Abstract

The strong lensing effect provided by massive clusters magnifies high-redshift galaxies in the background, allowing investigations in great detail. In this work, we present a multi-wavelength study of a strongly-lensed dusty star-forming galaxy (DSFG), HLSJ0257-2209 (hereafter HLS0257) at z = 4.69. Discovered by the Herschel Lensing Survey (HLS), it is lensed by the cluster MACSJ0257-2209 into 5 images with an astonishing total magnification factor of μ~180. Our ALMA observations resolved its CO (5−4), CO (12−11), [CII] 158 μm and [NII] 205 μm emission spectrally and spatially, detecting a rotating disk of molecular gas coincident with the luminous dust continuum. The spatial distributions and intensity ratios of these lines demonstrate the presence of a highly excited interstellar medium with a solar-like metallicity. In the source plane where the lensing effect is not detected, we detect five [CII]-emitting clumps with a linear scale of ~100 pc each, which may indicate the existence of compact, luminous star-forming gaseous clouds around the galaxy. Moreover, our HST/WFC3 near-IR images show a bright rest-frame UV continuum source ~650 pc from the DSFG, revealing a significantly reddened (i.e., dusty) Lyman break galaxy (LBG) at the same redshift. Compared with the past studies of individual high-redshift DSFGs, this interacting galaxy pair is of more representative mass and star-formation rate (~47 and ~6 M_☉ yr^{-1}), offering us an excellent test case to track the evolution of non-extreme dusty star-forming galaxies at z~5.

(1) Discovery

![Image of HLS0257 with Herschel Lensing Survey and LABOCA/APEX] (Top) Discovery and confirmation of HLS0257 with Herschel Lensing Survey (Egami et al. 2010) and LABOCA/APEX. Bottom: Dust continuum SED fitting of HLS0257. Best-fit model suggests a dust temperature of 40K, total-IR (8−1000μm) luminosity of 10^{10.6} L_☉, and SFR_ν of 47±2 M_☉ yr^{-1} (lensing magnification is corrected).

(2) Near-IR Follow-up

![Image of HLS0257 with Herschel Lensing Survey and LABOCA/APEX] (Top Left) Layout of first 4 images of HLS0257 with HST (grey-scale image) and ALMA (red contours). Top Right: Zoom-in view of HLS0257 Image A at rest-UV (HST, green contours), rest-optical (IRAC1, grey-scale image) and FIR (ALMA, blue contours). Bottom: Near-IR SED fitting of HLS0257. Best-fit model suggests a dusty UV continuum (α=1.0), a stellar mass of 2.6×10^{10} M_☉, and SFR_ν of 62±1 M_☉ yr^{-1} (lensing magnification is corrected).

(3) Resolved Features in the Source Plane

![Image of HLS0257 with Herschel Lensing Survey and LABOCA/APEX] (Left) HST/WFC3 F110W (heat map) and ALMA Band 7 (green contour) source plane image, constructed from HLS0257 Image A (magnification μ~50). Intrinsic physical scale is noted on upper-right corner. Middle & Right: ALMA [CII]158μm Velocity map in source plane, constructed from Image A & B. Contour levels are 3, 5, 8σ of RMS noise, and velocity range is ~200−2200 km/s. Note that the five 100-μm scale [CII] clumps noted in red square shows consistency in their relative positions and velocity.

(4) ISM Excitation and Ionization

![Image of HLS0257 with Herschel Lensing Survey and LABOCA/APEX] (Left) CO (5−4) velocity field of Image A in source plane, showing clear rotational structure. Right: Dynamical mass and gas mass profile of HLS0257, inferred from ALMA CO (5−4) observation. The gas mass fraction of HLS0257 is then estimated as 36%, with a depletion time of 132±13 Myr.

References:

Dissecting an Extremely-Lensed Dusty Star-Forming Galaxy at z=4.7

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