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A NEW MODEL FOR MOLECULAR CLOUDS AND CO EXCITATION IN AGN-HOST GALAXIES

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Livia Vallini^{2,3}, Francesca Pozzi^{1,2}, Viviana Casasola⁴
and collaborators

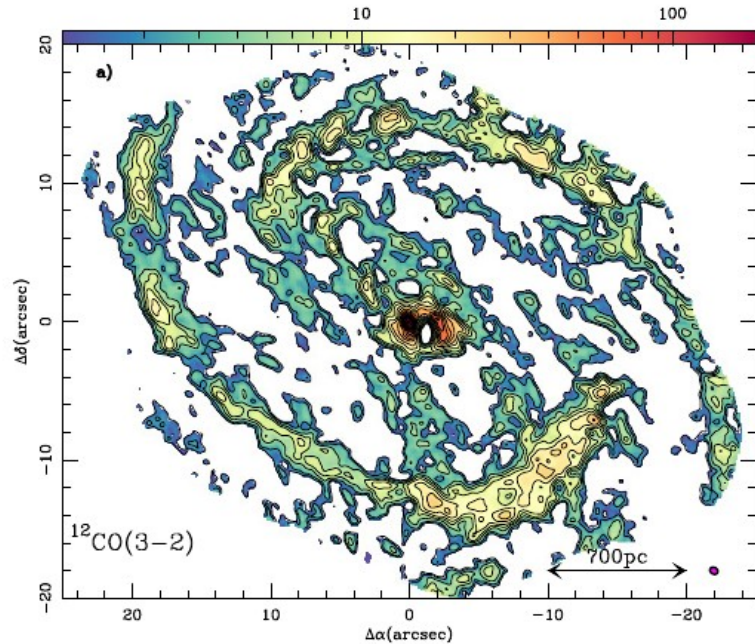
¹ University of Bologna ² INAF/OAS – Bologna ³ SNS – Pisa ⁴ INAF/IRA – Bologna



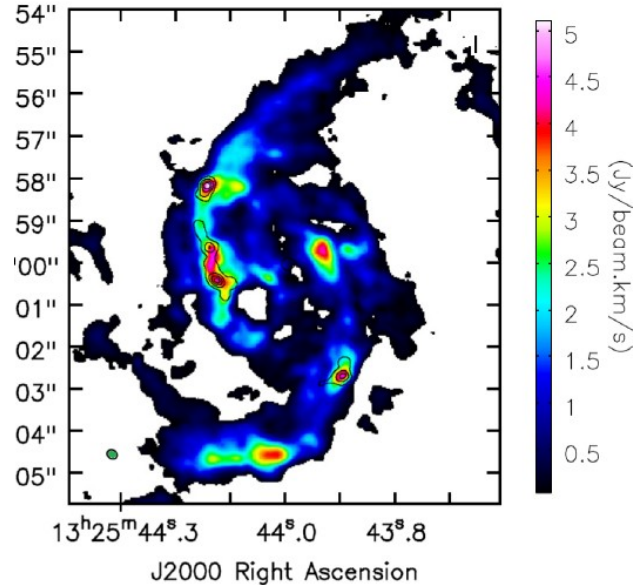
LOW-J CO LINES IMAGED BY ALMA IN LOCAL AGN



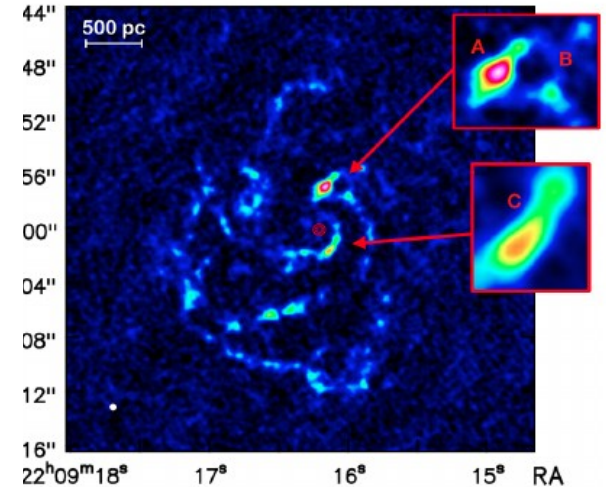
CO(3-2) in NGC 1068



CO(2-1) in NGC 5135



CO(2-1) in NGC 7213



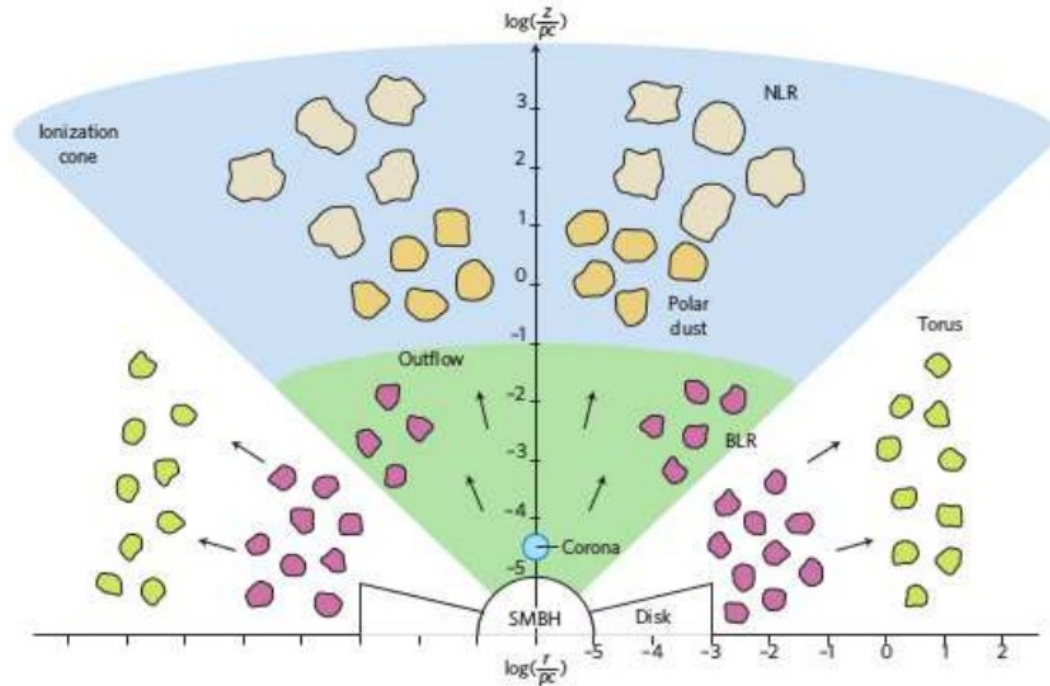
Garcia-Burillo+2014

Sabatini+2018

Salvestrini+2020



AGN STRUCTURE AND (SOME) OBSERVABLES



RADIATION

- AGN are powered by accretion on the supermassive black hole (**SMBH**)
- the **accretion disk** emits optical/UV photons, and most of them are
 - ▶ up-scattered by electrons in the hot coronal gas → **X-ray emission**
 - ▶ absorbed and re-emitted by dust (polar/torus) → **IR/sub-mm emission**

OUTFLOWS

- thermal/radiation/CR/jets-ram **pressures** produce winds and outflows
- gas can be then mechanically **dragged**

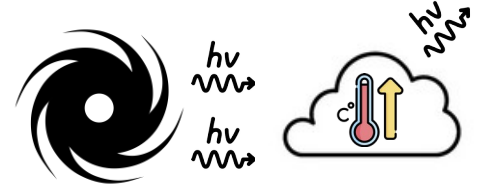


AGN FEEDBACK ON MOLECULAR GAS



radiative feedback: X-ray dominated regions (XDR)
(e.g. Van der Werf et al. 2010, Pozzi et al. 2017)

study gas **excitation**





AGN FEEDBACK ON MOLECULAR GAS

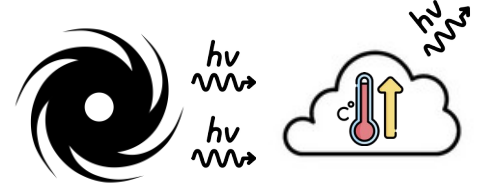


radiative feedback: X-ray dominated regions (XDR)
(e.g. Van der Werf et al. 2010, Pozzi et al. 2017)



mechanical feedback: outflows / shocks / jets
(e.g. Mingozi et al. 2018, García-Bernete et al. 2021)

