Laboratoire d'AstrOphysique de Grenoble

Laboratoire de Planétologie de Grenoble

UMR 5571 / UMR 5109

Scientific Project

Projet scientifique

2011 – 2014

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Summary

1. EXECUTIVE SUMMARY

1.1. Toward a new laboratory

We hereby present the project of a new laboratory that will be created by merging the "Laboratoire d'Astrophysique de Grenoble" (LAOG) and the "Laboratoire de Planétologie de Grenoble" (LPG). Before any final name is fixed for this "New Laboratory", we will provisionally refer to it as NL.

In summary, our project aims at gathering a group of top international level research teams with complementary and coherent skills in Astrophysics and Planetary Sciences at the University Joseph Fourier (UJF), within a single research unit (UMR UJF/CNRS). Our goal is not to have these teams working only side by side, but also to take advantage of the enormous added value that will be gained from their interactions. Indeed, all of the teams of the new laboratory already have active scientific links with each other.

Our research themes will address three out of the four key issues identified by the Science Vision Working Group of the European funding agencies network "ASTRONET", and significant advances and breakthroughs can be expected in the coming two decades:

- How do stars and planets form and evolve?
- How do we (and the solar system) fit in?
- Do we understand the extremes of the Universe?

To address these questions, the New Lab will gather three complementary approaches: observations, theory & modeling, instrumentation & laboratory experiments. These approaches will be organized in five teams with strong interactions between them (listed in alphabetical order):

ASTROMOL (*Molecular Astrophysics*): initial phases of stellar formation, interstellar chemistry, theoretical molecular physics, 8.90 research FTE.[1]

FOST (*Stellar and Planetary Formation, Brown dwarfs*): circumstellar disks, stellar-disk interaction, search & study of exoplanets and brown dwarfs, 13.40 research FTE.

GRIL: Instrumental research, Instrument development, R&T, 7.30 + 25.40 scientific and technical research FTE.

PLANETO: (Planetary sciences, previous LPG): planetary upper atmospheres, planetary surfaces and sub-surfaces, small objects of the solar system, 11.30 research FTE.

SHERPAS: Physical processes, High energy physics, MHD, accretion / ejection phenomena, 4.40 research FTE.

[1] Research FTE computed according to AERES rules (CNRS: 1, CNAP: 0.7, UJF: 0.5)

Two thematic groups will be added to these five teams in order to foster collaboration between teams and to strengthen the merging of both labs. These themes emerged from the scientific prospective work conducted in common between the two laboratories and were identified as the most promising in terms of scientific breakthrough and synergy. These thematic groups are:

- Compared planetology between the solar system and exoplanets.
- Chemistry of planets and interstellar medium.

For example, because research is a dynamic process, these thematic groups could pre-define possible new teams after a few years.

Finally, the skills of the laboratory will be strengthened by the existence of a common ***Technical Group*** **(25.4 technical FTE)** that will address the instrumental needs of the laboratory and its five teams. All Engineers and Technicians (ITs) of the new lab will belong to this group. It will bring a very strong expertise in ground-based and spatial developments to the project, as well as a long standing R&T culture and numerous collaborations with the high-tech industry.

1.2. Scientific Analysis

Our project is the result of more than six months of work and discussions between all staff members of the two previous laboratories. The results and conclusions of this work have been published on a dedicated website.

In this section, we further present an analysis of the situation of the new laboratory, given its scientific environment and internal skills.

1.2.1. Internal Strengths

The first and the main strength of our project is that all teams from the previous labs are strongly appreciated at the international level, and possess a high level of publications. Indeed, both labs were rated “A+” during the previous evaluation procedure (in 2006).

The merging of both laboratories is much more than the mere superposition of previously different research subjects. There is a strong coherence and complementarity between the thematic teams of the new lab. There are numerous research links and synergies between them, so that the definition of the thematic (transverse) groups was a natural and easy process. They appear in some cases as a natural extent of pre-existing collaborations. This coherence will be highlighted in our detailed scientific project later on, but can be illustrated in a nutshell via the thematic groups listed in section 1.1.

From an international point of view, the fact that we will address 3 out of the 4 key questions identified in 2007 by the Astronet working group will give a strong scientific pertinence to our project. The way these subjects are cast in our scientific project will be detailed later.

All Engineers and Technicians from both previous labs will be gathered in a unique Technical Group. Gathering their previous expertise, the new lab will then host a very strong instrumental potential for ground based (ESO, CFHT) *and* spatial instruments (ESA, CNES, NASA). Both labs have a long lasting and internationally recognized expertise in driving and realizing instrumental projects. This enrichment of the instrumental opportunities will even more re-enforce the virtuous circle of instrumental development and R&T feeding each other. As an example, LAOG hosts a Start-up working on adaptive optics. In the same way, a large number of developments in *Virtual Observatory* will be possible in a joint action between the astrophysical and the planetary sciences approach.

The project development process has been remarkable: since January 2009, the two laboratories have been working together on the merging project. A ten-person committee was created to organize numerous workshops open to all staff members of both labs. These workshops concerned science topics as well as general organization matters. A dozen of such workshops were organized over 3 months, totalizing dozen of hours of meetings. As a consequence, all members of both labs feel involved and committed to the project. The minutes and main conclusions of these workshops are available on a dedicated website on the intranet of the laboratory.

The new lab will be better related to the OSUG research themes via the planetary sciences theme and its natural links with earth sciences. We will gain efficiency in the organization of our administrative team and the instrumental team skills being larger, our reactivity will be better. Last but not least, the new lab is very young and active. The average age is 46 for the permanent scientific staff, and 44 for the scientific and administrative Engineers & Technicians.

Another strength of our project is related to the rich astrophysics and planetary sciences teaching that we can offer to the university and its students, from the earth atmosphere to the ultimate frontiers of the universe. The merging of the two labs will help to present a better and stronger teaching program to UJF students.

1.2.2. Internal Weaknesses

The main drawback of the merger will be a possible "centrifugal action" resulting from the numerous research themes present in the new laboratory. In the same way, concerning instrumental projects, it is true that both labs have worked on projects with different timescales and different cultures. The challenge of our NL will be to use these differences to build a new common expertise and respectful knowledge.

The research FTE are relatively well balanced between teams: about 10 FTE per team on average, with the exception of the team SHERPAS with half this value. However, there is no reason to have absolutely balanced teams in a laboratory. Moreover, it is one of our priority to strengthen the SPHERPA team, because of its theoretical skills and because it brings the high-energy astrophysics window to the laboratory.

The youth of the laboratory, already presented as a strength, can also turn into a weakness: we may lack senior scientists in the 55-65 age range, where one could find experienced people with no career struggle, who can fully act in the interest of the lab community.

A strong weakness of the project that will require all the attention of the new lab management is the fact that the staff of the two previous laboratories will be dispatched over 3 different buildings, located more than 100 meters apart. This is a crucial issue in our project and we will need the dedicated help of OSUG and UJF to overcome this important problem. There is one possibility to gather all the staff of both labs in two adjacent buildings. We would have to use the first floor of the CERMO, but this solution depends on the will of OSUG to actually support the project.

1.2.3. External Opportunities

Both in astrophysics and planetary sciences, the new laboratory will be strongly involved in many international ground based and space projects, for the technical aspects (instrument realization) as well as for their scientific exploitation. This concerns ground-based and spatial very large telescopes like VLT, VLTI, Herschell, Planck, ALMA, JWST, CTA, ELT (astrophysics); space missions as Mars-express, Cassini, Rosetta, ExoMars and other Mars space missions, Cosmic vision with Marco Polo and EJSM toward the Jovian system (planetary sciences).

From the instrumental and R&T point of view, Grenoble's local research and industrial network is unique in France and in Europe. It allows to develop collaborations on micro & nano technologies about photonics and detectors for future astrophysics instruments. From previous collaborations established by former LAOG, the new lab will be very well placed to foster such collaborations and developments. The presence of the ALPAO Startup in a neighboring building will be an asset for future adaptive optics projects.

The reshaping of the old and nearby CERMO building is indeed an opportunity for our project and the support from OSUG will be essential on this point.

The existence of a UJF industrial "filiale" (subsidiary) will allow quick and efficient technology transfer and valorization of our R&T developments through licenses and patents.

1.2.4. External Risks

Be it internal or external, it will be extremely difficult to build and to gather a unique laboratory since it will be dispatched in three different buildings. We will work to keep this risk as low as possible by implementing common thematic groups with research themes pervading all our teams. Also, the success of our project will rely on the possibility to gather and maintain performing administrative and instrumental (including computing and network) teams. Given the current situation both in CNRS and in UJF, there is a risk that we lack the essential administrative and technical positions that will be strategic for the new lab.

CNRS is now splitted into various thematic institutes. As a result, and because of this new structure, CNRS might lower its attention towards the New Lab Project although we are highly interdisciplinary and would need funds from different institutes. It is particularly unclear whether the CNRS institute of chemistry will effectively support the new laboratory.

There is also a risk that the support from OSUG will not be given at the level needed for our project, in terms of funding, building, and research and technical positions.

We extend this risk and chances analysis by a presentation of the position of our new laboratory in its environment, at the local, national, European and international level.

1.3. Position of the new laboratory in its working environment

1.3.1. Local

OSUG: We expect a better visibility inside OSUG, due to a re-definition of this institute on its main three research themes: internal Earth (LGIT+LGCA), fluid envelopes (LGGE & LTHE), and Astrophysics & Planetary sciences (LAOG+LPG). However, the planned extension of OSUG into a new mechanical laboratory like LEGI or 3SR might in the contrary diminish our visibility within OSUG.

UJF-UdG: Our new laboratory aims at developing research over the full astrophysical spectrum: from earth atmosphere to the cosmic background. However, the Grenoble university environment hosts another cosmology laboratory, namely the LPSC. Our new laboratory does not aim at working strongly in the cosmological and galaxy evolution domains, but an overlap exists between LAOG and

LPSC. For example, discussions have been conducted about a possible collaboration on LSST, and a recent common document has been set to summarize possible scientific convergences.

The new laboratory will hold a unique position at the interface between the current university departments TUNES (Sciences of the Universe) and SMING (Sciences of the matter). Moreover, if UJF does merge these two departments into one (and this will most probably be the case in the scientific project), then our new lab will occupy a very strong situation: first, thanks to our research themes, as we have numerous collaborations with other labs in the Grenoble environment (including privileged technological partnerships), and secondly, thanks to our teaching interests, in physics or sciences of the universe.

IRAM: There is a long-standing willingness to strengthen the links between IRAM and its neighboring labs. Indeed, LAOG and IRAM were established together in 1979 to work on radio astronomy, but the extremely fast growth of LAOG and the increase in the number of its research themes in the 1990s have diluted our links with IRAM. We have recently made some important progresses in this matter and a new memorandum of understanding between IRAM and LAOG-UJF should be signed in a near future.

CEA/LETI: We have a long-lasting collaboration with this major scientific institution. We will be very well positioned to pursue instrumental developments, e.g. on integrated optics, with this laboratory.

ALPAO: This Company is a Startup that was created in LAOG to work on adaptive optics devices. Since 2008, it is hosted by UJF in a nearby building. Two of our Engineers work 20% of their time for this Startup. Our privileged everyday interaction with ALPAO will give us a central position to develop research activities in the field of adaptive optics.

1.3.2. National

Our new laboratory will occupy a unique niche on the national scene. Laboratories and universities with unified astrophysics and planetary sciences research are not so common in France, especially if one takes into account the stellar and planetary formation research theme. At the national level, our lab will be involved in a large number of ‘national programs’ research grants (Interstellar medium: PCMI, Stellar Physics: PNPS, Planetary Sciences: PNP, High Energy Astrophysics: PCHE, Origin of life: OPV).

From the instrumental point of view, both previous labs were largely funded (at the national level) by INSU and CNES for ground-based and spatial R&T and instrumental developments. Our partnership list also includes major research institutes like ONERA, Alcatel, Astrium, etc. They have funded research projects and PhDs, so this also provides interesting job opportunities for our students. We will thus continue to occupy a leading position in instrumental developments at the national level. Astrophysical or solar system instrumental or spatial projects are evidently organized at an international level. This will allow us to be strongly present in big national projects.

1.3.3. Europe

As stated above, our research themes will place us in an ideal position to participate in the European astronomical prospective. European projects and networks in FP6, FP7, already remarkably funded our both previous labs, and we will work for the situation to remain so. We are leaders in some of the developments of the OPTICON European Infrastructure network.

We already have and will pursue numerous contracts with ESO and ESA European funding agencies, for ground based and spatial projects.

We are involved and renowned at the European level through numerous networks, some instrumentals (OPTICON: JRA1, Adaptive Optics, JRA2, Detectors, JRA4, Interferometry), some on astrophysical themes (Constellation, Jetset, Molecular Universe), some for services to the planetary sciences community (Europlanet RI: JRA3 for modeling and JRA4 for data bases).

1.3.4. International

We will maintain a high level of collaborations with international teams throughout the world, funded by NSF in the USA for instance, or other agencies. Our new strong instrumental team will allow us to get strong links with NASA. We are involved in instrumental developments with ESO that will put us closer to South American universities in Chile and also in Brazil (collaboration with teachers and researchers in Brazil). One of our associate teachers will be a member of a new international research unit in Chile. We do collaborate and will continue to do so with Eastern countries like Bulgaria, Ukraine, Israel, and Armenia. One of our associate teachers has a strong collaboration in Australia. We also have strong links with Japanese scientists on radar research.

1.4. Scientific Project

Our project is to unify Astrophysics and Planetary Sciences at the Grenoble University. All the research themes developed in our two previous labs will be gathered in a unique laboratory to fully exploit the synergies between our teams, to develop our main research themes where we are leaders, or to work on emerging new ideas. One key point is to benefit from and further encourage a strong *added value* by favoring interactions between teams, in particular on the research themes of the thematic groups working on chemistry and exoplanetology. These thematic groups emerged as very promising from our common prospective work, but fostering interaction between research themes is part of our laboratory culture, both in previous LAOG and in previous LPG.

Another key point of the new lab will be the presence of our instrumental team GRIL, and our remarkable technical group. We will occupy a unique position to address instrumental questions concerning breakthrough ground-based and spatial instruments.

The New Lab will gather numerous scientists working on observations, theory, models and laboratory experiments. These various approaches will complement each other.

One of our main scientific projects will be to study the formation of stars and planets, and to determine how well our own solar system fits in the global star formation framework. This project will involve all the teams of the new laboratory: Astromol for the initial phases of stellar formation, together with the study of the increasing molecular complexity when the central condensation forms. FOST when the central object is warm enough to be bright in the visible and the near IR. This step includes circumstellar disks at various stages: initial, debris, and protoplanetary. This team will also be involved in the search for planets and this connects this research theme with the team PLANETO who concentrates on the study of the objects of our own solar system. The study of solar system primordial matter, in comets, will teach us a lot about the way grains and rocks grow and stick in the primordial nebula. The Team SHERPAS will provide the theoretical backbone of the laboratory, including MHD and accretion / ejection physical processes, together with the study of the extreme environment in the universe. Beside these astrophysical teams, GRIL will add the opportunity to prepare and implement new instruments and concepts, together with the needed associated R&T activity for the next generation instruments. GRIL will be preferably related to the Technical Group of the lab that will address all the technical needs of the laboratory and its teams.

These necessary interactions will be fostered by the action of one deputy director (see below) who will assist the director in its mission of scientific steering in the lab, in collaboration with the people responsible of the thematic groups. A specific budget will be devoted to this action. Our goal is to show that the lab can operate as a group rather than as a mere conglomerate of separate teams.

