Probing the ISM properties of first galaxies through [CII] and CO line emission

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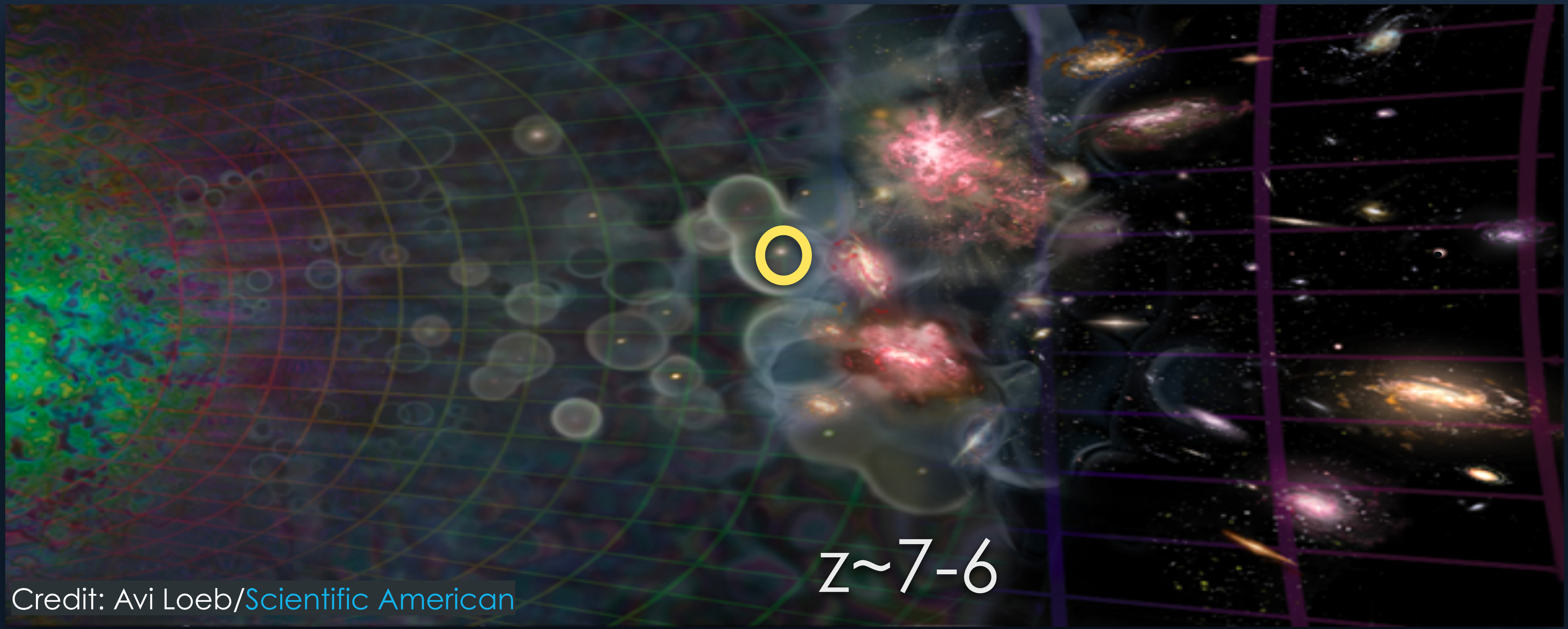
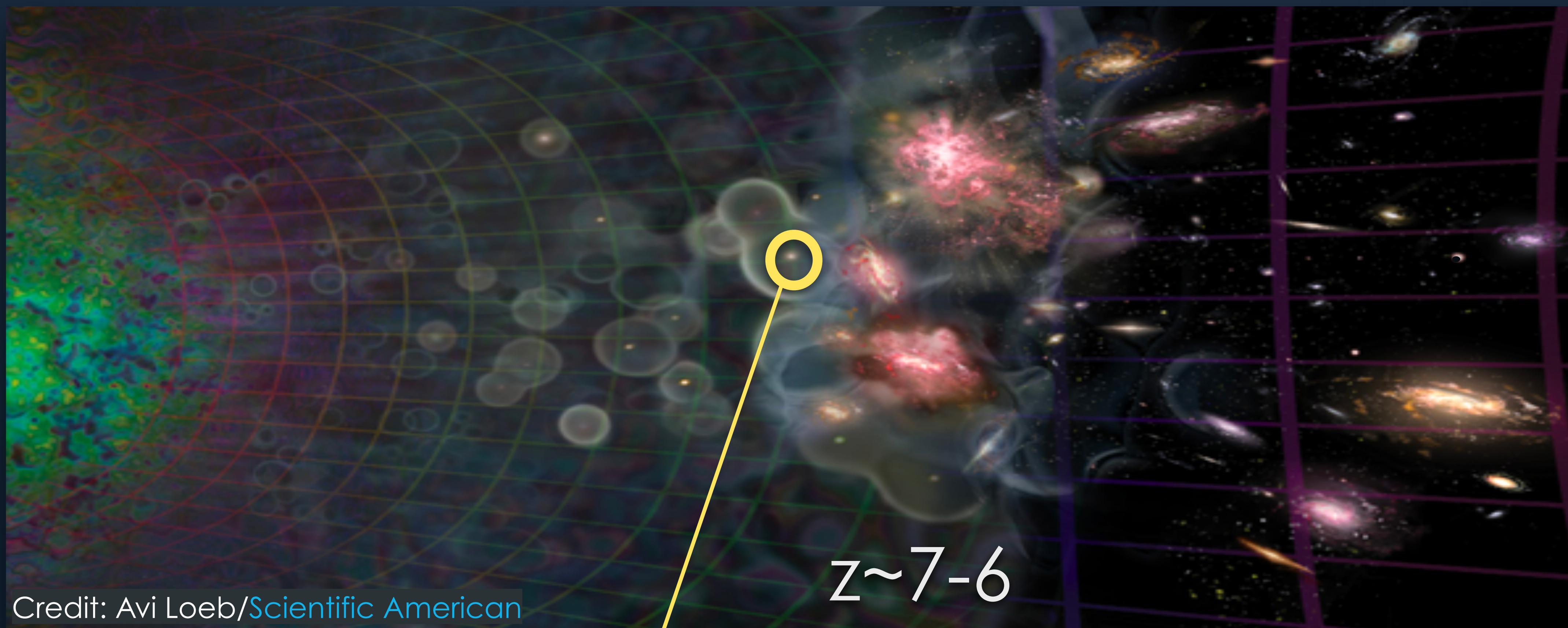
MARIE CURIE ACTIONS

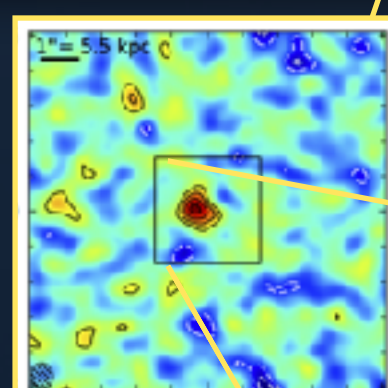
THE FIRST GALAXIES



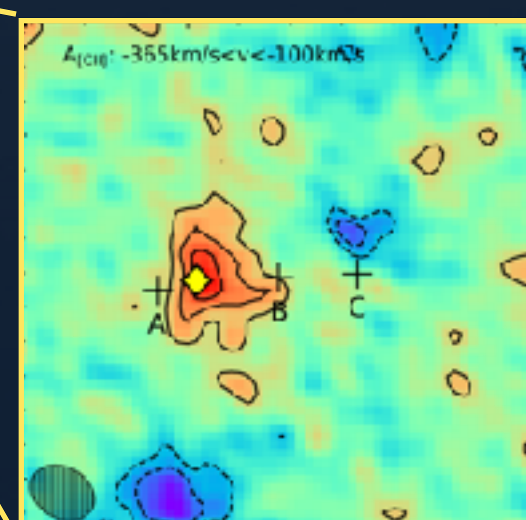
THE FIRST GALAXIES: THE ALMA VIEW



[CII] emission

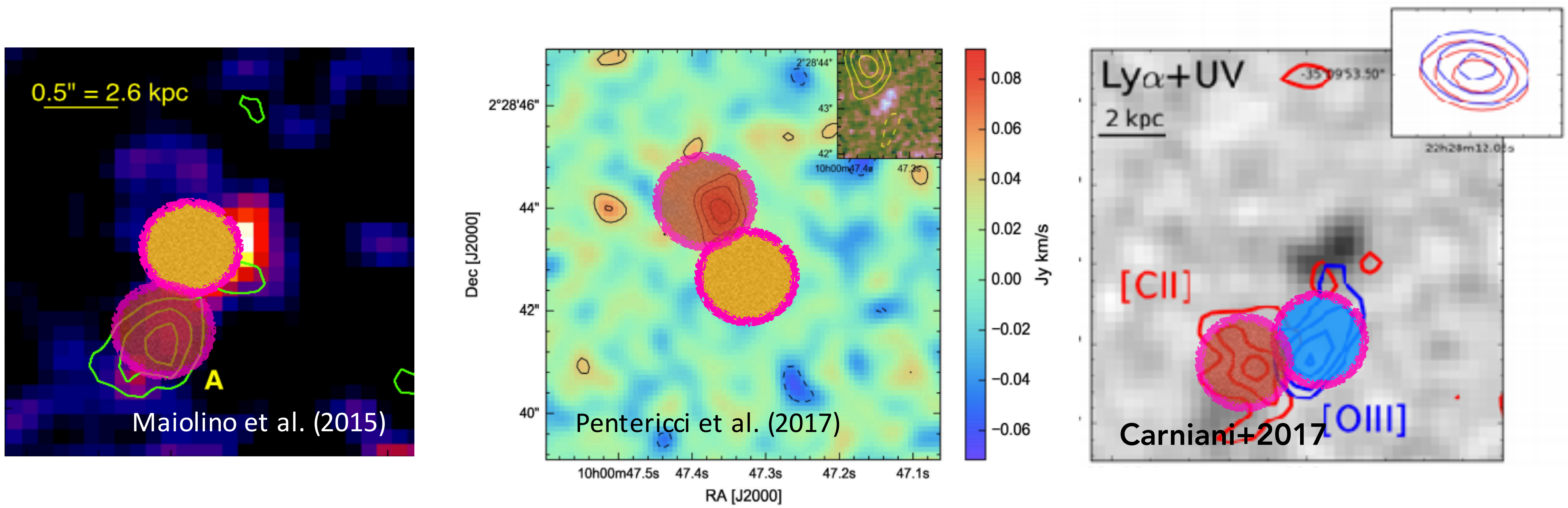


Carniani+2018



ISM OF FIRST GALAXIES: [CII] OBSERVATIONS

Spatial offset

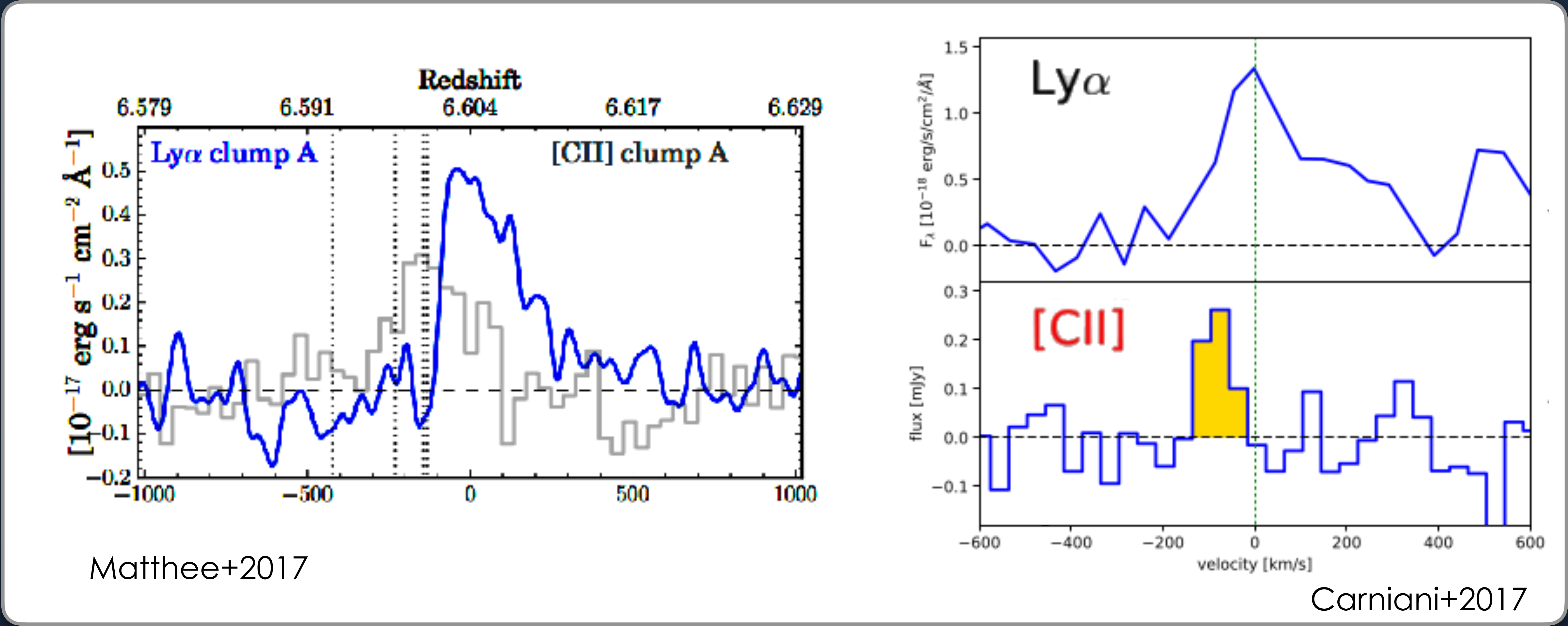


Spatial offset of the **[CII] emission** with respect to the **UV continuum**

Spatial offset of the **[CII] emission** with respect to the **[OIII] emission**

ISM OF FIRST GALAXIES: [CII] OBSERVATIONS

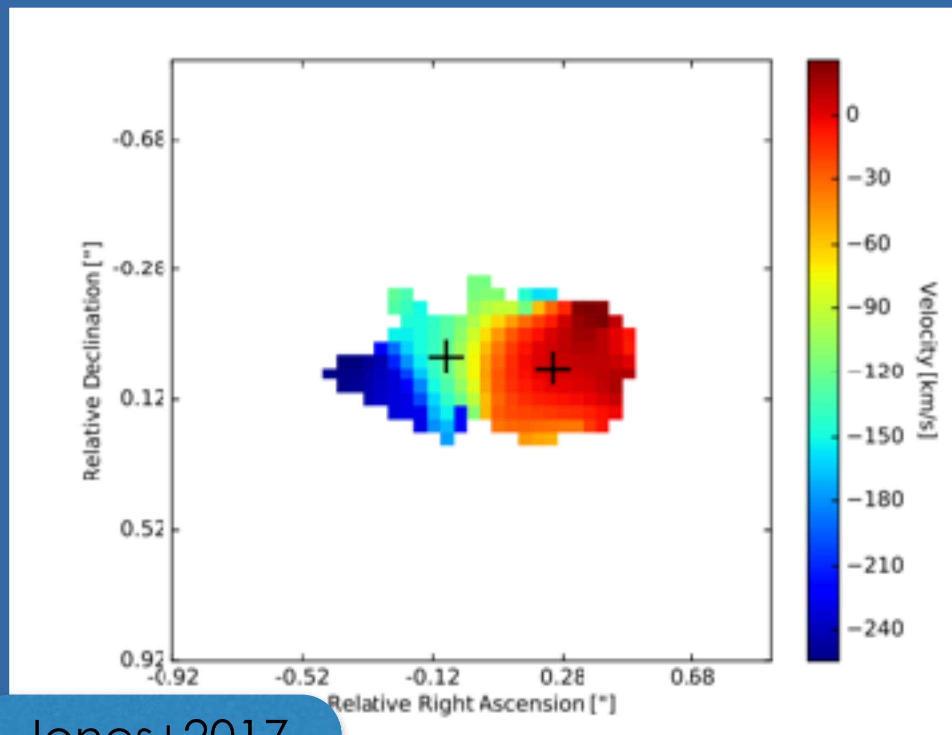
Spectral offset



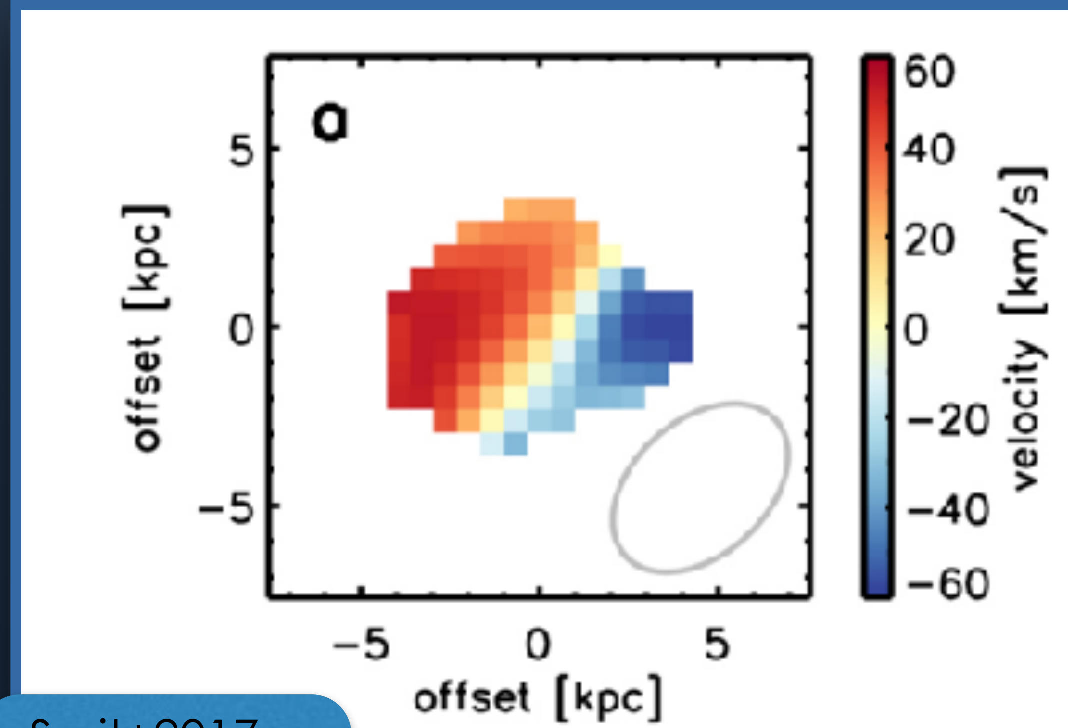
Spectral offset between the **[CII] emission** and the **Lya**

