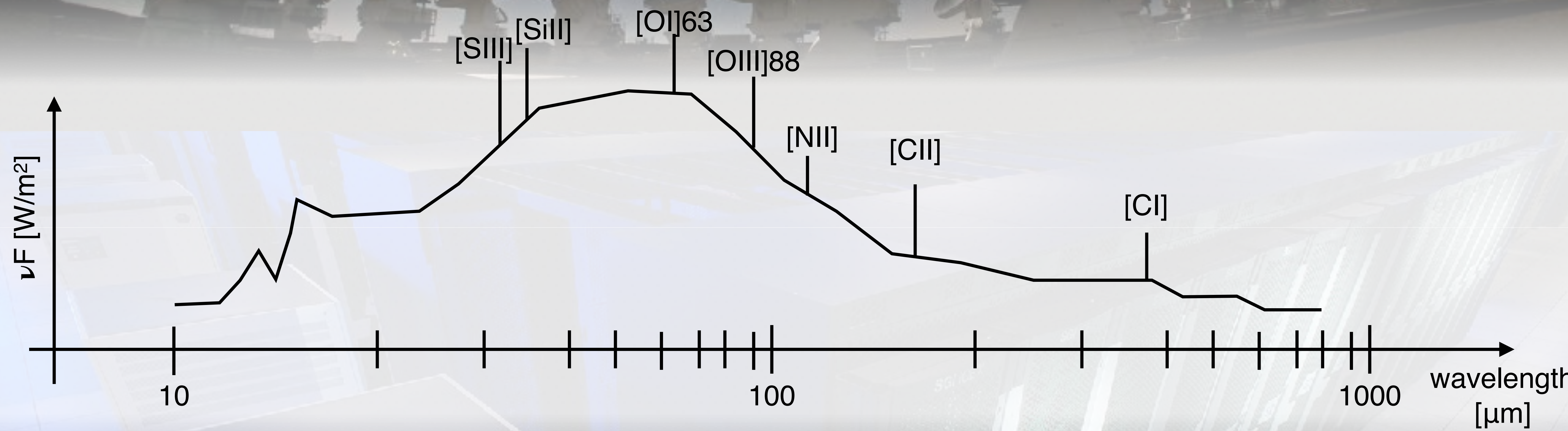
Simulations of FIR line emission from galaxies at high redshift

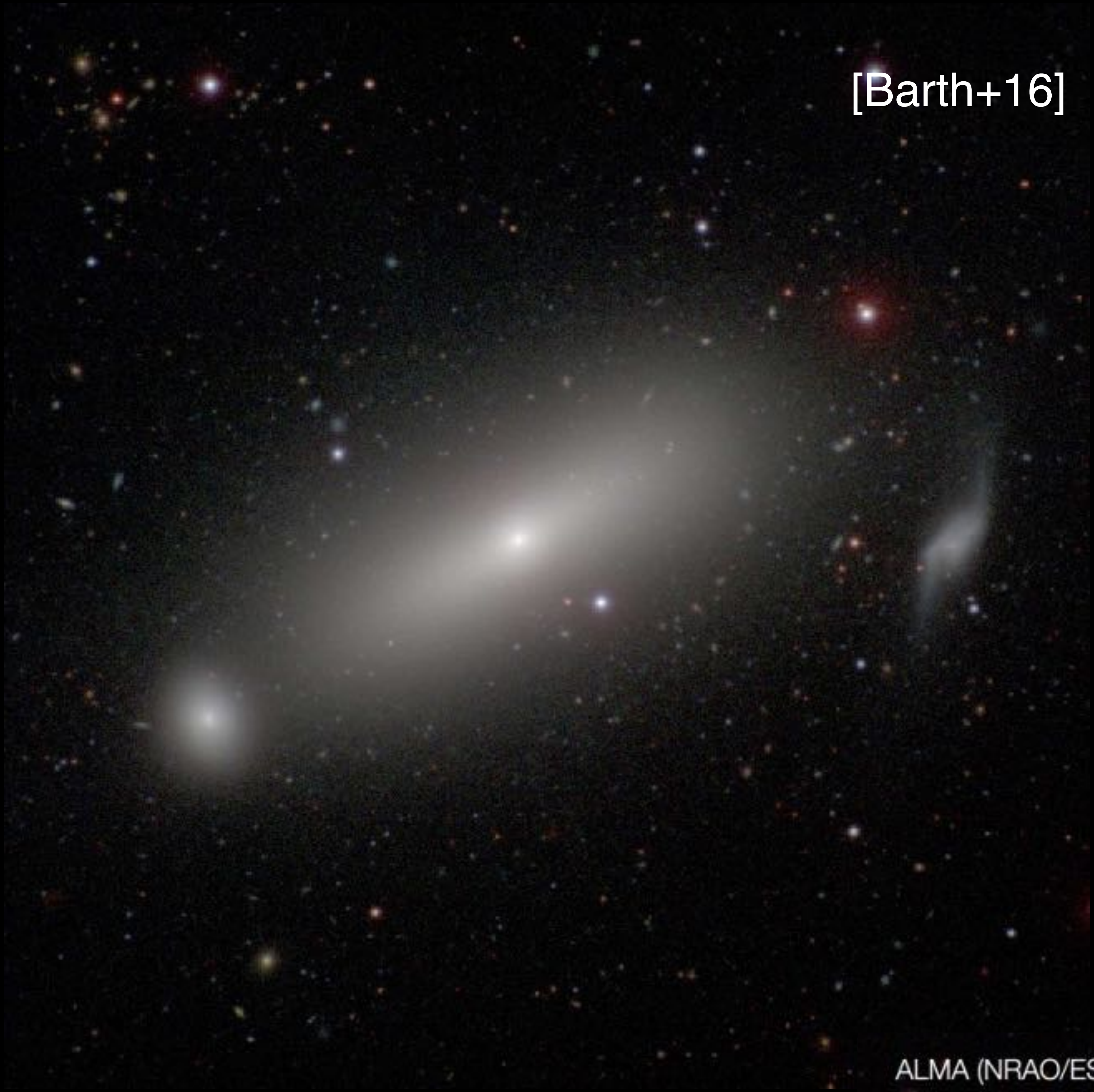
Karen Pardos Olsen



SESE, Apr 28 2018

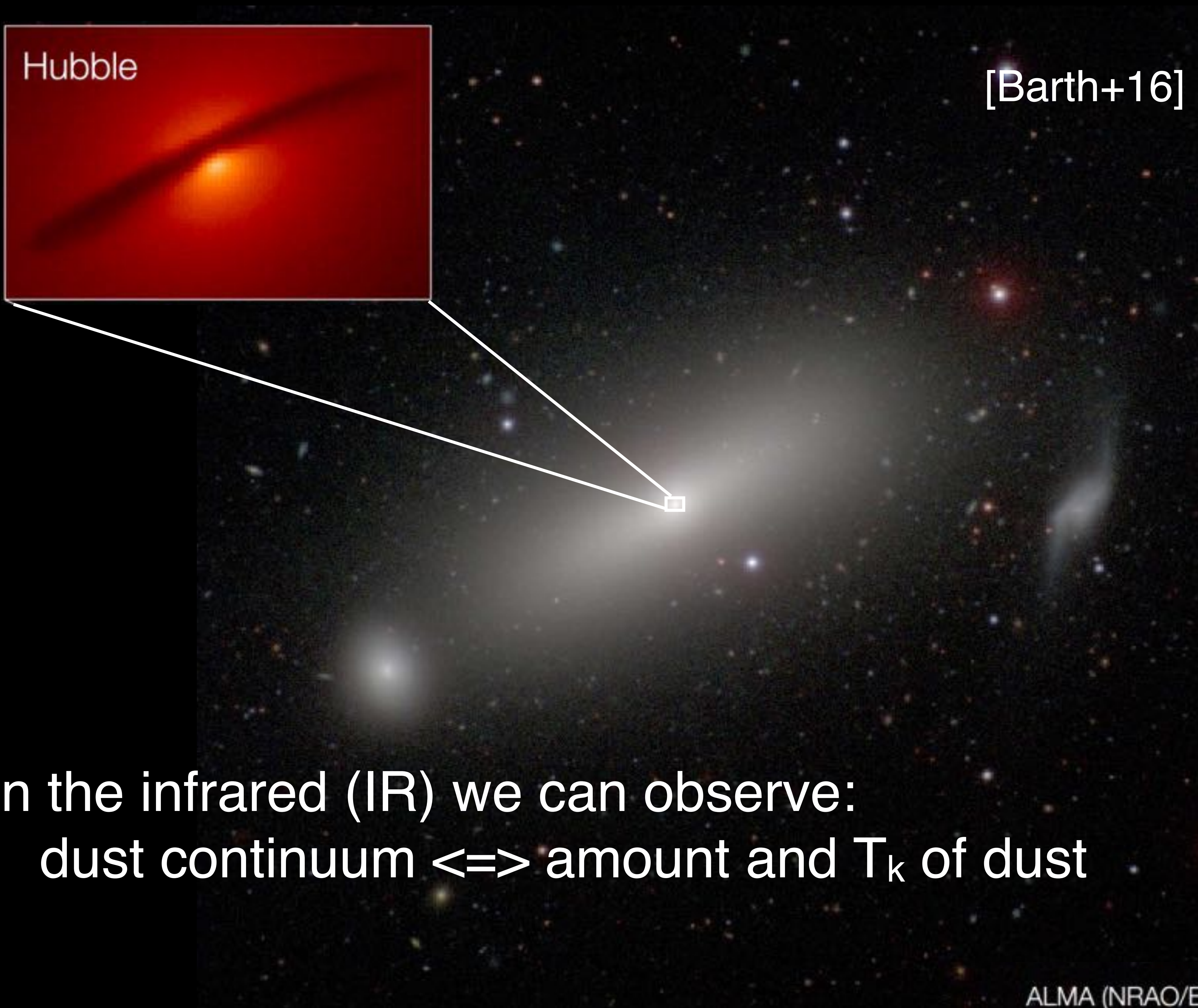
SESE, ASU

NGC 1332



ALMA (NRAO/ESO/NAOJ) /
Hubble Space Telescope (NASA/ESA) /
Carnegie-Irvine Galaxy Survey

NGC 1332



In the infrared (IR) we can observe:

- dust continuum <=> amount and T_k of dust

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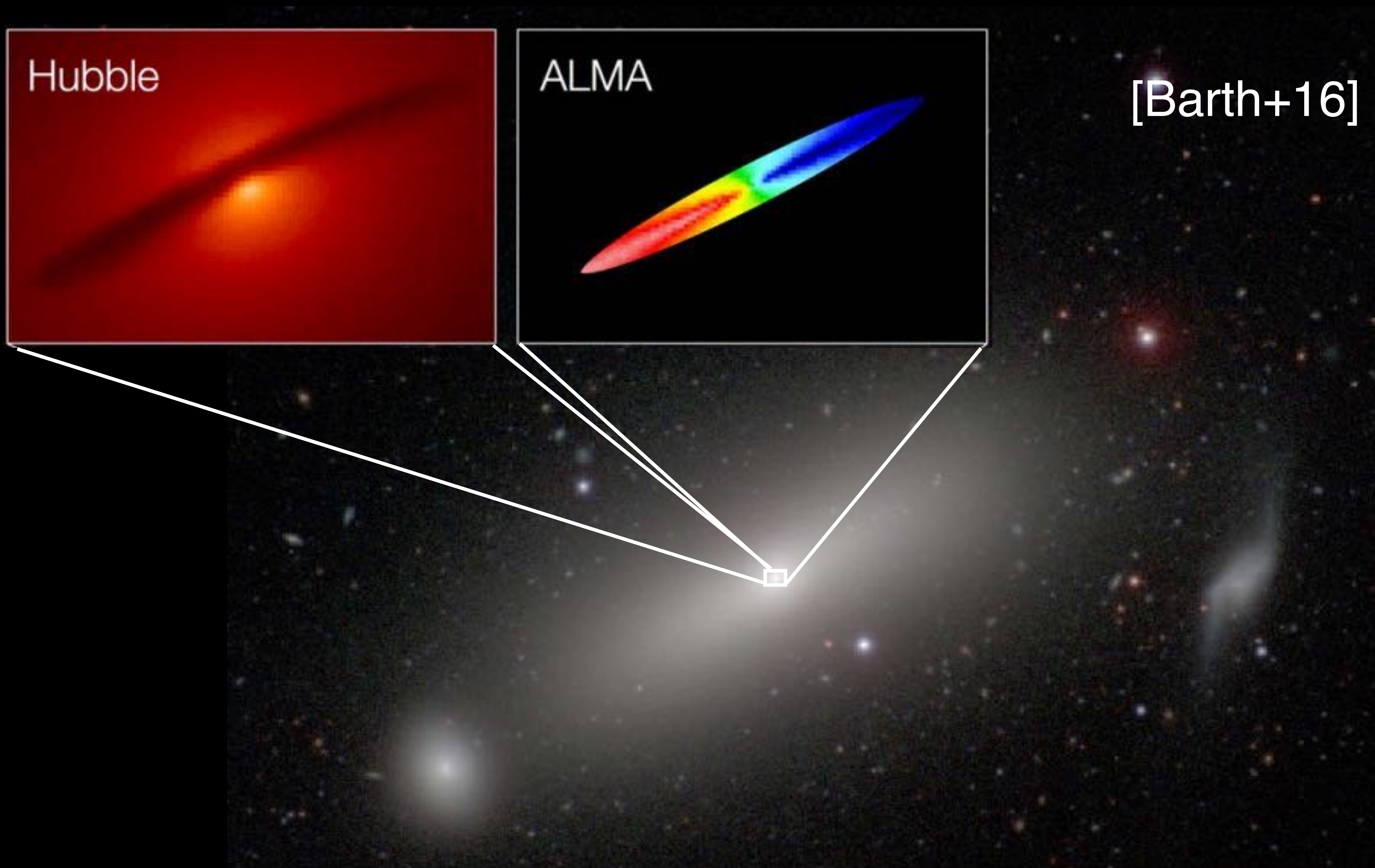

In the infrared (IR) we can observe:

- dust continuum <=> amount and T_k of dust
- line emission <=> amount, motion and state of gas

ALMA (NRAO/ESO/NAOJ) /
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Observing the gas at high redshift

Observing the gas at high redshift

Forbidden atomic emission lines from
the warm-phase interstellar medium (ISM)

