The ISM of High Redshift Galaxies

Hints from Emission Lines

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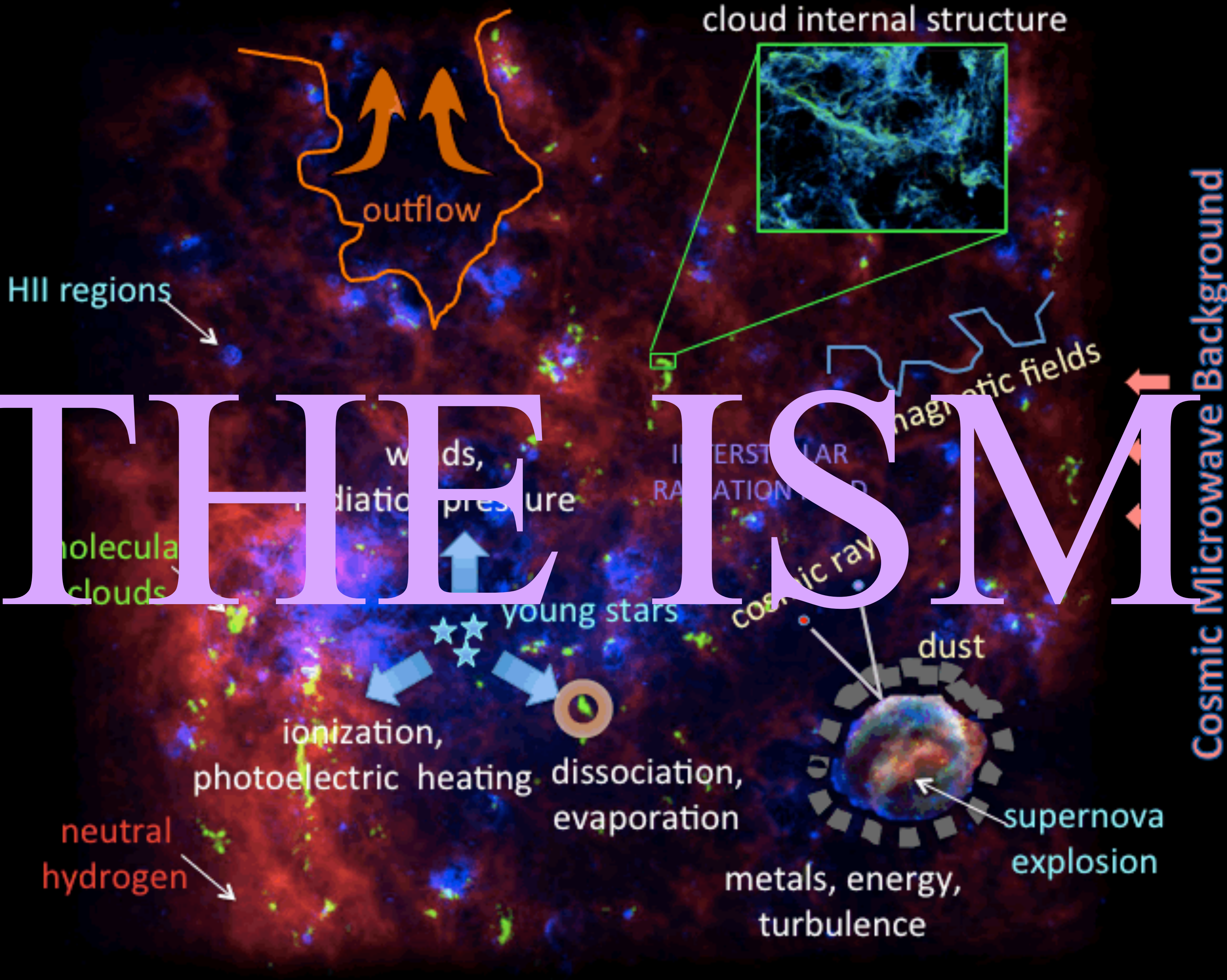
INTERSTELLAR

