（別紙様式５）

# 変革を駆動する先端物理・数学プログラム（FoPM）

## 国外連携機関長期研修　報告書

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1.　Background

I am conducting research on how galaxies form and evolve by observing extremely distant galaxies. In this field, the James Webb Space Telescope (JWST), which began observations in 2022, has been revolutionizing our understanding with groundbreaking discoveries about distant galaxies and black holes on an almost weekly basis. The JWST operates as a proposal-based telescope, meaning that anyone worldwide can submit a proposal during the annual application period. If accepted, they can carry out their desired observations. However, the competition is incredibly fierce, with an acceptance rate of only about 10%. Additionally, proposals are evaluated equally, regardless of whether they are submitted by students, experienced faculty, or even Nobel laureates. As a result, JWST is currently one of the most challenging telescopes to secure observation time on.

Among the institutions worldwide, the University of Texas at Austin is one of the most successful in securing JWST observation time. It is particularly active in observational and theoretical research on the early universe, which is my area of expertise. The university hosts prominent researchers such as Professor Steven Finkelstein, who leads the field in exploring distant Lyman-break galaxies through optical and infrared observations, including major surveys with the Hubble Space Telescope and JWST, and Associate Professor Caitlin Casey, a globally recognized authority on studying massive, dust-rich galaxies through radio and infrared observations, publishing a review article on the topic. The institution conducts vigorous research on distant galaxies across multiple wavelengths. Since JWST began operations, UT Austin has been a rare institution hosting several of the largest programs among JWST's public surveys, such as the COSMOS-Web, NGDEEP, and GLIMPSE. Notably, Dr. Seiji Fujimoto, a NASA Hubble Fellow and postdoctoral researcher at UT Austin, plays a pivotal role in many of these large-scale surveys, collaborating across numerous research groups within the institution. Dr. Fujimoto has also independently secured significant observation time with major telescopes such as Keck, ALMA, and JWST, leveraging a variety of observation and analysis techniques to publish a stream of groundbreaking discoveries. He is widely regarded as one of the most outstanding early-career researchers in the field. I have been deeply impressed and inspired by his research papers from which I have learned a lot. I particularly admire his research style, which transcends observational wavelengths and disciplines, allowing him to approach intriguing questions with his unique approach. Having previously collaborated with him on international projects, I reached out to request his mentorship for this opportunity.

2.　What I did during my stay at UT Austin

I stayed at UT Austin for about three months. During the first half of my stay, I worked on preparing a JWST Cycle 4 proposal, as the submission deadline fell in the middle of my visit. For the latter half, I conducted research on dust attenuation using JWST integral field spectroscopy data.

2.1. JWST proposal

One of the questions that interests me most is the mass ratio between galaxies and black holes in dusty, massive galaxies. To unravel the co-evolutionary relationship between galaxies and black holes, it is essential to measure black hole masses in more distant galaxies. However, due to sensitivity limitations, such measurements for dusty galaxies were only feasible up to z~3 before JWST.

Before coming to UT Austin, I had been studying a rare dusty galaxy at z~6 in detail using ALMA, and I had a plan to observe this galaxy with JWST to attempt a black hole mass measurement. However, after discussing this plan with Dr. Fujimoto, he suggested an approach that would allow us to observe a larger sample within a feasible amount of observation time. By linking the results to recently reported JWST observations, we could place the

findings in a broader context, creating a study with a more significant impact. We decided to include my original target galaxy as part of a larger sample and wrote a proposal accordingly.

After my arrival, I worked on sensitivity calculations, sample collection, and observation strategy development under Dr. Fujimoto's guidance. I also provided weekly progress reports and received feedback during group meetings with Professors Steven Finkelstein and Caitlin Casey's research groups. Additionally, I presented my proposal plan during a meeting where distant galaxy researchers gathered to share their ideas, and I received feedback on observational techniques. Although there were many challenges, we ultimately compiled a proposal to observe the 20 best dusty galaxy candidates, which we successfully submitted. Through this proposal preparation process, I learned an immense amount. Having primarily worked in radio astronomy before, I found writing JWST observation proposals daunting while in Japan. However, at UT Austin, it was common practice for everyone, including students, to write JWST proposals. Being surrounded by daily discussions on technical issues helped me gradually acquire the knowledge needed to conceive new observational ideas.

Beyond the technical aspects, I learned several important principles that apply universally to proposal writing, not just in astronomy. For instance, even if a proposal is not fully polished, it is crucial to circulate a draft with the main figures and structure to collaborators as early as possible. This allows for meaningful feedback while they still have ample time to provide it. I have always struggled with the bad habit of waiting until the last minute to share my drafts, but this time, I managed to circulate it two weeks before the deadline. Additionally, I realized the importance of carefully considering the overall structure and refining it thoroughly before diving into the details. Creating impactful figures also requires a thoughtful selection of parameter spaces and designing visuals that are clear and immediately comprehensible to reviewers. Learning these approaches was a major takeaway for me, as they can significantly enhance the quality of any proposal, regardless of the field.

2.2. Research on dust attenuation law with JWST IFU data

Stellar mass is one of the most fundamental physical properties of galaxies, but accurately estimating it requires correcting for the effects of dust attenuation. To do this, we assume a dust attenuation law. However, the attenuation laws used in distant galaxy studies are typically derived from observations of nearby galaxies, and there are no prior studies statistically examining these laws for distant galaxies at $z>3$. The primary challenge lies in the fact that, at such high redshifts, the Ha emission line is redshifted to wavelengths that ground telescopes and HST cannot observe, making it impossible to use the Balmer decrement method—the most precise way to measure dust attenuation. JWST, however, makes such observations feasible.

