Stage 2: Narrative Project Description

A Tokyo/Princeton Educational Partnership in Plasma Physics

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1 Introduction

The University of Tokyo (the Departments of Advanced Energy, Complexity Science and Engineering, Physics, Electrical Engineering and Earth and Planetary Physics) and Princeton University (the Princeton Plasma Physics Laboratory, PPPL) propose to establish a joint educational activity in plasma physics for undergraduate and graduate students. The scientific focus is interdisciplinary in two ways. First, within the field of plasma physics it is aimed at physics that applies to basic laboratory plasma experiments, to plasmas in space (in the solar system or heliosphere) and to plasmas studied for fusion energy. Second, the program will provide students experience in experiment, theory, and observation. This interdisciplinary application of plasma physics is a growing area of science, as the techniques and insights developed separately by the space plasma community and laboratory fusion plasma community are increasingly shared. This increasing interaction between the two communities is accelerating progress in both disciplines. Exposure of students to the research problems, common physics, and experimental and theoretical tools of both communities will provide them with educational experiences well beyond that received in the classroom. In particular this program will provide a platform for international exchanges of undergraduate students who have aspirations for pursuing a career in the global research environment.

The proposed educational program builds on a long and productive collaboration between senior researchers at the University of Tokyo and Princeton University. A long-standing collaboration has involved joint research on basic plasma experiments at both Tokyo and
Princeton. This work has involved visits of senior scientists that have interacted with graduate students on-site. The emphasis has been nearly entirely on senior researcher collaboration, with no organized training or exchange of graduate students, and no participation of undergraduates. However, the past research collaboration provides a firm foundation upon which to establish a new educational program for undergraduates and graduate students. The educational program builds upon the established research links and logistical support.

The proposed program has three components:

**A plasma summer school:**
Each summer will include a 7 – 9 week summer school for undergraduate and graduate students. The school will begin with 1 – 1.5 weeks of classes in interdisciplinary plasma physics. It will be followed by 6 – 8 weeks of research training for undergraduates at the site of the school, which will alternate between Princeton and Tokyo. The school will also include weekly student-run seminars for students to share research progress and cultural perspectives. We anticipate about 6 undergraduate participating each summer (3 from Tokyo, 3 from Princeton) and about 6 graduate students (3 from each side).

**Lecture series and workshops:**
For a three-month period, possibly in part overlapping with the summer school, we will organize weekly lectures for the students by senior researchers. The lectures will be video broadcast to encompass students and researchers at both universities. These lectures will be coupled with the on-going graduate courses of The University of Tokyo. Annually, a research workshop will be held, with senior researchers and students, to discuss new research results and collaborations.

**Graduate student exchanges:**
Graduate students will participate in joint research, relevant to their Ph.D. thesis research, in the partner university. We anticipate that the exchanges will involve about 6 students annually (3 from Tokyo, 3 from Princeton).
Below we describe the scientific area of the collaboration (Section II), past research collaboration as a foundation for the educational program (Section III), further details of the three components of the proposal (Section IV), the responsible staff members (Section V) and a budget explanation (Section VI).

II Plasmas in the Laboratory and Space

Plasmas are gases consisting of electrically charged particles. As most gases rise in temperature into the thousands of degrees the atoms of the gas become ionized – electrons are stripped away from the nuclei, resulting in a gas of negative electrons and positive ions. Plasmas are complex states of matter that exhibit a huge array of phenomena that challenge our ability to describe and understand collective behavior. Plasma physics has been particularly driven by two grand challenges. The first is to develop fusion energy as an energy source to transform the way the world produces energy. This requires producing, controlling – and understanding – a plasma at a temperature of 100 million degrees confined by a magnetic field. The sun produces its energy by fusion; the goal to produce fusion energy on Earth for electricity generation is often aptly described as producing a sun in a container. The second challenge is to understand the behavior of natural plasmas in the universe. The majority of matter in the visible universe is in the plasma state. Behavior of the solar system is significantly determined by plasma physics. The Earth is embedded within a plasma (the ionosphere and magnetosphere), the solar wind transports plasma from the sun to the Earth, and the Sun is a plasma. Moreover, plasmas are key to behavior at all scales in the universe – from the plasma filling the interstellar medium to extra-galactic jets of plasma that emanate from disks surrounding black holes.

