# LKB - Laboratoire Kastler Brossel

Rapport Hcéres

agence d'évaluation de la recherche
et de l'enseignement supérieur

Section des Unités de recherche

# Evaluation report

## Research unit :

## Laboratoire Kastler Brossel (LKB) – UMR 8552

## Ecole Normale Supérieure

March 2009

agence d'évaluation de la recherche
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# Ecole Normale Supérieure

Le Président
de l'AERES

**Jean-François Dhainaut**

Section des unités
de recherche

*Le Directeur*

**Pierre Glorieux**

march 2009

# Evaluation report

## The research unit :

Name of the research unit : **Laboratoire Kastler Brossel** (LKB)

Requested label : **UMR**

N° in case of renewal : **8552**

Head of the research unit : **Mr Paul INDELICATO**

## University or school :

**Ecole Normale Supérieure**

## Other institutions and research organization:

**Université de Paris 6**

**CNRS**

## Date(s) of the visit :

January, 29th and 30th, 2009

# Members of the visiting committee

## Chairman of the comittee :

Mr Jook WALRAVEN (Van der Waals Zeeman Institute, Amsterdam)

## Other committee members :

Mr Ekkehardt PEIK (PTB, Braunschweig)

Mr Hervé RIGNEAULT (Institut FRESNEL, Marseille)

Mr Alain BRILLET (Observatoire de Nice)

Mr Ariel LEVENSON (LPN , Marcoussis)

## CNU, CoNRS, CSS INSERM, (représentant INRA, INRIA, IRD...) representatives :

Mr Philippe BOUYER, CoNRS

Mr Georges BOULON, CNU

# Observers

## AERES scientific representative :

Mr Jean-Michel ROBBE

## University or school representative:

Mr Yves GULDNER (Directeur de la Recherche à l'ENS)

Mr Jean Michel RAIMOND (Directeur du Département de Physique de l'ENS)

## Research organization representative (s) :

Mr Christian CHARDONNET (représentant l'Institut de Physique du CNRS)

Mr Jean-Bernard ZUBER (représentant l'Université Pierre et Marie Curie)

## 1 • Short presentation of the research unit

- Numbers of lab members including researchers with teaching duties and full time researchers (50 + 4 emeriti), ingeneers (6), PhD students (42), technicians and administrative assistants(19)
- Numbers of HDR (37)and of HDR who are PhD students avisors (22)
- Numbers of PhD students who have obtained their PhD (47) and average lenght of a PhD during the past 4 years (40 months)
- Numbers of PhD students currently present in the research unit (42) ; Numbers of PhD students with fellowships (42)
- Numbers of lab members who have been granted a PEDR (14)
- Numbers of "publishing" lab members (50) among researchers with teaching duties and full time researchers

## 2 • Preparation and execution of the visit

The comité d'évaluation du LKB on 29-30 January has reviewed the activities of the laboratory.

**Jeudi 29 Janvier :**

- 8h15-8h30 Accueil
- 8h30-8h45 Réunion fermée du Comité
- 8h45-9h30 Exposé du directeur
- 9h30-9h55 Introduction axe 1 (Jean Dalibard)
- 9h55-10h25 Pause café
- 10h25 Introduction axe 2 (Antoine Heidman)
- 10h50 Introduction axe 3 (Pierre-Jean Nacher)
- 11h00 Introduction axe 4 (Maxime Dahan)
- 11h15 Introduction axe 5 (François Biraben)
- 11h40 Discussion générale, préparation des visites
- 12h00-13h30 Déjeuner avec le comité et chefs d'équipes (Recherche et support)
- 13h30-18h Visites équipes
- 19h30 Diner (avec les membres du Conseil Scientifique)

**Vendredi 30 Janvier :**

- 8h15-8h30 Accueil
- 8H30-9H30 Réunion préliminaire huis clos du comité
- 9h30-11h30 Visites équipes
- 11h30-12h15 Rencontre avec les représentants du conseil de laboratoire et les ACMO
- 12h15-13h30 Déjeuner avec le comité, doctorants, post-docs, jeunes chercheurs
- 13h30-14h00 Rencontre avec les représentants des doctorants et post-docs
- 14h00-14h45 Discussion avec les représentants des tutelles (ENS, CNRS, UPMC)
- 14H45-15H15 Discussion huis clos du comité 1ère partie
- 15h15-15h35 Discussion avec la direction
- 15H35-15H50 Pause café
- 16h-18h Fin de la discussion huis clos du comité

All material presented to the Committee was of excellent quality and so was the organization of the day: the atmosphere was optimal in order to allow the Committee to work with maximum effectiveness. Nevertheless, the Committee would have profited from more time for internal discussions and discussions with the management and speakers.

# 3 • Overall appreciation of the activity of the research unit, of its links with local, national and international partners

The *Laboratoire Kastler-Brossel* (LKB) is a world-class institution active in the field of modern atomic, molecular and optical (AMO) physics with strong links to condensed matter physics and quantum information processing. With in its midst an inspiring Nobel Laureate, its staff operates with high visibility in a well proven joint effort of the ENS, the *Université Pierre et Marie Curie* (UPMC) and the *Centre National de la Recherche Scientifique* (CNRS). The laboratory is located at three sites: *Ecole Normale Supérieure*, *Université Jussieu* and *Université d'Evry*.

