First Identification of 10-kpc scale [CII] Halo around Star-forming Galaxies at $z = 5-7$

Seiji Fujimoto (U. Waseda → DAWN)

in collaboration with

M. Ouchi, A. Ferrara, A. Pallottini, R.J. Ivison, C. Behrens, S. Gallerani, S. Arata, H. Yajima, and K. Nagamine

submitted to ApJ
arXiv: 190206760F

Extremely Big Eyes on the Early Universe @ Roma 9/9—13/2019

Outline

- Stacking Results

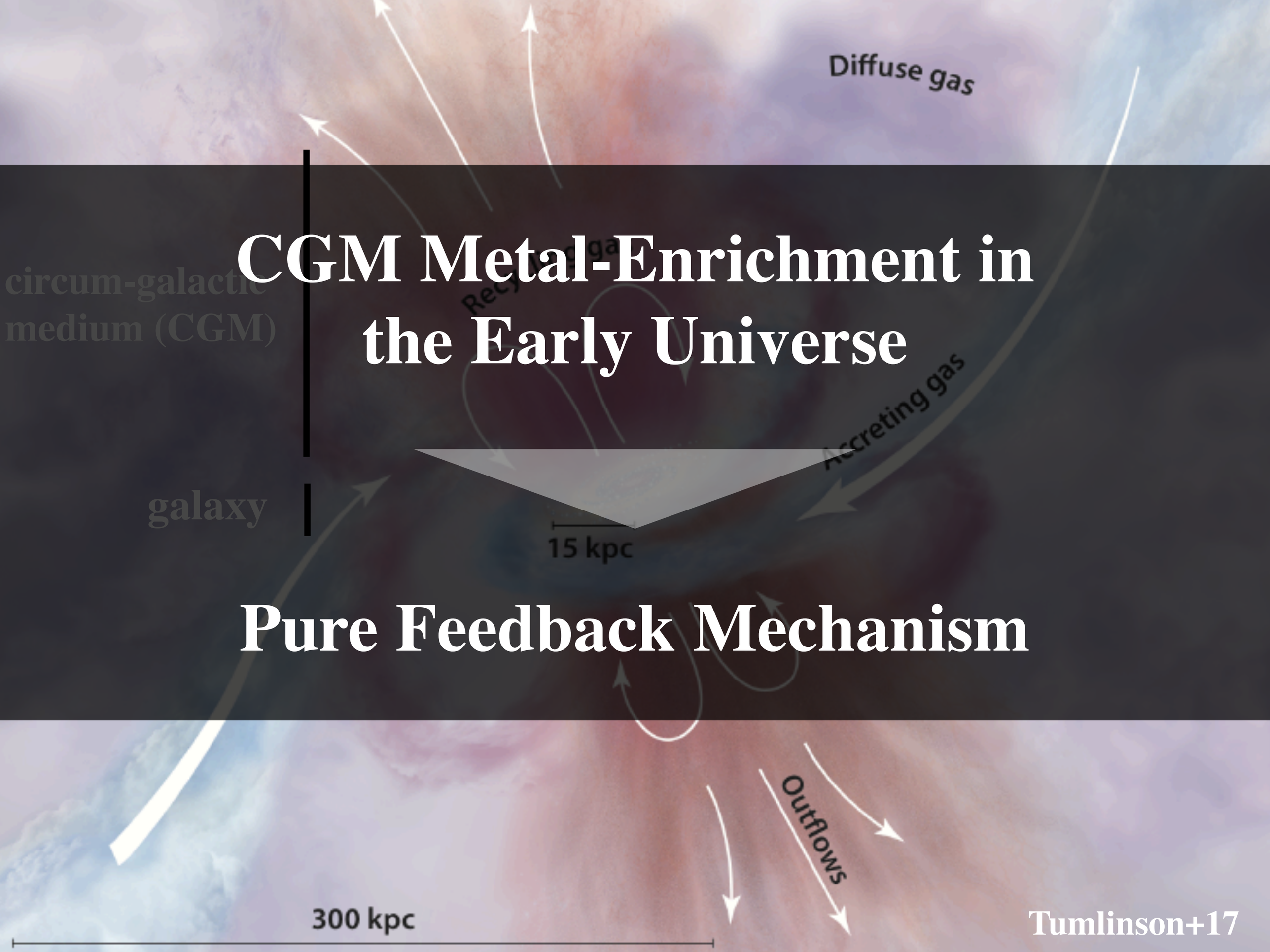
  Fujimoto et al. 2019 (arXiv: 190206760F)

- Individual Results

  Fujimoto et al. in prep.

- Future Prospects with ELT

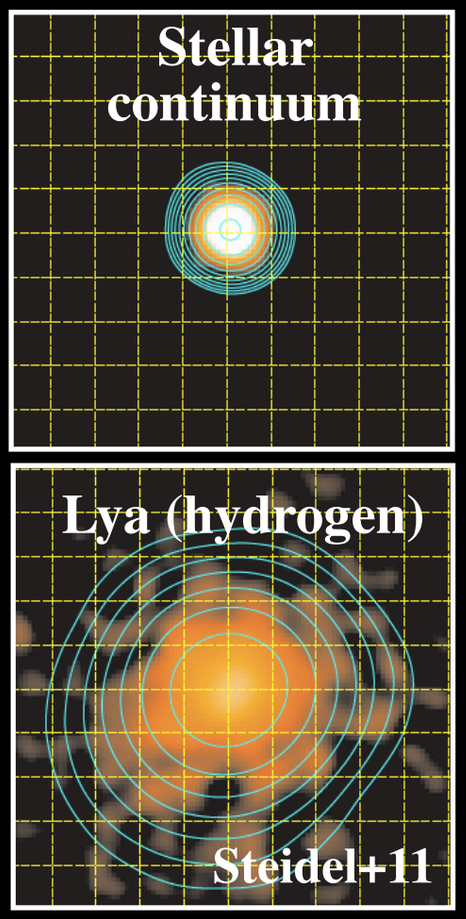
CGM Metal-Enrichment in the Early Universe



