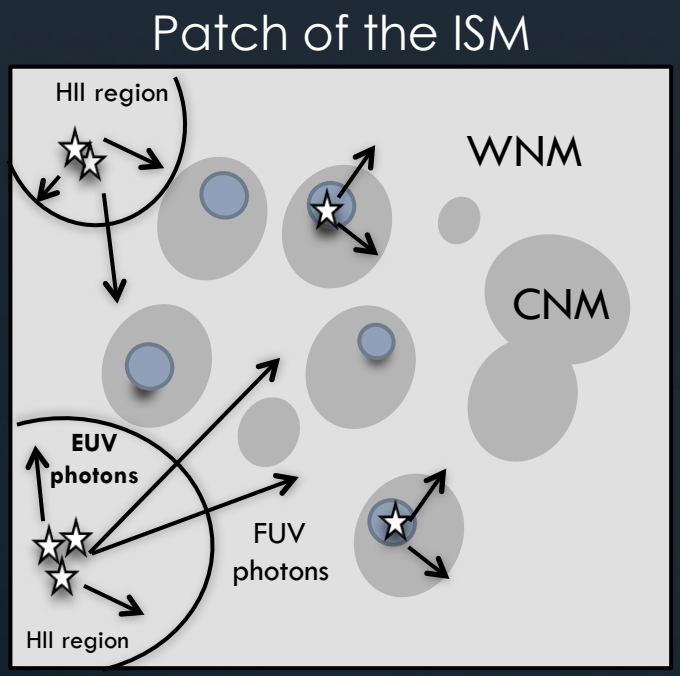
FIR line emission from the ISM of high-z galaxies

Livia Vallini – University of Bologna/INAF - OABo

Lunch Talk – The Cold Universe 2016

Motivation: why FIR lines



cold neutral medium (CNM)

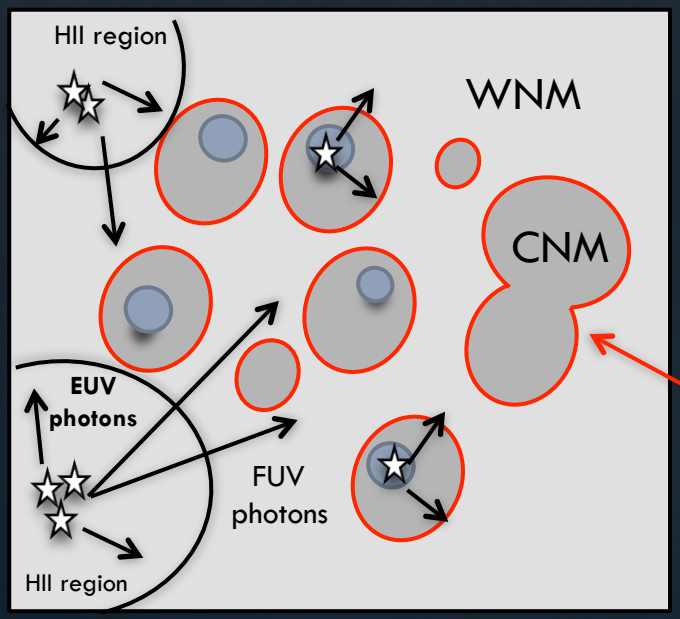
warm neutral medium (WNM)

} diffuse neutral gas

molecular clouds (MCs)

Motivation: why FIR lines

Patch of the ISM



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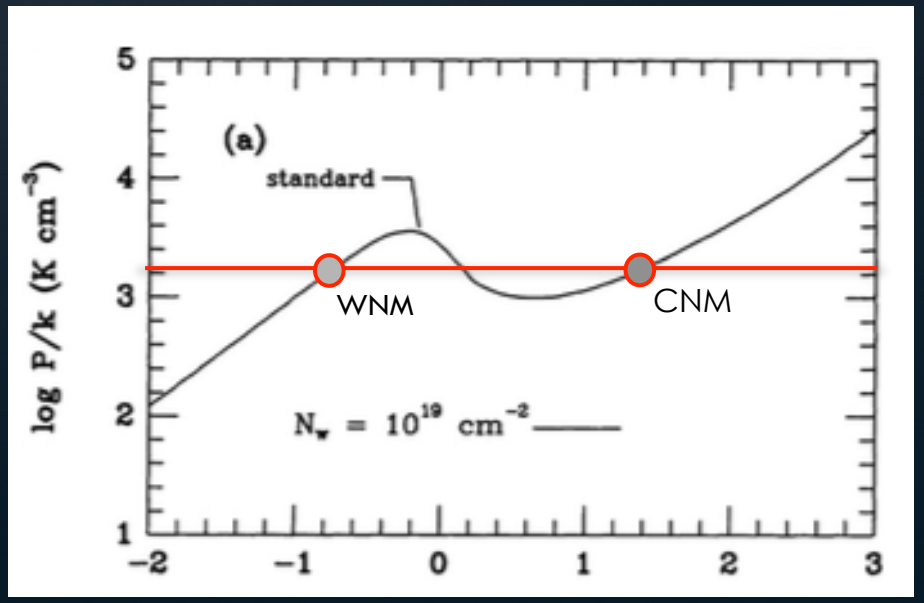
Pressure equilibrium



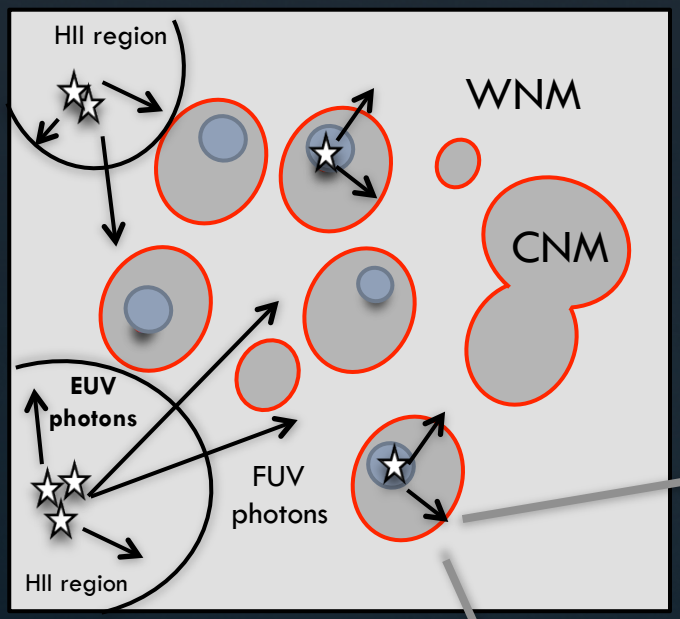
Wolfire+1995,2003

Heating: photoelectric effect on dust grains, cosmic rays, x-rays

Cooling: fine-structure line of metals, molecular lines, recombination on dust

Motivation: why FIR lines

Patch of the ISM



cold neutral medium (CNM)

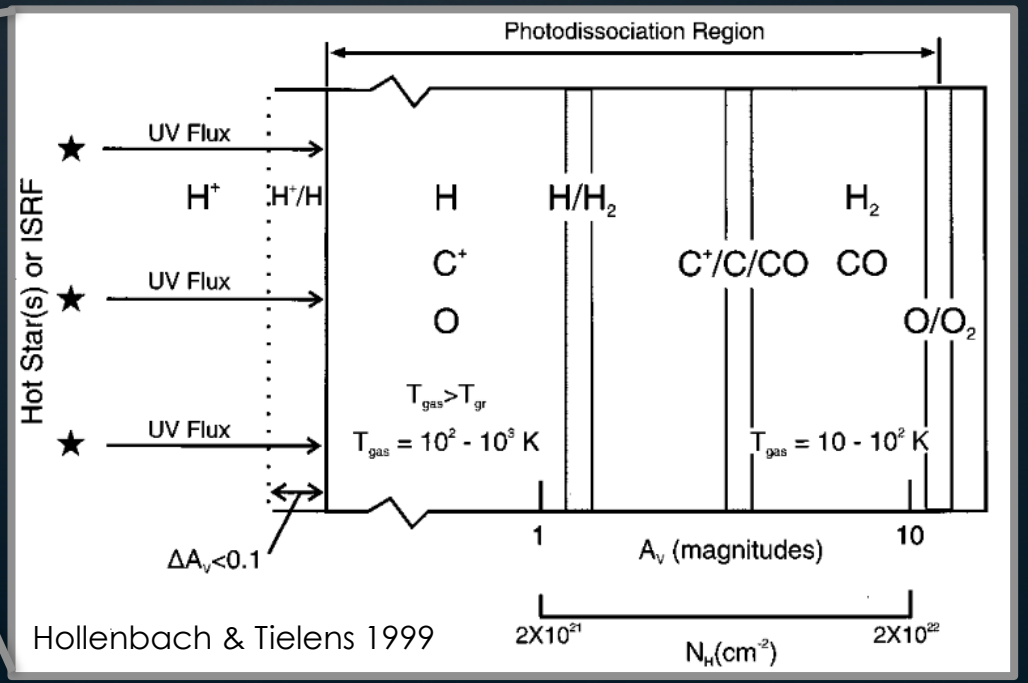
warm neutral medium (WNM)

} diffuse neutral gas

molecular clouds (MCs)

FIR metal (and molecular) lines are excellent proxies of:

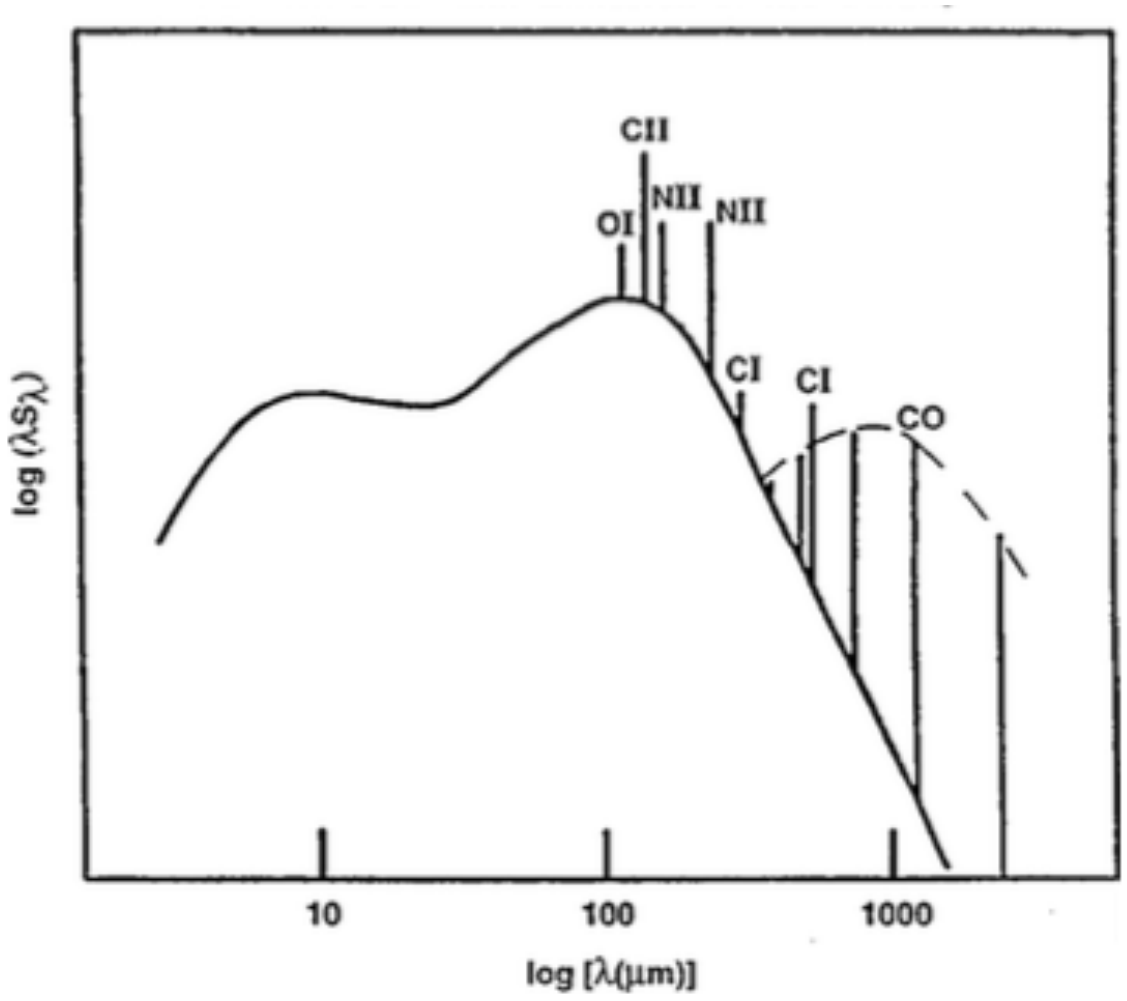
- the gas density
- the relative abundance of different gas phases
- the EUV/FUV photons flux
- the gas metallicity



