ALMA Observations of the Gravitational Lens SDP.9

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Recent surveys at submillimeter wavelengths have revealed a population of gravitationally lensed dusty star-forming galaxies at $z \sim 2$–7 [1]. By combining the high sensitivity and spatial resolution of the Atacama Large Millimeter/Submillimeter Array (ALMA) with the natural magnification of gravitational lensing, the detailed properties of these galaxies can be studied on spatial scales of tens to hundreds of parsecs. One such system is the gravitational lens H-ATLAS J090740.0–004200 (hereafter SDP.9). SDP.9 was first identified as one of the brightest sources in the Science Demonstration Phase (SDP) of the *Herschel* Astrophysical Terahertz Large Area Survey (H-ATLAS) [2], and consists of a massive early-type galaxy at $z_{\mathrm{L}} = 0.6129$ [3] lensing a background submillimeter galaxy at $z_{\mathrm{S}} = 1.5747$ into a bright arc and small counterimage.

ALMA data on SDP.9 were obtained during Cycle 3 (Program 2015.1.00415.S; PI: K. Wong) [4]. The Band 6 continuum was observed, as well as the CO J=6–5 line. During the observations, 49 12 m antennas were used, and baselines ranged from 84.7 m to 16.2 km with the C36-7 configuration. The total on-source time was 4526 s under stable weather conditions with precipitable water vapors ~0.50 mm.

We find that the source is split into two tangentially elongated arcs, as is suggested by previous SMA observations. The northern arc is less extended than the southern arc, and some clumpy structures are visible in both arcs. We measure the peak intensity and total flux density of each arc in both the continuum and CO maps. Taking the CO line flux integrated across both arcs in each velocity bin, we measure an updated source redshift of $z_{\mathrm{S}} = 1.5747 \pm 0.0002$.

We find no clear emission from the central demagnified image of the lens in the velocity-integrated CO(6–5) map down to a 3σ rms level of 0.0471 Jy km s^{-1}. The central image, which is predicted for non-singular mass distributions, offers a unique probe of the innermost central mass distribution of the lens [5,6], but we are unable to place meaningful constraints for this system.

We model the lens system using constraints from the ALMA imaging and archival *Hubble Space Telescope* (*HST*) imaging with the lens-modeling software GLEE [7]. The velocity gradient in the source galaxy is nearly orthogonal to the elongation of the lensed arcs, making a robust identification of multiple-image pair regions challenging. We find an Einstein radius of $\theta_{\mathrm{E}} = 0.66 \pm 0.01$ arcsec, a slightly steeper than isothermal mass profile slope, and a projected axis ratio of $b/a = 0.68^{+0.05}_{-0.04}$. The lensed image configuration is strikingly different between the *HST* and ALMA data. The *HST* data, which probe the rest-frame optical emission from the source, show a much more symmetric configuration, while the ALMA submillimeter data has the large bright southern arc and the much smaller northern arc. This difference suggests a spatial offset between the stellar component and the gas and dust component of the source galaxy, as has been seen in other lensed submillimeter galaxies at this redshift.

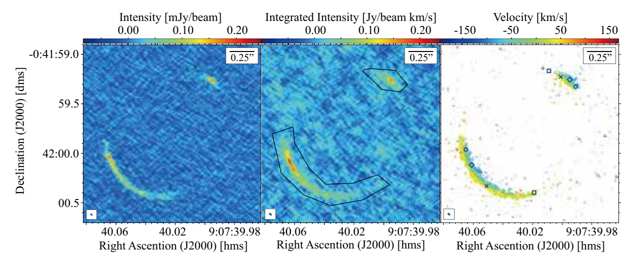

Figure 1: Left: ALMA Band 6 continuum image with Briggs weighting and no tapering. Center: velocity-integrated CO(6–5) intensity map. The black lines indicate the regions used to measure the integrated flux of the arcs. Right: CO(6–5) velocity map. Small symbols represent the conjugate points used for our mass modeling, with symbols of the same shape representing image pairs.

References

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