Pure Feedback Mechanism

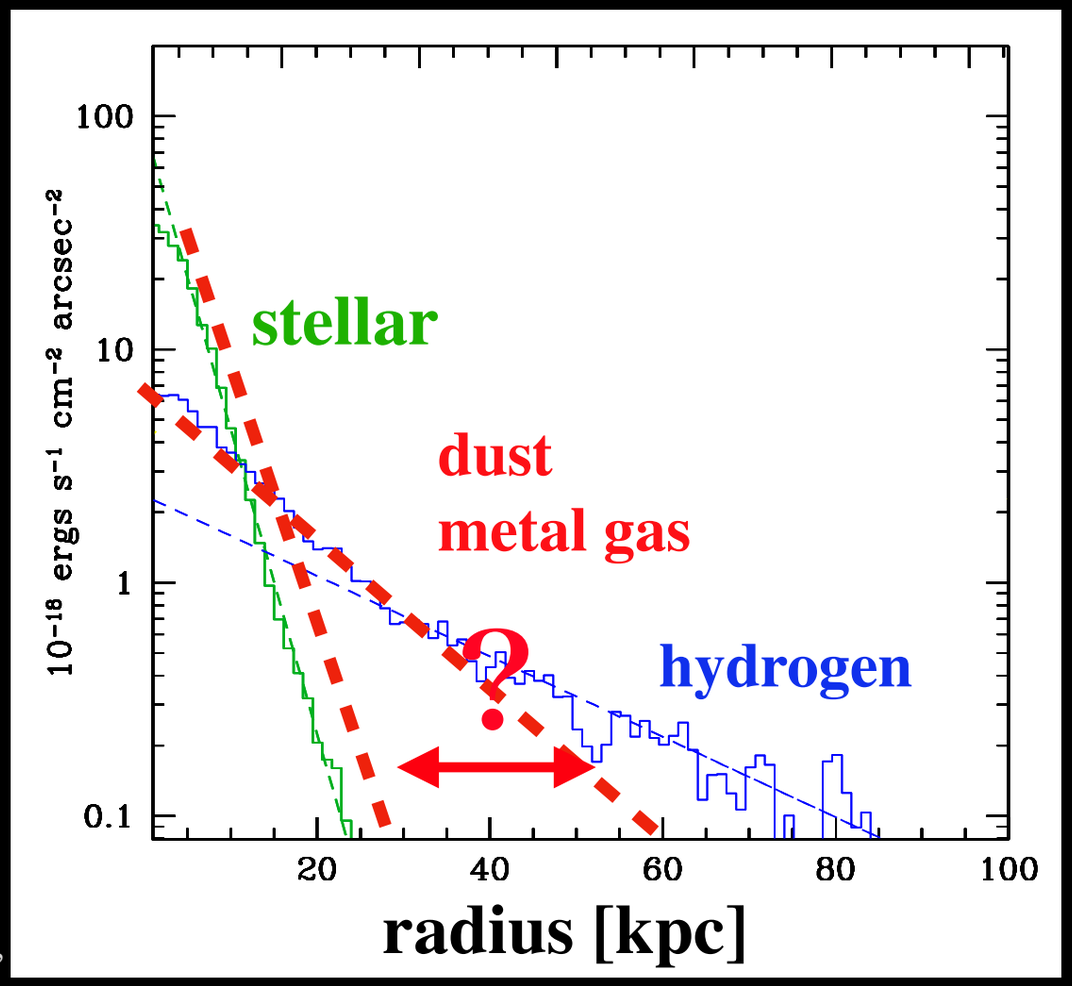
Tumlinson+17

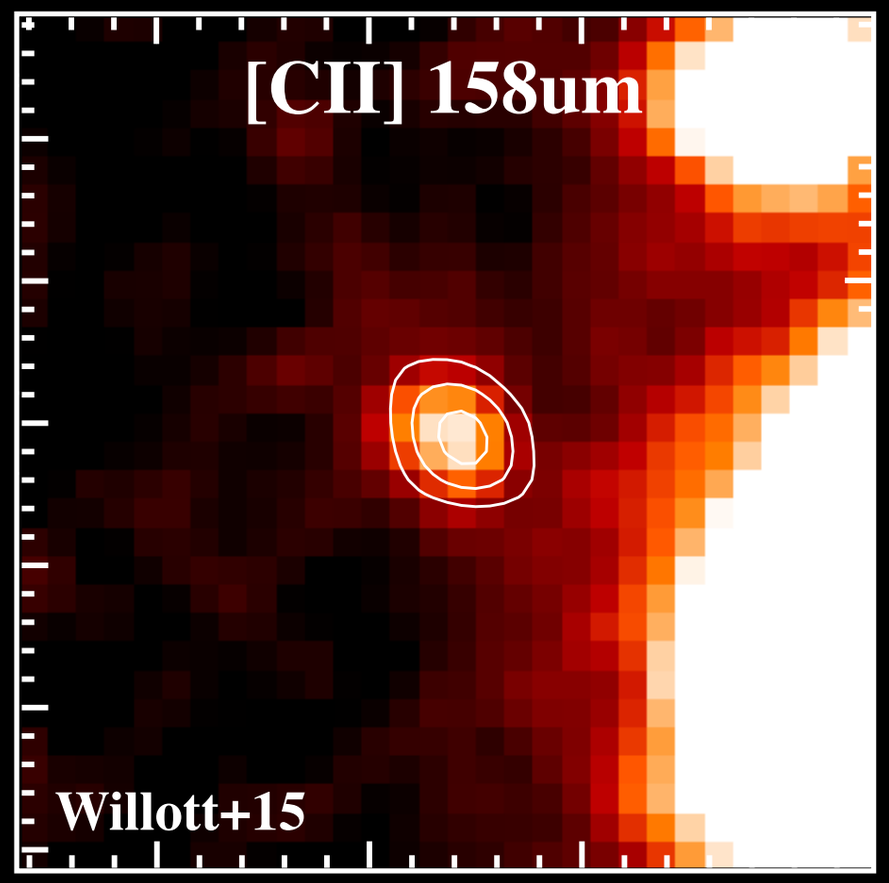
CGM-Scale Observations



see also e.g., Momose+14, Leclercq+17

surface brightness





- **Hydrogen spreads over CGM**
- **Dust & [CII] 158um … Good probe for CGM metal enrichment**

poor sensitivity … **Stacking**

e.g., Capak+15, Knudsen+16, Pentericci+16, Jones+17, Carniani+18, Smit+18

Data & Sample

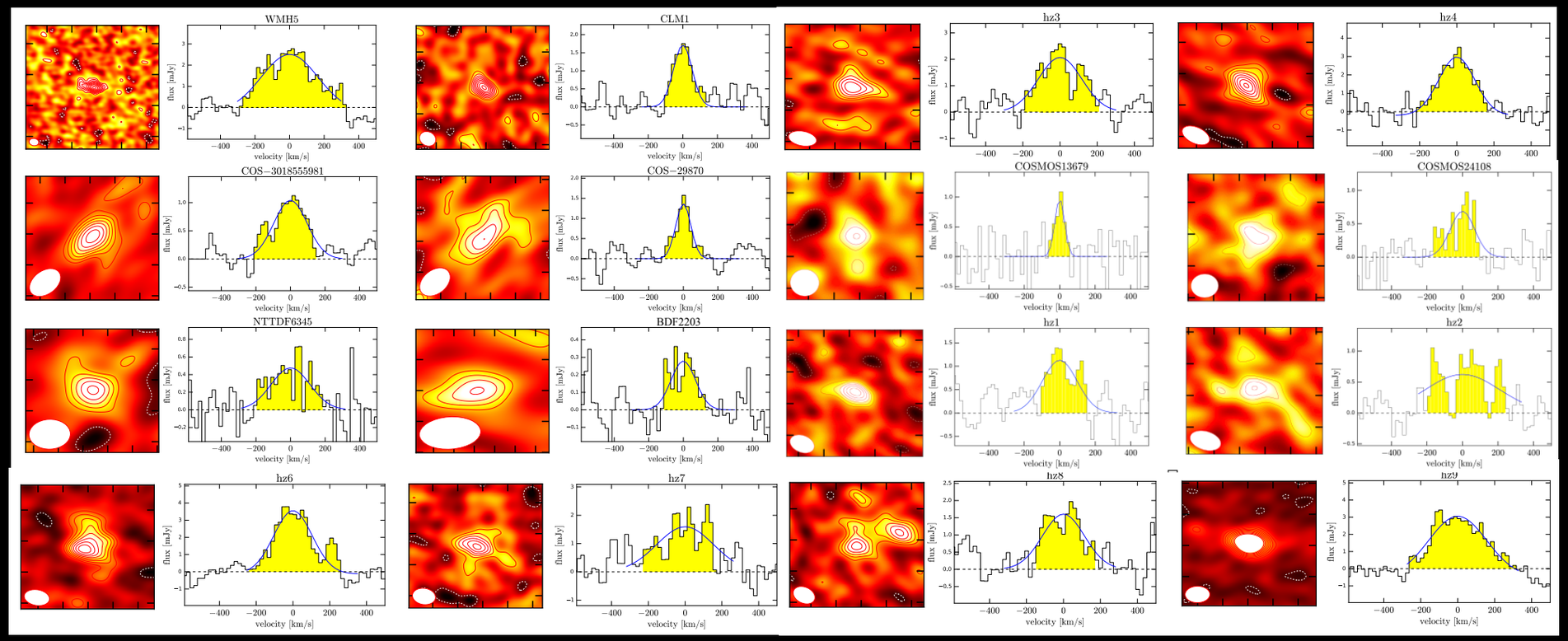
ALMA [CII] 158um line observations: our data + archive

i) [CII] detected at z > 5
ii) SFR < 100 M. / yr
iii) Not AGN
iv) Not Lyman-alpha blob (e.g., Himiko, CR7)
v) Not gravitationally lensed system
vi) FWHM of [C II] line > 80 km/s

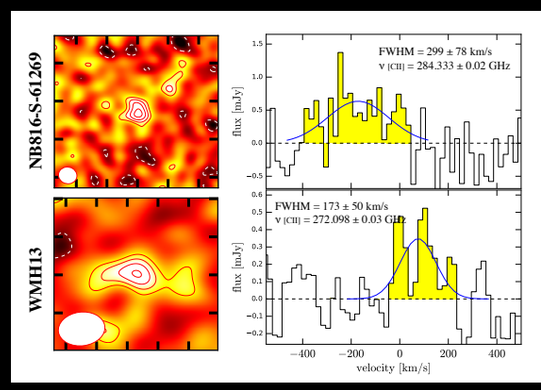
18 (12) normal star-forming galaxies at z=5.15-7.14 (with HST data)