Hollenbach & Tielens 1999

Motivation: why FIR lines

COBE observation of the far-infrared spectrum of our Milky Way

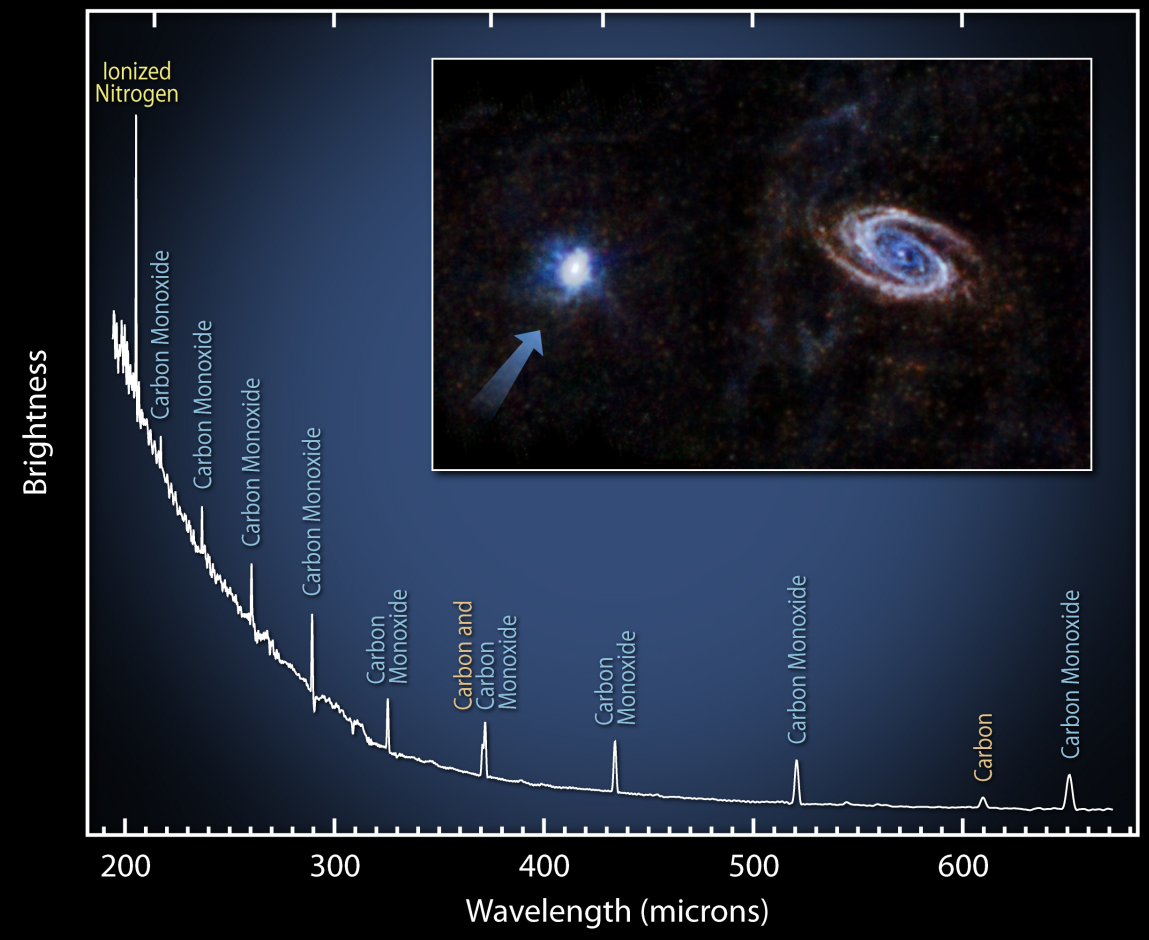


Hollenbach & Tielens 1999, adapted from Wright+1991

Motivation: why FIR lines

COBE observation of the far-infrared spectrum of our Milky Way

Herschel observation of the far-infrared spectrum of M82



Messier 82

Motivation: why FIR lines

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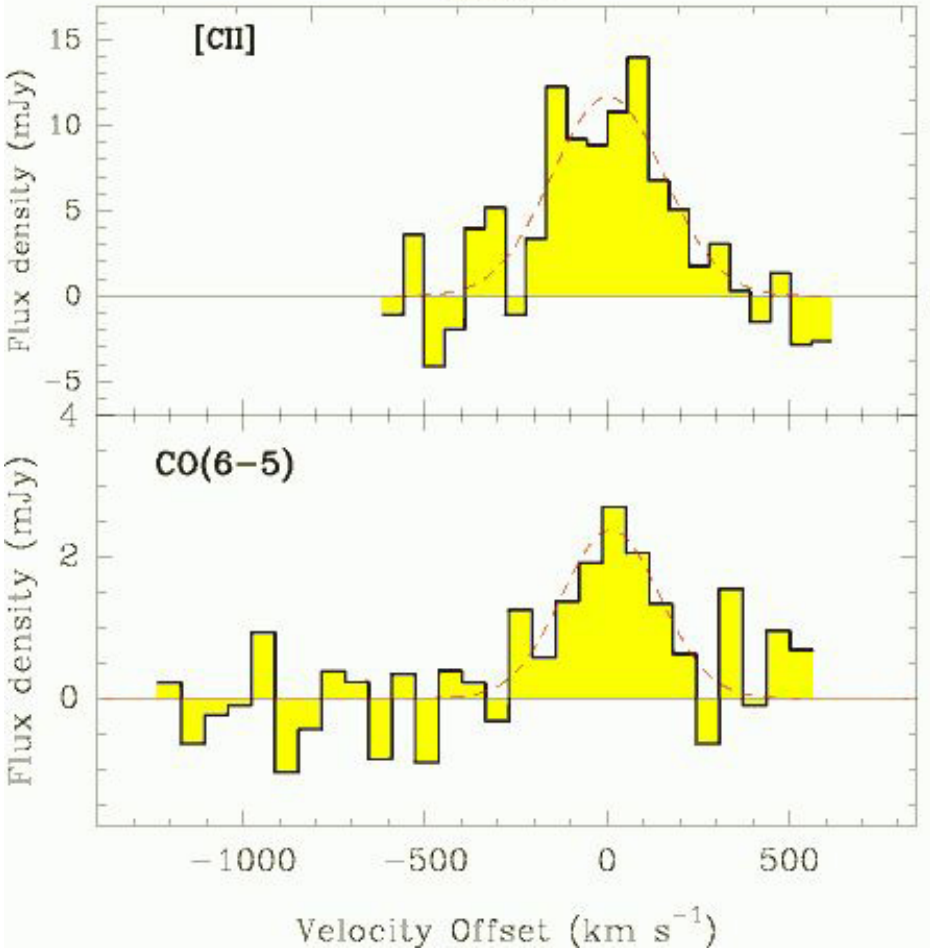
First [CII] detection at high-z in the quasar J1148 at z=6.6



Maiolino+2005

Motivation: why FIR lines

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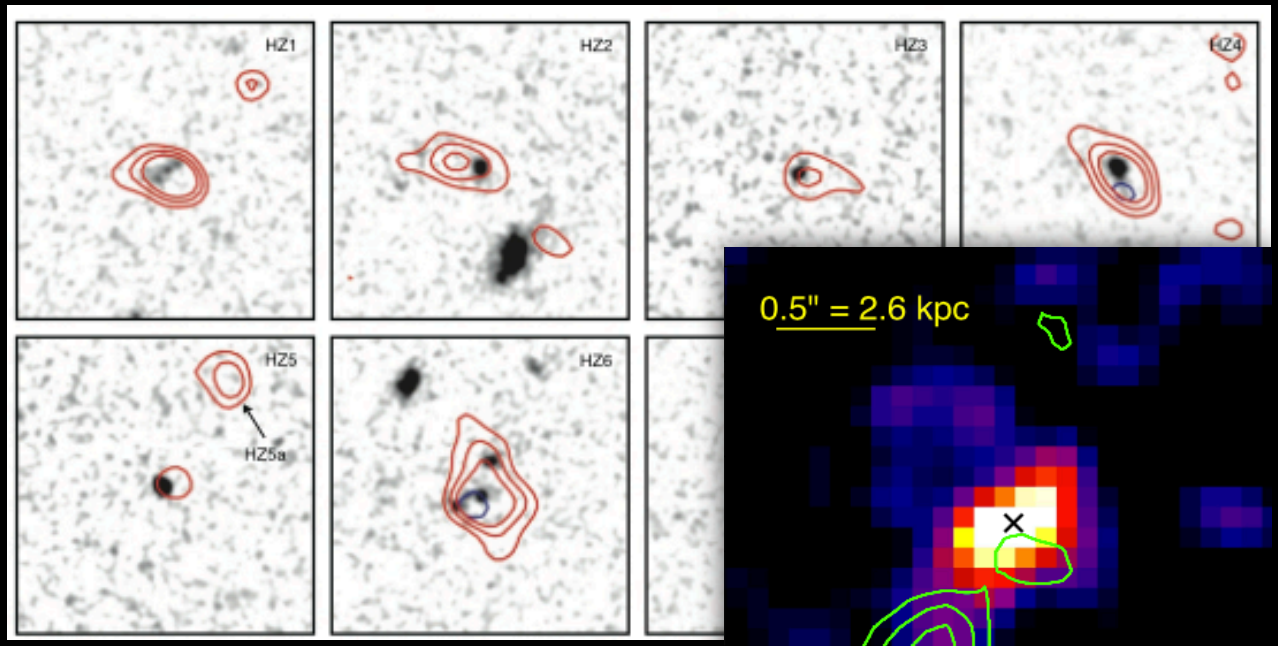
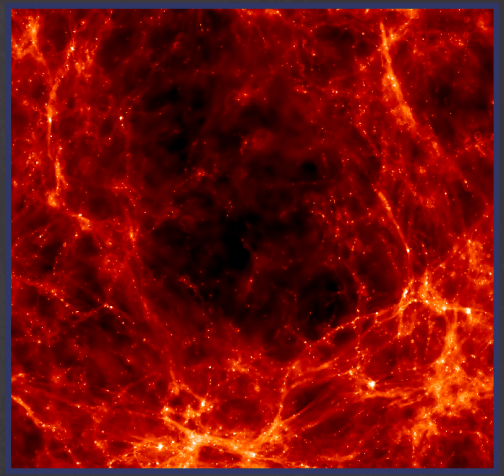
ALMA [CII] detections in z>6 normal star forming galaxies



