Research evaluation

EVALUATION REPORT OF THE UNIT

LKB - Laboratoire Kastler Brossel

UNDER THE SUPERVISION OF THE FOLLOWING ESTABLISHMENTS AND ORGANISMS:

Sorbonne Université

École normale supérieure – université Paris Sciences & Lettres - ENS-PSL

Collège de France

Centre national de la recherche scientifique - CNRS

EVALUATION CAMPAIGN 2023-2024
GROUP D

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High Council for evaluation of research and highter education

In the name of the expert committee :

Barend Van Tiggelen, chairman of the committee

For the Hcéres :

Stéphane Le Bouler, acting président

In accordance with articles R. 114-15 and R. 114-10 of the Research Code, the evaluation reports drawn up by the expert committees are signed by the chairmen of these committees and countersigned by the president of Hcéres.

To make the document easier to read, the names used in this report to designate functions, professions or responsibilities (expert, researcher, teacher-researcher, professor, lecturer, engineer, technician, director, doctoral student, etc.) are used in a generic sense and have a neutral value.

This report is the result of the unit's evaluation by the expert committee, the composition of which is specified below. The appreciations it contains are the expression of the independent and collegial deliberation of this committee. The numbers in this report are the certified exact data extracted from the deposited files by the supervising body on behalf of the unit.

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CHARACTERISATION OF THE UNIT

- Name: Laboratoire Kastler Brossel
- Acronym: LKB
- Label and number: UMR 8552
- Composition of the executive team: Mr Antoine Heidmann (Director) and Mr Pierre-Jean Nacher (Deputy director)

SCIENTIFIC PANELS OF THE UNIT

ST Sciences et technologies
ST2 Physique

THEMES OF THE UNIT

The unit's central theme has historically been the theory and experiment of cutting-edge aspects in quantum physics. With initially major contributions to quantum optics and quantum fluids, this theme has evolved in time to include new developments such as Bose-Einstein condensation, Fermi gases, atom chips, cavity QED and Rydberg atoms, quantum information, optomechanics, Casimir energy of the quantum vacuum and tests of fundamental interactions and metrology. More recent activity started in classical optics, such as imaging and scattering in disordered media as well as in general relativity and gravitational wave detection. A special axis "Frontiers and Applications" has been created to highlight the interfaces of all teams with biology, medicine and space, often supported by large international collaborations. This axis also fosters the creation of start-up companies and contacts with industry.

HISTORIC AND GEOGRAPHICAL LOCATION OF THE UNIT

The LKB unit was initially founded at the ENS-PSL-Rue Lhomond in 1951 by Alfred Kastler and Jean Brossel and obtained its current name in 1994. Already in 1967, part of the LKB moved to the Jussieu Campus and became co-supervised by Paris 6 university, today part of Sorbonne Université (SU). The Jussieu site has been subject to a long renovation that was finished in 2015. In 2014 two research teams moved to the Collège de France at Rue des Écoles, where an entire new building at the physics department became available some ten years ago. At Rue Lhomond, significant renovation work started in 2013 and is still ongoing. The three sites of the LKB in the 5th arrondissement of Paris are located roughly fifteen minutes walk from each other and have become a characteristic feature of the unit. Today, the Jussieu site at SU campus comprises 2 200 m^2, the site at Collège de France 1 000 m^2 and the ENS-PSL site 750 m^2. Renovation work will be pursued in the Grand Hall at least until 2026 and will liberate 1 500 m^2 for sixteen experimental rooms, one lecture hall and a few storage rooms.

In 2019, a major event at the site ENS-PSL Lhomond was the merging of four neighboring units (Laboratoire de physique théorique, Laboratoire de physique statistique, Laboratoire Pierre Aigrain and the Laboratoire de radio-astronomy) into one single unit, LPENS at the Physics Department of the ENS-PSL. Despite initially different views among the four authorities about the exact new role of LKB in this re-organization, the LKB finally did not participate in this fusion, especially because the LKB structure was already considered complex enough as it is. Nevertheless, the fusion has had major consequences for the organization of shared platforms and technical support, that were historically run by the "Fédération de Recherche du département de physique de l'ENS-PSL" of the Lhomond site. This Féderation CNRS/ENS-PSL was closed.

The LKB is unique in France with three Nobel laureates and five CNRS Gold Medals and seven members of the Academy of Science. In 2021, the first CNRS medal for scientific mediation was awarded to a member of LKB.

RESEARCH ENVIRONMENT OF THE UNIT

The LKB research unit is located inside one of the most prestigious scientific ecosystems worldwide. The unit has ENS-PSL, CNRS, Collège de France and Sorbonne université as direct supervising authorities. PSL (Paris-Sciences Lettres) is a Collegiate University with large autonomy of its members, which includes ENS-PSL and Collège de France. As such, PSL is an important partner of LKB, especially when it comes to global strategy on training of PhD and large programs. The three different sites (Lhomond, Jussieu and Collège de France) comprise numerous local teams in other research units of high international reputation. With the recent creation of the different overarching structures present in Paris Centre, such as SU created in 2018 (including former Paris 6), PSL in 2013 (including ENS-PSL, Collège de France and ESPCI) and university Paris Cité in 2019 (including former Paris 5 and Paris 7), the research environment in Paris Intramuros did not simplify but surely gained structure, visibility and coherence in strategy. Despite the improved local organization, the CNRS has remained a major support, especially for long-term research activities and for the technical, administrative and support services of the LKB. The LKB is a major player in several local research projects launched since the creation of SU, PSL and Paris Cité, such as the Quantum Information Center of Sorbonne université (QICS) and the Paris center of quantum technologies (PCQT) that unite forces in quantum physics and technology in Paris. Since 2011, the unit has benefited from the presence of the International Centre for fundamental physics and its interfaces (CFPI), a labex hosted by the physics department of ENS-PSL that provides junior chairs and international master programs supported by scholarships. Several platforms exist that are shared with local partners, such as the CryoParis cryogenic platform and HPC resources inside the platform MesoPSL. Today a single doctoral school of phyiscs EDPIF (école doctorale de physique en Ile-de-France) integrates the five hundred PhD students of SU, PSL, university Paris Cité and university Paris-Saclay. Worth mentioning is the successful establishment of the young team at the physics institute of the Collège de France. This separate "service" unit, supervised by Collège de France and CNRS, benefits from the knowledge and infrastructure of LKB and attracts young researchers at the highest level.

On the national level, the LKB is a partner in the project T-REFIMEVE that was selected as an Equipex in the call of PIA 3 and intended to offer a complete set of SI-traceable time and frequency signals at the highest international level to the scientific community and the industry. As a result, several teams of LKB are connected to the SYRTE (Systèmes de référence temps-espace) frequency comb in Paris. The unit is an active partner in many national CNRS research groups (GdR). Finally, many international collaborations exist, among which some large collaborations such as the VIRGO-LIGO Collaboration (gravitational wave interferometers), the Pharao/ACES space mission (atomic clocks in space) of ESA, the MICROSCOPE minisatellite to test the equivalence principle, and the project GBAR located at CERN to measure gravitational acceleration of anti-matter. Over the past years, 4 startups have been launched by LKB members and one is about to be launched.

UNIT WORKFORCE: in physical persons at 31/12/2022

Catégories de personnel	Effectifs
Professeurs et assimilés	11
Maitres de conférences et assimilés	17
Directeurs de recherche et assimilés	8
Chargés de recherche et assimilés	13
Personnels d'appui à la recherche	16
Sous-total personnels permanents en activité	**65**
Enseignants-chercheurs et chercheurs non permanents et assimilés	18
Personnels d'appui non permanents	5
Post-doctorants	19
Doctorants	71
Sous-total personnels non permanents en activité	**113**
Total personnels	**178**

DISTRIBUTION OF THE UNIT'S PERMANENTS BY EMPLOYER: in physical persons at 31/12/2022. Non-tutorship employers are grouped under the heading "others".

Nom de l'employeur	EC	C	PAR
CNRS	0	21	12
Sorbonne Université	20	0	3
ENS-PSL	2	0	1
Coll de France	2	0	0
Autres	4	0	0
Total personnels	**28**	**21**	**16**

GLOBAL ASSESSMENT

The LKB is an outstanding research unit, with a scientific activity in quantum physics and related fields that belongs without any doubt to the absolute top of the world. This scientific output enjoys high international visibility and recognition, is highly diverse and spans the entire range of activities from theoretical, numerical and experimental activities to real applications with high TRL level, the creation of startups and contributions to large international collaborations. The unit excels in the training through research of master and PhD students and is exemplary in its outreach. Despite many adverse circumstances, such as the Covid pandemic, major renovation works, the fusion of neighboring units at ENS-PSL, the multisite structure, and the lack of space, the unit succeeded in keeping a remarkable degree of internal coherence, and secured an uninterrupted service in administrative and technical support. In this respect, the LKB governance did an excellent job that merits a special compliment. The four supervising authorities CNRS, Sorbonne université, École Normale Supérieure and Collège de France, as well as Paris Sciences Lettres as a Collegiate University, managed to synchronize their actions efficiently and rapidly in a difficult context and in this way contributed to the success of LKB.

The current mode of operation of LKB reveals two tendencies. Some teams still successfully comply to the traditional model of permanent researchers being in charge of the scientific project, supported by a small number of postdocs or PhD students. Other teams have been more active in grant applications, and operate with a much larger number of PhD students, often partially supervised by postdocs, in a manner that is typically encountered in the Anglo-Saxon world. Both models have their virtues and drawbacks. Their co-existence should be encouraged. Finally, the current lack of space imposes severe restrictions and has become a major concern.

DETAILED EVALUATION OF THE UNIT

A - CONSIDERATION OF THE RECOMMENDATIONS IN THE PREVIOUS REPORT

1) "The unit must secure support from the supervising institutions on the improvement of working conditions for support personnel, including in particular more personnel, a better distribution of the work among the 3 sites, and more permanent positions for key support staff. More steps should be taken in facilitating the communication between the support staff and the non-permanent scientific staff such as doctoral students and postdocs".

Every year three to four support positions have been created by SU, ENS-PSL or CNRS through internal mobility or external recruitment. One person was recruited (AI CNRS) as executive assistant of the unit's governance and also deals with human resources. Nevertheless, the technical support did not grow, whereas the activity (number of contracts, recruitment of postdocs, etc.) continued to increase. A "Mattermost" instant messaging platform has been set up that enables quick exchanges between sites. Annual outside-wall meetings ("Prospective meetings") are organized for the entire unit to stimulate exchanges between confirmed researchers, support staff and young researchers and to discuss opportunities. The attractivity of these prospective meetings is demonstrated by the fact that about 150 out of 180 members participate. The well-being of PhD students is monitored by a '"thesis Monitoring Committee" involving a mentor and an expert from the executive committee. The benefits of this committee are confidential and not communicated.

2) "The unit must deal with the upcoming generation change in several teams (with a particular importance for the 2 teams at the Collège de France), and with the orientation of new recruitments towards a diversification from gas-phase atomic physics. More intensive and systematic exchange among the team leaders and permanent staff regarding emerging fields might be something to consider".

Upcoming retirements and leaving emeriti still represent a threat to some teams.

A scientific council with an advisory role exists where team leaders discuss emerging fields and global policy.

3) "Construction work has had a considerable negative effect on the pace of progress. As space continues to be an issue at LKB and future construction is planned for the coming years, this problem will also accompany the work at LKB. Furthermore, the reorganization of various labs in the department of physics at ENS-PSL poses some uncertainties about the role of LKB in the upcoming years".

The lack of space has become an even more pressing issue, because of the presence of an increasing number of temporary researchers recruited on contracts. Construction works in the Grand Hall at the Lhomond site are not finished yet, and the Jussieu site is saturated. Four units in the ENS-PSL physics department have fused together and this has had major consequences for the organization of shared platforms. The role and involvement of LKB inside ENS-PSL has not changed, and the official policy is still that the teams located at Collège de France will return to the Lhomond site once the renovation work have finished.

B - EVALUATION AREAS

EVALUATION AREA 1: PROFILE, RESOURCES AND ORGANISATION OF THE UNIT

Assessment on the scientific objectives of the unit

The scientific objective of the LKB is ambitious and can be summarized by "to be and to remain a world leader in a large variety of subjects in quantum physics, quantum technologies and related disciplines, and keep ahead of large international competition". A real willingness exists to focus the activity on fundamental research but with a strong link to quantum technologies. This objective is competitive and highly adapted to today's scientific landscape. The objectives are organized in four axes that cover more or less one single theme each and contain altogether fifty-nine research staff members - permanent or active emeritus, but that are not homogeneous in manpower. A fifth axis was created to highlight large-scale and interdisciplinary projects, and to foster the transfer to economic partners including currently four startups. It is difficult to understand the functioning of this axis from the report, but the committee has concluded that this axis is well managed, although its coexistence with the four research axes is somewhat confusing for observers outside the LKB.

The objectives are realized by the large success rate in competitive calls (during the evaluation period: 6 ERC and 31 national ANR projects were granted, and numerous projects were successful in several regional calls for tender on "Domaines d'Intéret Majeur" -DIM - concerning quantum technologies and nano-sciences) and by its capability to attract young researchers that today constitute 60% of all human resources. The LKB clearly manages to stay ahead of new developments and is capable of both launching its own new high-profile projects and making crucial contributions to large-scale programs.

Assessment on the unit's resources

The total annual budget last year of the unit exceeded 6 M€ among which roughly 90% stems from short-term grants. The recurrent support from authorities (excluding running costs for premises, brut salaries and special funds that vary in time) has remained roughly constant (small decline) and was equal to 560 k€ in 2020, of which more than half was provided by CNRS. The own resources of LKB have roughly doubled over the last 10 years and exhibit strong fluctuations. This Anglo-Saxon model has come to France, is efficiently exploited at LKB, is amply sufficient to realize the objectives, but is also fragile and precarious.