SFR ~ 10 - 70 M./yr

— Previously reported —

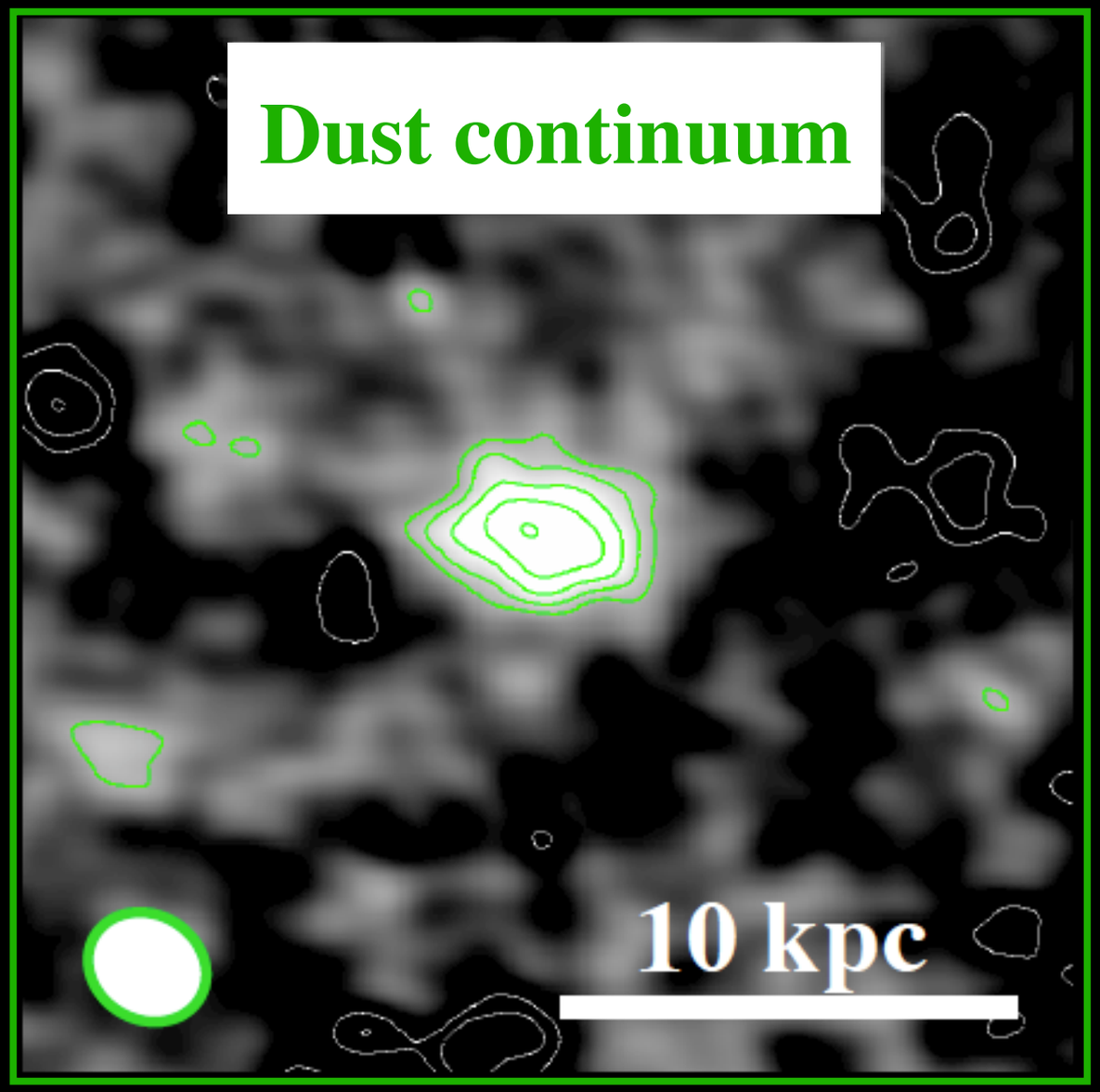


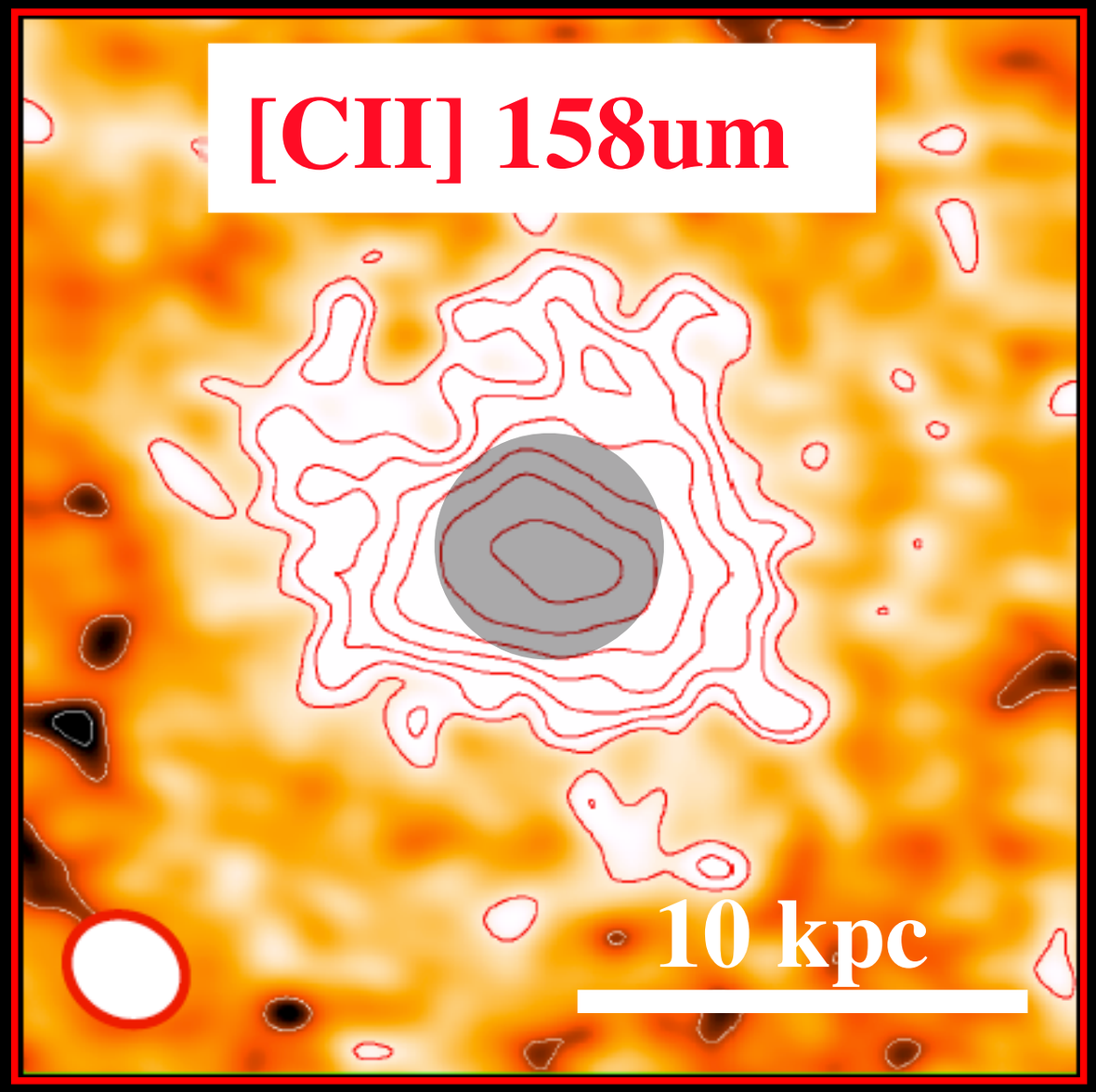
— New —



SF+19

ALMA Deepest Imaging for z~6 Galaxies



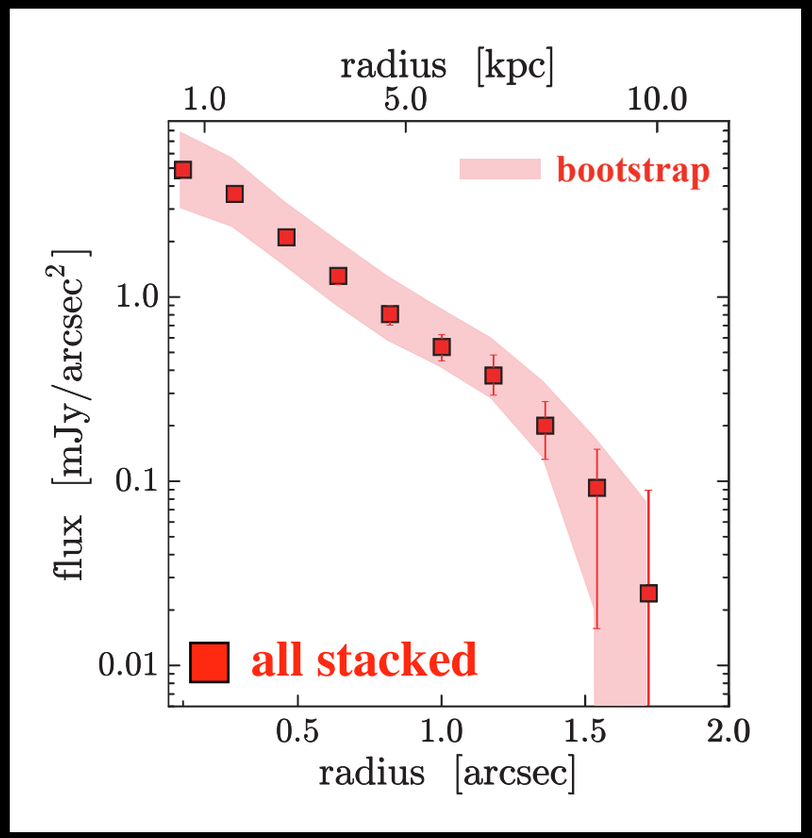


- **Dust continuum: ~10σ detection, compact morphology**
- **[CII] line: 20σ detection**
- **Extended structure up to radius ~ 10 kpc (9.2σ)**

