INAF ISTITUTO NAZIONALE DI ASTROFISICA OAS BOLOGNA

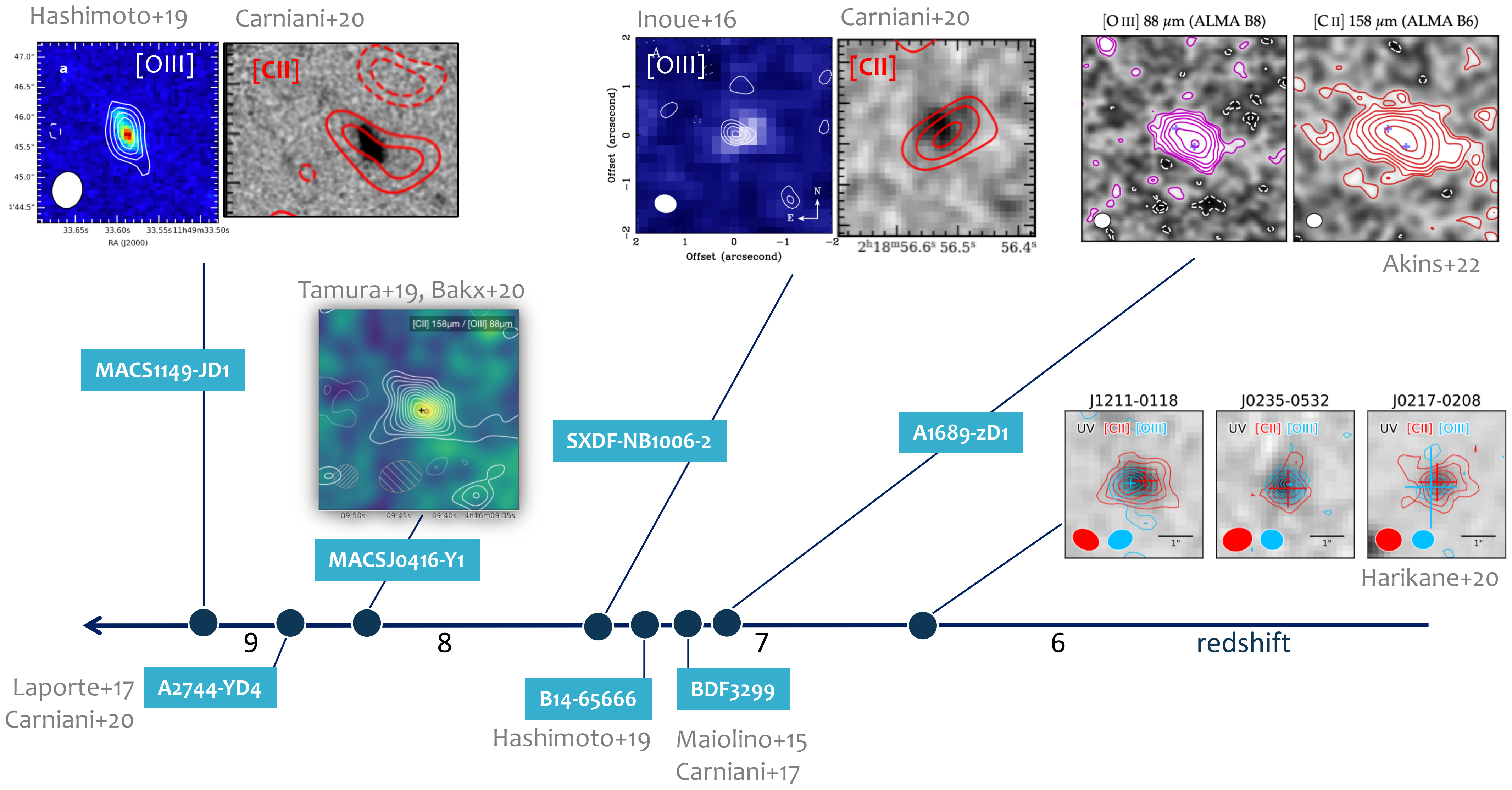
Spatially resolved Kennicutt-Schmidt relation in the EoR using [C II] and [O III] line emission

Livia Vallini

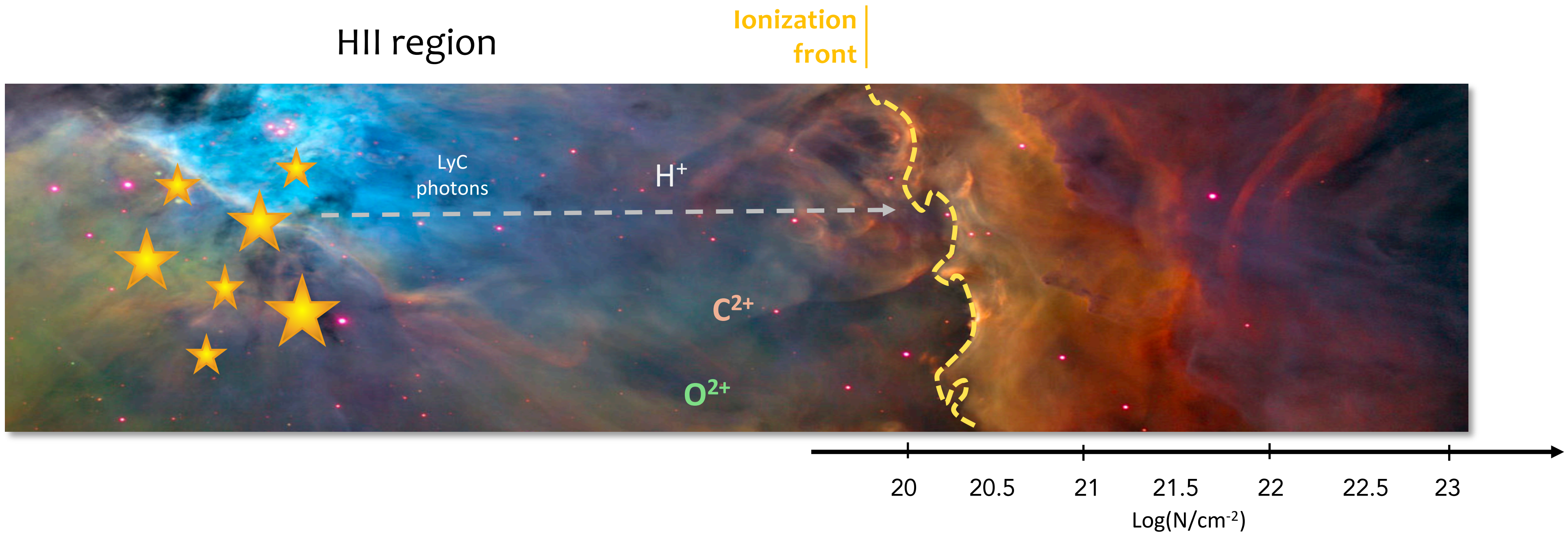
INAF - Astrophysics and Space Science Observatory of Bologna

in collaboration with: Joris Witstok, Laura Sommovigo, Andrea Pallottini, Andrea Ferrara, Stefano Carniani, Vladan Markov…

[CII] and [OIII] detections in EoR galaxies



Zoom-in on the [CII] and [OIII] emitting regions



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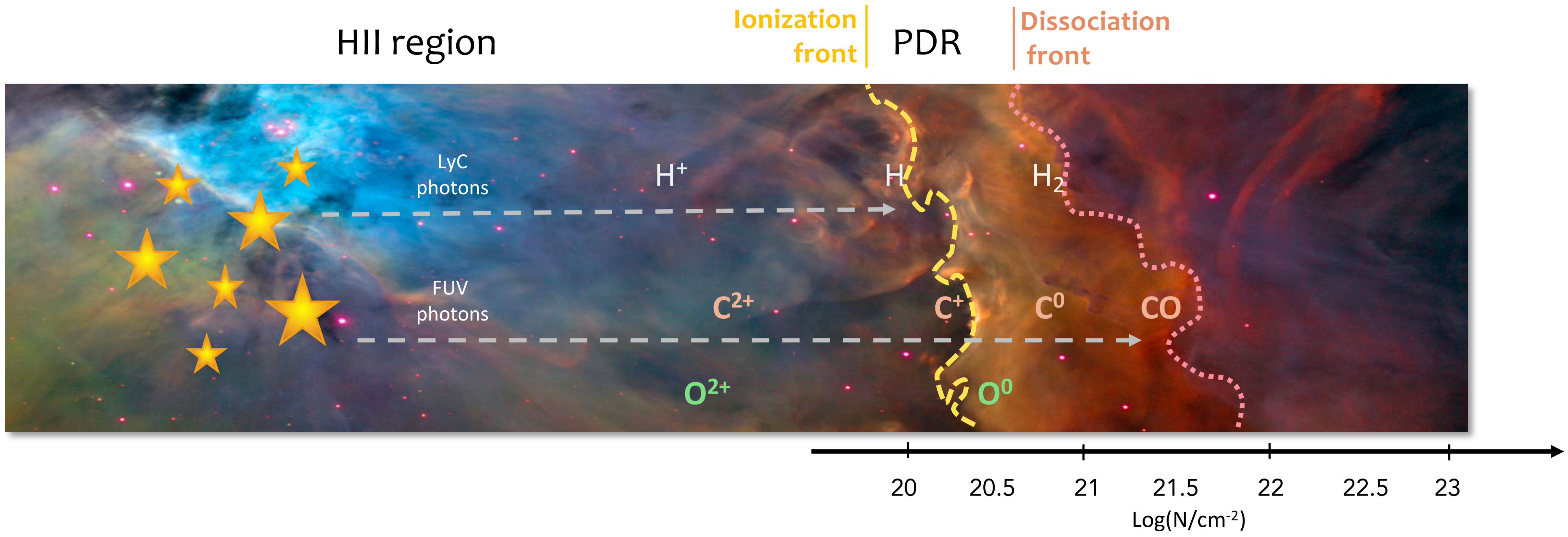

For further details: Wolfire, Vallini & Chevanche, *"Photodissociation and X-ray dominated regions"*, ARA&A, Vol 60, 2022

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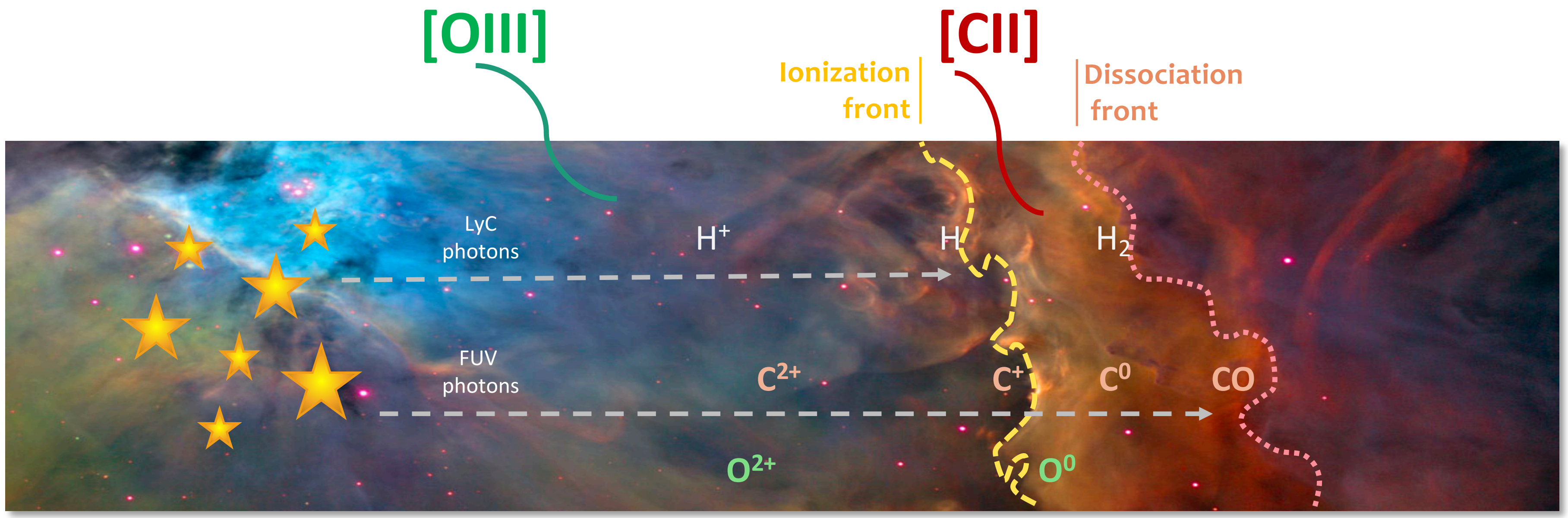

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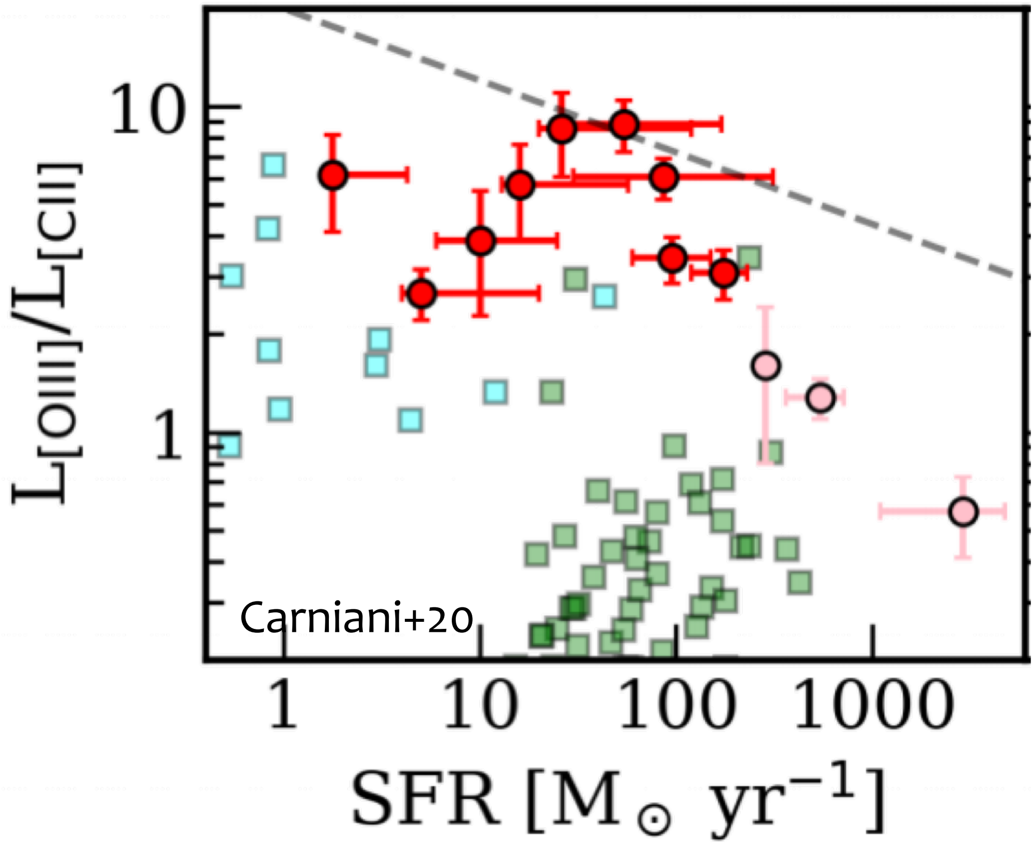
Key observational results in the EoR

