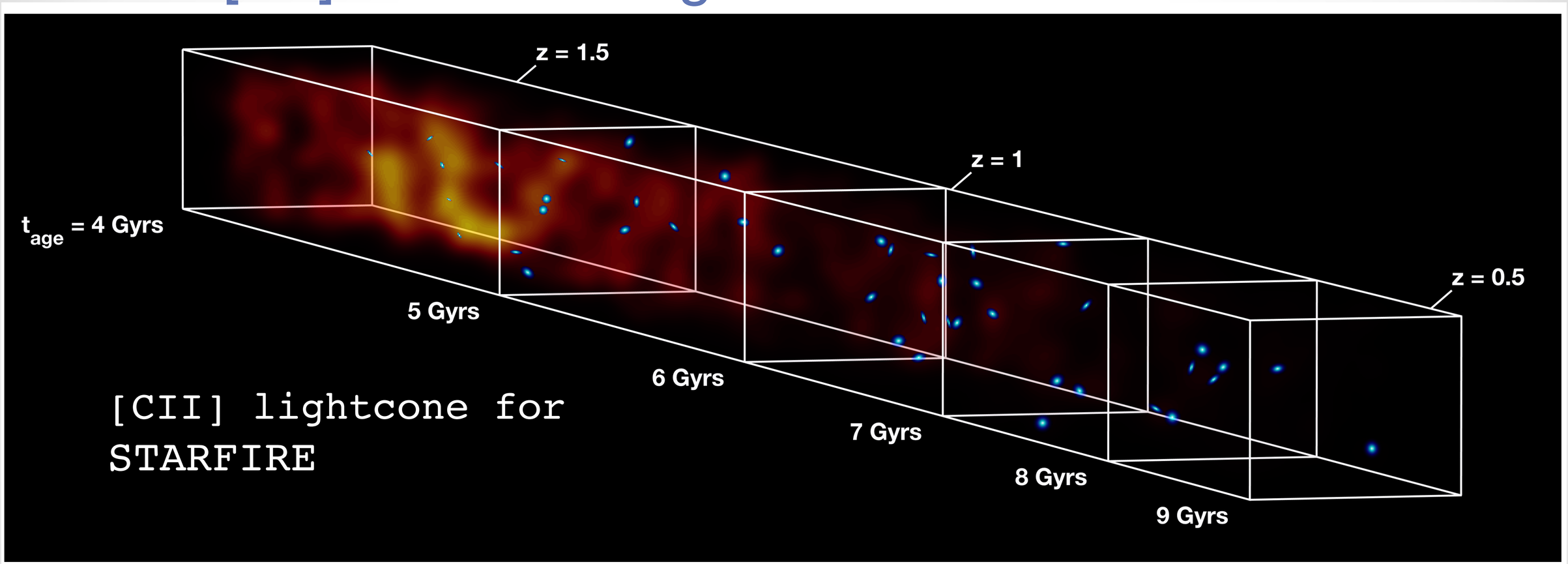
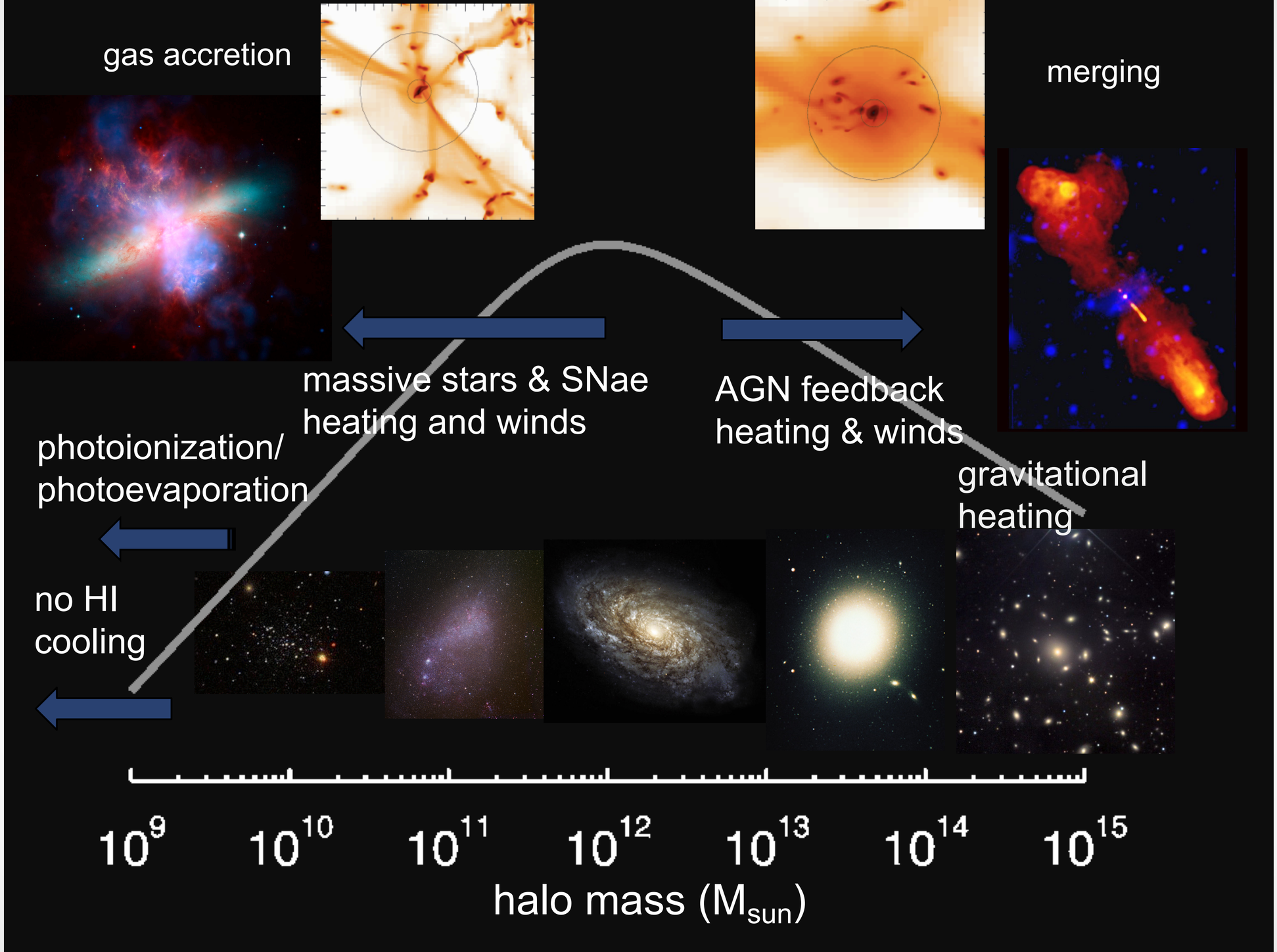
An efficient galaxy formation model for the CO and [CII] emission of galaxies over cosmic time.



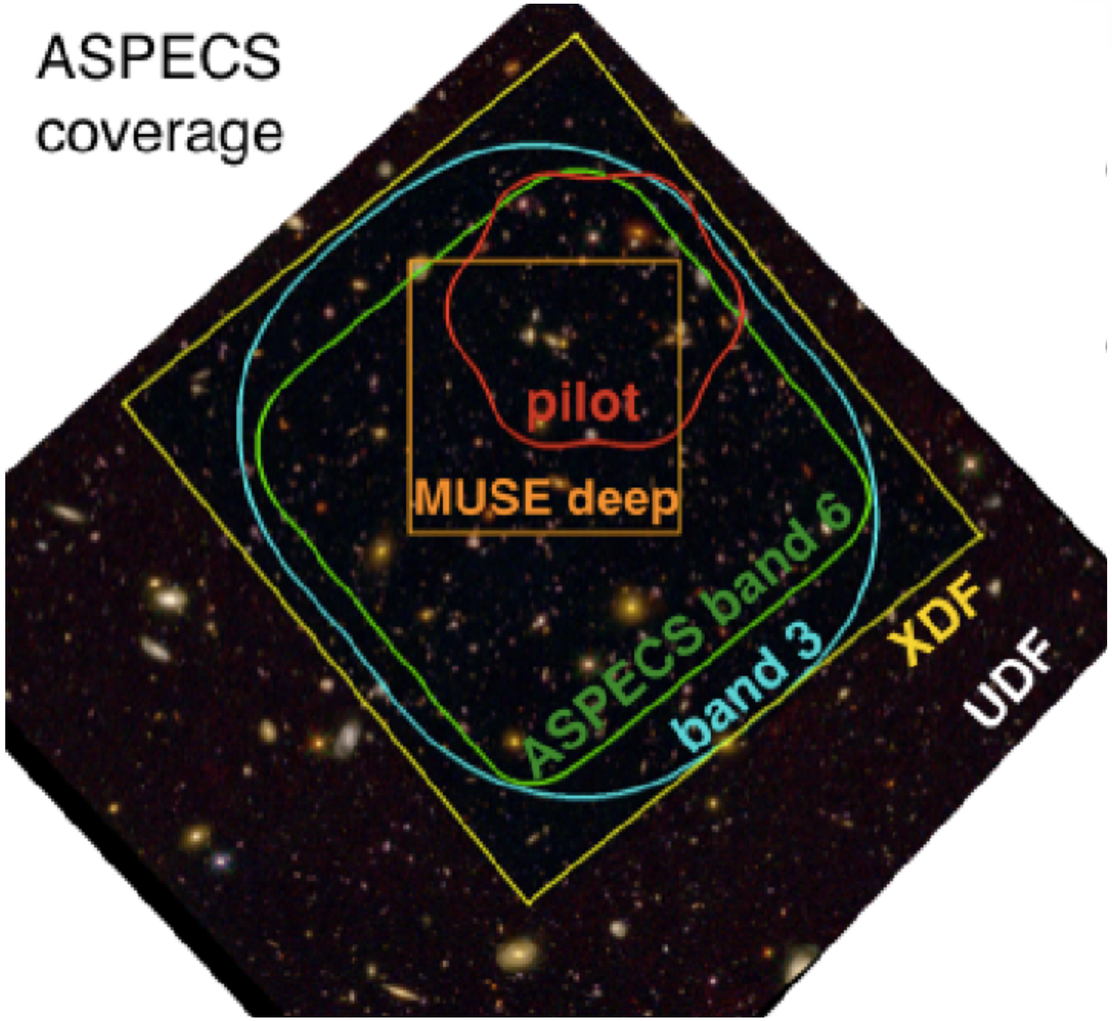
Gergö Popping

Desika Narayanan, Rachel Somerville,
Romeel Dave, Mark Krumholz, Andreas Faisst

Max-Planck-Institut für Astronomie Heidelberg
Max Planck Institute for Astronomy Heidelberg


gas accretion
merging
massive stars & SNae
heating and winds
AGN feedback
heating & winds
photoionization/
photoevaporation
gravitational
heating
no HI
cooling
10^9
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
halo mass (M_{sun})