ISM OF FIRST GALAXIES: [CII] OBSERVATIONS

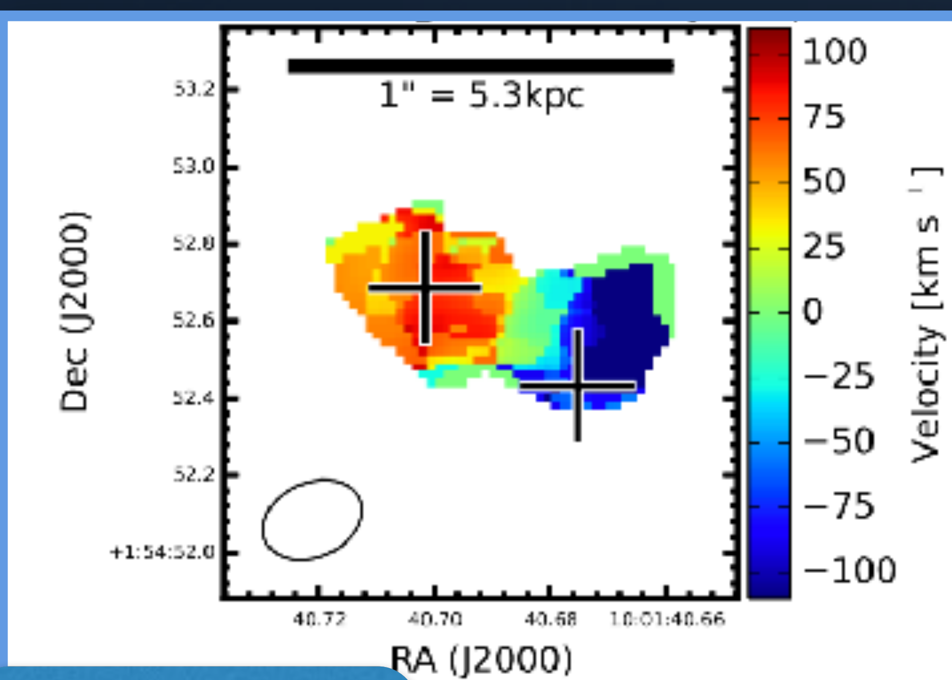
Kinematical studies



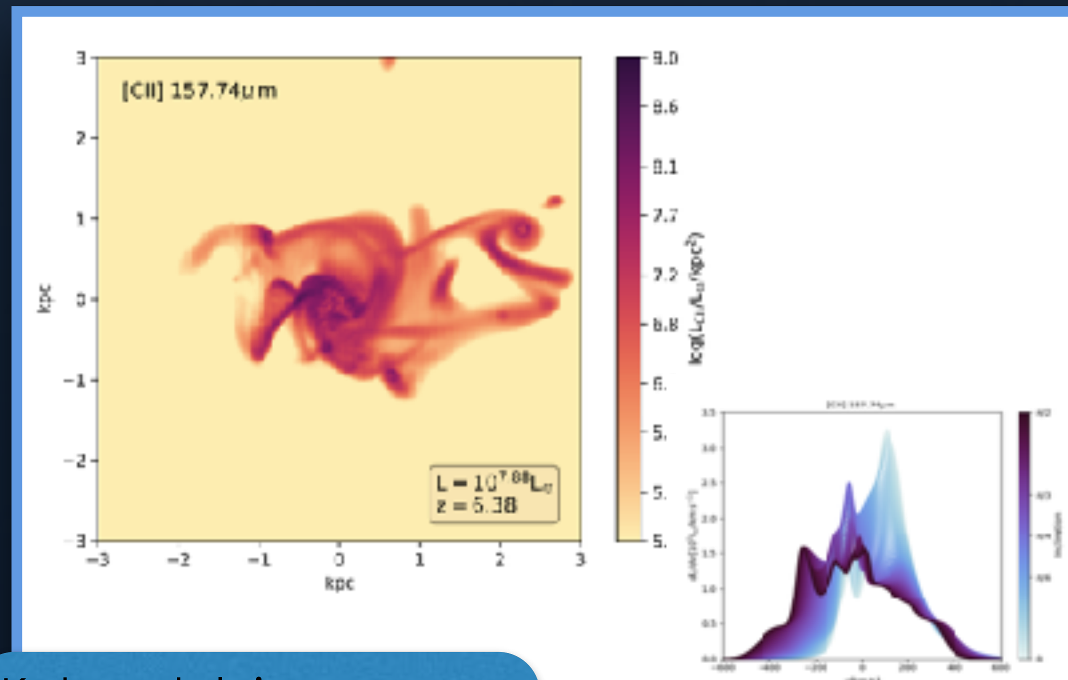
Jones+2017



Smit+2017



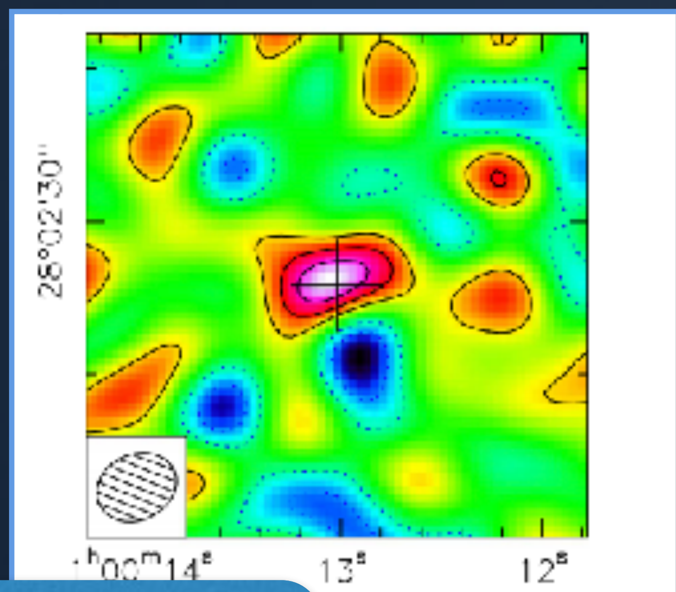
Hashimoto+2017



Kohandel+in prep

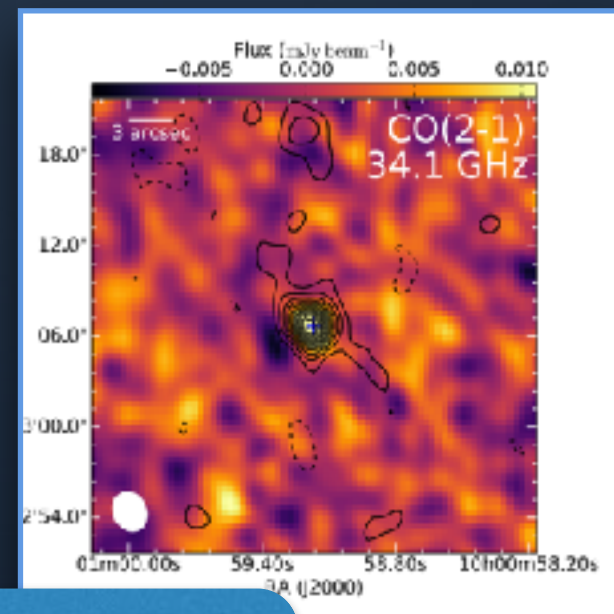
ISM OF FIRST GALAXIES: CO OBSERVATIONS

z>6 quasar

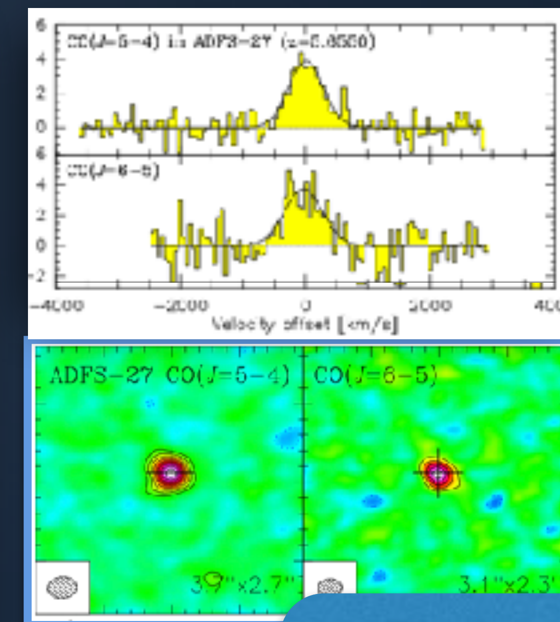


e.g. Wang+2016

SMGs at z>5.5: SFR>1000 M☉/yr



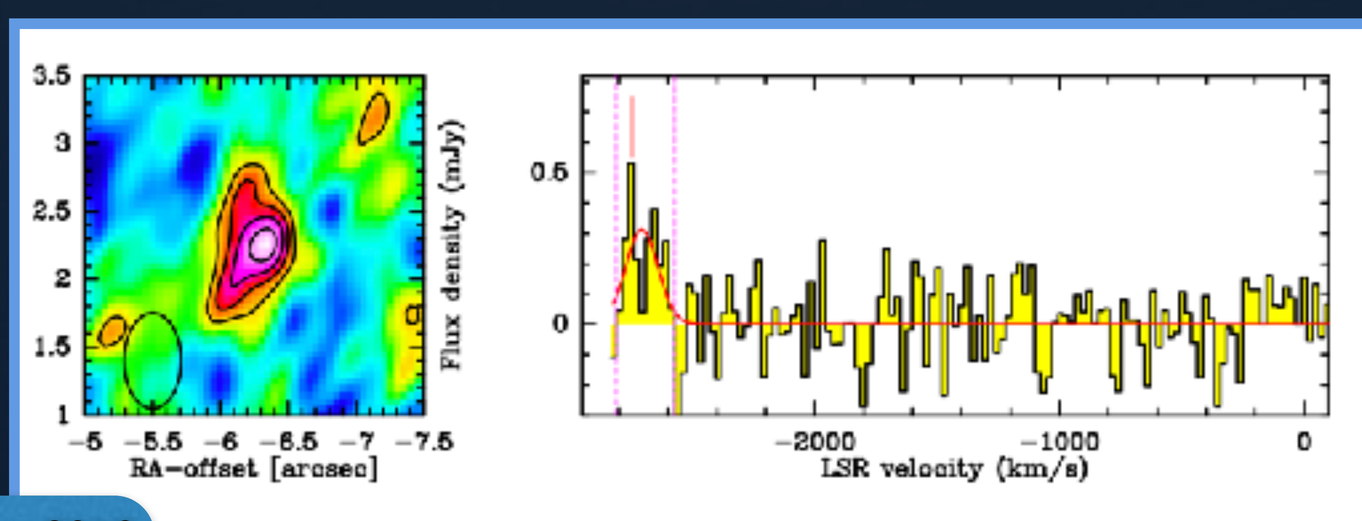
Pavesi+2018



e.g. Riechers+2017

see also: e.g. Walter+2007, Spilker+2015, Venemans+2017, Strandet+2017, …

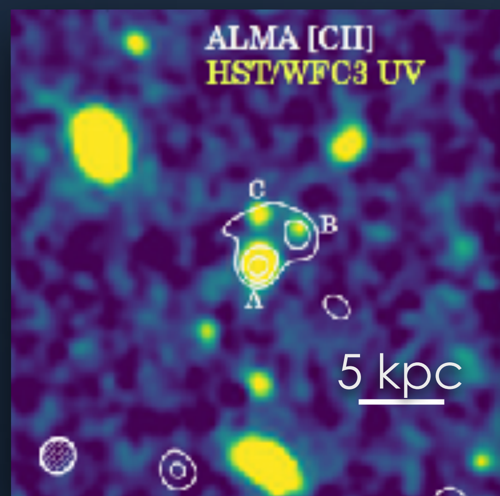
ALMA CO(6-5) detection in a galaxy z>6 with SFR<100 M☉/yr at z~6