Capak+2015, Nature

Maiolino, Carniani, Fontana, LV+2015

Outline of the work



cosmological simulations

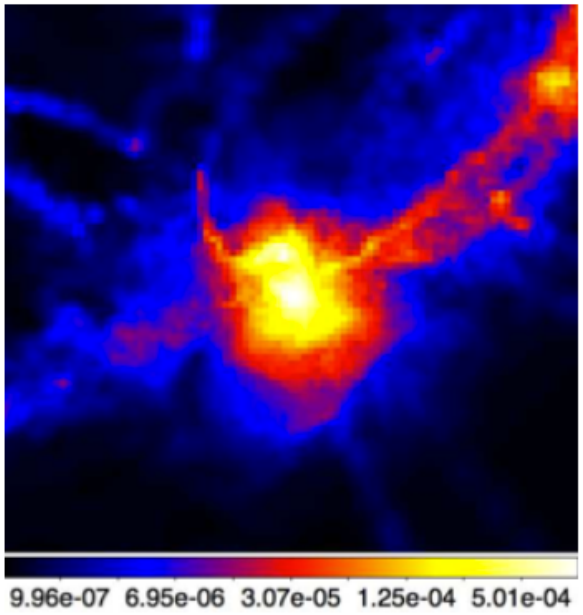
Sub-grid models describing physical processes that take place in the ISM and MCs

far infrared lines luminosity and their observability

observations

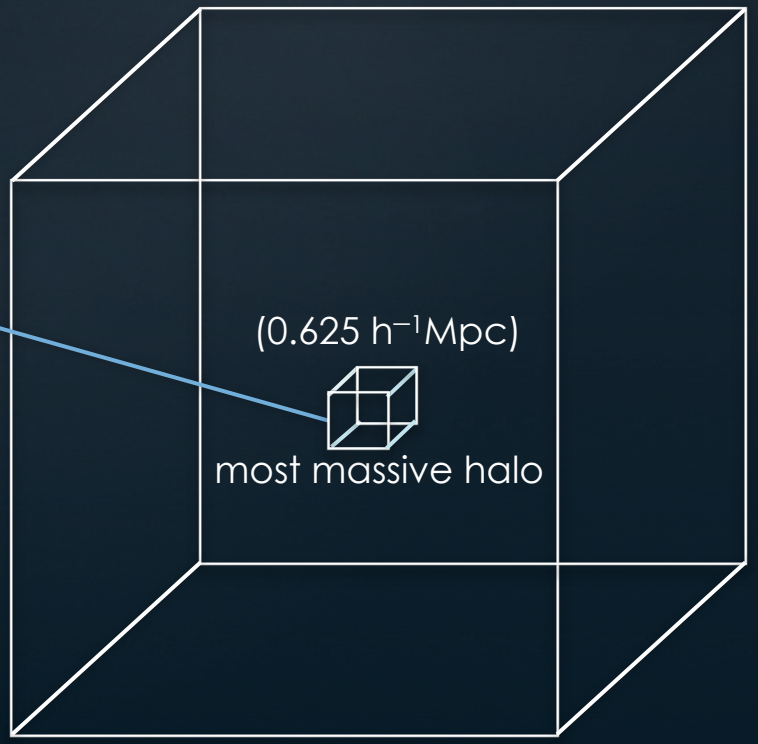
High resolution simulation

gas density [cm^{-3}]



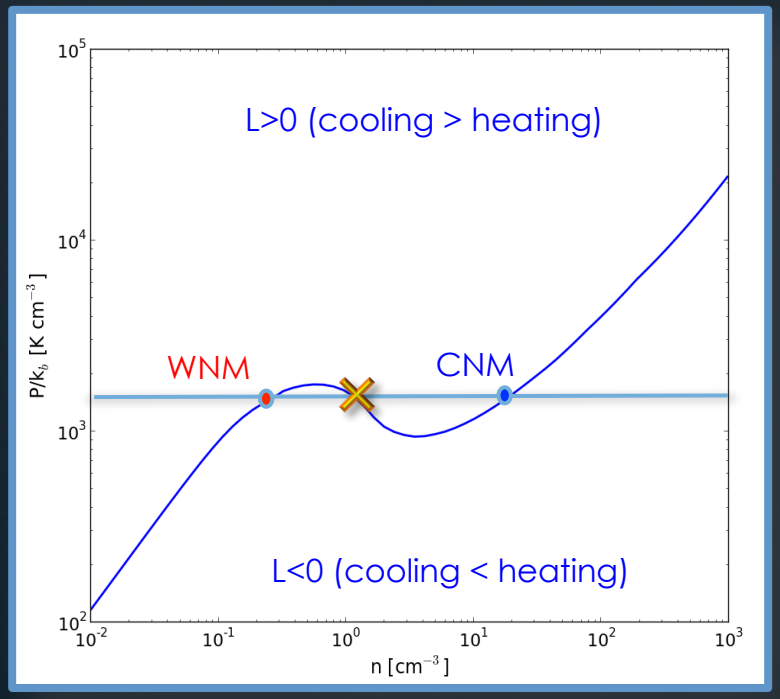
$M_h = 1.17 \times 10^{11} M_\odot$
$M_g = 2 \times 10^{10} M_\odot$
$r_{vir} \approx 20$ kpc

Baek+2012



Radiative transfer by considering
SFR and Z derived from observations

Thermal equilibrium of the neutral ISM

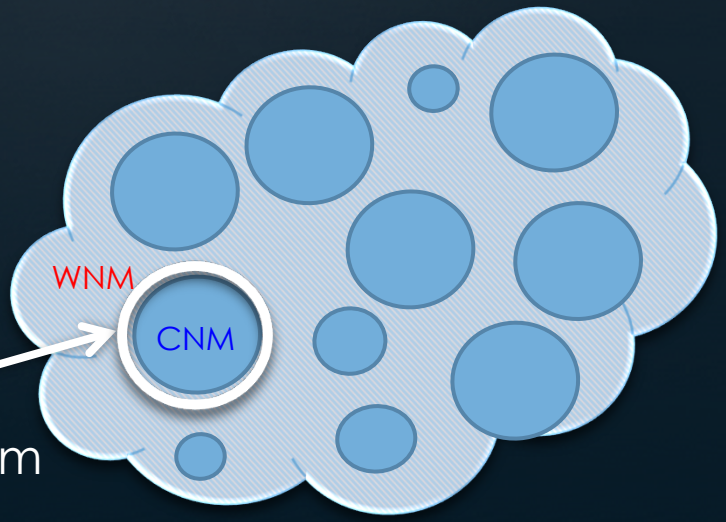


See also: Wolfire+2003

Cooling (Λ_{tot}) = Heating (Γ_{tot})

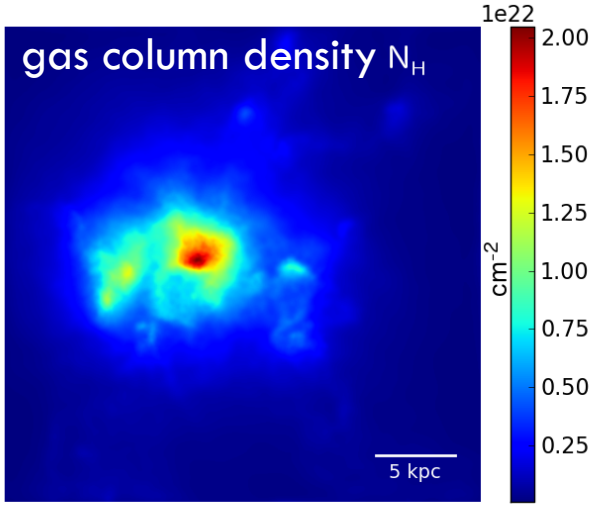
$$\mathcal{L}(n, T, x_e) = n^2\Lambda - n\Gamma = 0$$

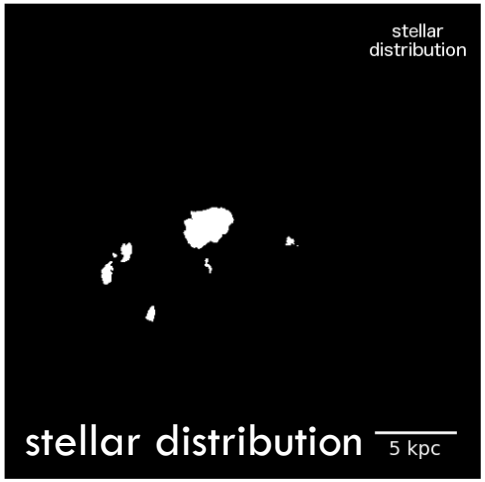
$$x_e = x_e(n, T)$$



pressure equilibrium
CNM ←→ WNM

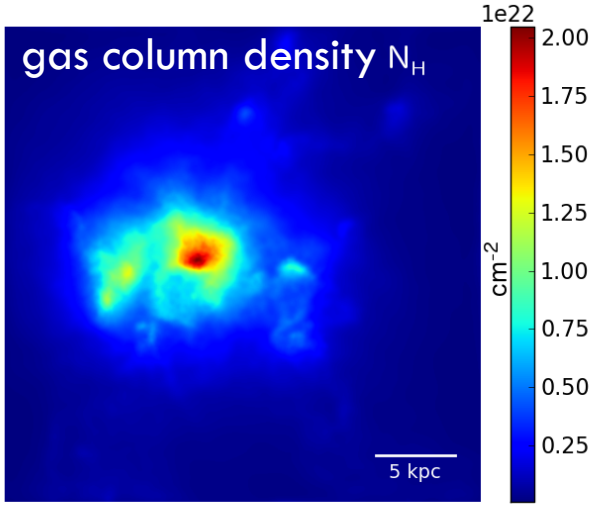
Warm and cold neutral medium distribution

