Extragalactic Universe:
Star formation activity of galaxies

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instytut kategorii A+, JRC collaboration partner

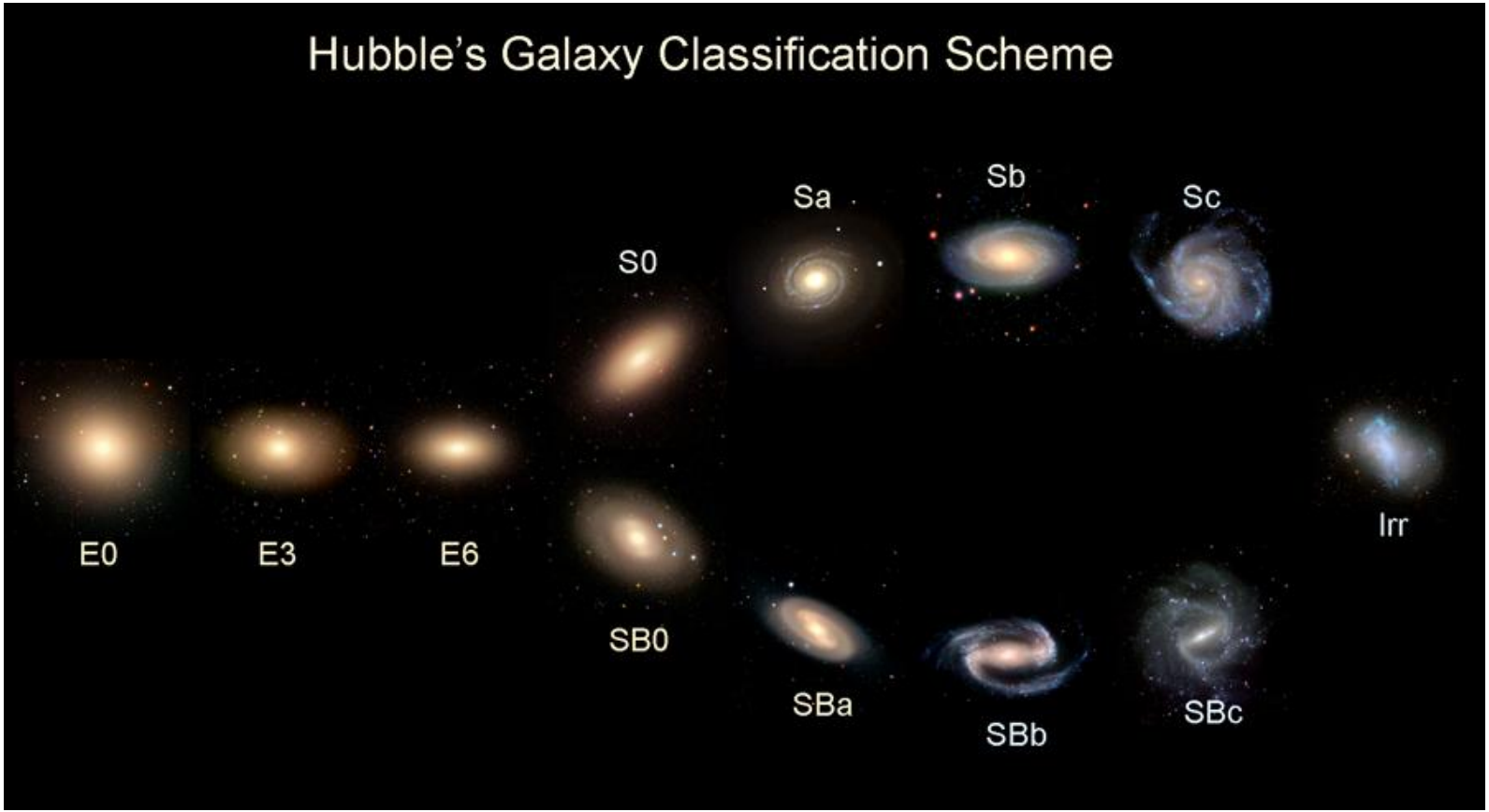
Extra-galactic universe, a "relatively" new field

M31, “Andromeda”

Edwin P. Hubble

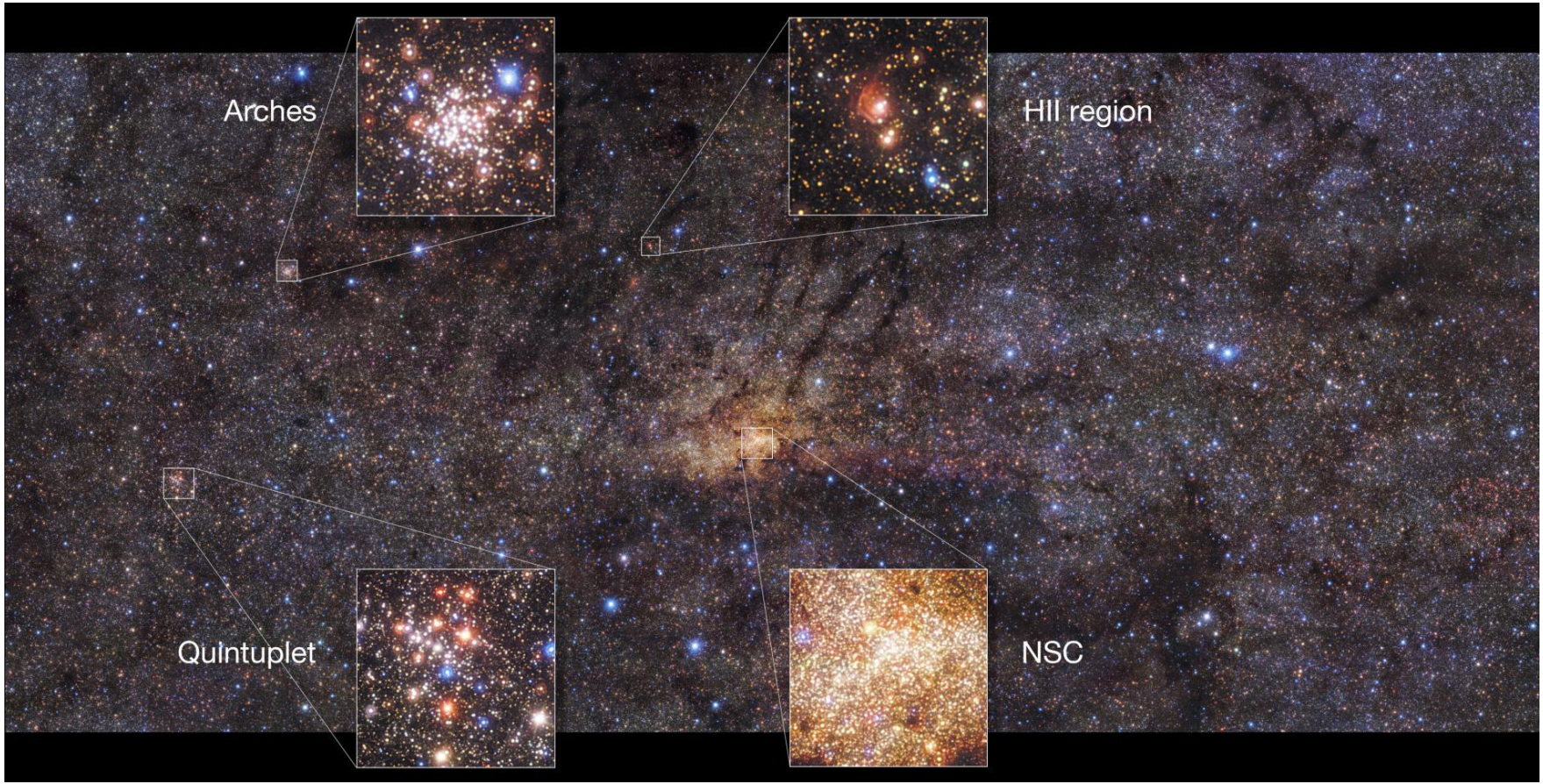
Classification of galaxies

Credits: IOWA university



Star formation in galaxies

Credits: ESO



Definition

The SFR is by definition the mass that is turned into stars per unit time. The unit of choice is usually solar masses per year ($M_\odot$/yr). It is also useful to define the SFR density, in volume or surface density, respectively ψ (in $M_\odot$ kpc^{-3} yr^{-1}) and Σ (in $M_\odot$ kpc^{-2} yr^{-1}).

SFR history

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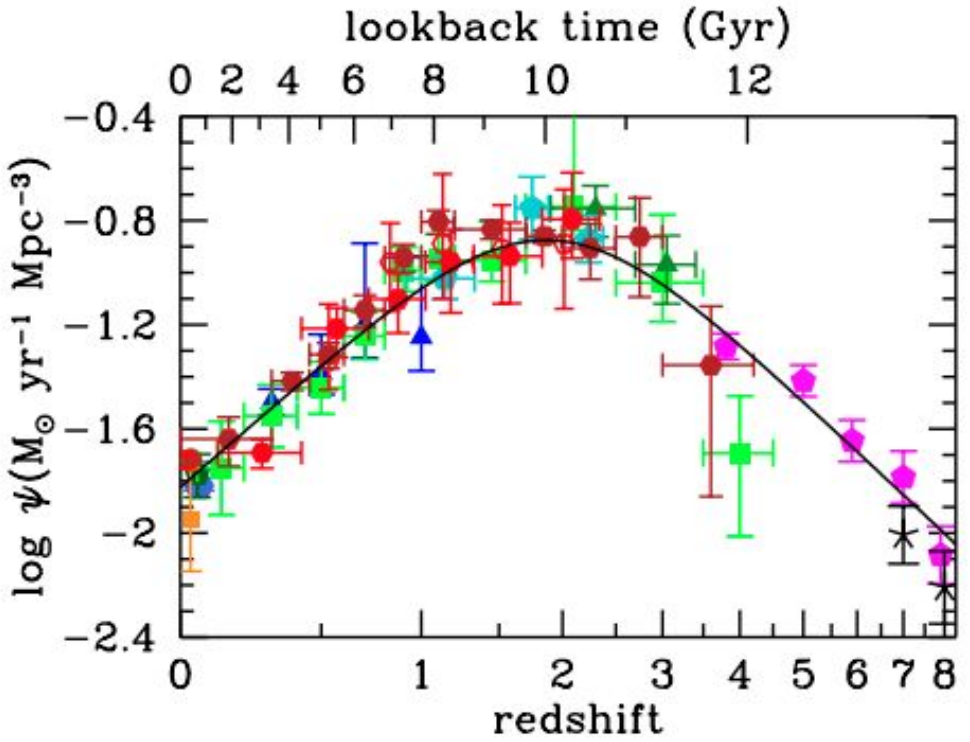

Piero Madau and Mark Dickinson.

SFR history

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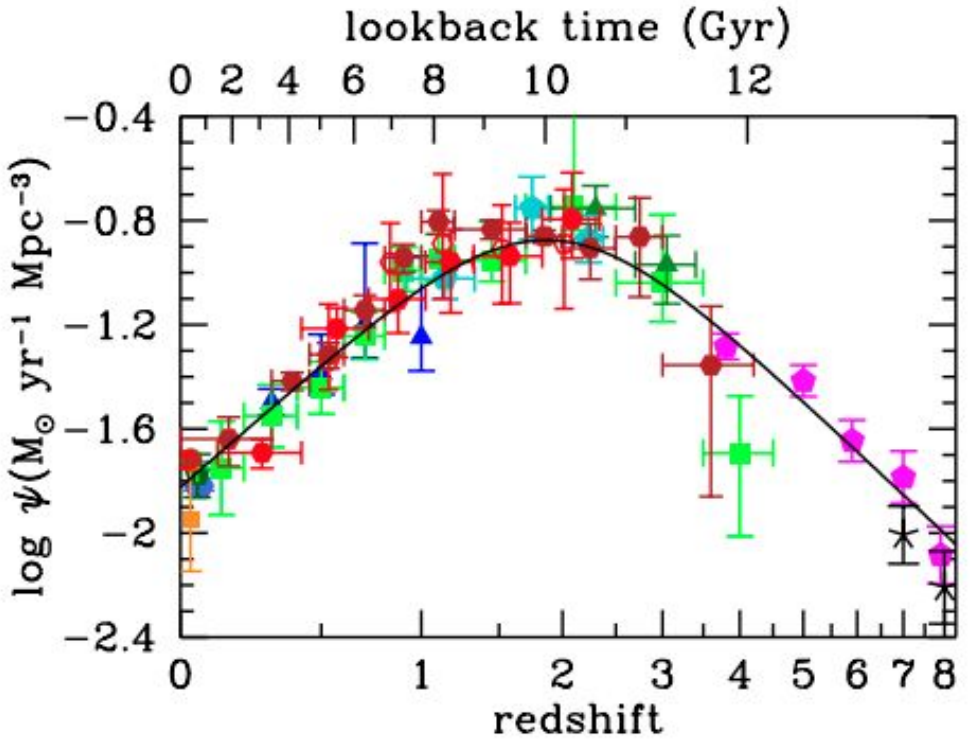
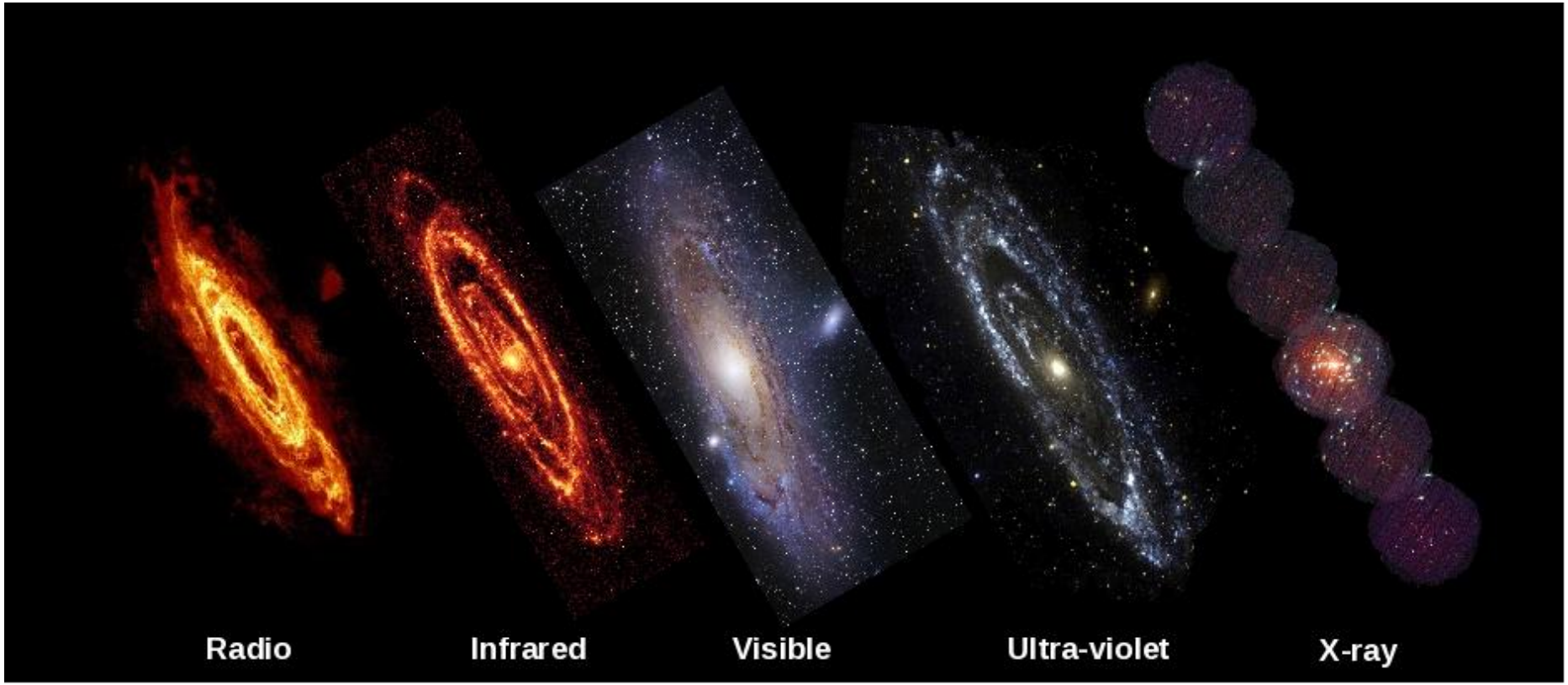


Piero Madau and Mark Dickinson.

How to have an idea on the galaxies properties?

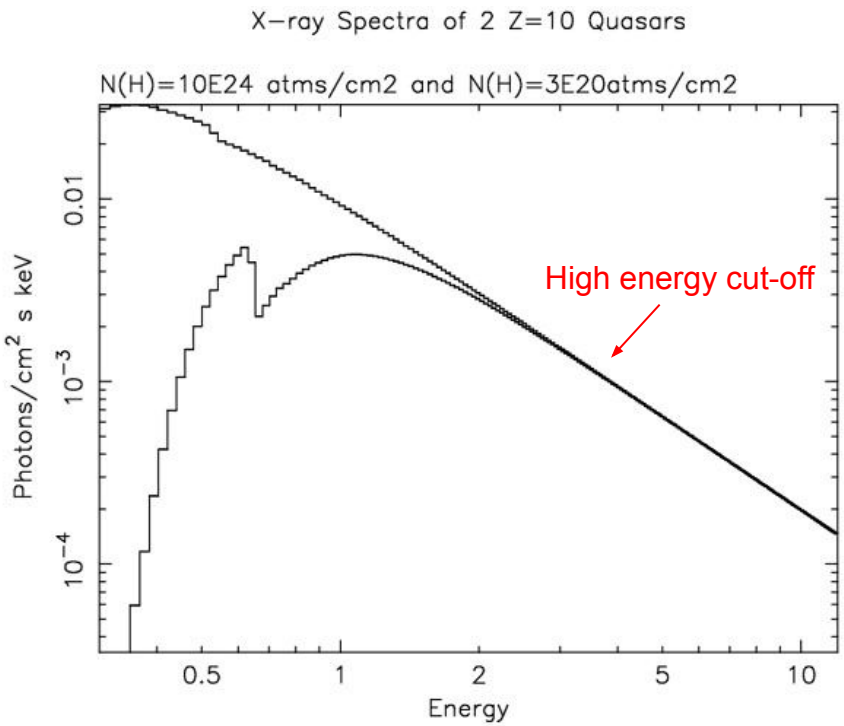
Is not so simple…

Credits: ESO

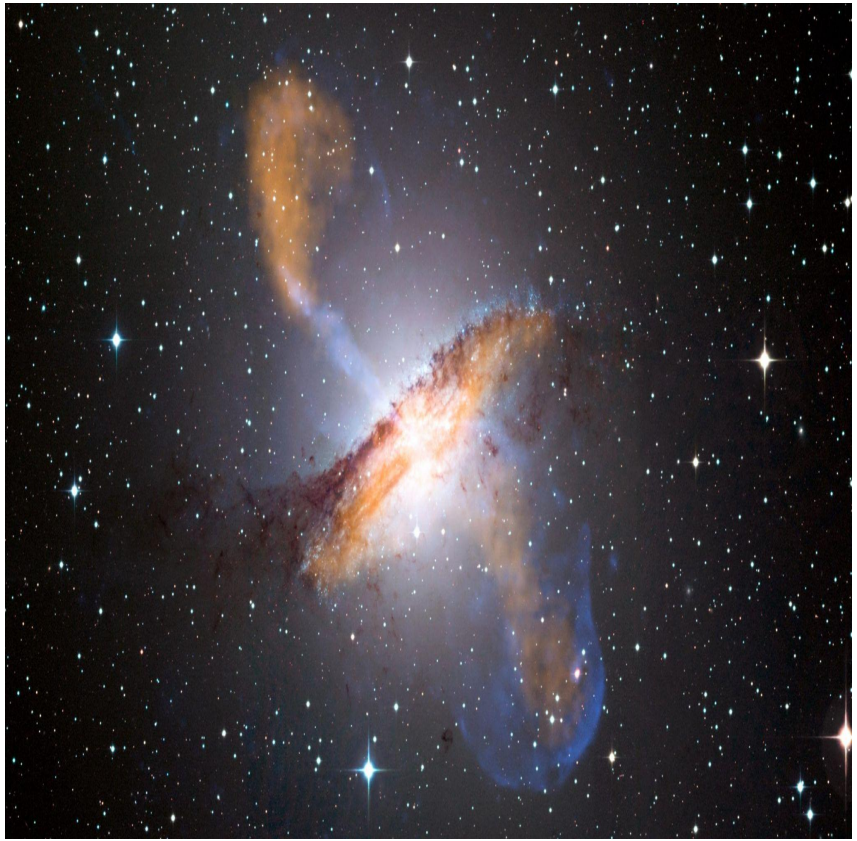


X-ray regime: AGN, X-ray binaries and hot gas

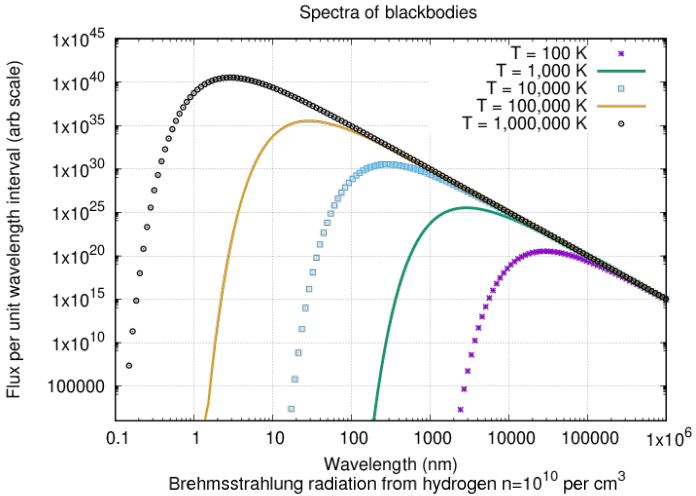
X-ray regime: AGN



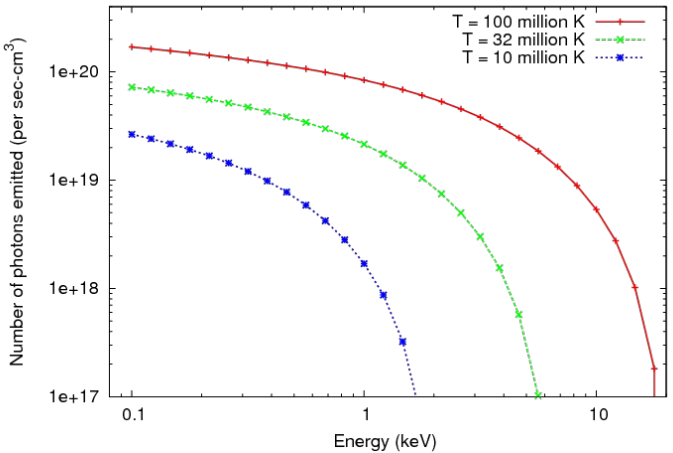
Credits: Mushotzky R. F.