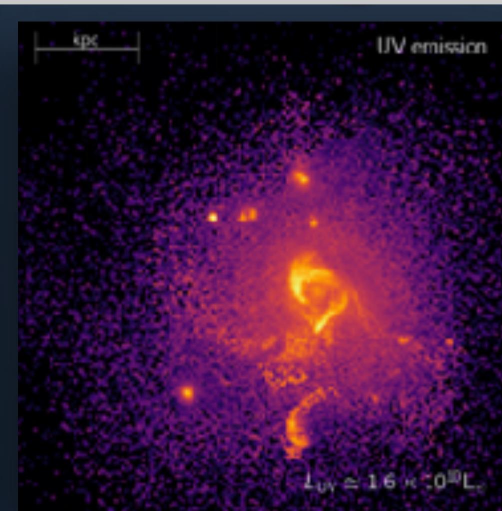
D'Odorico+2018

THE PECULIAR CONDITIONS OF FIRST GALAXIES

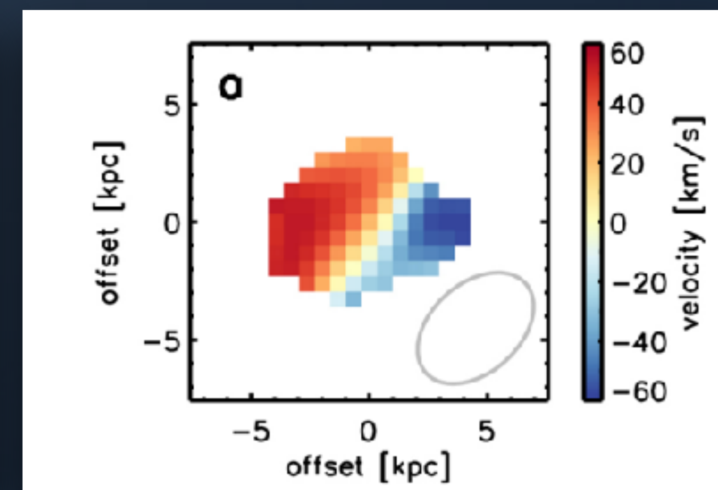
1. Compact, highly star-forming



Matthee+2017

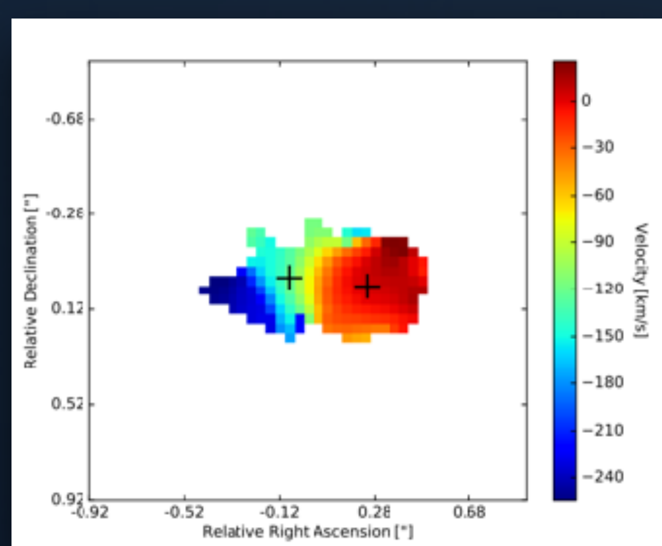


Berhens+2018

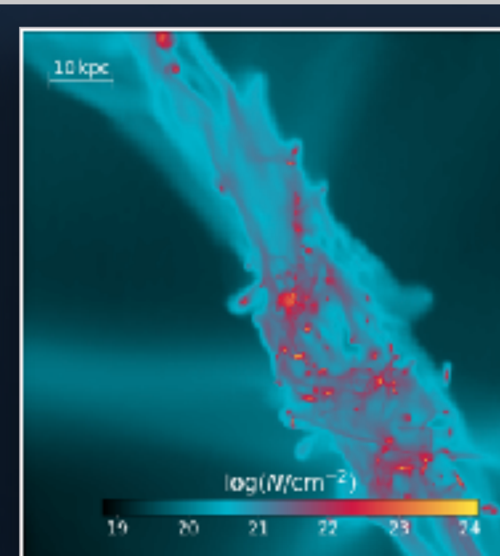


Smit+2017

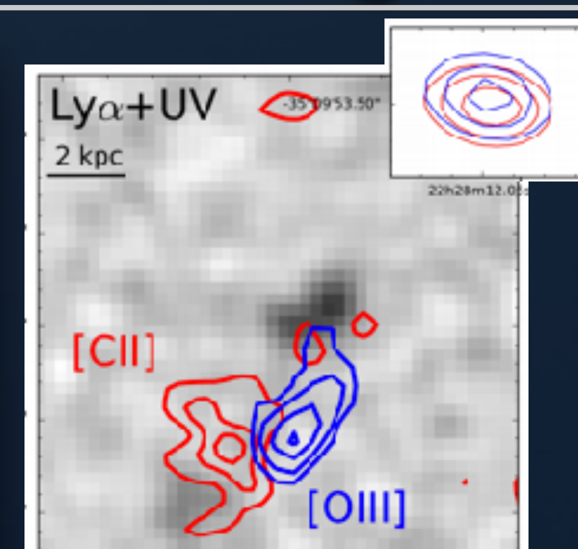
2. Accreting clumps, frequent mergers



Jones+2017

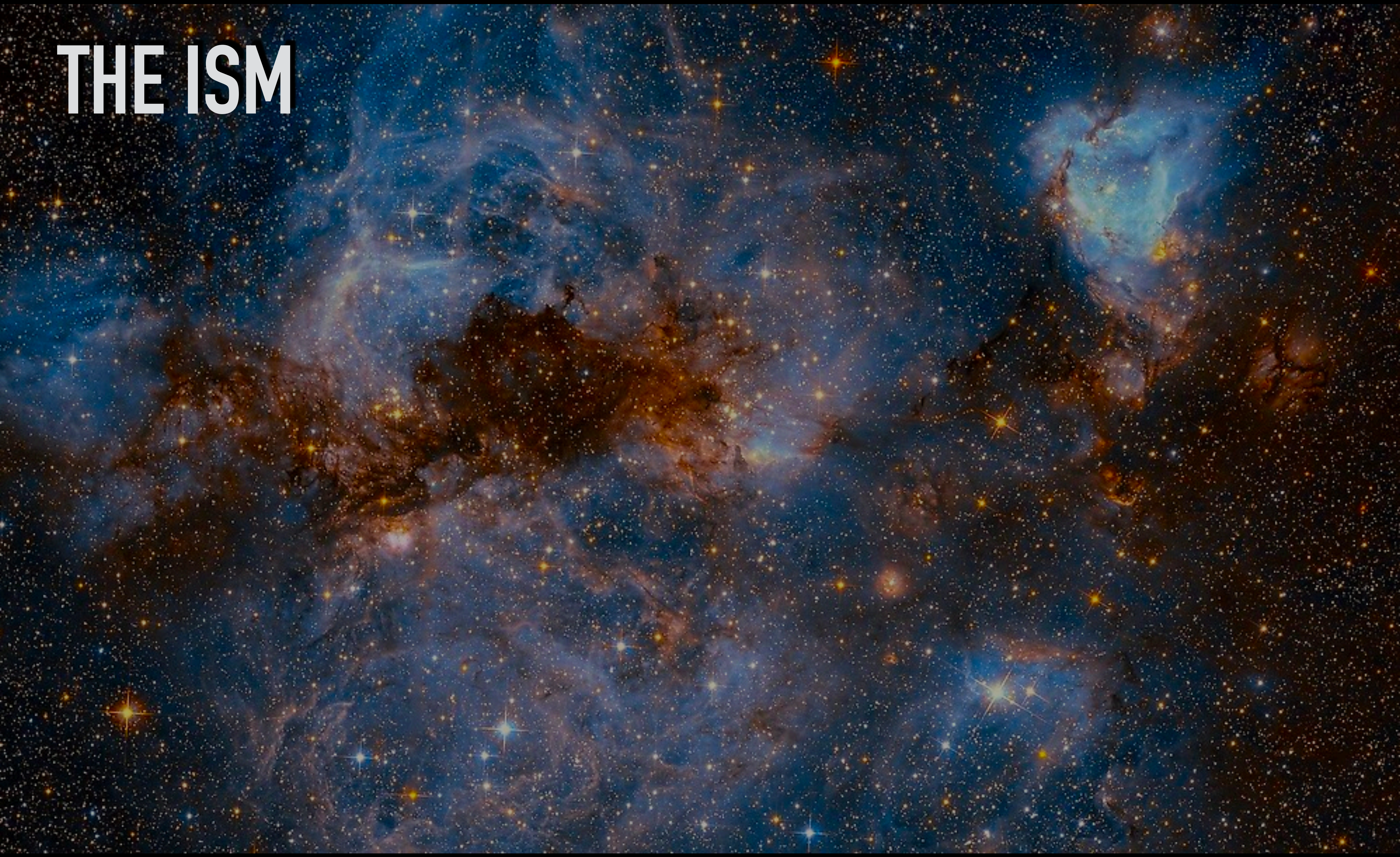


Pallottini+2017

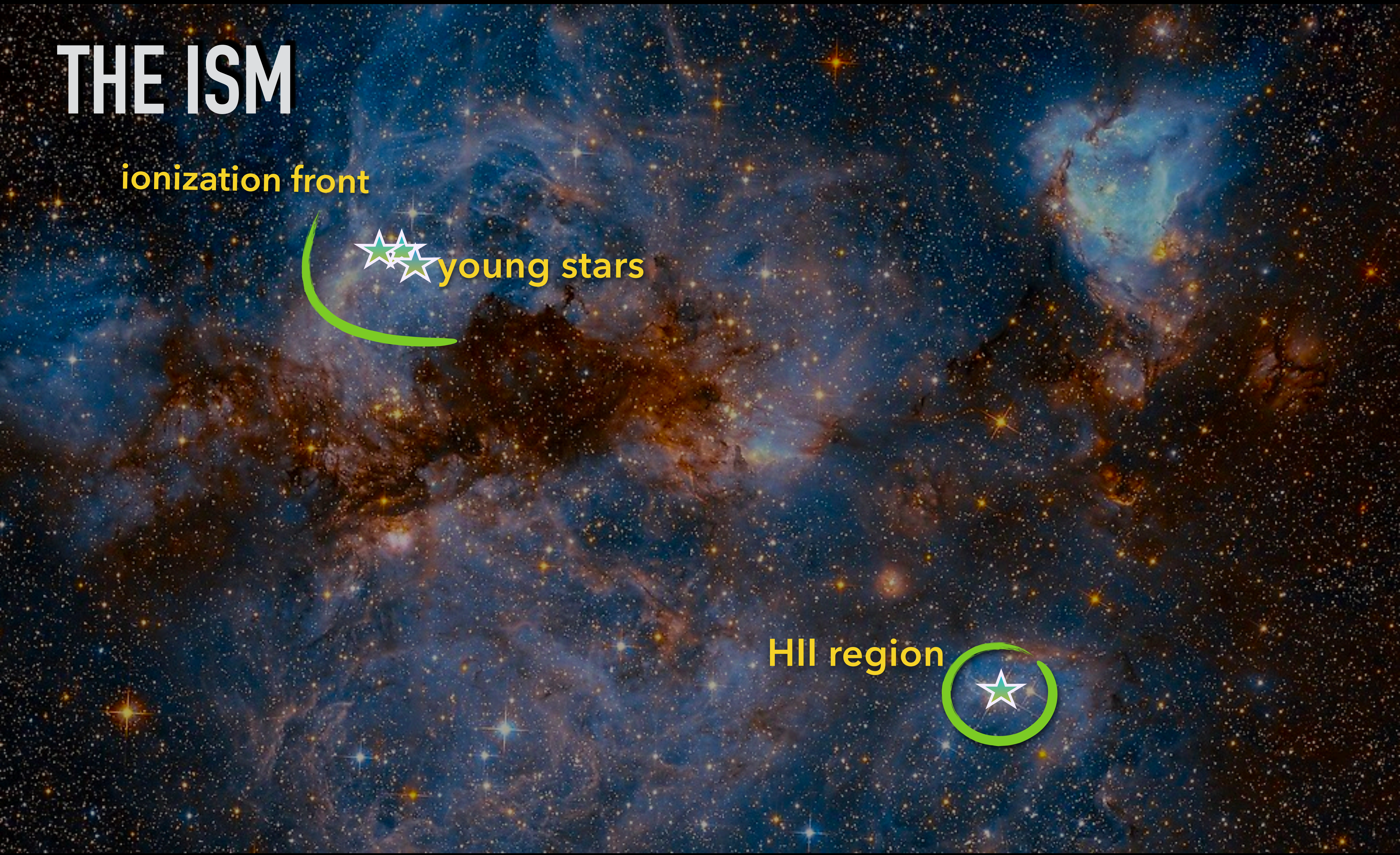


Carniani+2017

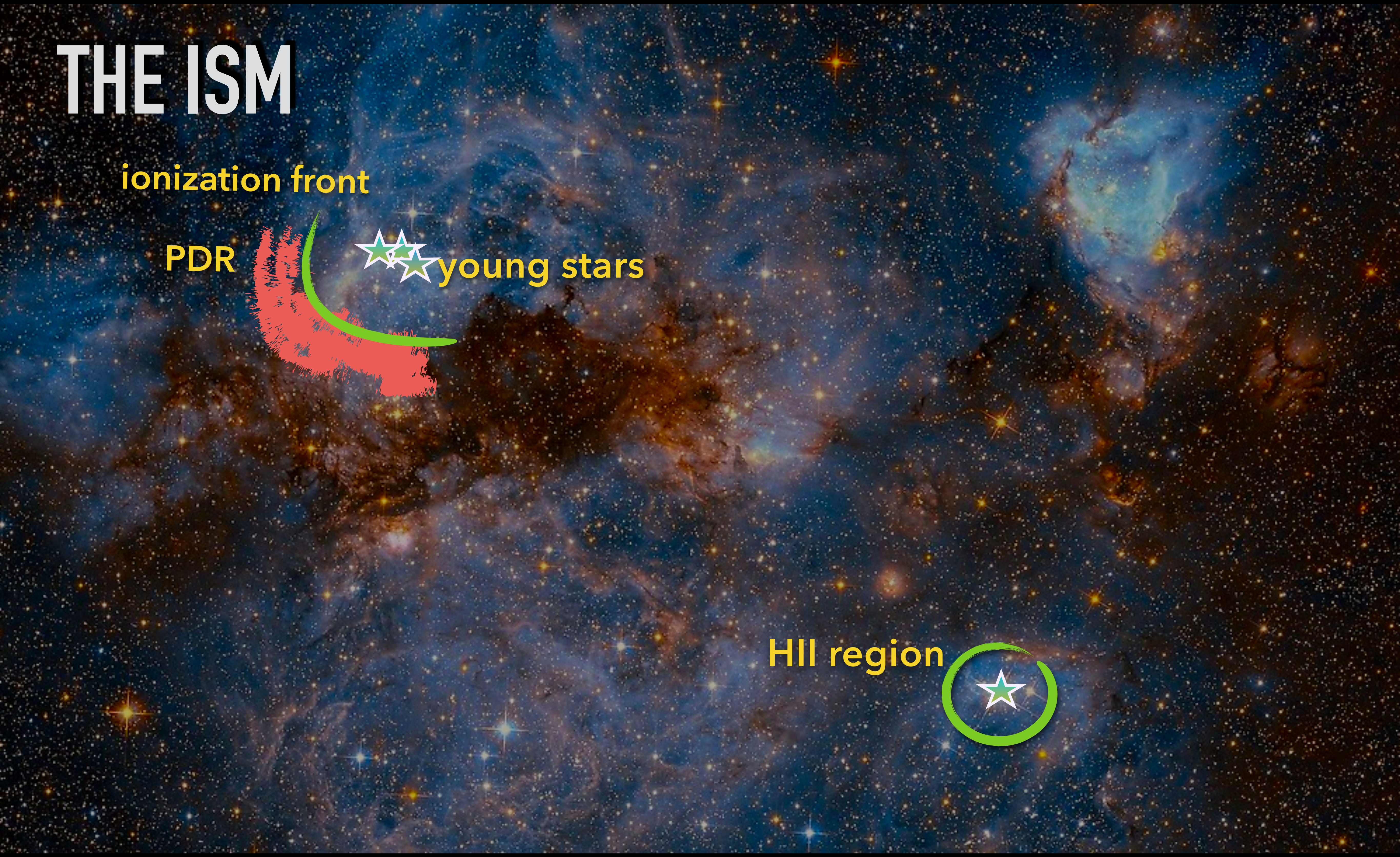
THE ISM



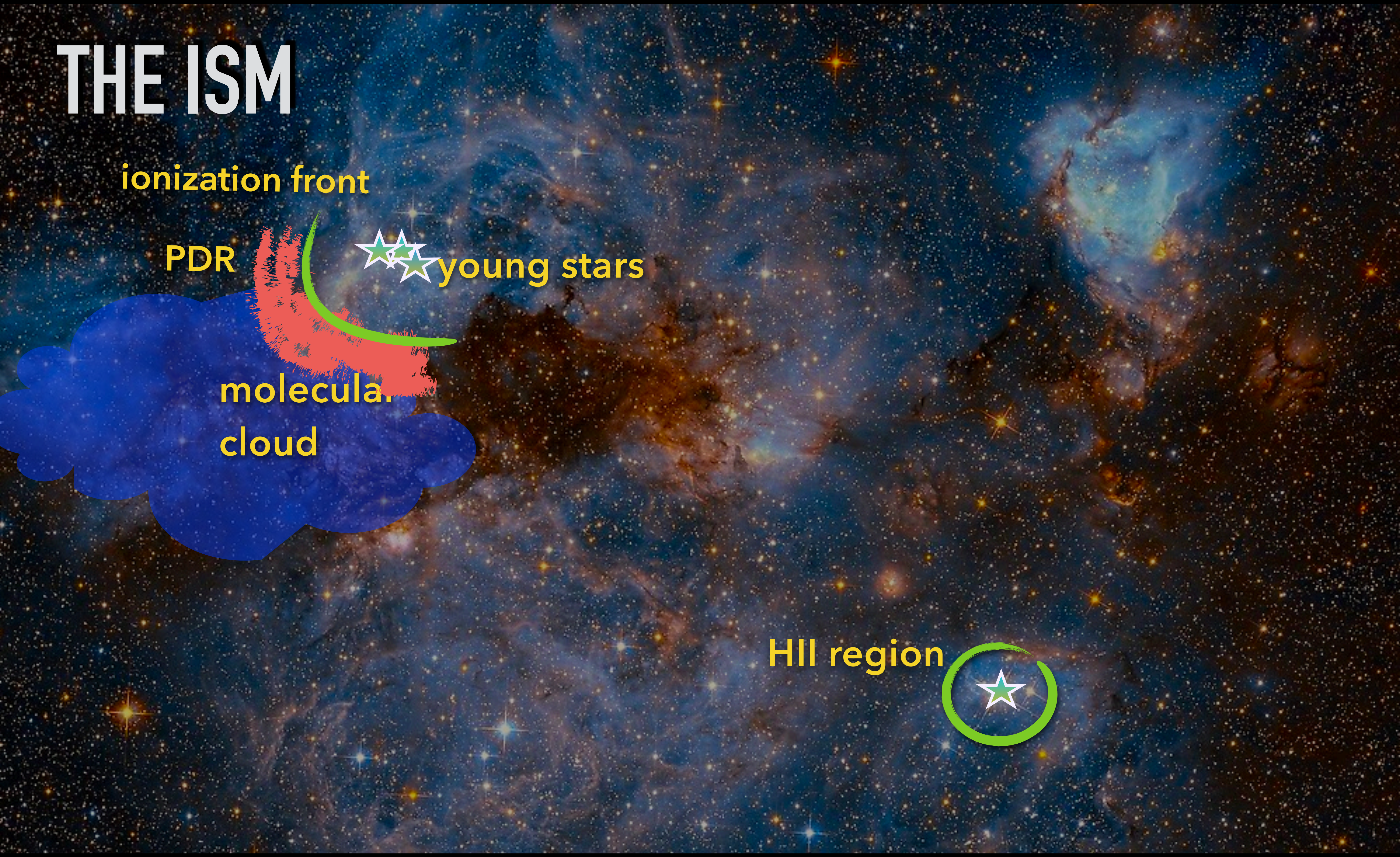
THE ISM



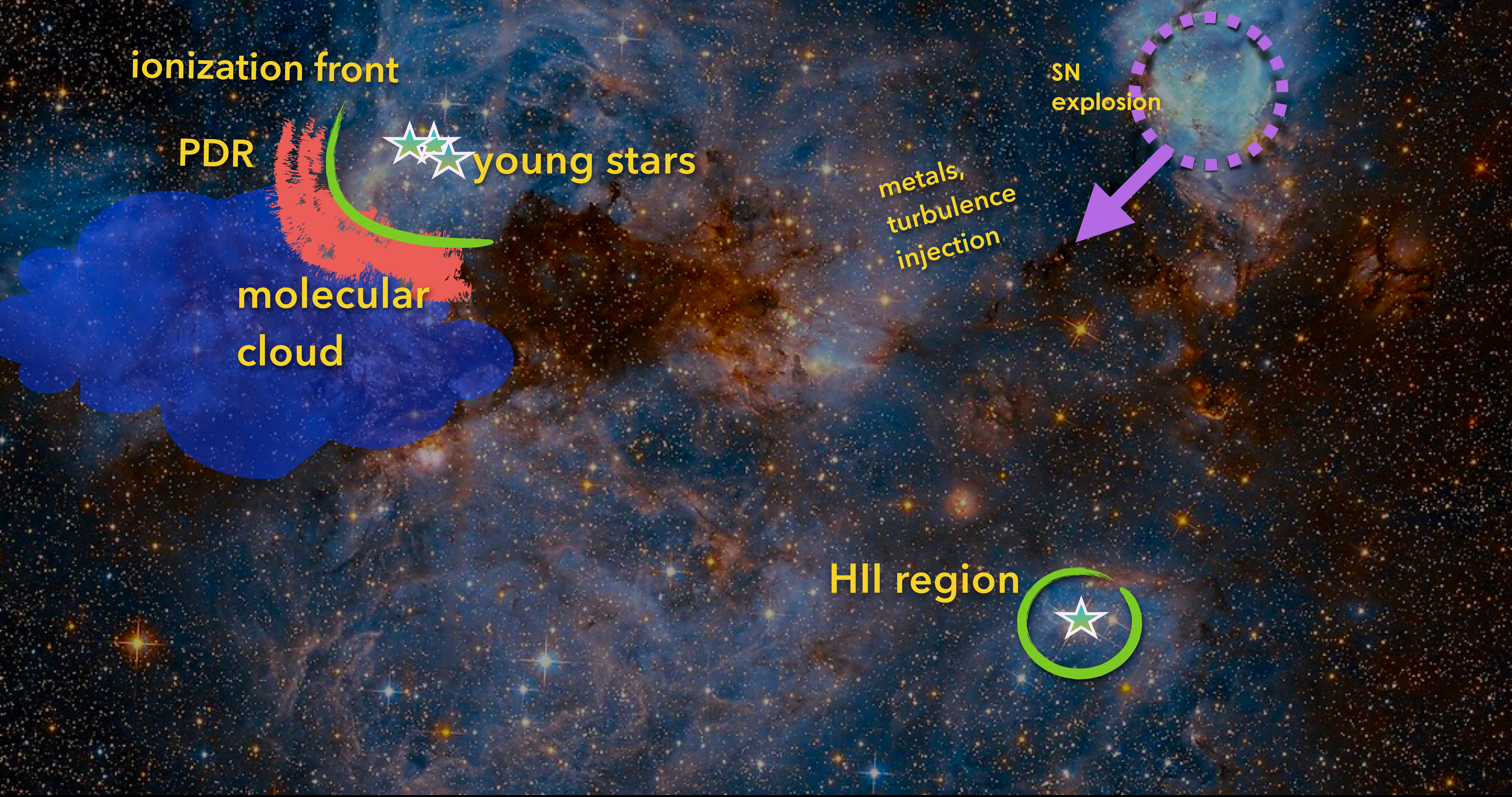
THE ISM



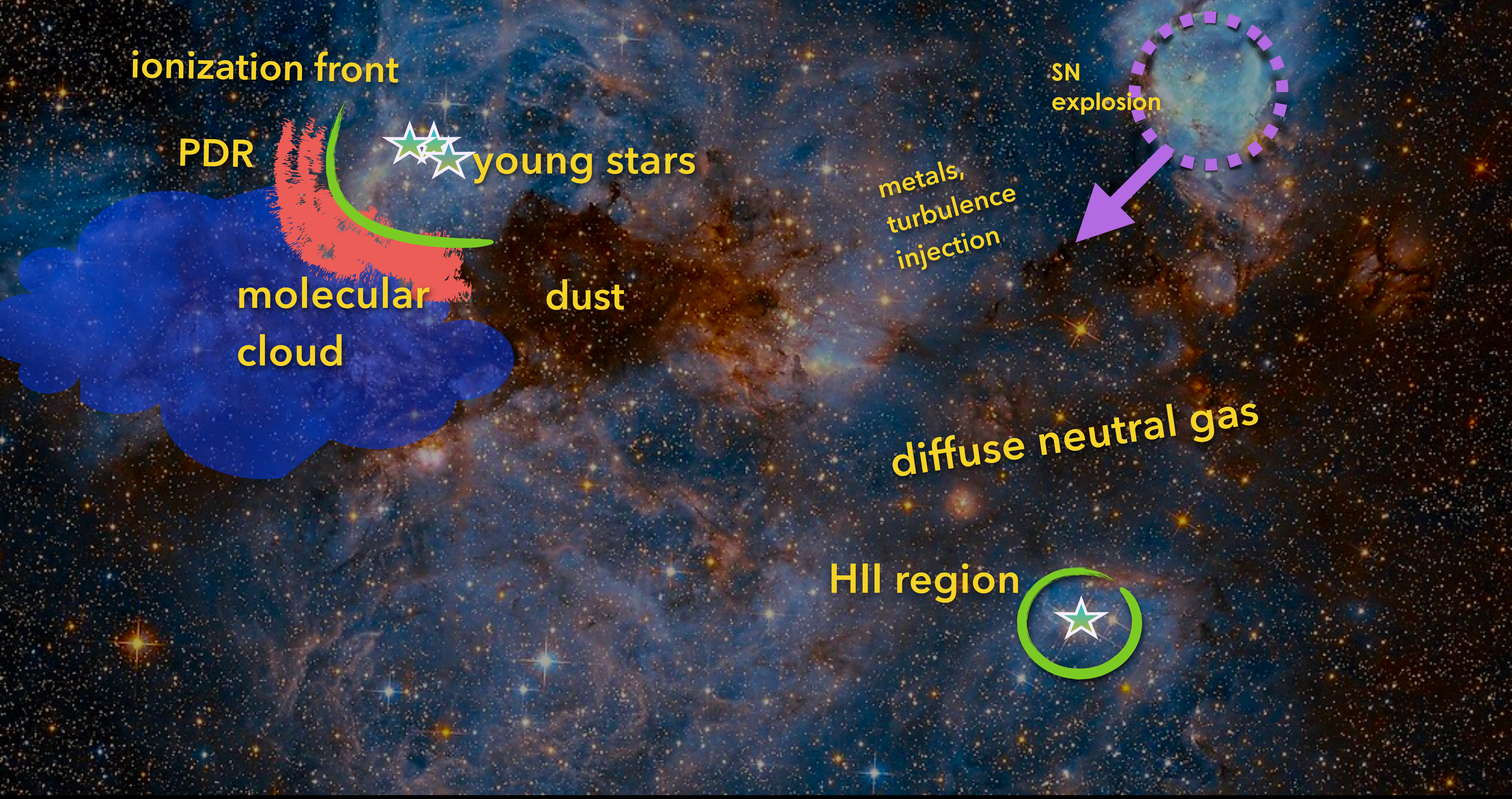
THE ISM

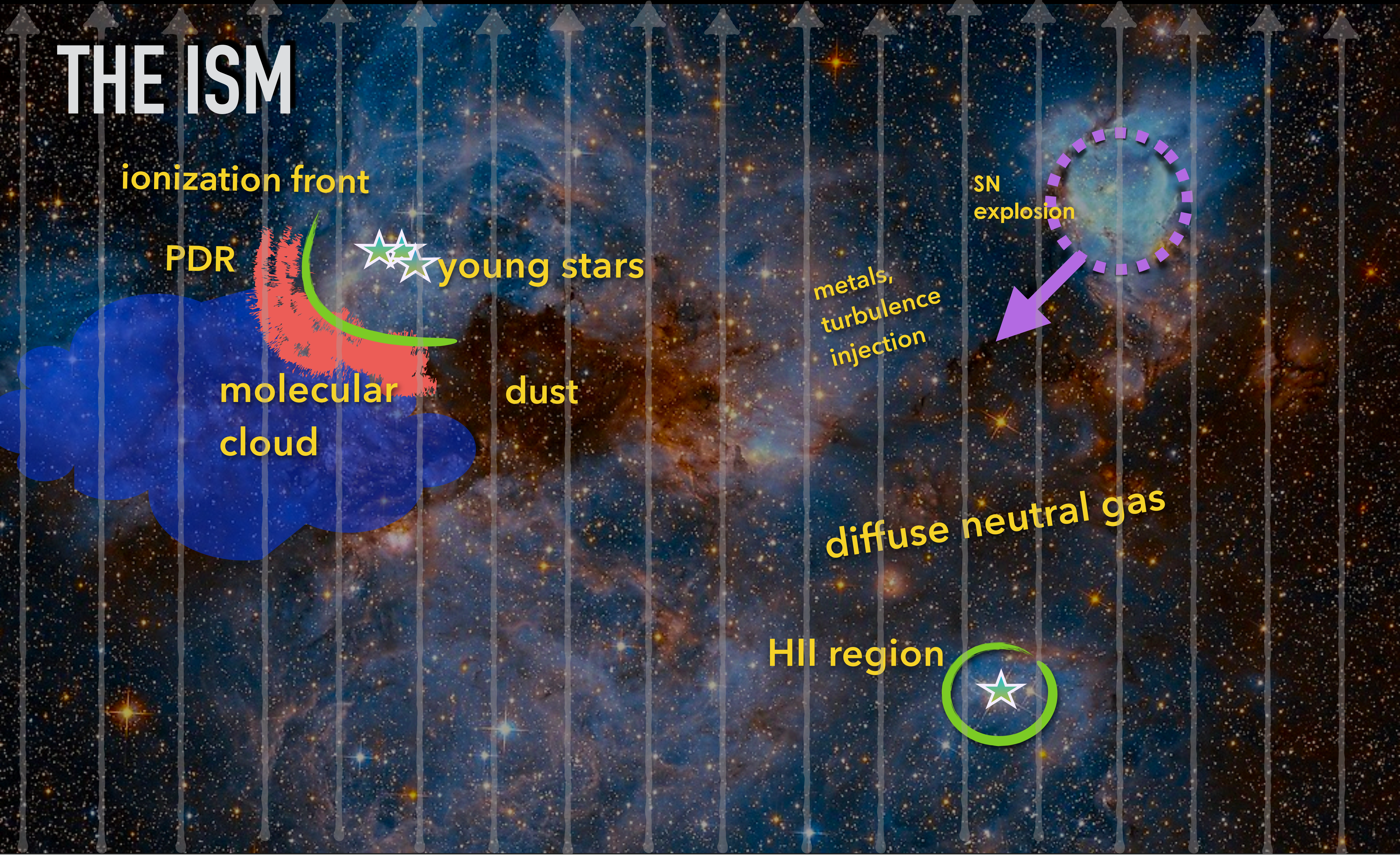

ionization front
PDR
young stars
molecula
cloud
HII region

THE ISM


ionization front
PDR
young stars
molecular cloud
SN explosion
metals, turbulence injection
HII region

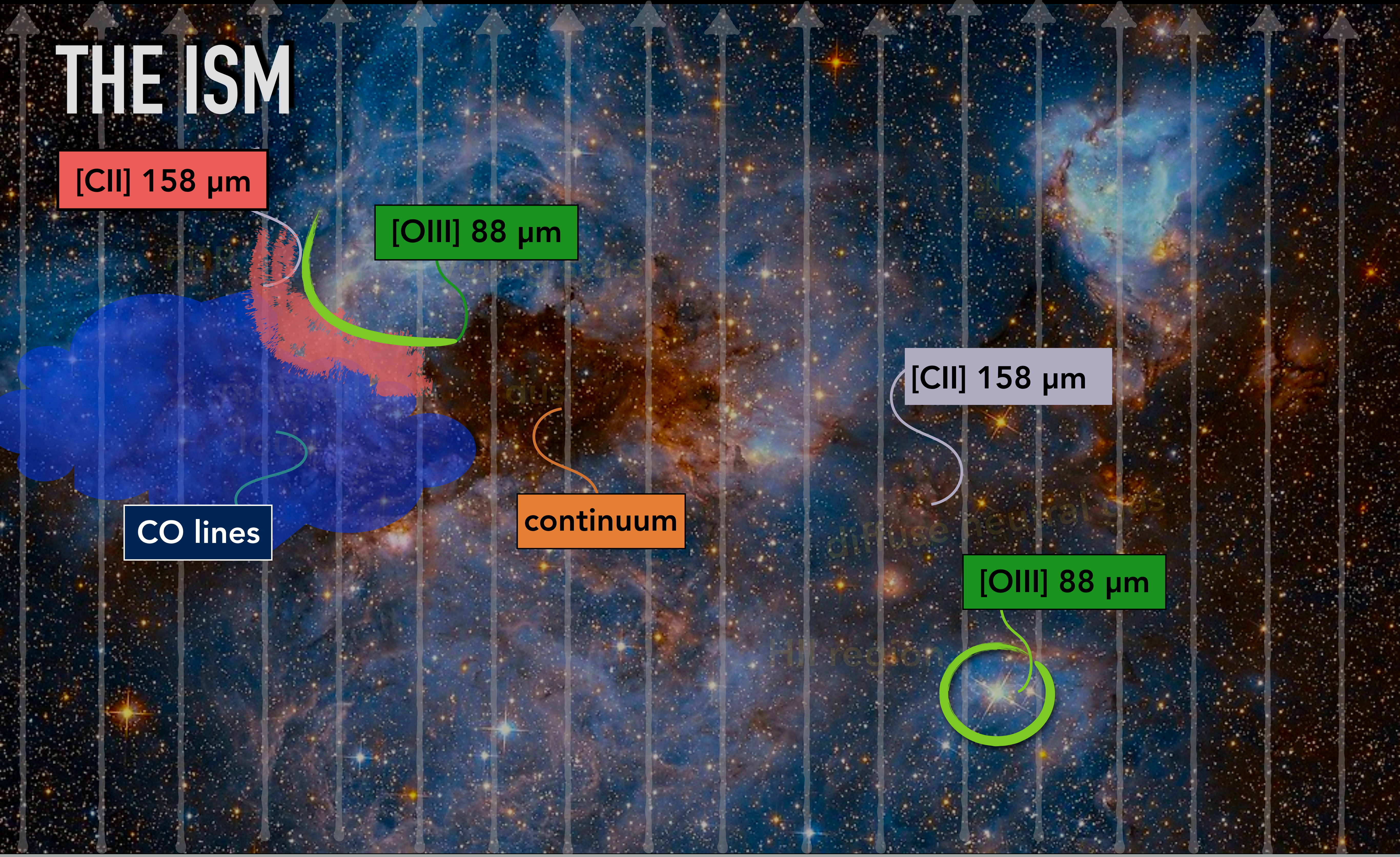
THE ISM


ionization front
PDR
young stars
molecular cloud
dust
SN explosion
metals, turbulence injection
diffuse neutral gas
HII region



