

Imaging the neutral medium of $z > 1.5$ galaxies via [CII] $158 \mu\text{m}$

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The [CII] $158 \mu\text{m}$ fine-structure transition is the brightest emission line of the Galaxy and has already been detected in $z > 1$ starburst galaxies. Being the principal coolant of the cold neutral medium, this line is an ideal tracer of cold gas at high redshifts. We study the ALMA detectability of gas rich galaxies at $z \sim 2$ with high resolution hydrodynamical simulations, including radiative transfer of ionizing radiation and a subgrid prescription to compute the molecular fraction and the [CII] $158 \mu\text{m}$ emissivity. Our preliminary results are encouraging as galaxies with gas masses $M > 10^{10} M_{\odot}$ have total fluxes between 4 mJy and 0.8 mJy, depending on their star formation rates and number of nearby satellites.

Cold gas $z > 1.5$: Imaging and spectroscopy in emission of cold gas has been limited by the available instrumentation, but the improved sensitivity and resolution of ALMA will enable the detection of the galaxy interstellar medium (ISM) at significant redshifts. The [CII] $158 \mu\text{m}$ transition, being the most luminous emission line in the Galaxy and the principal coolant of its cold neutral medium, is an ideal tracer for cold gas in star forming galaxies. Indeed, it has already been detected at $z > 1$ [1]. In particular, HI rich galaxies that exhibit the CII* $\lambda \sim 1335.7 \text{ \AA}$ absorption line are likely to be [CII] $158 \mu\text{m}$ bright sources.

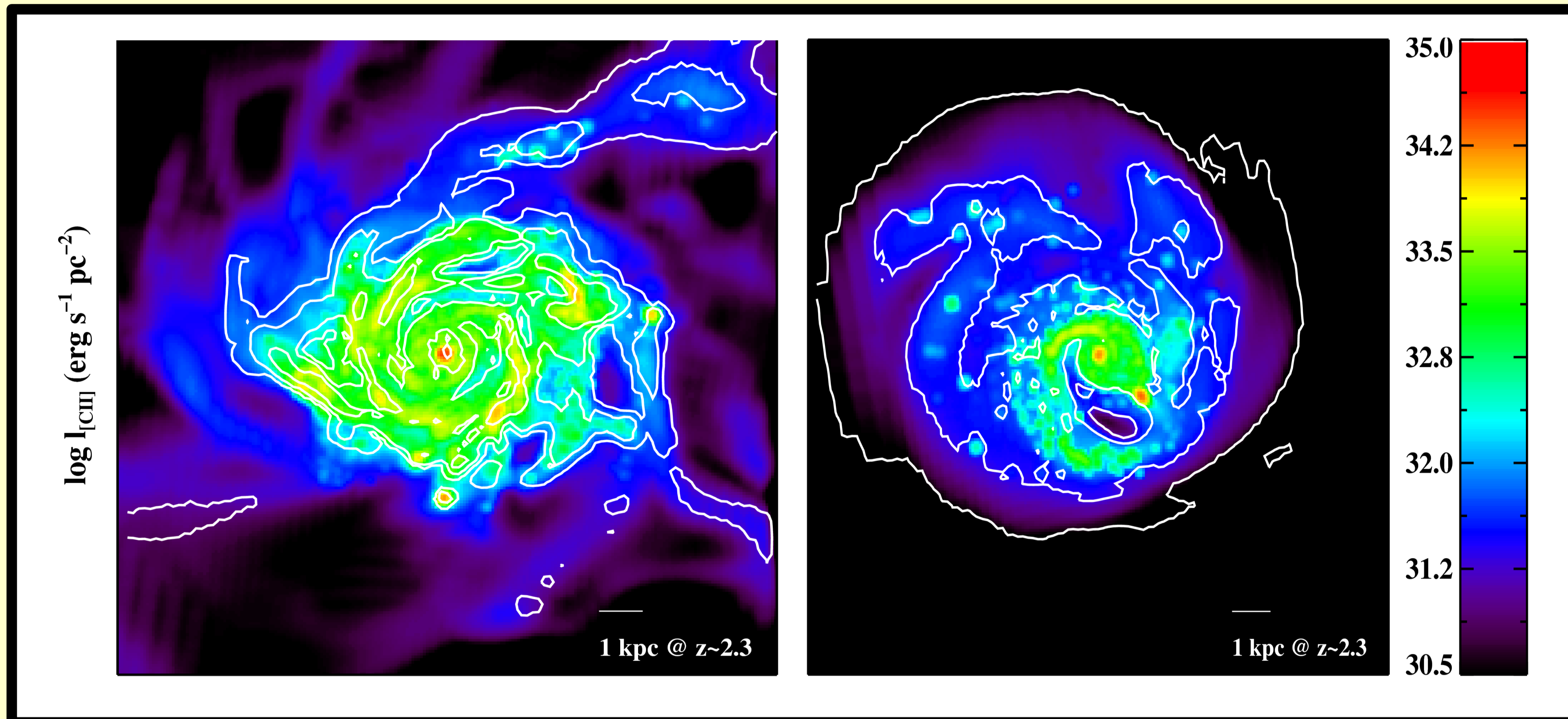


Figure 1: Simulated [CII] $158 \mu\text{m}$ maps for two galaxies at $z \sim 2.3$, with halo masses $\sim 4 \times 10^{11} M_{\odot}$ and $\sim 2 \times 10^{11} M_{\odot}$ and gas masses $\sim 5 \times 10^{10} M_{\odot}$ and $\sim 9 \times 10^9 M_{\odot}$. Contours are for neutral hydrogen column density at 2, 20 and $100 \times 10^{20} \text{ cm}^{-2}$.