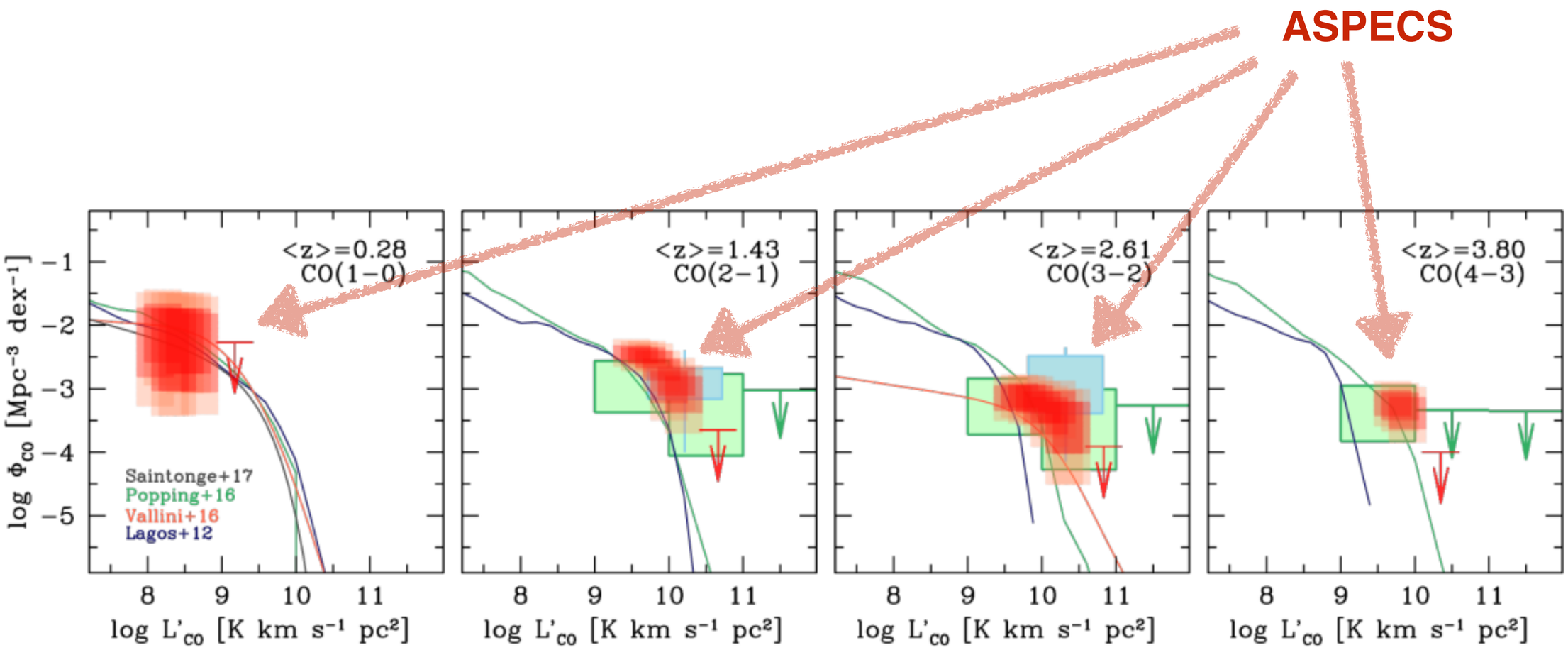
Blind CO efforts: ASPECS



The goal: measure the evolution of the cosmic density of H2 through CO with ALMA

Decarli et al. 2019 (submitted)

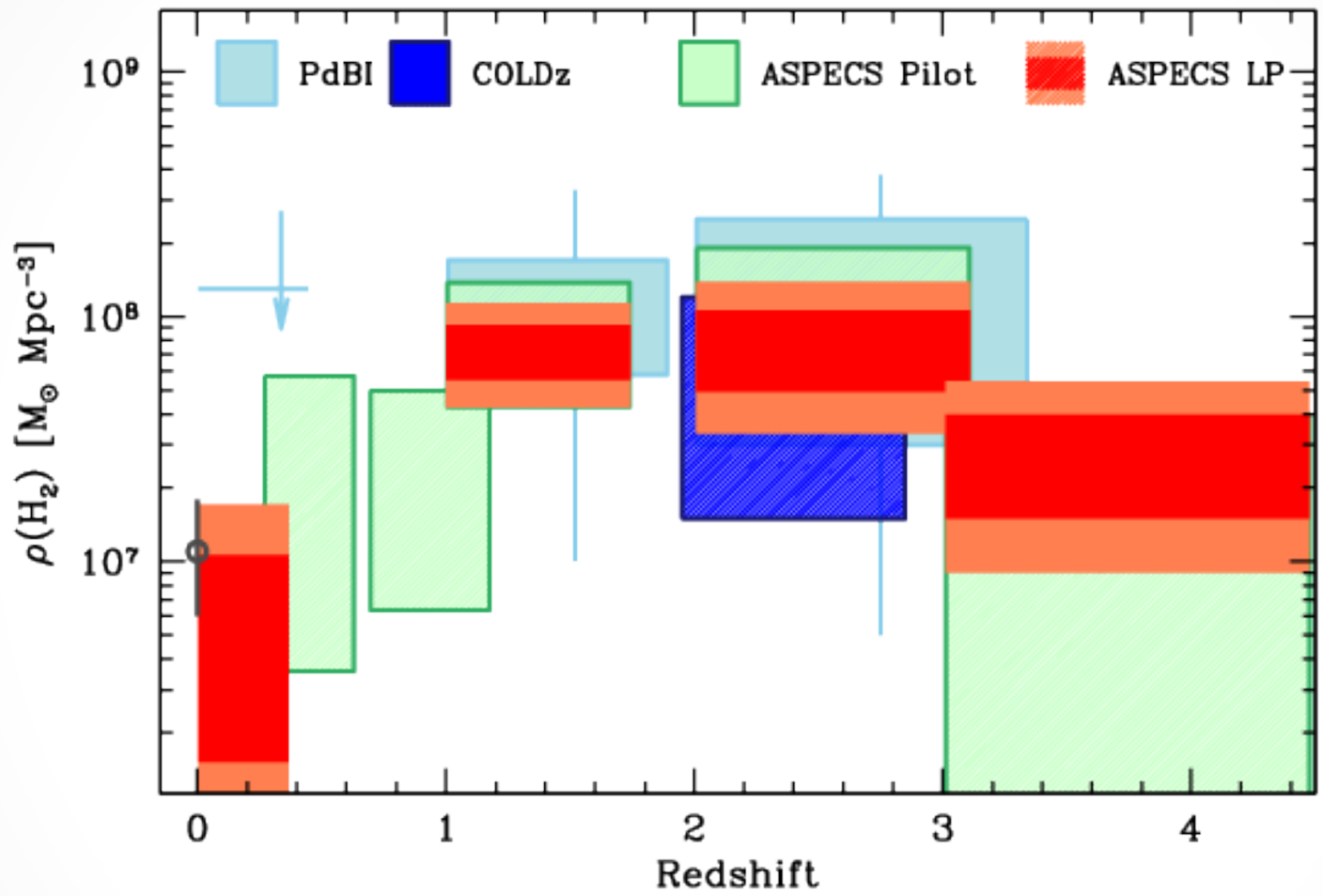
CO luminosity functions



based on ASPECS 3mm data

Decarli et al. 2019 (submitted)

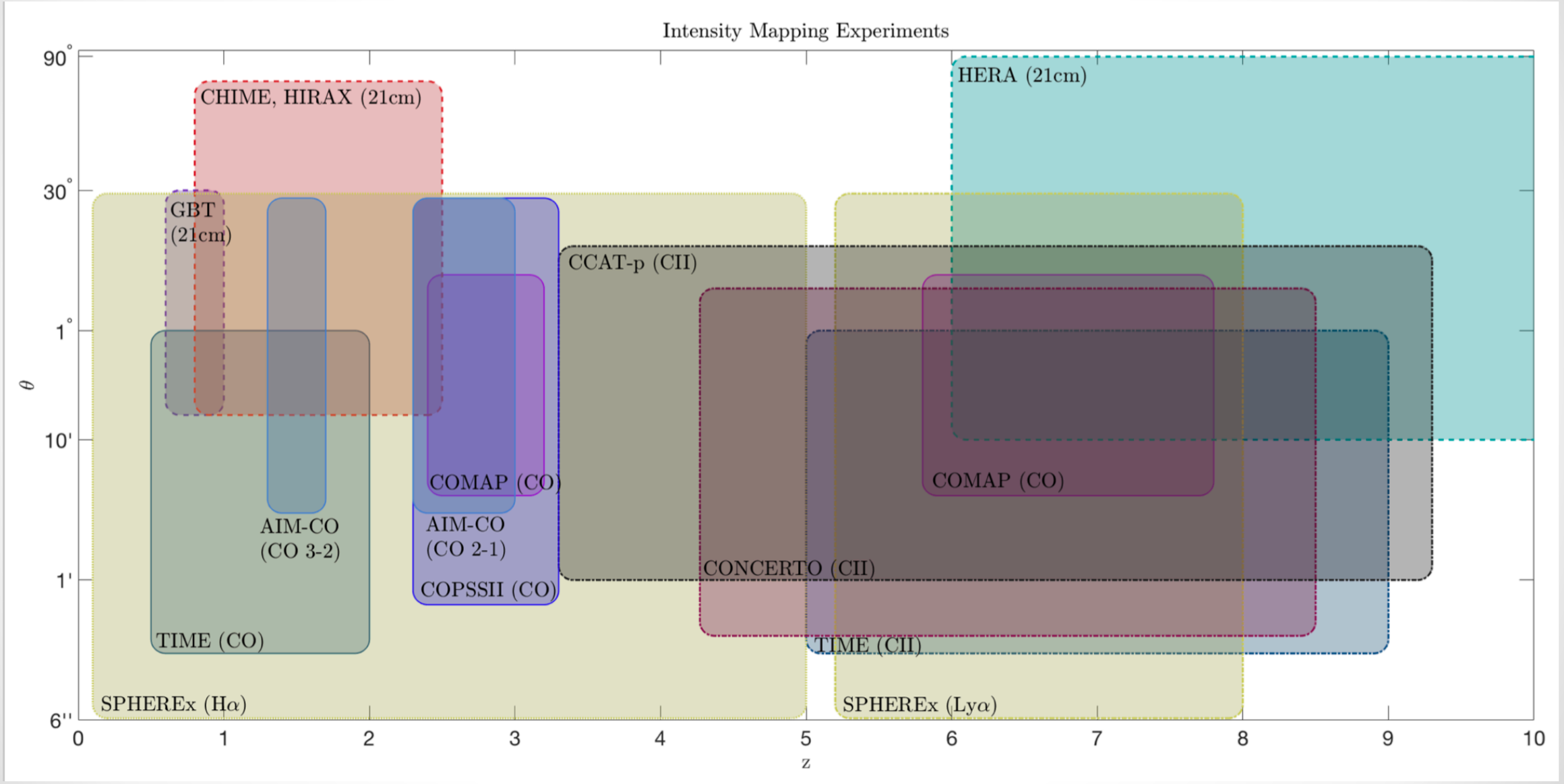
ASPECS: H2 cosmic density



A similar increase and decline in H2 cosmic density as SFR cosmic density

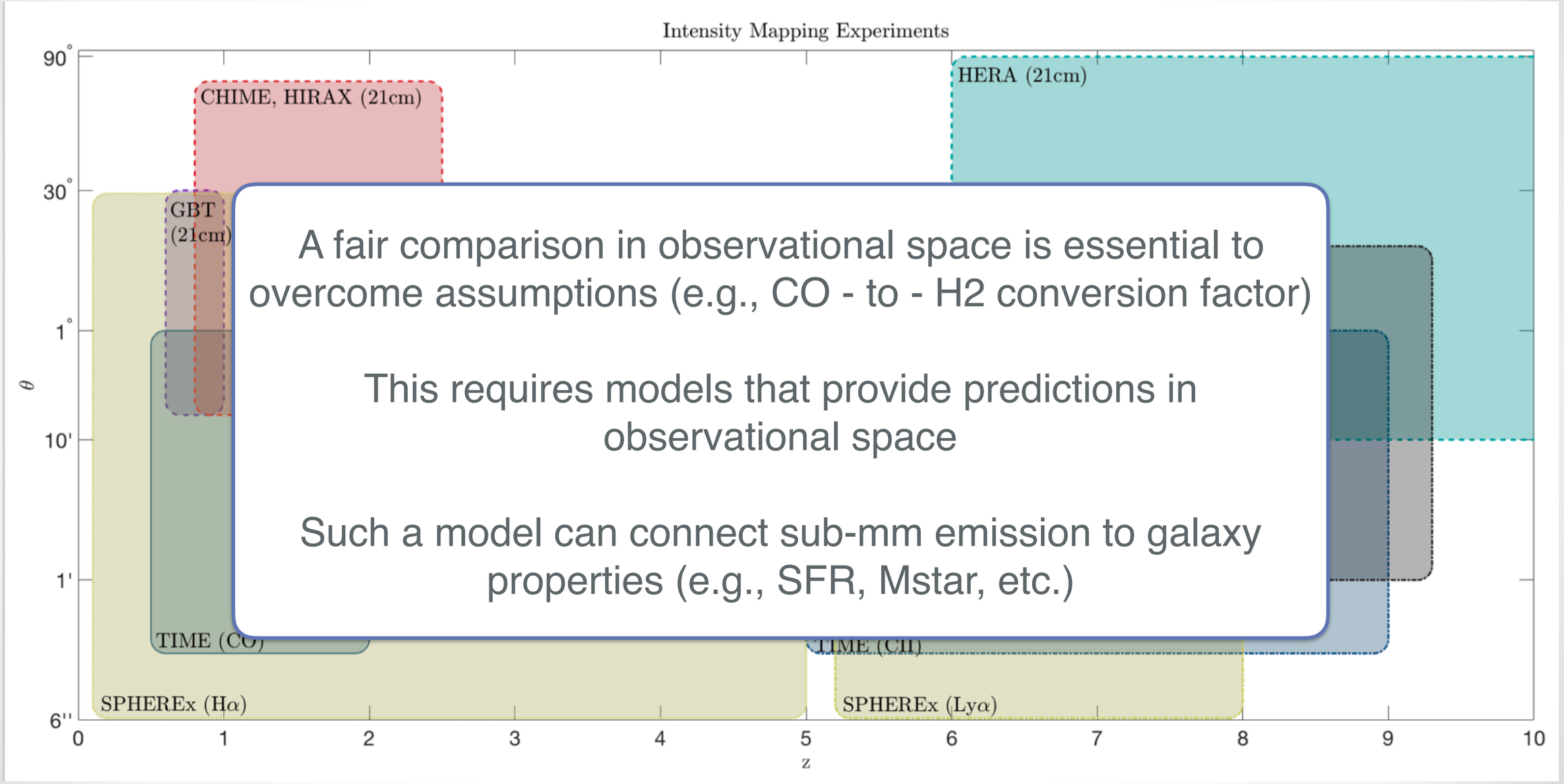
Decarli et al. 2019 (submitted)