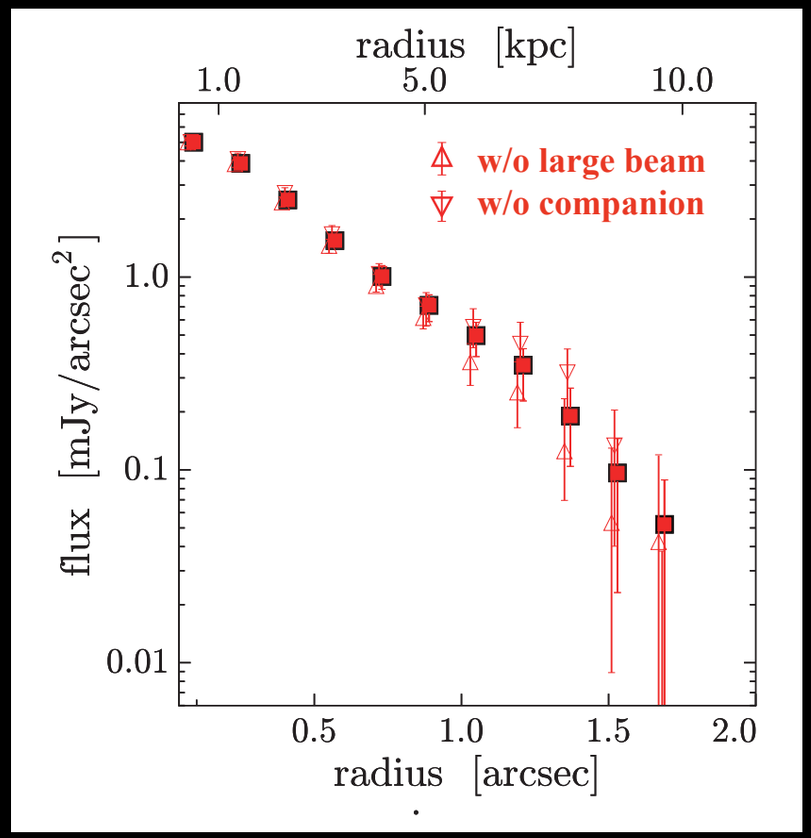
see also Michele's talk

Careful Tests

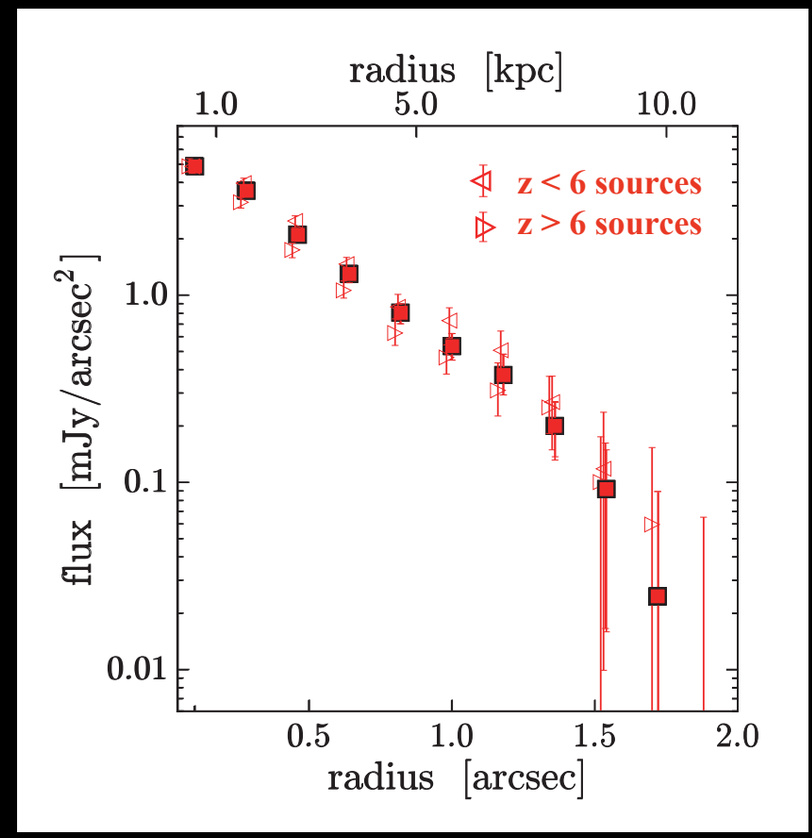
sample variance



removing specific data

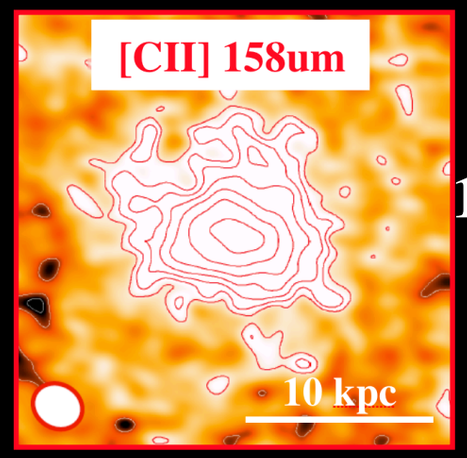


cosmic dimming effect

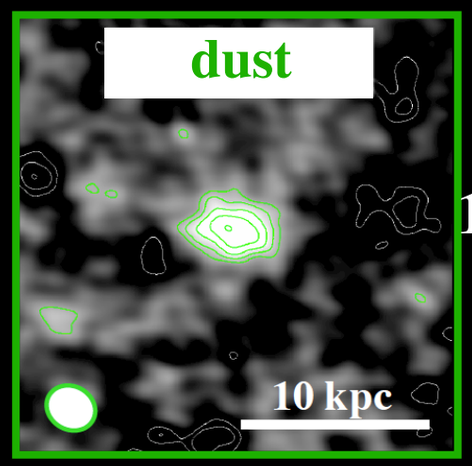


- ~10-kpc scale extended structure appears in any cases

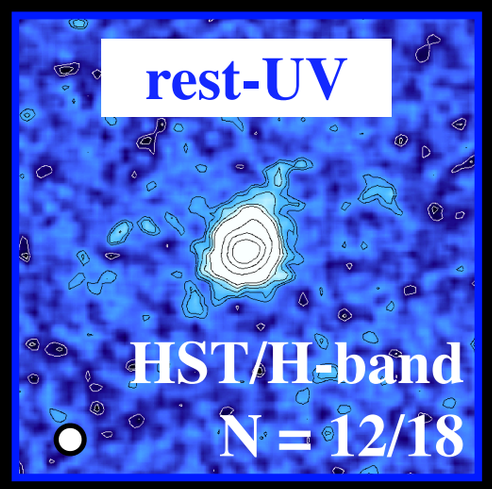
[CII] / dust / rest-UV

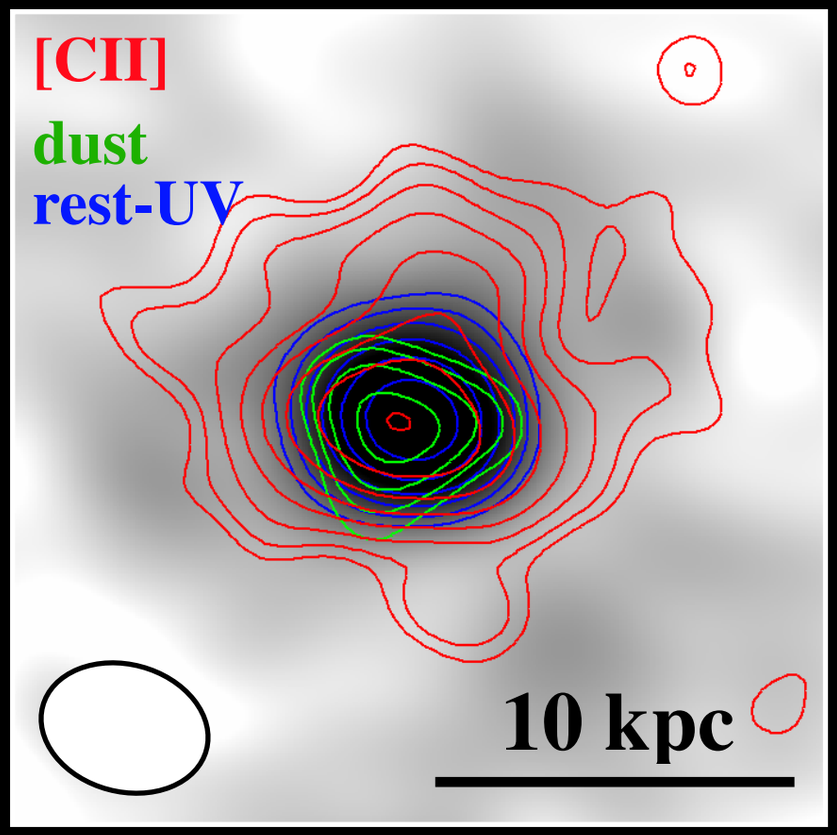


12/18

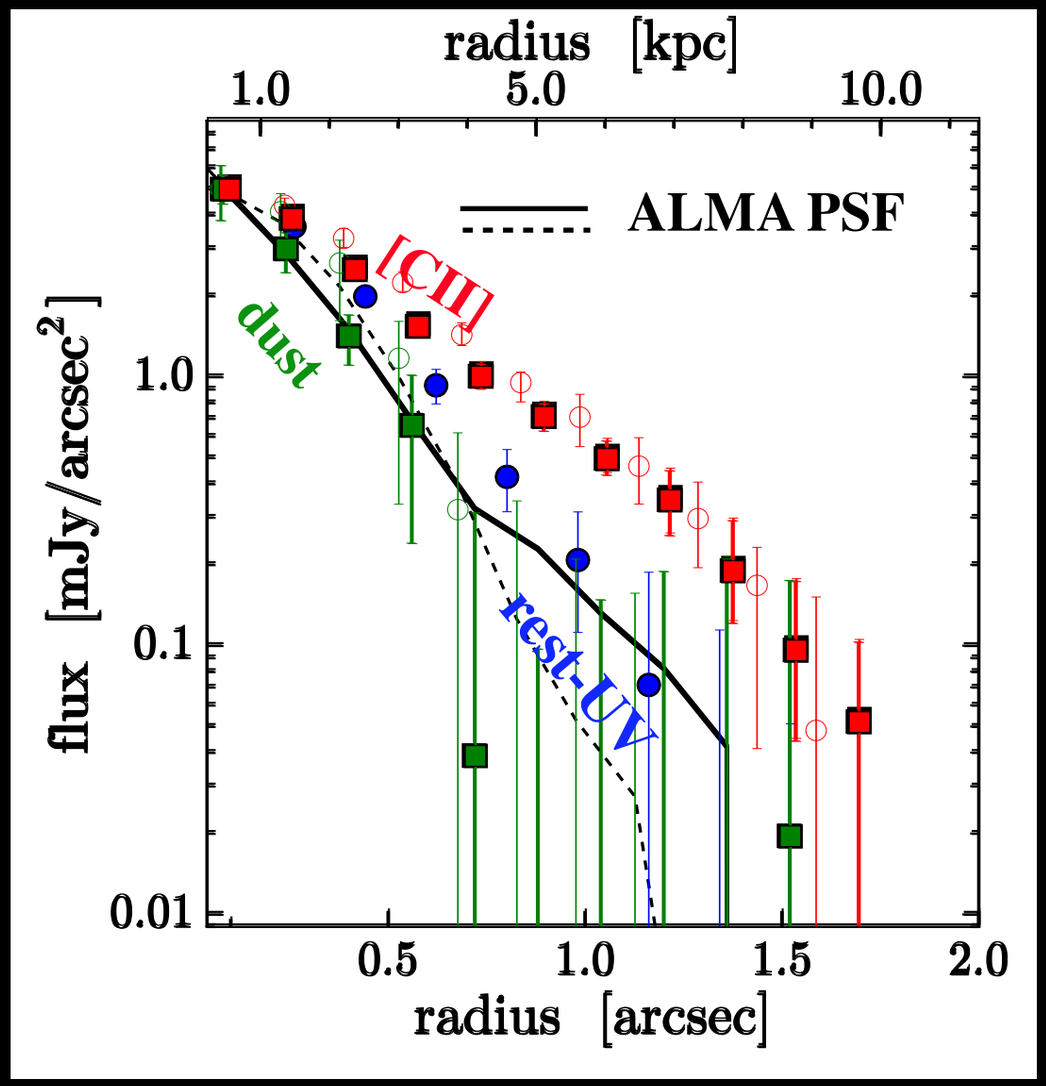