The ratio of administrative support to permanent research staff is roughly 1 : 6 and with currently no temporary contracts among them. This is a convenient situation. However, at LKB there are no less than two postdocs or PhD students per permanent research staff member that also ask for support. Overall one gets the impression that the LKB manages the difficult exercise of human resources as well as is possible.

A good balance exists between SU Faculty staff and CNRS full-time researchers, and with adequate recruitment given the difficult context. Among two faculty members of Collège de France, one associate professor is about to leave the LKB and is not replaced. There has been a systematic lack of promotion opportunities for assistant professors at Evry that needs attention.

Postdocs play a crucial role in the scientific activity of LKB but are more difficult to find and some graduated PhD students prefer working for quantum startups or do teaching. PhD students are needed by many teams and a significant fraction of PhD students are extended beyond the standard three years term using own resources. Because quality should rule over quantity, this extension of PhD durations seems justified even if it is a privilege that not all research units (in Paris) can afford.

Assessment on the functioning of the unit

The executive committee (EC) takes care of the daily steering and meets on a weekly basis. It is comprised of one director, one assistant director - both officially appointed by the authorities. Currently five assistant directors have been designed by the director, covering three sites and all four research axes, and one "general" administrator in charge of financial aspects and human resources. The technical director at Lhomond has become part of the new LPENS and is no longer part of the EC but this vacancy might be filled soon. The EC meets several times per year with the laboratory council that has representatives of the scientific teams, the technical and administrative support poles and PhD students from different sites. A scientific council exists consisting of team leaders, including one from the technical platform in Jussieu, that makes recommendations about scientific strategy and that is in charge of maintaining the dialogue and coherence among all teams and platforms. The administrative pole, directed by the "general administrator" has offices at Lhomond and Jussieu and moves regularly to Collège de France where one administrator - not member of LKB - deals with the two local teams. This functioning is highly satisfactory and responds to several specific challenges, the presence of different sites in particular.

The technical platform has undergone significant changes in organization since the fusion at the ENS-PSL site. Until 2019, the ENS-PSL platforms were shared among all units and managed by the physics department as a separate ENS-PSL and CNRS research federation, and SU platforms existed separately as part of LKB. After the creation of LPENS all technical staff, including those of LKB at Jussieu, was re-assigned to LPENS. Activity was managed by an executive committee that involved LPENS and LKB. Since early 2023, the platforms of technical support at Jussieu have become part again of LKB, though left the perimeter of ENS-PSL. The two teams at Collège de France are supported by local mechanics platforms. In the current configuration, the ENS-PSL platforms are in principle only accessible to teams at ENS-PSL and Collège de France, and Jussieu is supposed to use its own local platforms. At ENS-PSL, only the use of the clean room and the liquefier are charged explicitly to the users. Finally, the IT service - with three engineers - is intrinsically multisite but is in lack of an official desk. The presence of three sites, the lack of space, and the many structural changes have complicated the technical and administrative performance of LKB. The unequal priority access of LKB teams to different platforms is a pragmatic solution but is not ideal for internal coherence. Nevertheless, most LKB staff members seem to have grown accustomed to this precarious situation, convinced that problems will be solved soon one by one as they appear. So far, the LKB governance managed the best they could to cope with the above constraints. This will hopefully lead to a stable situation in 2026, when the works in the Grand Hall are finished and the teams at Collège de France move back to the ENS-PSL site.

1/ The unit has set itself relevant scientific objectives.

Strengths and possibilities linked to the context

The most important scientific objective is to stay at the forefront of new developments in quantum physics and related disciplines. The LKB is faithful to fundamental research as its major driving force, supported by the numerous successes in the past, and well aware of its value for current and future quantum technologies. A second objective is to keep internal coherence in spite of the three separate sites, the large variety of themes and methods, and the many overlapping scientific structures in Paris Intramuros. To accomplish this, the unit is extremely active and highly successful in competitive calls for tender, attracts many brilliant students on the master and PhD level, and seizes all possible local, national and international opportunities for support. A huge strength, exemplary for many other units, is the absence of a separation between theoretical, experimental and even applied activities, thereby boosting each other continuously. The unit has managed to be reactive and to initiate new and contemporary projects, in quantum technology, wave front shaping, cold atom and ion physics, metrology, anti-matter, MRI, often prioritized by national or European policy. The outstanding scientific output of LKB undoubtedly explains why four authorities with different profiles give their full and aligned support for recruitment and improved infrastructure.

Weaknesses and risks linked to the context

The space problem, due to the presence of an increasing number of PhD students and ongoing major renovations, is severe and persistent, and currently sets a limit to what is scientifically possible. For a few granted ERC projects, the premises have yet to be provided. The LKB also recognizes the struggle to support long-term projects with today's short-term mode of scientific funding. This model requires to have more and more administrative support which is difficult to provide by the authorities. In due time, the attractivity of students and ITA recruitments may decline as life in Paris centre is likely not to become less expensive. A severe risk that everybody wants to avoid is that the many prestigious research units in the Quartier Latin district start competing with each other for the recruitment of students and precious square meters. The competing and overlapping perimeters of the two large Communities of universities and establishments (Comue) PSL and SU is a source of potential conflict. Finally, two different modes of operation co-exist at LKB, sometimes inside the same research axis, with different practices.

2/ The unit has resources that are suited to its activity profile and research environment and mobilises them.

Strengths and possibilities linked to the context

The unit has the financial means to realize its ambitious scientific projects. An effort is made to share fluctuating resources among all teams on a steady basis. A lot of research is carried out by PhD students as evident from the 120 PhD graduations during the evaluation period. The LKB has managed to secure the administrative staff in spite of departures. Also, the IT service, consisting of currently two assistant engineers (among which one on temporary contract) has to cope with a network involving 180 users and many more terminals connected to experiments and external networks and will soon be reinforced by a permanent position on research engineer level. The announced return of the two teams at Collège de France to Rue Lhomond in 2026 is an opportunity but attention must be paid that the return of these teams is not accompanied by a reduction in technical support. Finally, LKB is supervised by scientific authorities with excellent reputation and complementary profiles in teaching, training through research and recruitment. They are all committed to take their share and clearly have made an effort to align their scientific and human-resource strategies.

Weaknesses and risks linked to the context

Like in many other research units in France and Europe, an increasingly popular "Anglo-Saxon" mode of operation within LKB, is fed by calls for tender that facilitate the recruitment of young researchers. Thanks to the high success rate and the capacity of LKB to attract the best students, the model works more than satisfactorily. Nevertheless, it is fragile and subject to fluctuations. The growth in funding and recruitment is not sustainable and has the risk of overloading administrative services and space available in the limited premises assigned to the unit.

Some teams are threatened by the retirement or departure of highly senior scientists and one very successful team (Quantum fluctuations & relativity) will disappear in the next contract. The departure of technical engineers and the need of quick replacement has always been a constant threat to the functioning of the LKB. This sword of Damocles will remain as long as life in Paris centre remains more expensive than elsewhere.

Although mutualizing has become a keyword in platform strategy, the strong fragmentation of the technical platforms without equal access for all poses a problem that may get worse in the future. The Jussieu platforms are shared with other units on the Sorbonne campus with some staff assigned to LKB. At the ENS-PSL site almost all staff has been assigned to LPENS following the ENS-PSL policy to concentrate all CNRS and ENS-PSL support at Rue Lhomond, Finally, at Collège de France a mechanical platform (3 members), shared with the "Jeunes Equipes" and the institute of chemistry, is not part of LKB but provides considerable support. The teams at Collège de France use the ENS-PSL services as well. Because of this somewhat chaotic fragmentation, not all members of LKB have the same kind of access to all technical platforms. Although the LKB is an important user, technical staff is assigned to LPENS, with the risk that the LKB has little input on their career planning.

If one considers that internal resources require daily attention, it becomes evident that administrative support is insufficient. This highlights a fundamental problem of contemporary research funding, also encountered in other units, albeit in a less radical form, namely that the supervisory authorities do not always have the means to recruit support staff - preferably permanent for obvious reasons of continuity - to cope with internal resource management and short-term recruitment.

The IT desk consists of three members among which two are on a temporary contract. The person in charge will soon be recruited to a permanent position. One communication officer is on a temporary contract.
The electronics platform of LKB is currently understaffed.

3/ The unit's practices comply with the rules and directives laid down by its supervisory bodies in terms of human resources management, safety, environment, ethical protocols and protection of data and scientific heritage.

Strengths and possibilities linked to the context

Despite a difficult context, the LKB governance managed to secure key positions in administration and technical support.

Weaknesses and risks linked to the context

Four main weaknesses have been identified.
Firstly, although the support staff appreciates the help obtained in the preparation of promotions, it considers the feedback provided by the executive committee about the outcome of the selection process during internal and external promotions unclear. Related to this is the fact that the support staff does not feel to be represented in the executive committee. Secondly, PhD students (estimated 30%) meet directly with their official supervisor less than two or three times per month and consider that to be too occasional. Next, almost all interviews pointed out that the lack of space constitutes a major obstacle to the performance of tasks and duties (5 support staff on 25 square meters; no desk for IT engineers, no space to start project funded by ERC). The lack of space is known to the LKB governance but its daily impact is probably underestimated. Finally, a disequilibrium exists in the gender of PhD students (150 male against 30 female PhD, that is 17% female) which is slightly larger than on average in physics.

EVALUATION AREA 2: ATTRACTIVENESS

Assessment on the attractiveness of the unit

Scientific attractivity can be measured by the number of visitors, the number of PhD and master students that have been attracted, and the involvement in national and international events and projects. The LKB makes a huge effort to attract Master and PhD students with their courses at SU and ENS-PSL including many from outside Paris and outside France. It welcomes each year roughly fifty new members (roughly a turn-over of a third of all human resources). Each year typically five foreign professors visit the LKB for a period of one month. On the national level many collaborations exist supported by research groups or projects funded by ANR. The list of international collaborations, almost always supported by grants, is very long.
The committee can conclude that the LKB is very attractive.

1/ The unit has an attractive scientific reputation and is part of the European research area.

2/ The unit is attractive because for the quality of its staff support policy.

3/ The unit is attractive through its success in competitive calls for projects.

4/ The unit is attractive for the quality of its major equipment and technical skills.

Strengths and possibilities linked to the context for the four references above

The LKB enjoys an exceptional international reputation. It is highly successful in competitive calls for tender: 6 ERC and 31 national ANR projects have been granted, and numerous projects were successful in several regional calls for tender on "Domaines d'Intéret Majeur" -DIM - concerning quantum technologies and nano-sciences). Several projects involve large European collaborations, for instance the GBAR experiment at CERN, the European Michelson interferometer VIRGO to detect gravitational waves, and the preparation of the PHARAO-ACES space mission of the European space agency to put atomic clocks in space. Most if not all experiments set up in the LKB are almost unique in the world and of high complexity. Two LKB Nobel Laureats have been active during the period of assessment. Around 40 staff members of LKB obtained prestigious awards, such as the highest national scientific distinction, the CNRS Gold medal attributed to Jean Dalibard (the 5th one for LKB since its existence), the Grand Prix Félix Robin of the French Physical Society, la Médaille de la Médiation Scientifique du CNRS, prix de l'Académie des sciences, Médaille de Bronze du CNRS, Prix Franco-Polonais Marie et Pierre Curie,… ; seven staff members were elected as IUF fellow. Finally, more than 30 stays in foreign laboratories have been reported, and more than 50 international events have been organized by members of LKB. Several staff members have taken up major responsibilities such as the direction of CNRS-physics Institute, participation in ERC panels, scientific council of CNRS, involvement in CNES and ESA, etc.

Weaknesses and risks linked to the context for the four references above

The lack of square meters as well as ongoing renovation works has reduced the quality of hosting staff and students, as is discussed elsewhere.

EVALUATION AREA 3: SCIENTIFIC PRODUCTION

Assessment on the scientific production of the unit

The LKB has produced an average of over one hundred publications per year in peer-reviewed journals. This number rises to one hundred and twelve per year if books, chapters and conference proceedings are also included. This represents 2.6 publications per year per ETPR. This is a significant number (around 2 on average in France) and is largely due to the presence of numerous excellent doctoral and post-doctoral students.
Some publications (46 since 2017) are officially ranked "highly cited" by Web of Science. The committee is impressed by the exceptional quality, originality and disruptiveness of numerous articles. Among the books and chapters many courses taught in e.g. Les Houches Schools can be found, as well the edition of Tome 3 of Quantum Mechanics in 2017 in several languages by three very eminent members of LKB. Finally, scientific output is measured by the number of PhD graduations (120 between 2017 and 2022), for forty-seven HDR (including active emeriti members); this implies 2.5 per HDR. Another good indicator for scientific excellence is the large number of invited and plenary talks delivered at international conferences. Based on all this information, the scientific output can be summarized to be of extremely large quality. It is undoubtedly ranked (once more) among the best performing research units in France.

1/ The scientific production of the unit meets quality criteria.

2/ The unit's scientific production is proportionate to its research potential and properly shared out between its personnel.

3/ The scientific production of the unit complies with the principles of research integrity, ethics and open science. It complies with the directives applicable in this field.

Strengths and possibilities linked to the context for the three references above

The scientific output has a large diversity, is original and has a high impact in many scientific communities. When normalized to the number of permanent researchers the output is impressive in quantity. All teams contribute to this production and no teams with insufficient production have been identified. All submitted papers have been deposited on HAL (founded by a prominent LKB member) or ArXiv and 95% (against 62% on average in France) of the scientific production during the evaluation period is openly accessible. Research integrity and ethics are active items of discussion during outside wall meetings animated by a prominent and knowledgeable member of LKB. Among the very many scientific highlights at LKB we can mention: 1) The successful ERC Proof-of-Concept project for the development of a miniature greenhouse gas analyser; 2) The realization of an atomic quantum Hall system; 3) The Landau phonon-roton theory revisited for superfluid He4 and Fermi gases as well as the *in situ* thermometry of fermionic cold-atom quantum wires; 4) The theoretical prediction of the Spin Hall Effect of light in a random medium; 5) Pioneering contributions to the development of quantum simulation with circular Rydberg atoms of alkaline-earth metal atoms; 6) The significant increase of quantum memories storage efficiency up to 90% which has led to the creation of Welinq start-up; 7) The experimental demonstration of a "fluxonium" qubit in a superconductor at unprecedented low frequency; 8) The active participation in the successful MICROSCOPE space mission and the study of free fall of anti-hydrogen; 9) Major advances in the He3 hyperpolarisation process and methodology leading to significant progress in NMR and MRI technology at low magnetic field and its possible applications in medical and biological domains, 10) The development of label-free super-resolution chemical imaging of biomedical specimens:. 11) Important contributions towards resolving the proton-size puzzle through precision spectroscopy in the H atom and the development of an atom interferometer driven by a picosecond frequency comb; 12) Highest precision first-principles calculations in H2+ and HD+ to test fundamental theory and determine fundamental constants.

