METHOD - 1 : plotting - 1.4

$i=1,\ j=0$

$j_\nu = \frac{h\nu_{10}}{4\pi} N n_1 A_{10} \phi_\nu$ → emissivity [$eV\ cm^{-3}\ s^{-1}\ Hz^{-1}$]

$j_{10} = \frac{h\nu_{10}}{4\pi} N n_1 A_{10}$ → integrated emissivity [$eV\ cm^{-3}\ s^{-1}$]

$\bar{j}_{10} = \sum_{i=0}^{log} j_{10} \cdot \beta \cdot pdf \cdot ds$ → emissivity for each cell in the sim. [$eV\ cm^{-3}\ s^{-1}$]

$I_{10} = \int_0^L \bar{j}_\nu\, dz$ → Intensity of each pixel in the Galaxy map [$eV\ cm^{-2}\ s^{-1}$]

$I_\nu = \frac{I_{10}}{\Delta\nu}$ → [$eV\ cm^{-2} s^{-1}\ Hz^{-1}$] ; $\Delta\nu = \nu_{10} \frac{\Delta v}{c}$; $\Delta v = 100\ km/s = 10^7\ cm/s$

$$\left\{ T = \underbrace{\frac{c^2}{2\nu_{10}^2 K_B} I_\nu}_{[K]} \right\} = \frac{c^2}{2\nu_{10}^2 K_B} \frac{I_{10}}{\nu_{10}\Delta v} \cdot c$$

$$\therefore (T \cdot \Delta v) = \underbrace{\left(\frac{c^2}{2\nu_{10}^2 K_B} \frac{I_{10}}{\nu_{10}} \right)}_{K} \cdot \underbrace{c}_{km/s}$$

$$L_{co} = \underbrace{(T \cdot \Delta v)}_{K\ km/s\ \cdot\ pc^2} \cdot (edge)^2$$ → Total Luminosity of the galaxy

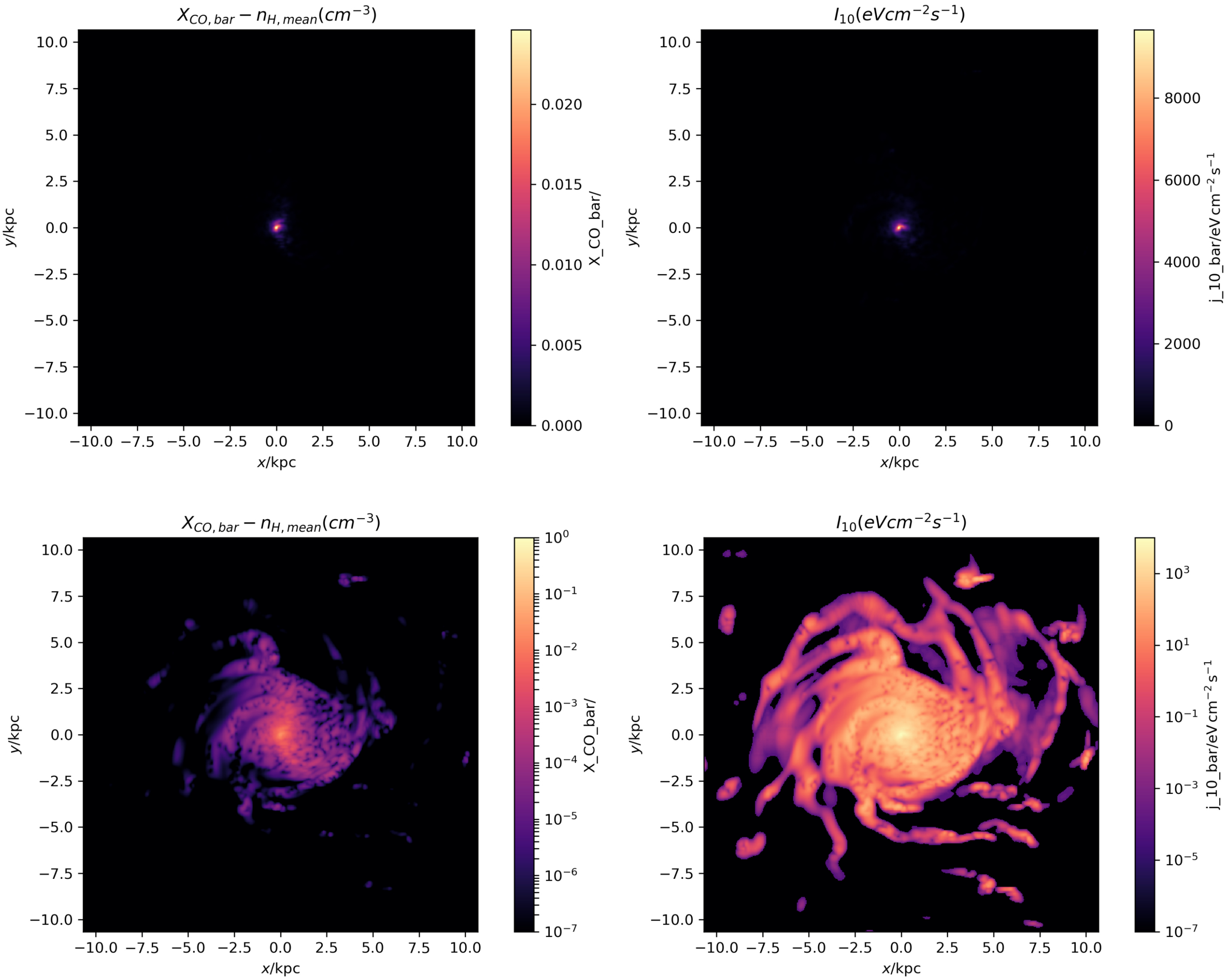
Results :

