1 CONTEXT AND PREVIOUS ACHIEVEMENTS

1.1 CONTEXT AND SCOPE OF THE PROJECT

The P2IO LabEx takes advantage of the unique concentration on the Paris-Saclay Campus of world leading laboratories, covering a broad disciplinary spectrum including particle physics, astroparticle, nuclear physics, astrophysics, accelerator science, instrumentation and associated interfaces, and combining experiment and theory. All the actors in these fields have joined their forces in the LabEx. Gathering a staff of about 2000 persons, P2IO represents a large fraction of the national effort, around 25% in physics of the origins of life, 40% in subatomic physics, 90% in accelerator science.

The scientific goals of P2IO are to answer fundamental questions about our Universe: what are the elementary components of our Universe and the laws and symmetries at play, what is the origin of elements and the behavior of nuclear matter in extreme conditions, what are the structure and evolution of our Universe, what are dark matter and dark energy, how galaxies, stars and planets formed, and what are the conditions for the apparition of life elsewhere in the Universe?

To address these questions at the forefront of the scientific international competition, the strategy of P2IO is to create or reinforce synergies between its laboratories, combining state-of-art instrumentation for space or ground-based observatories, for subatomic physics experiments and for cutting-edge particle accelerators, together with the most advanced techniques in data analysis and major progress in theory. P2IO also fosters the emergence of creative interdisciplinary applications in other domains, such as nuclear energy, biology and medicine, which result from the scientific and technological developments.

P2IO is a Labex of the Paris-Saclay IDEX. The research at Paris-Saclay University (UPSaclay) is organized in 10 departments. The research themes of P2IO are covered by two departments: the Physics of the two infinities (P2I) and the Geosciences and Astrophysics (SPU) departments; P2IO provides the link between them for their common domains, such as astroparticles, cosmology and instrumentation. P2IO partners are strongly involved in teaching and training, from Master to PhD level. P2IO is engaged in actions to strengthen this involvement in UPSaclay as well as actions to promote its scientific and technological results.

The 16 P2IO partners are individually renowned on the international scene. To summarize the added value of P2IO, we can just quote what the mid-term review committee has stated: 'P2IO has provided the opportunity for a very desirable improvement in collaboration between nearby strong groups. The investments in joint infrastructures will ensure this partnership is robust into the years ahead. The Labex brand will certainly have helped attract more international PhD and postdoc applicants. Perhaps the main advantage is having provided the opportunity to develop an intelligent plan to enhance inter-institution cooperation in science and in technology into the future.'

The project for the next five years aims at further developing the synergies between the partners, taking into account the emergence of new scientific and technological challenges, in view of strengthening the position of UPSaclay at the forefront of international research. In addition, the involvement in education and training, collaboration with other domains and links with industry will be reinforced.

1.2 MAIN PREVIOUS ACHIEVEMENTS

The mid-term evaluation of the LabEx was very positive: 'P2IO is a success story. … P2IO is operating very well, and is a model for the value of small structuring funds in encouraging very large established organizations to look again at themselves, and think innovatively for the future'.

For the mid-term review, we have elaborated our plans for the second part of the LabEx and decided to move from a so-called 'building the basements' phase to a 'taking the lead' phase. The building phase has been characterized by the creation of several common technological platforms, by strengthening and fostering the emergence of collaboration between P2IO members in research (through post-doc calls) and innovation (through R&D calls). The key aspects of the second phase was to attribute about half of the remaining budget to fund a few (3-4) multi-year projects combining, in a coherent way, the various possibilities of project funding by P2IO (PhD, post-doc, R&D, …); these so-called 'Emblematic' projects aim at fostering further collaboration between P2IO laboratories and at increasing the national and international visibility of P2IO. Another important evolution from phase one to phase two were the changes in governance, in order to ensure a better articulation between the LabEx management board ('CODIR'), the scientific community, the unit directors and the supervising bodies ('Tutelles') (see 3.1).

One of the main tasks of the new management board was to organize the selection of the Emblematic projects. This process took about 1 year, with a two-step call, a review of the proposals by the P2IO internal scientific and technical advisory committee and by three international referees per proposal. It worth noticing that the internal and external evaluations lead to a similar ranking. At the end of the process, five Emblematic projects were selected:

- Evolution of matter from interstellar medium to exoplanets with the James Webb Space Telescope.
- PRAE: Platform for Research and Applications with Electrons.
- Charting Terra Incognita of Exotic Nuclei.
- CANEVAS : A prototype camera for CTA, the future observatory of high energy gamma rays.
- HGCFC: High Granularity Calorimeter For Future Collider Experiments.

Actually, thanks to an extra funding of 500 k€ provided by the supervising bodies and two laboratory directors, it was possible to select one more project than initially planned. Moreover, three Emblematic projects obtained additional funding, which provides a further proof of their quality:

- PRAE received 1070 k€ from Region Ile de France in the framework of SESAME 2016 program,
- « Charting Terra Incognita of Exotic Nuclei» in the same SESAME call obtained an extra 580 k€,
- CANEVAS received 120 k€ form the OCEVU and OSUG2020 LabEx. The P2IO funding has been key to establish the international leading role of the Paris-Saclay CTA team in the development of a camera for CTA, while waiting for the acceptance and funding of the project at the government level (an initial grant of 2.5 M€ for the first camera expected to be mounted at a CTA site in 2020).

Since the beginning of the Labex, an International Scientific Council (ISC), consisting of international experts in the P2IO domains, has been appointed to review the scientific and technological research strategy, as well as to assess the progress of the actions launched by the Management Board (CODIR). Four two-day meetings of the ISC were organized (2012, 2014, 2016 and 2017). The 2016 and 2017 meetings were focused on the five Emblematic projects. In 2016, the Scientific Council concluded that « The selection of the Emblematic Projects represents a large step in the creation of a lasting legacy for P2IO and is indicative of the progress made in interdisciplinary and multi-laboratory cooperation »,

and in 2017 « The Council is satisfied with the excellent progress of the Emblematic Projects ».

The '**Explore**' and '**Transform**' actions were implemented by issuing calls for post-docs, PhD students, R&D, and to a lesser degree platforms. The 'Explore' actions have to be carried out by teams of at least two different P2IO laboratories, in order to foster existing or new collaborations. The LabEx particularly encourages the emergence of innovative projects as well as those at the interface between several research fields. The **"Transform"** actions aim at strengthening synergies between the laboratories of the LabEx. The emergence and development of new mutualized innovative platforms particularly illustrates this mission. Hereafter, we summarize the LabEx actions over the whole period of the LabEx.

Postdocs calls: Eight calls for post-doctoral allocations (one per year) were launched in the 2011-2018 period. Forty five two-years post doc allocations have been attributed. The competition was very strong, with the number of submitted proposals exceeding the number of selected projects by a factor of 8 on average. The selection was made in two steps: first the Scientific and Technical Selection committee made a pre-selection to reduce the number of applicants per grant from 8 to 2, followed by the final selection by the CODIR. A total of 4430 k€ was spent for postdoc allocations.

PhD calls: 6 calls for PhD allocations have been issued and 27 PhD students have benefited from P2IO funding. P2IO offers only half grants, which has been proven to be a successful strategy since all of those have been complemented by other funding sources. The number of applications in these calls again exceeds the number of available grants by a factor of 7. They are pre-evaluated by the Selection Committee with a final selection by the CODIR. 1370 k€ were allocated to this call.