This community of actions will be even more reaffirmed in the way the technical group will operate: instead of having engineers and technicians (ITs) affected to various projects in separated teams, the lab will have a common technical group gathering all the ITs. The Director and the laboratory council will define the scientific and technical projects of the lab, whereas the Technical Director will be charge of the operation of their technical management. Most of our instrumental projects are developed at the international level (see Team GRIL section).

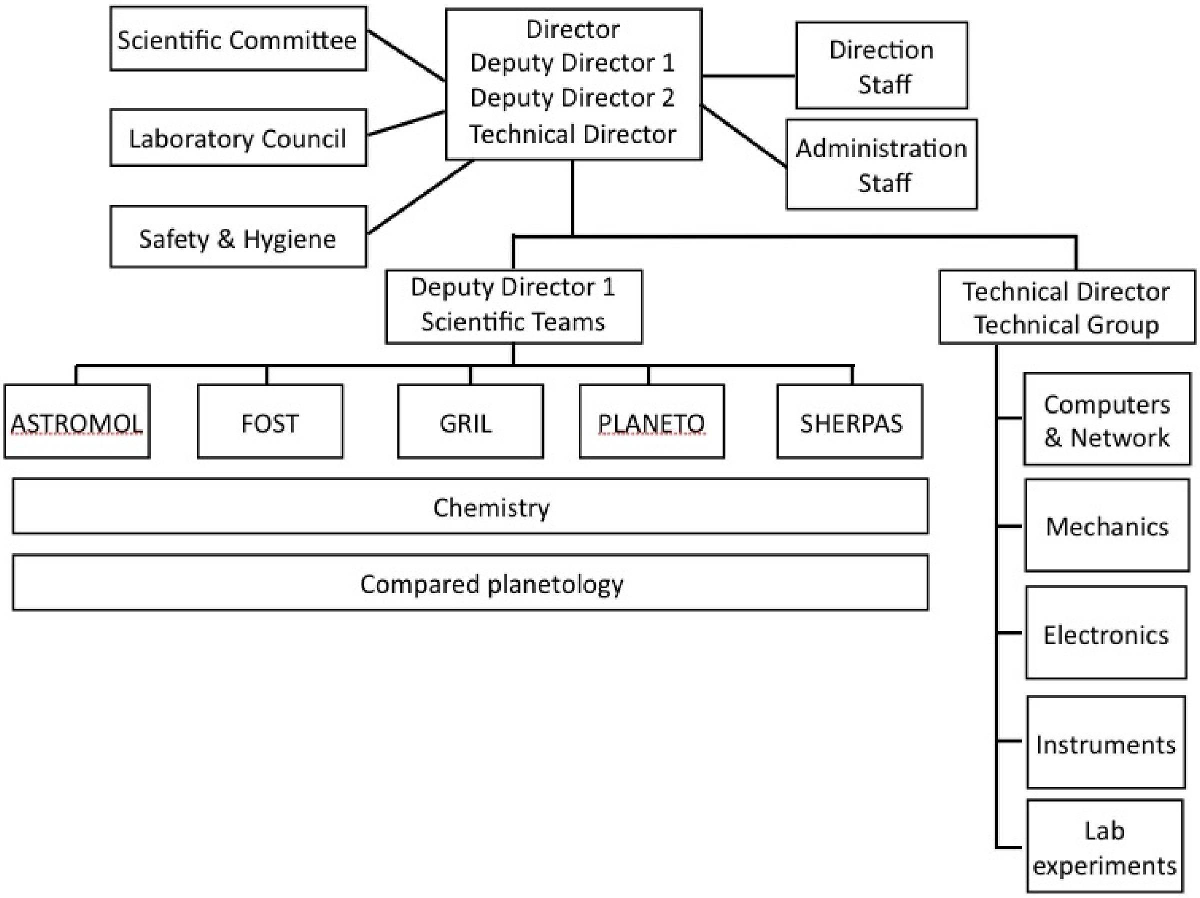
1.5. Governance & new laboratory organization chart

The governance of the new lab will operate according to the lab organization chart below. Given the size and the diversity of skills and knowledge within the new lab, we will appoint a scientific committee, with more than half of its members coming from outside the laboratory. Once or twice a year, this committee will help the Director with advices on the NL scientific policy.

Given the size of the NL, the Director will be assisted by two Deputy Directors and one Technical Director. One of these deputies will assist the Director to implement the scientific policy of the lab and the other will be more specifically in charge of budget matter. The Technical Director will be in charge of the operations of the Technical staff, in order to fulfill the scientific and technical goals decided by the laboratory. Concerning the laboratory (and its technical staff) commitment into instrumental projects, the decision making process should use the following way: 1) the scientific teams are expected to suggest possible instrumental involvements (possibly in association with scientists of other lab, at the national or international level), and discuss their immediate and strategic interests within a scientific perspective; 2) The technical director evaluates and reports on the current actual manpower availability and skills; 3) the final decision is made at the laboratory council and laboratory head level.

The five leaders of the lab's scientific teams will complement this Management Team. Given the size of the new lab, we will be particularly attentive to Human Resources questions.

The laboratory's policy will be discussed once a month during the laboratory council. The agenda will be set one week before every meeting, but recurrent periodic items will be discussed at specific periods of the year (thesis subjects in November then in March; recruitment priorities in March/April; next year budget in October; Laboratory funding requests in June, etc.). Every laboratory council will be followed by a "Direction staff" meeting (Direction + team leaders) for debriefing and operational decisions.



The detailed scientific programs of all five teams of the lab are presented below. A more complete operational chart will be provided for the committee visit.

2. ASTROMOL Team

2.1. Introduction

The *ASTROMOL* team's main field of research remains the "cold universe", and more precisely the cold and dense material out of which stars form, and its immediate surroundings. The expertise of *ASTROMOL* revolves mainly around the study of molecules and their evolution, both as tracers of the present physical conditions in various environments, and as astrochemical bricks for the long-term evolution towards increasingly complex species, including those found in comets and meteorites today.

The aims of *ASTROMOL* in this quadrennial mirror this expertise: we will study the role of molecules in the star and planetary system formation, the very cold early stages of star formation as well as the very energetic shocks or radiation interactions with molecular matter as well as modeling these events, either theoretically, with all the tools of molecular physics or else experimentally, by suitable laboratory spectroscopy. *ASTROMOL* will remain deeply rooted in its LAOG-LPG environment, and take advantage of all the local opportunities, including the emergence of a strong 'Chemistry' axis of research. It will expand its strong network towards ever more scientific collaborations, whether European or international.

2.2. From simple to complex molecules

2.2.1. Early stages of star formation

There is observational as well as theoretical evidence that star formation at the pre-stellar stage is influenced by turbulence, gravitation, magnetic fields, and chemistry. However it is yet unclear which processes dominate this initial phase. To find answers necessitates an accurate analysis of the physical structure (density, temperature and velocity) and the chemical properties of pre-stellar cores. These properties, a priori independent, are in fact linked since for example, the density influences the chemistry, which in turns can determine the collapse rate via the ionization fraction. High angular resolution is needed to probe the scales at which fragmentation occurs and the protostar forms. With the increasing angular resolution, analysis methods become more accurate, yet more elaborate: radiative transfer tools (e.g. multiwavelength, 3-dimensional continuum radiative transfer and line radiative transfer) that we worked out in previous years are necessary to carry out this study. A 3-dimensional study of the physical structure of pre-stellar cores (density, temperature) is now within reach, because ALMA will probe the small structures of cores at the fragmentation scale. We will extend our studies in order to determine grain size distribution in various cores, using in particular the Spitzer Telescope Archive.

2.2.2. Pre-stellar cores & disks

Protoplanetary disks are where planets form. Whether, how and what planet will eventually be formed depends on the structure and the evolution of the protoplanetary disks. The team FOST has a world-recognized expertise in modeling and observing the dust continuum from protoplanetary disks, but little experience in the gas component. The collaboration with FOST started in the last quadrennial. During 2010-2014, we will enlarge and fully exploit the collaboration by coupling models of the disk structure as derived by the continuum observations and modeling (the FOST contribution) with models of chemistry (in the gas and on the grain surfaces) and line radiative transfer as well as observations of the gas component (*ASTROMOL* contribution). Particular targets will be the water, whose lines will be observable with Herschel in the next three years, and lines from tracers of the ionization, sedimentation and turbulence in the disk, which will be observable with ALMA.

In addition, we plan to enlarge our studies of the gas component in protoplanetary disks by using near-infrared observations of molecules, thanks to the new high resolution spectrometers available for example at VLT (e.g. CRIRES). Here the goal is to shed a light on the history of the grain and molecular building process, by observing whenever possible, the same molecule (and isotopes, specifically the D-containing ones) in a sample of protostellar objects at different stages of their evolution. Once again, a first collaboration with FOST on CO has already led to published results. In the next quadrennial, we would largely take advantage of the possibilities offered by the near-infrared (and also optical) spectroscopy of molecules, other than CO.

Clearly, the molecular complexity systematic exploration (see point 2.2.4 below) is a key area of expertise that we would bring in to the understanding of the history of disks and of subsequent history of solar systems. This intimately connects to the 'Chemistry and Primitive Matter" axis of research together with the « Planeto » team, bringing its own expertise on meteorites as fossils of the primitive solar system.

2.2.3. Protostars

Once the collapse sets in, the gravitational energy of the collapsing matter is transformed into radiative energy. The collapsing envelope is warmed up and a peculiar chemistry follows. We know that in some low mass protostars "hot corinos" appear, warm and dense regions enriched of complex organic molecules. However, the sensitivity of the present instrumentation prevents from having any statistical study of hot corinos and only a handful of them have been studied so far. Furthermore, the spatial resolution is not high enough to resolve the hot corino. It is therefore unclear what exactly is at the origin of their appearance: the thermal sublimation of the ices in the envelope, the shocked gas or the disk. Recent observations seem to suggest that the chemistry may be influenced by the history and dynamics of the collapse. Are we able to really unveil all possible chemistry? And what are the routes to the formation of all these molecules? Grain surface or gas phase chemistry? When? How? These will be goals for future observations with ALMA. There is no doubt that the next few years will see a blossoming of those studies. *ASTROMOL* is well equipped to be the leader of the game.

2.2.4. History of molecular complexity

The aim of the team is to observe, to model and to understand how and where complex molecules form, how we observe them as efficiently as possible, and how could we be able to trace their history through the sequence leading to the formation of a Solar System. In order to fulfill these goals, we take advantage of our new environment:

a. The Herschel HIFI spectrometer, for which C.Ceccarelli is PI of the HF3S key program, aimed at the young stellar objects. Besides H_2O, which remains a special goal for our team (see the report part), the spectral range of HIFI, extending up to approx. 2THz, should allow to see light hydrides (e.g. CH, OH, NH, and their ionic forms) in cold environments and the torsional modes of more complex molecules (like the internal pseudo-rotation of methyl groups $–CH_3$), probing warmer environments (about 100 to 400 K).

b. The FORCOM[2]-ANR collaboration with Lille and Toulouse (observation, theory, spectrometry) focuses on the spectrometry and chemical calculation on icy grains instrumental to understand the possible observation pathways and plausible molecular history. A census of complex molecules is underway, with help of the unbiased spectral survey of the hot corino prototype, IRAS16293-2422 and the derivation of their abundance taking into account the structure of the protostar and the line radiative transfer. The future four years will focus on the fine-tuned analysis of the origin of the line emission observed with single dish telescopes: ALMA (and possibly NOEMA) will be ideal tools to unveil the relation between chemical and dynamical evolution (see below). The expertise in the excitation calculations (see point2.2.5c), shall expand in 2009-11 to much larger molecules, with the upcoming collaboration of *ab initio* specialists (U. Delaware) and the inclusion of internal modes in the inelastic scattering programs (U. Bordeaux). An ANR or another form of strong commitment is due soon, with Bordeaux, Meudon and possibly Besançon and/or Madrid.

[2] FORmation of COMplex molecules, ANR program 2009-12.

c. The strong new interactions with the Planeto group, which define new scientific limit conditions: chemical content of comets, isotopic contents of meteorites. Also, new challenges arise with the understanding of high atmosphere chemistry, especially for Titan.

d. IR spectroscopy will be a new tool for the *ASTROMOL* studies, allowing observations of several molecular ro-vibrational lines. In general, such observations are complementary to the radio-submillimeter observations because they sample different regions of the studied source, mostly the warmest and densest, opening up new possibilities.

e. The theoretical modeling of surface chemistry, with help of new theoretical tools (master equations, coll. Jerusalem U.) as well as pursuit of experimental activities (with planetary sciences) and input from theory (point b above)

2.2.5. Molecular excitation studies

A major difficulty in modeling the infrared and (sub)millimeter spectra of gas-phase complex molecules is the complete lack of state-to-state collisional rate coefficients. Accurate quantum scattering calculations for polyatomic species are computationally highly challenging, particularly when both rotation and low frequency vibrations such as bending and torsional modes are involved. Several items should be tackled:

a. The Potential Energy Surfaces (PES) calculations are always a prerequisite for all dynamical calculations. They should be performed in reduced dimensionality, emphasizing only the dynamics we intend to explore.
b. Smaller molecules or ions, where accurate PES and excitation schemes are within reach of present-day codes and computers. We shall pursue this approach for light molecules that are one of the key goals of the Herschel program (see point 2.2.4 above).
c. Larger molecules, for which hybrid strategies are sometimes necessary. Several successive specific frameworks are needed for examining the excitation scheme of a large molecule like methyl formate.
d. Approximate approaches to estimate and/or extrapolate rotational and ro-vibrational rates for polyatomic molecules with many degrees of freedom. This involves i) running quantum calculations for low-lying levels and low temperatures (<100 K) and ii) using classical calculations and/or extrapolation for high-lying levels and high temperatures.

Future systems might include large organic species such as methyl formate ($HCOOCH_3$) and acetaldehyde (CH_3CHO), as well as the very peculiar H_3^+. For these, rotational calculations will be performed at the standard quantum close-coupling level using *ab initio* potential energy surfaces (PES) of moderate accuracy.

There is a considerable demand to expand our theoretical tools towards a better understanding of experiments (U. Nijmegen) and of the high atmosphere molecular line shapes, based on accurate quantum calculations. This will be an opportunity for our team to strongly couple with the expertise on high atmosphere of Titan and also, in a more distant future to develop some diagnostic tools of other atmospheres, terrestrial or beyond.

2.2.6. Laboratory Experiments

Laboratory experiments will be pursued within the framework of the new thematic group on 'Chemistry', within the strong present collaboration between *ASTROMOL* and the LPG team. A complete project report is included in that section.

2.3. Jets & Energetic Processes

2.3.1. Introduction

Momentum, energy and chemical transfer involved in the interaction of star-forming events with the ambient medium play a very important role in the understanding of molecular cloud evolution and star formation. On very wide parameter scales this interaction proceeds over shocks, which are driven by the jets and outflows which accompany the accretion phase in protostellar systems. It is now accepted that these outflows result from the acceleration and sweeping-up of ambient material by a faster (and often not directly observable) wind/jet from the protostar. Jets are observed in all the young stellar objects from the very early Class 0 to the more evolved Class II objects.

The study of the shock-acceleration process in outflows is crucial to address the entrainment of the ambient material.