$T \sim$ (mean value) 10^{-4} K

$L_{co} = 8.34 \times 10^{11}\ K\ km\ s^{-1}\ pc^2$

If I use, $L_{co} = (I_{10} \cdot c) \cdot (edge)^2$

Then $L_{co} = 2.127 \times 10^9\ K\ km\ s^{-1}\ pc^2$



$X_{CO,bar} - n_{H,mean}(cm^{-3})$
$I_{10}(eVcm^{-2}s^{-1})$
X_CO_bar/
j_10_bar/eV cm^{-2} s^{-1}
x/kpc
y/kpc

METHOD - 2 : (1.7) - using 1.4 results

$i=1,\ j=0$

$j_\nu = \frac{h\nu_{10}}{4\pi} N n_1 A_{10} \phi_\nu$ → emissivity [eV cm^{-3} s^{-1} Hz^{-1}]

$\dot{j}_{10} = \frac{h\nu_{10}}{4\pi} N n_1 A_{10}$ → integrated emissivity [eV cm^{-3} s^{-1}]

$\bar{\dot{j}}_{10} = \sum_{i=0}^{100} \dot{j}_{10} \beta\, \mathrm{pdf}\, ds$ → emissivity for each cell in the sim. [eV cm^{-3} s^{-1}]

dx = width of each cell in the sim → [cm]

$l_{co} = \bar{\dot{j}}_{10} \cdot (dx)^3$ → Luminosity of each cell in the sim. [eV s^{-1}]

$L_{co} = \sum_{i=0}^{\text{all cells}} (l_{co})_i$ → Luminosity of the Galaxy [eV s^{-1}]

Result :