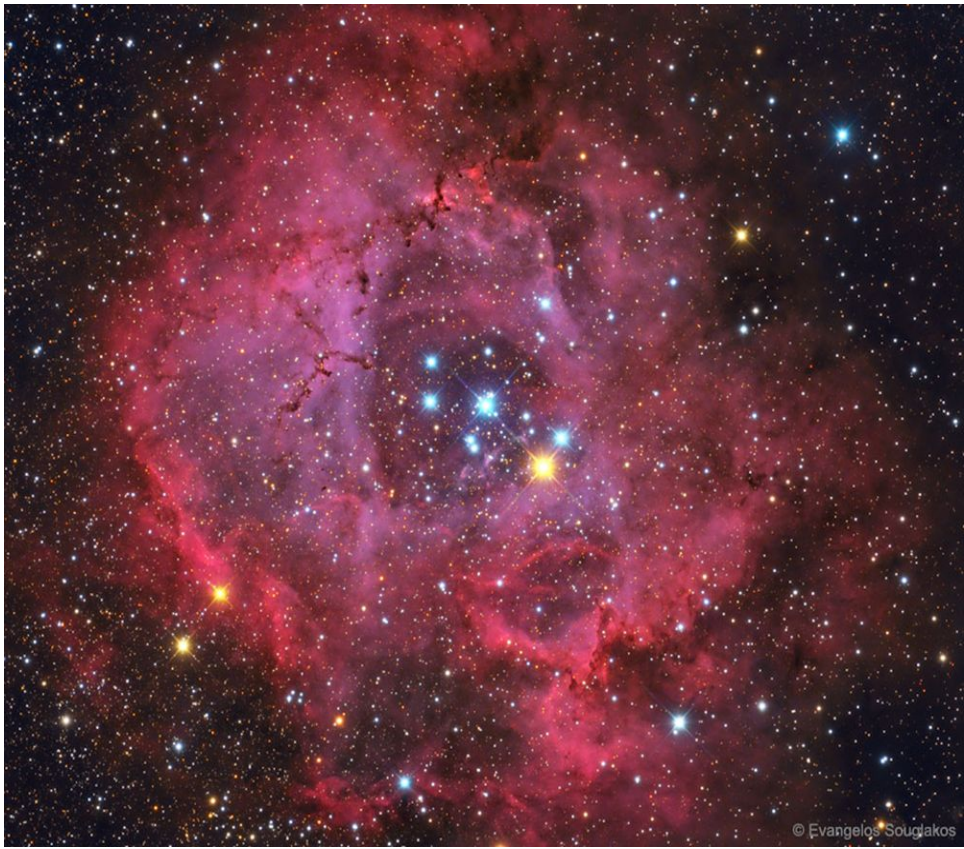


X-ray regime: hot gas



Brehmsstrahlung radiation from hydrogen $n=10^{10}$ per cm^3

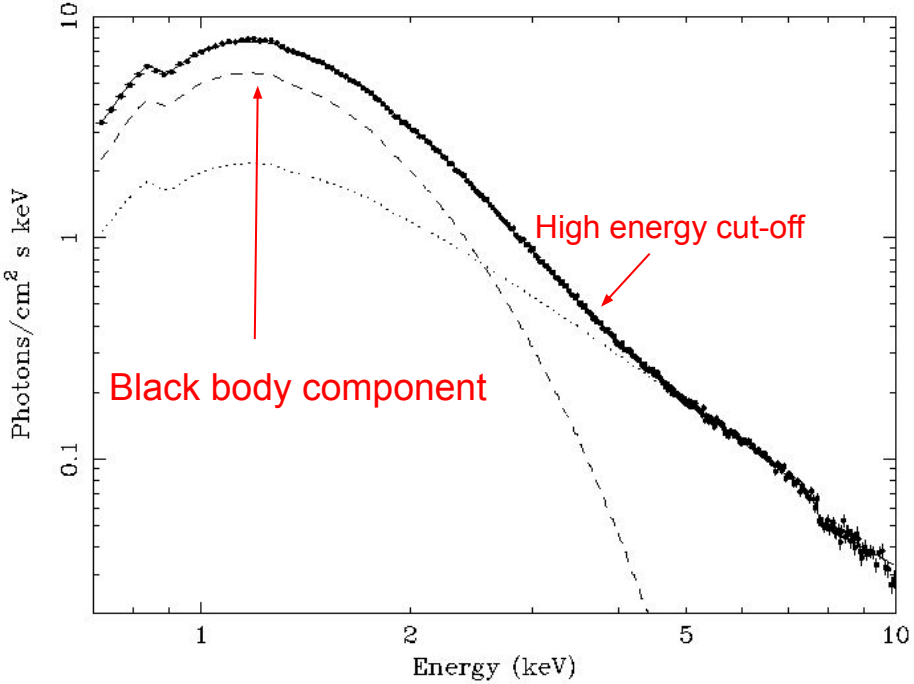




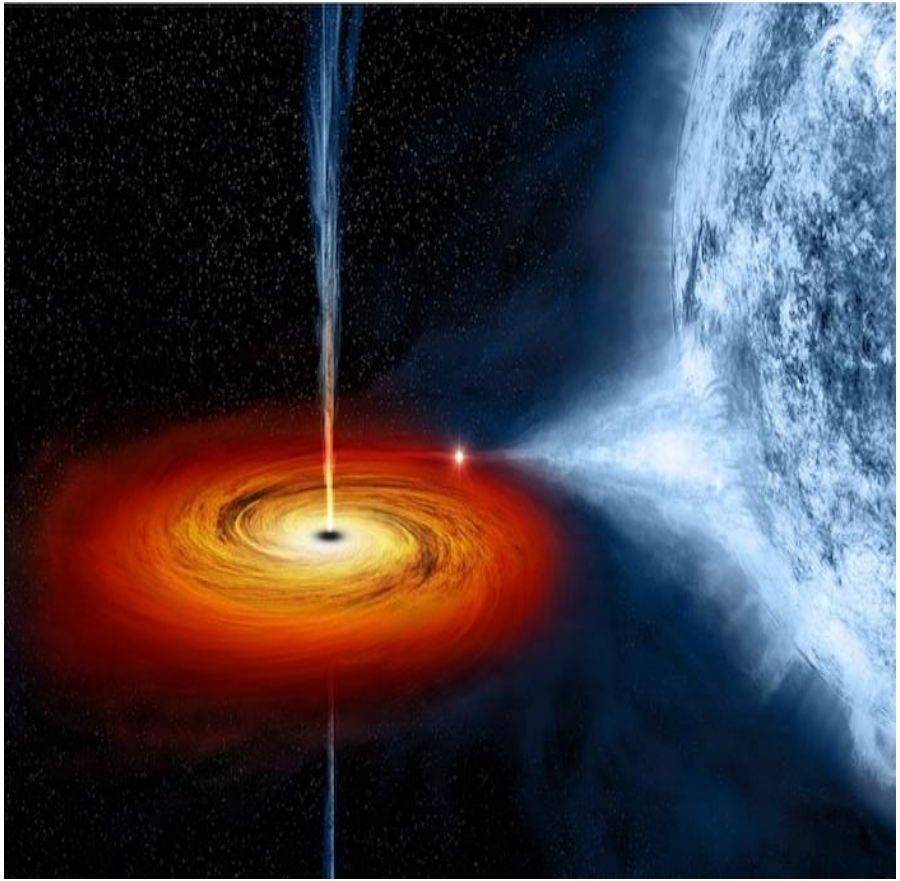
$T = 10^{6\text{-}7}K$

Credits: Michael Richmond

X-ray regime: X-ray binaries

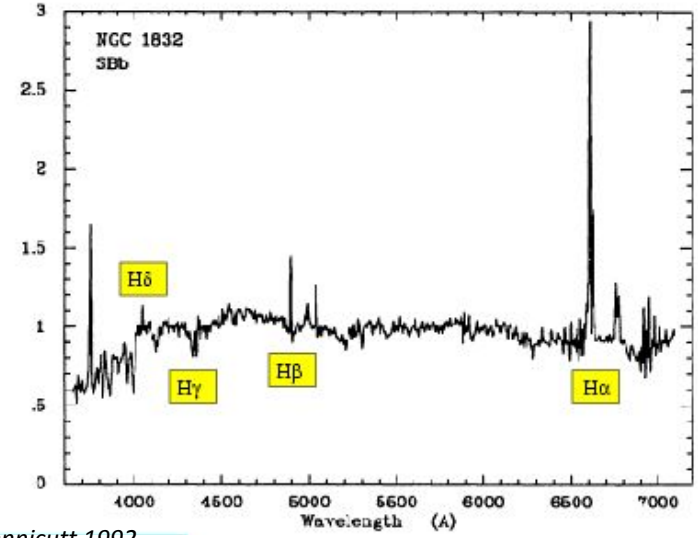


Credits: Dotani et al. 1997

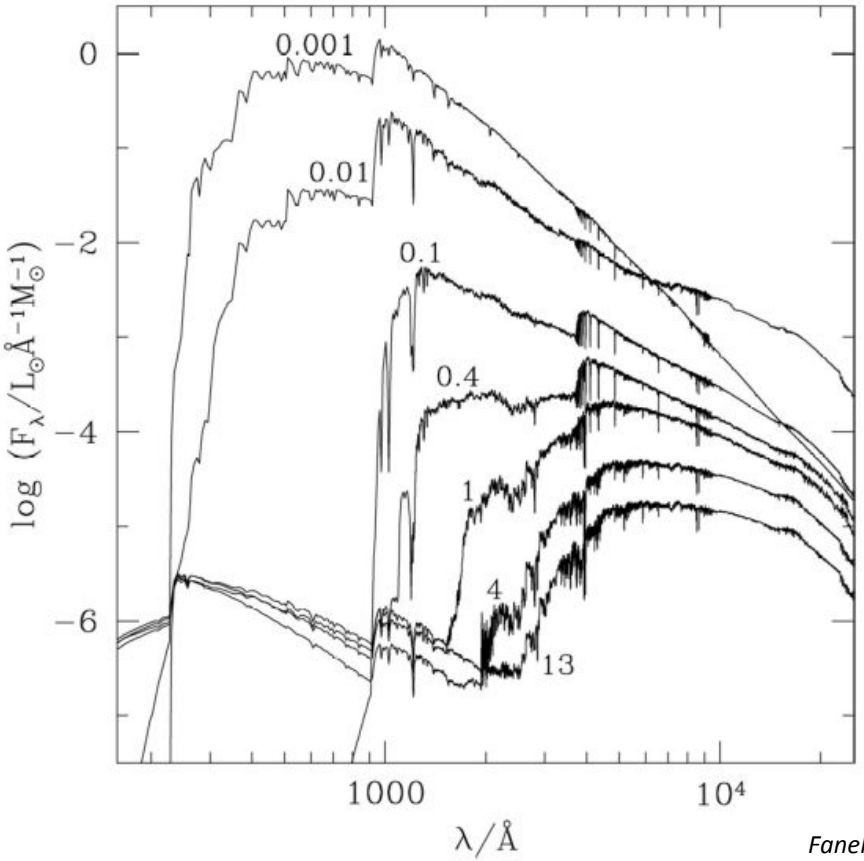


UV/OPT/NIR regime: stellar population

- Incredibly useful for SFR estimation, as directly trace the stellar population content of the galaxy.
- Very much attenuated by dust.

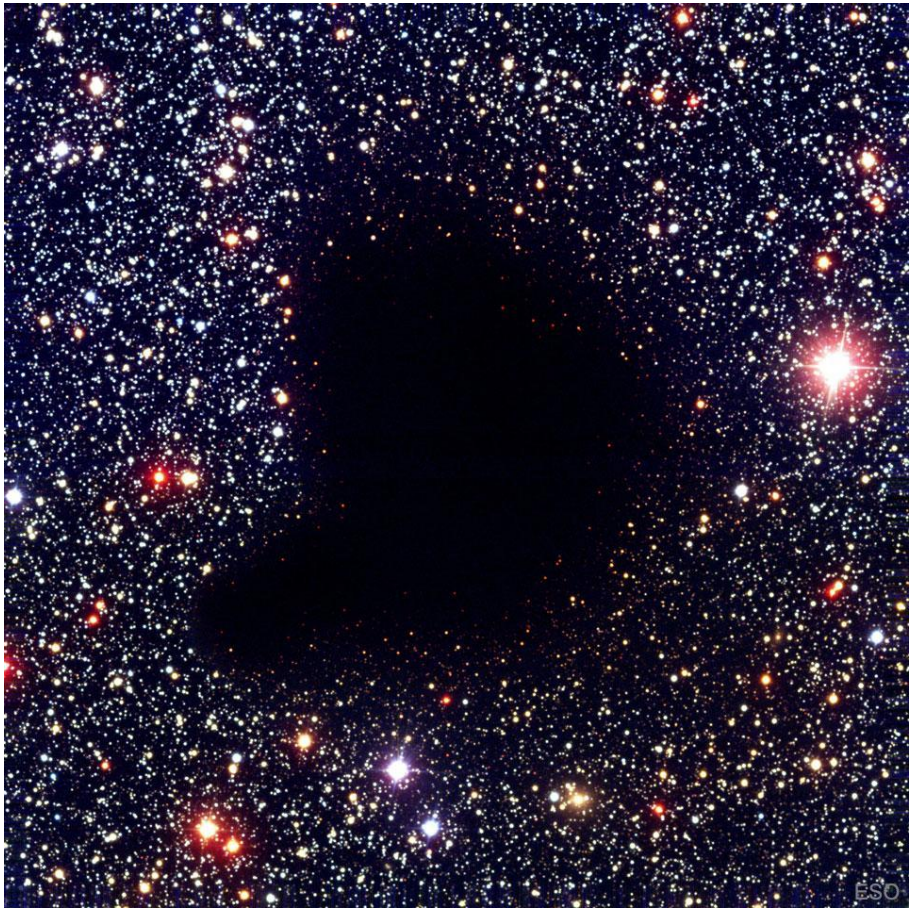


Kennicutt 1992



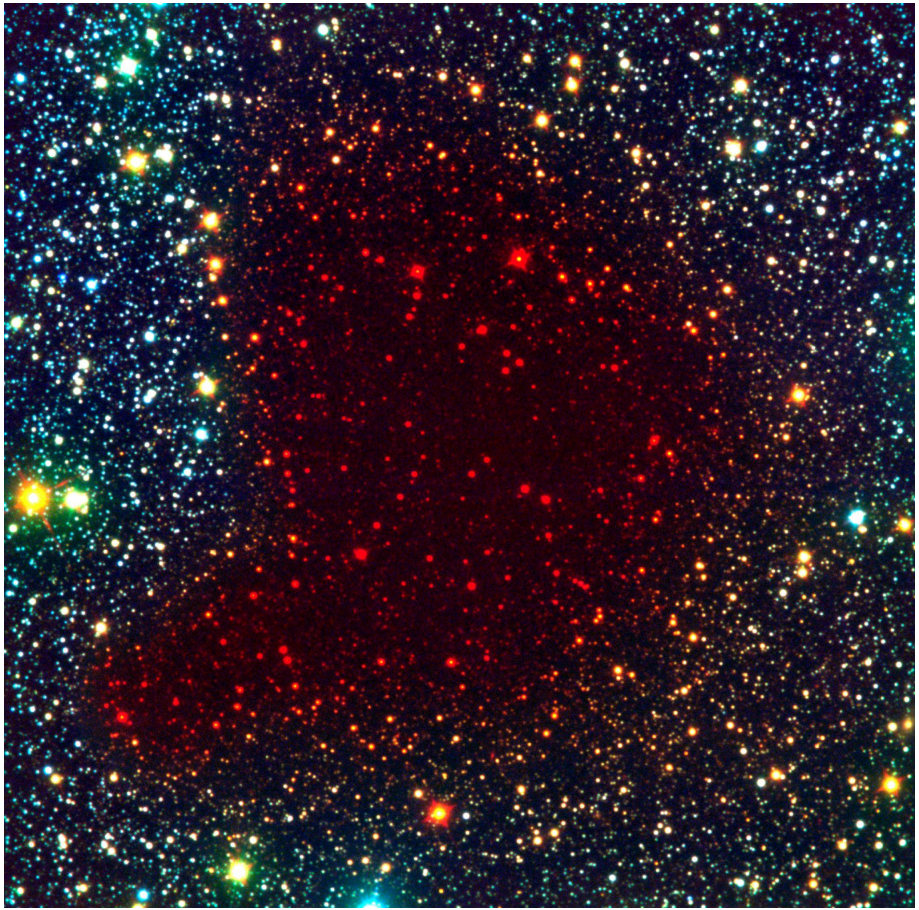
Fanelli et al. 1992

MIR and FIR regime: dust and PAH



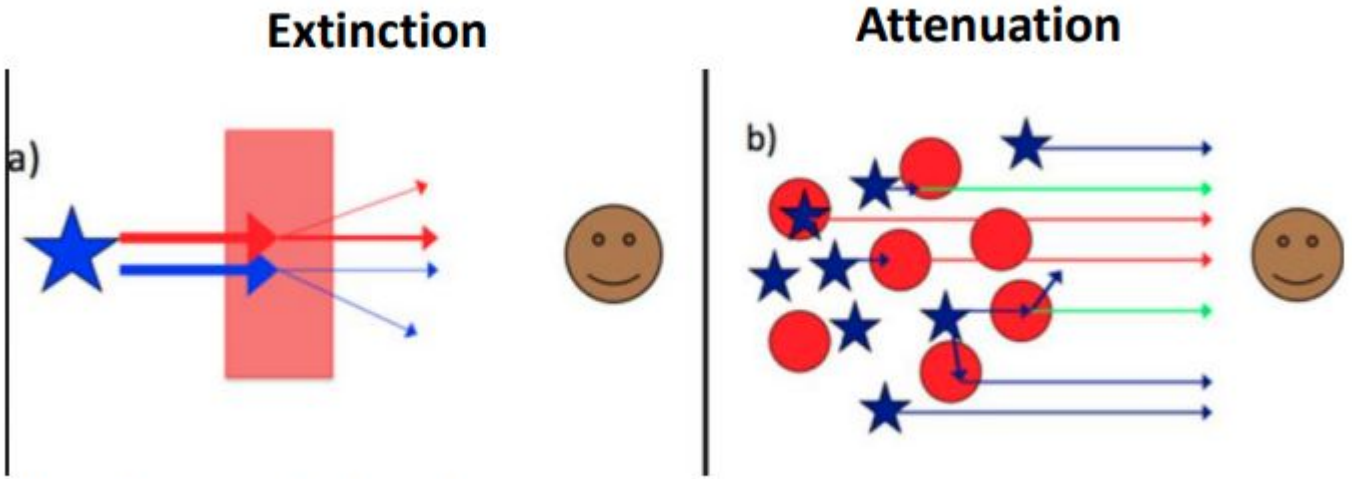
Dark nebula Barnard 68
in the Milky Way (ESO)

