

SIF3004 Final Year Project Proposal : RAdio Galaxy Environment Reference Survey (RAGERS) Project

Lim Ming Kang U2004991/1

Supervisor: Prof. Dr. Zamri Zainal Abidin

November 3, 2022

1 Problem Statement

At the cosmological redshift of $2 < z < 3$ (observing the condition about 10.9 billion years ago), the universe is actively producing new stars, with highest average star forming rates (SFRs). This period known as "the cosmic noon" (Schreiber & Wuyts, 2020). Galaxies known as "Dusty Star Forming Galaxies (DSFGs) are enriched with dust that serves as the materials to forming stars.

A comprehensive understanding of those galaxies is important in understanding galaxy formation and evolution in the early universe. (Geach et al., 2016)

Characterisation of the region where the aforementioned galaxies reside (galaxy overdensities) with redshift, and the effect of Active Galactic Nuclei (AGN) activity on the growth of the central overdensities are to this day still not thorough. (Team, 2021)

Obscured by dust, those galaxies are not feasible to be observed in visible region, a telescope capable in observing in far infrared wavelength is needed to detect the galaxies.

Raw telescope data needs to be reduced, cleaned and calibrated before doing analysis, as noise and false detections may be presence, the processes are essential to obtain a clean map for analysis.

The addition of far infrared data would be significant to multiwavelength analysis of galaxies especially in obtaining photometric redshift.

2 Objectives

1. To reduce raw telescope data hence obtain analysable data (eg. source count)
2. To study statistically (eg. surface number density) of galaxy overdensities in a source field
3. To obtain photometric redshift of submm galaxies in a source field using multiwavelength analysis.

3 Background

Submillimetre Galaxies (SMGs) are rare galaxies with high star formation rates ($> 100 M_{\odot} yr^{-1}$) (Da Cunha et al., 2021) populated in high redshift region. Suspected to be the progenitors of local massive galaxies (Casey, Narayanan, & Cooray, 2014), SMGs are valuable candidates to study evolution of galaxies in high redshift. One challenge in observing SMGs is the amount of dust, which serves as the building blocks for star formation, which obscure visible light. However, the dust absorbs the radiation emitted from new stars and reemits as far infrared wavelength (Casey et al., 2014), the observation of SMGs is possible with submillimetre telescopes.

Overdensities are regions in space where the density of matter is relatively higher than others. Examples are galaxy clusters and proto-clusters. Astronomical events such as mergers of galaxies usually happen in overdensities region. Also resides giant, powerful galaxies in aforesaid region. At $z > 1$, High redshift radio galaxies (HzRG) are usually in the region of overdensities where SMGs are. The dynamic between SMGs and HzRGs can be studied so have a more robust understanding of evolution of massive structure of the universe. (Saxena & Rottgering, 2018)

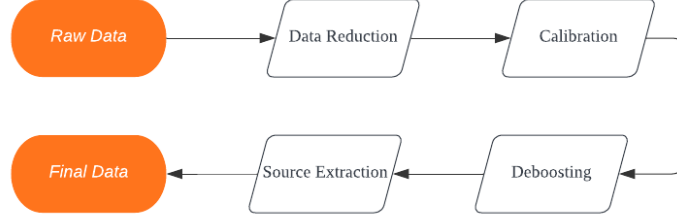


Figure 1: General process of data handling of raw telescope data

Telescopes There has been telescopes operating at submillimetre region. For instances the Atacama Large Millimeter Array (ALMA) telescope located in northern Chile, Fred Young Submillimeter Telescope, Caltech Submillimeter Observatory (CSO), William Herschel Telescope (WHT)(Phillips, Padin, & Zmuidzinas, 2013) and SCUBA-2 at James Clerk Maxwell Telescope (JCMT), whose data is used in the research of this proposal. They are built at high attitude, usually on top of the mountains (eg. JCMT at Mauna Kea, Hawaii(4092m)) to minimize the attenuation of incoming signal by the Earth atmosphere.(Phillips et al., 2013)