COSMIC MICROWAVE BACKGROUND

THE ISM

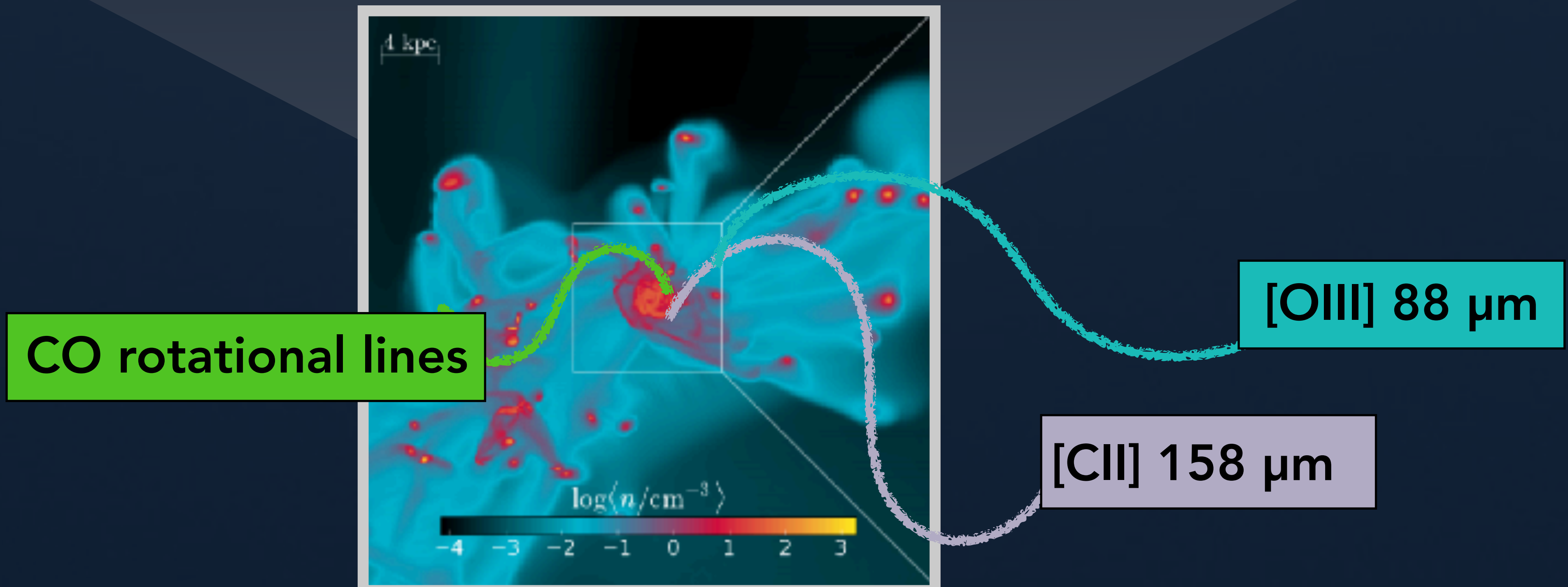


COSMIC MICROWAVE BACKGROUND

SIMULATING THE ISM PROPERTIES OF FIRST GALAXIES

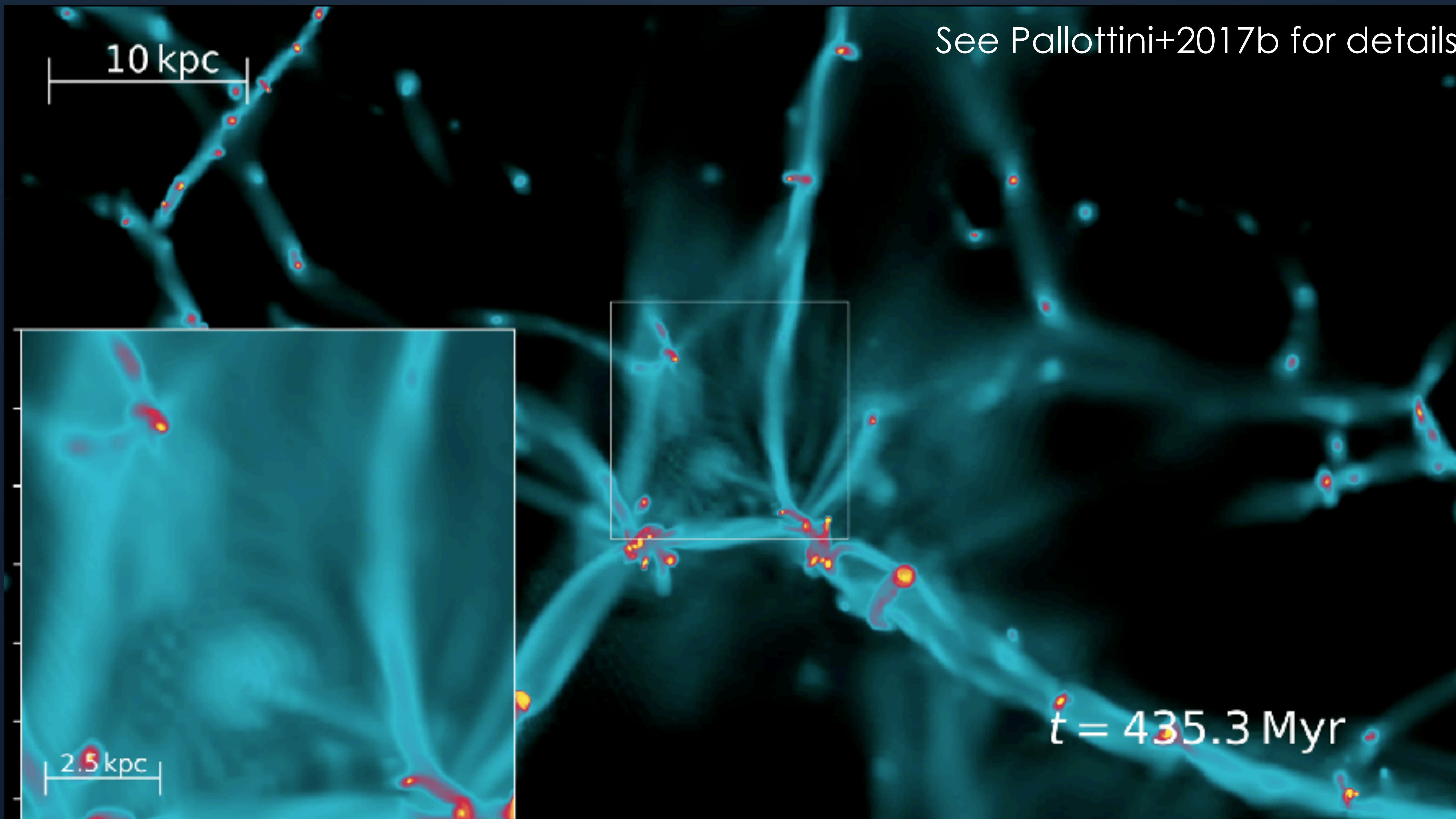
~10–100 PC SCALES

- **Detailed PDR calculations** to model the interaction of FUV photons with gas (photoelectric heating, metal cooling, etc)
- Consider the **internal density field of molecular clouds** on scales <1 pc (turbulence, self gravity)
- Account for the **feedback of star formation** (e.g. ionization feedback, photoevaporation feedback, etc)



Pallottini+17a

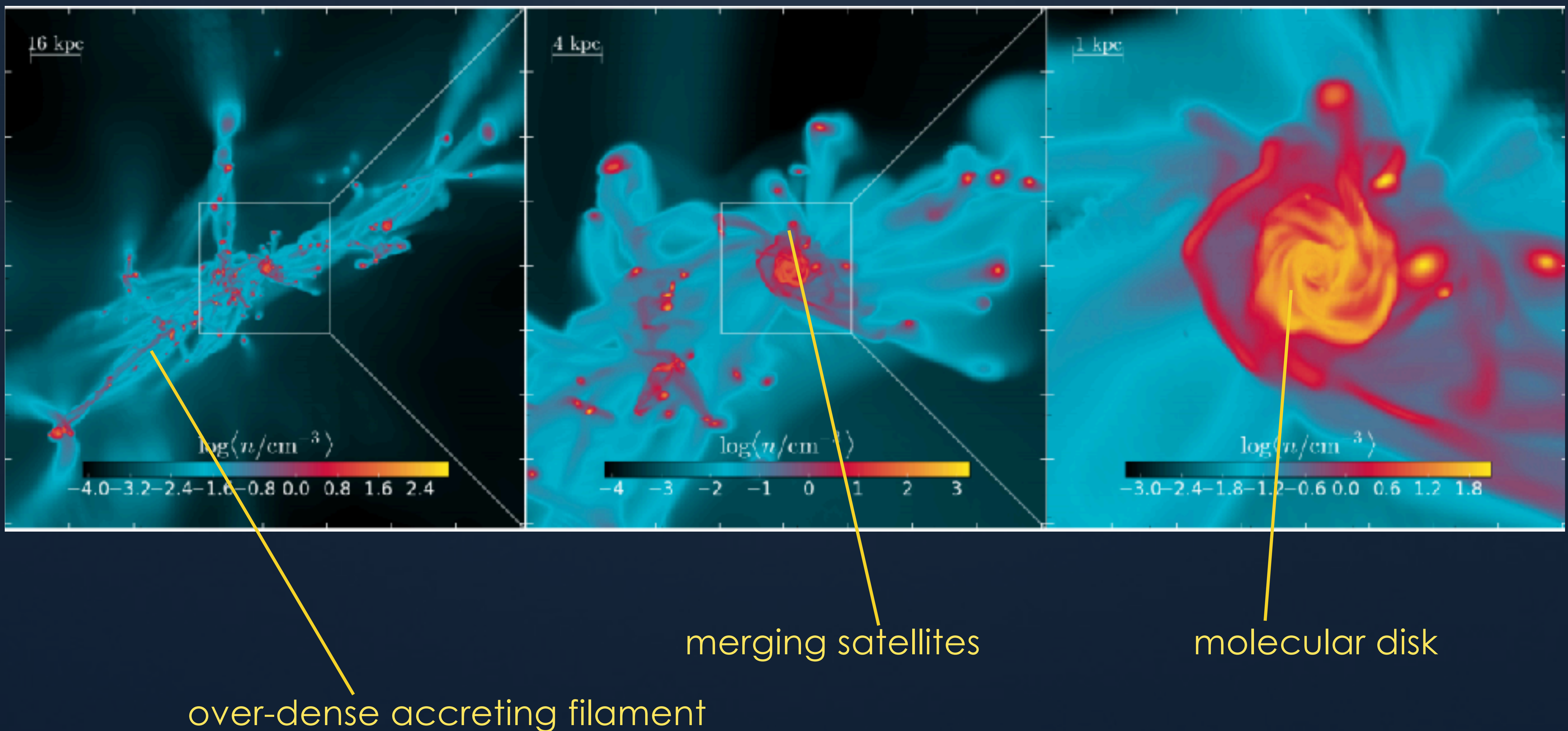
COSMOLOGICAL ZOOM-IN SIMULATION



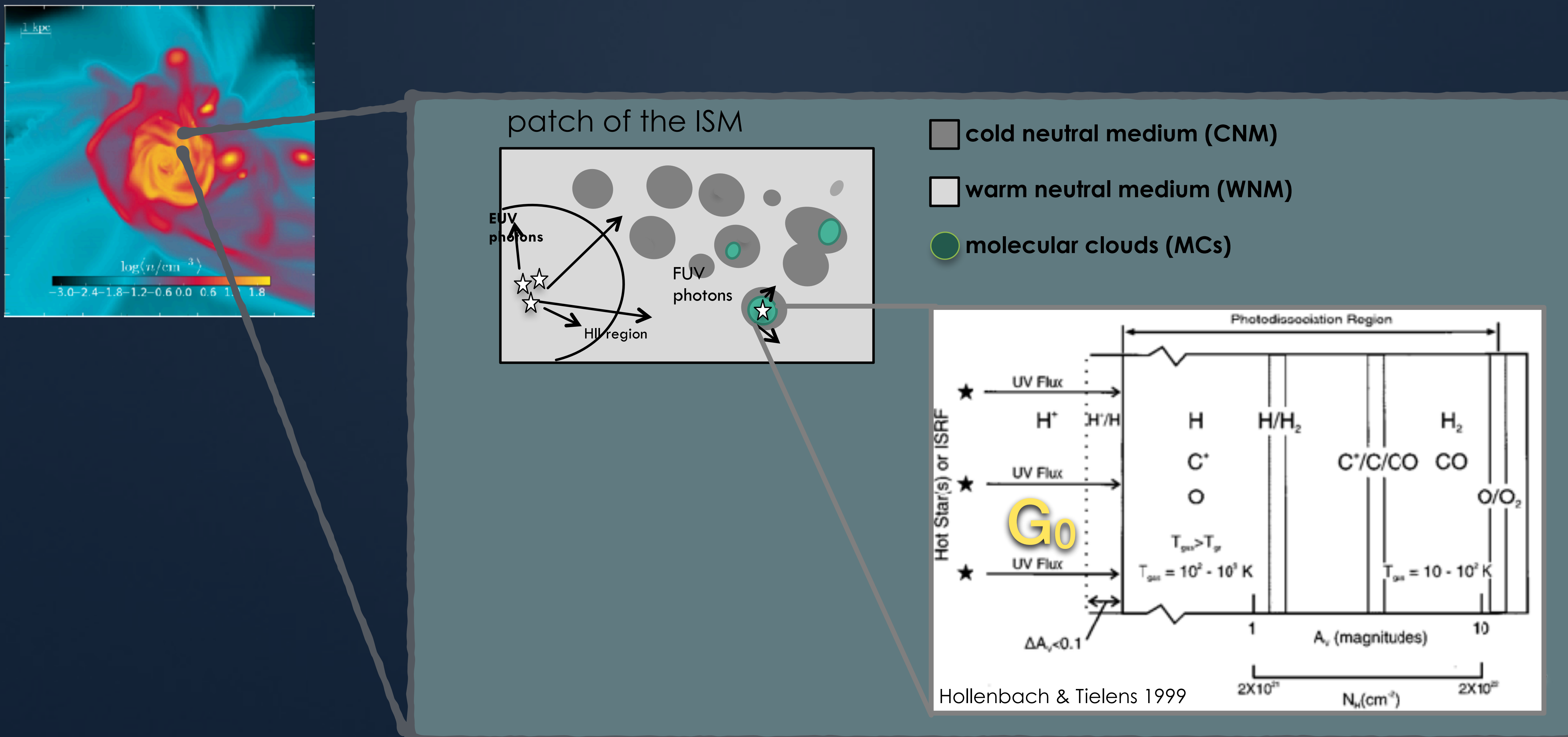
AMR code **RAMSES** (Teyssier 2002) spatial res=30pc Mass res=10^4 M_{sun}	**CHEMICAL NETWORK:** KROME (Grassi+2014)	**STAR FORMATION:** H_2 dependent SK relation	**STELLAR FEEDBACK:** SN explosion: thermal and kinetic (blast-wave model; Ostriker & McKee 1988)	**PROPERTIES AT z=6:** M_{DM} = 1 x 10^{11} M_{sun} M_{star} = 3 x 10^{10} M_{sun} Z = 0.5 Z_{sun}

COSMOLOGICAL ZOOM-IN SIMULATION

Pallottini+2017a,b



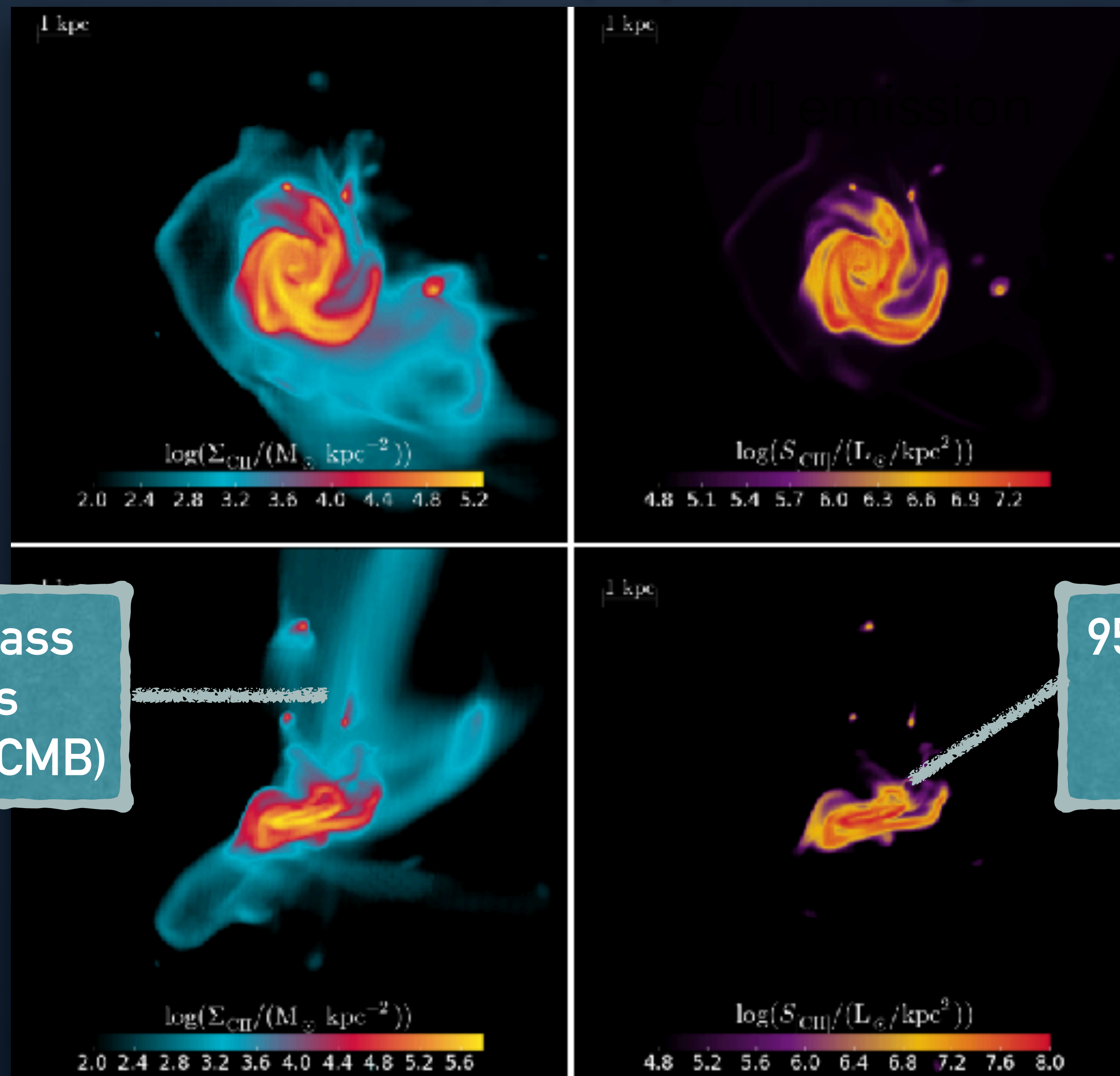
MODELLING THE [CII] EMISSION



- At high-z the CMB is a strong background (T~20 K @ z~6) and cannot be neglected! (Da Cunha+2013)

