Laboratoire d'AstrOphysique de Grenoble
UMR 5571

Scientific report

Bilan scientifique de l'unité

2005 – 2009

13 sept 2009

Summary

1. Acronyms used in this document

In order to ease the reading by our non-astronomers referees, we hereby provide a complete list of the acronyms used in the report.

AMBER : Astronomical Multi BEam Recombiner
ASTROMOL : team “Astrophysique Moléculaire” (LAOG)
CERMO : LAOG’s Extension Building
CFHT : Canada France Hawaii Telescope
CNRS : Centre National de la Recherche Scientifique
ESO : European Southern Observatory
FOST : team “Formation Stellaire” (LAOG)
GRIL : team “Recherche Instrumentale” (LAOG)
HARPS : High Accuracy Radial velocity Planetary Search project
HESS : High Energy Stereoscopic System
HSO: Herschell Space Observatory
IATOS : Ingénieurs, Administratifs, Techniciens, Ouvriers et personnels de Services
IRAM : Institut de Radio Astronomie Millimétrique
ITA : Ingénieurs, Techniciens, Administratifs
JMMC : Jean-Marie Mariotti Center
LAOG : Laboratoire d'Astrophysique de Grenoble
LPG : Laboratoire de Planétologie de Grenoble
LRU : Loi "Libertés et Responsabilités des Universités"
OSUG : Observatoire des Sciences de l'Univers de Grenoble
RAPID : Revolutionary Avalanche Photodiode Infrared Detector
SHERPAS : team “Hautes-énergies” (LAOG)
SMING : Pôle de recherche UJF Sciences de la Matière et Ingénierie
SWIFT : Stationary Wave Integrated Fourier Transform Spectrometer
TUNES : Pôle de recherche UJF Terre Univers Environnement Société
UJF : Université Joseph Fourier
VLT : Very Large Telescope
WIRCAM : Wide field InfraRed Camera

2. General Presentation of the Laboratory

2.1. Executive summary

The *Laboratoire d’Astrophysique de Grenoble* (LAOG) was established in 1979 by UJF and CNRS, along with the creation of IRAM and initially focused on radio astronomy. LAOG will celebrate its 30th birthday in 2009. During these past 30 years, the laboratory underwent a tremendous growth, both in the number of scientists and in the research themes addressed, reaching about 110 people in 2009. The Lab now includes 4 teams, defined during a major reorganization performed in 2003. These four teams are:

ASTROMOL (*Molecular Astrophysics*): initial phases of stellar formation, interstellar chemistry, theoretical molecular physics, 8.5 research FTE.[1]

FOST (*Stellar and Planetary Formation, Brown dwarfs*): circumstellar disks, stellar-disk interaction, search & study of extrasolar planets, brown dwarfs, 12.25 research FTE.

SHERPAS: Physical processes, Relativistic Plasmas, High energy physics, MHD, accretion / ejection phenomena, 5.4 research FTE.

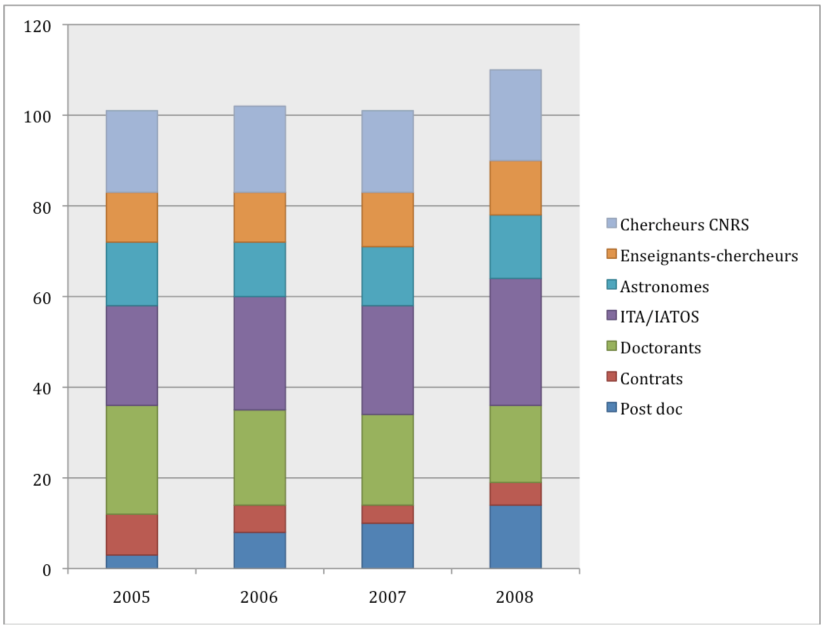
GRIL: Instrumental research, Instrument development, R&D, 3.15 + 23.40 research and technical FTE.

Each and every one of these teams is highly recognized at the international level. They all have a high publication ratio, and are the source of numerous scientific highlights in the past four years (list in section 1.4). Moreover, due to a lot of common scientific aims, these 4 teams work in a very coherent way. A lot of inter-team interactions have been built during the previous quadrennial period, mostly – but not only - around the scientific theme of "Stellar and Planetary Formation". In this context, each team conducts an independent research to bring its specificity to the laboratory, and at the same time, the team participates in the global image of the laboratory.

The FOST and Astromol teams interact almost naturally about stellar formation and disk physics, because of their fields of research. Similarly, the instrumental team GRIL focuses mainly on high angular resolution and high dynamic instrumentation as a favored tool to study star formation but also extra galactic sources. The team SHERPAS provides its theoretical skills and expertise on physical processes, especially for accretion-ejection phenomena, at work in young stars as in active galactic nuclei, while opening the high-energy observational window. This combination of skills results in a real "LAOG spirit", strengthening the LAOG scientific potential and making it very attractive. This is illustrated by the fact that in May 2009 LAOG was the astrophysical lab with the highest number of CNRS applications from young researchers. Many inter-team international publications have been produced (65 over the 2005-2008 period, out of a total of nearly 550) and several internal scientific workshops common to two or more teams have been organized, typically once a year. This synergy is a virtuous circle making arbitrations priorities easier for recruiting or sharing resources, by developing a genuine laboratory common strategy. In summary, LAOG as a whole is much more than the mere superposition of its teams, and we are very much attached to this ethic.

We believe that this ethic is very rewarding. Over the past quadrennial period, LAOG has produced outstanding scientific results. We have published more than 500 papers during the 2005-2008 period, ten or so papers in *Nature* & *Science*, four papers in PRL, hundreds of papers in A&A (2.8 papers per scientist in 2008). We have led 6 ANR projects, we participate to another, and 2 more are coming in 2009. We have signed the second biggest ESO contract for VLT 2nd generation instruments (SPHERE, 10 M€). We have filed four patents, and we host a high tech adaptive optics startup (ALPAO). We have 2 projects labeled by the MINALOGIC node and funded by the Inter ministry fund (FUI). We have obtained numerous scientific awards, among which one CNRS silver medal, and we have won one of the very few junior ERC position in France.

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



Growth curve of the laboratory over the quadrennial period

As a result, quadrennial after quadrennial, LAOG remains a very young and productive laboratory. Thanks to the attractiveness of the lab, it has always known a large recruitment rate (almost 12 new arrivals during the 2005-2008 period). Thirty years after the creation of LAOG, the average age of the scientists of the laboratory does not exceed 46 (in 2009). Even more remarkable, the average age of the technical staff (IATOS & ITA) is less than 44! LAOG is also young in its mind and its actions: the reorganization performed in 2003 was built from the inside and was consolidated during the current quadrennial, with strong interactions between teams and a never failing laboratory spirit. When they arrive at the lab, new researchers receive a 2 k€ grant with the help of the UJF TUNES department. Concerning new associate teachers, LAOG grants them with a 25% discharge from their teaching duty, so that they can start with their research projects in the lab.

Finally, we would like to emphasize the fact that this quadrennial report is exceptional. Indeed, it will mark the end of LAOG as such, as it prepares its merger with the *Laboratoire de Planetologie de Grenoble* (LPG). The merger will present unique scientific opportunities, particularly about the themes of the physics of exo-planets, and chemistry. It is a historical opportunity for our laboratory to get stronger while renewing its activities, proving (if needed) that research is a dynamic process.
This project will be mainly presented in the associated 'Scientific Project' document.

2.2. Main scientific objectives of the previous contract

Our main scientific objectives in the previous quadrennial contract have been:
• Addition of the "planet formation" field to the FOST "star formation" field. This objective has been reached beyond all expectations: the results of LAOG in the discovery and study of extra-solar planets are numerous and outstanding.
• Our way to study planet formation is twofold: on the one hand, we focus on young objects and circumstellar disks, on the other hand, we look for older planetary systems in the solar neighborhood. Both methods converge in the study of debris disks and exo-zodiacal dust. This later research theme has lived a strong development in FOST during the past quadrennial.
• Astrochemistry: this research theme is strongly growing in the Astromol team, so much so that the

theme of chemistry will be one of the thematic groups of the new laboratory LAOG-LPG.

• Presence of LAOG in the Herschel Observations preparation and scientific exploitation: this objective is fulfilled by Astromol, as this team is PI of an unbiased spectral survey on HSO. On the other hand, FOST was advised during the last evaluation visit of LAOG to get more involved in the scientific exploitation of HSO. This objective is achieved, as FOST is today involved in many HSO observational programs on disks, and CNES has recently allotted LAOG a post-doctoral position to work on HSO data reduction. Collaborations between FOST and Astromol on chemistry in disks in anticipation of HSO observations have been developed and will soon be published.

• Integration of the SPHERE ESO instrument: the contract was signed in 2006 and our integration hall has been upgraded in 2008, as well as the 1st floor of the CERMO building whose rehabilitation works were completed in late 2008.

• Disks physics, modeling of radiative transfer, disk mineralogy: achieved through a specific ANR grant obtained in 2008.

• Access and understand the high-energy universe through observations using the HESS instrument.

• Increase our potential in heavy MHD simulations.

• Scientific exploitation of LAOG-built instruments: as these instruments are developed in accordance with the interests of LAOG scientists, members of the lab use them predominantly for their projects. This is particularly true for the AMBER instrument that benefited from a strong investment from LAOG (see A&A booklet in 2007). Similarly, LAOG is the major user of the WIRCAM instrument (IR camera on the CFHT).

The following objectives are more about scientific policy than actual scientific results, but they are nevertheless very important in our achievements.

• Better visibility of LAOG in OSUG and UJF: In the structure of UJF's various research departments, the LAOG is well positioned at the interface between TUNES (Sciences of the Universe) and SMIng (Physical Sciences). We have worked out numerous proposals, and during the last two years, we have been allotted 3 post-doctoral positions by UJF.

• Better links with IRAM: IRAM is the only international institute in Grenoble that has no real links with the university. As a result, the scientific links between LAOG and IRAM which should have been evident, given our common scientific histories, paradoxically became a myth. We have worked to break this vicious circle in welcoming a new astronomer (in 2007) who performs her service task at IRAM. In addition, we have initiated meetings between UJF and IRAM and we are working to establish a memorandum of understanding that will allow other astronomer positions to be set between LAOG and IRAM as well as the share of PhD students, hence the start of a renewed IRAM-LAOG collaboration. This closing-by is already underway with regard to schools and workshops on imaging interferometry. The schools organized by LAOG now contain a session for IRAM and vice versa (e.g. session ASHRA / SF2A in July 2008).

• Recruitment: In its previous quadrennial report, LAOG published a 4-year recruitment plan designed to achieve the scientific objectives of its teams. Apart from a few exceptions, this recruitment plan is now fulfilled (see below).

2.3. Actions taken to reach these objectives

In order to achieve the objectives listed above, our quadrennial actions include:

• Laboratory Policy: Arbitration of requests and recruitment of new scientists in accordance with the general scientific policy of the laboratory. The laboratory allots complementary grants on a regular basis in order to allow the implementation of new projects. Numerous post-docs have been recruited (15 post-docs are present in the lab in 2009), and numerous visiting astronomers stays have been granted.

• ANR in 2005-2008: We have submitted and won numerous proposals to this funding agency since the beginning, on various subjects, from theory to instrumentation, within the scientific priorities of the laboratory and our quadrennial objectives. Our successful grants include: *Forcom* (chemistry), *Dusty Disks* (physics and modeling of disks), *Exo-planets*, *Micro-quasars*, *VLTI 2nd generation*, participation in *MAPP* for the study of star-disk interaction, *INOVEO* (Adaptive optics). Two more successful ANR grants are coming in 2009: *RALIS* (near IR integrated interferometry) and *CHAPERSOA* (Adaptive Optics).

• European grants: LAOG has participated in a large number of European projects and networks: JETSET, Molecular Universe, Constellation, HESS Collaboration, OPTICON.

• ERC: LAOG applied for and won one of the very few French European Research Council grants, about exploring the gamma-ray sky, the study of binaries, microquasars and their impact on understanding particle acceleration, relativistic wind and accretion / ejection phenomena in cosmic sources.

• Staff: recruitment of new positions in a global and consistent way within the laboratory, including non-permanent ones. During this quadrennial period, LAOG has seen the number of its post-doctoral positions explode, from 2 or 3 post-docs in 2005 to 15 in 2008. These post-docs have been funded by individual projects (ANR, European networks, etc.), or by a request from LAOG as a lab to CNRS or UJF; TUNES and SMIng University departments provided LAOG with 3 post-docs in 2 years.

• Active participation in the international HESS collaboration, with numerous observing campaigns and intense developments of time varying models to interpret the observations.

• Building: Resumption of the CERMO nearby building operation managed by OSUG in 2005-2006. Eventually the entire first floor of CERMO will be assigned to LAOG. The first stage of a rehabilitation of the Northern first floor aisle was completed at the end of 2008 thanks to the help of OSUG. It now hosts the people involved in the SPHERE and the ELT projects, together with various R&D labs.

• During the quadrennial period, we have acted for a better integration within OSUG (regular participation in Executive Committee, better visibility of astrophysics observation services, management of astronomers). The help of OSUG has allowed a quick expansion of LAOG in the neighboring building CERMO. This objective is however not entirely fulfilled. We have to work more to have our astrophysical operations well taken into account by OSUG, as there is a significant imbalance between the laboratories of earth sciences and astronomy. On the other hand, we have been very successful in our applications for resources by TUNES.

