eROSITA survey
Predehl et al. 2021, A&A 647, A1

HECATE - eROSITA: ~90.000 galaxies

Photometry for the entire sample
Luminosity calculation for each galaxy

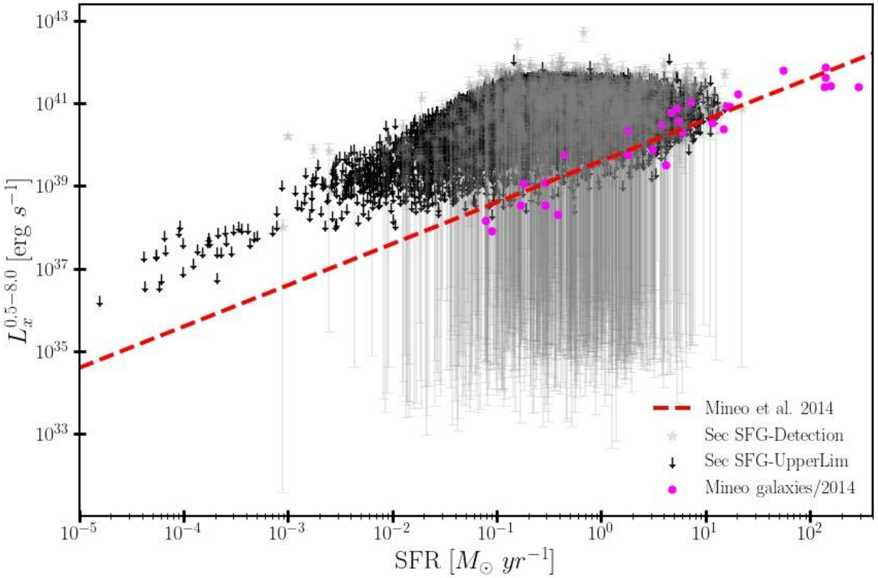
eROSITA all-sky X-ray survey

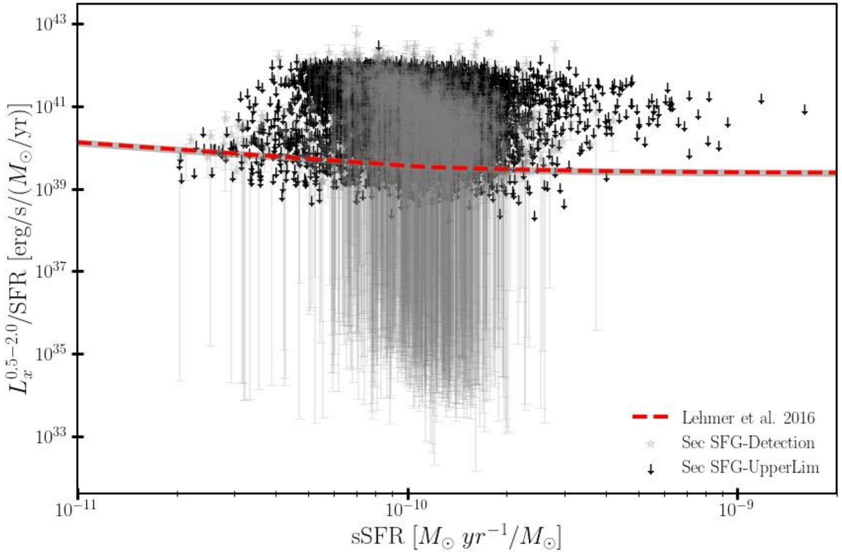
eROSITA provides us with the first **blind**, **unbiased**, X-ray survey of normal galaxies.

Our final sample-eRASS1

Detections
1403

Upper Limits
15021





~ 90 % of the available data → Upper Limits !

Maximum Likelihood fitting method

Quantities that we want to fit: x,y

For each galaxy we have:

- $x_{gal} = x_{gal}^{intrin} + \eta_{gal}\ ,\ y_{gal} = y_{gal}^{intrin} + \zeta_{gal}$
- Assuming a linear model with intrinsic scatter we have: $y_{gal}^{intrin} = a x_{gal}^{intrin} + b + \varepsilon(x_{gal}^{intrin})$

Assuming independent measurements and following a Bayesian approach we have the posterior probability of the model parameters:

$$P(\overrightarrow{p}|x_{gal}, y_{gal}) = \pi(\overrightarrow{p}) \prod_{gal} P(x_{gal}, y_{gal}|\overrightarrow{p})$$

where: $\pi(\overrightarrow{p}) = \pi(a)\pi(b)\pi(\epsilon)$ is the prior.

Considering that: i) data depends only on the measurement errors, ii) intrinsic values depends only on the intrinsic model, iii) the errors on x,y are independent we can calculate the Likelihood.

- Each point can be described by a different distribution.
- The distribution can be of any kind (not only known distributions: Gaussian, Poisson etc.)
- The model parameters are estimated by sampling the posterior distribution using MCMC technique.