$L_{co} = 10^{1.43}\ L_\odot$

$= 6.487 \times 10^{46}$ eV s^{-1}

| $L_\odot = 2.4342 \times 10^{45}$ eV s^{-1}

[In the paper,

$L_{co} = 10^{4.85}\ L_\odot$

SFR = 100 $M_\odot$/yr | z = 6

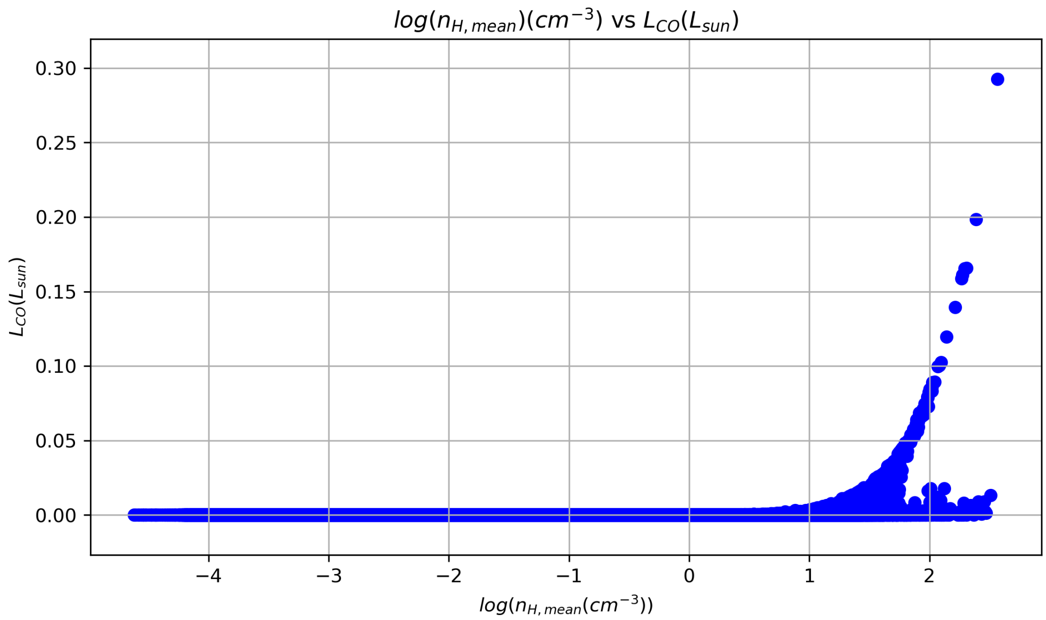
$M_* = 10^{10}\ M_\odot$

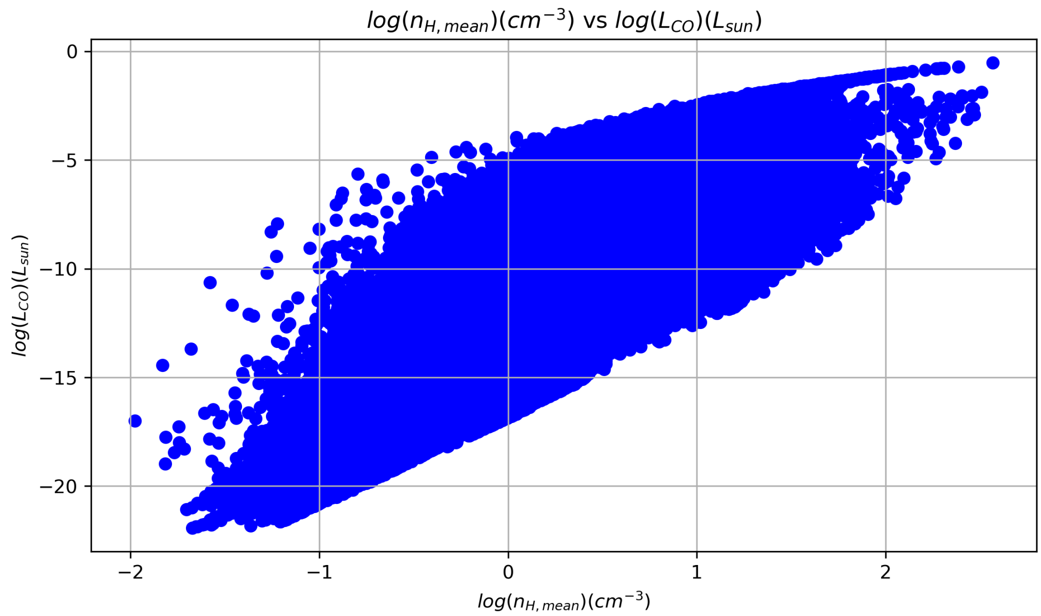
$\mathcal{M} = 30$

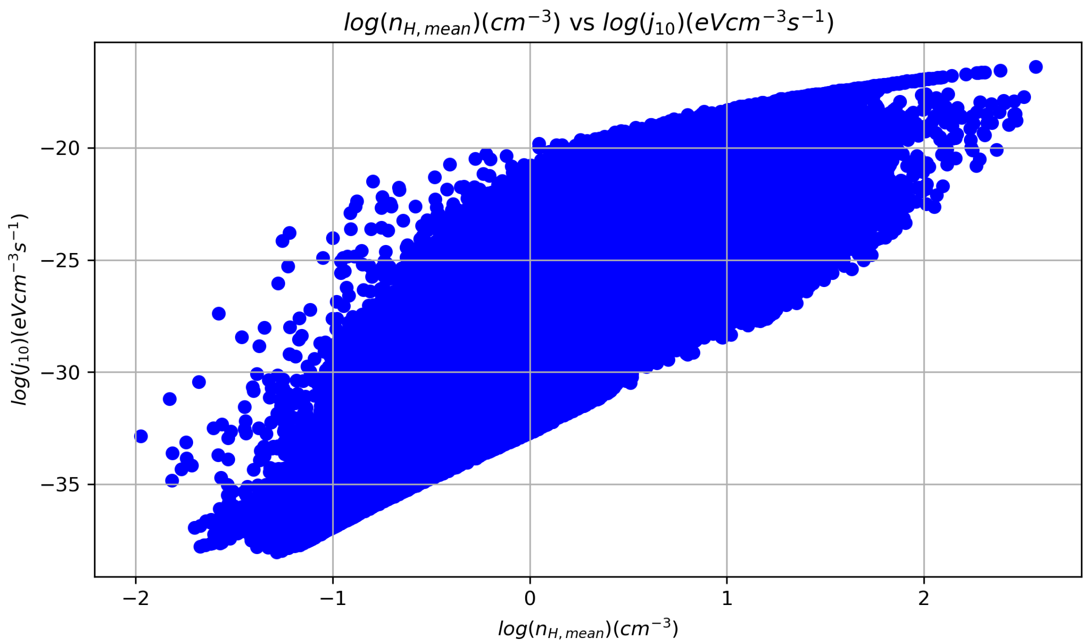
Kinetic Temp., T_k = 45 K]

→ L_{co} vs $\log(\bar{n}_H)$

→ $\bar{\dot{j}}_{10}$ vs $\log(\bar{n}_H)$] - attached


$log(n_{H,mean})(cm^{-3})$ vs $L_{CO}(L_{sun})$
$L_{CO}(L_{sun})$
$log(n_{H,mean}(cm^{-3}))$


$log(n_{H,mean})(cm^{-3})$ vs $log(L_{CO})(L_{sun})$
$log(L_{CO})(L_{sun})$
$log(n_{H,mean})(cm^{-3})$


$log(n_{H,mean})(cm^{-3})$ vs $log(j_{10})(eVcm^{-3}s^{-1})$
$log(j_{10})(eVcm^{-3}s^{-1})$
$log(n_{H,mean})(cm^{-3})$

Sub-grid :

$i=1,\ j=0$

$$j_0 = \frac{h\nu_{10}}{4\pi} N\, n_1 A_{10} \phi_0 \rightarrow [\text{eV cm}^{-3}\, s^{-1}\, \text{Hz}^{-1}]$$

$$j_{10} = \frac{h\nu_{10}}{4\pi} N\, n_1 A_{10} \rightarrow [\text{eV cm}^{-3}\, s^{-1}]$$

$$l_{CO} = j_{10} \cdot \beta \cdot \text{pdf} \cdot (dx)^3 \rightarrow [\text{eV}\, s^{-1}]$$

where, dx = mean-width of a cell in the sim.