4 Research Methodology

The research will be carried out on handling raw 0.85mm and 0.45mm data collected from JCMT SCUBA-2 under RAGERS Project, in collaboration with RAGERS Malaysia Team (from where the raw data is acquired). Data Reduction is run on Starlink software. The process of data handling is shown in Figure 1

James Clerk Maxwell Telescope (JCMT) is a 15m telescope designed to run on submillimetre wavelength (far infrared region). It is positioned at Maunakea, Hawaii.

SCUBA-2 is a camera attached on JCMT to observe at $450\mu m$ and $850\mu m$ (666GHz and 353GHz), which are frequencies emitted by light molecules containing hydrogen (eg. H_2O, CH) from the dust (Phillips et al., 2013). The data is formatted and stored in .sdf format, which is readable by starlink software.

The Radio Galaxy Environment Reference Survey is a JCMT program to observe overdensities within the Mpc region of 33 radio galaxies at redshift range $1 < z < 3.5$ and mass range $M_* \geq 10^{10.8} M_\odot$ (Team, 2021)

Source field is a region spanning across few Mpc centered around a HzRG, which is located at $1 < z < 3.5$

Starlink is a software consisting of several packages used to reduce and analyse data recorded by SCUBA-2 telescope, including (but not limited to) SMURF for data reduction and GAIA for data visualisation. Telescopes are usually associate with their proprietary software for data handling. For instances, CASA for ALMA, Starlink for JCMT and AIPS for Very Large Baseline Array (VLBA). It is extremely important to produce useful science data from noisy telescope data to remove as much noises as possible (eg. Radio Frequency Inteference (RFI)) and extract useful information to the max. Figure 2 shows an example of the comparison between raw telescope data, and image after data reduction.

5 Expected Results

A reduced, low noise data similar to figure 2b should be obtained. From the reduced data, surface number density as the function of radius from center HzRG can be calculated from the number counts. Figure 3 shows one example of graph of surface number density of cluster galaxies vs distance from a cluster center. A Spectral Energy Density (SED) of each detected submm galaxy

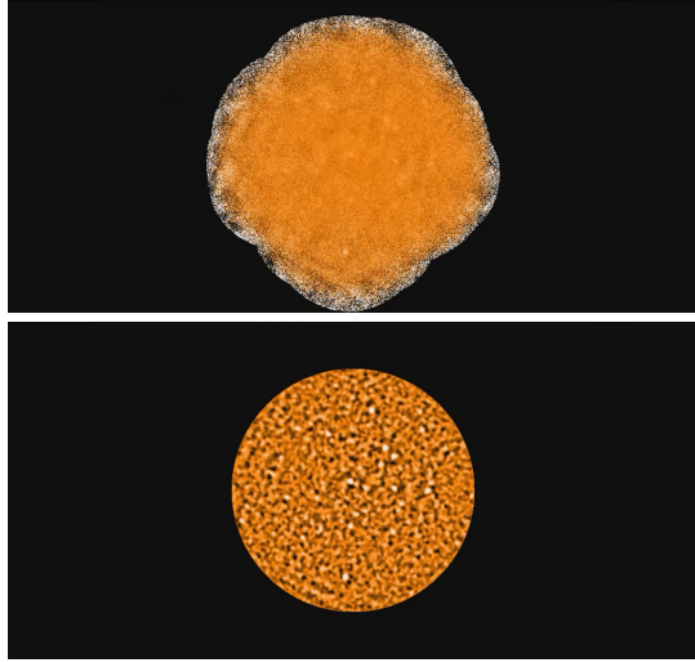


Figure 2: An example of the comparison between raw telescope data (up), where there is no clear galaxies count, and image after data reduction (down), where SMGs appear as white dots