The past decade has seen a growing interaction between the two communities – that of laboratory plasma physics and plasma astrophysics. Remarkably, there is an enormous amount of physics that is shared between phenomena in the laboratory and in the cosmos.
Experiments cannot nearly reproduce the conditions that exist in astronomical plasmas, but they are invaluable in isolating and studying physics processes that underlie astronomical plasma behavior. In addition, theoretical and computational tools are transferable between the two communities. The growing interaction between the two communities is boosting progress in both, leading to new collaborations and new insights.

The proposed educational program will introduce students to the common physics of laboratory and astronomical plasmas, as well as the leading edge challenges. They will be lectured to by leading practitioners at the interface between laboratory and astrophysical plasmas, and will participate in research, both experimental and theoretical. To contain the breadth of the program somewhat, the focus on astronomical plasmas will be mostly limited to plasmas within the solar system. This involves the plasma physics of the sun, the solar wind, and the Earth’s plasma sphere (although the basic phenomena studied are also highly relevant to plasmas far beyond the solar system). A phenomenon of particular importance is magnetic reconnection – a process in which magnetic field lines tear and reconnect. In so doing, the magnetic topology within the plasma is drastically altered, with huge effects on the plasma embedded in the magnetic field. Magnetic reconnection underlies phenomena from geomagnetic storms to solar flares to disruptive events in laboratory fusion plasmas.

III Past research collaborations

For roughly 20 years, there have been research collaborations underway between PPPL and the University of Tokyo. These have focused on the area of magnetic reconnection, particularly through joint experiments in the basic reconnection experiment at PPPL (the Magnetic Reconnection Experiment, MRX) and a similar experiment at the University of Tokyo (the TS-3/4 experiment). The collaboration has consisted of exchange visits of research scientists, joint experiments, and comparative studies of results from the two experiments. The collaboration has involved occasional graduate students, and has involved the interaction of visiting senior scientists with on-site students. In addition, we
have worked together to organize research workshops, such as the annual US-Japan Workshop on Magnetic Reconnection and the bi-annual international meeting IPELS (Interrelationship of Plasma Experiments in Laboratory and Space). These collaborations are not focused on education, but on research with the major participants being senior researchers. However, in establishing the research links, in the limited interactions between senior researchers and graduate students, and in the co-organization of scientific meetings the stage is set for the proposed activities. In part, this past work functioned as a pilot program for a portion of the proposal.

**IV Proposed Activities**

The proposed educational and associated research plan consists of three activities: a plasma summer school, a lecture series and workshop, and graduate student exchanges, as described below.

*The plasma summer school:*
Each summer will include a 7 – 9 week summer school for undergraduate and beginning graduate students. The location of the school will alternate between PPPL and the University of Tokyo, beginning in 2015 at PPPL. The school will begin with 1 – 1.5 weeks of classes in interdisciplinary plasma physics. For the first summer at PPPL, the classes will be merged with an ongoing program for US undergraduates – the National Undergraduate Fellowship Program, funded by the Department of Energy. This long-standing program starts with an intensive one-week school with lectures given by plasma physicists from across the US. This one-week experience has been documented to be extremely successful with large impact on the future paths of the students. The students of the Tokyo/Princeton program will partake in this lecture series, with possible supplements specific to our proposed program.