2.4. Scientific highlights

The current quadrennial period has seen an ever-increasing number of successes and scientific highlights, involving all four LAOG teams, with the main ones listed below. Many of these results have been the subject of national and international press releases, strongly participating in the University and CNRS' visibility.

Extrasolar planets and Brown dwarfs:

• Direct Detection of planetary mass companions with NACO: 2M1207 (Chauvin et al. 2005, A&A 438, L25), AB Pic B (Chauvin et al. 2005, A&A 438, L29) and a giant planet candidate of 8Mjup around Beta Pictoris (Lagrange et al. 2009, A&A 493, L21). This planet was predicted by Beust et al. 1996; 2000;

Mouillet et al. 1997). Its detection by LAOG is a bright example of synergy between astronomers and instrument designers.

• Detection of Earth-sized planets with HARPS (collaboration Geneva Observatory.). We are now able to discover thanks to radial velocity techniques telluric planets around M dwarfs (LAOG = 60% of planets around M dwarfs known to date). The system Gliese 581 harbors the smallest exoplanets known to date and the first planets in the habitable zone of a star (Bonfils et al, 2005, A & A 443, L15; Udry, Bonfils et al., 2007, A & A 469, L43; Beust et al. 2008, A & A 479, 277)

• Discovery of ultra-cool and/or very low mass field brown dwarfs. We detected the coolest brown dwarfs known so far with a temperature between 600 and 700 K (Delorme et al. 2008, A & A 482, 961). These very cool objects (T dwarfs and Y) are the missing link between substellar objects and planets. We also detected the lightest brown dwarf known to date (WIRCAM / CFHT, 3 objects below 10 Mjup in IC348; Burgess, Moral & Bouvier 2009, submitted)

Interferometry:

• Interferometry on young objects, with instruments developed LAOG (IONIC / IOTA, AMBER / VLTI): First measurement of phase closure (AB Aur, Millan-Gabet et al. 2006 ApJ 645, L77), and first spectro-interferometric observation (MWC297, Malbet et al. 2007, A&A 464, 43); detection of the BrGamma line (Tatulli et al. 2007, A&A 464, 55)

• Interferometric detection of exozodiacal dust (Absil and al., 2006 A&A 452, 237) in the disc of Vega. The dust amount is so high that an internal reservoir is necessary. The production rates needed 13 Hale-Bopp per day, which suggests an intense late bombardment episode (LHB).

• First astrophysical results obtained by the three-telescope near-infrared beam-combiner of the VLTI (special issue of A&A in 2007 and [ACL-385, 386, 387, 388, 389, 395, 396, 397, 444, 445, 464]) and first image reconstruction of a complex object with AMBER [ACL-572]

Young stars:

• First magnetic maps of young stars (Espadons measurements, coll. Donati, LATT Toulouse). First reconstruction of the magnetic field of a young star, quasi-bipolar. This magnetic topology was not expected in a fully convective star (Donati et al. 2005, Nature 438, 466, 2007, MNRAS 380, 1297; 2008, MNRAS 386, 1234)

Instruments and R&D:

• Beginning of the studies of SPHERE, 2nd-generation adaptive optics instrumentation for the ESO VLT [ASCL-4] by a consortium led by LAOG (Final Design Review successful in December 2008).

• First prototypes and lab study of Swifts, a concept of miniature spectrometer operating over a large spectrum of wavelengths [ACL-332]. Success in obtaining an Inter-Ministry Funding (Fond Unique Interministériel - FUI) in 2008.

• Developments of ultra-fast detectors adapted to adaptive optics (project of the OPTICON/JRA2 led by LAOG in collaboration with ESO - [ACT-515 & ESO press release 22/09]) and success in obtaining an Inter-Ministry Funding (Fond Unique Interministériel - FUI) in 2009 to develop avalanche photodiode matrices for fringe tracking and wavefront analysis.

• Design, manufacturing and characterization of first integrated optics beam-combiners at four telescopes for two 2nd-generation VLTI instruments (Gravity and` VSI - [ACL-554]) and perspectives of astrophotonics (special issue of OPEX in 2009 - [ACL-581, 595])

Theory and computing:

• Proof of the inefficiency of subcritical hydrodynamic turbulence by numerical simulations

• Estimation of the resistive transport coefficient through the magnetorotational instability, and proof that it can be comparable with the turbulent transport, which is a key condition for the existence of magnetized accretion-ejection structures. (G. Lesur's PhD work, SFP prize in 2007, adv. PY Longaretti; ACL-6 and ACL-347)
• Estimation of the truncation radius of a stellar accretion disc, and that a jet is necessary to brake the star rotation. (N. Bessolaz's PhD work, adv. J. Ferreira, in collaboration with the FOST team and R. Keppens (NL), ACL-420 and 533).
• 100 years of CPU time for the calculations of rotational quenching of molecules, resulting in the main highlight of the FP6 Program "Molecular Universe": Hit Parade of Molecules : H2O, NH3, CO, H2CO, HC3N, SO2.

High Energy Astrophyscics:

• Participation in the discovery of gamma-ray binaries in the HESS collaboration (ACL-135), one of the four major discoveries mentioned in the award of European Descartes Prize to HESS , and explanation by a pulsar wind interacting with a wind from a massive star by G. Dubus (ACL-174).
• Participation in the discovery of the most intense gamma-ray flare observed at TeV energy from an AGN, the exceptional flare of PKS 2155-304 in July, 2006 (ACL -325) and explanation by a pair dominated jet (ACL-459, T. Boutelier's PhD work, adv. G. Henri).
• Discovery of a million-degree plasma filling the cavity of the Orion nebula, with the XMM-Newton satellite. It is explained as the result of high-speed shocks (~ 2000 km/s) from the wind of the massive star exciting the nebula (theta1 Ori C: bright region to the top left) colliding with the ambient molecular material. Implications of this result are numerous, and include X-ray irradiation effects on circumstellar disks around young stars (the famous "proplyds") on the one hand, and at the interface with the walls of the molecular cavity, on the other.

2.5. Quadrennial Recruitment plan

The scientific objectives of LAOG in the current quadrennial period are obviously tightly linked to our cutting edge recruitments. In its previous report, LAOG published the recruitment plan needed to support its scientific objectives. Apart from a few exceptions, this plan has been fulfilled within the following recruitment list:

Theme	Needed in:	Fulfilled in:
Modelisation of protostellar environments (theory, observations)	2006-2007	2007 - 2009
Detection and statistical properties of exoplanets	2006-2007	2006
Advanced optics for very large telescopes	2006-2007	2006
High energies: scientific exploitation of HESS, FERMI	2006-2007	2007
Physics and Chemistry of protostellar disks	2007-2008	2007
Heavy MHD simulations, including relativistic range	2007-2008	2005
R&D in adaptive optics	2007-2008	2007
Guided optics for thermal IR interferometry	2007-2008	2006
Scientific exploitation of HSO data	2008-2009	2007

Spectroscopy and radiative transfer in lines	2008-2009	2009
Dynamical modeling of protoplanetary disks	2008-2009	Unfulfilled
Scientific exploitation of VLTI; preparation of 2n G instrumentation	2008-2009	2009
Physical characterization of exoplanets	2008-2009	Unfulfilled
mm interferometry, ALMA support	2009-2010	2008
IR spectro-imagery for multi-telescope interferometry	2009-2010	2009

During the same period, LAOG has lost a significant number of his scientists: N. Grosso (moved to Strasbourg), C. Nozieres and J.-J. Benayoun (retirement in 2007-08), P. Valiron (passed away in 2008), P. Varnieres (moved to Paris after 2 years in LAOG). Regarding this later move, it cancels the "Heavy MHD simulations" fulfillment need, and LAOG still needs to fulfill it.

3. Partnerships

Over the years, LAOG has developed a rich and top-level partnership network. These partnerships are developed at the national level with National Research Programs (PN) and also with the CNES; at the European level with numerous participations to the FP6 and now FP7 programs, together with ESO and ESA contracts, but also specific research programs such as *PICS*, *Egide*, etc.; at the international level via collaborations with US, Asia, Israel. These partnerships are an asset in our research development and demonstrate our strong visibility on the international scene; they are listed in the associated Table document. It is one of our main priorities to maintain and amplify our partnership network over the next quadrennial period, especially using the opportunity of our merging with LPG.

4. Financial analysis

4.1. Origin of LAOG funds

LAOG funds are of two kinds: recurrent and on call for tenders. In 2009, our recurrent funds (from CNRS and UJF) amounted to 250 k€, i.e. less than 2.5 k€ / capita (5.5 k€ / permanent scientist). This is highly insufficient to allow a proper operation of the laboratory, and especially now that the university charges our lab 70 k€ for building maintenance.

The global laboratory budget (including all scientific and instrumental projects) varies from year to year depending on the number of projects under development. Over the 2005-2008 period, it amounted to about 2-4 M€, including large projects like SPHERE, but excluding permanent staff salaries. It should be noted that a large fraction of this money only goes in and out the laboratory, as we are the PI of the SPHERE project, and dispatch ESO money to the other members of the SPHERE consortium.

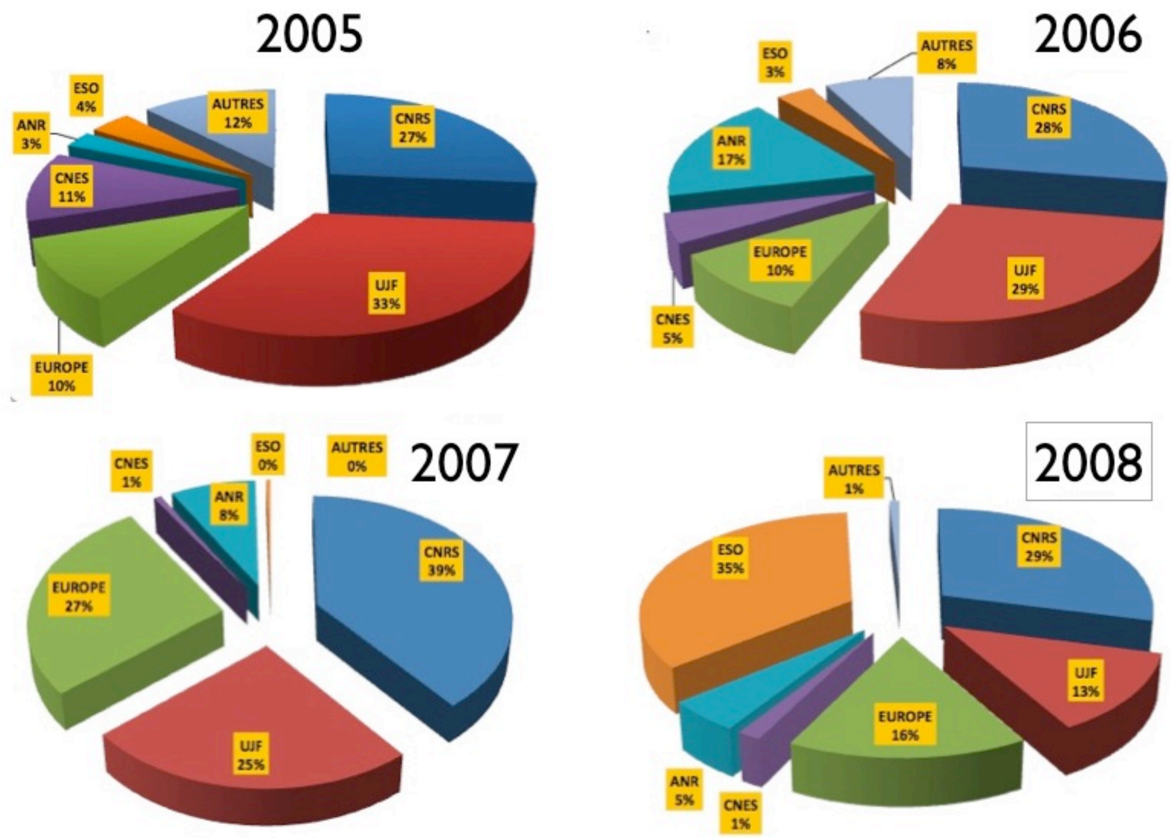
Global LAOG budget (in k€), without permanent staff salaries

	2005	**2006**	**2007**	**2008**
CNRS	415.80	481.90	930.80	943.35
UJF	525.50	502.40	582.80	412.60
EUROPE	156.33	182.11	645.66	509.79

CNES	178.00	84.00	16.80	50.80
ANR	42.00	303.00	187.10	162.99
ESO	60.00	58.15	9.60	**1138.50***
OTHERS	192.88	137.20	0.00	28.10
TOTAL	**1570.51**	**1748.76**	**2372.76**	**3246.13**

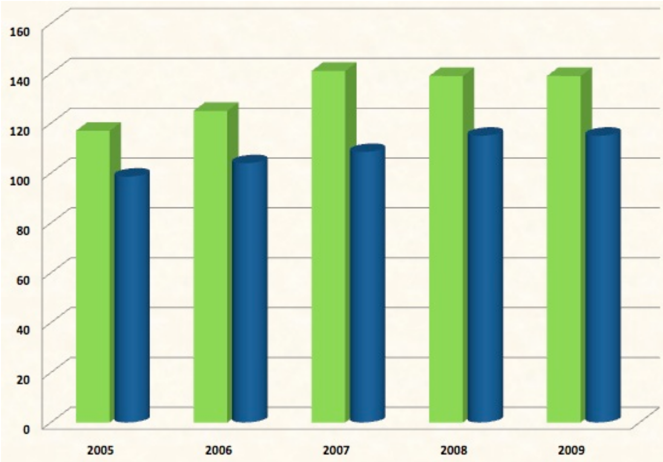
The following graph shows the variation of the relative distribution of our resources over the quadrennial period, excluding the salaries of the permanent staff of the lab, but including all the non permanent salaries, like PhDs, Postdocs, etc (the figures are listed in the above table).

The graph shows that our main sources of funds come from CNRS (dark blue), UJF (red), Europe (green) and the ANR (light blue). CNES is also a very important partner, for instrumental R&D, but also as a source of grant for post-docs. As it includes the PhD students' grants, the UJF participation can be the dominant one, as in 2005 and 2006. The dominant (orange) ESO participation in 2008(*) is due to the SPHERE contract, but a large part of this money is only dispatched between the SPHERE consortium members.