CO & [CII] Intensity mapping



Kovetz, et al. (2017)

CO & [CII] Intensity mapping



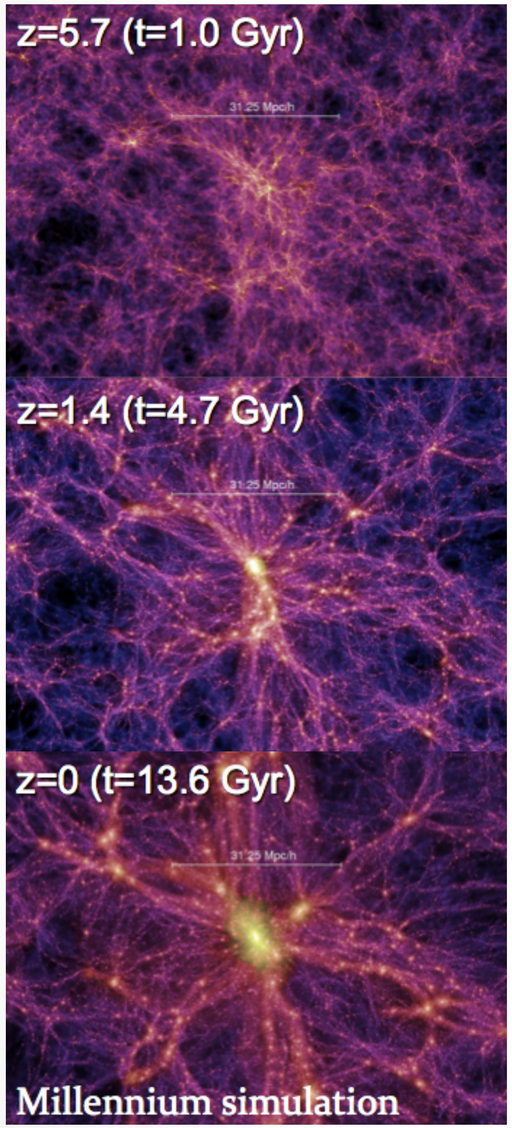
A fair comparison in observational space is essential to overcome assumptions (e.g., CO - to - H2 conversion factor)

This requires models that provide predictions in observational space

Such a model can connect sub-mm emission to galaxy properties (e.g., SFR, Mstar, etc.)

Kovetz, et al. (2017)

Semi-Analytic Model



- Gravitationally bound structures (halos) form as predicted by ΛCDM
- Gravity causes gas to accrete into halos and galaxies
- Accretion may be suppressed by presence of photoionizing background
- Stars formed out of cold, molecular gas
- Sizes are determined based on angular momentum conservation
- Cold gas is heated and removed from galaxy by SN
- Metals produced by stars enrich cold gas

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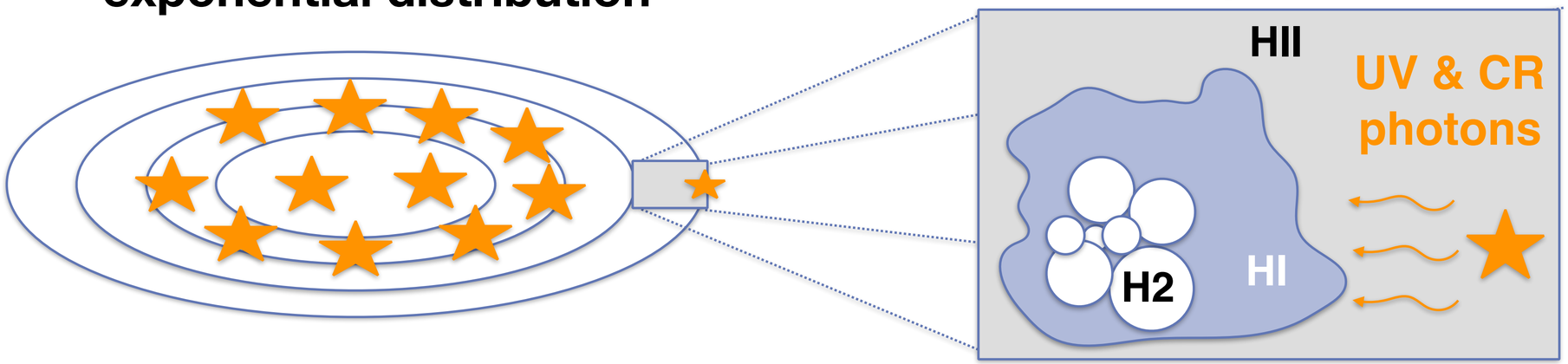
SAM galaxy with exponential distribution

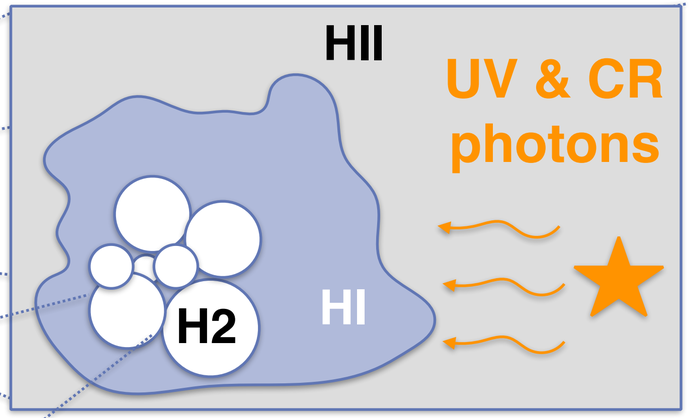
SAM galaxy with exponential distribution

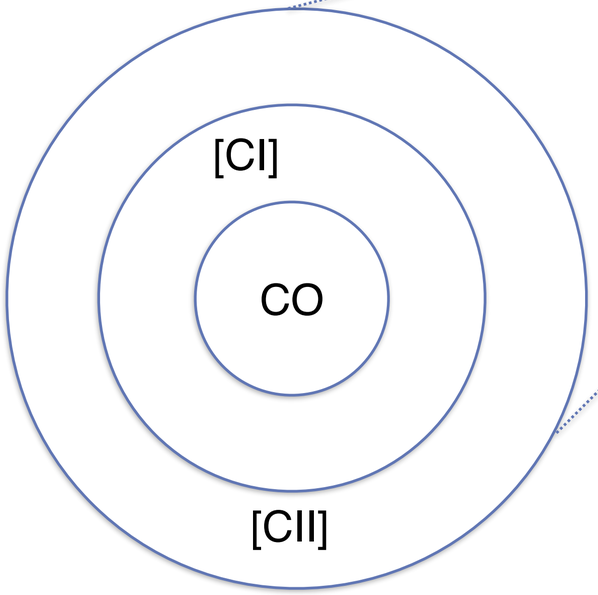
Slab of gas with sub-grid components



SAM galaxy with exponential distribution

Slab of gas with sub-grid components



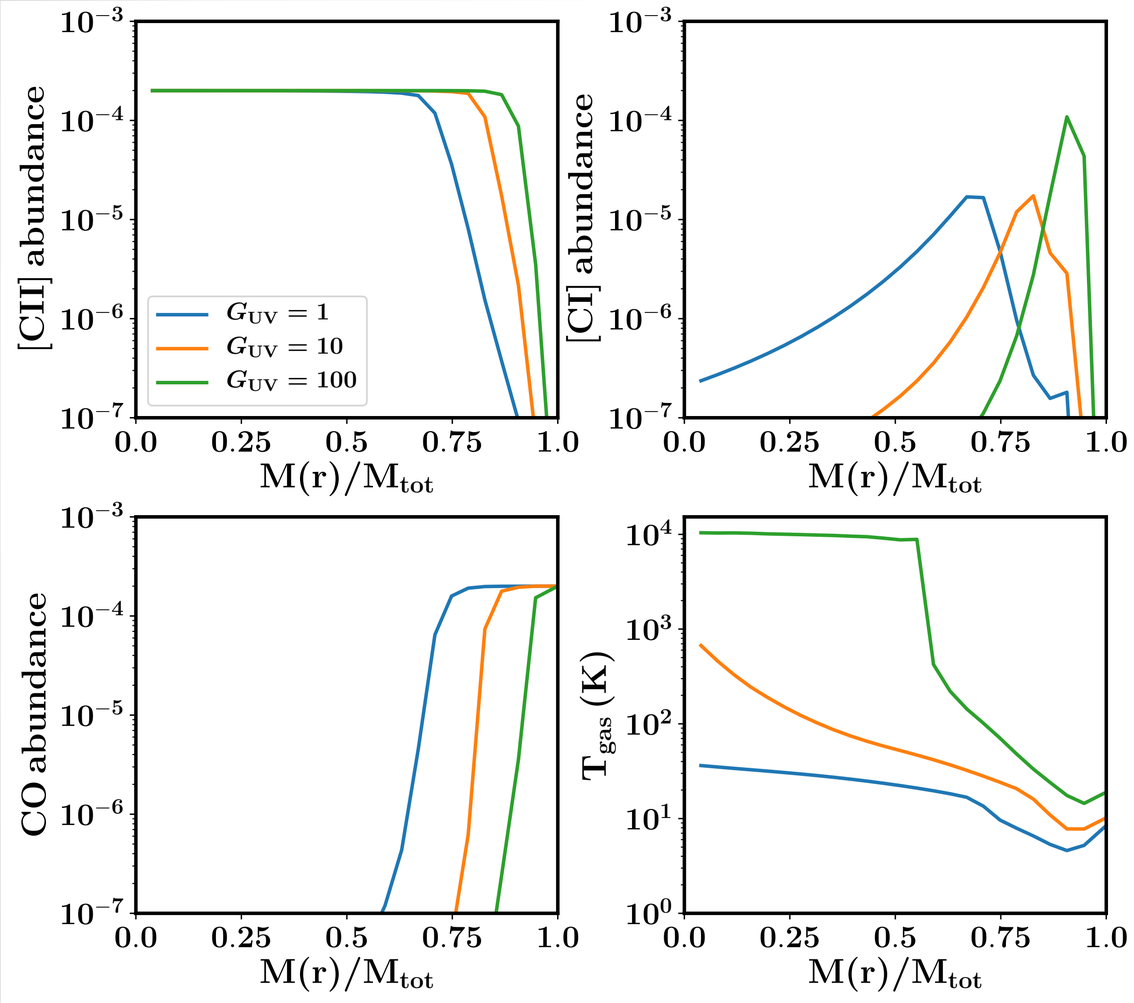


Within the cloud the model achieves:
- Chemical equilibrium
- Thermal equilibrium
- Statistical equilibrium

