# 日本天文学会早川幸男基金渡航報告書

**2023 年 09 月 10 日採択**

| **申請者氏名** | **仲宇星 (会員番号 7967)** |
|---|---|
| 連絡先住所 | 〒 169-8555 東京都新宿区大久保 3 丁目 4-1 |
| 所属機関 | 早稲田大学 |
| 職あるいは学年 | D3 |
| 任期 (再任昇格条件) | |
| 渡航目的 | 研究集会での口頭発表 |
| 講演・観測・研究題目 | ALMA and VLA view of a young, radiatively efficient radio-loud AGN residing in a starburst merger at $z$=1.92 |
| 渡航先 (期間) | 中国 (2023 年 10 月 09 日〜10 月 13 日) |

I have traveled to Hangzhou, China to present my own research as a contributed talk at the science conference: Galaxy Formation in Hangzhou hosted by the Institute for Advanced Study in Physics at Zhejiang University and the Shanghai Astronomical Observatory and Chinese Academy of Sciences. This conference focuses on the recent observational and theoretical studies of active galactic nucleus (AGN) feedback in all forms and wavebands. It constitutes three science topics: observations of AGN feedback, physics of AGN feedback, and algorithms that aim to provide better tools to estimate the black hole (BH) and feedback properties.

This conference includes invited talks given by world-renowned researchers including Luis Ho, Alexander Tchekhovskoy, Houjun Mo, Xiaohui Fan, Nicole Nesvadba, Raffaella Morganti, Santiago Garca-Burillo, and more. Their studies of AGN feedback cover a wide range of scales: from the pc-scale AGN dust tori, 100-pc scale circumnuclear discs, kpc-scale galactic discs, to hundred kpc-scale radio jets and the halo evolution in a cosmological scale. Their studies cover a wide range of AGN populations across the cosmic time: from low-luminosity AGNs in the nearby Universe, powerful radio galaxies around the cosmic noon, to luminous quasars at high-redshift universe. The observational studies cover a wide range wavelengths: from X-ray observations using XMM-Newton and Chandra, optical-to-mid infrared (MIR) spectroscopy and integral field unit (IFU) observations using James Webb Telescope, radio line emission observations using the Atacama Large Millimeter/submillimeter Array (ALMA), to low-frequency radio continuum observations using ALMA, Very Large Array (VLA), and Low Frequency Array (LOFAR). The theoretical studies provide concise but comprehensive understandings of the physics behind AGN activities and AGN feedback.

My current research focuses on a powerful radio galaxy at the cosmic noon based on ALMA, VLA, and Keck Telescope observations. The radio-loud AGN that resides in this galaxy has a bolometric luminosity of $L_{\rm AGN,bol} \sim 2.9 \times 10^{46}$ erg/s, suggesting that the BH is actively accreting gas. However, the powerful radio jets have a kinetic luminosity of $L_{\rm jet} \sim 2 \times 10^{47}$ erg/s, which is contradictory to the traditional understanding of active

BHs being jet-phobic. Alexander Tchekhovskoy's theoretical studies of the formation (and switch-off) of jets offer good explanations for this observational result. That is, BH jets can form when the accretion disc is either geometrically thin or thick. There are no jets or stunted jets only for the accretion discs that keep randomly re-orienting.

The ALMA observation of CO(6-5) line emission reveals a massive molecular outflow ($M_{\rm H_2} \sim 2\times10^9$) $\rm M_\odot$ which appears to be lopsided and perpendicular to propagation direction of the radio jets. Such a perpendicular structure has been introduced by the invited speaker Santiago Garca-Burillo. They have studied the circumnuclear environments of 75 nearby Seyfert galaxies based on CO and HCN+ observations. They find in general the molecular gas is kinematically and morphologically decoupled and perpendicular to the ionization bicones that represent jets on a few tens pc scale. This point is reflected as an objective in my JWST Cycle 3 proposal for my current target. The lopsidedness of the outflow has been reproduced in a simulation introduced by the invited speaker Raffaella Morganti. I have asked her a question regarding to this point and she argues that this lopsidedness is (possibly) due to the clumpiness of the interstellar medium, which prevents jets from channeling to result in large-scale outflow. I have been communicating with her to discuss this point in my current research and have invited her to join as a collaborator.

The molecular outflow in my current target is likely to be driven by jet-mode feedback, but with an extremely small jet-ISM coupling efficiency of 0.001. In the invited speaker Nicole Nesvadba's talk, it is argued that it doesn't take much for the jet to suppress star-forming activities in its host galaxy. I then asked her a question about how much this argument depends on the jet-ISM coupling efficiency. This is an extremely difficult question to answer since there are so many properties that determine the energy injection from jets to ISM including the evolution stage of jets, jets power, and how jets travel through the ISM. However, in general, this argument holds for a few percent coupling efficiency. Following this question, I asked Nicole whether a higher coupling efficiency could be expected when the jets are young. Nicole answered that, and commented by Raffaella, the duty cycle of radio AGNs is the key to understand this question.

The problem of duty cycle is partially understood for my current target in the published paper, and it has a young age with intermittent or transient activities. To statistically understand the lifetime of high-redshift radio galaxies, a lager sample is required. Hongming Tang has introduced the Radio Galaxy Zoo (RGZ) project which include 4 million radio sources. Sophia Dai has introduced an interesting population of high-redshift dusty AGNs, where there is co-increase in $L_{\rm AGN,bol}$, BH masses, and host galaxy star formation rates. Yijun Wang has introduced their exploration of radio luminosity function of radio-loud AGNs, and several radio galaxies have been identified up to redshift 4. These catalogues lay the first step for my future project.

I have joined the RGZ2 collaboration. Yijun and her supervisor are in need of a collaborator who has background in radio galaxies, and I will keep in touch with them.

I would like to express my sincere gratitude to Hayakawa fund for supporting this travel.