X14a ALMA Deep Field in SSA22:A near-infrared-dark submillimeter galaxy at z=4.0

Hideki Umehata (RIKEN), Kotaro Kohno, Bunyo Hatsukade, Tao Wang (U. Tokyo), Kouichiro Nakanishi (NAOJ), Yoichi Tamura (Nagoya U.), Mariko Kubo (Ehime U.), Natsuki N. Hayatsu (Ecole Normale Superieure), Ian Smail, A.M. Swinbank (Durham U.), Yiping Ao (PMO)

Deep surveys with Atacama Large Millimeter Array (ALMA) have uncovered a population of dusty star-forming galaxies which are faint or even undetected at optical to near-infrared wavelengths. Their faintness at short wavelengths makes detailed characterization of the population challenging. Here we present a spectroscopic redshift identification and characterization of one of such near-infrared-dark galaxy discovered by an ALMA deep survey. Detection of [C I](1-0) and CO(4-3) emission lines determines the precise redshift of the galaxy, ADF22.A2, to be $z = 3.9913 \pm 0.0008$. On the basis of multi-wavelength analysis, ADF22.A2 is found to be a massive, star-forming galaxy with stellar mass $M_* = 1.1^{+1.3}_{-0.6} \times 10^{11} M_\odot$ and SFR$= 430^{+230}_{-150}$ $M_\odot$ yr^{-1}. The molecular gas mass is derived to be $M(H_2)^{[CI]} = (5.9 \pm 1.5) \times 10^{10}$ $M_\odot$, indicating a gas mass fraction ($f_{\rm gas} = M(H_2)/(M_* + M(H_2))$) of $\approx 35\%$, and the ratios of $L_{[CI](1-0)}/L_{\rm IR}$ and $L_{[CI](1-0)}/L_{CO(4-3)}$ suggests that the nature of the interstellar medium in ADF22.A2 is in accordance with those of other bright submillimeter galaxies. The properties of ADF22.A2, including redshift, star-formation rate, stellar mass, and depletion time scale ($\tau_{\rm dep} \approx 0.1 - 0.2$ Gyr), also suggest that ADF22.A2 has the characteristics expected for the progenitors of quiescent galaxies at $z \gtrsim 3$. Our results demonstrate the power of ALMA contiguous mapping and line scan to obtain an unbiased view of galaxy formation in the early Universe.