Molecular cloud consisting of multiple zones and impinging radiation field

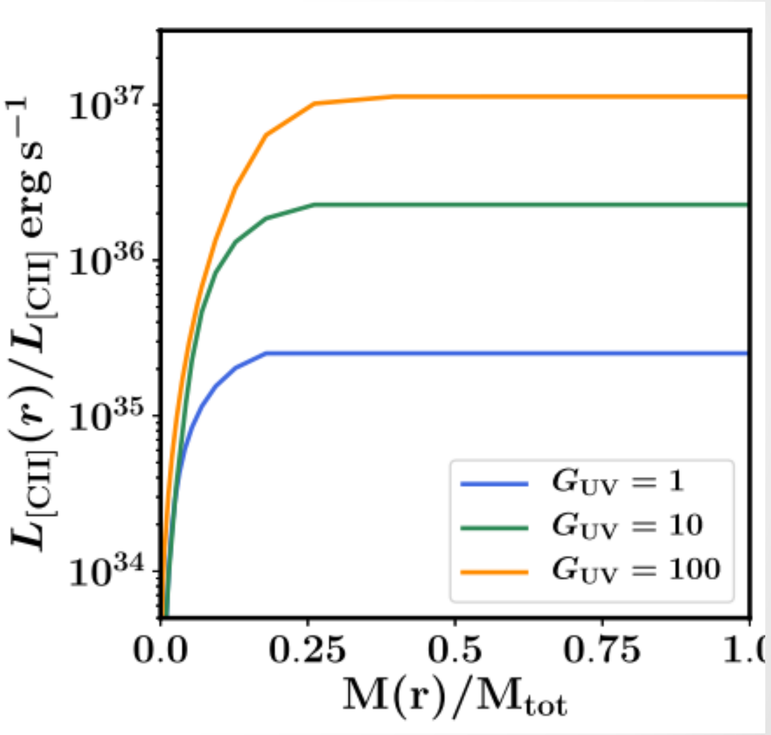
Chemistry

Abundance



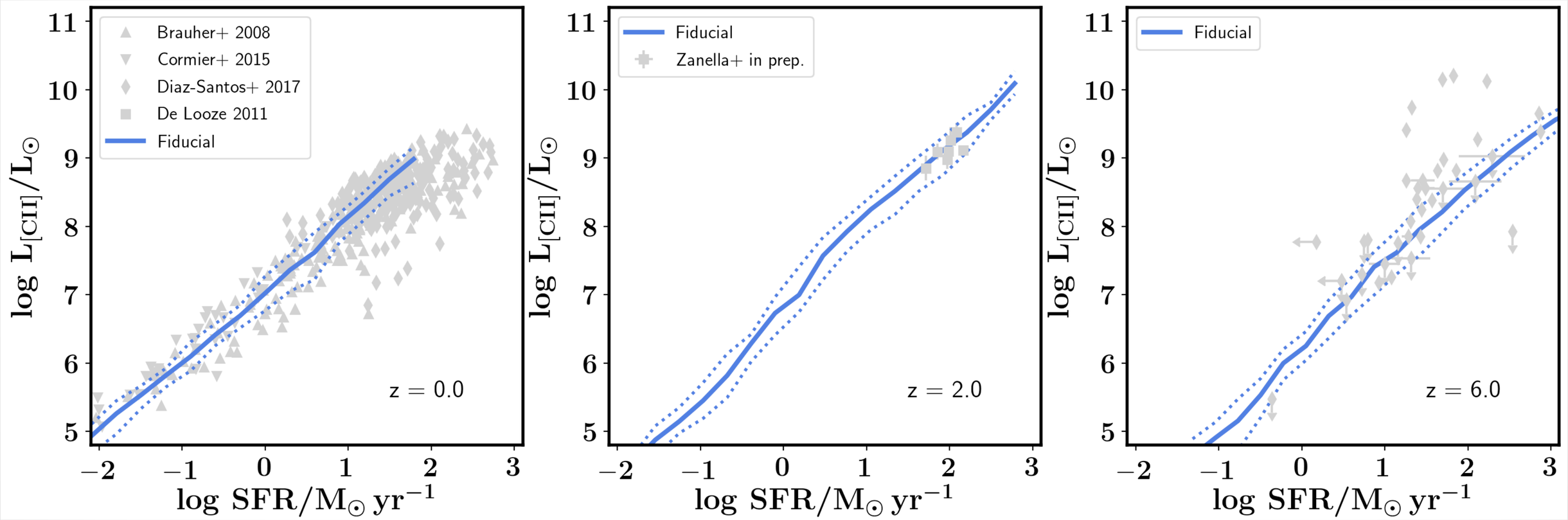
- Density
- UV radiation
- Metallicity
- X-ray radiation
- Cosmic rays
- Mechanical heating
- Dust properties

Luminosity

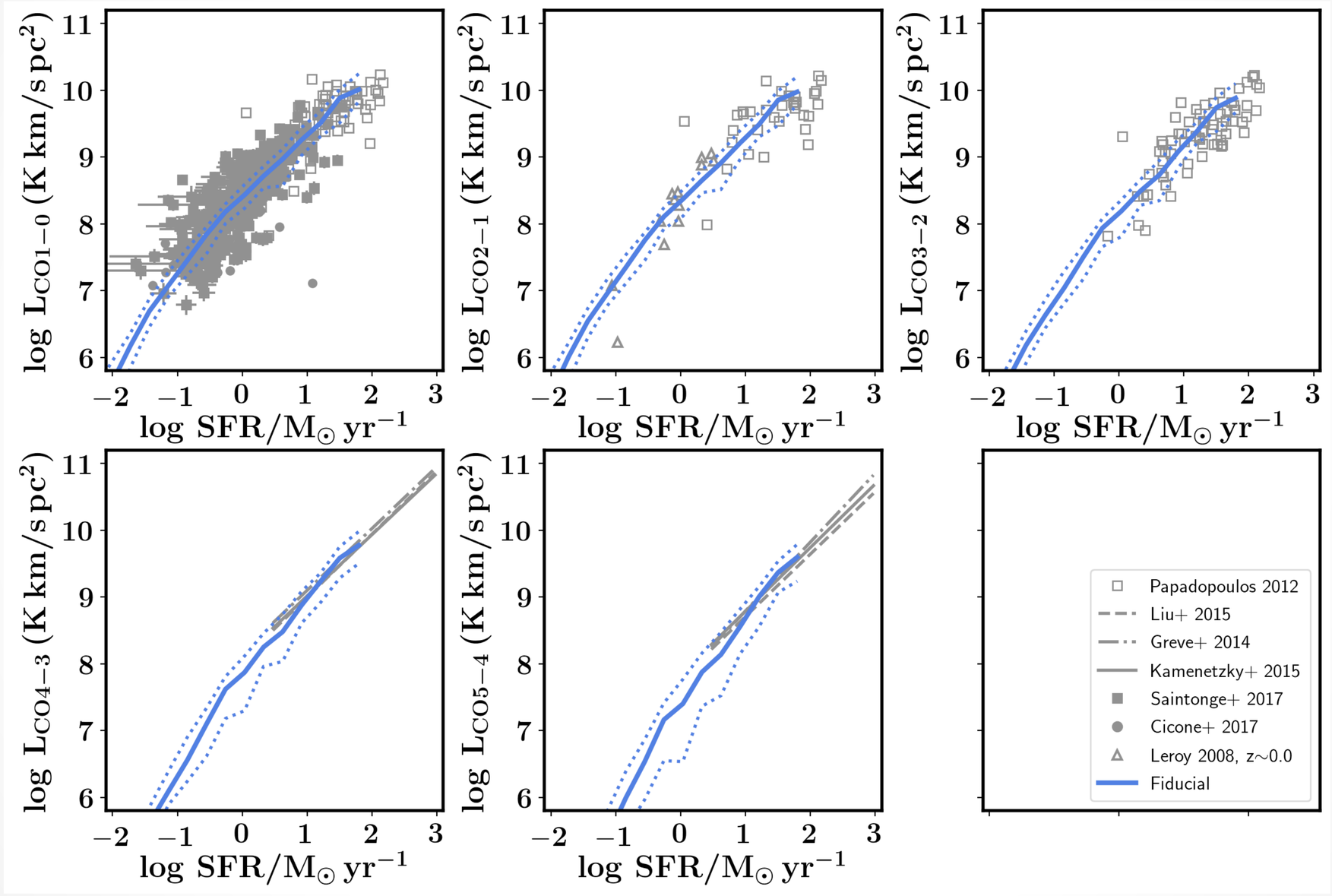


Popping, Narayanan, Somerville, Faisst, Krumholz (2019)

[CII] at z = 0 - 6

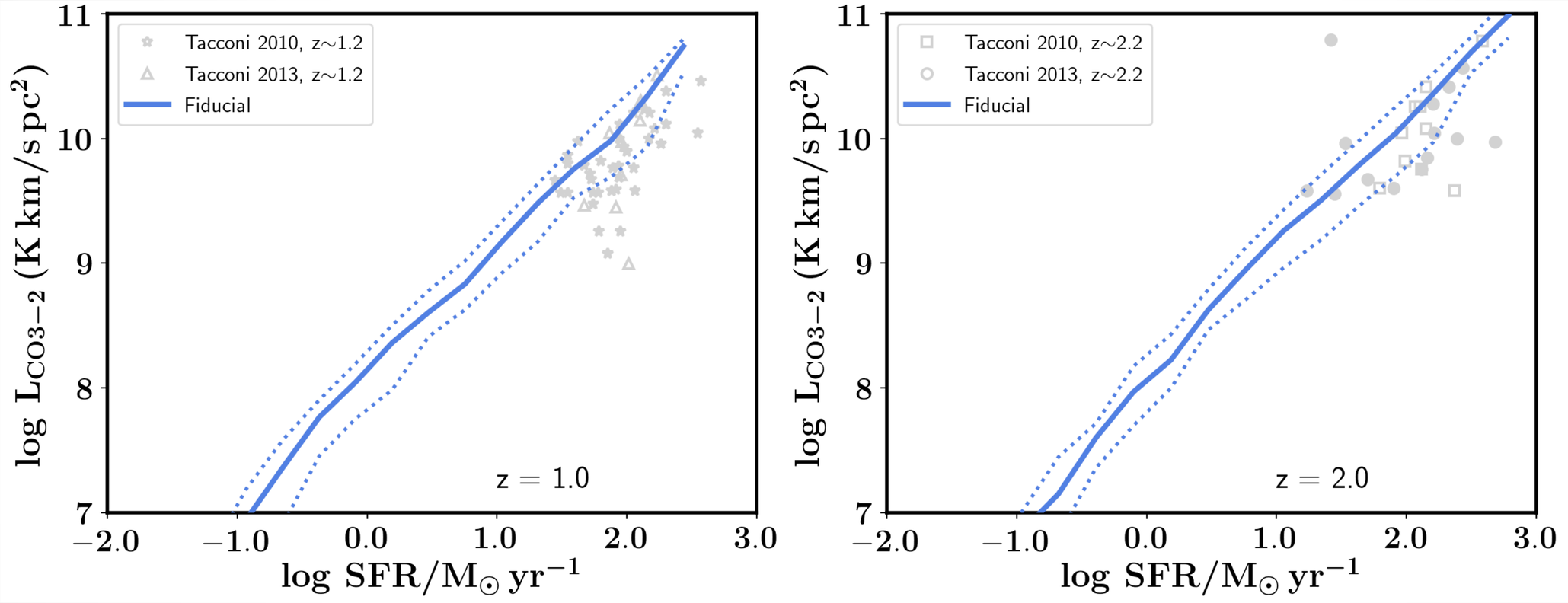

Brauher+ 2008
Cormier+ 2015
Diaz-Santos+ 2017
De Looze 2011
Fiducial
z = 0.0
Fiducial
Zanella+ in prep.
z = 2.0
Fiducial
z = 6.0
log L[CII]/L⊙
log SFR/M⊙ yr−1