An important point is the nature of the shock accelerating the outflow, either purely hydrodynamical (``J-type'') or magneto-hydrodynamical (``C-type''; Draine, 1980). In practice, the dynamical timescales are so short that magnetized shock structures do not attain steady-state and exhibit mixed C-/J-type features. The analysis of the emission is very much related to the modeling of shocks: except in a few cases, only the PdBI and mainly ALMA have the capability to resolve the emission of high-excitation tracers in the shock cooling region (about 10^3 AU). Complementary interferometric observations are therefore required to model the dynamical shock structure, whose chemical predictions are then compared with the observations. One of the main goals of HSO/HIFI will be to observe the far IR lines of H2O and CO, two major cooling agents in shocks, and the low E_{up} transitions of hydrides, which play an important role in the chemical and thermal evolution of the shocked gas.

Another important point is the chemical composition of protostellar jets, which are largely unexplored so far. This must be taken into account in the study of the Mach disk (it has been proposed that some of the observed chemical differentiation would find its origin here) and can bring direct constraints on the jet origin and launching mechanism (e.g. MHD molecular wind).

During the next 4 years, these two aspects of the protostellar mass-loss phenomena, shock and jets, will be intensively studied observationally with the instruments HIFI and PACS onboard HERSCHEL, as well as with ground–based telescopes, single-dish and interferometric.

2.3.2. Ionization of dense matter by hard radiation

Ionization is a very common process in a variety of astrophysical environments. Yet, it is poorly known in dense media like molecular clouds and circumstellar disks (inside which the usual UV radiation cannot penetrate), despite the fact that it is a crucial factor for both the coupling of matter with magnetic fields (hence for star or planet formation) and the radical chemistry and diagnostics. In molecular clouds, it is widely accepted that galactic cosmic rays are responsible for the ionization state, but the exact nature of the interaction and trapping of low-energy (~ 10-100 MeV) cosmic rays, probably by turbulent magnetic fields, is still very uncertain. Likewise, in circumstellar disks, it has been known for some time that X-rays from the central star can induce significant ionization deep into the equatorial (protoplanetary) material, yet the respective influence of ambient UV and galactic cosmic rays, and of X-rays, are unknown. In order to significantly improve our knowledge and understanding of ionization in dense media, we are engaged in two different directions, characterized by their high-energy environment:

1. circumstellar disks around X-ray luminous young low-mass stars: study at mm wavelengths of various radicals tracers of ionization (such as DCO^+ and HCO^+), modeling of X-ray penetration, relevance for chemistry, possible influence on the initial conditions for planet formation;
2. molecular clouds interacting with supernova remnants: recently discovered and spatially resolved p°-decay TeV emission from specific molecular clouds show that they can be efficiently irradiated by high-energy cosmic rays accelerated by a neighboring supernova shock; the challenge is to see if, and how, the associated low-energy cosmic rays can produce enhanced ionization throughout these clouds, with possible consequences on the efficiency of star formation.

2.4. *The Planck Satellite*

a. Cold cores program

ASTROMOL is part of the Core program, led by I. Ristorcelli and M.Juvela on Herschel to follow-up the cold cores detected by Planck (200 hours on 250 clouds with PACS and SPIRE). The main target is to measure their dust properties, radial profiles and mass distribution, using an initial unbiased sample from Planck.

b. Responsibility in Planck

FX Désert is responsible for the interface between the instrument team and the data reduction pipelines (instrument model). He is involved in the satellite operations, helping François Pajot, the Operation manager, in the HFI instrument calibration. He is part of the Grenoble (LPSC) team in charge of the data reduction of Time-ordered-information in HFI, "cleaning" the data before they are projected on the sky.

2.5. *Ways and Means*

2.5.1. Personnel

The planned departure of P Hily-Blant (jan. 2011-2014) to the upcoming UMI in Santiago (Chile) is a challenge for the pursuit of our goals. He should acquire in Chile many new opportunities pertaining to the efficient use of the ALMA interferometer: contacts, participation in consortia, students and collaborations. While simply hiring a new young colleague does not seem realistic, equivalent post-docs/visiting scientist positions are necessary so that *ASTROMOL* would be able to continue to fulfill its stated goals and commitments.

- New positions

One of the keys of the future of *ASTROMOL* is its recruitment policy. For the next quadrennial, two priorities emerge:

i. ***Molecular Theory*** Since *Pierre Valiron's* death, our theoretical chemical expertise is way below our needs. Also, our growing success and the uniqueness of our crossed expertise prompted the *ASTROMOL* team to put its emphasis on the theoretical effort. We would need in the next few years *two openings* in 'Theoretical chemistry and/or molecular physics for astrophysics', one at junior and one at intermediate level. The 13/04/17 sections CNRS and/or the 30/31/34 sections CNU are relevant.

ii. ***High-Energy astrochemistry.*** Modeling and theory. Interaction inside dense regions and disks with high-energy photons, electrons, particles. The proposed position would enhance Astromol capacities to deal with this new and very promising theme, which could benefit from the Sherpa and possibly LPSC environment. We would need *one opening* for that goal: CNRS 17/ CNAP / CNU 34.

iii. ***Interferometry (permanent or non-***permanent position). The planned departure of one of our scientists to participate to an international research unit in Chile will have to be compensated, in order to enhance our capabilities about the evolution of (sub)-mm observations toward interferometry (ALMA project upcoming and NOEMA project planned).

2.5.2. Organization in the new laboratory

While we have to fully take advantage of our new environment, including the LPG and the newly emerging Chemistry research theme, we shall retain our team structure, at least for a first part of the next quadrennial period. Many of our research themes are now very mature and need our whole attention, within the same framework (First stages of stellar formation, disks in collaboration with the FOST team, jets and high energy, and theory of molecular excitation). The research effort is and will be mainly supported by:

- The PCMI, PNPS and PNP national programs, the COST chemical universe action,
- The present-day PPF (B. Lefloch, PI) and its follow-up,
- Parts of the ANR contracts of C. Cecarelli and F. Ménard.
- A proposal in 'Theoretical Molecular Physics for star formation' should be set up, that would include the broadening of spectral lines as one of its goals.
- C. Ceccarelli would be candidate for an ERC advanced grant.

Chemistry thematic group

Members of *ASTROMOL* will actively take part in the development of that axis (themes, see in the relevant section). In the beginning of the new quadrennial, no independent financing is necessary, except for precise grants from national programs. A greater autonomy of that axis, possibly representing the backbone of a new team, is not excluded.

3. FOST

3.1. General features

The main objective of FOST is and remains the understanding of the stars and planets' formation. Both can no longer be investigated separately. Planetary systems are viewed today as a natural byproduct of stellar formation. The wide spectrum of FOST's activities and skills gives the opportunity to study all aspects of this research field. This also means characterizing the diversity of objects, in particular substellar objects and planetary systems. Great advances are achieved today in this research field. Part of them is due to FOST and we want to maintain our leading position. The merging of LAOG and LPG will offer the opportunity to FOST to further investigate the physics of planetary systems and to initiate a real comparison with the Solar System. Three main tightly interconnected issues will basically need to be investigated in the upcoming years:

- What are the conditions for planetary formation in young disks?
- How does a protoplanetary disk evolve towards a planetary system? How important is the debris disk phase in this scenario?
- What is the diversity of planets and substellar objects? How does the Solar System fit in?

These issues have been quoted as important items for the upcoming years in the Astronet prospective. To fulfill these goals, we need to keep improving both our observational *and* modeling capabilities. We are involved into large upcoming observational programs such as HERSCHEL and SPHERE, into the design of instrumental projects like SPIROU, and we keep developing our computing capabilities.

3.2. Prospective in the field "Stellar Formation, young stars and disks"

In this research field, in relationship with the ongoing and scheduled observation programs, we plan to further investigate the role of magnetic field in stellar and planetary formation, studying protostellar jets and circumstellar disks. But there is a crucial need for developing our modeling capabilities, to be able to model data from the upcoming new HRA instruments. This need was already underlined in our 2005 plan. Part of it was fulfilled, but some aspects still need to be developed, as detailed below.

There is growing evidence today that the magnetic field play an important role in the evolution of protoplanetary systems. We want to get clues about its central role in the accretion/ejection process, in planet formation and migration in disks, in the rotational evolution of stars, and more generally in young stars properties (e.g. X-ray). To achieve this we need to get a full characterization of the magnetic field topology and its evolution in young low-mass stars. The main related ongoing program is MONITOR (up to 2012). We want to derive rotational evolution models for young stars, to investigate the issue of the link between the rotational history and planet formation. This will probably need a large observing program at CFH and ESO. We also plan to continue our activity in the reconstruction of magnetic maps of stars. This work is supported by the MAPP ANR grant (coll. Donati, Toulouse; up to 2012). We are involved in a large CHFT (680h) observing program. Our mid-term projects in this topic are to include young stars and field dwarfs, to look for magnetic star-disk connection in YSOs and to get dynamo parameters in field dwarfs. This will be possible with SPIROU and VSI.

Another issue related to magnetic field is the origin of protostellar jets. Our immediate objective is to continue HRA observations of jet sources with AMBER/VLTI, to understand the origin of the Brγ emission. Several of our upcoming observing campaigns have been accepted. With E. Whelan (starting soon a Marie Curie grant a post-doc at LAOG; 2009-2011), we will perform a spectro-imagery survey, and investigate the excitation conditions, the mass loss rates and the collimation in ~10 sources. This program will constitute a touchstone in the next 2 years. We also want to initiate a statistical approach to look for correlations between jets and stellar properties. We have planned an

ESO spectral survey at NTT SOFI/EFOSC2 to analyze 180 Spitzer sources. But beyond these statistical properties, a key issue to investigate is the temporal variability. To do this, we want to analyze multi epoch data to look for temporal variability. We want to understand the origin of nodes in jets and the stochastic nature of mass loss. Concerning models, we plan to develop wind disk models to derive prediction on the continuum infrared and forbidden lines emissions. We also plan to build a 2D radiative transfer code in permitted lines, in relationship with MCFOST.

The study of protoplanetary disks aims at investigating their properties as a function of the various stellar and environmental parameters. The final goal is to derive the initial conditions for stellar *and* planetary formation, via a comparison with the solar system case. This requires observations and modeling. There are ongoing observational campaigns with HST for imaging (GEODE), NAOS and AMBER at VLTI, and very soon HERSCHEL (GASPS and DIGIT program) for which we have been granted 650 (400+250) hours. With HERSCHEL, we want to model the continuum up to 300µm. Our midterm project is ALMA (~2012). The goal will then be to study the continuum and the chemistry, in relationship with ASTROMOL. We will also keep studying the mineralogy of crystalline silicates in planet formation regions around young stars. Thanks to the merging of LAOG with LPG, a comparison with solar models will be initiated, and constraints on exoplanetary systems will be derived. Many FOST members are involved in the development and the use of interferometric imaging instruments (GRAVITY, PIONIER, VSI). The priority is to get the first image ever of the environment of a young star, resolved at the AU scale. The first step is to constrain the radial structure of disks. We are currently working on the detectability of gaps in disks with interferometry.

Concerning debris disks, we also have scheduled campaigns with HERSCHEL to observe them and look for exozodiacal dust clouds (DUNES and DIGIT programs.). Exozodis emission is not only important by itself, but it can also affect the detectability of Earth-sized exoplanets. It can affect the contrast and simulate planets when structures are present. Today, most space agencies work with the solar zodi model. We showed that the solar zodiacal cloud is not representative for the diversity of exozodis. We thus need to characterize this diversity observationally. Interferometric observations of debris disk will be extended to look for close-in dust population, with CHARA and VLTI. On a longer term, we are interested in next generation nulling interferometers. We are currently discussing our implication in Darwin's precursor missions, ground based (ESO/GENIE?) as well as spatial (FKSI).

Our main tool for modeling young disks is the MCFOST transfer code, to fit data and produce synthetic disk images. The recent recruitment of C. Pinte at CNRS (2009) will considerably help developing MCFOST, which is widely used today for many purposes inside and outside LAOG. This extended use of MCFOST implies to improve the work interface. A wrapper dedicated to data exploitation is currently under development by G. Duchêne at UC Berkeley. We also plan to combine MCFOST with hydrodynamical codes (SPH, coll. S. Maddison) to investigate the growth and migration of dust. Finally, a long term objective is to introduce chemistry in the code, in collaboration with ASTROMOL. This will allow modeling radiative transfer in spectral lines, which is not yet possible with MCFOST.

The need for dynamical N-body modeling (symplectic codes) is steadily growing at FOST. We simulate structures observed in disks to derive constraints on the geometry and/or on the presence of planets. This activity will keep growing in the upcoming years, in relationship with the operation of HERSCHEL and SPHERE. We want to investigate more deeply the high activity episodes suspected in systems like Vega and to compare with related Solar System scenarios for the Late Heavy

Bombardment (coll. A. Morbidelli, Nice). The frequency of such phases is unknown. We also plan to use the codes to simulate the structures expected in disks in binary environment (truncation, spiral arms…; coll. Y Wu, Toronto). A general emerging trend is that we need to add some physics to the codes. We need to simulate the dynamics of dust , planetesimals, planets and/or stellar companions. But for debris disk we need to incorporate collisional cascades into the code. To study younger systems, we need to handle gas dynamics. This is part of our code development projects for the next years. To do this we have collaborations with A. Krivov (Iena, for collisions), and with L. Fouchet (Bern, for gas).

The work on protoplanetary disk is supported by the "Dusty Disks" ANR grant (P.I. Ménard) The collaboration with Jena is supported by ISSI (Bern, Switzerland) in the framework of a team led by J.-C. Augereau and A. Krivov.

3.3. Prospective in the field "IMF and low mass objects"

There is now a clear overlap in mass between the lightest/coolest brown dwarfs and giant planets domains, and it is therefore important to determine the lower mass part of the IMF if we want to understand both the stellar and planetary formation processes. These objects are the last missing link between planets and substellar objects. We will therefore pursue our effort in constraining the IMF from 30 M_J down to a few M_J. We will also keep looking for very low mass BD and isolated planetary mass objects (IPMO) in young clusters. We have started a large observational program with WIRCAM and will carry out the data analysis for the next couple of years. For detected objects, we will perform follow-up observations to study the physical properties of young IPMOs.

When looking at clusters, an important issue is to know whether the observed present-day mass function is representative of the IMF. As a cluster evolves, dynamical processes act to deplete its lowest mass members. It is therefore necessary to investigate the effect of dynamical evolution on the shape of the mass function. E. Moraux obtained a young scientist ANR grant starting in 2009 (DESC: Dynamical Evolution of young Stellar Clusters) to develop this topic using N-Body simulations. The project will be done in collaboration with the Galaxy team in Strasbourg. There is support for one postdoc at LAOG to develop the available codes and run the simulations. The project aims at addressing the following issues: - What are the initial conditions of cluster formation? - What determines the distribution of stellar masses in clusters? - Is there a universal mass function of stars, brown dwarfs and giant planets produced in all clusters? - How does the cluster environment affect the evolution of the statistical properties of young stars?

This spectral characterization of cool objects is of prime importance for the study of exoplanets. We will thus keep looking for ultra-cool brown dwarfs in the CFBDS survey. Our objective is to detect and characterize Y dwarfs. We are currently discussing with the UKIDSS team to share and characterize our coolest objects. In addition to NH_3 absorption lines, other spectral signatures are expected for even cooler objects. The Y spectral class corresponds to the temperature domain of giant planets aged a few 10^5 yr, which will constitute a major objective for SPHERE. Hence, our spectral characterization tools in this temperature domain will ensure the best analysis of the future exoplanets SPHERE data.