Weaknesses and risks linked to the context for the three references above

A tendency seems to exist to publish more in high-impact journals, undoubtedly triggered by the many PhD and postdocs students that are still convinced that this will help their career. Occasional APC are paid with internal resources or even recurrent funding. Several establishments such as CNRS and SU consider this as a decline in publishing habits and with an unnecessary waste of research funds and foster other ways of open science.

EVALUATION AREA 4: CONTRIBUTION OF RESEARCH ACTIVITIES TO SOCIETY

Assessment on the inclusion of the unit's research in society

The interactions with the socio-economic world have been developed considerably, and a separate axis "Frontiers and applications" has been created to display these activities. Collaborations exist with major partners such as Airbus, Thales, IBM, L'Oréal, etc. A few Cifre theses are active (on infrared imaging and optical transformations) and fifteen patents have been filed since 2017. No less than four startup compagnies have been created since 2013 and are still connected to LKB activity: Cailabs (42 M€ raised) on light shaping, Light-on (4 M€ raised) on AI with light, Welinq on quantum memories based on cold atoms with high retrieval, and Mirega on the creation of a miniature greenhouse gas analyzer using high-quality Fabry-Perot fibre-based cavities. A fifth startup (Raiman) is about to be launched on low-cost compressive Raman Imaging.
Many members of the LKB, including the two Nobel laureates, interact with the general public in different ways: science books, public debates and presentations. Of particular interest is the role of one member of LKB (scientific mediation medal of CNRS 2021) with actions on YouTube (Merci la Physique), his monthly chronicles in "Pour la Physique" and his role as new scientific commissioner at the Palais de la Découverte. Several teams of LKB participate actively in the Fête de la Science on the Sorbonne campus at Jussieu. A list of three hundred and fifty actions in outreach exists, undertaken during the evaluated period.

1/ The unit stands out for the quality and the amount of its interactions with the non-academic world.

2/ The unit develops products for the cultural, economic and social world.

3/ The unit shares its knowledge with the general public and takes part in debates in society.

Strengths and possibilities linked to the context for the three references above

The LKB appointed a communication officer, though still on a temporary contract. Also, a member of the research staff has been appointed valorization officer. The committee is impressed by the actions undertaken by LKB to disseminate physics and its applications. Many debates have taken place, also involving the Nobel Laureates. The LKB is present and visible in the press and the media. Gender equality and the encouragement for women to do physics is an important activity. Noteworthy is the article "Douzes femmes en Recherche - variation quantique" involving four female staff members of LKB.

Weaknesses and risks linked to the context for the three references above

The highly desired display of valorization, interdisciplinarity and large collaborations across all twelve teams by means of an "empty" axis "Frontiers and Applications", that coexists with the scientific axes, is appreciated and seems to operate well inside the walls of LKB but its exact role and meaning is not transparent to the outside community.

ANALYSIS OF THE UNIT'S TRAJECTORY

The scientific objective of LKB to stay a world leader in all aspects of quantum physics will be pursued. After 2023, the three sites will continue to exist until the renovations at ENS-PSL are finished. As of 2024, two teams (Complex quantum systems and Quantum fluctuation & relativity) will merge, and 100 m^2 will become available for LKB at Sorbonne Université. After renovations, two LKB teams and one team from the "Jeunes équipes" will return to the Lhomond site. At that moment the Collège de France will cease to be among the three hosts of premises and the surface currently occupied by LKB will eventually be allocated to a new chair in physics. Collège de France might even step down as a supervising authority. The considerable reorganization of the technical platforms at ENS-PSL is already ongoing.

In the new term 2025-2030, the governance will change. The accent of the new director will still be on the importance of fundamental long-term research, on an increased attractivity of technical, IT and administrative support, and on the search for a solution of the "3 x 3 PhD issue" of supervising at most three PhD per HDR at any instant with at most three-year duration. Being an active player himself, the creation and follow-up of start-ups will get his attention, in particular the availability of vital square meters necessary during their early stages. A huge opportunity of the LKB is of course the proximity of high-level training provided by ENS-PSL, SU and PSL.

RECOMMENDATIONS TO THE UNIT

Recommendations regarding the Evaluation Area 1: Profile, Resources and Organisation of the Unit

The co-existence of two different modes of operation at LKB, sometimes inside the same axis (the rising model supported by many grants, with few permanent researchers and many students and postdocs, and the more classical business model in France with a dominant role of the permanent members in small teams, comprising few students) needs attention. Both have advantages and drawbacks and can be successful. This co-existence is precious and should be preserved but is not straightforward when space is severely restricted.

The lack of space has become a major threat to the well-functioning of support units, research teams and individual PhD students and researchers. Until 2026, when most renovation works are hopefully finished, space availability should be considered as major parameter in any decisions taken on grant proposals or recruitments. A possible action could be to allocate temporary space to teams with punctual contracts. However, the consequences of such allocations should be carefully assessed.

Three faculty members of the university of Evry (university Paris -Saclay) are all part of team on trapped ions. The two associate professors may need some help in getting promoted at their university, which is clearly outside the perimeter of both SU and PSL. The possibility of involving the university of Evry into LKB activity and the nature of this involvement should be discussed to improve the situation.

The LKB puts forward in the self-evaluation report that "the limitation imposed by the doctoral school on the number of PhD per supervisor be less than three is a problem in facing international competition". Even if the committee recognizes that this rule does not always exist elsewhere, removing this limitation may induce other problems, such as an exacerbation of the space problems, overburdened administrative staff, a potential reduction in the quality of supervision, and either a shortage of PhD students or a reduction of their quality.

The committee recommends to have again an appointed or elected representative of the technical support staff in the executive committee.

The committee recommends to find a way to increase the visibility of the fifth axis on valorization and interdisciplinarity to the outside community, for instance by assigning staff members with clear tasks and projects.

Recommendations regarding the Evaluation Area 2: Attractiveness

The unit is highly attractive in its scientific production. The LKB should continue and increase its existing efforts to attract female PhD students.

Recommendations regarding Evaluation Area 3: Scientific Production

The committee would like to incite staff members to publish in free open access (diamond) journals, and to avoid paying high APC, following recommendations of SU and CNRS. Publication in high-impact journals is arguably not needed to get international visibility. The LKB has the opportunity to be exemplary in this matter.

Recommendations regarding Evaluation Area 4: Contribution of Research Activities to Society

The committee has no recommendation. The unit is exemplary and even reinforced these actions during the last term.

TEAM-BY-TEAM OR THEME ASSESSMENT

Team 1: Atom chips

Name of the supervisor: Mr Jakob Reichel

THEMES OF THE TEAM

The atom chips group, located at the ENS-PSL site, is working on several aspects of quantum technologies, especially quantum metrology and quantum simulation using atomic gases, typically cooled to or close to quantum degeneracy. It has focussed on the use and development of atom chips and integrated fiber-based Fabry-Perot cavities in which it has investigated spin-squeezing and multi-atom entanglement. The group has a long-term collaboration with the laboratory SYRTE, in which atom chips are being used to develop a high performance, miniaturized atomic clock. An active theory component is present working on theoretical descriptions of quantum gases as well as on theoretical developments in quantum metrology such as spin squeezing and quantum non-demolition measurements.

CONSIDERATION OF THE RECOMMENDATIONS OF THE PREVIOUS REPORT

The only critical suggestion from the 2018 report was: "The team should make an effort to attract more female PhD students." In the current evaluation period one sees one female PhD student and ten males, which remains low.

WORKFORCE OF THE TEAM: in physical persons at 31/12/2022

Catégories de personnel	Effectifs
Professeurs et assimilés	3
Maitres de conférences et assimilés	1
Directeurs de recherche et assimilés	0
Chargés de recherche et assimilés	0
Personnels d'appui à la recherche	0
Sous-total personnels permanents en activité	**4**
Enseignants-chercheurs et chercheurs non permanents et assimilés	0
Personnels d'appui non permanents	0
Post-doctorants	1
Doctorants	2
Sous-total personnels non permanents en activité	**3**
Total personnels	**7**

EVALUATION

Overall assessment of the team

The team has an excellent publication track record with twenty-eight publications (2.33 publications per year per ETPR. Its international visibility is high, allowing it to attract students from outside of France (4 of 11). It also participates in high level European collaborations, the MacQsimal project in particular. The team leader secured an ERC grant in 2016 which permitted substantial investments. The team has also initiated a valorisation project based on its technological developments concerning fiber Fabry-Perot cavities. The valorisation project is supported by the SATT of Sorbonne Université. Thus, the overall performance of this rather small team is excellent.

Strengths and possibilities linked to the context

The close collaboration between the two experimentalists and the theorist is an important strength in this rapidly developing, intensively competitive field. The collaboration with experimental group in Switzerland to perform nuclear spin squeezing on helium-3 puts them in a unique position to develop new quantum technologies. The collaboration with the SYRTE Laboratory on the TACC (Trapped atom clock on a chip) is also an excellent means of leveraging the group's expertise to make rapid progress on compact atomic clocks. The group has a long-standing tradition and ability to collaborate effectively with outside researchers. This ability increases its impact beyond what is usually expected from a group of four permanent researchers.

Weaknesses and risks linked to the context

The group's self-evaluation notes its difficulty in attracting PhD students, although there are currently two in progress. The group also recognizes that it would do well to recruit a CNRS researcher who could work full time on their many projects. Given the competition within the LKB, this may prove to be a difficult task as well.

Maintaining the investments enabled by the ERC grant will require securing continued funding from other sources. Currently the many quantum technology initiatives in France and in Europe are promising but the group must continue to submit proposals.

Analysis of the team's trajectory

The group's tradition of forming close collaborations with other teams within the LKB, in other French laboratories and internationally should allow it to continue maintain its high level of research. The new start-up project concerning fiber Fabry Perot sensors is exciting, as is the project to realize a new generation of atomic clocks on a chip. The theoretical proposal to apply its expertise in quantum non-demolition and other quantum manipulation techniques to the use of polarized helium-3 is quite novel as are other activities which address quantum metrology issues. The plan to use of fiber cavities to implement quantum simulators with long range interactions is promising and one hopes that such a proposal can be realized in the near future.

RECOMMENDATIONS TO THE TEAM

The committee recommends to continue the good work. The tradition of collaboration with other groups and to increase the number of permanent researchers e.g. by a CNRS recruitment.

Team 2: Bose-Einstein condensates

Name of the supervisor: Mr Jean Dalibard

THEMES OF THE TEAM

The research of the team, located at Collège de France, is in the field of many-body quantum physics with atomic Bose-Einstein condensates, mainly focussing on quantum simulation. During the period of assessment, it has been based on four experimental platforms: ultra-cold dysprosium, 2D Bose gas of Rubidium, Ytterbium atoms in optical lattices and sodium spinor gas, as well as an emerging platform in "mixed dimensions" led by the recently recruited permanent CNRS researcher.

CONSIDERATION OF THE RECOMMENDATIONS OF THE PREVIOUS REPORT

The recommendations in the 2018 report were:

1. special care has to be taken to facilitate the career development of the younger permanent members of the team considering their high scientific level and ambition;
2. considering the growing complexity of each experiment, it should be thought how to help the graduate students in obtaining a deep insight into all aspects of the involved science and technology;
3. consideration of a long-term and sustainable financial strategy to keep the platforms at a competitive scientific level.

1. The level of the research is still extremely high during the period (high impact of publications, ERC grants, recruitment of high-level PhD students, etc.), which validates the strategy of the team both concerning the scientific and managing issues.

2. In order to help the students to have a global view of the activities of the team, scientific exchanges have been strongly encouraged through different events: journal clubs organized by PhD students, invitation of PhD students and postdocs to participate to PhD seminars and LKB seminars.

3. The team has followed the last recommendation by closing two platforms.

WORKFORCE OF THE TEAM: in physical persons at 31/12/2022

Catégories de personnel	Effectifs
Professeurs et assimilés	1
Maitres de conférences et assimilés	2
Directeurs de recherche et assimilés	1
Chargés de recherche et assimilés	1
Personnels d'appui à la recherche	0
Sous-total personnels permanents en activité	**5**
Enseignants-chercheurs et chercheurs non permanents et assimilés	2
Personnels d'appui non permanents	0
Post-doctorants	1
Doctorants	9
Sous-total personnels non permanents en activité	**12**
Total personnels	**17**

EVALUATION

Overall assessment of the team

The team has continued to explore many-body quantum physics with Bose Einstein condensates with impressive results and activities. The research is of fundamental nature, but the tools developed and the understanding of the physics of such systems will undoubtedly be useful for the development of quantum simulations in quantum technologies.

Strengths and possibilities linked to the context

The Bose Einstein condensate team is a world-renowned experimental and theoretical team in the field of quantum gases. The team addresses important and broad topics directly related to major themes of quantum simulations, such as quantum optics, light-matter interaction, atomic physics and condensed matter physics. The strategy to maintain equipment of high level is based on a continuous source of funding mainly by grants (about 300 k€ per year including 3 ERC, 2 ANR, and local financing) in addition to funding from LKB authorities (70 k€ per year). Since the platforms feature similar technical characteristics, equipment can be shared among platforms.