12/18



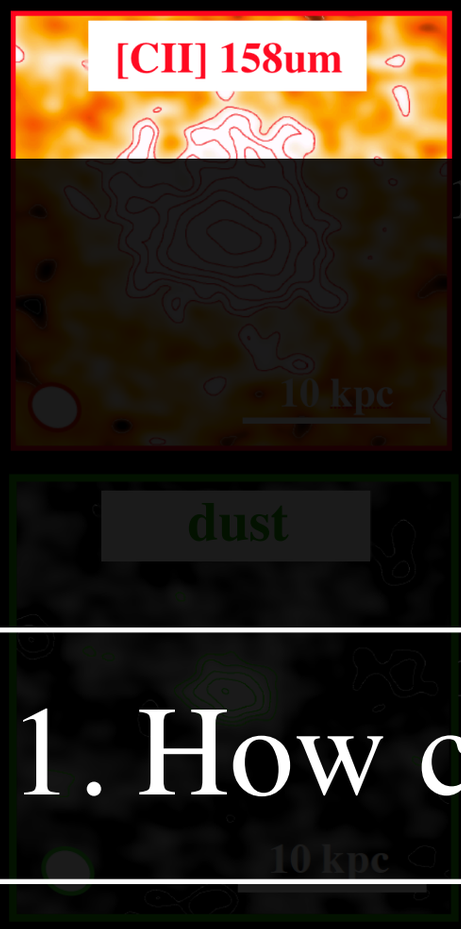


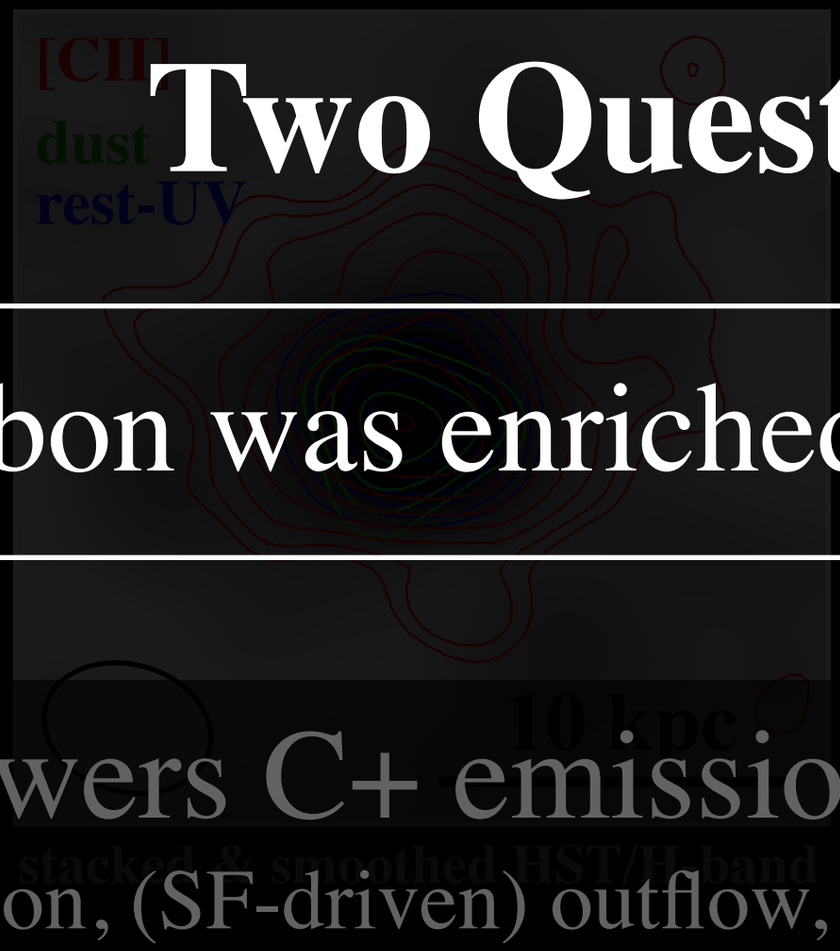
stacked & smoothed HST/H-band

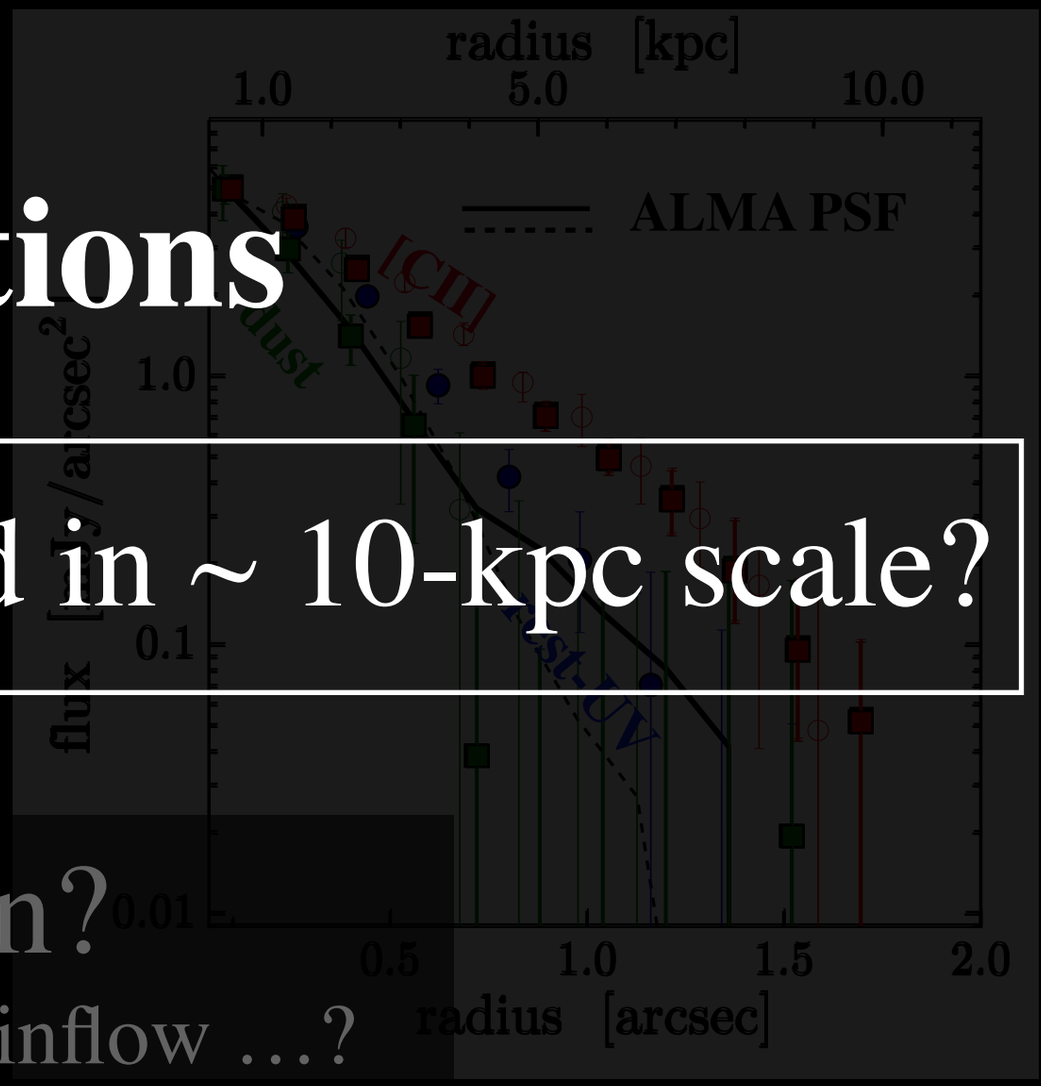


- [CII]: extended more that rest-UV & FIR

[CII] / dust / rest-UV







Two Questions

1. How carbon was enriched in ~ 10-kpc scale?

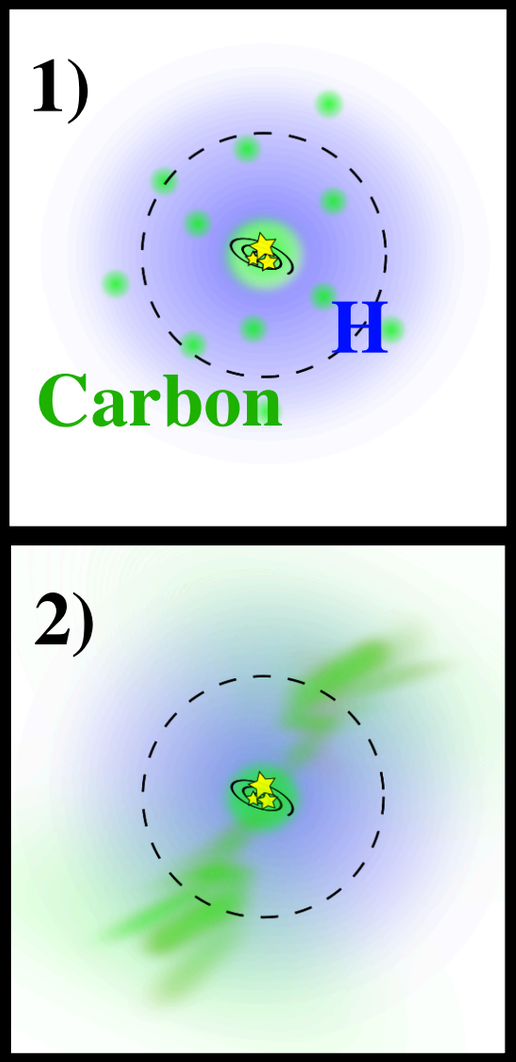
2. What powers C+ emission?
   photoionization, (SF-driven) outflow, inflow …?
   see also Michele's talk