3.4. *Prospective in the field "Exoplanets"*

The two specificities of FOST's activity in the exoplanet research field are direct imaging, and the search for terrestrial-like planets around M stars (with radial velocity technique), some of them being potentially habitable. We want to keep our leading position in these fields, and take advantage from the new upcoming instruments. This motivates our implication in the design of these instruments. We also need to reinforce our modeling capabilities to be able to handle complex systems with many planets. And finally, we want to investigate more deeply the field of physical studies of exoplanets.

In radial velocity studies our objective for the upcoming years is twofold: we first want to keep searching for exoplanets around stars of different types (A to M). But given our recent advances, a second objective is the search for both Earth-sized and habitable planets. M dwarfs are well suited for this purpose: small planets are easier to detect, and the habitable zone is closer to the star. The observations are made at ESO/HARPS and OHP/SOPHIE. We expect to reach 1 $M_{\oplus}$ planets within a few years and to detect many examples of systems with planets in habitable zone like Gliese 581. This is the objective of the SPIROU instrumental project (see below).

Searching small exoplanets does not only mean building accurate instruments. One also needs to be able to efficiently analyze the data. In this context, two difficulties arise. First, below a 1 m/s accuracy threshold, the radial velocity signal is very likely to be affected by stellar effects (spots, asterosismology, etc…) that need to be correctly modeled. That is why we want to keep studying the hosts stars in the near future, and to keep improving our numerical methods to identify and reject stellar signals. Secondly, regardless of the mass of the host star, Earth-sized planets are likely to reside in systems where more massive planets are present. Consequently, the signal is often complex and one needs to fit several planets simultaneously. Moreover, secular perturbation effects between planets may not be negligible. This is why we want to improve our fitting procedures. Our objective is to combine the fitting procedures with our N-body symplectic codes and genetic algorithms to take into account the perturbations *at the time* of the fit, which has not been done yet. To do this we will need a new post-doc. We will also keep investigating the stability and the secular evolution of the extrasolar systems discovered, as we did in the cases of Gliese 581 and HD 60532.

Concerning direct exoplanet imagery, the next goal is to image giant planets and to perform spectroscopic studies. We want to keep looking for low mass and exoplanet companions with NACO. But the main instrumental project in this research field is SPHERE, a second-generation adaptive optics instrument, currently under construction at LAOG (P.I. Beuzit, with several FOST members involved), and scheduled for 2011 at ESO. SPHERE will be able to image $1M_{jup}$ planets in 100 Myr old systems, and $10M_{jup}$ planets in 1 Gyr old systems. A key issue is to constrain the frequency of Jupiters beyond 5 AU (a distance hardly reachable with radial velocity surveys due to the time basis), and to understand how it varies with the stellar characteristics. This will help constraining the efficiency of the different formation mechanisms (core accretion, instability…) of giant planets. We also plan to directly detect hot Jupiters and to perform spectroscopic studies with second generation VLTI interferometers. Such a detection turned out to be difficult with AMBER, but we think that this will become easier with instruments able to recombine 4 VLTI telescopes, first with PIONIER and then with GRAVITY and VSI. We also recently discovered a new method using phase closure when the visibility gets null to detect exoplanets around resolved stars [ACL-564].

As we indentify now very different exoplanets, we need to carry on with our implication into the physical study of extrasolar planets. Thanks to the refurbishment of HST, the next four years will see the beginning of high resolution spectroscopic investigations of the atmospheres of exoplanets in the UV and the near IR. These studies will focus on the 50 transiting planets known today, including hot Jupiters, hot Neptunes and also super-Earths, whose number is expected to explode thanks to the CoRoT and the Kepler missions. Investigating this research field is particularly relevant as LAOG is about to merge with LPG. The new laboratory will take an active part in the scientific exploitation of HST (coll. A. Vidal-Madjar, IAP), making use of two specificities: First, our implication in the radial velocity and planet imaging campaigns will enable us, in case of a discovery, to rapidly react and plan observations to characterize the planet. This is crucial in a highly competitive environment. Secondly, the experience on the Solar System planets (Mars, Titan and the gas giants) of the planeto team of the laboratory will give a new perspective on the physics of exoplanets and will allow to initiate a real compared exoplanetology.

3.5. Implication in instrumental projects

FOST regularly contributes to the design of instrumental projects. This is of course in direct relationship with the participation of many FOST members to GRIL team. But FOST also supplies scientific cases to instrumental projects. These contributions are always related to our main research interests, the immediate goal being to have access to guaranteed observing time. The first instrumental project we are involved in is SPHERE (see above). It is currently designed at LAOG and will be operating in 2011. Many FOST members are implicated in SPHERE. SPHERE will be able to go beyond the capabilities of NACO and to directly image giant exoplanets. Moreover, SPHERE will offer a new tool to investigate the physical properties of exoplanets.

Our mid-term project is SPIROU (see above). It has been selected in phase A at CFHT in 2009, and is scheduled for 2015. Many FOST members (X. Delfosse, T. Forveille, C. Perrier, J. Bouvier) are active members of the project. SPIROU is a spectropolarimeter dedicated to measuring radial velocities in the near IR. The main scientific objective is the detection of Earth-like planets in the habitable zones of low mass stars. Another objective is to perform magnetic field measurements towards very low mass stars and brown dwarfs and to reconstruct their magnetic topology. The implementation of a data reduction center is also planned at LAOG to handle the data of exoplanet search missions like SPHERE and SPIROU. Many FOST members will take part in this reduction center.

We are also interested in interferometry. AMBER and CHARA observations campaigns demonstrated the power of interferometry to probe the innermost regions of circumstellar disks. The next step is the development of image reconstruction. This will be possible with upcoming instruments like PIONIER, GRAVITY and later VSI. We are involved in the design of these projects. On a longer term, we are currently discussing our possible implication in the space interferometer project FKSI. FKSI will be able to detect and characterize exoplanets and debris disks with zodiacal dust down to the Solar System level. It will explore the atmosphere of non-transiting giant exoplanets.

3.5.1. Needs in personal

Our research field is characterized today by rapid advances and a high level worldwide competition. It is therefore difficult, in such a rapidly evolving environment, to define our exact needs in personnel for the coming four years. In order for us to continue our development, it is essential that we remain at the top of the research in our domain and that we keep a broad enough expertise to enable us to handle all aspects of a given issue, maintaining our capabilities in the triptych instrument design –

observations – modeling. This allows the identification of a short list of profiles that need or will probably need to be fulfilled in the upcoming years.

1. **Detection of extrasolar planetary systems and statistical properties** (urgent, 2010-2011): FOST assumes a world leading position in the search for exoplanets around M and A-F stars (using HARPS and SOPHIE). A large part of the work is done today by non-permanent staff (1 post-doc, 1 PhD). The competition is here extremely acute, so there is an urgent need to reinforce our permanent staff. This is also relevant in the context of the design of SPIROU in the next years.

2. **Dynamical simulations of disks and planetary systems** (short term 2011-2012): The reinforcement of our modeling capabilities was underlined in our 2005 research plan, putting forward radiative transfer modeling and dynamical simulations. The recent recruitment of C. Pinte fulfills the former topic, but the latter is still unsatisfied. Meanwhile, the need for dynamical simulations in FOST kept growing. Today this concerns not only structure modeling in disks, but also dynamical studies of extrasolar systems, together with the development and improvement of the codes. This research is clearly understaffed at FOST (1 staff member, not full-time).

3. **Physical characterization of exoplanets and low mass objects** (mid-term 2012-2013): As mentioned above, the physical study of exoplanets is a rapidly growing topic. We want to take advantage of the merging of LAOG and LPG to keep developing our expertise in this domain. This will be done in the framework of an "exoplanets" transverse axis between FOST and the planeto team. This characterization concerns exoplanets as well as low mass brown dwarfs. This research is currently done at FOST by 1 post-doc. There is therefore a real need here.

4. **High Angular Resolution observations of disks and planetary systems** (mid-term 2013-2014): The studies of disks are fed by mutiwavelengths observations using a wealth of techniques and instruments, such as direct imaging, interferometric image reconstruction, chemical (gas) and mineralogical analysis of the dust constituents, lines observations. FOST wants to consolidate its position to contribute to the international consortia that will perform the analysis of the observation at VLT, VLTI, ALMA and JWST. This implies the recruitment of a new staff member able to lead some of these observational projects in relationship with modeling effort at LAOG.

5. **Magnetism of disks, stars and substellar objects** (long term 2014-2015): We are involved in large programs to characterize the magnetic topology of young stars. The observations are made with ESPADONS and will be furthermore done with SPIROU, with an extension to brown dwarfs. At present all data reduction is done in Toulouse (Donati). We would like to have this expertise at FOST to reinforce our reactivity. This will imply the recruitment of a new staff member to conduct observations and modeling (in collaboration with SHERPAS).

Finally, we would like to point out our needs in technical personnel to help developing numerical codes. Many people at FOST work at developing and using numerical simulation codes (see above). Code development is very time consuming. Hence we would like to recruit an engineer (ITA) specialized in scientific programming to help theoreticians to develop codes.

4. GRIL Team

4.1. Context and strategy

The research project in instrumentation for the new laboratory will occur within the framework of the next-generation instrumentation plan for the VLT(I) and of the first generation instrumentation plan for the E-ELT. Concerning space-oriented instruments, the future developments will occur in the framework of the Cosmic Vision program initiated by ESA and aiming at the development of planetary exploration missions in the timeframe of 2017 to 2025.

Within such a context, our prospective exercise in instrumentation will probably have to be modified and/or modulated by several external constrains such as the reinforcement of partnerships with industrial or academic partners inside large consortia (i.e. Swifts or RAPID for instance) or decisions and schedules imposed by the agencies for the future instruments (case of EPICS for the ESO E-ELT or Cosmic Vision program for ESA). As a consequence, it appears critical for us to keep a leading role in the area of system analysis activities. We will thus pursue our involvement in instrumental activities with this goal in mind, as detailed in the following sections:

1. Studies of instrumental concepts for future observation facilities
2. Overview and mastering of measurement and stability aspects for wavefront sensing and high dynamic-range techniques
3. Study of the critical points to master the measurement procedure and the servo-loop aspects for the optimal design and use of a fringe tracker
4. Characterization and full mastering of the calibration aspects of integrated optics components
5. Global overview of the various integrated optics technologies according to the wavelength range of the future instrumentations
6. Mastering of technical aspects for adapting the Orbitrap concept to spatial applications
7. Advanced data reduction up to image reconstruction
8. Software and operation of radars for planetary sciences missions

4.2. What will the merging of the two laboratories bring?

Several meetings and workshops have been organized since January 2009 between LAOG and LPG. They focused on instrumentation issues: presentation of the manufactured instruments, used components and test benches, work methods and analysis of the merging' impacts on the instrumental staff. The aim of the previous GRIL LAOG team is confirmed in its action to develop and foster exchanges and collaborations between all the lab members involved into instrumental activities. This action is more than ever essential within the context of an enlarged range of skills and involvements in the new laboratory. The existence of a team gathering all instrumental activities is motivated by the interest of such a scientific animation whereas the day-to-day manpower management, technical staff decision, and decision making about new projects is handled at the lab head level.

Concerning the instrumental activities, the merging of LPG and LAOG will bring:

- New solicitations (due to the spread of the outline of the new laboratory).

- Extended range of skills (gathered in a single team), which will lead to a better reactivity and use of the competences. As an example, collaborative work already exists since 2009 on two projects:
    - the development of the flight software and of the Electrical Ground Support Equipment of the WISDOM radar experiment for the Exomars/ESA lander mission (Mars lander equipped for exobiology investigation to be launched in 2016),
    - the portage into space environment of a new concept of ultra-high-resolution mass spectrometer, Orbitrap, which is proposed as a payload on the Marco Polo mission (medium-class mission for asteroid sample return) and EJSM (large-class mission towards Jupiter and Ganymède).
- Exchanges of know-how between the instrumental experts of both laboratories. For instance, complementary know-how on virtual observatories exists in both laboratories and these skills will be reinforced and consolidated in 2010 with the recruitment of a software developer who will be specialized in the development and management of databases.

The research project in instrumentation for the new laboratory will be built upon the nationally and internationally acknowledged expertise and resources of both LAOG and LPG, including:

- Manufacturing / Integration / Commissioning / Servicing of instruments for large ground based equipments and for space missions,
- Concept studies
- R&T developments,
- Instrumentation for laboratory experiments

The GRIL team will endeavor to maintain a good balance between these complementary activities since this remains an effective way of being involved in each generation of instruments and of being leader on innovative developments.

4.3. Manufacturing / Integration / Servicing of instruments

This section will focus on large projects although other projects of smaller scope will most certainly occur during the next quadrennial period.

The adaptive-optics instrument SPHERE will be delivered to ESO in the first half of 2011, after the ongoing manufacturing, assembly, integration, and test phase. By contract, the consortium shall provide manpower to ESO at Paranal for the commissioning and the operation of the first two years. The new lab is also very interested in setting up a SPHERE Data Center in Grenoble for processing the scientific data of the 260 nights of Guaranteed Time Observations. The scope of this Data Center could also be extended to the processing of all SPHERE data, on behalf of the ESO community, if an agreement is reached with ESO. Contacts have been taken with existing data centers (like Terapix) to help us evaluate the required resources. Finally, in collaboration with ONERA and ESO, we have obtained additional funding from Opticon/FP7 to study and implement possible improvements to the control of the SPHERE residual wavefront errors. These improvements will include the development of faster control algorithms for the real-time computer, the validation of the on-line phase diversity method recently proposed by ONERA, etc. We expect most of these contributions to be implemented at the time of first light.

The new laboratory intends to play a major role in the field of interferometric imaging. The leading project will be the second-generation VLTI instruments VSI, selected by ESO in 2007, whose goal is to provide images at the milli-arcsecond spatial resolution coupled to medium/high spectral resolution in the near infrared. Due to the technical challenge of combining 6 different telescopes, required for VSI to reach its main science cases, we have started to pave our way by strengthening our expertise in the development of integrated optics beam combiners. As an intermediate step, we will provide the GRAVITY instrument with a 4-beam combiner, prefiguring the VSI one and allowing to gather early experience in interferometric imaging. In the meantime, since GRAVITY will not come into operation before 2013 and since the actual schedule of VSI will be strongly correlated to the availability of two additional Auxiliary Telescopes, we have proposed our own visitor instrument for the VLTI (PIONIER) and expected to start observations in 2010. Although PIONIER will remain a relatively simple instrument as compared to GRAVITY, MATISSE and VSI, it should allow to combine the beams of the 4 auxiliary telescopes of the VLTI and thus produce exciting astrophysical results on a very short timescale, therefore helping to catch up with the advance of the US teams in this field of interferometric imaging.

The Consert radar Experiment is in-flight on board of the Rosetta/ESA probe which will rendezvous the 67P Churyumov-Gerasimenko Comet in 2014. The preparation and the execution for the science sequence is a Marathon: development of the Consert Ground Segment up to 2012, inter-operability with the Rosetta Ground Segment and validation up to 2013, preparation of the final science sequence for first nucleus observation (Nov. 2014), execution of the science sequences (11/14) and after data analysis, archiving, distribution. This challenge for our laboratory will require a significant effort in term of manpower during a long period and resources (priority of computational resources and service continuity during 2014).

The Wisdom radar experiment is developed under LATMOS responsibility for a launch in 2016. Our laboratory develops the On-Board software and the Electrical Ground Support Equipment. Software and documentation will be delivered at each phase of the project up to the platform integration and test. It will be followed by the implication in the instrument operations during the mission.