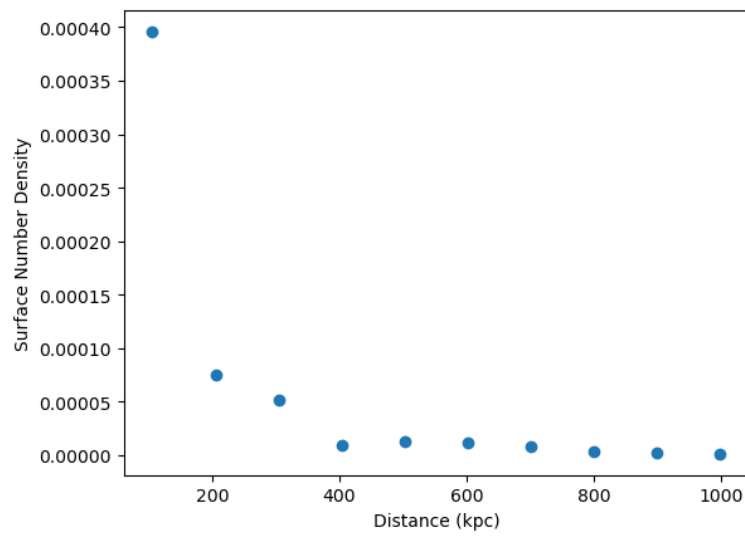


Figure 3: Surface number density as the function of distance from cluster center

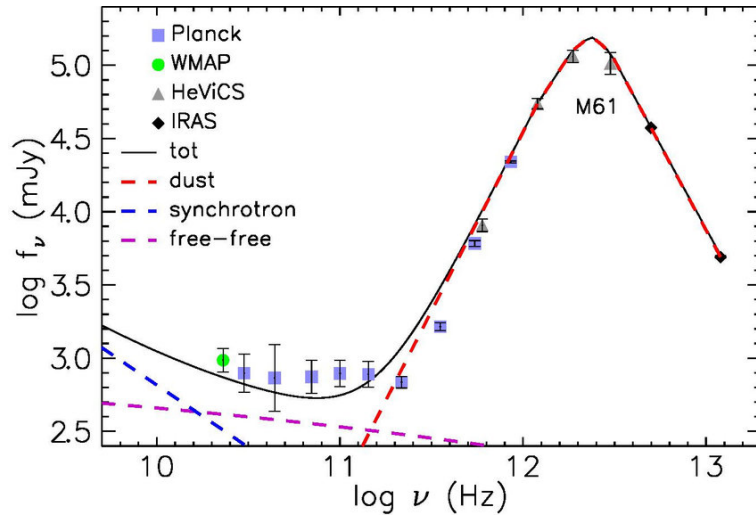


Figure 4: An example of Spectral Energy Density graph, a logarithmic graph of flux density vs frequency

can be calculated by combining multiwavelength flux density to obtain photometric redshift. An example of the stated graph is shown in figure 4, obtained from article (De Zotti, Bonato, & Cai, 2018)

6 Significance

Surface number density is essential in studying the effect of HzRG on the environment. The addition of 0.85mm and 0.45mm in SED will give a more accurate photometric redshift of galaxies, which is crucial to study the evolution of galaxies with redshift. More comprehensive data of proto-cluster dynamic will probe into a more robust understanding of galaxies structure evolution.