The laboratory reported major scientific advances over the full spectrum of its scientific activity. To the finest results obtained belong certainly: a) the quantum-non-demolition experiments in which photons can be counted without being destroyed using non-resonant circular Rydberg atoms; b) the first demonstration of the Berezinskii-Kosterlitz-Thouless transition in a two-dimensional quantum gas using matter-wave interference to investigate the proliferation of free vortices; c) the observation of the vacuum Rabi splitting caused by a Bose-Einstein condensate in a high-finesse optical microcavity in-between two optical fibers; d) the validation of the Cesium atomic clock for the PHARAO/ACES space mission as a major technological achievement; e) the elegant precision measurement of h-bar/m using momentum transfer by photons using Bloch oscillations in an optical lattice together with an atom-interferometry method; f) the study of micromechanical resonators (MEMS), demonstrating self-cooling of a micro mirror. Aiming for residual mechanical noise limited by quantum fluctuations, this research of this kind holds promise in technological applications of the finest kind, like in gravitational wave detection; g) the experiments on polariton spin dynamics and analogies between polariton transport and superfluid flow; h) noise-less amplification of images; i) the use of quantum dots for labeling and tracking of motor proteins in living biological cells.

All these advances underline the continuing scientific excellence of the senior staff. This quality is also evident from the dozens of invited lectures at international conferences and numerous recent prizes, like the 'Prix des trois Physiciens' of the ENS, the 'Grand Prix Jean Ricard' of the French Physical Society, the 'Charles Townes prize' of the Optical Society of America, the 'Great Cross of the order of merit' of Brasil, the Prix Aimé Cotton, appointments in the 'Institut Universitaire de France', the 'IBA-Europhysics' prize, etc.. The LKB combines internationally leading research with graduate and undergraduate education according to the highest international standards. In this way the laboratory plays a leading role in the graduate and post-graduate education of AMO physics in France. During the visit the committee was impressed by the quality of the PhD students and the success of the LKB in attracting excellent junior staff and postdocs.

Aside from the research the staff of the LKB is strongly engaged in the activities of many scientific and science related organizations, covering the full spectrum in France (College de France, Academy of Sciences, French Physical Society, Research Council of Paris …) and major international organizations, including advisory boards of the Max Planck Society, Physical Societies, international conferences and science publishers. The staff also active in outreach activities of various kinds.

The LKB vigorously and successfully competes for funding at the national and the international level. In addition to the CNRS and University funding and the Funding from the College de France the LKB was very successful in attracting financial support from the *Agence Nationale de Recherche* (ANR), including an *Institut Carnot*. A particularly successful initiative from the LKB was the foundation of IFRAF (*Institut francilien de Recherche sur des Atomes Froids*), a concerted activity of all parties active in the field of cold atoms in the Paris region, supported by the region Ile de France. The LKB also holds 7 European collaboration contracts and 6 extra-European contracts, including prestigious grants of the *European Research Council*.

The committee supports the policy of the director and his management team to define 5 areas of active research (*transverse axes de recherche*) as a caliber to monitor the vitality of the main research areas of the LKB. Also the clear definition and redefinition of research teams along this caliber is a positive indicator of actions to stimulate and demonstrate laboratory wide cohesion and attention for human resource management.

Floor space has been a pressing issue at LKB over the years. Two important actions are to be mentioned in this context. First the perspective of additional laboratory space at the College de France for the domain of quantum information with atoms (LKB) and semiconductors (*Laboratoire Pierre Agrain* of the ENS). The second action was initiated by IFRAF and resulted in additional office space. The committee noticed the difficult conditions under which the research has to be carried out alongside construction work at Jussieu and compliments the local staff for maintaining their positive attitude, scientific quality and productivity. An upcoming renovation of the ENS building, while offering a great opportunity to meet contemporary housing standards, offers again a challenge to the researchers as well as the management of the LKB and the ENS to minimize disruptions of the highly competitive research in the laboratory.

# 4 • Specific appreciation team by team and/or project by project

The research at the LKB is organized in 13 research teams, each consisting of one or more groups, and active along 5 main research areas:

**Research area 1 : Quantum Gases**

**1. Atom Chips**

This group was created in 2004 and results from an LKB initiative to attract a bright young researcher in the field of atom chips. This became possible with the aid of 'Young EURY' and 'Chaire d'Excellence' awards. The team is now composed of 4 permanents (1PR, 2MC and 1CR recently recruited), has trained (or is training) 7 PhD and 4 postdoctorants and hosted 2 visitors. In the context of setting up a new activity the scientific production is remarkable with 16 publications in peer-reviewed international journals among which 1 Nature and 5 Phys. Rev. Lett. and 12 invited presentations to international conferences. Initially the activities were strongly based on the "historical" collaboration with the T. Hänsch group at Munich. As the research activity developed, a considerable increase in importance of results obtained at LKB, both experimental and theoretical, was achieved. Today the 3 ongoing projects are developed within the LKB facilities. The principal highlight of the past 4 years is the demonstration of strong coupling between a Bose-Einstein condensate and an optical cavity on an atom chip. This was achieved mainly thanks to the development of an original, fibered optical microcavity and opens up several perspectives of applications in different domains. Among other highlights one can note the theoretical analysis of conditions for optimal spin squeezing in a BEC in the presence of losses and under conditions that can fruitfully guide the experimental demonstrations. The experimental demonstration of BEC expansion, achieved in the Bremen University tower, in the context of collaboration with SYRTE for the realisation of a microchip-integrated atomic clock, should also be highlighted.

The projects that will be carried out by the Atom Chip group are essentially a continuation of those under development, plus a few additional projects resulting from emerging international collaborations: ions chip (R. Blatt, Innsbruck), fibered optical cavity for colour centres (C. Becher, Sarrebruck) and micro-mirror cooling (A. Zeilinger, Vienne) a domain that could also benefit from the know-how already developed at LKB. In addition, the historical collaboration with T. Hänsch team is continuing.

**Conclusion: The Atom Chip group, well supported during the past quadrennial, has proved itself and is now constituted around a consistent core of permanent members. It is certainly a success story for the LKB scientific policy.**

| Note de l'équipe | Qualité scientifique et production | Rayonnement et attractivité, intégration dans l'environnement | Stratégie, gouvernance et vie du laboratoire | Appréciation du projet |
|---|---|---|---|---|
| A+ | A+ | A+ | A+ | A+ |

**2. Bose-Einstein Condensates**

The committee congratulates the LKB with this exceptional team (1DR1, 1DRCE; 1PHCdF, 1CR2, 1MC). The team combines the highest scientific quality with an impressive productivity as well as major administrative achievements with regard to IFRAF; 14 PhD-students, 9 PostDocs were or are trained; 6 senior visitors were hosted. The team consists of two groups.

One group (1DRCE, 1PHCdF, 1MC) works on the properties of metastable triplet helium and reported as a highlight the formation of exotic long-range molecules by photoassociation and extracted a precision value for the s-wave scattering length, a parameter of vital importance to describe the gas phase. With two-photon photo-association spectroscopy is was possible to populate the highest bound vibrational level of the quintuplet potential and to demonstrate for the first time a dark resonance between two free atomes and a molecule. From this measurement the mentioned scattering length could be determined even with a 20 times improved accuracy. In the mean time the experimental apparatus is upgraded and a young MC has joined the group to study triplet helium in optical traps and lattices.

The second group (1DR1, 1CR2) reported ground-breaking research on the Bose gas in two dimensions, in particular the observation of the Berezinskii-Kosterlitz-Thouless transition using matter-wave interference to investigate the proliferation of free vortices. With the appointment of the CR2 the group started a new experiment to investigate micro-condensates of sodium in strongly correlated quantum states. Further, important advances were reported with an experiment to realize a CW guided atom laser. This experiment is being moved to Toulouse with the appointment of the responsable DR1 of the group on a professorship at the Université Paul Sabatier.

**Conclusion: The committee congratulates the LKB with this exceptional team.**

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|---|---|---|---|---|
| A+ | A+ | A+ | A+ | A+ |

**3. Ultracold Fermi gases**

During the last years, this team (1DR1; 1DR2, 1MC) has obtained remarkable success in two domains: the fundamental study of strong correlations in fermionic gases, and the Pharao project in the technology domain, a collaboration with LNE and SYRTE to realize a space-based Cs clock with cold atoms.

With the Fermi gases the team is certainly at the top level in the world, both with respect to theory and experiment. This is evident from the very high number of invited talks and the publications in high-visibility journals. The most remarkable results in this field are probably the demonstration of the controlled crossover from the superfluid pairing side (BCS) to the Bose-Einstein condensate (BEC) molecular side in a two-component Li quantum gas, together with the measurement and interpretation of the velocity distribution in all regimes.

The projects to study interacting gases in 1D and 2D optical lattices produced by laser interference, and to study mixtures of fermionic atoms of Li and K, are also very promising. This holds for the experimental as well as the theoretical part. With 4 ongoing PhD's, 3 PhD presentations in the last 2 years, and a few post-docs, the team strongly participates in the education of young researchers. With an ERC-Senior grant the research on fermionic systems is well supported for the coming years.

CNES recently confirmed the future flight of the ACES project in year 2012. Its central element is the Pharao cold atoms Cs clock, fruit of a previous collaboration with LNE and SYRTE. This experiment will give France a leadership in terms of clock accuracy and time transfer. The analysis of the scientific data will be the responsibility of LKB.