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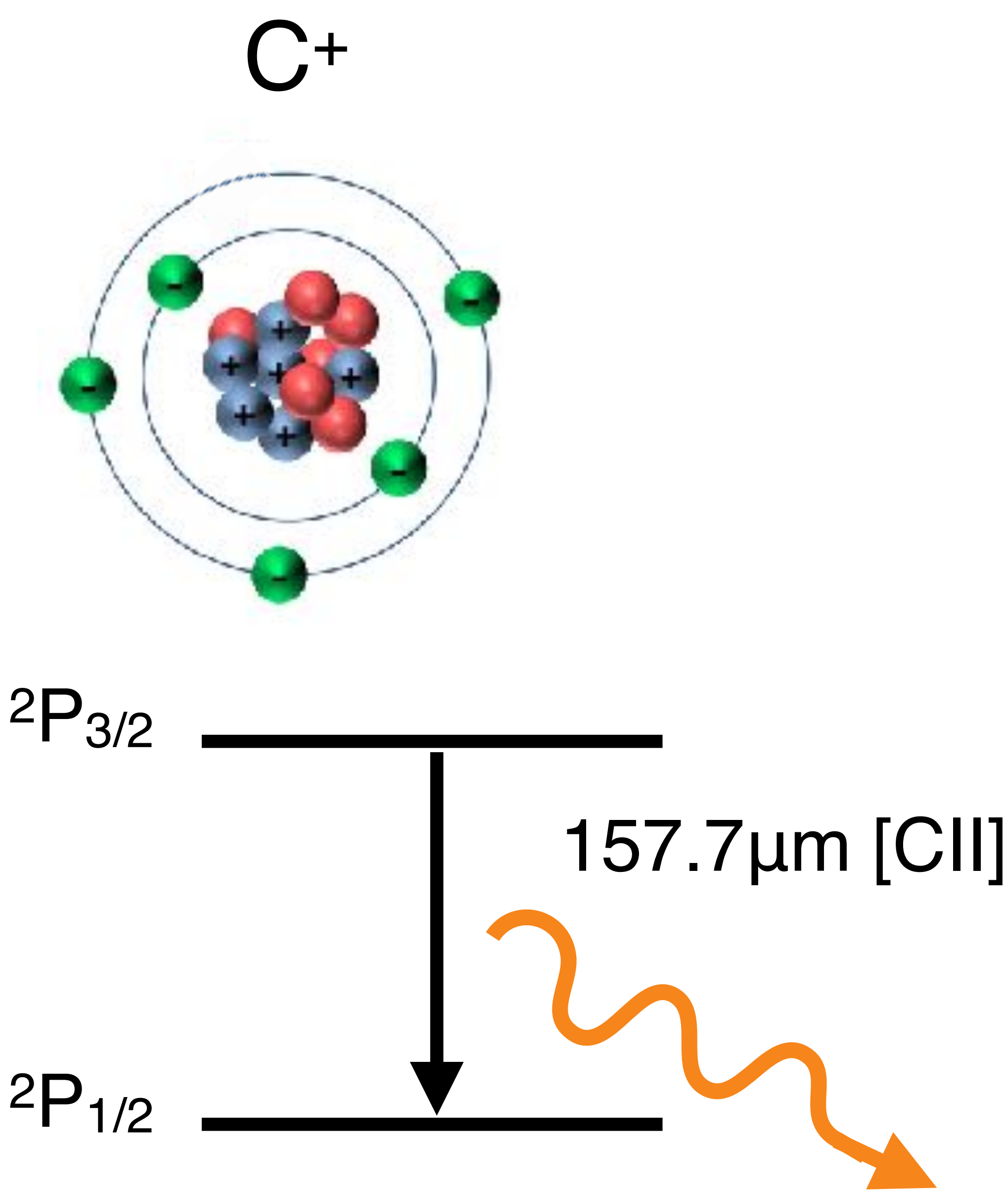
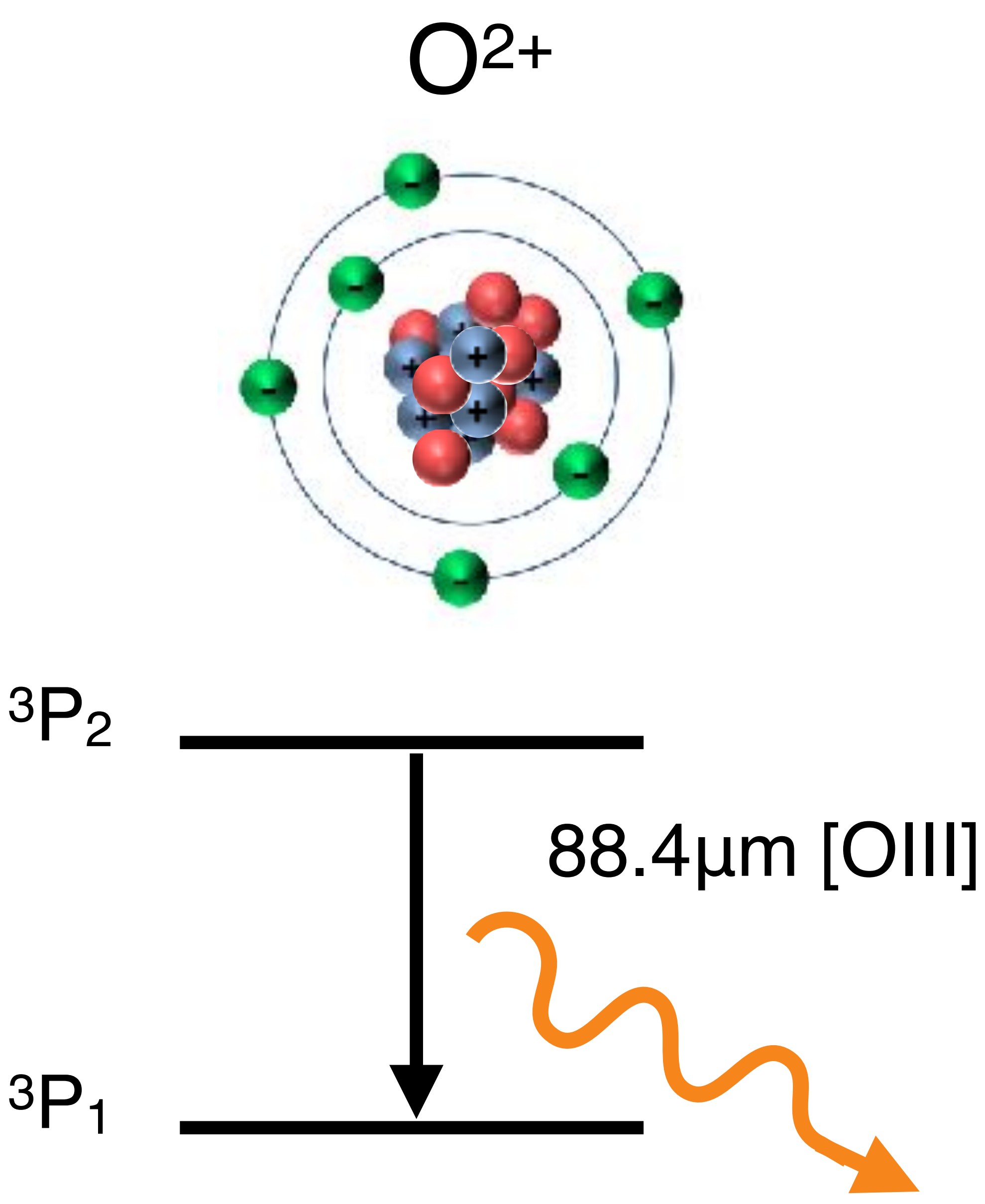
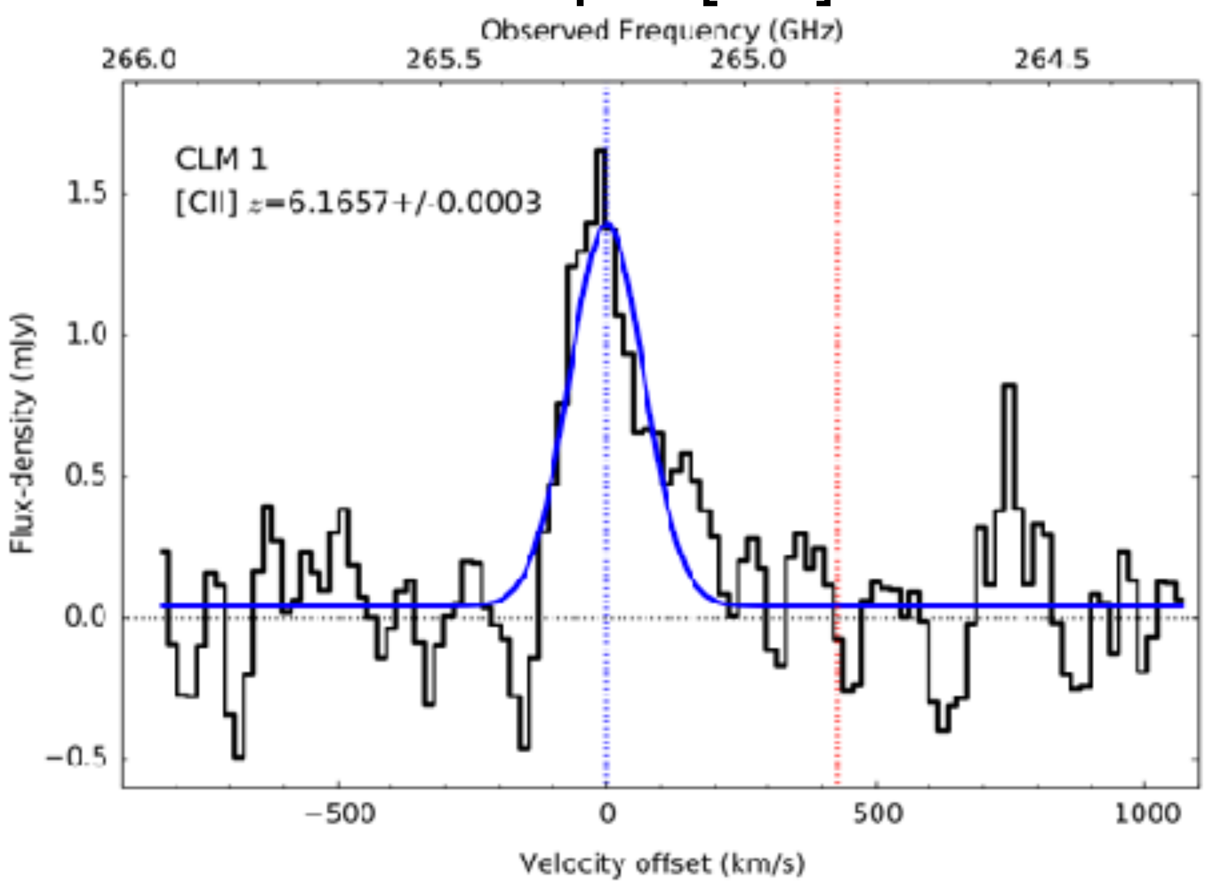




Observing the gas at high redshift

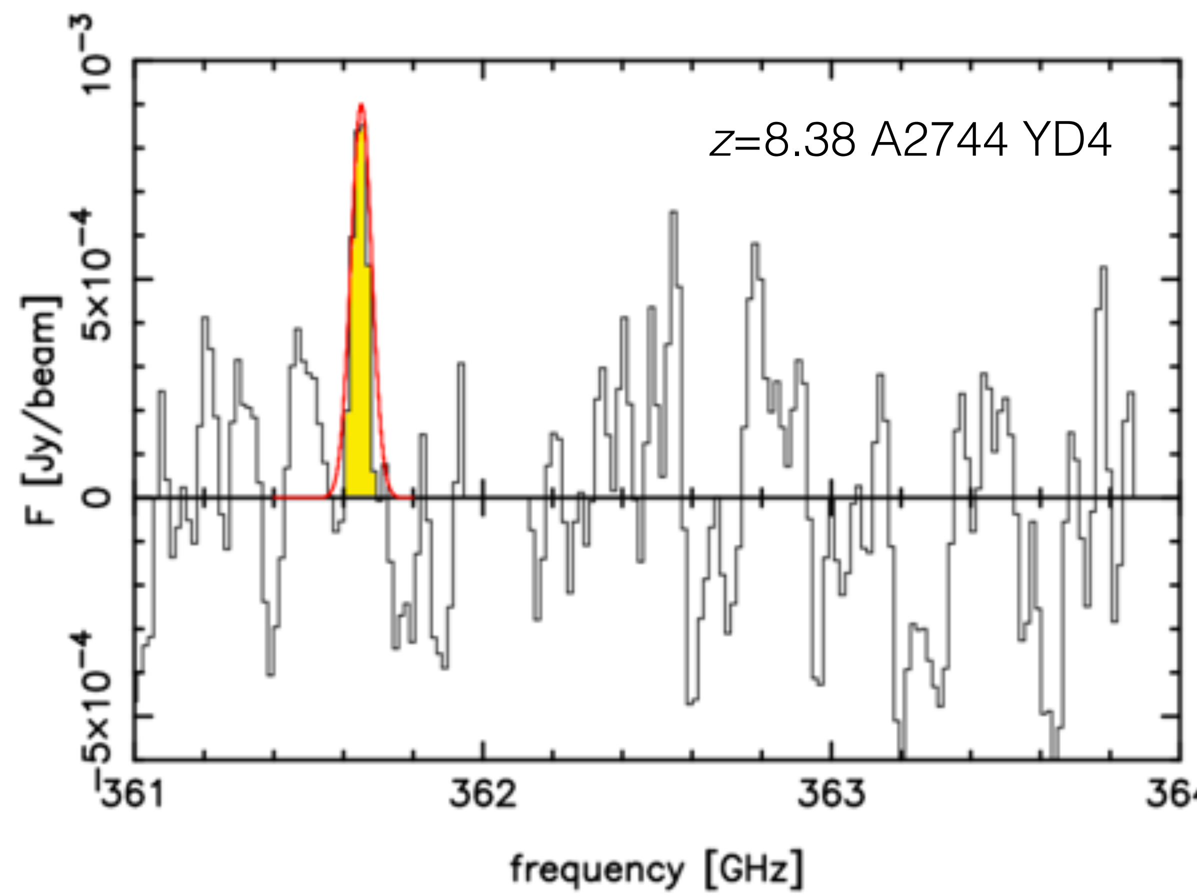
Examples

157.7μm [CII]



1.6hrs ALMA time (μ~1.13)
[Willott+15]

88.4μm [OIII]



2.5hrs ALMA time (μ~2)
[Laporte+17]

Observing the gas at high redshift

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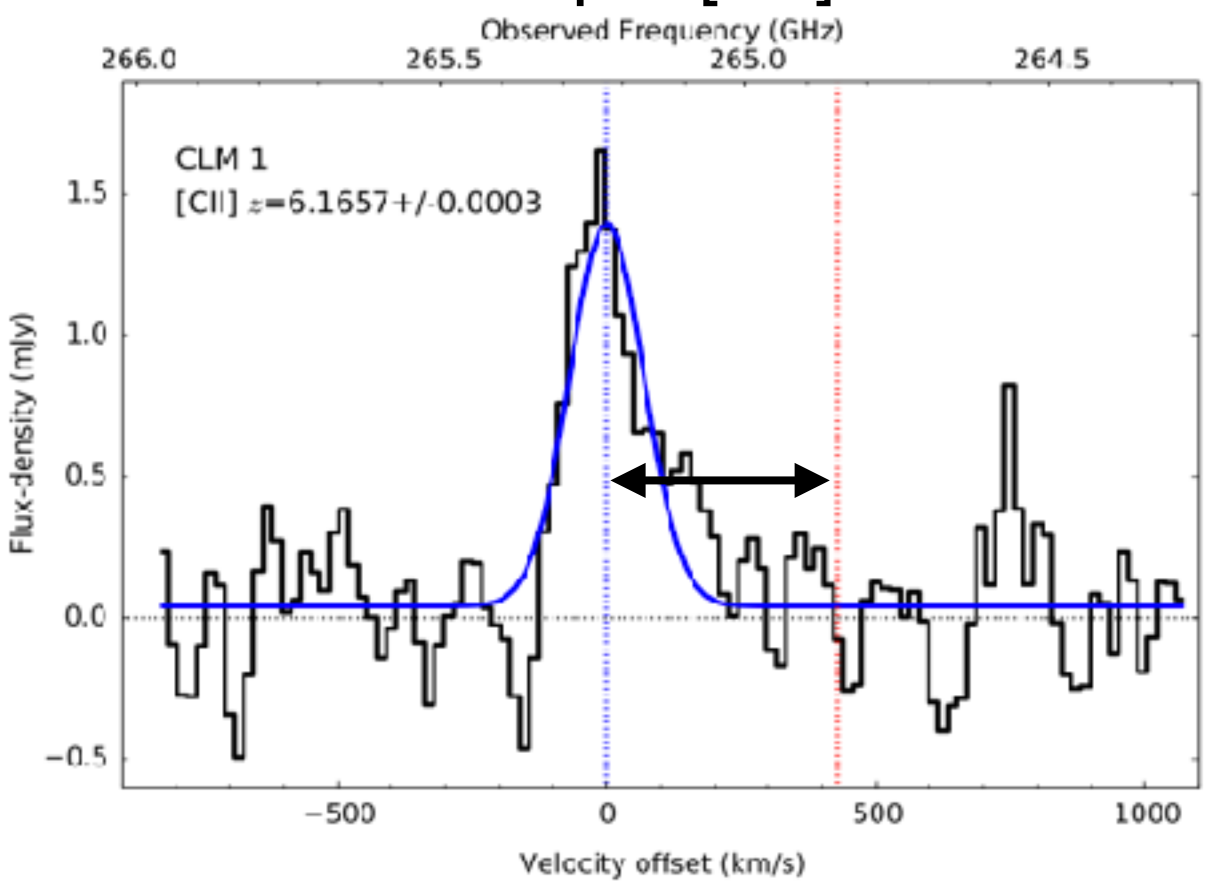

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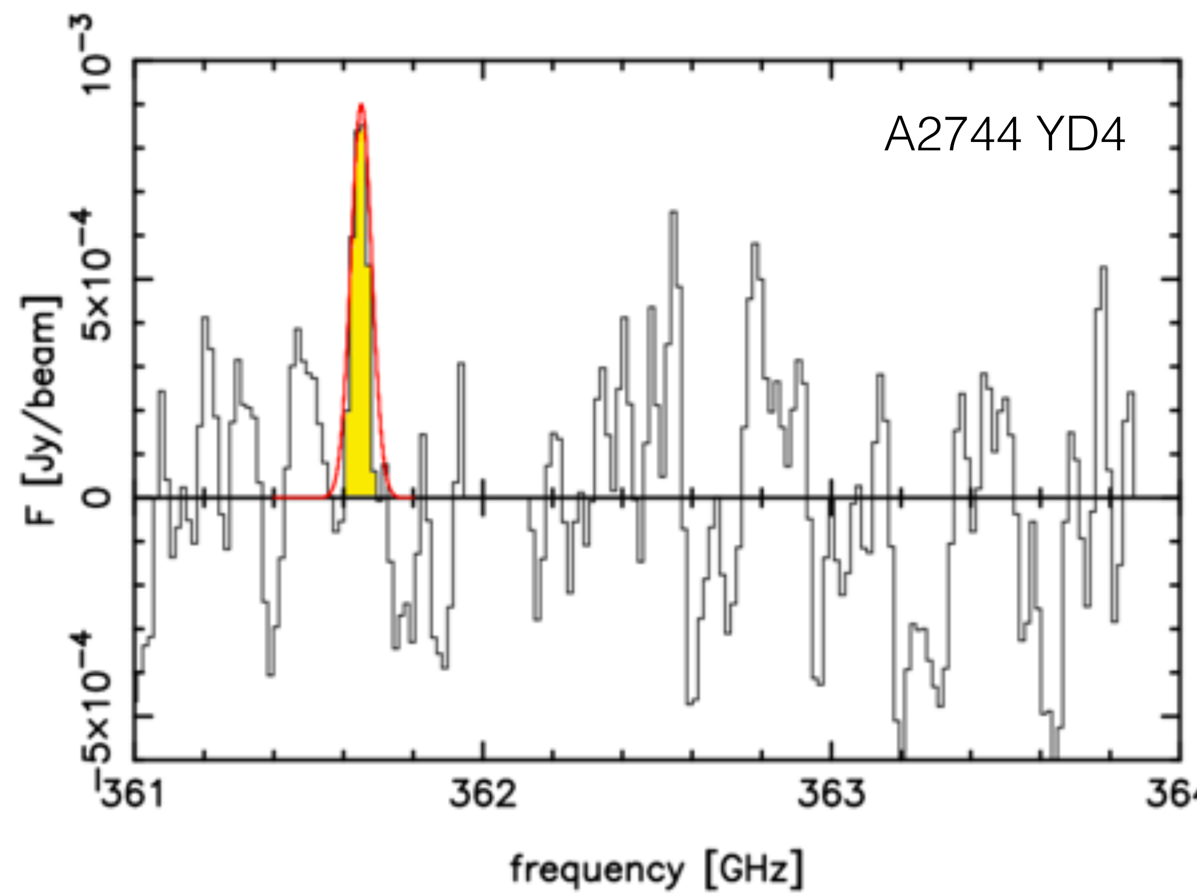
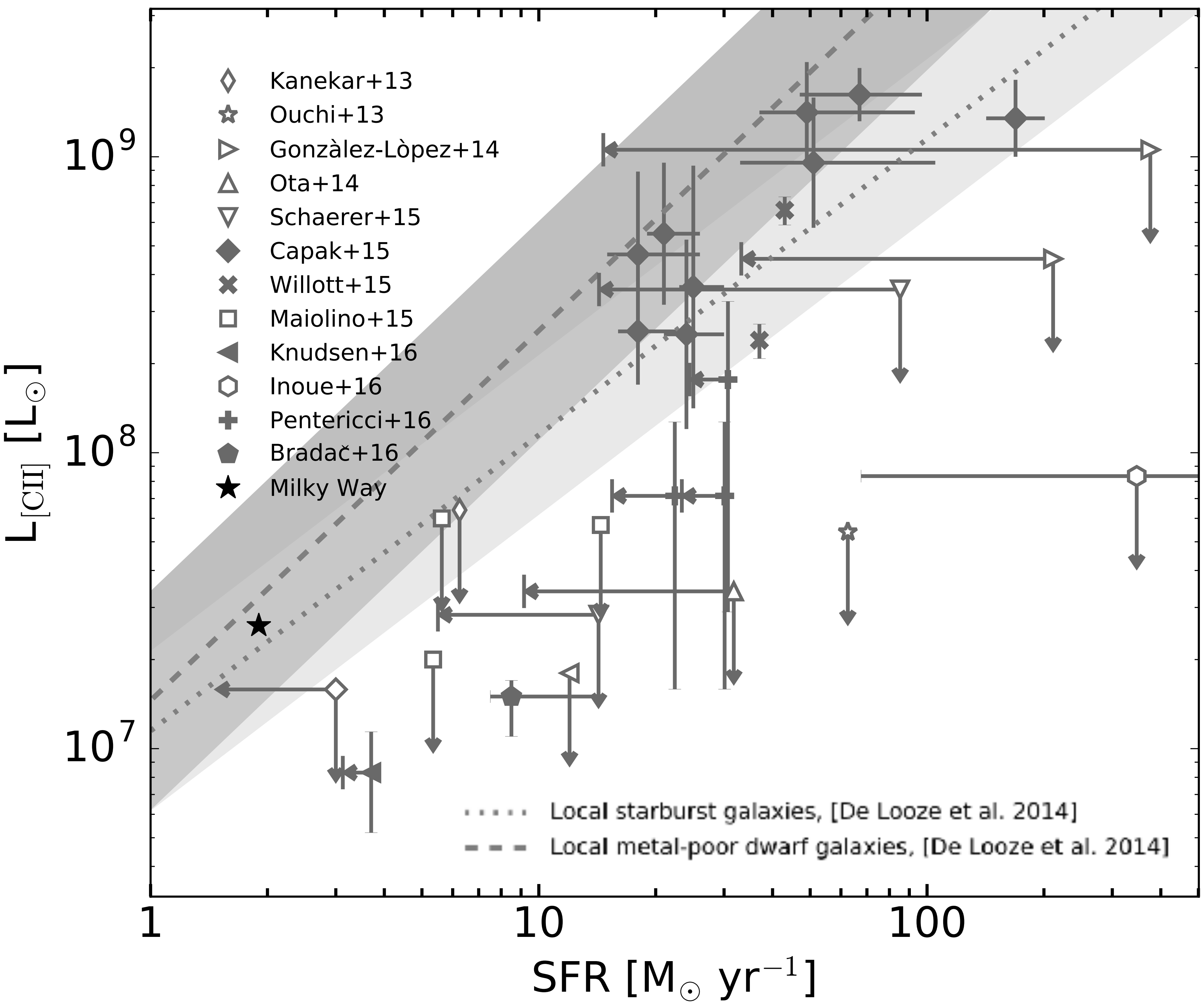