R&D calls: the aim of this call is to select innovative R&D projects that have to be, in addition to their outstanding technological quality, proposed by several teams from different P2IO units. Four calls for R&D projects have been launched and a total budget of 1.4 M€ has been spent for the 27 project selected out of the 84 proposed.

Platform calls: the aim of this call is to fund new platforms, shared by the P2IO laboratories, and widely open to other national laboratories and industry. The support of common technological platforms was of primary importance during the « building the basements » phase. This is reflected by the fact that five platforms have been supported during that phase at a total funding level of 1M€. During the « taking the lead » phase, one call was organized and a single platform was supported at a 193 k€ level.

Emilie du Châtelet call: A continuous support for the organization of workshops and invitations of visiting scientists was provided since the beginning of the LabEx. Until 2015, this support was attributed on a continuous flow basis. In 2016, it was decided to organize calls (« Emilie du Châtelet » program) to have a better selection mechanism; a total of 120 k€ was distributed in 2016-2017.

- **Training and outreach:**

Outreach and training initiatives are an integral part of the Labex project and contribute significantly to its visibility within the Paris-Saclay University as well as nationwide. The main goals of these initiatives are (i) to make the wide audience aware about the scientific questions and challenges dealt with in P2IO, (ii) to encourage students to get involved in P2IO research and technological developments and (iii) to enhance the development of existing training tracks and foster the creation of new tracks related to P2IO. Our training actions are mainly aimed at students in physics or engineering at master level. We summarize them below.

Every year in July, we organize a school "Rencontres des deux infinis" related to P2IO research topics and gathering approximately 30 students in physics and engineering from France and neighboring countries. Most students are at the level of university 3rd year and will start their master right after the school in September. A selection of current research topics is presented to students by researchers of P2IO laboratories. Students also visit P2IO research platforms and take part in debates on a variety of issues (e.g. energy resources, Higgs boson, cosmic radiation …). The feedback from students and participants is very positive and triggers several vocations for P2IO research per year.

For students in Master 2 tracks P2IO funded experimental projects on research platforms in order to train students in the skills and practices relevant for current research and technology (e.g. irradiation and material characterization, manipulation of particle beams, detection of cosmic rays…), and, each year, educational trips to international research facilities (CERN, astronomical observatories) were organized. These trips allow the students to discover the leading facilities and place them in the context of real data collection and analysis. Finally, P2IO has contributed to the funding of two MOOCs: "Des particules aux étoiles", "Voyage de l'infiniment grand à l'infiniment petit".

Events for the general public ("Nuit des 2 Infinis") were co-organized with the LabEx EnigMass (Grenoble region). In 2015, in the framework of the International Light Year, P2IO organized a special event called « Nuit de la lumière ». All these events took place in Massy opera and attracted both adults and secondary school students from all over Ile de France region. The attendance was very good (approximately 200-300 participants). As a group of physicists from P2IO are members of the Virgo collaboration, it was decided to participate in the 2017 national event called « Nuit des ondes gravitationnelles » related to the discovery of gravitational waves. P2IO members were responsible for the organization of the event in the movie theater in Paris (« salle du Grand Rex »). A large audience of 2500 people attended this exceptional event. Note also the large media coverage on French radios and TV of the discovery of a cavity in the Kheops Pyramid with the Micromegas technology.

- **Valorisation/Result exploitation**

Most of the P2IO laboratories are involved in very large infrastructures, and have major contributions to large international projects in particle physics (LHC , future colliders,…), nuclear physics (GANIL), and astrophysics (PLANCK, EUCLID, JWST...). They have therefore strong links with industry for a long time; actions towards industry are done in collaboration with the "French industrialists for large scientific equipment association" PIGES. Additional efforts done by P2IO are the following:

- Better coordination between valorization contacts of individual laboratories
- For each R&D or platform project, specific requirement on the possible valorization (patent, identified industrial partner)
- Collaboration with the Paris-Saclay Idex valorization experts; participation in the "pre-maturation call". The best example of this policy is given by the support of an innovative outreach effort in 2016. The project is to build a catchy video game called Quark Touch. It is a challenge to use a video game to teach particle physics concepts and tools without the player losing the excitement of the hunt and the sense of adventure. The development team combines particle physics expertise with an engineer expert in video game development who was hired thanks to a 25 k€ allocation. The Paris-Saclay Service d'Accélération du Transfert de Technologie completed this allocation by a 45 k€ grant. Thanks to this support, the development phase progressed well and a demonstrator is presently available for testing.

2 PROJECT DESCRIPTION AND EXPECTED IMPACT

2.1 SCIENTIFIC SCOPE AND CONTENTS OF THE PROJECT FOR THE NEXT FINANCING PERIOD, EXPECTED IMPACT

For the next financing period, P2IO will continue along the lines that have contributed to its success while renewing the scientific priorities in order to take into account emerging themes and further enhancing the collaboration between the partners with the aim of strengthening the position of UPSaclay at the forefront of international research.

The overall goal of P2IO is to address the fundamental questions about our Universe listed in section 1.1. The organization of the Labex into 4 Scientific, 3 Technological and 2 Interdisciplinary themes:

- S1: Symmetries in the subatomic world,
- S2: Dark universe and multi-messenger astronomy
- S3: Strongly coupled nuclear matter
- S4: Formation of stellar and planetary systems, conditions for emergence of life
- T1: Innovations in accelerator science and related spinoffs
- T2: Advanced sensors and spinoffs
- T3: Simulation and knowledge extraction from complex data
- I1: Nuclear energy for the future
- I2: Bio-medical technologies: Imaging and radiation-based therapy

has been preserved but the denomination of the themes and the scientific priorities in each of them (presented in Annex 1) have been updated to take into account the achievements of the former period and the emergence of new scientific or technical issues. For instance, in the S2 theme, following the recent observation of gravitational waves (GW), which opens new avenues for multi-messenger astronomy, the emphasis has been put on research devoted to multi-messenger cosmic observations, in which P2IO teams have a unique expertise. Other examples of evolution of the scientific priorities concern the quest for increased precision in the tests of the Standard Model (S1) and in the study of nuclear matter (S3) and the emergence of the exoplanet topic in S4. Priorities in the technological themes regard the development of state-of-the-art techniques, such as the building of high performance accelerators in T1, novel instruments in T2, and use of massive computing and machine learning in T3, enabling major advances in the scientific domains of the Labex. These innovative techniques together with the unique scientific expertise of the P2IO staff can benefit other domains, in particular nuclear energy (I1) and health with novel instruments for imaging and therapy (I2).

The three missions, **'Explore', 'Transform' and 'Structure'**, that were underlying the actions of the Labex will also be preserved and intensified.

- **'Explore'**

In the next financing period, the main part of the P2IO budget will be devoted to innovative research projects that should lead to major scientific progress within the scientific priorities of the Labex and contribute to the international visibility of UPSaclay. Two types of projects will be funded:

- Flagship Projects: following the success of the Emblematic Projects funded during the former period and the need to intensify the structuration of the P2IO partners into highly internationally

visible teams, a call will be opened for larger scale projects. Flagship Projects are expected to gather teams from several partners of P2IO and lead to major scientific or technological breakthroughs. They will be able to request between 0.6 and 1.2 M€, which could be used to fund R&D equipment, postdocs or PhD students. A total amount of 2 M€ will be allocated to this action. Expressions of Interest (EoI) for these Flagship Projects have already been called for in 2017 and presented to the international Scientific Committee, who 'appreciated that the EoIs brought to the arena emergent areas and new frontier research topics not included in the previous set of emblematic projects'. The call will however be also open to projects that have not submitted an EoI. In order to provide sufficient time to complete the projects, the call will be opened as soon as the prolongation of the Labex is officially confirmed and the selection procedure, described in the Governance section, launched, so that the projects could begin in early 2020.

