1 Abstract

The Princeton Astrophysics Department and the Todai Physics Department have built a very solid collaboration over the last five years, centered around joint observing projects. In preparation for our upcoming HyperSuprimeCam (HSC) survey, we propose to strengthen our collaboration by involving undergraduate students from both departments in HSC-related research. To coordinate projects of interest, and travel between both departments, we also propose to hire a postdoctoral Fellow. By creating a steady flow of researchers at all levels between our two institutions, we hope to solidify our partnership and facilitate world-class research.

2 Introduction: The Todai-Princeton Astrophysics Collaboration

Significant scientific contacts and collaborations between the Department of Astrophysical Sciences (Astrophysics) and the Japanese astronomical community began over 30 years ago, and important connections of department faculty with astrophysicists at the University of Tokyo (Todai) began to develop approximately 20 years ago. During the past 5 or so years these informal associations have grown dramatically in scope and have been formalized via a series of MOUs, cross-appointments and major joint research projects. The University of Tokyo is now the single-most important institutional partner of Astrophysics.

The University of Tokyo is the essential partner in all four of the large observational projects that are being, or will be, carried out with the National Astronomical Observatory of Japan (NAOJs) 8.2-meter Subaru optical/infrared telescope (located atop Mauna Kea on Hawaii’s Big Island) and in collaboration with numerous Todai astronomers and astrophysicists working primarily at either the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU, a research institute operated by Todai on its Kashiwa campus) and/or in the Todai Departments of Physics and Astronomy, located on its Hongo campus. In addition, ambitious instrumentation construction projects for major future Subaru observing programs are being carried out in large part by groups in Astrophysics and in MAE (there led by Astrophysics associate faculty member Jeremy Kasdin) with much of the funding provided by the Japanese government via grants to Todai faculty members and then subcontracted to Princeton. The total financial resources, including the value of the Subaru observing time, being devoted to these four major international efforts in observational astrophysics, in all of which Princeton Astrophysics is playing a key role, somewhat exceeds US$120 million. At least as important as their scale, the scientific goals of these four projects are squarely aligned with the Departments two major research foci on cosmology and exoplanets (with two of the four projects in each of these two areas). In short, large collaborations with colleagues at
No less important to the Departments research productivity and intellectual environment than these long term and large-scale projects, collaborations on a variety of topics in theoretical astrophysics between Astrophysics and Todai faculty, research staff and graduate students are very common and active. These are facilitated by frequent and often extended visits by researchers from both institutions to the other and are grounded in a handful of cross appointments of Astrophysics and Todai faculty. A generous Global Collaborative Network grant from Princeton University has facilitated our travel and interactions thus far. Here, we propose to build on our current success by supporting undergraduate students and a postdoctoral researcher to act as visiting researchers at each institution, facilitating communication focused around our upcoming survey.

Princeton astronomers have been, and continue to be, world leaders in cosmological map-making. Surveys of the sky, and the resulting catalogs of the galaxies, stars, asteroids, and quasars included in the images, are a treasure trove for astronomical investigations of all sorts, from studies of our Solar System to the structure of the universe on the largest scales. In this proposal, we focus on our next project, in collaboration with the University of Tokyo, to map more of the sky to a greater depth, and with higher precision, than has been possible to date. Our scientific motivations for doing so range from investigations of the formation of our own Milky Way Galaxy, to the nature of the so-called “Dark Energy” which is thought to be responsible for the observed acceleration of the expansion of the universe.

We focus here on an imaging survey of the sky, which will catalog and characterize the various objects seen in highly sensitive pictures of the night sky. Our Japanese colleagues are nearing completion of what will be the most powerful imaging camera in the world to date, the HyperSuprime Camera (HSC). Astronomers from Princeton, Japan, and Taiwan are planning a five-year survey with this camera on the Subaru Telescope. Our project will involve Princeton researchers at all levels: undergraduate and graduate students will take part in the scientific analysis of the data, our existing and growing software team of postdoctoral researchers will take the lead in developing the state-of-the-art software tools for processing the data, and junior and senior faculty will lead all aspects of this project, from survey design to science. We propose to fund the researchers (undergraduate students and postdoctoral researchers) who can mine this rich data trove for science results.