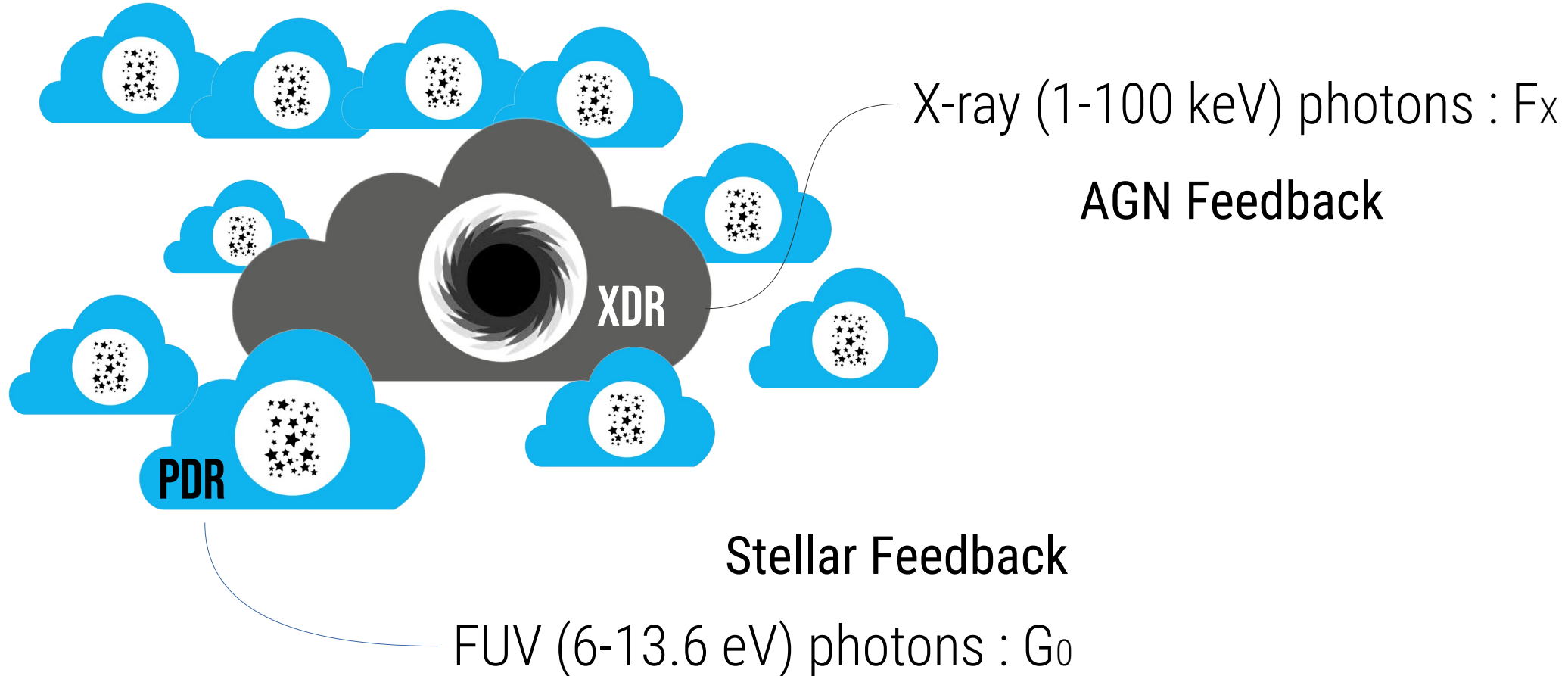
study gas **excitation**



study gas **kinematics**

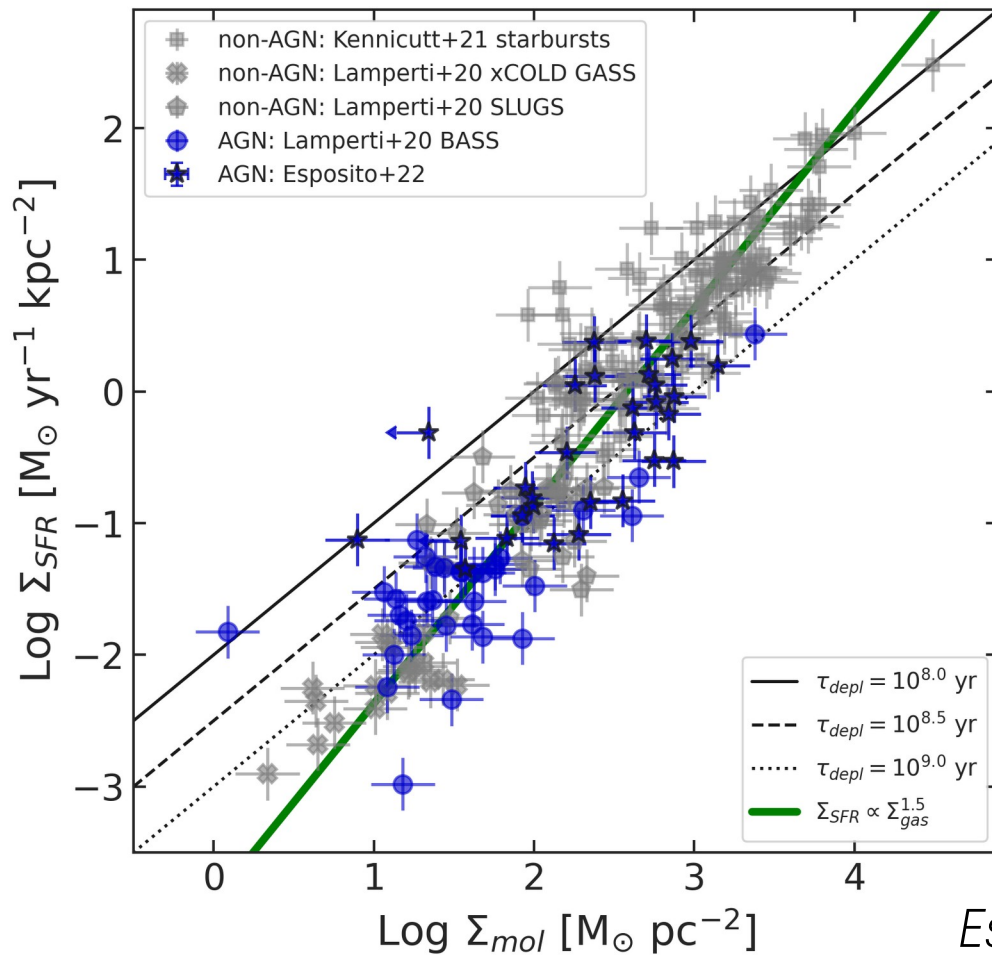


AGN VS. STELLAR FEEDBACK





AGN EFFECT ON KPC-SCALE: NOT EVIDENT

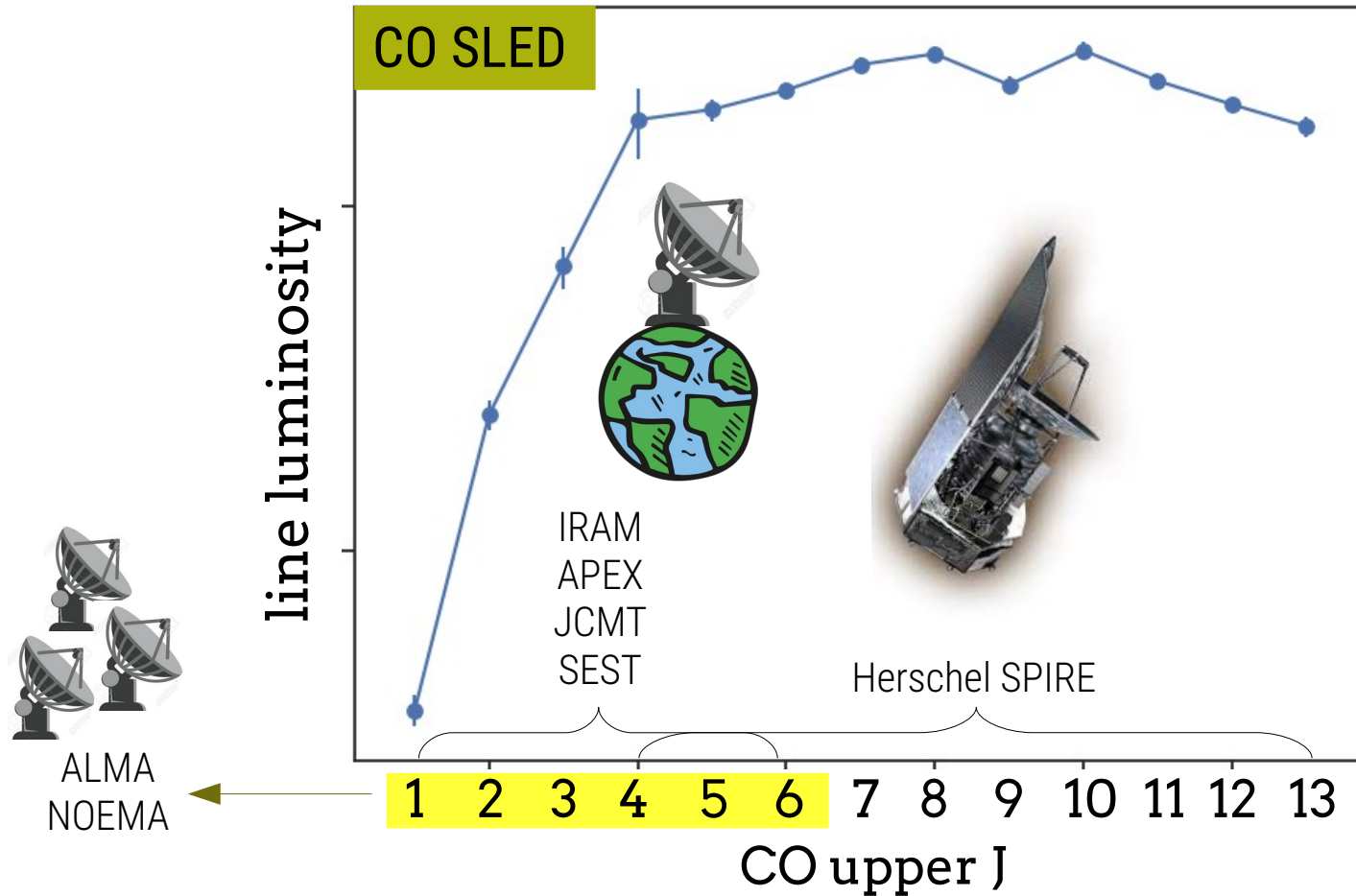


comparing non-AGN with
a sample of local AGN
on the Schmidt-Kennicutt plane
(molecular mass vs. SFR)

CO(1-0)