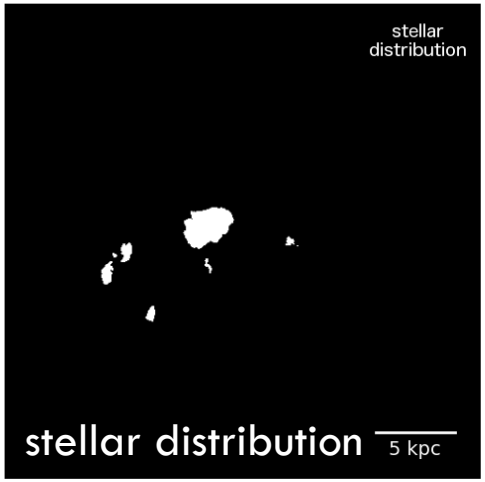


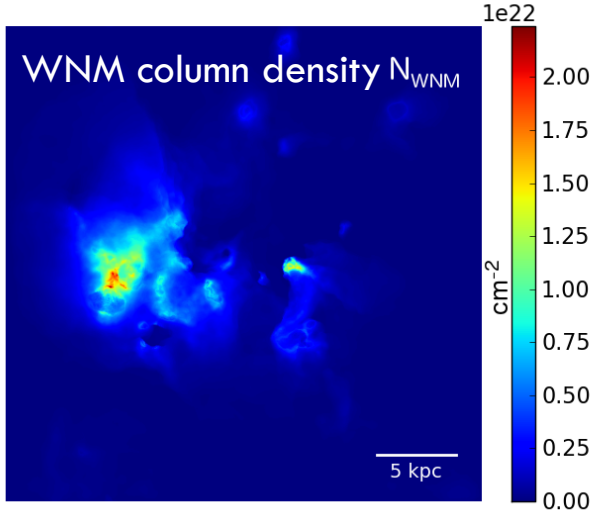


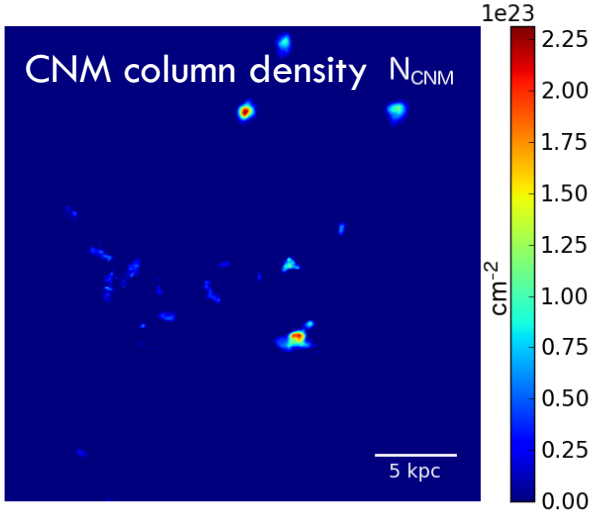
Vallini et al. (2013)

Warm and cold neutral medium distribution







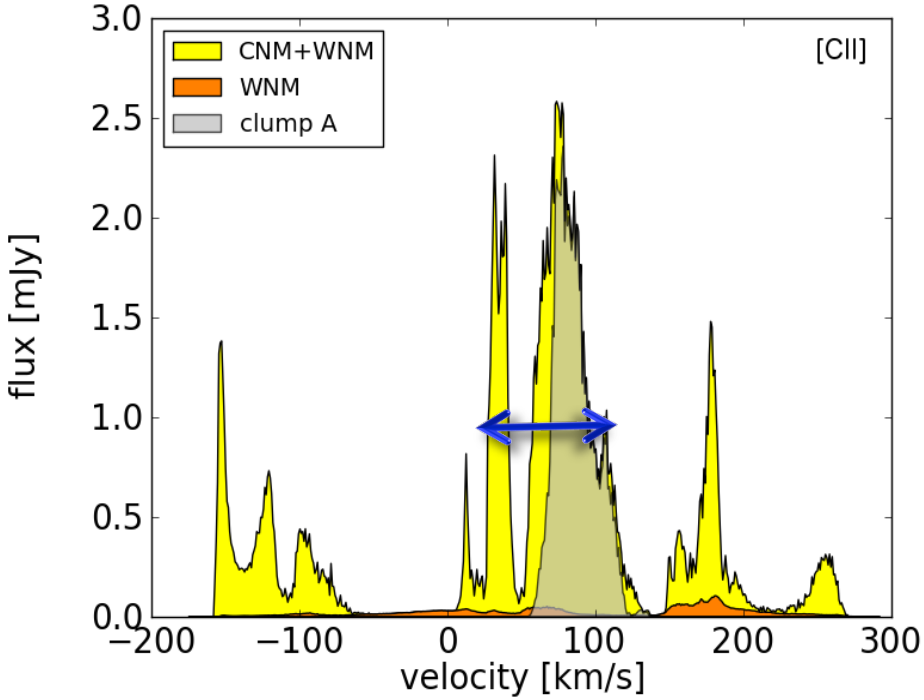


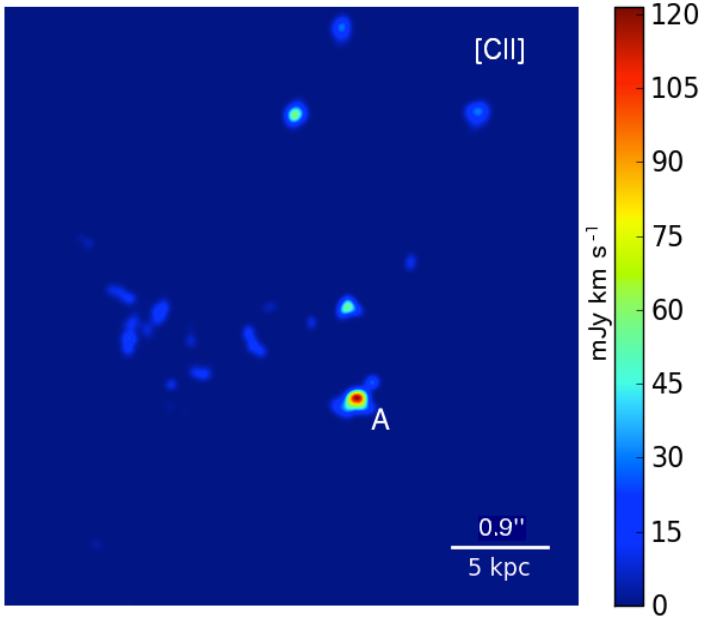
Vallini et al. (2013)

[CII] spectrum and map

[CII] emission

Vallini et al. (2013)





Linewidth: ~70 km/s

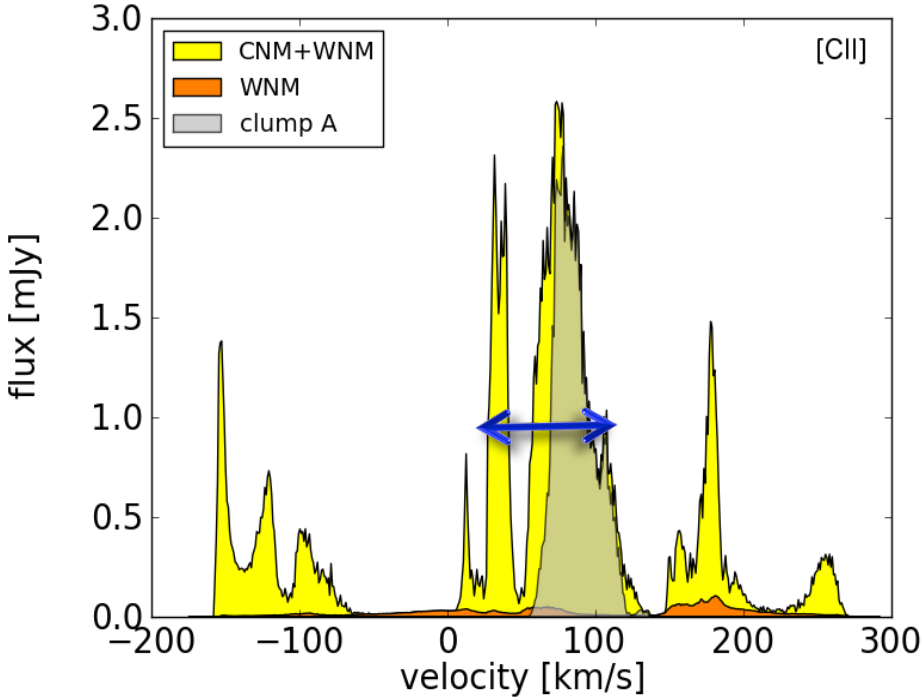
Velocity channels: ~1 km/s

[CII] spectrum and map

[CII] emission

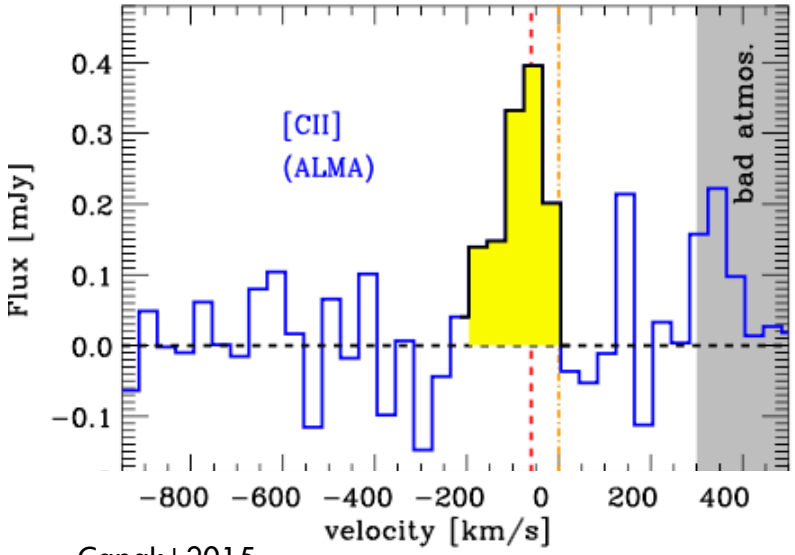
Vallini et al. (2013)

Simulated

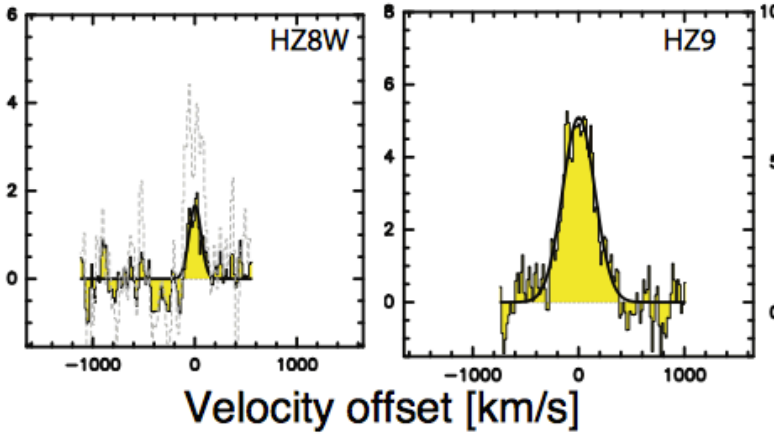


Observed

Maiolino+2015



Capak+2015



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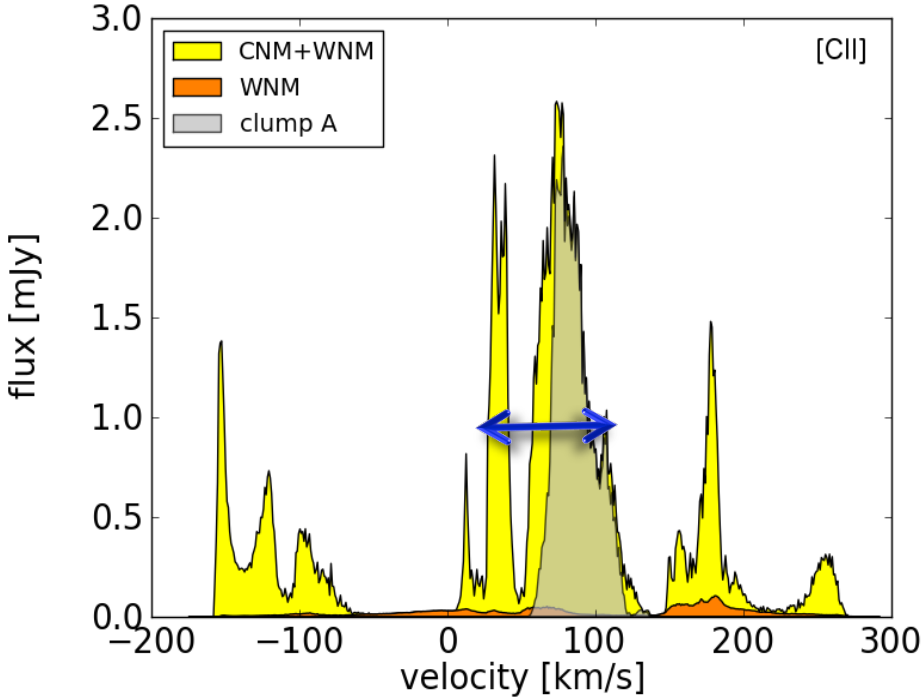