erc

CORTÉS

@ferrara_sns

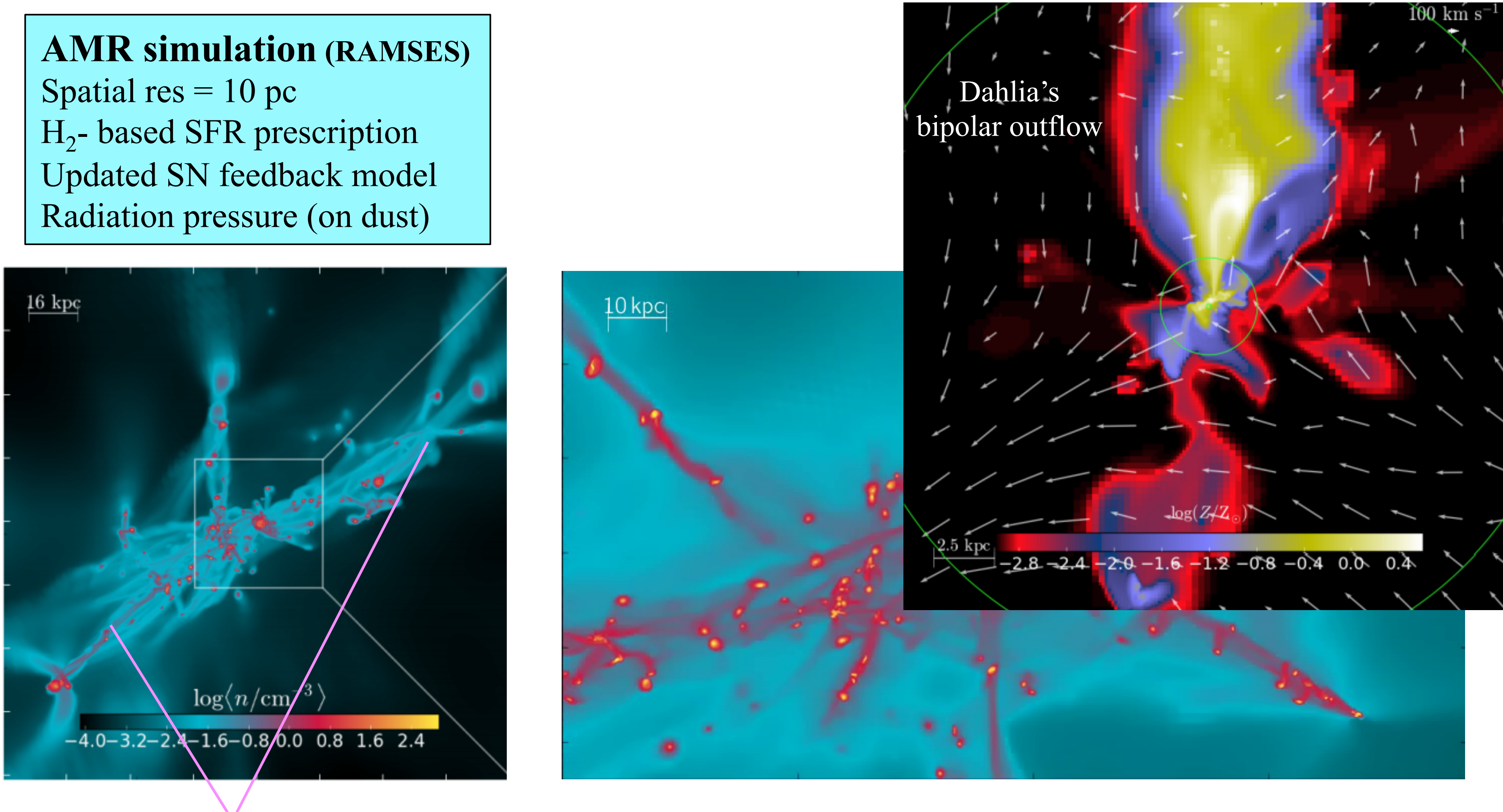
THE ISM


cloud internal structure
outflow
HII regions
young stars
dust
ionization,
photoelectric heating
dissociation,
evaporation
neutral
hydrogen
supernova
explosion
metals, energy,
turbulence
Cosmic Microwave Background

Pallottini+17a

"DAHLIA", A LBG @ $z = 6$

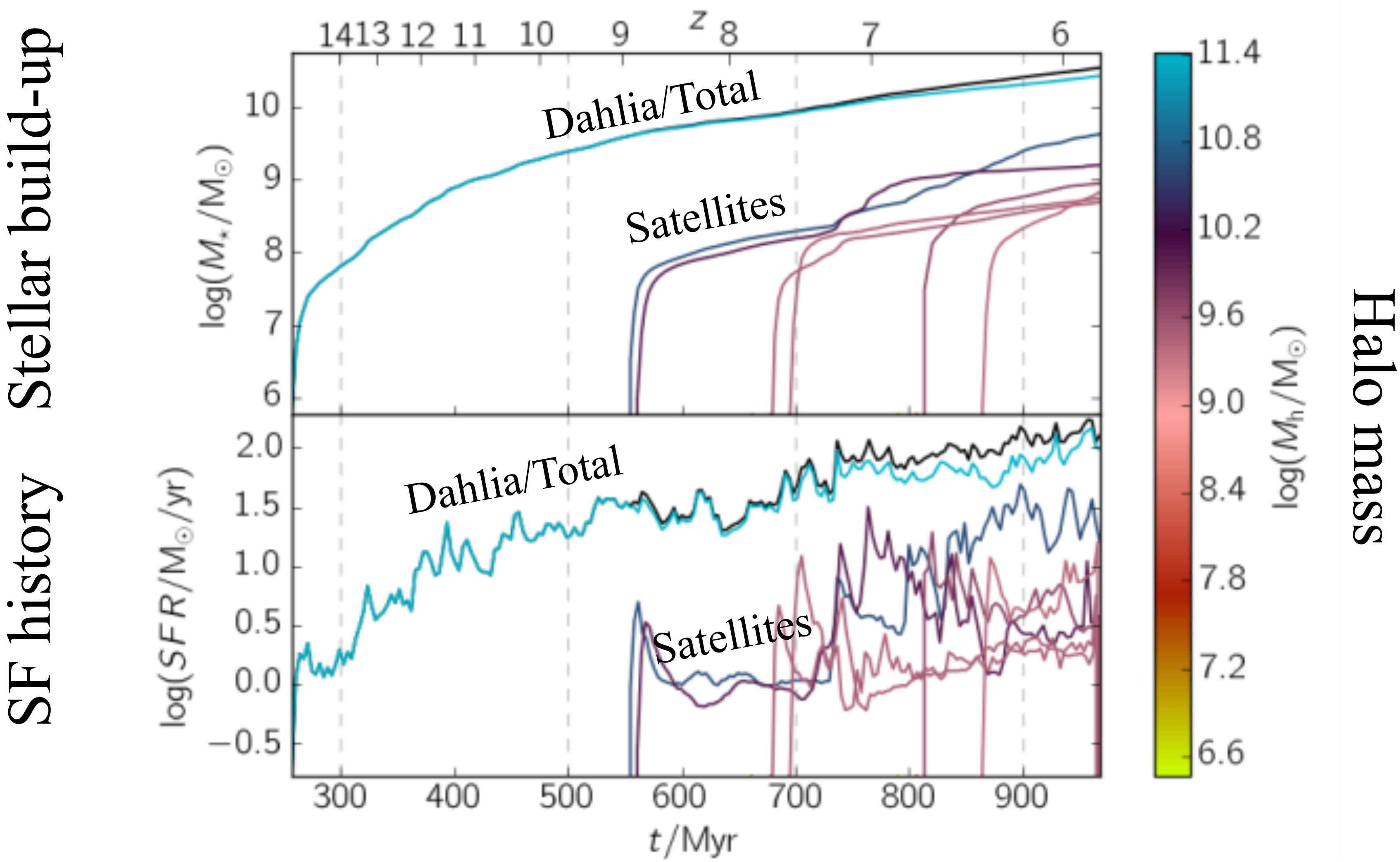
AMR simulation (RAMSES)
Spatial res = 10 pc
H_2- based SFR prescription
Updated SN feedback model
Radiation pressure (on dust)