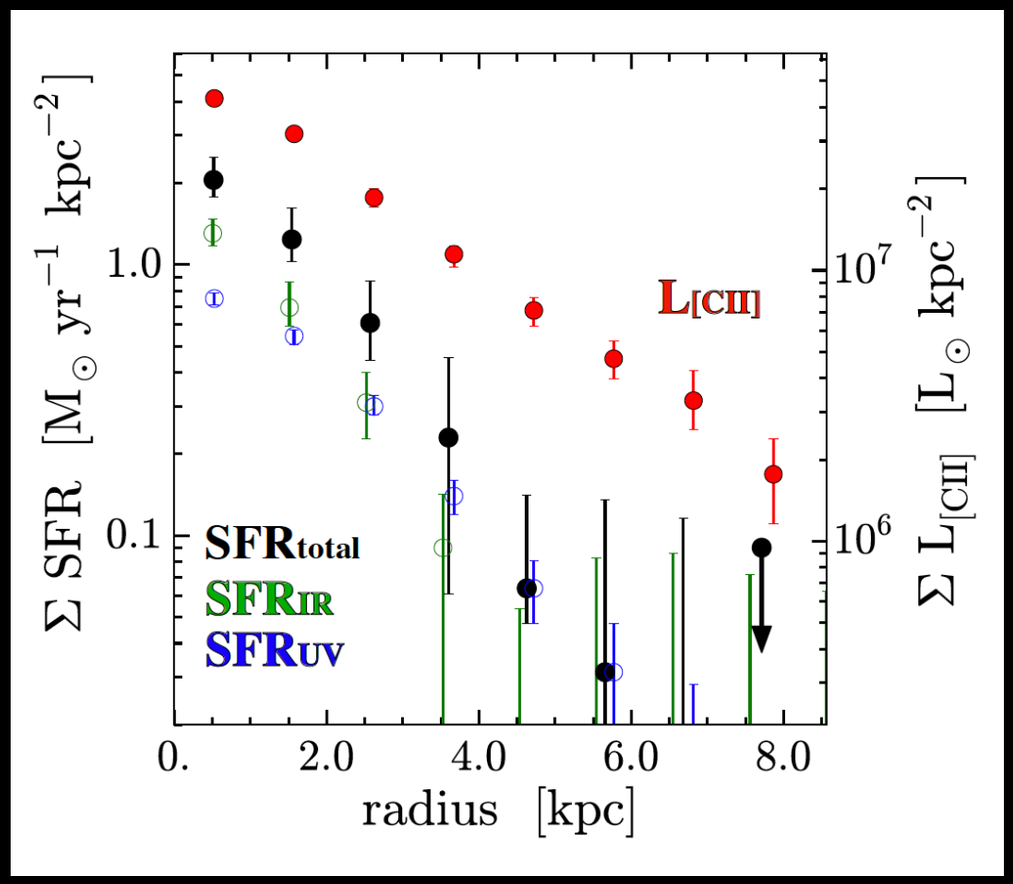
- [CII]: extended more that rest-UV & FIR

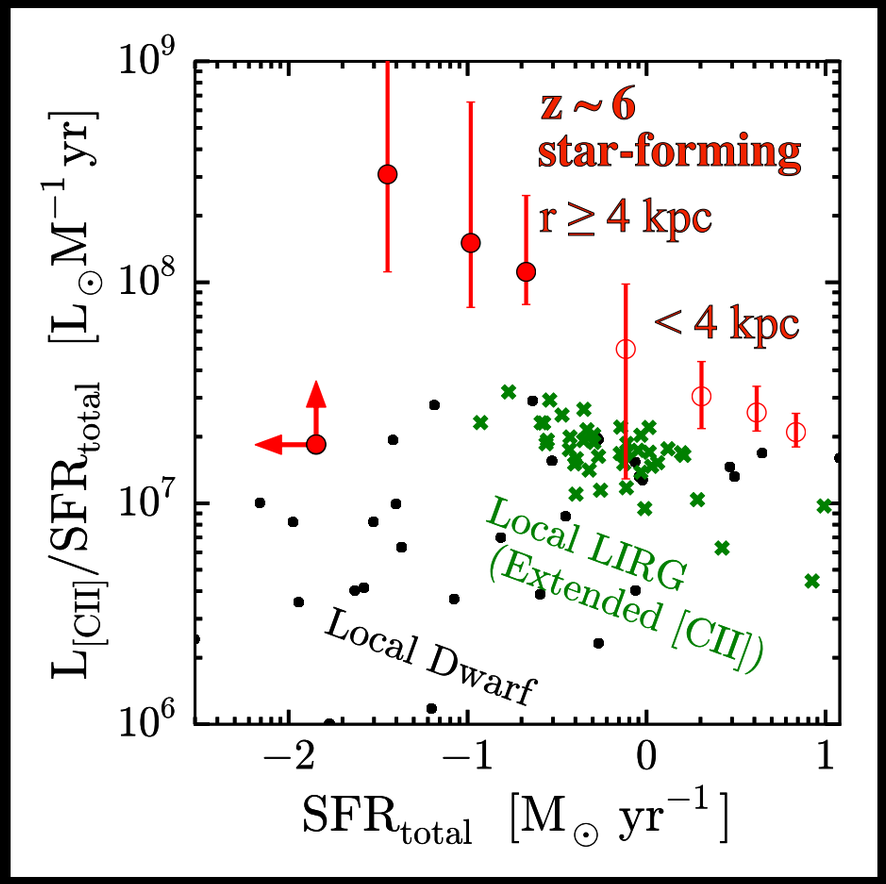
How Carbon Enriched ?

~~1) Satellite galaxies~~

2) past outflow activity







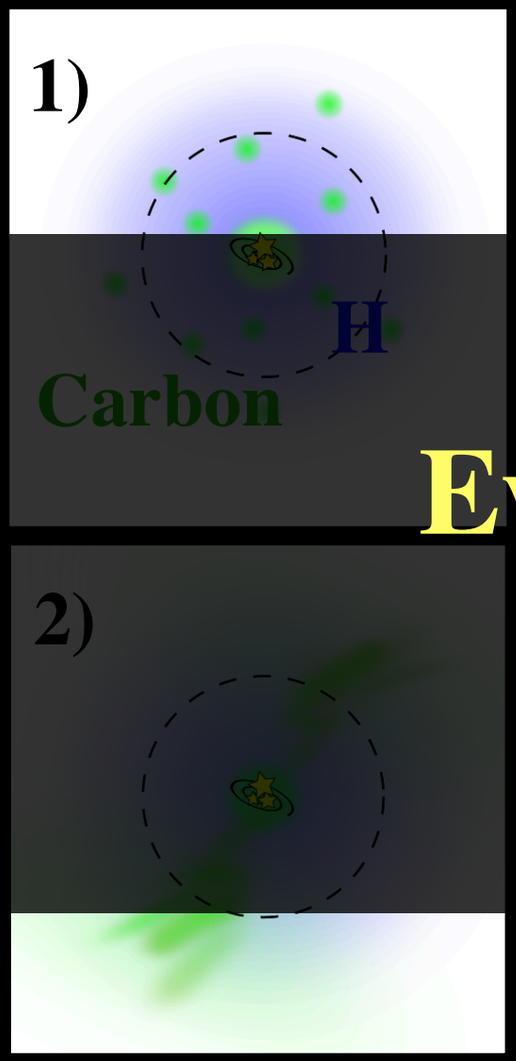
from Diaz-Santos+13, Delooze+14

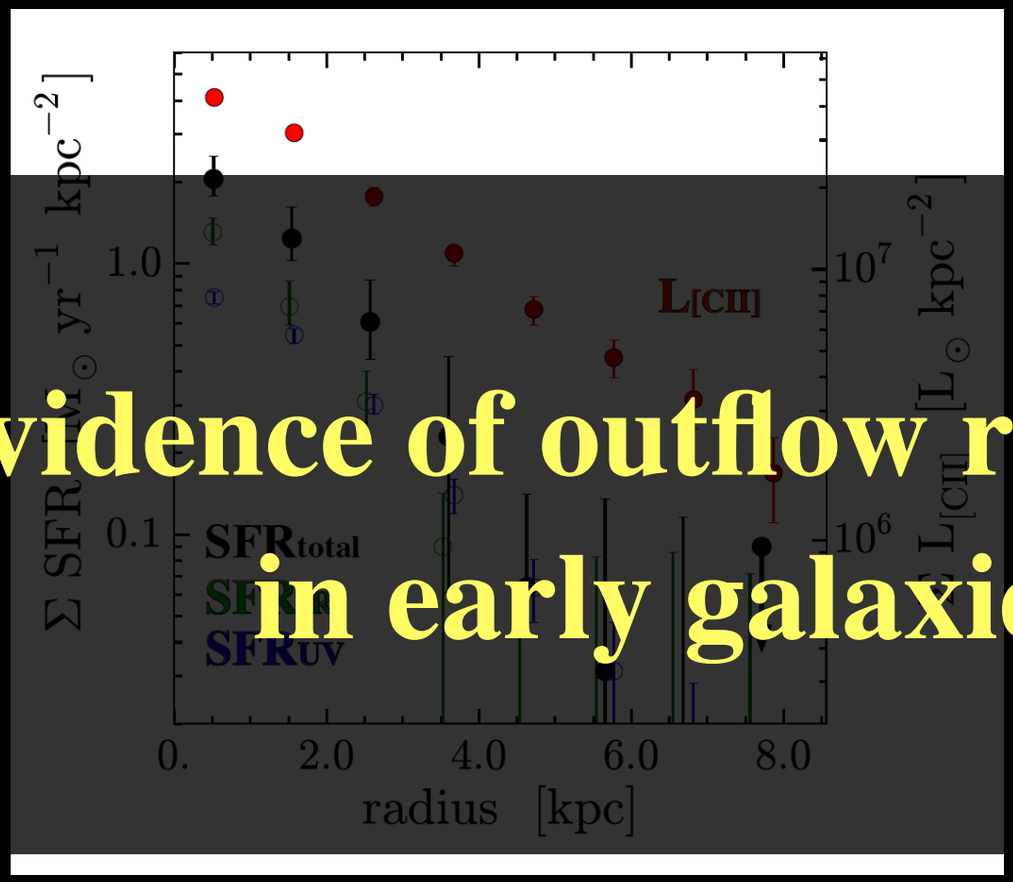
$L_{[CII]}$ / SFR ratio ~ 1 dex higher than low-mass galaxies