Relative distribution of LAOG fund sources over 2005-2008, excluding permanent staff salaries

The previous graph shows that the UJF funding is an essential part of our budget, mainly because it includes the PhD salaries. However, a note of caution must used here: on the one hand, the number of PhDs in LAOG has been alarmingly decreasing during the recent years and on the other hand, the recurrent funding by university stays notably below the CNRS one (see graph below). Now that UJF has doubled its fee (72 k€ instead of 36k€), we need an urgent re-evaluation of our university recurrent funding.



UJF (blue) and CNRS (green) recurrent funding. The UJF part remains 20 % below the CNRS one.

4.2. LAOG permanent staff salaries and consolidated budget

The salaries of the permanent staff of the laboratory are provided by UJF and CNRS only. Before 2007, we did not have a precise estimate of the amount of this resource, therefore preventing us to produce an accurate consolidated budget of the lab. Since 2007, UJF and CNRS do provide the figures regarding the permanent staff salaries: for 2007 and 2008, the LAOG permanent staff salaries amount respectively to 4 and 4.4 M€.

In conclusion, in 2007 and 2008, the LAOG consolidated budget amounted to 6.3 and 7.6 M€ respectively.

4.3. Common Laboratory budget

We estimate that a fair annual common budget for the lab amounts to 400 k€ (see below). This common lab budget is mandatory to provide a high standard of working means, including library and internet access to bibliography, lab car, small projects internal R&D and new ideas, scientific team funding, general lab expenses (Xerox, telephone, etc.), instrumental lab expenses, etc.

In order to complement our insufficient recurrent funds, every project in the lab participates by a small percentage (usually 10%) in the common laboratory scientific operation. The following table shows our common expenses for the years 2005-2008 (in French).

Objet Dépenses	2005	2006	2007	2008	Détail des dépenses
Bibliothèque	*19,918*	*11,186*	*11,840*	*14,985*	*abonnement, livres scientifiques*
Fonctionnement Général	*59,240*	*60,705*	*56,640*	*61,290*	*photocopieurs, affranchissement, papeterie, véhicules, réception*
Dépenses exceptionnelles	*17,366*	*15,750*	*0*	*0*	*véhicule 2006 , journées du LAOG, impression quadriennal 2007*
Aides Equipes	*0*	*40,383*	*21,000*	*36,200*	*Subvention pour Aide Equipes*
Missions LAOG	*83,916*	*33,481*	*22,400*	*50,320*	*Missions prises en charge par le LAOG pour séminaires, jury thèse, invitation*
Informatique	*79,158*	*65,563*	*53,500*	*75,010*	*Informatique*

Matériel Technique et R & D	*80,916*	*106,993*	*32,000*	*64,460*	*mécanique, instrumentation, cryogénie, électronique*
Infrastructure UJF	*25,200*	*37,000*	*37,000*	*37,000*	*Infrastructure Hébergeur UJF pour 3000 m2 environ*
Infrastructure et Mobilier	*22,811*	*20,678*	*32,600*	*27,239*	*maintenance et réparation portes, salle blanche, hall d'intégration etc...*
Personnel	*23,050*	*31,170*	*10,770*	*42,386*	*CDD, décharge enseignement, gratifications de stage, formation permanente*
TOTAL	*392,837 €*	*424,915 €*	*279,757 €*	*410,898 €*	

5. Teaching and research training

5.1. Education

The position of LAOG within UJF is particular: it is linked to the Department (UFR) of Physics for teaching (10 UJF teachers + 17 CNAP scientists in 2009) but there are few astrophysics teaching lectures at the Department of Physics. LAOG is also linked to OSUG for Research (same Scientific Direction: DS3), but there are very few joint research projects between LAOG and other laboratories within OSUG. Despite (or because of) this situation, LAOG has developed an original strategy: by designing lectures in astrophysics organized in a consistent manner from L1 to M1 (60 hours) in the Department of Physics, by hosting and strongly supporting the second year of the astrophysics lectures of the UJF Master of physics, and finally by participating very actively in outreach activities, either toward the general public, or teachers of primary and secondary schools, and also through the degree “Diffusion des savoirs” at OSUG. We are very aware of the importance of maintaining the existence of a very visible astrophysical teaching on the UJF campus. We provide a teaching "offer" which is too often presented as options but is nevertheless organized in a coherent way from L1 to M1 and then M2. Astrophysics is frequently cited as a very attractive theme to new students at the University. It is clear that we could offer a lot more lectures to the University about the numerous research subjects of our laboratory. We plan to strengthen our efforts on this question.

The "Astrophysique et Milieux Dilues" M2 is a specialization in general Astrophysics occurring during the 2nd year of the Master in Physics at UJF. It was created in 1991 by a LAOG professor and, since then, has been hosted and managed by the LAOG with great mutual benefits, both for our laboratory and our students. The latter have the privilege to share a day-to-day life with astrophysicists (informal discussions with researchers, LAOG seminars) and also directly benefit from lab support (classroom, computers, library, travels to other labs). The lab also has the opportunity to attract well-trained students for PhD thesis about local scientific topics. Given the current context of lower interest in physics studies worlwide, hosting a M2 in Astrophysics is a real asset for our laboratory.
It should be noted that our M2 is one of the two main “Master 2” in astrophysics in France with a broad spectrum in lectures (from planetary physics and star formation to high-energy physics and cosmology). Moreover, the students can apply for PhD subjects on thermonuclear fusion and magnetic confinement devices. High-level lectures on MHD and plasma physics, as well as our proximity to the Center of Cadarrache (where ITER will be built), make this M2 an attractive alternative to studies in Paris.

The M2 "Astrophysique et Milieux Dilues" welcomes an average of 10 students per year, 7 of which continue with a PhD thesis. The recruitment's rate of these students is very high (above the national average), with almost half of them getting a permanent position in Astrophysics (in France but also abroad) or in Fusion research (39 jobs out of 81 PhD for the 2000-2001 students).

Finally we would like to emphasize that LAOG is very present in UJF's teaching management., Our members occupy or have occupied during the previous quadrennial period the following responsibilities: Director of the department of licenses, Responsible for the astrophysics M2 lectures, Deputy Director of the Department of Physics. LAOG members of CNAP are involved in teaching activities, both in the Physics department and at OSUG. Finally, several LAOG research engineers are involved in teaching physics and applied sciences at UJF.

5.2. Research training

Research training is one of the major LAOG tasks. We are affiliated to the Doctoral School of Physics of Grenoble. We are very worried because for several years now, there has been a significant decrease in the number of PhDs performed in our laboratory. However, this decrease is more than compensated by the increase of our post-doctoral positions (see table below). Several factors may be invoked to explain this effect, which is probably present in other UJF theoretical laboratories: general decline in the number of PhD students in science, LAOG positioning "ambiguity" between Physics and Earth Sciences, LAOG affiliation to a single Doctoral School while its research themes are largely multidisciplinary, inadequate ANR funding for post-docs only (improvements are on their way on this point), deliberate choice of project leaders who prefer an experienced post-doc to a beginner student.

We estimate that PhD students are a fundamental part of our laboratory team, and this is illustrated by the high level of scientific production associated with PhDs (see associated Table document). We have worked to reverse this negative trend. In 2009, we will welcome 5 new PhD students, among which 3 will be financed by funds other than the Doctoral School. This is not a very high number of PhD students for a laboratory like LAOG, especially given the number of HDR members (with a research supervision grade) in the lab, but it is nevertheless more than the average values we are accustomed with.

Evolution of the number of students and postdocs at LAOG over the last 5 years.

Year	2004-05	2005-06	2006-07	2007-08	2008-09
PhD Students	19	19	17	15	13
Post-docs	1	3	8	9	14
Total	20	22	25	24	27

To encourage more students to come and do their PhD at LAOG, the laboratory leads and strongly supports the M2 astrophysics lectures: we provide them with a classroom, a laboratory environment, and access to seminars. Many LAOG scientists are involved in teaching these lectures.

A major renewed effort has been devoted to help LAOG PhD students during this quadrennial period, through four events. 1- "PhD-Day": since the creation of the laboratory, one day per year is devoted to the presentation of the PhD works to all members of the laboratory. Post-doctoral students are invited in turn to give a seminar during their stay at the laboratory. 2- Thesis committee: a "committee of theses" was set up in September 2007. It is led by the Deputy Director and consists of 4 "referents" (one per scientific team). The main objective is to assess a smooth execution of PhDs through an annual meeting between each PhD student and the committee. This interview takes place at the end of the year, just after the signing of the “PhD Charter” (involving the student, the PhD advisor and the director of the laboratory). Students are requested to focus on PhD planning, publications (articles, conferences), teaching and outreach. At the end of this interview, the committee sends a report to the PhD student, his supervisor and his team leader. The Committee takes special care to comply with the timetable to avoid overruns beyond the PhD 3-year contract. 3- “Academic research recruitment day”: since 2007, a half-day is dedicated to explain the recruitment’s rules in the public research in astrophysics (CNRS, University and CNAP), for PhD students and postdocs. LAOG researchers who are current or former members of national selection committees give presentations about their expertise in this field. 4- ”"Industry recruitment day”: Since 2007, a half-day is dedicated to recruitment in the industry, for PhD students and postdocs. Former PhD students (from LAOG or not) who have found employment or have started a business in the private sector give presentations. Emphasis is placed on the value of a PhD in the industrial context. Several contacts have been made between LAOG and industrials interested in specifically recruiting PhDs (see http://www-laog.obs.ujf-grenoble.fr/Enseignements/Thesards/infopostdocs.htm). Following such a meeting in 2008, a PhD student of LAOG found a job within a Grenoble company (in the area of Bayesian networks and programming probability) before his PhD was even completed!

5.3. Seminars

LAOG spends a significant budget to organize first class seminars, proposed to all laboratory members, including PhD and Master students. The seminars’ list and announcement can be accessed on the LAOG’s main web page (http://www-laog.obs.ujf-grenoble.fr/). 46 seminars were organized in 2008-2009 and the archive can be accessed on the web. To these laboratory seminars one must add intra team specific seminars that can nevertheless be attended by members of other teams. We consider that this seminar activity is an essential part of the scientific life of the laboratory. Postdocs are also strongly encouraged to give a seminar while staying at LAOG.

6. Licenses and patents

In its instrumental development strategy, LAOG has very soon been aware of the importance of the valorization of its research. LAOG maintains a strong R&D activity, a policy that is very attractive for high-level engineers: GRIL hosts 10 research engineers for only two technicians! Among these high level engineers, there are two CNRS crystal holders, and two have their HDR. This high-level R&D team led us to file several patents and incubate a start-up in the adaptive optics domain (ALPAO, micro-mirrors technology). In June 2008, the ALPAO company was funded and is nowadays hosted by UJF in a neighboring building.

In the FP6, LAOG was responsible for the JRA2 Opticon European Network (FP6, network type I3, 2004-2008). The purpose of JRA2 was to build detectors to be used in European second generation adaptive optics systems. The detector, called CCD220, is now manufactured by the company e2v technolologies (France and Great Britain).

In the FP7, LAOG is responsible for WP2 of the European network Opticon FP7, the new name for FP7. This WP is dedicated to research on sensors for adaptive optics and laser guide stars. The contract began in 2009 and will last 4 years. Industrials, who will be involved in this project, will be selected in 2010 following a European call for tender.

LAOG also conducts two projects labeled by the competitiveness cluster Minalogic:

FUI SWIFT PROJECT: A 30 month-project, labeled by the global competitiveness cluster MINALOGIC, and funded by the Single Inter-Ministry Fund (FUI), with a consolidated cost of 4M€. This project involves the Rhone-Alpes community, and the Isère General Council, 2 companies (E2V, TeemPhotonics), and four laboratories associated with CNRS: LAOG; IMEP-LAHC; LTM; LNIO.

RAPID project FUI : Labeled by Minalogic pole of competitiveness in 2008. Selected for funding in March 2009 by the Single-Inter-Ministery Fund (FUI). The RAPID project is an initiative of LAOG. It concerns the development of infrared array detectors with high sensitivity, based on avalanche photodiode for all applications at very low photon flux from the visible to the near infrared (up to 5 µm). Astronomy is one of the applications chosen to demonstrate the value of this development. The partners involved in the project are Sofradir (project leader), Biospacelab, CEA-LETI, LAOG, LAM in Marseille) and ONERA. The project, which started in May 2009, will last 48 months. The total cost for the project is 13M€, and LAOG is financed up to 850 k€.

Patents since 2005:

2009 Deformable mirror: Charton, Julien; Hubert, Zoltan; Jocou, Laurent; Stadler, Eric; Beuzit, Jean-Luc; Kern, Pierre; 2009; published as FR2876460 (A1), JP2008516277 (T), WO2006040477 (A1), EP1800175 (A1), CN101040204 (A), US2009059340 (A1), European Patent Office;

2007 Publication number: FR2889587 (A1). Publication date: 2007-02-09. Inventor (s): LECOARER ETIENNE; BENECH PIERRE, PIERRE KERN; Lerondel GILLES; Blaiz SYLVAIN; MORAND ALAIN. Applicant (s): UNIV GRENOBLE 1 [FR]; NAT INST POLYTECH GRENOBLE [FR]. Classification: - international: G01J3/45; G01J3/45. - European: G01J3/453B; G01J3/02; G01J3/28B; G01J3/453C Application number: FR20050008429 2005080. Priority number (s): FR20050008429 20050808

2006 Publication number: WO2006064134 (A1), Publication date: 2006-06-22, Inventor (s): LE COARE ETIENNE [FR]; BENECH PIERRE [FR]. Applicant (s): UNIV JOSEPH FOURIER [FR]; NAT INST POLYTECH GRENOBLE [FR]; THE COARE ETIENNE [FR]; BENECH PIERRE [FR]. Classification: - international: G02B6/42; G01J3/26; G01J3/12; G02B6/42 - European: G01J3/45. Application number: WO2005FR03147 20051215. Priority number (s): FR20040052992 20041215

2005 ELECTROSTATIC MEMS COMPONENTS PERMITTING A LARGE VERTICAL DISPLACEMENT: Charton, Julien, Divoux, Claire; 2005; WO2005069473 - 2005-07; Applicant: CEA, CNRS, Julien Charton, Divoux Claire;

7. Outreach

For nearly 15 years now, LAOG, in collaboration with the LPG, has been conducting outreach activities for the general public and schoolchildren. It is difficult to disentangle the actions that are conducted at the initiative of the laboratories, OSUG, or individuals regardless of their affiliation. All these actions take place in a very good cohesion and with a willingness to share tasks. OSUG provides some teaching hours (CNAP personnel) to welcome schoolchildren. The LAOG and the LPG benefit from this measure to organize pupil visits in their premises or on the planetary trail.