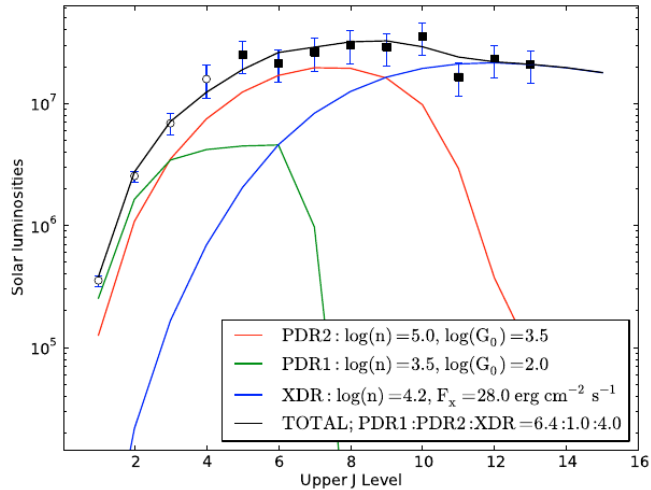


MOLECULAR GAS OBSERVATIONS

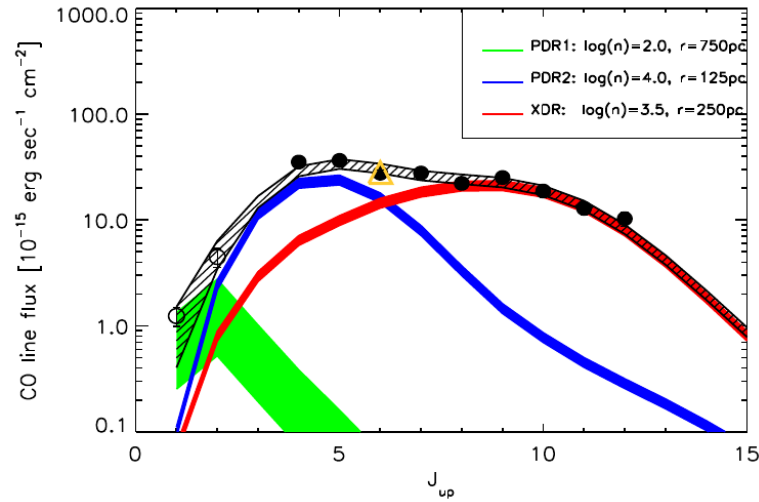




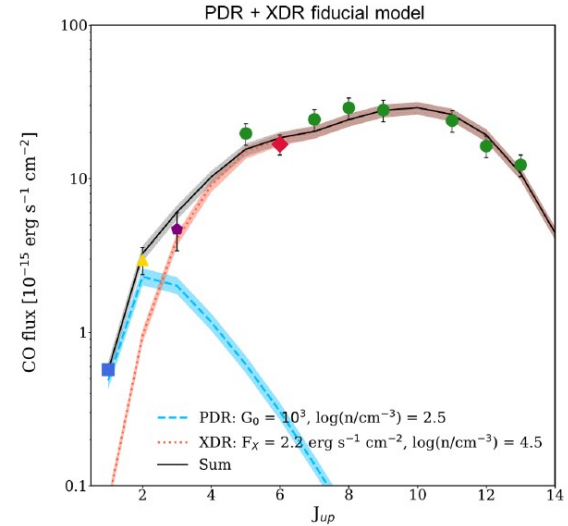
PDR AND XDR CO SLEDs: LITERATURE RESULTS



Van der Werf et al. 2010
used Meijerink+2006 model
to fit the Mrk 231 CO SLED



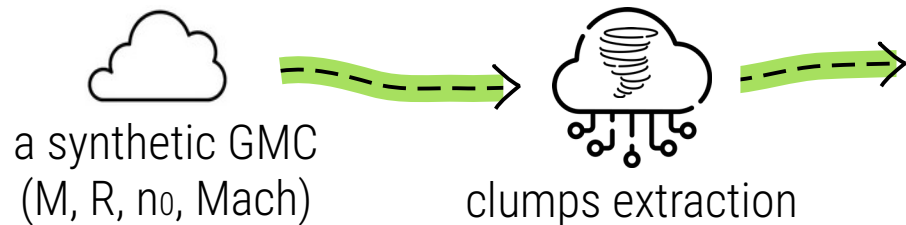
Pozzi et al. 2017
used the CLOUDY code
to fit the NGC 7130 CO SLED



