Uncovering Early Galaxy Evolution in the ALMA and JWST Era
Proceedings IAU Symposium No. 352, 2019
E. da Cunha, J. Hodge, J. Afonso, L. Pentericci & D. Sobral, eds.

doi:10.1017/S1743921319009542

ALMA twenty-six arcmin^2 survey of GOODS-S at one millimeter (ASAGAO)

B. Hatsukade[1], K. Kohno[1,2], Y. Yamaguchi[1], H. Umehata[1,3], Y. Ao[4], I. Aretxaga[5], K. I. Caputi[6], J. S. Dunlop[7], E. Egami[8], D. Espada[9,10], S. Fujimoto[11], N. Hayatsu[12,13], D. H. Hughes[5], S. Ikarashi[6], D. Iono[9,10], R. J. Ivison[13,7], R. Kawabe[9,10], T. Kodama[14], M. Lee[15], Y. Matsuda[9,10], K. Nakanishi[9,10], K. Ohta[16], M. Ouchi[11,17], W. Rujopakarn[17,18,19], T. Suzuki[9], Y. Tamura[15], Y. Ueda[16], T. Wang[1,9], W.-H. Wang[20], G. W. Wilson[21], Y. Yoshimura[1], M. S. Yun[21] and ASAGAO team

[1]Institute of Astronomy, Graduate School of Science, The University of Tokyo, 2-21-1 Osawa, Mitaka, Tokyo 181-0015, Japan
email: hatsukade@ioa.s.u-tokyo.ac.jp

[2]Research Center for the Early Universe, The University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-0033, Japan

[3]RIKEN Cluster for Pioneering Research, 2-1 Hirosawa, Wako-shi, Saitama 351-0198, Japan

[4]Purple Mountain Observatory & Key Laboratory for Radio Astronomy, Chinese Academy of Sciences, 8 Yuanhua Road, Nanjing 210034, China

[5]Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE), Luis Enrique Erro 1, Sta. Ma. Tonantzintla, Puebla, Mexico

[6]Kapteyn Astronomical Institute, University of Groningen, P.O. Box 800, 9700AV Groningen, The Netherlands

[7]Institute for Astronomy, University of Edinburgh, Royal Observatory, Edinburgh EH9 3HJ UK

[8]Steward Observatory, University of Arizona, 933 N. Cherry Ave, Tucson, AZ 85721, USA

[9]National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan

[10]SOKENDAI (The Graduate University for Advanced Studies), 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan

[11]Institute for Cosmic Ray Research, The University of Tokyo, Kashiwa, Chiba 277-8582, Japan

[12]Department of Physics, Graduate School of Science, The University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo, 113-0033, Japan

[13]European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching, Germany

[14]Astronomical Institute, Tohoku University, Aramaki, Aoba-ku, Sendai, Miyagi 980-8578, Japan

[15]Department of Physics, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan

[16]Department of Astronomy, Kyoto University, Kyoto 606-8502, Japan

[17]Kavli Institute for the Physics and Mathematics of the Universe, Todai Institutes for Advanced Study, the University of Tokyo, Kashiwa, Japan 277-8583 (Kavli IPMU, WPI)

[18]Department of Physics, Faculty of Science, Chulalongkorn University, 254 Phayathai Road, Pathumwan, Bangkok 10330, Thailand

[19]National Astronomical Research Institute of Thailand (Public Organization), Don Kaeo, Mae Rim, Chiang Mai 50180, Thailand

[20]Institute of Astronomy and Astrophysics, Academia Sinica, Taipei, Taiwan

[21]Department of astronomy, University of Massachusetts, Amherst, MA 01003, USA

Abstract. The ALMA twenty-six arcmin^2 survey of GOODS-S at one millimeter (ASAGAO) is a deep ($1\sigma \sim 61\mu$Jy/beam) and wide area (26 arcmin^2) survey on a contiguous field at 1.2 mm. By combining with archival data, we obtained a deeper map in the same region ($1\sigma \sim 30\mu$Jy beam^{-1}, synthesized beam size $0.59'' \times 0.53''$), providing the largest sample of sources (25 sources at 5σ, 45 sources at 4.5σ) among ALMA blank-field surveys. The median redshift of the 4.5σ sources is 2.4. The number counts shows that 52% of the extragalactic background light at 1.2 mm is resolved into discrete sources. We create IR luminosity functions (LFs) at $z = 1$–3, and constrain the faintest luminosity of the LF at $2 < z < 3$. The LFs are consistent with previous results based on other ALMA and SCUBA-2 observations, which suggests a positive luminosity evolution and negative density evolution.