References

- Casey, C. M., Narayanan, D., & Cooray, A. (2014). Dusty star-forming galaxies at high redshift [Journal Article]. *Physics Reports*, 541(2), 45-161. doi: <https://doi.org/10.1016/j.physrep.2014.02.009>
- Da Cunha, E., Hodge, J., Casey, C., Algera, H., Kaasinen, M., Smail, I., ... Decarli, R. (2021). Measurements of the dust properties in ($z \approx 1-3$) submillimeter galaxies with alma [Journal Article]. *The Astrophysical Journal*, 919(1), 30.
- De Zotti, G., Bonato, M., & Cai, Z.-Y. (2018). Star formation across cosmic time with radio surveys. the promise of the ska [Journal Article]. *arXiv preprint arXiv:1802.06561*.
- Geach, J. E., Dunlop, J. S., Halpern, M., Smail, I., van der Werf, P., Alexander, D. M., ... Zemcov, M. (2016). The scuba-2 cosmology legacy survey: 850 μ m maps, catalogues and number counts [Journal Article]. *Monthly Notices of the Royal Astronomical Society*, 465(2), 1789-1806. Retrieved from https://doi.org/10.1093/mnras/stw2721https://watermark.silverchair.com/stw2721.pdf?token=AQECAHi208BE490oan9kkhW_Ercy7Dm3ZL_9Cf3qfKAc485ysgAAAtswggLXBgkqhkiG9w0BBwagggLIMIICxAlBADCCArOGCSqGSib3DQEHATAeBglghkgBZQMEAS4-RgxGP7CgJBvjuf85FCU9p11CzAZLTA0vifhaLMvr_byivUbbBMX5FWDKkifKlzykgcC40piDIIMLfGnpZzj2ca_of4eNSN1dwdVp4Avr-JHaXaABGoK3Z8XGnkareVM62CyAxPxy4x7dv112NIoFRDdq3i08JFGJzqRe1gJASu4sjaH7FOR_y2I-8tjKqWjiCwTvWmJ4E4EMugWSn-ps5KU0vym2GJTkdZMniFBDXinZmwYbiYGigQAI-4uvIYqimIP1Zkb0a5NCwouYJg8wI-MO31ChM_Eh7AjeEt2yFHZ2G9yrk2dygVJzg0a9QX0Giwlw5g_SNHcDe9BD-4pZxSsJvGWFQTHKh4zd9Dr_4UsBY1-XBzG30a7WhVk8DHZ-1Ci55uBagx0V9SF0GEqXSaKdmK0Vmc_Iz48LzjYSxtNY1kcpbZLONJtJ4A23DkBJUSp8ZVm5d7UR3niCbKcNGWy_tAE0gl-7w80WQ4C3IHk12WHWdJf09q02aIaxZUajXePUxD14-imXsEILaxvpUCjml18Mhq6HuPet2BmWvSxM4ud0z0mh_YBLHUimuHST3A1YNgBN1oUG3GBZd0Zuv34bxjkHvLoU-twuB0sRR96rPgbmlftpAwE-3KmMJv93eTLiYWaiQoEaxTZ4fUMcWBEH6YJKu9xE0HJWURNadE7rrA0k7jIxihOuf015buTDA doi: 10.1093/mnras/stw2721
- Phillips, T. G., Padin, S., & Zmuidzinas, J. (2013). Submillimeter telescopes [Book Section]. In T. D. Oswalt & I. S. McLean (Eds.), *Planets, stars and stellar systems: Volume 1: Tele-*

- scopes and instrumentation* (p. 283-313). Dordrecht: Springer Netherlands. Retrieved from https://doi.org/10.1007/978-94-007-5621-2_7 doi: 10.1007/978-94-007-5621-2_7
- Saxena, A., & Rottgering, H. (2018). High-redshift radio galaxies at low radio frequencies [Journal Article]. *arXiv preprint arXiv:1810.08119*.
- Schreiber, N. M. F., & Wuyts, S. (2020). Star-forming galaxies at cosmic noon [Journal Article]. *Annual Review of Astronomy and Astrophysics*, 58(1), 661-725. Retrieved from <https://www.annualreviews.org/doi/abs/10.1146/annurev-astro-032620-021910> doi: 10.1146/annurev-astro-032620-021910
- Team, R. (2021). *The radio galaxy environment reference survey*. East Asian Observatory. Retrieved from <https://www.eaobservatory.org/jcmt/science/large-programs/ragers/>