MIR and FIR regime: dust and PAH



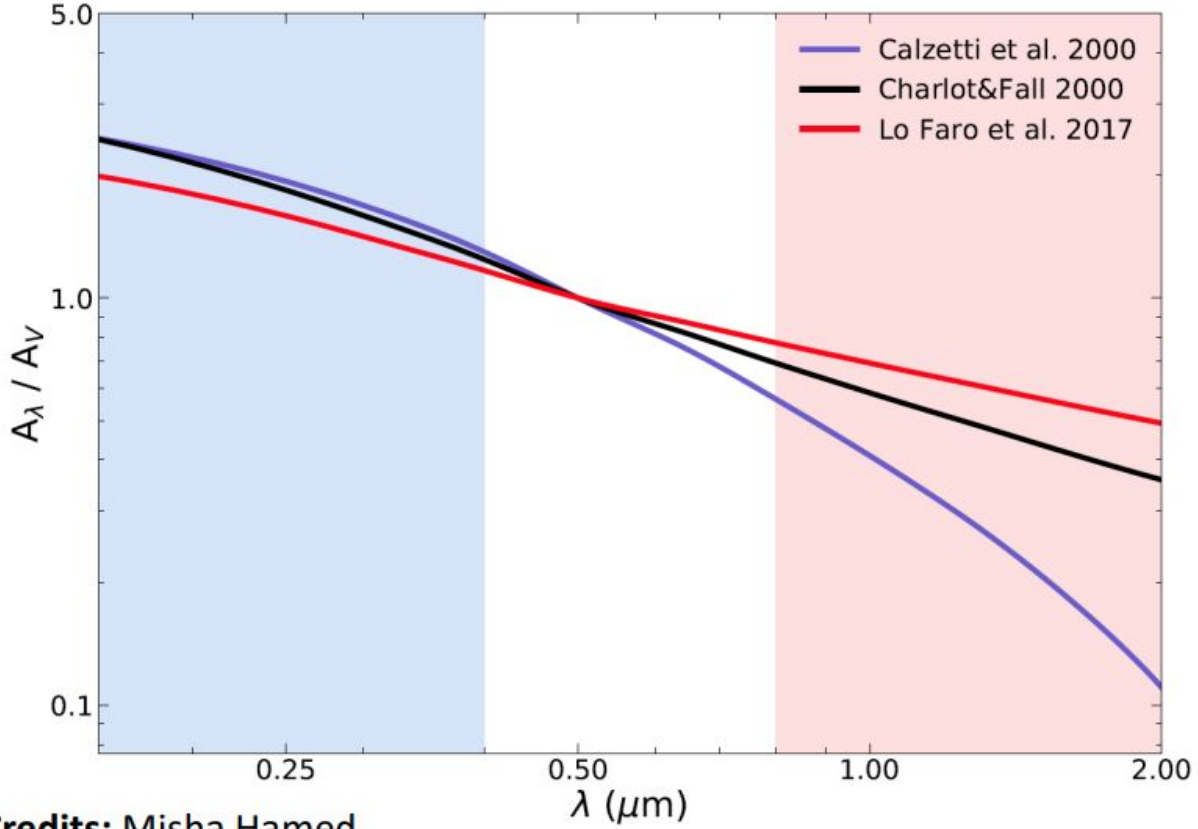
Dark nebula Barnard 68
in the Milky Way (ESO)

Extinction vs Attenuation



Credits: Daniela Calzetti

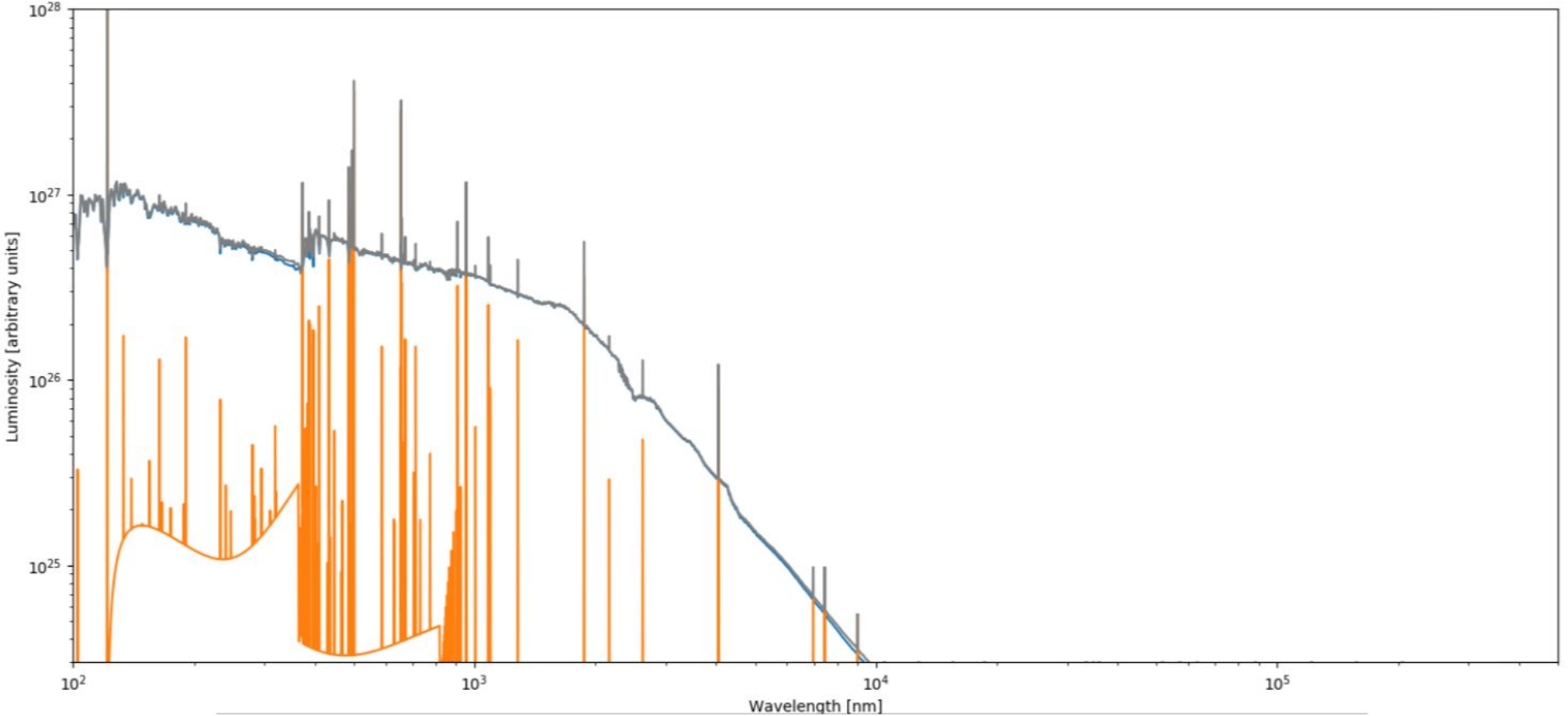
Attenuation laws



Credits: Misha Hamed

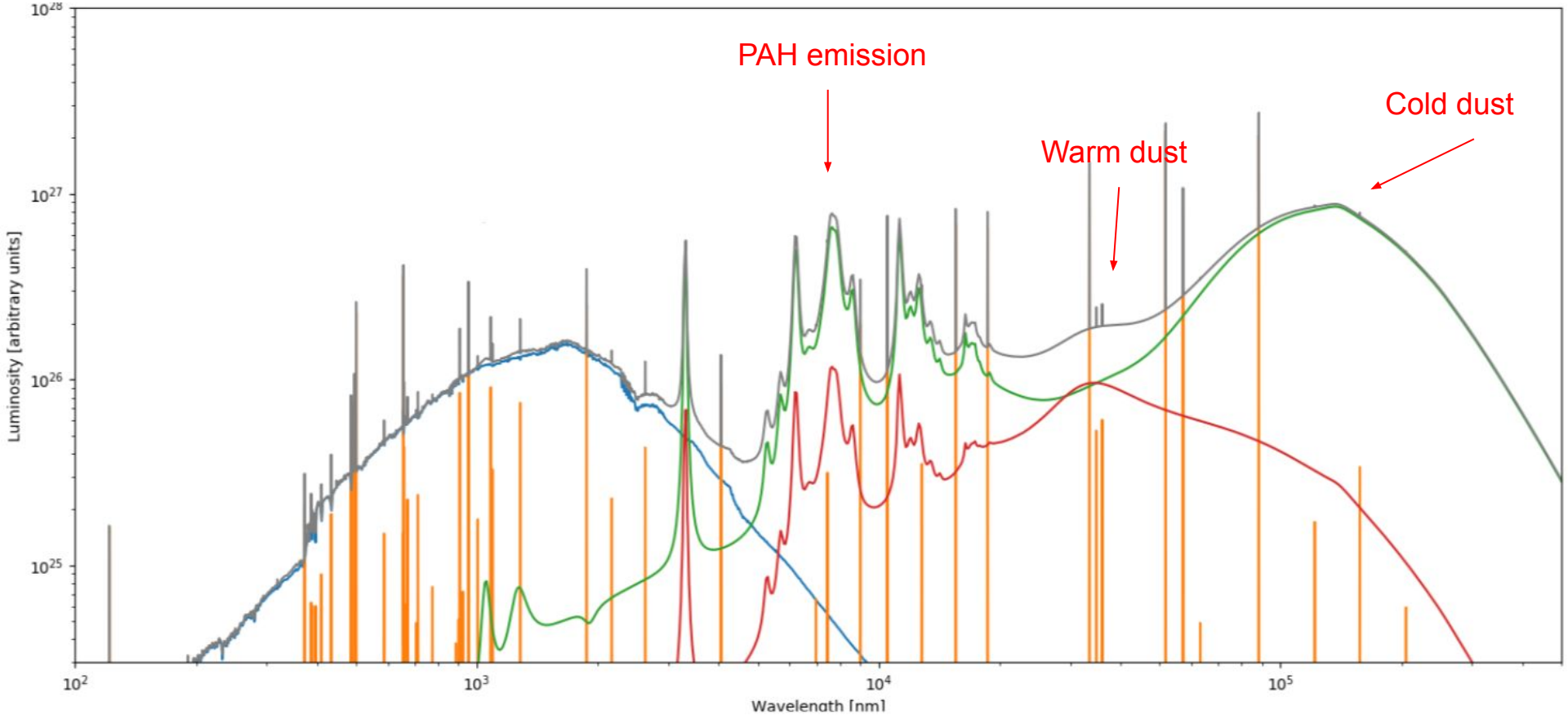
Dust emission

Credits: Misha Hamed

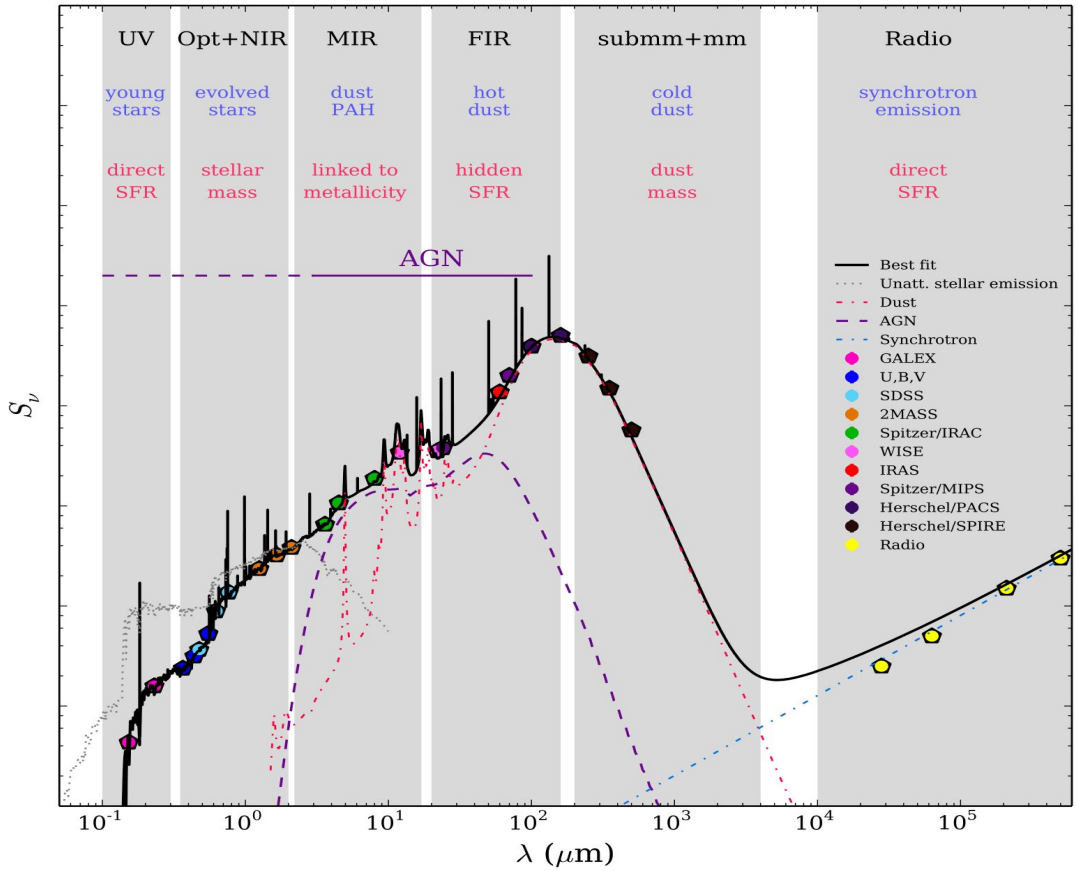


Dust emission

Credits: Misha Hamed



To summarize



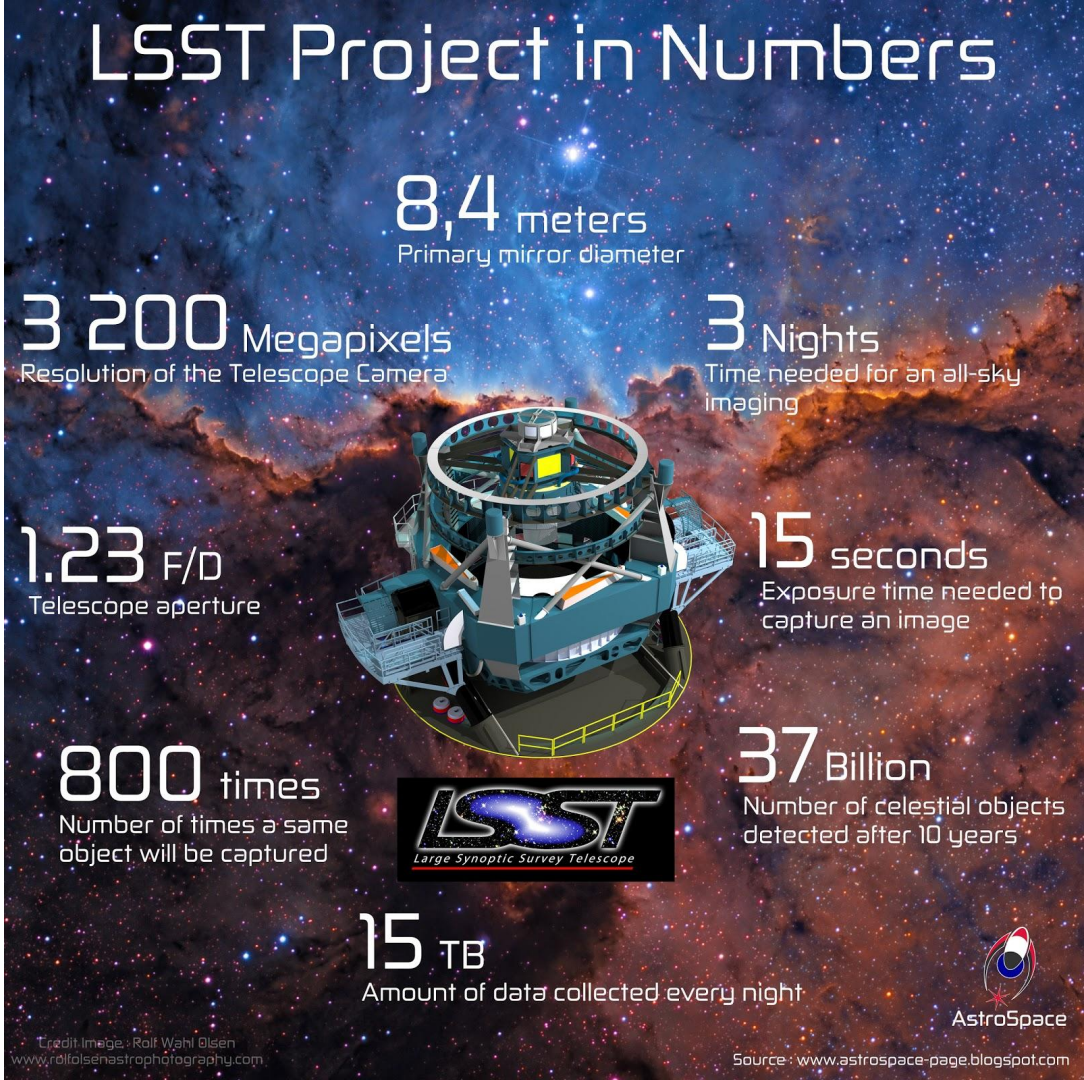
Credits: Misha Hamed

Estimation of galaxies physical properties using LSST data

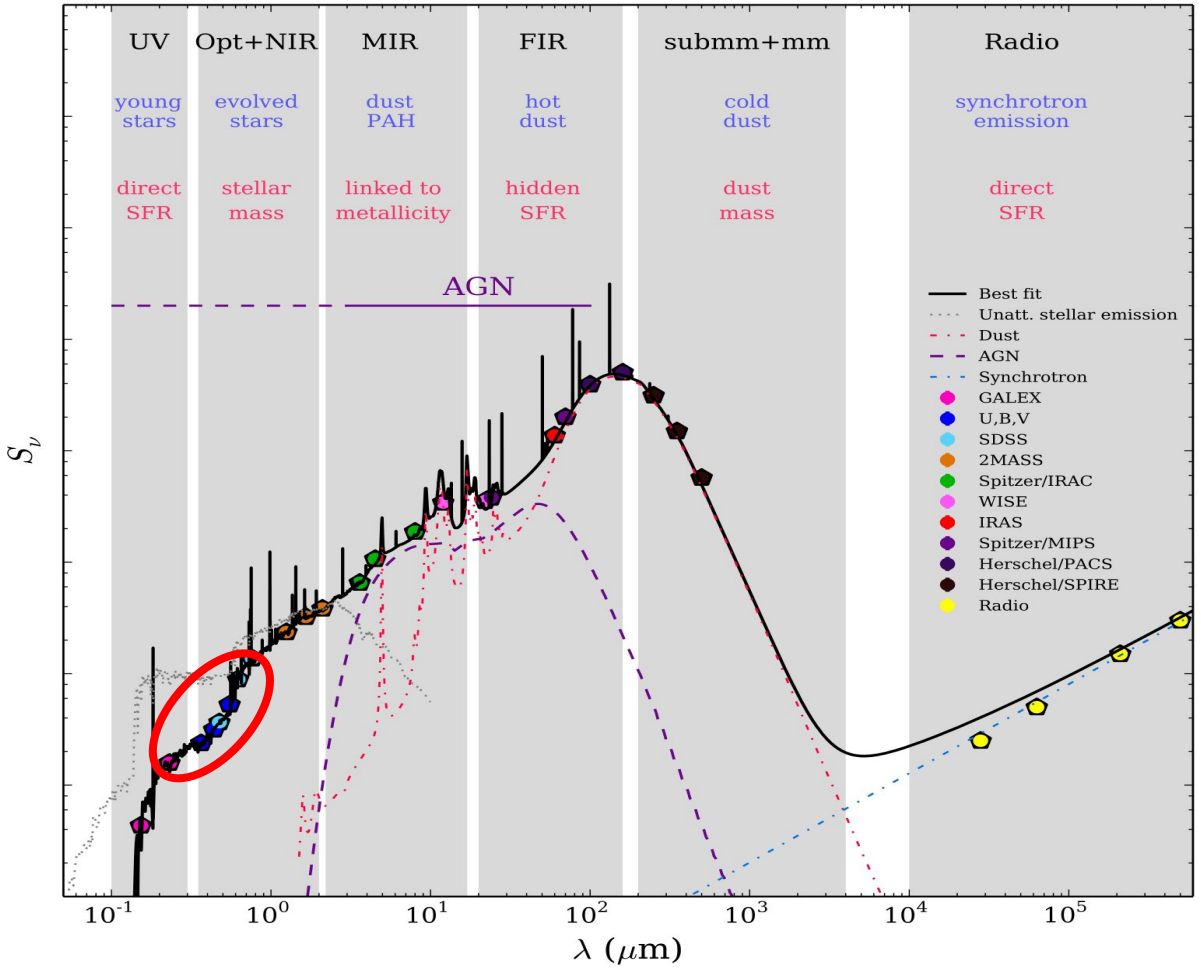
Riccio, G. et al. 2021

Large Survey of Space and Time

- Will observe about 18,000 deg^2 of the southern sky with 6 filters.
- the 5σ (SNR greater than 5) magnitude limits are expected to be r<24.5 for single images, and r<27.8 for the full stacked data.