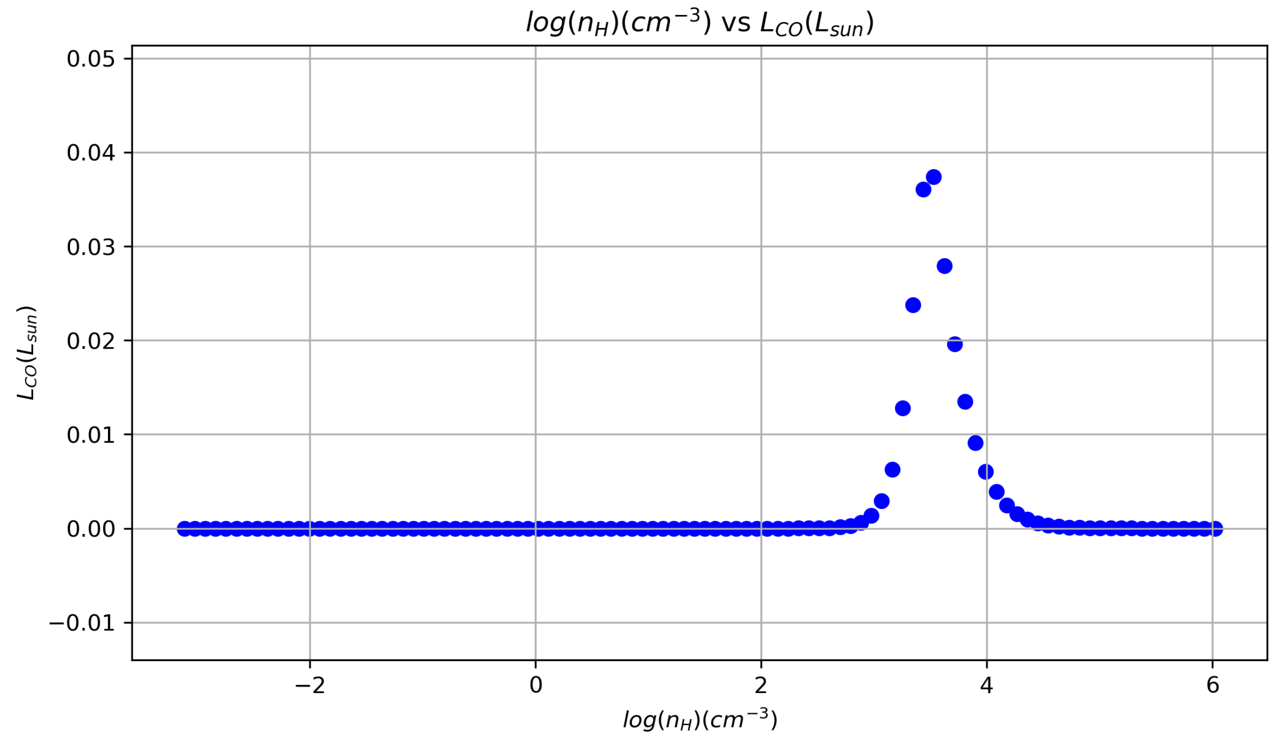
$= 3.5 \times 10^{20}$ cm

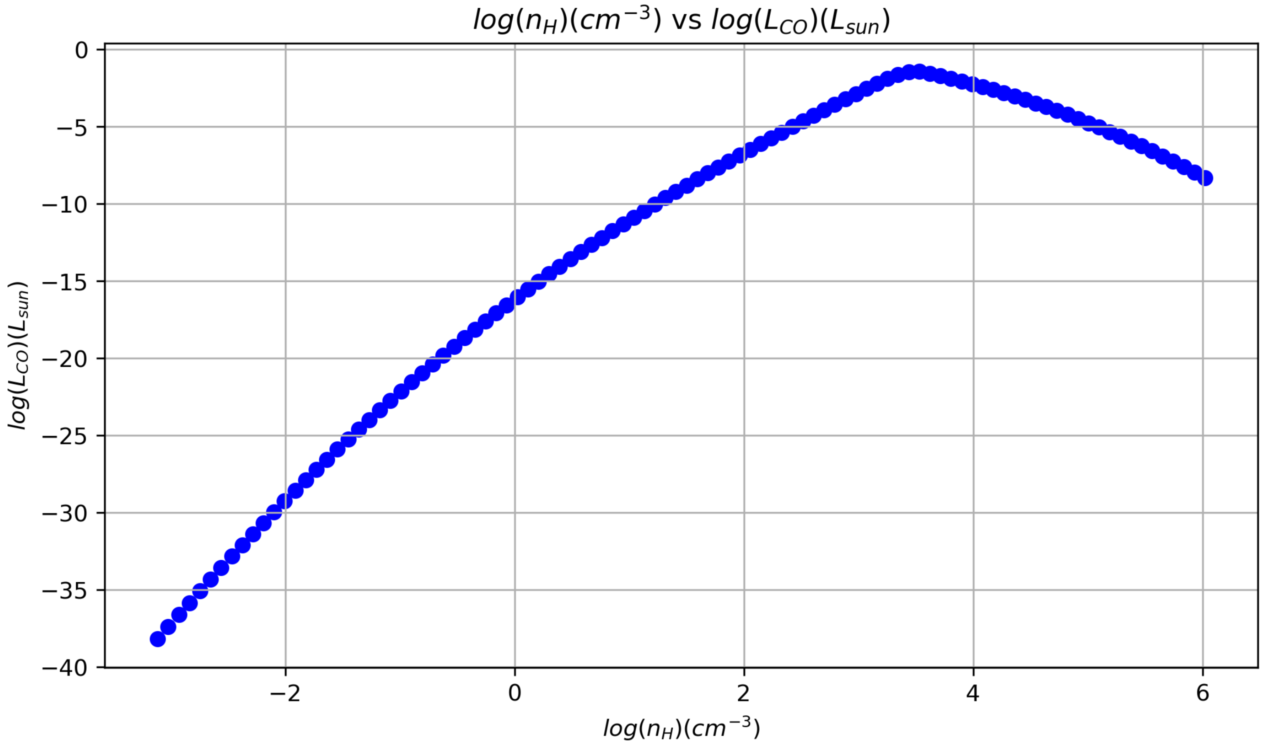
$$L_{CO} = l_{CO} / L_\odot$$

Result :