I joined a JWST IFU observation program in which Dr. Fujimoto was in charge of data reduction. As part of this program, I analyzed approximately 20 main-sequence galaxies at $z\sim5$ using the Balmer decrement method and SED fitting to study dust attenuation laws. While the results are not yet fully finalized, we anticipate submitting a paper to a journal early next year. This research marked my first experience analyzing optical and infrared spectroscopic data from a telescope like JWST. Not only did I acquire new knowledge and analytical skills, but I also gained valuable advice on conducting research within a large team. Below, I highlight two key lessons from this experience.

The project I participated in involved more than 50 researchers from diverse backgrounds. After the proposal was accepted, each member submitted a brief internal proposal outlining their intended research using the observational data. Overlapping topics were then discussed, and responsibilities were divided to determine who would write papers on which topics. One piece of advice I received when writing my internal proposal was to clearly define what physical quantities would be plotted on the X and Y axes of the key figures for the final paper. While this might seem obvious, focusing on it helped me eliminate unnecessary information and effectively communicate my scientific goals.

Another important lesson was how to establish my presence within the team. For example, the topic of dust attenuation science attracted interest from multiple members, creating a competitive environment. I was fortunate to be assigned this topic because of my connection with Dr. Fujimoto, whose significant contributions to the project included data reduction. However, from the perspective of the project's PI and other members, I was an unknown student who had joined the project midway. It was natural for them to have concerns about whether I could deliver a high-quality paper. Following Dr. Fujimoto's advice, I began analyzing the observational data as soon as it arrived, several months before my visit to UT Austin. I conducted a comprehensive preliminary analysis—not limited to dust attenuation but also covering fundamental aspects of the data—and shared my findings at the first team meeting. This allowed me to demonstrate my analytical capabilities and establish my presence within the team, earning their trust to handle this topic. Furthermore, I was advised to share my progress and a draft outline of my paper with the team once my analysis results had reached a certain stage. This early engagement allowed me to receive feedback from experienced researchers, which proved invaluable. For instance, I was introduced to highly relevant prior studies and learned early on about the specific observational quantities that theoretical researchers were most interested in. This feedback not only improved the quality of my research but also ensured that my work aligned with the broader goals of the project.

2.3. Other activities

Every Friday morning, approximately 30 members of the distant galaxies research group gather for a meeting known as the CFC meeting. During my first week, I gave a self-introduction presentation, outlining the research I had conducted so far and the plans for my stay. While preparing for this presentation, I received various pieces of advice, including the importance of tailoring the presentation style based on its purpose. In this case, the main goal was to spark interest in myself as a researcher. Therefore, I skipped the finer details of my research and instead focused on showcasing the skills I possess and the telescope observation time I have secured in the past. Additionally, I presented two new research papers during the CFC meetings. Although the topics were outside my expertise and I had limited preparation time, which made the task challenging, I gained valuable knowledge by thoroughly reading the papers and presenting them in front of experts in the field. Through this process, I realized the efficiency of assigning oneself specific tasks, like daily paper reviews, to focus and achieve a learning goal within a short period. This approach is something Dr. Fujimoto also practices, and I found it highly effective, so I plan to adopt it in my future work. During my stay, I also participated in a workshop where researchers specializing in distant galaxies from other institutions with close ties to UT Austin gathered to present their work. I gave a concise presentation on my research, which allowed me to receive feedback while being inspired by the presentations of my peers, especially those from researchers in my generation.

Throughout my stay, I was also reminded of the importance of not only focusing on personal gains but also considering the impact on others. For example, when attending group meetings, I kept in mind that my participation might take up others' time. It became clear to me that I should strive to contribute to these meetings in a way that provides value to others as well. This includes preparing thoroughly, rehearsing what I plan to say, and presenting clearly and fluently to maximize the benefits for both parties. This mindset of maximizing mutual benefits, not just personal ones, is a perspective that will undoubtedly be crucial when I apply for jobs in the future.

During one of Steven's group meetings. I'm in the back left, and Dr. Fujimoto is in the foreground.

The Saturn V rocket I visited at the Space Center Houston.

3. Final remarks

Through this stay, I not only acquired knowledge and skills related to astronomical research but also learned universally important principles and approaches to action that will be valuable no matter which career path I choose. These lessons have become an incredibly significant asset for my future. One of the things that struck me while observing the research environment of world-class, highly productive researchers was that the research outcomes published as papers represent only a small fraction of their overall efforts. Behind the scenes, there is an enormous amount of trial and error, as well as discarded ideas. These numerous ideas are not constrained by the researchers' existing knowledge or skills. Instead, they arise from a willingness to learn relentlessly about topics that spark curiosity and through extensive communication with experts in those areas. Among these ideas, only the most outstanding ones are refined into proposals and, ultimately, published papers. To execute this process requires exceptional communication and time management skills, which I now realize are incredibly challenging to master. However, I am inspired to aim for such a level myself. Honestly, I never expected that my outlook on the future would change so dramatically in just three short months. Dr. Fujimoto provided me with highly specific advice on future planning and strategies for securing positions if I decide to pursue an academic career. This guidance significantly enhanced the clarity of my previously vague career plans. I would like to express my deepest gratitude to FoPM for providing this invaluable opportunity, to my advisor, Professor Kono, and to everyone at UT Austin, especially Dr. Fujimoto, for welcoming and supporting me during my stay.