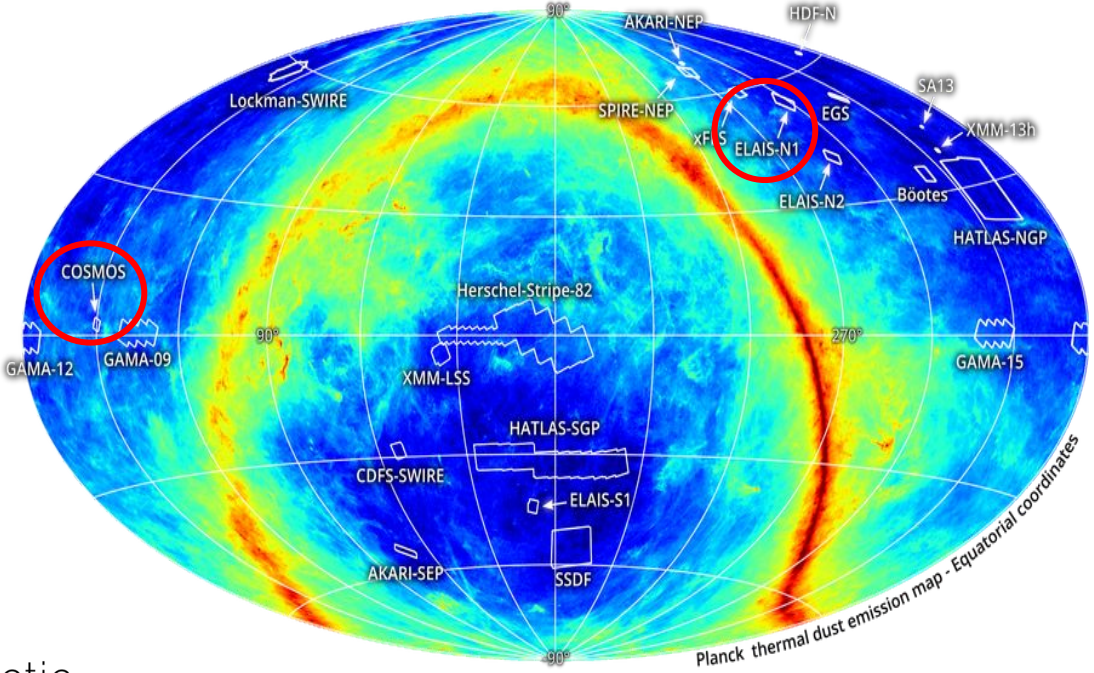
Why LSST?



M. Hamed

Data

We select a sample of 65.889 galaxies over the redshift range 0<z<2.5 from ELAIS-N1 and COSMOS fields of the Herschel Extragalactic Legacy Project (HELP) survey.



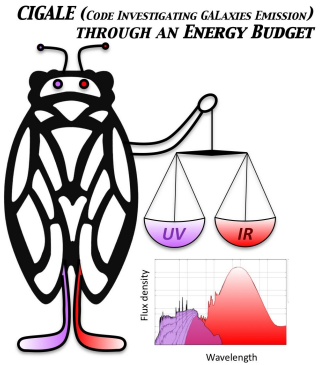
HELP

Herschel Extragalactic Legacy Project

Shirley et al. 2019

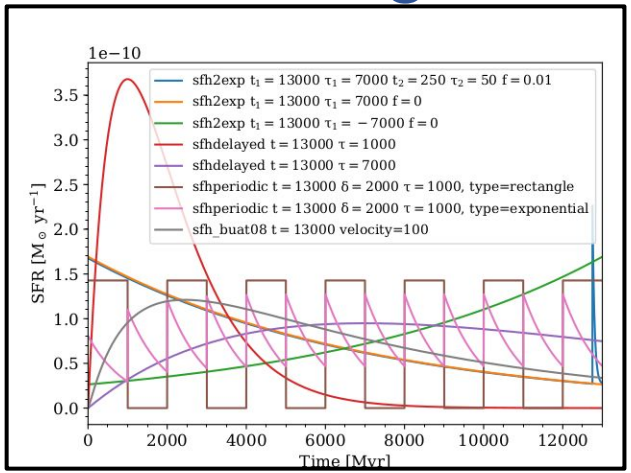
SED fitting with CIGALE

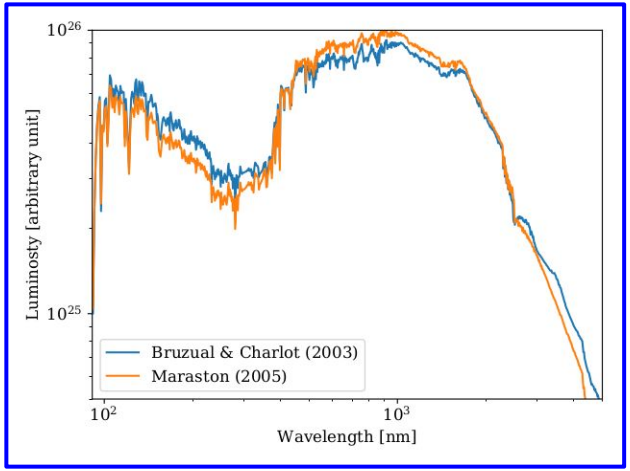
To perform the SED fitting we use the Code Investigating GALaxy Emission (CIGALE) tool (Boquien et al. 2019).

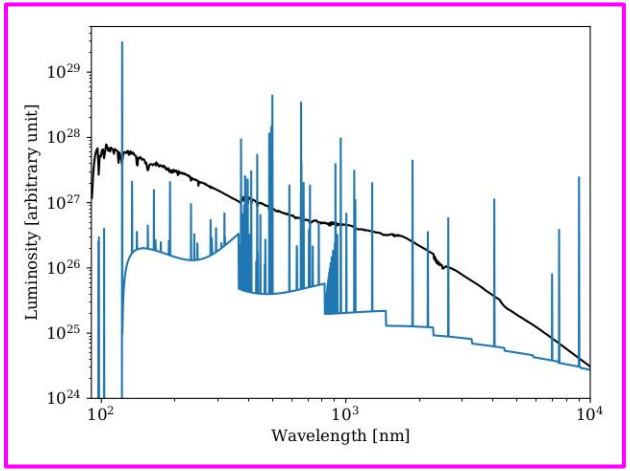


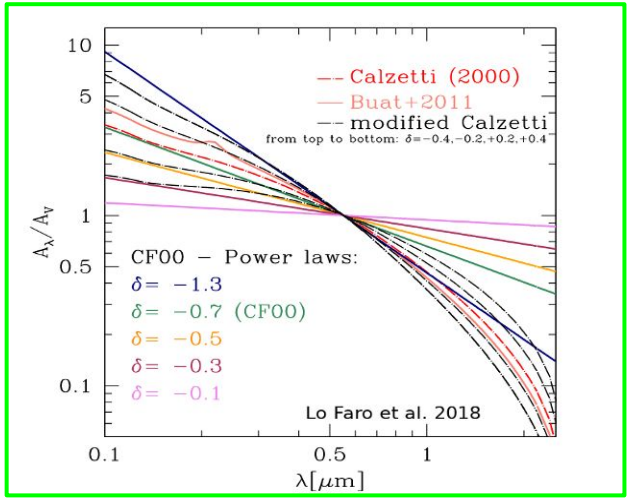
SED fitting with CIGALE

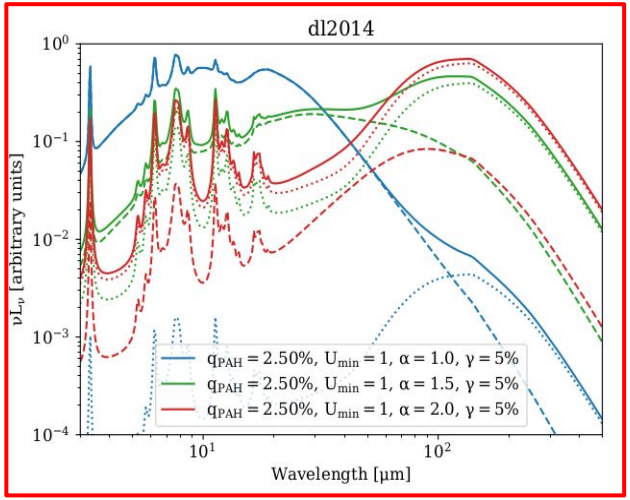
SFH+SSP+nebular+dust attenuation+dust emission+AGN

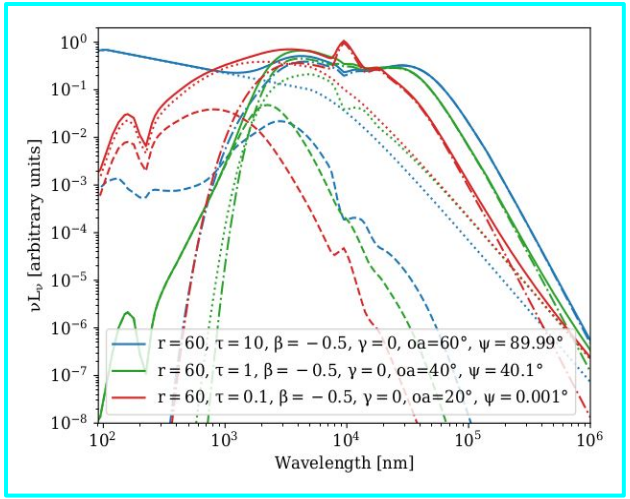


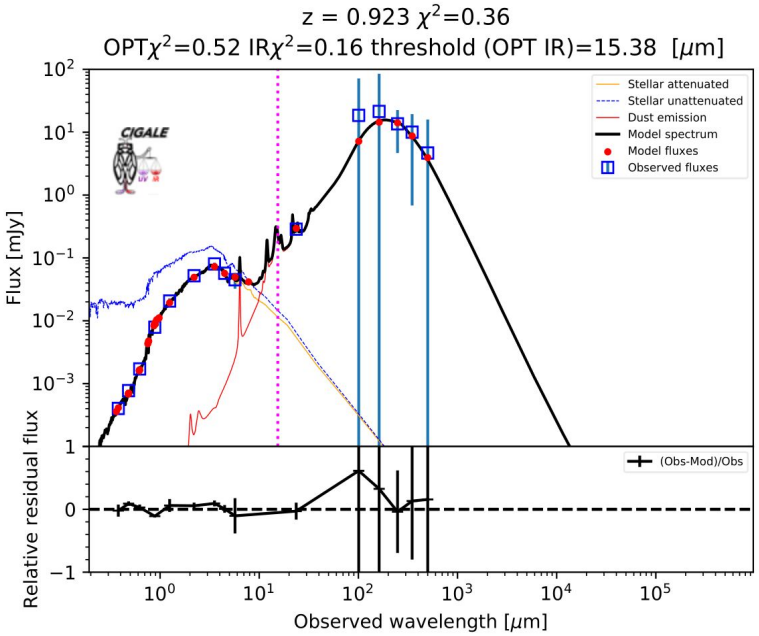




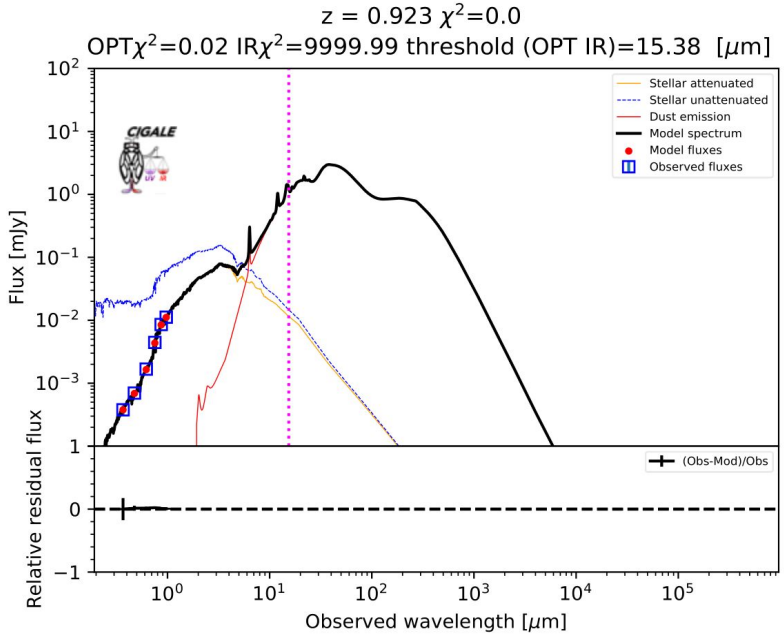






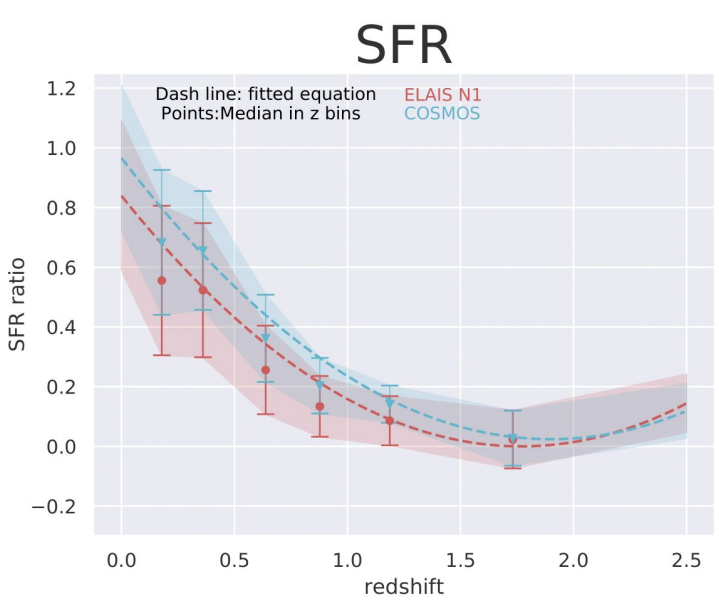


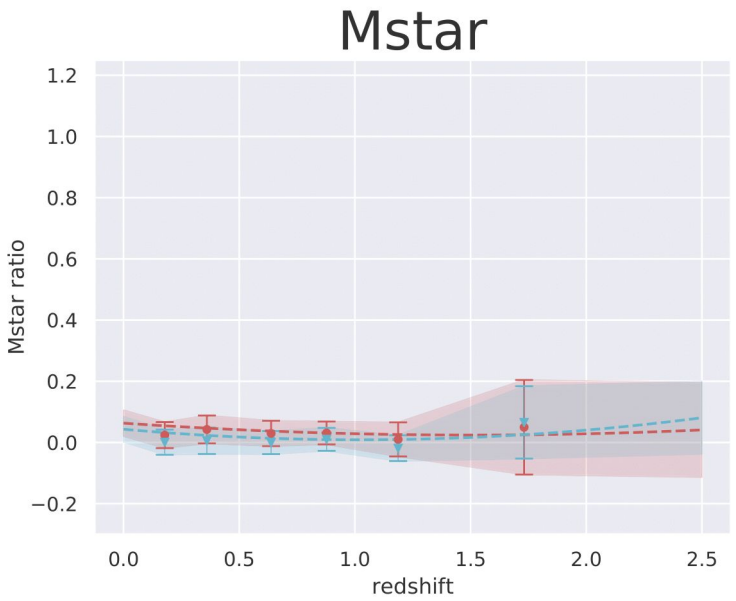
UV-to-FIR: $SFR = 37.7\, M_{\odot} yr^{-1}$, $M_{star} = 6.05 \cdot 10^{10} M_{\odot}$



LSST: $SFR = 68.9\, M_{\odot} yr^{-1}$, $M_{star} = 5.59 \cdot 10^{10} M_{\odot}$

How to quantify the differences?



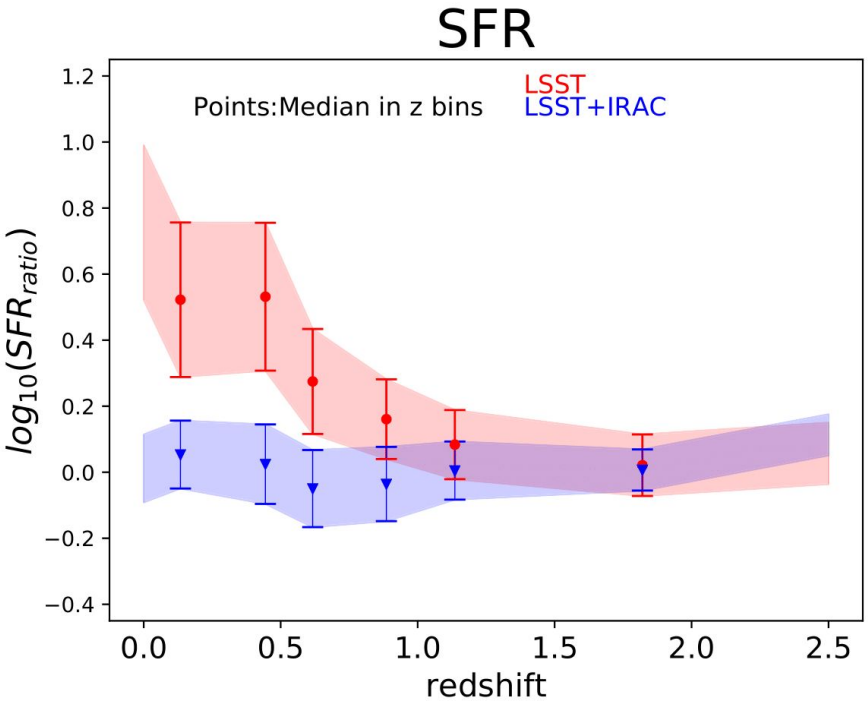


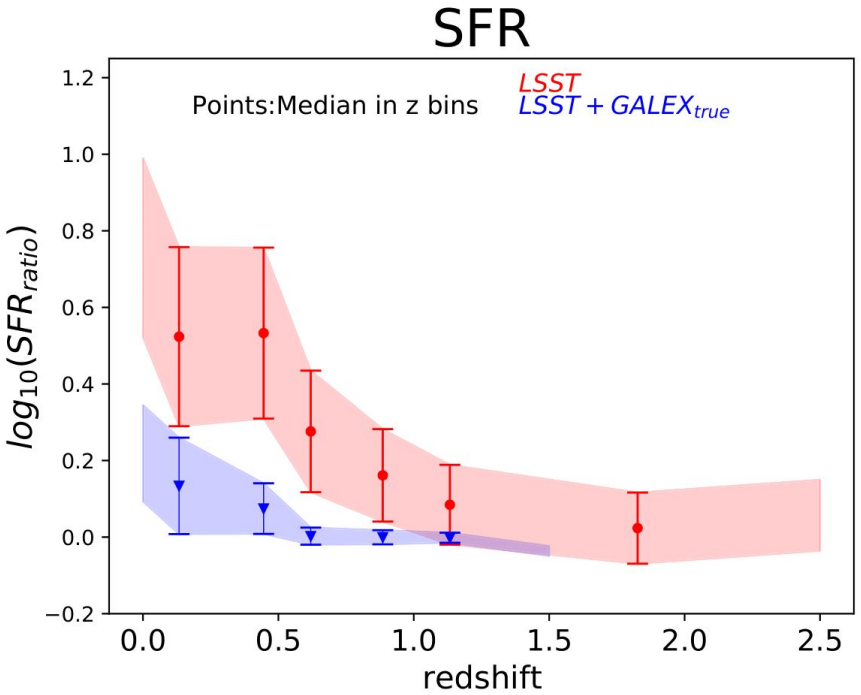
Correction formula for the SFR:

$$log_{10}\frac{SFR_{LSST}}{SFR_{real}} = 0.26 \cdot z^2 - 0.94 \cdot z + 0.87$$

Riccio et al. 2021

How to correct the difference?