3 Building on our Success

Over the past five years, we have built a very successful collaboration with our partners in the Physics Department at Todai. We give some key examples below:

- We have already begun successful exchange of students in both directions. Princeton undergraduates Lehman Garrison and Joel Zinn each spent a summer 2012 in Tokyo working on astrophysics related to the HSC survey. Both of them have successfully continued their study on the dynamics of the Galactic disk and on gravitational lensing, respectively, and submitted senior theses in May. Professor Turner has
coadvised a graduate student, Yuka Fujii, who had multiple extended visits to Peyton Hall, culminating in three joint papers. Finally, in the fall our first Japanese graduate student will begin his first semester. While we have had many strong visiting students in the past, Naoki Arakawa will be the first student to enroll officially in our program, a clear sign of the trust that is developing between our Universities.

- The single largest symbol of our successful collaboration is the recent acceptance of our large program to take 300 Subaru nights to perform the HSC survey. Many people, both on the Todai and Princeton side, contributed significantly to the success of that proposal. We have regular telecons between different portions of the collaboration on a regular (weekly or monthly) basis, as well as email distribution lists that keep us all informed of the progress in each institution. We also have regular in-person meetings, which are essential to the functionality of the collaboration as well.

- Finally, in addition to direct preparations for the HSC survey itself, many science collaborations have grown through our sustained interactions with our Japanese colleagues. For instance, David Spergel and Masahiro Takada recently coauthored a paper on luminous galaxies, Rachel Mandelbaum was heavily involved in the thesis of Hironao Miyatake with Takada and Hironao is now a postdoctoral fellow in Princeton. Jenny Greene and John Silverman have recently completed a paper on the black holes in tiny galaxies. Researchers here and at Plasma Physics Laboratory have initiated discussions with the plasma physicists at Todai. Finally, we note that our collaboration reaches beyond Todai to the entire astronomical community in Japan, and thus is well in line with the overarching goals of this program.

Between the world’s most powerful imager and our strong collaboration we are almost poised for success. However, as we prepare for the deluge of data that will begin Jan. 2014, we must invest in human capital. Specifically, we must identify individuals to analyze the HSC data who can move regularly between our two institutions. Faculty members do not have the flexibility. Instead, it is our undergraduate students who are in the perfect position to dive into the data and supporting theoretical endeavor. There is no better way to energize our young students then to put them at the forefront of original research. To ensure continuity of research goals across our two institutions, we also wish to hire a full-time researcher at the postdoctoral level.

4 The Upcoming HyperSuprime Camera Survey

The Astrophysical Sciences department at Princeton University is a world leader in astronomical sky surveys. The Wilkinson Microwave Anisotropy Probe (WMAP), led by scientists in the departments of Physics and Astrophysical Sciences at Princeton, has made a detailed map of the Cosmic Microwave Background, leading to our current standard model of the overall structure and makeup of the Universe. Similarly, the Sloan Digital Sky Survey (SDSS) was conceived and led by Professor James E. Gunn; it has been in operation since the year 2000 and has obtained images of over 1/3 of the entire sky, cataloging and characterizing roughly half a billion galaxies, stars, quasars, and asteroids. The survey also obtained spectra of over two million of these objects, resulting in
the most comprehensive three-dimensional map of the nearby universe to date. The resulting data from these two surveys have been used by thousands of scientists all over the world, and have resulted in over 5500 publications in the refereed literature over the last decade. Their tremendous productivity (which has contributed substantially to Princeton astrophysics’ first-place ranking in the recent National Research Council evaluation of graduate programs around the country) is a result of the universal nature of such surveys: while both WMAP and SDSS were designed to address very specific scientific questions relating to the structure and makeup of the universe, the raw data that these surveys gathered to work on these problems were of broad utility for a huge range of scientific questions. Moreover, both surveys made their data public to the world, allowing scientists on every continent to make important discoveries.

