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Unveiling the nature of HST-dark galaxies by using SPICA

KOHNO, Kotaro (IoA/The University of Tokyo),
WANG, Tao (IoA/The University of Tokyo, National Astronomical Observatory of Japan)

ABSTRACT: Recent ALMA observations start to convincingly suggest the presence of mm/submm-selected galaxies without any significant counterpart seen in the optical and near-infrared: HST-dark galaxies. Such HST-dark but IRAC-detected (a.k.a. H-dropout) galaxies seem to be a key tracer of the early phases of massive galaxy formation, which can not be captured by the Lyman break technique using state-of-the-art near-infrared ultra-deep surveys using HST/WFC3. However, the difficulties to obtain spectroscopic redshifts of these HST-dark galaxies hamper the efforts to advance our understanding of this newly recognized important population. Here, we argue that the mid-infrared spectroscopy using SPICA will play crucial roles to unveil the nature of these HST-dark ALMA galaxies, by providing spectroscopic redshifts via PAH features, and indication on the presence or absence of growing super-massive black holes via high ionization fine-structure lines and mid-infrared continuum.

"HST-dark" galaxies have been identified since the very beginning of submillimeter cosmology using SCUBA (e.g., Smail, Ivison, & Blain 1997, ApJ, 490, L5), and in fact pre-ALMA facilities like SMA have uncovered bright submillimeter galaxies (SMGs) which are totally invisible in HST optical and near-infrared bands like GN10 (Wang, W.-H., et al. 2009, ApJ, 690, 319). GN10 is one of the representative SCUBA-selected bright submillimeter galaxies, with an 880 um flux of 12 mJy. Such bright sub-millimeter galaxies are, however, very rare.

Now ALMA has revolutionized this field by enabling us to conduct unbiased deep surveys at short-millimeter-waves (mostly done at λ ~1.3 – 1.1 mm or ALAM Band-6), which uncover much fainter (i.e., a few x 100 uJy at 1.2 mm, or ~10 times fainter than the classical bright SMGs like GN10), ergo more ubiquitous and representative hidden galaxy population. In fact, our 26 arcmin^2 deep survey of GOODS-S (ASAGAO; Hatsukade et al. 2018, PASJ, 70, 105) has uncovered 2 near-infrared-dark ALMA sources with an average 1.2 mm flux density of ~0.6 mJy (Figure 1), down to a K-band depth of 26 mag.