Keywords. cosmology: observations, galaxies: evolution, galaxies: formation

---

We performed the ALMA twenty-six arcmin^2 survey of GOODS-S at one-millimeter (ASAGAO; Hatsukade *et al.* (2018); Kohno *et al.* (2016); Ueda *et al.* (2018); Fujimoto *et al.* (2018); Yamaguchi *et al.* (2019)). The central 26 arcmin^2 area of GOODS-S was observed at 1.2 mm, providing a map with $1\sigma \sim 61$ μJy beam^{-1} (250 kλ-taper) and a synthesized beam size of $0.51'' \times 0.45''$. By combining the ALMA archival data available in GOODS-S, we obtained a deeper map for the 26 arcmin^2 area, which has a rms noise level of $1\sigma \sim 30$ μJy beam^{-1} for the central region with a 250 kλ-taper and a synthesized beam size of $0.59'' \times 0.53''$. We find 25 sources at 5σ and 45 sources at 4.5σ in the combined ASAGAO map, providing the largest source catalog among ALMA blank field surveys.

The larger sample allow us to construct 1.2 mm number counts with smaller uncertainties from Poisson statistics. The flux coverage of the number counts connects the fainter range probed by ALMA deep observations and the brighter range constrained by ALMA follow-up observations of single-dish detected sources. We find that our number counts are consistent with previous ALMA studies (e.g., Hatsukade *et al.* (2016)). By integrating the derived differential number counts, we find that 52^{+11}_{-8}% of the extragalactic background light (EBL) at 1.2 mm is revolved into the discrete sources. The integration of the best-fitting function reaches 100% at $S_{1.2\mathrm{mm}} \sim 20$ μJy, although there is a large uncertainty to extend the function to the fainter flux range.

By using the 5σ sources, we construct IR luminosity functions (LFs) in the ranges of $1 < z < 2$, $1.5 < z < 2.5$, and $2 < z < 3$. Our study constrains the faintest luminosity end of the LF at $2 < z < 3$ among other studies. We find that the ASAGAO LFs are consistent with those of Koprowski *et al.* (2017), supporting the evolution of LFs (positive luminosity evolution and negative density evolution with increasing redshift). The integration of the best-fitting LF down to the lowest luminosity of the sources ($\log(L_{\mathrm{IR}}/L_\odot) = 11.78$) gives a star-formation rate density (SFRD) of $7.2^{+3.0}_{-1.9} \times 10^{-2}$ $M_\odot$ yr^{-1} Mpc^{-3}. We find that the IR-based star formation of ASAGAO sources contribute to ≈60–90% of the SFRD at $z \sim 2$ derived from UV–IR observation, indicating that the major portion of $z \sim 2$ SFRD is composed of sources with $\log(L_{\mathrm{IR}}/L_\odot) \gtrsim 11.8$.

References

Fujimoto, S., Ouchi, M., Kohno, K., *et al.* 2018, *ApJ*, 861, 7
Hatsukade, B., Kohno, K., Umehata, H., *et al.* 2016, *PASJ*, 68, 36
Hatsukade, B., Kohno, K., Yamaguchi, Y., *et al.* 2018, *PASJ*, 70, 105
Kohno, K., Yamaguchi, Y., Tamura, Y., *et al.* 2016, *IAUS*, 319, 92
Koprowski, M. P., Dunlop, J. S., Michałowski, M. J., *et al.* 2017, *MNRAS*, 471, 4155
Ueda, Y., Hatsukade, B., Kohno, K., *et al.* 2018, *ApJ*, 853, 24
Yamaguchi, Y., Kohno, K., Hatsukade, B., *et al.* 2019, *ApJ*, 878, 73

https://doi.org/10.1017/S1743921319009542 Published online by Cambridge University Press