Mingozi et al. 2018
used CLOUDY and shocks
to fit the NGC 34 CO SLED



A NEW MODEL FOR MOLECULAR EMISSION

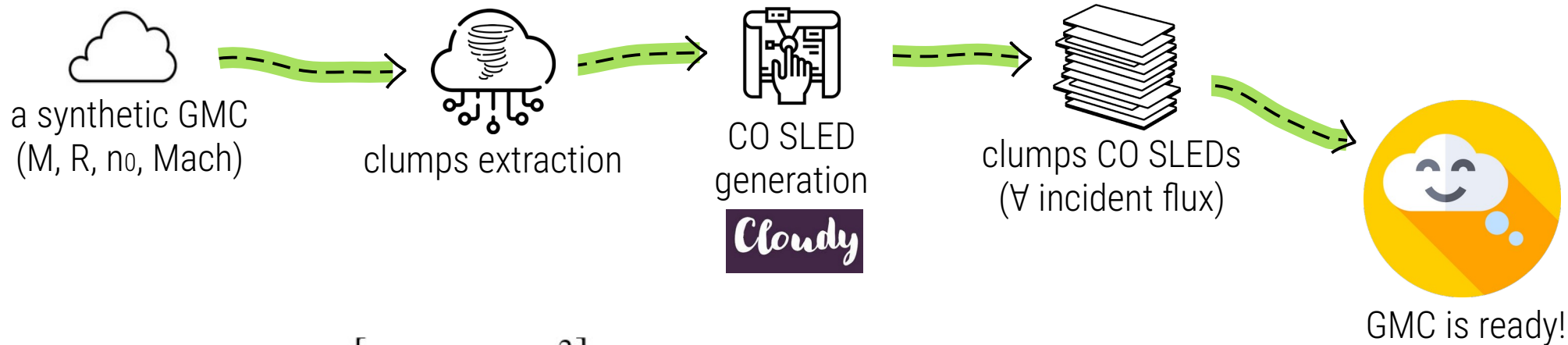


$$p_s ds = \frac{1}{\sqrt{(2\pi\sigma_s^2)}} \exp \left[-\frac{1}{2} \left(\frac{s - s_0}{\sigma_s} \right)^2 \right]$$

GMC internal structure: turbulence-driven lognormal PDF
(Vazquez-Semadeni 1994, Federrath & Klessen 2013)



A NEW MODEL FOR MOLECULAR EMISSION



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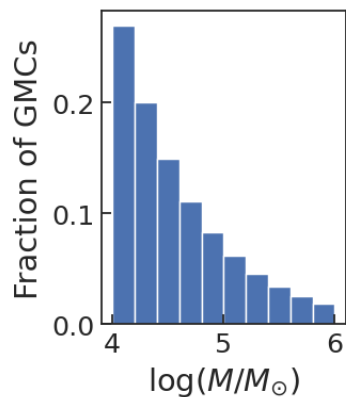
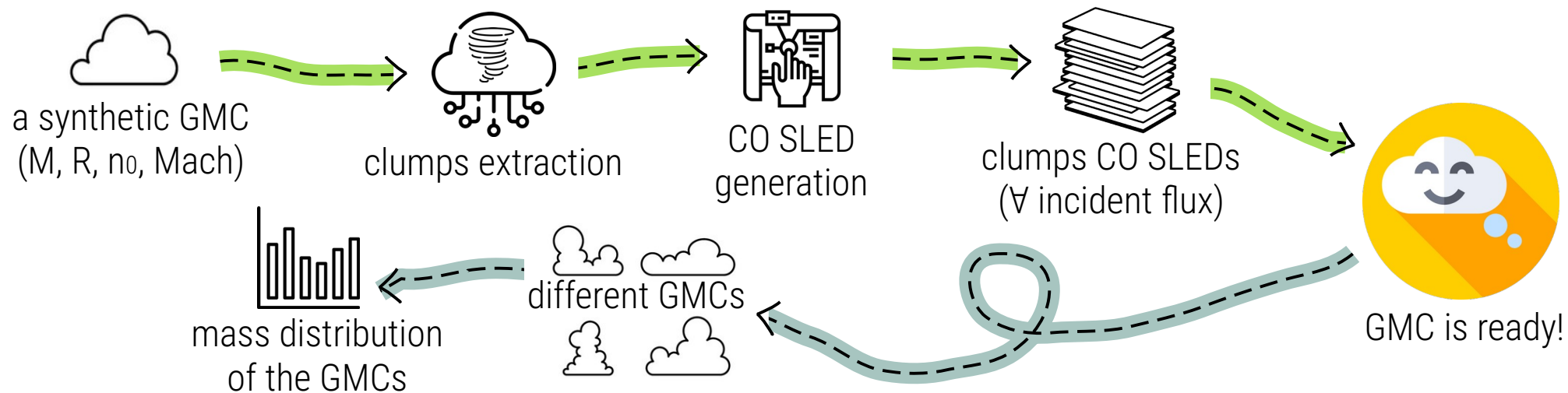
GMC internal structure: turbulence-driven lognormal PDF
(Vazquez-Semadeni 1994, Federrath & Klessen 2013)



radiative transfer (PDR and XDR models)