7.1. Human Resources

In 2007-2008, OSUG has provided 125 CNAP teaching hours on actions concerning school visits and general public communication on astrophysics and planetology outreach. This volume increased to 250-300h in 2008-2009. This allocation does not cover all the outreach activities of LAOG and LPG. It only takes into account those who are accountable for the lab CNAP personnel.

OSUG now hires a full time outreach personnel, who spends about 50% of its time on actions driven by LAOG and LPG.

An outreach group, named 'Cellcom now chaired by a LPG member after many years of LAOG leading, defines the orientation and priorities of the OSUG outreach in agreement with OSUG laboratories. In LAOG, the CoCom (Communication Committee, chaired by a LAOG member) outreach group runs major outreach activities.

Many researchers, engineers and technicians donate their time for these actions. It is however noted that the growing burden of work makes it increasingly difficult to find actors who are motivated in operations for the dissemination of science. Better recognition of these tasks could only be beneficial if only to comply with the heavy investment they can ask.

7.2. Major achievements in recent years

The planetary trail “Manuel Forestini” has seen numerous visits from school groups, but also from the general public during events like the French “Festival of Science”. Located in the arboretum on the campus since 2003 in Grenoble, it consists of models of the sun and the planets, to scale. It was inaugurated in 2007, and its implementation followed by LPG and LAOG personnel. The trail still needs a regular follow-up and recovery operation, usually because of the accidental deterioration of some of the planets artifacts (see http://www.obs.ujfgrenoble.fr/sentiers/sentierplanetaire/)

7.3. Summary of regular operations

All the years of visiting classrooms, nocturnal observations, conferences, etc ... are organized. We give figures for the 2007-2008 academic year as a typical year. These actions are increasing for the years 2008-2009 (but the picture is not yet encrypted).

- 32 visiting classes (1h30 or 3 hours depending on the visits): the visits focus on the observation of the sun, tours of the planetary trail “Manuel Forestini” and demonstration of planeterrella,
- 16 nights of nocturnal observations for the general public (20 people / session) performed with the 40cm telescope of the OSUG dome
- Numerous public lectures (they are not all referenced) and interventions (ten) in the classroom.

Over all the years we are asked to take stands at events, including the Planetarium de Vaulx-en-Velin.

7.4. AMA09

With AMA09, multiple events have been scheduled to work alongside "regular" site visits:

- Co-organizatio of a series of 9 lectures, under AMA09, "Higher, more beautiful" with the St Martin d'Hères “youth club” (MJC), see http://bruissonnant38400.blog4ever.com/blog/lirarticle-14679-1178116.html. Average audience of 80 persons / conference
- Steering 2 Grenoble appointments of "100 major national conferences of AMA09"

see http://www.obs.ujf-grenoble.fr/osug/content/view/299/161/

- Co-organization of "100h astronomy (observation for all) - AMA09", from the sites of the Observatoire de Grenoble and an amateur observatory in Trièves:

cf. http://bruissonnant38400.blog4ever.com/blog/lirarticle-14679-1178161.html

- The St Martin d'Hères MJC will hold a one-week event on astronomy at the Science Fair. The OSUG 2009 will be a partner of this action.

8. Technical Staff training and promotions

8.1. Training

All engineers and technicians (ITs) of LAOG belong to a common technical group, which is strongly related to the instrumental team GRIL, under the supervision of the technical director. This situation is very motivating for the technical staff and we are very attentive to their promotions. Each year, each IT has an interview with his supervisor and possibly with the director, or the technical director. The promotion files are filled out on this occasion.

There is a very strong synergy between the 4 research teams of LAOG, with ITs fully involved in instrumental and software research activities, and scientists holding leading positions in major international projects. The extent of ongoing projects and the current structure of the laboratory have strong implications on our training needs, either in technical or methodological skills. The laboratory management team is very concerned with skills development, because it is one of the guarantee of a good personal adaptation to their tasks at all stages of their careers.

The annual training plan of the laboratory, as requested by our tutelles, is set as a working canvas through preliminary meetings between the director and the training correspondents. We then study the global requests from department heads about future requirements in terms of team management, and of course, we examine individuals' needs by means of a questionnaire.

The priority areas of training are primarily related to instrumentation, languages, management (teams and projects) and management tools. Thematic workshops and schools are mainly attended by lab scientists but also by the ITA. A specific training related to our work environment is also offered: medical first aid, handling of fire extinguishers, handling heavy loads, etc.

Generic CNRS training are usually requested and granted, as well as some other specific trainings offered by external agencies: space techniques and technology, complex product management and development, and use of specific software are also provided if correctly justified.

Following this policy, the number of training has increased significantly over the recent years:

Year	Training	Number of people involved
2005	25	18
2006	26	19
2007	32	21
2008	53	34

When a given training session interests many people, we can organize it in the laboratory. Over the past few years, the following sessions took place: Spanish, medical first aid, electric empowerment.

Some CNRS ITA also participate in the CNRS working networks on mechanics, electronics, optics and information technology (see attached LAOG Training plan in 2008).

8.2. Promotions

LAOG is very attentive to the promotion of its technical staff. Indeed, when scientists are promoted at the university (UJF staff) or national (CNRS & CNAP) level, on their personal initiative (independently of any LAOG advice), engineers and technicians are evaluated within LAOG before any promotion. We encourage every member of the staff to apply for internal competition as soon as they can, and we spend a significant amount of time and energy to update the career files of everyone in the lab in order for them to get access to internal promotion. This promotion can be a change of grade (IE2 – IE1), or a change of status (AI – IE2), this later being of course more interesting. Over the 4.5 past years (2005- mid 2009), 10 members of the technical and administrative staff have been promoted to a higher position, or have successfully applied to an internal competition. However, during the last 5 years, there has been no status promotion (apart from internal competition) for any technical staff of LAOG. We feel that CNRS and UJF should revise their promotion policy on this point.

9. Quality Insurance Unit

It is a long lasting LAOG wish to establish professional quality procedures, especially given the high number of instrumental projects conducted in the lab. A roadmap of a Quality Insurance Unit was discussed among the GRIL Team by the end of 2006. Mid February 2007, the *Quality Insurance Unit* was officially created by the Management of LAOG. At first, the unit was composed of 4 voluntary members and was then reinforced with the recruitment of a Project Assistant on December 1st 2007. As of mid 2009, most of the points foreseen in the roadmap have been implemented:

- Document management with the creation of templates.
- Configuration control management of the documents, software, and electronic projects.
- Software management with the definition of programming standards.
- Absence management and creation of time sheets to evaluate the time spent by each agent on different activities.
- Creation of a server dedicated to the sharing of administrative documents: 2 full-time jobs during 2 or 3 months.
- Complete overhaul of the laboratory intranet

The use of these tools has been offered to the laboratory on a voluntary basis. Two years after its creation, more and more users are now using the tools provided by the Quality Insurance Unit: *Absence management* tool under Twiki, *Configuration Control Management* under CVS, and the Unit support is now often required by project managers. Indeed, our quadrennial report has been written using the administration server to share Word and Excel documents. The Executive Committee, the Management staff and the Laboratory Council regularly use dedicated Twiki Web sites to prepare meeting agenda and dispatch preparatory documents. The Quality Insurance Unit is now fully functional and LAOG will encourage all its members to use these "good practices" in their projects, instrumental or not.

10. Health and Safety (H&S)

Monitoring of H&S is one of LAOG's priority; the ACMO works in close relationship with the lab Head. According to the rules, we have designed a so-called "document unique" that identifies all the working risks in the laboratory.

10.1. Review of incidents:

One feeling of faintness and one epileptic crisis implying the intervention of medical emergency, without any serious consequences in either case.

10.2. Identification and risk analysis:

The laboratory does not use products or machinery yielding a major risk for the personnel or the environment: we use no chemicals, radioactive or biological products. The main risks come from some experiments related to optics research and development conducted in laboratory and the occasional use of machine tools in a workshop as well as the handling of a crane located in a hall of integration.

10.2.1. Risks associated with optical experiments:

These activities are grouped in rooms with limited access to authorized personnel only through a door with a lock code.

- Use of small amounts of liquid nitrogen, with a risk of burns and death by asphyxiation in the event of poor ventilation in a confined place;

The room is equipped with a ventilation opening onto the open air on the outside and the door remains open during N2 transfers; an oxygen detector is present in the room.

- Use of a low power visible helium-neon laser, which can nevertheless be hazardous to the eyes.

A display panel recalls the presence of lasers.

- Use of an infrared laser of median power that can cause burns.

The laser was installed in a specific room equipped with an emergency push button and a lamp indicating its operation on the outside; a transparent casing, but still opaque to infrared radiation was put in place above the optical bench as well as a sign recalling the obligation to wear the goggles provided. People working on this laser were trained about the risks associated with the use of lasers.

10.2.2. Risks associated with mechanics

The mechanical workshop is located in a room whose access is restricted to authorized personnel only through a door with a lock code. The use of standard tools is not limited, but the use of the drill column is limited to one category of person who received a basic technique training.

Access to specialized machine tools such as lathe or milling is not self-service, the tools being stored in a cupboard with a lock. Only a few people with proper training are allowed to use this type of machine. The machines have also been upgraded to meet the standards.

The integration hall is equipped since its construction with a crane of 5 kdaN capacity. The use of this equipment may present a risk when used by inexperienced persons. A two half-day training has been provided in our facilities to people using the crane.

10.2.3. Miscellaneous:

The stairs of the main building built before 1992 have been upgraded to meet the standards and handrails have been added.

10.3. Health and safety Operation

A Committee for the distribution of tasks and think tank, leaded by the ACMO and the director of the laboratory has been set up. Also, to limit the risks in case of fire, a group of dedicated people, organized by building zones is in place to assist with calm and discipline the evacuation of the laboratory during any outbreak of alarms.

A dedicated website hosted on the lab intranet presents the activity and reminds the security instructions. There you will also find the reports of H&S meetings and initiatives. One can also download the charter for the use of technical facilities. A booklet has also been designed to inform new lab members with the security rules.

10.4. Devices used for training and important actions

The courses that were taught in the context of the hygiene and safety are:

- Handling of fire extinguishers - First Medical Aid - Use of crane - Laser Risks.

Some important actions have been undertaken during the recent years:

• Design of a H&S page on the Intranet.

• Design of various charters for the use of the technical workshops, signed by all users.

• Installation of a defibrillator.

• Purchase of a stretcher.

11. LAOG Social Report : permanent staff as of June 17, 2009

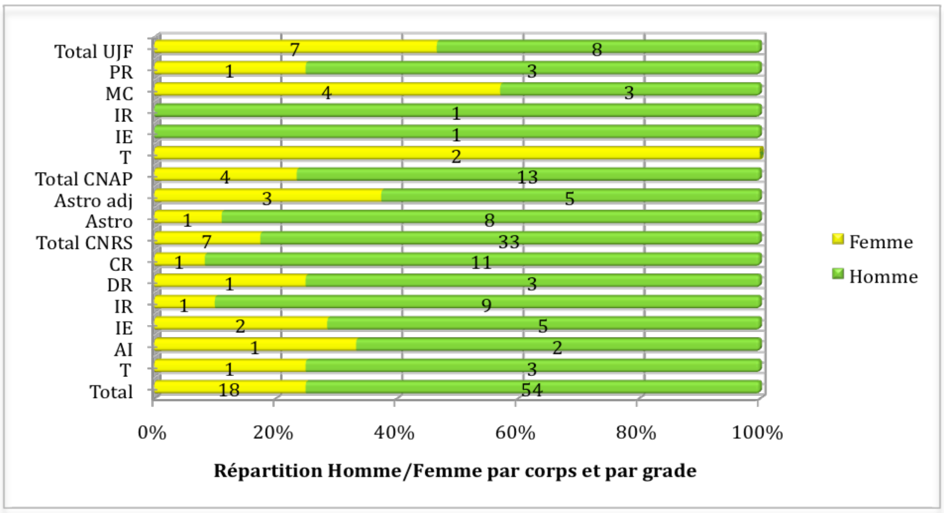
In this section we present an analysis of LAOG's staff figures. The figures used in the graphics below can be found in the accompanying tables of our global report (+/- 0.5). On the overall, there are exactly 75% of men and 25% of women in the LAOG staff. Although it might not be unusual in an astrophysics lab, it shows that LAOG is attentive to hire and promote women.

Within its scientific staff, LAOG hosts 11 UJF, 17 CNAP and 16 CNRS. These numbers are unbalanced in the disadvantage of the university. LAOG recently obtained new teachers positions, but it is among the UJF staff that we had almost all our recent retirements. As a result, the LAOG UJF staff has been stable for more than a decade, when the growth of the laboratory was mainly provided by CNAP and CNRS people.

From the scientists' career point of view, on the overall, there are 38% equivalent full teachers (grade A), and 61% equivalent associate teachers (grade B); this appears as a reasonable ratio. However, if one finds that the situation is better in the CNAP staff (50-50), while the UJF staff is close to the LAOG average (36-64), the situation is worse in the CNRS staff (25-75). It is clear that LAOG lacks CNRS A-grade members. This is very unfortunate first for the scientists themselves, because given the results of our laboratory, their members deserve a decent career evolution, and it would also be a real source of motivation; second, it is unfortunate for the laboratory itself, because we need A-grade members to be able to take more responsibilities, in the interest of all the community. We feel that CNRS should reconsider its promotion policy and balance the possible small money savings against the real large energy loss when people are not recognized at their true value.