- Emergence Projects: beside the Flagship Projects, smaller scale, more prospective projects, opening new scientific or technical opportunities, including possible technology transfer, will also be supported. These projects should involve at least two partners and will be able to request between 50 and 250 k€ for equipment, postdocs or PhD students. Two calls will be opened, in 2020 and 2021, so that the projects could start beginning of 2021 and 2022, respectively.

In addition, Emilie du Châtelet calls will be continued with 2 or 3 calls per year to support the organization of workshops or conferences, invitation of visitors and outreach activities. A total amount of 200 k€ is foreseen.

- **'Transform'**

During the former period, an important effort has been undertaken to create mutualized technological platforms that are now essential in the P2IO research panorama. In the future, P2IO will continue to support new innovative platforms or significant upgrades of existing ones leading to a higher visibility or to new capabilities. Specific actions allowing the use of the platforms for the training of students will be encouraged (see section on education and training). Two or three calls will be issued and a total amount of 600 k€ distributed.

- **'Structure'**

One of the main goals of P2IO is to develop synergies between the partners, who often are already working together within large national or international collaborations, so that they can benefit from their complementarities, in some cases reach a critical mass allowing the achievement of large-scale projects, and further gain in international visibility. The funding of the Flagship projects will obviously contribute to this goal. In addition, there are two domains in which additional structuring will be fostered: multi-messenger astronomy and accelerator and magnet technological infrastructures.

- Multi-messenger astronomy

As mentioned above, the observation of gravitational waves has opened a new era of multi-messenger astronomy, the investigation of the Universe combining information from multiple cosmic messengers, high-energy charged particles, photons, neutrinos, and gravitational waves, with impact in many domains from astrophysics to nuclear physics. P2IO have pioneering teams involved, with key roles and often leadership, in many international experiments or projects aiming at detecting these messengers. Moreover, P2IO has many renowned theorists working in the concerned domains, including the interface between astrophysics and nuclear physics. It is therefore, the right time to help this community to combine their efforts so that UPSaclay could appear as one of world-leading team

of multi-messenger astronomy. Besides possibly funding projects through the 'explore' calls, a 'structure' action of P2IO will be the organization of long-term (around one month) workshops, every year, at the Institut Pascal (IPa), during which world-renowned theorists will be invited to work closely with P2IO teams, lectures will be organized and support to young scientists provided. This will contribute to the structuring of the community and increase its visibility.

- Accelerator and magnet technological infrastructure

P2IO concentrates nearly 90% of the national effort on accelerator R&D. For many years, its teams have been building high technology platforms, some funded by P2IO, spanning all the necessary activities of research, development, fabrication, assembly and verification, which are now used in collaboration with industry for the construction of most of the accelerator-based research infrastructures in Europe. Recently, the European Commission has funded a project, AMICI[1], involving three of the P2IO partners, which aims at proposing a network of the European Technological Infrastructures in the domain of superconducting accelerators and magnets, in order to keep European industry at the forefront of the international competition in view of the construction of future scientific research infrastructures in the world. Clearly, UPSaclay is one of the most important nodes of this network and P2IO can strengthen its international positioning by funding actions leading to enhancing synergies between the three concerned laboratories and fostering opening to industry.

A total amount of 500 k€ will be devoted to the **'Structure'** actions.

2.2 RESEARCH-LEARNING INTERFACE AND EXPECTED IMPACT

The main contribution of P2IO to training will continue to be the funding of fellowships for PhD and postdocs students. In addition to PhDs and postdocs that could be funded within the Emergence and Flagship projects and by the **'Structure'** actions, each year (except the last year) a call will be launched in view of allocating fellowships covering half of the cost of a PhD or of a two-year postdoc position, the second half being covered by laboratories or other sources.

The other training and outreach actions carried out by P2IO in the former period, which were proven very successful as shown in section 1.2, will be pursued. P2IO will continue to support the organization of schools such as "Rencontres des deux infinis" for PhD and M2 students, visits of M1 and M2 students to P2IO laboratories and of M2 students to international research facilities, participation of PhD students to international workshops and conferences, events for the general public, such as the "Nuit des deux infinis"…

In addition, P2IO will support actions aiming at using the P2IO technical platforms for innovative experimental training (TPs) and making them available to a large number of students. Actually, the wide variety of P2IO research themes from very basic research to different types of applications, allows setting up attractive and innovative TPs for different courses (Bachelor, Master, Engineer Schools, Doctoral Schools, and even professional training). The goal is to expose the students to the latest scientific and technological advances, allow them to meet research teams while mutualizing the facilities and equipment.

[1] AMICI (Accelerator and Magnet Infrastructure for Cooperation and Innovation), H2020 project 01/01/2017-30/06/2019, Grant Agreement n°731086, http://eu-amici.eu/home

P2IO will also foster the creation of a network gathering all staff members involved in teaching activities in UPSaclay in view of sharing teaching experience or defining new courses, in particular in relation with the P2IO platforms. Support will be provided to web site developments, interactive applications, demo videos, etc. intended as teaching aids.

It is expected that these actions will promote our scientific disciplines among students, and therefore attract more of them in our laboratories. A particular effort will be done towards the engineer schools of UPSaclay in view of diversifying the origin of our students as well as contributing to the integration of P2IO within all the dimensions of UPSaclay.

P2IO will dedicate a total amount of 1.45 M€ to the actions described above. This will be done in close concertation with the existing and future teaching structures of UPSaclay, the Schools, in particular by discussing with the persons in charge of the master and doctorate programs. The CODIR (see the governance section) will have one member specifically in charge of the teaching and training actions.

2.3 VALORIZATION STRATEGY OF THE PROJECT AND SOCIO-ECONOMIC IMPACT

- Scientific dissemination and communication

The web site of P2IO will be upgraded and continuously updated with news about the scientific and technical results obtained by the P2IO teams, in close connections with the websites of UPSaclay and of the partner institutions. The results will be presented each year in a P2IO day gathering the entire community. The SCOPI (Séminaires Communs des Origines et de la Physique des 2 Infinis) seminars organized together with P2I and SPU will be continued. Through the Emilie du Châtelet calls P2IO will encourage the organization of events oriented either towards the scientific community or towards the general public (for example open days or colloquia) and the realization of communication tools such as descriptive leaflets, videos, press kits, interactive applications, etc...

- Technology transfer and actions towards industry

As explained in section 1.2, P2IO partners have always been closely collaborating with industry for the realization of accelerators and large-scale instruments. P2IO will continue to collaborate with PIGES and support the organization of events intended for enterprises. Technology transfer is generally the prerogative of the partner institutions. However, P2IO will contribute to the support of actions leading to a possible transfer of technology through the Emergence actions.

P2IO partners operate a large number of scientific and technological platforms that are or could be used by industry. UPSaclay has recently organized a census of these platforms in order to provide a centralized information to enterprises. P2IO will contribute to this action and in addition support actions aiming at facilitating the access of industrial partners, in particular SMEs, to its platforms and training of their personnel. This is also in line with the recommendations of the AMICI project cited above in the perspectives of a European accelerator and magnet technology infrastructure. Giving more visibility to this infrastructure and attracting SMEs will also have a positive socio-economic impact for the IdF region, which has contributed through SESAME funding to the development of some of the technological platforms.