ADDING A GMC MASS DISTRIBUTION



$$\frac{dN}{dM} \propto M^{-1.64}$$

following Roman-Duval et al. 2010,
Dutkowska & Kristensen 2022



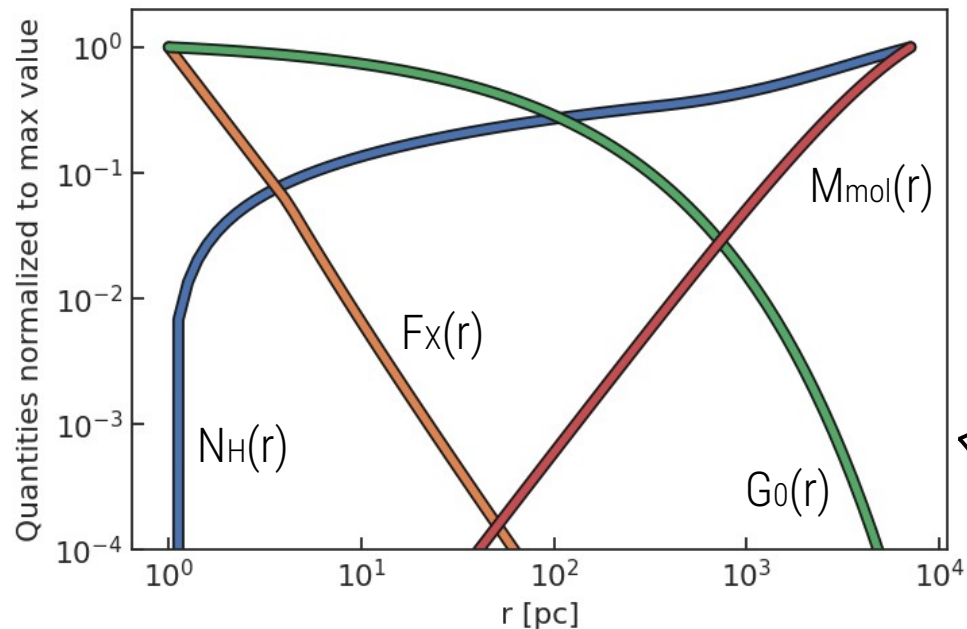
A NEW MODEL FOR MOLECULAR EMISSION



$h\nu$



edge-on galaxy view



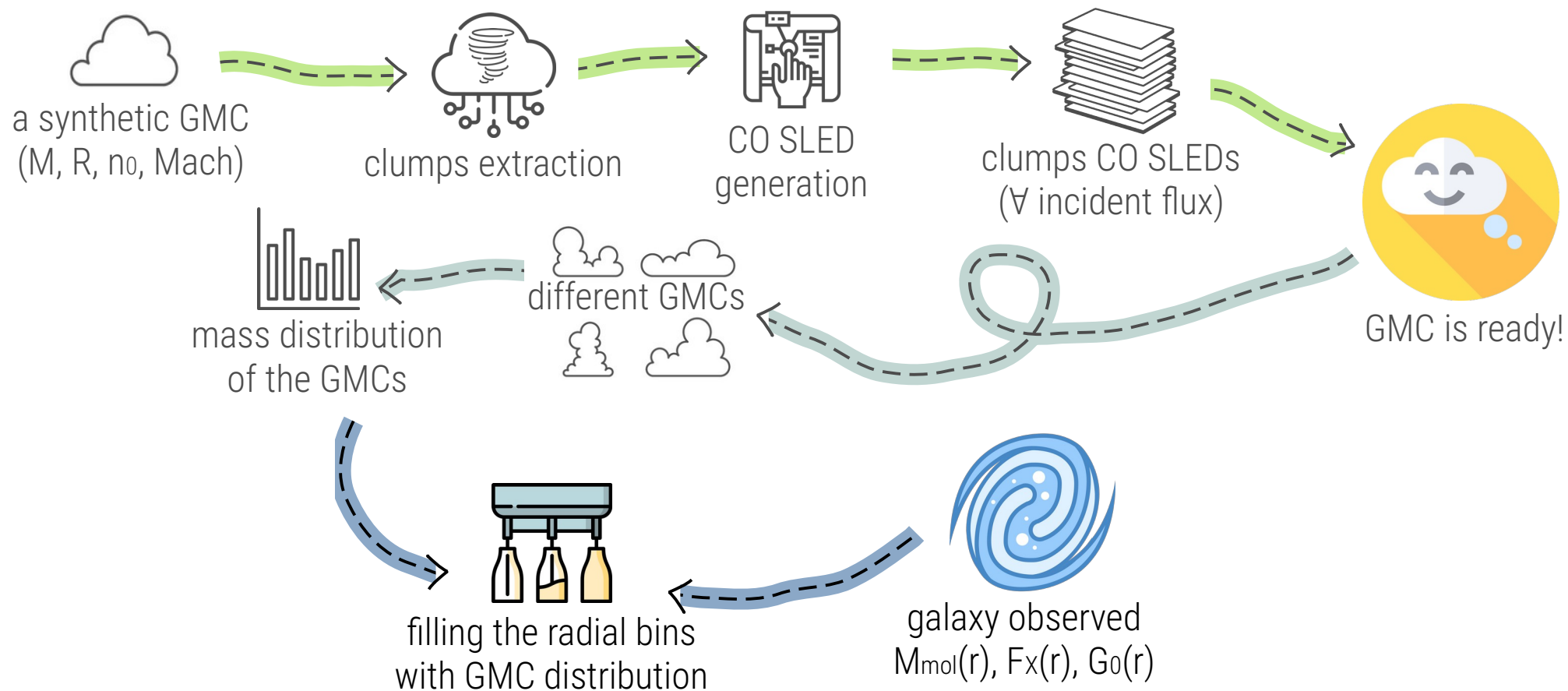
galaxy observed
 $M_{mol}(r)$, $F_X(r)$, $G_O(r)$