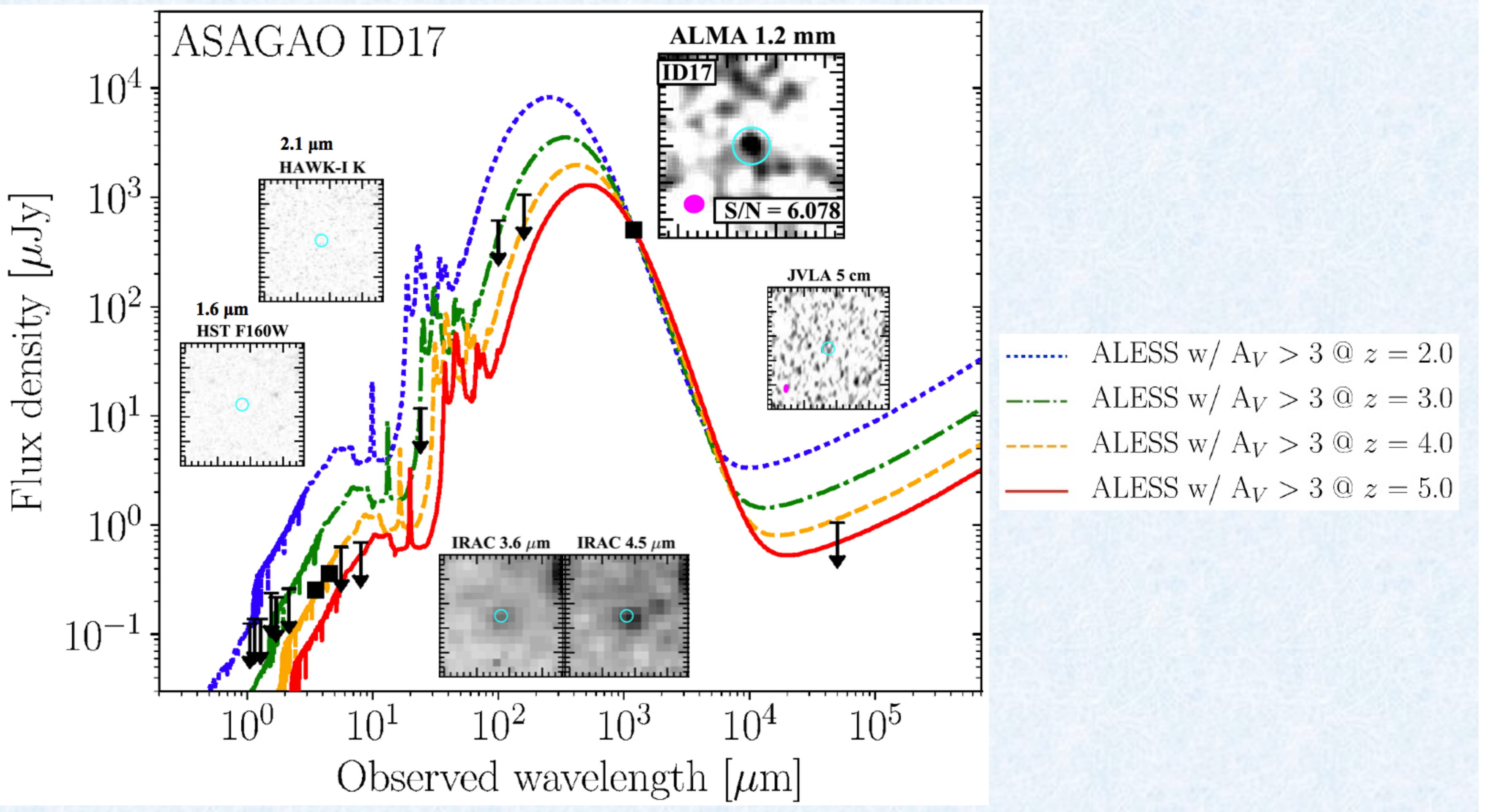

Figure 1: An example of a faint (S_1.2mm = 0.56±0.09 mJy; ~10 times fainter than the classical bright SMGs like GN10) ALMA-selected galaxy in GOODS-S, which is invisible in the ultra-deep HST/F160W (H-band), VLT/HAWK-I (Ks-band), and JVLA 5 cm images. The source, ASAGAO-ID17, is associated with a red IRAC counterpart, implying z~4. Taken from Yamaguchi, Y., KK, WT et al. 2019, ApJ, 878, 73.

What are they? Wang, T., and their collaborators exploited rich multi-wavelengths data in COSMOS and GOODS-S to study the nature of F160W(H-band)-invisible but IRAC-detected sources (a.k.a. H-dropout; Figure 2 (left)), indicating that we are witnessing the massive galaxies in their forming phase at a redshift range of z = 3 – 6. They represent the bulk population of massive galaxies at z > 3 (Figure 2 (right)), which have been completely missed by the LBG selection using HST/WFC3 (Wang, T., et al., 2019, Nature, 572, 211). However, the lack of secure (spectroscopic) redshift measurements hamper the efforts to advance our understanding of this newly recognized important population.

