*Resolving the Rise and Fall of Star Formation in Galaxies*
*Proceedings IAU Symposium No. 373, 2023*
*T. Wong & W.-T. Kim, eds.*
doi:10.1017/S1743921322003726

# The physical properties of IR-bright Dust-Obscured Galaxies

**Nofoz Suleiman**[1], **Yoshiki Toba**[2], **Sándor Frey**[3] **and L. Viktor Tóth**[1,4]

[1]Astronomy Department, Eötvös Loránd University, 1117 Budapest, Hungary
email: n.suleiman@astro.elte.hu

[2]National Astronomical Observatory of Japan, Japan

[3]Konkoly Observatory, ELKH CSFK, Hungary

[4]University of Debrecen, Institute of Physics, Hungary

**Abstract.** This work aims to represent the physical properties of a sample of infrared-bright dust-obscured galaxies (DOGs) studied by Suleiman et al. (2022) by fitting the spectral energy distributions (SEDs). Twenty-eight DOGs were examined at redshifts $0.47 \leq z \leq 1.63$ discovered by combining images of the Subaru Hyper Suprime-Cam (HSC) survey, VISTA Kilo-degree Infrared Galaxy (VIKING) survey, and the *Wide-field Infrared Survey Explorer* (*WISE*) all-sky survey, and detected at *Herschel* Spectral and Photometric Imaging Receiver (SPIRE) bands. The results show a correlation between the star formation rate (SFR) and the dust luminosity of Suleiman et al. (2022) DOG sample, the SFR ranges of the sample according to different redshifts, and a comparison between Suleiman et al. (2022) sample and other samples of DOGs.

**Keywords.** catalogs — galaxies: active — infrared: galaxies — surveys

## 1. Introduction

Extreme star formation generates enormous amounts of dust, which plays a crucial role in shaping the observed SED of a massive evolving galaxy in different phases. Dust absorbs most of the ultraviolet (UV) and optical photons and re-emits them in the far-IR (FIR) and sub-millimeter (sub-mm) bands. As a result, starburst-dominated and active galactic nuclei (AGN)–starburst composite systems will appear to be IR luminous, leading to the observed populations: ultraluminous IR galaxies (ULIRGs), sub-mm galaxies (SMGs) and dust-obscured galaxies (DOGs; Dey et al. 2008). The study of IR luminous galaxies at high redshift will aid in understanding the extreme scenarios in the early stages of massive galaxy evolution.

Color-based selection criteria were proposed for the efficient interpretation of a statistically significant sample of dusty ULIRGs at $z \sim 1.5 - 3$ (Dey et al. 2008). Taking advantage of the unprecedented sensitivity and angular resolution at IR wavelengths of the *Spitzer Space Telescope*, a population of optically faint ($22 < R_{\mathrm{Vega}} < 27$) and mid-IR bright ($F_\nu(24\ \mu\mathrm{m}) > 0.3$ mJy) DOGs were selected, defined as those sources having $F_\nu(24\ \mu\mathrm{m})/F_\nu(R) > 1000$. The comoving number density of DOGs shows its peak at $z \sim 1 - 2$ (e.g., Dey et al. 2008, Toba et al. (2017), Suleiman et al. 2022) that corresponds to the peak of star-formation rate (SFR) density and the growth rate of SMBHs (e.g., Richards et al. 2006). This strongly suggests that DOGs are linked to the most active objects in terms of the co-evolution between galaxies and SMBHs. In this context, DOGs

© The Author(s), 2023. Published by Cambridge University Press on behalf of International Astronomical Union. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted re-use, distribution, and reproduction in any medium, provided the original work is properly cited.

https://doi.org/10.1017/S1743921322003726 Published online by Cambridge University Press

with a high IR luminosity conceivably shelter a rapidly growing SMBH, and therefore they are important for understanding the evolution of galaxies and SMBHs.

## 2. Sample selection and used data

The IR-bright DOGs sample was discovered by Noboriguchi et al. (2019). They selected IR-bright DOGs by combining the *WISE* all-sky data and the deep optical imaging data obtained with the Subaru HSC. Furthermore, they provided NIR imaging data to preselect relatively red objects among the objects observed by HSC, in the same way as Toba et al. (2015).