2.4 SCIENTIFIC AND PEDAGOGICAL INTEGRATION WITHIN THE STRATEGY OF THE LEADING INSTITUTION AND OF THE PARTNER INSTITUTIONS

The governance structure of P2IO, which involves the directors of the different labs in the DU assembly (see section 3.1), ensures that the strategy of P2IO is and will remain aligned with the strategy of the partner institutions.

In UPSaclay structure, the scientific and technological domains covered by P2IO Labex are shared between two Departments, P2I and SPU. P2IO appears naturally as a bridge between the two departments, in particular in the domains at the interface between them, such as astroparticle and multi-messenger astronomy or instrumentation. From the beginning of UPSaclay, P2IO has established a fruitful relationship with P2I and SPU: for instance, several outreach (SCOPI seminars for instance) or training actions were co-funded with one or the two departments and P2IO has elaborated its scientific priorities taking into account the strategy that the two Departments have recently defined. This strong interaction will be pursued in the future structures of UPSaclay. In particular, there will be a systematic concertation about the calls for projects in order to avoid possible overlaps.

P2IO will take advantage of the existence of Institut Pascal within UPSaclay and of its facilities to organize, together with P2I and SPU, every year a long-term meeting on multi-messenger astronomy, which in return should contribute to the international recognition of both IPa and Paris-Saclay. Also, the recognition of UPSaclay as a node of a possible European distributed technology infrastructure for accelerators and magnets would contribute to its international prestige.

P2IO activities have many interfaces with other domains. Contacts will be reinforced and when possible participation to concerted actions fostered, for instance with the Labex PALM (Physics : atom, light, matter) for laser-plasma acceleration and neutron sources, with the IRS (Initiatives de Recherche Stratégique) BME (BioMedical Engineering) in technologies for health, in possible transverse initiatives such as Instrumentation, Artificial Intelligence, or Energy.

3 PARTNERSHIP

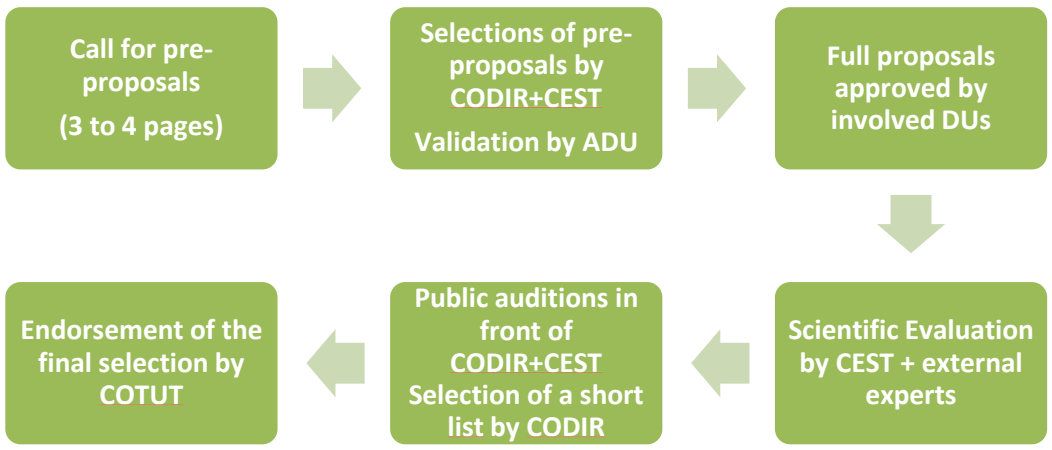
3.1 GOVERNANCE

As explained in section 1.2, the current governance of P2IO is slightly different from the original one. The main change concerned the composition of the management board ('CODIR'); the new management board is now composed of the Labex coordinator, the deputy coordinator and twelve scientific experts (instead of Unit Directors). These twelve experts, nominated by the LabEx coordinator and deputy coordinator, in concertation with Unit Directors (DUs), were chosen in order to fully cover the scientific and technological themes in the LabEx. This composition will be kept for the next period. The Assembly of Unit Directors (ADU) will gather the directors of the 16 laboratories (Units) constituting the Labex. The other governing bodies will be unchanged. The governance structure is therefore the following:

- **The managing team,** composed of the Coordinator and a deputy Coordinator, nominated by the supervising institutions in concertation with the Unit Directors, who will implement the decision of the CODIR and represent the Labex in front of the ANR and the different authorities.

- **The management board (CODIR)** consisting of the Coordinator, the Deputy Coordinator and 12 experts nominated by the DUs on proposals from the Coordinator, representing the different themes of the Labex, including one expert on theory and one teacher-researcher in charge of teaching and training actions. The CODIR will meet at least 6 times per year. It will decide on the actions of the Labex and the sharing of the budget, organize the selection process following the different calls with help of the evaluation committee (CEST) and make the final selection that is proposed to the ADU or the COTUT.
- **The Assembly of Unit Directors (ADU)** composed of the directors of the 16 laboratories (Units) constituting the Labex. It will nominate members of the CODIR. It will endorse the selection of the projects or, for the Flagship projects the phase 1 selection. It shall meet at least twice a year.
- **The Supervising Body Committee or Conseil des Tutelles (COTUT)** consisting of a representative from UPSaclay plus one representative from each partner institution. The COTUT will meet at least once a year and will evaluate the actions, approve the strategy, endorse the sharing of the budget and the final selection of the Flagship projects, nominate the member of the International Scientific Committee on proposals from the CODIR.
- **The International Scientific Council (ISC)** composed of 12 renowned scientists nominated by the COTUT on proposals from the CODIR. The ISC will meet every two years. It will assess the scientific quality of the projects funded by the Labex, check that the key performance indicators, such as the number of publications, new partnerships established, international student attracted or external funding obtained, are in progression and advise the CODIR on the overall strategy of the Labex.

In addition to these bodies, the CODIR will set up an adhoc scientific and technical evaluation committee (CEST) composed of 8 to 12 members chosen for their scientific and technical expertise to conduct the evaluation process of the projects submitted in response to the different calls. As regards the Flagship projects, given their strategic importance and the amount of budget involved, a specific two-step procedure will be applied. Experts external to Paris-Saclay will be associated to the evaluation. The process is summarized in the figure below.



3.2 CONSORTIUM MODIFICATIONS

The perimeter of the Labex remains unmodified although some of the involved laboratories have changed status (CEA/Irfu is now divided into 6 Units (Departments)) or denomination. This explains the modification of the number of partner Units compared to the 2010 submission.

3.3 PARTNERS' DESCRIPTION, RELEVANCE AND COMPLEMENTARITY

- **CPHT (Centre de Physique Théorique)**

CPHT has a long tradition in the field of fundamental interactions with major contributions in quantum fields, particles and strings. The particle physics team investigates quantum chromodynamics at the border of the domains in which nature is respectively described in terms of quarks and gluons and in terms of hadrons. The more formal work in field theory is based on the concepts of the renormalization group and the functional integral, either in constructive or in perturbative approach. The string theory group currently focuses on symmetries and properties of compactifications, low-energy effective actions and physics beyond the standard model. String-inspired models provide also a groundwork for addressing paramount questions of cosmology. For the next years, CPHT aims at keeping diversity, both towards more theoretical aspects, and towards the observationally motivated directions of hadronic physics, cosmology and physics within and beyond the standard model, while extending collaborations with experimentalists from IRFU and IPN (mostly in the field of hadronic physics) as well as with theorists from IPHT and LPT (both in high energy QCD and in string-inspired theory).