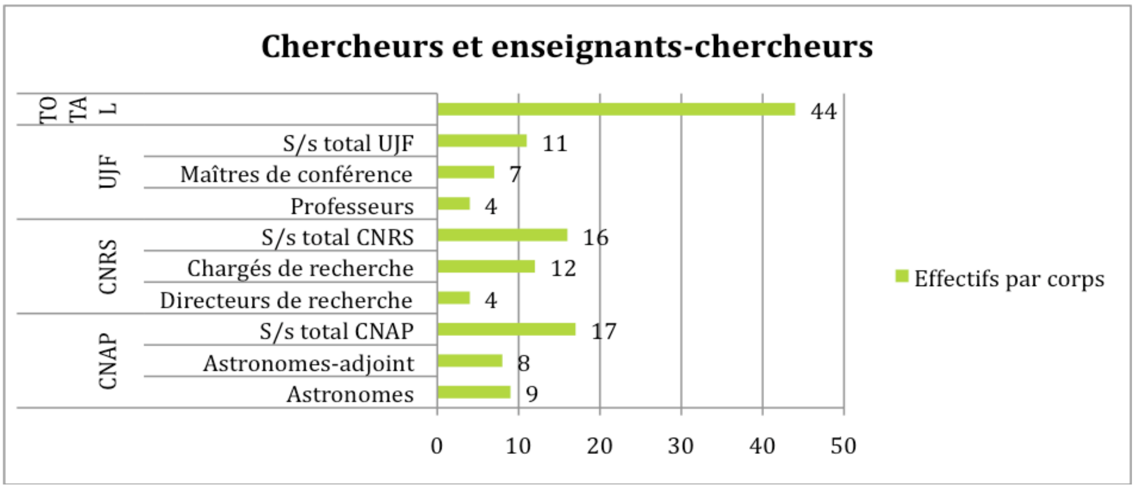
LAOG also acts to hire handicapped people. We systematically consider requesting for a disabled person when we apply for new staff on the CNRS *Labintel* application. In 2007, we have been very fortunate to hire a handicapped person for our documentation management.

11.1. Staff Demography according to jobs

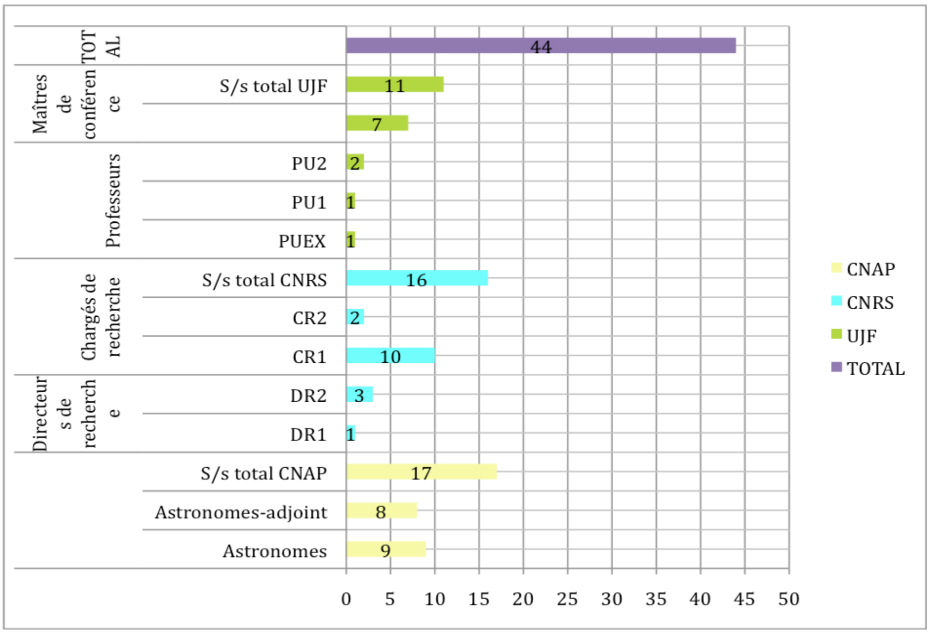


11.2. Scientists and teachers staff

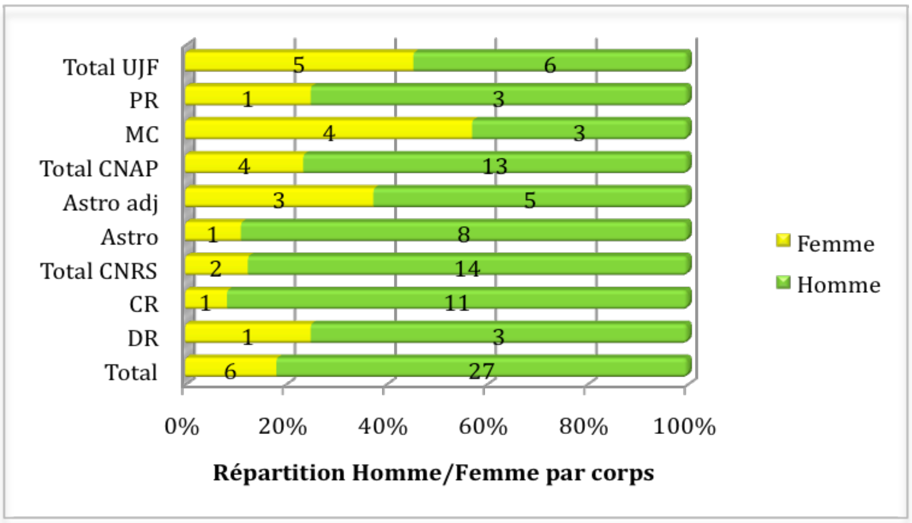
11.2.1. Staff distribution per supervisory authority



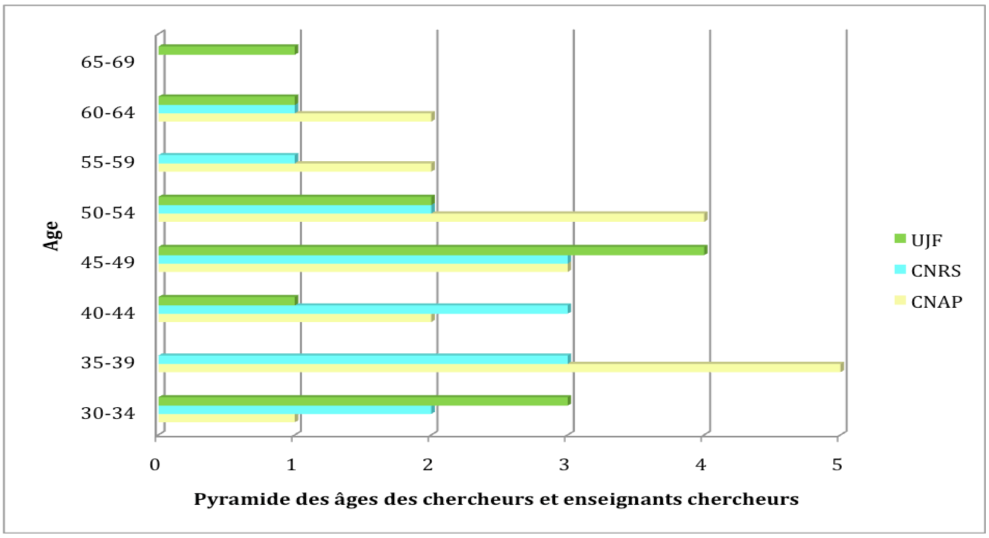
11.2.2. Staff Distribution



11.2.3. Researchers and teachers' demography

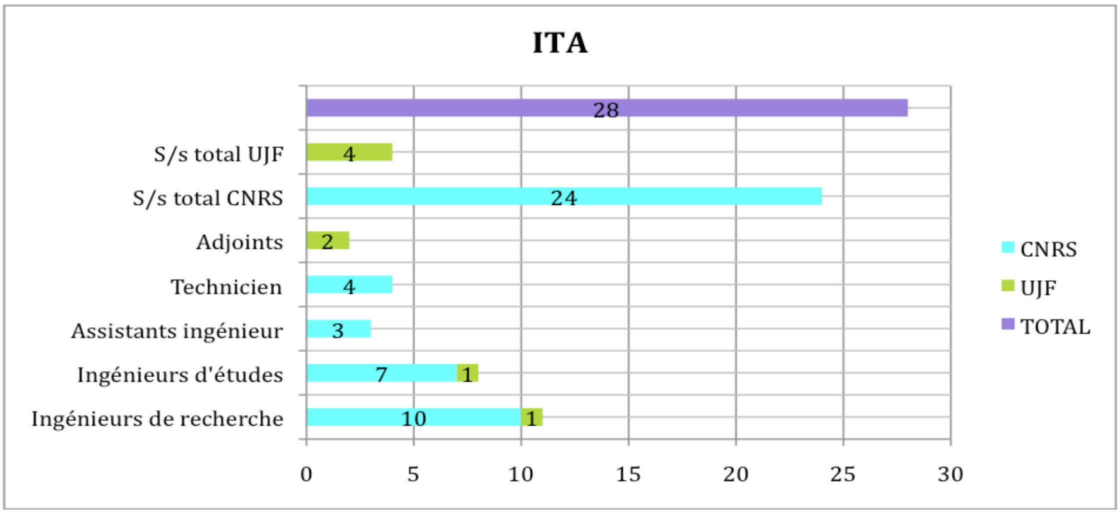


11.2.4. Population Pyramid of researchers and teachers

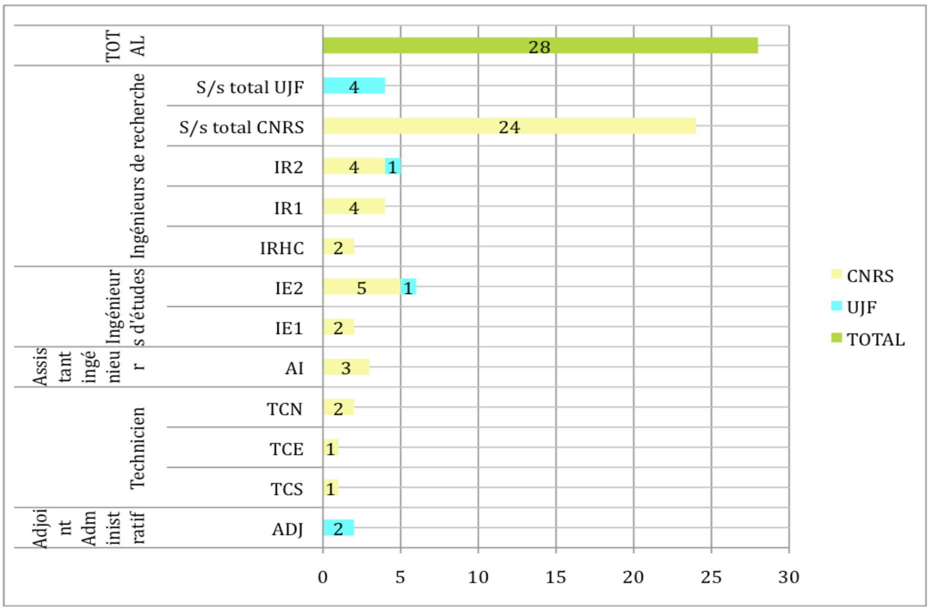


11.3. Engineers, Technicians and Administrative (ITA) staff

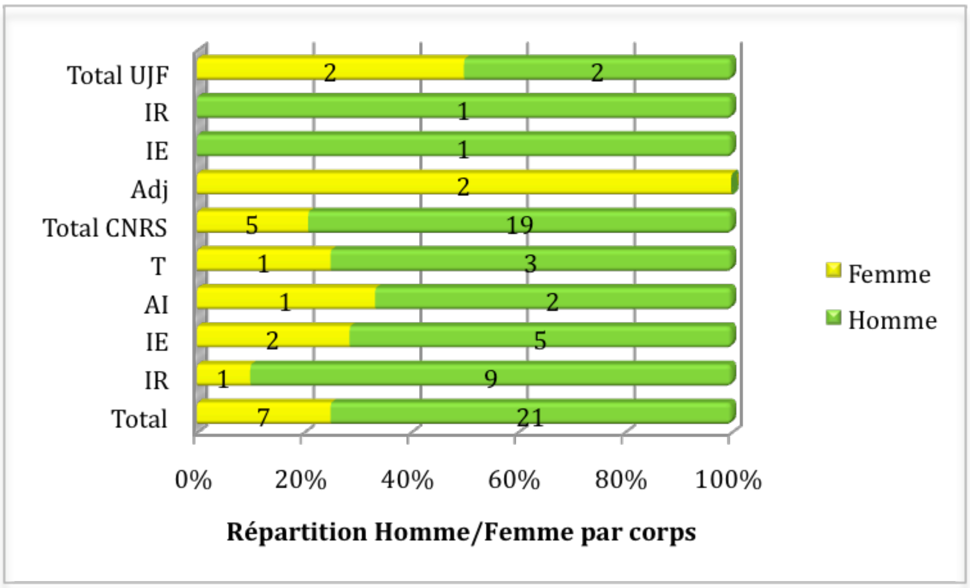
11.3.1. ITA Staff distribution according to jobs



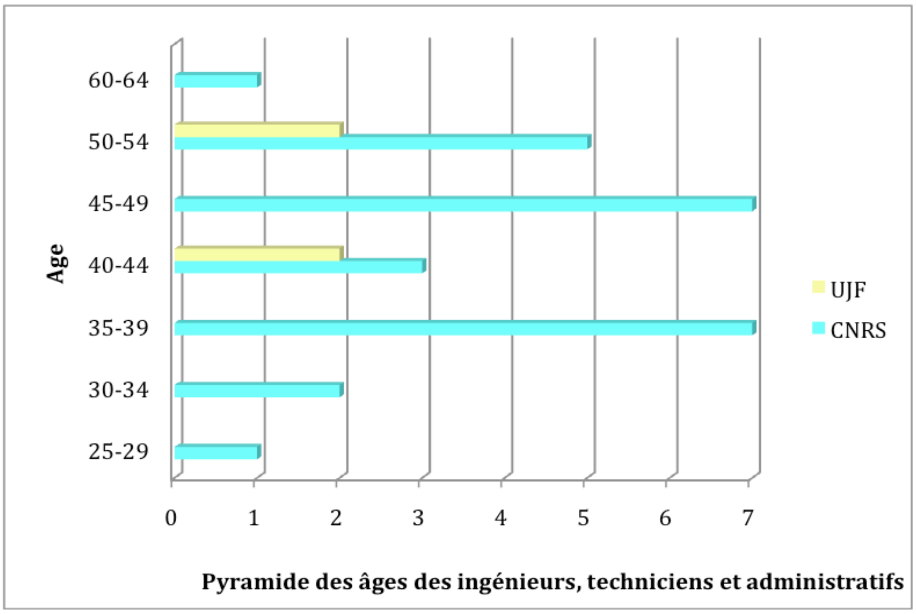
11.3.2. ITA Staff distribution according to grade