2.5hrs ALMA time (μ~2)
[Laporte+17]

Improvement of intrinsic redshift, compared to when using Lyα!

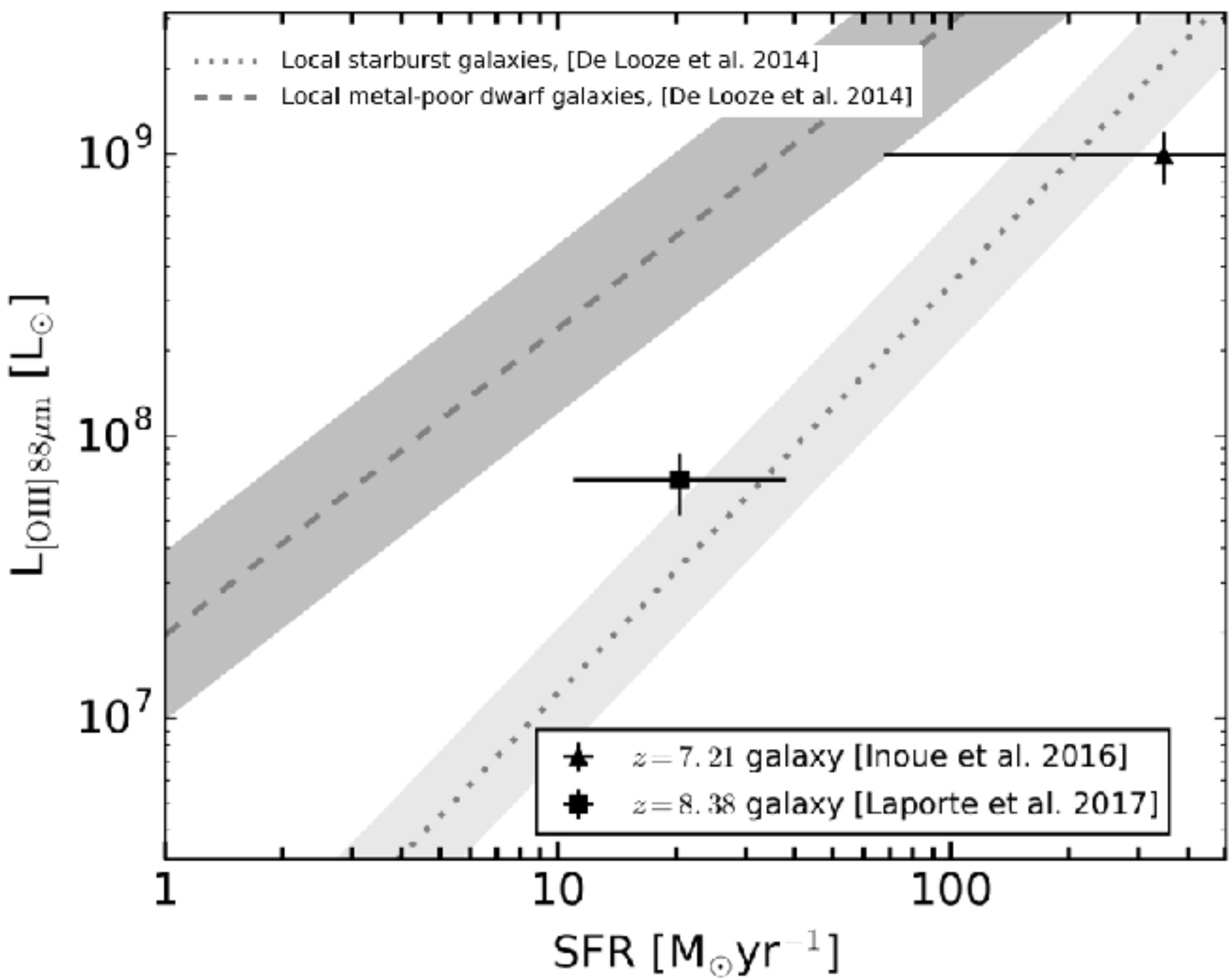
[CII]-SFR relation at high redshift (?)

- Ionization potential (11.3eV) below that of hydrogen (13.6eV)
- Excited by collisions with either electrons, atoms or molecules



[OIII]-SFR relation at high redshift (?)

- Ionization potential about the same as for hydrogen (13.5eV)
- Excited by electrons



Observing the gas at high redshift

Questions that arise:

1. Why is there no strong [CII]-SFR relation?

2. How does *Z* affect [CII]?

3. What is the origin of [CII]?

4. [OIII] a better SFR-tracer?

SÍGAME

(=‘follow me’ in Spanish)

SImulator of GAlaxy Millimeter/submillimeter Emission

http://kpolsen.github.io/sigame/

SÍGAME

(='follow me' in Spanish)

SImulator of GAlaxy Millimeter/submillimeter Emission

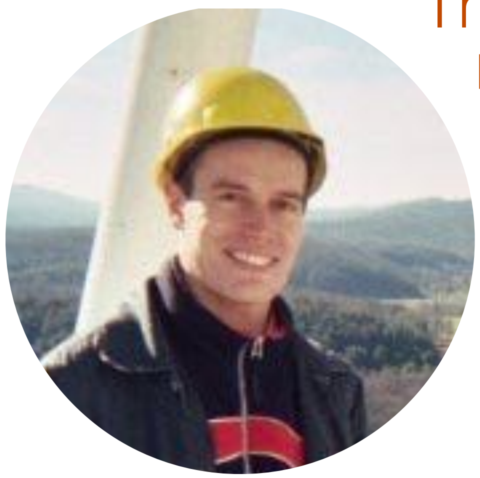
Aim:

- derive line emission from all ISM phases simultaneously
- cosmological simulations with self-consistent Z
- reliable local pressure and radiation field strength
- full chemistry
- control over the dust!

http://kpolsen.github.io/sigame/

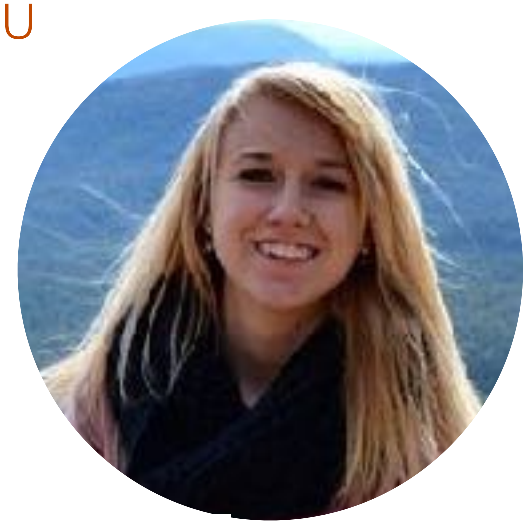
SImulator of GAlaxy Millimeter/submillimeter Emission

Current team:



Thomas R Greve
Dept of Physics and Astronomy, UCL, UK

Stephanie Stawinski
SESE, ASU



Luis Niebla Rios
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Jacob Cluff
SESE, ASU

Lily Whitler
SESE, ASU

Robert Thompson
National Center for Supercomputing Applications, Urbana, IL, USA

Desika Narayanan
Haverford College, PA, US

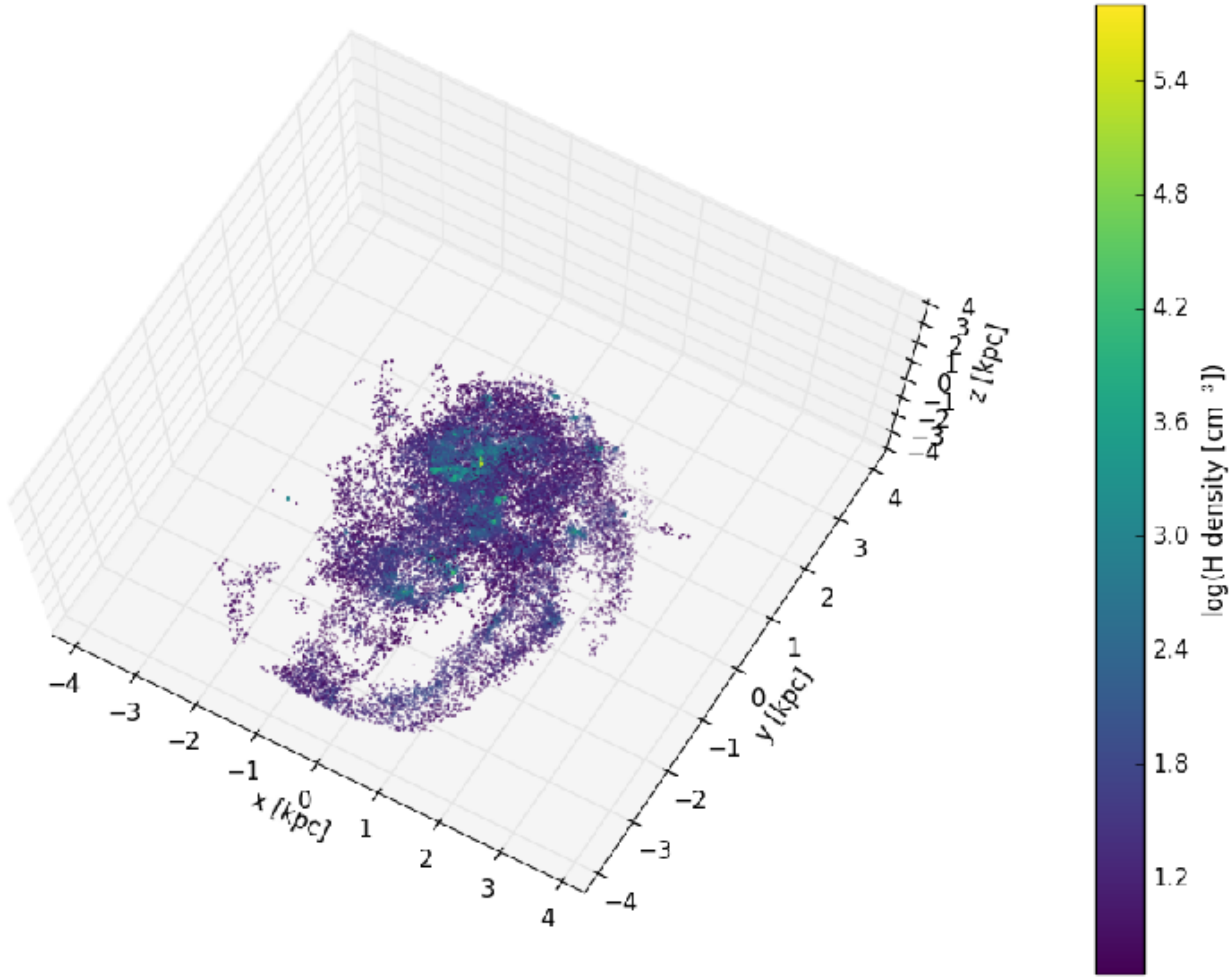
Romeel Davé
University of Western Cape, South Africa

Previous team members: Christian Brinch, Jesper Rasmussen, Jesper Sommer-Larsen, Sune Toft, Andrew Zirm

Key steps

Cosmological Smoothed Particle Hydrodynamics (SPH) simulations

(GIZMO simulations with MUFASA winds, see Davé+16 MNRAS 462)



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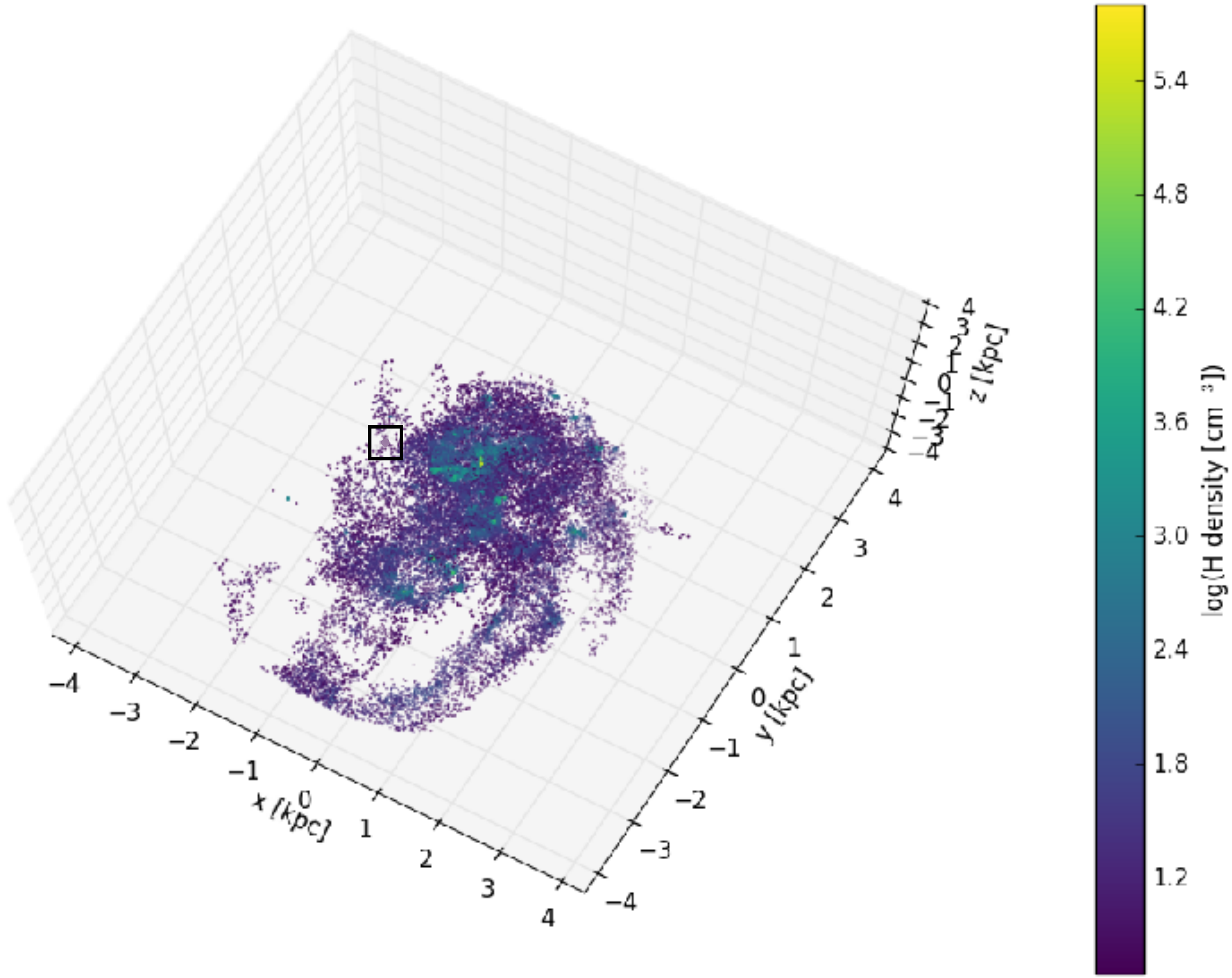
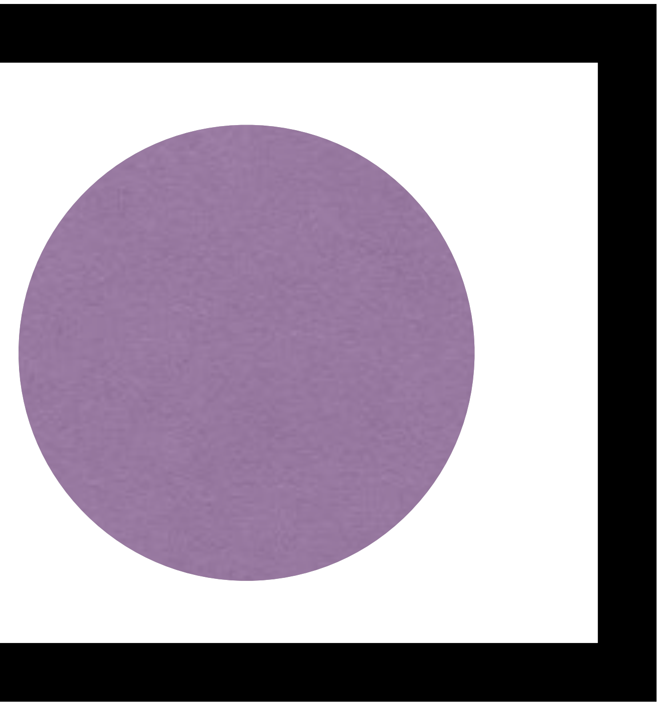