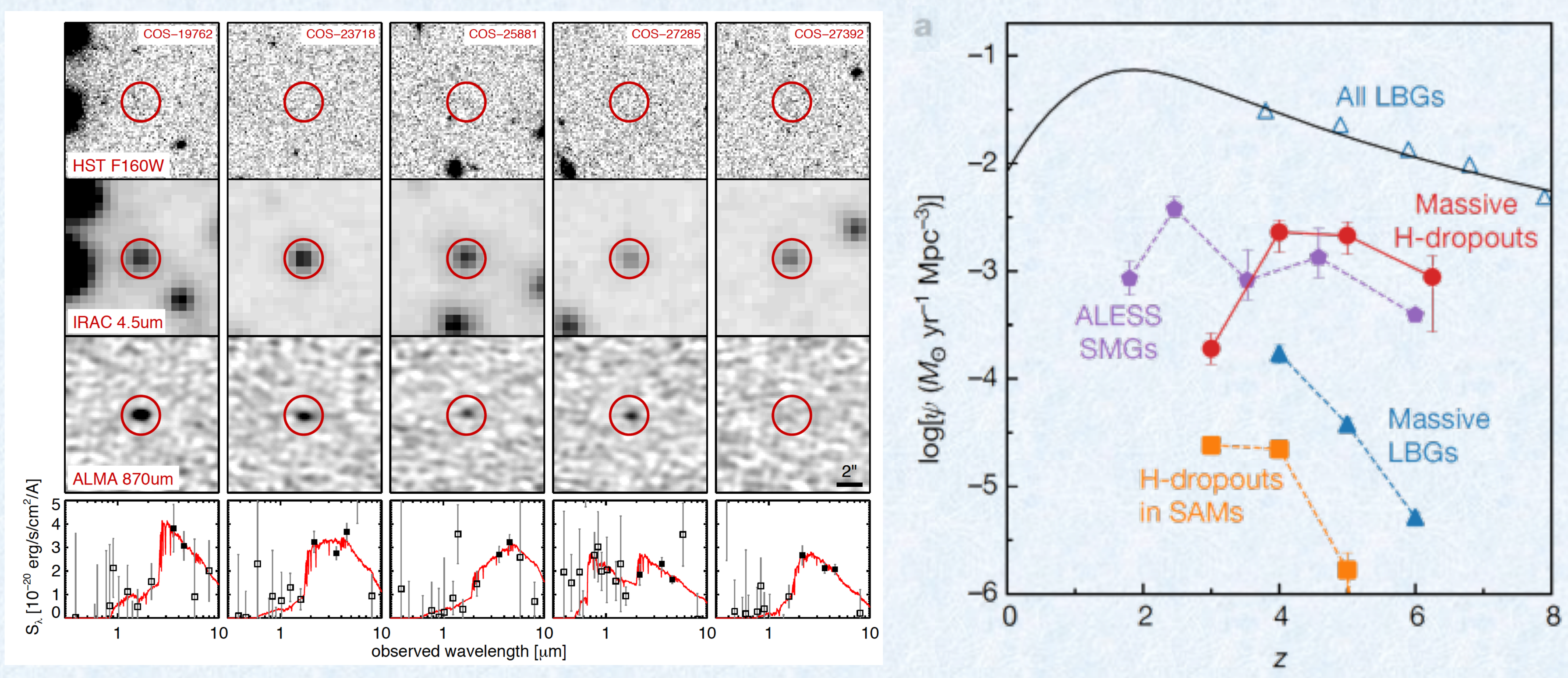

Figure 2: (left) Example images and UV-to-NIR SEDs of H-dropout galaxies. The typical 870 μm flux is ~1-2 mJy, and the sky density of these ALMA-detected H-dropouts is approximately 5.3 x 10^2 deg^{-2}, which is 2 orders of magnitude higher than Herschel/SPIRE-selected extreme starbursts. (right) Contribution of H-dropout galaxies to the cosmic star-formation rate density. Filled orange squares shows the SFR density from H-dropouts in semi-analytic galaxy formation models, which can not reproduce the uncovered massive forming galaxies seen as H-dropouts. Taken from Wang, T., KK, et al., 2019, Nature, 572, 211.

Roles of SPICA can be summarized as follows.

(1) Pointed spectroscopy using SMI and SAFARI will provide unambiguous spectroscopic redshift measurements via bright PAH features at 6.2 and 7.7 μm. Furthermore, deep spectroscopy using SAFARI will detect high-ionization fine-structure lines such as [O IV] 25.9 μm up to the epoch of re-ionization. Highly magnified but intrinsically-faint HST-dark galaxies have been uncovered by ALMA Lensing Cluster Survey (PI: K. Kohno), an ALMA cycle-6 large program, and they must be best targets for such deep spectroscopy.

