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Sample Selection

The dusty-spectrum sources targeted for the ALMA observations described here were found in the SPT survey. The full survey comprises 2540 deg^2 of mapped sky, but constraints of data analysis and followup limited the area available for target selection at the time of the ALMA Cycle 0 deadline to 1300 deg^2. The initial SPT target list was extracted from the SPT maps according to the procedure described in a previous paper[4] and the selection outlined in the manuscript. Before observing these sources with ALMA, we required that they have followup observations with the LABOCA 870 μm camera on the Atacama Pathfinder Experiment telescope to improve the accuracy of their positions. At the time of the ALMA Cycle 0 proposal deadline, we had completed this followup for 76 sources within 1300 deg^2 of the survey area. We selected 47 sources for imaging and 26 sources for spectroscopy with ALMA; 24 of the 26 spectroscopic sources were also in the imaging sample. The sample selection targeted sources with the highest SPT 1.4 mm fluxes, subject to the restrictions of the ALMA call for proposals. The most important restriction was the requirement that sources be located within 15 degrees of each other on the sky. This should not affect the statistical properties of the sample, however, it merely prevented the observation of a complete set of SPT sources above a defined flux threshold.

Detected line features

The detected CO and C I line features are shown in Figure S.1. Additional lines are detected in some spectra, including ^{13}CO transitions in two sources. However, the detection of both ^{12}CO and ^{13}CO transitions in the same source does not break redshift degeneracies because both transitions are harmonically spaced; at a given frequency of detection, every pair of CO isotopic transitions of the same rotational level (J) will have the same observed spacing. Emission lines of H_2O and H_2O^+ are detected in the spectrum of SPT0346-52.

ALMA imaging

Continuum images from the ALMA observations at both wavelengths are shown in Figure S.2 for all 49 sources observed with ALMA in one or both of the 3 mm redshift search or the 870 μm imaging projects. The positional coincidence between the bands confirms that the redshifts are derived for the same objects that are seen to show structures indicative of gravitational lensing. Nearly all sources are resolved at the 0.5″ resolution of the 870 μm data, most likely due to gravitational lensing. Exceptions may be due to lensing by groups/clusters, with image counterparts that are either faint or too widely separated to be detected in the small (18″) primary beam of the ALMA antennas at this wavelength, or because some of our objects have small image separations. Lensed dusty sources with similar image separations are already prominent in the literature, in-

cluding APM 08279+5255[28], which has three images separated by $<0.4''$. Conclusive evidence of lensing in many objects, including the most compact, awaits IR imaging and spectroscopic redshifts for the sources (and any candidate lens galaxies). The 23 objects for which we have the most complete data (the 26 sources of the 3 mm spectroscopic sample, less three without detected lines, less two without IR imaging, augmented by the two sources[22] for which we had prior redshifts) are shown in Figure S.3.