CO at z=0



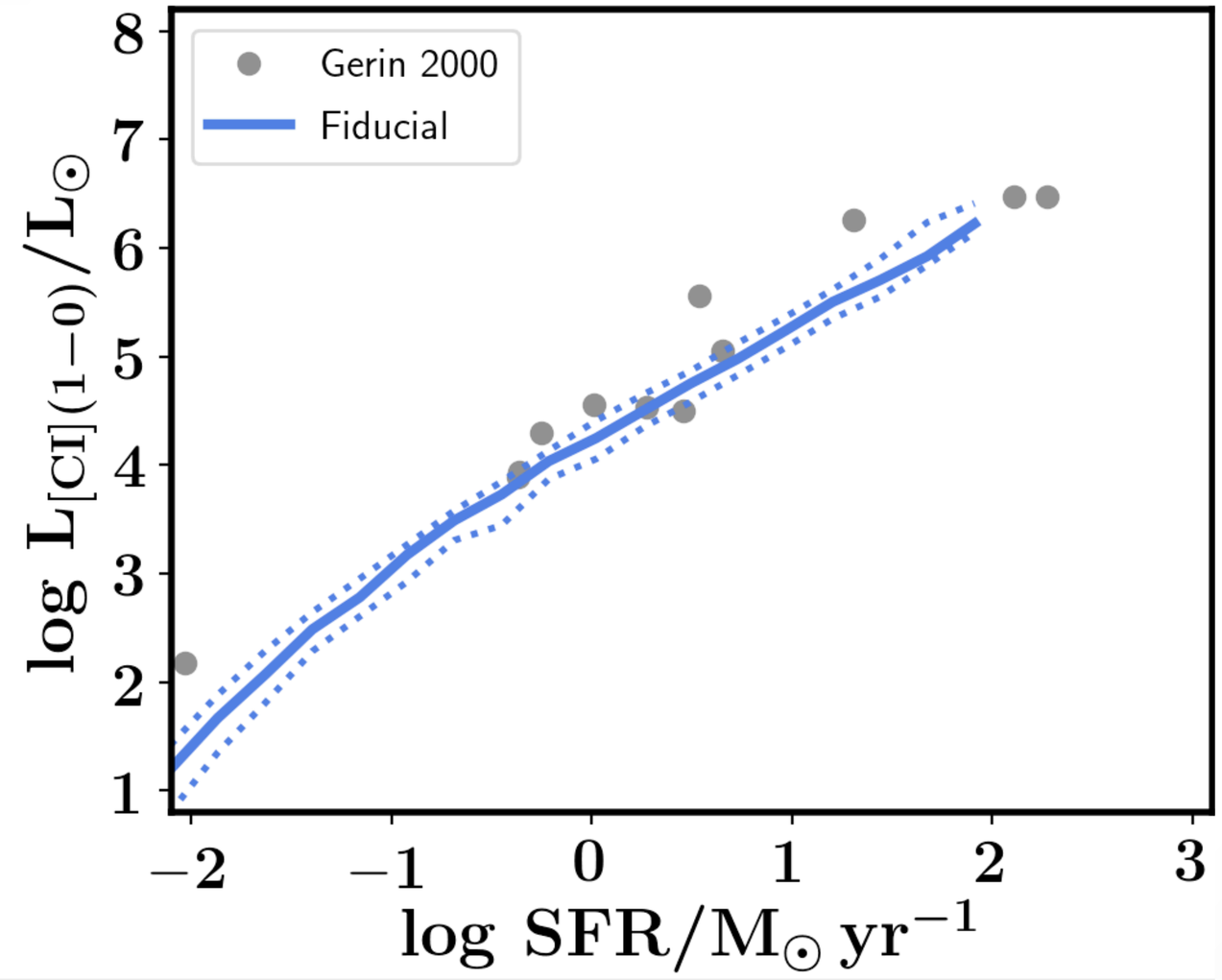
Popping, Narayanan, Somerville, Faisst, Krumholz (2019)

CO at z=1 & z=2



Popping, Narayanan, Somerville, Faisst, Krumholz (2019)

[CI] 1- 0 at z=0



Popping, Narayanan, Somerville, Faisst, Krumholz (2019)

How efficient is efficient?

- A sub-volume from the Bolshoi-Planck simulation: 142^3 cMpc from z=0 to z=8
- [CII], [CI] 1-0 & 2-1, CO 1-0, 2-1, 3-2, 4-3, 5-4 for every galaxy in the box at all modelled snapshots
- ~75 million catalogue entries
- ~120 cpu hours

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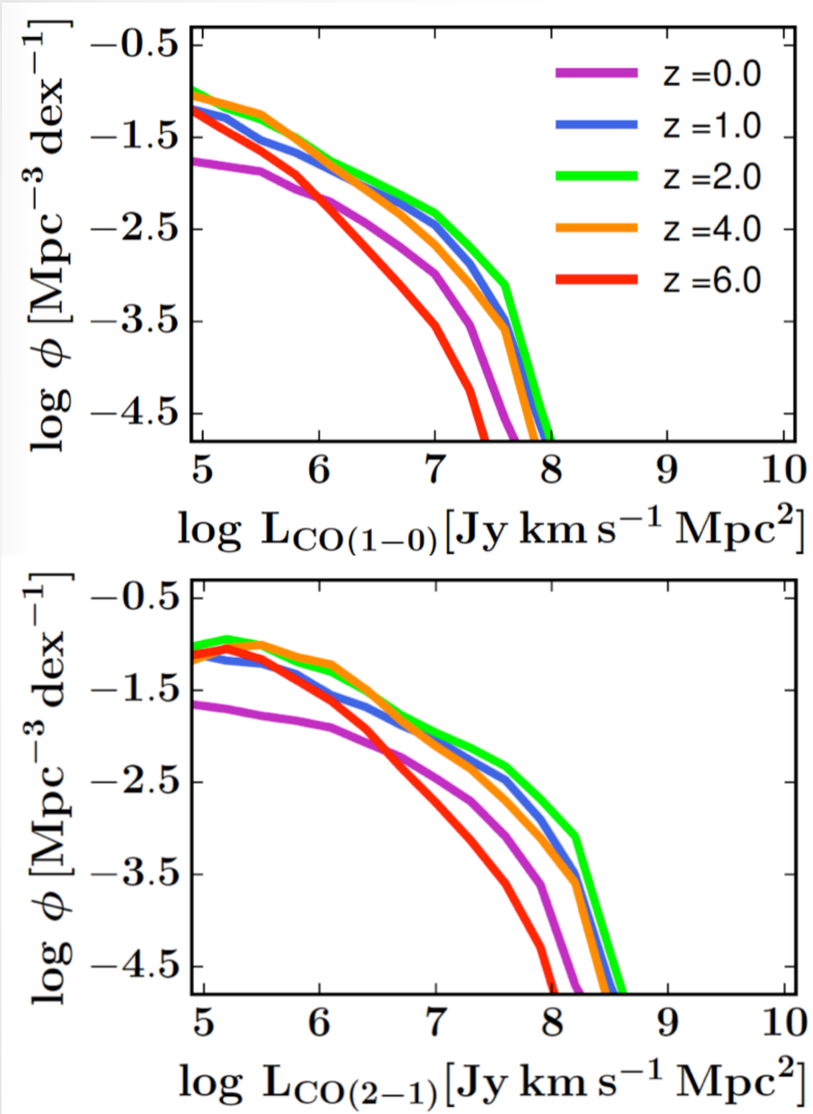
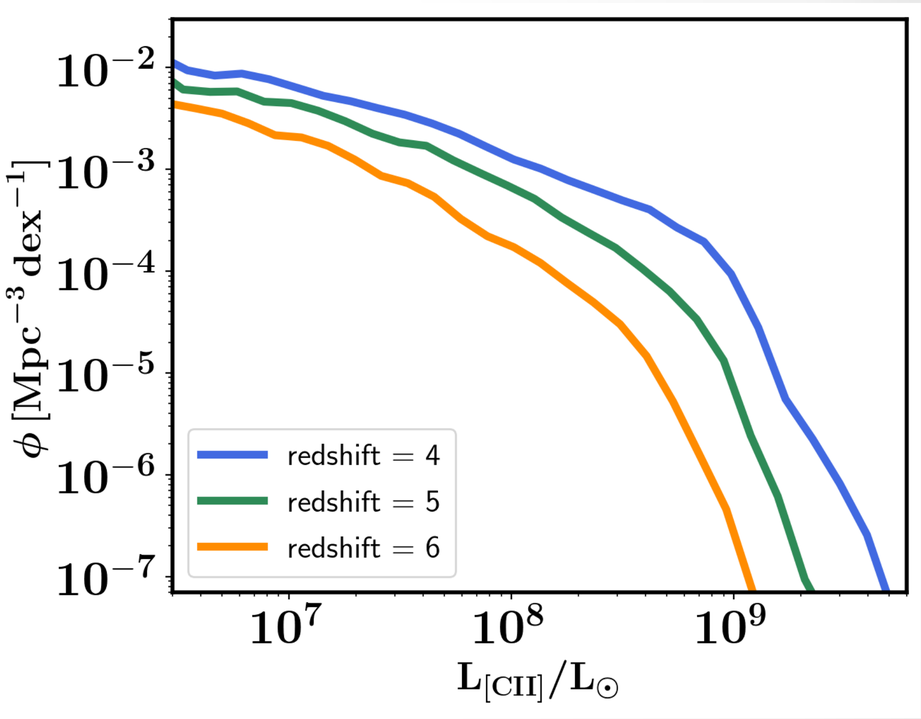
Applications

CO luminosity functions

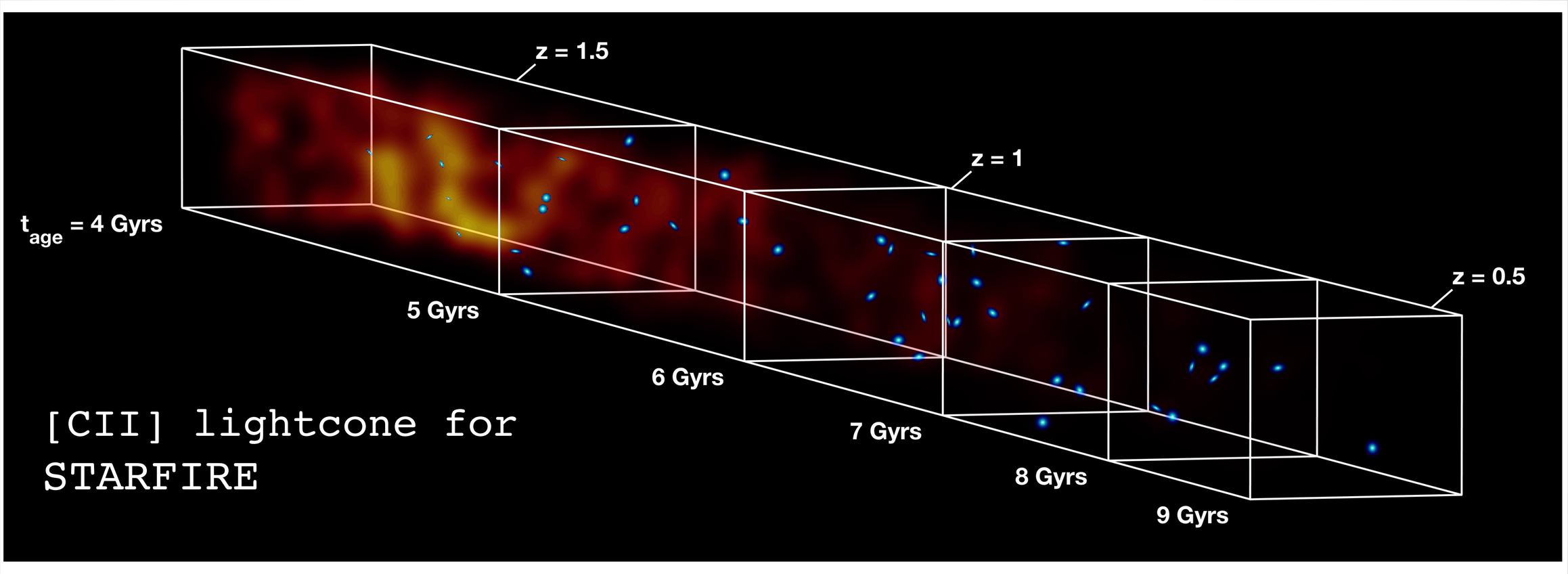


[CII] luminosity functions



Popping et al. (2016, 2019)