- **CSNSM (Centre de Sciences Nucléaires et de Sciences de la Matière)**

CSNSM is a joint research unit between CNRS/IN2P3 and Université Paris-Sud employing more than a 100 people, including 40 researchers and faculty-researchers, 40 engineers and technicians in support services, and about 25 Ph.D. students and post-doctoral fellows. CSNSM is remarkable through the multidisciplinary nature of the performed research: Nuclear Structure, Astrophysics, Solid State Physics, Irradiation and Materials. The CSNSM lab also interacts with industry on both fundamental and applied topics thanks to its irradiation platform SCALP (Synthesis and Characterization using ion AcceLerators for Pluridisplinary research). It comprises the JANNuS-Orsay facility, i.e. a Transmission Electron Microscope coupled to two ion accelerators, allowing in situ observation of the ion-induced modification in materials at the nanoscale, in particular in nuclear materials.

- **DACM (Département Accélérateurs, Cryogénie et Magnétisme)**

The DACM is a Department of CEA/Irfu. Its mission is to develop and build particle accelerators, ion sources, accelerator cavities, cryogenic systems and superconducting magnets designed for Irfu scientific programs, and several major CEA programs. It features extensive equipment and systems for assembly, integration and testing, including magnet winding and assembly rooms, vast cleanrooms for accelerator systems, small-scale test stations for materials characterization and large-scale workstations capable of testing complete assemblies (coils, superconducting cavities and injectors). DACM is involved in the major accelerator projects worldwide (LHC, ESS, IFMIF, SPIRAL2, FAIR, XFEL, etc..) and superconducting magnets projects (Iseult, R3B-Glad, JT60SA, ITER, ..) with the other departments of P2IO and numerous national, European and international partners. It also conducts advanced R&D that prepares the future for our technologies, providing the instruments required for progress in fundamental and applied research.

- **DAp/AIM (Département d'Astrophysique, UMR Astrophysique, Instrumentation, Modélisation)**

The DAp/AIM is an Irfu department that has for mission to conduct astrophysics research to answer the major questions of the discipline on a broad spectrum of fields, ranging from solar physics to cosmology, to insure in liaison with space agencies and ground-based observatories, the prime contracting of instruments or subsystems needed for astrophysics research and to contribute to the development of data analysis centres. DAp/AIM shall contribute to research-based training and form the new generation of astrophysicists and instrumentalists. To achieve its missions, the scientific strategy of DAp/AIM is based on three main pillars: instrumentation, multi-wavelength observations, theory and numerical simulations with skills spanning the entire chain from R&D to signal processing, scientific exploitation of the data and modelling and theory.

- **DEDIP (Département d'Électronique des Détecteurs et d'Informatique pour la Physique)**

DEDIP is a department of Irfu aiming at inventing and constructing next generation detection systems. It is able to design, realize critical key blocks of the detection chain and implement the full chain from sensors to complex data extraction. It also carries out a large R&D effort focused in the domains of gaseous detectors, microelectronics, real time systems and data visualization. DEDIP shares a lab with DAP specialized in the development and implementation of new signal processing methods based on statistics, sparsity and machine learning for astrophysics applications. DEDIP hosts high end technological infrastructures, such as the CICLAD facility allowing the study and the integration of large detectors, the CTA platform housing a large dark room used for the characterization of the cameras and the MGPD workshop allowing both R&D and manufacturing of gaseous Micromegas detectors. DEDIP is an active actor in the CAPTINNOV platform. It also hosts a Tier2/3 node of the IDF Computing Grid as well as clusters for astrophysics and accelerators. It widely contributes to the upgrades of LHC detectors at CERN often in collaboration with P2IO laboratories (LLR and LAL), the development of the NECTARCAM cameras for CTA with LLR and IPNO, and detector developments for hadronic physics with a major contribution to CLAS12 and ongoing R&D for the future EIC. It is also involved on several ESA or CNES space missions such as SVOM, EUCLID and SPICA.

- **DIS (Département d'Ingénierie des Systèmes)**

The DIS counts a hundred of permanent staff and about 20 non-permanent staff. It is a mechanical engineering and instrumentation department of Irfu at CEA-Paris Saclay supporting the physics and technical departments of the Institute. It is structured in different labs, dealing with mechanical engineering, electronics, control system, power electronics and instrumentation. DIS designs and procures warm and cryogenic elements for particle accelerators but also control systems of such equipment. It is also specialized in designing superconductive magnets and related cryogenic infrastructures in close collaboration with DACM, in the domain of thermal and mechanical engineering, specific control systems but also power circuits and associated quench protection systems. DIS has also developed competences in space and ground activities for astrophysics through specific tools and methods in mechanical engineering but also in electronics and instrumentation. Through its internal R&D programs, DIS envisions growing complexity of the forthcoming systems, as well in instrumentation as in mechanical design by investigating structural optimization in connection with metal additive manufacturing. Nb_3Sn issues for magnets is investigated in collaboration with Centrale Supélec with opportunities to realize a connection with P2IO.

- **DPhN (Département de Physique Nucléaire)**

The DPhN of CEA/Irfu employs about 70 people, including 45 staff physicists leading basic research in experimental and theoretical nuclear physics, as well as measurements and modeling related to societal topics, including, among others, nuclear energy. The main goal of DPhN is to provide a better understanding of the strong interaction and its manifestations at two different scales: at high energy or small when the degrees of freedom are quarks and gluons, confined within hadrons or in a deconfined state such as a plasma, and at lower energy or larger distances when nucleons assemble into nuclei, the core constituents of atoms. For many years DPhN has been working in strong synergy with other P2IO laboratories, in particular with IPNO, CSNSM and LLR on nuclear and hadronic physics, and with CPhT and LPT on theoretical nucleon structure studies. DPhN received P2IO support within the "terra incognita" large-scale project as well as numerous PhD, postdoc and visitor grants. In addition, P2IO financed specific actions related for instance to R&D for neutron beam monitoring and muon tomography, a societal topic of high visibility initiated by DPhN in the Paris-Saclay area.

- **DPhP (Département de Physique des Particules)**

DPhP is a Department of Irfu hosting about 70 staff physicists, along with 30 doctoral students and 10 post-doctoral researchers working in particle physics, astroparticle physics and observational cosmology. It is involved in either ATLAS or CMS experiments at the LHC, with responsibilities in detector operation and physics, with emphasis on Standard Model precision measurements, Higgs and top physics, and searches for new physics. Detector R&D for future ILC and FCC colliders is also actively on-going. DPhP is also involved in neutrino physics: in the T2K long-baseline experiment in Japan, reactor experiments such as Double Chooz, and R&D on enriched crystals for the next-generation neutrinoless double-beta decay search experiment CUPID. The GBAR experiment aims at measuring for the first time the acceleration of antimatter in Earth's gravity field. In astroparticle physics, the main projects are ANTARES and H.E.S.S., and the preparation for CTA. DPhP is at the forefront of multi-messenger astronomy with high-energy probes. In Cosmology the focus is on the characterization of dark components of the Universe, through the exploitation of large spectroscopic galaxy surveys, SDSS/BOSS and the DESI project, coupled with detailed simulations of structure formation. The DPhP works in close collaboration with other IRFU departments as well as many P2IO laboratories, in particular LAL, CSNSM, IPNO and LLR.