The team is very well organized having five permanent researchers (3.5 ETPR), and recruiting at least one new PhD student every year for each platform.

The scientific production is high (38 peer-reviewed papers, so 1.8 /ETPR/year including high impact papers: 1 in Science, 6 in Nature, Nature Comm. or Nature Phys., 11 PRL, and 1 PRX; 57 invited conferences) and equally shared between the platforms. All papers are available on ArXiv and HAL.

The team is active in scientific outreach, with articles in Science & Vie, Science & Avenir, La Recherche interviews and radio broadcasts in France Culture.

The team has an attractive scientific reputation and contributes actively to the European research area (ERC grants, Marie Curie fellowships, IUF prize, coordination of a QuantERA consortium, courses at Collège de France). In 2022, the team leader received the CNRS Gold Medal.

Weaknesses and risks linked to the context

The main risk comes from the possible discontinuation of one or more platforms due to lack of long-term funding (concerning material and or human resource issues) despite the scientific success. The experimental work always runs the risk of failure of important, expensive items such as the lasers. The risk might even increase with the creation of a new cold atom platform. On the other hand, two of the current platforms have been or will soon be discontinued. This will help to limit the danger.

There is a relatively low number of postdocs compared to competitive teams outside France, the team attributes this fact to a lack of sufficiently qualified applicants. Even with adequate recruitment, moving the platforms while maintaining their scientific productivity will represent a significant challenge.

Analysis of the team's trajectory

The Bose-Einstein condensates team will continue its exploration of quantum physics using ultracold gases. This is amply justified, by the interest of the subject and the growing international activity in the area of quantum simulation. Many fundamental research questions remain to be explored. The team is flexible enough to discontinue platforms in favour of new experiments related to new exciting ideas and prospective funding possibilities. Thus, plans exist to stop the sodium and ytterbium platforms and to start two new projects: one concerning Bose gases in the strong interaction regime (Rydberg Bose gases), funded by an ERC, and one using mixed (two and three) dimensions, funded by an ANR project coordinated by the recently recruited permanent researcher.

RECOMMENDATIONS TO THE TEAM

The Team must continue with the same level of disruptiveness and success. It has to anticipate the return to the ENS-PSL site without losing the precious successful activity that has been built up over the years.

Team 3: Ultracold Fermi gases

Name of the supervisors: Mr Yvan Castin & Mr Tarik Yefsah

THEMES OF THE TEAM

The team, located at the ENS-PSL site, has theoretical, numerical and experimental activity on correlated Fermi gases (lithium and potassium). Mixtures of Bose and Fermi gases are also studied. Experimentally, many properties, such as disorder and mutual interactions, can be accurately controlled and many-body properties e.g. two-body correlations or three-body losses and virial coefficients can be measured. Several innovative experimental platforms have recently been mounted, on the unitary Fermi gas with infinite scattering length and maximum correlation, the triangular optical lattice with fermionic occupation, and the quantum gas microscope that will allow monitoring of individual atoms in a superfluid. The theory team is developing a (Feynman-) diagrammatic Monte-Carlo method to make numerical studies of correlated fermions. It is also investigating collective modes of fermionic superfluid gases, possibly composed of bosonic bound pairs of fermions with opposite spin. Their many properties include phonon excitations and phonon-fermion interactions, damping, virial constants. An important development was the revisiting of Landau's theory of phonon-roton theory.

Some team members are actively involved in the preparation of the ACES/PHARAO space clock mission that aims to put a high precision Caesium clock (10^-16 sec) in space, probably due in 2025. The project will contribute to a future redefinition of the SI second via distant clock comparisons. New tests on the gravitational frequency shift will also be performed. One team member is involved in the MICROSCOPE space mission on the equivalence principle.

CONSIDERATION OF THE RECOMMENDATIONS OF THE PREVIOUS REPORT

The recommendation of the previous assessment was essentially to keep the high level of scientific quality, and no weak points were identified.

WORKFORCE OF THE TEAM: in physical persons at 31/12/2022

Catégories de personnel	Effectifs
Professeurs et assimilés	0
Maitres de conférences et assimilés	1
Directeurs de recherche et assimilés	1
Chargés de recherche et assimilés	2
Personnels d'appui à la recherche	0
Sous-total personnels permanents en activité	**4**
Enseignants-chercheurs et chercheurs non permanents et assimilés	1
Personnels d'appui non permanents	0
Post-doctorants	1
Doctorants	2
Sous-total personnels non permanents en activité	**4**
Total personnels	**8**

EVALUATION

Overall assessment of the team

Despite its small size, the team is extremely active in a large diversity of modern topics. It produced 54 publications in peer reviewed journals (that is 1.8 /year/ETPR), several in high impact journals. The team has many collaborations and is well supported by grants (3 SIRTEQ- réseau Île-de-France quantum technologies, 4 national ANR, 1 ERC). It is actively involved in HPC clusters located at Jussieu and shared with other units. Worth mentioning is the teaching of the environmental transition by one team member and the direction of the Ecole de Physique at Les Houches by another. Many plenary and invited presentations have been delivered by all team members, including public lectures on high precision time measurement. This team has an excellent scientific activity.

Strengths and possibilities linked to the context

There is a strong interaction between theory and experiment, with a real team spirit, as well as collaborations outside the team and outside the LKB. A large diversity of activity exists, including a long-term space mission. No less than twelve PhD students graduated during the evaluation period. There is a real engagement for low carbon footprint and green environment inside this team. All publications are deposited on HAL, and several team members publish in Open Access Journals, such as CRAS and New Journal of Physics. A great effort for outreach is made by the whole team, for instance "the Young for the Young" " initiative or the popularisation talks concerning the (high-precision) measurement of time.

Weaknesses and risks linked to the context

Most of the funding seems to be related to the experimental activity, and even if theory needs much less financial support, only one project was funded by ANR in 2022 associated directly to the numerical activity. Among permanent researchers, postdocs and PhD, gender parity is below the LKB average.

One ENS-PSL Junior Chair has been active between 2017 and 2021 with only three publications with many co-authors.

Analysis of the team's trajectory

No major changes are imminent after 2024. The former group leader has become an active emeritus scientist, heavily involved in the space mission PHARAO. The group is led by one senior theoretician and one junior experimentalist, eager to start working on the experimental set-ups he has mounted since his arrival in 2016. Many useful collaborations outside team and unit will continue to exist.

RECOMMENDATIONS TO THE TEAM

Like in the former evaluation report, no recommendations are necessary except two evident ones. The committee firstly recommends to prepare the habilitation of junior researchers and secondly, in view of the many activities that also seem long-term, the team could benefit - and is sufficiently attractive to hire - new young researchers.

Team 4: Complex quantum systems

Name of the supervisor: Mr Nicolas Cherroret

THEMES OF THE TEAM

The team, located at the Jussieu site, studies theoretically and numerically the dynamics of cold atomic gases and light in the presence of spatial disorder and many-body interactions between the atoms and the photons. Four topics are studied: (i) wave localization in disordered media, (ii) wave localization vs. interactions, (iii) Spin-orbit interaction of light in disordered media, and (iv) non-equilibrium dynamics of quantum fluids. The first topic is the historical activity of the team. The growing last topic is carried out in collaboration with the quantum optics team.

CONSIDERATION OF THE RECOMMENDATIONS OF THE PREVIOUS REPORT

The recommendations from the 2018 previous report concerned: 1) expansion of the team activities and attraction of external funding; 2) the small size of the group (only two permanent researchers), a larger team would make it more attractive for newcomers and 3) more collaborative projects, in particular with the atomic physics and the quantum optics group.

The first and third recommendations have been considered. In particular, the historical activity of the team was shifted towards the interplay between particle interactions and disorder with new collaborations with experimental groups (such as the quantum optics team, as well as outside the LKB).

The second recommendation will be realized during the next term as the team will merge in 2024 with the team "Quantum Fluctuations and Relativity".

WORKFORCE OF THE TEAM: in physical persons at 31/12/2022

Catégories de personnel	Effectifs
Professeurs et assimilés	0
Maitres de conférences et assimilés	0
Directeurs de recherche et assimilés	1
Chargés de recherche et assimilés	1
Personnels d'appui à la recherche	0
Sous-total personnels permanents en activité	**2**
Enseignants-chercheurs et chercheurs non permanents et assimilés	0
Personnels d'appui non permanents	0
Post-doctorants	0
Doctorants	3
Sous-total personnels non permanents en activité	**3**
Total personnels	**5**

EVALUATION

Overall assessment of the team

The Team is small but has a strong scientific activity, that is well recognized by the community, despite the small number of PhD and postdocs students. The team has been able to extend its expertise, beyond its traditional activity, towards the interplay between particle interactions and disorder with new collaborations with experimental groups.

Strengths and possibilities linked to the context

This small theoretical team composed of two permanent researchers, with a reduced activity starting from 2021 of one prominent member due to illness, and who deceased one week before the interview, has a strong activity in terms of publications in journals oh high visibility (39 papers in the period, 3.25 per year per ETPR which is much larger than the unit average, including 1 Nature Comm. and 7 PRL) as well as many invited conferences (20).

One member has been co-director of the GDR Complex since 2018 (successful GDR, renewed in 2022).

The team runs a relative large computer network (with a few hundred cores), accessible to other teams of LKB and LPTMC.

The number of contracts only funded by ANR is moderate but appears to be sufficient for the team to develop their high-quality theoretical research. The team develops numerical tools hosted in Github and made freely available under a GPL license.

Weaknesses and risks linked to the context

There are no international contracts.

Analysis of the team's trajectory

In the next term, the team will merge with the equally small team on Quantum Fluctuations and Relativity. A CNRS researcher has been recruited in 2023. Even if the two groups have a different focus, some collaborations will be facilitated and the goal will essentially be to create a new and larger theoretical group at the Jussieu site of the LKB. This strategy appears to be well justified as long as the team continues collaborating with experimental groups and if it succeeds to attract more PhD ad postdoc students.

RECOMMENDATIONS TO THE TEAM

Giving the large expertise, the team could consider securing more international grants in order to finance and attract more PhD and postdocs. This strategy should be shared within the new merged team. The larger theoretical expertise in this future team will certainly contribute positively towards this strategy.

Team 5: Rydberg atoms

Name of the supervisor: Mr Michel Brune

THEMES OF THE TEAM

The scientific activity of the team, currently located at the Collège de France, focuses on the use of circular Rydberg states in quantum metrology and quantum simulation. These activities emerged from the exploration of cavity quantum electrodynamics (CQED) with circular Rydberg atoms and superconducting millimeter-wave cavities, which resulted in the 2012 Nobel Prize in physics. While still exploring original applications of CQED, e.g., in quantum thermodynamics, the strategy followed by the team now exploits the knowledge and expertise in the control of circular Rydberg states in new scientific directions that have been established during the evaluation period. The development of complex, home-built, experimental infrastructures remains a distinguished feature of the team.

A first research direction exploits coherent superpositions of Rydberg states with tuneable electric and magnetic dipoles in the development of ultra-sensitive electric and magnetic field sensors. The main research axis is the development of original quantum simulators based on trapped interacting circular Rydberg atoms under full control of the positions and quantum states of the atoms. The activity has three main thrusts. The first use hollow laser beams to trap circular Rydberg atoms of Rubidium and form atom arrays for quantum simulation on the millisecond time scale. The second direction investigates circular Rydberg states of Strontium and exploits the control possibilities offered by the optically accessible core electron. The third research direction aims at realizing a new scheme to inhibit the spontaneous emission of the circular states, enabling quantum simulations with large arrays of spins over exceptionally long times.

CONSIDERATION OF THE RECOMMENDATIONS OF THE PREVIOUS REPORT

The three recommendations of the previous report have been taken at heart and implemented as follows:
1) The team should continue its activities as detailed in the report, both building on existing strengths and initiating new activities.
The significant thematic evolution shows that this recommendation has been taken very seriously.
2) The team should be particularly attentive to the promotion of the younger staff.
An effort is made to involve the younger staff in all aspects of the research activities, which offers excellent prospects for future promotions. Two of the young permanent members have received their HDR in 2019. The younger members of the group have also become highly visible internationally.
3) The team should pursue its plans or re-orientation, as detailed in their self-evaluation report, towards the field of Rydberg atoms. In doing so, it should take the necessary steps to make sure that the resources of the group remain available and properly balanced between the various research directions. This might mean reducing some of the current research activities.
The focus on quantum simulations with circular Rydberg states is the perfect implementation of this recommendation.

WORKFORCE OF THE TEAM: in physical persons at 31/12/2022

Catégories de personnel	Effectifs
Professeurs et assimilés	0
Maitres de conférences et assimilés	2
Directeurs de recherche et assimilés	1
Chargés de recherche et assimilés	1
Personnels d'appui à la recherche	0
Sous-total personnels permanents en activité	**4**
Enseignants-chercheurs et chercheurs non permanents et assimilés	2
Personnels d'appui non permanents	0
Post-doctorants	0
Doctorants	9
Sous-total personnels non permanents en activité	**11**
Total personnels	**15**

EVALUATION

Overall assessment of the team

The team consists of an excellent mix of experienced researchers, researchers early in their careers and young researchers in training. The two emeriti still actively contribute to the visibility of the team and take their share in the tasks at the interface between research, society and the economic world. This enables the younger team members to focus on the realisation of the ambitious research strategy and the development of an own, home-built and worldwide unique research infrastructure. A key asset of the group is the access to the mechanical workshop of the Institute of Physics at the Collège the France.
The team has been successful in securing competitive funding from ANR and European funding sources, notably through an advanced ERC grant awarded to the team leader. It is also embedded in an excellent network of national (e.g., PEPR QUBITAF) and international (e.g., EU-FET flagships PASQUANS, EU-ERA-NET COFUND QuantERA) collaborations, including industrial partners (e.g., Pasqal); ten PhD theses and two HDR have been completed between 2017 and December 2022. The research of the team has been reported in more than sixteen top-quality peer-reviewed publications (i.e. about 4 publications/ETPR during the evaluation period) as well as two editorials in Phys. Rev. X, two conference proceedings, and no less than forty-five invited lectures at leading international conferences and summer schools. The team is internationally highly recognized and has global impact in defining new research axes.
The recent thematic evolution of the team is remarkable and fits in its tradition of scientific innovation and excellence. It also illustrates the team's ability to develop new fields of activity while remaining at the forefront of international research.