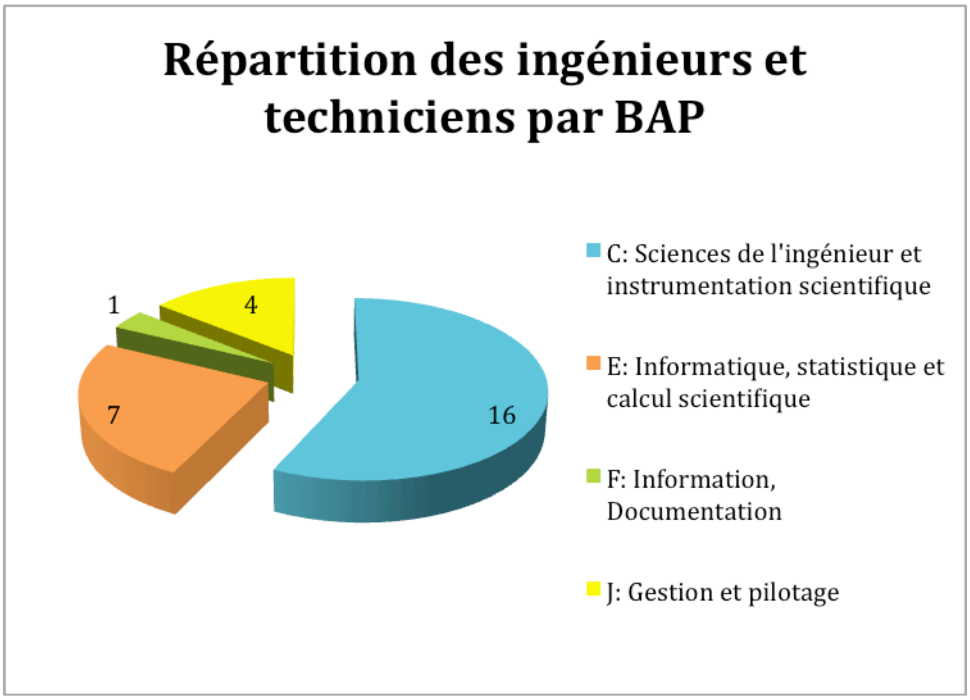
11.3.3. ITA Demography



11.3.4. Population Pyramid for ITAs



11.3.5. Staff distribution according to jobs



12. Detailed Scientific Report

12.1. ASTROMOL

The 'ASTROphysique MOLéculaire' team was constituted about 6 years ago, around Pierre Valiron (who passed away in August 2008) and Cecilia Ceccarelli. It now encompasses 11 permanent positions, junior and senior. While its scope of expertise kept increasing, the strength of Astromol has always been its very clearly stated aims: studying sun-like stellar evolution by means of molecular observation AND studying evidence of molecular astrophysical evolution for its own sake, by all means available, observation, theories, models. Thanks to the intimate blend of observation and theory, Astromol kept its original position both in terms of astrophysics and molecular physics. By now, it is widely recognized in the national and international scene (2 national prizes, PI-ships, conference and professorial invitations, publications). Its attractiveness is substantiated by the number of people who joined the team over the years [2] and those who were hired[3] .

12.1.1. General presentation: Chemistry and Star formation

Molecular complexity in space and star formation go hand by hand. In fact, the sequence that brings matter from the diffuse (molecular cloud) to the condensed (planetary system) phase is a unique and rich laboratory where, step after step, molecular complexity increases. This chemical evolution provides hints on the physical changes of the gas that will eventually form a star. Of all molecules, the N- and O- bearing Complex Organic Molecules (COMs) stand out due to their possible role in the appearance of life. Figure 1 provides a schematic view of the star formation process and the molecular complexity evolution. A variety of studies of comets and meteorites lead us to think that the Solar System substantially followed the same pathway. (Fig. 1).

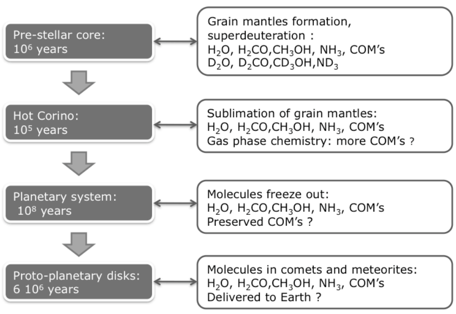


Figure 1: Schematic view of the different stages in the formation of a planetary system similar to the Solar System and the concomitant evolution of molecular complexity, in particular of the Complex Organic Molecules (COMs), in the material delivered to the forming planets. The times reported on the left indicate the approximate duration of each stage.

12.1.2. Scientific results

From the Cloud to a Pre-Collapse Condensation

The first steps that bring matter from the diffuse state of molecular cloud to a condensation that will eventually collapse into a star represent a key phase, for the destiny of the star. Not yet fully understood, it remains the object of scrutiny in many ways.

1. ***Turbulence and collapse:*** Observations performed at the IRAM-30m telescope have shown the

[2] L. Wiesenfeld (2004), T. Montmerle (2004), C. Bacmann (2008).

[3] A. Faure (2003), S. Maret and P Hily-Blant (2008).

largely unexpected result that the turbulence in the compressible and magnetized molecular clouds can mimic turbulence in incompressible and unmagnetized flows (Hily-Blant et al 2009). It is still very unclear when and how the collapse starts. We have carried out pioneering studies of the kinematics of several pre-stellar cores, by means of observations and modeling of several lines from different molecules that probe different regions, mainly the protonated ions H_3^+, N_2H^+ and their deuterium substituted variants (ACL-60, 204, 299, 336, 374, 436).

2. ***The ortho-to-para ratio (OPR) of H_2***: Depending on the relative alignment of the H nuclear spins, H_2 can be in the ortho or para form. The two forms interconvert extremely slowly, behave differently in collisions with other molecules and have a different chemistry for energetic reasons. Attempts to measure the H_2 OPR have been going on for a long time, since models are very unclear in their predictions. In the last years, we have explored two new methods: ***(i)*** indirect measurements by observations of molecular lines, based on the different collisional propensity rules between ortho and para H_2 (ACL-590; Troscompt et al., 2009, accepted) ***(ii)*** observations of H_2 in warm shocked gas, from which it is possible to infer the H_2 OPR in cold gas. We consistently measured that H_2 is mostly in the para form in the cold molecular gas.

Water: a key molecule

For that line of investigation : we were the 'Local node' of the FP6 Molecular Universe program (P. Valiron, then, A. Faure), we invited for several months J. Noga (U. Bratislava) as a visiting scientist and we had many invited conferences (P. Valiron, A Faure, L Wiesenfeld), including the James Franck Colloquium in Chicago (LW) and the Royal Society Meeting on H_3^+ (A. Faure).

Among the molecules we have investigated, water was the focus of much of our efforts : H_2O plays a major role in the cooling of the (warm) molecular gas. It is the third more abundant molecule and obviously bears a very peculiar importance in astrochemistry and in the history of molecular complexity. Being unobservable from earth, it is also an obvious major target for the HIFI instrument onboard the Herschel satellite.

Our team devoted considerable observational and theoretical effort to that molecule, with several noticeable results: (i)The ***observation*** of the water ^{18}O isotope with ground telescope (van der Tak et al. 2006), the HDO isotopologue (Parise et al. 2005, Ceccarelli et al. 2005) and the first detection of the heavy water, D_2O (Butner et al. 2007) (ii) The ***calculation*** of several relevant molecular collisional effects (see below) (iii)The involvement in several ***experiments***, either directly or as providers of models for the measured results.

On the theory side, from 2005 to 2008, our team was deeply involved in the FP6 Research Training Network "Molecular Universe'' (contract number MRTN-CT-2004-512302). Our task in this network was to revisit a number of van der Waals molecular systems of astrophysical interest, with the objective to derive new and precise collisional state-to-state rate coefficients. These coefficients, which are crucial for non-LTE radiative transfer studies, are very difficult to measure in the laboratory and astronomical models rely only on theoretical estimates.

In 2005, a full nine-dimensional *ab initio* Potential Energy Surface for H_2O-H_2, i.e. including all vibrational deformations, was computed by our team by combining the standard CCSD(T) method with high accuracy CCSD(T)-R12 (explicitly correlated) calculations, with a code developed between our team and the University of Bratislava. The accuracy of ~ $1 cm^{-1}$ in the whole attractive region is still highly challenging for a 9D PES and, in this respect, our H_2O-H_2 PES represents a benchmark for van der Waals molecular studies.(ACL-447)

The 9D H_2O-H_2 PES has been employed in several applications: 1. ***A rigid-rotor*** (five-dimensional) PES has been obtained by averaging the 9D PES over the ground state vibrational wave-functions of H_2O and H_2. (ACL-87). 2. ***Rate coefficients*** for the vibrational relaxation of the first excited bending state of H_2O by H_2 have been computed at the quasi-classical level of theory. Our results were found to be consistent with the single experimental measurement at 295K (ACL-87, 47). 3. ***At the quasi-classical level***, rate coefficients for the rotational (de)excitation of H_2O by H_2 have been computed and compared to the quantum calculations performed by the LERMA group in Meudon. The classical rates were found to be accurate within a factor of 3 for the dominant transitions (ACL-207, 319, Dubernet et al. 2009). They have been extrapolated up to 5000K, (ACL-431) 4. ***The impact*** of the new H_2O-H_2 classical rates on non-LTE radiative transfer calculations was investigated by our team and others. Significant differences with respect to the He rates of Green et al. (1993) have been observed at temperatures below 300K, showing that He cannot be employed as a substitute for H_2, except possibly at high temperatures (ACL-319). **5. Also,** our expertise allowed us to calculate in a similar way several other collisional coefficients of molecules with H_2 and/or He, most notably: HC_3N (ACL-399), H_2CO (ACL-602), SO_2 (in coll. with LERMA, Spielfiedel et al, 2009), NH_3 (Maret at al., submitted, 2009).

Molecular deuteration and complexity

For that line of investigation, we have been : PI and PM of the ANR (2008- 2012) 'FORCOM', PI of the HS3F guaranteed time program on HIFI, and co-PI of he COST action 'The chemical universe' (both, C Ceccarelli). B Lefloch is PI of a PPF (Grenoble-Toulouse-Bordeaux). C. Ceccarelli had many invited conferences, including the Nobel Symposium in 2007. M. Elitzur (U. Tennessee) spent the year 2005 in the team.

All the way during the formation of a star, the chemical complexity of the gas increases dramatically. During the cold pre-collapse phase, atoms and simple molecules, like CO, freeze-out onto the dust grain mantles. Once frozen on the grain mantles, grain surface reactions form hydrogenated molecules by subsequent H and D atoms additions (notable examples are H_2O, H2CO, or CH_3OH and their deuterated isotopologues; e.g. Tielens & Hagen 1982) and maybe even more complex molecules in slightly warmer dust (e.g. Garrods & Herbst 2006). The molecules frozen in the grain mantles are subsequently released into the gas upon warming of the dust by the forming star. Once in the gas phase, molecules may undergo reactions that further increase the molecular complexity. Therefore, there is a tight and complex interplay between gas and grain surfaces chemistry on the one hand, and between chemical complexity increase and protostar evolution on the other hand. Two major topics stand out:.

Hot corinos: Hot corinos were discovered by Astromol members with studies dating 2000-2004. They are warm and dense regions at the center of low mass protostars, enriched of several complex organic molecules (COM). Hot corinos became soon popular, as they may represent the Solar System progenitor, namely the Solar Nebula during the warm phase. For example, the article with the first discovery of COMs in the first hot corino by Cazaux et al. (2003) has been cited almost 100 times in 5 years. The term "hot corino" is now commonly used. In the 2005-2009 period, we have enlarged our studies to characterize the largest possible number of hot corinos, with emphasis on the chemical aspects. We carried out a thoughtful study in a sample of hot corinos of the formaldehyde and methanol and several other COMs abundances (ACL-16, 407). We found that a substantial fraction (~10%) of elemental carbon is in these molecules. Furthermore, hot corinos seems more efficient in synthesizing COM's from CH_3OH and H_2CO than the more massive hot cores. In this context, we started a parallel study of a sample of intermediate mass protostars, to understand how the mass of the forming star impacts its chemical composition (ACL-360, 361, Crimier et al., 2009). We have also carried out studies at the IRAM Plateau de Bure Interferometer of some hot corinos to understand their origin and physical structure (Bottinelli et al. submitted, 2009). An important, though not yet fully exploited study carried out by our group is ***the unbiased spectral survey*** of the hot corino prototype, IRAS16293-2422, obtained at IRAM and JCMT in the bands accessible from ground from 80 to 370 GHz. Finally, we have started a coordinated study, using theoretical chemistry tools, to understand the formation routes of COM's by looking at the isomeric forms (ACL-552), and to compute the COM collisional coefficients necessary to derive correct estimates of their abundances (ACL-431).

Deuterium chemistry: As reported in the previous Report, Astromol had a leading role on the discovery and study of the "super-deuteration" phenomenon, namely the large increase of the abundance ratio of molecules bearing D-atoms with respect to H-atoms (see e.g. the review Ceccarelli 2005 IAU Asilomar conference). In the last four years we have been keeping a leading role on those studies, now carried out by several groups in the world. Let us mention i) H_2D^+ to study the kinematics (ACL-60) and/or the peculiar chemistry towards the centers of pre-stellar cores (ACL-154, 191, 436, 590) ii) various molecules, notably water (ACL-33,122, 376) methanol and formaldehyde (ACL-195) that present an enhancement of the D/H abundance ratio with respect to the elemental D/H ratio up to 13 orders of magnitude. Those studies have paved the detection and studies of the molecular deuteration in the midplane of protoplanetary disks, where the bulk of material forming possibly planets lie (ACL-49, 328) and suggested possible ways to detect cold baryonic dark matter (ACL-227). Last, but not least, we have started an experimental program to investigate the D and H atoms exchanges on dust grains, simulating the conditions prevailing during these cold pre-collapse phases. A first experimental study, performed in between LAOG and LPG, has already showed that likely this is an important process to take into account (ACL-571).

Nitrogen chemistry: Despite its foremost importance, nitrogen chemistry in space is poorly understood. The first issue deals with the most important nitrogen reservoir in molecular clouds and in the pre-collapse condensations. Nitrogen is mostly in atomic form, rather than N_2, as supposed before ACL-202. This has important consequences and allows to understand isotopic anomalies observed in meteorites, and confirms that comets and other bodies of our solar system have inherited -- at least partially -- of the chemical composition of pre-collapses condensation. It also shed a new light on the N chemistry in these objects, in particular on the N_2H^+ abundance increase at the center of the pre-stellar cores (ACL-374), or the large abundance of CN in regions where all the other C-bearing molecules are frozen onto the cold dust grains (ACL-504).