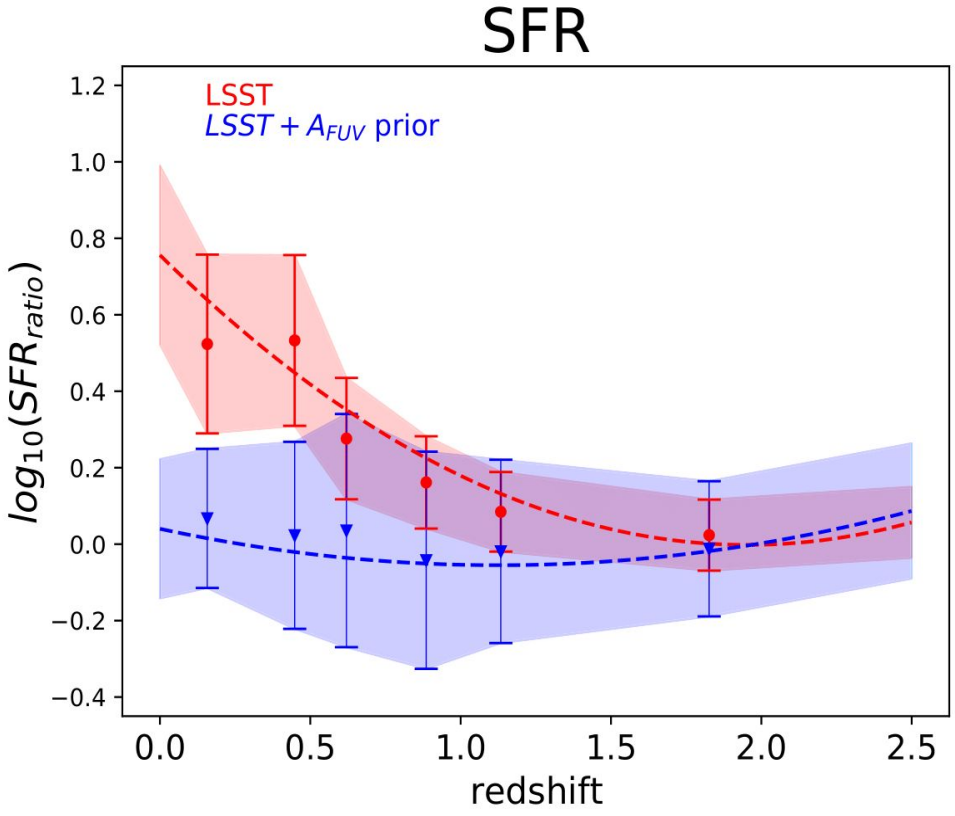


Riccio et al. 2021

AFUV vs Mstar relation

- A relation was found to exist between AFUV and Mstar $AFUV = a\,(z)\,log_{10}(Mstar) + c$ (see Salim et al. 2018, Bogdanoska et al. 2020…).

- The relation seems to deeply depends on redshift.



Riccio et al. 2021

Conclusion part 1

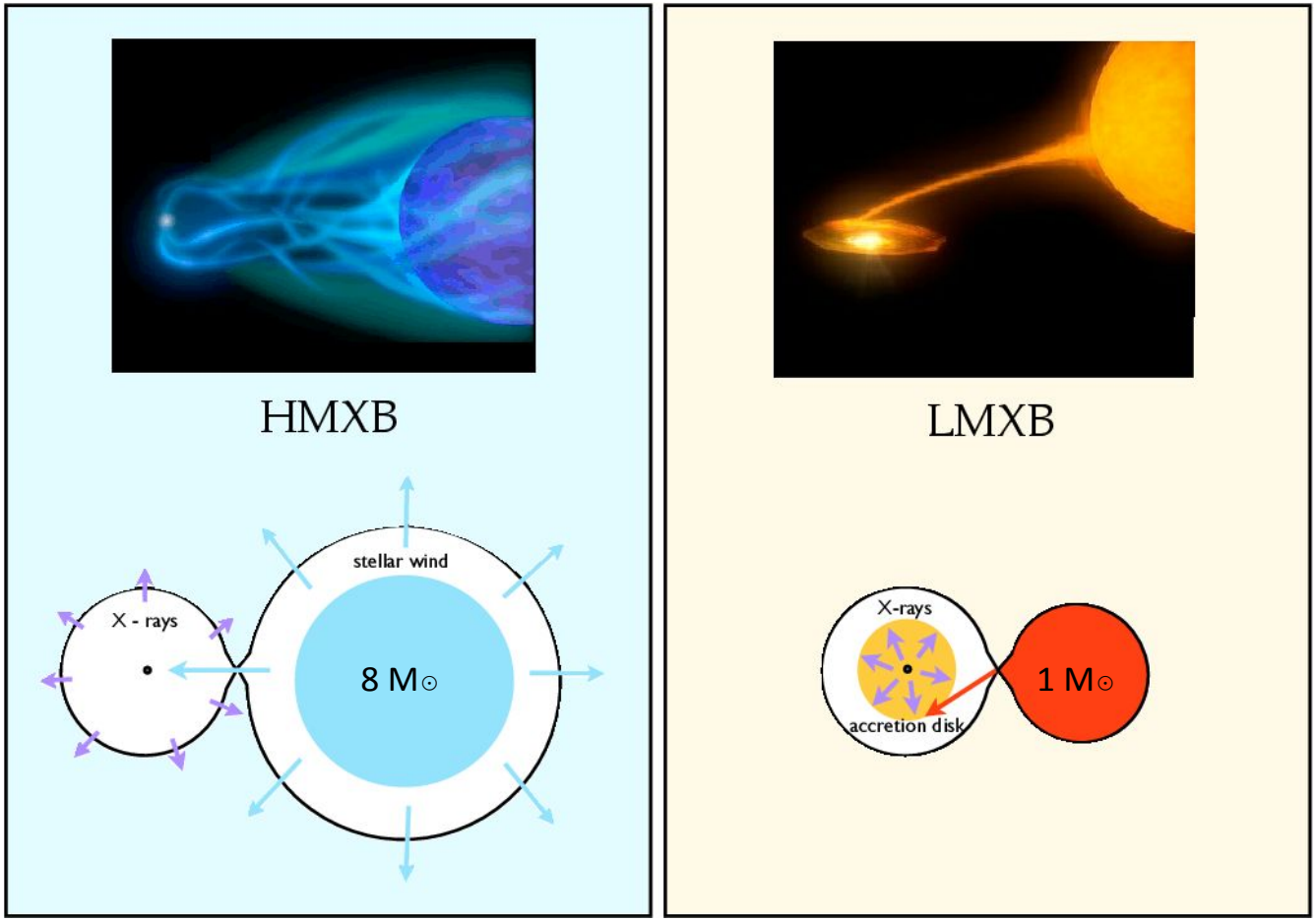
- We obtain an overestimation of the dust related parameters, such as SFR, dust luminosity and dust mass. The overestimation depends on redshift.

- We corrected the SFR overestimation either adding MIR or UV observations to the LSST sample, or fitting the data with a polynomial function, obtaining:
$log_{10} \frac{SFR_{LSST}}{SFR_{real}} = 0.26 \cdot z^2 - 0.94 \cdot z + 0.87.$

- The stellar mass is instead well estimated using our simulated LSST sample.

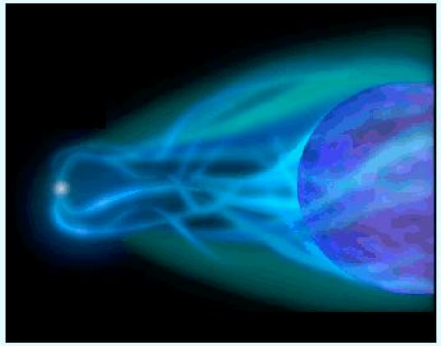
- A prior knowledge of the AFUV vs Mstar relation can be used to correct the SFR overestimation.

X-ray binaries and SFR

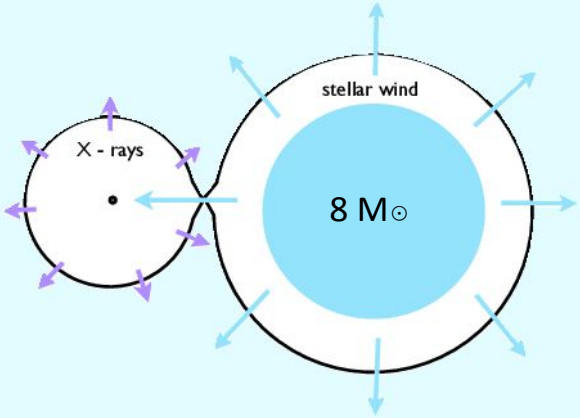


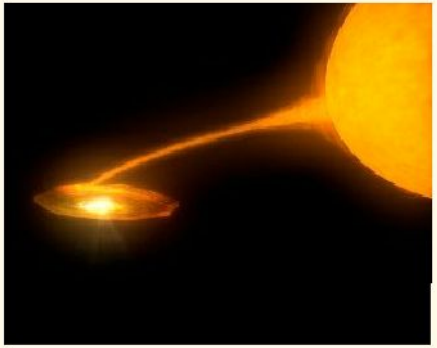
X-ray binaries and SFR

Related to SFR

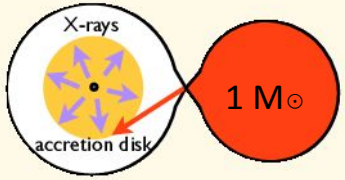


HMXB



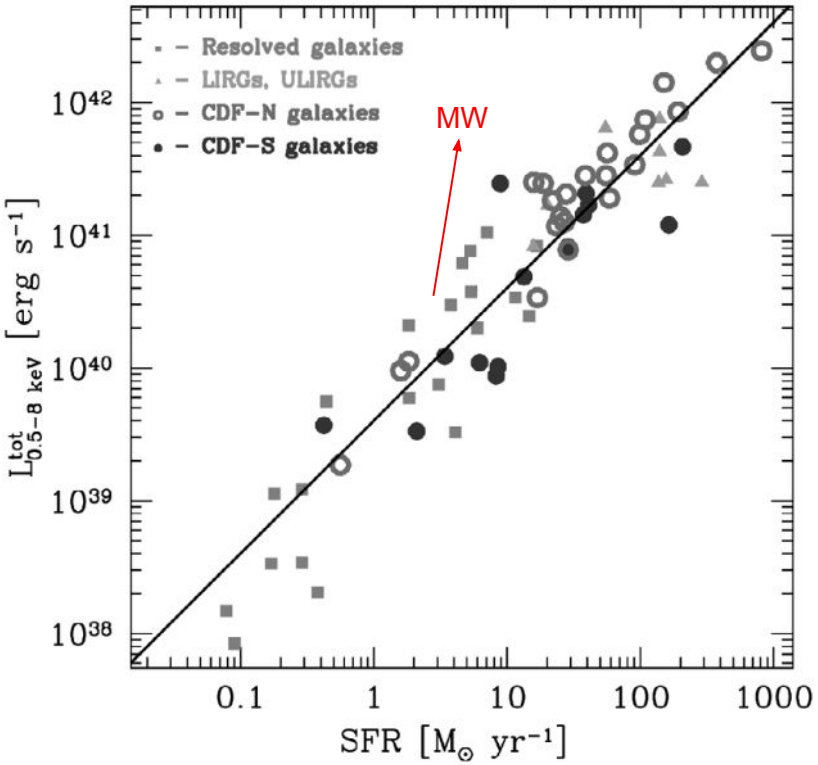


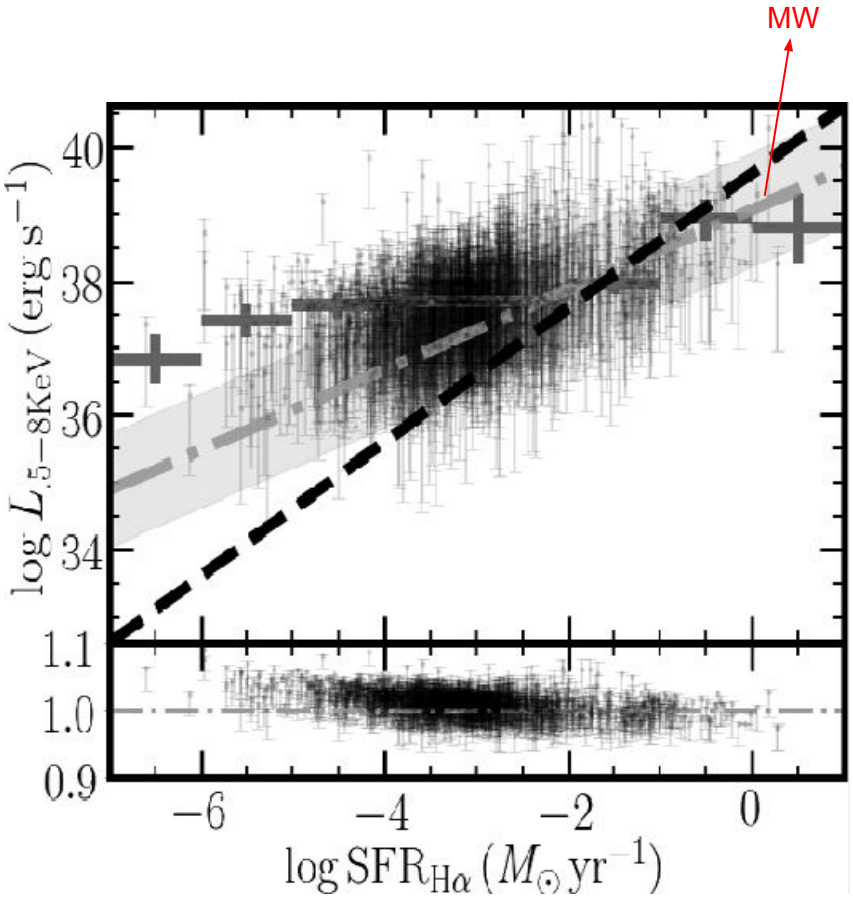
LMXB



Related to Mstar

X-ray luminosity-SFR scaling relation

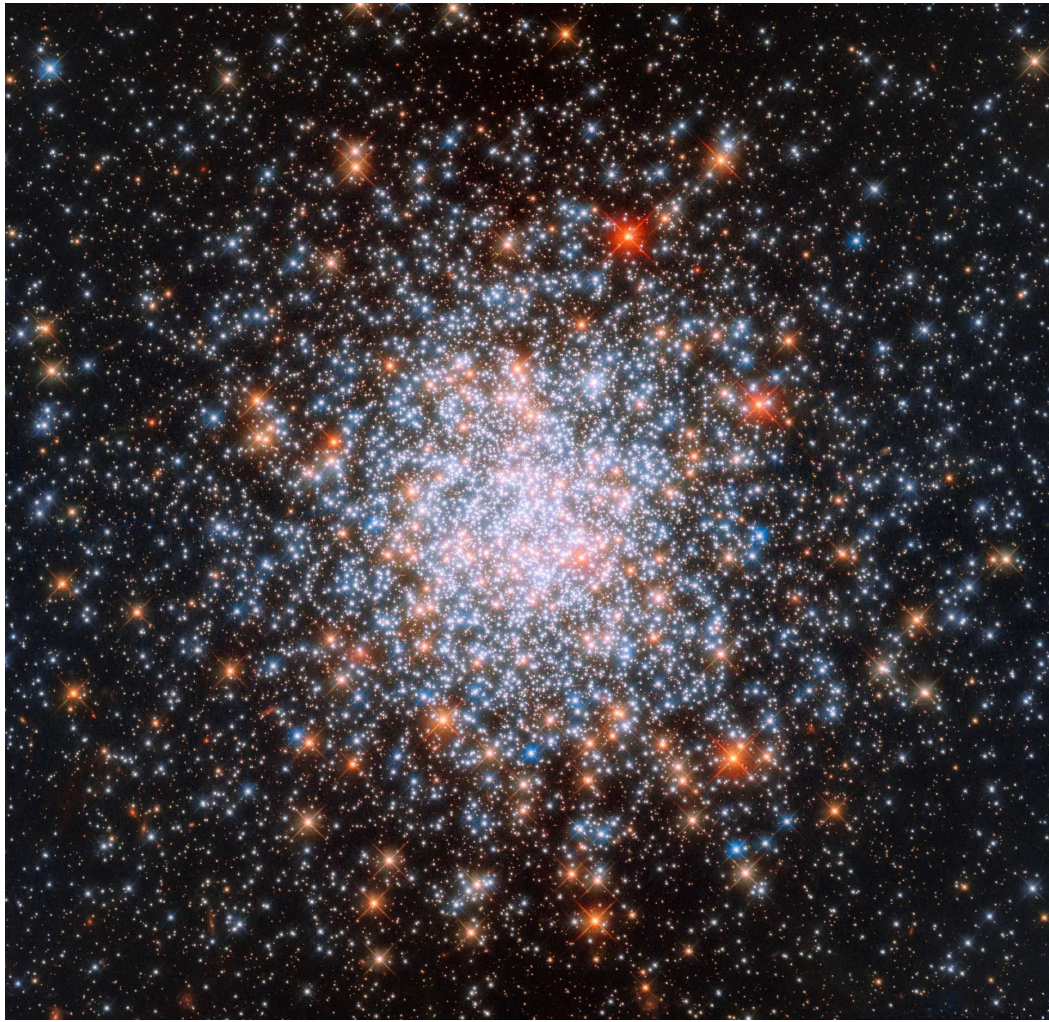




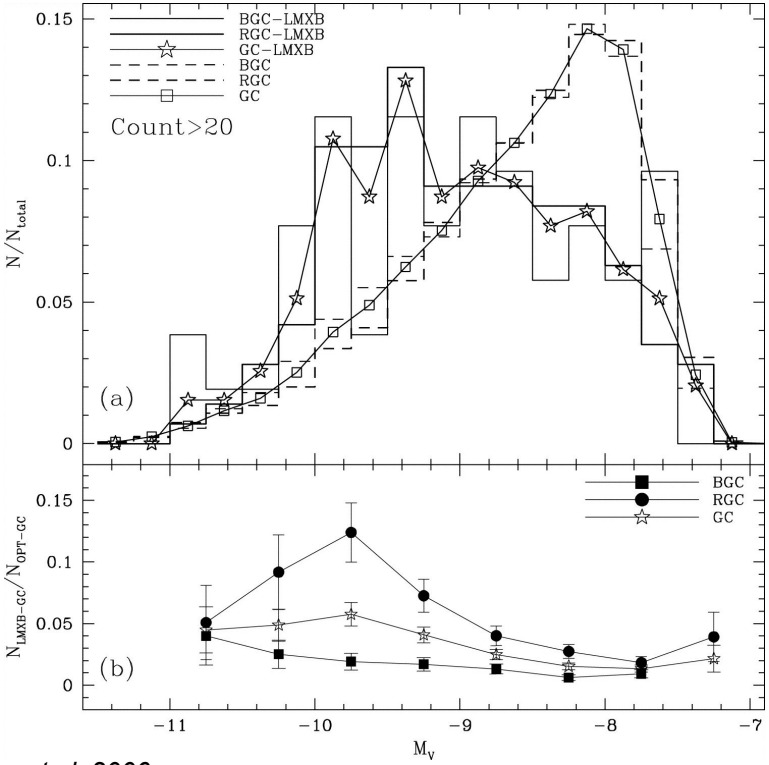
Credits: Andreas Zezas

GC-LMXB connection

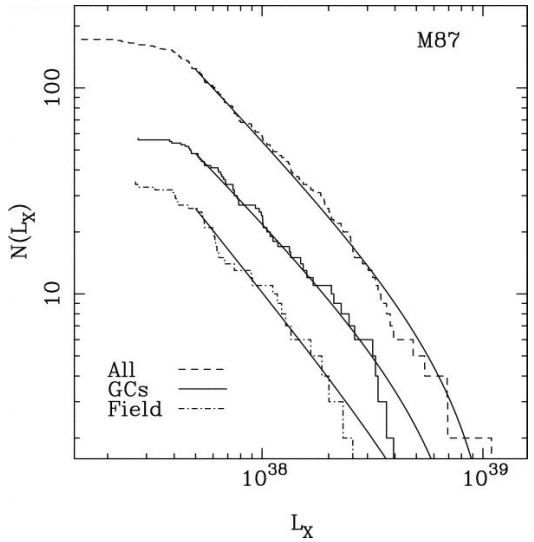
A significant fraction of LMXBs was found in globular clusters, especially in E and S0 galaxies, thanks to the earliest observations with Chandra. GCs have an important role in the formation and evolution of the LMXBs.