Strengths and possibilities linked to the context

The main strengths of the team are its unique expertise in quantum technologies and quantum physics, its clearly defined research strategy in a very topical research area, the excellence of the team members at all levels, the access to excellent mechanical and electronics workshops, and the integration in an excellent network of national and international collaborations. The team also benefits from the role played by the emeriti in the academic, socio-cultural and socio-economic world at large. An emeritus professor of the team has been lead editor of the open-access journal Phys. Rev X. of the APS.

Weaknesses and risks linked to the context

The weaknesses and risks identified in the self-evaluation report include the high degree of competition in the development of quantum technologies, including competition from very active start-up companies, and the world-wide shortage (giving rise to high prices) of helium. Adequate measures to deal with these weaknesses and risks are described in the report. A particular source of uncertainty, and perhaps the main risk at present, is associated with the return of the team to Rue Lhomond and concerns the relocation of the laboratories with highly complex scientific equipment, potential space restrictions, and potential changes in the access to workshops and technical platforms. In this context, it is worth mentioning that, currently, the group benefits from significant external resources, from technical support of the mechanical platform at the Collège de France that will be crucial to replace after the move to the ENS-PSL site.

One of the talented young permanent researchers of the team will move to Toulouse in the near future because the impossibility of promotion to professor (Chair) level at the Collège the France. During the visit, the team has explained potential strategies for a replacement and these options must be given high priority.

Analysis of the team's trajectory

The thematic evolution from CQED with circular Rydberg states to quantum simulation with circular Rydberg states is an excellent response to the general, rapid evolution of research and technology in quantum physics. Three original lines of research have been identified for the mid-term strategy: (i) quantum simulation with arrays of laser-trapped Rubidium atoms and circular Rubidium Rydberg states; (ii) exploitation of the optically active core electron in quantum simulation with circular Strontium Rydberg states; and (iii) inhibition of spontaneous emission for quantum simulation on extremely long time scales. These new lines of research offer ideal prospects for scientific innovation and discovery in the best tradition of this team. The current status of the new projects could be assessed during the site visit and both the instrumental developments and the progress realised in the past years were found to be really impressive.

The team has dealt very well with the transition of two of its prominent researchers into the emeritus status and has invested considerable efforts in the development of a promising and highly original research strategy. One cannot overemphasize this achievement. The team is now in an ideal position to face the challenges linked with the return from Collège de France to ENS-PSL with hope and optimism.

RECOMMENDATIONS TO THE TEAM

Three recommendations can be made. First, continue without compromise with the excellent, innovative and forward-looking strategy established in the past years and earn the fruits of the large efforts invested in the elaboration of this strategy. Second, maintain the current balance of the team and continue to provide the best research conditions to the three younger permanent members of the group. They are in an excellent position to apply to ERC grants and just need the optimal timing.

Finally, the responsibilities of the current group leader - including the direction of the "Jeunes Équipe at Collège de France" - have continuously increased over the past years, and the younger generation should be mobilised to release some of the pressure resting on his shoulders.

Team 6: Quantum optics

Name of the supervisors: Mr Alberto Bramati, Mr Nicolas Treps and Mr Julien Laurat

THEMES OF THE TEAM

The activities of the team cover optical quantum communication, quantum simulation, quantum computation, and quantum sensing. In particular, this team has a strong and worldwide renown expertise in experimental optical implementation of the above-mentioned quantum technologies. The team is divided into three subgroups: "Quantum networks" led by J. Laurat, "Quantum fluids of light and nanophotonics" led by A. Bramati and "Multimode quantum optics" led by N. Treps.

CONSIDERATION OF THE RECOMMENDATIONS OF THE PREVIOUS REPORT

No weaknesses were raised in the former report. The team was encouraged to pursue its excellent dynamics. A lack of space leading to the densiification of the experiments was mentioned by the previous committee. This problem is expected to get worse with increased financial resources for quantum technologies. The lack of space impacts the number of visiting researchers as well.
Three recommendations were proposed in the former report.
1) The team was encouraged to continue to be innovative both in their fundamental research and potential applications.
Important results have been obtained by the team. The academic production is outstanding. In addition to the collaboration with Cailabs, that was co-founded by one member of the team, a start-up, Welinq, was co-founded by another member of the team. New collaborations started with Pasqal and Xanadu.
2) It will be important for the young generation of leaders to take care of exchanging and sharing their complementary knowledge and expertise, which is a necessary condition for maintaining leadership on such a broad spectrum.
This point is not covered in the report. In particular, the interactions and meetings within and between the three sub-groups is not clearly described. The on-site interview confirmed that the three sub-groups operate as three distinct teams. Nevertheless, it happens that sub-groups share some expertise and small equipment.
3) The high degree of ambition of the projects and their numbers will require a strong dynamism in order to obtain the necessary funding and staff. The team should not hesitate to abandon some of them if the means are not sufficient.

Financial resources as well as labour forces are in line with the number of projects. However, the limited space available might be a hindrance to the development of these projects.

WORKFORCE OF THE TEAM: in physical persons at 31/12/2022

Catégories de personnel	Effectifs
Professeurs et assimilés	3
Maitres de conférences et assimilés	3
Directeurs de recherche et assimilés	0
Chargés de recherche et assimilés	2
Personnels d'appui à la recherche	0
Sous-total personnels permanents en activité	**8**
Enseignants-chercheurs et chercheurs non permanents et assimilés	3
Personnels d'appui non permanents	0
Post-doctorants	9
Doctorants	28
Sous-total personnels non permanents en activité	**40**
Total personnels	**48**

EVALUATION

Overall assessment of the team

The team obtained excellent results during the evaluation period. In particular, it has demonstrated the first creation of entanglement between particle-like and wave-like qubits which has led to the realization and patenting of a qubit-encoding device converting discrete-variable-qubits into continuous-variable-qubits. In the framework of quantum memories and quantum repeaters, the team has pushed the storage efficiency up to 90%. This unique and outstanding result has led to the creation of the Welinq start-up. The study of quantum fluids of light through photon-photon interaction in nonlinear optical cavities and hot Rubidium vapour has conducted to several original results. In addition, the selective control of nano-particule emission properties has been pushed to explore and control the properties of hybrid photonic devices where single nanocrystals are coupled to different photonic structures.
The team activities are supported by extensive financial resources originating mainly from research contracts (3 ERC, 3 Quantum Flagship projects, 8 European projects, 13 ANR projects), generating a budget that exceeds one million euros per year. The team benefits from high national visibility (3 IUF members, one CNRS bronze medal, steering committee of the GDR TEQ) as well as from international visibility through the involvement in several committees (Majulab, NSF-ERC Center for Quantum Networks, training Twinning program NonGauss) and the numerous (96) invited talks. The members of the team are strongly invested in the training of doctoral students, with a huge number (50) of PhD students giving an average of 10 doctoral students/year over the evaluation period. Despite heavy institutional and teaching responsibilities, the publication track record is outstanding with 110 publications in peer reviewed journals during the evaluation period corresponding to 2.75 publications/ETPR/year.

Strengths and possibilities linked to the context

The team possesses almost all assets to carry out its fruitful research activity: scientific positioning at the international level, equipment, financial resources, recruitment of two young CNRS permanent research scientists and one assistant professor during the evaluation period, collaborations with academic partners and partnerships with industrial actors, and more importantly, a clear strategic vision for the coming years.

Some resources are shared between the three subgroups of the team which guarantees a secure and smooth functioning. The team is perfectly aware of its highly favourite scientific environment and has demonstrated its ability to seize the most relevant opportunities (ex: Quantum Flagship, PEPR quantique, EU grants, Startup…).

Weaknesses and risks linked to the context

There are no real weaknesses or risks related to the context. Nevertheless, as acknowledged by the team, the additional administrative and scientific responsibilities taken by senior members, might slow-down the team momentum. Moreover, the lack of space is still an open issue, especially to recruit the many PhD. An additional problem applies to the three subgroups because their premises are not adjacent to each other.

Analysis of the team's trajectory

The trajectory of the team is described in detail. It relies on well identified objectives that are in line with ongoing theoretical and experimental activities of the team.

The quantum networks subgroup is planning to boost the activity related to hybrid entanglement of light supported by the project "OQulus" (PEPR Quantique). The achievement of an efficient optical quantum memory is expected to open the way towards the realization of two quantum memories separated by fifty kilometers which will take place in the framework of the project "QucomTestbed" (PEPR Quantique) and the partnership with the WELINQ start-up. Moreover, the improvement of quantum memories will take place within the project "QMemo" (PEPR Quantique). The experiments using cold atoms and nano-photonics will be oriented towards the realization of all-fibered all-optical, high-storage and efficient quantum memories which is supported by a recent ERC grant.

The Multimode quantum optics subgroup intends to continue multimode squeezing in nonlinear waveguides in order to achieve, simultaneously, temporal and spectral multiplexing which should enable the generation of versatile cluster states. This activity benefits from an ERC grant. In addition, the subgroup will pursue its experimental and theoretical activities on continuous-variable quantum-computing dedicated to quantum networks as part of the two projects "NISQ2LSQ" and "OQuLus" (PEPR Quantique) with a potential technology transfer to the PASQAL Start-up. In parallel, the partnership with CAILABS company is expected to open up new opportunities such as distance estimates beyond the Rayleigh diffraction limit using quantum-like protocols and/or non-Gaussian quantum light sources.

The subgroup working on quantum fluids of light and nano-photonics has demonstrated quantum effects in quantum fluids of light based on polaritons and hot Rubidium vapours. These studies are expected to shed light on quantum phenomena that might occur around astrophysical objects such as black holes, or to simulate advanced models for condensed matter. These latest activities benefit from an ERC grant obtained very recently (2023). The nano-photonics activity will be pursued with new perspectives such as the coupling of nanofibers, waveguides and plasmonic structures to various solid-state quantum emitters. It will be extended to new horizons within a European project started with biologists and physicians to exploit the sensitivity of nanofibers.

The project of the team is based on well-established academic and industrial partnerships. Moreover, the three subgroups have managed to secure an important amount of financial resources for the coming years (3 recent ERC grants, Quantum FlagShip, PEPR quantique…). They managed to recruit three young permanent researchers during the evaluation period, i.e, in 2019, 2021 and 2022. All these elements will help the team to maintain its scientific activities at the highest level for the years to come.

RECOMMENDATIONS TO THE TEAM

The team is invited to pursue its research activities and maintain its excellent international visibility. Given the large number of projects, care must be taken to keep a good equilibrium between scientific workload and collective duties in management. In particular, one member belonging to the "multimode quantum optics" subgroup is going to be appointed director of the LKB. The Committee encourages the recruitment of a young scientist to maintain the research efforts at the highest level in this subgroup. The moderate interaction between the three subgroups seems adapted to the proper and smooth operation of the team, and no change seems to be necessary.

Team 7: Optomechanics and quantum measurements

Name of the supervisor: Mr Antoine Heidmann

THEMES OF THE TEAM

The team is one of the pioneers in the study and applications of optomechanical coupling. While still exploring the use of squeezed light to overcome the standard quantum limit in interferometric measurements, the team has built on its unique expertise to extend its work in two new directions.

The first one concerns the engineering of a self-calibrated optomechanical thermometer, using optomechanical crystals enabling temperature measurements at nanoscale over a wide temperature range taking advantage of both the optical and mechanical degrees of freedom and optomechanical correlations.

The second direction focuses on hybrid optomechanical and superconducting systems, with the aim of implementing a control of the mechanical degrees of freedom of an ultra-coherent macroscopic mechanical resonator through their coupling to a superconducting qubit operating in the MHz frequency range.

CONSIDERATION OF THE RECOMMENDATIONS OF THE PREVIOUS REPORT

Three recommendations were made in the previous report and have been considered.
1) The scientific production of the group and its quality are at a very high level. Continue the great work!
This period has been marked by a significant reorientation of the team's research themes. A considerable effort has been made to set up the various building blocks required for the targeted ambitious experiments. The current results are highly promising and place the team in a-favourable situation to achieve its scientific goals.
2) The team should evaluate why there are no female scientists in the group. They should make an effort to attract female scientists to their team.
While no progress can be observed on this front, the team is aware of this imbalance and is sensitive to gender parity issues. Actions have been taken to try to attract women to pursue doctoral degrees or to post-doctoral positions, albeit without success.
3) The team has a very clear scientific strategy centred about its strong expertise in interferometry and related fields, ranging from the detection of gravitational waves to the detection of motion of micromechanical resonators. The team has recently extended its scope to circuit QED, which offers interesting opportunities for the realization of novel quantum states of light and matter in a hybrid system. The team should try to ensure sufficient access to clean room facilities.
The team's new activities heavily rely on access to nanofabrication facilities for the processing of the patterned soft-clamped membranes or fluxonium qubits. In addition to developing processes in the cleanroom facilities hosted at SU and ENS-PSL, the team has strengthened its close links with various teams specialised in nanofabrication. Notable collaborations include those with C2N, CEA and LPENS.