Key steps



Key steps

Step 1:
Derive "large-scale" properties

Fluid element:
[r, v, m_{SPH}, T_{SPH}, Z_{SPH}, h, x_e, f_{H2}]

Derived properties:
[G_0, P_{ext}]

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$m_{diffuse} = (1-f_{H2})m_{SPH}$

$R_{diffuse} = h$

$n_{diffuse} = m_{diffuse}/(4/3\pi h^3)$

$T_{diffuse} = T_{SPH}$

$m_{dense} = f_{H2}m_{SPH}$

$R_{GMC} \propto (m_{GMC})^{1/2}(P_{ext})^{-1/4}$

$\sigma_{v,GMC} \propto (m_{GMC})^{1/2}(P_{ext})^{1/4}$

$n_{GMC}(R) \propto R^{-1}$

Step 2: Divide into dense and diffuse gas

[Elmegreen+89; Swinbank+11]

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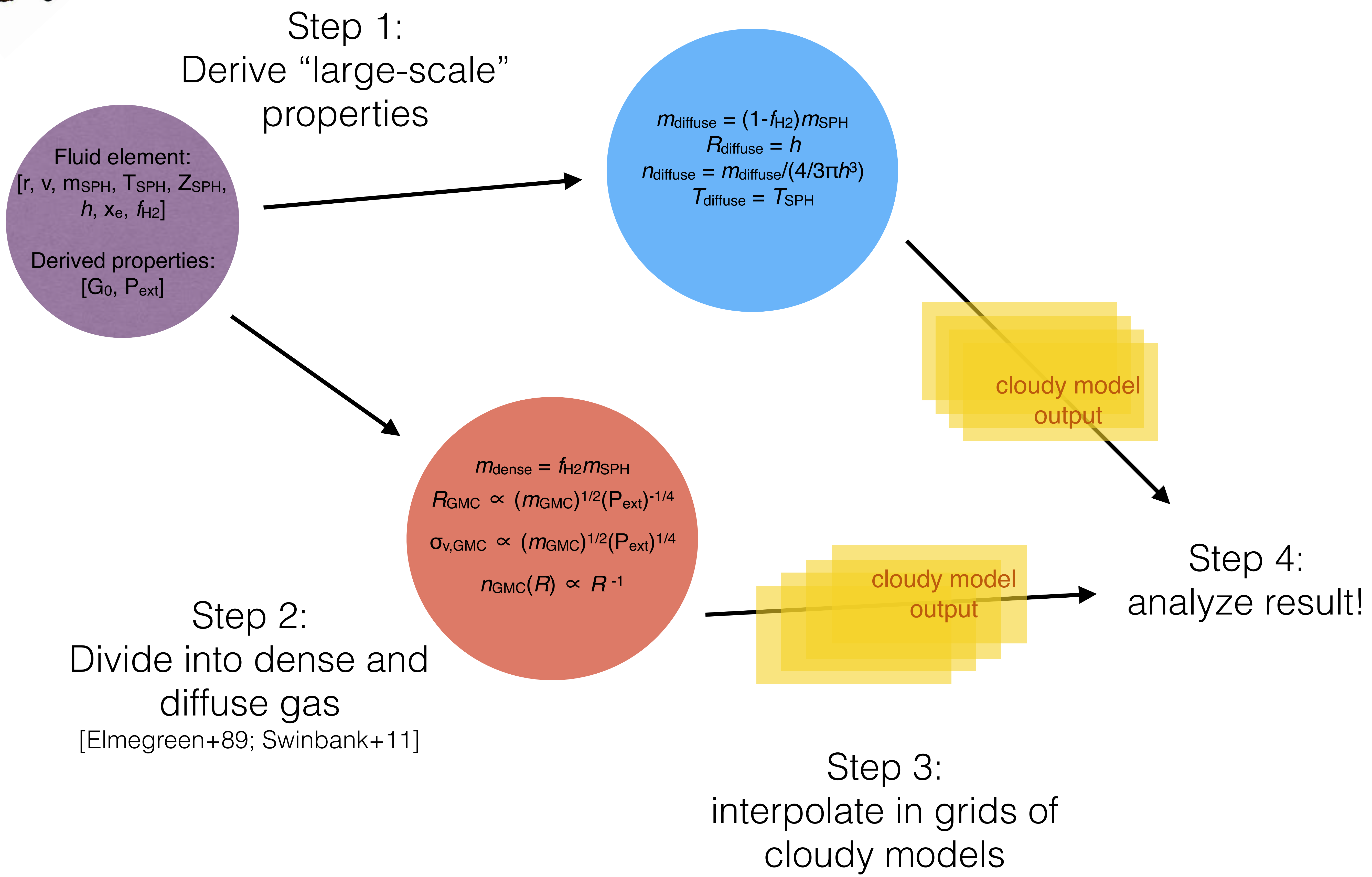
cloudy model output

cloudy model output

Key steps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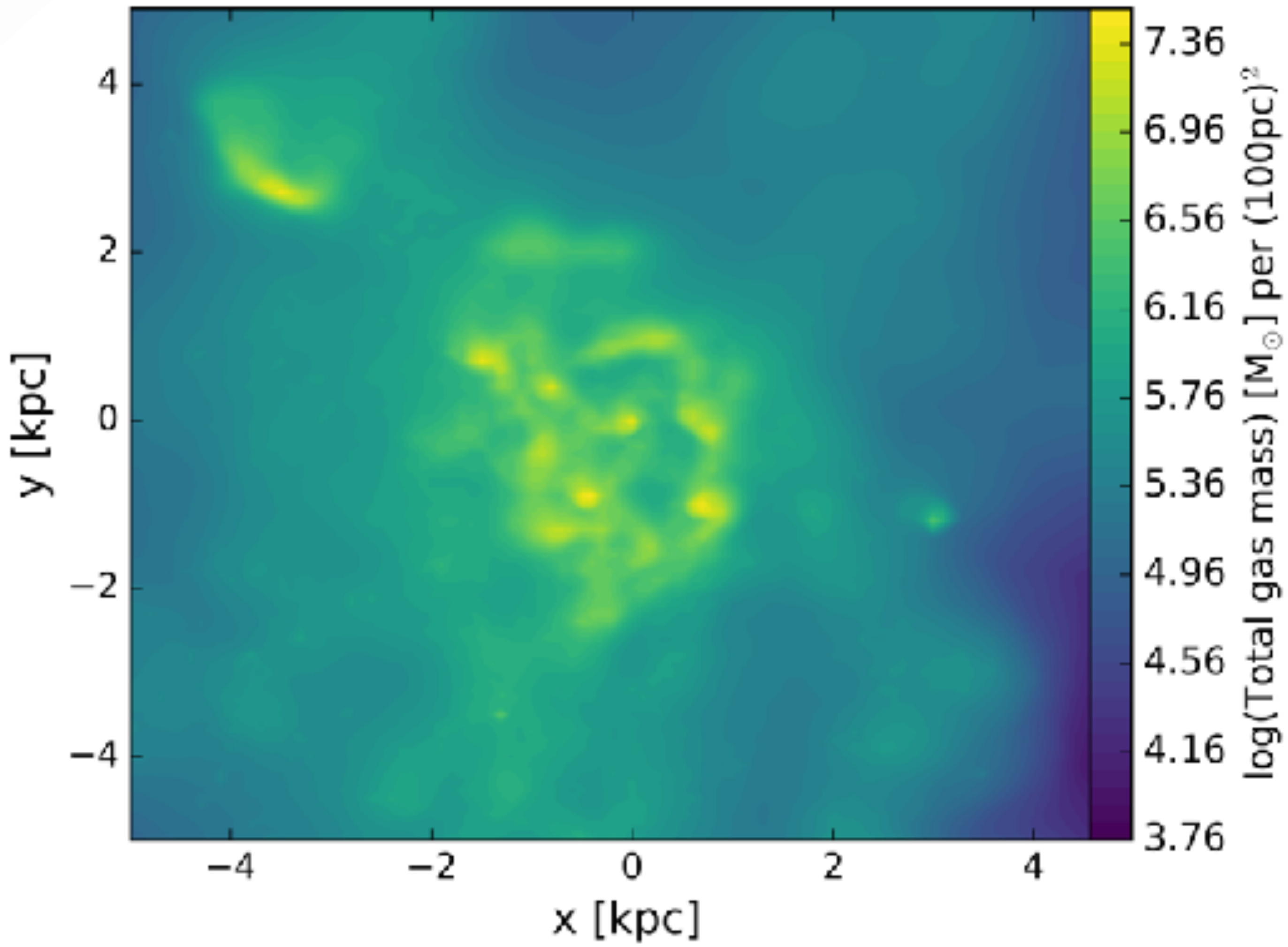
cloudy model output
Step 2:
Divide into dense and diffuse gas
[Elmegreen+89; Swinbank+11]
Step 3:
interpolate in grids of cloudy models
Step 4:
analyze result!

Deriving local gas properties

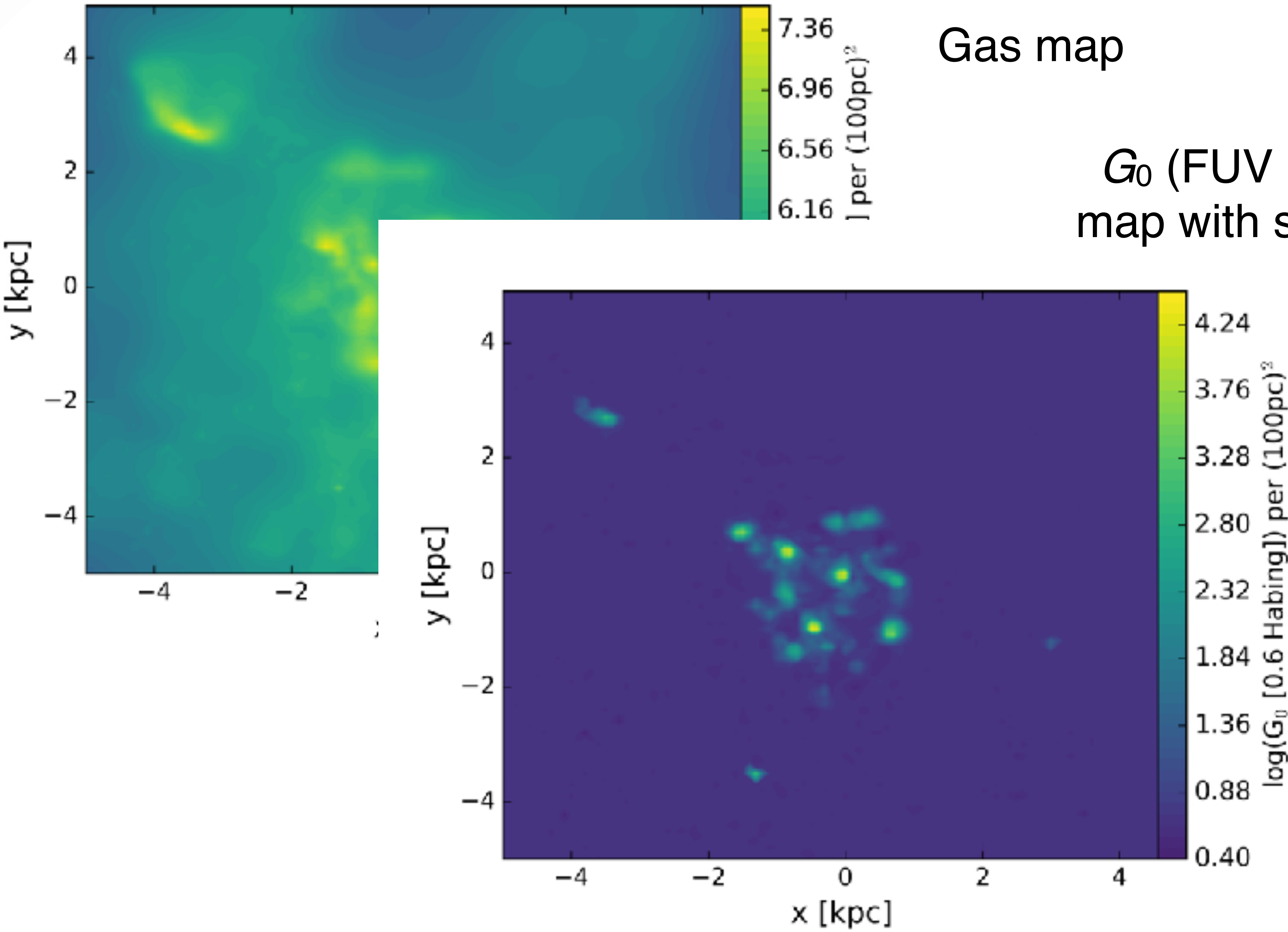


Gas map

Deriving local gas properties

Gas map

G_0 (FUV radiation) map with starburst99



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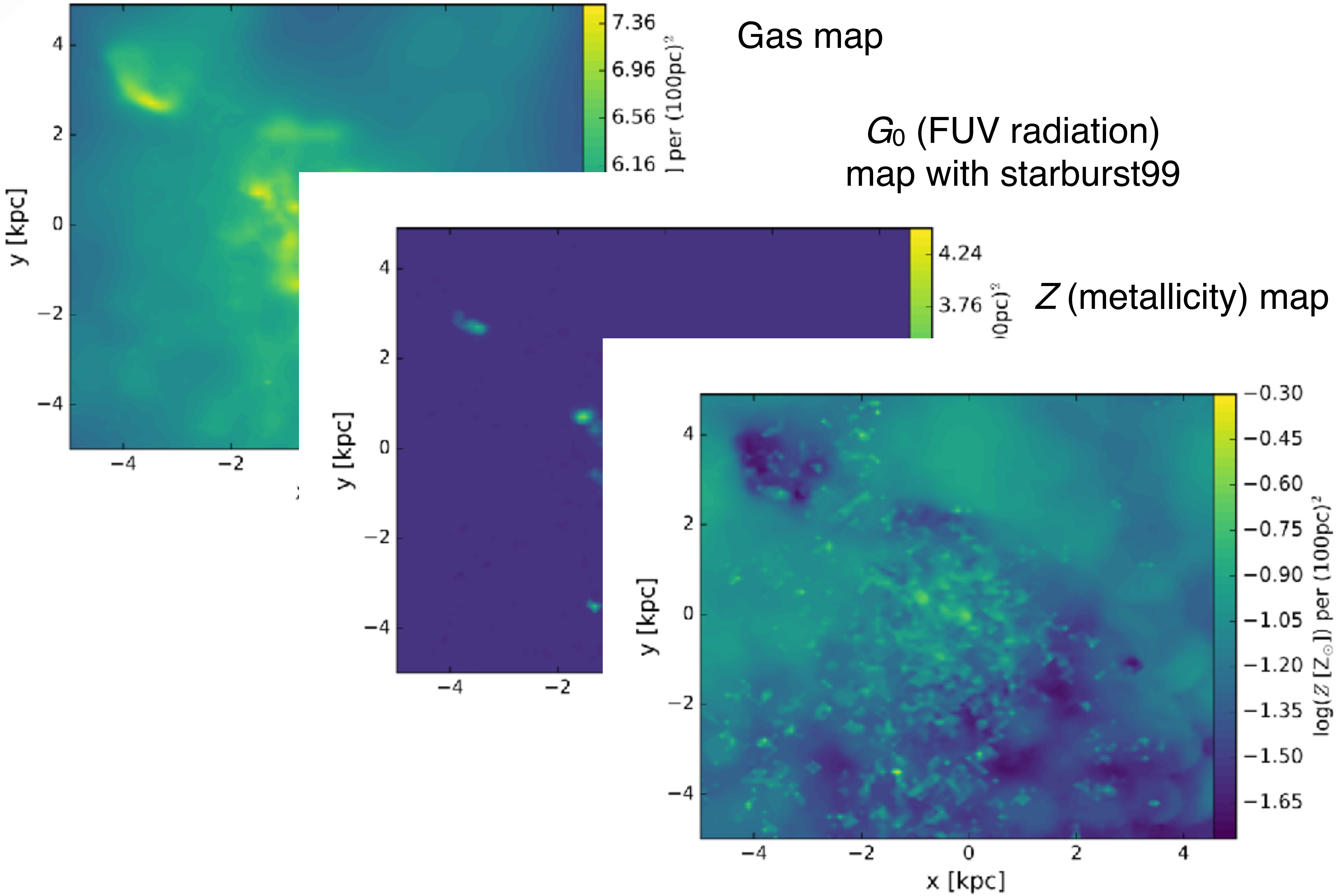
Deriving local gas properties