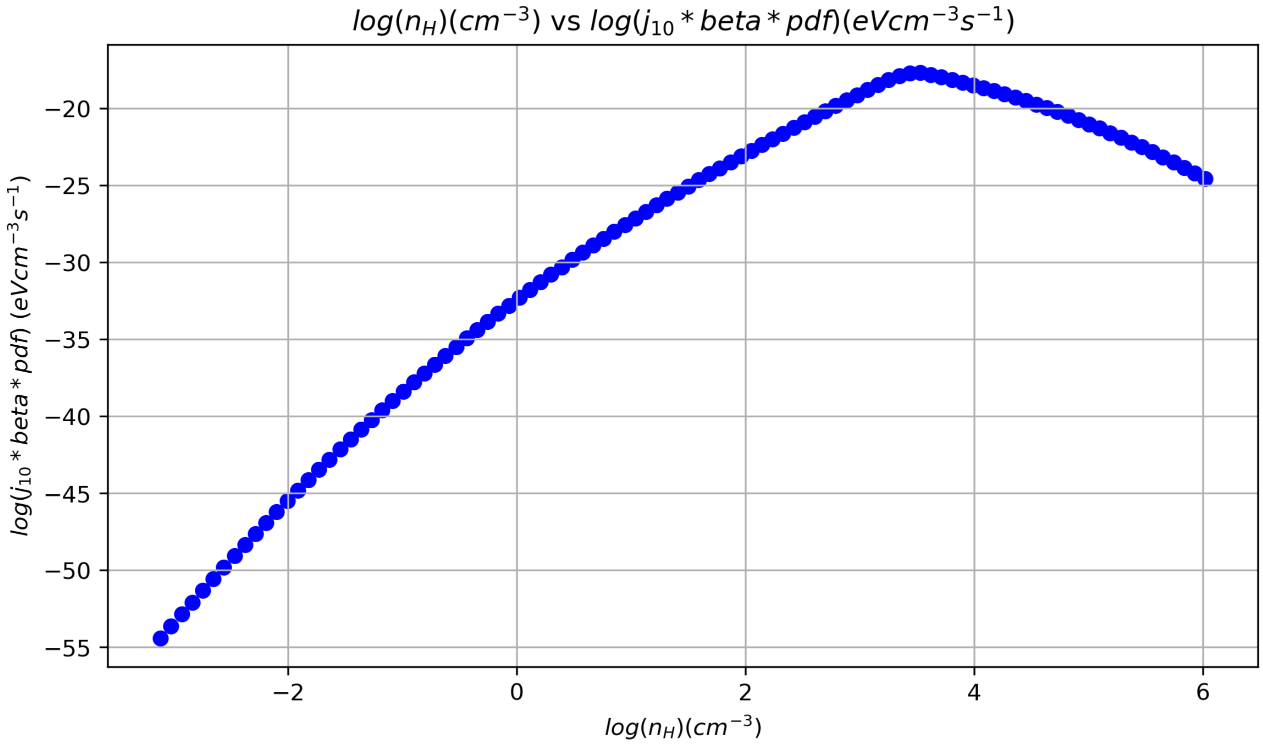
① L_{CO} vs $\log(n_H)$ – attached

② $(j_{10} \cdot \beta \cdot \text{pdf})$ vs $\log(n_H)$ – attached.