Kouroumpatzakis et al. 2020, MNRAS,494,5967

Application of the Maximum Likelihood fitting method

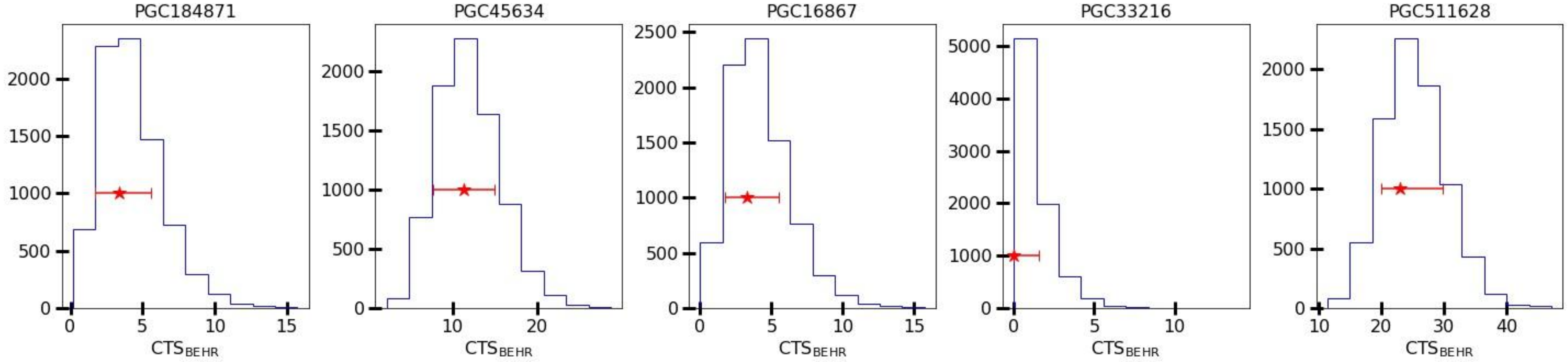
Assumed linear model:

$$log(L_x) = alog(SFR) + b + \sigma$$

For the application of the fitting method we need the error distributions of Lx for each data point within the sample.

To find that we use BEHR code (see D. Van Dyk et al. 2001,T. Park et al. 2006)

- ➢ BEHR is a code which calculates the Posterior probability of the intensity for extremely faint sources based on Bayesian approach.
- ➢ It accounts for the source and the background counts assuming Poisson distributions for both.

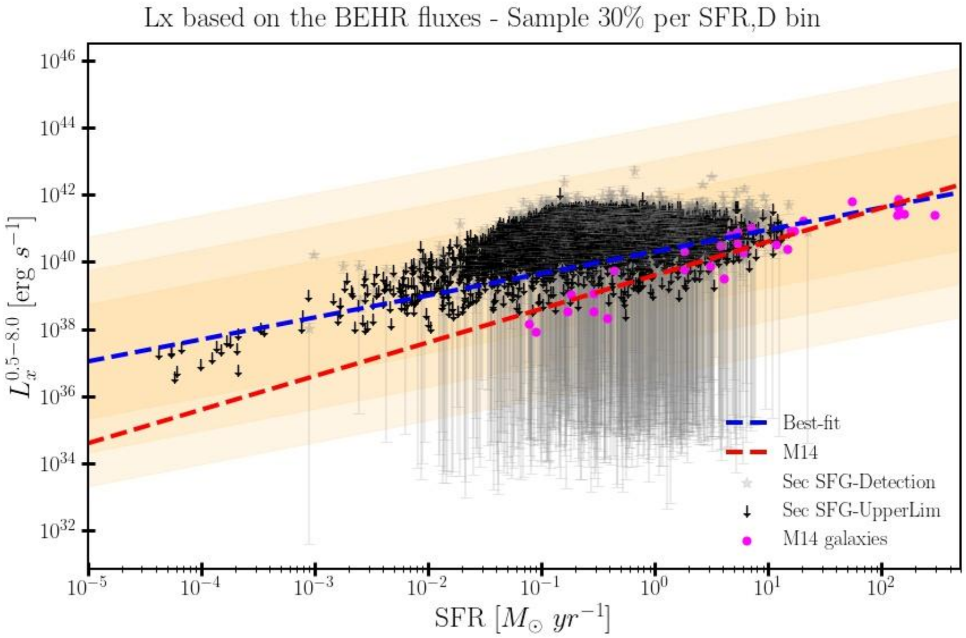


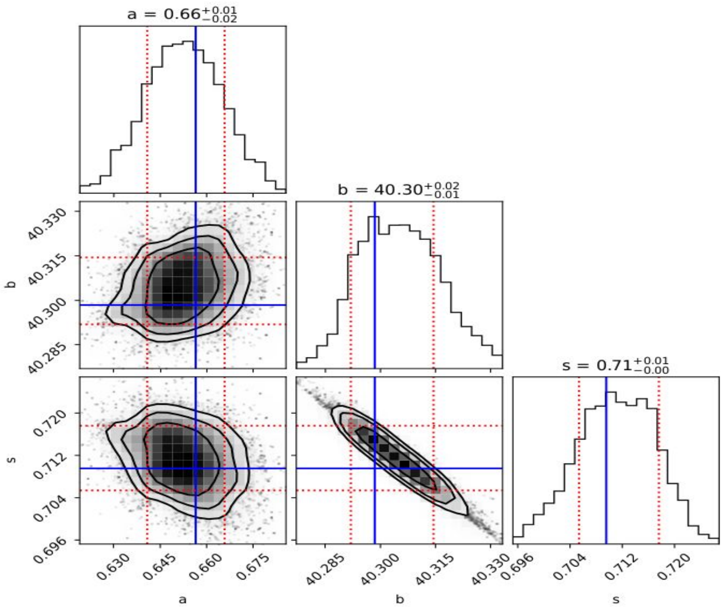
Application of the Maximum Likelihood fitting method