The school will be followed by 6 – 8 weeks of research training for undergraduates at the site of the school. A range of experimental facilities is available to the students. At
PPPL, students can work on an experiment in magnetic reconnection (MRX), a major fusion facility (the National Spherical Torus Experiment-Upgrade, NSTX-U), and an exploratory fusion experiment to study the effect of novel boundaries on fusion plasma confinement (the Lithium Tokamak Experiment, LTX). At the University of Tokyo students can work on the basic experiment in magnetic reconnection, TS-4 and on a fusion toroidal confinement facility (the University of Tokyo Spherical Tokamak, UTST), which shares physics in common with the NSTX-U facility at PPPL. The experiments are located at the Kashiwa and Hongo campuses. Students can also participate in analysis of data from the Hinode solar satellite which is operated under the auspices of the University of Tokyo. The Hinode, launched in 2006, is a Japanese solar satellite equipped with three advanced solar telescopes: the optical telescope (SOT), the X-ray telescope (XRT) and the EUV imaging spectrometer (EIS). These telescopes will reveal the heating mechanism, the dynamics of active solar coronae as well as magnetic reconnection phenomena. The summer school students will participate in analysis of data from this satellite and receive research training. The facilities involved in the proposed work are illustrated in Figure 1.

![Experiments and Hinode satellite available at PPPL and the University of Tokyo for research training and collaboration](image)

The school will also include weekly student-run seminars for students to share research progress and cultural perspectives. The dominant interactions between students will
occur informally through daily interaction in the classroom and the laboratory. However, it is scientifically enriching for the students to present research results to other students at seminars, as well as to have organized discussions on physics and larger issues (on fusion energy, scientific life in the US and Japan etc.). We anticipate about 6 undergraduate participating each summer (3 from Tokyo, 3 from Princeton) and about 6 graduate students (3 from each institution).

**Lecture series and workshops:**
For a three-month period, possibly in part overlapping with the summer school, we will organize weekly lectures for the students by senior researchers. The lectures will build upon the basic information conveyed to the students in the summer school classes and will, in part, connect to their research activities. The lectures will in total be interdisciplinary, covering fusion plasmas, space plasmas, laboratory measurement techniques, and theoretical techniques. These lectures can be a part of the on-going graduate courses of University of Tokyo: Advanced Plasma Physics, Plasma Diagnostics and Fusion Science Special Lecture, and an undergraduate course: Plasma Physics and Engineering. Although oriented towards students, the lectures will also be of interest to researchers. The lectures, presented by scientists from both institutions, will be video broadcast to encompass students and researchers at both universities.

Annually, a research workshop will be held, with senior researchers and students, to discuss new research results and collaborations. This will likely include about 15 – 20 participants, and will focus on research projects that involve the students. One option is to have this workshop follow the larger annual US-Japan Workshop on Magnetic Reconnection. Those workshops are quite distinct. The US-Japan Workshop involves many institutions and is focused on research carried out by research scientists. The proposed research workshop will be a smaller gathering of only Princeton and Tokyo students and researchers, focused on our collaboration. However, having it co-located with, and following, the US-Japan Workshop could provide an extra scientific opportunity to students and ease travel logistics.
Graduate student exchanges:

Graduate students will participate in joint research, relevant to their Ph.D. thesis research, in the partner university. This will require careful advance planning such that joint experiments are well-defined, measurement tools are available and functional, and data analysis programs are developed. Projects will be selected that can lead to journal publications and be synergistic with the student’s research at their home institutions.

We are considering the following research related exchanges; 1) Results from the solar flare experiments in MRX at Princeton will be compared with solar observations from Hinode at Tokyo. An exchange of graduate students can be made between the two research groups. 2) A particle acceleration theory of Prof. Hoshino's group in Tokyo will be tested in MRX at Princeton; 3) Current drive and plasma startup schemes tested by Takase's group at Tokyo can be applied to NSTX-U in Princeton, and 4) Fusion stability simulation done by Dr. Elena Belova's group at Princeton can be applied to stability experiments by Prof. Ono's group in Tokyo.