The laboratory will also be involved in the optical design of a near-infrared spectropolarimeter for the CFHT, called SPIROU. This development will occur in close relation with the FOST team since one of the main goals of this instrument is the measurement of radial velocity variations in the near infrared with a very high precision (the goal is to reach 1 m/s) for the detection and characterization of extrasolar planets, especially around low mass stars.

4.4. Conceptual studies

Since phase measurement is a very important concern for interferometric imaging, we have considered to be strongly involved in the development of fringe tracker concept and to acquire internally the corresponding know-how, which was a mandatory pathway towards imaging at high angular resolution with VSI. Within this context, we decided to lead a conceptual design study of a fringe tracker for the VLTI in 2009. Results of the conceptual studies will be presented to ESO at the beginning of 2010. The new laboratory may be contacted for participating to the consortium in charge of manufacturing the 2nd-Generation Fringe Tracker for the VLTI (whose Call for Tender by ESO could be launched in 2010).

During the next quadrennial, the laboratory will most certainly be solicited for the design of the EPICS instrument for the E-ELT (phase B of the EPICS project is expected to start in 2011 or 2012). We will have interesting assets to remain involved in such conceptual studies and system analyses, especially in the field of high contrast imaging.

Apart from existing or planned instruments, the laboratory will pursue his research on new instrumental concepts. These activities stand on two major expertises: on one side, the knowledge of the stringent scientific requirements considering the astrophysical targets and, on the other side, the instrumental know-how, including R&T activities and overall technology survey. Among arising questions lies the analysis of innovative interferometric setups that may take into account the need for larger resolution, sensitivity and imagery capability. Some solutions may make use of older concepts revisited thanks to new technology availability, like fast and very sensitive detectors. Another track is a larger use of the potential of photonics, seeking for fully integrated instruments, under so-called astrophotonic concepts. As an illustration, we will organize a workshop entitled "Quantum of quasars: opening the window of quantum optics in astrophysics" in October 2009 to bring together astrophysicists, quantum optics physicists, and engineers working on ultra-fast detection to explore how quantum optics and astrophysics could be (re)connected to achieve a better understanding of cosmic objects and light itself.

4.5. R&T developments

We will develop prototypes of high spectral resolution micro-spectrographs (SWIFTS) and of matrices of infrared avalanche photodiodes (RAPID) funded by two inter-ministerial grants (Fond Unique Interministériel or FUI) obtained in 2008 and in 2009 respectively (see Bilan). The perspective for both projects is related to potential future astronomical instrumentation:

- In the mid-term, Swifts could be an attractive approach for the development of miniaturized imaging spectrometers able to perform mineralogy studies on planetary surfaces or atmosphere studies of various bodies of the Solar System on board spacecrafts.
- In the longer term, it could be particularly interesting to concentrate a large number of optical and detection functions into integrated components able to couple in a single device beam combination, fringe tracking, spectrometry and detection capabilities (see Section "Concept Studies").
- Applications of the infrared avalanche photodiodes to wavefront sensing and fringe tracking will be investigated in detail by 2014. These detectors (with low noise, very high sensitivity and high frame rate) will probably be of particular interest for the E-ELT.

The development of lithium niobate waveguides for the L and M bands will continue at least until 2012, thanks to the ANR grant awarded in 2009. We aim at providing single-mode components for space interferometers designed for imaging or nulling in order to perform exoplanet detection and characterization. Such combiners could be an attractive solution for future instruments like FKSI, dedicated to the study of exoplanets and exozodis. For such space missions, the laboratory would only be involved in the delivery of specific components but not at the system level.

A 3 year R&T contract with CNES for the space portage of Orbitrap concept (ultra-high-resolution mass spectrometer) has started in 2008. This activity will essentially consist in the support and the management of a project involving 4 laboratories, which should deliver a demonstration instrument (TRL5) by 2011. The hardware assembly will be conducted at LPC2E, in Orléans. The corresponding concept has been proposed for inclusion into two forthcoming missions.

4.6. Instrumentation for laboratory experiments

In 2008, the Planeto team acquired an ultra high-resolution mass spectrometer. The projects underlying this acquisition are related to the study of chemical processes occurring in Titan upper atmosphere. To this end, the commercial instrument will be modified to incorporate a reaction cell for quantitative rate constant measurements. Another project aiming at the study of negative ions chemistry will rely on the development of an electron attachment source to be incorporated into the device. Both developments will rely on the involvement of laboratory expertise in fields such as mechanics, electronics, informatics...

The radar experiments, field survey of analogue terrains are the equivalent of the lab experiment for instruments' validation and data inversion algorithm definition. This activity will support the Consert and Wisdom experiments and is also important for the definition of the next generation instrument.

Building on the expertise gained in the development of a first Mars simulation chamber "SERAC" to study the hydration of minerals in martian conditions, the Planeto team will develop a new martian simulation chamber at lower temperatures to study martian processes implying CO_2 and H_2O ices. It will be installed in a cold room and fit to the spectro-gonio-radiometer. New sample characterization techniques also have to be designed and implemented.

4.7. Emergent projects

The next decade will probably see the first launch of an interferometer in space, in the framework of the Exoplanet Exploration Program of NASA. Thanks to its acknowledged expertise in interferometric instrumentation and data processing, LAOG has been approached to participate in two different projects: the Fourier-Kelvin Space Interferometer (FKSI) and the Space Interferometry Mission (SIM). At this time, it is still unclear which of these two missions will fly, but either way our laboratory has a great opportunity to start getting involved into space interferometry. The LAOG contribution could either be at the beam combiner level for FKSI, or more at the system level for SIM. In both cases, the team's know-how will be very valuable for the projects.

The next-generation radar instruments consist in space-borne "Marsis-like" instruments or in small instrument on-board of rovers or landers ("Wisdom-like" GPR or "Consert-like" bistatic radar). The Planeto Team is involved in the projects or studies of the low frequency radars proposed in the frame of the future space-mission (Europa, Ganymede, Titan, Near Earth Object, Comets). The new lab implication in the future studies and development will be planned depending on opportunities. Today the Planeto Team is involved in the preliminary study of the orbital radar concept for Laplace mission in collaboration with the JPL and the University of Trieste (ESA study, CNES founding) and also in the Marco Polo lander study (DLR – "Consert-like" instrument).

A database service "GhoSST" on experimental spectroscopy and thermodynamics of solids will be developed in the framework of two FP7 European projects (Europlanet and VAMDC). It should obtain the official "service label" by INSU in 2009. (see also OSUG project).

4.8. GRIL Recruitment plan

The proposed researcher recruitment plan of this team includes researchers able to accurately understand the interest, limitation and capability of various instrumental concepts. Such abilities are critical to be able to propose and demonstrate new concepts, to analyze, orient and benefit from new technological opportunities, to propose and define the suitable instrument (instrument scientist) for breaking through new observational results in a given science case. The following list is motivated by the potential of new concepts and challenges arising in the international community from both new technological potentialities and specific science goals, and for
which the new laboratory is one of the best location in Europe to make such developments flourish. It includes:

1. **High contrast imaging** (urgent, 2011): gaining orders of magnitude in contrast performance to open the window of direct detection and characterization of a variety of exoplanets requires the intimate understanding of the ultimate limitations of the new upcoming instruments (SPHERE – delivery in 2011), a complete review and re-analysis of new ideas and concepts for the next generation of instruments on the ground (EPICS) or from space, their demonstration, discussion against re-focused science priorities, and possibly the implication in the final design and characterization of such new instruments. In this context, we need the opening of a new position in order to increase our capabilities of performance analysis, operation, and exploitation of (X)AO-based instrumentations. This instrumentalist would be an efficient support for the SPHERE Data Center. Some specific and urgent needs associated to the phase of integration and testing of SPHERE, and first phase of on-sky testing may require an additional temporary position.
2. **Long baseline interferometry** (short-term, 2012): on-going research is essential here to fully understand and characterize the critical functions of an interferometer, to analyze the astrophysical needs in terms of sensitivity, accuracy and imaging capability together with the new technological potentialities (integrated optics, detectors, phase measurement concepts, etc.). In the framework of the 2nd-generation instrumentation of the VLTI and to prepare the post-VLTI era of imaging arrays in the optical range, a researcher position is required as complementary to system engineers, for both the proposition and demonstration of more performing concepts and the developments of community instruments.
3. **Signal processing** (mid-term, 2013): the two previous domains (high contrast imaging and interferometry) directly depend on more and more elaborated signal processing capabilities. Improved capability would very constructively interact with the instrument system analysis and design on the one hand, and with the optimal astrophysical use of existing instruments. As examples, in high contrast imaging, the optimal signal extraction is a still widely open topic to benefit from multi-channel (spectral, temporal, spatial) information: it directly

impacts the design of new instruments and motivates coordinated efforts for the analysis of future data sets (SPHERE data center). In interferometry, optimal measurement of the fringe phase and amplitude is also a critical issue. Interferometric imaging is a highly motivating and demanding topic where the research for optimal information coding and the image reconstruction capability are great challenges. This topic motivates one or preferably two permanent positions.

4. **Project scientist in adaptive optics** (mid-term, 2014): in the framework of the Extreme-AO developments and E-ELT projects, we need a project scientist who ensures a strong and efficient link between the scientific requirements and the system analysis in order to increase our capacities. Such a position can be merged with a FOST need.

5. PLANETO Team

5.1. Introduction

After only 10 years of existence, LPG has established a recognized synergy between instrumental R&T, laboratory experiments, cosmo-material analysis, models and observation analysis in order to address key problems in Planetary Science. This use of physics and chemistry in the context of space exploration in which we are deeply involved (Pi and CoI 'ships) is our specificity. The range of skills available in LPG allows studying objects of the solar system from their outermost exosphere / ionosphere to their dense surface and sub-surface. Laboratory merging will result in the PLANETO team, which will inherit from LPG and develop new objectives for the next quadrennial.

First, the team is deeply involved in the Rosetta mission which will rendezvous its target comet by 2014. Crucial information on its **formation and evolution** will be gathered for the next 2 years as it approaches the sun. We will have to prepare for this arrival from a scientific, technical and organizational point of view. Secondly, the increase in complexity (multi-dimensional data) and quality of observational techniques and of spatial and temporal coverage in the last years implies specific study of the **physics of remote sensing** and opens the perspective to study the **evolution of planets and planetary environments** at different **timescales**.

Heritage and space exploration prospective thus lead to redefine our research themes within the Astronet key question: "***How do stars and planets form and evolve?***" In 2011-2014 our team shall contribute at the best international level of planetary science in:

- Primordial solid matter and comets exploration

- Mars as a presently active and evolving object

- Physics of planetary surface and subsurface remote sensing

- Evolution of outer atmospheres under the sun: planetary space environments and weathers

- Molecular evolution: chemistry

The merge will also lead to new organization and infrastructure for project developments. R. Thissen was chosen as the new leader of the PLANETO team. The themes will (when possible) involve researchers from different disciplines, with the desire to prolong the impulse from the successful thematic groups. The creation of a common technical platform and a double membership status between GRIL and PLANETO teams will boost the effectiveness of R&T developments and concept studies for planetary exploration. In addition, the existence of new thematic groups spanning across the new laboratory will strengthen existing research topics and lead to new ones within the future quadrennial (see the profusion of tracks in the description of thematic groups). At the OSUG level, an incentive effort is also organized (Planetol'OSUG, lead by J. Lilensten), and the Planeto team shall take its share in this federative operation.

5.2. Primordial solid matter and comets exploration

This thematic will constitute the cornerstone for our team as the Rosetta mission will encounter the Churyumov-Gerasimenko comet in 2014. The preparation of the analysis of the ROSETTA mission will be a major issue, along with pursuing the study of cosmo-materials and experimental studies of pre-solar chemistry.

Rosetta will characterize the comet subsurface with the Consert tomography radar instrument (built and operated under the PIship of W. Kofman & A. Hérique), and the molecular composition of the surface and tail when approaching the sun for the following year (Virtis instrument, CoI B. Schmitt & E. Quirico). Interpretation of those results will rely on considerable preparatory works, including computer model development or model material characterization, fields in which the team has already produced excellent work. There is a need to support this activity, through a permanent position. The activity on this thematic will increase throughout the quadrennial and will be intense from 2013 on.

Model Development will be oriented towards comet internal structure (presently described as shells, fractal, or accretion, the latter having been developed in Grenoble) in terms of physics and thermal conductance. The next step will be to progress in the radar signal inversion in order to decipher the structure and composition of the comet nucleus. The in-house support from the theme "Physics of remote sensing" will be very profitable.

LPG has established a competence in the study of carbonaceous matter in chondrites and interplanetary dusts, and of post-accretion processes which acted in their parent bodies. A major issue is the physicochemical processes which account for the present chemical and isotopic composition of carbonaceous matter. We will pursue our efforts and focus on combined chemical and isotopic analysis of cometary grains available in-house (stratospheric IDPs, STARDUST grains). Experimental studies of the thermo-degradation of natural and model materials will be performed to constraint the interpretation. Further experimental studies in collaboration with the ASTROMOL team are described in the frame of the new "Chemistry" thematic group.

Finally, the experimental determination of the vapor pressure of molecular solids at low temperature, the differentiation of ices and the formation/decomposition of clathrates are important for modeling and understanding (i) the differentiation occurring during the volatiles condensation of the solar nebula (ii) the sublimation of cometary nuclei (iii) the surface/atmosphere interactions of icy objects such as Pluto or TNOs. A major issue lies in understanding the formation of comets, through the crystalline or amorphous state of water ice, and possibly clathrates, which lacks observational evidence.

5.3. Mars as a presently active and evolving object

In the future, Mars is and will be under continuous and multiple scrutinies. Datasets collected and the extracted Martian properties are of extreme quality, and are now available for several Martian Years.

LPG has developed recognized competences (CoI'ships for 5 martian space instruments) related to Mars dataset interpretation. Let us cite (i) infrared spectra measurements on ice and minerals (ii) physical analysis of Mars images by modeling the radiative transfer of solar light in the surface and in the atmosphere and by massive inversion (iii) simulations of the surface echoes for radar observations (iv) methodological support on Physics of remote sensing (v) ionospheric description using the TRANS* family code (vi) analog soils atmosphere water exchange experiments. The Mars thematic group led to an increased use of planetary geographic information system and developed an efficient synergy between physics, chemistry and geology.

Our objectives for this theme are (i) to quantify the different water reservoirs of the planet, in particular those related to the surface and the sub-surface: hydrated and hydroxylated minerals within the regolith as well as ground ice and ice caps. (ii) to investigate by analyzing observations and by performing experiments as well as models exchange processes at work between these reservoirs at timescales ranging from days to millions of years (iii) to study aspects of the polar geology such as the stratigraphy of the cap layers, geomorphology, ice tectonics using radar sounding and compositional mapping (iv) to study the sub-surface structure statistics from volume radar scattering measured by SHARAD and MARSIS (v) to monitor seasonal ices and obtain their physical properties over more than three martian years in order to understand processes ranging from local microphysics to global meteorology and (vi) to investigate the total electron contents, ionospheric emissions, their coupling with the crustal magnetic field and to study the role of the ionosphere on the atmospheric escape flux.

5.4. Physics of planetary surface and subsurface remote sensing

Accurate analysis of planetary data requires performing research on the physics of remote sensing from propagation of electromagnetic waves or radiative fluxes into natural media to the process of measure by the embarked instruments. In close synergy with the other themes, we will elaborate models of planetary materials and structures, perform 3D simulations of reflection and transmission and develop numerical methods of physical analysis. Planetary surface and subsurface are complex and dense media with multi-scale structures that scatter waves. Consequently, descriptive models are necessary to model the reflection of light or radar pulses by these media. In both domains, full power of the physical analysis of planetary data requests applied mathematics. Hence, model inversion will be based on simulations, machine learning approaches and statistics.

