Open Issues in Gravitation

Thibault Damour

2021 Balzan Prize for Gravitation: Physical and Astrophysical Aspects

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Thibault Damour has been a Professor of Theoretical Physics at the Institut des Hautes Etudes Scientifiques, Bures-sur-Yvette, France since 1989. He will head this three-year project, to be carried out at his institution with the involvement of the Albert Einstein Institute at the Max Planck Institute in Potsdam and the Istituto Nazionale di Fisica Nucleare in Turin. Emmanuel Hermand, also of the IHES, will be his Deputy Supervisor.

Scientific Background

Although gravity is the oldest investigated interaction both observationally and theoretically, it remains a mystery in many aspects. The aim of this research project will be to involve a group of international young scientists, together with a group of more high-level senior scientists, in frontier research in some of the key theoretical challenges currently left open in the field of gravitation.
Einstein's theory of gravitation (General Relativity, GR, 1915) has revolutionized our understanding of gravity, and is at the basis of the description of the macroscopic universe, from the big bang to the accurate modeling of the motion of planets and satellites. Many of the predictions of GR have been beautifully confirmed by many observational or experimental data, such as cosmological observations, binary pulsar timing, solar system experiments, tests of the equivalence principle, gravitational wave (GW) observations, atomic clock experiments, and observations of massive black holes at the centers of galaxies. However, as often in physics, these successes have opened new questions and present new challenges.
On the one hand, several ongoing observational efforts in gravity physics like LIGO, Virgo, or LISA need ever-increasing theoretical support. In particular, the upcoming third generation of ground-based GW detectors (the Einstein Telescope in Europe or the Cosmic Explorer in the US) is setting new goals for the accuracy of the modeling of the dynamics and GW emission of coalescing binary systems. The upcoming (low frequency) space GW detector LISA is also posing theoretical challenges that have not yet been fully met. Thus, it is important to think ahead towards improved or new analytical methods for tackling the gravitational interaction of binary systems.
On the other hand, new avenues for investigating some age-old puzzles in theoretical

gravitation that are still unsolved have appeared in recent years. To mention a few: the existence and structure of cosmological singularities, and/or cosmological bounces; the nature of black hole entropy and the black hole information paradox; the gravitational interaction of black holes (effacing principle, quantum scattering versus classical scattering, radiative effects); quantum effects in cosmology. There is also the general theoretical issue of understanding whether there exist theoretically consistent and phenomenologically viable, modified theories of gravity (beyond GR), in hopes that they might "explain away" the current need to invoke both dark energy and dark matter. Damour has worked in all of the observation-related and purely theoretical topics mentioned above and is still actively interested in them.

Proposed Research Project

Optimally a group of international young scientists will use the research framework offered by the Institut des Hautes Études Scientifiques (IHES) during short- or long-term visits. IHES would create two complementary Balzan Visiting Scholar positions:

1. A Balzan Junior Researcher position will be reserved for young people under forty years of age, or for whom less than ten years have passed since finishing their PhD.
2. In parallel, a Balzan Visiting Professor, a position with no age restrictions, could also be awarded to senior scholars and high-level scientists.

Both types of position will have variable durations, from one week to one year or more, depending on the focus of the visit. The selection process will fall under the responsibility of the Scientific Committee of IHES. These visiting positions will not be constrained a priori with the idea of setting up a collaboration on a precise scientific problem in gravity. The basic concept of IHES is not to be programme- or topic-oriented, but to provide a quiet environment where visiting scientists can freely discuss, brainstorm, and exchange ideas on the Balzan research project topic, Open Issues in Gravitation, in small groups with high-level permanent IHES professors and IHES-associated researchers. The main idea is to give young people the possibility to gain new insights into gravitational physics that might have an important long-term impact on their work. These discussions may lead to the publication of research results in leading international peer-reviewed journals, with due acknowledgment of the Balzan Foundation. Moreover, some of the Balzan visiting professors will be asked to give special Balzan lectures, which can take the form of videotaped seminars or series that could be both remotely visible in real time (via Zoom) as well as film-edited for uploading on the YouTube channel of IHES.

Highly active international groups directed by two of Damour's former post-docs, namely Alessandra Buonanno (Albert Einstein Institute, Potsdam) and Alessandro Nagar (INFN, Turin), have been contacted for collaboration. Since both groups involve pools of young researchers, it is hoped that a significant proportion of the Young Balzan Researchers at IHES will be sent by the Albert Einstein Institute and INFN. Moreover, the directors of the two groups have agreed to be officially added as affiliated institutions to Damour's research project. Senior scholars in the affiliated institutions will also be invited to visit IHES as Balzan Visiting Professors.