over-dense accreting
filaments

Pallottini+17a

DAHLIA: STELLAR COMPONENT



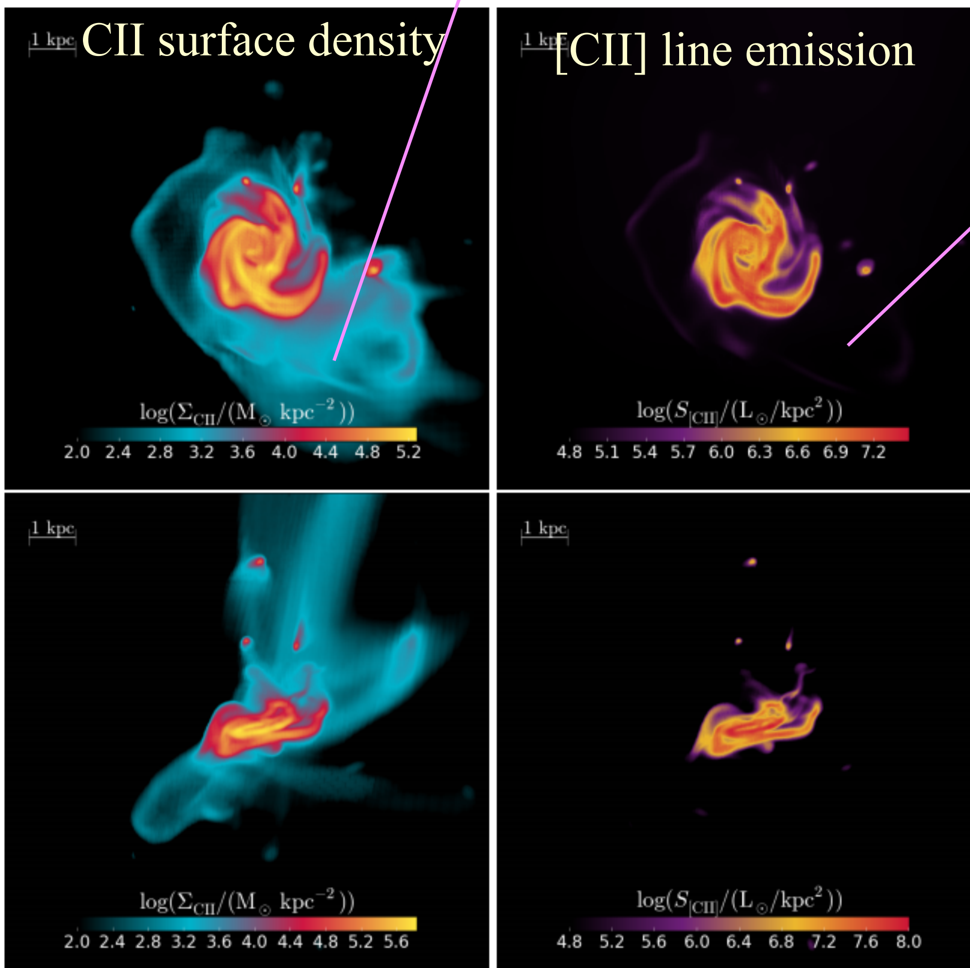
DAHLIA: ISM SEEN IN [CII]

Pallottini+17a

⅓ of CII mass in diffuse, low-Z, weakly emitting gas (invisible due to CMB)

Face on

Edge-on



Total [CII] Luminosity

$L_{CII} = 3.5\times10^7\ L_\odot$

❖

95% of emission co-located with H_2 disk

[CII]-SFR RELATION

Maiolino+15, Capak+15, Knudsen+16, Pentericci+16

Best fit relation (*Yue+15*)

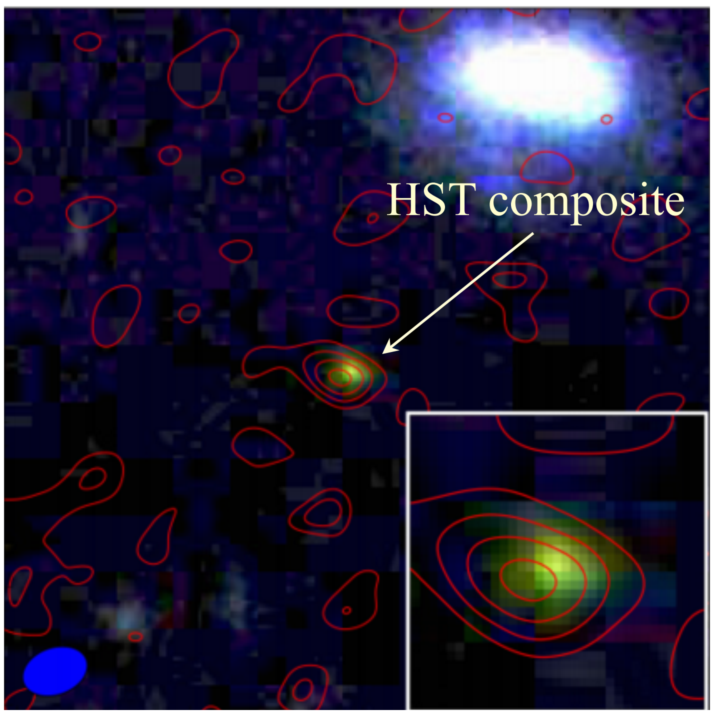
$$\log L_{CII} = 7.0 + 1.2 \log(SFR) + 0.021 \log Z + 0.012 \log(SFR) \log Z - 0.74 \log^2 Z$$

