Characterizing the ISM Using Fine-Structure Lines in a z=5.7 Hyper-Starburst Galaxy Merger

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SPT0346-52 is a gravitationally lensed dusty star-forming galaxy at z~5.7 from the South Pole Telescope sample[1]. It is an extremely luminous hyper-starburst system with intrinsic far-infrared luminosity > 10^{13} $L_\odot$ and star formation rate density ~4200 $M_\odot$ yr^{-1} kpc^2. Based on ALMA observations of [CII]158 emission, we have determined the prodigious star formation rate density is likely driven by a major merger of two components[2]. Continuing this work, we have ALMA Bands 6 and 7 observations of four fine structure lines in this dusty star-forming galaxy: [CII]158, [OI]145, [NII]205, [NII]122. we use a pixelated, interferometric lensing reconstruction code to model the visibilities observed by ALMA and "de-lens" emission to obtain the spatially resolved interstellar medium (ISM) in the source-plane.

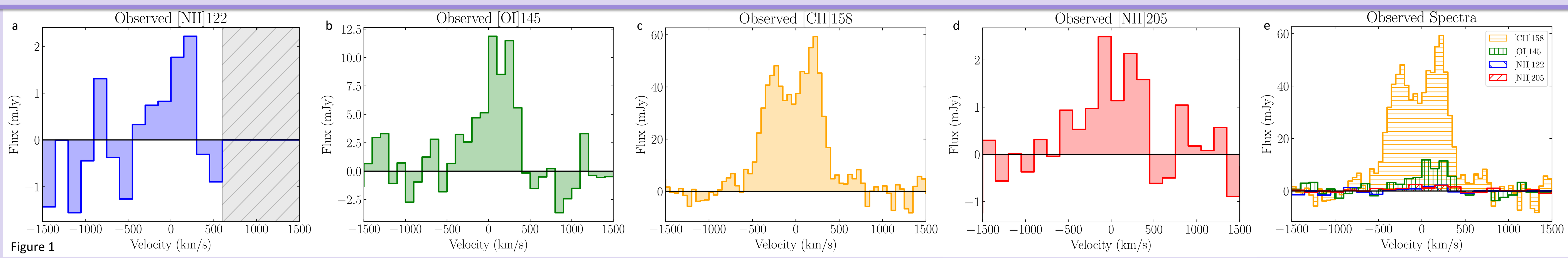

Figure 1

Observed Spectra from Visibilities

Figures 1a-d show the observed spectra of, from left to right, [NII]122, [OI]145, [CII]158, and [NII]205. Figure 1e shows all four spectra overlaid. Spectra were obtained using model-weighted complex visibilities using

$$F_\nu = \frac{\sum_i \frac{\tilde{v}_{\nu,i}}{\tilde{m}_i} \left|\tilde{m}_i\right|^2}{\sum_i \left|\tilde{m}_i\right|^2}$$

Here, F_ν is the flux per velocity channel, $\tilde{v}_{\nu,i}$ are the data visibilities, and $\tilde{m}_i$ are the model visibilities. This method helps extract spectra for faint lines from the visibilities that would be difficult to obtain from CLEANed images.

Pixelated Lens Modeling

We used a pixelated, interferometric MCMC lensing reconstruction code, RIPPLES, to model the foreground lensing galaxy and reconstruct the sources[2,3]. A singular isothermal ellipsoid with shear was independently fit to the visibilities for each of the continuum data sets, fitting for mass, position, ellipticity, and shear. The mass of the foreground galaxy was well-constrained by all four models, but there is degeneracy between the ellipticity and shear leading to slightly different models.