We will concentrate on the following points:

(i) Develop new generation of surface optical reflectance models using Monte-Carlo, ray tracing and global illumination. Those models will include 3D surface-atmosphere radiative transfer codes to simulate realistic images of solid planets as currently sampled by hyperspectral multi-angular instruments (e.g. CRISM@MRO).

(ii) Validate surface reflectance models by measuring in-house the reflectance of well characterized (tomography X) analogs to planetary materials with our spectro-gonio-radiometer.

(iii) Extend our simulation of surface radar diffusion to small scale roughness with a parametric modeling coupled with the next generation Martian and Lunar digital elevation model to improve Sharad and Selene data analysis (quantitative permittivity estimate) and to design the next generation of radars (EJSM, Marco Polo).

(iv) Model the physics of multi-wave scattering by sub-surface interfaces and validate from terrain measurements to develop original characterization of the subsurface (e.g. Moon regolith inhomogeneities).

(v) Simulate the 3D tomography through comets and asteroids at specific geometries (extinction, flyby) to support Consert and prepare Next Generation Consert.

5.5. Evolution of outer atmospheres under the sun: planetary space environments and space weathers

We developed a long lasting expertise in earth thermosphere observation by ground radar sounding. The need to develop a model description led to the TRANS* family of codes that were latter extended to planetary thermosphere/ionosphere problematic. Our scientific objectives contribute to the study of the evolution, dynamics and composition of planetary space environments. We will concentrate on the following points:

(i) Polarization of planetary upper atmosphere emissions: effect of fields on H_3^+ polarization in the giant planets, observations of the thermospheric visible / UV light polarization on Earth and potentially Mars / Venus.

(ii) Model the coupling of the different atmospheric layers, in particular the mutual impact of the space environment (magnetosphere, thermosphere, ionosphere) with the lower atmospheres (Titan, Venus, Mars, Earth) through cosmic and proton precipitation effects to understand the evolution of the planetary upper atmospheres, in particular the escape fluxes (emerging theme).

(iii) Understand the impact of the solar activity on the Earth space environment: energy transfer from solar wind perturbations (CME, Coronal holes) to the magnetosphere and down to the thermosphere. Participate in the improvement of the empirical thermosphere model developed by CNES (DTM). Make operational the reconstruction of the solar energetic flux at the origin of the diurnal ionospheres (from Ly alpha to XUV wavelengths) for space weather applications.

(iv) Address the exoplanet molecular detection and auroral phenomena (emerging theme).

5.6. Molecular evolution, Chemistry

One aspect of this theme is the study of chemistry occurring inside or at the surface of primitive material. It is intimately related to the ASTROMOL Team activity and is described in detail in the "Chemistry" thematic group.

On the other side, this thematic aims at describing the elusive evolution of matter occurring today in Titan atmosphere and on the other side the molecular evolution that can be traced back to the origin of the solar system, from the study of primitive materials. Titan can be described as a planetary scale chemical reactor that leads to the poorly described aerosols, visible in its atmosphere and surface. The chemical processes occur at a global scale and need to be treated in a planetary evolution context. Hence, methane lifetime is driven by chemistry, reservoirs for methane and chemical products such as lakes still have to be confronted to observations, and evolution into complex molecules is an intriguing object of study with exobiological connotation.

Our specific objectives will be:

	Permanent	Man. year	Post-docs	Phd students

	researchers					
Primordial matter – comets	6	8.4	2	- internal structure modelisation - ice physics and comet nucleus modeling	2	- tomography radar signal inversion - physico chemistry of primordial ices
Mars	8	11.6	3	- water reservoirs - Sub surface structure - 3D/1D coupled model of mars ionosphere	4	- Quantification of water reservoirs - polar geology - physical properties of seasonal ices (2)
Remote sensing	6	7	2	- Remote sensing theory and models	1	- Remote sensing and Jupiter exploration
Outer atmospheres	4	14.2	1	- Polarization/radiative transfer	4	- Proton/cosmic precipitation in atmos. - CME impact on earth atmosphere - exo-planet comparative planetology - EUV flux description
Chemistry	5	14.8	1	- Space bound orbitrap development	3	- Positive ion molecule chemistry - negative ion molecule chemistry - representative material analysis
TOTAL	**14**	**56**	**9**		**14**	

(i) large scale measurements of cation molecule reaction rate constants and branching ratio (follow up of the Chimie Titan + ANR, R. Thissen PI) inside the orbitrap instrument that will be extended to the larger size molecules (aromatics, PAHs, …), possibly including some oxygenated species in the neutral or ionic reactives.

(ii) Large scale measurements of anion molecule reactions in the frame of the EU TacTic contract of V. Vuitton.

(iii) High resolution mass spectrometry (HRMS) of complex mixtures produced in laboratory after activation of simple molecules in representative media (tholins from LATMOS, yellow stuff from PIIM, Marseille).

(iv) Characterization of the evolution of organic matter (model material such as poly-HCN), triggered by physico-chemical perturbation such as temperature, irradiation, hydrolysis, acidic attack and characterized by FTIR and HRMS.

(v) Development of a space bound mass analyzer based on the orbitrap concept (see the prospective of GRIL team for further details). Two targets identified: EJSM for dust detector and Marco Polo in Mass Spectrometer.

5.7. Means to develop our objectives

As W. Kofman, senior researcher, will apply for emeritus, no retirement is expected in the next quadrennial.

Six permanent researchers are qualified HDR at LPG, it is expected to have 6 more researchers (R. Thissen, S. Douté, A. Hérique, M. Barthélémy, F. Pitout, V. Vuitton) qualified at the end of the 2011-2014 quadrennial.

5.7.1. Laboratory experiments:

Let us remind the instruments available in the lab to perform the different projects:

FTIR spectrometers: transmission in crystals, ice or thin films

FTIR Microscope (shared with OSUG and ENS Lyon): IR mapping by transmission, reflection or ATR

Spectro-gonio-radiometer: bi-directional spectral reflectance of granular surfaces, down to -25°C

Martian environment cell « SERAC »: Adsorption/exchange of water in minerals

Thermodynamic cell: Equilibrium and kinetics measure of gas condensation/sublimation (ices, clathrates)

Primitive sample preparation: Extraction of organic matter from meteorites

Orbitrap v1: high resolution mass analyzer and codes for complex mixtures analysis

Hereafter, instruments which are under development or planned to fulfill our objectives (these technical developments are described in the prospective of the GRIL Team):

Orbitrap v2: ion molecule reaction characterization instrument: funded by the ANR "Chimie Titan +", R Thissen.

Orbitrap v3: optimized negative ion source (electron attachment) optimized to reproduce the attachment of electron in the titan ionospheric environment (funded by the European project TacTic of V. Vuitton).

SERAC II: measuring the bidirectional and spectral properties of solar light reflection by CO_2 martian analogs.

Martian environment cell «CO_2»: A new cell will be built to understand processes involved in the evolution of CO_2 and H_2O ices (condensation, metamorphism, sublimation, segregation) in Martian conditions (temperature, pressure, heat sources) and the evolution of their spectral signatures. An ANR will be proposed.

5.7.2. Databases:

the team will distribute the datasets produced through its activity in two ways:

(i) **The "GhoSST" database** service on experimental spectroscopy and thermodynamics of solids is under development (in the framework of the EuroPlaNet and VAMDC FP7 European projects). This will provide laboratory data concerning optical parameter of planetary surface/grain analogs (minerals and ices), necessary for the analysis of spectroscopic measurements from spacecraft or ground based instruments.

(ii) Participation in **the KIDA project**, expertise on previous datasets, and release of new ion-molecule results.

5.7.3. Ground observations:

we will keep running experiments with EISCAT and participate in the preparatory phase (FP7 Infrastructure) of its evolution: EISCAT-3D).

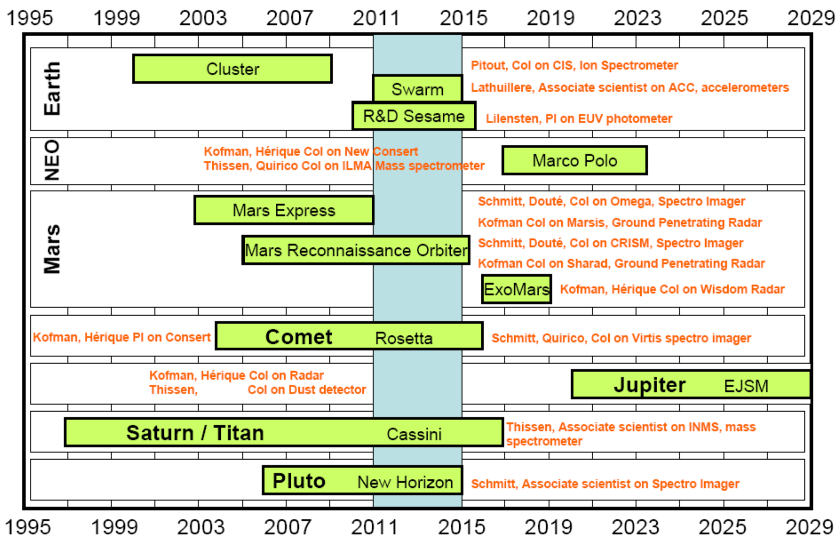
5.7.4. Instruments transported in representative sites:

(i) We will participate with Norwegian and Polish colleagues in the SPP **polarization measurement in Svalbard**, hopefully with the first observation from a stratospheric balloon, and participate in the adaptation of the ALIS optical network (Kiruna) for thermospheric emissions polarization measurements. We will submit an ANR to fund a new optical device to observe the polarization of thermospheric optical lines at Earth (SEPAGE).

(ii) Ground penetrating **radar measurements** are planned on Martian permafrost terrain analogues **in Siberia**. This is to improve our interpretation of the data from Sharad and Marsis radars. We will ask funds from the Europlanet for this activity.

5.7.5. Numerical modeling:

(i) We will develop our proton transport code to make it operational for space weather applications. We will adapt it to Mars, Venus and Titan where their effect has never been fully described. We will achieve the radiative transfer code adapted to planetary atmospheres, and couple it with the electron/proton transport code, with applications to Venus, Mars, giant planet and exoplanets. We will start to model the thin Mercury atmosphere under the EUV solar variability. We will continue to examine the role of the cosmic rays on the terrestrial planets.



(ii) Simulations of Comet nuclei formation and evolution have been developed to better describe their physical behaviour. This new quasi-3D approach for non-spherically shaped comet has been developed to analyze the effect of the irregular shapes on its thermal evolution, its local crust formation and the onset of its activity. Numerical simulations towards realistic models of comet nuclei will facilitate the inversion procedures and the interpretation of the data obtained during the rendezvous of the Rosetta mission.

<u>Space observations:</u>

Numerous members of the team are involved in past, present or future space missions operations. The diagram on the right only represents missions in which some responsibilities are officially undertaken.

Beyond this, we may have specific access to data sets, through recognized association.

5.8. STRATEGY to reach our objectives:

5.8.1. General scientific incentive:

Yearly participation in international conferences: EPSC, AGU, LPSC, DPS, EGU, MetSoc, …

Participation in ISSI (Bern) International teams,

Involvement in the "international year of chemistry" (2011)

1 international conference organization in Grenoble (SASP 2012) on ion molecule reactivity,

1 thematic workshop organization per year,

Monthly seminar on the specific topic of planetary science (invited and local researcher + Phd students).

5.8.2. Funding:

Local: University Joseph Fourier TUNES and SMING.

Regional: Rhône-Alpes Cible program.

National: participation in programs including at organizational level: PNP, PNST, PCMI, OPV, Exobiology.

European contracts: COST astromol, EuroPlaNet, VAMDC, return grant, ESA.

Funding from CNES for all instrument developments, analysis preparation, mission operations data analysis (provided official association in instruments).

Institutional and support funding from CNRS-INSU (and hopefully INC)

ANR Blanche for "solid CO_2 microphysics on Mars: an experimental and observational investigation"

ANR Blanche on polarization instrument and conceptual developments

5.8.3. Manpower:

Ministry, Regional, local, CNES or European grants will fund the non-permanent positions.

The wealth of technical developments and responsibilities of operation undertaken by our team will be performed inside the GRIL team. We particularly support the recruitment plan of that team in order to extend the technological competences related to space projects and operations.

Permanent position recruitments identified for the team for the next quadrennial are summarized in the table here after B level positions. Beyond this list we would like to underline (i) the need to assure internal promotion for MdC in order to stabilize the thematic that they actively develop (ii) the strong support for the new position of theoretician chemist expressed in the chemistry thematic group.

Primordial matter – comets	1	Internal structure models
	1	Spectroscopy analysis of primitive material
Mars	1	Geophysicist for Mars/radar studies

Remote sensing	1	Ices spectroscopy/remote sensing
Outer atmospheres	1	modeling of exo-planets and polarization
Chemistry	1	MdC on experimental planetary chemistry - UFR Chemistry
Total	**6**	

6. SHERPAS Team

The SHERPAS group will pursue its efforts in understanding the basic phenomena at work in accretion and ejection processes, including the high energy phenomena. It has identified several key activities that should be developed in the near future, mainly on two topics : the numerical simulations of MHD process, and the involvement in new instruments and theory of high energy phenomena. We hope to benefit from new recruitments to compensate for the retirement of a senior scientist (G. Pelletier), and we plan to ask for new national (ANR) and European (ITN) fundings to support them. We detail below the main topics we plan to address in the near future.

6.1. MHD theory and simulations

The modeling of MHD processes appears to be a unavoidable step to understand accretion and ejection. It requires more and more sophisticated models and heavy numerical simulations, which has been up to now essentially insured thanks to the hiring of PhD students and post-docs. Hiring researchers able to lead this kind of research has already been a priority of the group in the last 4-year plan, but has not been fulfilled yet. Clearly, the ability of the group to pursue this activity will depend on the arrival of this kind of researchers. We hope to be able to hire junior and senior scientists to help reinforcing this activity, as well as asking for ANR and European fundings. Fruitful collaborations are starting with the Torino group, especially with C. Zanni who spent his post-doc in LAOG thanks to a JETSET grant, and has been recently hired in this University.

The key scientific issues that have to be addressed are:

For fundamental processes, it is important to clarify the existing characterization of MRi-induced turbulent transport at higher Reynolds numbers and in vertically stratified disks to eliminate potential numerical artefacts. A completely different avenue to understand the dynamics of turbulent transport could be achieved through the analysis of unstable periodic solutions of the MHD equations. This possibility is currently under investigation, and seems promising for the near future (P.Y. Longaretti, coll. G. Lesur).

The global transport of magnetic field in accretion discs is a whole new and complex topic. It addresses secular variability of the accretion-ejection process, on time scales comparable to the disc lifetime. It also relies on how turbulence depends on the strength of the magnetic field and on the boundary. Global simulations are necessary to quantify these effects, and preliminary results have already been obtained. (J. Ferreira, coll. C. Zanni).

The star-disc interaction is another active topic in the group. We intend to study the dependency on accretion rate and magnetic field, through 2D and 3-D simulations, the latter being necessary to handle properly inclined dipole and/or multipolar fields. Using the Hall-MHD code of Turlough

Downes, we plan to investigate the dynamics around the reconnection point to get global budgets so as to design sub-grid tools for global simulations. Then, we plan to apply these results to study global star-disc interaction within the ReX-wind framework (J. Ferreira with T. Downes, C. Zanni).