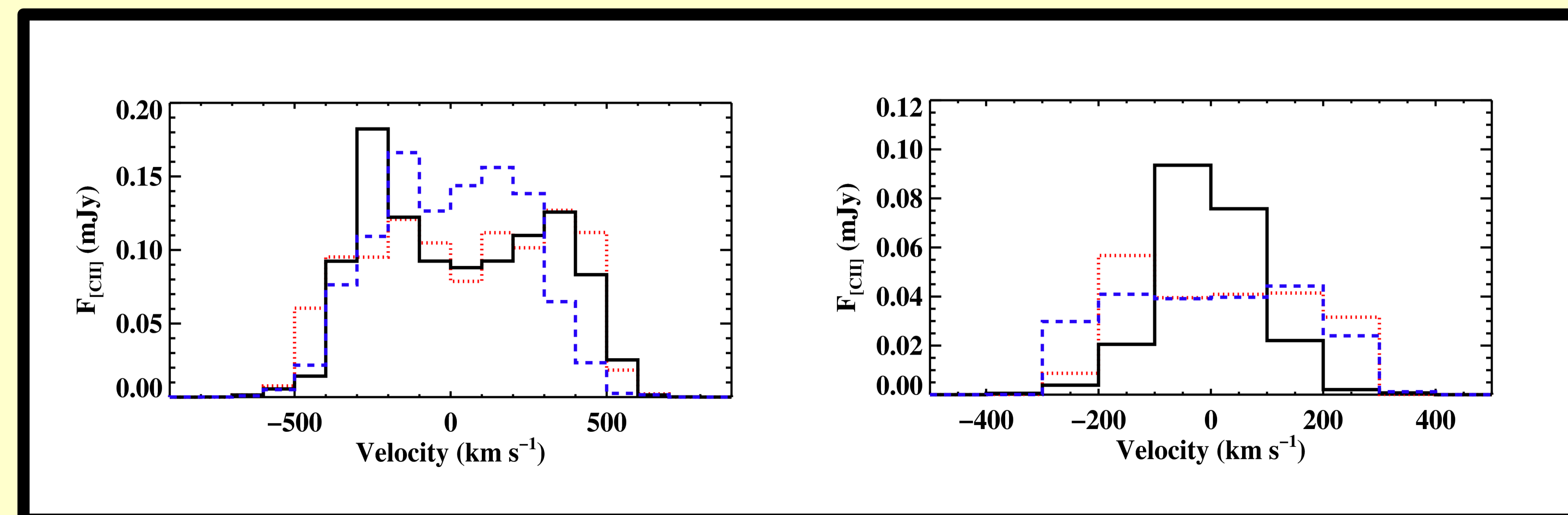


Figure 3: Simulated [CII] $158 \mu\text{m}$ line spectra at redshift $z \sim 2$ with resolution of 100 km/s , in three different projections (colored lines). The more massive galaxy is rotating at $\sim 300 \text{ km/s}$ and the less massive at $\sim 200 \text{ km/s}$.

Hydrodynamical simulations: We use state-of-the-art adaptive mesh refinement hydrodynamical simulations [2] of galaxy formation. In post-processing, neutral and molecular hydrogen densities are determined with a Monte Carlo radiative transfer code [3] and with a semi-analytic model [4].

[CII] emission: We generate [CII] $158 \mu\text{m}$ emission line maps (Figure 1) for two galaxies with gas masses $\sim 5 \times 10^{10} M_{\odot}$ and $\sim 9 \times 10^9 M_{\odot}$ and with star formation rates of $\sim 100 M_{\odot}/\text{yr}$ and $\sim 10 M_{\odot}/\text{yr}$. [CII] $158 \mu\text{m}$ luminosities in the cold neutral medium are computed from a two-phase ISM prescription [5] and a sub-grid model for grain photoelectric heating and [CII] $158 \mu\text{m}$ cooling [6], combined with the UV radiation field and metallicity from the simulations. A surface brightness map for the massive galaxy at $z \sim 2$ with resolution of $\sim 0.5''$ is in Figure 2. Figure 3 shows galaxy spectra at 100 km/s resolution.

ALMA visibility: The velocity integrated density fluxes are $\sim 100 \text{ mJy km/s}$ and $\sim 20 \text{ mJy km/s}$ for the two galaxies, with a density flux up to 400 mJy km/s when nearby satellites are included. ALMA will be able to detect disks of comparable luminosity.