WORKFORCE OF THE TEAM: in physical persons at 31/12/2022

Catégories de personnel	Effectifs
Professeurs et assimilés	0
Maitres de conférences et assimilés	3
Directeurs de recherche et assimilés	1
Chargés de recherche et assimilés	1
Personnels d'appui à la recherche	0
Sous-total personnels permanents en activité	**5**
Enseignants-chercheurs et chercheurs non permanents et assimilés	0
Personnels d'appui non permanents	0
Post-doctorants	0
Doctorants	6
Sous-total personnels non permanents en activité	**6**
Total personnels	**11**

EVALUATION

Overall assessment of the team

During the evaluation period, the team has gone through a major thematic re-orientation by launching two new research direction lines, while continuing its activities on light squeezing in interferometric position measurements in the context of LIGO-Virgo collaborations. This involved major experimental developments and implied a significant nanofabrication effort. The team is now in a perfect position to achieve all innovative scientific objectives. These top-notch results, upon which their project is based, have been the subject of over 10 publications during this period, in addition to the significant number of publications within the LIGO-Virgo collaborations (over 100).

The team has managed to secure competitive funding, by being proactive and by diversifying sources of funding from the ANR, but also from regional calls for tender, PIA, Europe and international programs with USA and Japan. It is involved in doctoral training with five completed PhD theses and currently six PhD students in the team, and participates in an ITN European project. In addition to its involvement in large-scale instruments, such as VIRGO, the team has committed itself to the valorisation of its research, with the filing of one patent and a recent collaboration with the start-up Alice&Bob.

The team is heavily involved in research administration and coordination (laboratory direction, direction of the mecaQ CNRS research network, organization of two summer schools, and participation in the organization of several national conferences). The team's involvement in the dissemination of science is remarkable.

Overall, the team handles all aspects of the researcher's duty with a good balance.

Strengths and possibilities linked to the context

Building on its unique expertise in optomechanical coupling, from concepts up to advanced experiments, the team has undergone a significant shift in its research topics towards innovative and promising directions in a competitive international context. It has successfully strengthened the necessary collaborations to establish all the required building blocks and is well-positioned now to achieve its ambitious goals. These new directions, related to quantum sensing and metrology, as well as to hybrid interfaces between qubits of different natures, respond well to the ambitious challenges set by the National Quantum Plan and the Quantum Flagship.

Weaknesses and risks linked to the context

Some weaknesses and risks have been identified by the team itself. One relates to the strong international competition in the field of optomechanics. However, the team has managed to initiate innovative research avenues objectives with the potential to distinguish itself. An additional weakness lies in the low number of experienced, habilitated researchers (only 2 out of 5), which limits the number of doctoral students that can join the team. Habilitation is also prohibitive for potential promotions to professorships. A related issue is the limited promotion opportunities for-associate faculty staff within the team.

Analysis of the team's trajectory

Now that the team has successfully established the essential conditions necessary to realise its new projects, it is well-positioned to address the scientific questions at hand and to conduct the related experiments. These include: 1) beating the standard quantum limit in interferometric position measurements by integrating the mechanical nanomembrane in the fibered optical cavity in the dilution fridge 2) demonstrating the self-calibration of the thermometer exploiting all optical and mechanical degrees of freedom and their coupling; 3) implementing an hybrid interface by coupling a mechanical oscillator to a superconducting qubit in the MHz frequency range. These lines of research are original and promising, and with the support of its well-established international network of collaborations, the team is fully capable of achieving these objectives.

RECOMMENDATIONS TO THE TEAM

The major recommendation is to reap the rewards of the significant scientific efforts made by achieving the targeted innovative scientific objectives defined for the three pursued direction lines. New thematic developments can be leveraged to benefit even more from the opportunities provided by the framework of the National Quantum Plan and the Quantum Flagship. A few recommendations are to encourage the junior permanent staff to defend their HDR as soon as possible, and to continue the team's efforts to improve gender parity.

The team should maintain the good balance between all aspects of research (science, administration, outreach…) and continue to lead the research lines with the collective spirit that characterizes the team and that strengthens its internal, diverse scientific activity.

Team 8: Quantum fluctuations and relativity

Name of the supervisor: Mr Serge Reynaud

THEMES OF THE TEAM

The team, located at the Jussieu site, has been working for a long time already on Casimir forces induced by fluctuations of the electromagnetic quantum vacuum or by thermal fluctuations in photon occupation. A recent major highlight is the prediction of long-range Casimir forces in electrolyts such as salted water, recently observed in collaboration with a team in Rio de Janeiro. A second activity is the experimental test of the equivalence principle between gravitational and inertial mass, carried out by the space mission MICROSCOPE involving fifty scientists in France and Germany. The project has decreased the disagreement between both masses by a factor of one hundred compared to previous tests (final results published in PRL, September 2022, highlighted in France, at APS,…). Finally the team is involved in a test of gravitation on anti-hydrogen (GBAR) using quantum interference that has been set-up at CERN, supported by an international collaboration of some sixty scientists, involving also LKB members of other teams. One group member has been appointed scientific commissioner for physics in the renovation period of the "Palais de la Découverte" and has become a major player for scientific outreach, which is without any doubt a new major activity in research.

CONSIDERATION OF THE RECOMMENDATIONS OF THE PREVIOUS REPORT

The only recommendation was to beware of the critically low availability of senior staff because of the many administrative and animating duties. It was recommended to the only junior researcher to prepare his HDR.
The subcritical aspect has become worse: A member of the team retired and obtained emeritus status, another one left the LKB for senior administrative duties at Jülich, A third one obtained his habilitation but left the LKB for the LAC in Orsay. A last one concentrated all his scientific activity to the popularization of physics which is largely applauded but which has reduced his activity in research.

WORKFORCE OF THE TEAM: in physical persons at 31/12/2022

Catégories de personnel	Effectifs
Professeurs et assimilés	1
Maitres de conférences et assimilés	0
Directeurs de recherche et assimilés	0
Chargés de recherche et assimilés	1
Personnels d'appui à la recherche	0
Sous-total personnels permanents en activité	**2**
Enseignants-chercheurs et chercheurs non permanents et assimilés	1
Personnels d'appui non permanents	0
Post-doctorants	0
Doctorants	0
Sous-total personnels non permanents en activité	**1**
Total personnels	**3**

EVALUATION

Overall assessment of the team

Despite the few members in the team, the scientific output is diverse and exemplary in many respects. The team had pertinent contributions to two large projects (as was already emphasized in previous report) by combining theory and experiment in a fascinating way, and high success to communicate to a large public. This proves that it is still possible to reach a high scientific level with large disruptiveness without large grants.

The team published thirty-six papers in peer-reviewed journals (1.7/year/ETPR), sometimes with authors from other teams at LKB, and had two PhD graduation related to the GBAR mission. Worth mentioning are the Les Houches lecture notes on Casimir physics. Around two hundred and forty concrete actions have been listed related to popularizing science, which is undoubtedly unique in France.

Strengths and possibilities linked to the context

The team has very large national and international visibility and recognition. Its activity is original and on the edge of physics. The large activity on physics dissemination is unique and exemplary. Scientific collaborations exist with other teams (complex quantum systems, metrology)

Weaknesses and risks linked to the context

The team is too small to survive departures.

Analysis of the team's trajectory

Already in 2024, this team will disintegrate. Two members will continue their actions on Casimir energy and the GBAR experiment, and join the team on Complex quantum physics that is also located at Jussieu. Two other members have already left the LKB.

RECOMMENDATIONS TO THE TEAM

The committee would like to congratulate members and former members with the scientific success that this small team has achieved over the years. The fusion with the team on Complex quantum physics is highly supported.

Team 9: Polarised helium, quantum solids and fluids

Name of the supervisor: Mr Pierre-Jean Nacher

THEMES OF THE TEAM

The team, located at the ENS-PSL site of LKB, develops experimental studies in the field of isotopes and all the physical states of helium (low temperatures, NMR and MRI). The team also works on theoretical and fundamental aspects of quantum theory, in particular efforts are made to develop a dynamic model that realises the Von Neumann collapse under the effect of gravity.

CONSIDERATION OF THE RECOMMENDATIONS OF THE PREVIOUS REPORT

Some recommendations were made in the previous report and have been globally considered, given the difficult context of the evaluation period. Regarding scientific production and activities, the committee recommended that "The team should be attentive to finalizing pending studies and to publishing their results." The team is now reduced to three permanent staff following the decease of a professor in 2019, and the retirement of the group leader in 2023, even he is still active in research as an emeritus CNRS director of research. The committee made the comment concerning the HDR defence for younger members. The MCF of the team defended his HDR during the evaluated period.

The previous Committee recommended to "pursue formal collaborations with French or European research teams using spin-polarized 3He or 129Xe", and also to "pursue the idea of transferring concepts from hyperpolarized gas NMR towards manipulation of quantum bits". The team is involved in two collaborative ANR projects started in 2019 and 2020 that contribute to preserve the team expertise on hyperpolarized gases at the national level. As was already noticed by the previous Committee, the team still needs to increase its attractiveness in terms of the subjects it covers, to compete with more contemporary fields such as quantum technology, in order to recruit new permanent staff and to increase the number of PhD students and postdocs.

WORKFORCE OF THE TEAM: in physical persons at 31/12/2022

Catégories de personnel	Effectifs
Professeurs et assimilés	0
Maitres de conférences et assimilés	1
Directeurs de recherche et assimilés	1
Chargés de recherche et assimilés	1
Personnels d'appui à la recherche	0
Sous-total personnels permanents en activité	**3**
Enseignants-chercheurs et chercheurs non permanents et assimilés	1
Personnels d'appui non permanents	0
Post-doctorants	1
Doctorants	3
Sous-total personnels non permanents en activité	**5**
Total personnels	**8**

EVALUATION

Overall assessment of the team

The team's production is qualitatively of excellent quality, even though the quantitative aspect is moderate (16 major publications during the period, that is 0.8 /year/ETPR). Important original and innovative results have been obtained following the development of a new alternative measurement technique in the cavitation experiment of superfluid helium4. These compressibility measurements, combined with previous density measurements have allowed to estimate the cavitation pressure, which clearly disagreed with previous estimates. This may lead to a better understanding of nucleation in experiments related to the phenomenon of cavitation. The team also obtained a major result in the investigation of the He3 hyperpolarisation process and methodology progress in NMR and MRI technology at low magnetic field and its possible applications in medical and biological domains.
The team is recognized nationally and internationally and benefits from an important visibility as evidenced by the numerous national and international collaborations and partners. The team is well involved in financing and managing its research activity as witnessed by its role in the international MARGIN project (2020 – 2024). The project HELPING (ANR, 2021-2025) aims to target the nuclear-spin-1/2 isotopes (3He and 129Xe), involved in a variety of basic or applied physics experiments, as well as in NMR-based studies in chemistry, material sciences, biology, or medicine.
Outstanding results were obtained in the nuclear spin hyperpolarisation (HP) of 3He in gas discharges as well as in low field NMR and MRI. A timely research activity aims to identifying the physical mechanism of the recently discovered high field HP method called polarisation of atoms in a magnetized plasma. In relation to these studies an experimental activity has been developed to implement a spatially and temporally resolved stimulated Brillouin spectrometer efficient to measure the compressibility of the metastable states of superfluid 4He.

Strengths and possibilities linked to the context

The scientific activity of the team is timely and original. The team benefits from a unique scientific expertise and know-how that allow to successfully develop its research activity in the field of high nuclear polarisation in 3He. The team has developed more specialised instruments to achieve the different new experiments. The team is very active in seeking collaborations and in financing its experimental projects. The production of the team is of excellent quality.

Weaknesses and risks linked to the context

The team's experimental research themes on low temperature physics have established a limited connection with today's well-supported quantum technologies and the recruitment of doctoral students is probably impacted because doctoral students tend to be more attracted by quantum technologies.

The significant reduction in workspace within the ENS-PSL department in recent years has had a significant impact on the team's polarized helium projects in terms of both research and equipment, and therefore on the attractiveness of the team as a whole. The lack of manpower in this team is a severe risk for the future.

Analysis of the team's trajectory

The team will continue its research activity over the next five years along the same lines as its current research without major changes in its themes announced. In particular, it plans to continue developing its helium4 project. Note that this activity has been slowed down by the departure of the doctoral student who largely contributed to obtaining significant results on this subject.

The scientific research project of the team will focus, essentially, on two objectives. The first objective is devoted to achieving a direct measurement of the cavitation pressure of superfluid helium4 at 1 K by developing simultaneous measurements of both the density and the compressibility of the liquid at the destabilization threshold. As for the second objective, the team focuses on the application of the Brillouin compressibility measurement method to acoustically-induced metastable states of solid helium4 where the team has discovered an unexpected instability.

The team also intends to resume experimental projects on helium3 which suffered from difficulties encountered over the last two years due to laboratory closure.

The team will suffer from a lack of workforce and is already not large (4 including an emeritus). Among the three permanent members, there is an upcoming retirement with emeritus status who plans to stay actively involved in a project of hyperpolarisation. New application-driven collaborations are under consideration, in particular in Europe for NMR-based magnetometry and metrology involving hyperpolarised 3He gas. Also, the team plans to continue its collaboration with the LSDRM in Saclay, as part of the HELPING project, on experimental and theoretical investigations of hyperpolarisation in helium gas discharges.

The launch of work focused on investigations of mechanisms and operating conditions at intermediate field intensity should be emphasized. This work aims at widening the scope of innovative tools, triggered by the renewed interest for dissemination of low-field, low-cost, and low impact NMR and MRI systems.

Theoretical activity is carried out mainly by a distinguished emeritus on the well-known difficulty of the traditional "Bohm" interpretation of quantum mechanics to get a clear form of field theory.

Investigations are going on to explore a different version where the guidance equation is based, in particular, on the energy current and to establish its relation with gravity theory.
Given the large number of projects, the lack of manpower is a real problem.

RECOMMENDATIONS TO THE TEAM

The first recommendation is to establish thematic contacts with other teams. This may be relevant, particularly to make the connection to quantum technologies where similar problems or analogies may arise. This may also help to find other financial supports with the possibility to recruit postdocs and more importantly PhD students. The team is encouraged to develop more activity towards social (medical) applications by using its precious expertise and know-how, in particular in the field of MNR and MRI. The team should secure its unique expertise in Helium super-polarisation. Finally, the team should establish, in connection with the LKB governance, an evolution strategy to compensate for the upcoming departures (retirement), for instance by getting priority in CNRS or faculty openings.