Simulations of jet propagation and radiation will be carried also in the context of young stars, using the radiative-MHD code of Turlough Downes and/or PLUTO and asymptotic solutions of self-confined rotating cylindrical jets (with T. Downes, C. Zanni). We also plan simulations with PLUTO of accretion disc driving jets with radiation, in the optically thin (and eventually thick) regime, and the investigation of the effect of radiation cooling in the mass loading of the jet (with C. Zanni, S. Massaglia).

6.2. High energy phenomena

High energy astrophysics has impressively grown during this last decade and the perspectives are still flourishing. We intend of course to continue and develop the activity , which fits perfectly into the ASTRONET « Understanding the extreme of the Universe », mainly on the following topics :

X-ray binaries : The origin of long term and short term variability of X-ray binaries, including the hysteresis cycles, the jet production, and the quasi periodic oscillations (QPO) is still unclear. The next years will be devoted to the development of the model through different directions. Direct comparison of the SEDs to real data should bring crucial constrains on the model (like the evolution of the magnetization with the accretion rate, linked with the transport of magnetic field problem). The rapid variability is also an important characteristics of the X-ray binaries that will be incorporated in our framework, following the oscillating corona model already developed in the group (Cabanac et al. 2009). Instabilities should also naturally appear in the transition region between the JED and the standard accretion disc. This will also be studied through numerical MHD simulations. (J. Ferreira, P.O. Petrucci, G. Henri, and various coll.).

Gamma-ray astrophysics : HESS has spectacularly opened the VHE sky since it started operations in 2003. The first sensitive array in the southern hemisphere, HESS has enabled the detection of several dozen Galactic sources. In the same time, the first-year Fermi catalogue will be released at the end of 2009 and is expected to contain more than a thousand sources. Known populations see their numbers increase, new types of sources are discovered, but many — if not most — sources remain unidentified. 2010 should see the beginning of HESS-2 operations. HESS-2 is a 28 m telescope placed at the centre of the HESS array that will allow a decrease in threshold energy to tens of GeVs and an increase in the sensitivity of the array. Blazar studies will benefit from this update, given their soft VHE spectra. Bridging the energy gap between Fermi and HESS will also be particularly interesting for binaries since different spectral components may dominate in HE and VHE gamma-rays [18]. Fermi operations are expected to continue throughout, all data becoming directly public. The present group, with support from the ERC up to July 2013, is well positioned to continue to benefit from this rich observational context in its studies of active galactic nuclei and binaries. (G. Dubus, P. O. Petrucci, G. Henri)

The past year has also seen the beginning of a collaboration with the ASTROMOL group and the IN2P3 group in Montpellier (LPTA) around gamma-ray sources associated with molecular clouds. HESS reported on several morphological associations of gamma-ray sources with molecular clouds, based on comparisons with CO survey maps, notably in the vicinity of supernova remnants [19,20]. Gamma-ray emission is due to the interaction of high-energy cosmic rays (protons) freshly accelerated in the supernova shock with the dense material in the nearby cloud. The interaction creates pions whose subsequent decay produces gamma-ray radiation. Lower energy cosmic rays lose energy by ionising matter rather than by pion production. The current objective is to measure the ionization rate in selected clouds associated with VHE gamma-ray sources. Observing programmes have been approved at IRAM, JCMT and APEX. High rates will unambiguously reveal the presence of a cosmic ray accelerator in the vicinity (a holy grail of astroparticle physics) and pave the way towards more ambitious studies on searches for the nature of "dark accelerators" (HESS sources with no obvious multi-wavelength counterparts), the density of cosmic rays in the Galaxy, their diffusion properties, their impact on the chemistry of the ISM and star formation, etc. There is a definite motivation to develop this subject at a crossroad of LAOG expertise in the next "quadrennial", with the perspective of CTA in sight. (G. Dubus and ASTROMOL coll.)

The Cherenkov Telescope Array (CTA) is a project building upon the successes of the European HESS and MAGIC collaborations with an expected first light on the 2015 horizon. The aim is a ten-fold improvement in sensitivity that should increase the number of VHE sources into the thousands, generating great discovery potential and consecrating VHE astronomy as a mainstream technique (CTA will be an observatory and not a proprietary instrument). CTA has been recognized as a top priority in the European roadmaps ASTRONET (astronomy), ASPERA (astroparticle), ESFRI (infrastructure) and in the roadmap of the Ministère de la Recherche. LAOG is currently involved exclusively in the Physics Work Package of the collaboration, more specifically the AGN, binaries and survey tasks (GD leads the surveys task). These groups are responsible for identifying key scientific goals and defining simulation goals to be performed by the other work packages (Monte-Carlo) in order to optimize the array design and performance. LAOG is not involved in hardware development although there is interest in applying in-house detectors to Cherenkov observations or to intensity interferometry piggy-backing on IACTs. The neutrino detector KM3NET is another major program for the coming decade where theoretical expertise from LAOG could be put to use. More generally, LAOG should be ready to take advantage of the vibrant astroparticle physics programme in France in a context where there is an increasing demand for astrophysical expertise on the projects led by particle physics and few places where this can be found.

The problem of acceleration of VHE particles through relativistic shocks, that are thought to be produced in Gamma-Ray Bursts, is also an important topic, mainly driven by G. Pelletier. Progress in the understanding of the relevant mechanisms, which require the excitation of strong magnetic turbulence, could be obtained with large PIC (Particles in Cells) simulations, for which a collaboration is designed, especially with the great expert in France, namely Bertrand Lembège, including a new PhD student, D. Touli. We are quite confident that the problem will be solved for electron acceleration. However the enigma of UHE Cosmic Rays generation is still quite opened. An investigation of GRB shocks modified by an upstream plasma produced by a neutron shell decay is promising in this prospect. Again we are currently exploring these new avenues for the future, although the question of the continuation of this activity after the retirement of G. Pelletier is still unclear.

6.3. Astrocladistics

Concerning the specific domain of astrocladistics, we intend to maintain this original approach whose first results appear to give promising new results. An article on globular clusters has been submitted, several samples of galaxies are being analyzed or re-analyzed and the results should at last stir the interest of astrophysicists. It will be essential that a PhD thesis can be started. The collaborations with astrostatisticians will continue to grow, especially with Tanuki and Asis Chattopadhyay of the University of Calcutta, and in conjunction with the Center for Astrostatistics at the University of Pennsylvania. A project for a 3-year Franco-Indian project has been proposed in 2009 (D. Fraix-Burnet and coll.)

The multivariate analysis methods are inevitable in astrophysics. They may concern many data. Specifically, colleagues of the LPG (plan√©to) here in Grenoble began to take the plunge. We look forward to sharing experiences in a thematic group in the future laboratory resulting from the merger of LAOG and LPG. Concerning the themes of the team Sherpas, it seems interesting to use appropriate methods when comparing a theoretical model with many parameters with data that could benefit from an objective and multivariate classification. Mathematical modeling of the evolution of galaxies, leading to diversity, is an important step to separate the physical process of transforming the simple evolution or cosmic. But it is also an aspect that would allow mathematicians, statisticians, bioinformaticians and evolutionary biologists, to discover and develop their own tools and concepts through a different framework, that of galaxies.

7. Thematic groups

7.1. Compared planetology between solar and extra-solar systems

The laboratory resulting from the merge between LAOG and LPG will host teams at the highest level of international research in fields such as solar system planetary science and extra-solar planets study. This will lead to the development of new studies aiming at general characterization of exo planets. On the one hand, it is possible to compare results of detailed models describing the solar system objects to the observables recovered on the extra-solar planets and on the other hand, the fast extending number of extra solar systems and the collection of their characteristics allow to study the average of exceptional character of our system. New tools for the extra solar planet characterization such as JWST which will soon permit to record atmospheric spectra of planets in transit with a precision level never reached before, will require new and detailed models in order to compare them with the solar system objects.

Some themes of research essential to the characterization of planets at the interface between LPG and the FOST team of LAOG have already been identified. The following list is not exhaustive and shows the present motivations for collaborative development proposals between the two teams.

- Planetary auroral emissions and magnetospheric interaction star-planet: this will request the portage of methods optimized for giant planets in solar system towards exo planets. Noteworthy are the hot Jupiters, potentially in strong magnetic interaction with their star. There is already a PhD under progress on this topic.
- Measurement of the atmospheric composition of extra-solar planets during their transit: development of observational brackets and coupling of models including physical and chemical description of atmospheres. Study of the escape processes, determination of the pertinent observables as a function of the instrument limitation leverage. Determination of photoabsorption cross sections.
- Upper atmosphere of extra-solar planets: definition of observational proxies, specifically for

the telluric planets, for which the deep atmosphere will ever be difficult to observe because of its limited extension. Comparison with the upper atmosphere of Earth, Venus and Mars.

- Surface of extra-solar earth-like planets (rocky planets) close to their host star : Mechanism for heating crust and superior mantle (primordial energy, nuclear decay, tidal effects, external heating). Ocean and volcanic magma. Emission of lava and steam. Comparison with the spectra of thermal emission from the volcanoes of Io and Earth.
- Surface of extra-solar earth-like planets (rocky planets) at large separation from their host star : comparison with the icy bodies in the solar system (composition of ice and observational signatures of reflected light). The proxy will be difficult to reach before a spatial mission as TPF-C, but preparatory work may be undertaken.
- Habitability : comparison between this concept in the solar system and another solar systems.
- Study of the chemistry of atmosphere in function on the general chemical composition of the planetary system and of the central star.
- Dust in protoplanetary disks : constraints of their emission via the determination of the grains scattering matrices in the solar system.
- Disk of debris / exozodiacal dust: the process of comets evaporation are a crucial input for the dynamical models of generation of exozodiacal dust. The results of Consert / Rosetta are expected to constraint such process. Need to determine the optical constants of silicate and carbonaceous materials at high temperatures close to sublimation, to interpret the observed debris disks.

7.2. Chemistry. Materials and processes leading to the formation of planetary systems.

Two major transversal research areas related to chemistry will be developed in the laboratory created from the merging of LAOG and LPG. The first area concerns the evolution of solid matter, from proto-stellar environments (ASTROMOL) to proto-planetary and debris disks (FOST) and little bodies in the solar system (PLANETO). The second transversal research area is related to the study of gas phase chemistry in star forming regions (ASTROMOL) and Titan's upper atmosphere (PLANETO). These transversal topics will lead to the creation of internal collaborations and will allow the sharing of complementary skills. ASTROMOL and FOST have a strong expertise in observation, modeling and theoretical chemistry. PLANETO is specialized in laboratory experiments, analysis of extraterrestrial matter, and spectroscopy of solids and is involved in many ongoing and future space missions.

7.2.1. Evolution of solid matter

The first research area concerns the physical-chemistry of ices in proto-stellar environments. There, the grains ice mantles sublimate and feed the gas phase with complex molecules. These molecules either condensed after formation in the gas phase or were formed inside the grains themselves. Models considering gas phase chemistry only cannot explain the abundance and/or deuteration of several major molecules. It is therefore important to constrain the chemical and isotopic evolution of the molecules originating from heterogeneous chemistry. A PhD concerning D-H exchanges and crystallization as well as evaporation of trapped molecules is under way. It is developed in the framework of the FORCOMs ANR and co-directed by ASTROMOL/PLANETO. The experimental results will be extrapolated to astrophysical conditions in order to produce quantitative data that will be used in numerical codes of chemical evolution.

The mineralogy of T-tauri and debris disks is a topic of interest for both FOST and PLANETO. Chondrites and interplanetary dust particles are representative of the mineral phases present in the solar nebula and are also potentially present in proto-planetary disks. By comparing both environments, it is possible to look for specific compounds in order to better understand the formation of mineral grains by condensation and/or crystallization of pre-solar, mostly amorphous dust. The search for highly refractory minerals and carbonaceous species is another interesting topic that will be tackled with two complementary approaches: observations (FOST) and solid spectroscopy/mineralogy (PLANETO).

The two topics described above allow comparing the volatile and proto-stellar as well a proto-planetary refractory phases with those present in small bodies of the solar system: comets and asteroids. These topics will be put forward in the framework of the ROSETTA mission (2014) that will bring new data related to the chemical composition of a comet.

7.2.2. Molecular complexity

The second transversal research area concerns gas phase and heterogeneous chemistry as well as molecular complexity (ASTROMOL, PLANETO). The study of atmospheric and ionospheric chemistry of Titan will especially be developed in the next four years. LPG is implicated in several experimental projects relying on data provided by space missions (CASSINI-HUYGENS). However, important questions such as temperature effects and molecular growth processes are difficult to address with an experimental approach only. LAOG (ASTROMOL) has an important knowledge in theoretical chemistry that is a valuable complementary approach. This team has a strong expertise in dynamics that is directly applicable to Titan's atmosphere. A first common project has already led to a submitted publication (Faure et al. JPCA, 2009). In the future, molecular structure calculations in order to better identify equilibrium states of chemical reactions will be developed by the theoreticians from ASTROMOL.

8. Adequacy of human and financial resources to the project

8.1. The Unit scientific animation policy

Maintaining and promoting a common scientific policy is becoming a real challenge due to the increase of the proportion of external funding for the scientific projects of the teams. However, a lot of projects or ideas would not have been possible, or even existed inside a team in the absence of the external environment and input provided by the other teams and the laboratory as a whole. In order to maintain a high level of personal motivation while keeping a high level of inter teams collaborations, one of the deputy directors will be charged to assist the director in the scientific animation of the lab. We will define an annual budget to promote inter team activities, mainly based on the thematic groups.

8.2. Prospective analysis - in the medium and long term - of the needs and skills required for the scientific and technological mutations identified ; the training Policy

8.2.1. Scientists

Astronomy and planetary sciences communities are very close but still distinct communities in the astrophysical field of research, as can be seen in the detailed title of our CNRS 17th section: "Solar System and far universe". This is reflected by the somehow large diversity of the recruitment needs listed in the various team projects. Fortunately, we can lean on the two thematic groups to pre-design what could be the main streams of the new laboratory and foresee mid-term plans in terms of skills needs.

Stellar and planetary formation as a global process will be one of the major research fields of the lab during the next quadrennial period. In a near future, it is clear that more and more physical measurements of exoplanets' physical parameters (size and mass but also temperature, atmospheric chemical composition, etc.) will become available. The gathering of astronomers and planetary science people's skills in one lab will place us at the lead of the physical interpretation of these measurements. We will therefore need to complement our skills in this field, and this includes the possibility of modeling planetary atmosphere.

In the same way, the growing availability of multi planetary systems and associated imaging of disk structures calls for a capacity of dynamical simulation of disks and multi body systems. Such recruitments will concern FOST and PLANETO teams. Another field would also link the research themes of these two teams, potentially involving Astromol, namely the study of primordial matter in the solar system, in comets, but also in circumstellar disks.

The exploration of the solar system, and the study of primordial material in comets and other remnants of the formation of the solar system, in relation with the stellar and planetary formation theme, is also a strong direction to hire new scientists in the lab.

Chemistry now appears as a must, both for Planeto and Astromol teams. We will certainly need to strengthen our staff in this domain, at minimum in the molecular theory because of the sudden and dramatic passing away of Pierre Valiron in 2008, but also in a way linked to the study of solar system & disks primordial matter.

From the instrumental point of view, we will be ready to participate in two great adventures of the next decade: E-ELT and imaging by interferometry. This means recruiting in the fields of high contrast adaptive optics and multi-telescope interferometry.