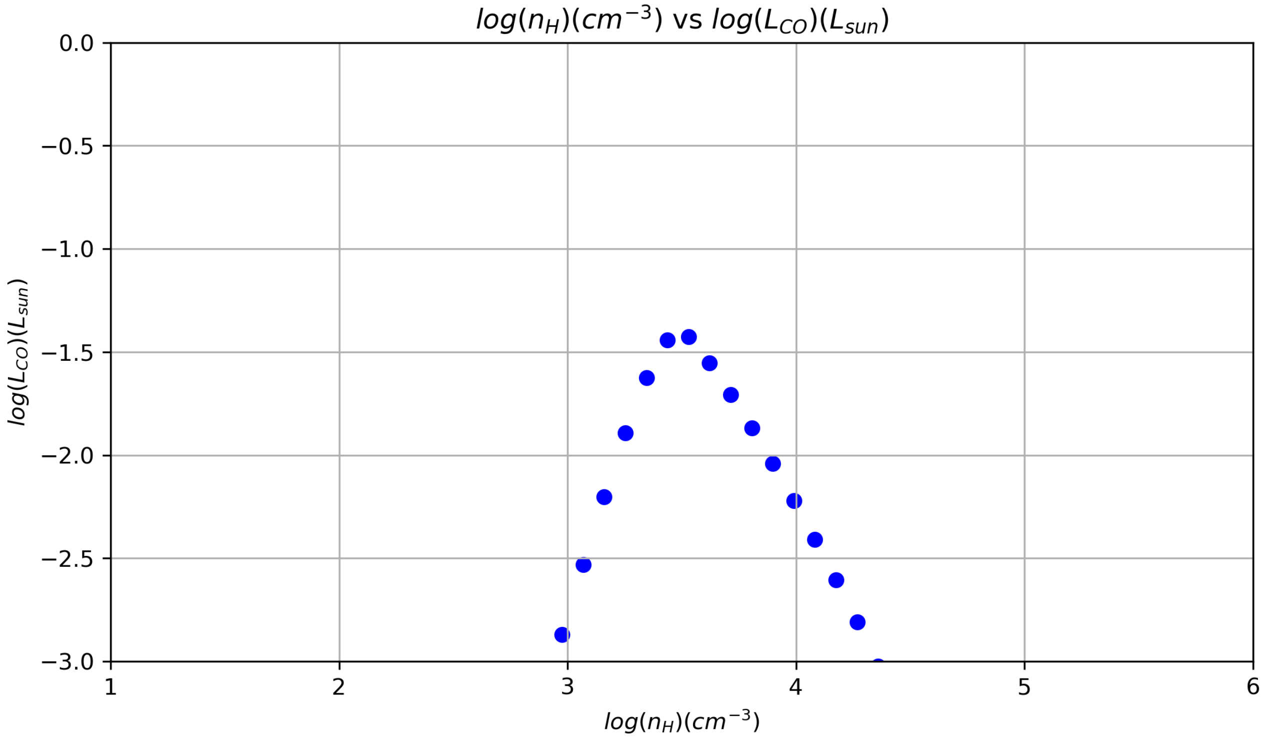




$log(n_H)(cm^{-3})$ vs $log(L_{CO})(L_{sun})$
0
−5
−10
−15
−20
−25
−30
−35
−40
$log(L_{CO})(L_{sun})$
−2
0
2
4
6
$log(n_H)(cm^{-3})$



$log(n_H)(cm^{-3})$ vs $log(j_{10} * beta * pdf)(eVcm^{-3}s^{-1})$
−20
−25
−30
−35
−40
−45
−50
−55
$log(j_{10} * beta * pdf)$ $(eVcm^{-3}s^{-1})$
−2
0
2
4
6
$log(n_H)(cm^{-3})$