In Suleiman et al. (2022), we used the *Herschel* point source catalog (HPSC; Marton et al. 2015) beside catalogs which were already used in Noboriguchi et al. (2019): the HSC (optical), VIKING (NIR), and *WISE* catalog data (MIR).

## 3. Methodology

The main physical properties of IR-bright galaxies were determined in Suleiman et al. (2022) by fitting their SEDs. The SEDs covered the rest-frame wavelength ranges from FUV to FIR (from 0.15 to 106 $\mu$m). They have been modeled using the CIGALE† software package (Burgarella et al. 2005, Noll et al. 2009). When constructing the SEDs, CIGALE manages a balance between the energy that is absorbed by dust and the energy that is re-emitted in the IR.

We used CIGALE to determine the physical characteristics of our DOGs, including SFRs, IR luminosities, stellar masses, dust attenuation, and others. Furthermore, CIGALE contains a useful methodology for evaluating the validity of the parameters and any potential degeneracies by building a mock catalog that is examined using techniques similar to those used to analyze the observed data.

## 4. Results and discussion

The dust luminosity is a good tracer of SFR, the reason is that the bulk of star formation is obscured, and dust emission is generated by the absorption of photons produced by massive stars. It was interesting to check the relation of the SFR with dust luminosity produced by CIGALE findings because CIGALE seeks to account for both obscured (radiated in the FIR) and unobscured (radiated in the UV) star formation. Additionally, CIGALE accounts for that portion of dust luminosity which is heated by earlier stellar populations. Our result in Suleiman et al. (2022; Eq.(1); $SFR[M_\odot\,\mathrm{yr}^{-1}] = (3.6 \pm 0.5) \times 10^{-44} L_{\mathrm{dust}}[\mathrm{erg\,s}^{-1}]$, where $L_{\mathrm{dust}}$ refers to the infrared luminosity integrated over the full MIR and FIR spectrum $(8-1000\ \mu\mathrm{m})$) is marginally consistent with Kennicutt et al. (1998) in (Eq.(2); $SFR[M_\odot\,\mathrm{yr}^{-1}] = 4.5 \times 10^{-44} L_{\mathrm{dust}}[\mathrm{erg\,s}^{-1}]$) with $2\sigma$ confidence.

We examined the distribution of SFR values in the sample. The SFR varies from 26 to almost 1900 $M_\odot\,\mathrm{yr}^{-1}$ at different $z$ (see Fig. 7 in Suleiman et al. 2022). The median and mean values are 600 and 755 $M_\odot\,\mathrm{yr}^{-1}$, respectively (Suleiman et al. 2022).

In addition, we compared the SFR range for five DOG samples at different redshifts with our sample (see Fig. 8 in Suleiman et al. 2022). The luminosities seen in Hot DOGs would require extreme SFRs of the order of $10^4\ M_\odot\,\mathrm{yr}^{-1}$ (Eisenhardt et al. 2012, Assef et al. 2015).

## References

Assef, R., Eisenhardt, P., *et al.* 2015, *ApJ*, 804
Burgarella, D., Buat, V., *et al.* 2005, *MNRAS*, 360

† https://cigale.lam.fr/

https://doi.org/10.1017/S1743921322003726 Published online by Cambridge University Press

Dey, A., Soifer, B. T., Desai, V., *et al.* 2008, *ApJ*, 667
Eisenhardt, P., Wu, J., Tsai, C., *et al.* 2012, *ApJ*, 755
Kennicutt, Jr., Robert, C. 1998, *ARA&A*,
Marton, G., Schulz, B., Altieri, B., *et al.* 2015, *arXiv preprint arXiv:1510.08325*
Noboriguchi, A., Nagao, T., *et al.* 2019, *ApJ*, 876
Noll, S., Burgarella, D., *et al.* 2009, *A&A*, 507
Richards, G., Strauss, M., *et al.* 2006, *AJ*, 131
Suleiman, N., Noboriguchi, A., *et al.* 2022, *PASJ*, 74
Toba, Y., Nagao, T., *et al.* 2015, *PASJ*, 67, 86
Toba, Y., Nagao, T., *et al.* 2017, *ApJ*, 835

https://doi.org/10.1017/S1743921322003726 Published online by Cambridge University Press