MODELLING THE [CII] EMISSION

C+ surface density | [CII] surface brightness



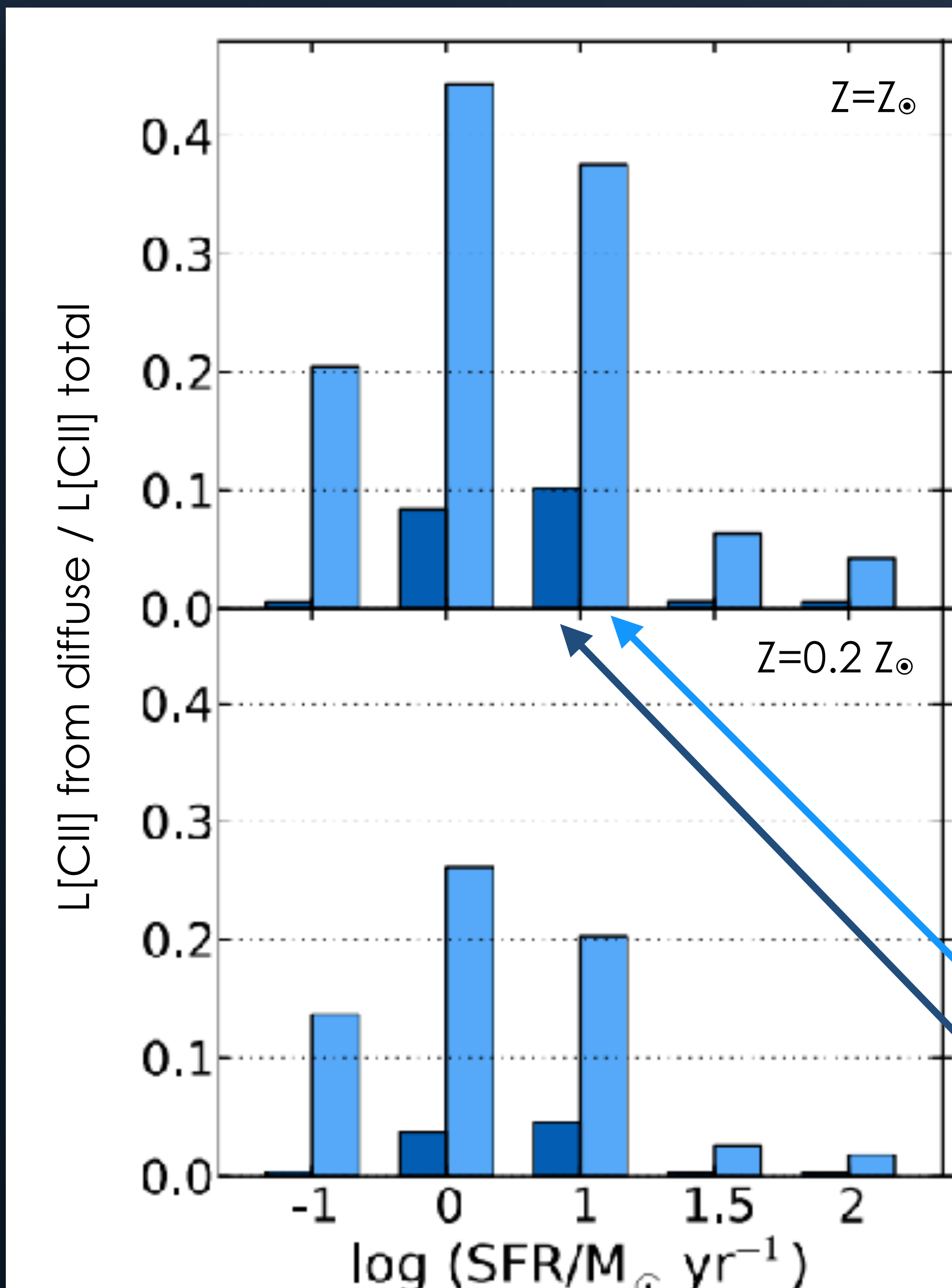
1/3 of the CII mass in diffuse gas (invisible due to CMB)

95% of the emission colocated with the H_2 disk

Vallini+2015, Pallottini+2017a

EFFECT OF THE CMB ON THE [CII] EMISSION

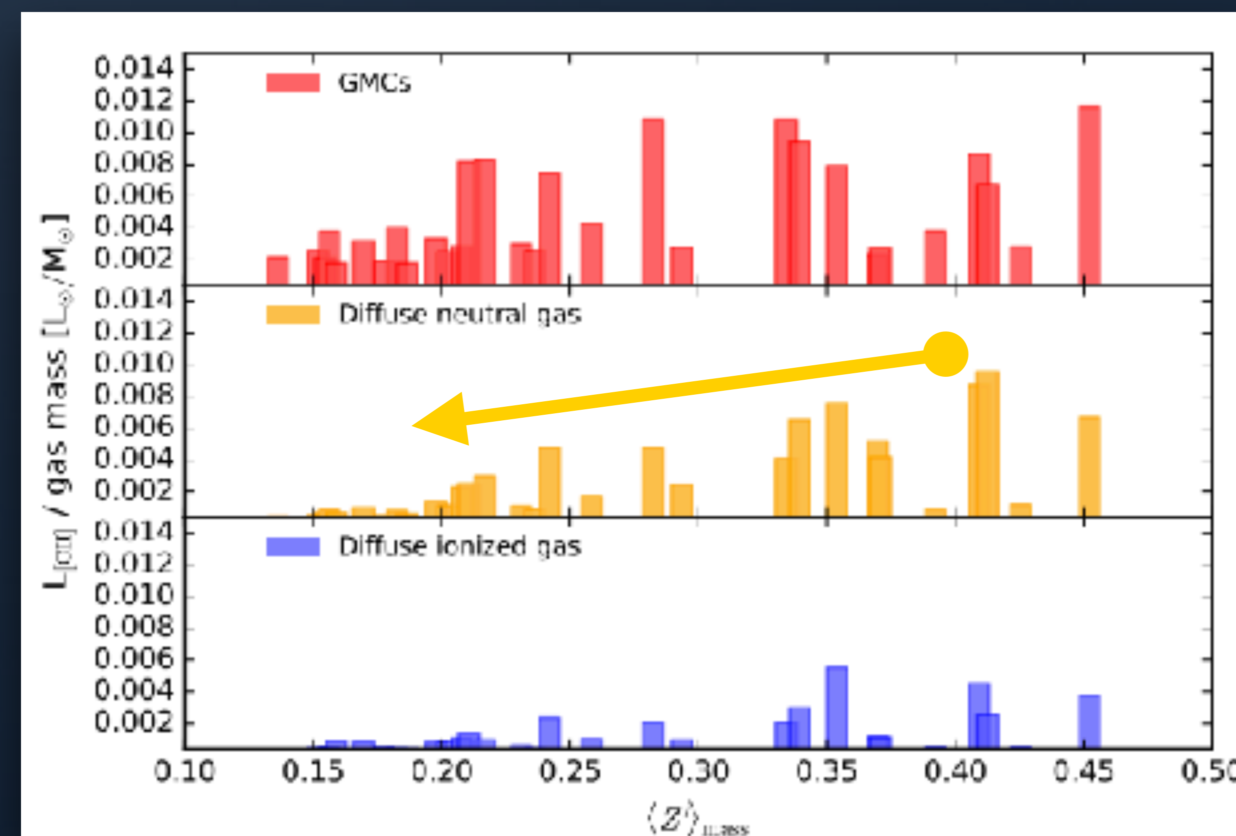
Vallini+2013, 2015



not considering CMB

considering CMB

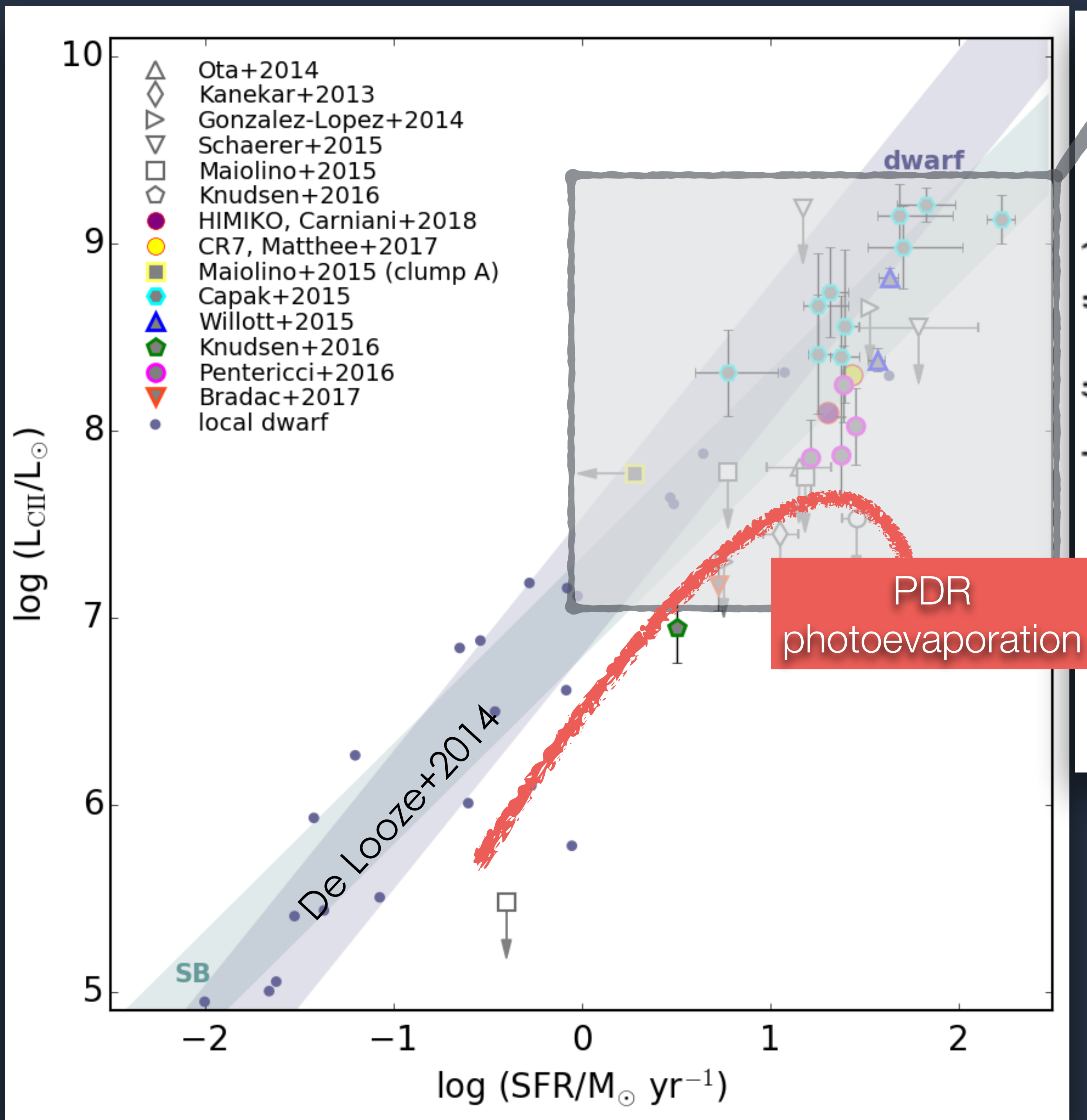
Olsen+2017



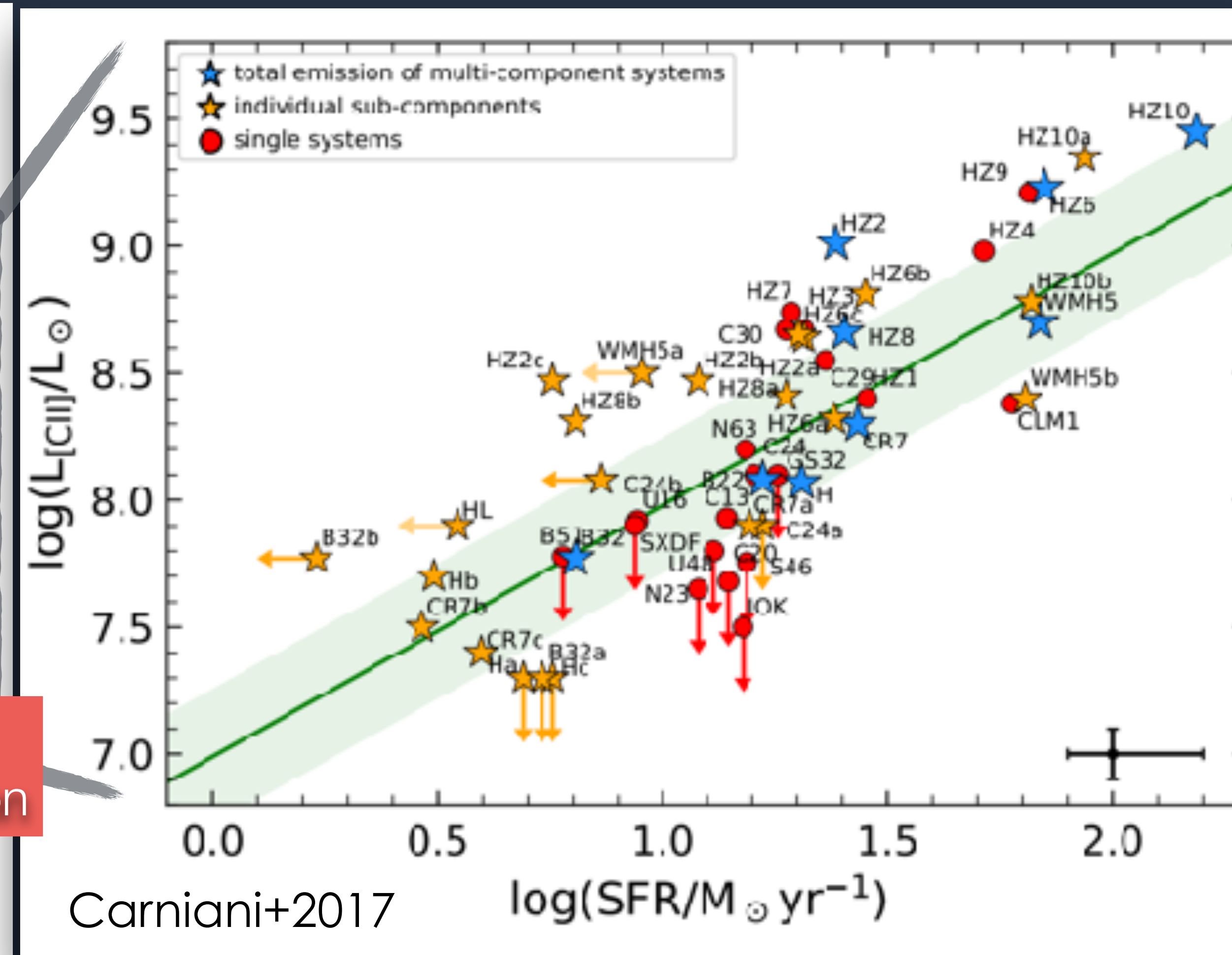
Da Cunha+2013

$$\frac{S^{J_u\,[\mathrm{obs\ against\ CMB}]}_{\nu/(1+z)}}{S^{J_u\,[\mathrm{intrinsic}]}_{\nu/(1+z)}} = 1 - \frac{B_\nu[T_{\mathrm{CMB}}(z)]}{B_\nu[T^{J_u}_{\mathrm{exc}}]} . \qquad (32)$$

[CII]-SFR RELATION AT HIGH-Z

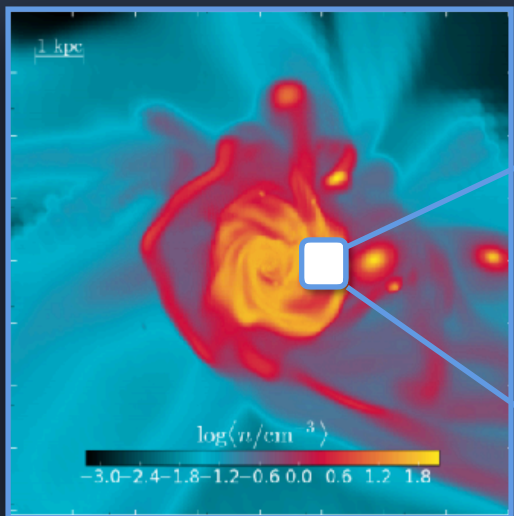


Vallini+2015 updated with data up to 2018

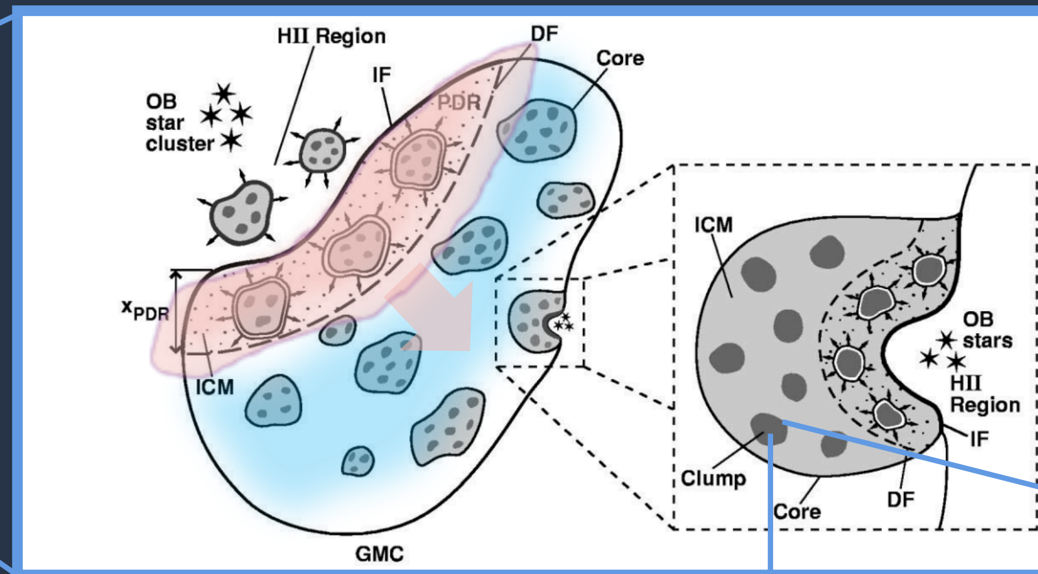


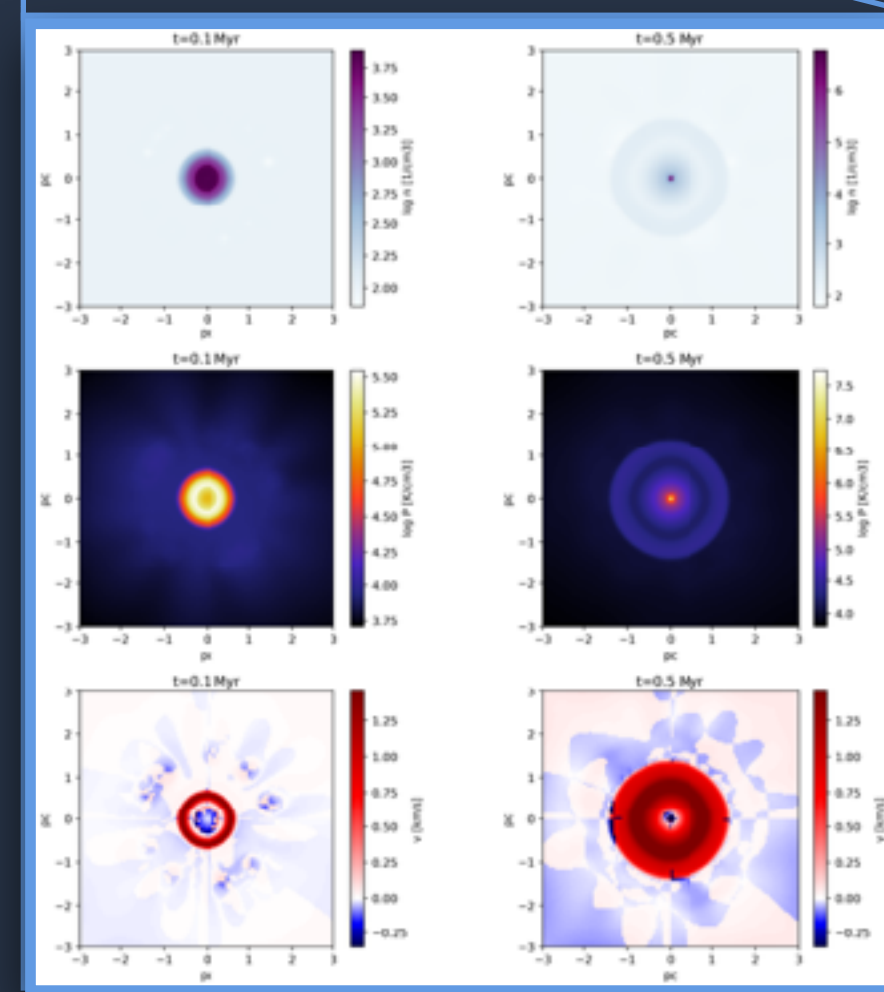
The multiple component objects are split into several individual components with their own SFRs and $L_{[CII]}$

[CII]-SFR RELATION AT HIGH-Z, PHOTOEVAPORATION FEEDBACK



Gorti&Hollenbach+2002, (only FUV)

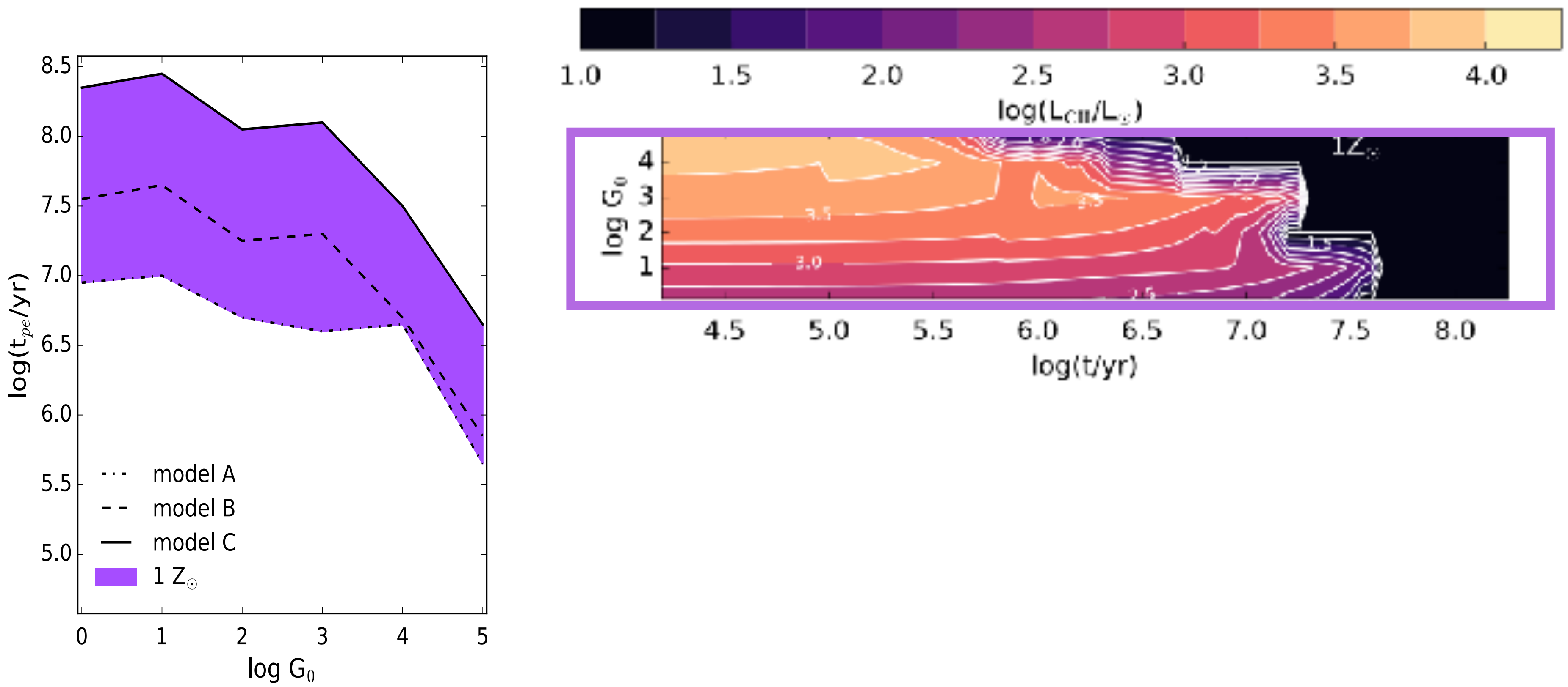




Decataldo+2017 (FUV+EUV)