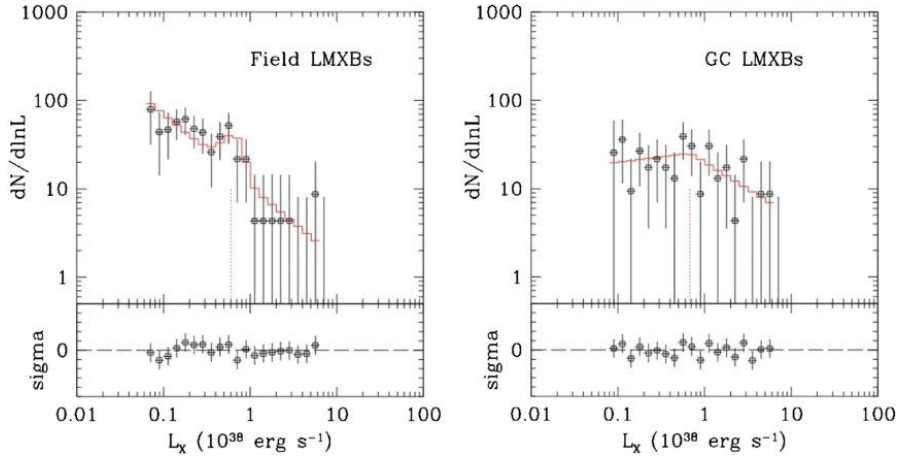
GC-LMXB connection



Kim et al. 2006



Jordan et al. 2004



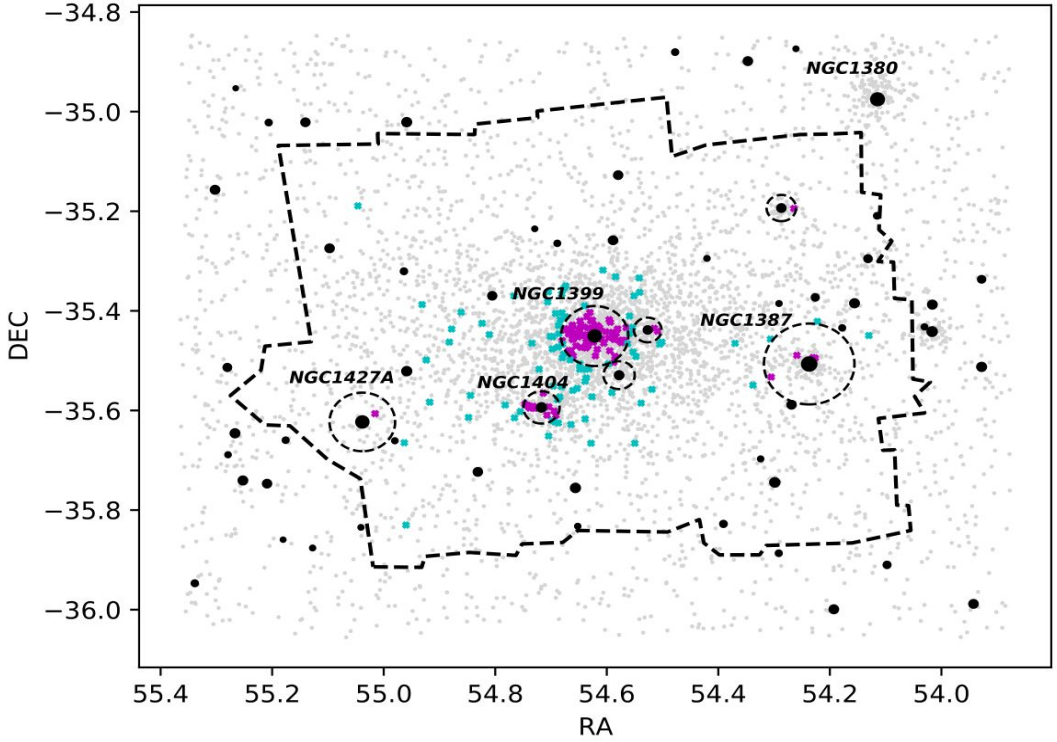
Kim et al. 2009

Properties of intra-cluster LMXBs in Fornax Globular clusters

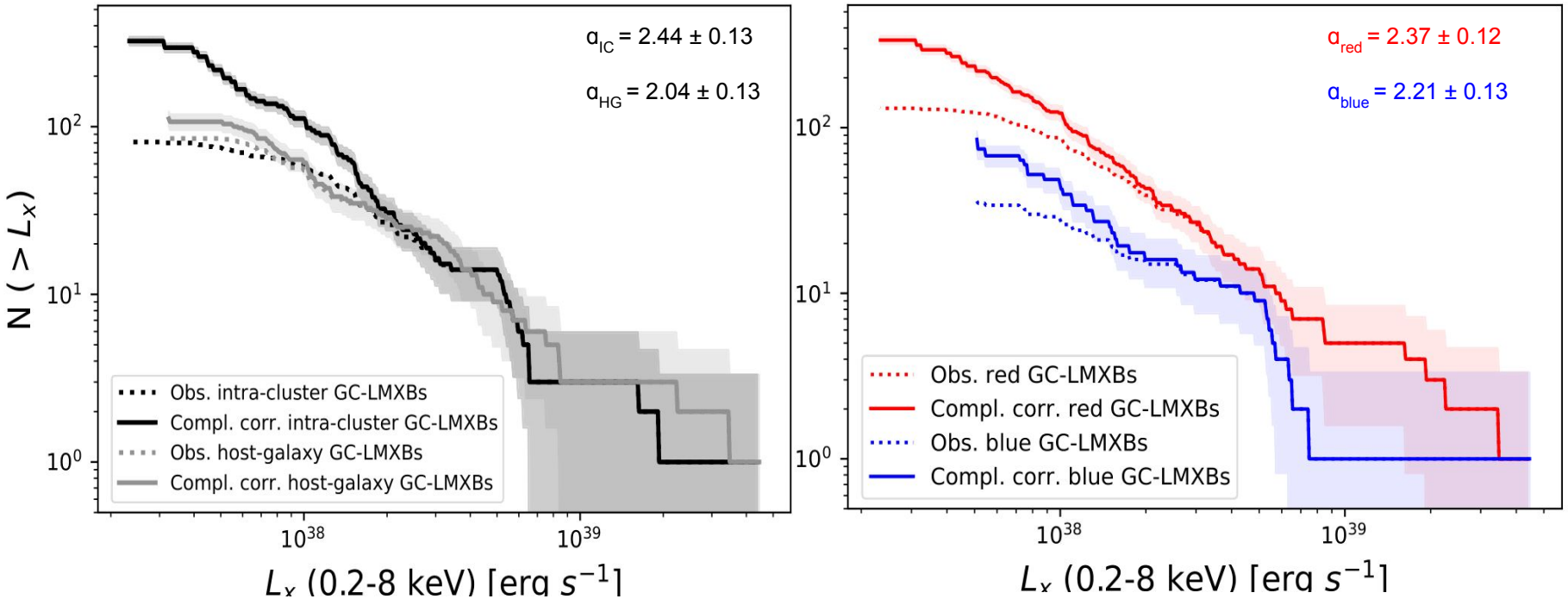
Riccio, G. et al. 2022

We identify 168 GC-LMXBs:

- 86 host-galaxy
- 82 intra-cluster

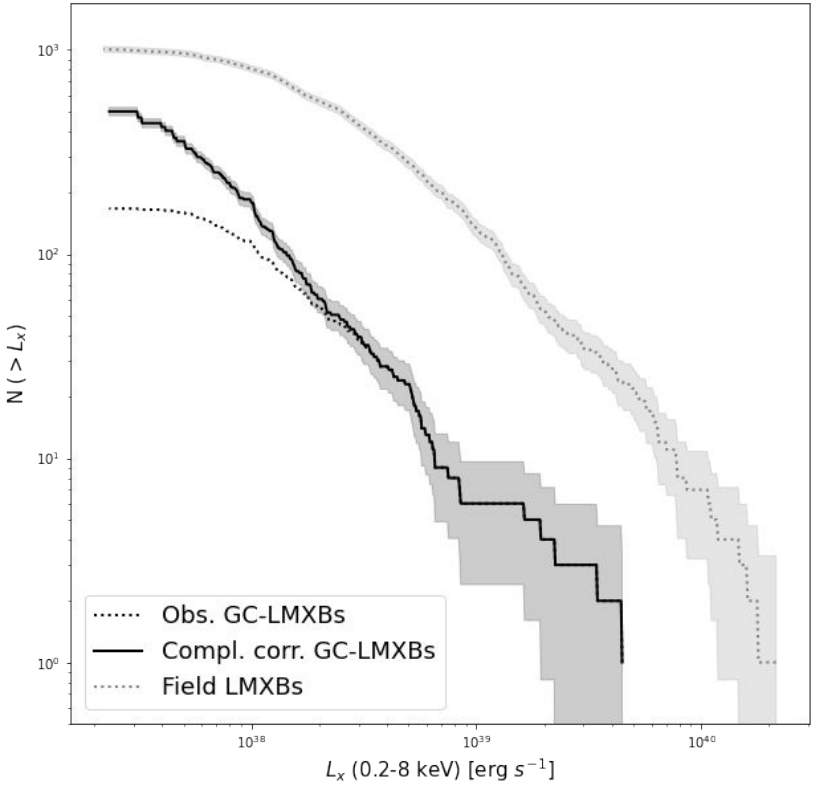


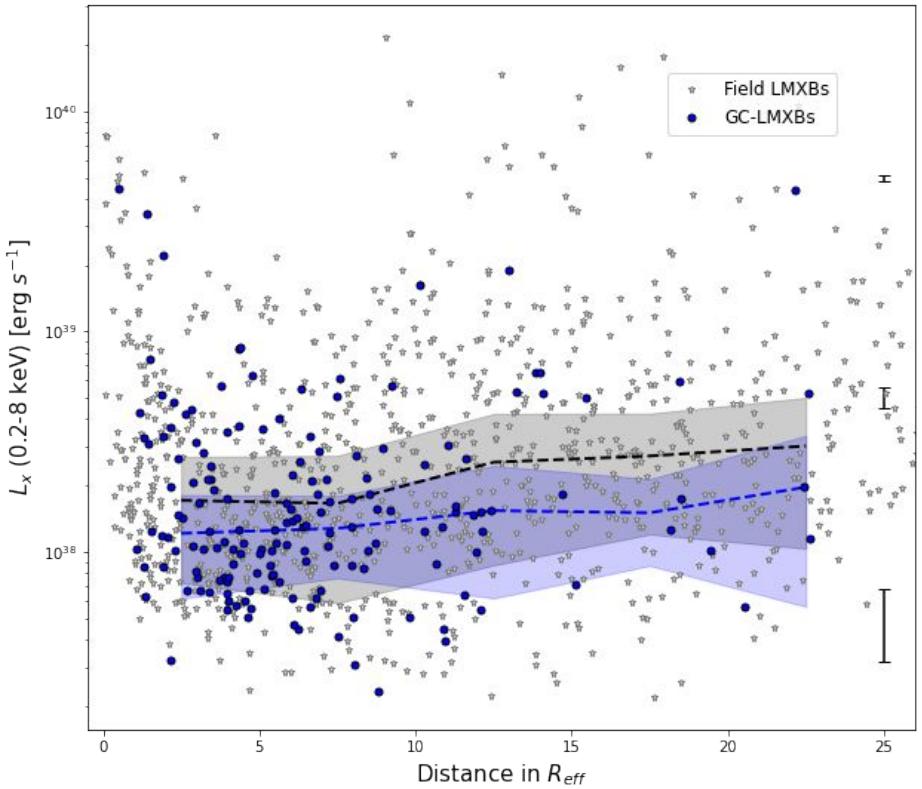
X-ray properties of the GC-LMXBs



Riccio et al. 2022

Field vs GC LMXBs





Credits: Riccio Gabriele

Conclusions part 2

- The fraction of GC-LMXBs is dependent on the galactocentric distance; this effect is particularly evident for the red population.

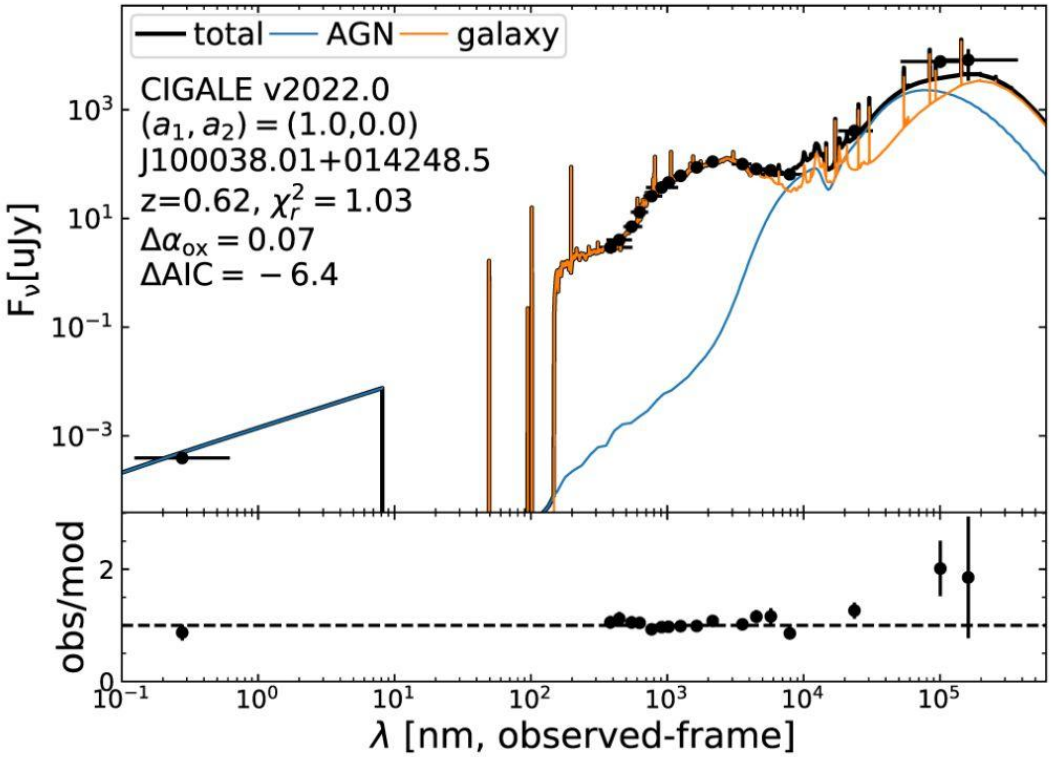
- Intra-cluster LMXBs tend to form in red and bright GCs, as has been found for their host-galaxy counterparts.

- The completeness-corrected X-ray luminosity function of the intra-cluster population of GC-LMXBs follows a power law with a slope consistent with the one found for field LMXBs in literature.

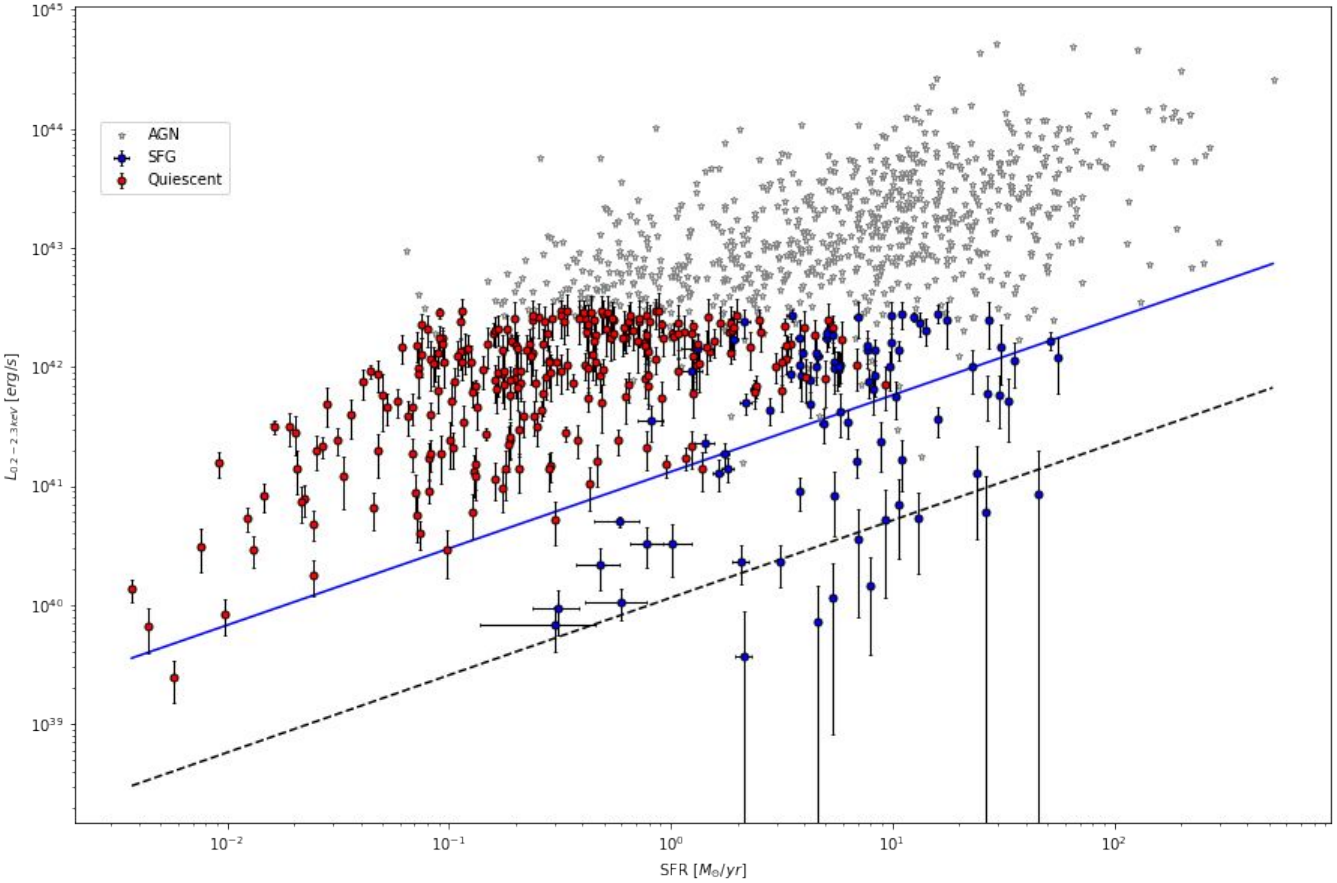
- The X-ray emission from GC-LMXBs is comparable with the one for field LMXBs.