To complement this laboratory project, we will need to strengthen our theoretical team, and its high energy thematics. This will address two needs: in theoretical simulation skill, at the senior level, to compensate for the retirement of Guy Pelletier (former leader of this team) and to be able to support our participation in high-energy imaging projects like CTA.

The result of this reflexion is summarized in the following "recruitment roadmap".

8.2.2. 2011-2014 Recruitment Roadmap

We hereby provide a recruitment/mobility roadmap for the next 4 years, elaborated from the laboratory detailed scientific project (team chapters), and processed at the laboratory level. Scientific needs have been listed chronologically with respect to the current status of the corresponding research project in each team. This document concerns possible recruitment and / or mobility in CNRS, CNAP, University. Within each year, the order is arbitrary.

Of course, the laboratory council will be consulted to revise this plan annually, according to the outcome of previous recruitment competitions, the evolution of national priorities and the available candidate pool.

Years	**Research fields**
2010-2011	Theoretical astrochemistry: neutral and ionized media
	Detection of exoplanets and statistical properties High contrast imaging
	Primordial matter, comets (modelling and spectroscopy)
	High performance numerical computing for MHD simulations
2011-2012	High energy astrochemistry (modelling)
	Dynamical simulations of disks and planetary systems
	Long baseline interferometry
	Mars (radar studies and spectroscopy)
	Exploitation of new high-energy instruments
2012-2013	Molecular physics and chemical reactivity
	Physical characterization of exoplanets
	Signal processing
	Outer atmospheres of exoplanets (modelling)
	Numerical computing for fundamental MHD processes
2013-2014	Millimetre interferometric observations
	High angular resolution observations of disks and planets
	Adaptive optics (project scientist)
	Experimental planetary chemistry
	MHD simulations of accretion-ejection systems

8.2.3. Administrative and Technical staff

The following analysis is performed assuming that our essential technical and administrative needs for 2010 have been fulfilled. These needs include: 1) permanent administrative position (Engineer Assistant) to strengthen our staff given the ever increasing number of projects (ANR, Europe, etc.); 2) permanent Engineer Assistant to participate to the ever increasing instrumental needs of the lab, given the high level R&T performed, and the new needs from the merging of the labs; 3) non-permanent Engineer Assistant to assist the technical staff with the integration of the SPHERE instrument. Moreover, we also assume that our needs in system & network operation will be met. Indeed, the LPG has lost a position in this category and it has been replaced by a mutual OSUG position. It will be essential for our project that the Engineer recruited on this 'OSUG' position spends a major part –if not all- of his/her time on LAOG-LPG projects.

Our recruitment policy for the technical staff during the next quadrennial 2011-2014 period will be organized along three axes: i) development of system activities, ii) setup of the SPHERE data center, iii) reinforcement of our potential for laboratory measurements and tests.

System activities: the involvement of the laboratory in instrumental development will in the coming years be oriented more toward conceptual studies and system activities. This will particularly be the case in the area of adaptive optics, with an emphasis on extreme adaptive optics and very high dynamic range imaging, as well as for interferometry where fringe tracking activities represent a critical step for the definition of future instruments.

Data center: following the large efforts invested in the development of the SPHERE instrument (which delivery is expected in the spring of 2011), it will be essential to have an optimized pipeline for data reduction and analysis, to guarantee an adequate scientific return to our community. The deployment of a dedicated SPHERE Data Center in Grenoble represents a unique opportunity to achieve this objective. Such a data center will require support staff at various levels. If software development activities can be conducted by staff on short-term contracts (CDD) in some specific cases, the need for permanent staff is obvious, especially for the overseeing of the hardware and network infrastructure as well as for the management of the software development and maintenance. The deployment of the SPHERE data center shall of course be coordinated with the foreseen evolution of the JMMC and with similar efforts at the level of OSUG.

Laboratory activities: Due to the merging of the two laboratories, the outline of the new Instrumentation team will be enlarged, leading to more numerous lab activities around a large number of different testbenches. These benches have to be operated, maintained, driven by control software ; data have to be recorded, processed and archived by dedicated softwares. Also, due to the evolution of some of the key people from laboratory to more system-oriented activities, new staff will have to be hired to maintain the potential in measurement as well as in instrumentation deployment and maintenance.

In addition to these main priorities, astronomers developing large simulation codes in various domains might gain a lot in term of efficiency if they can get support from an expert in numerical methods, such as a research engineer with background in applied mathematics. Due to the various involvement of the new laboratory in radar simulations, radiative transfer in spectral lines, disc modeling, etc. The position can be a permanent one, possibly within the framework of manpower sharing at the OSUG UMS level.

Although the laboratory remains quite young, on a 5 to 7-year term, we will face the major issue of the retirement of a senior project manager. The turnover of this crucial position will have to be anticipated, for instance by the training of technically skilled staff to project management techniques.

Finally, we emphasize that we would be very interested into defining a pool of OSUG system managers (IT) to work on common projects (system and network, databases) throughout the various labs of OSUG. However, we insist on the fact that this operation must be actually defined in common between the OSUG laboratories and OSUG head, on a mutual respect basis, with a project and a work plan well defined from the beginning.

8.3. Partnerships' policy

Due to their national and international activities, LAOG and LPG have developed over the years a vast top-level network of partnership. This is an essential key to our research success and our skills are renowned worldwide. Our collaborations and funds sources go from local industry to international agencies. The merging of our two laboratories will even multiply the number and the importance of our partnerships. These partnerships include (at the local, national and international level):

IRAM: We will strengthen the links already established in 2007 and 2008 in order to hire other astronomers who would perform their duty tasks at IRAM while working on their research activities in the NL. This will concern radio astronomers, essentially in the Astromol team, and will place us in a very strong position to participate in the ALMA project. At the same time, we will work on the common methods used in radio and optical interferometry, involving the GRIL team and people in FOST working on young stellar objects.

CEA (GIANT): We are part of the Minalogic project and we have numerous R&T collaborations with LETI, in particular on integrated optics projects as well as infrared detectors.

Optical neighbor labs: We currently collaborate with many optical labs in Grenoble (IMEP, LSP). We will further develop these collaborations.

Floralis: This UJF's subsidiary is an essential partner concerning our industrial valorization. It is a strong support for patents and licenses. We can expect that the establishment of a common unique LAOG-LPG technical group, gathering ground-based and spatial instrumentation skills, will multiply the opportunity to develop new patents. We will be very attentive to strengthen our links with this partner, to even better value our R&T, and to allow students and interested ITs to develop their own projects.

Region Rhone-Alpes: this major regional organization has heavily participated in the funding of the current LAOG building and laboratory, but this was long ago. We will renew our links with this organization to get it more involved into funding our projects.

ANR: five years after its establishment, ANR is now a major key partner of our research activities. We will continue to develop our projects with the French National Research Agency (ANR). As a theoretical lab, we are mainly concerned by "white" projects, but our instrumental team and its associated R&T activities will provide many new subjects in applied physics.

CNES: The French national spatial agency will be one of our most important partners in the near future and will continue to play a major role in the support of the new lab as we will be strongly involved in on-going and future important space missions (Rosetta, Mars missions, Cosmic vision, etc.).

Europe: We will continue our policy of European contracts, on instrumentation (OPTICON Europlanet, VAMDC), on FP7 networks, or on thematic networks. We will apply to be a Marie Curie node.

ESO: This European observatory will be one of our main partners in the years to come. The current SPHERE contract is an example of this important partnership. PIONIER, VSI, EPICS are just examples of the numerous and essential projects that we are developing and will continue to grow in the next decade.

OSUG, CNRS/INSU and UJF are not actual "partners" but rather essential supporting authorities. We are very attentive and very motivated by the ongoing French research reforms. We give here a few examples of the links we plan to strengthen our links with these authorities.

OSUG: having the planetary sciences join astrophysics in a unique lab will strengthen our position in the Grenoble observatory by establishing bridges between astrophysics and earth sciences. We will be very attentive to have our research projects considered and supported by OSUG, the support of which we will more than ever need in our efforts to gather the two labs in two close buildings. We will take advantage of our strong technical group to participate in and to benefit from pooling efforts in OSUG, mainly in computing and networks, if it based on a mutual on a mutual interest basis.

UJF: We will even more interact directly with our university. The creation of the unique University of Grenoble is a real chance for our new lab, as it will dim the frontiers that currently exist between physics and earth sciences, as illustrated by the current distinct university departments TUNES and SMING. The teachers of our lab will be able to participate in both departments with less administrative barriers. In order to enhance our presence in front of the university students, we will strengthen our lectures in LMD.

8.4. Financing our project

On the one hand, the global lab budget includes the projects (instrumental and thematic) that represent most of the money that flows through the lab. Frequently, the project money just goes in and out of the lab when the PI dispatches the funds between the various groups of a consortium. The project leaders mainly manage this part of the budget.

On the other hand, we will maintain a common laboratory budget to pay for the mandatory expenses (University fee and every expenses in the lab), insure a high quality research environment and a stimulating place for everyone in the lab, fund innovative R&T to prepare future breakthrough instruments and also fund new risky but promising research projects. This common part of the budget will be fed by two main sources: recurrent funding by CNRS and UJF, and a “scientific participation” of every project in the common functioning of the lab. Most of the time, this participation amounts to 10%.

Given the advent of the merging of LAOG & LPG, we will add to this amount a supplementary budget to encourage new and inter teams projects.

8.5. The investment policy and its consistency with the scientific project of the unit, identifying the main proposed acquisitions and possible co-financing provided

A strong characteristic of our budget is that we do not have enough internal financial resources to fund heavy investments, concerning building or large instruments. Our recent integration hall, and the ESO SPHERE instruments have indeed been funded by specific external grants. One of our main investment priorities in the years to come will be to insure that all the personals of the two labs work in two close by buildings (current LAOG building & CERMO). OSUG and UJF support will be essential on this point and we will participate to all and every working meeting and action to support this project. A first priority action will be to ease the passageway between the two current lab buildings.

8.6. Funding allocation policy.

In the current French research system, every scientist in a lab has access to two kinds of resources: “personal” resources available from projects s/he designed, and funding s/he obtained from competitive applications, at the local, national or international level; “common” resources eventually available from the lab. Our policy will therefore be multifold:

- *Encourage* every scientist of the lab to apply for external funding for any new project or idea. Every project or external funding in the lab will participate to the common scientific operation of the laboratory. The level of this participation will be discussed and decided every year in the Laboratory Council.

- *Provide* every scientist in the lab with a panel of high level common resources for his/her research activities, concerning e.g. office, computing, library, seminars, publications, laboratory car, organization of workshops, etc.

- *Provide* (with the help of the University) every young newcomer in the lab with a specific individual grant to allow him/her to develop his/her new projects and ideas.

- *Maintain* a Director reserve to eventually fund innovative projects.

- *Provide* a budget to insure the scientific steering of the inter teams projects and the thematic groups.

- *Investigate* the possibility to partly grant PhDs on LAOG internal funds, with the participation of the university, taking benefit of its budget autonomy.

8.7. Research valorization, licenses, patents

Our experience in this matter mainly comes from the LAOG part of the new lab. We have a long-standing tradition of patenting our instrumental research. This is due to the high level of R&T activity developed in the lab to prepare future instruments. This is also the consequence of the very high level of our research engineers, and, we believe, the fact that all engineers and technicians are working together in a common technical group, because it fosters discussions, and the emergence of new ideas. This has given birth to several recent industrial application successes like the ALPAO Startup, numerous patents, two recent inter-ministry finding (FUI). We therefore have a very strong background and a very good motivation from our engineers to continue this action. The presence of the UJF subsidiary “Floralis” is an invaluable asset to help us develop new ideas and industrial projects. This policy is linked to one of our formation actions, namely an annual meeting we will continue to organize between local and national industrials and the lab PhD students. We want to convince our students that their astrophysical or planetary sciences thesis can be a strong value when looking for a job, and we believe that weaving links between students, engineers and industry representative is a good way to value our research activity, and not only in the instrumental field.

8.8. Scientific and Technical Outreach

Both the LAOG and the LPG have been at the forefront of the OSUG outreach action since many years. This action will continue in cooperation with OSUG and with its help, but also at a more specific level, thanks to the impetus and the motivation of numerous scientists and engineers in the lab. We expect to continue to participate in events like « Fête de la Scienoe » and cycle of general public lecture on the Grenoble area. As scientist expert, we will be strongly involved in the preparation and the accompanying of exhibition like « Un monde en couleur, de Gabriel Lippmann à la nano photonique » actually at Palais de la découverte, Paris (scientist expert : Etienne LeCoarer) or « Planètes... », in preparation by Drome CCSTI (scientist expert : Jean Lilensten and Xavier Delfosse).

Because of the specific attractiveness to the public of astrophysics and planetary we are strongly requested to participate or organize activities in scientific outreach on the Grenoble area. One cause of the high demand to our laboratory is the lack of specialized structures at Grenoble to welcome the general public. As part of the City of Arts and Sciences we have an ambitious project (named Opéra de l'Univers) between the city of Pont de Claix and OSUG (with the new laboratory in the forefront) to develop a planetarium and a Earth and Universe science museum. Such structure could be in the future the main location in Grenoble to communicate with the public research and discoveries from the new laboratory. We are at the origine of the project and we will participate as scientist expert and as contact with the APLF (association des planetariums de langue française). A strong structural colaborations will be established between the Opéra de l'Univers and OSUG to allow regular participation of researchers and engineers in preparation of exhibition, conferences and to train animators of the Museum.

8.9. R & T projects, industrial applications

We will start the new quadrennial period with very important industrial application projects: SWIFT and RAPID have obtained major funding, including Inter ministry funding (FUI), and will be operated through the years to come. We will also continue our interaction with the ALPAO Startup. We will develop our instrumental activities with a special care dedicated to the balance between our current commitments with our partners like ESO (SPHERE and PIONIER / VSI) or CNES, and an indispensable R&T activity needed to prepare future instruments and projects.

8.10. Hygiene and Security

The hygiene and security issue is taken very seriously by our lab. The main risks have been described in a “document unique” (French procedure) and include lasers, heavy mechanics, and will now include the chemical risk.

A major concern for the new lab will be the building used by the planeto team (former LPG). This building should be renewed by the University but is currently potentially extremely dangerous in case of fire.

One of the points identified by the lab security agent is the necessary availability of an air-conditioned room for people suffering from the strong heat in summer.

8.11. Critical Units

We do not have patrimonial issues, and most of our critical issues concern the network security and the intellectual industrial protection of our patents. We rely on Floralis for the protection of our patents. In the recent years, our computing team has produced a very important effort to strengthen the network security. Since 2 years, the LAOG IT team has undertaken a main project aiming at bringing up to date its security policy. Our architecture has been adapted and procedures have been renewed favoring user comfort, but not to the detriment of both software tool ease of use and security constraints. Thus, internal resources access is controlled by partitioning the network segments and by managing server firewalls. Public services (web, FTP, mail, etc.) have been installed in a semi-open area (DMZ), and nomadism related technologies have been implemented, in partnership with the university. Confidentiality, availability and data integrity are guaranteed thanks to a reliable storage system as well as a clear and detailed policy concerning backup and archiving of critical data. On the most exposed servers, we install verification and control tools. We use security advisories provided by prevention organizations, and we build disaster recovery procedures. Several times a year, we define and apply preventive check and awareness actions. We manage the technical infrastructure (energy, air conditioning) as well as access permissions to computer rooms.

The next coming years will raise 2 major stakes which will impact our structure: the foreseen merge between LAOG and LPG will give rise to an entity with more than 200 user accounts, for which the information systems will have to be merged and the security policy of the information system issued from the CNRS /university co-supervision will have to be adapted.