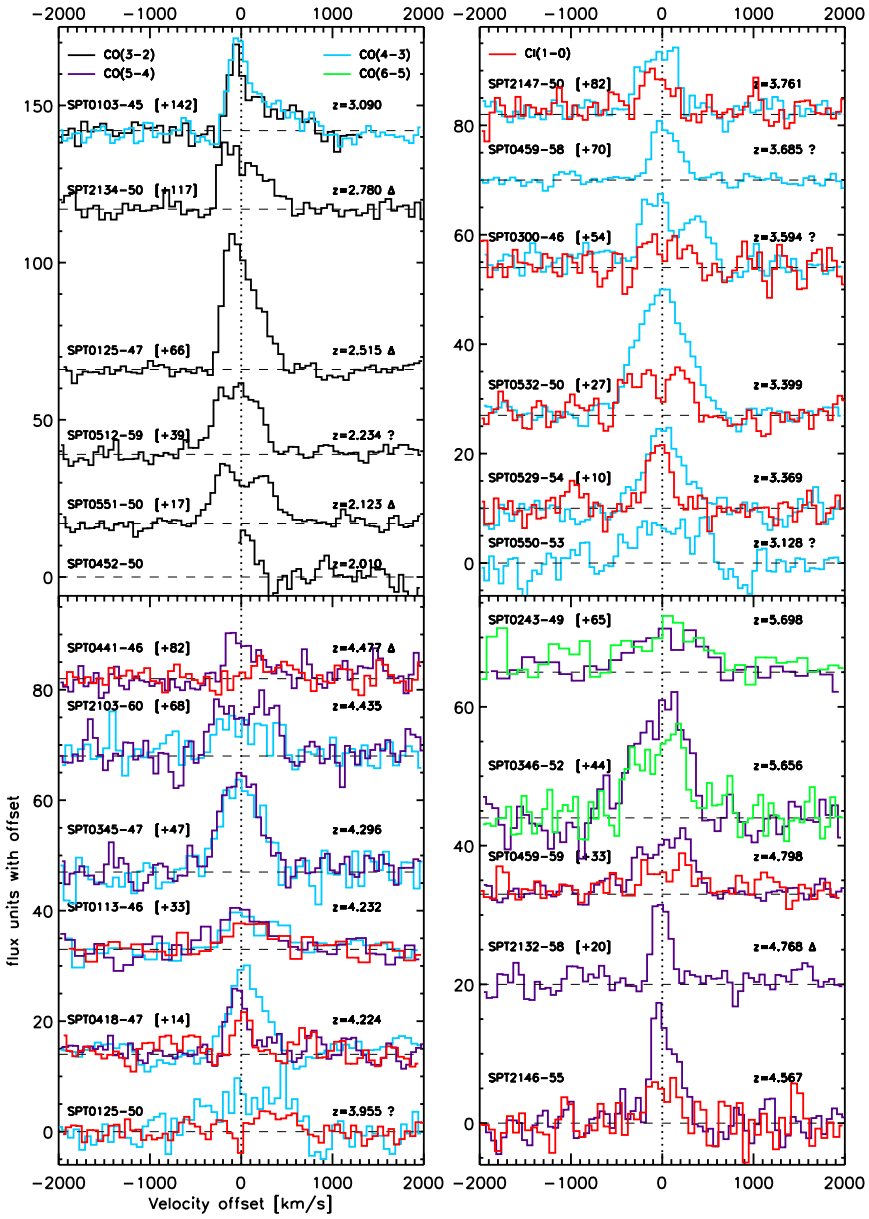

Figure S.1: The CO(3-2), CO(4-3), CO(5-6), CO(6-5) and C I(1-0) emission lines observed with ALMA for 23 out of the 26 SPT sources, which were used to determine the source redshifts. The vertical axis is observed flux density, sources are offset from zero for clarity with the offsets specified in square brackets next to the source names. Redshifts marked with 'Δ' are confirmed using additional observations from other facilities[23], while redshifts marked with '?' are uncertain and are shown at the most likely redshift. SPT0452-50 has a single line, but is determined to be at $z = 2.010$ rather than $z = 1.007$ because the implied dust temperature for this source would be far lower than in any other source (13 K) were it at the lower redshift[23].

