Uncovering Early Galaxy Evolution in the ALMA and JWST Era
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Kinematics of $z \sim 4-6$ Lyman break galaxies in ALPINE

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Abstract. The past century has seen massive improvements in the study of galaxy kinematics. While early work focused on single nearby galaxies, current studies with modern IFUs and interferometers (e.g., SINFONI, ALMA) allow for extension of this field to high redshift. However, the sample of galaxy observations at $z > 4$ that feature the sensitivity and resolution required for resolved dynamical characterization has been small. The **ALMA Large Program to INvestigate CII at Early times (ALPINE)** targeted 118 star-forming galaxies at $z = 4-6$, representing a vast increase in the sample size of potentially dynamically-characterizable sources. Using a set of diagnostic plots, we are able to characterize roughly half the sample, revealing a vast kinematic diversity and high merger rate. For the nine targets that show rotational signatures, initial tilted ring fitting with ^{3D}Barolo shows promise. With further observations (e.g., ALMA, NOEMA, MUSE), the true nature of each source will be revealed in unprecedented detail.

Keywords. galaxies: high-redshift, galaxies: interactions, galaxies: kinematics and dynamics

1. Introduction

Kinematics of local galaxies have been studied for more than a century (e.g., Pease 1918), and developments over this time have allowed for larger sample sizes and more detailed modelling (e.g., Förster Schreiber *et al.* 2009; de Blok *et al.* 2016; Wuyts *et al.* 2016). With the advent of modern instruments (e.g., VLT, MUSE, ALMA), it is now possible to observe high-redshift galaxies at high resolution, allowing for the precise study of their motions. However, while studies at higher redshift, including De Breuck *et al.* (2014; $z = 4.8$), Jones *et al.* (2017; $z \sim 4-6$), and Smit *et al.* (2018; $z \sim 6.8$), have determined the kinematics of high-redshift galaxies, a larger sample is required to make statistically significant inferences.

The need for a larger set of $z > 4$ galaxies was one of the driving goals of the ALMA Large Program to INvestigate CII at Early times (ALPINE, PI: O. Le Févre; Faisst *et al.* 2019, Le Fèvre *et al.* in prep.), which observed 118 normal, star-forming galaxies at $4.4 < z_{spec} < 5.8$ in [CII] and FIR dust continuum emission with ALMA in cycles 5 and 6. Here, we present an initial study of the kinematical diversity of the sample.

2. Methods

A preliminary examination of the 118 ALPINE [CII] cubes revealed a vast array of dynamical properties. In order to characterize each, we created several diagnostic plots (Figure 1): moment zero (integrated intensity) and moment one (velocity field) maps, position-velocity (PV) plots along two orthogonal axes, and integrated spectra.

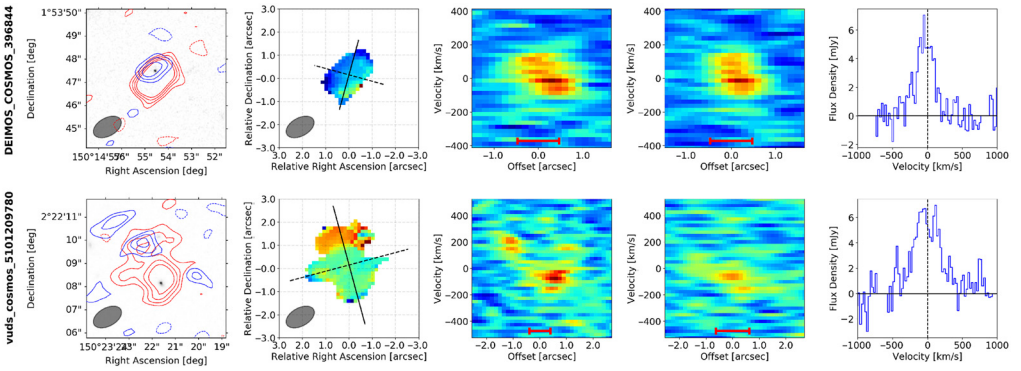

Figure 1. Examples of a rotator (top row) and merger (bottom row) from ALPINE. Column 1: HST/ACS I-band image (greyscale), [CII] emission (red contours), and FIR continuum emission (blue contours). Column 2: [CII] velocity field, with the pseudoslits for each PV diagram marked by solid (major axis) and dashed (minor axis) lines. Columns 3 and 4: position-velocity diagrams for the major and minor axes, respectively. Column 5: integrated [CII] spectrum.

Using these and ancillary multiwavelength photometry, we classified each galaxy into one of five categories: rotators, mergers, dispersion-dominated, disturbed, or weak.

Rotators show a single source in all images, a tilted PV slice along the major axis, and a straight PV slice along the minor axis. **Dispersion-Dominated Galaxies** also only show a single source, but have identical PV slices along orthogonal pseudoslits. **Mergers** show multiple sources, separated in position and/or velocity. **Disturbed Galaxies** are sources that feature strong line emission, but do not fall into one of the three above classes. **Weak Galaxies** include both those where no significant [CII] emission was detected, and those whose emission is too weak to determine its true nature.

3. Results

In this initial analysis, we find that roughly half of the ALPINE sources are weak, $\sim 20\%$ are mergers, and the remaining $\sim 30\%$ is evenly split between rotating, dispersion-dominated, and disturbed galaxies. Since this sample was intended to represent normal galaxies at high-redshift (i.e., not Malmquist biased), this suggests that the underlying sample shows a great diversity of kinematic states.

A more in-depth classification scheme has now been implemented, and will be presented in Le Fèvre *et al.* (in prep). In addition, the rotating galaxies will be further analyzed in Jones *et al.* (in prep).

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