from Esposito et al. 2022

Esposito et al. 2023, almost submitted

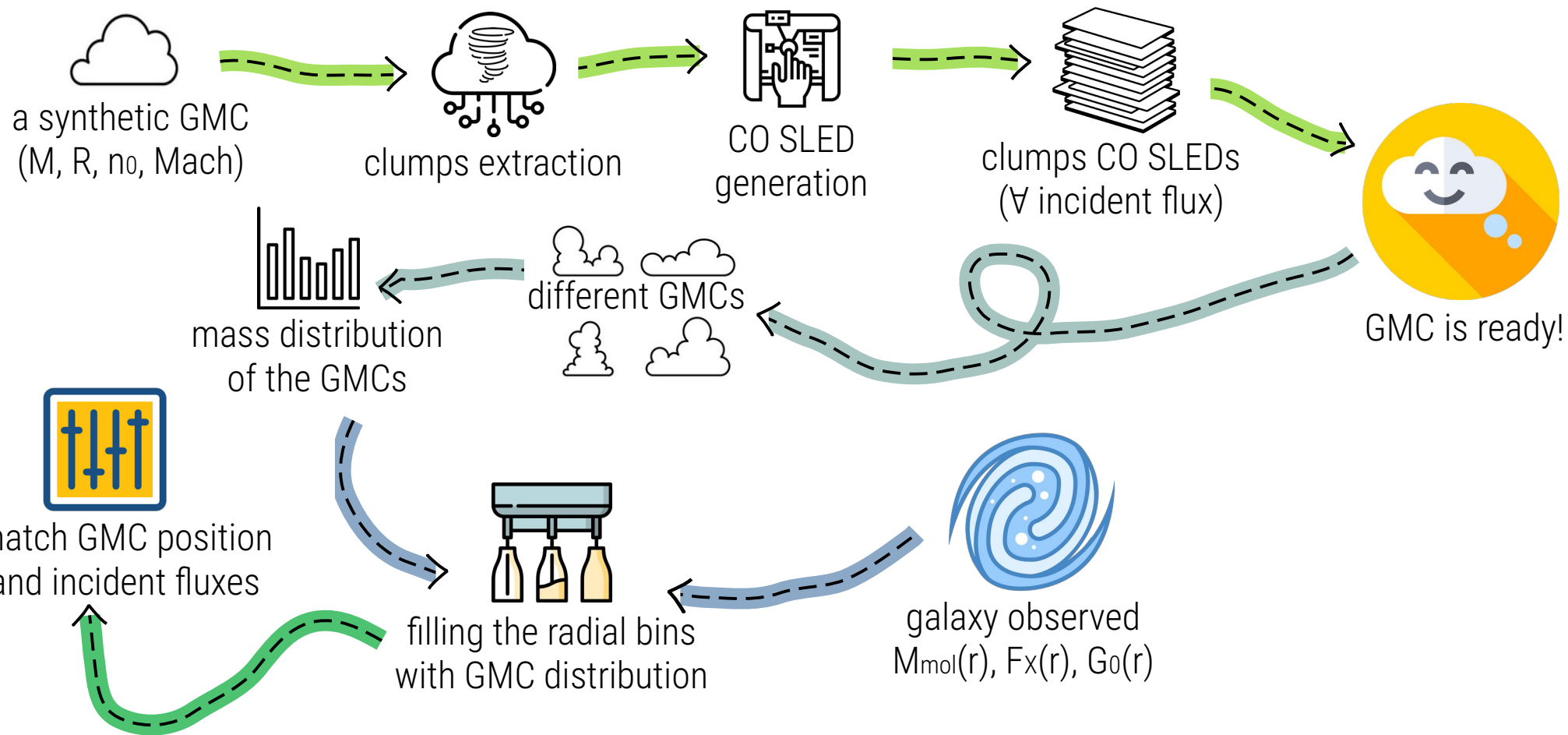


CO SLED GENERATION: THE WORKFLOW



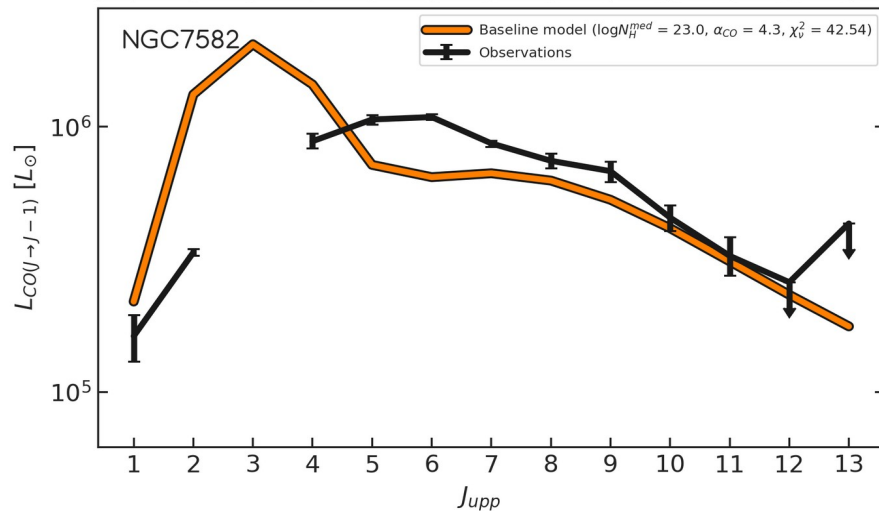
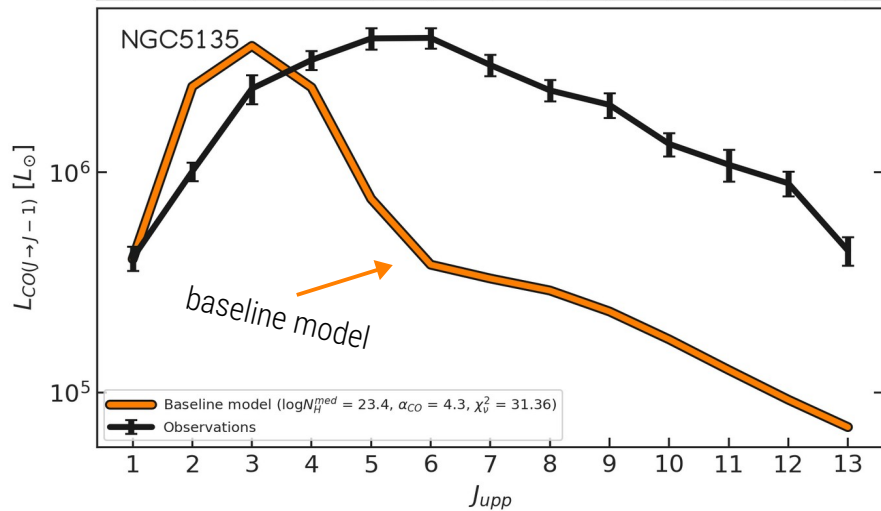
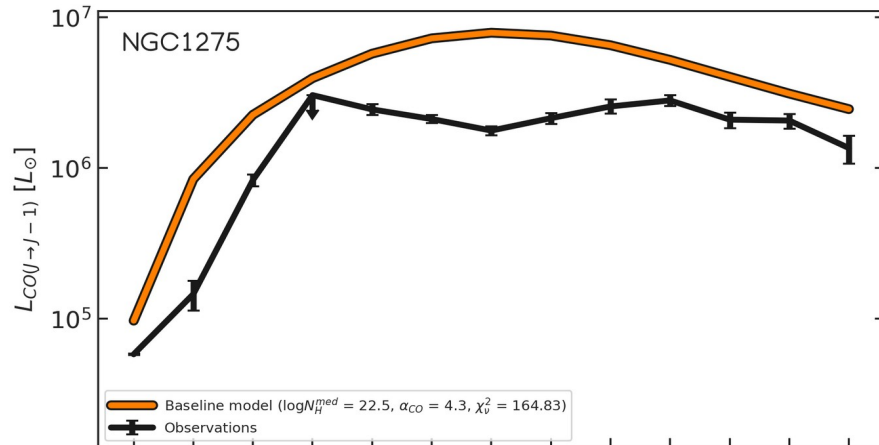
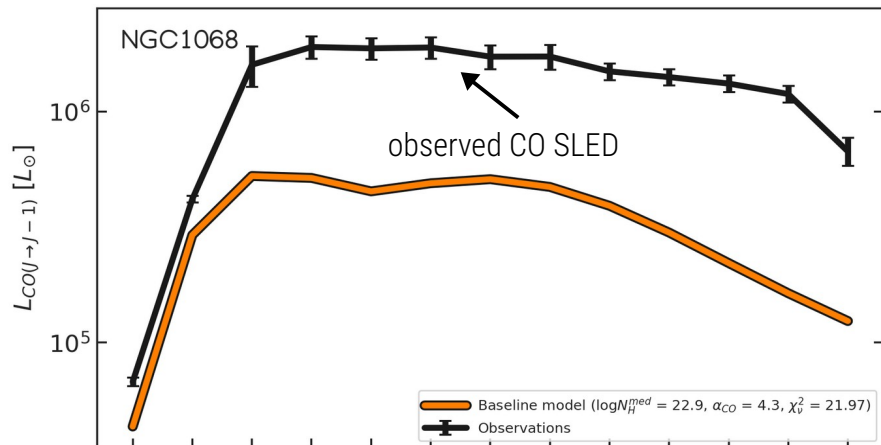


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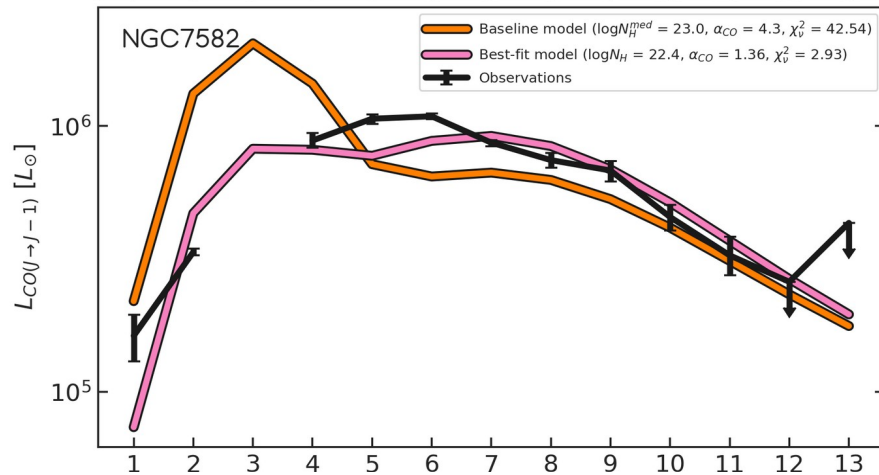
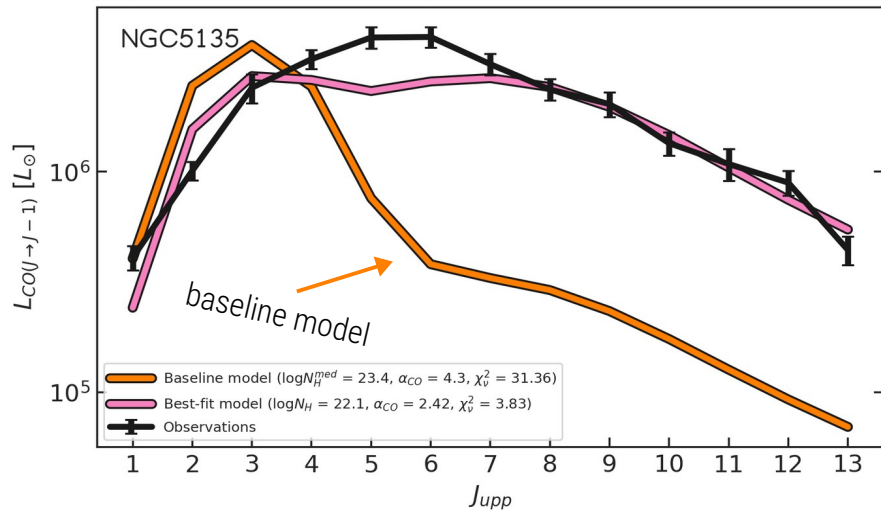
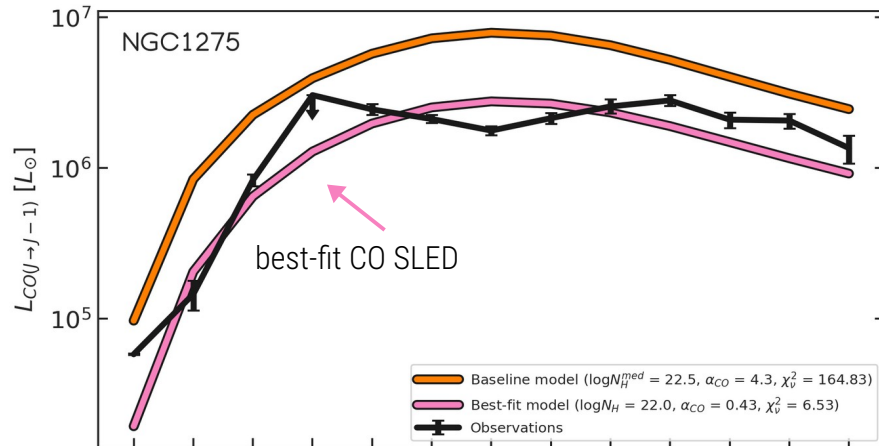
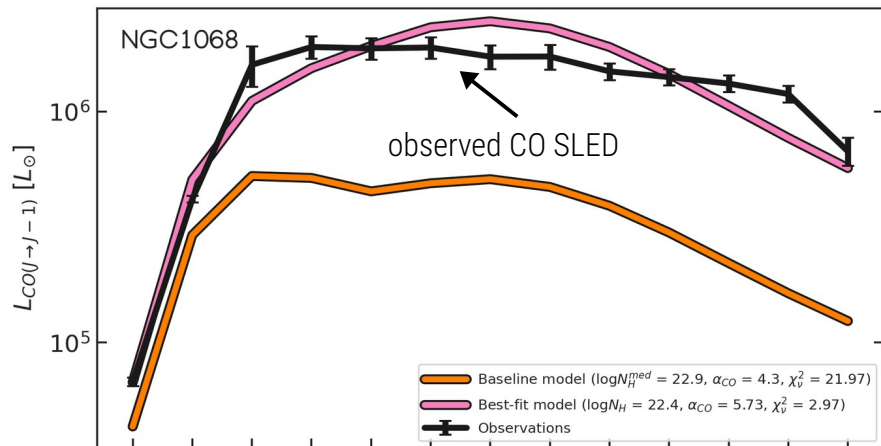