- **IAS (Institut d'Astrophysique Spatiale, UMR 8617)**

IAS is a joint research unit of the CNRS and the Université Paris-Sud. It employs 40 researchers and teacher-researchers, 75 engineering, technical and administrative staff, 25 PhD students and postdoctoral fellows. The main research themes are the study of the sun, the planets of the solar system and exoplanets, extraterrestrial matter and interstellar matter, galaxies and cosmology. The laboratory has a strong technical component in the field of space instrumentation. It is a major interlocutor with national (CNES) and international (ESA, NASA) space agencies and works with numerous industrial partners (Thales, Air Liquide, ADS). IAS manages a national facility, the space experiment calibration station for instrument calibration and space environment test equipment. The IAS Data and Space Operations Centre, IDOC, manages certain operations for several missions (SOHO, Mars Express, etc.). The laboratory contributed in a major way to instruments of the ESA missions: solar (SOHO), planetary (Mars-Express, Cassini-Huygens, Rosetta) stellar (COROT). It had the project management of the main instrument HFI, to which the LAL also contributed. Several projects are under

development or under study, and some of them in partnership with DAP/AIM: future space telescope (JWST),solar physics missions (Solar Orbiter), study of the planets Mercury and Mars, detection of biological activity signatures in the atmosphere of extrasolar planets (ARIEL), study of the primordial universe (EUCLID). R&D activities are carried out in preparation for these various missions. IAS is part of the Observatoire des Sciences de l'Univers de l'Université Paris-Sud (OSUPS).

- **IMNC (Imagerie & Modélisation en Neurobiologie & Cancérologie, UMR 8165)**

IMNC is jointly supported by IN2P3-CNRS and both Paris Diderot and Paris-Sud universities. It develops scientific skills in physics and biology to answer crucial questions of therapeutic stakes in cancerology and neurobiology combining latest simulation, instrumentation and modeling approaches. The unit gathers around 40 highly skilled collaborators, physicists, methodologists, biologists and engineers along three scientific axes: imaging focused on the diagnosis and treatment of solid tumors with the development of specific multimodal imaging systems; modeling focused on the study of process guiding the migration of tumors; radiotherapy focused on the development of new and original irradiation methods in hadrontherapy and very high-energy electron. IMNC works within a broad network of international collaborations such as OpenGate, physics laboratories (LAL, IPNO, IPHC, CPPM,…) and biomedical centers (AP-HP, Institut Curie, Institut Joliot). P2IO has played a key role by supporting two IMNC Emblematic projects, SONIM and PRAE. IMNC has strongly benefited from the constitution of the Virtual Data platform. IMNC is an essential element of P2IO enhancing the interface with Life Sciences, in particular in cancerology and neurosciences.

- **IPhT (Institut de physique théorique, UMR 3681)**

IPhT is a research institute of the Direction de la recherche fondamentale (DRF) of CEA, and of the Institut de physique (INP) of CNRS. It hosts approximately 50 permanent researchers (with a rough proportion of 2/3 of CEA researchers and 1/3 of CNRS researchers), and about 60 doctoral students and postdocs. The research themes of IPhT cover most of the active subjects in theoretical physics. One group, devoted to the study of cosmology, particle and nuclear physics, is directly concerned by the Labex P2IO and most of its permanent researchers are members of the Labex. The activities of this group cover the theoretical aspects of the following subfields, ranging from phenomenology in close contact with experiments to more formal developments: nuclear matter at high temperature and density, heavy ion collisions, calculation of amplitudes for the LHC, physics beyond the standard model, dark matter, formation of large scale structures in the early universe and gravitational waves.

- **IPNO (Institut de Physique Nucléaire d'Orsay, UMR 8608)**

IPNO is a Joint Research Unit of CNRS/IN2P3 and Paris-Sud University. It comprises about 300 personnel, among which ~2/3 of engineers and technicians. The research led at IPNO focuses on nuclear physics with important technological developments in accelerators and instrumentation needed for this field as well as a strong involvement in theoretical domains. IPNO also carries out research in hadronic physics (nucleon structure and quark-gluon plasma physics), astroparticle physics (with cosmic and gamma rays observatories) and inter-disciplinary research topics such as nuclear energy and radiochemistry, with activities around nuclear waste management and exploration of innovative energy scenarios for the future, and cluster and multi-atom physics. The EQUIPEX ANDROMEDE, obtained in 2011, allows for the use of new probes for the study of matter with large molecules and nanoparticles, for material and biological analyses or for astrochemistry research. IPNO operates three on-site accelerators (ALTO, with a Tandem and a Linac, and ANDROMEDE) and one

platform (SUPRATECH) devoted to R&D on superconductive accelerator cavities. IPNO has also an important expertise in the field of radioprotection and dosimetry.

- **LAL (Laboratoire de l'Accélérateur Linéaire)**

LAL is a joint research unit of CNRS/IN2P3 and Université Paris-Sud, involved in several areas of fundamental physics such as Particle physics, Cosmology, Astrophysics as well as Particle detector physics, Accelerator physics and their medical applications. Its collaborating physicist and engineer teams (electronics, mechanics, software) are the key of its success in taking part to big project construction, data taking and analysis (GW discovery by Ligo-Virgo, Higgs boson discovery and characterization by Atlas/Lhc, CMB Cosmology by Planck HFI e.g.). LAL works in collaboration with many other laboratories and industrial partners at the local, national and international scales

- **LLR (Laboratoire Leprince-Ringuet)**

LLR is a joint research unit of CNRS/IN2P3 and Ecole polytechnique devoted to particle and astroparticle physics. The largest research group is working on CMS at CERN LHC and is one of the major group leading the upgrade of the CMS detector for the high luminosity period of LHC. The T2K (Tokai to Kamiokande) group works on neutrino oscillations and participates to the SuperKamiokande experiment in Japan. The ILC/ILD team works on future developments for the International Linear Collider. Gamma-ray astronomy is another important field of research, with groups participating in HESS, CTA and FERMI experiments. The LLR also studies a novel technique for particle acceleration, based on laser induced plasma waves. These programs have benefitted from the expertise developed by LLR in mechanics and quality standards needed for satellite experiments, and in electronics for large bandwidth signal processing and data transmission. In addition, the computing group successfully operates a node of the « GRIF » (« Grille de Recherche d'Ile de France ») computing grid. In the past, LLR team developed and made valorization of a beam profiler for hadrontherapy machines. Many members of LLR are involved in higher education at many levels, in particular at Ecole Polytechnique.

- **LPT (Laboratoire de Physique Théorique, UMR 8627)**

LPT is joint research unit of CNRS and Université Paris-Sud. This pluridisciplinary laboratory is involved in the understanding of the behaviour of matter in its less known aspects: infinitely small scales (particle physics), infinitely complex systems (statistical physics), infinitely large structures (cosmology). These activities are based on common ideas and computing tools, studied and developed in mathematical physics. The models built by LPT scientists are improved through a permanent comparison between their predictions and the results obtained by experimental teams : particle accelerators and colliders, experiment in solid-state and condensed-matter physics (including biophysics), astrophysical and cosmological observations. Many of the research projects are linked with the other theoretical laboratories of P2IO and with experiments where experimental laboratories of the Labex are involved.