Energetic Processes :

We were invited at many international conferences (9 for T.Montmerle) and organized one IAU conference and one Les Houches School. B. Lefloch is a visiting faculty and scientist at CSIC (Madrid).

Shocks in SF Environments

Momentum and energy transfer in the interaction of star forming events with the ambient medium play a crucial role in molecular cloud evolution, turbulence injection, and star formation. Over a very wide parameter range this interaction proceeds via molecular shock fronts driven by high-velocity outflows and jets. Those are observed in all the young stellar objects where infall and mass accretion is occurring. Among those, jet-driven bow shocks are particularly commonplace. Most of our understanding of protostellar shock physics relies on numerical modeling, which predicts a double shock structure for protostellar shocks. However, such a structure could never be verified observationally for non-dissociative (MHD) shock. Shocks are of importance not only for the dynamics, but also for the chemical evolution through temperature and density changes, ionization, ice mantle evaporation, endothermic water formation, ortho-to-para H2 interconversion, and dust shattering and sputtering in the ion neutral drift zones.

The Astromol team is carrying out several projects using the large ground-based single-dish telescopes (IRAM 30m, JCMT, CSO) and the Plateau de Bure Interferometer to investigate: (i) ***The structure*** of outflows and the associated molecular shock front, in a sample of a few sources (ACL-443) in collaboration with S. Cabrit (LERMA) and K. Schuster (IRAM) and (ii) ***Shock-driven chemistry*****:** a detailed study of the highly-energetic Herbig-Haro object HH2 in Orion proved that outflow shocks were mostly responsible for the peculiar molecular composition of the ambient gas (ACL-104). The evolution of dust grain properties in the shocks of HH2 are currently studied with Spitzer in collaboration with C. Joblin (CESR), O. Berne and J. Cernicharo (CAB, Madrid).). Finally, we are pursuing the computation of rate coefficients for electron-impact excitation of the relevant molecules and molecular ions (ACL-63, 159, 164, 287, 555). Electron collisions are crucial to properly model both the molecular populations and the ionization fraction in harsh environments (ACL-164, 168, 437).

High-energy processes

Low-mass young stars show magnetic activity similar to the Sun, but enhanced by 3 to 4 orders of magnitude, as seen directly in X-rays. We have been involved in two major international surveys of X-ray emission from young stars: the "Chandra Orion Ultradeep Project" (COUP: ACL-31,39), and the "XMM-Newton Extended Survey of Taurus" (XEST: ACL-355), revealing the statistical properties of thousands of young stars (T Tauri stars and early-type stars).

Young stars are the seat of high-energy interactions that give rise to feedback effects on the dense material lying in their vicinity: circumstellar disks and molecular clouds. Hence, we infer that they should also emit an intense flux of energetic particles (p, ^{3}He and ^{4}He nuclei). X-rays and energetic particles then interact with circumstellar disks, (i) ionizing them (which can be observed directly in the mm range via radicals like HCO+ and DCO+: ongoing programs at JCMT and IRAM 30m and (ii) generating spallation reactions, the products of which we can see today in solar-system meteorites (Montmerle et al. 2006). High-mass stars generate an intense mass loss (10^{-7} - 10^{-6} Msol/yr) in the form of very fast winds (up to a few 1000 km/s); in turn, (iii) these winds shock the surrounding cold molecular material and are able to heat it up to several million degrees, visible in the form of diffuse X-ray "bubbles", which we have discovered with XMM_Newton in the Orion nebula (Güdel et al. 2008).

The Cold Universe

The Cosmic Microwave Background is cold (2.725 K) because of the expansion of the Universe and the galactic dust is cold (~20 K) within the interstellar radiation field (equivalent to a 3 K blackbody) because of its emissivity law. This coincidence makes the analysis of the CMB anisotropies dependent upon the understanding of the sub-millimeter emission of the interstellar medium. This emission, being optically thin, is an important tracer of the clouds that will eventually condense to form stars.

We have worked on the data analysis of the Archeops balloon-borne mission, containing a focal plane similar to Planck HFI that observed the Northern sky during 12 hours in 2002. We made a survey of its 300 point-sources, which besides two supernova remnants (Crab and Cas A) are all dust cloud condensations in the Milky Way (see Figure 4). We have uncovered a strong anti-correlation between the temperature and the emissivity index of the dust for a temperature range of 7 to 17 K clouds, extending a previous result by Pronaos. No explanation is so far convincing for this behavior. This population of sources may prove useful to determine the focal plane geometry during the early phase of Planck in-flight calibration, before planets can be observed. (ACL-499)

General achievements, management.

Two prizes were awarded to members of the team: The "Marie Curie prize – Scientific Woman of the Year" to C. Ceccarelli, 2006 and the Silver CNRS Medal, FX Désert, 2009. Also, we had three new young scientists in 2005-8: one CNRS new position, one Astronomer (coming from Bordeaux), one 'Maître de Conférence' (Junior Professor), new position. T. Montmerle, member of the team, was the LAOG director from 2003 to 2006.

The Astromol team has presently 11 permanent members; among them, 3 joined the team in 2008. We have a constant flux of 2 thesis students and, most of the time, one long term visitor. P. Valiron (DR-CNRS), a prominent member of LAOG and the astrophysical community, passed away on August 31, 2008.

The Astromol team has managed several large projects, among them a key node of the FP6 'Molecular Universe' program, a PPF, several grants of the INSU national programs, the PIship of a key program of Hershel (HF3S), of a COST action, and of the 'FORCOM' ANR. In order to do so, we have always been very careful in planning ***and*** managing:

1. The recruitment plans have always proceeded hand in hand with the main scientific goals, including the choices of theses, post-docs and long-term senior visitors.
2. Managing of the projects and of the team as such is splitted among the various PIs and the director of the team (successively, C. Cecarelli, T. Montmerle and L. Wiesenfeld). Furthermore, care has always been taken to allow for supporting some emerging or sideways programs.
3. The budget of the team is defined at the beginning of the year; it is organized along the various supported projects of the team. The expenses are defined by the budget and not by the day to day cash flow (trésorerie), thanks to the overall lab support.
4. Members of the team have always been actively participating in the various managing levels of the LAOG, the OSUG, the University and the CNRS, ensuring an intense cooperation and exchange of relevant information within the team and the lab.

C. Kahane was director of the UJF DLST from 2002 to 2007. The team had 4 thesis, 2 post-docs and 3 years of visiting scientists. Also, L. Wiesenfeld was visiting faculty at UCLA (Dept of Physics & Astronomy) for the first term in 2007. P. Hily-Blant was invited to participate in the Kavli Institute, Santa-Barbara.

Our involvements in the main local, national and international committees: Pierre Valiron was head of the 'CSA', Commission INSU des Spécialistes en Astronomie; Bertrand Lefloch is member of the PCMI committee; L. Wiesenfeld is an elected administrator of the University. T. Montmerle, B. Lefloch, and C. Cecarelli are TAC members of Chandra, XMM, IRAM and GBT. C Ceccarelli is in the ERC panel in the European Union. T.Montmerle is the upcoming Secretary General of the IAU.

Several conferences (national, international) were organized by team members: National PCMI in

2006 (LW, AF), International conference on Quantum Stabillity (2005 and 2008), L. Wiesenfeld; T Montmerle organized a Les Houches School and several scientific conferences.

12.1.3. Team publications

ACL - (107 publications over the 2005-2008 period).

5, 9, 16, 28, 29, 30, 31, 33, 38, 39, 47, 48, 49, 55, 59, 60, 62, 63, 68, 71, 82, 87, 104, 108, 109, 111, 116, 120, 122, 128, 134, 144, 157, 159, 163, 164, 166, 168, 170, 177, 190, 191, 195, 198, 202, 203, 204, 206, 207, 208, 213, 214, 215, 217, 227, 230, 237, 240, 267, 287, 290, 292, 293, 297, 299, 300, 313, 314, 319, 328, 336, 350, 353, 355, 360, 361, 374, 376, 378, 399, 401, 403, 404, 405, 407, 415, 418, 431, 433, 434, 435, 436, 437, 441, 443, 447, 452, 475, 477, 481, 486, 499, 500, 504, 534, 536, 541.

12.2. FOST

12.2.1. General Presentation

Staff as of 01/09/2009

DR CNRS	F. Ménard, J. Bouvier, A.-M. Lagrange
CNAP Astronomers	H. Beust, A. Chelli, C. Perrier, G. Duvert, T. Forveille
UJF staff	J.-L. Monin (PR), E. Moraux (MCF)
CR CNRS	A. Chalabaev, J.-L. Beuzit, G. Chauvin, C. Dougados, F. Malbet
Ast.-adjoints CNAP	N. Meunier, X. Delfosse, D. Mouillet, G. Duchêne, J.-C. Augereau, J.-P. Berger
Post-docs	A. Eggenberger, D. Ehrenreich, C. Martin-Zaïdi, E. Tatulli, X. Bonfils, C. Alves de Oliveira
PhD students	V. Agra-Amboage, J. Olofsson, A. Burgess, M. Bonnefoy, S. Renard, M. Desort
Former Post-docs 2005-2008	W.J. de Wit, D.J. James, T.R. Kendall, H. Ozawa, S. Alencar, O. Absil, S. Lacour, C. Zanni
Former PhD students 2005-2008	R. Reche, N. Bessolaz, G. Montagnier, P. Delorme, M. Benisty, O. Hernandez, C. Pinte, X. Bonfils, S. Guieu, F. Galland, F. Millour, C. Gil

Scientific themes

FOST (*FOrmation Stellaire, objets SubStellaires, et Systèmes planéTaires)* is a team studying the formation and the characterization of stellar and planetary systems. Inside this main theme, the spectrum of FOST's activities is broad and can be classified into three main complementary parts:

- A « Young stars and disks » part, which includes the study of the properties of stars (magnetic activity, physics of mass loss), of circumstellar disks and of disk-star interaction processes.
- An « Exoplanets and extrasolar systems » part, which includes research and characterization of exoplanets (around M dwarfs and A-F type stars) and the study of their physical properties in relationship with high angular resolution observations to directly image them.
- An « IMF and low mass objects » part, which includes the study of the IMF in stellar formation regions and clusters, and the search for ultra-cool and low mass field dwarfs.

The specificity of FOST is to hold together a wide spectrum of competences in a coherent research field. Instrument designers, observers, modelers and theoreticians work together around common projects. FOST interacts with the other LAOG teams: with GRIL around the conception of instruments, with SHERPAS on the physics of disk-star interaction, the stellar magnetic activity and the physics of jets, with ASTROMOL on grain-gas coupling and chemistry in protoplanetary disks.

In recent years, the « exoplanets » activity in FOST became significantly more important. Similarly, the modeling activity also grew. We present here scientific results obtained with new instruments like AMBER, NACO and WIRCAM. We contributed to design these instruments in collaboration with GRIL, and we were also involved into. HARPS and SOPHIE. The thematic evolution and the use of these instruments for astrophysical purpose were part of our 2005 research plans. As shown below, most of the objectives have been fulfilled.

Visibility

FOST assumes a world leading position in all its research activities. We published 267 refereed publications between 2005 and 2008 with a grand total of 3800 citations, and several tens of invited lectures in international conferences. Since 2005, we have had 14 post-docs (6 are present today), 9 foreign visitors for stays longer than 1 month. We have been involved in the organization (SOC, LOC) of 28 national and international conferences or schools. We have been granted 2 senior ANR grants (P.I. Lagrange, Ménard) plus one in collaboration with LATT (P.I. Donati). 3 team members are P.I.s of work Packages in European (RTN) networks. 6 members took part in national recruiting committees (CNRS, CNAP, CNU), and 7 were (or are still) members of national funding committees (PNPS: president Ménard, PNP, CSAA, OPV, ANR, ASOV, ALMA, HRS). T. Forveille is associated editor of *Astronomy & Astrophysics*. A.-M. Lagrange was associated director of INSU between 2002 and 2006. 6 of us are members of scientific and time allocation committees of various observatories (OHP, ESO, CFH, ETSRC), and 9 were invited at least once since 2005 as experts in international evaluating and grant allocation committees. Finally, 2 of us were awarded national prizes (Lagrange, Malbet).

Organization and management

FOST includes 21 permanent staff members, 6 post-docs and 6 PhD students. Between 2005 and 2008, 3 new permanent positions were allocated to FOST (+1 in 2009: C.Pinte): G. Chauvin (CNRS), N. Meunier (CNAP, transfer), D. Mouillet (CNAP, transfer). One member (N. Grosso) moved to Strasbourg. 7 staff members are also members of the GRIL team. Since 2005, 2 FOST members (Beust, Ménard) were promoted to senior positions (+1 in 2009: Beuzit).

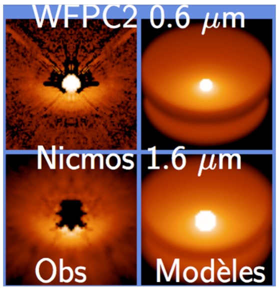
H. Beust is Head of FOST since 2007 (F. Ménard until 2007). Important decisions are usually made during regular FOST meetings. Team seminars are organized every week. Lectures are usually given by visitors or team members. Special attention is given to our PhD students. To ensure a valuable follow-up of their work, and to get them used to presenting it, one of them is asked to present the status of his/her PhD in 15 minutes before the beginning of each seminar. Each of them makes a presentation 2-3 times a year. This “PhD of the day” practice was initiated in 2007. Between 2005 and 2008, 12 FOST students defended their PhD. 2 FOST members also defended HDR since 2005 (Malbet, Delfosse). The current policy of FOST management is to encourage all junior members to defend HDR as soon as possible, typically once they have supervised their first PhD thesis. Extraordinary several days’ meetings (“FOSTiades”) are organized regularly to discuss the present status of the team’s research and to define our prospective.