X-ray luminosity-SFR scaling relation for a sample of eROSITA detected galaxies

Riccio et al. in prep.

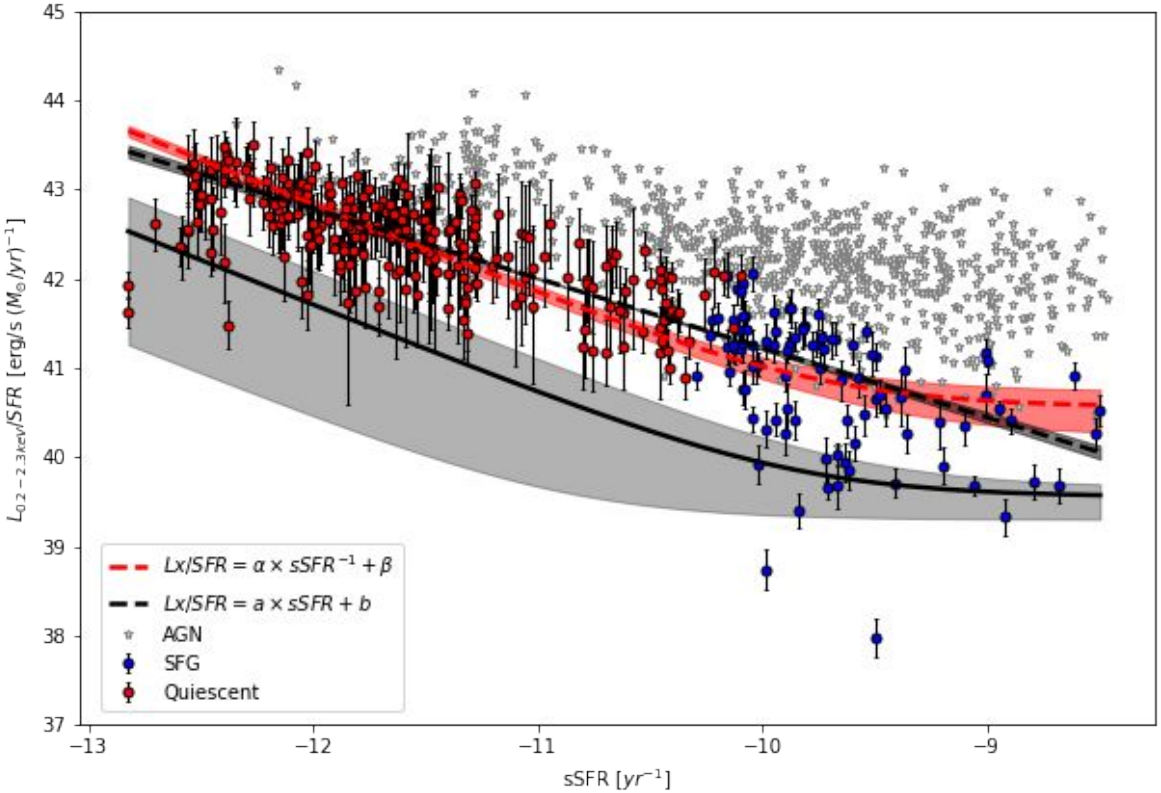


X-ray luminosity-SFR scaling relation



Riccio et al. in prep.

X-ray luminosity-sSFR scaling relation



Riccio et al. in prep.

Final conclusions

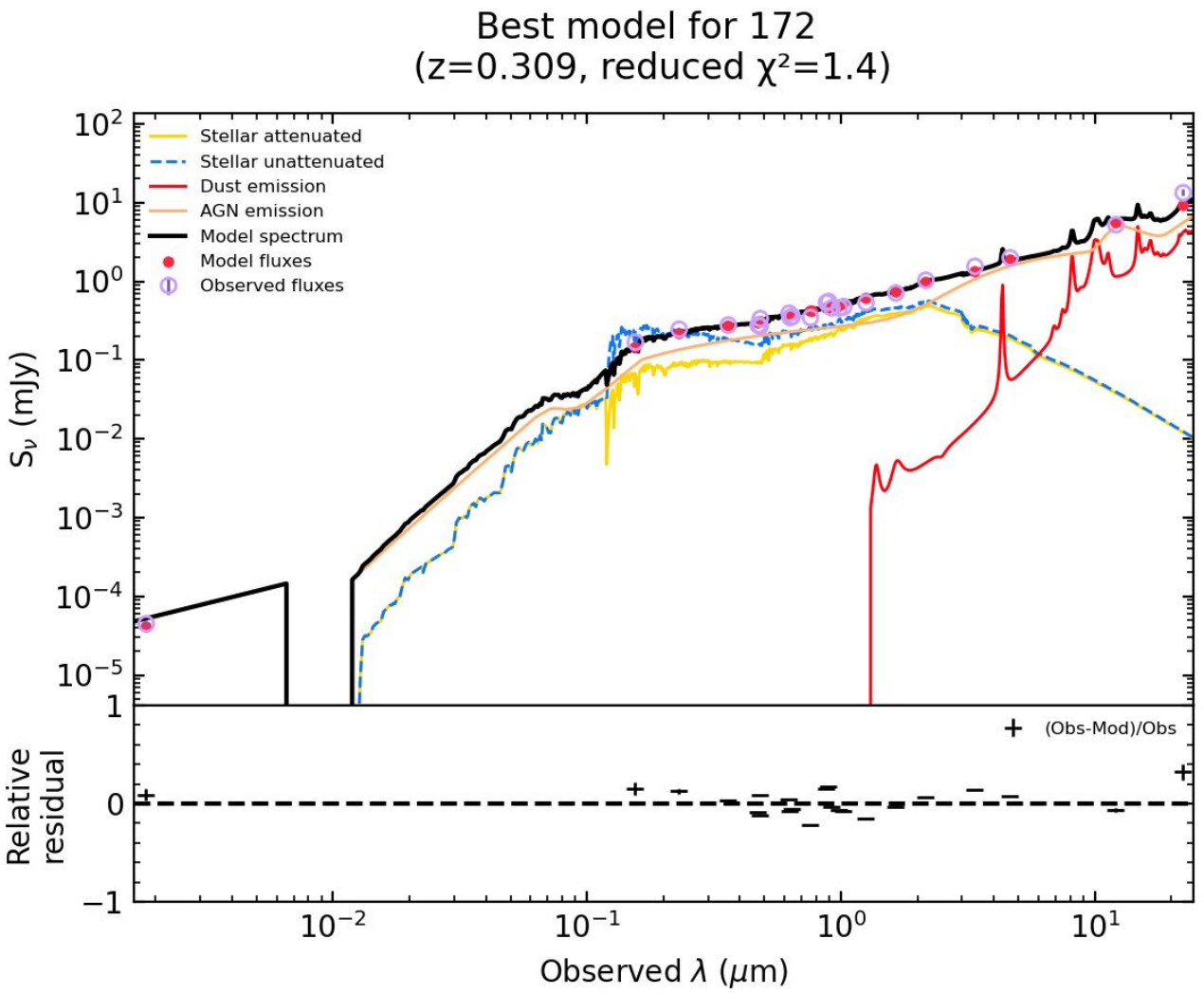
- Information of AFUV could be inferred from AFUV-Mstar relation (important for future LSST studies).

- The X-ray emission from GC-LMXBs is comparable with the one for field LMXBs (important to understand the total X-ray emission of galaxies and relation with SFR).

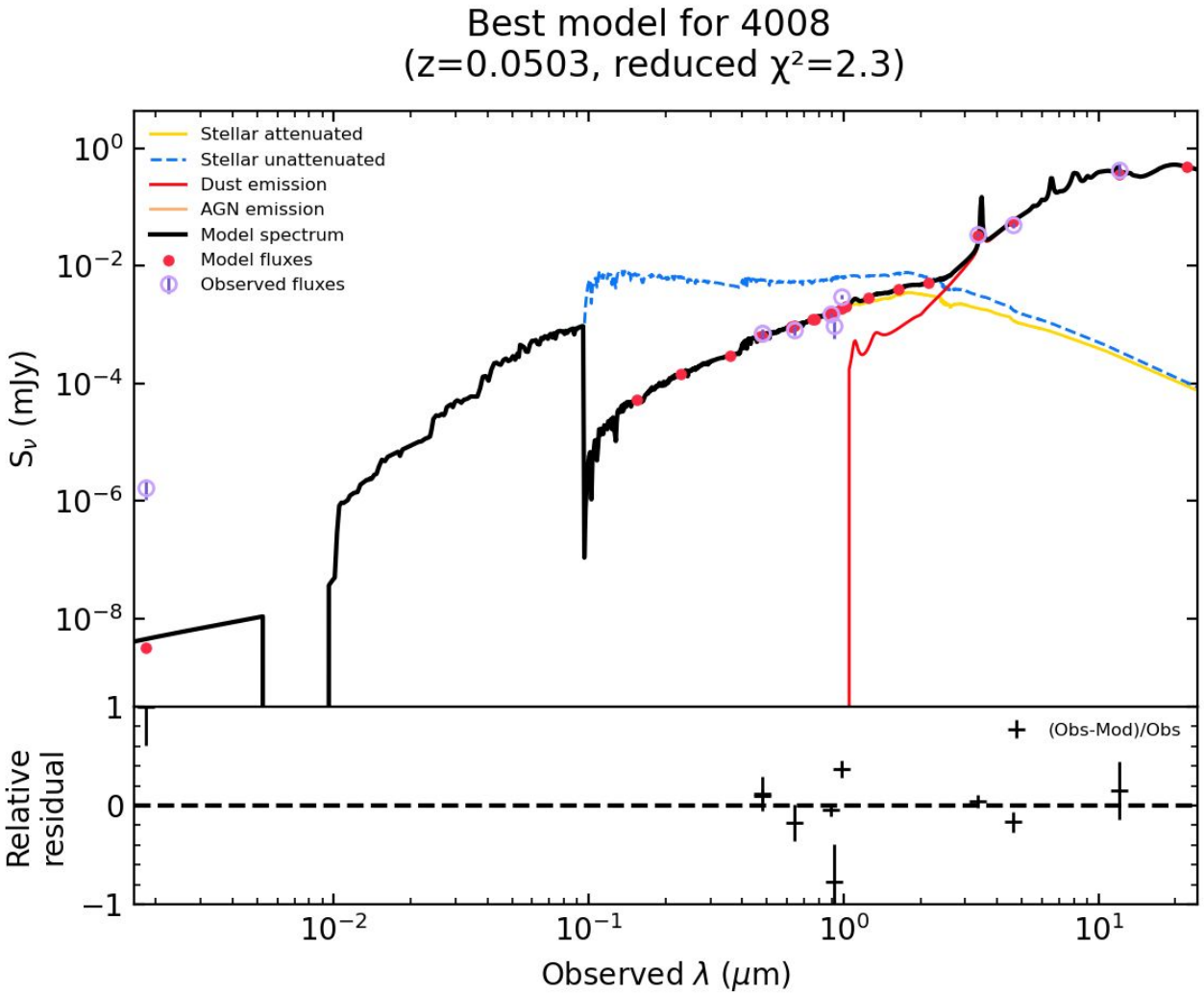
- Future X-ray surveys could explain an offset of the Lx-SFR scaling relation in comparison with the previous studies (in preparation).

Thank you for your attention!

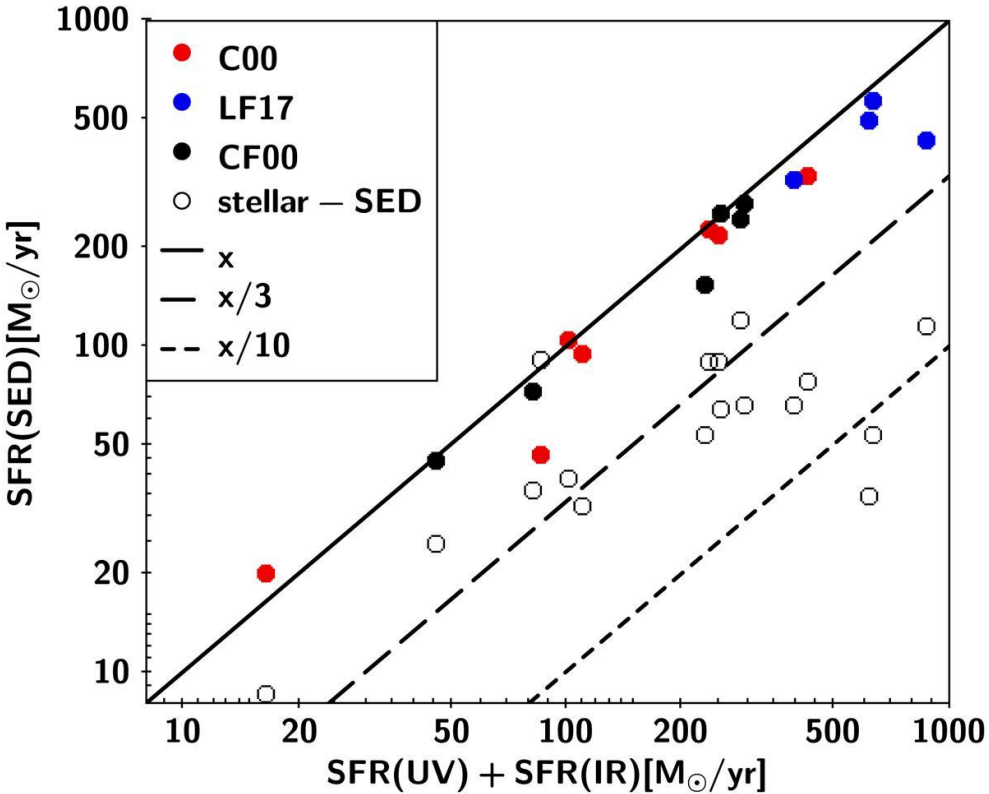
Modeling the X-ray emission



Modeling the X-ray emission



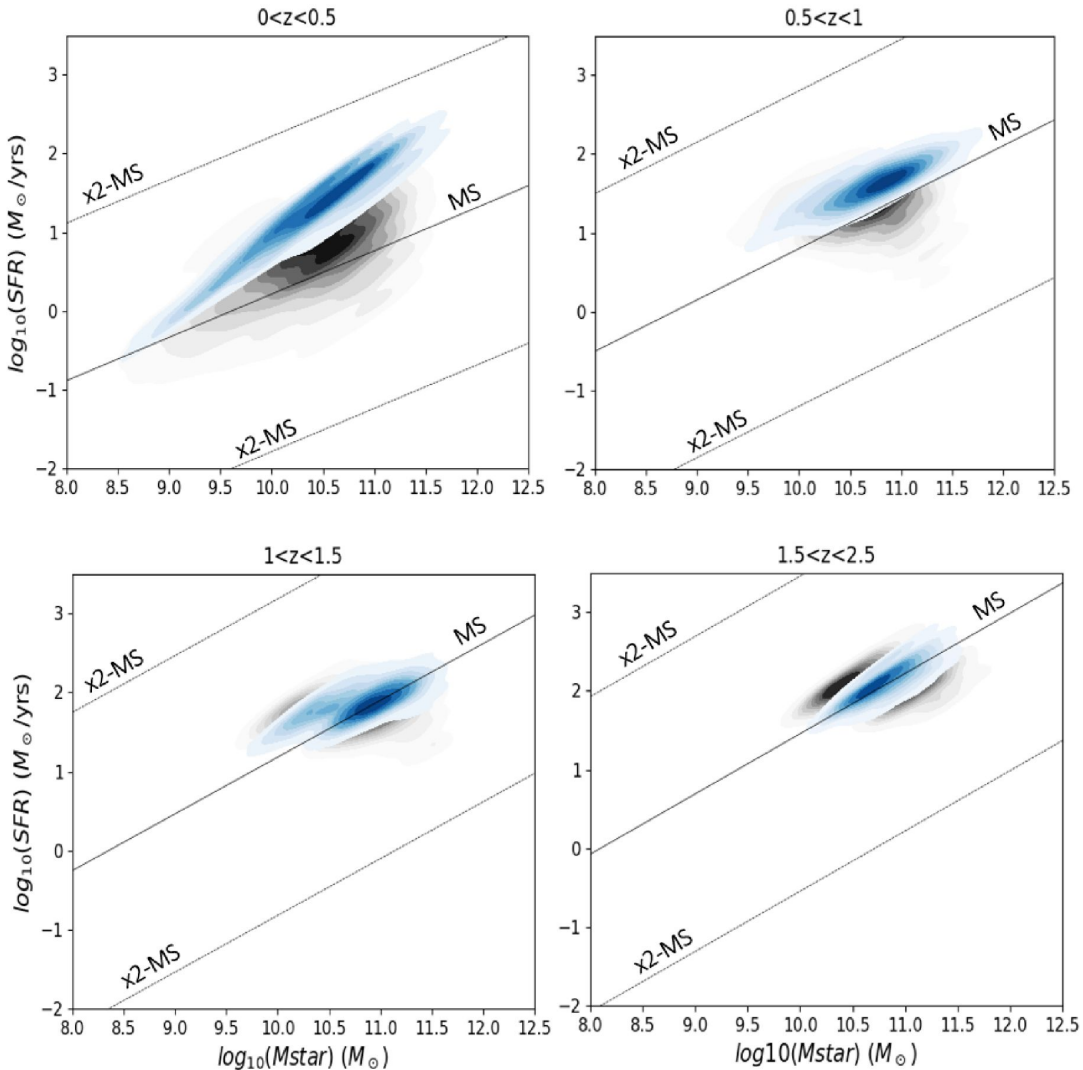
Why SED fitting to estimate SFR?



Buat et al. 2019

Main-sequence

- Clear difference at low redshift.
- The results overlap going to higher redshift.