CO SLEDS OF GALAXIES: BASELINE MODEL



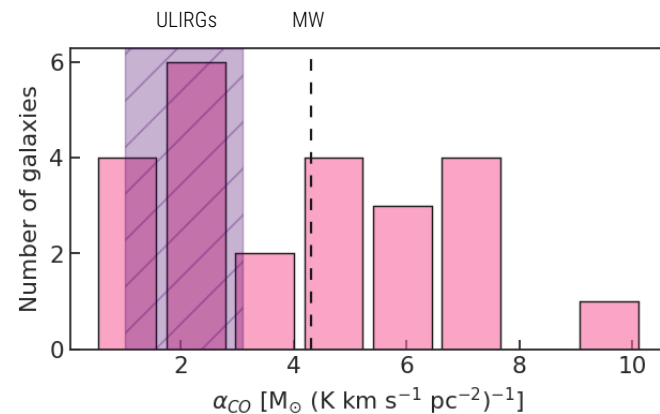


CO SLEDS OF GALAXIES: BEST FIT (ALPHA-CO, N_H)





NEW MODEL: RESULTS



$\alpha_{CO} = 3.8^{+3.9}_{-2.1}$

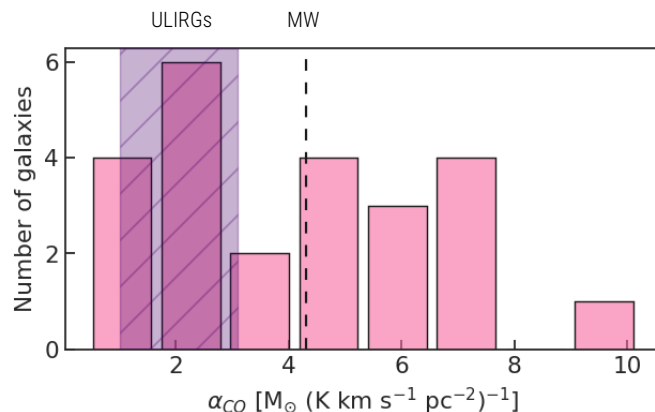
Modelling molecular clouds and CO excitation in AGN-host galaxies

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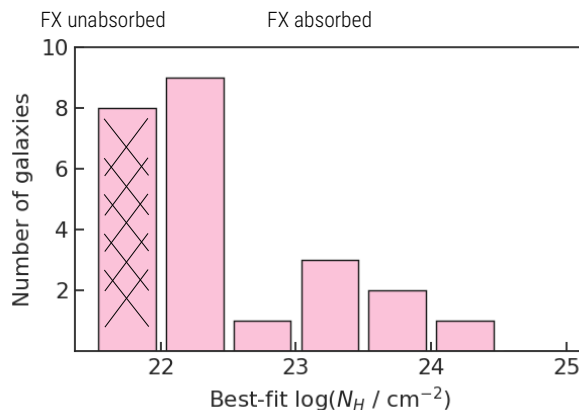




NEW MODEL: RESULTS



$\alpha_{CO} = 3.8^{+3.9}_{-2.1}$



$\log N_H = 22.4^{+1.4}_{-0.2}$

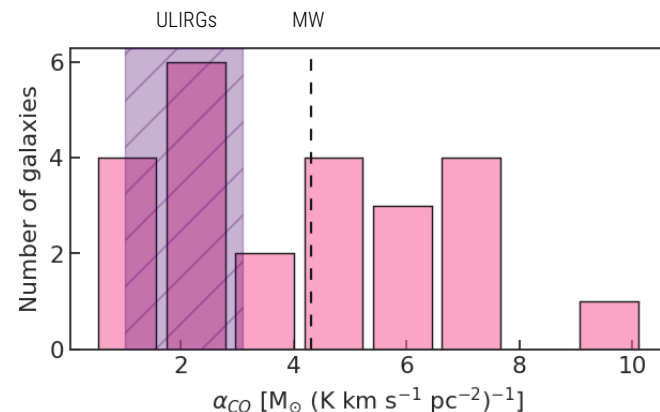
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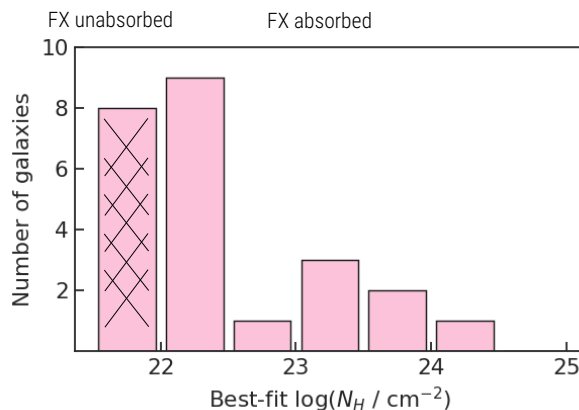




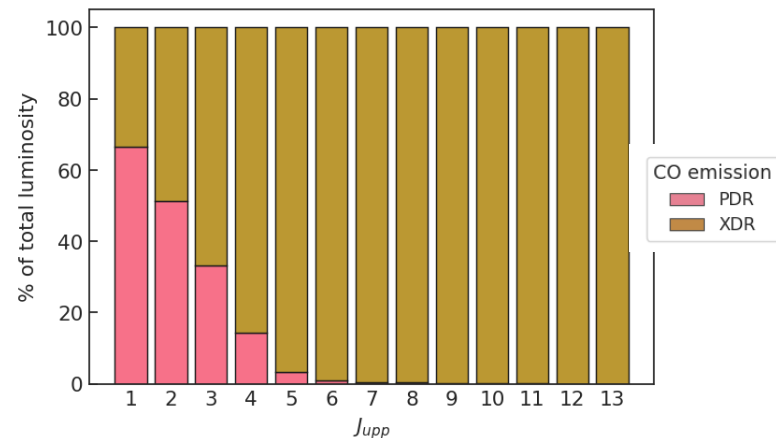
NEW MODEL: RESULTS



$\alpha_{CO} = 3.8^{+3.9}_{-2.1}$



$\log N_H = 22.4^{+1.4}_{-0.2}$



XDRs are fundamental to reproduce CO SLEDs from AGNs (for $J_{upper} > 4$)