Team 10: Complex media optics

Name of the supervisor: Mr Sylvain Gigan

THEMES OF THE TEAM

The complex media optics team, located at the Lhomond site, carries out original research focusing on light control and manipulation tools, the physics of the propagation of light in complex media, with a strong expertise in advanced computational imaging, Raman spectroscopy, and optical computing applications. These themes address scientific challenges at the interface of a wide range of disciplines, such as computer science, biology, chemistry and material science.

CONSIDERATION OF THE RECOMMENDATIONS OF THE PREVIOUS REPORT

No specific recommendations were raised in the former report. One comment concerned increasing collaboration and interaction within LKB, in order to broaden the size of the group and the research topics. In terms of personnel, during the period of evaluation the team welcomed a new permanent member CNRS researcher and drastically increased the number of postdocs and PhD students (around 15 persons). These aspects demonstrate how the team has continued to develop his research activities actively by harnessing strong national and international partnerships supported by multiple grants.

WORKFORCE OF THE TEAM: in physical persons at 31/12/2022

Catégories de personnel	Effectifs
Professeurs et assimilés	1
Maitres de conférences et assimilés	0
Directeurs de recherche et assimilés	0
Chargés de recherche et assimilés	1
Personnels d'appui à la recherche	0
Sous-total personnels permanents en activité	**2**
Enseignants-chercheurs et chercheurs non permanents et assimilés	6
Personnels d'appui non permanents	0
Post-doctorants	6
Doctorants	5
Sous-total personnels non permanents en activité	**17**
Total personnels	**19**

EVALUATION

Overall assessment of the team

The team's scientific activities are recognized nationally and internationally at a level of excellence in the fields of light propagation and control in complex media, advanced imaging, computational imaging, and more recently on optical computing. The team is positioned at an exceptional scientific level in cutting-edge, interdisciplinary fields, thanks in particular to the emergence of new scientific and technological challenges such as wave front shaping, super-resolution imaging and artificial intelligence in which the team had developed visionary expertise.
The scientific output is exceptional in terms of volume and quality of publications. During the evaluated period, PhD students benefited from an original kind of supervision and environment, based on original managerial approaches and the use of various tools and digital platforms, that replaces the more traditional way of supervising. The team's international impact is also impressive. This is reflected by the fact that most of the team's invited lectures are given at many prestigious conferences in the field, and in the prestigious national and international prizes that have been awarded to the leader of the team.

The team's attractiveness is excellent on national and international level, particularly when it comes to recruiting PhD students.
The team is developing a strong partnership with various socio-economic players at regional and national level, with numerous industrial projects, patents and one start-up co-founded in 2016, for example.

Strengths and possibilities linked to the context

The team's scientific activity is outstanding, at the top level of research worldwide. The team benefits from state-of-the-art know-how in the light control and manipulation tools, the physics of propagation of light in complex media and disordered materials, but also in advanced computational imaging, which it has been able to use to become a key player in emerging fields such as artificial intelligence in optics and photonics, as well as in imaging in complex media at the interface with biology and chemistry.

Noteworthy, this team counts only two permanent researchers (ETPR = 1.5), one benefitted from ERC dispense) and many more non-permanents researchers, which highlights the scientific business model towards which part of the LKB is growing. The team's scientific production is exceptional and of high standard, with close to seventy publications, among which many publications in Nature, PRL and Phys. Rev X. The publication rate, which has exceeded 8 publications/ETPR/year in recent years, is impressive and of course supported by the many non-permanent researchers. The team's international profile is exceptional. This is reflected by a high rate of publications co-authored by foreign universities and by the large number of invited lectures (73) at prestigious conferences in the field (8 are plenary, keynote or tutorial lectures at major international conferences).

The dynamism and excellence of the team members is reflected by the numerous awards they have received and the high level of national and international recognition they have achieved: two 'Highly cited papers' in Web of Science, a junior IUF, numerous conference and school organizations and awards as OPTICA Fellows and OPTICA Senior Member.

Among the fifteen PhD students/Post-docs, more than half comes from foreign universities (Brazil, China, Israel, Korea, Poland and Italy). The team also attracted multiple fellowships such as Marie Curie Fellow, Cambridge Fellow, SNF Fellows, and more than ten invited professors and researchers.

The large number of research projects at European and national level, from competitive calls such as ERC and H2020 – FET OPEN highlight the team's excellent dynamism and attractiveness.

The team is developing a strong partnership with socio-economic stakeholders, in particular through Lighton, co-founded in 2016 by the PI of the team.

Weaknesses and risks linked to the context

The large number of PhD students, postdocs and interns, and the small number of senior scientists leads to a deficit in supervision if the number of students continues to increase in the future.

Analysis of the team's trajectory

During the next term, the team aims to develop its research in three main fields: 1) advanced imaging and propagation of light in complex media, 2) Optical and neuromorphic computing and 3) a totally new field for the team involving new approaches combining wavefront shaping and battery design. For the first two, the team is already an international leader. All these areas of research are highly competitive at world level. It is also mentioned in the self-assessment document that the team will need to continue to improve its skills in computational methods such as machine learning. This means that the team will have to manage somehow to maintain the same level of excellence in these active and competitive areas by making new recruitments with multidisciplinary profiles (mainly in machine learning and optics) and by increasing the current amount of permanent research staff (1.5 ETPR), also given that the group leader is going to be part of the LKB executive board in the next term.

RECOMMENDATIONS TO THE TEAM

The committee congratulates the team on maintaining an excellent level and encourages it to maintain the current level.

Given the many team activities and the large number of PhD students, postdocs and interns, a long-term vision on needs and strategy would make it possible to increase the number of permanent researchers, with HDR. This strategy should also anticipate new responsibilities of the group leader (proposed as one of the deputy directors of LKB, and currently already acting deputy) of the teams and space constraints due to the various projects running in parallel.

Team 11: Metrology of simple systems and fundamental tests

Name of the supervisors: Mr François Nez, Ms Saïda Guellati-Khelifa & Mr Paul Indelicato

THEMES OF THE TEAM

The research of the team, located at the Sorbonne Université campus, is devoted to high-precision measurements in atoms and exotic atoms and their analysis, and aims at testing the standard model of particle physics as well as at determining fundamental constants of nature. Its scientific activity which comprises both experiment, theory and numerical simulations, is organized in three largely independent subgroups which have both their own, specific projects and projects shared with other teams at LKB.
The group-specific activities concern (i) atom interferometry, with a special focus on the precision determination of the fine-structure constant through measurements of the photon-recoil velocity of rubidium (and in a recent development also ytterbium) using ultracold atomic samples and recently frequency combs; (ii) precision spectroscopy of the hydrogen atom and muonic hydrogen to test quantum electrodynamics in light atoms and determine the Rydberg constant and the proton charge radius; and (iii) studies of highly charged ions and muonic atoms to test quantum electrodynamics in heavy many-body atoms and to characterize heavy nuclei.
The team plays an important role in several international collaborations usually requiring large facilities, such as the GBAR collaboration devoted to gravitational measurements in antimatter, to which all three subgroups contribute; the CREMA collaboration that aims at measuring the Lamb shift in light muonic atoms, to which groups (ii) and (iii) contribute; the SPARC collaboration for experiments on stored highly-charged ions, as well as collaborations on nuclear-size measurements in muonic atoms, on parity violation in Radium, on microcalorimetry in exotic atoms, on new sources of ultracold light particles and atoms to study their quantum properties in a gravitational field, and finally on the observation of gravitational waves.
Through its group-specific activities and its extensive network of collaborations, the team contributes to a broad range of topics in metrology and atomic, nuclear and fundamental physics.

CONSIDERATION OF THE RECOMMENDATIONS OF THE PREVIOUS REPORT

The recommendations of the previous report were threefold.

1) Team leaders and younger permanent staff could be encouraged to seek additional international funding opportunities, like ERC, the EU metrology program managed by Euramet, or NIST metrology grants. With their highly topical research program and their activities in prominent international cooperations, applicants from this team could expect good prospects from such funding programs.
This aspect has been partially addressed during the current evaluation period. Three NIST international projects have been granted (about 200 k€ in total). Funding from H2020 Horizon Europe is still absent during the period (an ERC starting grant will begin in 2024). The team is very successful in national calls for tender, with several grants funded by ANR and, more recently, also financial support from France 2030, PEPR QFCA, and labex First-TF programmes.
2) The new project GBAR offers a good opportunity to intensiify the internal cooperation with the team trapped ions, that follows a strongly related scientific motivation with complementary experimental methods.
3) The group should continue to follow its sound strategy. The long-term character of the group's highprecision experimental projects requires a strategic planning and attention to new opportunities for developing the topics and methods further.
Recent high-level scientific results have been obtained by the group and reported in high-quality publications. The team successfully pursues its long-term strategy. The recruitments of one permanent researcher and one temporary hire funding until 2024 have opened new opportunities and generated a positive dynamic, enabling new activities in atom interferometry with ytterbium atoms, the development of quantum sensors for spectroscopy of muonic and antiprotonic atoms and experiments on quantum reflection and upgrades of the experimental facilities.

WORKFORCE OF THE TEAM: in physical persons at 31/12/2022

Catégories de personnel	**Effectifs**
Professeurs et assimilés	1
Maitres de conférences et assimilés	2
Directeurs de recherche et assimilés	2
Chargés de recherche et assimilés	2
Personnels d'appui à la recherche	0
Sous-total personnels permanents en activité	**7**

Enseignants-chercheurs et chercheurs non permanents et assimilés	2
Personnels d'appui non permanents	0
Post-doctorants	0
Doctorants	6
Sous-total personnels non permanents en activité	**8**
Total personnels	**15**

EVALUATION

Overall assessment of the team

The scientific quality of the team is excellent and highly recognized internationally. Very important milestones have been achieved by all three groups during the evaluation period, including exceptionally precise measurements of the Lamb shift and hyperfine splitting in H-like and He-like heavy ions, of the photon-recoil shift in Rubidium, and of the 1s-3s transition of the hydrogen atom. These measurements contribute to the accurate determination of the fine-structure constant and the Rydberg constant and to test the standard model of particle physics. The most recent result of the team in 2020 has put the uncertainty of the fine structure constant beyond eleventh digit, with considerable impact. On the theory side, the team provides internationally leading expertise in the quantum-electrodynamics (QED) treatment of H-like ions and in the solution of the relativistic many-body problem in heavy atoms. The successes and the international high standing of the team is not only illustrated by the numerous high-quality publications and the large number of invited lectures at major conferences, but also by the excellent integration in large international collaborations.
The team is successful in securing competitive funding from ANR and national funding programmes (PEPR, labex), as well as internationally from the precision-measurement grant program of NIST. Researchers in the subgroups of "hydrogen spectroscopy" and "heavy ions and exotic atoms" have received prizes from the French Physical Society. The research of the team since 2017 is documented in more than eighty peer-reviewed articles (2.4 publication /year/ETPR), eleven contributions to conference proceedings and has been presented in forty-seven invited lectures at workshops and conferences. Six PhD theses and one HDR have been completed between 2017 and December 2022. Particularly noteworthy is the large number (41) of popular scientific contributions on metrology, several of which were stimulated by the recent revision of the SI unit system. This activity demonstrates that the team is a sought-after and highly respected provider of information on metrology in France and beyond, and also illustrates the considerable efforts invested by the team in outreach activities.

Strengths and possibilities linked to the context

The main strength of the team is the combination of high-quality research projects based on the expertise of the three groups in atom interferometry, hydrogen spectroscopy, the spectroscopy of highly-charged ions, and theory (bound-state quantum-electrodynamics and relativistic treatment of many body atoms) with projects involving international collaborations and large facilities. Through the specific competences of the three groups, the team is a highly demanded partner for such collaborations and has a high impact. A second strength is the excellent and diverse research program in fundamental physics and the continuous contributions over many years to very impactful projects on (i) the determination of physical constants, such as the fine-structure constant and the Rydberg constant, (ii) tests of quantum electrodynamics and of the standard model of particle physics, and (iii) exotic atoms (antihydrogen, muonic hydrogen, muonic atoms). A third strength is the high level of technical expertise and instrumentation available in the different groups for atom interferometry, frequency metrology, and experiments on highly charged ions. A fourth strength is the integration, in the past years, of very promising and talented young permanent researchers in the groups of "hydrogen spectroscopy" and "heavy ions and exotic atoms". Finally, the team has a very strong theoretical activity (QED and relativistic many-body problem), which provides great opportunities and synergies between theory, numerical simulations and experiments.

Weaknesses and risks linked to the context

The broad scope and quality of scientific activities is exceptional for a team involving only fifteen researchers. Both can be maintained at present thanks to a good balance between experienced senior researchers and dynamical junior researchers, and the involvement of two emeriti. In the future, the need of a consolidation may arise and this represents a certain risk. The continuation of the new project "atom interferometry with ytterbium" is threatened through the end, in 2024, of the fixed-term contract of the researcher driving this project.

The increasing number of international collaborations may result in a shortage of work force that could, in the long term, be detrimental for the group-specific projects that are equally important.

The focus on metrology may (unjustifiably) not appear as attractive as other topics to students that are about to start a PhD. This aspect, combined with the lack of postdocs, is currently a weakness of the team. This weakness is fortunately largely compensated by the recent hiring of very dynamical young permanent researchers and PhD students.

Analysis of the team's trajectory

The team has a long tradition of research excellence in metrology and is internationally regarded as one of the center of excellence in this field. The research of all three groups has developed very positively during the evaluation period. The team has an excellent long-term research strategy, which is convincingly presented in the evaluation report.

Through the recruitment of talented permanent young researchers, the teams "hydrogen spectroscopy" and "heavy ions and exotic atoms" have been able to consolidate their activities (upgrades of existing experimental facilities, strengthening of international collaborations) and initiate new promising directions such as the development of quantum sensors for spectroscopy of muonic and antiprotonic atoms and the development of experiments on quantum reflection and gravity with cold H atoms. New experiments will be carried out on muonic hydrogen to better characterize the proton and the heavy-ion facility will be upgraded.