**Recommendation: It is highly important that CNRS, the University, and CNES quickly create new positions and support LKB in the preparation of the new Pharao tasks.**

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|---|---|---|---|---|
| A+ | A+ | A+ | A+ | A+ |

**4. Complex Quantum systems**

This theory group was previously allied under the name 'Dynamique des Systèmes Coulombiens' with the experiments on ions in Evry (group-13). The present activity consists of 1 DR1 and 1 CR1. In addition, this team counts 4 PhD Students (3 finishing in 2009), had and still has few post-docs and visitors. Presently the research is focused on the behavior of cold atoms in the presence of chaos and disorder.

The group has numerous important contributions in the field of quantum chaos and coherent transport properties with many publications in high impact factor journals. The team is especially involved in collaborations with 2 experimental groups: a group of in Lille studying quantum chaos and dynamical localization, and a group in Nice working on light propagation and localisation in cold atomic gases. A collaboration with a theory team in Nice is suspended (with the departure of the PI to Singapore). The collaboration with Lille resulted in exceptional results in the last year, in particular related to Anderson Localisation of matter waves.

The new theoretical work on propagation and Anderson Localisation of matter waves is contributing to a field with a high national and international visibility, in particular in the community of mesoscopic physics and wave propagation. With the recent experimental advances in cold atom physics - degenerate quantum gases and disorder, there will be a growing interest in advanced theory in the subject, which will add to the visibility of the group when invited to international conferences more dedicated on quantum gases.

In the coming years the group size will reduce to just one senior scientist (with the CR1 leaving for a stay of at least two years in Singapore). Although this carries the risk of isolation of this activity within the LKB, the numerous collaborations and the recruitment of post-docs and PhD students can help keeping this theoretical activity at its high level and increase its impact in the community of cold quantum gases. Further strengthening could come from closer collaboration with other theoretical activities within LKB either in the field cold atoms or in the field of degenerate polaritons.

**Recommendation: It is important that the team continues to play its central role in the topics of wave propagation and disorder, and to assure that the recent evolution in the team size does not result in isolation. The new research directions offer valuable opportunities for interactions within the LKB and elsewhere in the Paris region.**

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| A | A+ | A | A | A |

**Research area 2 : Quantum Optics and Quantum Information**

**5. Cavity Quantum Electrodynamics**

This activity (1PCdF, 1PRCE, 1Dr2; 1CR1) represents one the florets of French and international research in the field of quantum physics and cavity QED. The exceptional results regularly obtained by the group are the result of a clear and long-term strategy based on unique knowledge and the design of unique experiments at a tremendous level of complexity and reliability. The number of high level publications, citations as well as the number of invited talks reveals the exceptional quality of the group.

With the recruitment of a CR1 the team initiated a new experiment with the aim to improve the source of Rydberg atoms and to open new perspectives to their line of research. Based on cryogenic atom chips, this successful new experiment widens the group research field by entering the degenerate quantum gases community with a world premiere. Many groups follow the example. Presently the group anticipates the departure of the CR1, which forces the group to rely more on the very good students and post-docs they usually hire. Although they succeed in that already, it represents anyhow a risk for the long term since the departure leaves the group with 3 high profile senior scientists, who, in spite of their dedication, are not optimally positioned to ensure the continuity of detailed experimental knowledge over the years. It seems thus absolutely necessary to hire additional permanent research staff to keep the research activity at the current high level or higher.

**Recommendation: The committee supports the priority given by the laboratory to recruit a junior scientist in this team. This will help the team to keep developing its world leading research on quantum non-demolition measurements and to enter the new field of degenerate gases with superconducting atom chips.**

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|---|---|---|---|---|
| A+ | A+ | A+ | A+ | A+ |

**6. Fundamental Noise in Measurements**

This team (1DR2; 2MC) is focused on quantum noise and particularly on the effect of the radiation pressure in high sensitivity optical measurements.

Both ongoing experiments deal with the action of the opto-mechanical coupling: indeed, the radiation pressure and pressure fluctuations can move mirrors, excite their mechanical resonances, and couple these motions with the amplitude and phase of the electromagnetic field reflected or transmitted by an optical system. At the quantum level, the fluctuations are small, and the observation of the expected correlations requires the use of very quiet and low loss (optically and mechanically) systems, operating at cryogenic temperatures, in order to minimize the thermal noise. In these very sophisticated experiments, the sensitivity to mirror displacements is now reaching $10^{-20}$ $m.Hz^{-1/2}$! With this result, and with the observation of mirror cooling by the radiation pressure, the team is clearly at the top level, worldwide.

Ultrasensitive instruments such as gravitational wave interferometric detectors constitute an obvious domain of application for these theoretical and experimental studies, and part of it has been realized in collaboration with the French-Italian Virgo project. The ongoing work about the effect of radiation pressure on mirror resonances (parametric instabilities) is done in collaboration with an Australian team, associated with the US LIGO project. Another field of application concerns the mechanical micro-resonators, with the goal of reaching and controlling their quantum regime through the opto-mechanical coupling (collaboration with ONERA, nanoscience national and European programs).

As a result of internal mobility within the LKB for different reasons, this successful team has recently lost a DR1 and a PU2. Although the quality and quantity of its publications remain very good and it deserves to be well supported and reinforced.