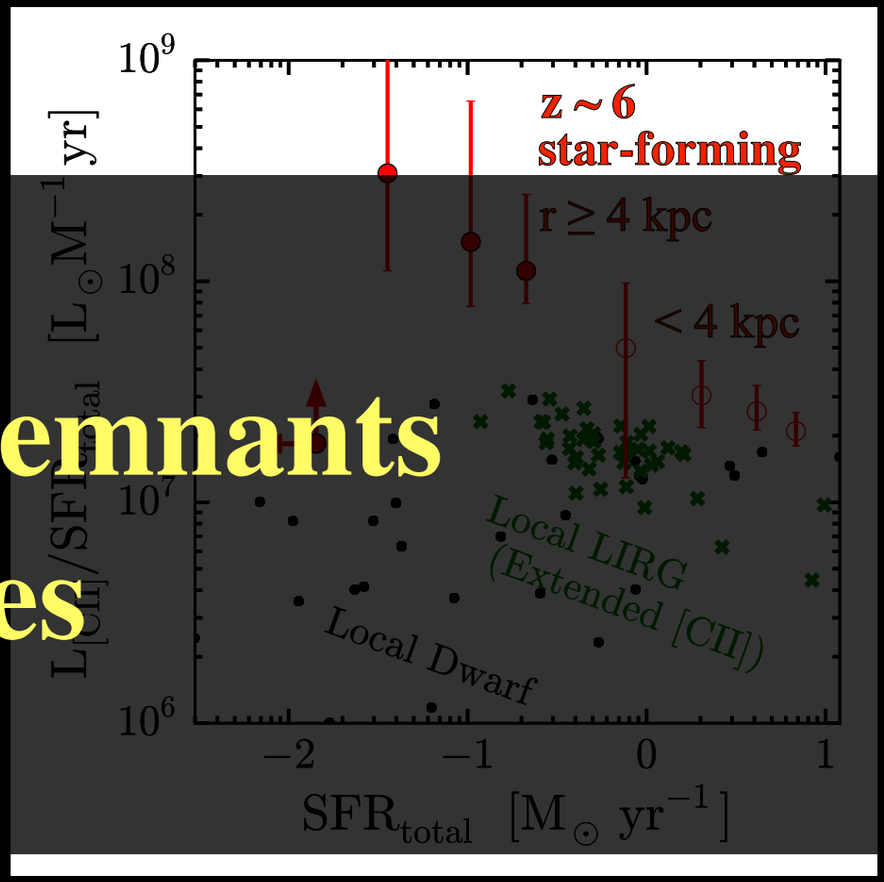
How Carbon Enriched ?