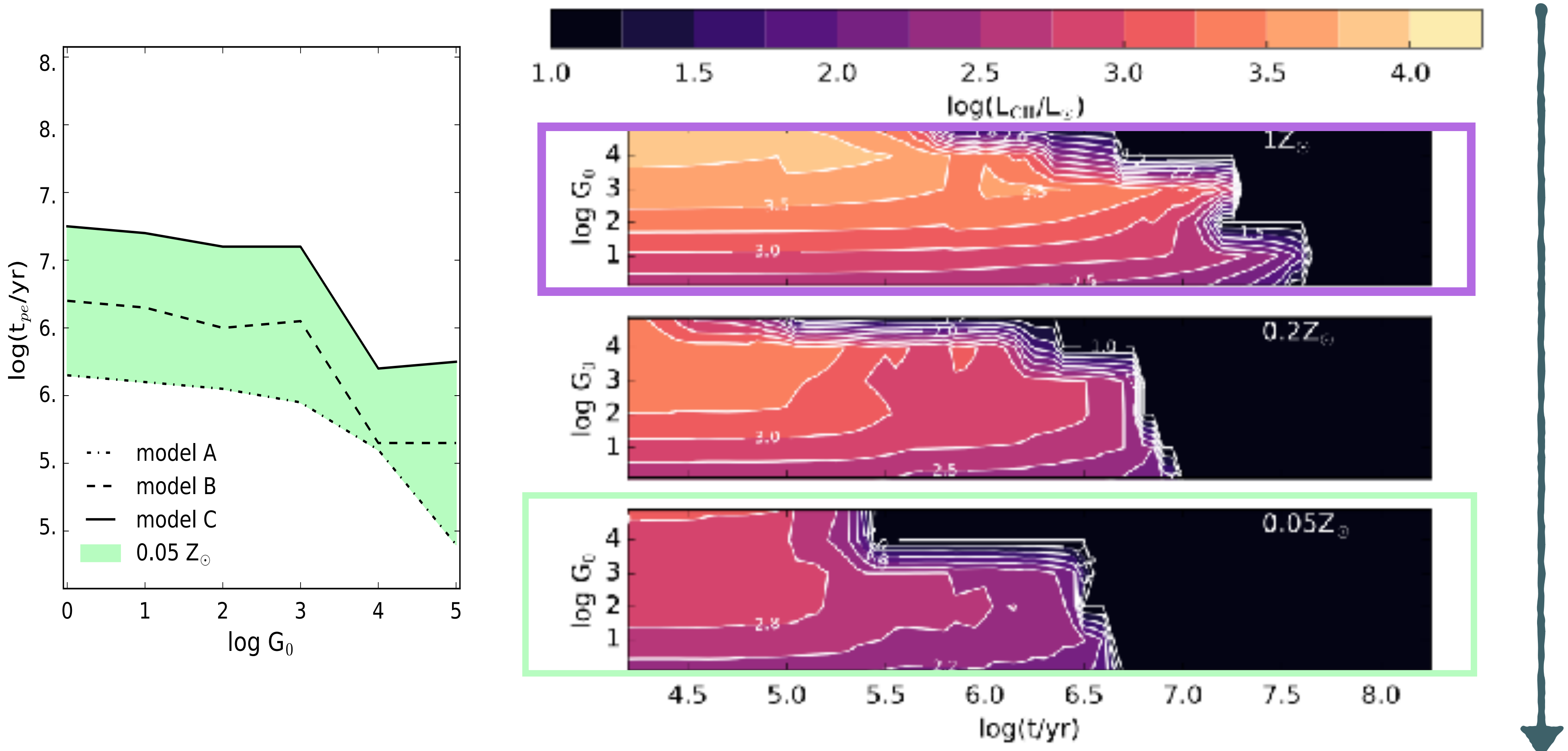
THE EFFECT OF PHOTOEVAPORATION ON THE [CII] EMISSION

Vallini+2017



THE EFFECT OF PHOTOEVAPORATION ON THE [CII] EMISSION

Vallini+2017

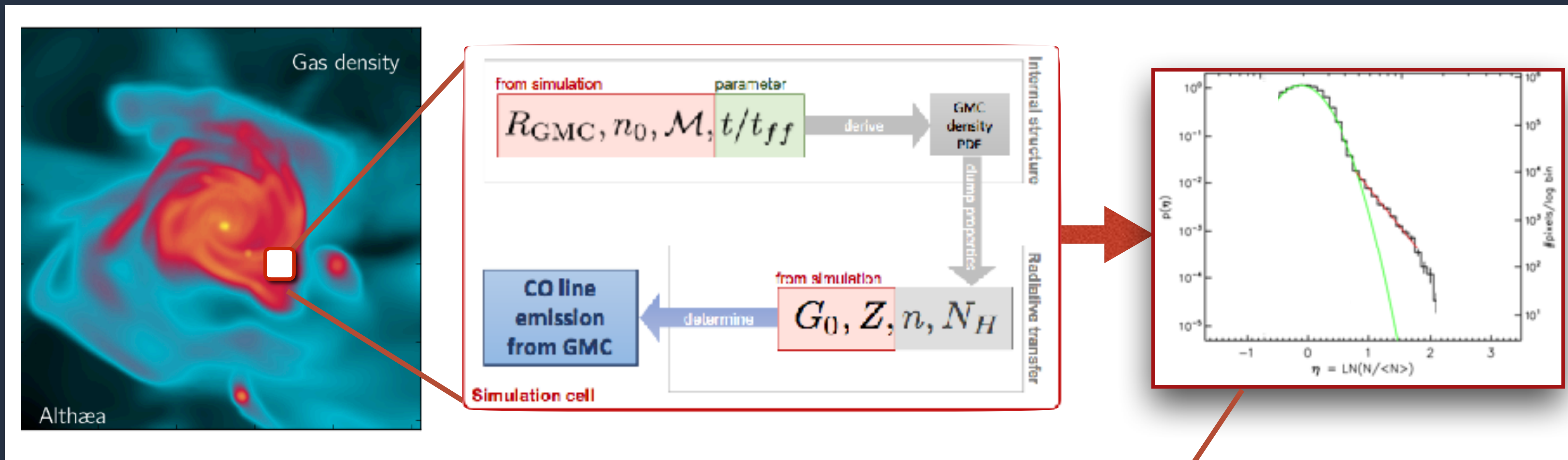


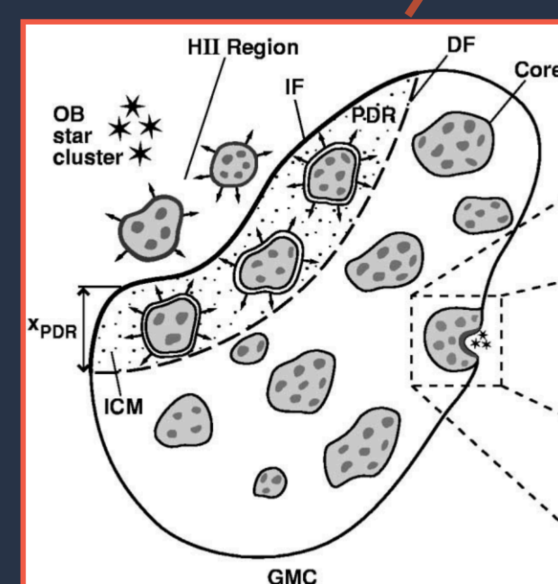
faster photoevaporation with decreasing Z

CO EMISSION FROM HIGH-Z

Vallini+2018

See e.g. Padoan+2011,2014, Ostriker+2001,Federrath+2013, Girichidis+2014





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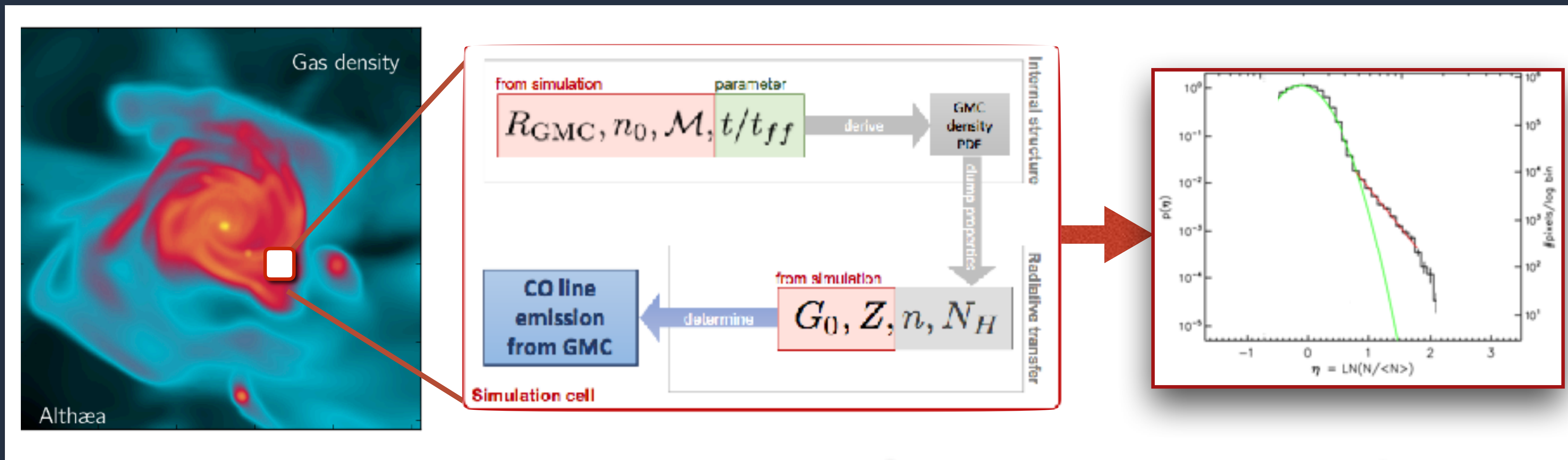
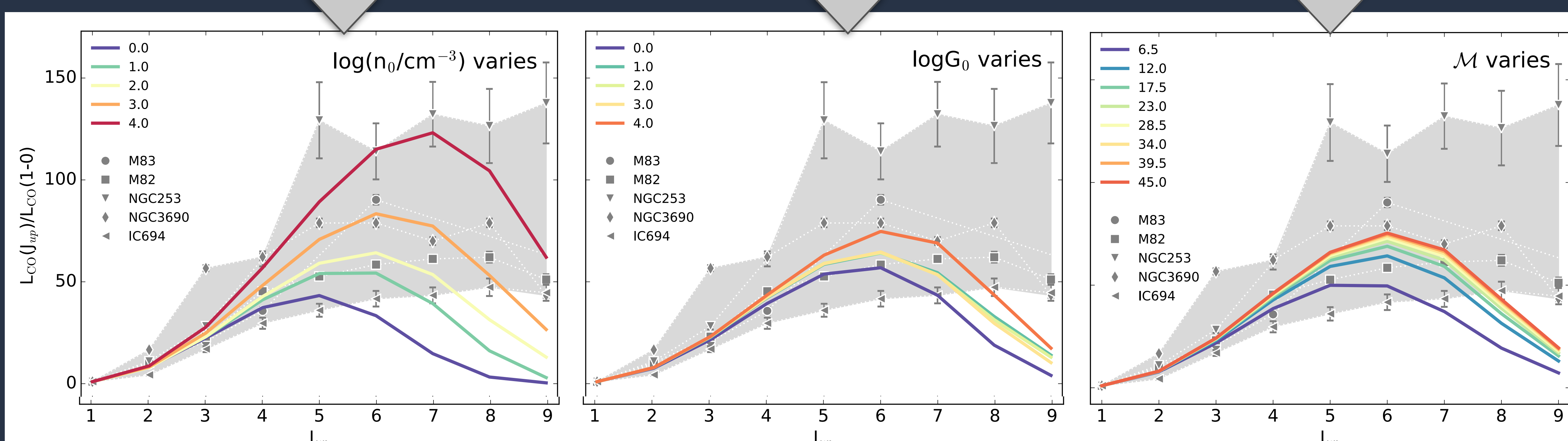


varying mean density

varying Habing field

varying Mach number



Vallini+2018

CO EMISSION FROM HIGH-Z

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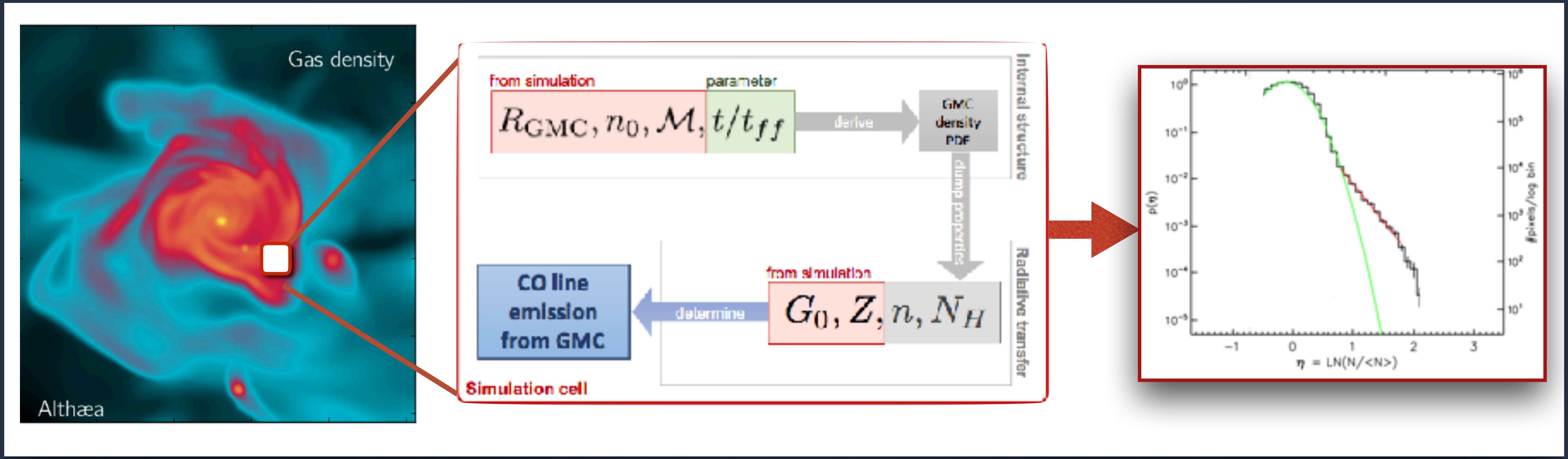
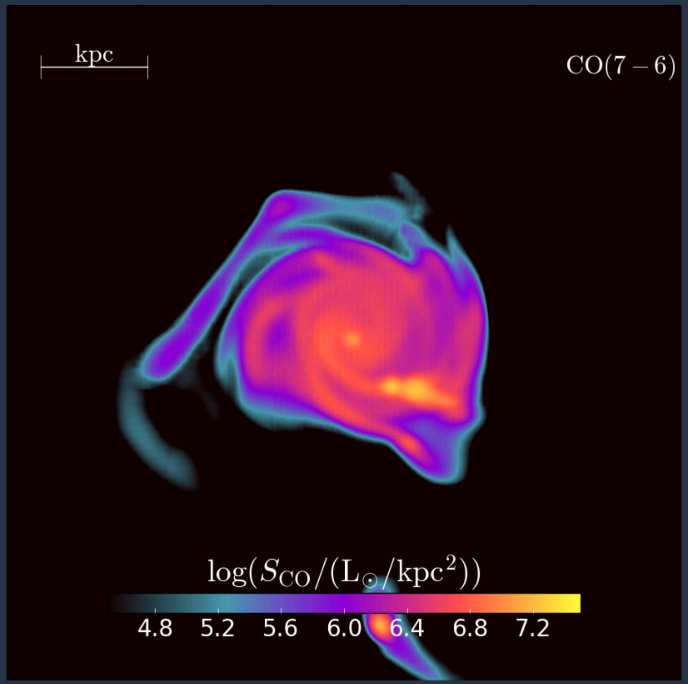
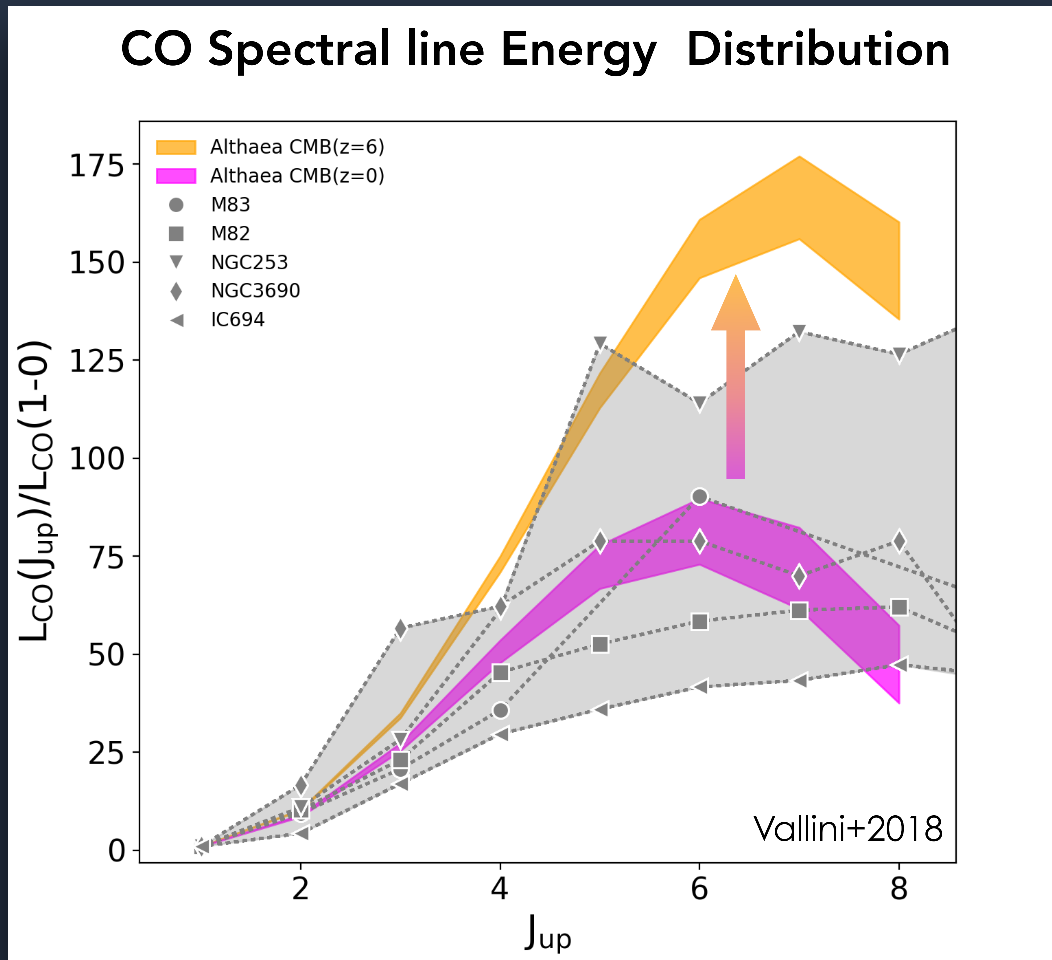


CO(7-6) surface brightness map

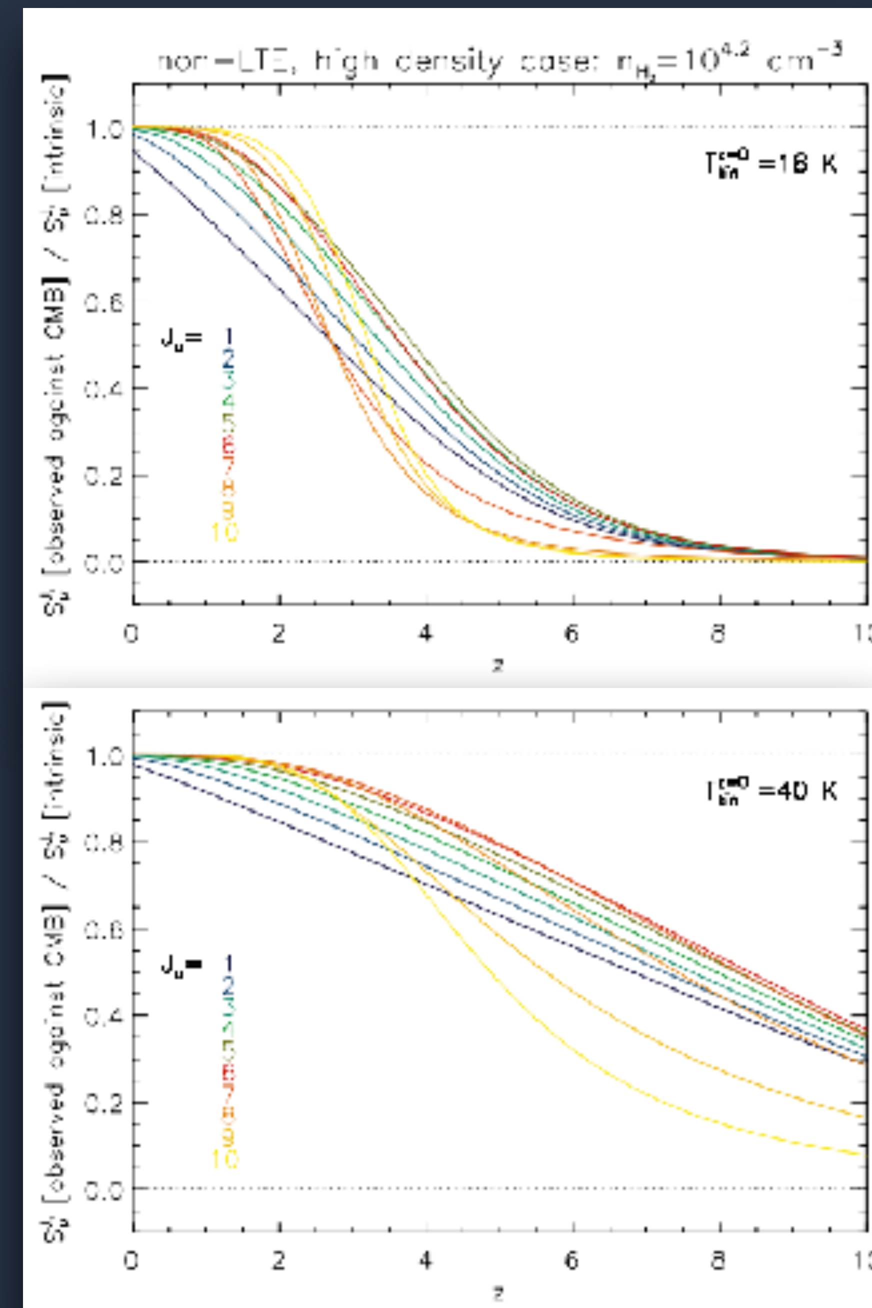


- $L_{CO(7\text{-}6)} = 10^{7.1}\ L_\odot$ i.e. ≈ 1/16 of the [C II] luminosity.
- To **detect** the CO(7-6) line with a S/N=5 an ALMA observing time of **~20h** is required.