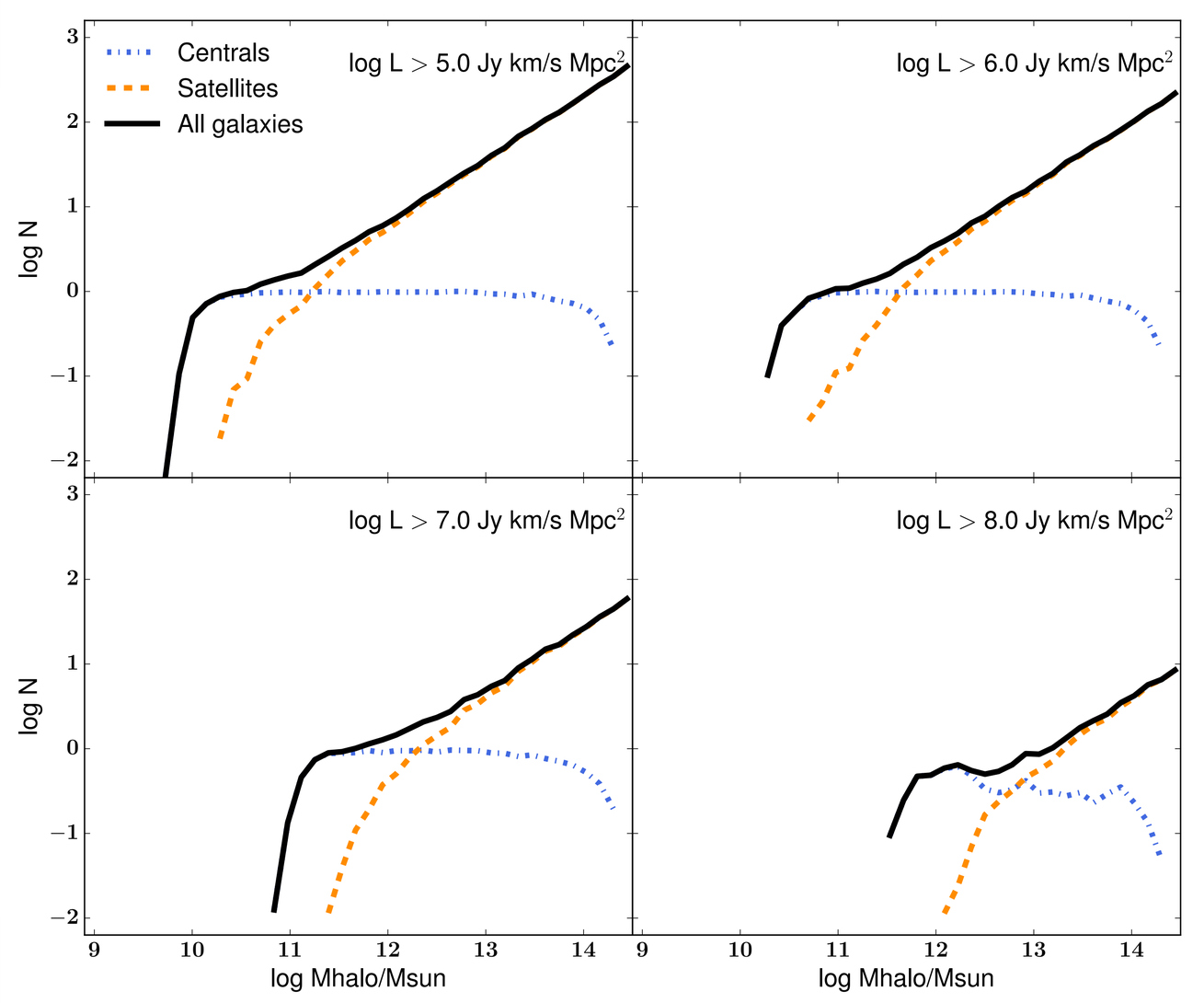
Applications



Lightcones for [CII] & CO. E.g., an efficient way to explore CO - [CII] confusion for high-z [CII]

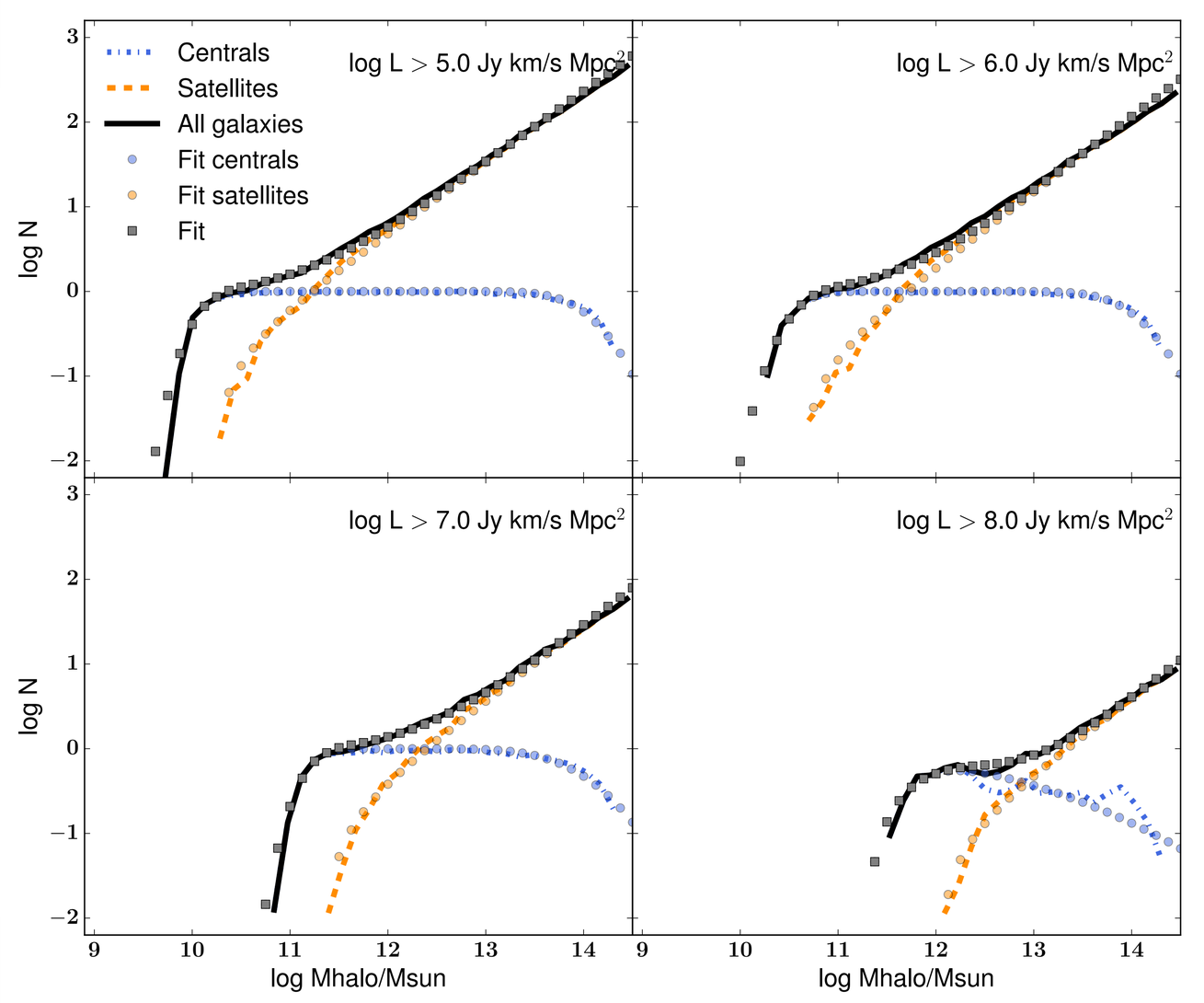
Thanks to Garrett Keating!!!!

Applications



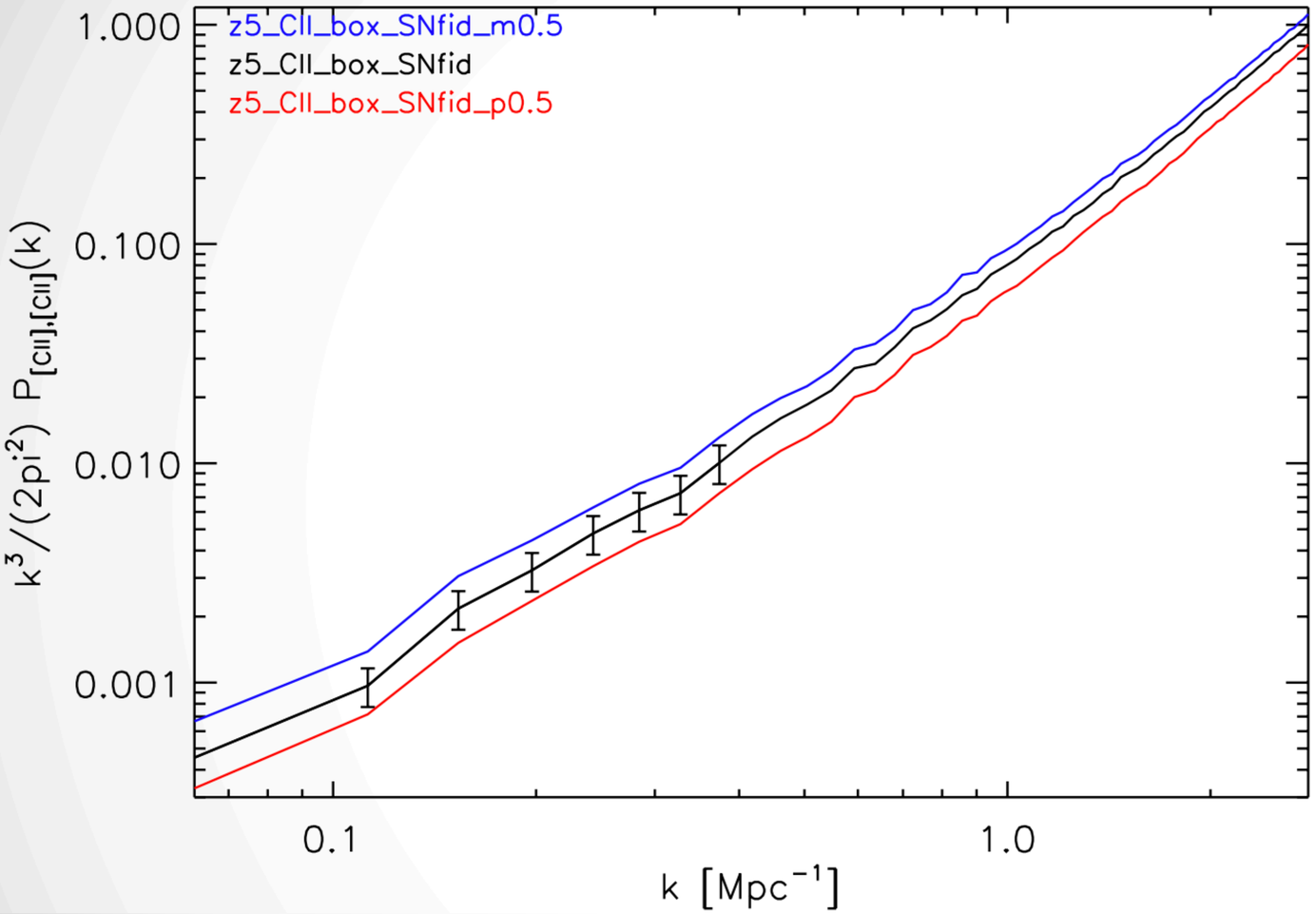
Halo occupation function for CO 3-2 at z=2