~~1) Satellite galaxies~~

2) past outflow activity





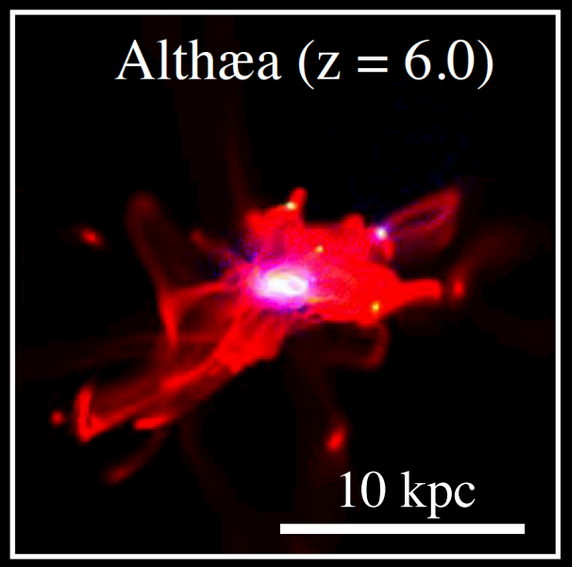


Evidence of outflow remnants in early galaxies

from Diaz-Santos+13, Delooze+14

$L_{[CII]}$ / SFR ratio ~ 1 dex higher than low-mass galaxies

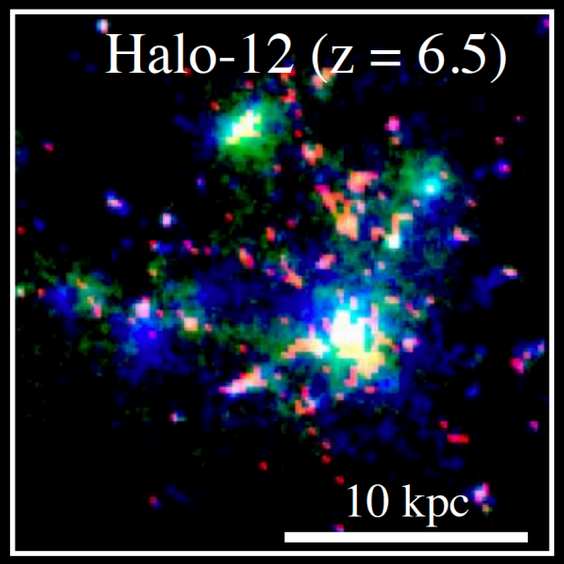
Comparison with Model



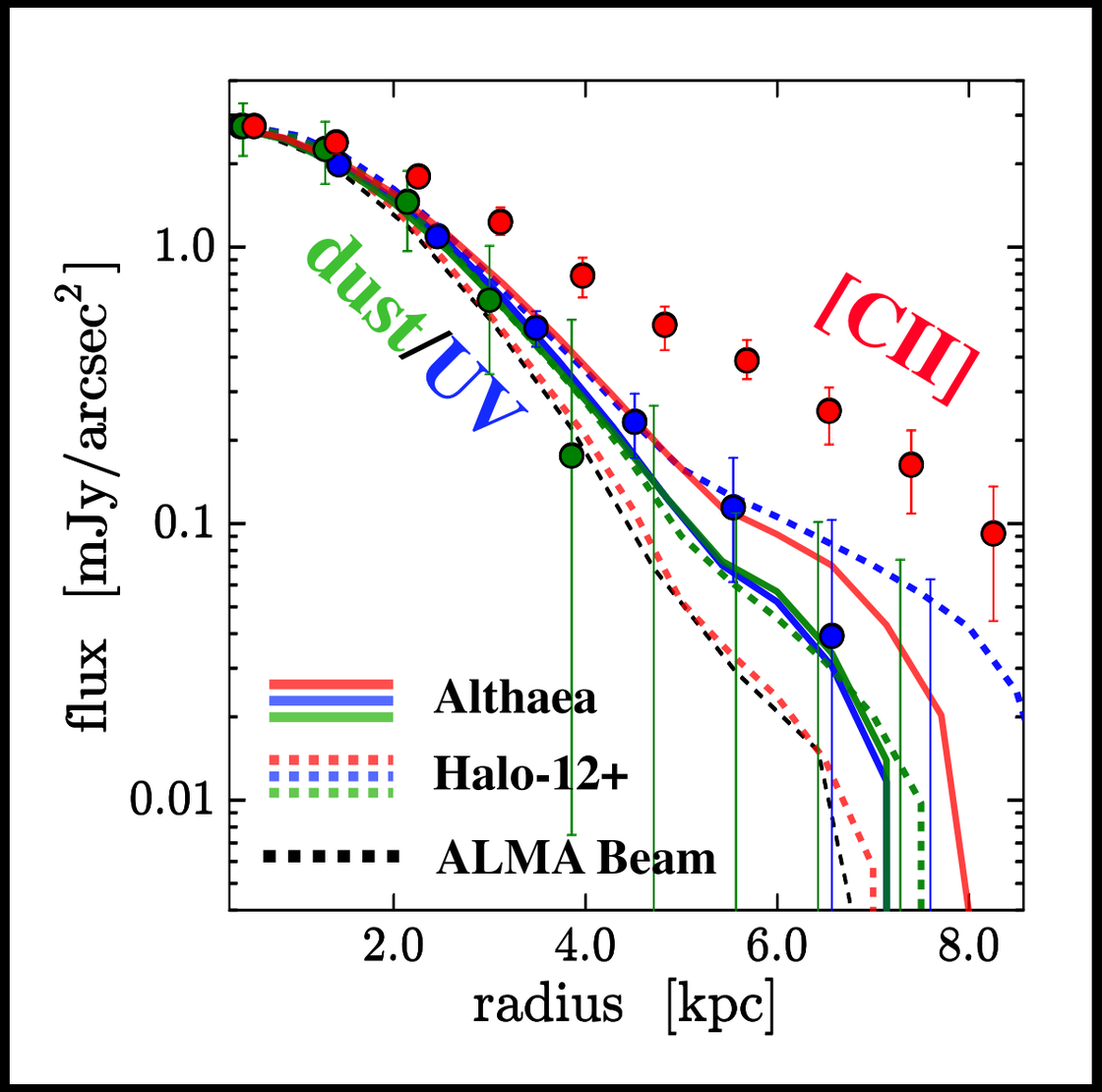
[CII]
dust
rest-UV

Pallottini+17a,b

see also Mahsa's talk

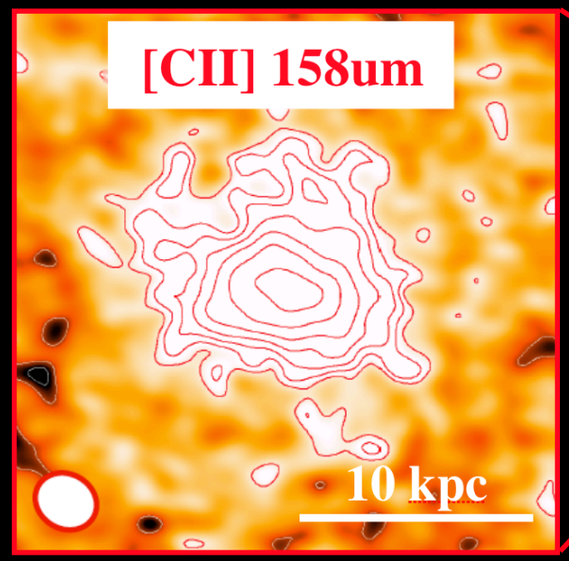


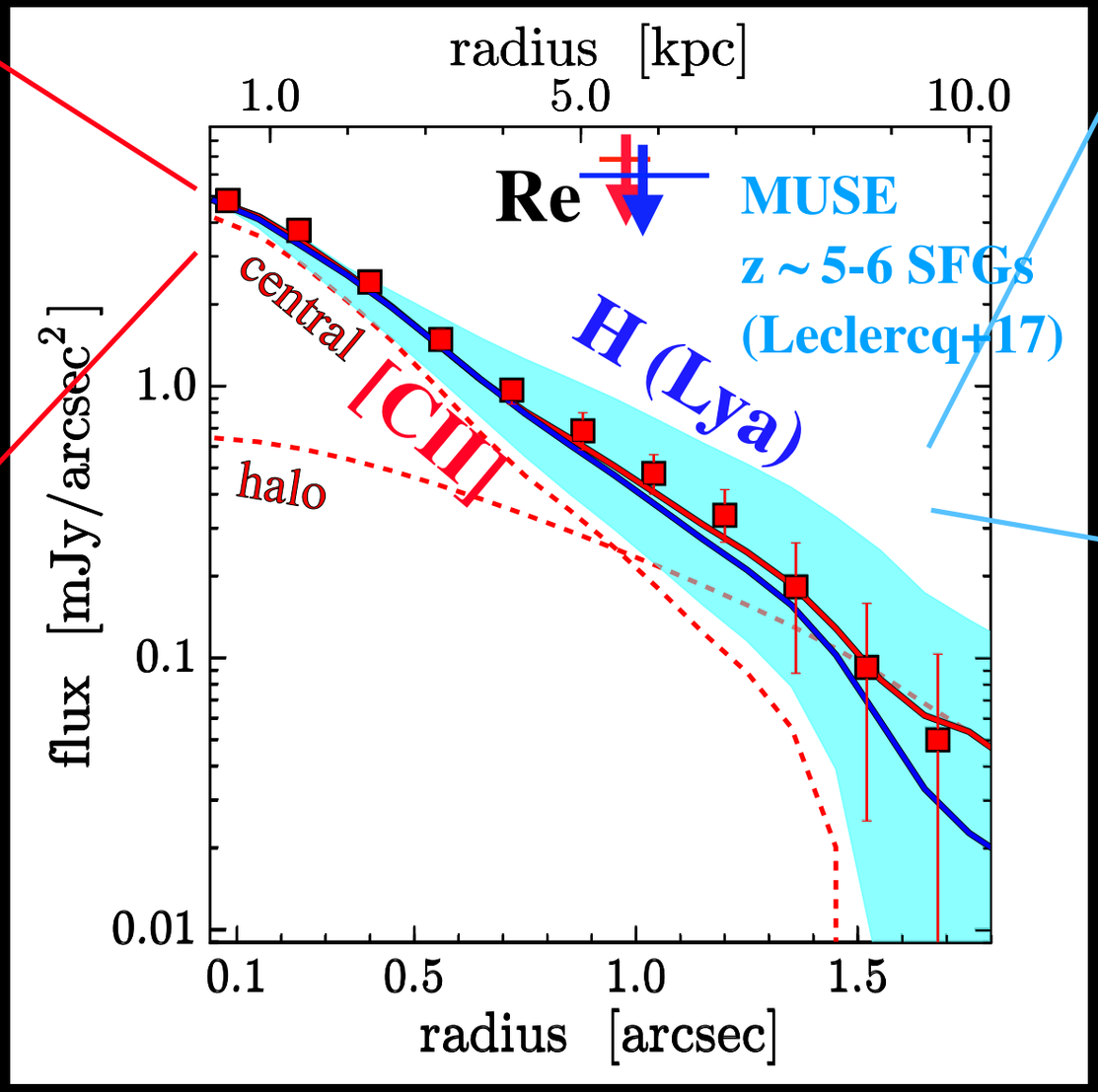
Yajima+17
Arata+18

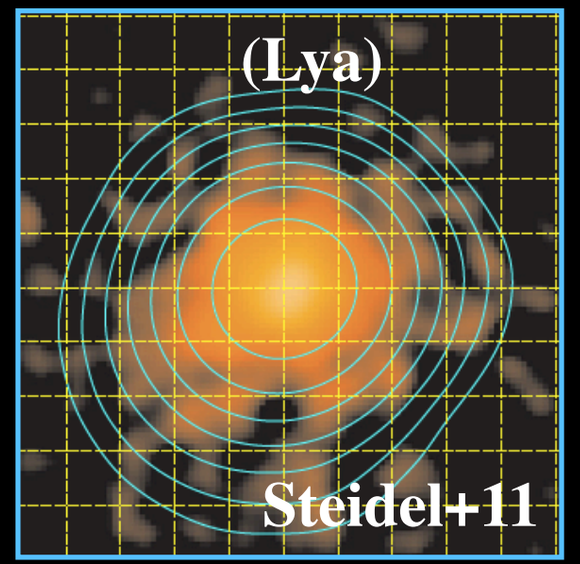


- **rest-UV & FIR continuum … reproduced**
- **[CII] … Not reproduced**
- **[CII] halo → Challenging the current galaxy formation models**

Comparison with Lya Halo







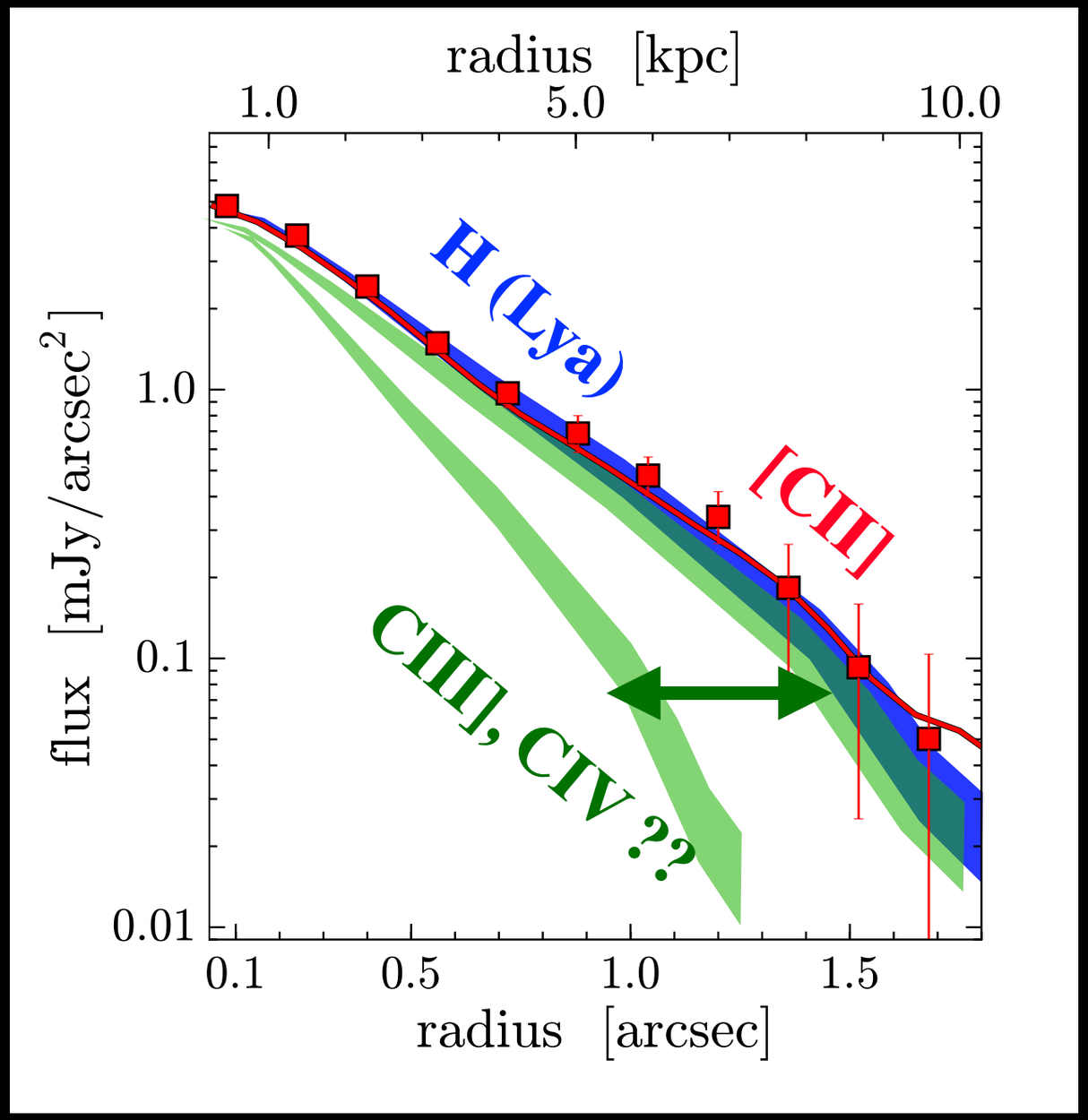
- **Consistent with Lya Halo Profile**
- **Central: Re ~ 1.1 +/- 0.1 kpc, Halo: Re ~ 5.6 +/- 0.2 kpc**
- **Individual comparison is essential**

see also Jorryt's talk

Individual Results

Future Prospects

Individual Halo with ELT



Detecting halo (r ~10 kpc) emission at z ~ 6 …

- Lya: ~ 0.6 hour*

- CIII], CIV: ~ 10 hour*

*Assumptions:
S/N ~ 3 [arcsec-2]
Line luminosities … Stark+16
Radial profile … Leclercq+17

- 2D (+3D) comparison of multi-phase halo gas structures

Summary

- Discovery of r ~ 10-kpc scale [CII] Halo **statistically** & **individually**
- [CII] halo …
  - Evidence of outflow remnants
  - Challenging current models
  - Potentially associated with Lya Halo
- Future with ELT … 2D (+3D) structure of multi-phase halo gas