- **SERMA (Service d'Etudes des Réacteurs et de Mathématiques Appliquées)**

An R&D unit of the Nuclear Energy Directorate of CEA, SERMA is developing a complete set of radiation transport softwares to address core physics, criticality-safety, radiation protection and shielding as well as nuclear instrumentation calculations for nuclear energy. It proposes state-of-the-art high-level simulation softwares to nuclear analysts, for CEA internal purposes or CEA partners and conducts an active R&D, within local, national and international partnerships. SERMA keeps an active position in

the academic field, being in charge of many courses at the master level, and training of students through its internship, PhD and post-doc programs. The combination of its capacities, numerical analysis, applied mathematics, uncertainties and optimization methods, software development and production, radiation physics, reactor physics, dosimetry, safety, R&D and teaching, makes SERMA a valuable partner for industry as well as academic institutions. In P2IO, SERMA collaborates with DPhN (nuclear physics data), IPNO (nuclear fuel cycle modeling and scenarios), CSNSM (radiochemistry), but also all the units involved in High Performance Computing for Physics, LLR or LAL among others.

4 FUNDING JUSTIFICATION

4.1 EXPENSES JUSTIFICATION

The different actions that P2IO intends to fund have been described in section 2 and the budget dedicated to each of them explained. In addition, 276 k€ will be allocated to hiring a project manager through a fixed-term contract in CEA and 174 k€ will be reserved for the organization of meetings of the different bodies of the Labex and of dissemination and communication actions over the five years, which makes a total of 450 k€ for operating of the Labex. The project manager will be in charge of the administrative management of the Labex, the organization of the different events, the links between the partners and with the ANR, and of the valorization, dissemination and communication actions, in particular the website feeding and maintaining. The overall sharing of the budget between the different actions is given in the Table below with the foreseen dates of the different calls. This will allow to dedicate 2.5 M€ to equipment, fund around 28 years of postdoc, 20 PhD ½ grants, 280 k€ for invitations and travel and 490 k€ for small equipment, event organization and communication actions. With the 4% of overheads for UPSaclay and 4% for the institutions, the total requested is 6.81 M€.

Action type	Action	Type of funding	Calls for proposals	Total budget total (M€)
OPERATING	Project manager hiring, meeting organization, communication actions	Fixed-term contract salary, travel, sub-contracting…		0,45
EXPLORE	Flagship projects (requesting 0.6 to 1.2 M€)	Equipment, PhD and posdoc fellowships	2019 for a beginning of funding in 2020	2,00
	Emerging projects (requesting 50 to 250 k€)		End 2020	0,60
			End 2021	0,50
	Emilie du Châtelet calls	Workshops, invitations, small equipment …	2 to 3 each year	0,20
TRANSFORME	Support to platforms including TP platforms	Equipment	2 ou 3 calls	0,60
STRUCTURE	Support to multimessenger astronomy and to technological infrastructure	Workshops, visitors, postdocs	Each year	0,50
TRAINING	Training of young researchers	1/2 cost of PhD and postdoc fellowships, trainees	Each year (first 4 years)	1,45
	Support to trainees, teaching tools realization, travels, schools	Small equipment, travel, schools and trainee fellowships	Each year	
TOTAL (without the 8% of management fees)				6,30

4.2 FUNDING PLAN

The 16 laboratories constituting PI2O represent a global annual manpower investment around 100 M€ and an operating budget of about 17 M€. During the next five-year period, the stakeholders of P2IO

laboratories will continue, as far as possible, to ensure the same level of support. In the 'Fiche Financière', the amount of external funding expected for the 2020-2025 period has been estimated of the same amount as obtained during the last 5 year: In the former period, P2IO laboratories have been receiving substantial additional funding (several tens of M€) related to large research infrastructures from the Ministry for National Education, Higher Education and Research TGIR line and from CNES. For the next period since several projects are already engaged, such as the upgrade of LHC, Virgo, LSST, CTA, and other ones are under discussion, such as DUNE/PIP-II, Hyper-K, LISA... As was done for CTA, P2IO could provide the seed money for some of them.

P2IO laboratories have been very successful in obtaining funding from the Ile de France (IdF) region, in particular through SESAME and DIM ACAV calls. P2IO will support the application to such calls by, for instance, in some cases, contributing to the part not funded by the region. P2IO teams have a rather high success rate in response to ANR and European project calls and have obtained more than 25 ERC grants. P2IO will encourage them to apply for external funding, for instance for ERC Synergy grants between several laboratories of P2IO, and could contribute seed money for preparatory work.

ANNEXE 1: SCIENTIFIC PRIORITIES

- **S1: Symmetries in the subatomic world**

The crucial discovery of the Higgs boson at LHC has allowed to confirm and complete the framework of the Standard Model (SM) of particle physics. In the coming years the experimental studies will focus on three key sectors, necessary to answer the many open questions still raised by the SM.

- The high-energy frontier. ATLAS and CMS will continue the search for new particles as well as the more precise measurement of the Higgs couplings and of the electro-weak sector. After the high luminosity stage, a new phase is being studied with ambitious projects like HE-LHC (center of mass energy of 33 TeV) as well as new colliders (ILC, FCC).
- The high luminosity frontier, with the search for possible deviations from the SM in the flavour sector (*b* and *c* quarks) by the experiments LHC-B and Belle-II.
- Neutrino physics, which opens the road to the study of a new source of CP violation in the lepton sector (a crucial element to explain the matter-antimatter asymmetry in the Universe). The new phase of the T2K experiment is a first step in this direction. The new projects of long baseline experiments in construction (DUNE) or in preparation (Hyper-Kamiokande) will allow precision studies of the neutrino mixing matrix. Several experiments searching for neutrinoless double beta decay are in progress and the future experiments in this sector require important technological developments. Two Flagship proposals have been submitted, related to the participation to Hyper-Kamiokande and to the development of scintillating bolometers.

- **S2: Dark universe and multi-messenger astronomy**

During the last decade this field has metamorphosed. Cosmological parameters have been measured with few per-mil precision, thanks to the clean sky-mapping of CMB by Planck, and Baryonic oscillations by BOSS. The next generation cosmology projects will exploit weak lensing (Euclid, LSST), and the quest for CMB polarization B-modes will go on both from ground and space.

Gravitational waves observed by LIGO and VIRGO opened a brilliant portal to the observation of violent phenomena such as black hole fusion, neutron star collision, nucleosynthesis of heavy baryons in

kilonovae. Our laboratories with continue to take part in this field through participation into large projects such as LISA. The Labex is a natural place to help coordinate observations of all products expected to be connected with Gravitational Wave emission, high and low energy photons, neutrinos, charged cosmic rays. One proposal of Flagship project belongs to this field.

In particular, gamma- and cosmic-ray detection, in which some of our laboratories played a pioneering role, are crucial counterparts in multi-messenger observations. The CTA ground array has received explicit supports from our Labex (through the Canevas Emblematic project). P2IO is also involved into Space projects for these next 5 years (Fermi extended operations, SVOM...).

- **S3: Strongly coupled nuclear matter**

Electron-proton or -ion colliders projects (LHeC at CERN and US EIC) aim to address many key questions ranging from nuclear to particle physics. This includes obtaining the complete 3-dimensional tomography of the internal content of hadrons, in terms of their quark and gluon degrees of freedom. The heavy-ion collective effects, occurring already at rather moderate energies, should allow finding quantitative evidence for saturation of the gluon density, as well as for detailed studies of how do quarks and gluons propagate in nuclear matter and join together to form hadrons. The P2IO teams are leaders in these projects, covering every aspect (theory, phenomenology, detector facilities, targets, accelerators), and have the potential for strengthening the already very strong relations existing between the different experimental and theoretical groups of P2IO.