Applications



Well described by a 7 parameter fit (modified Zheng fit)

Applications



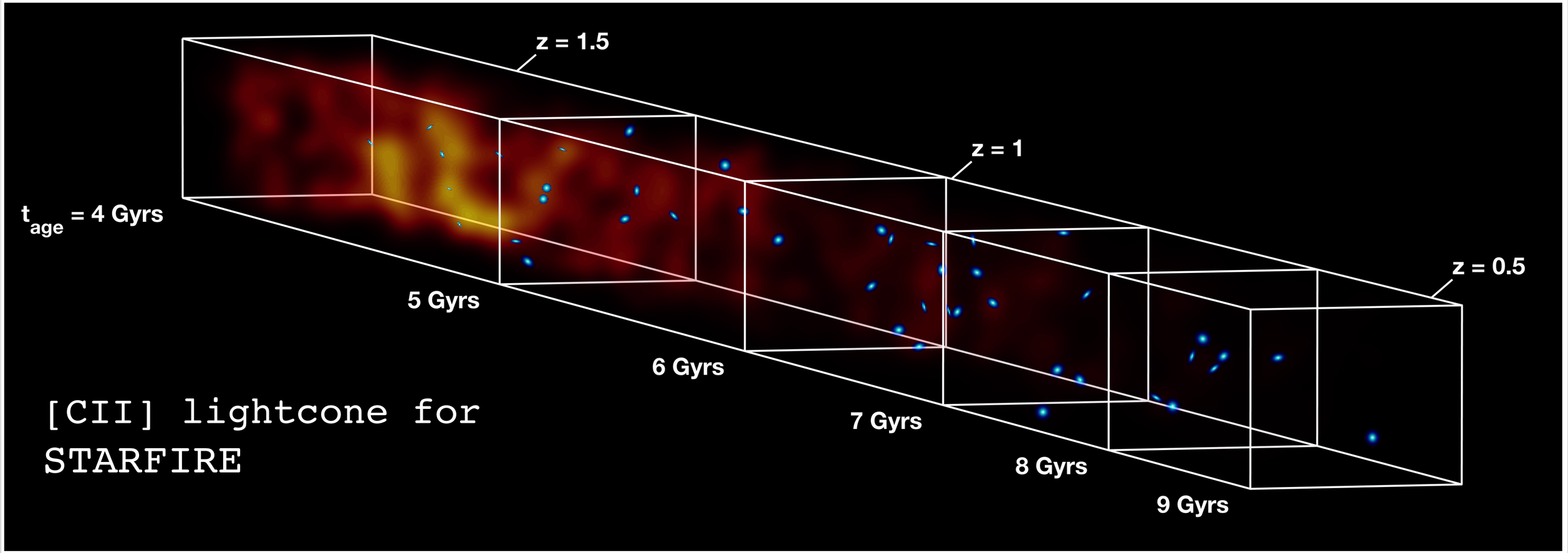
Quickly explore how different implementations of physical processes manifest themselves in the sub-mm line power spectrum

[CII] power-spectrum at z=5 for 3 different SN feedback scenarios that differently affect low-mass galaxies.

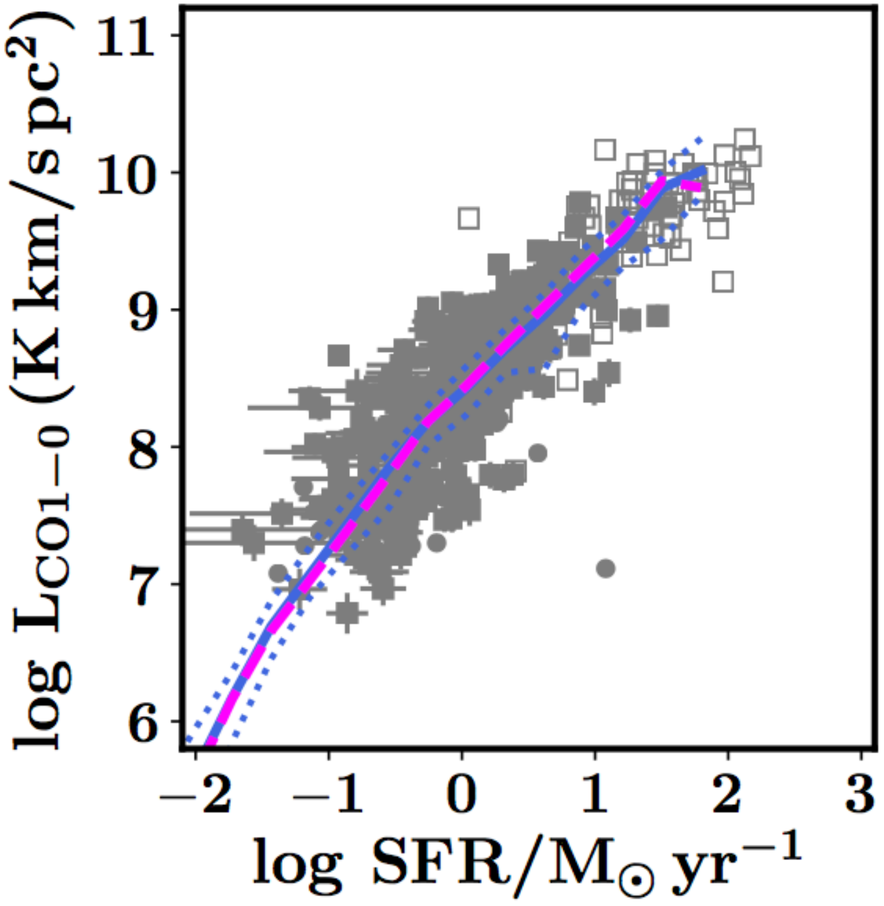
Thanks to Bade Uzgil!!!!

Conclusions

- Efficient galaxy formation model for the [CII], [CI], and CO emission of galaxies
- Physically motivated predictions for sub-mm line intensity mapping
- Wide range of applications



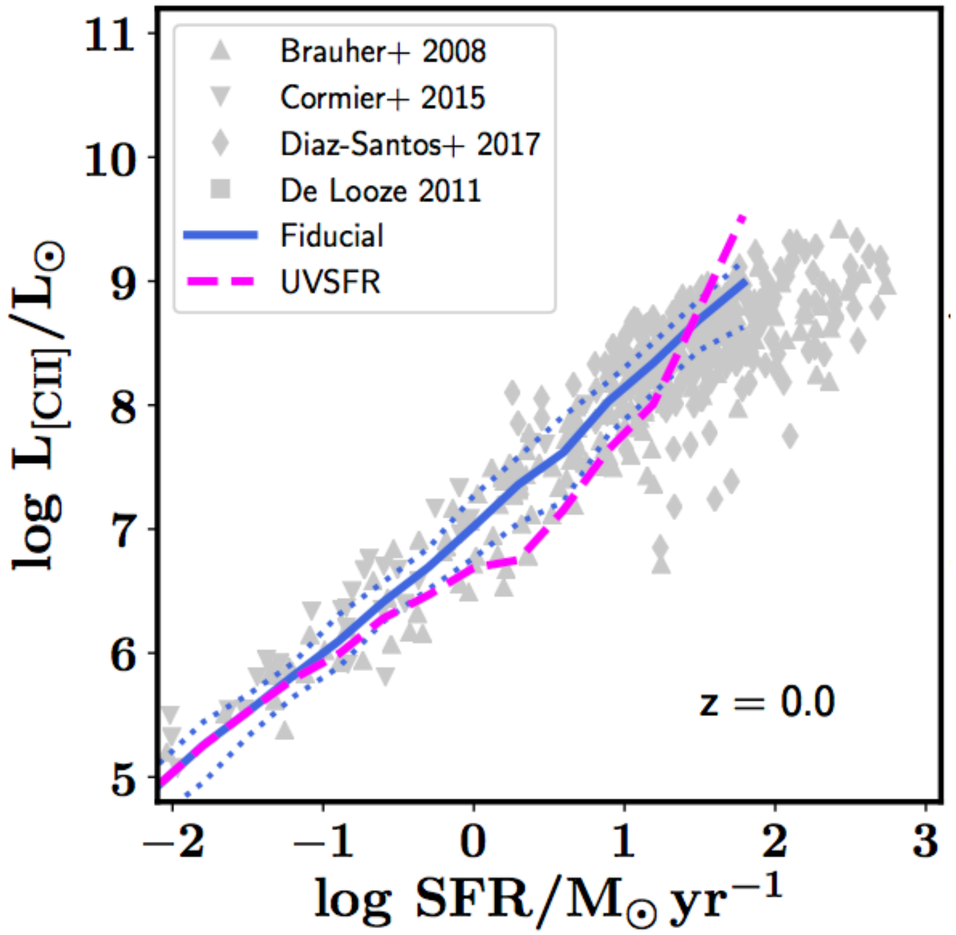
Sub-grid choices matter?



Two different approaches to calculate the strength of the UV radiation field on molecular clouds

Popping, Narayanan, Somerville, Faisst, Krumholz (2019)

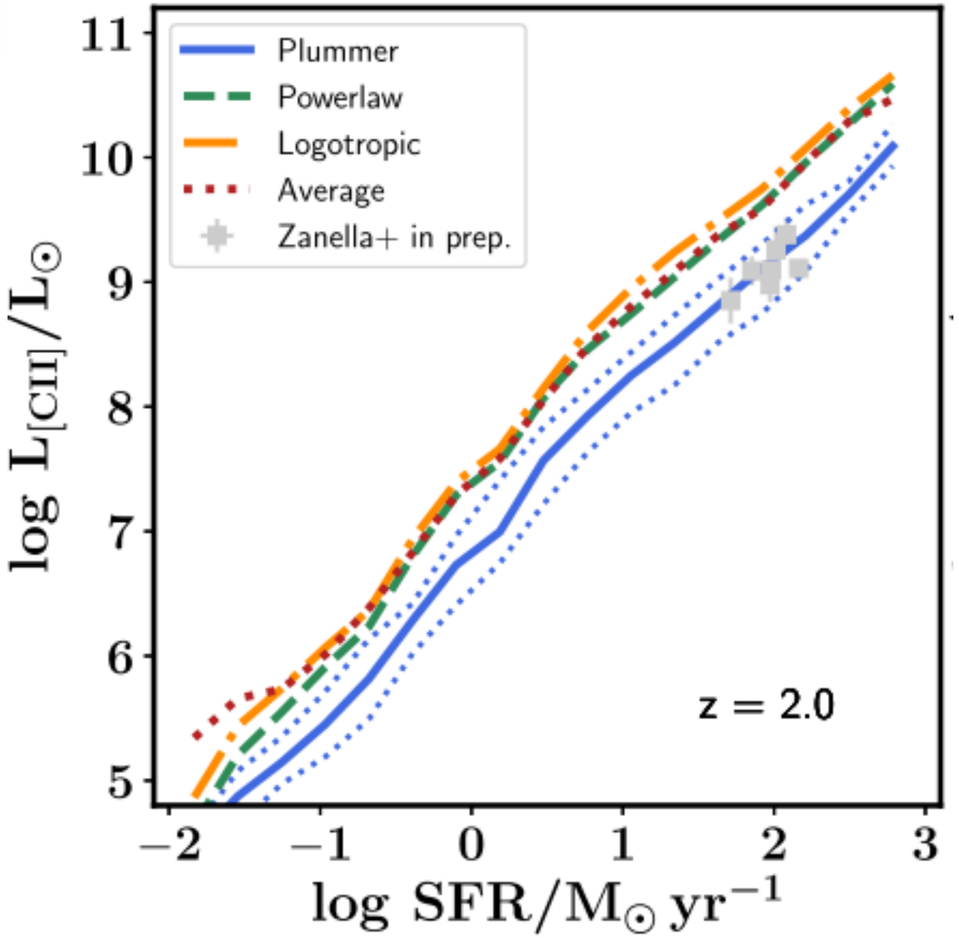
Yes they do!