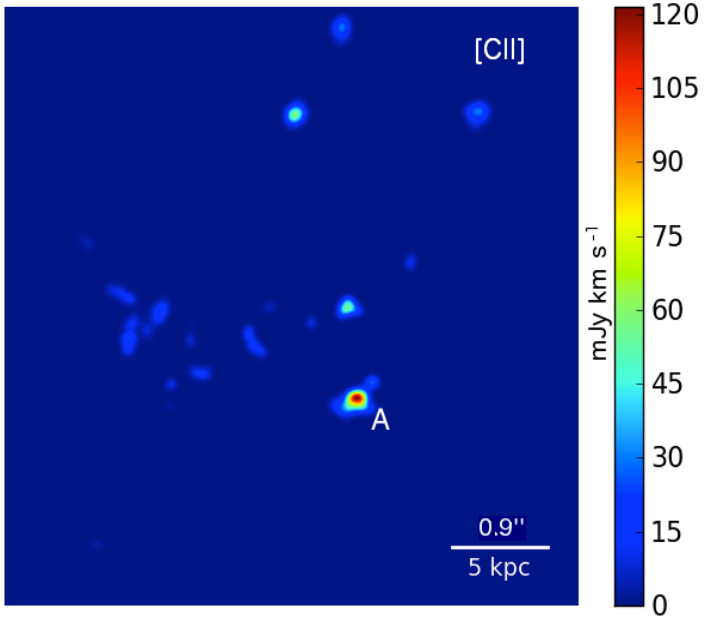

Linewidth: ~70 km/s

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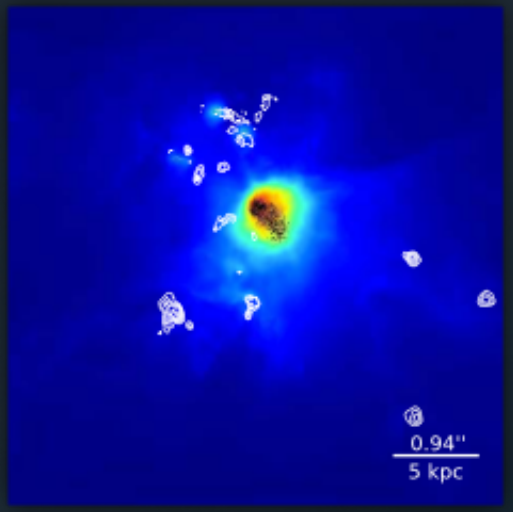
Interpreting observations

Maiolino, Carniani, Fontana, LV+2015



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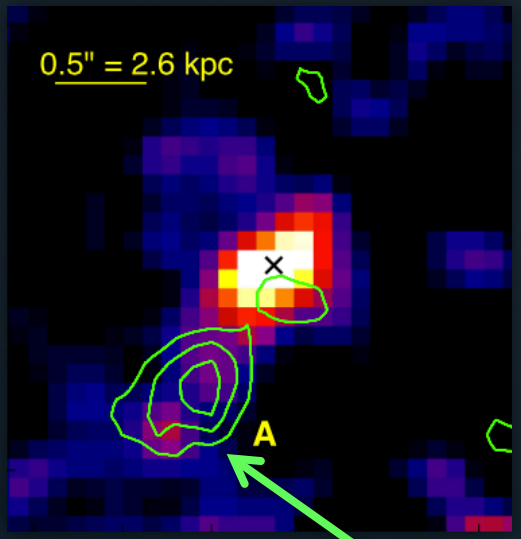
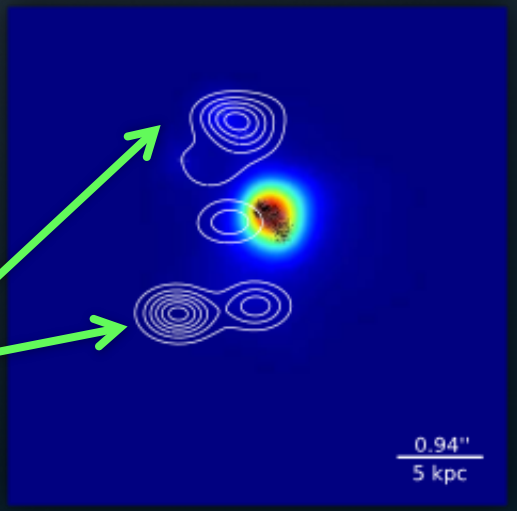


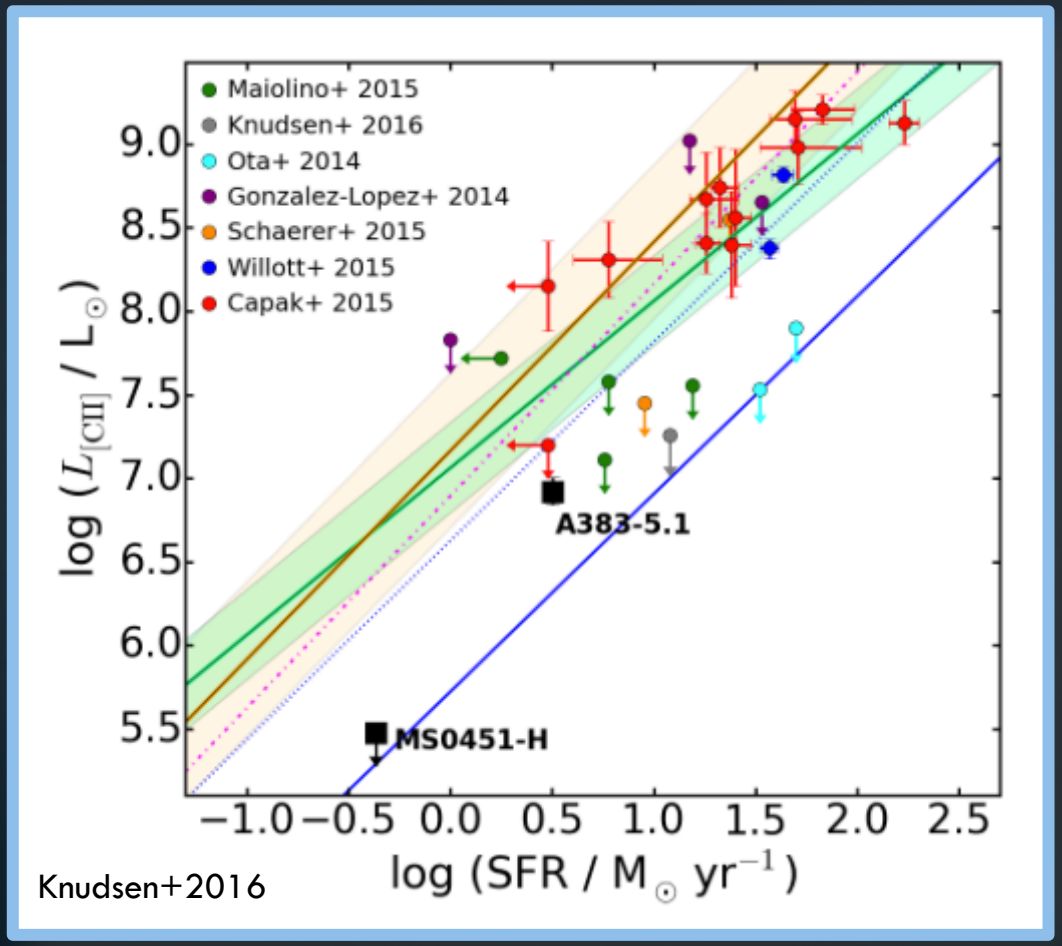
Observation

[CII] emission



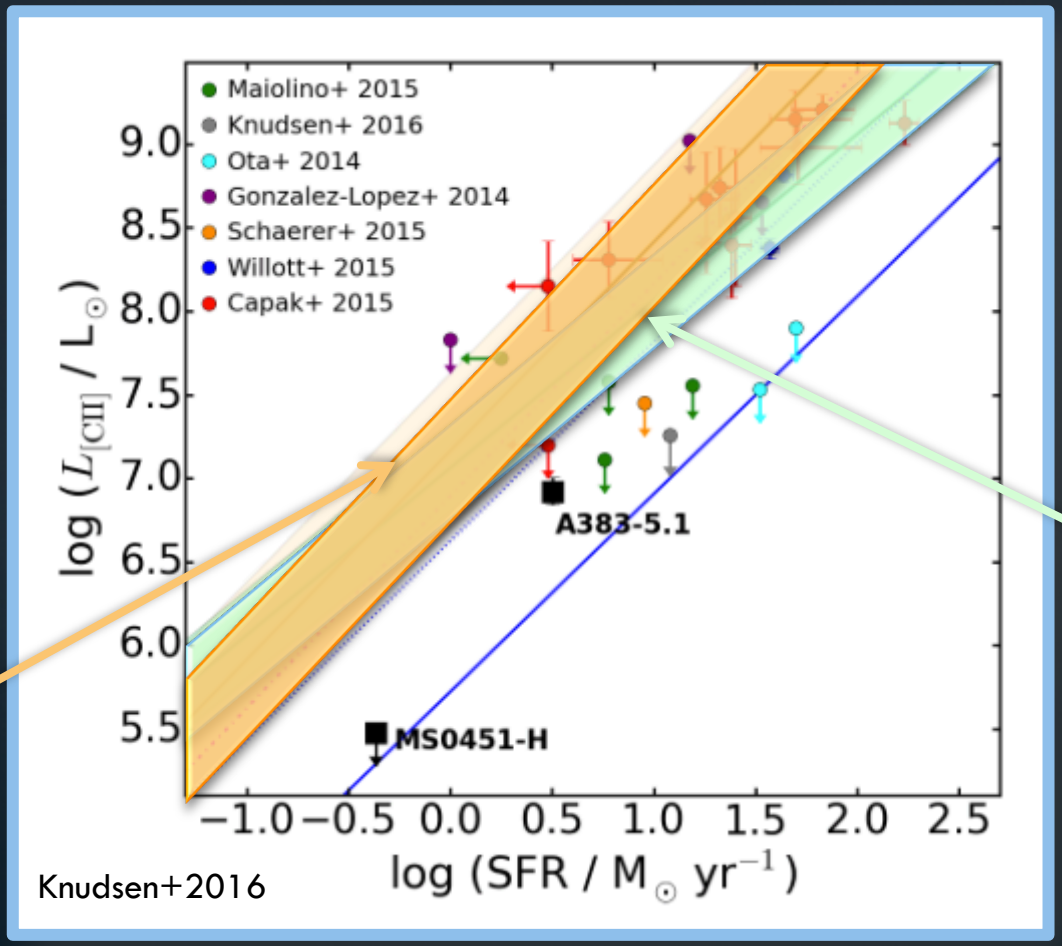
Simulation
(Vallini+2013)