Gas map

G_0 (FUV radiation) map with starburst99

Z (metallicity) map

SÍGAME

Definition of ISM phases

Depending upon the output from simulations and cloudy models, SÍGAME divides the gas mass into:

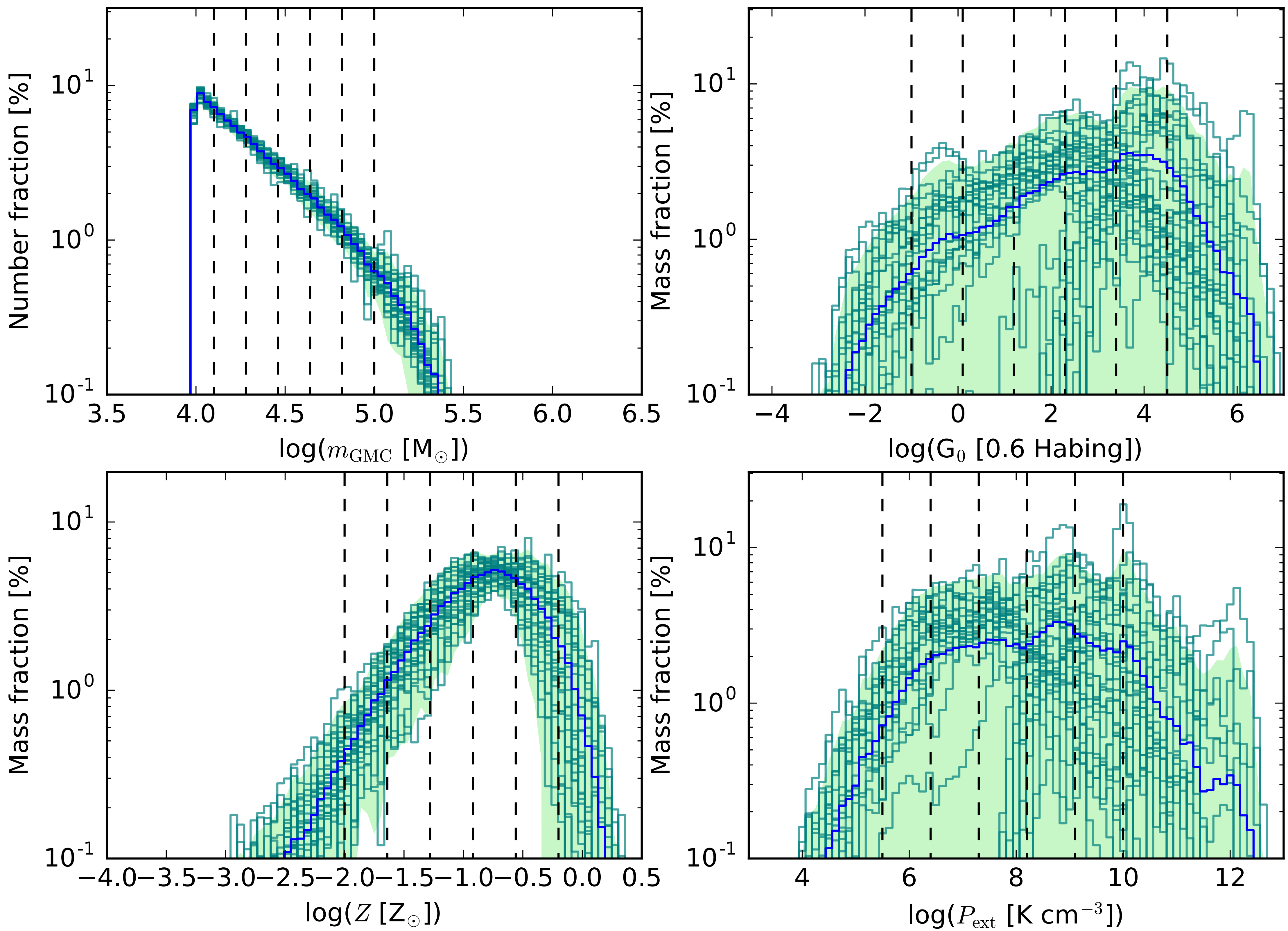
dense gas → **GMCs** (Giant Molecular Clouds): mostly molecular (but can contain partly ionized PDRs)

diffuse gas {

- **DNG** (Diffuse Neutral Gas): part of the diffuse gas clouds that is mostly neutral
- **DIG** (Diffuse Ionized Gas): part of the diffuse gas clouds that is mostly ionized

Cloudy models

Illustrating the GMC model grid



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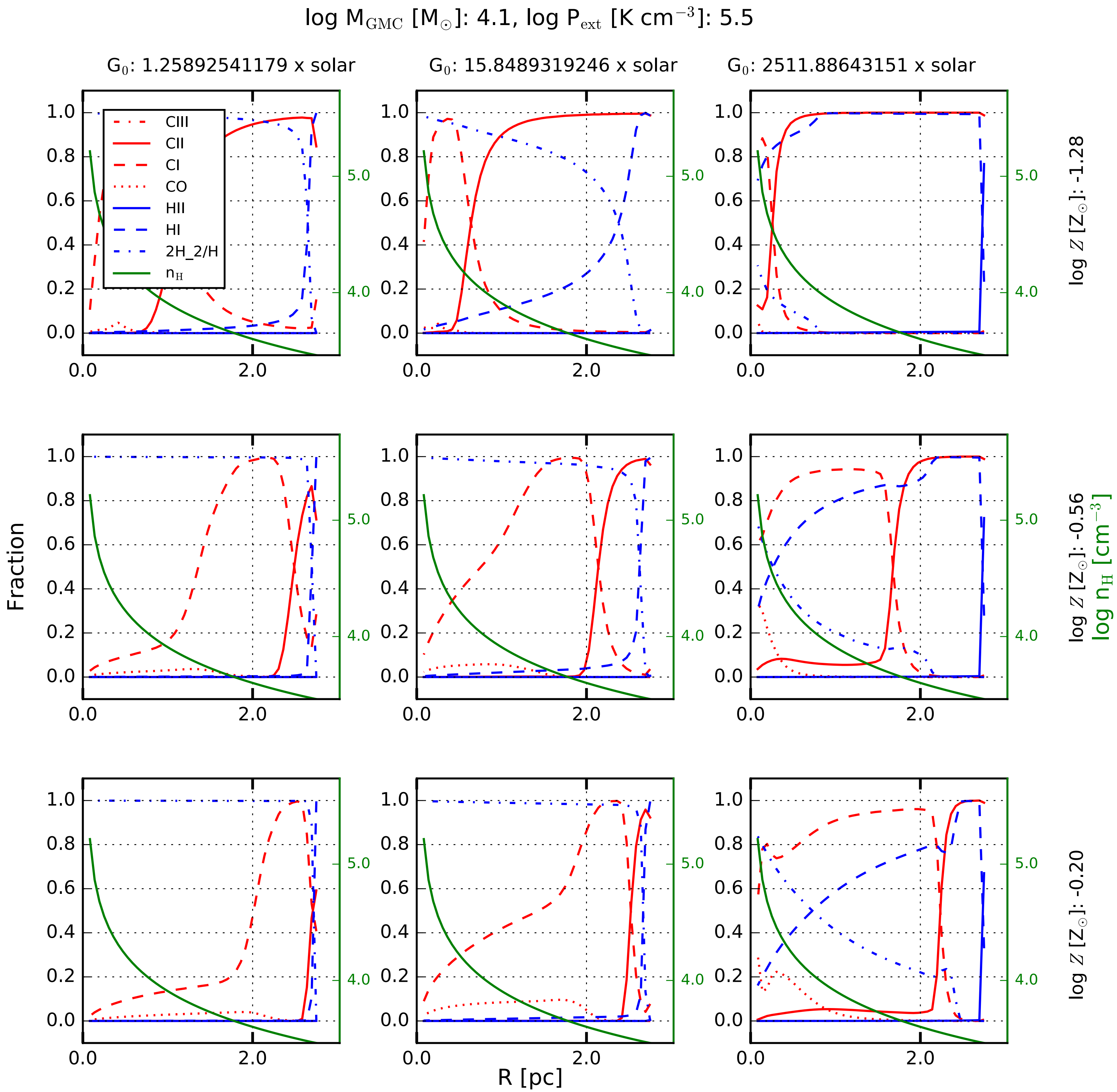

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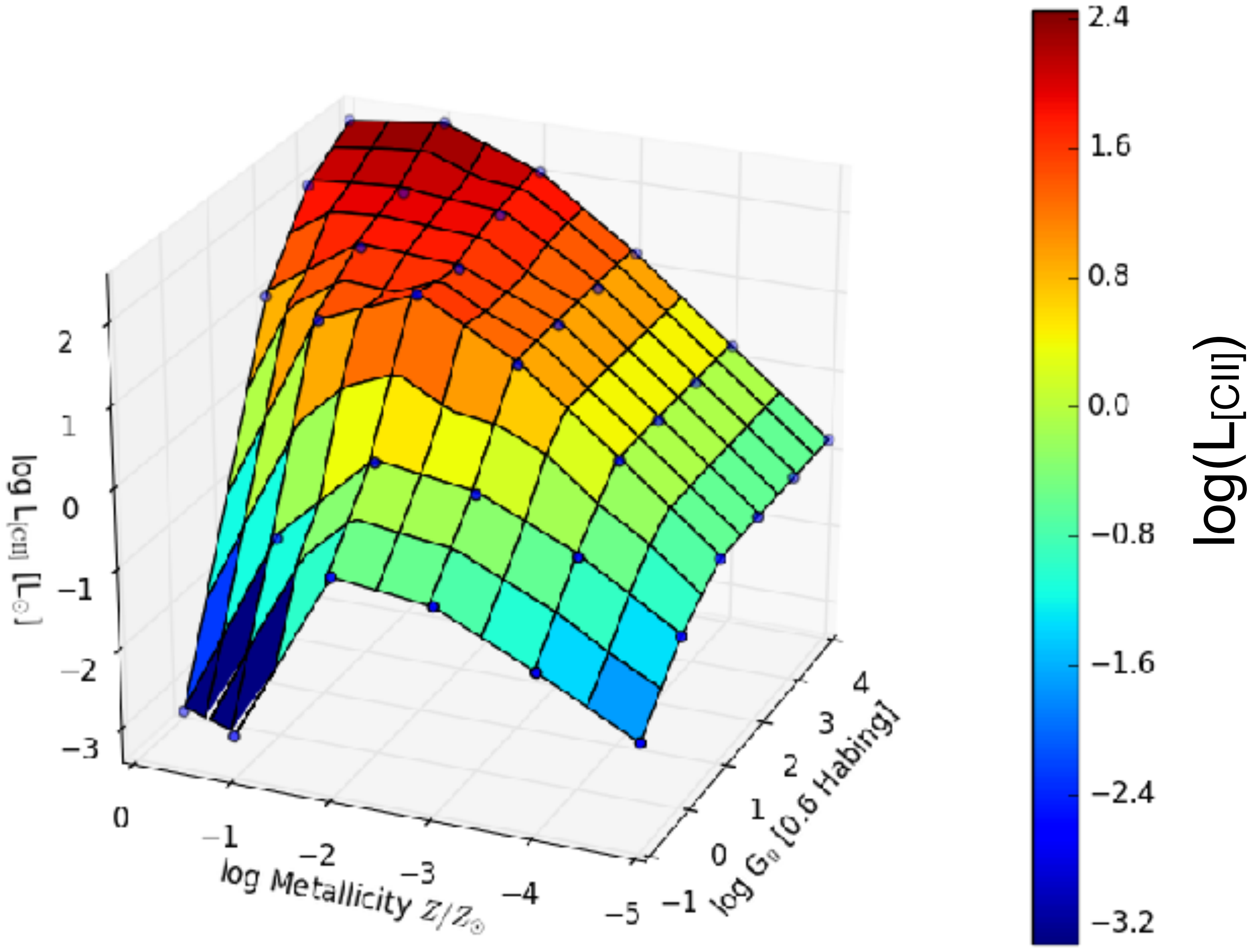

Work by Luis N Rios

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Questions that arise:

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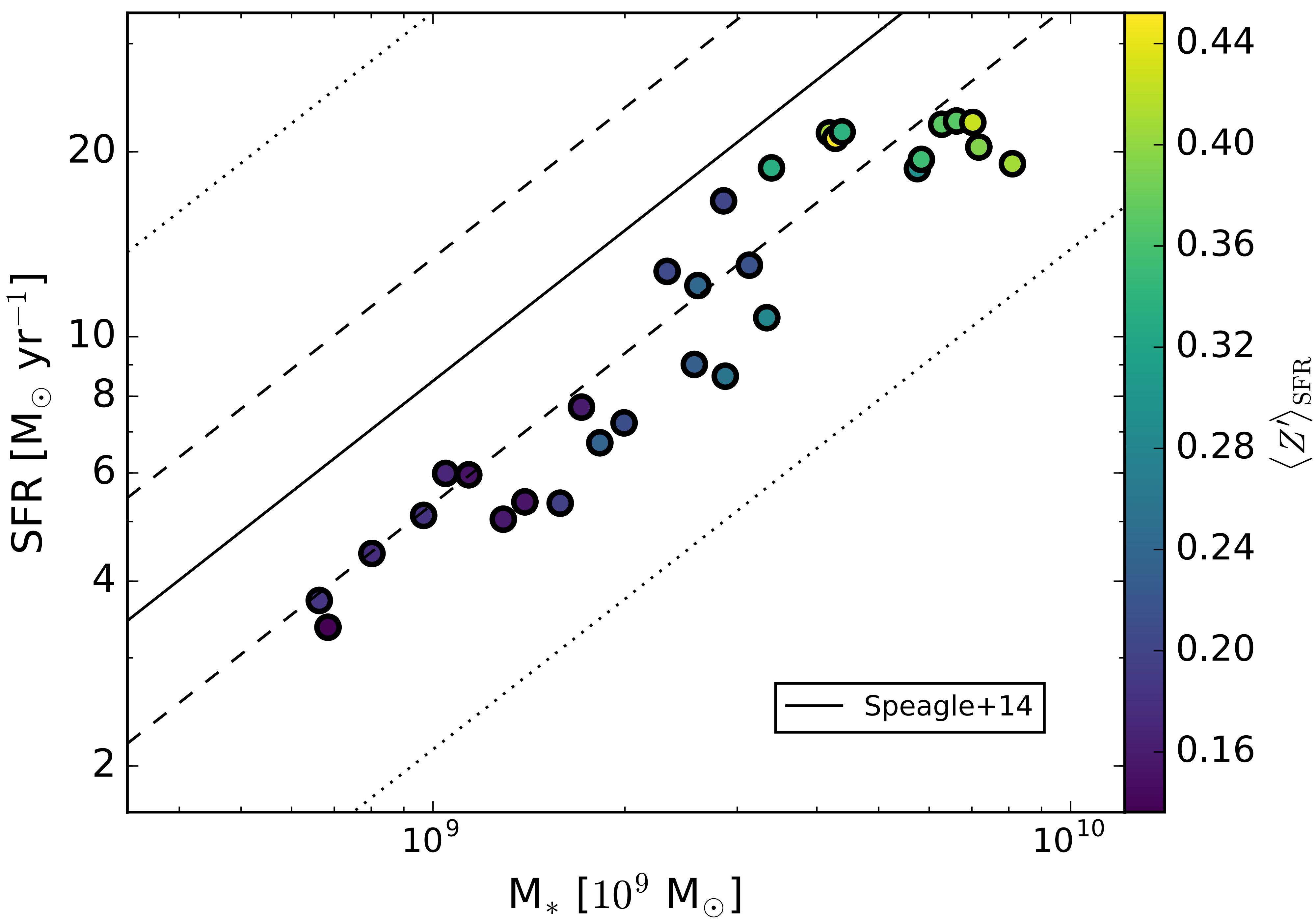
2. What is the origin of [CII]?
3. How does metallicity, *Z*, affect [CII]?
4. [OIII] a better SFR-tracer?