(2) The proposed blind spectroscopic imaging deep survey of 1 deg^2 field spending 600 hrs using SMI (Figure 3; Kaneda et al. 2017, PASA, 34, e059) can potentially uncover ASAGAO-ID-17-like HST-dark galaxies at z ~3-4. The underlying mid-infrared continuum will also be useful to address the co-growth of SMBHs and host galaxies.

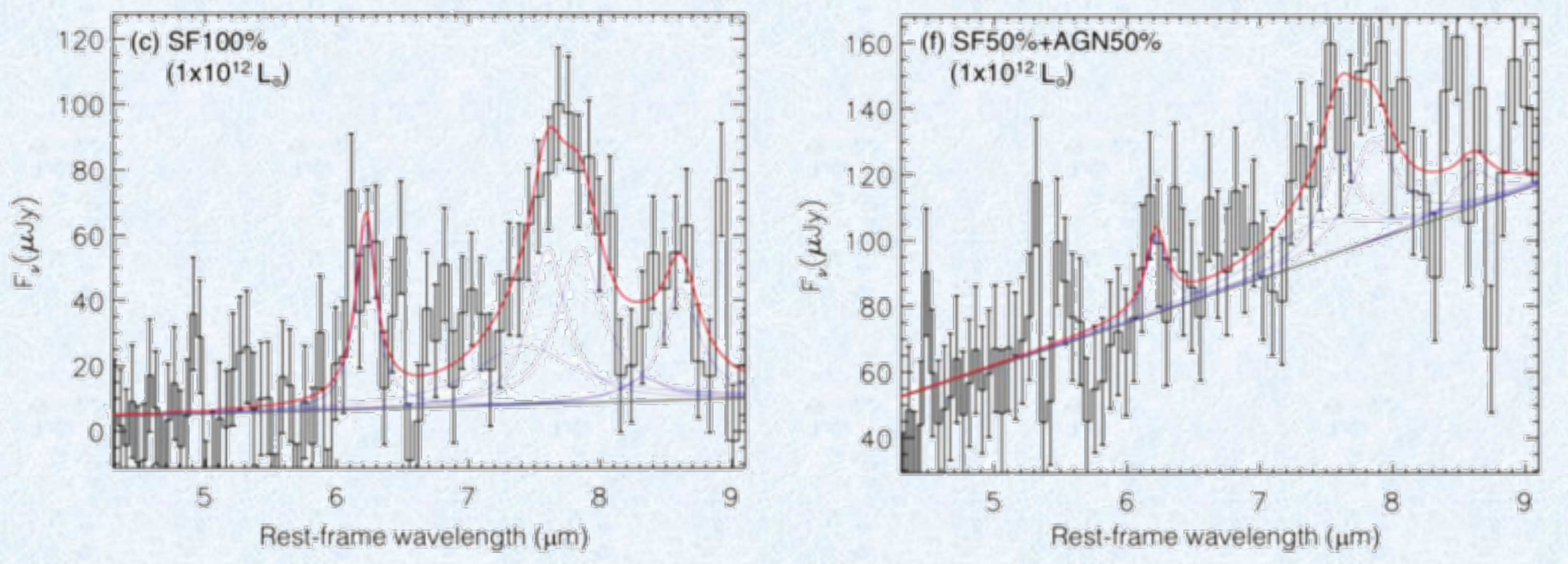

Figure 3: Simulated spectra of star-forming (left) and AGN-hosting (right) galaxies with L(IR) of 1 x 10^{12} $L_\odot$, which is comparable to the L(IR) of the NIR-dark galaxy ASAGAO ID-17 (Figure 1). The proposed unbiased spectroscopic deep survey of 1 deg^2 field can potentially uncover such NIR-dark galaxies and test whether a growing SMBH coexists in obscured star-forming massive galaxies.