Application of the method to eRASS1 data fitting the scaling relation L_x - SFR

Assumed linear model:

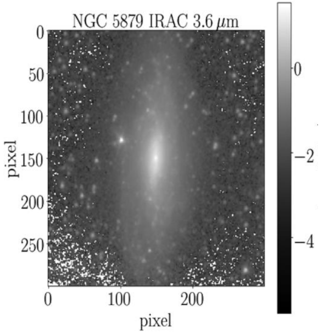
$$log(L_x) = alog(SFR) + b + \sigma$$

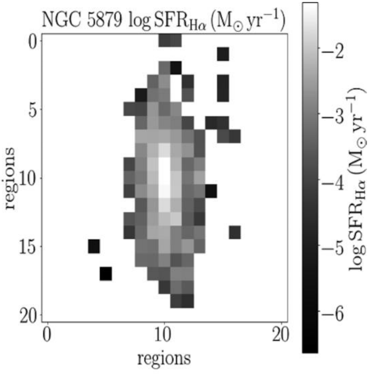


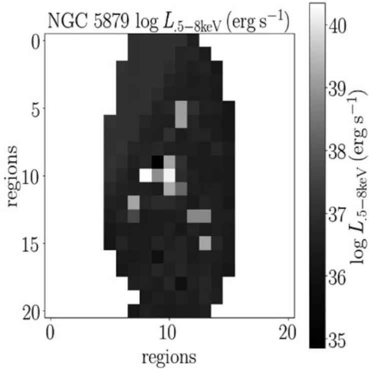


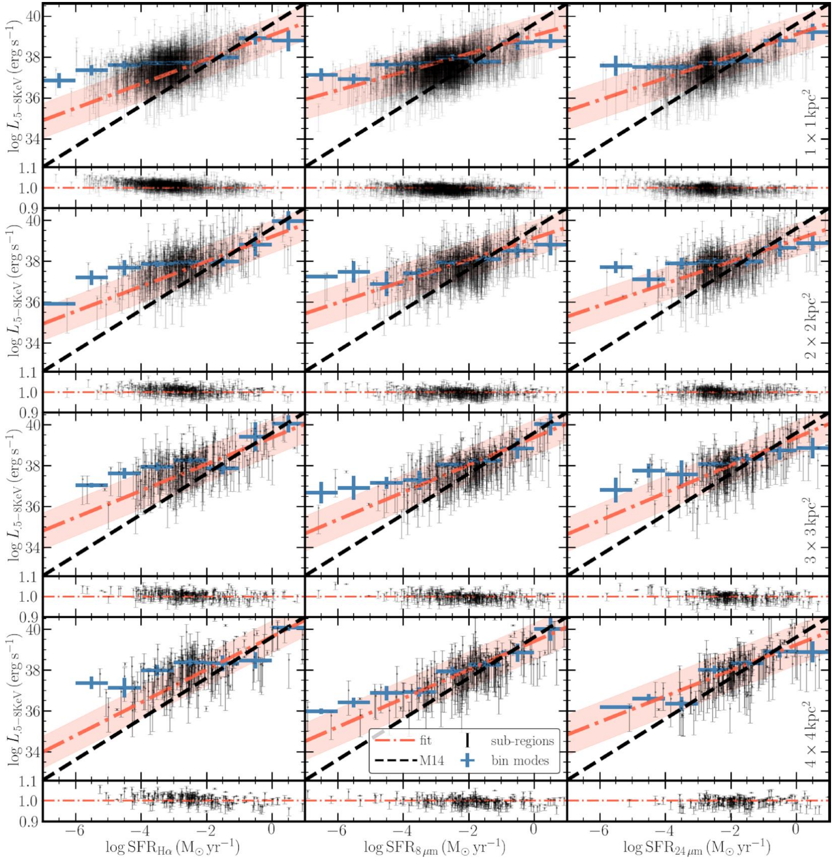
Application of the Maximum Likelihood fitting method

Application of the method to other works









Kouroumpatzakis et al. 2020, MNRAS,494,5967

Take home message

★ A Maximum Likelihood fit method that:
  ○ Produces unbiased scaling relations since it accounts for both, Detections & Upper Limits
  ○ Very useful on data from all-sky blind surveys (e.g. eROSITA), Chandra Source Catalog

★ Can handle data points described from different error distributions.

★ Can handle Upper limits in both x & y

★ It accounts for the intrinsic scatter.