The group "atom interferometry" has also initiated new promising directions: integration of a frequency comb in the atom-interferometric experiments and extension of the photon-recoil experiments to ytterbium atoms, however, only through a young researcher on a fixed-term contract (Junior Research Chair labex-ENS-PSL-ICFP) until 2024. The team considers a recruitment within the next two years in this group to be vital for the continuation of these new directions in the atom-interferometry group. The main short-term goal is the clarification of the five-sigma discrepancy between the values of the fine-structure constant determined from atom-recoil experiments.

On the theory side, the focus will be placed on refining the QED treatment of H-like ions, to extend it to antiprotonic atoms and on improving the (already advanced) code for the solution of the relativistic many-body problem in heavy atoms.

RECOMMENDATIONS TO THE TEAM

The committee recommends all permanent researchers to pursue their efforts in obtaining international funding from the ERC and European programs in metrology. The high impact of their research in the past years represents an excellent starting point. The team would also benefit from the recruitment of one or two additional PhD students and one or two postdocs. The international collaborations are extremely successful and illustrate the high attractivity and high quality of the team. Their increasing number may result in a shortage of work force affecting the equally important group-specific projects. The team should continue its efforts to maintain enough work force and technical and instrumental resources to accomplish its key activities.

Team 12: Trapped ions

Name of the supervisor: Mr Laurent Hilico

THEMES OF THE TEAM

The team's activities are centred around precision spectroscopy on trapped ions, with a special focus on the spectroscopy of H2+ and HD+. This fundamental research involves both theory and experiment. H2+ and HD+ are molecules with a single electron and its spectrum can be calculated with extreme precision. The team is involved in the detailed comparison of theoretical predictions with experimental results obtained at high-resolution, which enables testing the theory (molecular quantum mechanics with full treatment of nonrelativistic and quantum electrodynamics corrections). It also provides a route to determine physical constants such as the proton-to-electron mass ratio and the proton-charge radius.

This activity is extended by an experimental project devoted to studies of sympathetic cooling of target ions using their interactions with laser-cooled ions in RF ion traps for applications to cooling of antimatter ions (e.g., antiprotons and Hbar+) in the realm of the GBAR collaboration.

CONSIDERATION OF THE RECOMMENDATIONS OF THE PREVIOUS REPORT

The recommendations of the previous report were threefold
1) The team's scientific production has been at a high level so far and its activity on the hydrogen molecular ion has found timely applications in large-scale projects of relevance to fundamental tests, metrology, and ion clocks. It has the potential to further strengthen its visibility and impact by improving on public outreach.
The team leader has contributed to two popular scientific publications on the subjects of antimatter and the scientific method, and the team has been involved in the organization of two meetings on precision physics. More outreach activities could have been beneficial. In this context it is important to note that the team has a high teaching load at the university of Evry and rightly focuses its efforts on maintaining a high scientific productivity.
2) The team size might become critically low in the next period and its scientific activity could have to rely excessively on external collaborations and the hiring of post-doc researchers. Long-term viability of the team could be compromised by the departure of one member. Synergies and coordination with team 11, which shares several scientific interests notably through the involvement in the GBAR project, could strengthen the overall contribution to the project without hampering the specific contributions of the team in its current form.
In the self-assessment report, the team mentions the difficulties in hiring postdoctoral researchers and the fact that it did not have opportunities to recruit new members on permanent positions in the past years. It also admits that its "non-aggressive human resource policy" is a weakness. This indicates that this recommendation has been considered but that no solution has been found yet.
3) The overall strategy is sound and ambitious and benefits from the close connection between theory, experiment, and simulation. The team is encouraged to strengthen its visibility within the GBAR project to which it is increasingly contributing.
The team contributes to the GBAR project and six peer-reviewed articles and two conference proceedings document this activity. The list of publications provided by the team for the evaluation only includes three of these articles and thus underestimates this activity.

WORKFORCE OF THE TEAM: in physical persons at 31/12/2022

Catégories de personnel	Effectifs
Professeurs et assimilés	1
Maitres de conférences et assimilés	2
Directeurs de recherche et assimilés	0
Chargés de recherche et assimilés	0
Personnels d'appui à la recherche	0
Sous-total personnels permanents en activité	**3**
Enseignants-chercheurs et chercheurs non permanents et assimilés	0
Personnels d'appui non permanents	0
Post-doctorants	0
Doctorants	4

Sous-total personnels non permanents en activité	**4**
Total personnels	**7**

EVALUATION

Overall assessment of the team

The team, located at the Jussieu campus, has a state-of-the-art expertise in precision spectroscopy on molecular hydrogen ions. It is embedded in an excellent network of national (teams from LAPTh, MPQ, LPL) and international (teams at Vrije Universteit, Amsterdam; Florida State university, Thallahassee, USA; Technion, Israel; The university of Cincinnati, USA; Nagoya university, Japan) collaborations and actively contributes to the GBAR collaboration. The team is also involved with two other laboratories MPQ (Paris) and PIIM (Marseille) in the Gbarproxy project which investigates how to cool ions of low mass through their electrostatic interactions with laser-cooled ions of higher mass (sympathetic cooling).
The team has developed, over the years, an impressive, even unique, experimental infrastructure to measure the spectrum of the fundamental three-body molecular ion H2+ with unprecedented precision and accuracy. The fruits of the efforts invested in this project will be earned when the first measurements will have been performed. The team is also world leading in first-principle calculations of the properties of H2+ and HD+ and numerous highly visible results have been published in the past years that are used as state-of-the-art references.
The team has secured competitive funding from ANR and regional and national funding programmes (SIRTEQ Région Île-de-France, QUanTiP Région Île-de-France, labex FIRST-TF). Its scientific output is documented in twenty-six articles in peer-reviewed journals (2.9/year/ETPR), three conference proceedings, three book chapters, ten invited conferences as well as two patents. Several of these contributions are the product of large international collaborations (e.g., GBAR). Four PhD theses have been completed between 2017 and December 2022. The articles on the theoretical activities of the group deserve a special mention as they have moved the frontiers in precision calculations in simple molecular systems and paved the road to use H2+ and HD+ as systems to determine physical constants and to test fundamental theory. As a result of this activity, the team was invited to be part of an international committee to make recommendations for the next global adjustment of the fundamental constants that will include new experimental results obtained on HD+.
Considering the small size of the team (3 permanent staff members with heavy teaching load (ETPR = 1.5) and four PhD students and its limited financial resources, this output is remarkable.

Strengths and possibilities linked to the context

Precision spectroscopy in the fundamental ions H2+ and HD+ has become a very topical research area because of its significance for the determination of physical constants and for testing fundamental theories. The team was one of the first groups active in this field and enjoys a high recognition.

The team possesses the key advantage of having state-of-the-art activity in both theory and experiment, which provides a competitive advantage over other groups. It is also involved in the CODATA task group on fundamental constants, so that it covers all facets of this important topic.

The team makes the most accurate first-principles calculations in three-body quantum systems that exist today, and its theoretical results are highly requested by several other experimental groups.

The team has developed a unique experiment to measure Doppler-free two-photon transitions between vibrational levels of H2+ and may be the first to measure ultraprecise transition frequencies in this fundamental ion. All components of the experiments are operational and have been tested and there is a large potential for a breakthrough to occur in the coming years.

The team maintains several excellent collaborations with scientists bringing complementary expertise (e.g., V. Korobov in Dubna on the theory side, the group J. Koelemeij in Amsterdam on the experimental side, and the MMT group at LPL for access to SI-traceable frequency calibration, the group QITEW of the MPQ laboratory at université Paris Cité). The team makes an important contribution to the GBAR collaboration and the GBARproxy project.

Weaknesses and risks linked to the context

The experimental activity is resource intensive, both in terms of personnel and equipment. The difficulties associated with the recruitment of postdocs mentioned in the self-assessment document represents a risk. At present, the experimental activity benefits from the excellent support provided by the optics and instrumentation platforms.

While the simultaneous state-of-the-art activities in theory, experiment and simulations is a strength and trade-mark of the group, they require large efforts from the three permanent researchers of the team, who are all heavily involved in teaching activities at the university of Evry. This may soon become a threat if a solution is not found to free or generate new capacities for research within the team.

A structural weakness is the lack of promotion perspectives for the two associate professors related to the fact that Evry is not among the supervising units of LKB.

Analysis of the team's trajectory

The team’s trajectory is well defined with well-defined roles for its three members. Now that all components of the experiment designed to measure the rovibrational transitions in H2+ have been tested individually, the next steps involve the actual measurement of these transitions and the exploration of systematic effects. The coming phase is thus of crucial importance and likely to yield results of considerable scientific significance. On the theory side, the planned extension of the current theoretical work on the properties of H2+ and HD+, which is needed to provide the reference theoretical data needed for the comparison with the results of the next generation of experiments, is important but highly non-trivial: it requires a switch from the current non-relativistic-QED treatment to a fully relativistic treatment and the development of non-perturbative methods to evaluate QED corrections. If successful, this work, for which the team will benefit from advice from the team "Métrologie des systems simples et tests fondamentaux", will open up new perspectives. The studies of the sympathetic cooling dynamics of fast Be+ ions with laser-cooled Sr+ ions planned for the next phase are important, also in the light of long-term projects aiming at producing the Hbar+ ion (made up of an antiproton and two positrons) at CERN.

The projects of the team are well thought over and have good prospects of being successful. The activity will benefit from the national and international collaborations established in the past years. A potential concern is the high teaching load of all three permanent members. The work force of 1.5 EQRT is small in view of the ambitious goals of the team.

RECOMMENDATIONS TO THE TEAM

The main bottleneck in the scientific activity is the small work force. The experimental activity would really benefit from an experienced postdoctoral researcher. The theoretical activity could be significantly boosted by a reduction of the teaching load, and an application to IUF is strongly recommended. Applying for support from the ERC is also suggested as a means to recruit additional work force and to mitigate the teaching load. The scientific excellence of the ongoing projects justifies to apply for such grant.

Given the thematic proximity with the team “Métrologie des systems simples et tests fondamentaux”, an intensification of the scientific contacts between these two teams is recommended. The common activities within the GBAR collaboration, the share of frequency-metrology tools, stimulated by the successful involvement of one researcher in both teams, and the interactions of the researchers of both teams involved in theory represent an excellent basis for this intensification.

The simultaneous presence of state-of-the-art activities in theory and experiment in this team, with a significant involvement and collaboration of all three permanent researchers, is a very precious asset. The team should remain aware of the risks of a fragmentation that could arise from the high project-specific demands on the theory and experimental sides of the activity.

CONDUCT OF THE INTERVIEWS

Dates

Start: Monday 16 October 2023 at 08:30

End: Wednesday 18 October 2023 at 16:00

Interview conducted: on-site

INTERVIEW SCHEDULE

Lundi 16 octobre 2023 sur le site de Sorbonne-Université (4 place Jussieu)

Monday 16 October 2023 at Sorbonne-Université (4 place Jussieu)

08:45 - 09:00 Introduction of the committee and the program
09:00 - 10:30 Presentation by the unit director
10:30 - 11:00 Closed meeting of the committee - break
11:00 - 12:00 Presentation of the quantum optics and quantum information theme
12:00 - 14:00 Break
14:00 - 14:45 Presentation of the fundamental Interaction testing and metrology theme
14:45 - 15:00 Closed meeting of the committee
15:00 - 15:45 Closed meeting with doctoral and post-doctoral students
15:45 - 16:00 Closed meeting of the committee - break
16.00 - 18.15 Visits to experiment rooms

Tuesday 17 October at the École normale supérieure-PSL, rue Lhomond

09:00 - 10:00 Presentation of the quantum gases research theme
10:00 - 10:15 Closed meeting of the committee - break
10:15 - 11:00 Presentation of the atoms and light in dense or complex media theme
11:00 - 11:30 Closed meeting of the committee - break
11:30 -12:00 Closed meeting with IT platform director
12:00 -12:45 Closed meeting with team leaders
12:45 -13:00 Closed meeting of the committee
13:00 -14:30 Break
14:30 -15:15 Closed meeting with Biatss, ITA and CDD staff
15:15 - 15:30 Close meeting of the committee
15:30 - 16:15 Closed meeting with researchers and teacher-researchers
16:15 -16:30 Closed meeting of the committee
16:30 -18:00 Visits to experimental rooms

Wednesday 18 October 2023 at the Collège de France, Place Marcellin-Berthelot

09:00 - 09:45 Presentation of the frontiers and applications theme
09:45 - 10:00 Closed meeting of committee – break
10:00 - 11:45 Visits to experimental rooms
11.45 - 12.00 Closed meeting of committee
12:00 - 13:30 Break
13:30 -14:15 Closed meeting with the supervisory authorities
14:15 - 14:30 Closed meeting of the committee
14:30 -15:30 Closed meeting with the unit management
15:30 - 17:30 Closed meeting of the committee

GENERAL OBSERVATIONS OF THE SUPERVISORS

Marie-Aude Vitrani
Vice-Présidente Vie institutionnelle et démarche participative
Sorbonne Université

à

Monsieur Eric Saint-Aman
Directeur du Département d'évaluation de la recherche
HCERES – Haut conseil de l'évaluation de la recherche et de l'enseignement supérieur
2 rue Albert Einstein
75013 Paris

Paris, le 6 mai 2024

Objet : Rapport d'évaluation DER-PUR250024428 - LKB - Laboratoire Kastler Brossel

Cher Collègue,

Sorbonne Université vous remercie ainsi que tous les membres du comité HCERES pour le travail d'expertise réalisé sur l'unité de recherche « LKB ».

Sorbonne Université n'a aucune observation de portée générale à formuler sur le rapport d'évaluation transmis.

Je vous prie d'agréer, Cher Collègue, l'expression de mes cordiales salutations.

Marie-Aude Vitrani
Vice-Présidente Vie institutionnelle
et démarche participative

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