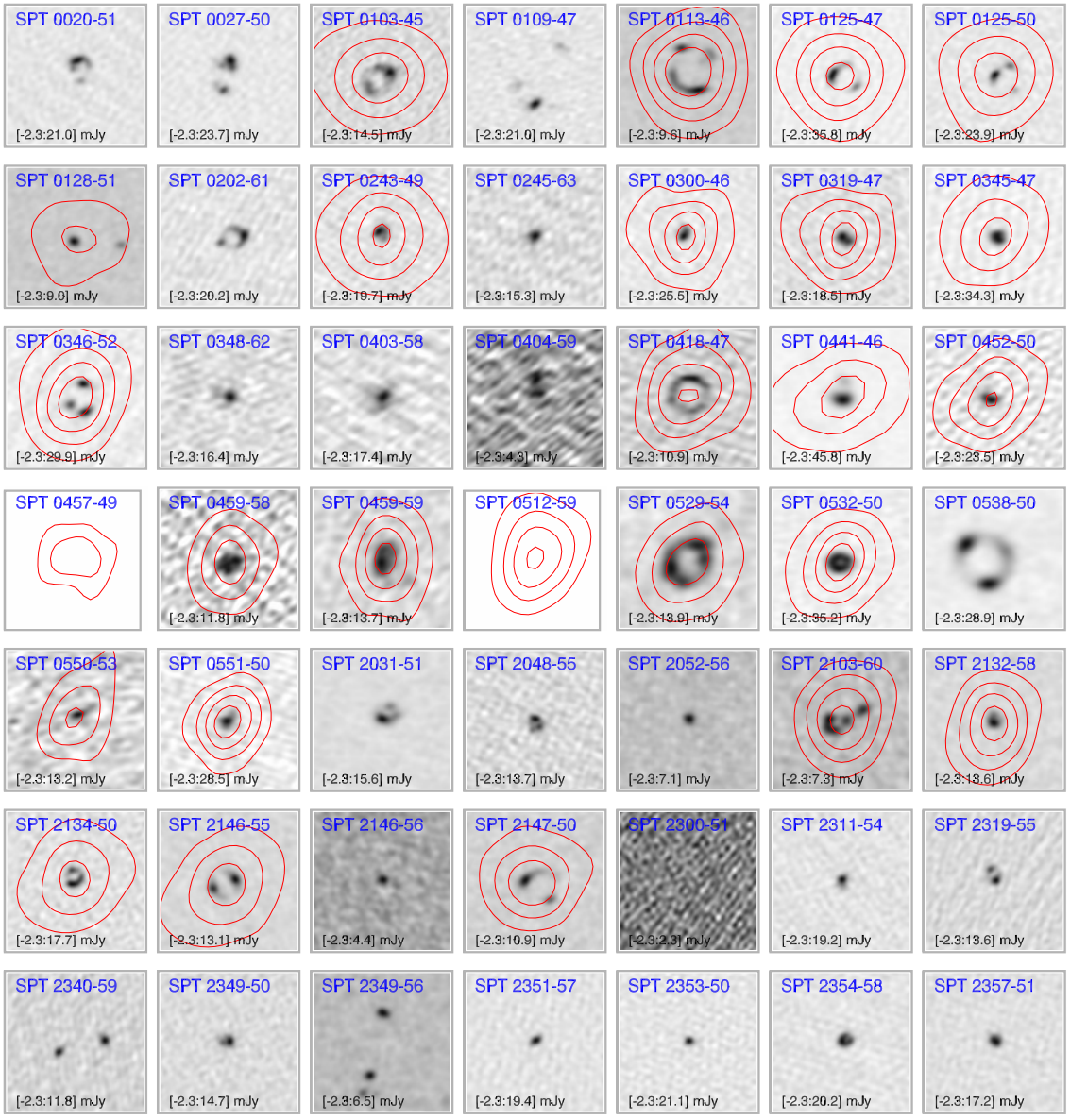

Figure S.2: Continuum images of the 49 sources observed at 3 mm and/or 870 μm wavelength with ALMA. The 47 sources for which 870 μm data were acquired are shown in greyscale, with the 3 mm images overlaid in red contours. Two sources from the redshift sample that lack 870 μm data appear as red contours on a blank background. Images are $10'' \times 10''$, the 870 μm and 3 mm images have $0.5''$ and $5''$ resolution, respectively. The correspondence between the positions at the two wavelengths unambiguously links the lensing structure visible at 870 μm to the 3 mm spectra. The 3 mm contours are plotted in units of 3σ, starting at 3σ for sources at S/N$<$15, and 5σ for sources at S/N$>$15, except SPT 0457-49, where the contours are 3 and 4σ. The grey scale stretch of each image is indicated in the lower left hand side of each panel and is roughly from -1σ to the peak value.