**Recommendation: In view of the quality and vitality of the research and in view of the recent loss of senior staff this team deserves to be reinforced. This would also be beneficial to the necessary transfer of know-how towards the domains of applications.**

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|---|---|---|---|---|
| A+ | A | A+ | A | A+ |

**7. Quantum Optics**

The team (1PRCE, 1DRCE; 1PR, 2MC) is outstanding, a true 'institution' in the field of quantum optics and has been at the root of several world premieres. In addition, the team plays an important role in the education of young scientists. It is organized in two complementary groups, one mainly devoted to multimode quantum optics and quantum information (involving 1PRCE and 2MC) and the other focused on quantum light - diluted or solid matter interactions (involving 1DRCE and 1PR). During the quadrennial, the group was joined by 1 MC, and at the same time 1DR and 2MCs left the group. In keeping with the academic tradition of young scientists leaving to fertilise other groups, this flux has unfortunately left the group in a critical situation. This has been partially compensated by the strong attraction of this team to students during the passed quadrennial; the team has trained or is training 19 PhD and 4 post-doctorants. The group activity is abounding with 8 contracts, 52 invited talks and 60 publications in international peer reviewed reviews including 14 PRLs, 1 Nature and 1 Science. The PRCE was awarded with the senior IUF chair and the PR with the junior IUF chair. During the quadrennial both groups have initiated an important evolution of themes with substantial success.

Multimode quantum optics constitutes a new field with an important potential in quantum communication and information. The field is demanding both from the experimental and theoretical point of view. The highlights of the group are numerous and spread between noiseless image amplification to bright entangled states. These place the group in a leading international position. An extremely promising field was also opened with a theoretical letter on temporal multimode quantum states. Here the proposed quantum frequency comb has potential interesting metrological applications.

The quantum state of light and matter interaction is a crucial field in quantum information and numerous and prestigious teams are working in this international arena. One of the major subjects here is to store non classical light states in quantum memories. The team has obtained outstanding results in this direction. Among them is the polarisation squeezing in cold Cs atoms and the possibility of generation of entangled light states. Several predictions of spin squeezing and efficient transfer of optical quantum fluctuations into atomic states via EIT, paves the road to efficient quantum memories for quantum continuous variables.

**Recommendation: The committee supports the reinforcement of the Quantum Optics group by the recruitment of a young CR scientist in order to consolidate one of the emerging activities of the team.**

| Note de l'équipe | Qualité scientifique et production | Rayonnement et attractivité, intégration dans l'environnement | Stratégie, gouvernance et vie du laboratoire | Appréciation du projet |
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| A+ | A+ | A+ | A+ | A+ |

**8. Quantum fluctuations and relativity**

This theory team (1DR1, 1DR2; 1MC) works in close collaboration with experimental groups in various domains of physics, including quantum physics and general relativity. The research deals with various domains of science, from nanotechnologies to gravity in the solar system, through time transfer and various fundamental physics projects in space. The ability of this team to identify experimentally significant results in relation to difficult theoretical problems is highly remarkable and rather unique. In particular, the team has developed original studies of the Casimir effect, dealing with static, dynamic, and geometrical aspects (non planar surfaces), which are becoming important in the domain of nanotechnologies. The DR2 participates in various European grants and networks in this domain, including Institut CARNOT.

The study of quantum measurements in a spacetime framework, including the effect of a stochastic gravitational wave (GW) background on the propagation of the electromagnetic field, allows deriving constraints on the GW background from clock synchronization data, and the study of the effect of these same waves on the motion of microscopic and macroscopic objects allows evaluating the importance of gravitational decoherence.

By reanalyzing the data of the Pioneer spacecraft, the team could confirm, with improved accuracy, the apparent violation of the gravity laws resulting from its motion when escaping the solar attraction. In parallel, together with another ENS laboratory, they developed a new theoretical framework allowing the quantification of a deviation from General Relativity, within the ensemble of metric theories.

The team operates in an active network of theoreticians and experimentalists, within the LKB and with external partners. It is associated with most space projects in fundamental physics, as a result from the strong activity of the DR1 in that field: after having strongly contributed to the cohesion of the French community involved in experimental gravitation with the direction of the GREX, he is now chairing the CNES committee for fundamental physics.

**Conclusion: This is an excellent team demonstrating the broad scientific base of the LKB and operating in the finest tradition of the ENS.**

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|---|---|---|---|---|
| A+ | A+ | A+ | A+ | A+ |

**<u>Research area 3 : Atoms in dense or complex media</u>**

**9. Polarized Helium, Quantum fluids and solids**

This team (1DR2, 1PR; 2DR1, 1CR1, 1DREM) consists of two complementary groups, one investigating spin-polarised 3He in various contexts and the other focussed on Cs impurities in solid 4He. The DREM maintains a small theory activity.