These data have been a particularly rich source of research projects for undergraduate and graduate students at Princeton; close to half of the junior papers, senior theses, and PhD theses from the astrophysics department over the past decade have been based on one of these two surveys, and these students have gone on to become respected independent researchers in their own right at top universities in the US and abroad. Furthermore, planning and executing the next generation of surveys has served as the focal point for our collaboration with researchers at University of Tokyo.

The HSC survey that we hope to support under this collaborative network is inspired by, and represents a major extension of, the SDSS. The SDSS carried out a comprehensive accounting of the nearby universe, studying the physical characteristics and distribution of millions of galaxies. However, our telescopes are time machines: because of the finite speed of light, the light from these distant galaxies takes billions of years to reach us. Thus we see these objects not as they are now, but as they were in the cosmic past. This means that surveys with telescopes and instruments sufficiently powerful to detect distant galaxies can probe the properties of galaxies when the Universe was much younger than it is today, and thus learn how they evolved with cosmic time. This is the principal motivation for carrying out SDSS-like surveys on a much larger telescope. The Subaru Telescope, with a primary mirror of more than ten times the area of the Sloan Telescope, can image an area of sky seven times larger than the full Moon in a single shot, making it the most powerful telescope in the world for survey work. Princeton University has entered into a formal agreement with NAOJ to jointly carry out sky surveys using the telescope, with Princeton astronomers playing key roles in planning for the surveys, designing the complex instruments, and developing the software pipelines for processing and analyzing the terabytes of data that these surveys will produce. Thanks in part to generous support from Princeton, we have figured out how to collaborate successfully with our Japanese collaborators across continents and time zones. What is needed now are researchers to carry out these surveys and to mine them for their scientific riches.

5 The Undergraduate Exchange Program

Our plan is as follows. Each year of the grant, two fourth-year students from Todai will spend two months at Princeton to conduct a short research project. Depending on the interest of the student, each will work on an appropriate research topic either in theoretical or computational studies related to large cosmological surveys, or on the analysis and
interpretation of HSC data. We would like to put our emphasis on education, training and the students' exposure to world-class research. Candidate students will be selected primarily from the Department of Physics, but those from the Department of Earth and Planetary Science and Astronomy are also eligible, in the case of appropriate research interests. The students will participate in a wide range of astrophysics in the course of their stay, through our daily journal discussions, graduate student tea-time, weekly talk series, graduate student seminar, and regular meetings with their host professors. These formal and informal daily gatherings will provide many opportunities for scientific interactions beyond those specific to the research project.

The two-month research experience is counted as a part of the requirement for Theoretical or Experimental Physics Exercise II that all Todai fourth year students need to complete for graduation. Typically, the visiting students will have completed all other necessary course units for graduation before departing for Princeton, and thus will graduate upon successful completion of a short research project at Princeton. Each student will give a short oral presentation of their research and prepare a short (around 10 pages) written summary as well, as preparation for a journal publication.

On the Princeton side, the visits will work in a similar way. Princeton students will be sent to visit Todai in the summer, typically after their third year. At this stage, they will have completed two junior thesis projects in Princeton, and will be in a good position to choose a summer project that can turn into a senior thesis as was the case with Joel and Lehman. Each student will have two advisors at the University of Tokyo, one at the Todai campus and one at IPMU, so that the student will have ties to each institute. This model also worked well for Joel and Lehman.

At Todai Physics, we also have a weekly department colloquium and astrophysics seminar series held together with Research Center for the Early Universe. Similarly, at Kavli IPMU most of the daily and weekly activities such as tea-time discussions and a cosmology/astronomy seminar series are open to students. Furthermore, science workshops called “Focus Week” are held about every two months, with discussion topic ranging from algebraic geometry to the formation of black holes, offering a truly intellectual and interdisciplinary atmosphere to young scientists and students.

6 The Role of a Joint Postdoctoral Fellow

We propose to employ a full time postdoctoral fellow working on galaxy evolution using data from the HSC survey. The postdoc will work at Princeton for the first 1.5 years, and then move to Todai/IPMU for the latter 1.5 years. The postdoc will also visit the two institutes multiple times per year so that he/she can closely work with our colleagues working on the HSC survey. We will provide necessary facilities, including office space and computers at both the departments, and also at Kavli IPMU.