See also: Harikane+20, Arata+20



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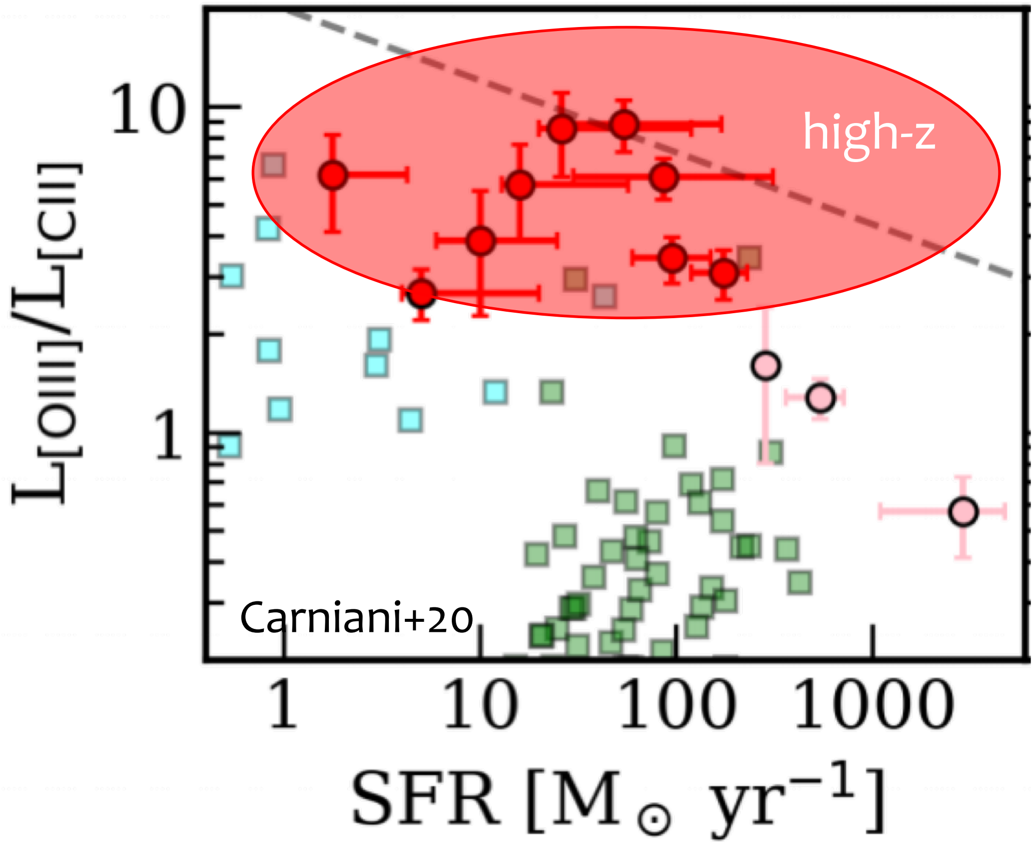

High-z $L_{[OIII]}/L_{[CII]}$ higher than the average
for z=0 a galaxies, including metal poor dwarf galaxies

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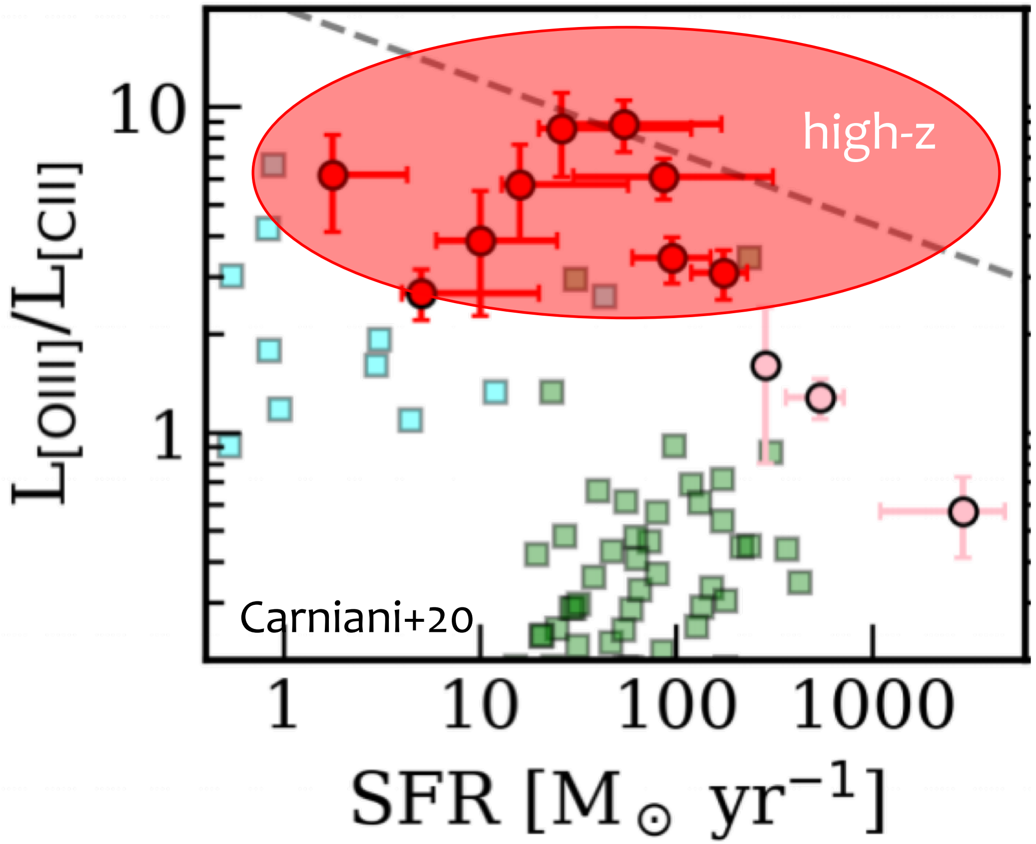
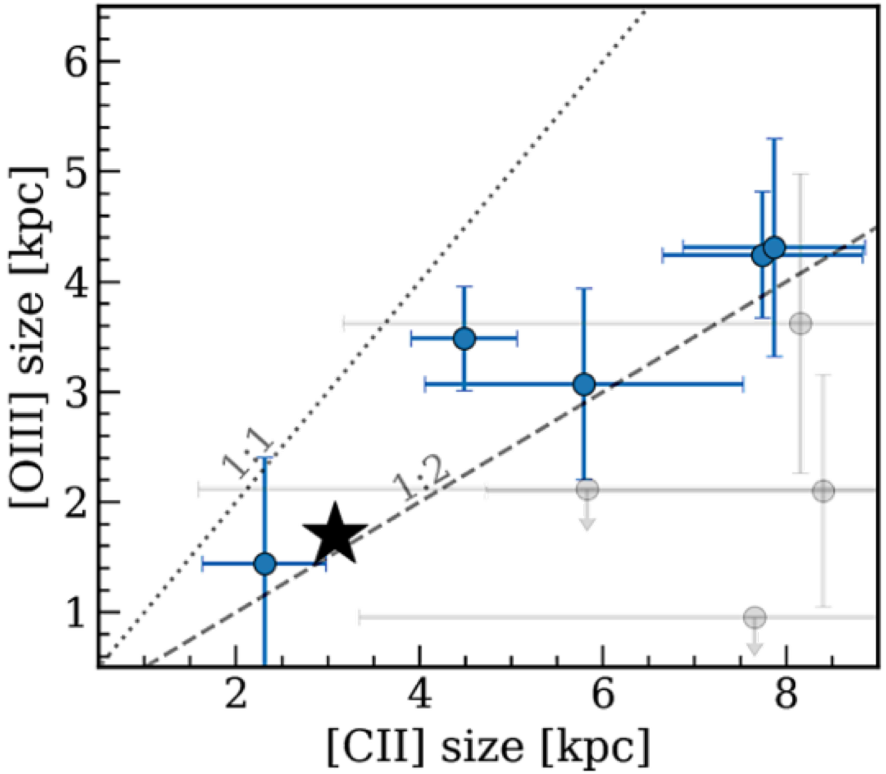


Carniani+20



High-z $L_{[OIII]}/L_{[CII]}$ higher than the average for z=0 a galaxies, including metal poor dwarf galaxies

[CII] is **2x more extended** than [OIII]
[CII] **flux missed** when angular resolution comparable to the size of the emitting region

What about spatially resolved quantities?

If instead of $L_{[OIII]}/L_{[CII]}$ we are able to observe and study the $\Sigma_{[OIII]}/\Sigma_{[CII]}$ the different extension of the emitting regions are explicitly accounted for

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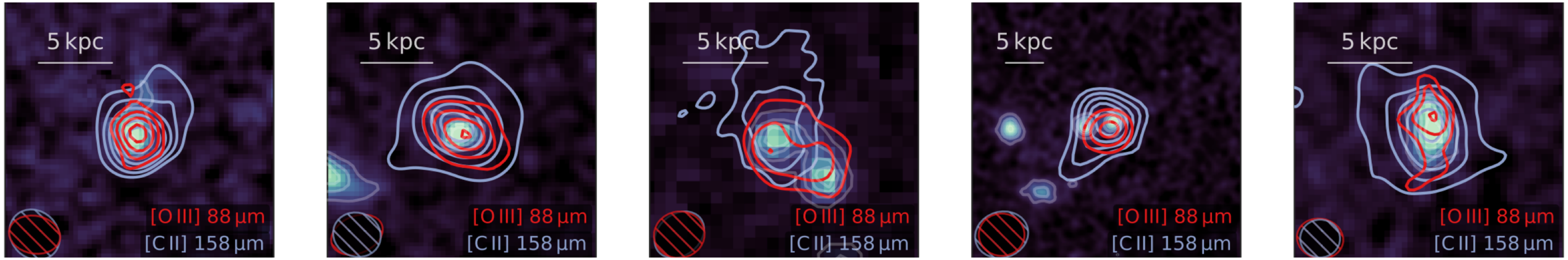

Witstok+22

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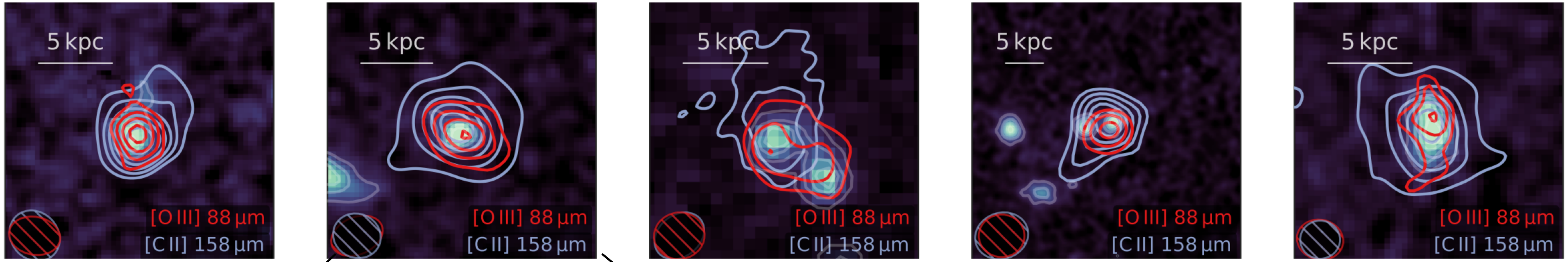

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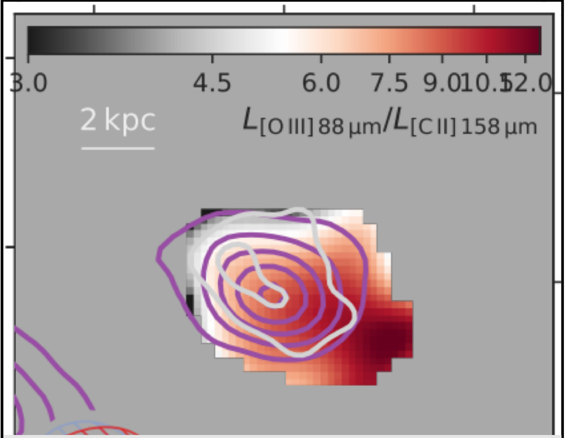

spatially resolved
[OIII]/[CII] ratios

It is possible to characterize the
local physical and chemical conditions
of different gas phases

What about spatially resolved quantities?

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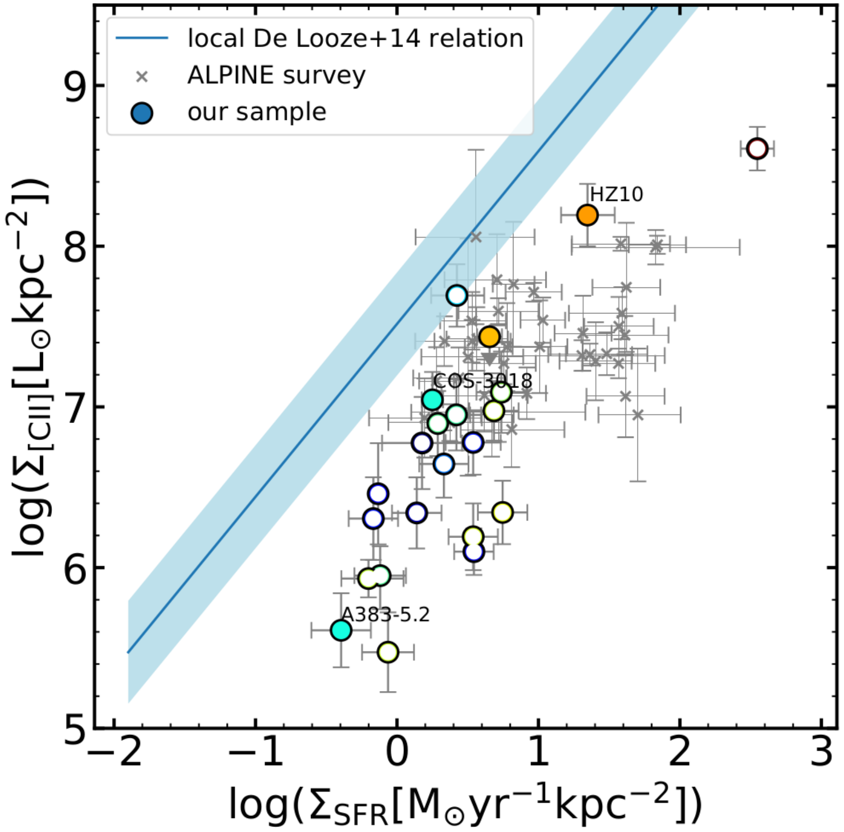
Markov, LV+22