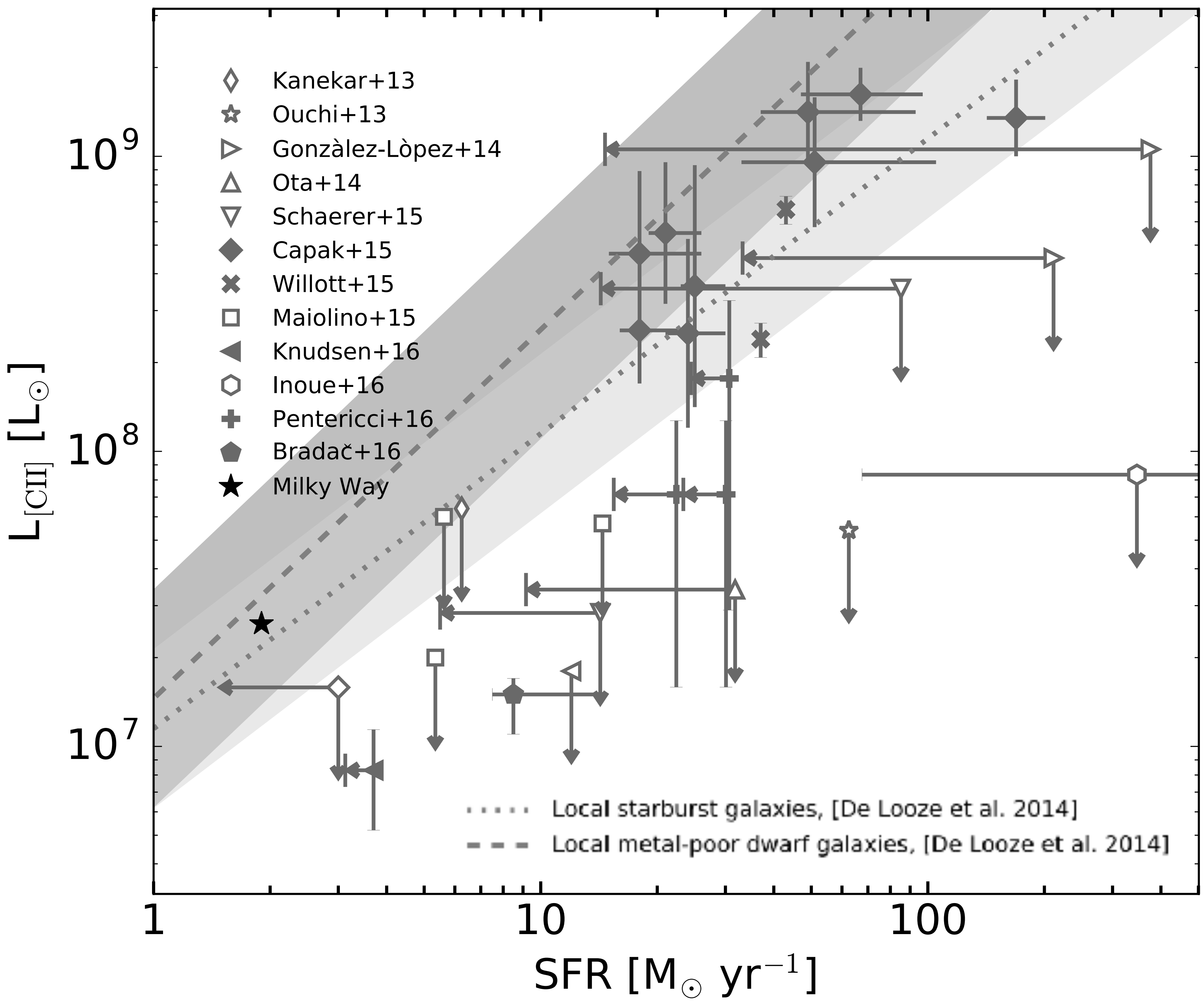
Results at z ~ 6

Model galaxy sample:
30 star-forming galaxies at 5.75 < z < 6.25 from GIZMO/MUFASA suite



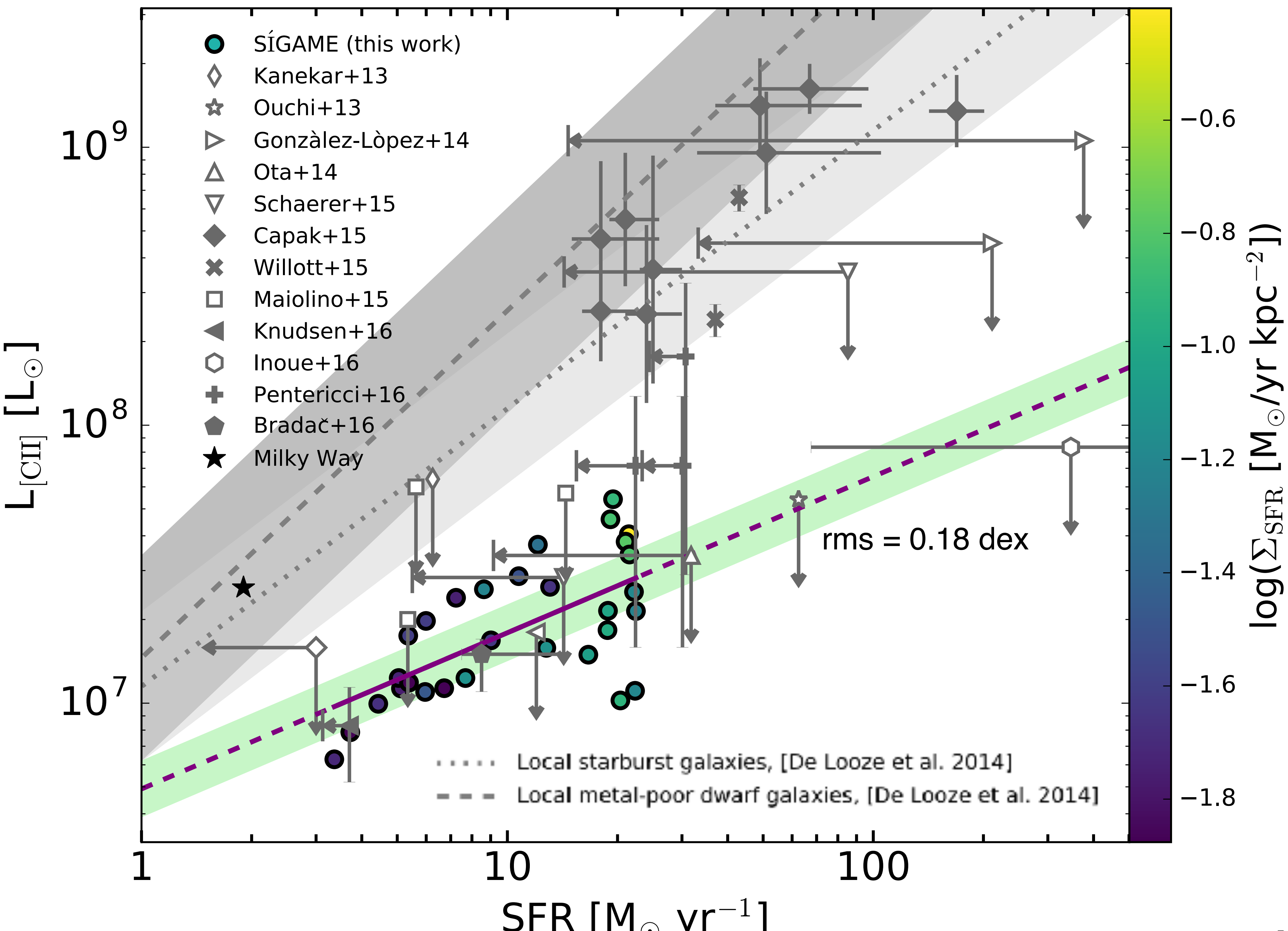
Results at z ~ 6 (1)

[CII]-SFR relation, observed galaxies:



Results at z ~ 6 (1)

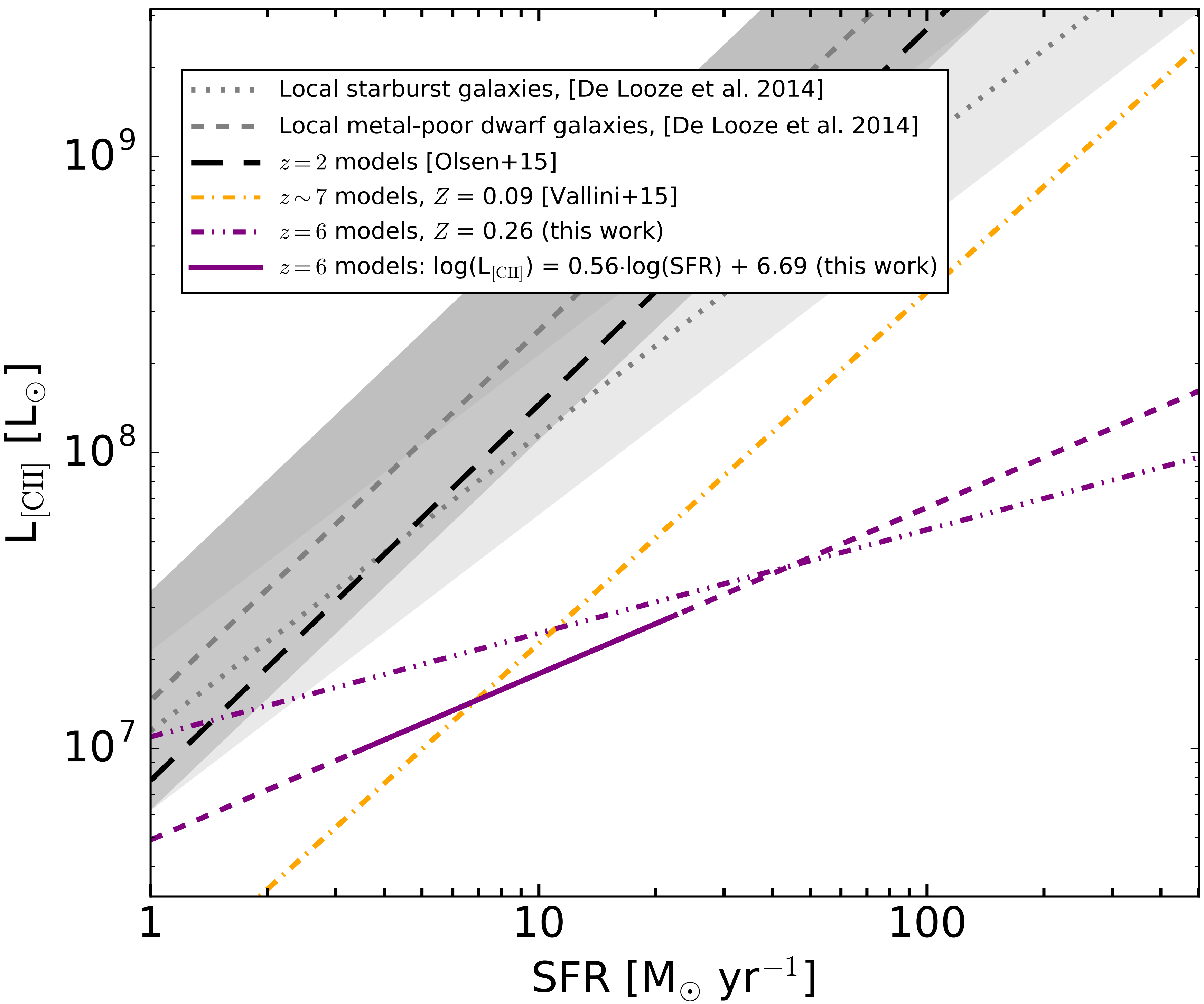
[CII]-SFR relation, observed galaxies + model results:



[Olsen+17 in prep.]

Results at z ~ 6 (1)

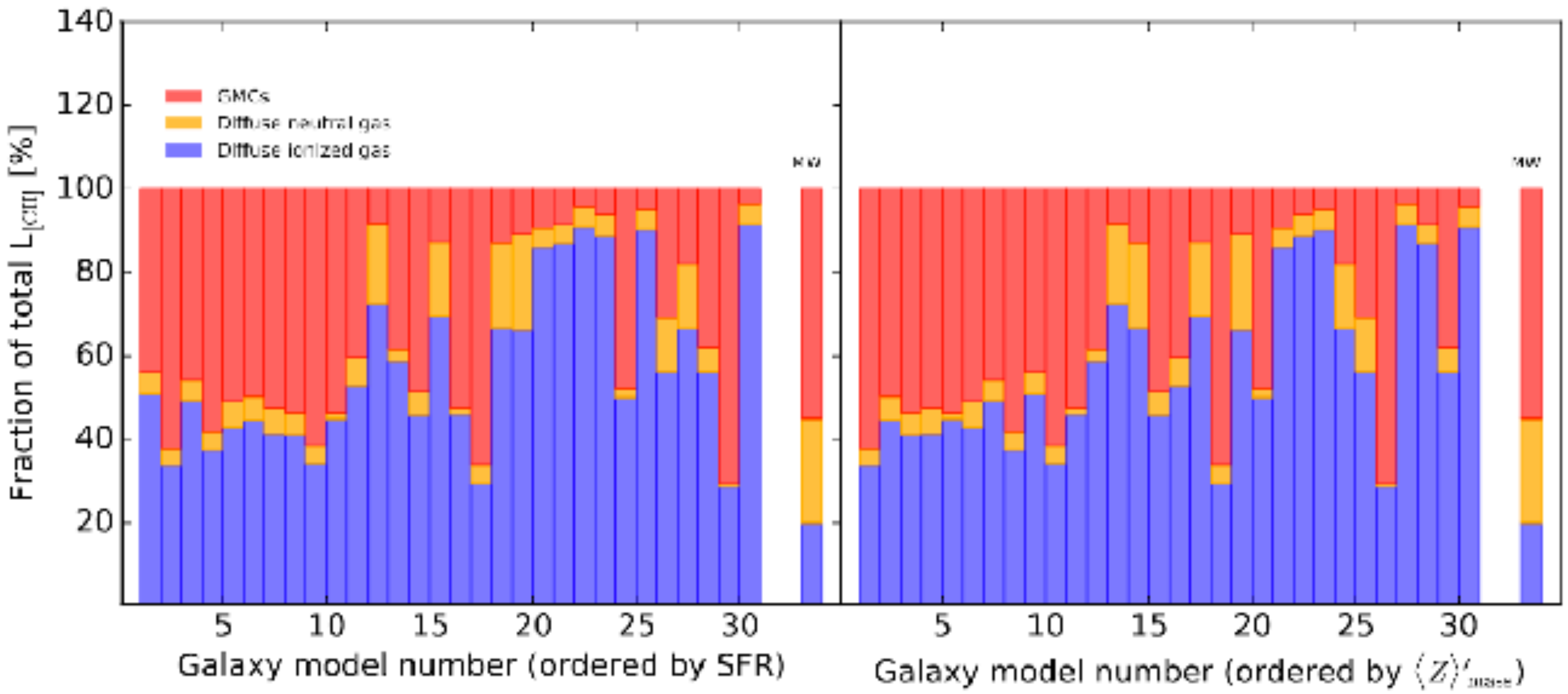
[CII]-SFR relation, comparing models:



[Olsen+17 in prep.]

Results at z ~ 6 (2)

Origin of [CII]



mass fraction are similar, but [CII] contribution from each ISM phase is not!

[Olsen+17 in prep.]

Results at z ~ 6 (2)

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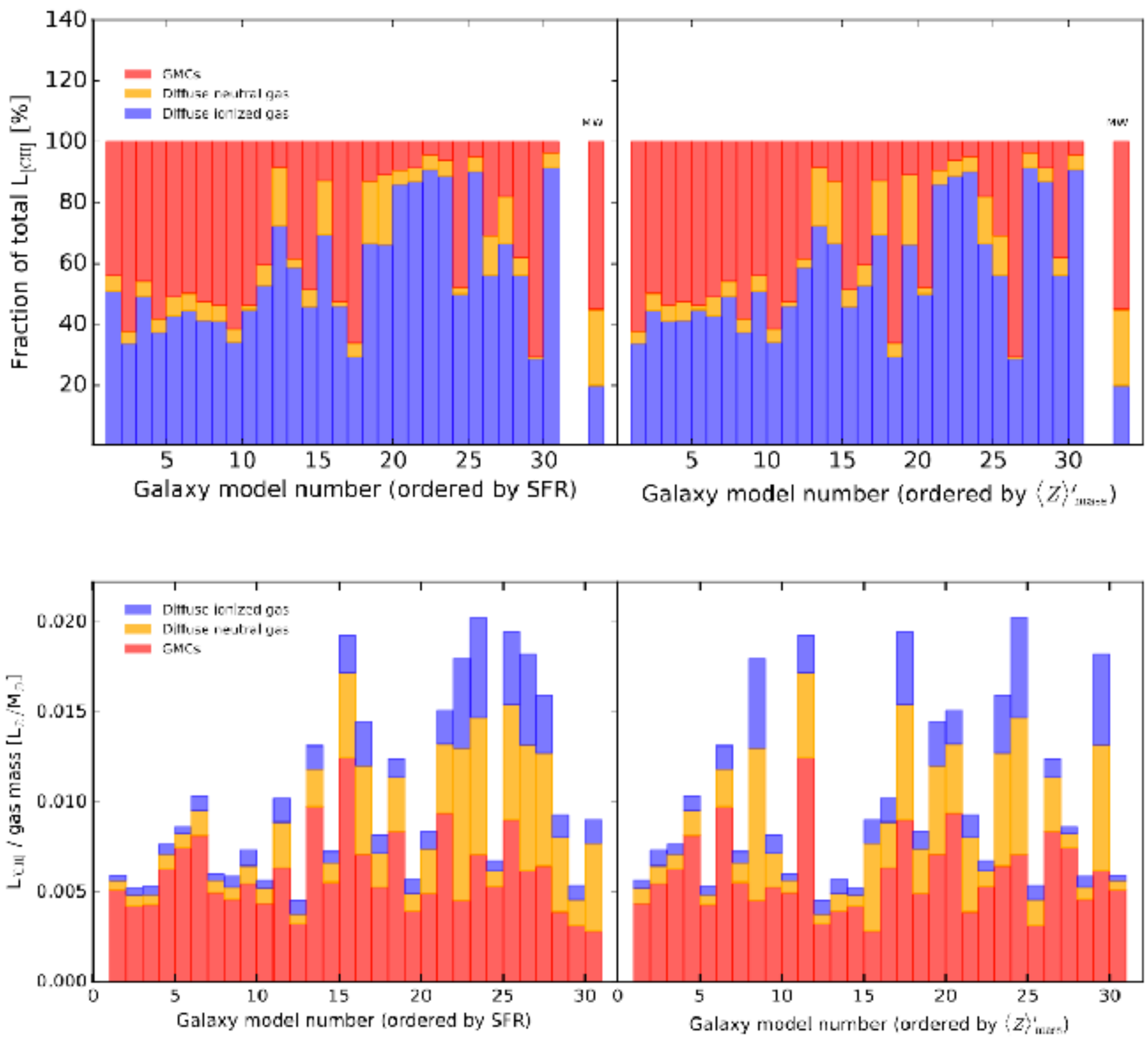

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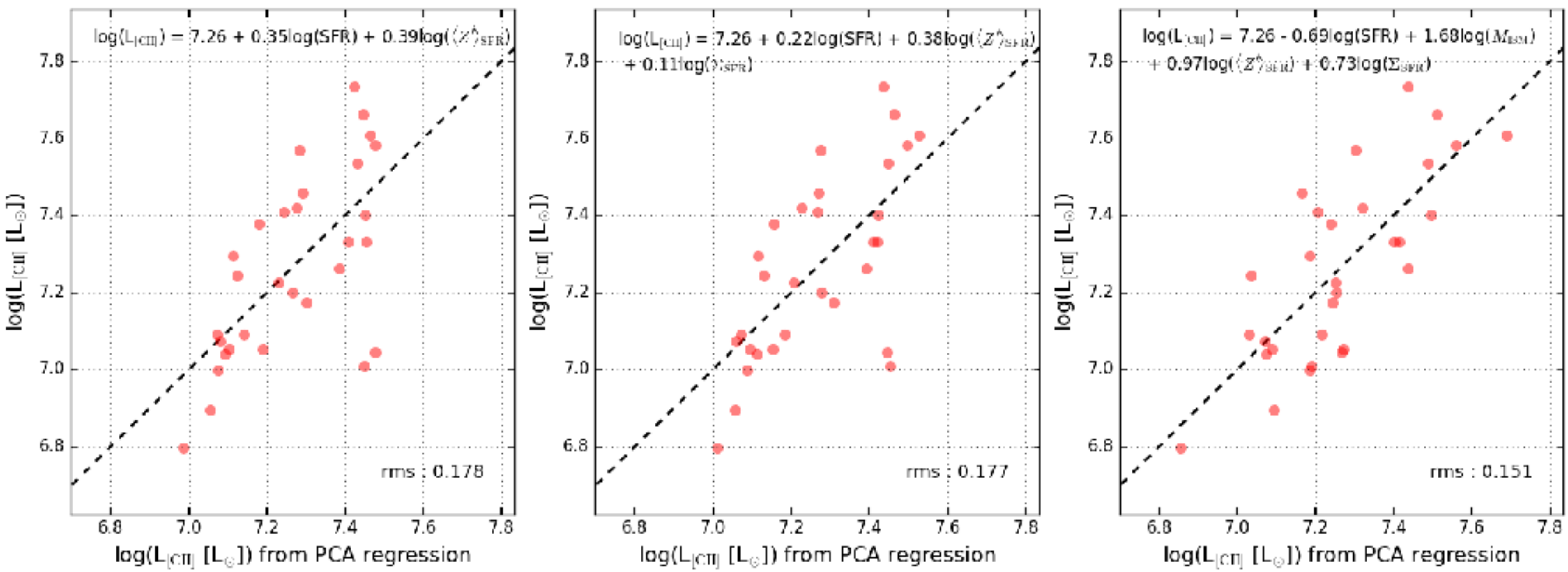
"[CII] efficiency"

due to the ability of the gas to emit in [CII]

[Olsen+17 in prep.]