The group working on 3He investigates spin-polarisation by optical pumping, RMN instabilities in polarised liquid 3He and polarised 3He lung imaging (involving 1DR2, 1 CR1, 1DR1). The group lost a MC and gained the DR1 as a result of internal mobility within the LKB and hosted an expert sabbatical visitor. Cooperation with Poland and Germany under the Polonium program is very fruitful and contributed two PhD-students 'shared' with Mainz and Cracow. The evaluation shows a clearly high level of expertise and international recognition. New results have been obtained in NMR time-reversal as a probe of incipient turbulent spin dynamics, NMR time reversal experiments in highly polarised liquid 3He-4He mixtures and nonlinear NMR dynamics in hyperpolarised liquid 3He. The team is exploring the full parameter space for optical pumping (pressure, magnetic field, laser intensity). The new post-doc position with CEA by DIPOL ANR will be very helpful but is arguably not sufficient for the long-term vitality of this demanding research activity.

Lung imaging is another topic of this group. This activity, at the 'Interface Physics-Biology-Medicine' (Research Area 4), has a strong impact because of its important potential in medical applications. However, the development of lung imaging met high difficulties to exploit such techniques due to both, earlier systematic American patents and the strong regulation on in-vivo experiments by the French laws. The development of a small size mobile IRM prototype has been important to make experimental progress in this context. New advances are to be expected mainly within the framework of the Phelinet European network on imaging in ultra-low fields, which is supported with one PhD and one postdoc.

The research on the optical properties of metallic impurity atoms in hcp solid 4He involves 1PR and 1DR. It was started in 2004 with the construction of the cryogenic apparatus, a major task successfully completed. The hexagonal deformation of the Cs ground state by the solid matrix in principle allows to measure the nuclear anapole moment, which violates parity. Such highly demanding measurements require excellent quality of the crystalline matrix. This is also crucial for the investigation of the wings of the narrow optical resonances of rare-earth atoms embedded in solid helium, which contain information of the excitations of the solid. Optical studies of this type offer a new window on the existence of vacancies in solid 4He and the phenomenon of supersolidity, in particular at negative pressures. For this research the group collaborates with the solid-helium group at the *Laboratoire de Physique Statistique* (LPS) of the ENS (UMR 8850). The implantation of the impurities slowed down the project. Substituting YAG pulses by low energy femto-second laser pulses and turning to growth from the doped liquid is expected to improve the implantation process.

The theory group (1DREM) is small but active and bundles a lot of knowledge, not only with regard to the optical pumping issues of the experimental team but also with regard to the foundations of quantum mechanics and physics in general. The daily presence of such knowledge contributes to the outstanding scientific environment of the LKB. Also the important contributions to science publishing and the Quantum Mechanics textbook should not remain unmentioned.

**Recommendation: With the approaching retirement of 2 DR1's, this research line (with so many rich contributions over the years) deserves attention. For the vitality of the solid helium group on the short term the committee supports reinforcement by the recruitment of one post-doc and one PhD student.**

| Note de l'équipe | Qualité scientifique et production | Rayonnement et attractivité, intégration dans l'environnement | Stratégie, gouvernance et vie du laboratoire | Appréciation du projet |
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| A | A | A | A | A |

**<u>Research area 4 : The interface Physics-Biology-Medicine</u>**

**10. Optics and Biology**

This team (1CR1, 1MC; 1CR2) addresses fundamental problems in biology with original and dedicated optical tools that are implemented by the group itself. The research focused on cell biology (membrane, molecular motor, DNA-protein interactions and more recently cell mechanics). Ongoing researches on single molecule detection in vitro and in vivo have been addressing the difficult problem of labelling with organic and inorganic fluorophores, a quite difficult topic that requires interdisciplinary expertises. The overall research quality is excellent, as proved by the publication quality, the worldwide invited conferences and personal awards from CNRS and the French Academy of Sciences.

The team is one of the leading groups in France at the Optics/Biology interface. It runs tight and fruitful collaborations with biologists based in France and abroad. With three permanent researchers, ten PhD students and PostDocs, the group has a reached a mature size and is correctly funded by national and international agencies.

The integration within the Biology Dept. of the ENS is notable as it permits daily interaction and collaboration with biologists and provides access to advanced bio-materials and biological expertise that would not be possible in a physics laboratory only. Furthermore the location of the group both into the LKB and into the Biology Department of the ENS is the ideal situation that makes the group activity relevant both for the physics and the biology communities.

The group scientific perspectives are clear and well directed towards the open problems in biophysics that involve single-molecule detection. A fruitful collaboration is expected with Team 11 (holographic imaging) to track particles in 3D.

**Conclusion: The LKB research at the interface of optics and biology is successful with national awards and international recognition. The working environment of the research team is optimized in close collaboration with the Biology Department of ENS. A successful joint project on particle tracking with Team 11 creates added value for the groups within the LKB.**

| Note de l'équipe | Qualité scientifique et production | Rayonnement et attractivité, intégration dans l'environnement | Stratégie, gouvernance et vie du laboratoire | Appréciation du projet |
|---|---|---|---|---|
| A+ | A+ | A+ | A+ | A+ |

**11. Optics and NanoObjects**

This newly defined team (2DR2, 1PR) is active in nanophotonics and optical detection methods.