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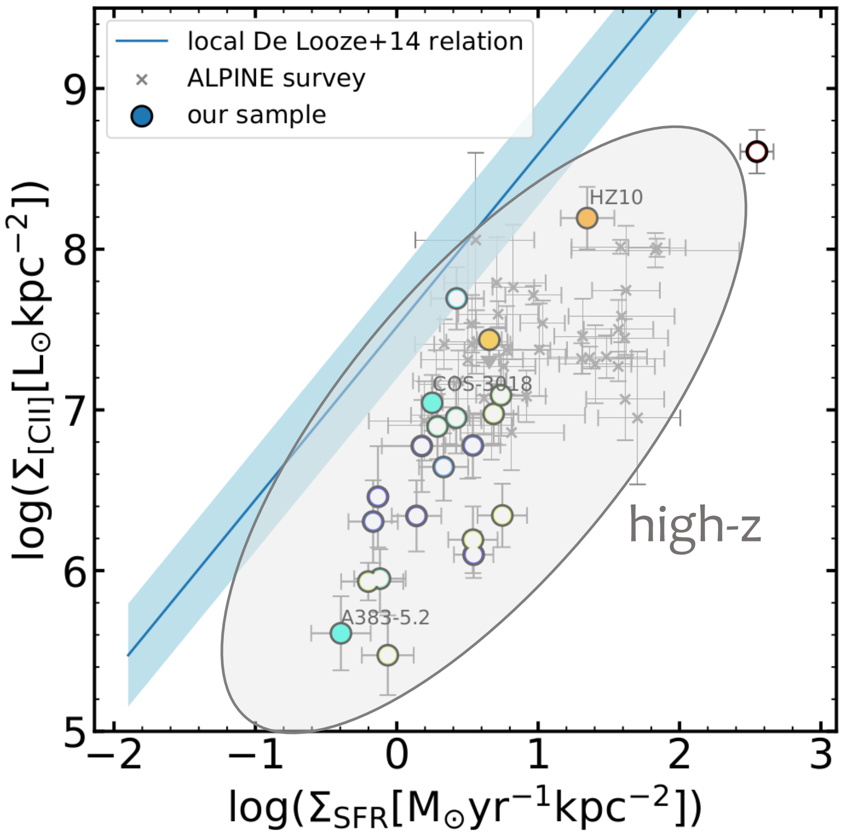

high-z galaxies are always below the local $\Sigma_{[CII]}$-Σ_{SFR} relation

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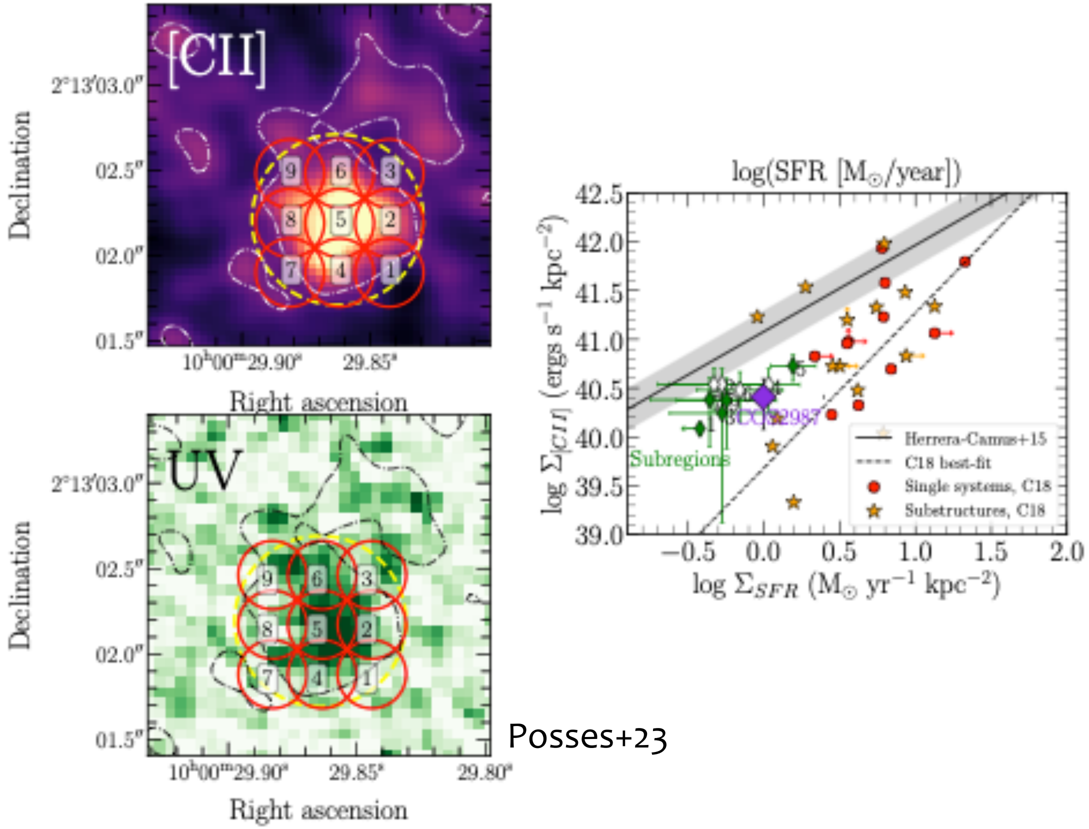

Posses+23

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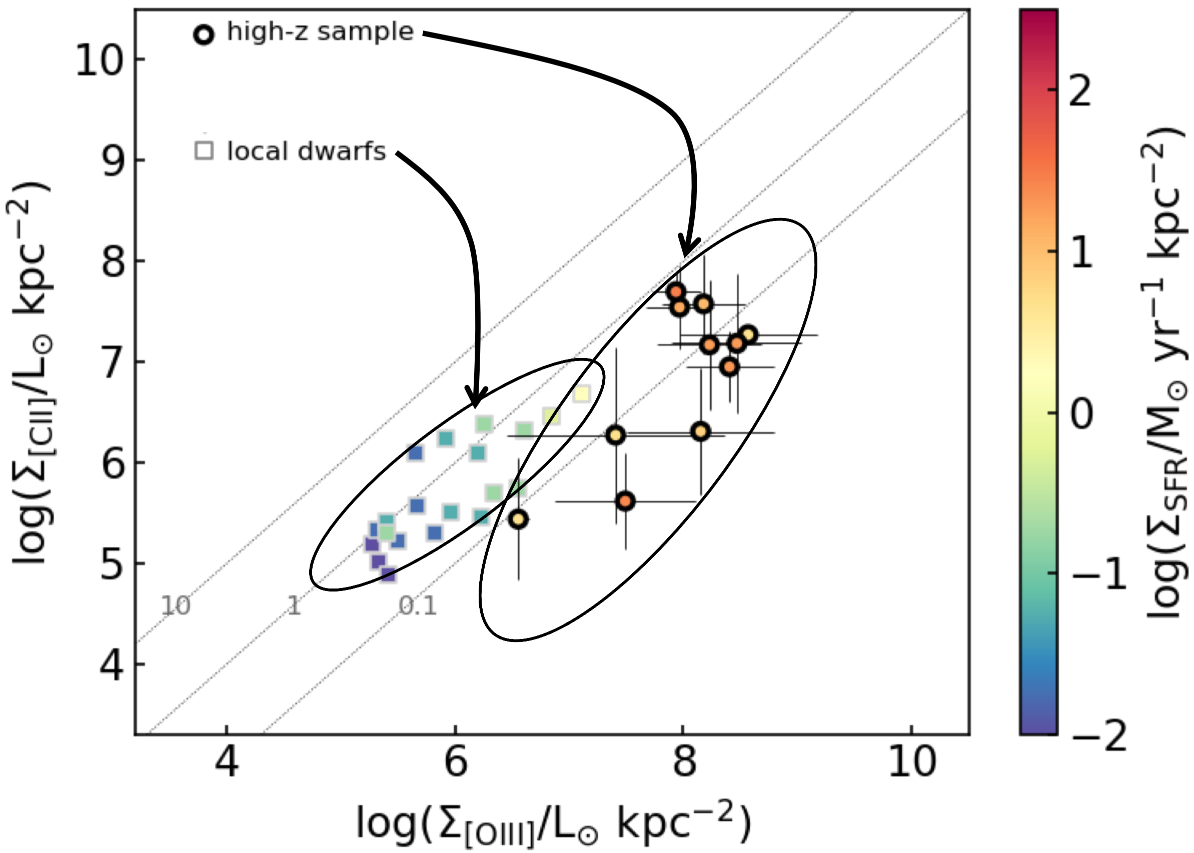
Spatially resolved [CII] and [OIII] in EoR galaxies: lessons from simulations

Vallini+21



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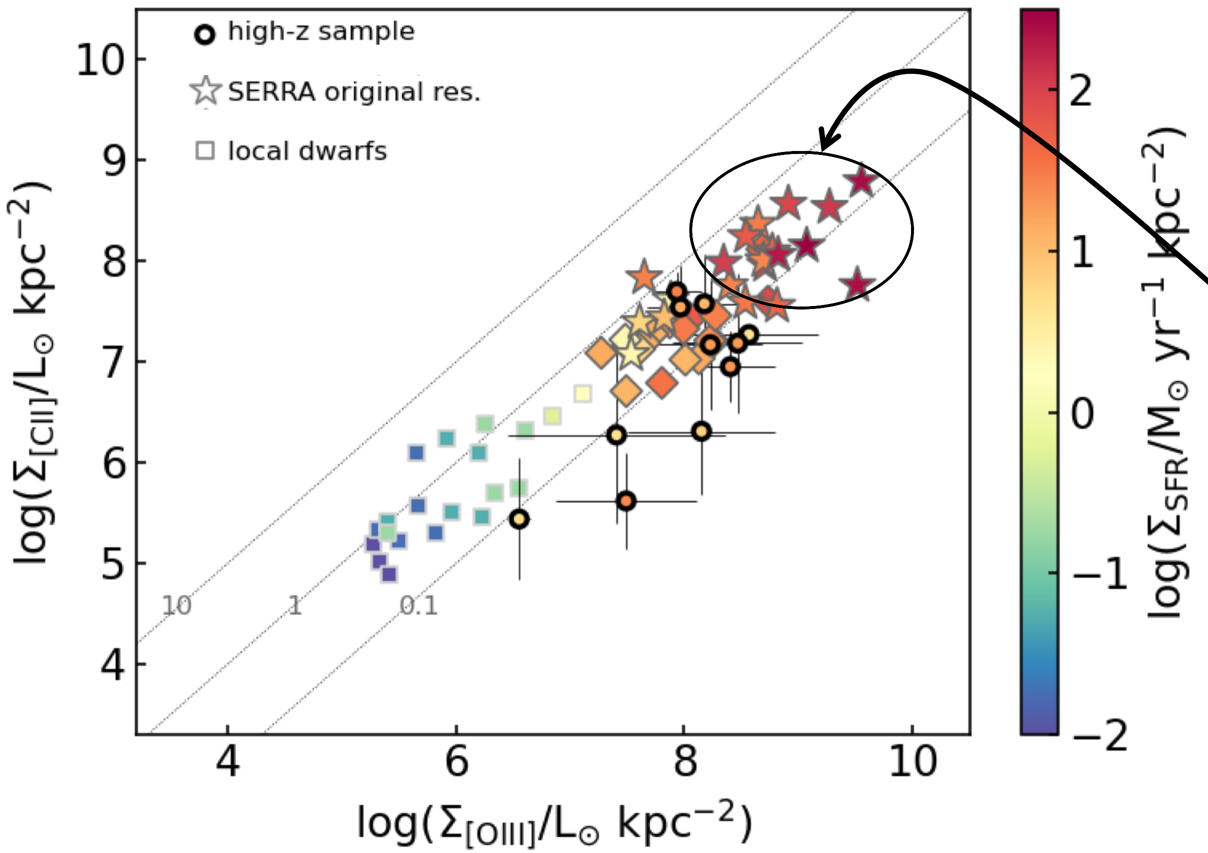

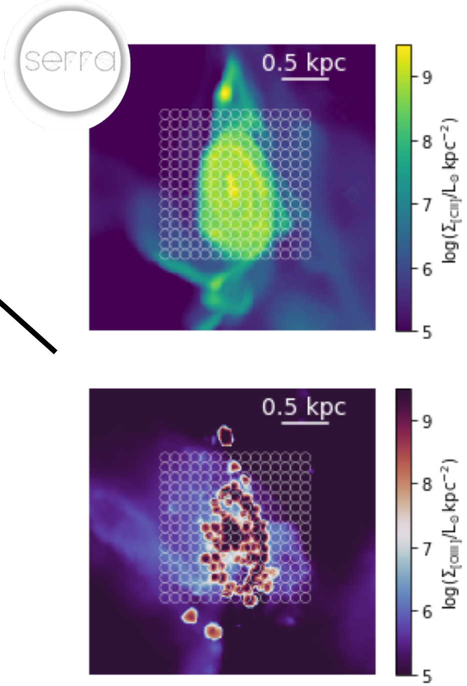

SERRA Simulation at z=7.7

Pallottini+22

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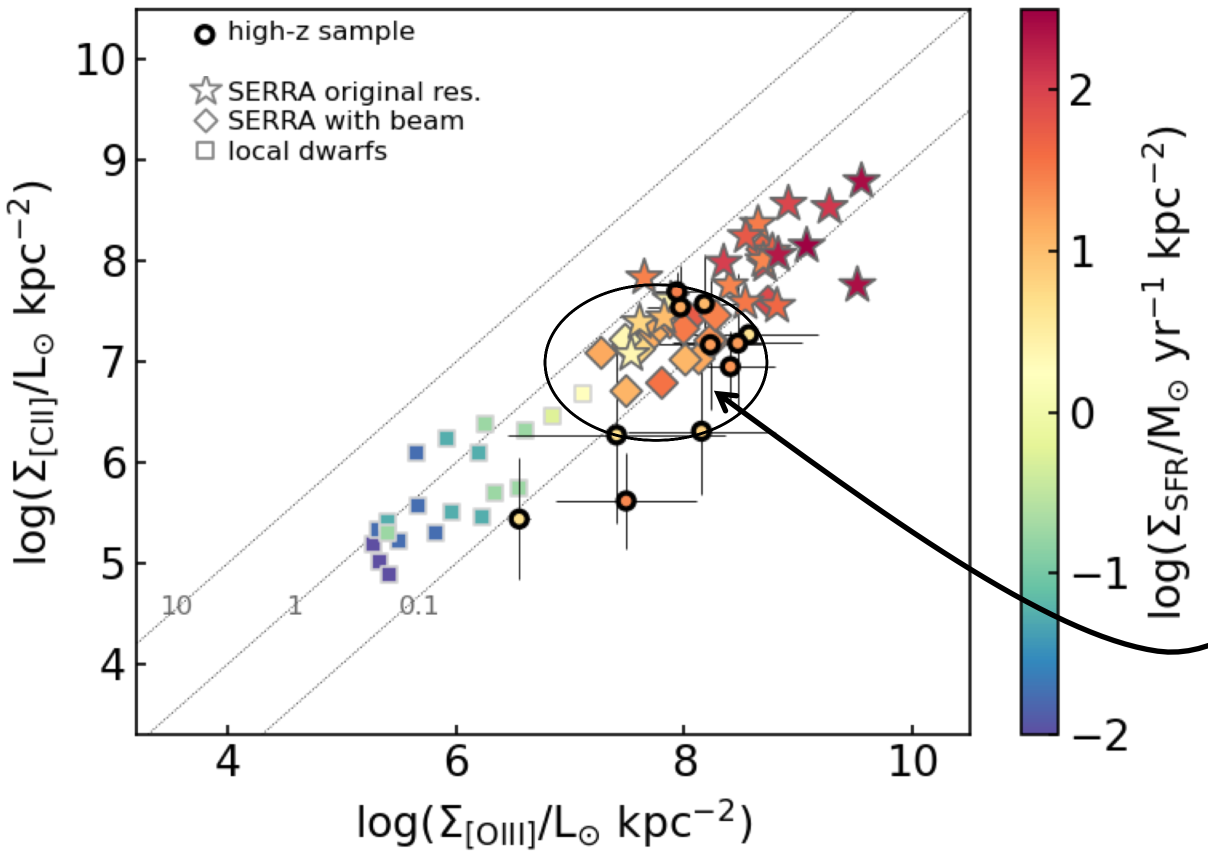