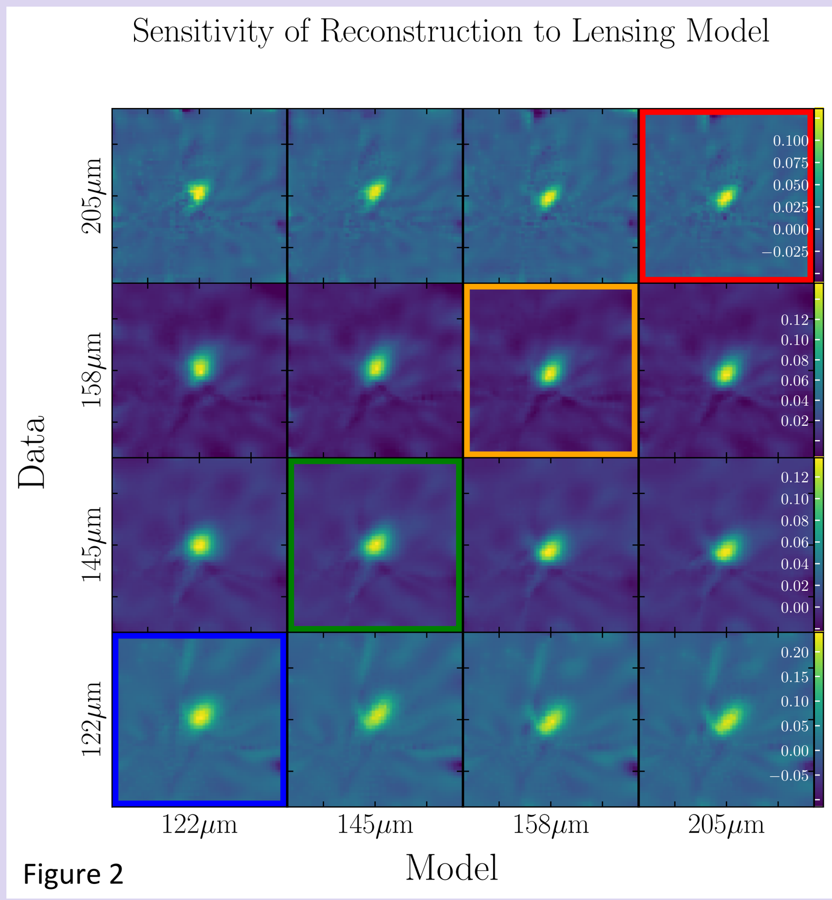

Figure 2

Model Comparison To test the robustness of these models, we applied each model to all four of the data sets and created a source-plane reconstruction. In Figure 2, each row was reconstructed using the same data visibilities and is on the same color scale. Each column was reconstructed using the same lens model. The outlined panels show reconstructions whose models were fit to those data sets. Colorbar units are mJy/pixel. Qualitatively, the reconstructions using different models of each data set (each row) show similar morphologies and fluxes. All of these reconstructions are of continuum emission and should look very similar.

Source-Plane Reconstructions

Figures 3a-d show source-plane lensing reconstruction of the continuum emission at 122, 145, 158, and 205 µm. Figures 3e-h show source-plane reconstructions of [NII]122, [OI]145, [CII]158, and [NII]205 integrated over velocity. Contours of the [CII]158 emission are overlaid. The lines are all reconstructed using the same regularization parameter. All colorbar units are mJy/pixel.