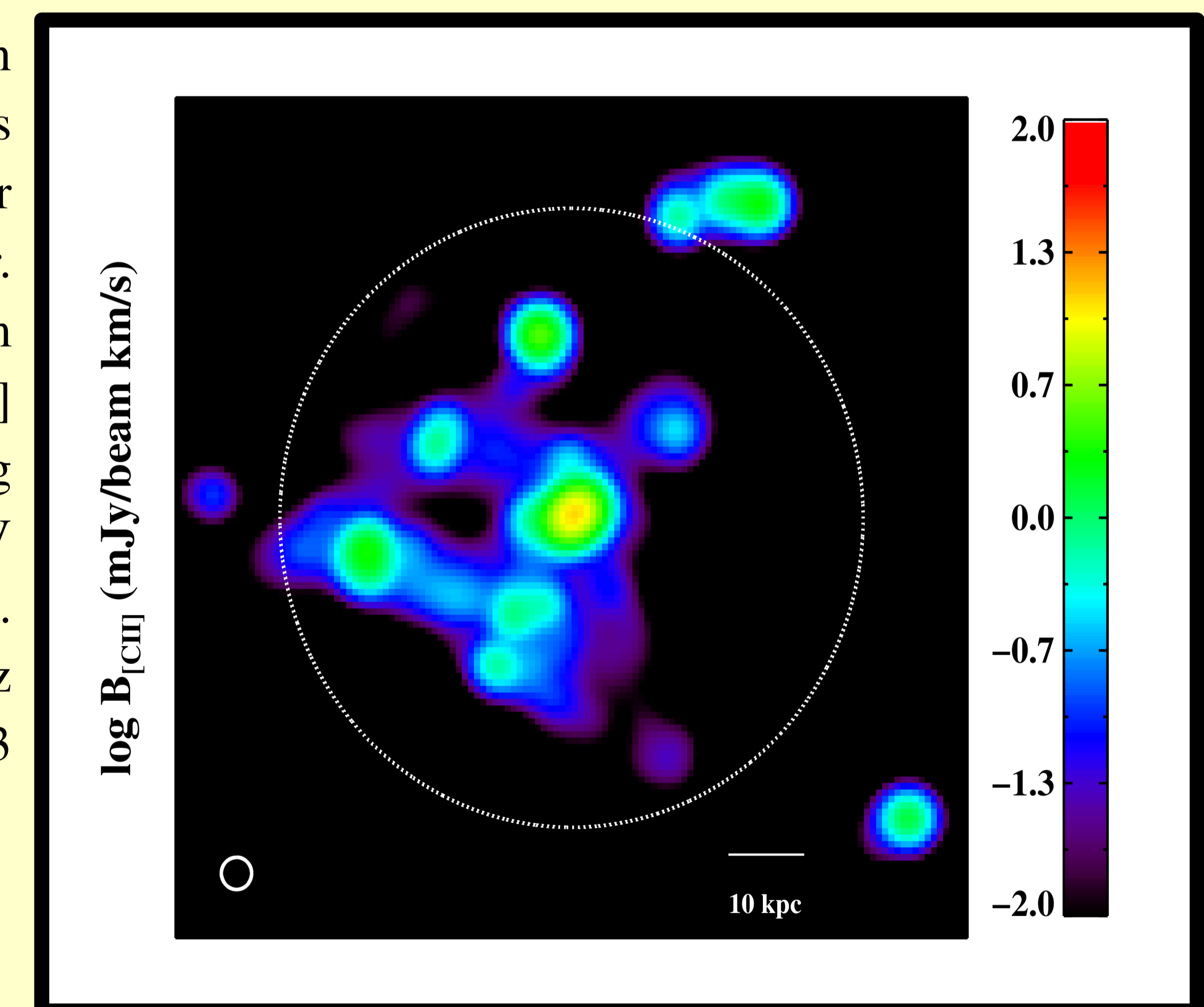


Figure 2: Simulated surface brightness of the $\sim 4 \times 10^{11} M_{\odot}$ galaxy at $z \sim 2$, imaged at the resolution of $0.5''$ (ALMA band 9 in a compact configuration). The ALMA field of view is marked with a dotted circle.

Summary:

- We predict the [CII] $158 \mu\text{m}$ luminosity in $z \sim 2$ galaxies with gas masses $M > 10^{10} M_{\odot}$.
- We use hydrodynamical simulations, with radiative transfer and prescriptions for the neutral medium.
- The velocity integrated density fluxes for two simulated galaxies are $\sim 100 \text{ mJy km/s}$ and $\sim 20 \text{ mJy km/s}$.
- ALMA will detect gas-rich disks at $z > 1.5$, enabling imaging and spectroscopy of the ISM via [CII] $158 \mu\text{m}$.

[1] Stacey et al., 2010, ApJ, 724, 957

[4] McKee and Krumholz, 2010, ApJ, 709, 308

[2] Ceverino et al., 2010, MNRAS, 404, 2151

[5] Nagamine et al., 2006, ApJ, 647, 60

[3] Kasen et al., in preparation

[6] Wolfe et al., 2003, ApJ, 593, 215

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