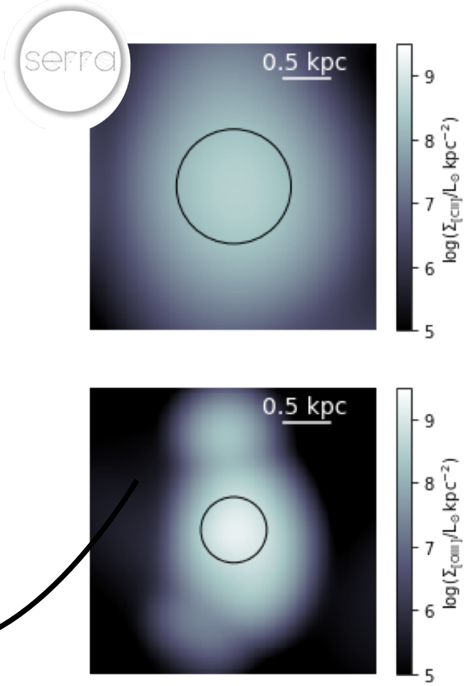

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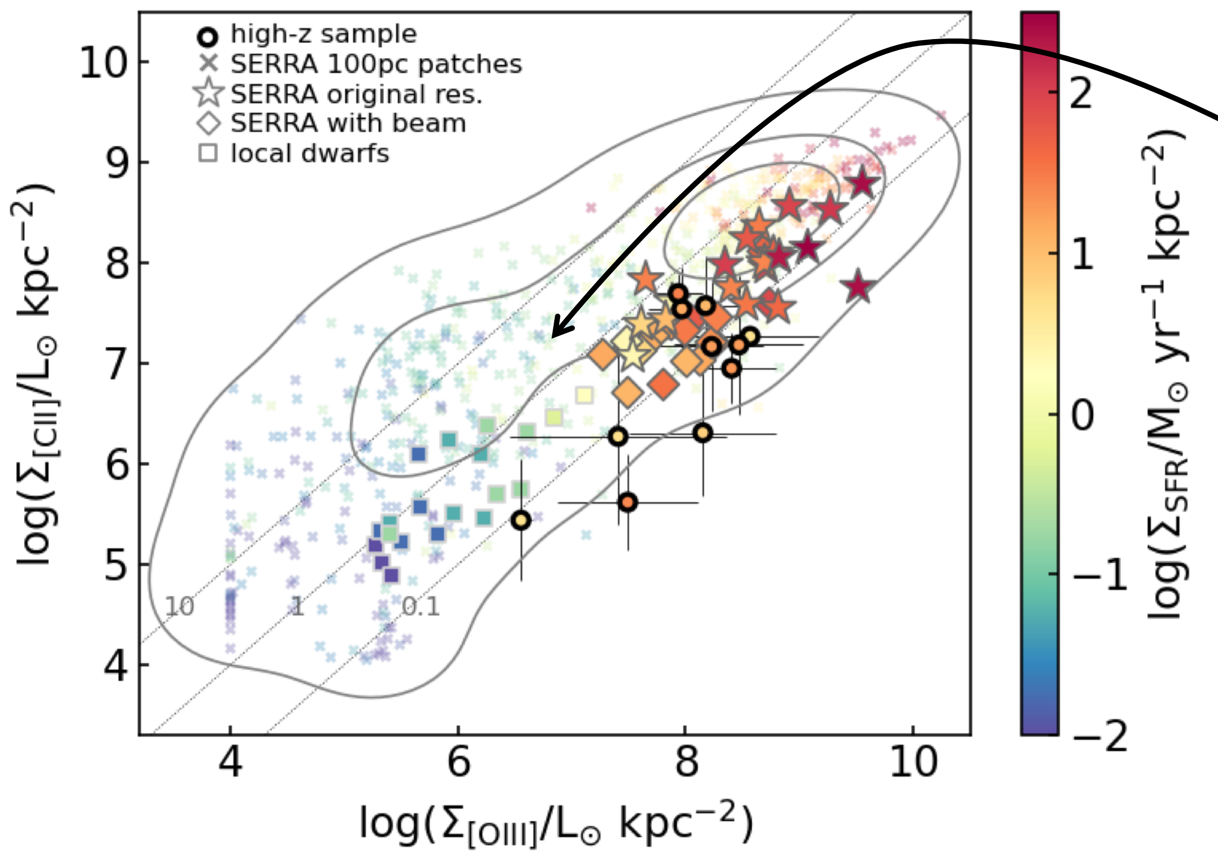

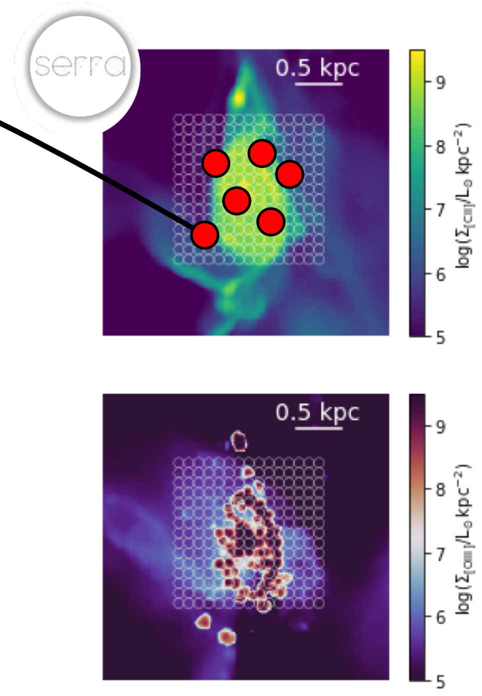

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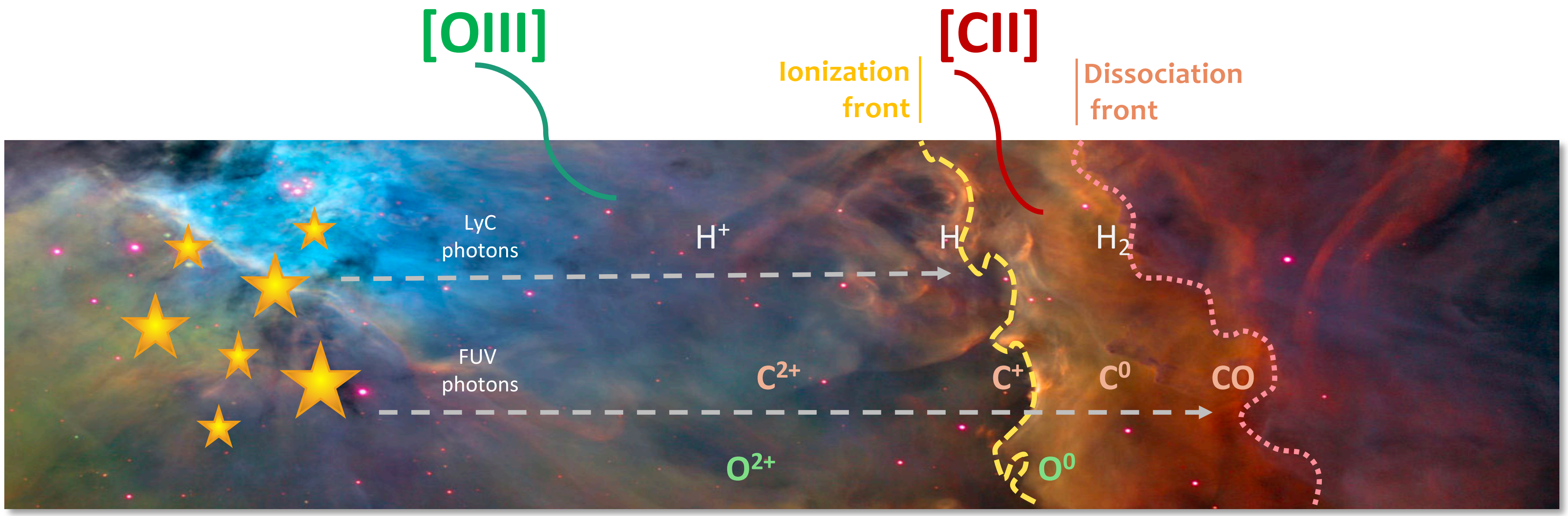
High $\Sigma_{[OIII]}/\Sigma_{[CII]}$ ratios are not due to observational biases,
but they arise from the extreme gas conditions prevailing in the ISM of early galaxies

A physically motivated model for the [OIII] vs [CII] emission



We developed a physically-motivated analytical model describing the relative emission from HII regions and PDRs
(have a look at Ferrara+19, Vallini+20,21 for all the equations)

A physically motivated model for the [OIII] vs [CII] emission

$$F_{[\mathrm{OIII}],88} = n\Lambda_{[\mathrm{OIII}],88}\mathcal{A}_O Z N_i(\kappa_s, Z)$$

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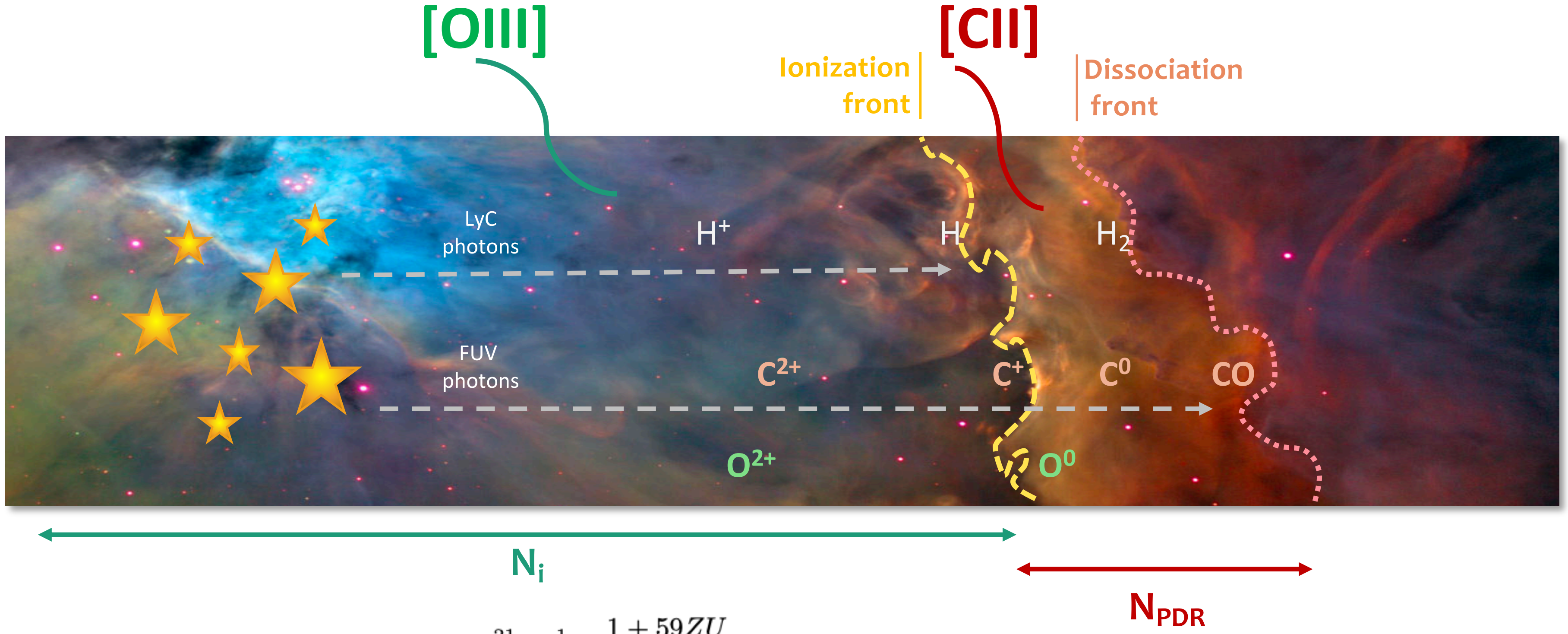

$$N_i = 1.7\times 10^{21} Z^{-1} \ln\frac{1+59ZU}{1+21.7ZU}$$

$$N_{\mathrm{PDR}} = \min\left[\frac{1.7\times 10^{21}}{Z}\ln\left(1+\frac{10^5 U}{1+0.9Z^{1/2}}\right), N_0\right] - N_i,$$

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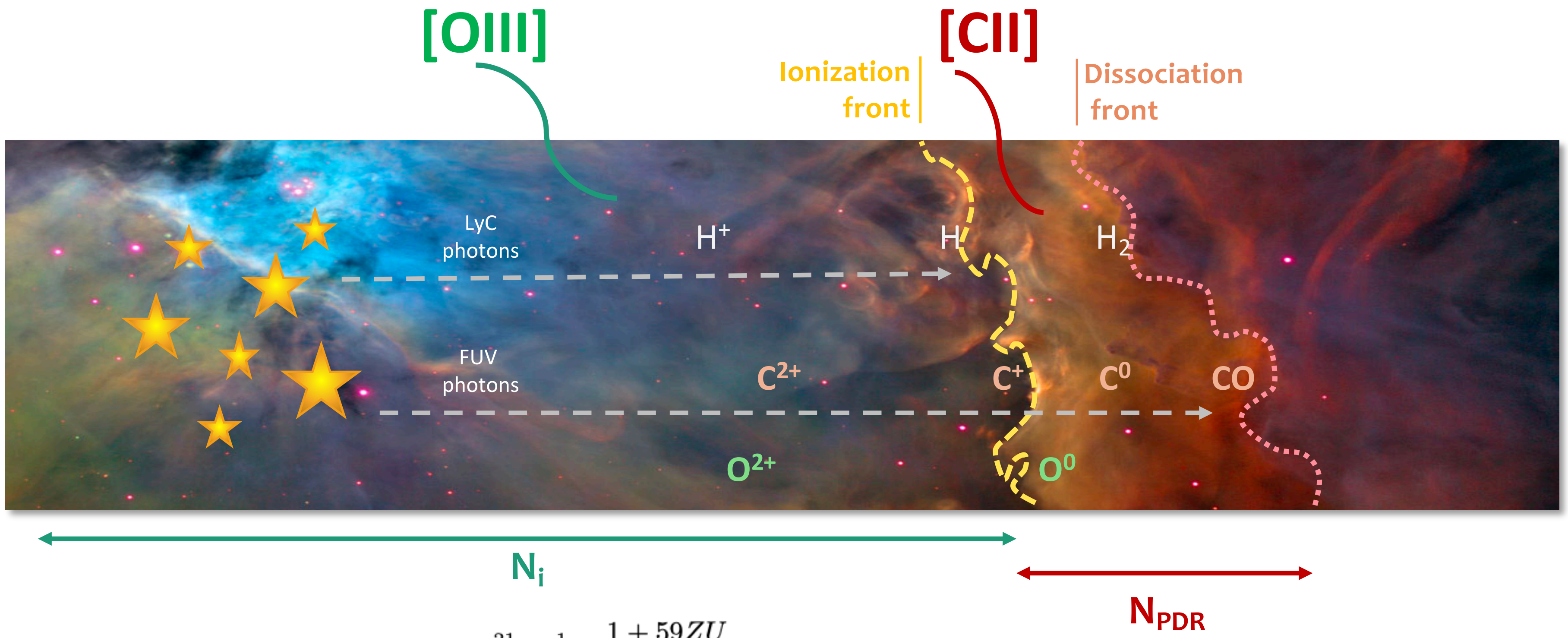