We primarily seek candidates whose expertise is observational study of galaxy evolution. Specifically, the postdoc will look at the evolution in the shapes of galaxies over the
last five billion years of cosmic time. HSC is uniquely suited to this problem, since it will provide exquisite images over very large areas on the sky. The postdoc, working with a broad cross-section of the Todai and Princeton community, will use the unique strengths of HSC to link the evolution in galaxy shape with rate of mergers, the typical dark matter halo hosting the galaxy, and the ages of the stars. Together, these clues will help us to understand how galaxies came to look the way that they do. We are still working to measure galaxy properties in an optimal way, for a variety of experiments in HSC. This postdoctoral fellow will thus be intimately involved not only in their direct science, but also in problem-solving and data analysis that impacts the entire collaboration.

Many of us on both sides of the collaboration are interested in pursuing these topics using HSC. Thus, we envision our new postdoctoral fellow serving as a focal point for our nascent galaxy evolution group. In our experience, postdoctoral fellows do serve this purpose extremely well. For instance, Hironao Miyatake was a graduate student with Masahiro Takada, one of the leaders of HSC. Hironao collaborated with many Princeton astronomers during his thesis. Hironao is now a postdoctoral fellow here in Princeton. He organizes weekly HSC meetings, involving both Princeton and Tokyo collaborators, and keeps running tallies of ongoing projects in cosmology. The new postdoctoral fellow that we envision here will play a similar role.

Finally, we will encourage the postdoc to overlap with the undergraduate visitors to the maximum extent possible. It is our hope that this postdoc will serve as a mentor and as a source of common ground between the two institutes for the students. Thus, during the period when our exchange students stay at each respective institute, the postdoc can work closely with them, as well as provide continuity between projects. While individual students will only visit for a few months at most, they will have the postdoctoral fellow as a contact when they return to their home institution.

7 Members of the Collaboration

Princeton and Japanese astronomers have a long history of collaboration on scientific problems of mutual interest. The Japanese were partners in the SDSS collaboration, and Japanese and Princeton astronomers worked together on its instrumentation. Princeton is a member institution in Tokyo University's recently formed Institute for the Physics and Mathematics of the Universe (IPMU), and the agreement we've entered with NAOJ is specifically to use the Subaru Telescope for astronomical studies of common interest. This agreement is administered by an organization called the NAOJ-Princeton Advisory Council, with representation from both institutions, and was originally formulated to support two major projects. The first of these is a search for planets around other stars; this is led on the Princeton side by Professors Ed Turner and Jill Knapp, and was the subject of a successful Princeton Global Collaborative Network proposal three years ago. The second of these is focused on wide-field imaging surveys, and forms the basis of the present proposal.

NAOJ, under the leadership of Dr. Satoshi Miyazaki, is building a wide-field imaging camera for Subaru, called Hyper-SuprimeCam (HSC); this instrument will be ready to start observing the sky in late 2012. The individuals at the University of Tokyo who will be involved in this exchange include:
- Dr. Naoki Yoshida of IPMU, a cosmological theorist with interests in galaxy and star formation.
- Dr. Hitoshi Murayama, director of IPMU, and an internationally renowned particle physicist.
- Dr. Hiroshi Karōji of IPMU, who is leading the management of the PFS project.
- Dr. Hajime Sugai of IPMU, who is working with Dr. Karōji on project management and instrumentation.
- Dr. Masahiro Takada of IPMU, a cosmologist with expertise in gravitational lensing.
- Dr. Naoki Yasuda of IPMU, a supernova and software expert who worked with Princeton astronomers on the SDSS.
- Dr. John Silverman of IPMU, who studies the evolution of galaxies and black holes.
- Dr. Kevin Bundy of IPMU, who is an expert on star formation in galaxies at high redshift.
- Dr. Alexie Leauthaud of IPMU, who uses gravitational lensing to probe the evolution of galaxies.
- Dr. Yasushi Suto of the University of Tokyo. He has been named a Princeton Global Scholar, and has played a key role in making connections between Princeton and Japanese astronomers to bring the collaboration to its present level.