The [CII]-SFR relation: open issue at high-z



Knudsen+2016

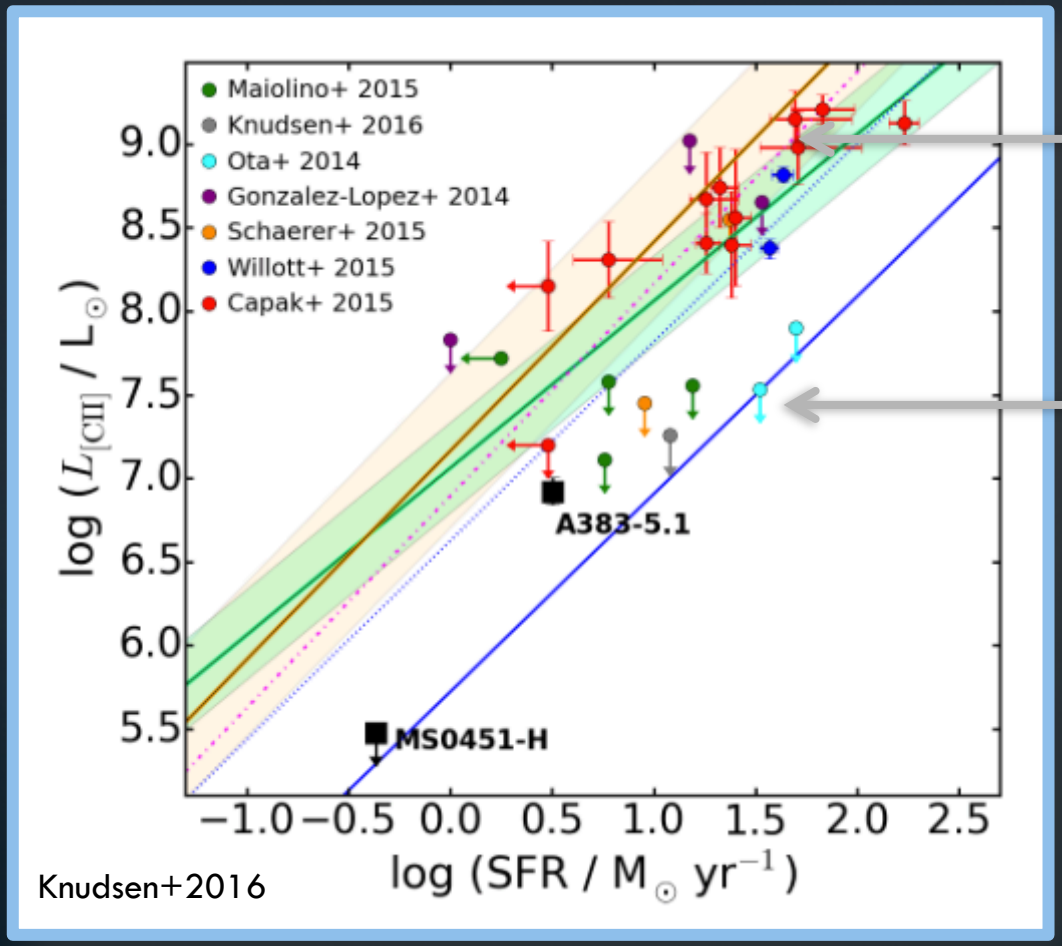
The [CII]-SFR relation: an open issue at high-z



dwarf galaxies
DeLooze+2014

local SB galaxies
DeLooze+2014

The [CII]-SFR relation: an open issue at high-z



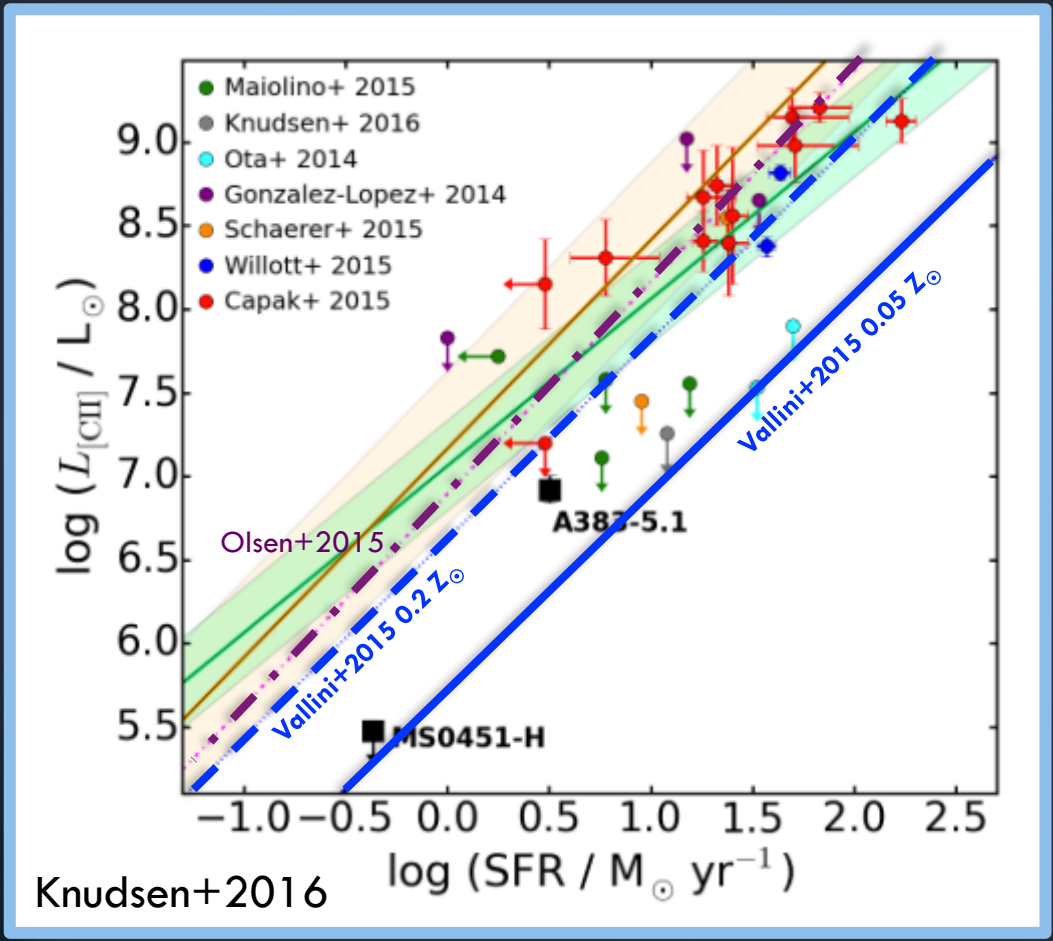
detections

?

upper limits

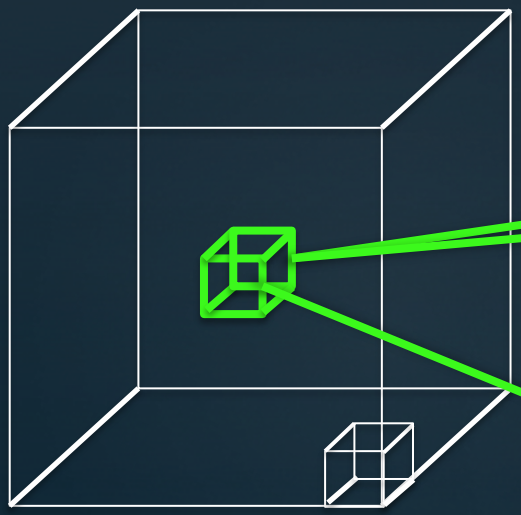
- What causes the deviation from the local [CII]-SFR relation?

The [CII]-SFR relation: an open issue at high-z



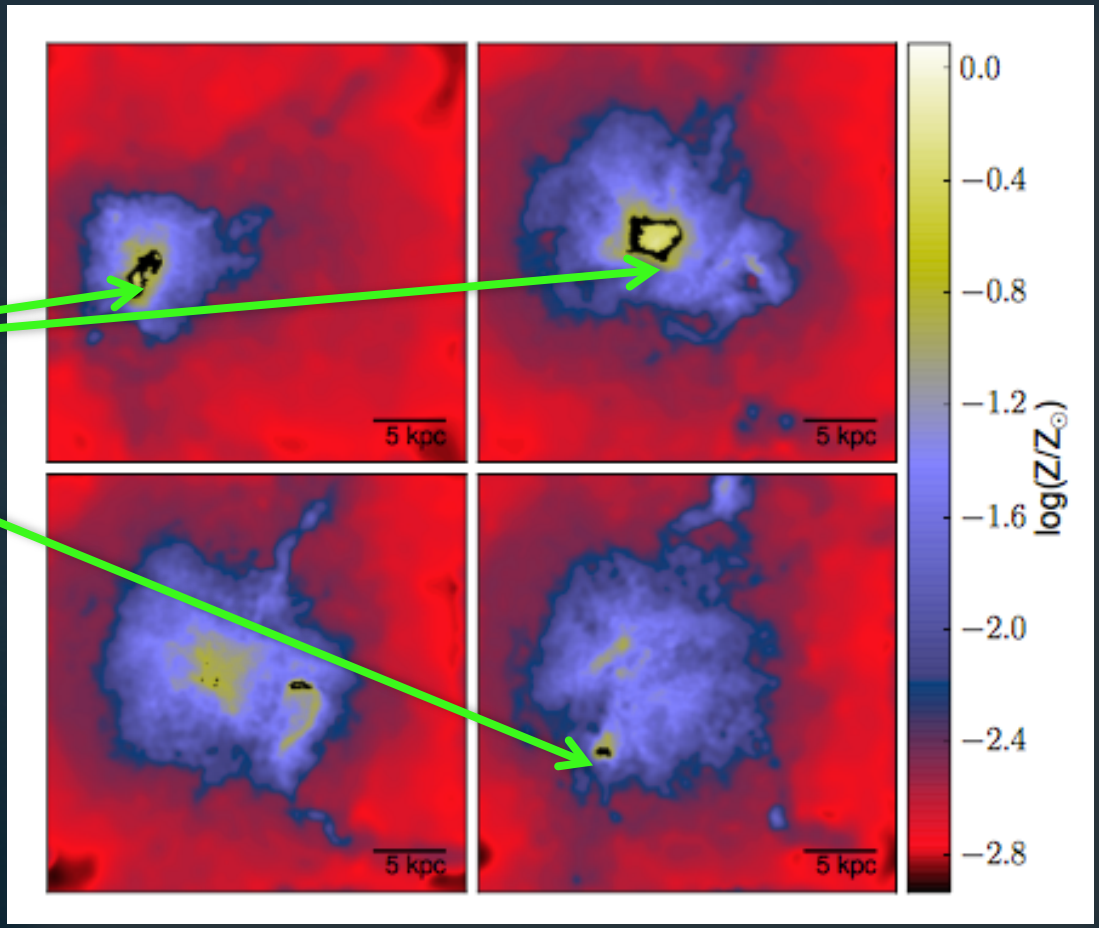
- What causes the deviation from the local [CII]-SFR relation?