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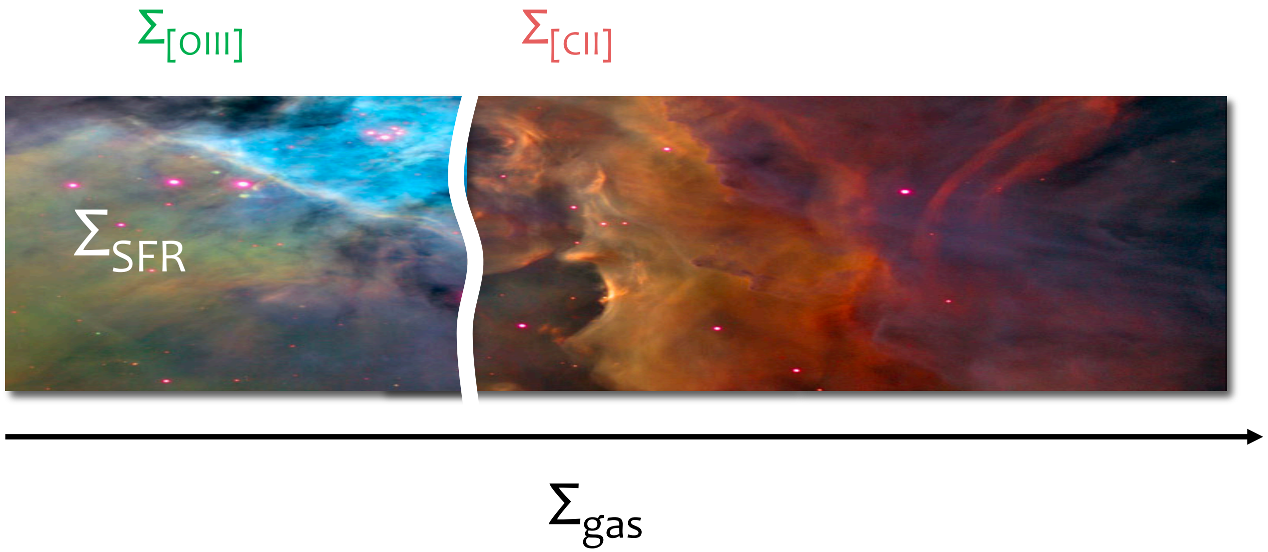
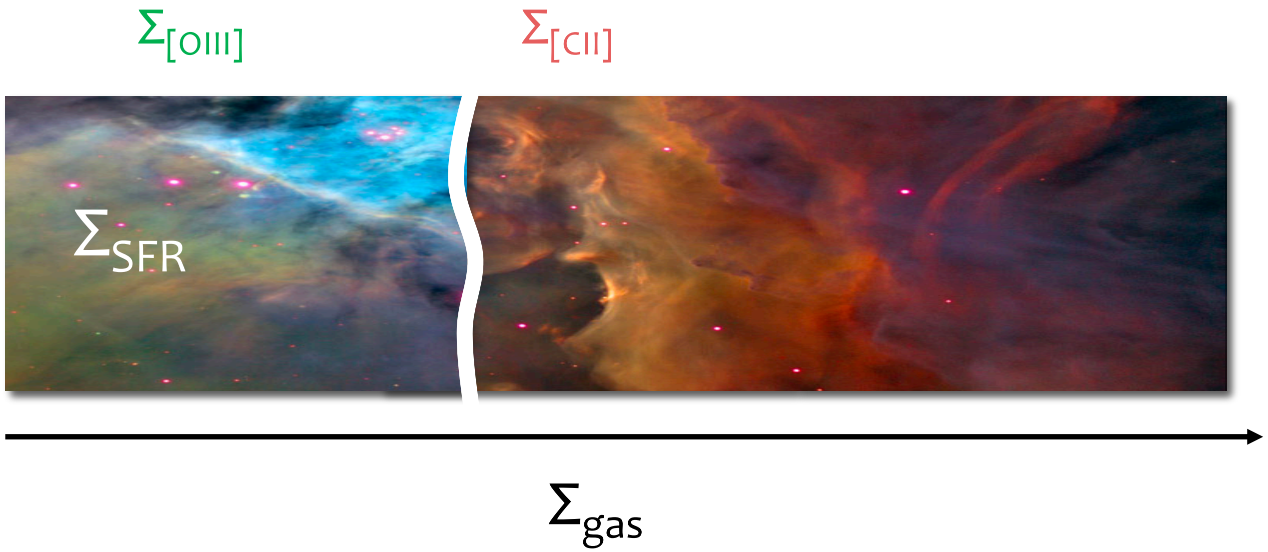
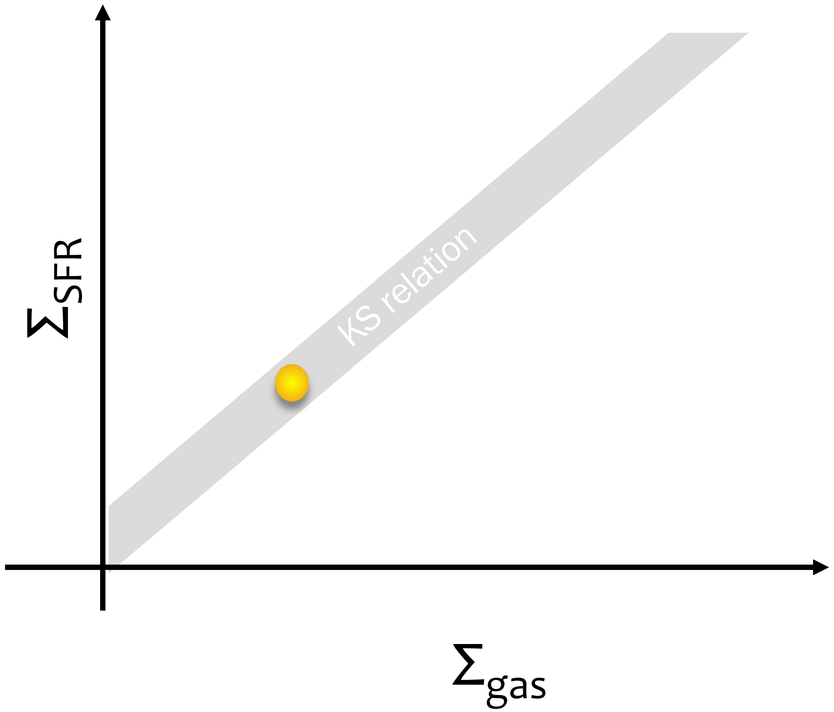


The effect of deviations from the Kennicutt-Schmidt relation



The KS relation $\Sigma_{SFR} = \mathbf{k_s} \, \Sigma_{gas}^{1.4}$



For detailed equations: Ferrara+19, Vallini+20,21

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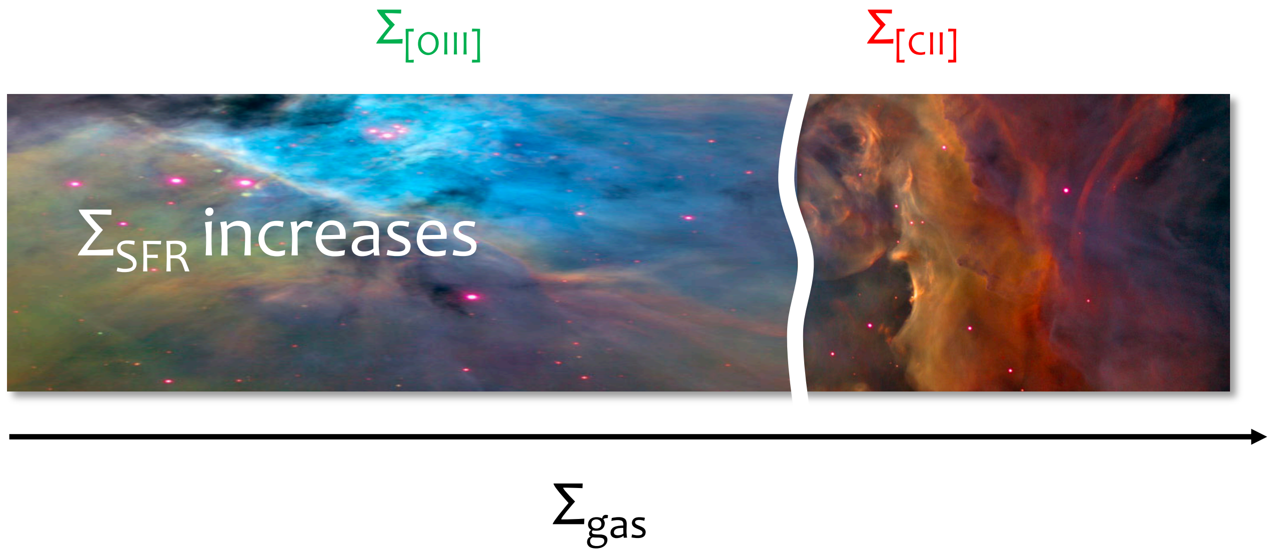

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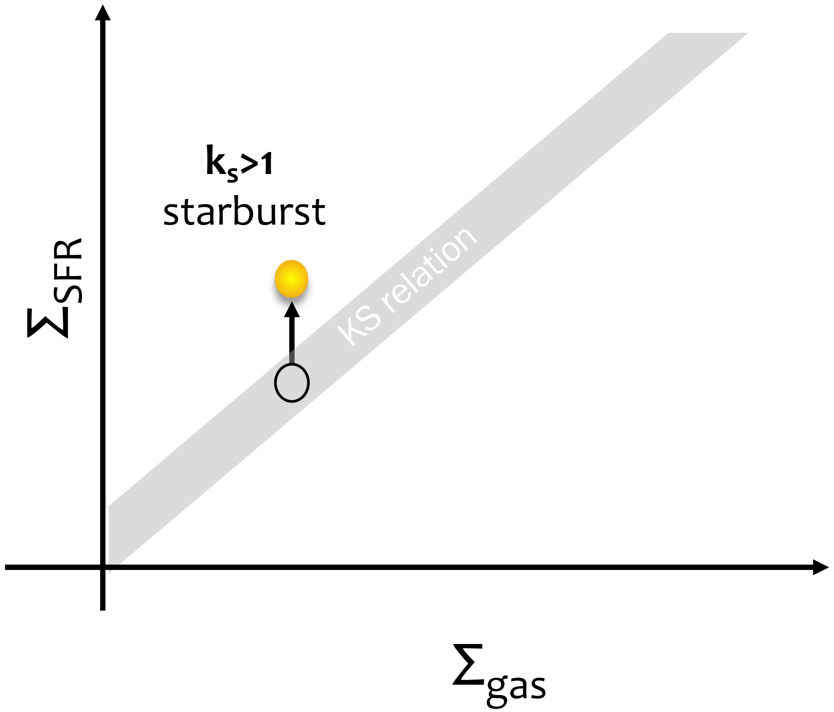

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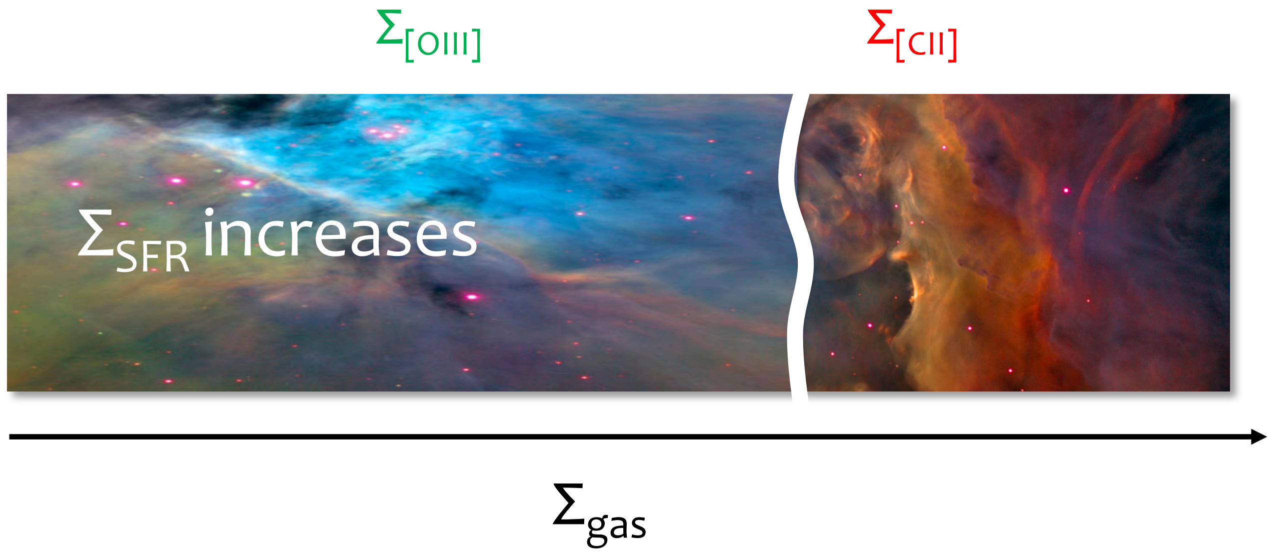

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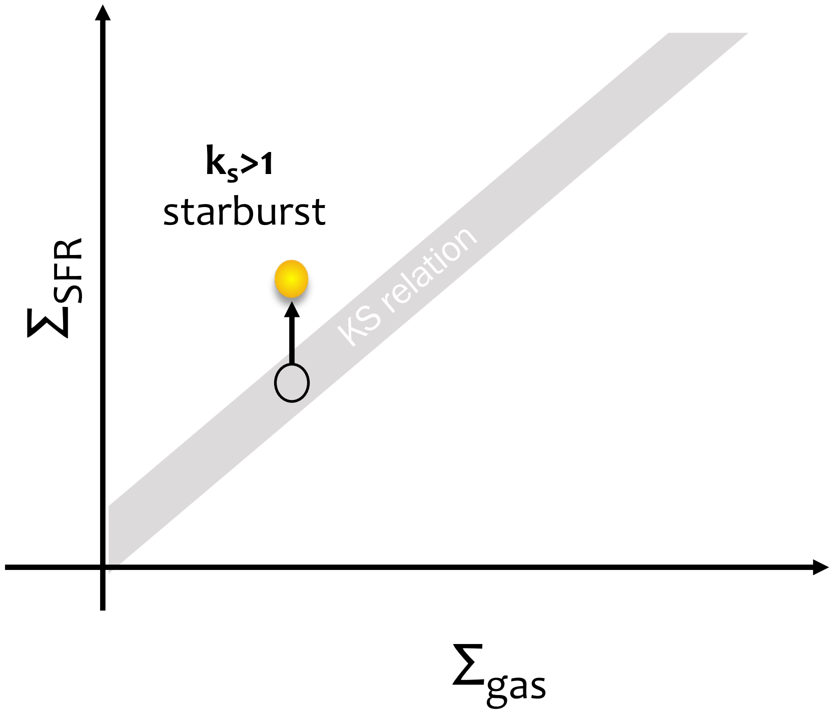
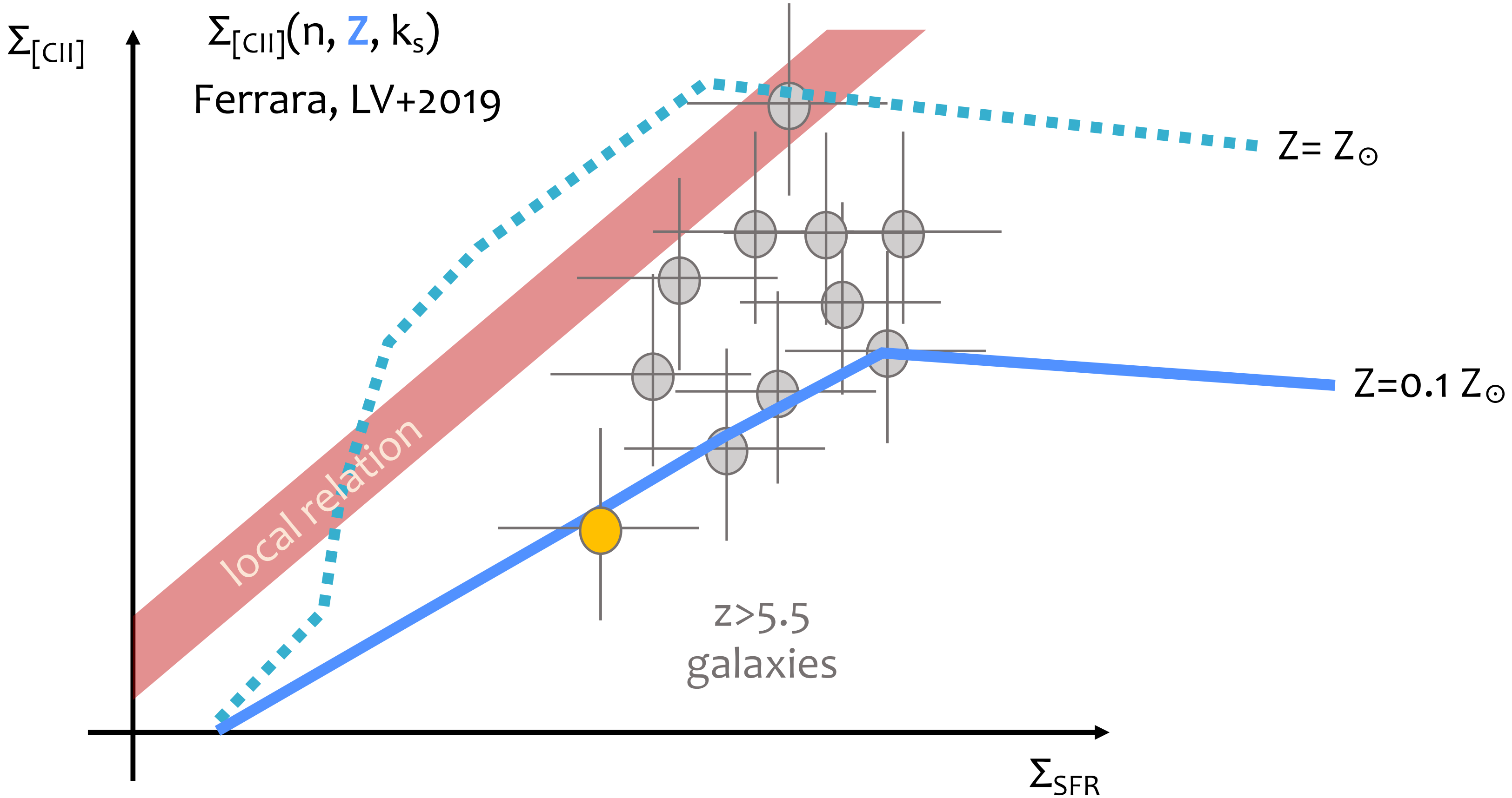