ALMA [CII] detection

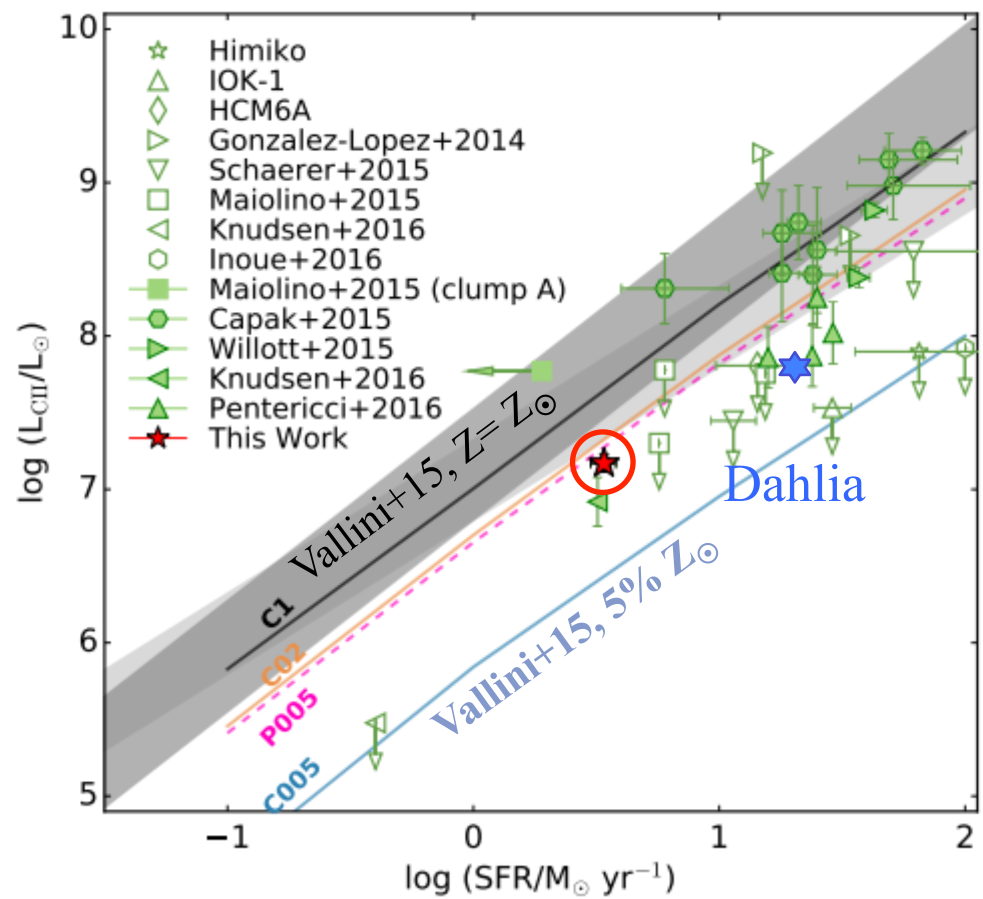
5× Lensed LAE @ z=6.765

$L_{CII} = 1.4\times10^7\ L_\odot$

Low [CII]-Lyα shift = 20 km/s



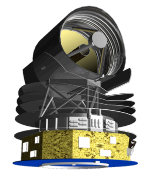
Bradac+17



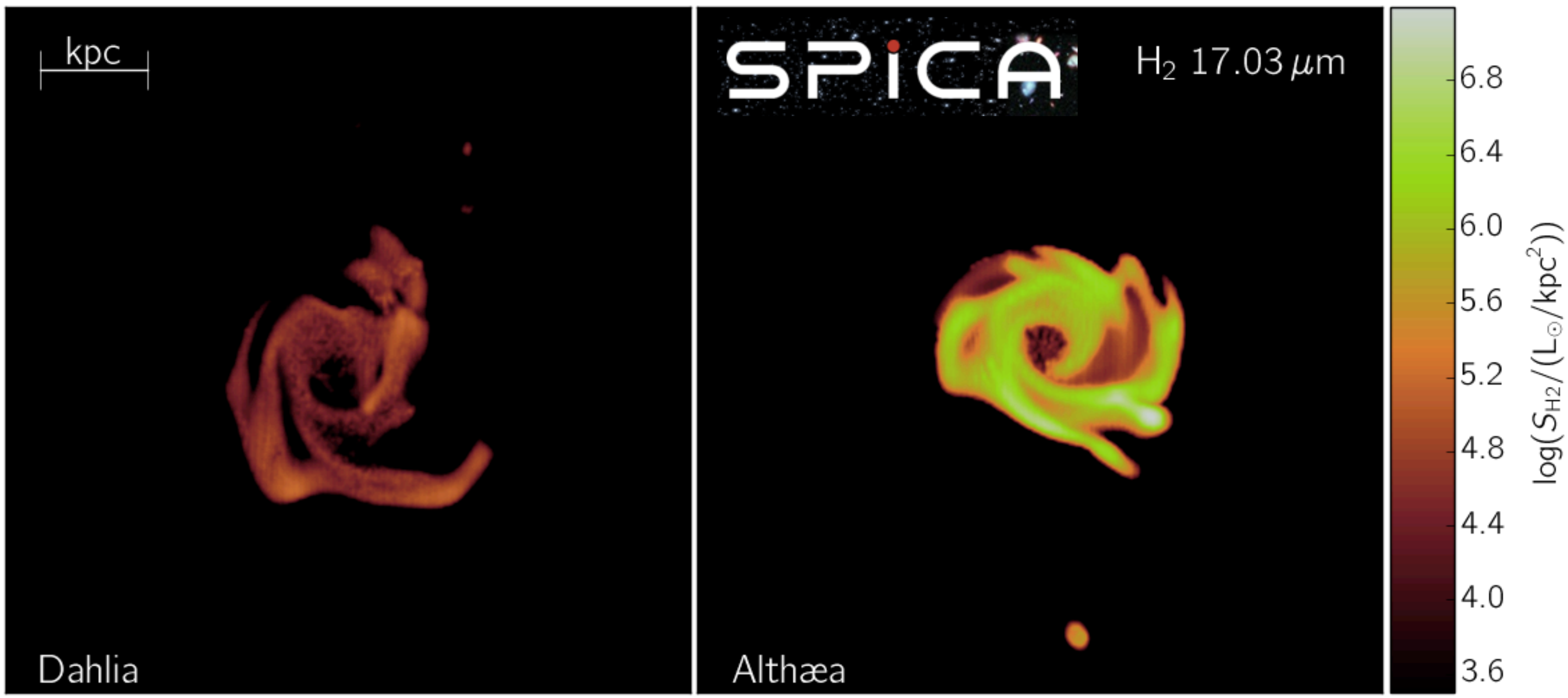
Pallottini+17b

THE IMPACT OF CHEMISTRY

Equilibrium
[Krumholz model]



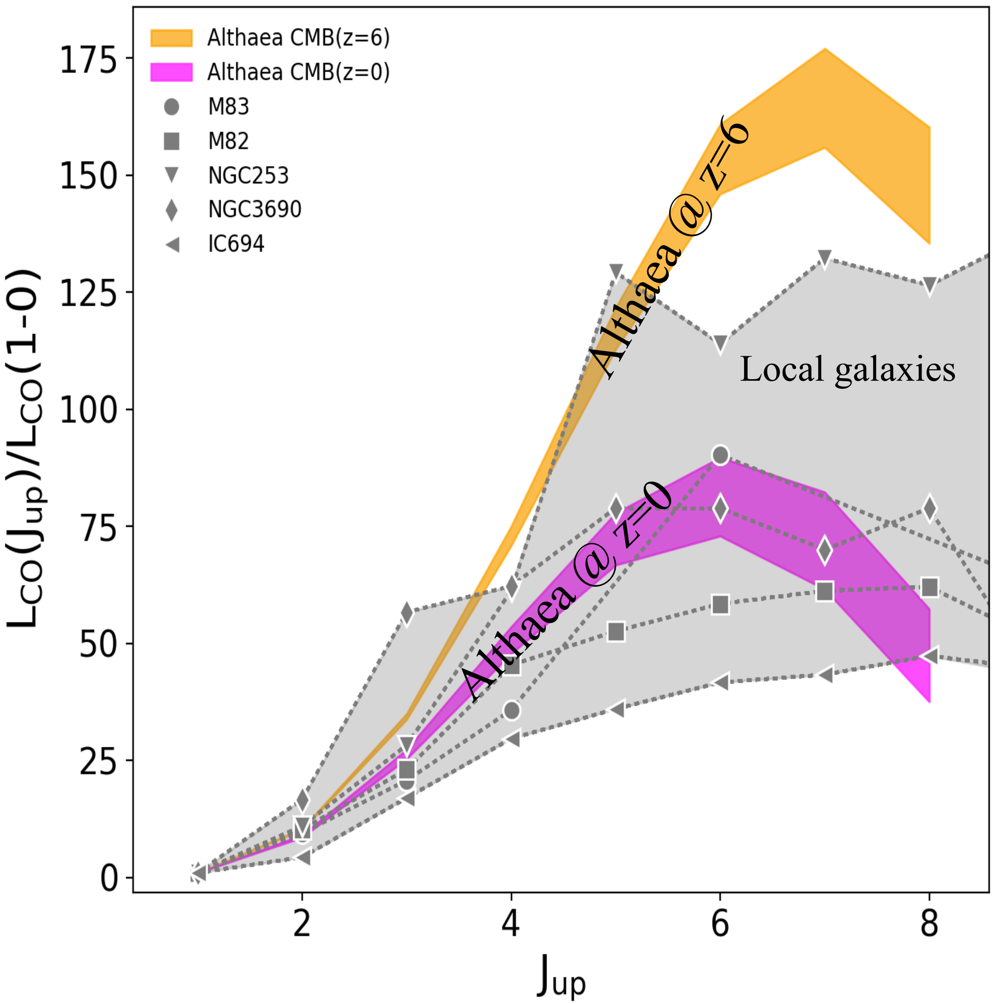
Non-equilibrium
[Coupled with KROME]