THE CMB EFFECT ON THE CO SLED

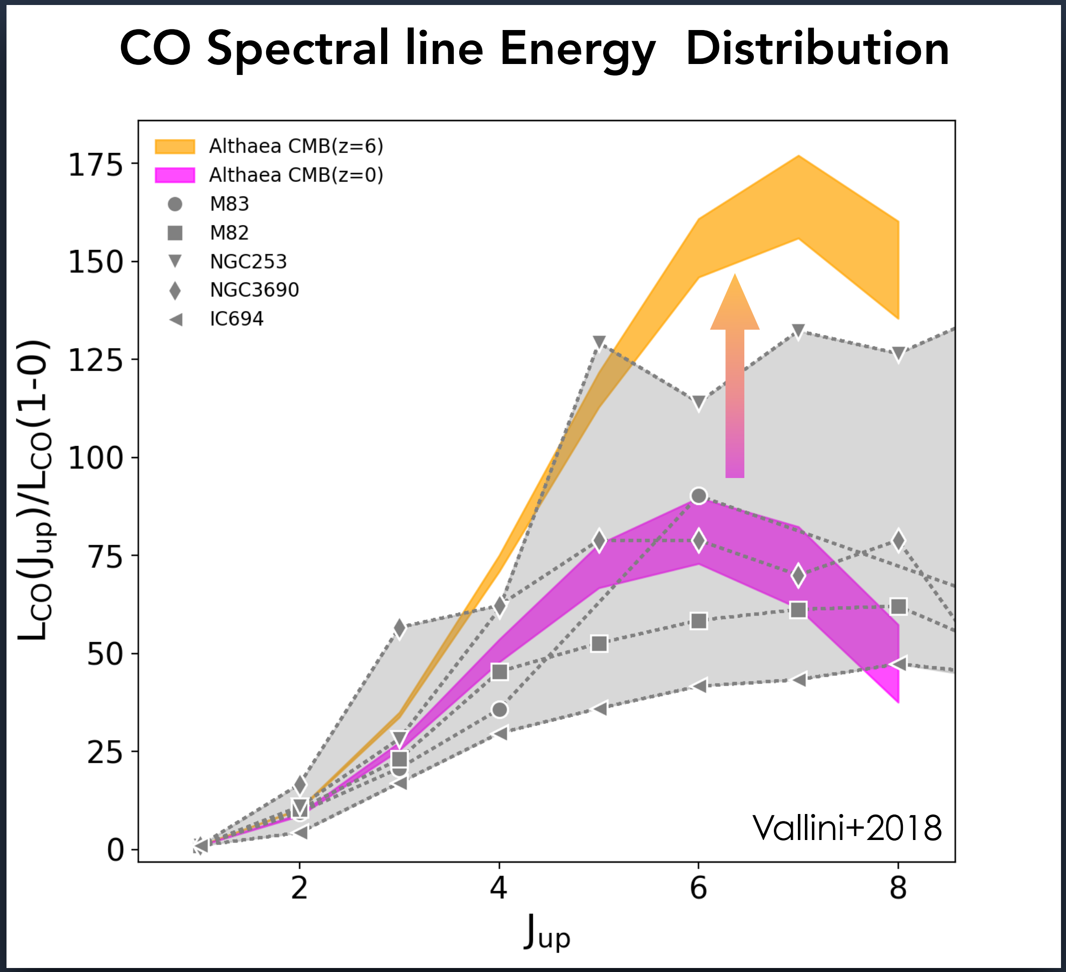


- the increased density and temperature boosts the CO SLED and shifts the peak
- The CO SLED peaks at CO(7-6) (observable from z>6 with ALMA)



Da Cunha+2013

THE CMB EFFECT ON THE CO SLED



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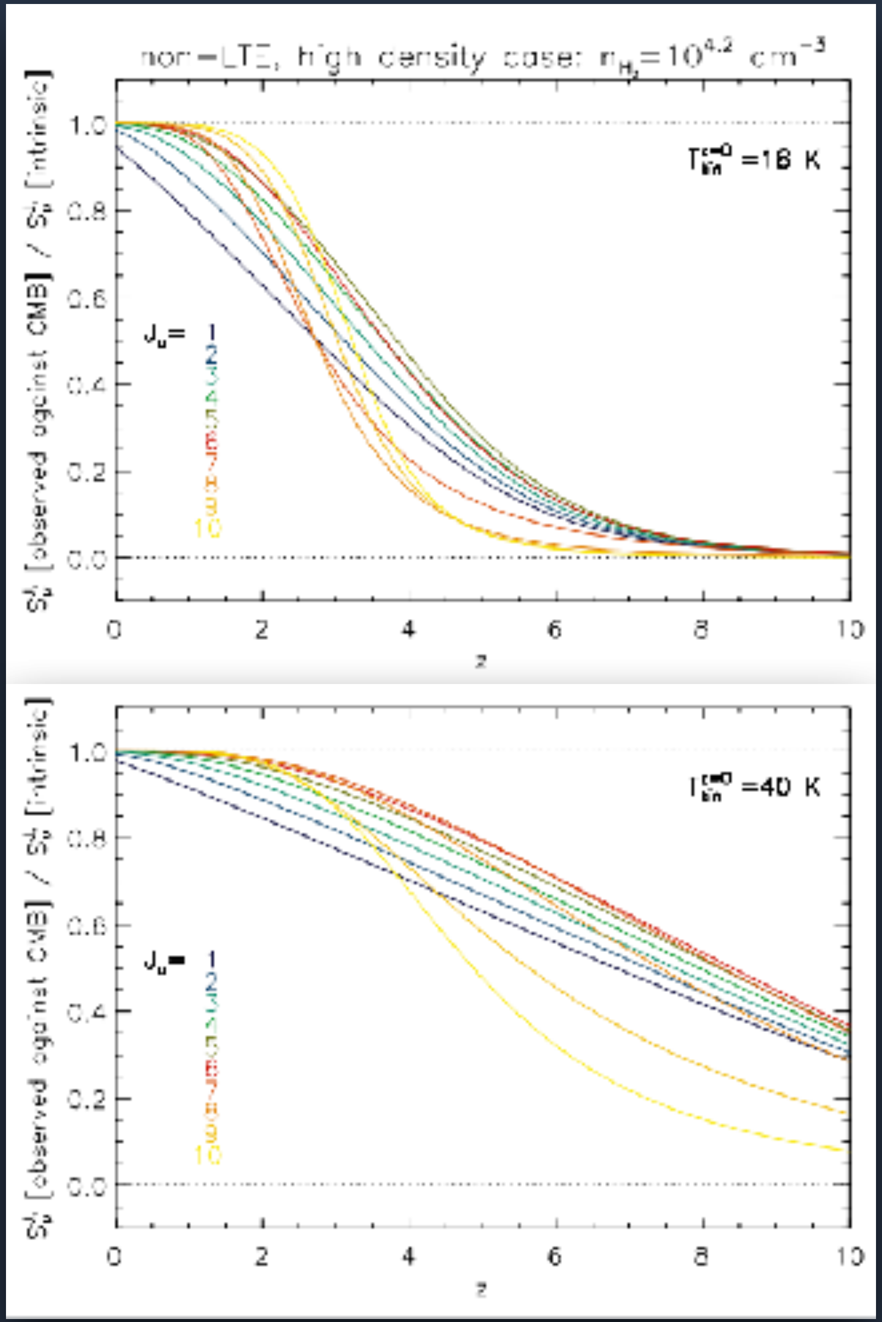


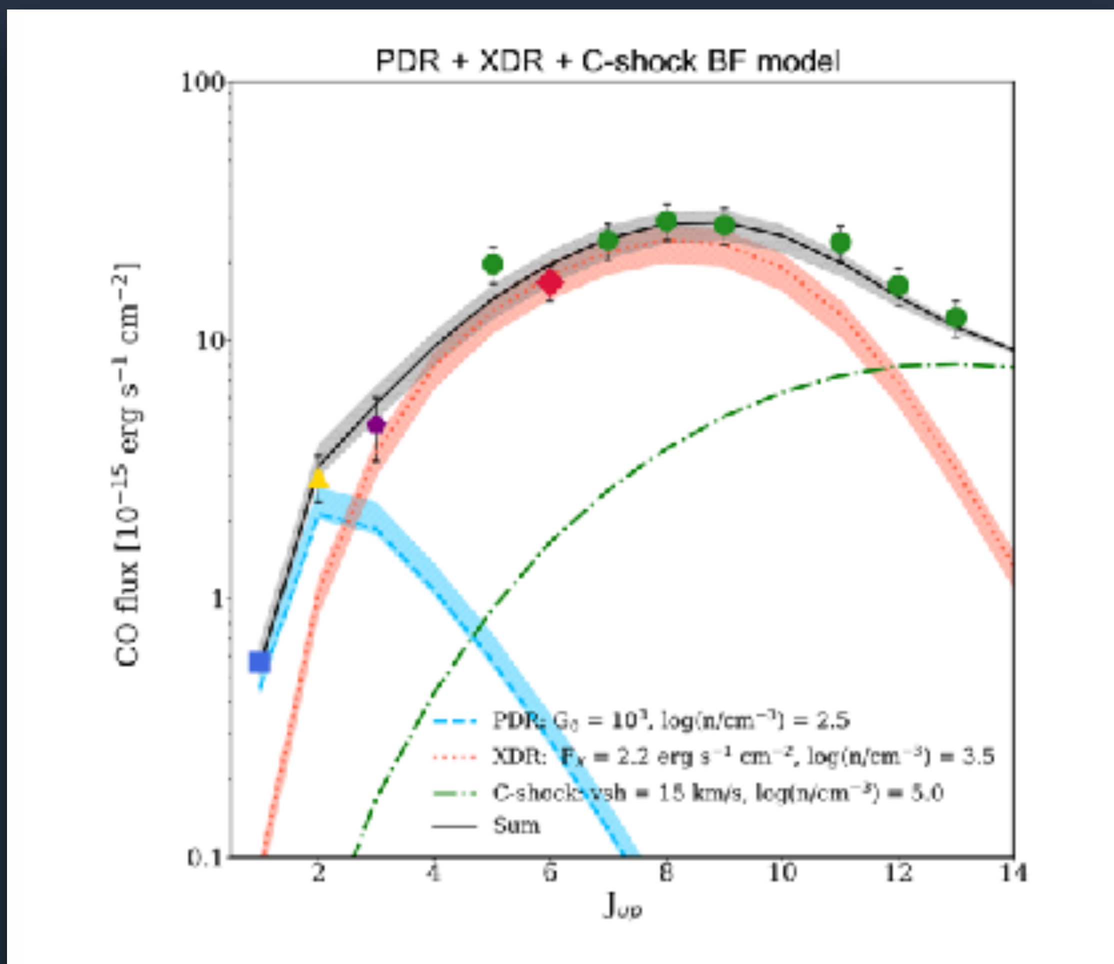
Da Cunha+2013

Caveat: shocks and/or X-rays might influence the shape of the CO SLED

EXAMPLES IN THE LOCAL UNIVERSE

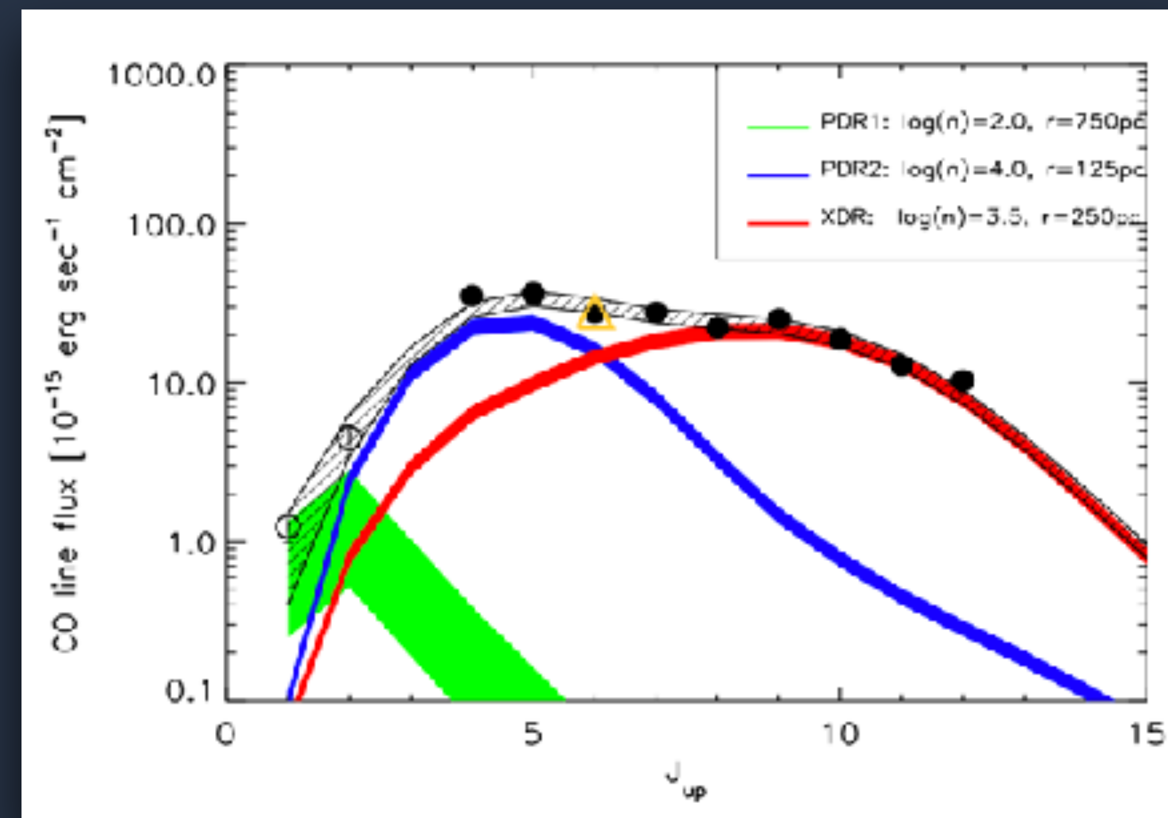
Caveat: shocks and/or X-rays might influence the shape of the CO SLED

NGC 34



Mingozzi,LV+2018

NGC 7130



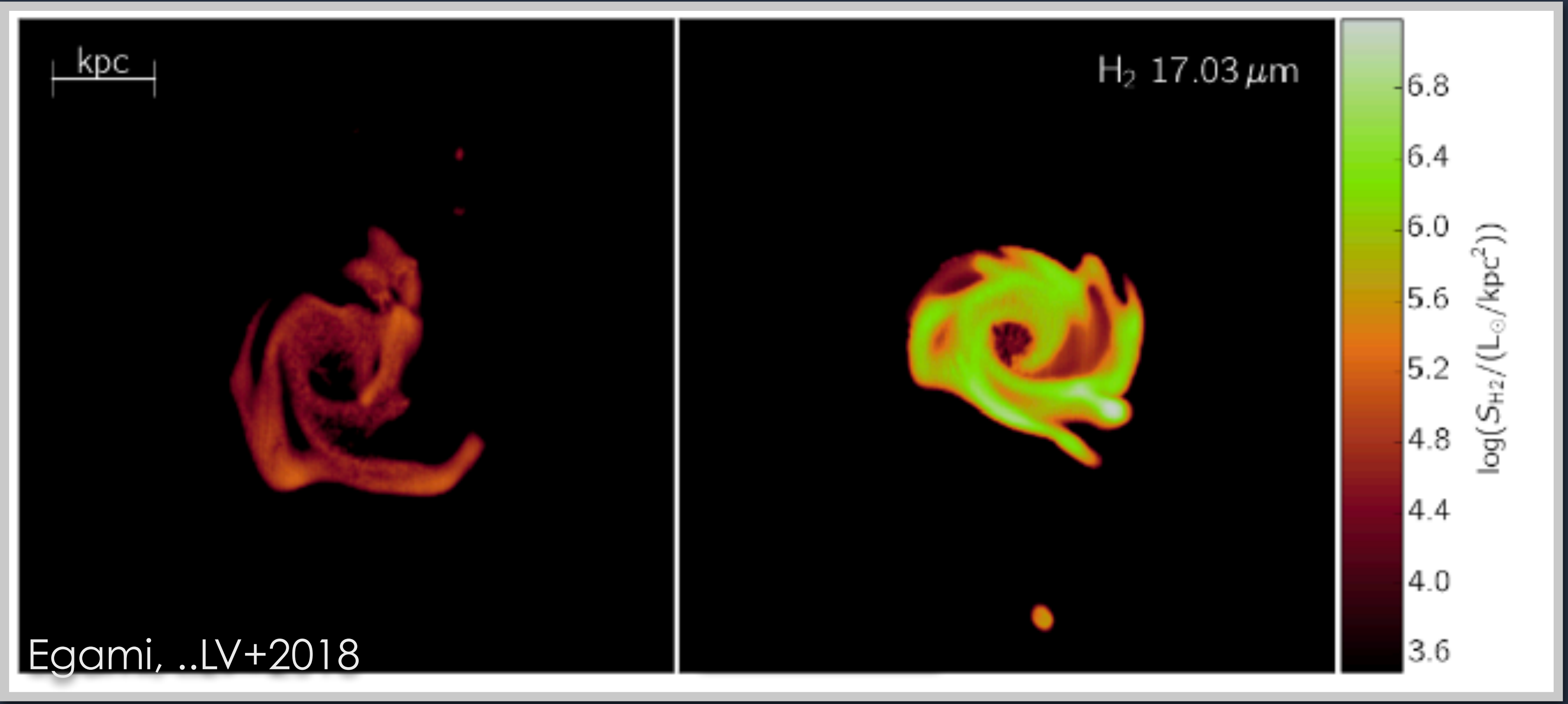
Pozzi,LV+2017

H_2 ROTATIONAL LINES: A SHOCK TRACER

Shocks are luminous sources of H_2 vibrational/ro-vibrational lines whose excitation temperature (T~500 K-3000 K) is much higher than that of CO lines

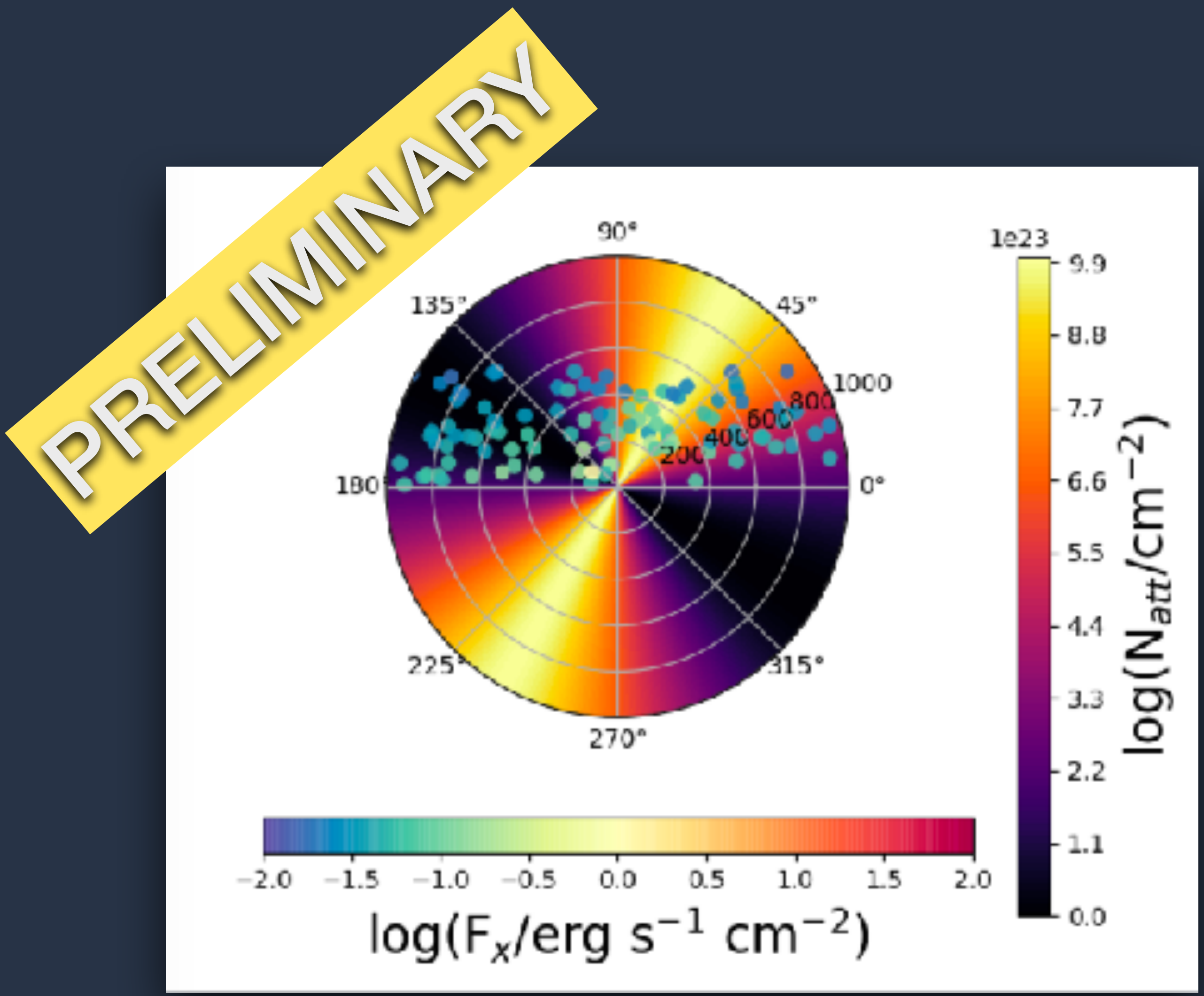
For a wide range of shock conditions, H_2 molecules are not dissociated, and the gas becomes warm enough for lines to be excited by collisions.