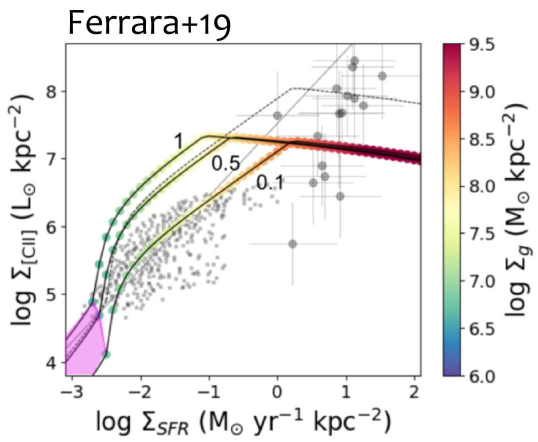
Starburst → larger U and G_0 → larger **ionized gas** & **low PDR column densities → Decrease $\Sigma_{[CII]}$**

Starburst → larger U and G_0 → larger **ionized gas** & **low PDR column densities → Increase $\Sigma_{[OIII]}$**

For detailed equations: Ferrara+19, Vallini+20,21

The effect of low metallicities on the [CII] emission





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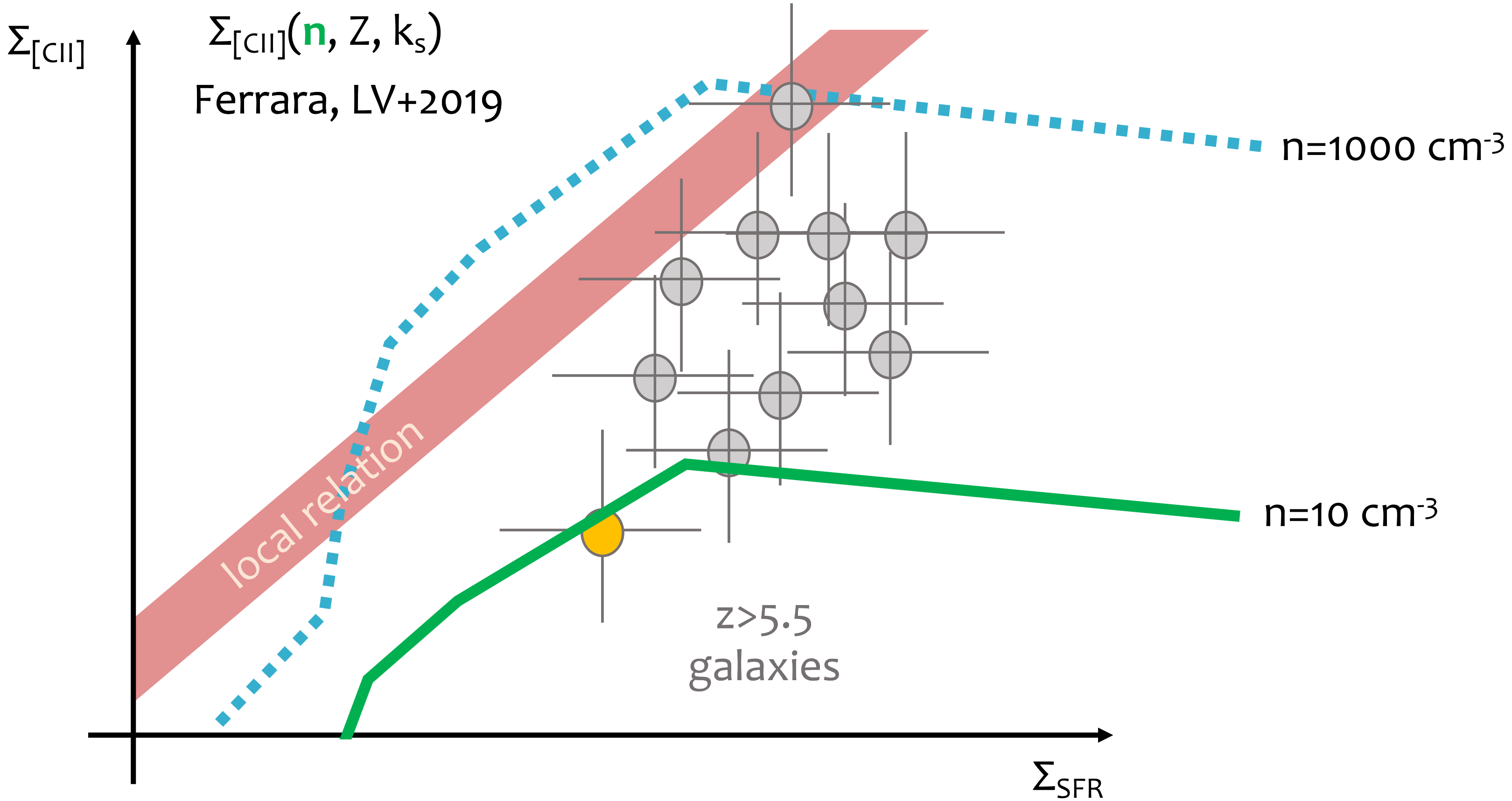
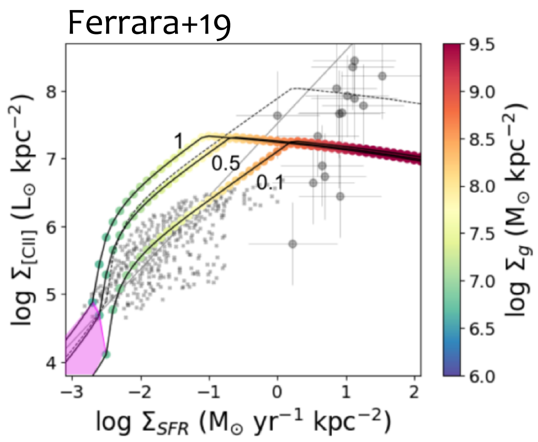
The effect of the low density on the [CII] emission





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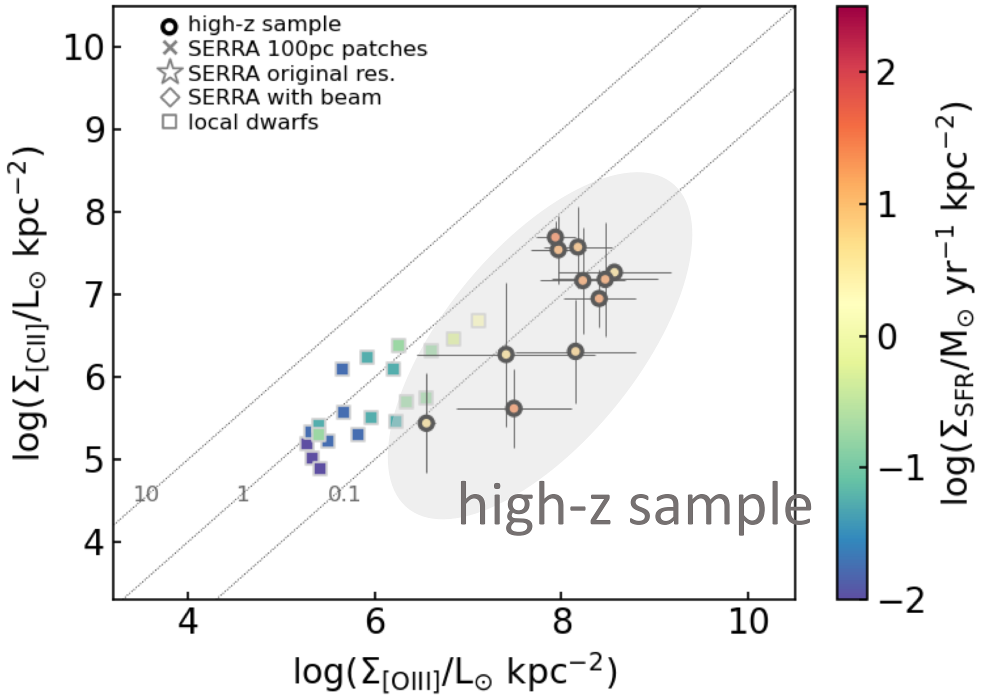
Three observables



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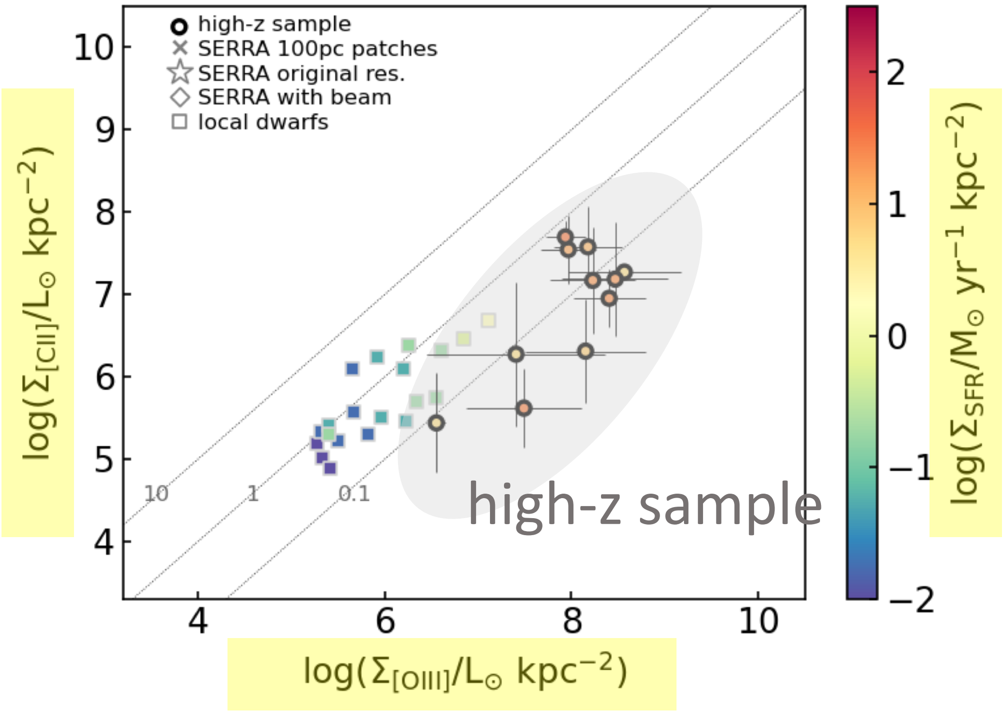
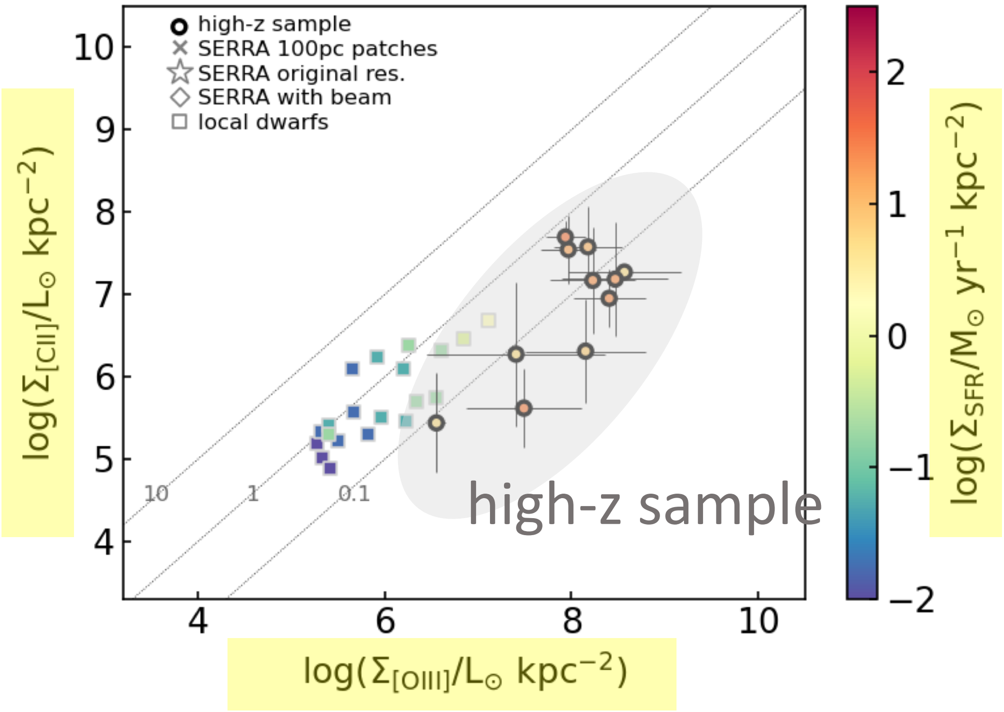


Disentangling the ISM properties

Three observables



Three parameters

- Gas density - **n**
- Deviation from KS relation - $\mathbf{k_s}$
- Gas metallicity - **Z**

GLAM is publicly available on GitHub

GLAM

The code (GLAM - **G**alaxy **L**ine **A**nalyzer with **M**CMC) and **Jupyter Notbooks** are released at: https://lvallini.github.io/MCMC_galaxyline_analyzer/

337 lines (337 sloc) | 108 KB

Raw Blame

In [1]:
```
import numpy as np
from MCMC_routines import MC_model,galaxy_template
```

Set the galaxy template:

Default values are

- **Sigma_SFR** = 2.0 $M_\odot$/yr/kpc^2
- **Sigma_CII** = 3e7 $L_\odot$/kpc^2
- **Sigma_OIII** = 7e7 $L_\odot$/kpc^2

stadandard assumed error is 20%

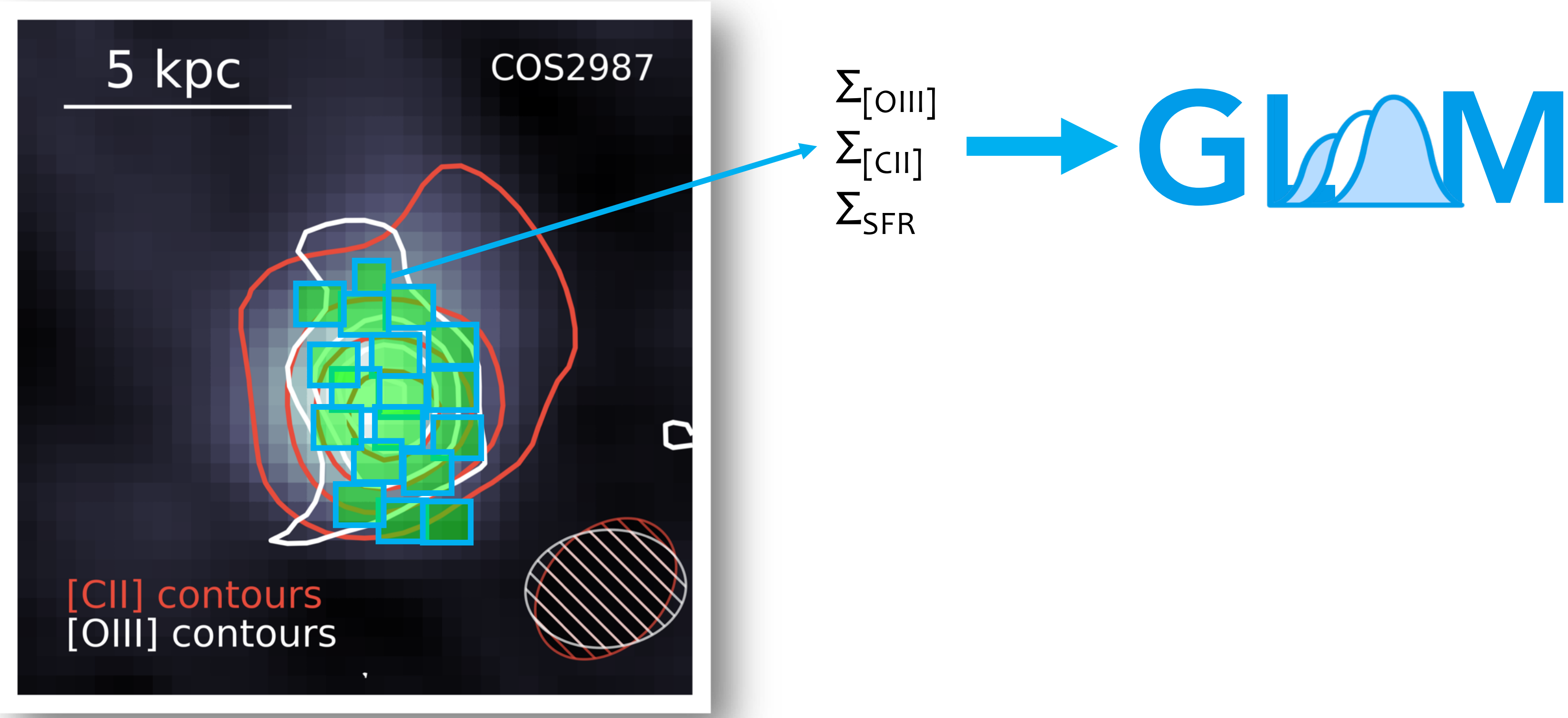
In [2]:
```
galaxy_example = galaxy_template()
galaxy_example.print_info()
```

```
Galaxy input data
  Sigma_SFR          =  2.0 Msun/yr/kpc^2
  Sigma_CII          =  30000000.0 Lsun/kpc^2
  Sigma_OIII         =  70000000.0 Lsun/kpc^2
  relative error on Delta        =  20.0 %
  relative error on Sigma_CIII   =  20.0 %
  relative error on Sigma_OIII   =  20.0 %
```