Results at z ~ 6 (3)

The importance of metallicity

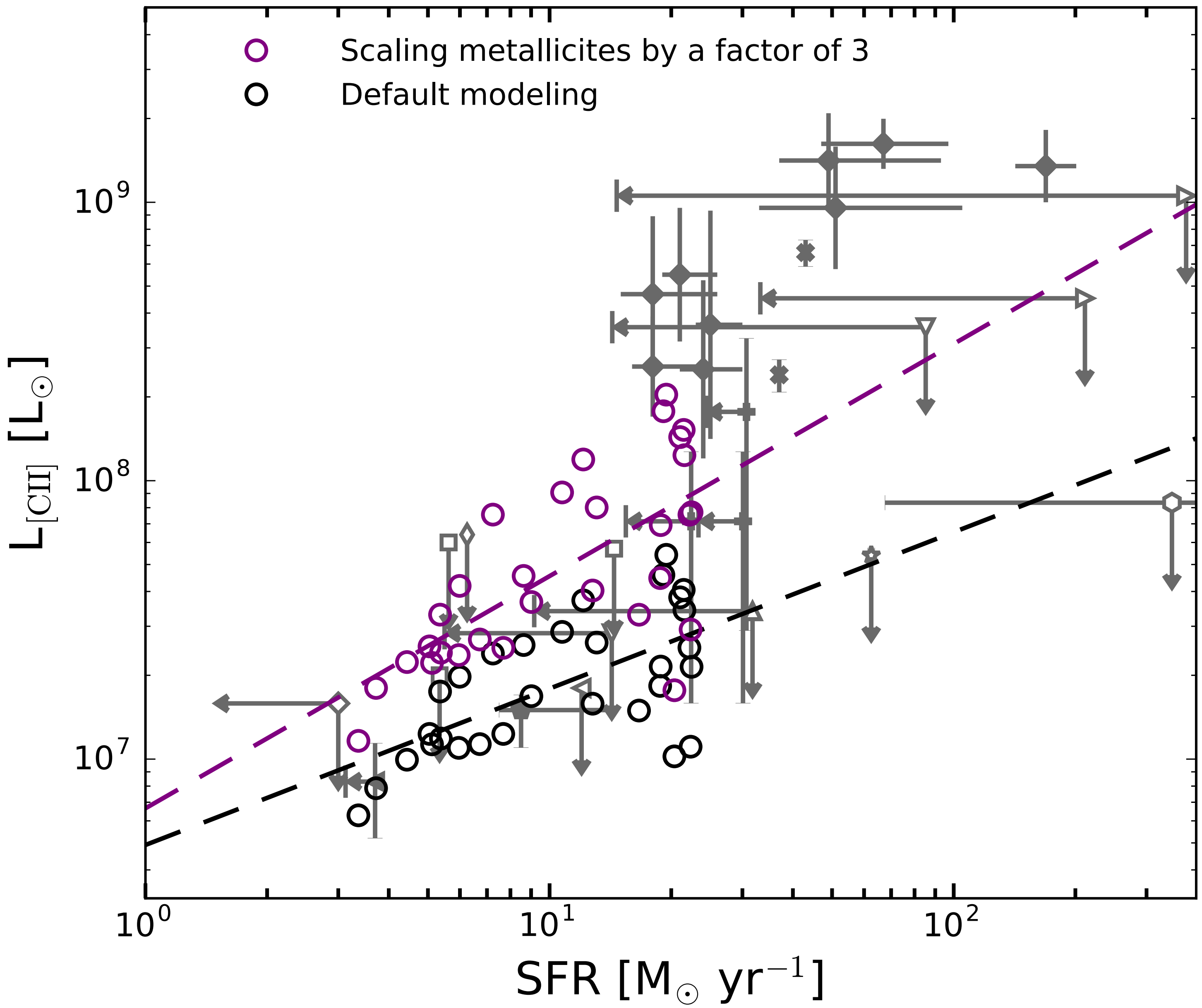


-> Not really important within our sample, probably due to limited range in *Z* (0.14-0.45)

[Olsen+17 in prep.]

Results at z ~ 6 (3)

The importance of metallicity

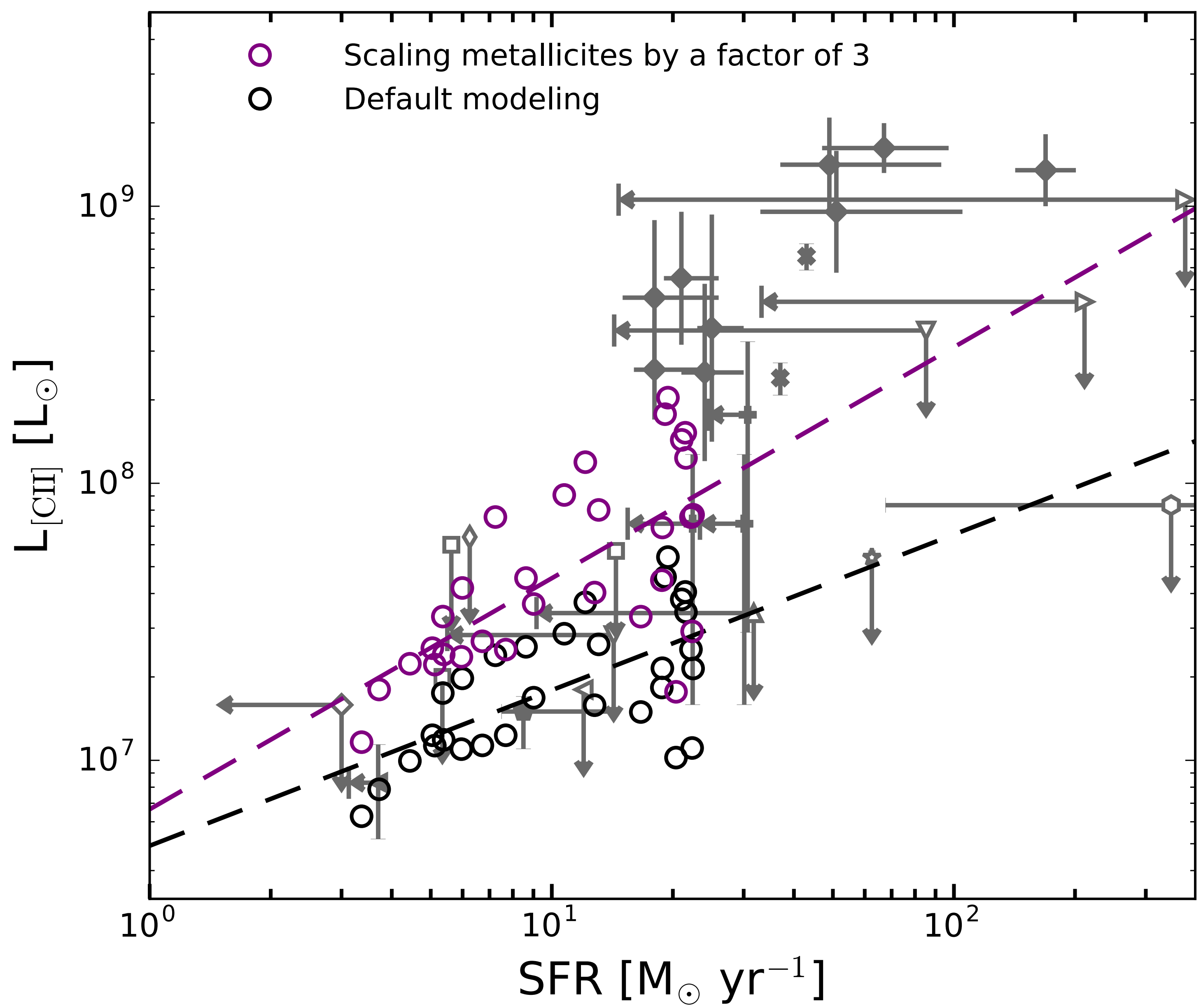


-> scaling *Z* by factor of 3: big impact (see also [Vallini+15])

[Olsen+17 in prep.]

Results at z ~ 6 (3)

The importance of metallicity



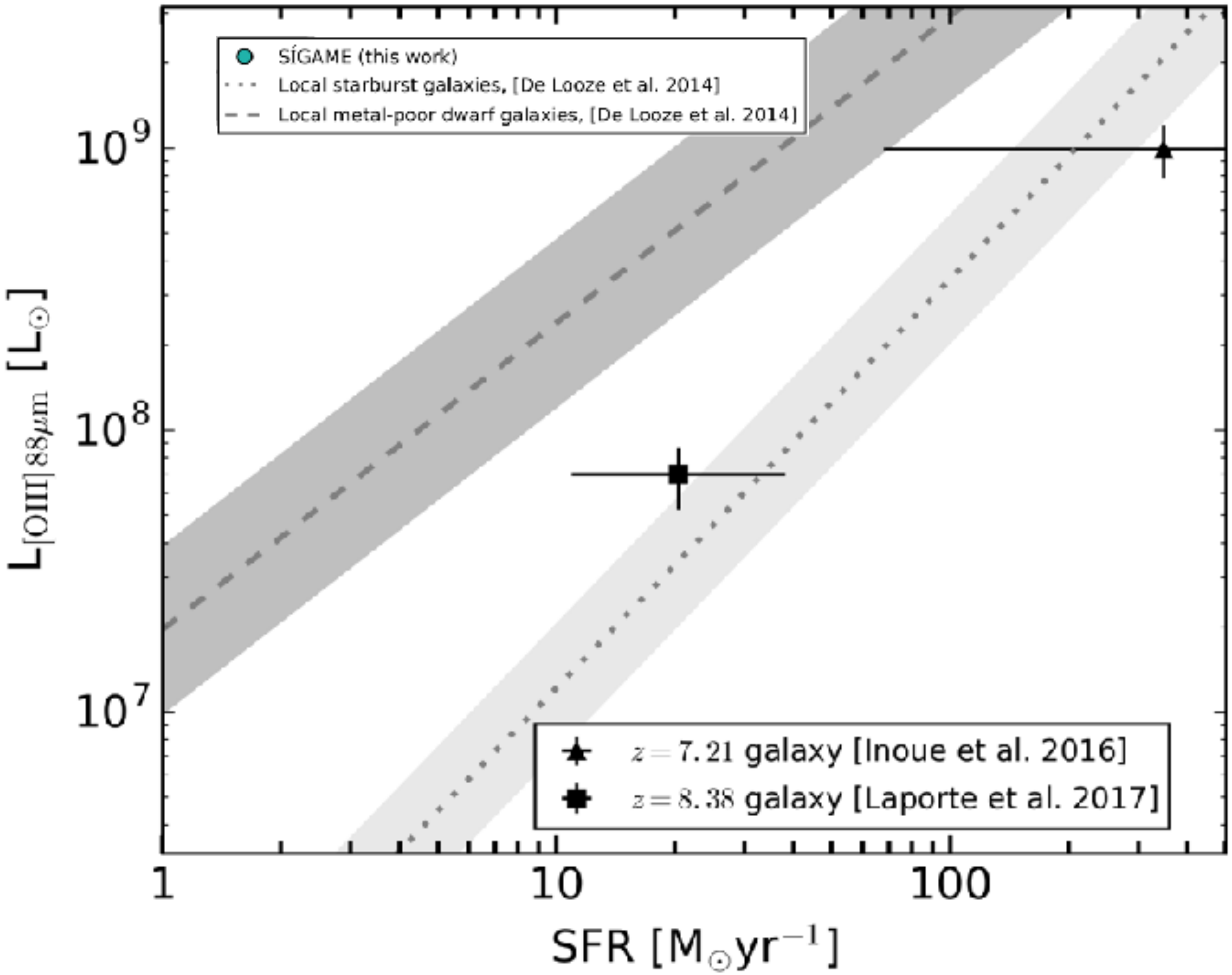
-> scaling *Z* by factor of 3: big impact (see also [Vallini+15])

-> In addition, observed SFRs could be very understimated [Capak+15]

[Olsen+17 in prep.]

Results at z ~ 6 (4)

[OIII]



[Olsen+17 in prep.]

Results at z ~ 6 (4)

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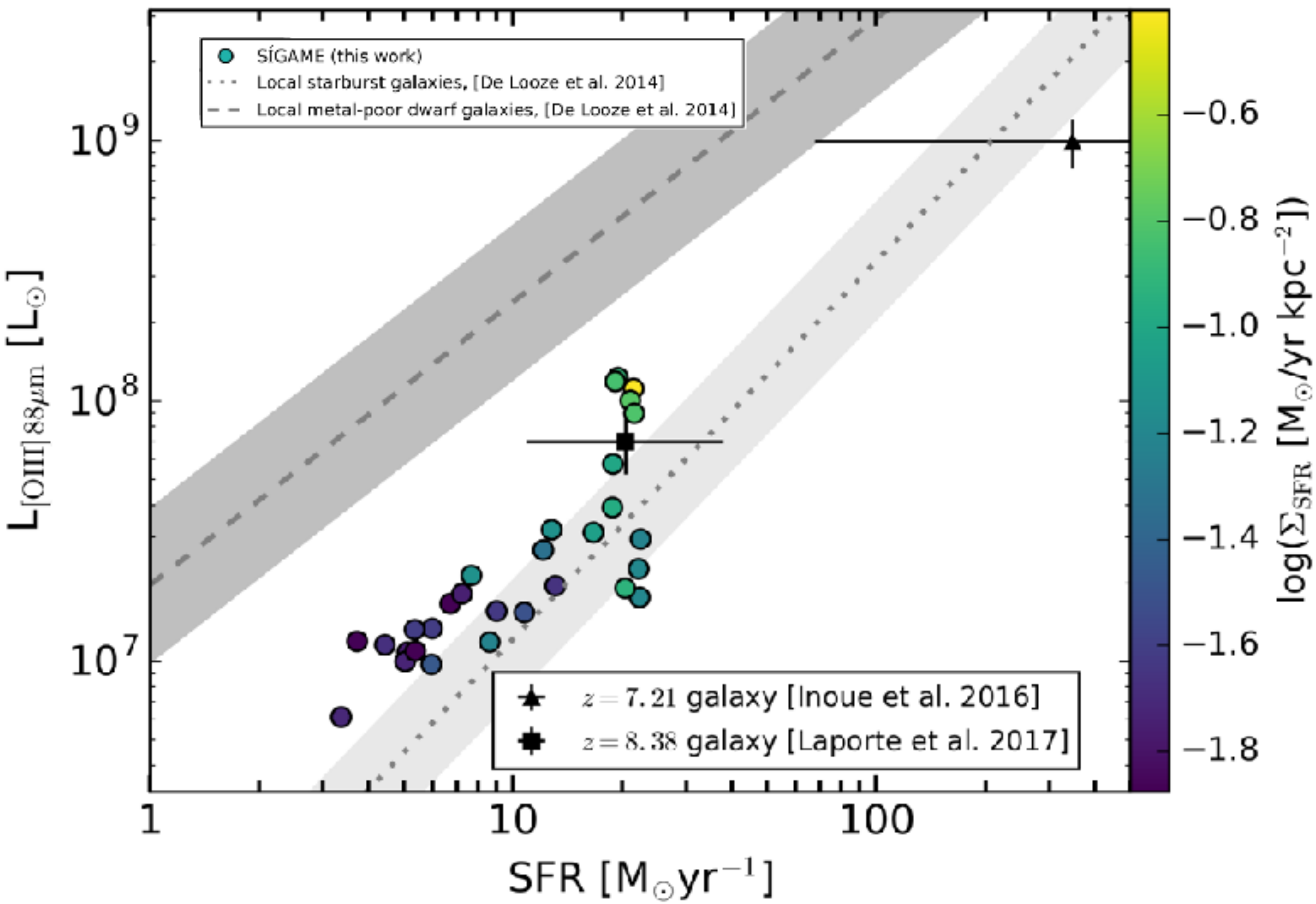


-> good agreement with high-z observations and local SB relation

[Olsen+17 in prep.]