We list here a few key external collaborators in Japan, who are associated with the HSC survey but not University of Tokyo employees:

- Dr. Satoshi Miyazaki of NAOJ; he is leading the team that built HSC.
- Dr. Hisanori Furusawa of NAOJ, who is working on the software pipelines that will analyze HSC data.

On the Princeton side, our principal interests, expertise, and contributions we are bringing to this collaboration include:

- Development of the software to analyze the images from the HSC. Prof. Robert Lupton, who built much of the software systems for the SDSS, is leading this effort: he has a team of Princetonians working with him on this including Senior Research Associates Craig Loomis and Steve Bickerton and postdocs Jim Bosch, Paul Price, and Dustin Lang. They are working with Drs. Furusawa (NAOJ) and Yasuda (IPMU) in Japan.
- Development of observing strategies for the first year of the survey, including a clear plan for early science goals. Prof. Michael Strauss, working closely with Professors Jim Gunn, Jenny Greene and David Spergel (department chair), and postdoctoral fellow Hironao Miyatake has been leading this effort on the Princeton side.
• Development of scientific techniques to measure the evolution and cosmological properties of galaxies. Former research associate Rachel Mandelbaum and Prof. David Spergel have been particularly interested in aspects of this problem, but all of us have had input on this.

• Carrying out scientific analysis with the data! This is of course the ultimate goal of these surveys, and is why we now need students and postdoctoral fellows to contribute their time.

8 Specific Program and Budget Elements

Our proposal consists of two components. The first is to support an extensive undergraduate exchange program between our two institutions. The second is to partially fund a postdoctoral research Fellow to travel between our two institutions. We elaborate on each element below, together with budget estimates:

• Undergraduate exchange program (in two parts):

  We include the visit of two Todai students to Princeton for two months. We budget an allowance for two months for each student, to be used for per diem and for accommodation and also for other local costs. We also include a round ticket from Tokyo to Newark.

  Furthermore, we include the visit of two Princeton students to Tokyo for two months. We budget an allowance to be used for per diem and for accommodation and also for other local costs, assuming that the students stay in the Todai International Lodge.

• We further request partial funding for a postdoctoral fellow to travel between our two institutions and facilitate collaboration. We propose to split the cost of the postdoctoral fellow between the Kavli IPMU of Todai (18 months), the Princeton Astrophysical Sciences Department (9 months), and this proposal (9 months). The salary for a postdoctoral fellow for the latter 18 months from early 2015 to mid-2016 will be paid by Kavli IPMU of Todai.

Finally, we emphasize the long-term sustainability of our program beyond the confines of this grant. We have a long history of collaboration with our Japanese astronomical colleagues. Both sides plan to contribute directly to support the postdoctoral fellow we request here. Furthermore, both sides have made a strong financial commitment to the ongoing Subaru programs. However, the vast majority of these investments go to hardware and software. The relatively modest investment requested here, by directly supporting human resources, will have a disproportionate impact on our interaction levels and productivity.

9 Concluding Remarks

We propose to build on the strong collaboration between the Todai Physics Department and
the Princeton Astrophysics department by directly funding undergraduate and post-doctoral researchers to travel between the two institutions. The two departments have a strong record of scientific collaboration within large international research projects such as Sloan Digital Sky Survey. In the past twenty years, many of our faculty members have had mutual visits, postdoctoral fellows have developed collaborative works, and graduate students have had fruitful experiences at the both departments.

Our proposal of exchanging undergraduate students and establishing a joint research position will complement and further enhance the existing relationship, involving virtually all the members from undergraduate students to senior faculty.

Finally, we wish to express our interest in developing a long-term partnership between Princeton and Todai. The proposed exchange program is only an initial effort. Going forward, we intend to make the two departments work virtually as a home for colleagues at all levels, from undergraduates to senior professors. Our next step will be initiating co-taught courses, summer/winter schools for undergraduate students, and flexible exchange programs for senior scholars.