- H_2 forms at much higher density (≈ 300 vs 30 cm^{-3});
- ISM becomes more clumpy boosting (by 7×) [CII] line emission.

Vallinii+17, arXiv1709.03993

CO AT HIGH REDSHIFT?



High gas surface density

+

Large Mach number ($\mathfrak{M} \approx 30$)

+

Warm GMCs ($T_k \approx 45K$)

CO SLED peaks @ $J = 7$

Low α_{CO} = ⅓ α_{CO}(Milky Way)

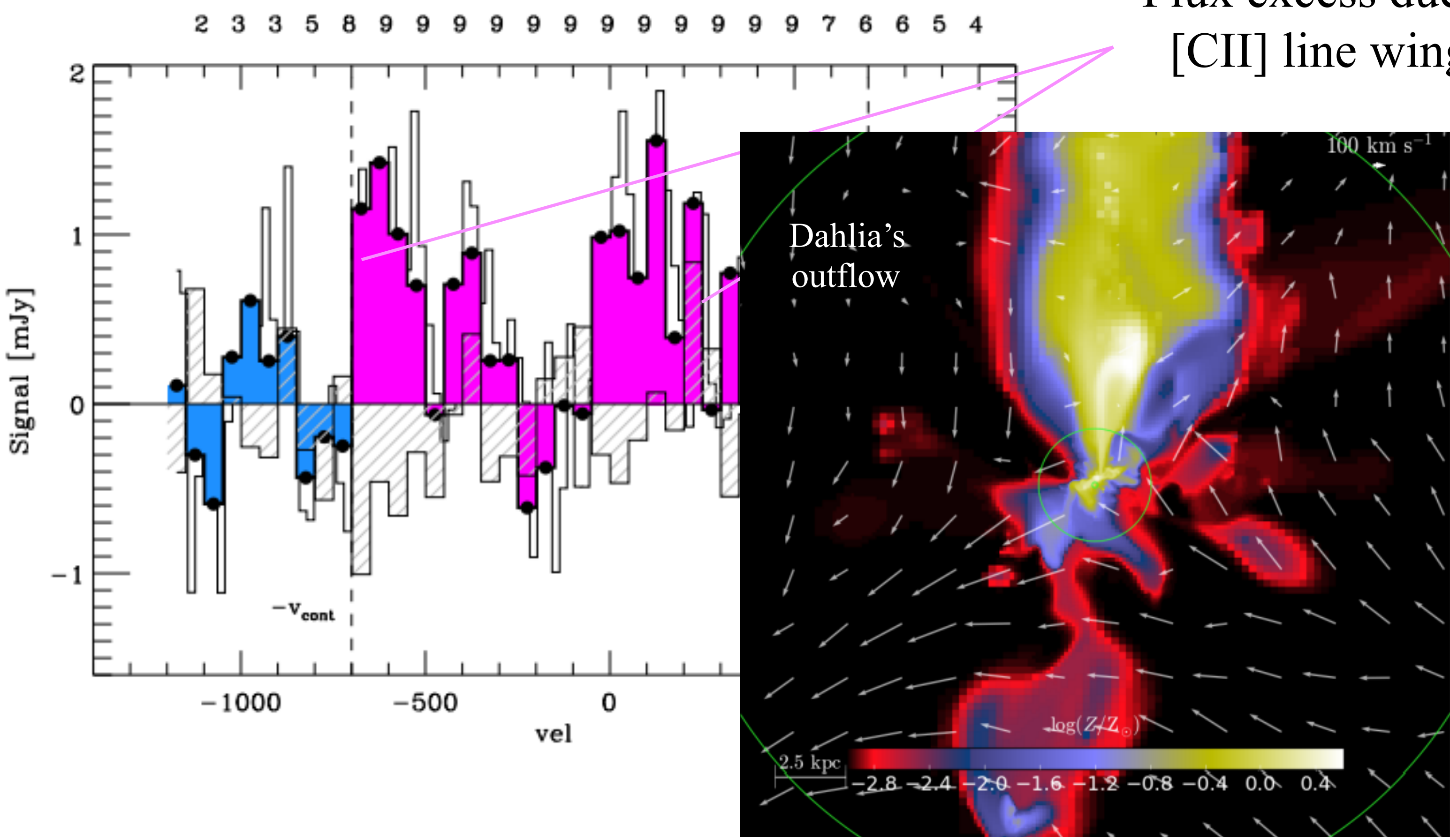
CO(7–6) line @ 5σ with ALMA detected (resolved) in 13 (38) hr

Gallerani+17, in press

OUTFLOWS

Stacked residuals after gaussian subtraction for the 9 [CII] emitters in Capak+15 sample