The nanophotonics activity (1DR2, 1PR) concentrates on the interaction between solid state emitters with highly resonant microcavities (micro-spheres and micro-torus). The research quality is very good and addresses fundamental problems that have applications in new laser sources. Collaborative research programs are conducted with a Grenoble based CEA group for the manufacture of the micro-resonators. To gain in flexibility, it would be valuable to transfer the CEA expertise toward an 'Ile de France' based nanofabrication facility. This would also permit to grow into the LKB an expertise in nanofabrication that might be valuable also for other groups (atom-chip, bio-chip…).

The optical detection activity (1DR2) focuses on heterodyne holography of nanoparticles. This is a very interesting technique that has been applied to various domains including bio-medical applications. The scientific expertise is high as proved by the publications and the ongoing collaboration with the group at ESPCI. A fruitful collaboration is expected with the 'Optics and Biology' team (Team 10) to develop microcavity based bio-sensors and bio-particles tracking in 3D.

The scientific perspectives are good both for nanophotonics (silicium and rare-earth lasers) and for heterodyne holography (blood flux and particles tracking) but it would be particularly valuable to combine the expertise.

**Recommendation: To realize the full potential of this new team the committee recommends to raise a common project, combining the nanophotonics with the holographic detection expertise. Also the joint project with Team 10 on 3D particle tracking in biological samples creates added value for both groups within the LKB. The group needs PhD students and/or postdocs to run properly its activities.**

| Note de l'équipe | Qualité scientifique et production | Rayonnement et attractivité, intégration dans l'environnement | Stratégie, gouvernance et vie du laboratoire | Appréciation du projet |
|---|---|---|---|---|
| A | A | A | Non noté | A |

### 12. Metrology of simple systems and fundamental tests

This team (2DR1, 2CR1; 2MC, 1CR2, PREM) unites the activities on precision spectroscopy of the hydrogen atom, the measurement of the fine structure constant via an atomic recoil frequency or h/M with the study of highly charged ions and matter in strong fields. A joint project of the two subgroups is the spectroscopy of muonic hydrogen.

The first two projects aim at improved measurements of two of the most important fundamental constants, the Rydberg constant and the fine structure constant. Significant progress in accuracy has been obtained recently on the h/M measurement and a new and improved experimental setup is close to being completed. The hydrogen project is active in a more mature field of research where further progress will likely be incremental rather than at a fast pace. An important contribution may come from the experiment on muonic hydrogen that is undertaken within an international collaboration at the Paul Scherrer Institute.

The research on highly charged ions is performed at the source SIMPA and also in cooperation with international laboratories like GSI. The ion source SIMPA together with an electrostatic ion trap constitutes an inventive diversification of the experimental possibilities of the LKB. In parallel, the group of pursues a successful program of atomic structure calculations.

The scientific productivity and the international visibility of both groups are excellent. They work in an area where precision metrology contributes to fundamental physics, a field that has a tradition of excellence at LKB and continues to promise further insights.

The laboratories of this team are presently amidst an environment producing severe perturbations due to the ongoing construction work on the Jussieu campus. In spite of this the groups have maintained a remarkably high scientific productivity.

**Recommendation: For this excellent team it seems important to better communicate the fascinating prospects for precision metrology in order to attract promising young scientists in competition with new and upcoming areas of physics. In view of the ongoing construction work it remains important to emphasize the importance of a good and stable working environment, in particular for metrology groups.**

| Note de l'équipe | Qualité scientifique et production | Rayonnement et attractivité, intégration dans l'environnement | Stratégie, gouvernance et vie du laboratoire | Appréciation du projet |
|---|---|---|---|---|
| A+ | A+ | A+ | A+ | A+ |

### 13. Spectroscopy of $H_2^+$

This team (1PR2; 2MC) is working on a long standing challenge in the domain of precision metrology of simple, calculable quantum systems. The aim of the experiment is a precision determination of the electron-to-proton mass ratio in by precision spectroscopy of $H_2^+$. During the past four year period the group has performed a comprehensive theoretical study of energy levels and transition probabilities in this molecule. It has developed frequency stabilized infrared lasers and frequency references and has built an ion trap experiment for the two-photon excitation of a vibrational transition in trapped $H_2^+$ ions. The work has resulted in 10 refereed publications. First experimental runs for laser-excitation of the v=0-1 two-photon transition have been performed in 2008, without success in observing the resonance so far. The group has a very clear perspective on the possible and necessary experimental improvements and extensions in the short and middle-term.

The group has obtained added visibility by co-organising an international workshop on applications of trapped ions that has initiated new links between groups working in this field in Europe. Cold trapped ions promise to constitute an interesting complement to the range of quantum systems studied experimentally at LKB.