Future!

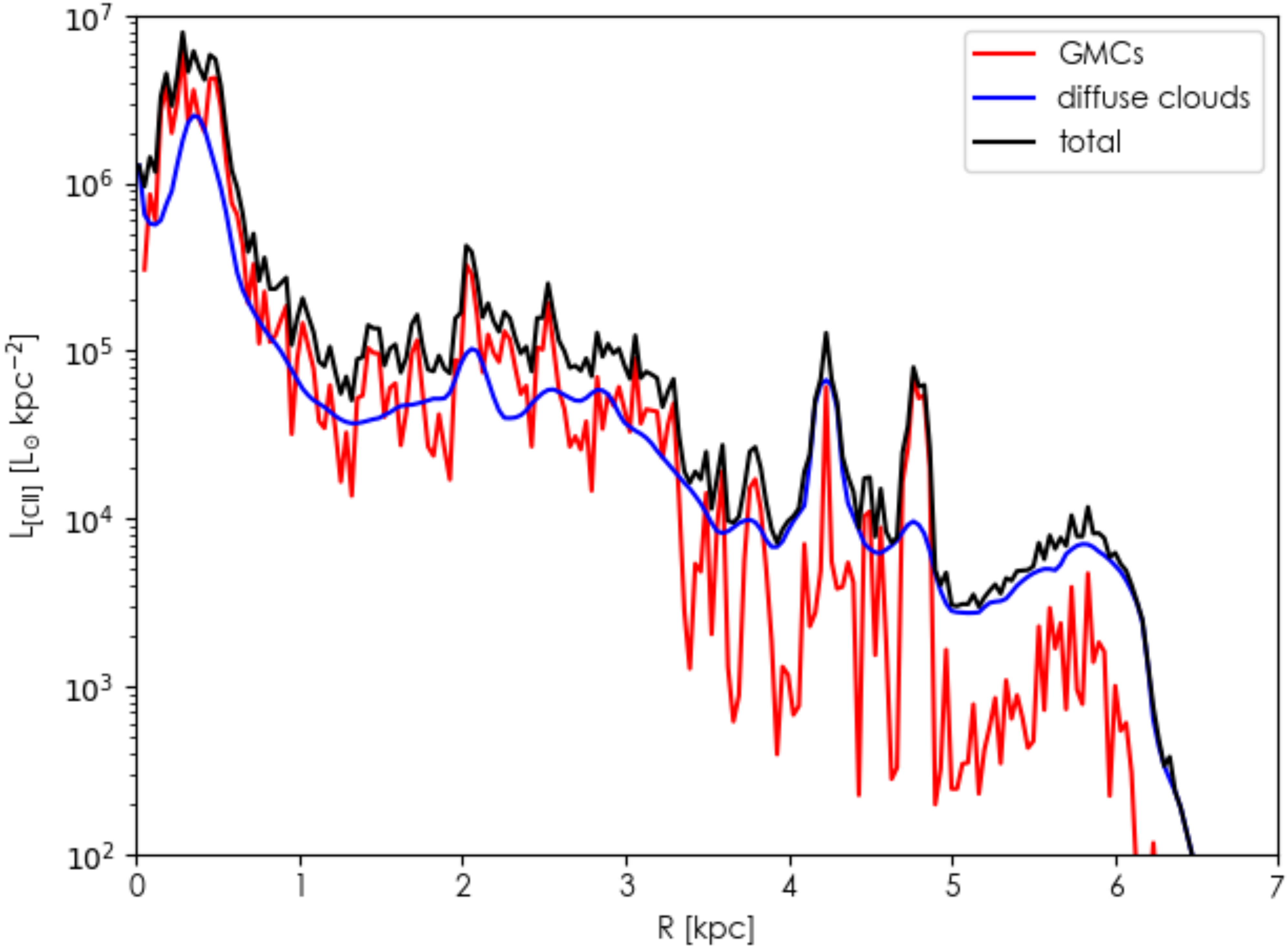
Where to go next with SÍGAME…

- Make the code public!
- Try on different set of galaxies, with wider dynamic range in parameters
- Go to lower redshifts to compare with resolved observations…

[Olsen+17 in prep.]

Radial profiles

Work by Lily Whitler

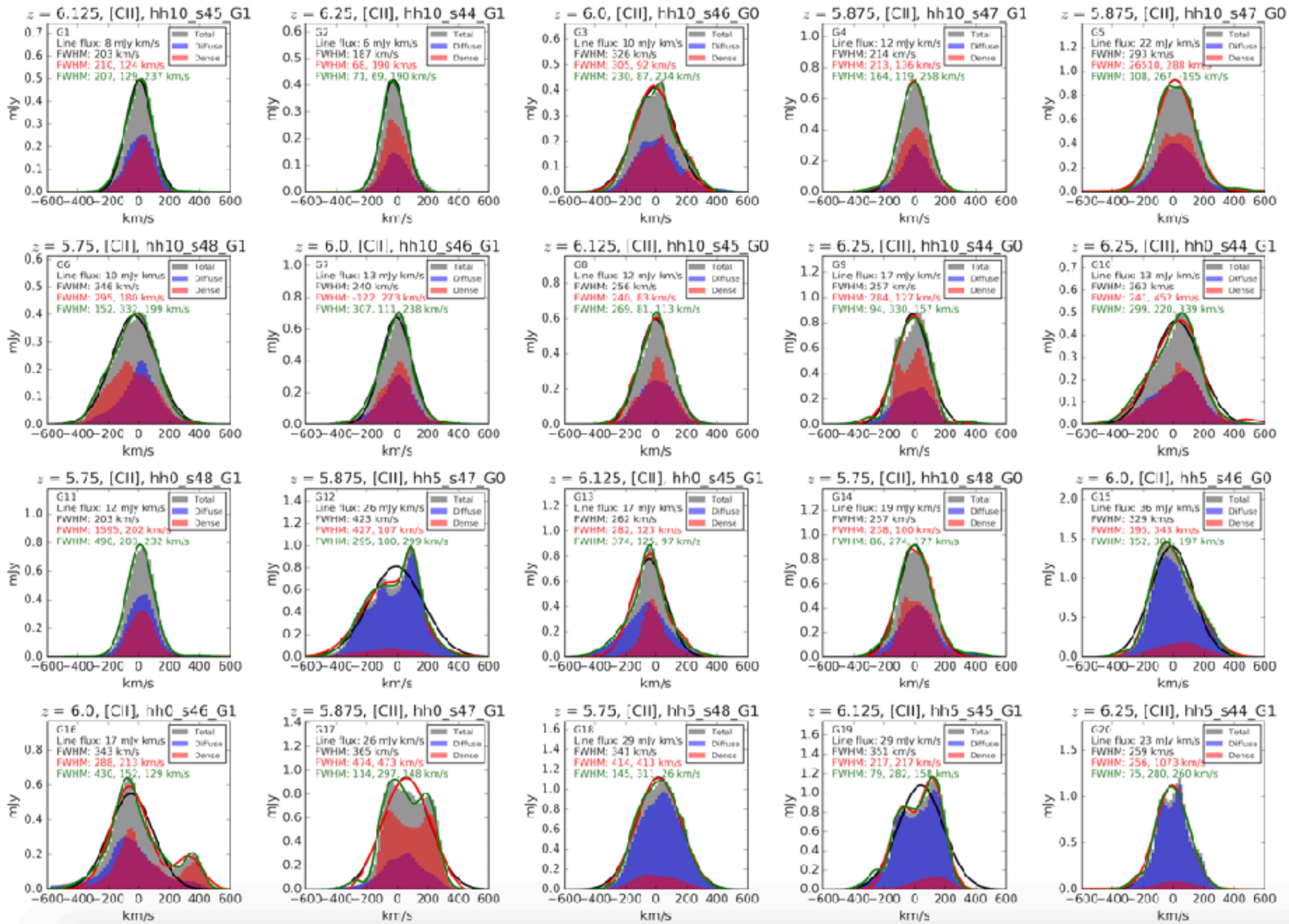


$L_{[CII],GMC} = 7.45 \times 10^6\ L_\odot$

$L_{[CII],dif} = 3.01 \times 10^6\ L_\odot$

Line profiles

Work by Jacob Cluff



Velocity cubes

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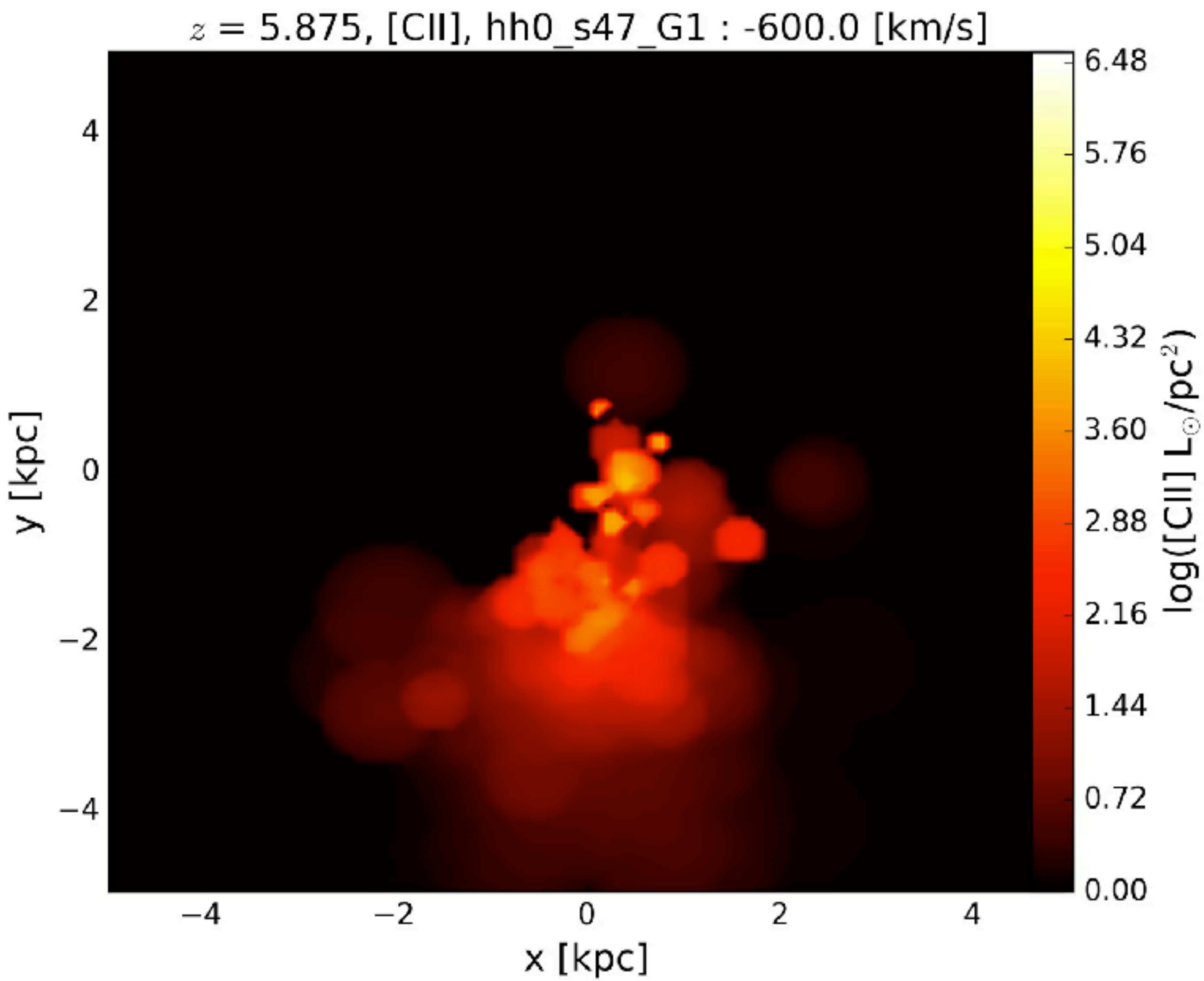

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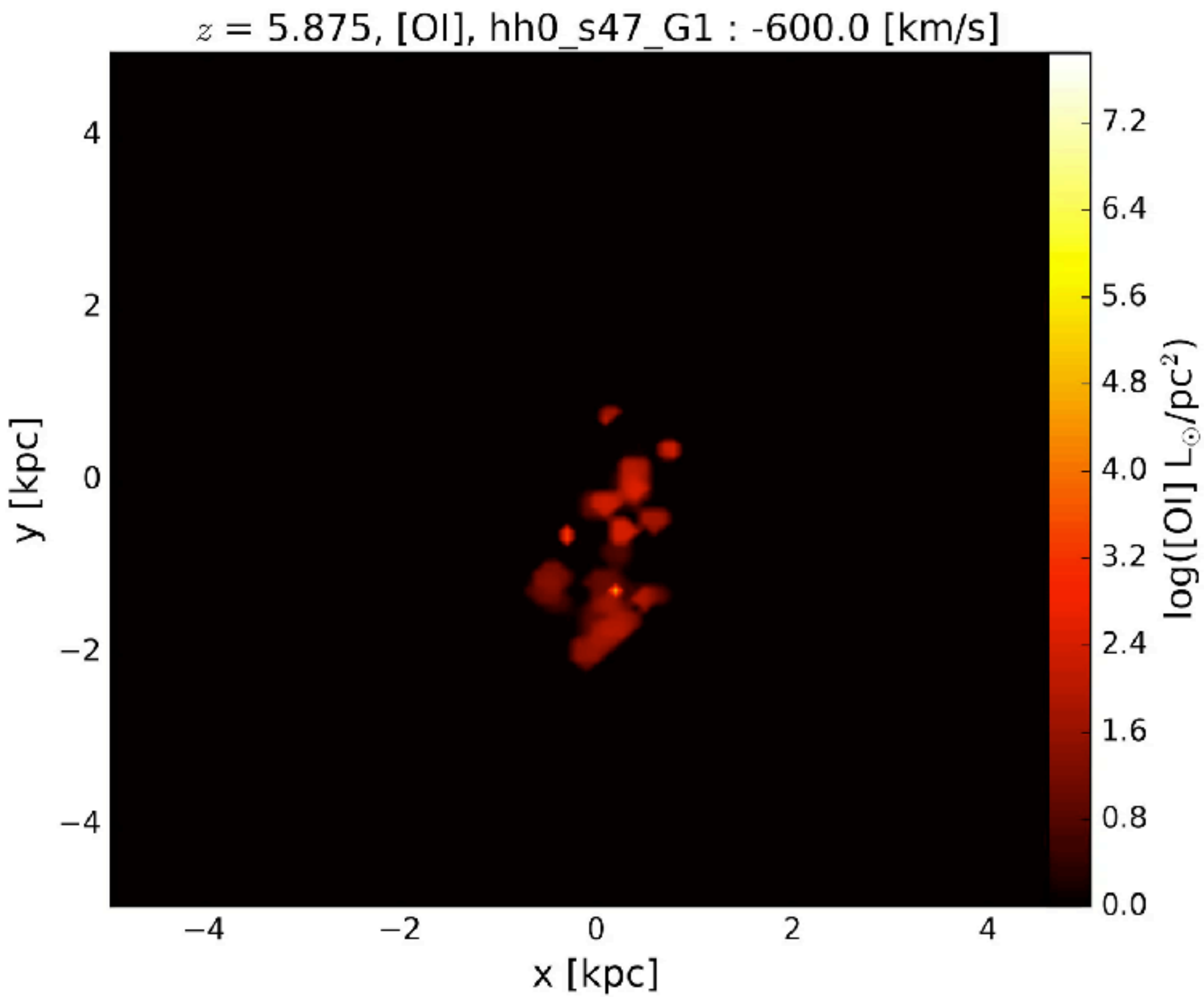
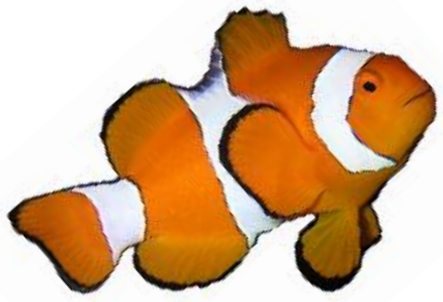


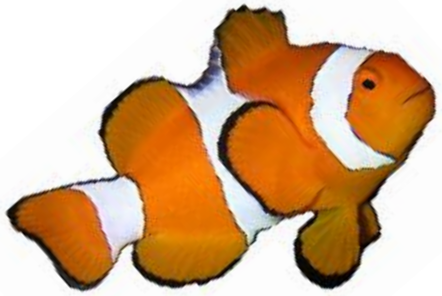


SÍGAME

SImulator of GAlaxy Millimeter/submillimeter Emission

Conclusions at z~6:

- We predict a [CII]-SFR relation, though weak
- Within our range in Z, [CII] does not depend strongly on Z
- Most of the [CII] emission arises in diffuse gas
- GMCs less important [CII] emitters at high SFR
- $L_{[OIII]}$ - SFR in agreement with observations
- Radial and line profiles on the way…



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[CII] with SÍGAME at z = 2:
Olsen+15, ApJ 814 76

CO line emission with SÍGAME at z = 2:
Olsen+16, MNRAS 457 3

Plea to observers!:

- extragalactic mass-size (and velocity dispersion) relations for molecular gas
- cosmic ray intensity in different environments

Stay tuned: http://kpolsen.github.io/sigame/ !!

(See also: http://www.digame.online/ - DIrectory for Galaxy Millimeter/submillimeter Emission)