Low-energy nuclear physics aims at explaining the complexity of nuclear properties, the origin of the chemical elements and the limits of nuclear stability. New experimental results from exotic nuclei combined with theoretical developments using effective field theories respecting the symmetries of QCD combined with modern many-body theories will advance the field rapidly in the next decade. With member laboratories at the forefront of all these topics and their federation with the project Terra Incognita, P2IO will play a leading role in future European infrastructures for nuclear research.

- **S4: Formation of stellar and planetary systems, conditions emergence of life**

The study of Comet Tchouri with the Rosetta Probe is a spectacular example of the excellence of P2IO teams in the field of solar system exploration. This exploration will keep on being very active with the BepiColombo space mission for the exploration of Mercury, JUICE mission for the exploration of Jupiter and its satellites, Mars exploration program and Solar Orbiter mission to study solar activity.

We will keep on collecting and analyzing extraterrestrial samples collected on Earth and conducting laboratory experiments for a better understanding of the various physical processes at work. In parallel, numerical simulations using massively parallel computers will be developed at the best international level, such as magneto-hydrodynamic modeling of the Sun, modelling Sun-planet interactions. The solar system will be contextualized through the study of stellar systems that is developing strongly on multiple fronts: observational (Kepler/K2, TESS) and JWST Mission - 2021), instrumental development for space missions (Plato - 2026, and ARIEL - 2028), sophisticated data reduction, modeling of stars, exoplanets atmospheres and star-planet interactions.

- **T1: Innovations in accelerator science and related spinoffs**

Building the next generation of high-intensity particle accelerators, high-luminosity colliders, advanced light sources or laser-plasma accelerators requires innovative conceptual and technological

developments, in particular regarding very high field superconducting magnets, high gradient acceleration cavities, laser-plasma acceleration and control of extreme beams. It includes, for instance, the mastering of new high critical temperature superconducting materials, innovation in cryogenics to limit the use of helium and in high-reliability and high-performance RF systems. The use of high power lasers impacting directly on matter or through the excitation of plasma waves is an ambitious and promising technology that could allow producing compact systems.

P2IO is involved in several projects located in Paris-Saclay: LUNEX-5 5th generation of free electron laser source, APOLLON multi-PW laser-acceleration, PERLE accelerator complex based on an energy recovery linac (ERL) for various applications, SONATE compact high-intensity neutron source. Many of these projects are carried out in collaboration with teams from the PALM Labex or PHOM department.

The upgrade or creation of dedicated technological platforms will be necessary to develop these technologies, build prototypes and characterize them.

- **T2: Advanced sensors and spinoffs**

The refinement of detection techniques and development of specific detector systems by P2IO laboratories will address the needs of experimental teams leading key projects in our domains. This includes searches for dark matter, research on the nature of neutrinos, precision tests of the Standard Model, studies of cataclysmic phenomena in the Universe through measurements of high-energy gamma rays with the future CTA observatory, as well as experiments at high-energy colliders like CERN or EIC, or novel facilities like PERLE. The key challenges will be improving the detector response in high counting-rate and luminosity environments, reducing backgrounds and detection thresholds, as well as increasing resolution, dynamic range, and efficiency of detection systems often located in harsh environments (radiation, low temperature …). Possible developments include the exploration of new detection materials, the improvement of pulse-shape discrimination techniques as well as R&D on related electronics, with the aim of providing viable detector technology for next-generation experimental facilities.

The success of this program requires a close collaboration between the teams involved from the earliest stages, including mechanical integration, electronics, and data processing. In parallel, we will apply these developments at the technical platforms like SCALP, ALTO, ANDROMEDE or Virtual Data, as well as via collaboration agreements with the industry.

- **T3: Simulation and knowledge extraction from complex data**

P2IO has brought support to the development and management of common computer infrastructures: shared access computer rooms/data centers, innovative distributed file storage and backup software solutions. On the physics application side, support was also given to advanced architecture and algorithmic R&D to exploit parallelism for data selection and analysis tasks. In the next phase, P2IO will foster and support emerging efforts in the labs to solve the upcoming computing challenges of data processing and simulation in our scientific community:

- The intensive computing challenge: Processing and simulating large physics datasets, ranging from complex detector events to telescope images, require massive computing resources and advanced architectures. Notably, astrophysics simulation will benefit from the upcoming exa-scale supercomputing infrastructures. Efficient parallelism and efficient architecture are two key aspects to

match the rapidly evolving processors with the physics workflow in an automatic and sustainable way, to produce software stacks and data pipelines intended to live over several decades.
- The big data challenge: On the I/O side, the recent explosion of data volume recorded or simulated by experiments introduces new data storage and locality challenges. New tools inspired by "big data" approaches need to be developed. On the algorithmic side, Artificial Intelligence approaches have proven to be very efficient for big data problem solving, and could play an increasing role in our experimental and theoretical physics paradigms. Deep machine learning methods are a promising avenue is this prospect, the foundation of many R&D efforts in our community.

P2IO is involved in this research, benefiting from the close links with the data science community, in particular the UPSaclay Center for Data Science, an interdisciplinary network of data scientists.

- **I1: Energy: nuclear energy for the future**

P2IO teams involved in nuclear energy-related research primarily work in the following scientific fields: nuclear physics, radiochemistry, materials science, modeling, numerical simulation, experimental simulation, instrumentation, accelerator and magnet conception and expertise. The primary objective of these teams is the further development of nuclear (i.e. fission but also fusion) energy research thanks to radiation transport software for reactor core physics, radiation protection and shielding, nuclear instrumentation, or the development and the experimental simulation with ion accelerators of the radiation tolerance of materials to be used in fission and fusion reactors.

The foci of these studies is the future of electricity production, recycling and waste management, and the evolution of the energy mix, as part of France's energy transition strategy. The results of this research will benefit the fields of reactor physics, nuclear structures (nuclear data), and material physics research, and also lead to technical developments (such as improvements to neutron sources or instrumentation), and developments in numerical simulations associated with HPC. An important goal for the next phase is to improve the integration of nuclear energy into global energy discussion within Paris-Saclay, and to increase the synergy between research on nuclear energy and the more fundamental themes of P2IO, in particular nuclear physics.

- **I2: Bio-medical technologies: Imaging and radiation-based therapy**

The health axis of the P2IO Labex is organized around two unifying themes: imaging and radiotherapy. The shared vision is to propose new instrumental and methodological approaches in order to improve the exploration and understanding of life, but also to access to early diagnosis and more personalized treatment of patients, especially in cancerology and neuroscience.

P2IO's laboratories have strong expertise to play a major role in the fields of life sciences and health by offering new innovative approaches. In imaging, this could include the challenge of reconstruction-less PET imaging that requires pushing the limit of time-of-flight PET scanners by developing gamma detection systems with very high timing resolution. In radiotherapy, these skills can also be used for proposing new treatment paradigms by combining multi-particle approaches with original irradiation modalities (minibeams, very high dose rates, nanoparticles ...) in order to multiply the biological and ballistic efficiency of radiation beams. These interdisciplinary federating projects can benefit from a local stimulating collaborative environment (Institut Curie, CPO, SHFJ, DOSEO, IRSN, IRS Nanotherad and BME from Paris-Saclay, Neurospin, MIRCEN) and from the complementarity of advanced instrumental platforms (THOMX, PRAE, PIMPA, ANDROMEDE).