No difference in CO, but we do see differences in [CII]

Popping, Narayanan, Somerville, Faisst, Krumholz (2019)

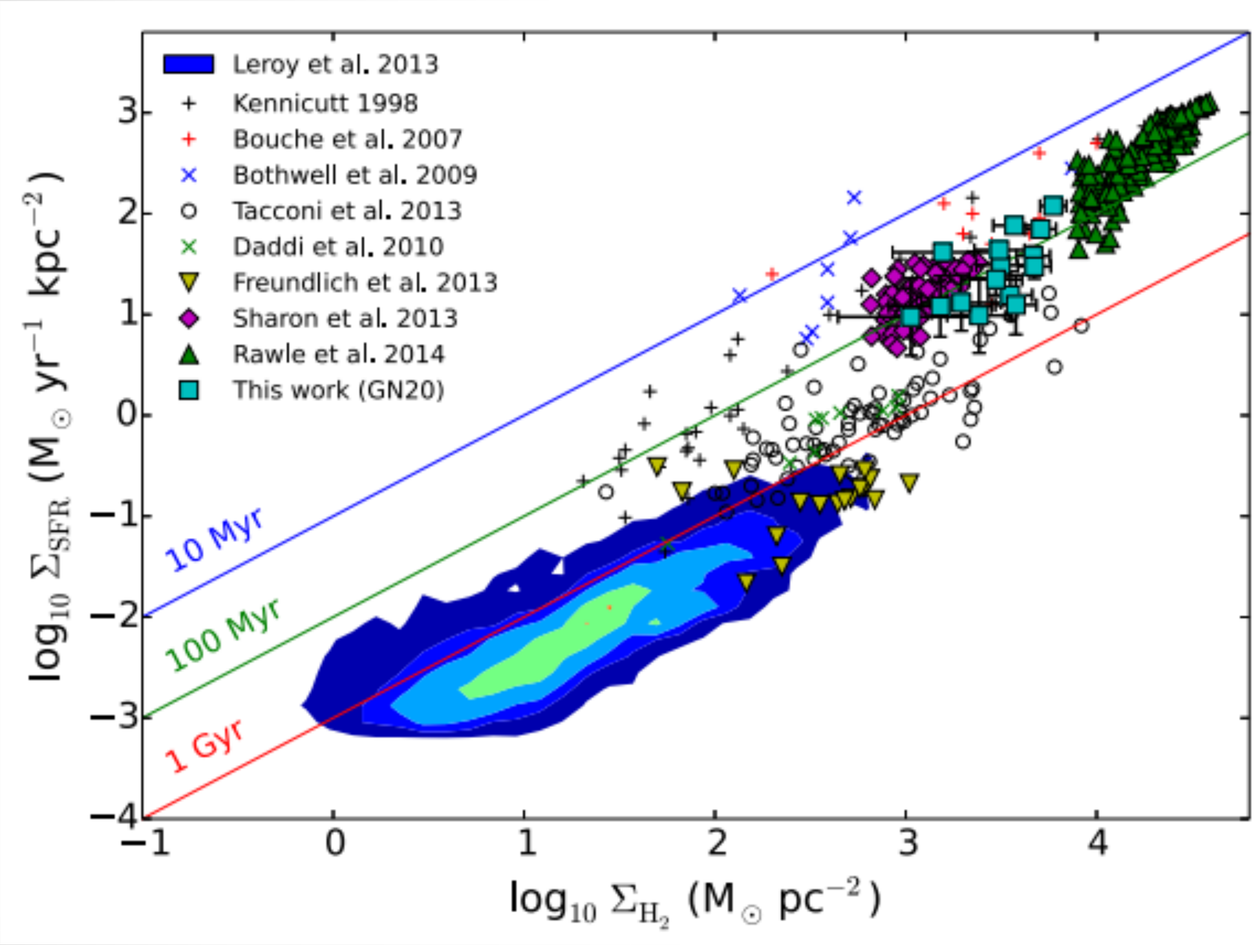
Yes they do!



Different assumptions for density profiles of molecular clouds result in different luminosities

Popping, Narayanan, Somerville, Faisst, Krumholz (2019)

UV radiation field



Relate the UV radiation field to the **local SFR surface density**?

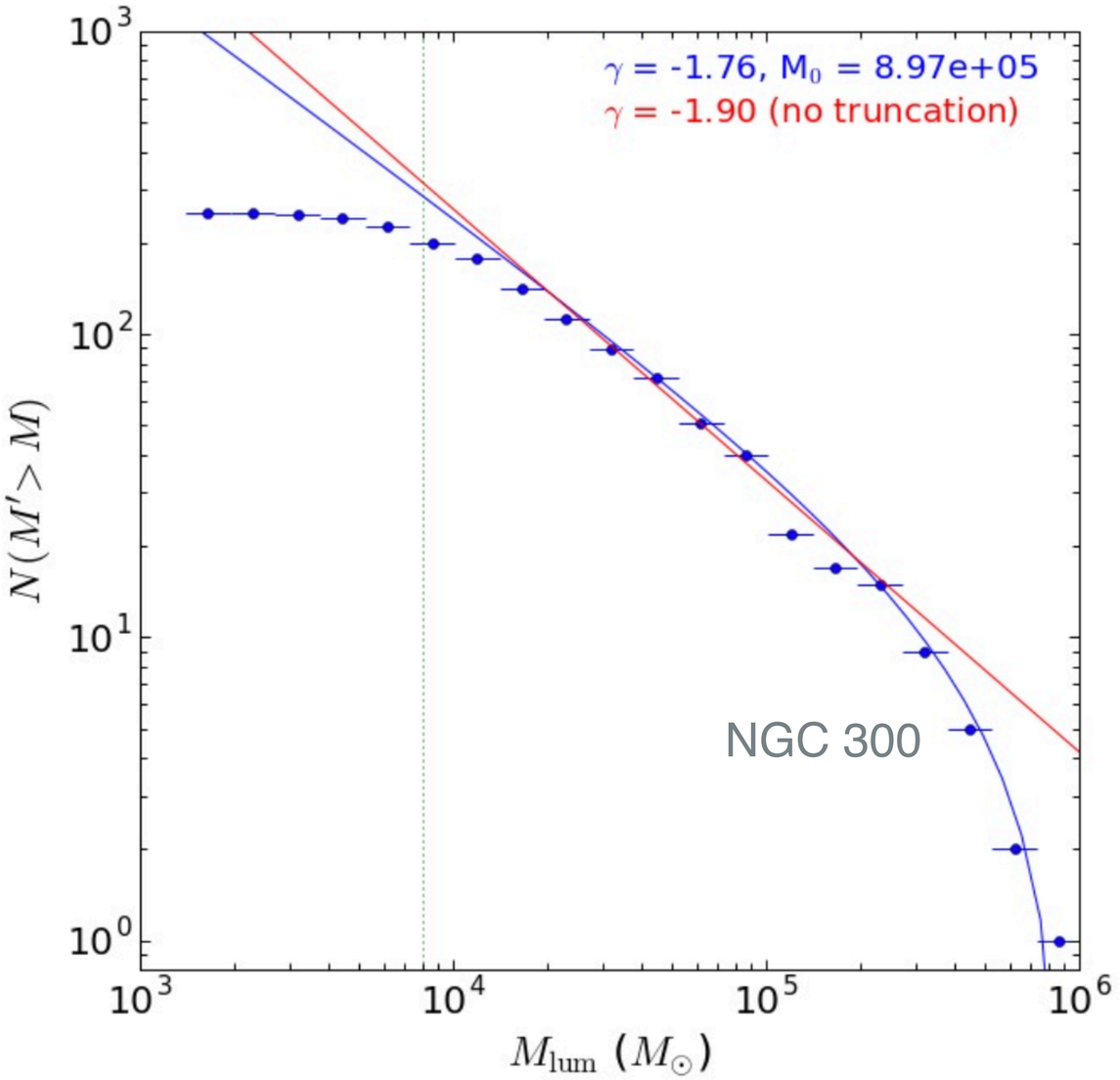
Or the **integrated SFR**?

Or calculate amount of **UV photons from stellar population codes**?

How do we **account for diffuse dust**?

Hodge+ 2014

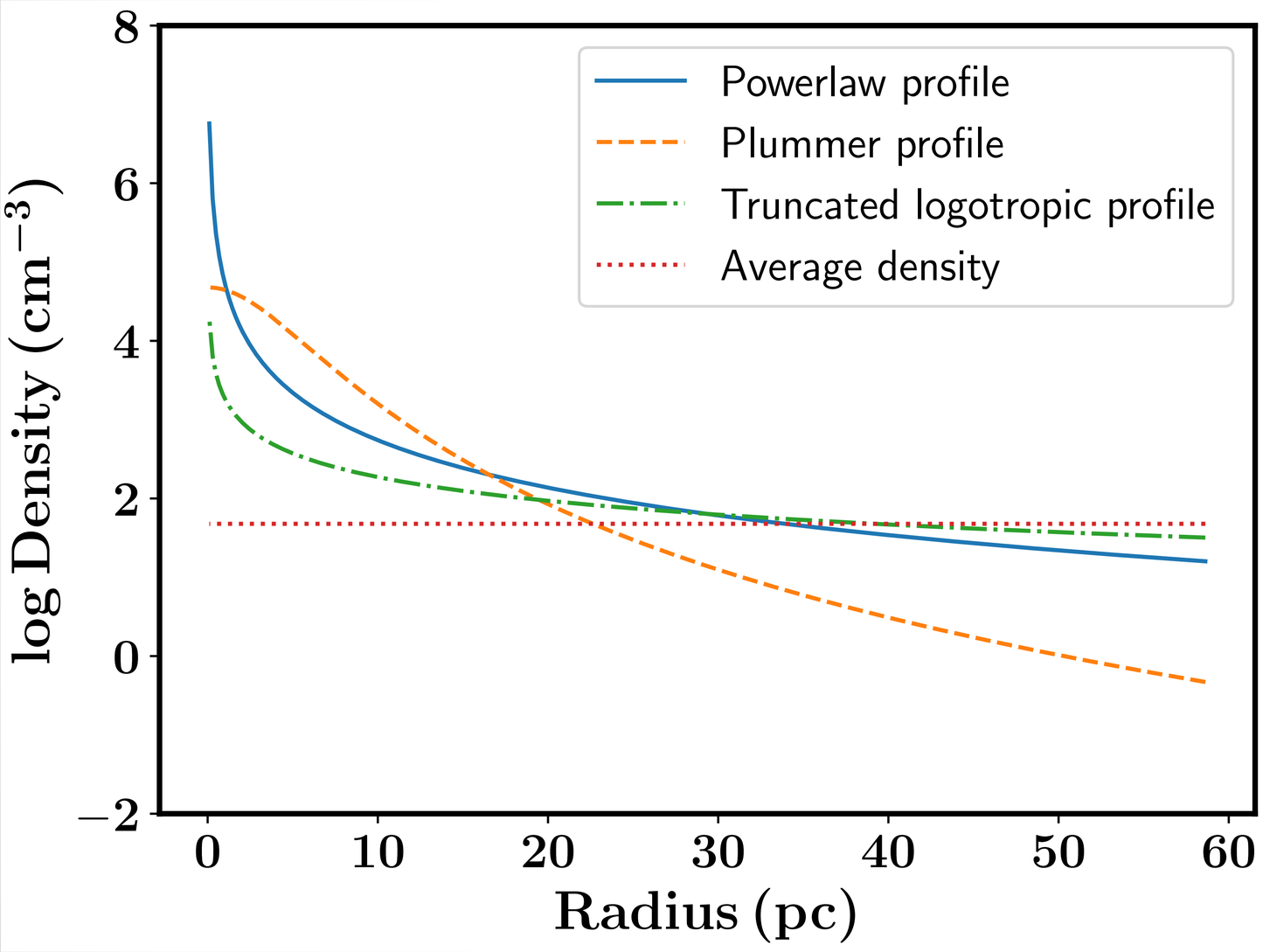
Molecular cloud distribution function



Populate a grid-cell with molecular clouds following mass distribution

Faesi et al. (2018)

Density Profiles



A variety of cloud density profiles adopted in the literature

Popping, Narayanan, Somerville, Faisst, Krumholz (2019)