**Recommendation: Since all the permanent members of the group have teaching duties it seems important to strengthen the project with personnel working full-time on the experiment, either an experienced postdoc or dedicated PhD students.**

| Note de l'équipe | Qualité scientifique et production | Rayonnement et attractivité, intégration dans l'environnement | Stratégie, gouvernance et vie du laboratoire | Appréciation du projet |
|---|---|---|---|---|
| A | A | A | A | A+ |

# 5 • Appreciation of resources and of the life of the research unit

– Governance:

LKB has become a large institution with very diverse sources of funding. The management of the laboratory is organized through two councils:

- The laboratory council which is composed with elected and named members and meet four times per year to treat the general aspects of the life inside the laboratory. It has been emphasized that the general atmosphere is very good and convivial and that the director is always ready to listen to problems which could appear and to find adequate solutions.
- The scientific council of the laboratory, composed with senior scientists of most teams, which discuss all scientific aspects: recruitment, critical mass, budget, investments… The laboratory has an active policy in starting new research directions and terminating others at the appropriate moment. The choice of topics is strong, in most cases excellent.

The committee compliments the LKB, in particular its director and his management team, for the effective actions to promote the cohesion within the laboratory. These include the definition of transverse research areas and the involvement of the scientific council in this context. Other activities are, bi-yearly prospective days, special seminars for and by the PhD students, structured introduction to the LKB as well as guidance for the PhD-student and postdocs at the level of the institute. The recruitment of technical staff offers great difficulty as the mechanisms for selection of staff takes place at the national level and is not transparent.

– The ITA/ITARF staff:

The representatives of the ITA/ITARF have expressed their general fulfillment of their needs. They have mentioned that the safety is well taken into account in the laboratory. They have also mentioned that there are too few promotions and felt that their missions are poorly recognized by the institutions.

– The PhD students and PostDocs:

The committee has met with the PhD students and PostDocs, who appreciated to work in good conditions in the laboratory. They consider to be well integrated in the different teams. All of them are financially supported and the mean time of their PhD is about forty months. A lot of general seminars are organized by the laboratory. A regular seminar, opened to all PhD students, allows them to present their research work once or twice during their training. The number of PhD students is proper for a laboratory of this size, but their distribution over the teams is not quite satisfactory. A comment was made about stagnation in the processing of orders in the period from mid December to mid January, understandable from students in experimental physics on a 3 year PhD contract.

– Meeting with the representatives of ENS, CNRS and UPMC:

The LKB is the largest of the physics laboratories of the ENS, not only housed within the ENS buildings but also at other locations, most notably in Jussieu at the campus of the Université Pierre et Marie Curie. All parties involved consider the LKB a well proven successful joint effort of the ENS, UPMC and the CNRS.

During the four past years, updating of the laboratories in Jussieu has generated some annoyance in the research activities. The ENS has now planned to renovate its own building. The members of the laboratory have expressed their concern and were assured from the representatives of the institutions that the disruption of the research will be kept to the lowest possible minimum.

# 6 • Recommendations and advice

- Strengths :
  - The LKB offers to its staff a world-class environment for research at the cutting edge of modern atomic, molecular and optical physics with strong links to condensed matter physics and quantum information processing.
  - The research program is based on challenging and often trend setting research strategies.
  - The balance between theory and experiment is excellent.
  - The staff of the LKB is strongly engaged in the full spectrum of the scientific network in France, including outreach, and also internationally recognized.
  - The management has an excellent strategy to facilitate the research and to promote laboratory-wide cohesion both with regard to the scientific and the technical staff.

- What needs to be improved :
  - The renovation at the Jussieu campus and the upcoming renovation of the ENS building are disrupting the research. This is a handicap, in particular for the most competitive groups.
  - The LKB cannot develop a consistent policy with regard to its technical staff as the mechanisms for selection of staff take place at the national level and are not transparent.

- Recommendations :

The linear growth in personnel of the LKB since the beginning of the 1990 is clear sign of vitality and strength and should be encouraged. At the same time it deserves to be kept in balance with the housing situation in order to conserve the cohesion of the laboratory and to assure its continuing competitiveness as an attractive environment for research and education.

Certainly in international context the push for valorization is important and can definitely not be ignored. Therefore, the continuing attention for technology transfer (for LKB in particular to advanced applications) is to be encouraged.

The renovation of the ENS building is a great opportunity to upgrade to a contemporary housing standard. The committee recommends to ENS to involve the LKB staff where possible in order to assure an optimal result for the laboratory rooms and to minimize the disruption of the research.

The recommendations per team are given in section 4.

| Note de l'unité | Qualité scientifique et production | Rayonnement et attractivité, intégration dans l'environnement | Stratégie, gouvernance et vie du laboratoire | Appréciation du projet |
|---|---|---|---|---|
| A+ | A+ | A+ | A+ | A+ |

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Ref : YG/EF 2009.021

Paris, le 16 avril 2009

**OBJET : Rapport d'évaluation du Laboratoire Kastler-Brossel (LKB) - UMR 8552**

Je vous remercie de la transmission du rapport d'évaluation du Laboratoire Kastler Brossel (UMR 8552)qui n'appelle pas d'observations particulières de notre part. Nous soulignons néanmoins que l'appellation officielle de notre établissement est « École normale supérieure » et non pas « … de Paris ».

Avec nos salutations les meilleures.

Yves GULDNER