Emission from the PDR



$M_{gas} > M_{Jeans}$

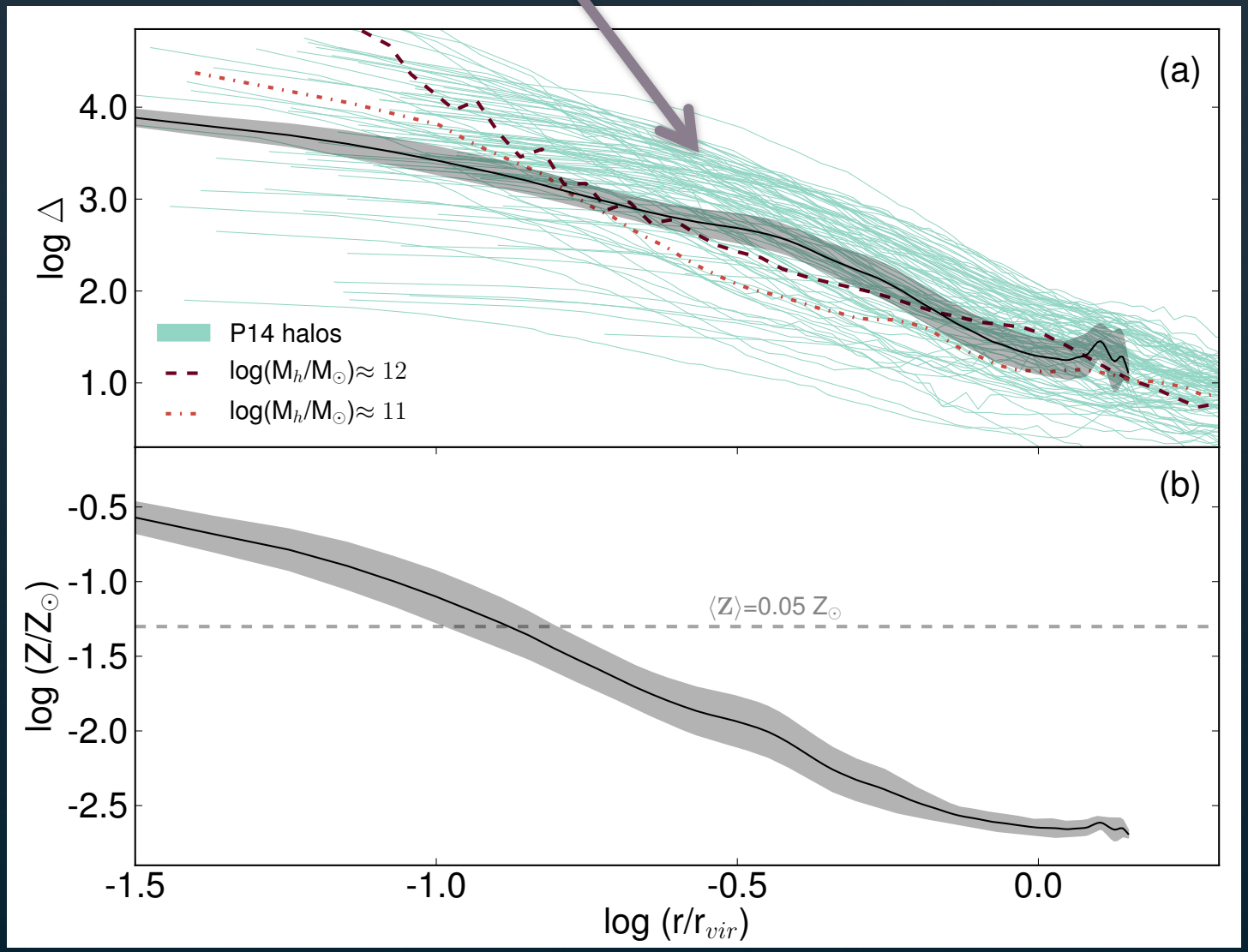
molecular clouds



Vallini+2015

Metallicity profile

Cosmological simulation of metal enrichment in high-z galaxies developed by Pallottini+2014



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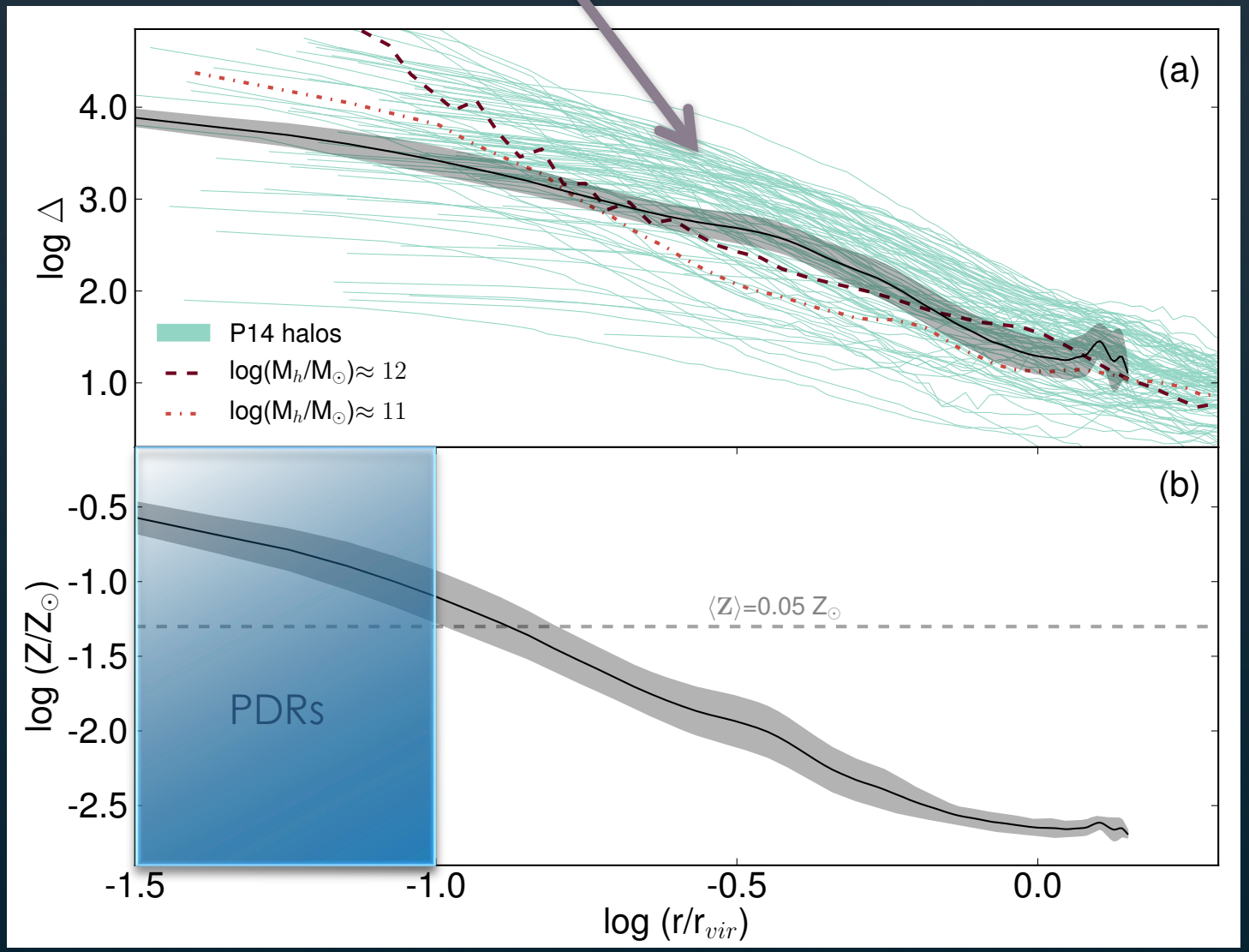


Vallini+2015

Effect of the increased CMB temperature

The T_{CMB} increases as (1+z) hence at high redshift it becomes a stronger background against which we observe the [CII] line.

If: T_{ex}([CII]) → T_{CMB} the fraction of the of the intrinsic line flux observed against the CMB radiation approaches to zero.

$$\zeta \equiv \frac{F_\nu^{\rm ag}}{F_\nu^{\rm int}} = \frac{[B_\nu(T_s) - B_\nu(T_{\rm CMB})]\,\tau_\nu}{B_\nu(T_s)\tau_\nu} = 1 - \frac{B_\nu(T_{\rm CMB})}{B_\nu(T_s)}$$