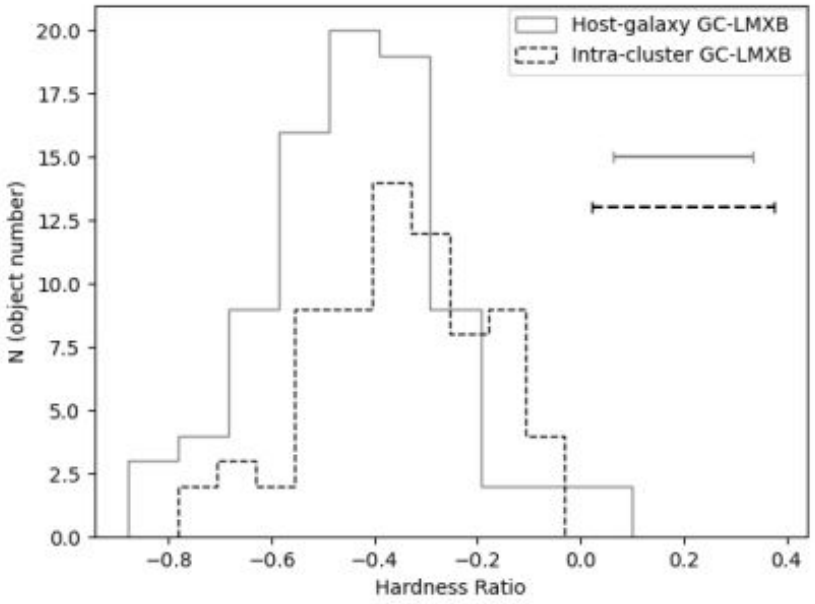


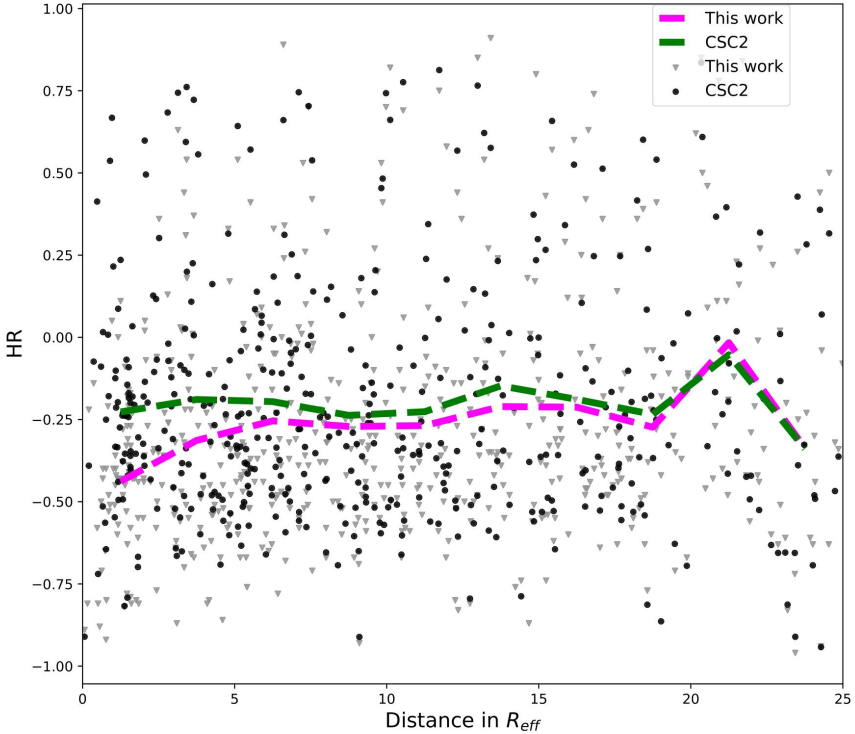
Riccio et al. 2021

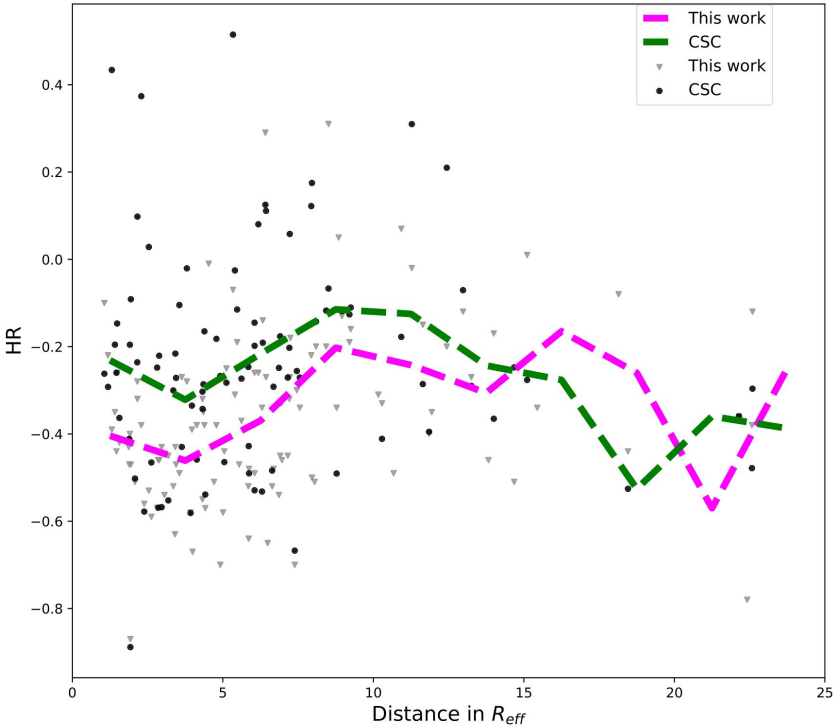
The difference is real?

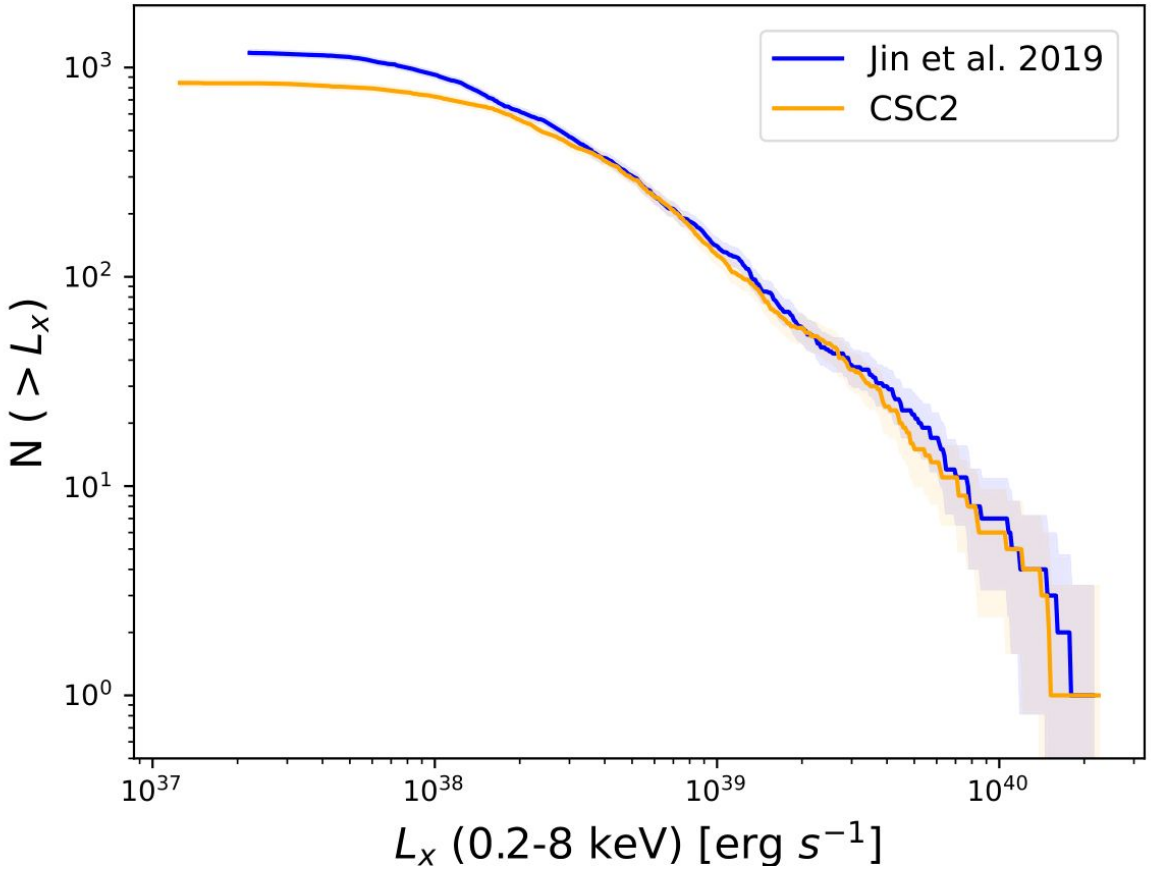
- Intra-cluster sources are more heavily contaminated by harder background sources than the host-galaxy population.

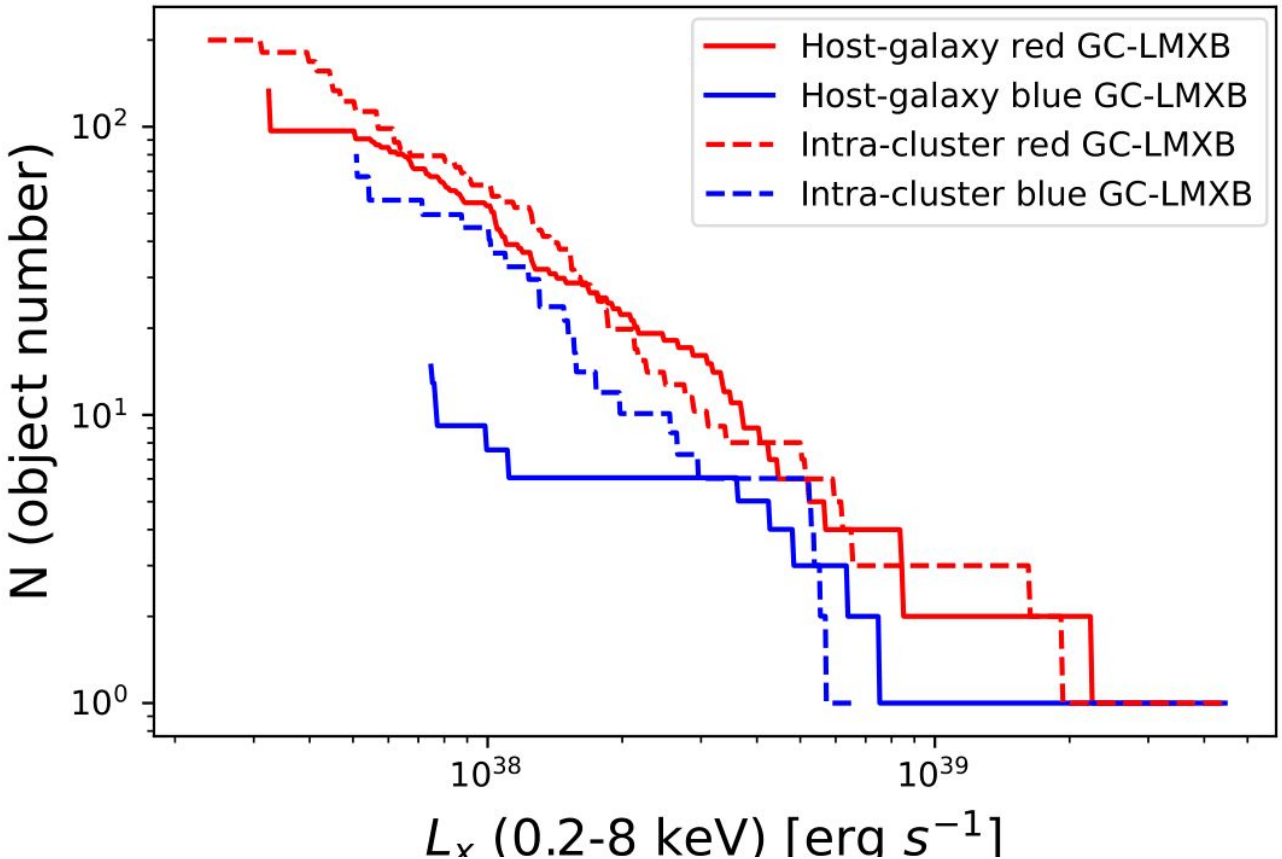
→ 10 contaminants

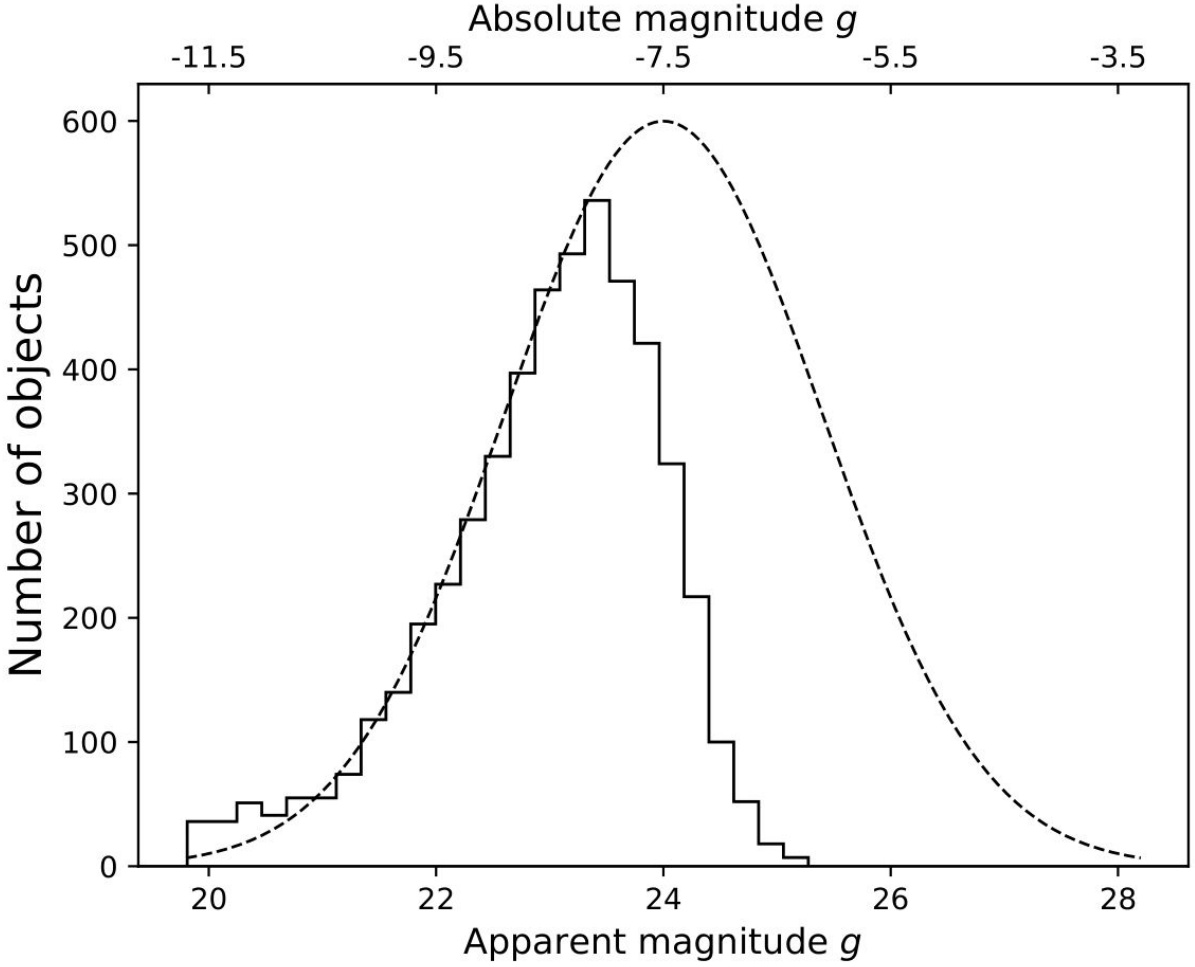



This work
CSC2
This work
CSC2
HR
Distance in R_{eff}


This work
CSC
This work
CSC
HR
Distance in R_{eff}


Jin et al. 2019
CSC2
10^3
10^2
10^1
10^0
N (> L_x)
10^{37}
10^{38}
10^{39}
10^{40}
L_x (0.2-8 keV) [erg s^{-1}]


Host-galaxy red GC-LMXB
Host-galaxy blue GC-LMXB
Intra-cluster red GC-LMXB
Intra-cluster blue GC-LMXB
N (object number)
10^2
10^1
10^0
10^{38}
10^{39}
L_x (0.2-8 keV) [erg s^{-1}]


Absolute magnitude g
-11.5
-9.5
-7.5
-5.5
-3.5
Number of objects
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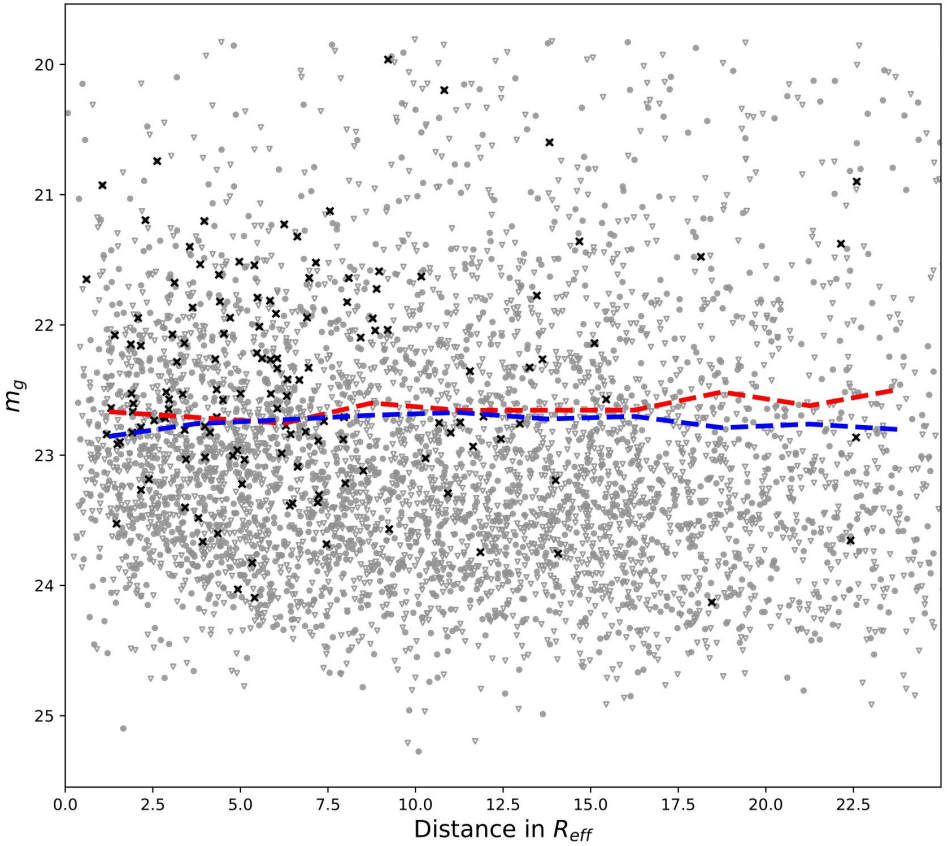
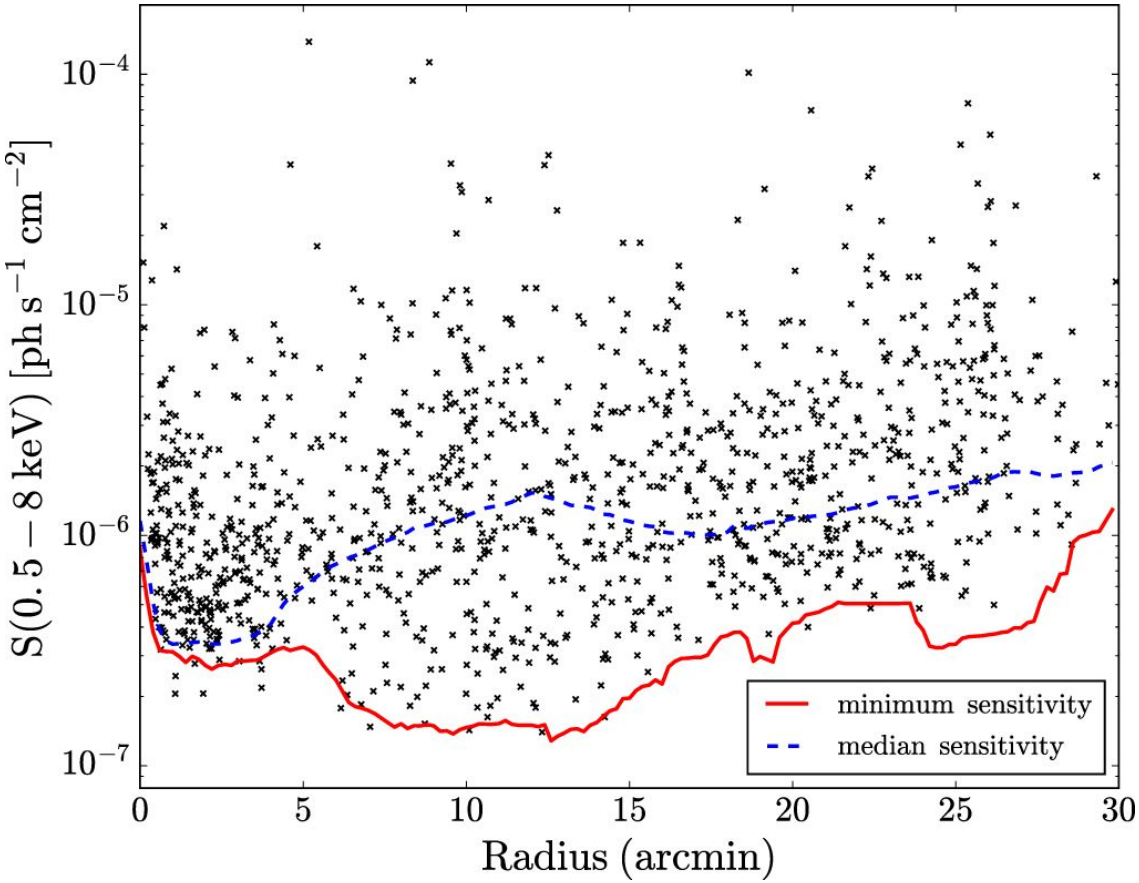
500
400
300
200
100
0
20
22
24
26
28
Apparent magnitude g


20
21
22
23
24
25
m_g
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
Distance in R_{eff}



Jin et al. 2019