You can change your inputs and relative errors as follows

Get GLAM here

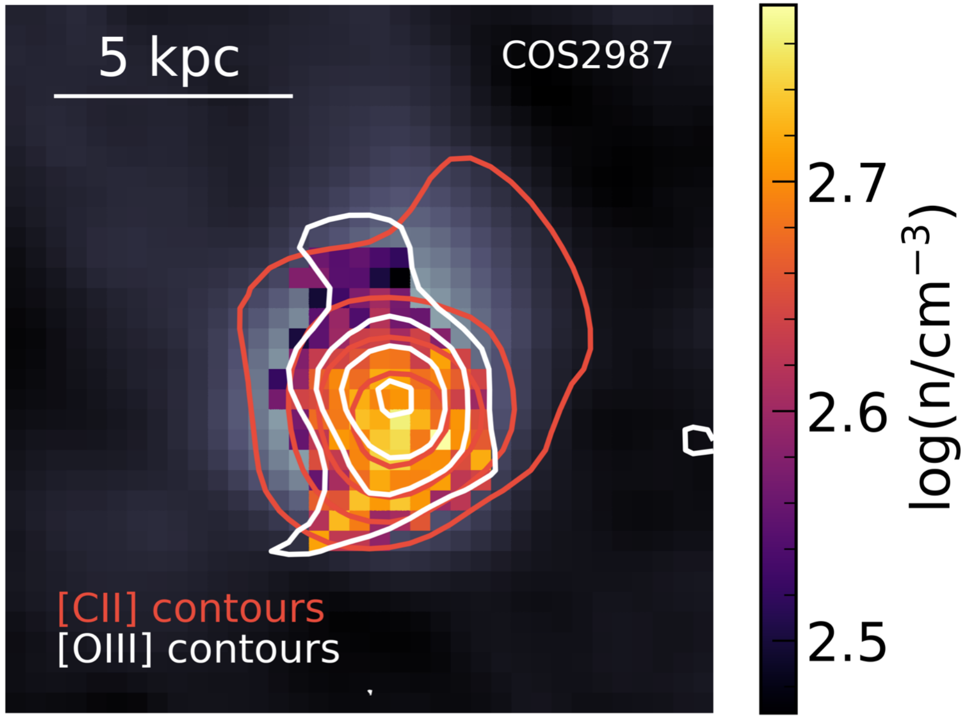
GLAM at work on spatially resolved data in five bright LBGs



data from Witstok+22

GLAM at work on spatially resolved data

Vallini+23, in prep.



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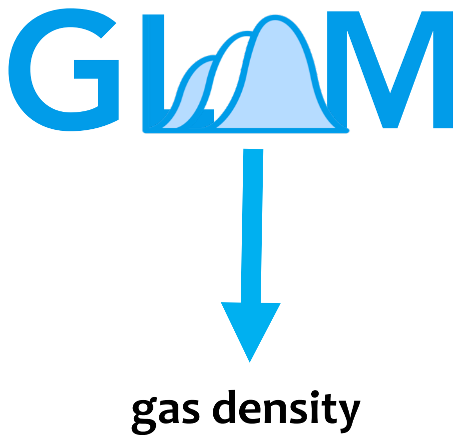

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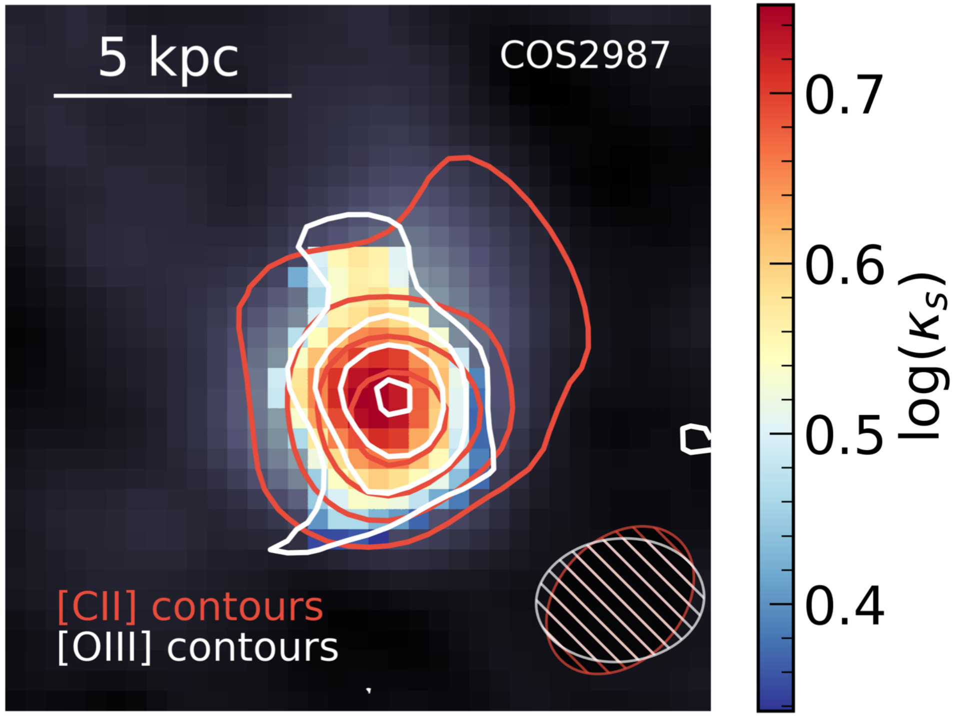

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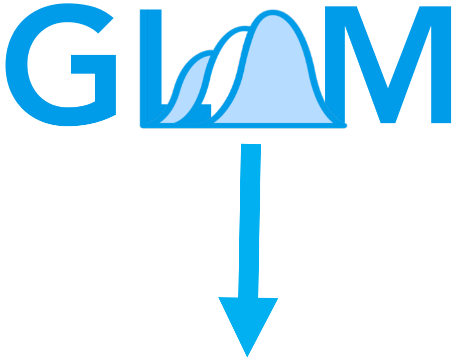

burstiness parameter

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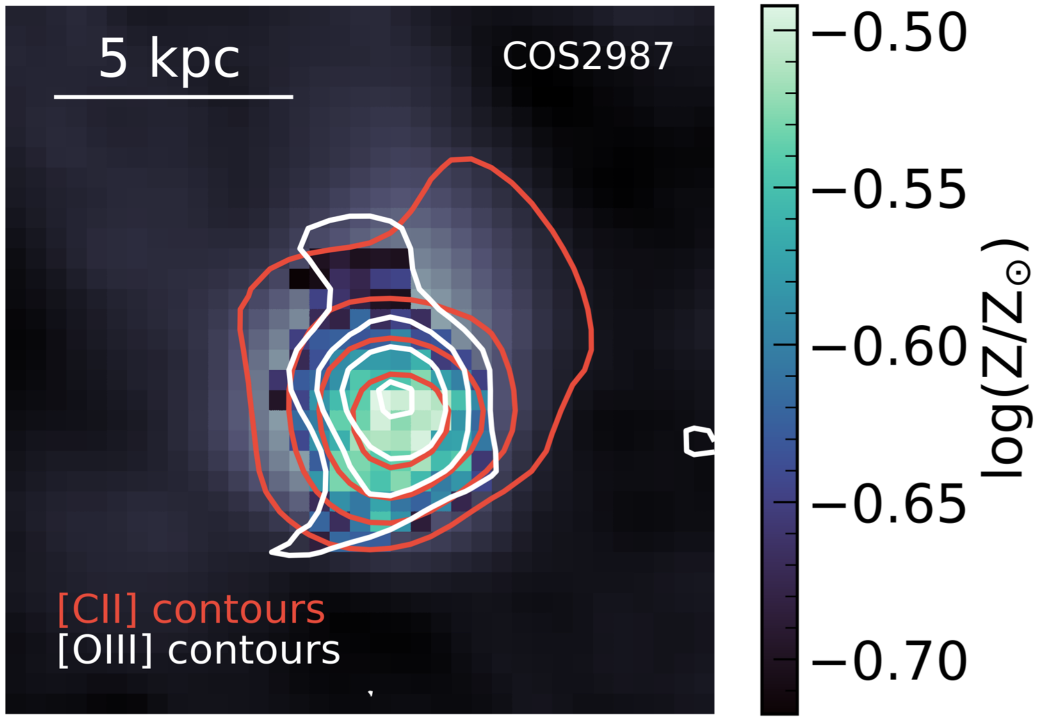
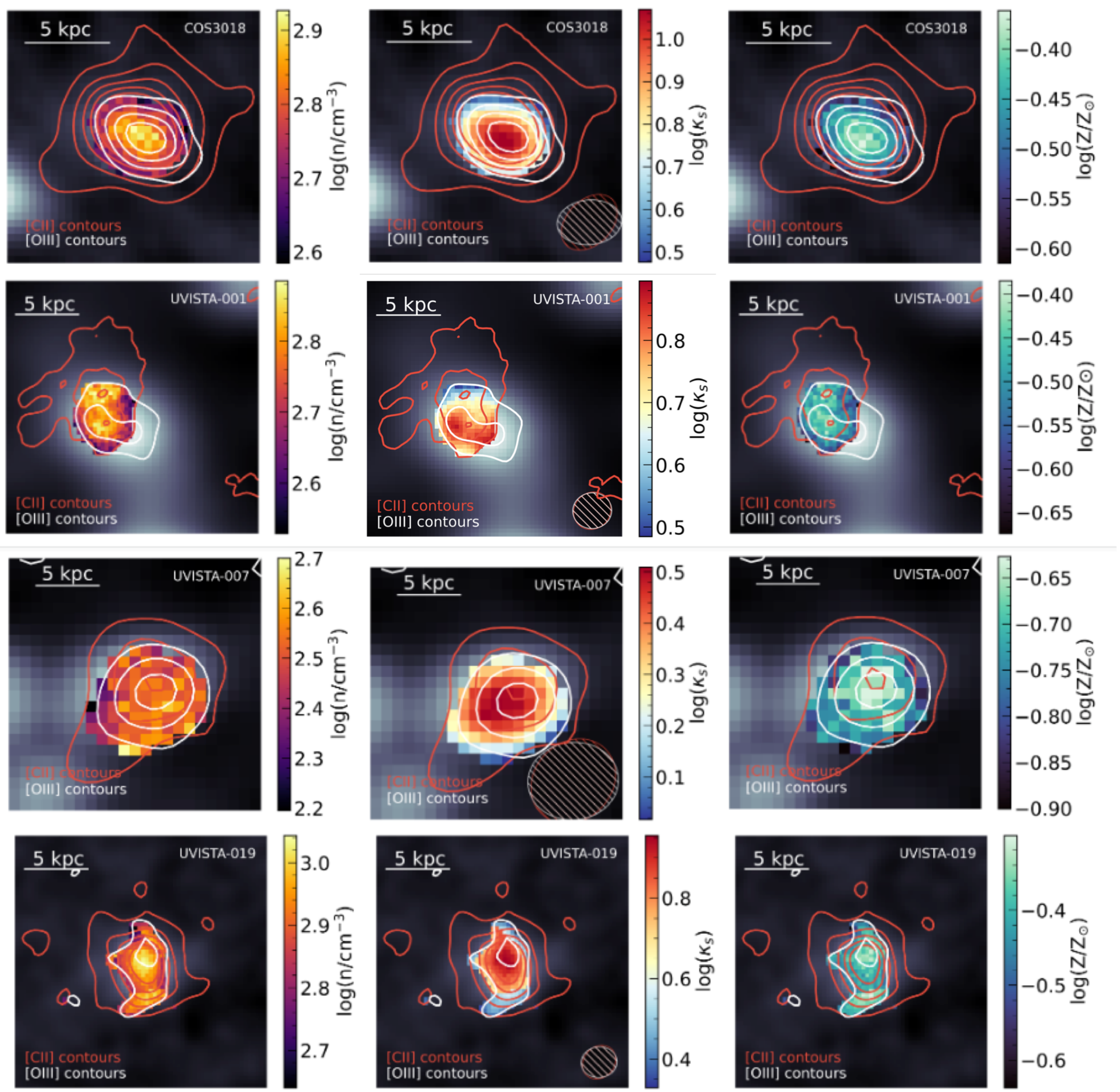