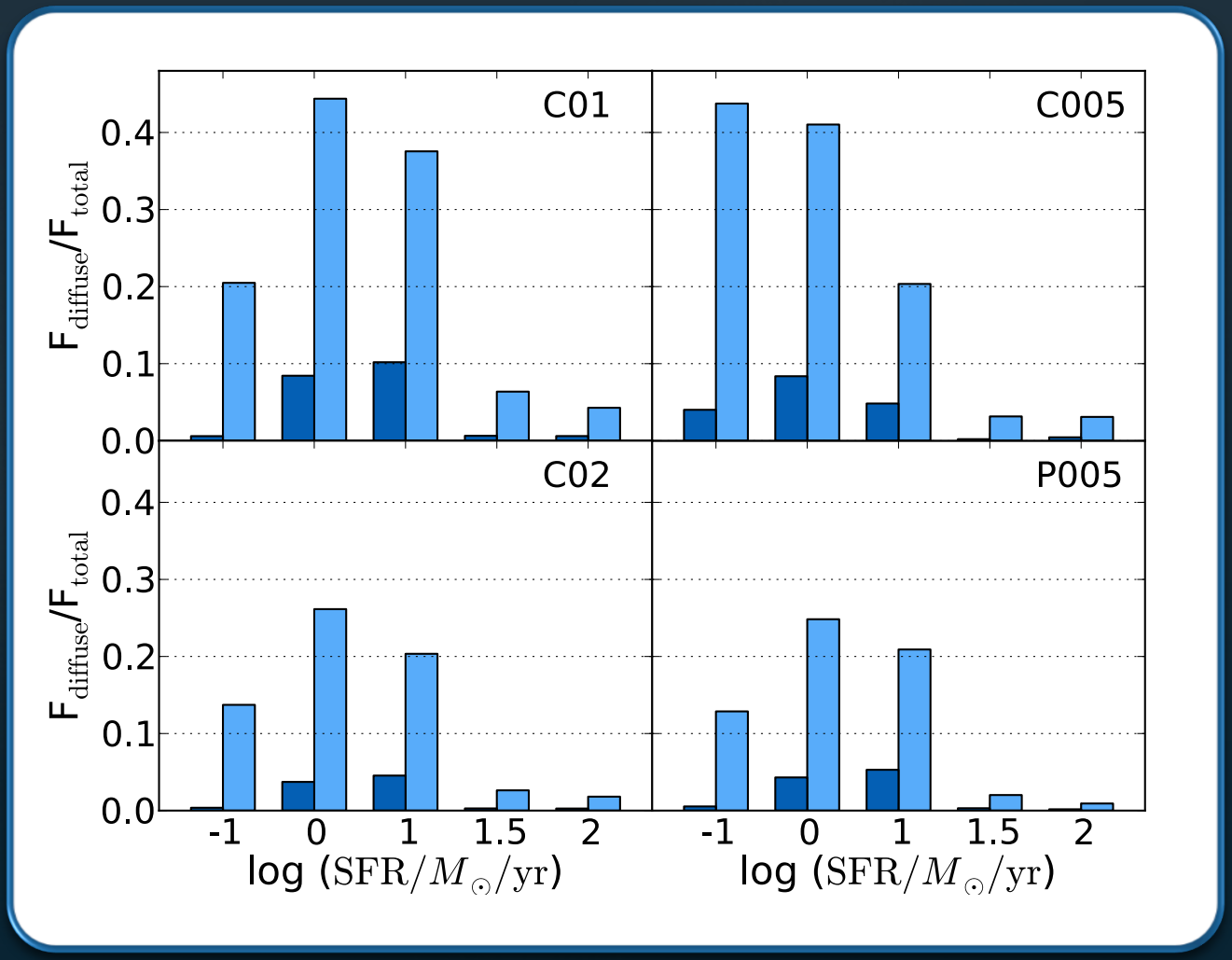
ς= 0.1- 0.2
diffuse gas

ς= 0.8 -1.0
PDRs

Contribution of the diffuse neutral gas

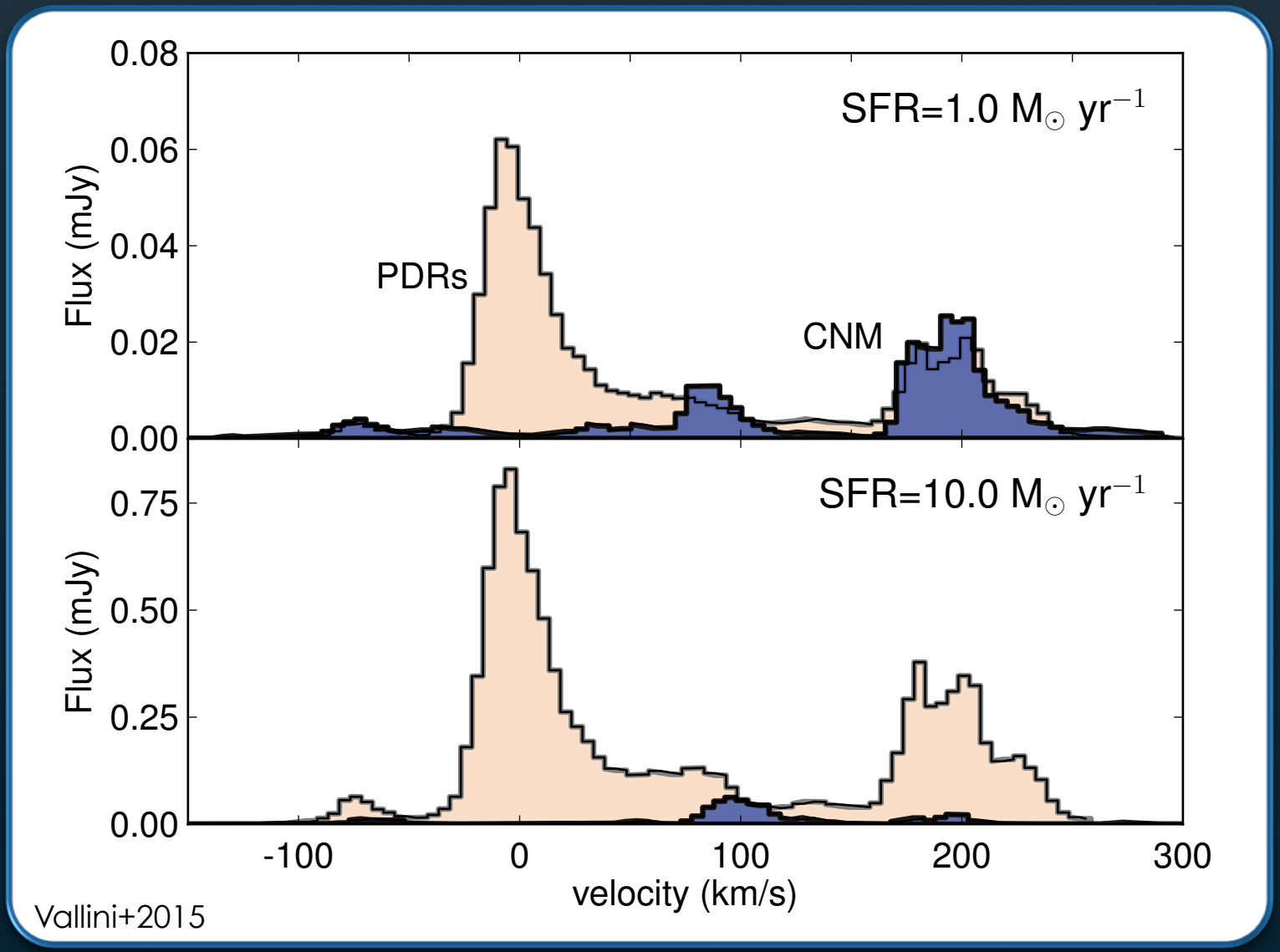
without CMB

with CMB



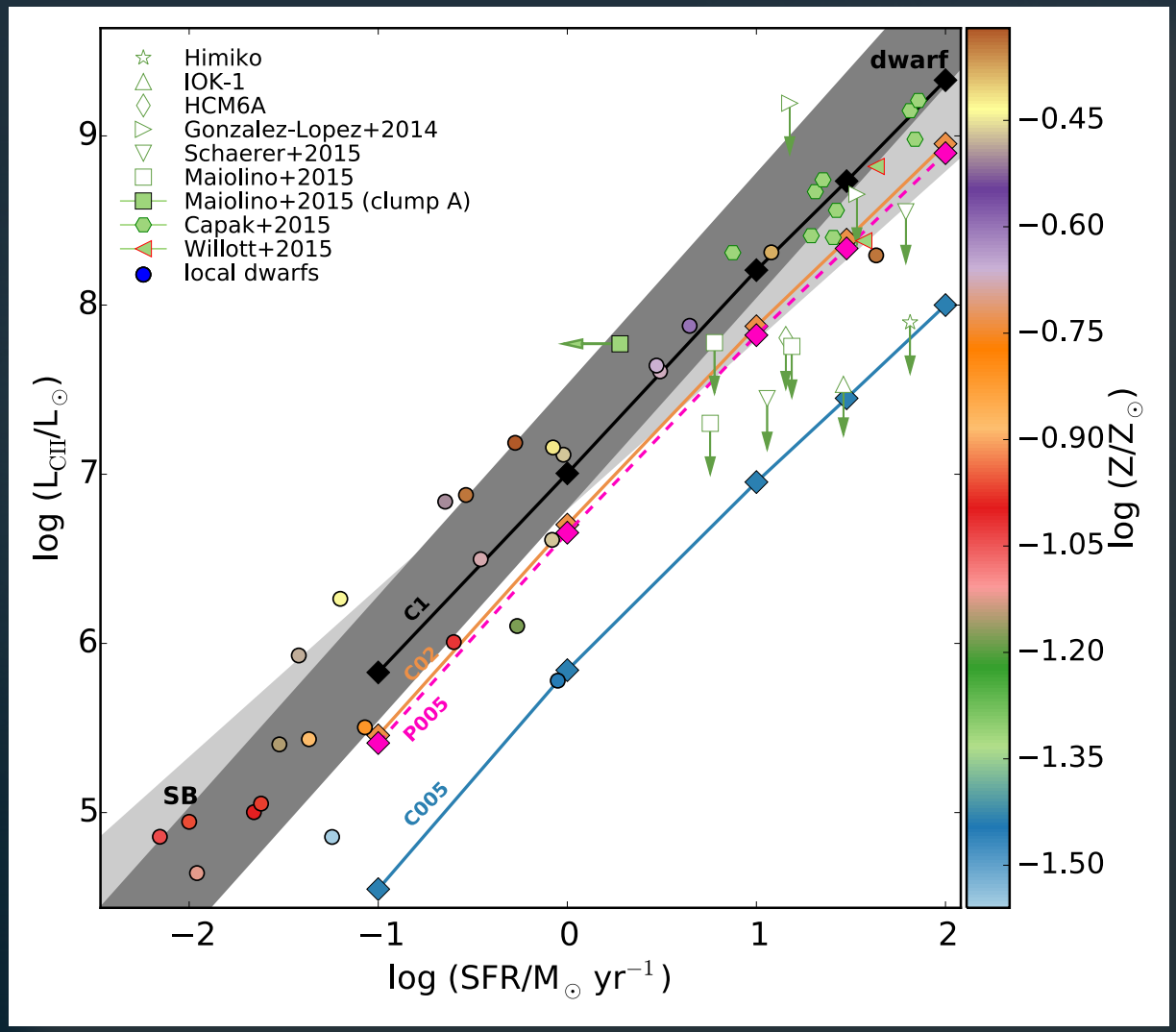
Vallini+2015

[CII] spectrum: PDRs+CNM



Vallini+2015

Effect of metallicity on the [CII]-SFR relation



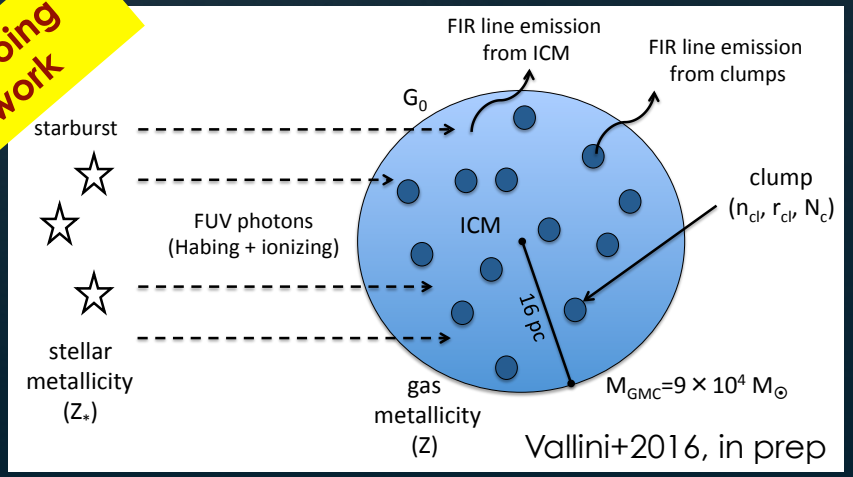
Vallini+2015

Conclusions and future prospects

- The fraction [CII] of the emission arising the diffuse medium is < 10% if we take into account of the effect of the CMB background.
- The emission from PDRs arises from the central region but we expect also other peaks from the overdense regions at the periphery of the galaxies → significant structure in the [CII] maps.
- The[CII]-SFR holds at high-z and the deviation can be due to (i) extremely low metallicities or (ii)

feedback effect of SF on the molecular clouds (e.g. photoevaporation induced by FUV radiation).

ongoing work



Let's discuss about this topic next Friday!