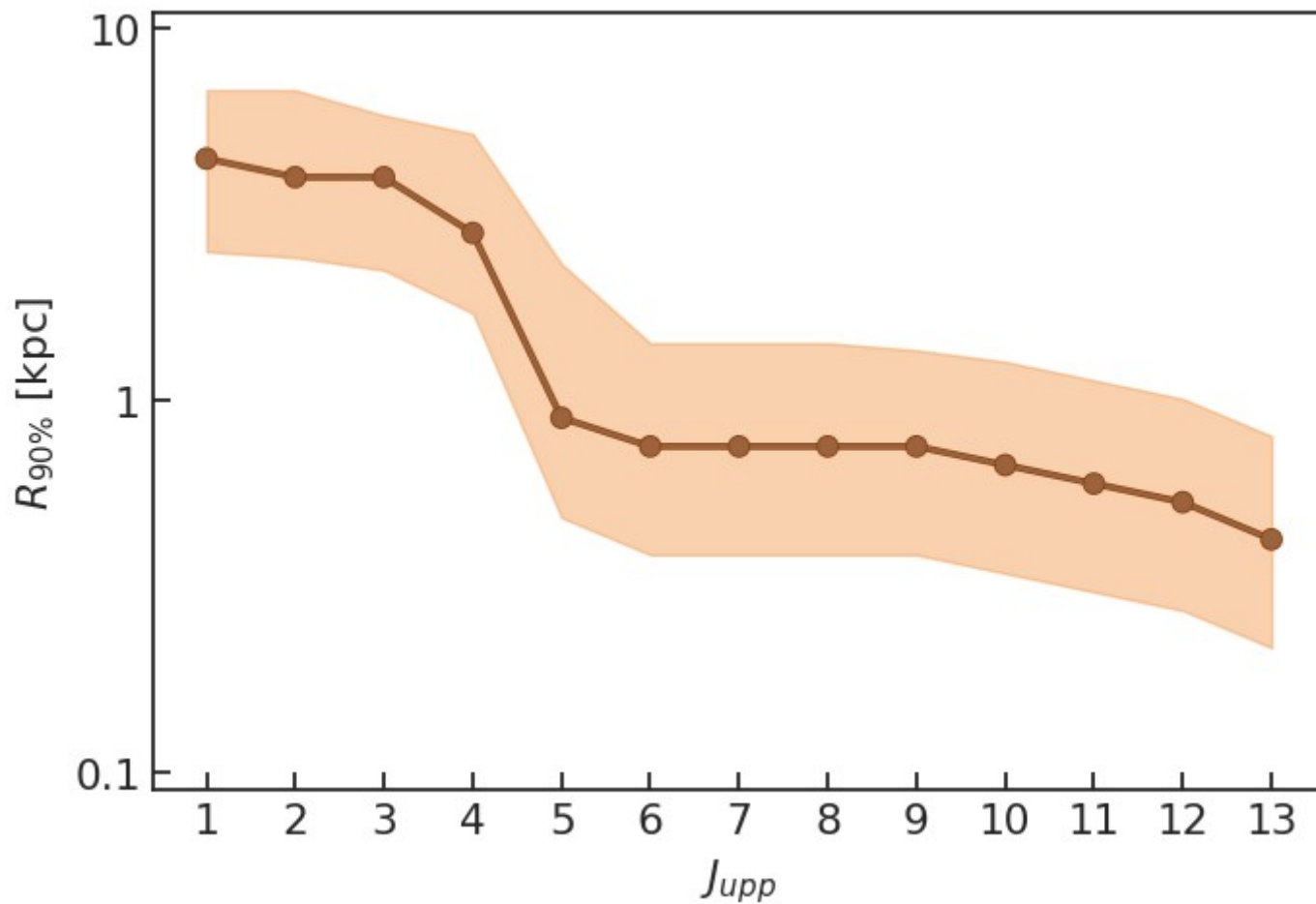
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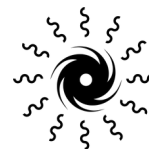




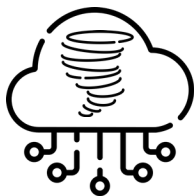
NEW MODEL: CO SLED RADIAL BUILD-UP



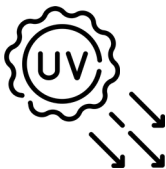
high F_x



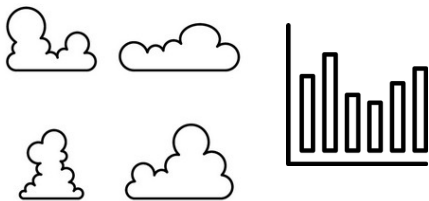
MODEL IN A NUTSHELL



GMC internal structure
(turbulent clumps)



radiative transfer
(PDR and XDR)



GMC mass distribution
in observed $M_{\text{mol}}(r)$

CONCLUSIONS

The model can **reproduce** observed CO SLED and **infer** galaxies properties (α_{CO} , N_{H})

AGN feedback (as opposed to stellar feedback) is the **dominant** mechanism for $J_{\text{up}} > 4$

Given observed galaxies properties (M_{mol} , L_{X} , G_0) it can predict **intensity** and **physical size** of CO lines



arXiv:2305.14111v1 [astro-ph] 14 May 2023

Modelling molecular clouds and CO excitation in AGN-host galaxies

Federico Impirotto^{1,2*}, Livia Vallini³, Francesca Portal⁴, Viviana Casaccia⁵, Alessandro Alari⁶, Santiago García-Barril⁷, Roberto Decarli⁸, Francesco Calzavara⁹, Cristian Vignati^{1,2}, and M. ...

ABSTRACT
We present a new physically-motivated model for estimating the molecular line energy content (i) the internal density structure of giant molecular clouds (GMCs) in active galactic nuclei (AGNs), respectively producing photoionization within the GMCs, and (ii) the mass distribution of GMCs within the galaxial profiles of molecular mass, for UV flux and X-ray flux for a given conversion factor α_{CO} , and the X-ray attenuation column density N_{H} of the galaxy. We model the molecular line energy content of the galaxy, simulating their carbon monoxide spectral line energy distribution (SLED), and we calculate, for each galaxy, the best-fit parameters. We find a median $\alpha_{\text{CO}} = 4.3 \pm 0.4$ for the XDR component of the CO SLED to dominate the CO SLED of molecular gas density to take into account PDR or XDR.

Key words: ISM: clouds – photoionization region

1 INTRODUCTION
The molecular gas content of galaxies is measured by CO and other galaxy nuclei (García-Barril et al. 2021; Madau & ...)

2 OBSERVATIONAL CONSTRAINTS
The observed CO SLED is a function of the molecular line energy content (i) the internal density structure of giant molecular clouds (GMCs) in active galactic nuclei (AGNs), respectively producing photoionization within the GMCs, and (ii) the mass distribution of GMCs within the galaxial profiles of molecular mass, for UV flux and X-ray flux for a given conversion factor α_{CO} , and the X-ray attenuation column density N_{H} of the galaxy. We model the molecular line energy content of the galaxy, simulating their carbon monoxide spectral line energy distribution (SLED), and we calculate, for each galaxy, the best-fit parameters. We find a median $\alpha_{\text{CO}} = 4.3 \pm 0.4$ for the XDR component of the CO SLED to dominate the CO SLED of molecular gas density to take into account PDR or XDR.

3 RESULTS
We present a new physically-motivated model for estimating the molecular line energy content (i) the internal density structure of giant molecular clouds (GMCs) in active galactic nuclei (AGNs), respectively producing photoionization within the GMCs, and (ii) the mass distribution of GMCs within the galaxial profiles of molecular mass, for UV flux and X-ray flux for a given conversion factor α_{CO} , and the X-ray attenuation column density N_{H} of the galaxy. We model the molecular line energy content of the galaxy, simulating their carbon monoxide spectral line energy distribution (SLED), and we calculate, for each galaxy, the best-fit parameters. We find a median $\alpha_{\text{CO}} = 4.3 \pm 0.4$ for the XDR component of the CO SLED to dominate the CO SLED of molecular gas density to take into account PDR or XDR.

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soon on arXiv and github