Flux excess due to [CII] line wings

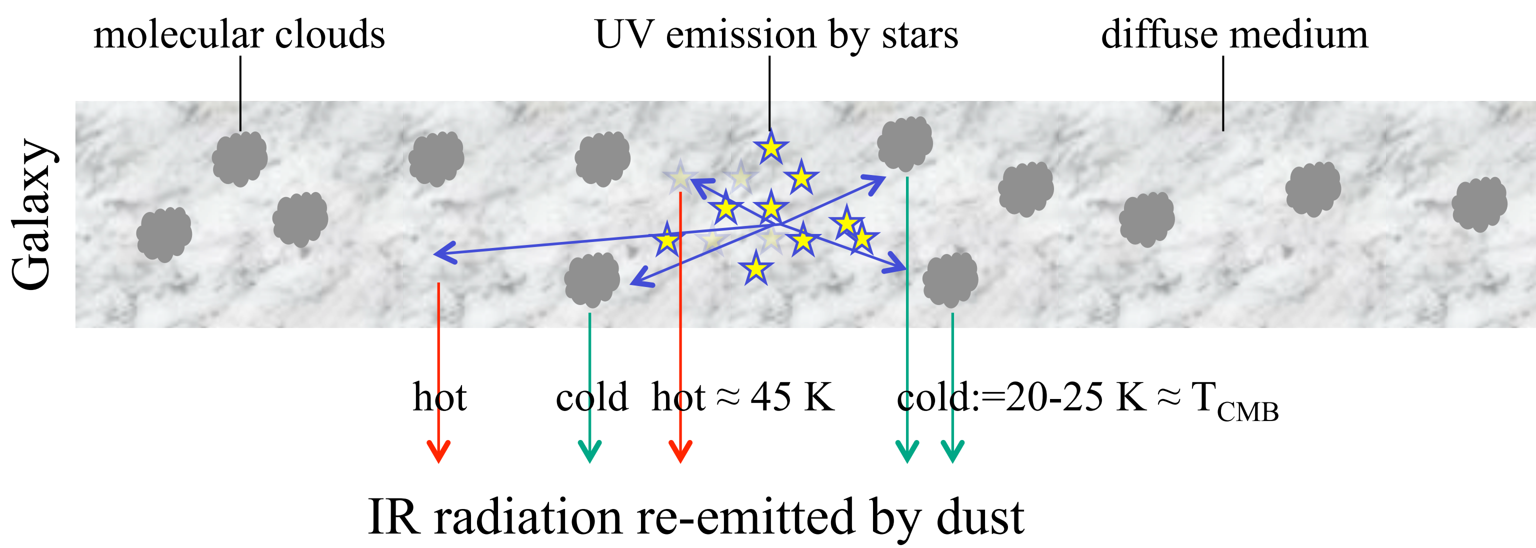


DUST AND IRX-β RELATION

Ferrara+16, 17

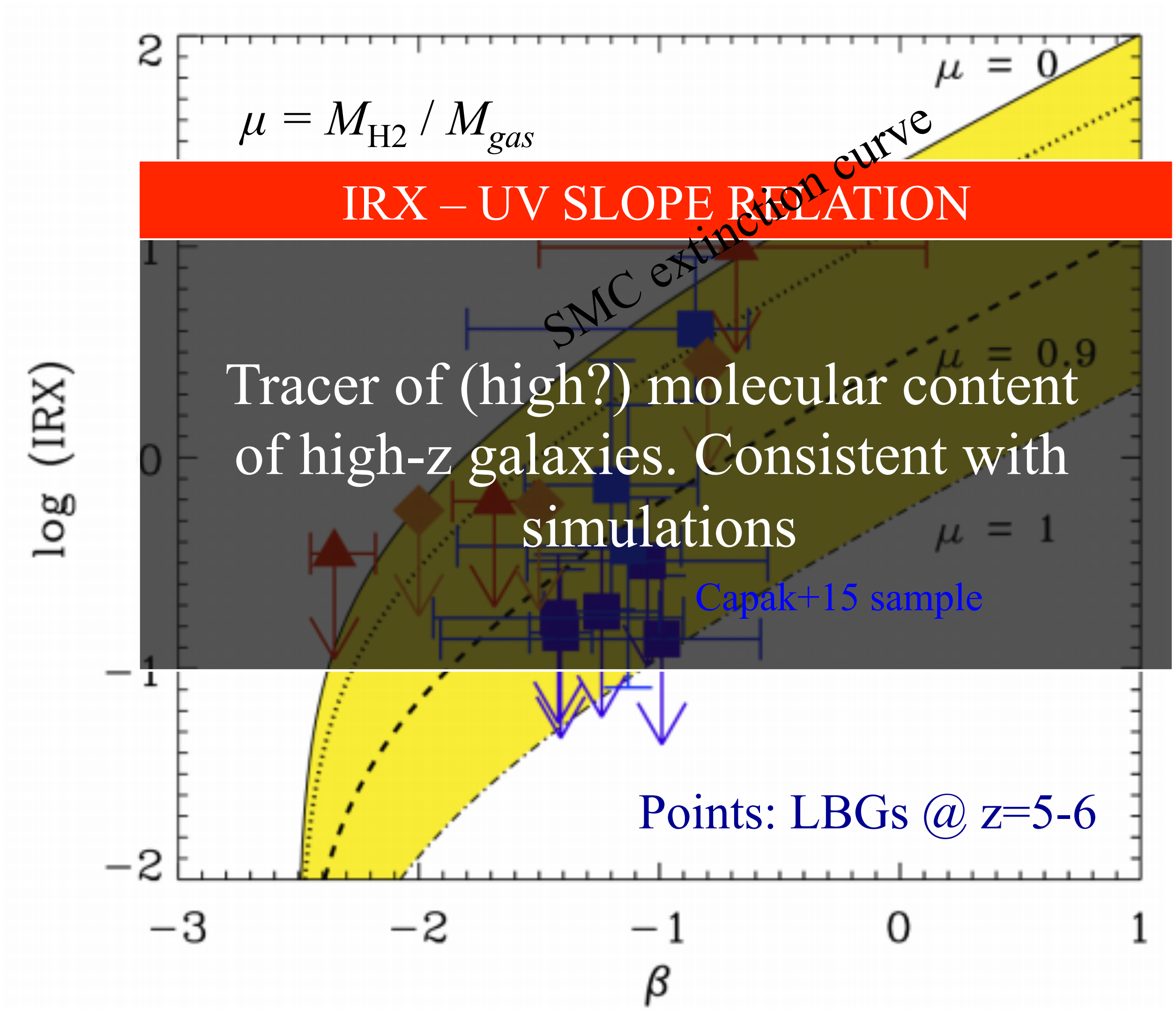
- [CII]-detected high-*z* LBGs in Capak+15 sample show FIR deficit, i.e. they are "infrared dark"
- They show a marked deviation from the local infrared excess, IRX (8-1000 μm), vs. UV slope (β, defined in 1600-2500 Å) relation