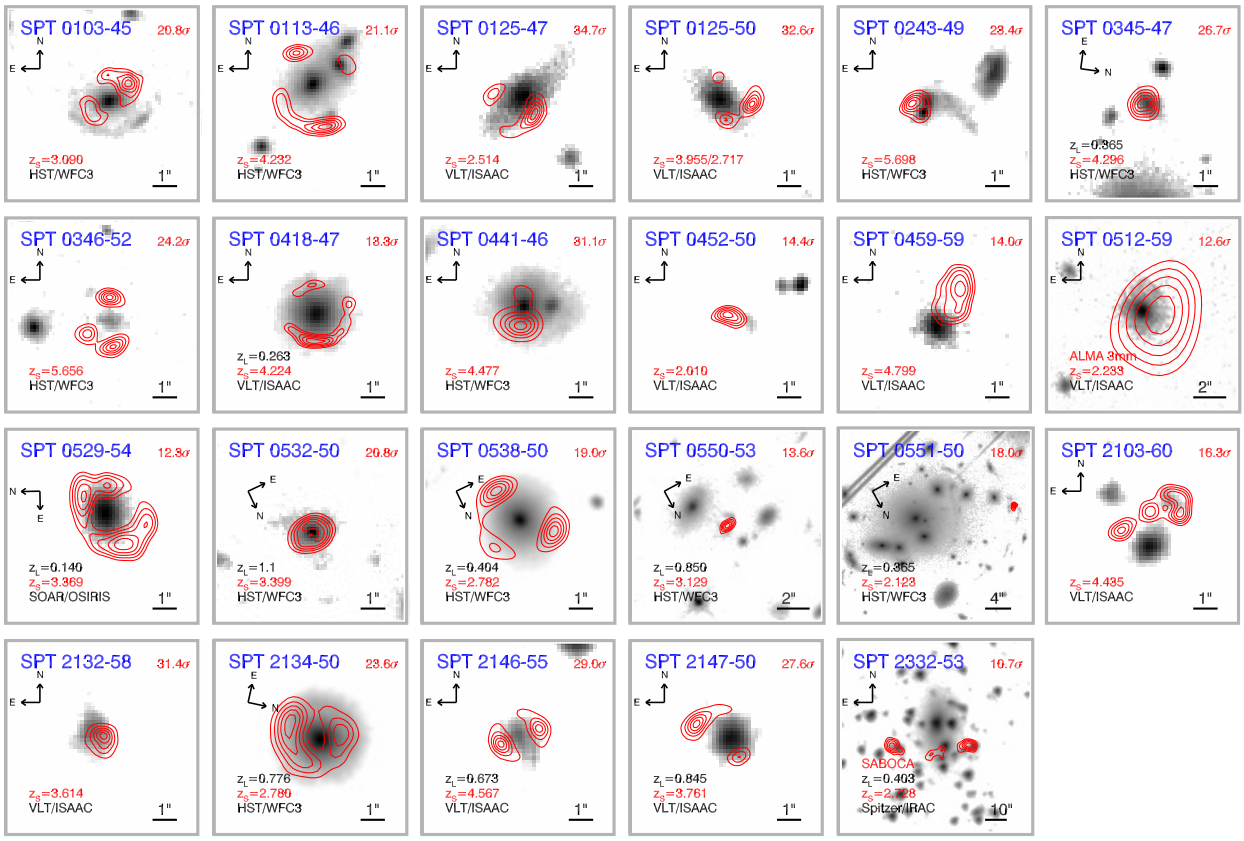

Figure S.3: Images of the full set of 23 sources for which we have ALMA 870 μm 3 mm, or SABOCA 350 μm imaging, deep NIR imaging, and a redshift for the background galaxy (including ambiguous redshifts). Except for SPT 0512-59, ALMA 870 μm emission is represented with 5 red contours, spaced linearly from five times the image noise to 90% of the peak signal to noise, specified in the upper right of each panel. For SPT 0512-59, which lacks ALMA 870 μm data, we show the ALMA 3 mm continuum contours. For SPT 2332-53, which lacks ALMA 870 μm data, we show the APEX/SABOCA 350 μm continuum contours. The redshift of the background source ($z_{\rm S}$) is specified in red. Greyscale images are near-infrared exposures from the *Hubble Space Telescope* (co-added F160W and F110W filters), the Very Large Telescope (K_s), the Southern Astrophysical Research Telescope (K_s), or the *Spitzer Space Telescope* (3.6 μm) and trace the starlight from the foreground lensing galaxy. The images are shown with logarithmic stretch. When known, the redshift of the foreground galaxy ($z_{\rm L}$) is specified in black. In nearly every case, there is a coincidence of the millimetre/submillimetre emission, determined by the redshift search data to arise at high redshift, with a lower redshift galaxy, a galaxy group, or a cluster. This is precisely the expectation for gravitationally lensed galaxies. Three cluster lenses are apparent, SPT 0550-53, SPT 0551-50, and SPT 2332-53, with two other systems lensed by compact groups (SPT 0113-46, SPT 2103-60).