We anticipate that the exchanges will involve about 3-5 students annually (2-3 from Tokyo, 1-2 from Princeton).

V. Participating Staff

The proposed program will be executed by a committed group of senior researchers from each institution. The PPPL staff includes Prof. Stewart Prager, Dr. Masaaki Yamada, Prof. Hantao Ji, Prof. Amitava Bhattacharjee, and Dr. Masa Ono. Prof. Prager will function as the principal investigator, drawing on earlier experience directing an interdisciplinary, multi-institutional NSF center – the Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas – that spanned topics similar to those of the current proposal. The proposed work builds upon a long-standing collaboration between Dr. Yamada and Prof. Yasushi Ono, the principal investigator from the University of Tokyo. Dr. Yamada, the originator of the Magnetic Reconnection
Experiment, and Prof. Ono will assume responsibility for the execution of the proposed work. They will draw upon their combined experience in prior Princeton-Tokyo research collaborations. Prof. Ji, an experimentalist and Prof. Bhattacharjee is a theorist, both with deep experience in magnetic reconnection and all physics topics contained within the proposal. Dr. M. Ono is the project head of the NSTX-U facility and an expert in tokamak confinement physics. All US staff members have extensive experience collaborating in Japan, and in many cases living in Japan.

The University of Tokyo staff consists of Prof. Y. Ono in Department of Advanced Energy/ Electrical Engineering, Prof. Takase in Department of Complexity Sciences/ Physics, Prof. Hoshino and Prof. Yokoyama in Department of Earth and Planetary Physics and Prof. Inomoto in Department of Complexity Sciences/ Electrical Engineering. Prof. Y. Ono, the Univ. Tokyo-side principal investigator, directs an interdisciplinary center for magnetic self-organization and reconnection for Japan. Prof. Y. Ono is the project head of the TS-4 and an expert of tokamak merging / reconnection experiment. Prof. Takase and Prof. Inomoto are the project head of TST and UTST, respectively and are the experts of spherical tokamak experiments. Prof. Hoshino is a space physicist and theorist with deep experience in magnetic reconnection and self-organization and Prof. Yokoyama is a solar physicist analyzing the magnetic reconnection measured by the solar satellite Hinode. All Japanese staff members have extensive experience collaborating in US, and also living in Princeton.

VI Budget Explanation

We are planning about a 42 person-month exchange, with requested funds covering travel expenses (36 for students and 6 for faculty and research staff) as shown in “Breakdown of funds requested.” FTE charges are covered by the home research funds and not included in this request or the attached table.
The partnership is facilitated by significant internal funding provided through other channels. The Faculty of Frontier Sciences of University of Tokyo allows us to use the visiting professor position for leadership positions of the proposed plasma school and exchanges. Additionally, the University of Tokyo will also use the internal faculty supporting fund to support the proposed plasma schools: UTSIP (University of Tokyo Summer Internship Program), UTRIP (University of Tokyo Research Internship Program) and another one for interdisciplinary collaboration; the Science Fusion budget to host the plasma schools and workshops at Tokyo. Finally, the Tokyo-side will utilize the exchange programs GSP (Global Summer Program) to send U. Tokyo students to Princeton University. For long-term sustainability of the new program, we will also try to receive several international collaboration budgets from the Japan Society for the Promotion of Science (JSPS).

In Princeton, research funding from NSF and DOE underlies the program through support of senior researchers, graduate student stipends, and experimental facilities. Such support derives particularly from the Princeton participation in the NSF Center for Magnetic Self-Organization and the DOE-funded Magnetic Reconnection Experiment. In addition, we will request funds from Friends of TODAI (FOTI), US-based association for University of Tokyo alumni, in order to facilitate the student exchange.

All of the funding sources mentioned above are expected to be long-term, able to support the proposed Princeton-Tokyo plasma education collaboration beyond this proposal period. Especially, the visiting scholars in both universities are expected to be a core for the proposed collaboration.