H_2 line emission produced by transitions between two rotational energy states (J=3->1) in the ground electronic vibrational level (v=0)
0–0 S(1) (v = 0 → 0; J = 3 → 1) at 17 μm.



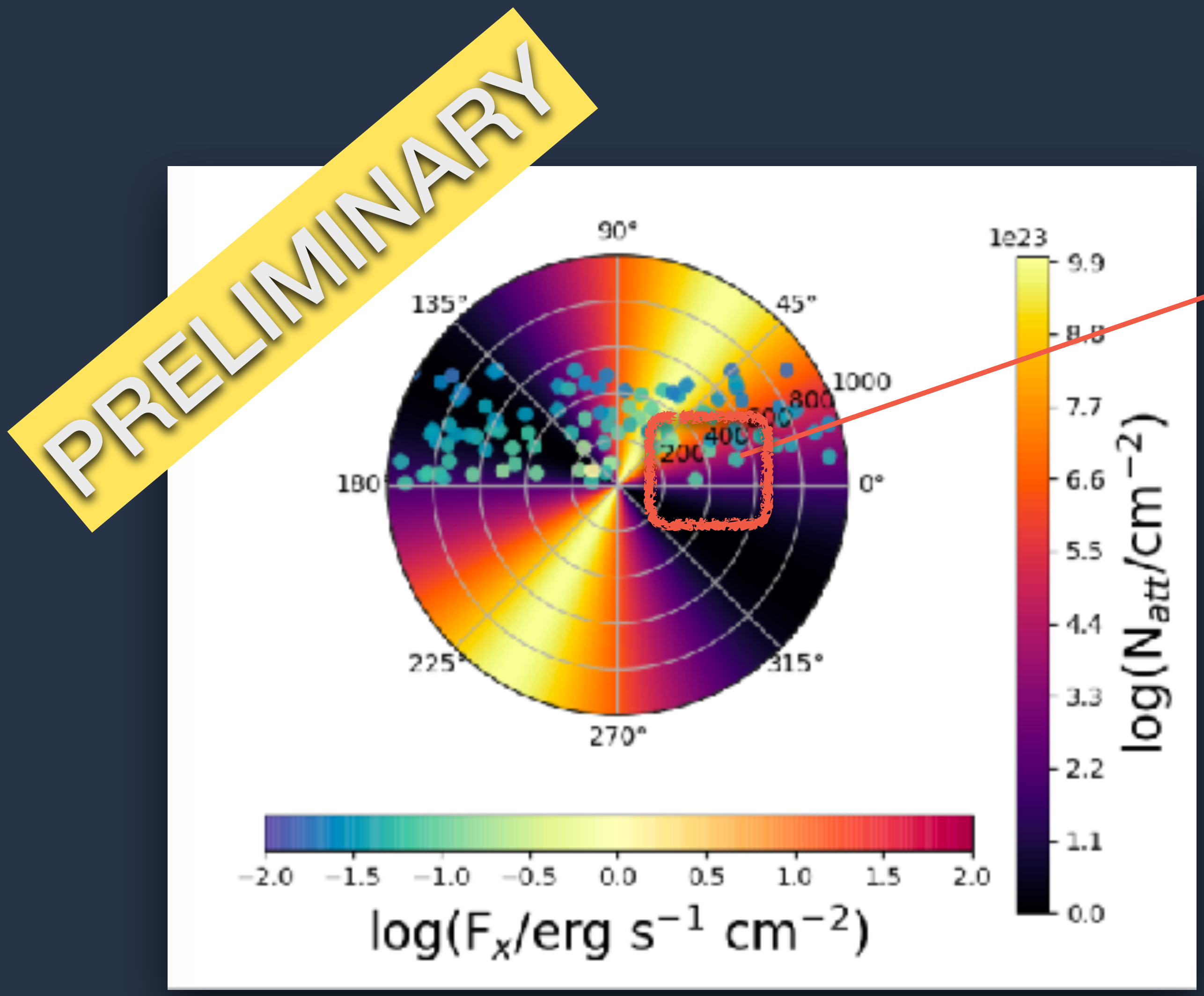
In the SPICA bands from high-z

THE EFFECT OF THE X-RAYS ON THE CO EXCITATION

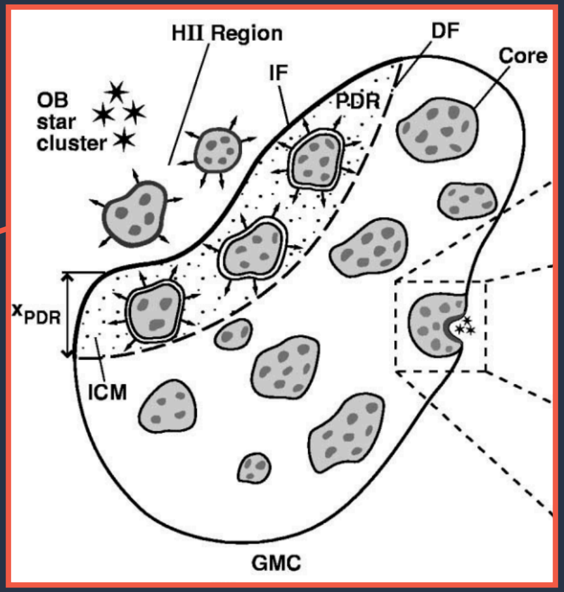


Vallini, Tielens+2019 in prep

THE EFFECT OF THE X-RAYS ON THE CO EXCITATION

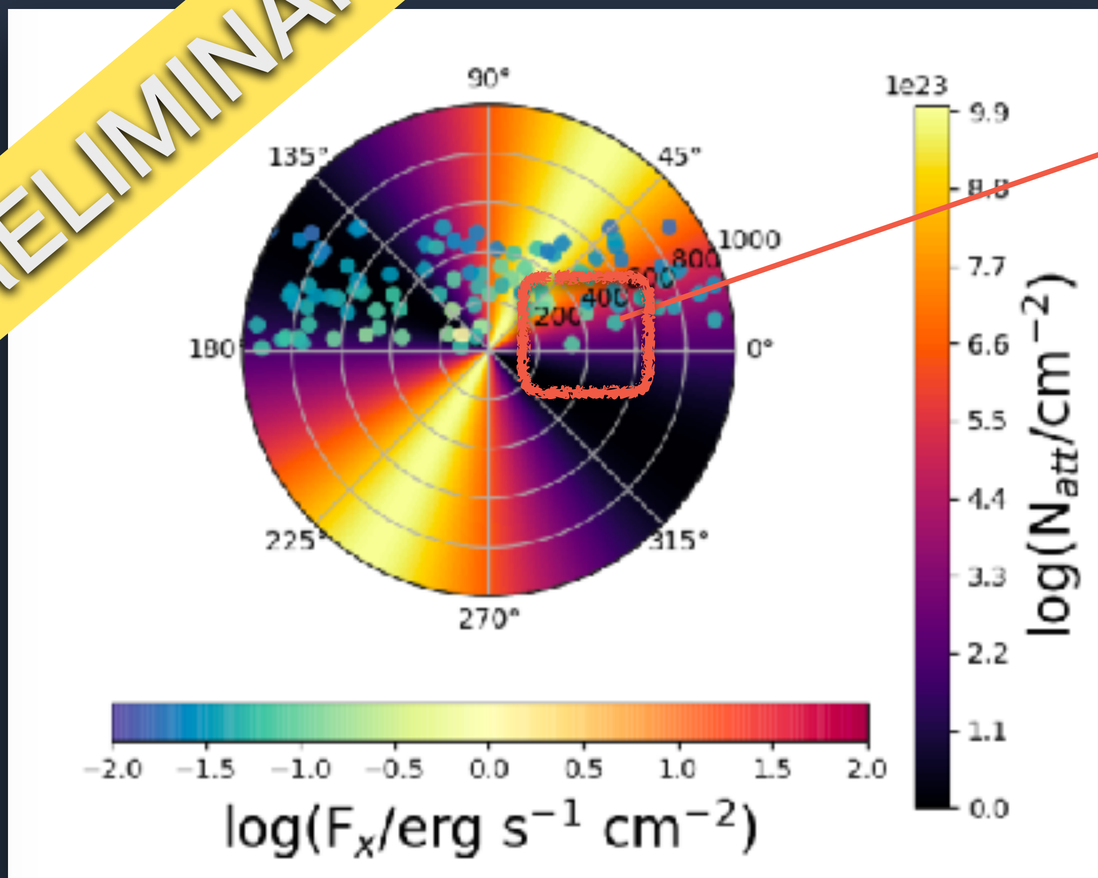


Vallini, Tielens+2019 in prep

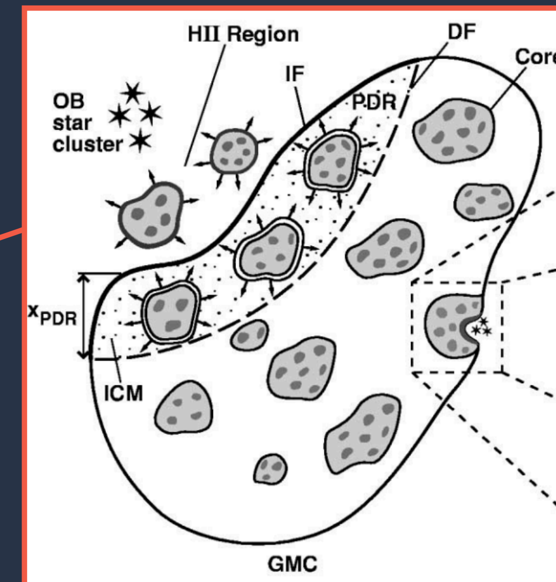


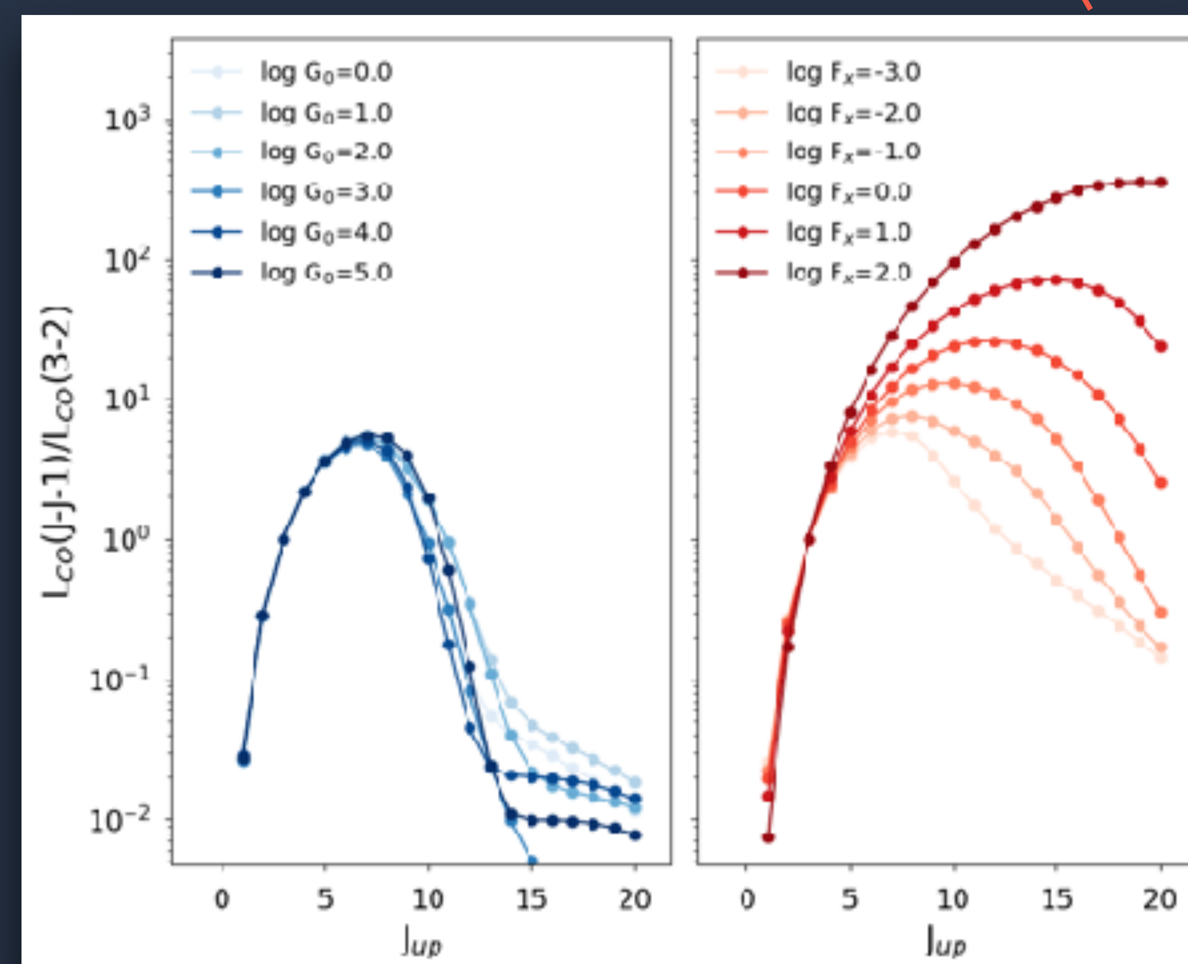
THE EFFECT OF THE X-RAYS ON THE CO EXCITATION

PRELIMINARY



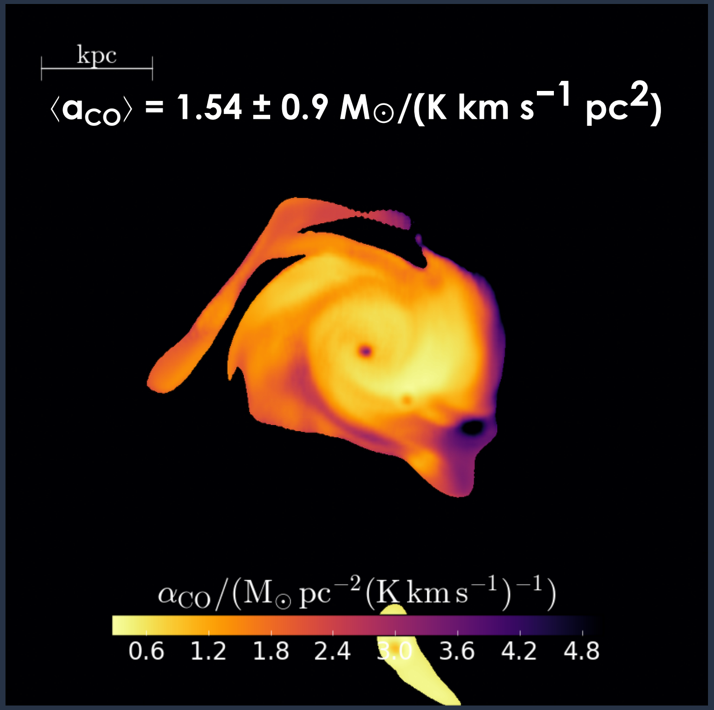
Vallini, Tielens+2019 in prep





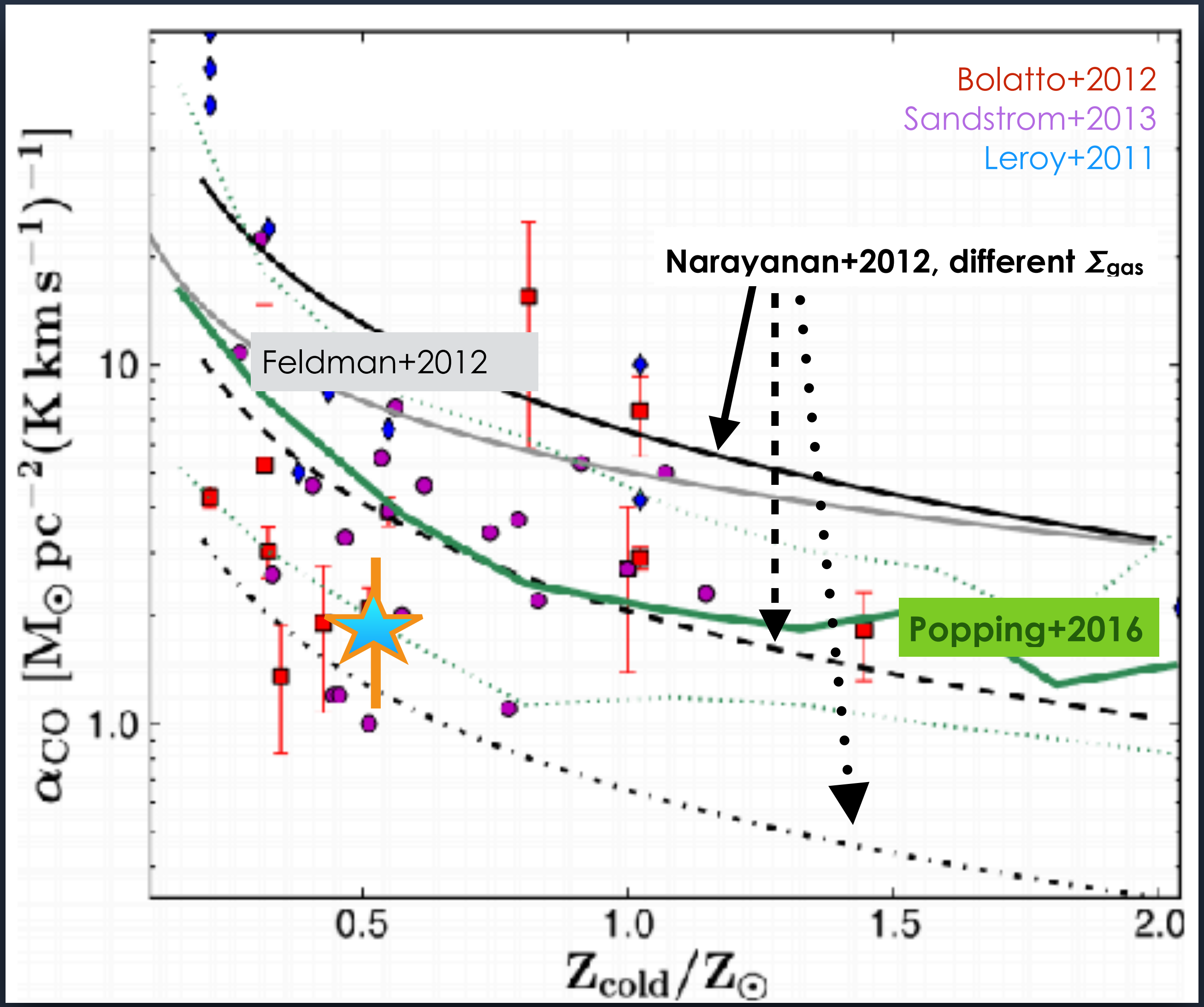
THE CO-to-H_2 CONVERSION FACTOR

The CO-to-H2 conversion factor:



Vallini+2018

Popping+2016



- little spatial variation throughout the disk.
- dispersion is primarily introduced by density variations in the disk.

CONCLUSIONS

- [CII] line emission influenced by CMB, photoevaporation and metallicity.
- CO line emission at high-z boosted by high surface density, and the high turbulence.
- Differential effect of CMB background on the observed luminosity of the various CO lines (low-J lines more affected)
- High-J CO lines can be detected with ALMA from z~6-7 galaxies in ~20 hours.
- If there are shocks and/or X-ray, the CO SLED is more excited and thus the detection could be much easier.

SPICA-ALMA SINERGIES

H_2 line detection with SPICA might help in understanding the importance of shocked molecular gas in galaxies at high-z.