A POSSIBLE SCENARIO



DUST AND IRX RELATION

Ferrara+16a,b, Dunlop+16, Bouwens+16



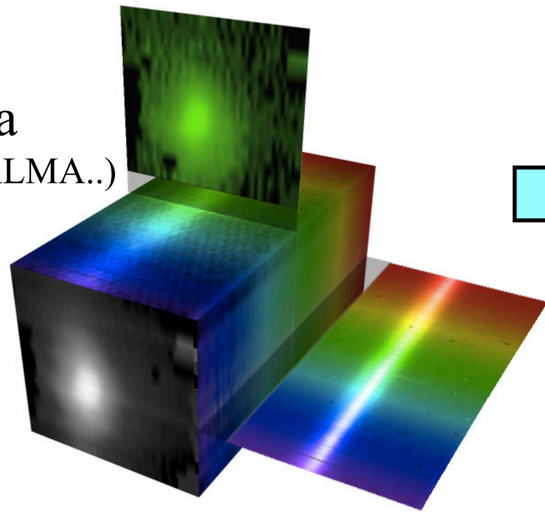
IRX – UV SLOPE RELATION

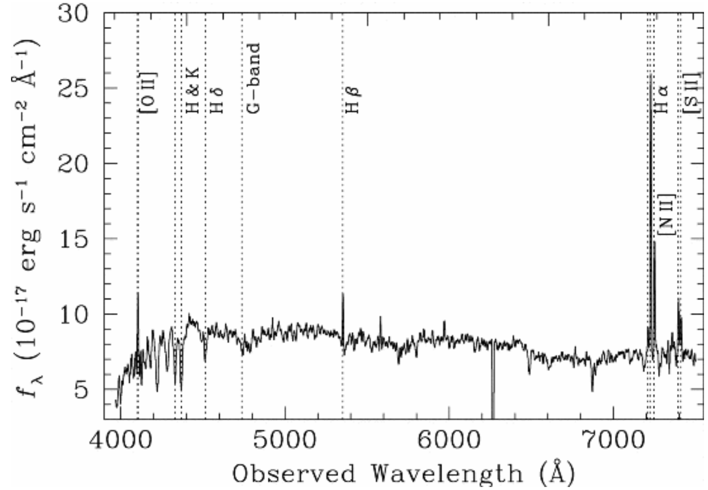
Tracer of (high?) molecular content of high-z galaxies. Consistent with simulations

Ucci+17a,b

FROM OBSERVABLES TO PHYSICS

IFU data
(MUSE, JWST, ALMA..)





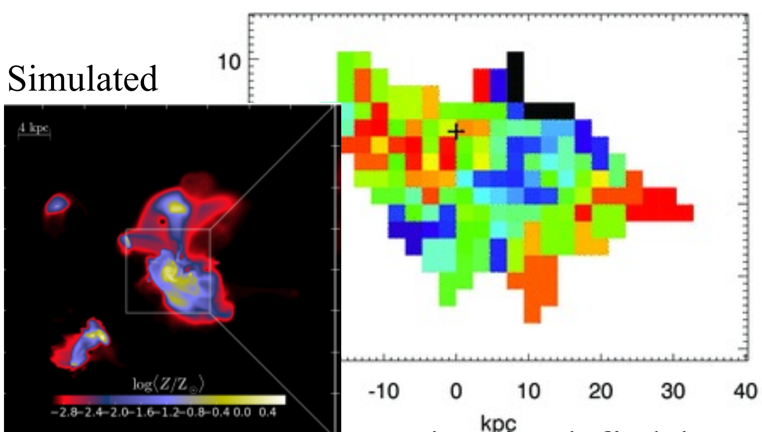
Spaxel
(emission lines)

GALAXY MACHINE LEARNING
FOR EMISSION LINES
GAME

A Supervised Machine Learning code
to extract physical properties from emission line spectra

Observed

Simulated



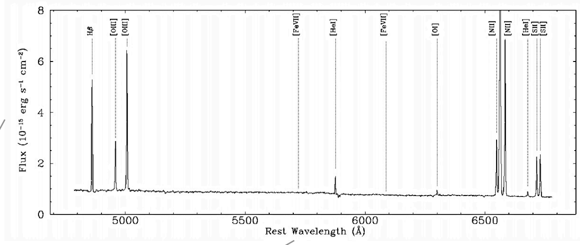
Physical fields
(density, metallicity, ionization..)

Ucci+TBS

APPLICATION TO LOCAL BCGs

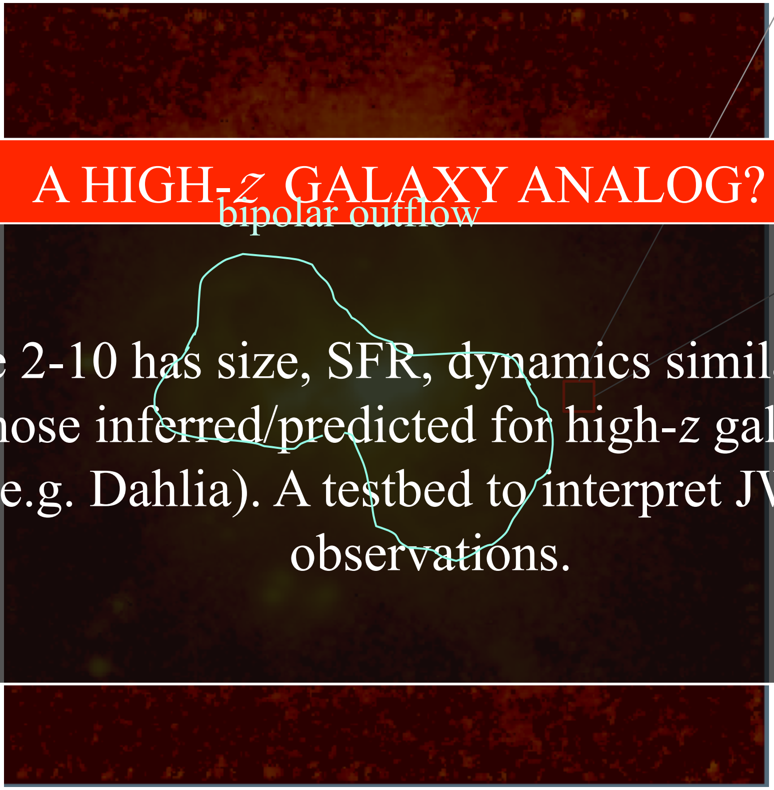
Henize 2-10 @ 8.23 Mpc

MUSE IFU Hα Image (PI: Cresci)



0,000 spectra
from 4650-9300 A
(R=1750-3750)

320 x 320 spaxels
(spatial resolution 0.2”)