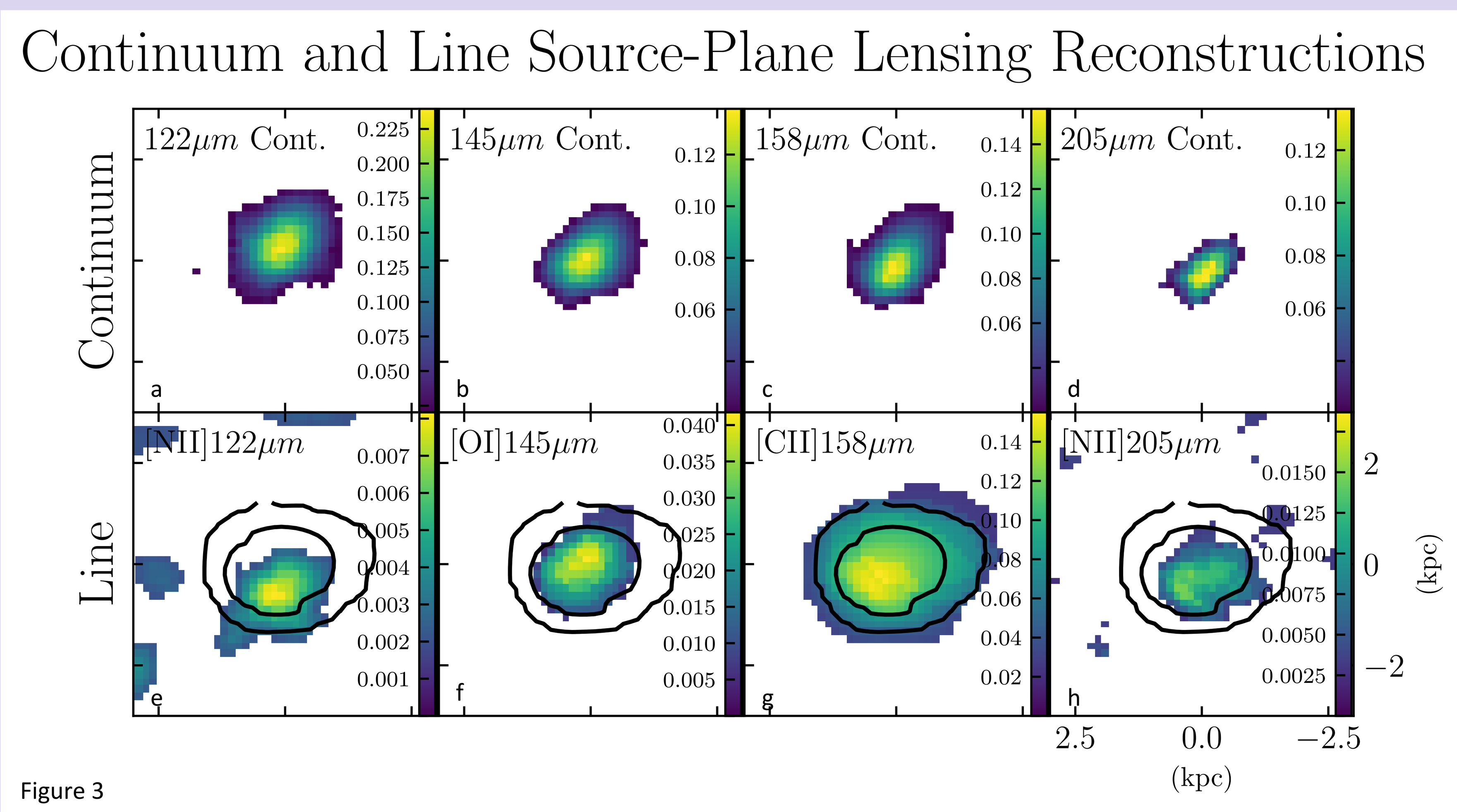

Figure 3

Morphology The [CII]158 emission is more extended than the [NII]205, [OI]145, [NII]122, or dust continuum emission. The brightest component of the [OI]145 emission is offset compared to the brightest [CII]158, [NII]205, and [NII]122 emission, as well as the peak dust continuum emission. The differences between the [NII]122 and [NII]205 emission are being explored.

What Can We Learn?

With these four lines, we can study the spatial and velocity distributions of several phases of the ISM. Because it has a lower ionization potential than hydrogen, [CII]158 traces both ionized and neutral gas. It is the dominant gas coolant in far-UV heated gas. [NII]122 and [NII]205 are emitted by ionized gas and can be used to trace star-forming regions. The ratio of the two [NII] lines can also be used to measure the electron density of the gas. [OI]145 arises from dense, neutral gas. In addition, the continuum emission is dominated by radiation from dust, thus allowing us to compare the gas and dust phases of the ISM.

Two Components

Previous analysis of the [CII]158 emission revealed two components whose merging drives the intense star formation in this system[2]. Figure 4 shows the red (+158km/s, left column) and blue (-309km/s, right column) components of the [CII]158 (top row) and [OI]145 (bottom row) emission. The two components are also observed in [OI]145.

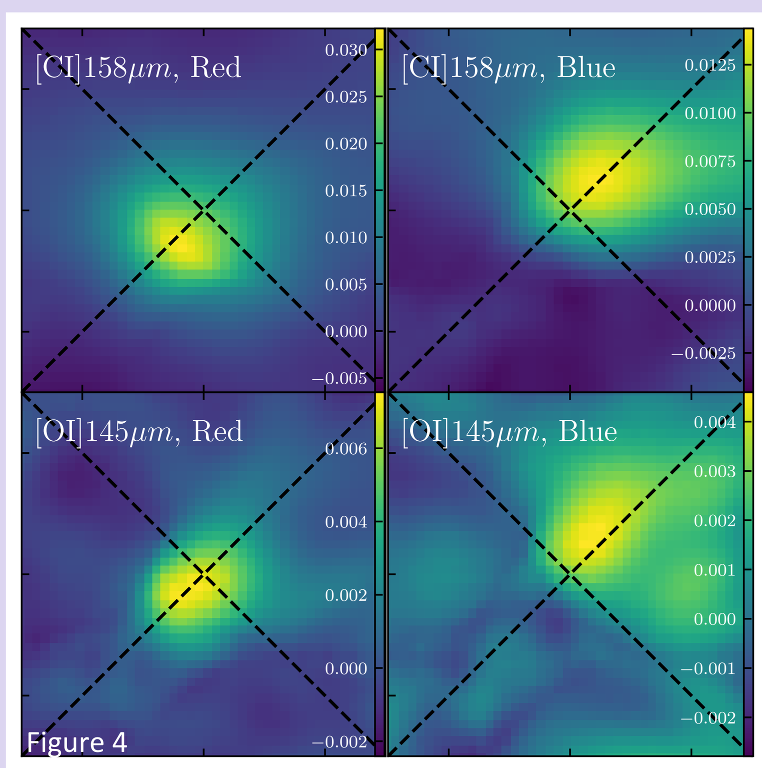

Figure 4

References

[1]Vieira et al. 2010, ApJ, 719, 763

[2]Litke et al. 2019, ApJ, 870,80

[3]Hezaveh et al. 2013, ApJ, 767, 132