data from Witstok+22

GLAM

gas metallicity

GLAM at work on spatially resolved data



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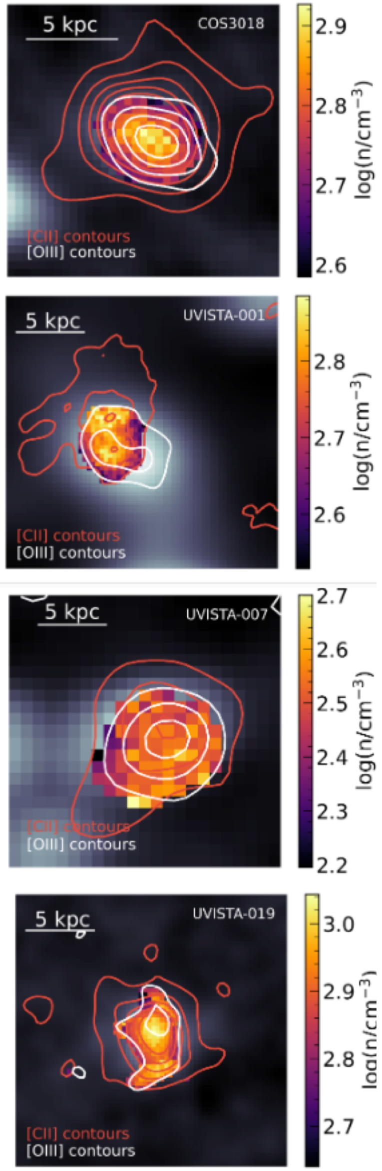
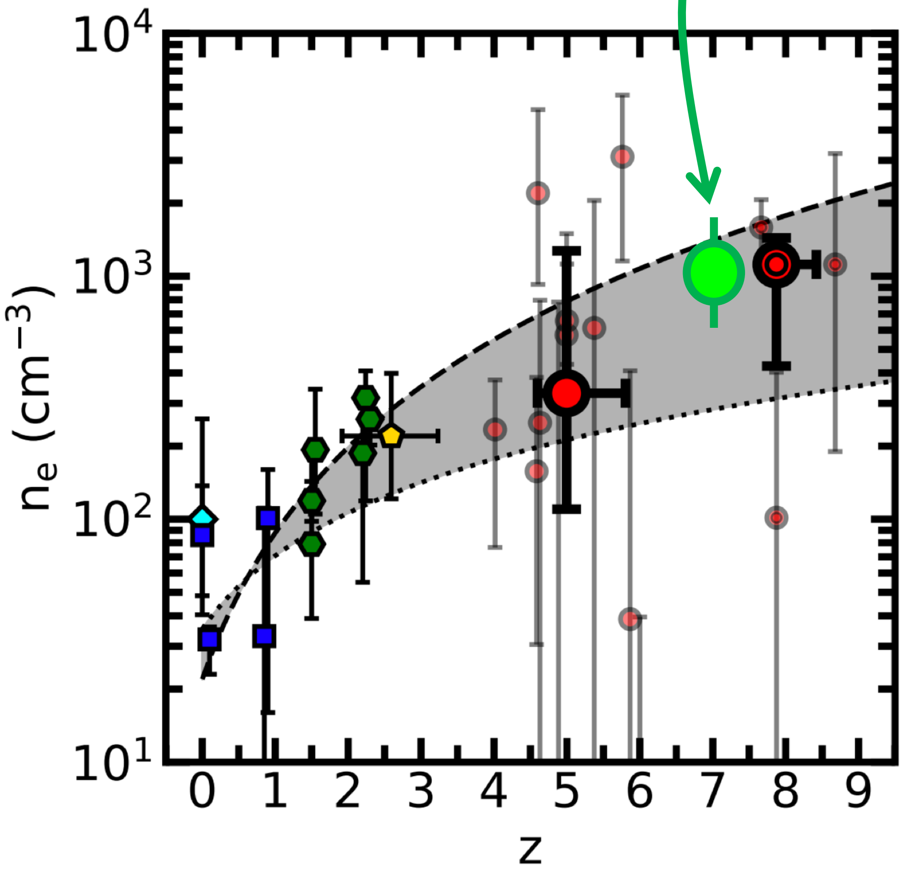
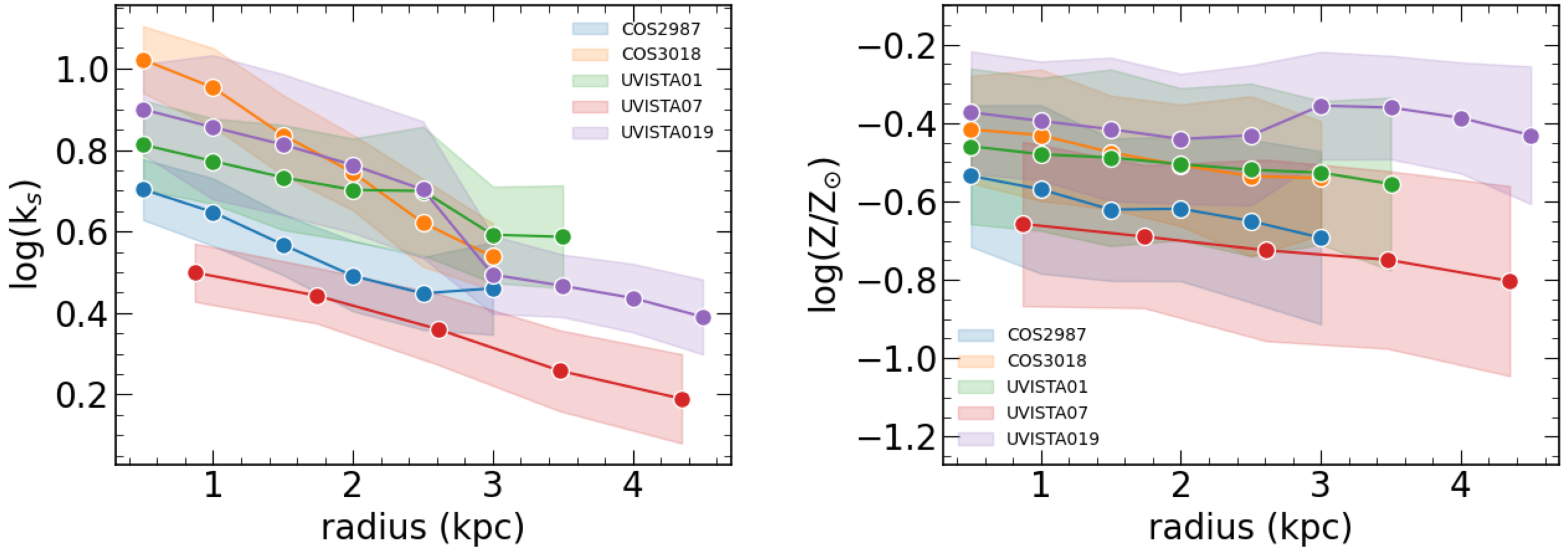


median density derived in the sample

Isobe+23



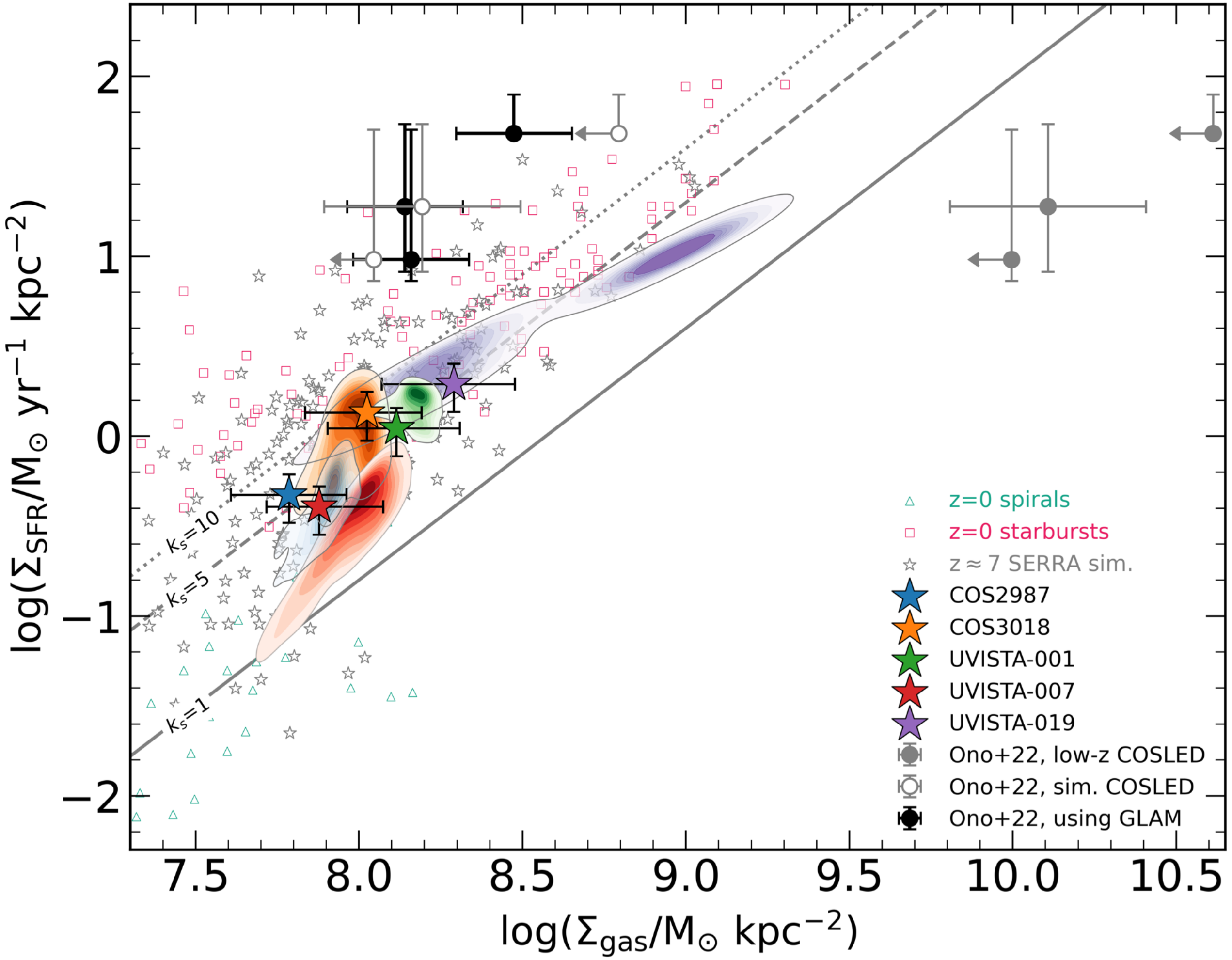
Radial profiles: burstiness and metallicity



Vallini+23, in prep.

The Kennicutt-Schmidt relation

Vallini+23, in prep.



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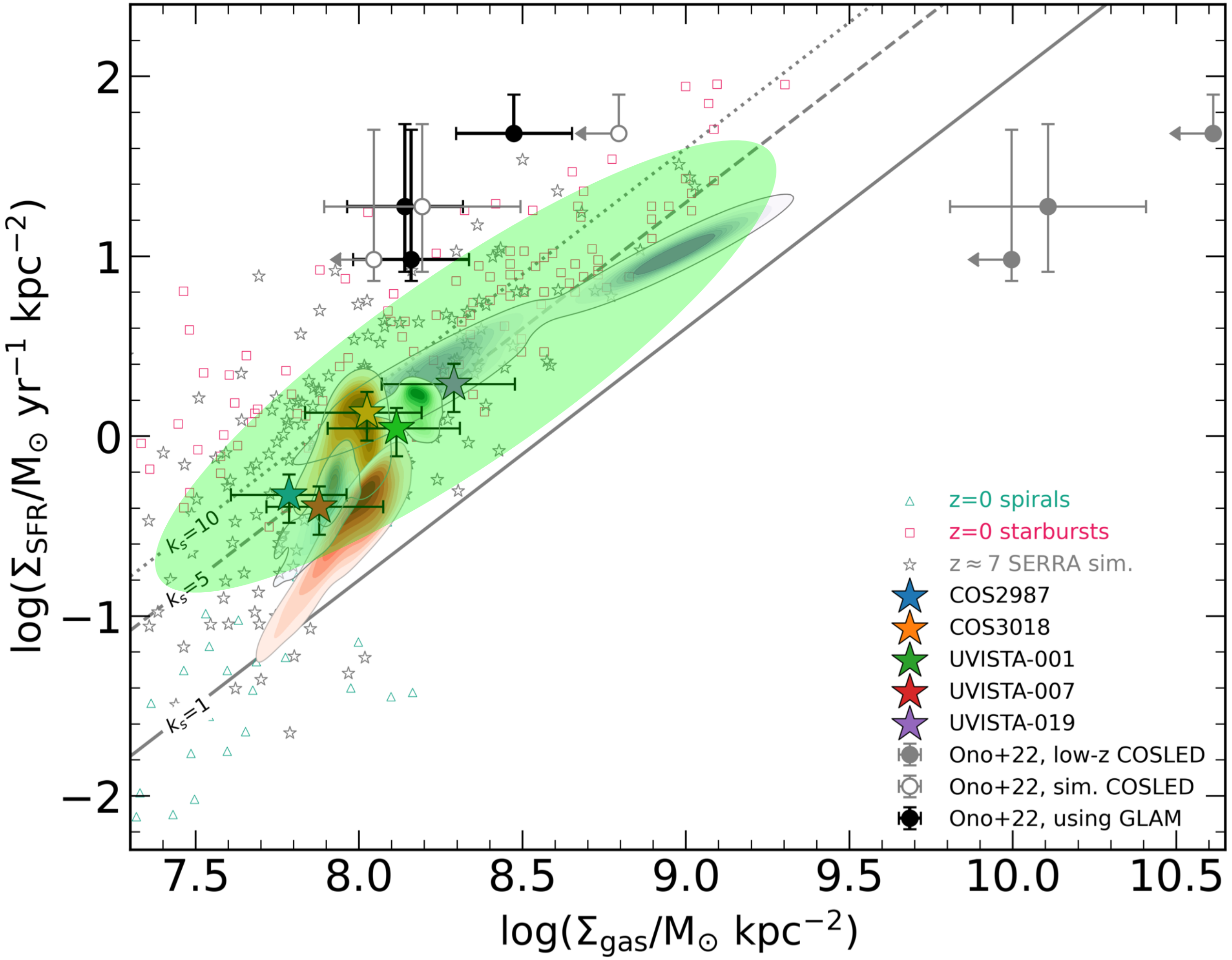
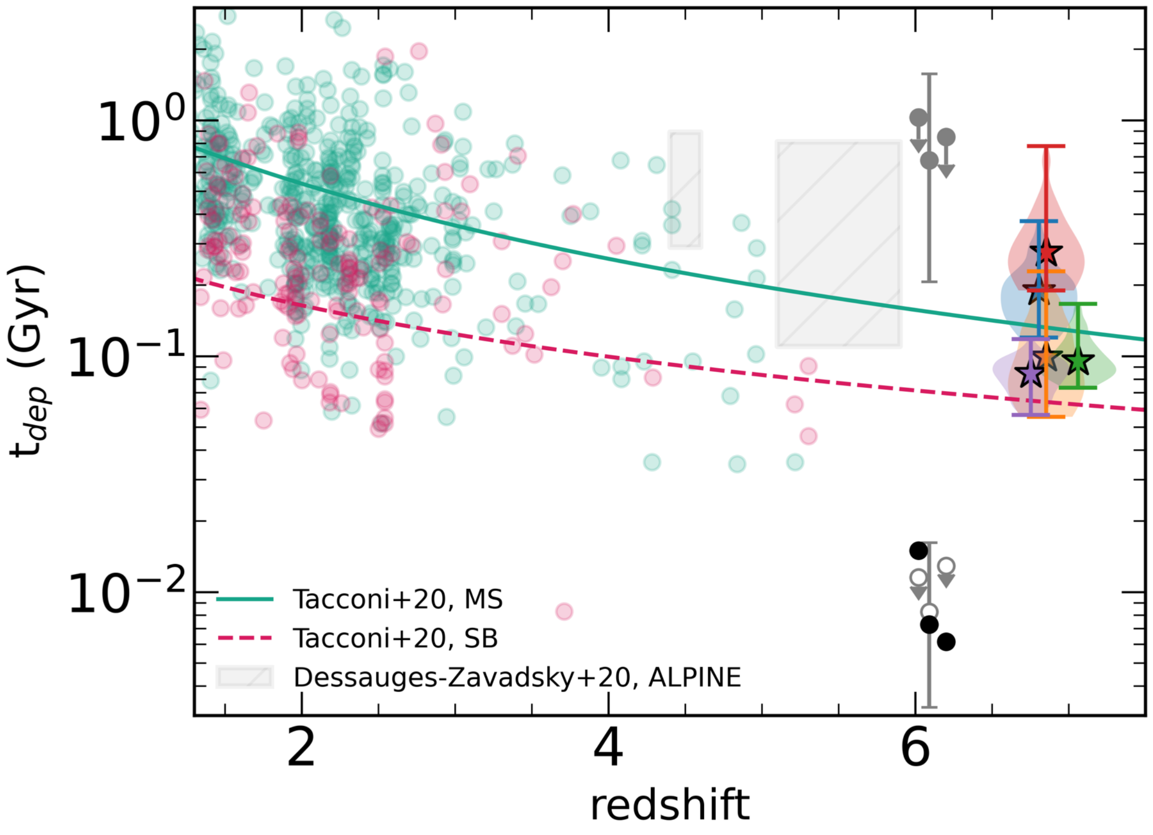


Evolution of the depletion time

Vallini+23, in prep.



Conclusions

The gas density peaks within the range log(n/cm−3) = 2.5 – 3.0, depending on the source.
The **gas densities obtained are higher than typical values in local galaxies**, hence suggesting an overall increase in the mean gas density in the ISM at early epochs.

Conclusions

- The gas density peaks within the range log(n/cm−3) = 2.5 – 3.0, depending on the source. The **gas densities obtained are higher than typical values in local galaxies**, hence suggesting an over-all increase in the mean gas density in the ISM at early epochs.

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The gas depletion times, derived by using the KS relation, **are in the range $t_{dep} \approx$ 80–250 Myr**.
They fall between that predicted by the extrapolation out to $z \approx 7$ of for MS and SB galaxies