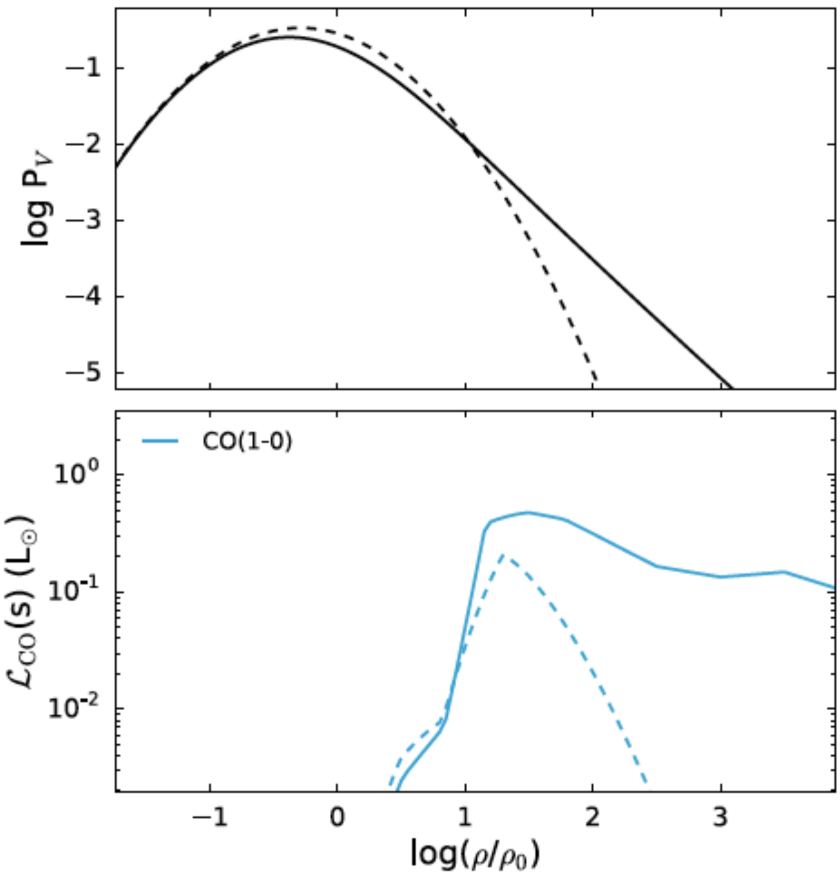


Figure 2. Upper panel: initial lognormal volume-weighted density PDF (dashed line, $\mathcal{M} = 5$), and the evolved density PDF (lognormal+tail hereafter, solid) after $t/t_{ff}(\rho_0) = 0.4$. Lower panel: specific CO(1–0) luminosity for the initial (dashed) and evolved (solid) cases shown in the upper panel.

Table 1. Parameters of the fiducial GMC.

$R_{GMC}/(pc)$	$n_0/(cm^{-3})$	$\rho_0/(g\,cm^{-3})$	$M_{GMC}/(M_\odot)$	$\log(Z/Z_\odot)$	$\log G_0$
15	100	2.34×10^{-22}	4.9×10^4	0	2

ABSTRACT

We study the CO line luminosity ($L_{\rm CO}$), the shape of the CO spectral line energy distribution (SLED), and the value of the CO-to-H_2 conversion factor in galaxies in the Epoch of Reionization (EoR). For this aim, we construct a model that simultaneously takes into account the radiative transfer and the clumpy structure of giant molecular clouds (GMCs) where the CO lines are excited. We then use it to post-process state-of-the-art zoomed, high resolution (30 pc), cosmological simulation of a main-sequence ($M_* \approx 10^{10}\,{\rm M}_\odot$, SFR $\approx 100\,{\rm M}_\odot\,{\rm yr}^{-1}$) galaxy, 'Althæa', at $z \approx 6$. We find that the CO emission traces the inner molecular disc ($r \approx 0.5$ kpc) of Althæa with the peak of the CO surface brightness co-located with that of the [C II] 158 μm emission. Its $L_{\rm CO(1-0)} = 10^{4.85}\,{\rm L}_\odot$ is comparable to that observed in local galaxies with similar stellar mass. The high ($\Sigma_{\rm gas} \approx 220\,{\rm M}_\odot\,{\rm pc}^{-2}$) gas surface density in Althæa, its large Mach number ($\mathcal{M} \approx 30$) and the warm kinetic temperature ($T_{\rm k} \approx 45$ K) of GMCs yield a CO SLED peaked at the CO(7–6) transition, i.e. at relatively high-J and a CO-to-H_2 conversion factor $\alpha_{\rm CO} \approx 1.5\,{\rm M}_\odot({\rm K\,km\,s^{-1}\,pc^2})^{-1}$ lower than that of the Milky Way. The Atacama Large Millimeter/submillimeter Array observing time required to detect (resolve) at 5σ the CO(7–6) line from galaxies similar to Althæa is ≈13 h (≈38 h).

Key words: ISM: clouds – ISM: molecules – galaxies: high-redshift – galaxies: ISM – infrared: ISM.