64” = 2.56 kpc

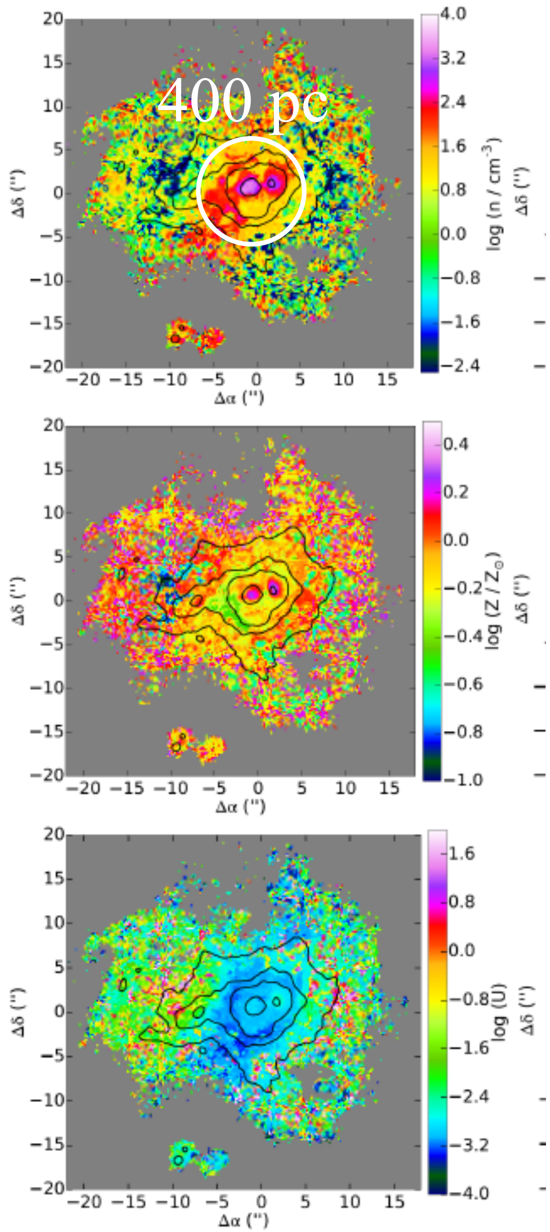
A HIGH-z GALAXY ANALOG?

He 2-10 has size, SFR, dynamics similar to those inferred/predicted for high-z galaxies (e.g. Dahlia). A testbed to interpret JWST observations.

Henize 2-10 physical

High (> 500 cm^{-3}) central density

Gas density

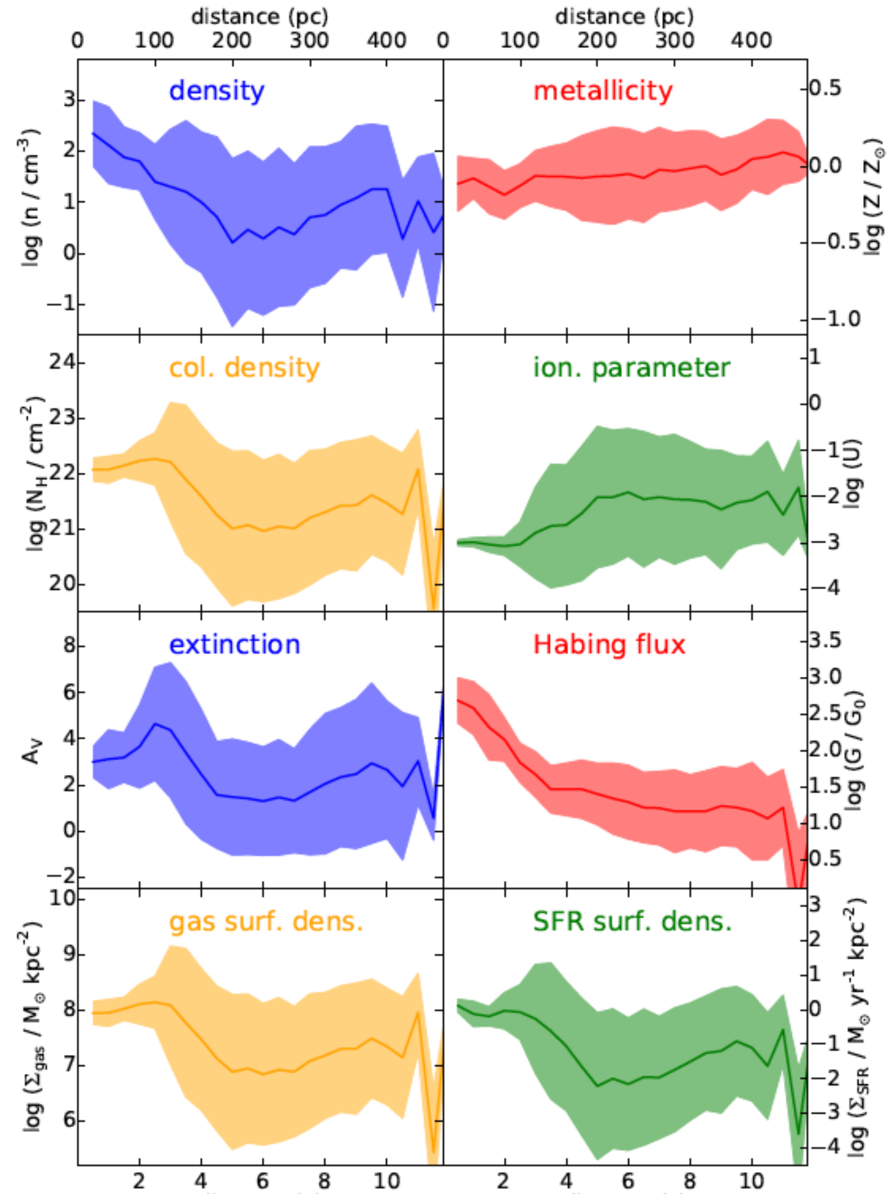


Metallicity

Supersolar *Z*

Ionization parameter

High in the external regions



Radial profiles

- ✧ Little is known about the internal properties and ISM of high redshift galaxies

- ✧ Progress made by combining FIR (ALMA), NIR (JWST) spectra + dust continuum

- ✧ ALMA detections + hi-res simulations show that $z > 5$ galaxies:
  - Are compact and have large reservoirs of dense gas
  - Are considerably metal/dust enriched and possibly obscured in SF regions
  - Have large SFR/area and strong interstellar radiation fields and outflows
  - Are detectable in high-J CO lines

- ✧ Supervised Machine Learning approaches (GAME) to IFU optical/FIR data very successful when applied to local galaxy studies

- ✧ Strong potential of SML for JWST and ALMA applications at high-z