The typical global annual work budget of FOST is 100 k€. This mainly includes scientific collaboration, laptop equipment, and payment for trainees. FOST is partly funded by LAOG (15%), but more than

60% of our budget comes from national thematic funding programs (PNP, PNPS). The rest is allocated by ANR and various European grants (networks, EGIDE, ECONET)

12.2.2. Scientific Results

Activity in the field “Young stars and circumstellar disks”



Observation and model of the IM Lupi disk [ACL-448]

In this part we describe our activity in the field of young stellar and planetary systems. This concerns the study of the physical properties of the stars as well as the physics of protoplanetary disks. The study of multiplicity and jets in protostars, magnetic interactions and disks are complementary approaches to the same global theme. Their coherent study is important to better understand the subsequent evolutions. A key parameter in the evolution of young stars is the magnetic field, which controls the accretion of matter, the physics of jets as well as the evolution of the rotation and of the angular momentum. This may have an impact on the formation and the migration of planets in the disks. Disks at various ages are the cornerstone of planet formation and their early evolution. Our study of disks aims at better understanding this relationship.

Early stages of stellar evolution, disk-star interactions and magnetic activity

(Dougados, Agra-Amboage, Bouvier, Duchêne, Zanni, Bouvier, Moraux, Alves de Oliveira, Forveille, Delfosse, Bessolaz)

The determination of the degree of multiplicity of proto-stars and low mass objects (and comparing to main sequence) can be used to constrain the process of fragmentation of dense cores in the gravitational collapse. With VLT/NACO, we have measured this rate in a sample of imbedded protostellar sources [ACL-288]. We infer a much higher multiplicity rate than in the field. We concluded that the fragmentation of dense cores almost always leads to the formation of multiple systems that evolve dynamically in less than 1 Myr. This evolution can be triggered by the own instability of the system of by disruptive encounters. We showed that this result holds for dense star forming regions like Orion as well as for distributed ones like Taurus. This work is the follow-up of the previous work that was made possible thanks to the infrared wide field spectrometer of NACO, an instrument built in LAOG. This is an example of results driven by the synergy between instrument designers and astronomers.

All protostars launch collimated bipolar jets which origin, probably magnetic, is not well understood yet. The jets themselves are studied at FOST observationally and theoretically, in the framework of the European network (RTN – FP6*) Jetset*, with C. Dougados as leader of one of the work packages. The theoretical study is made in collaboration with SHERPAS. The goal is to understand the physics of their launching. Concerning observations, high angular resolution studies of collimation and acceleration regions of the jets (<500 AU) have been conducted, together with the development of diagnostic tools for the physical conditions of the gas. Observational predictions have been derived from steady-state MHD models. These developments were scheduled in our preceding research plan. The observations (OASIS/CHFT and SINFONI/VLT) allowed to investigate the influence of the central star (a microjet was detected around RY Tau; Agra-Amboage et al., in press) as well as the molecular origin of the jets (Agra-Amboage et al., in prep). We detected signatures of rotation in jets, and investigated their kinematic connection with disks. In one case (RW Aur) we derived a constraint about a possible recent stellar flyby undergone by the system [ACL-212]. The detection of rotation in jets allowed a comparison with the theoretical prediction of MHD models [ACL-194], which led to constraints on the kinematic parameters of these jets.

Magnetic interactions also control the inner interaction zone (<0.1 AU) between stars and disks. The non-axisymmetric structure (warp) triggers periodic spectrophotometric variations. When these variations are monitored accurately, it is possible in some cases like AA Tau to reconstruct the shape of the interaction zone [ACL-382]. The light curves of several T Tauri stars have been monitored during more than 20 years to look for magnetic cycles (program ROTOR) [ACL-508]. The recorded variations could reveal in some stars a large scale magnetic reconfiguration within only a few years (see Bouvier et al. 2007, chapter in "*Protostars & Planets V*"). An IAU Symposium was organized in Grenoble in May 2007 on the disk-star interaction theme.

FOST takes part in the MONITOR project (P.I. Aigrain, Exeter), which aims at detecting planetary transits towards stars in young associations and measuring the distribution of rotation periods of young stars as a function of their age in clusters. This work is also part of our effort to characterize exoplanet host stars (see below). The result [ACL-446] reveals a correlation between the magnetic history of the stars and the presence of planets. The planet host stars tend to be systematically slow rotators, while those with no planets would be fast rotators. Another ongoing large program at CFHT (680 hours), supported by the MAPP ANR grant (P.I. Donati, Toulouse) aims at mapping the magnetic surface of young stars. The magnetic structure of some T Tauri stars has already been obtained, revealing strong fields with a complex geometry [ACL-305, 487]. This large program also includes magnetic field measurements of very low mass main sequence stars, with two outcomes: 1) The fully convective stars can harbor a magnetic field despite a very low differential rotation, 2) The magnetic field geometry depends highly on the mass, with a turnover threshold at ~0.4-0.5 $M_{\odot}$ [ACL-261, 450, 449]. This answers a question mentioned in our 2005 research plan.

Study of protoplanetary disks, radiative transfer

(Ménard, Tatulli, Duchêne, Monin, Martin-Zaïdi, Augereau, Olofsson, Berger, Chelli, Duvert , Malbet, Pinte, Benisty, de Wit)

Our study of protoplanetary disks, from both observational and theoretical approaches, aims at investigating the relationship between their geometrical properties, the stellar and environment parameters, and the consequences on planet formation. This work is supported by the ANR grant *Dusty Disks* (P.I. Ménard). The ongoing observational campaigns are conducted with HST for imaging (GEODE), NAOS and AMBER at VLTI, and very soon HERSCHEL. Concerning models, significant advances have been made in recent years. The main tool is the MCFOST code, initially developed by F. Ménard and now by C. Pinte. This Monte-Carlo radiative transfer code produces synthetic disk SEDs and images. The fit of synthetic images to observational data allows to constrain the physical parameters of a disk. This code is our key tool for data analysis. Its application field extends now to disks around T Tauri stars, brown dwarfs and one Herbig Ae. The most complete example of multi-frequency (optical to millimetric) and multi-scale analysis is IM Lupi which constitutes the reference study [ACL-448]. A Bayesian analysis of MCFOST simulation outputs allowed constraining parameters like the inclination of the disk, its flaring rate, its internal truncation radius, etc… These studies are also completed by molecular hydrogen observations in the mid-infrared, like for instance in the case of the Herbig Ae star HD97048 [ACL-559]. Observing the gas in young disks is an important issue, as it represents most of their mass. The disks are also investigated in binary systems (polarimetry) [ACL-

268] (Monin et al. 2007, PPV). The observations tend to show that mixed systems, i.e. with only one circumstellar disk around one of the two components, are rare.

The mineralogy of protoplanetary disks is also investigated. Within the Spitzer consortium c2d, J.-C. Augereau analyzed the nature of silicate grains in more than 100 IR spectra of T Tauri stars [ACL-243], and conducted with J. Olofsson a mineralogical study of crystalline silicates in planet formation regions around young stars. It reveals the quasi systematic presence of micron-sized grains in the upper atmosphere of disks, suggesting the presence of diffusion and fragmentation processed. It also identified a kind of “crystallinity paradox”, since the hot regions are less crystalline than the cold ones. This is an indication for grain transport and/or amorphization processes.

Using long baseline interferometry (~100m) in the near infrared, we also investigated the physics of the innermost regions of protoplanetary disks (a few AUs). In recent years, we observed young systems with interferometers we contributed to design in close relationship with GRIL, such as IONIC3/IOTA and AMBER/VLTI. This way we performed the first closure-phase measurement towards a young object ever (AB Aur) [ACL-200], and the first spectro-interferometric observation of a young star (MWC297) [ACL-385]. An important result is the direct detection of hydrogen Brγ emission towards these stars [ACL-389, 492, 444]. We have shown that the size of the inner regions can range from 0.1-0.3 AU to the size of the stellar magnetosphere. Hydrogen emission turns out not to be a direct accretion tracer. It rather behaves as a wind tracer, scaling as the accretion rate within the disk. We also have results concerning the structure and the morphology of disks [ACL-70, 179, 445].

Exozodis and debris disks

(Beust , Augereau, Absil, Rèche)

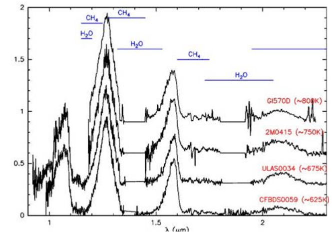
Debris disks are older than protoplanetary disks. They presumably harbor already formed planetary systems. The viewed dust particles result from collisional cascades in a population of planetesimals. These disks systematically show up asymmetries that are interpreted as signatures of planetary perturbations. The members of FOST develop and use symplectic dynamical N-body codes to simulate these deformations. Conversely, a parametric fit of the data allows to constrain with these simulations the orbital characteristics of suspected planets. This way we had predicted for years the presence of a giant planet in the β Pictoris system by analysis of the spectral signatures of evaporating comets (FEBs) [ACL-378]. The planet candidate imaged recently [ACL-601] fits the prediction and could account for the phenomenon. The disk of HD 141569 was also analyzed this way, which led in particular to constrain the presence of planets [ACL-604]. In many cases (such as Vega), the asymmetric structures are attributed to resonant confinement of planetesimals, much like the solar Kuiper Belt. R. Rèche [ACL-509] showed that this picture was realistic under specific conditions.

The same model could explain the presence of important amounts of hot dust particles close to Main Sequence stars. This dust, also called exo-zodiacal dust (or exozodis), was initially detected by optical inteferometry around Vega in 2006 [ACL-211]. It has been now identified around 6 other stars [ACL-461]. The dust production rates implied are so important that internal reservoirs are required to refill these exozodiacal disks, suggesting cometary bombardment episodes possibly triggered by the migration of planets. J.-C. Augereau leads an ISSI (Bern, Switzerland) international working group on this issue. The interferometric observations are made mainly with CHARA, but also at Keck Nuller and the VLTI. FOST is deeply involved in DUNES (140h, plus meetings organization), a key program of HERSCHEL dedicated to debris disks. HSO will be indeed well suited to study exozodis. In our 2005 prospective, our implication into the disk investigation programs of HERSCHEL was mentioned as an important objective. This has been fulfilled now.

Activity in the field of « IMF and low mass objects »

Search for very low mass brown dwarfs

(Delfosse, Forveille, Bouvier, Moraux, Burgess , Delorme)



NIR spectrum of ultra-cool brown dwarfs [ACL-480]

Very low mass brown dwarfs offer the opportunity to probe the link between stellar and planetary objects. Since 2007, we initiated a large program at WIRCAM/CFHT to look for very low mass objects (<13 M_J). This research is made within the European network (RTN – FP7*) Constellation*. J. Bouvier is P.I. of the Work Package 3. Recent results have revealed the existence of 3 isolated planetary mass objects (IPMO) in IC348 (Burgess et al., A&A, submitted, press release at JENAM 2009). Here again, this was enabled thanks to our collaboration with GRIL in the WIRCAM project.

We also look for ultra-cool brown dwarfs. In recent years, this research focused particularly on the detection with the CFBDS of objects in a so far unexplored domain of parameters. The spectral characterization is made with the VLT and GEMINI; we are studying how the atmospheres behave between 1200 and 600 K (response to the temperature and the chemical composition). The CFBDS, initiated by X. Delfosse and T. Forveille, was the first survey able to detect a sufficiently homogeneous sample of T dwarfs, thus constraining the IMF towards very low masses. It led to the first detection of brown dwarfs with temperatures between 600 and 700 K (detection of NH_3 in the IR spectrum; T, possibly Y-dwarfs) [ACL-488, 480]. They are a kind of missing link between planets and substellar objects. Characterizing them is therefore of prime importance. Investigating the T-Y dwarf domain was in our 2005 research plan. This objective has been fulfilled.

Initial mass function (IMF) of low mass objects

(Bouvier , Moraux, Burgess , Alves de Oliveira, Forveille Delfosse, Dougados, Monin, Ménard, Guieu, Delorme)

Another way to constrain low mass objects formation models is to study their IMF, in young associations and in star forming regions. This is a crucial issue, as the formation mechanism of brown dwarfs is not well understood yet. It is well stated now that the IMFs in young clusters, stellar formation regions and galactic field are roughly identical, from $\sim$0.03 $M_{\odot}$ up to $\sim$10 $M_{\odot}$. It is well modeled using log-normal deviate with a peak around 0.3 $M_{\odot}$ (cf. analysis of Blanco 1 [ACL-333]; IC 4665, [ACL-239], and MonR2 [ACL-139]). A refined analysis of the populations in clusters reveals segregation effects. The brown dwarf deficit seems deeper in older clusters (see study of the Hyades [ACL-502]). The analysis of the population in Taurus (MEGACAM/CFHT survey data) showed that the substellar objects preferentially gather in outer regions [ACL-254, 375]. All this speaks in favor of dynamical segregation effects. The study of the Hyades clearly indicates a mass function affected by the dynamics. We have being carrying out for years now (a work conducted by E. Moraux; see [ACL-131]) N-body dynamical investigations of clusters to constrain this process. The results confirmed the preliminary hypothesis. Hence the dynamical study of the η Chamaeleontis association [ACL-310] where no object lighter than 0.1 $M_{\odot}$ is present showed that the present mass function can be reproduced starting from a standard IMF (log-normal) and a compact initial configuration. This is an example of our ability to develop theoretical studies as a natural extension of our observations.

Activity in the field « Exoplanets »

We work at detecting and characterizing extrasolar planets. Investigating more deeply this research field was in our 2005 plan as a natural extension of our work on stellar formation issues. This way we probe the response of the planetary formation processes to initial conditions in protoplanetary disks which are different for different types of stars. This concerns indirect detection (radial velocity) as well as direct imaging with NACO/ VLT around nearby stars in young associations.

Detection by radial velocity

(Delfosse, Forveille, Lagrange, Bonfils, Desort, Perrier, Beuzit , Ehrenreich, Galland)

Radial velocity observations are the main technique used today to detect exoplanets. The planets we want to detect at FOST (planets around M dwarfs and A-F type stars) are more difficult to detect than around G-K type stars. FOST is currently responsible for the detection of 60% of the known planets around M dwarfs and of 100% around early type (A-F) stars so far. Searching and characterizing such planets, our objective is twofold. First, we must obtain a relevant statistics of planets orbiting stars with various masses (and compare with solar-type stars). We have detected an important population of Neptunes, Super-Earths around M dwarfs. Conversely, we detect few hot Jupiters. In the case of M dwarfs, our second objective is telluric and/or habitable planets. We are members of the HARPS and SOPHIE consortiums. This enabled us (coll. with Geneva Observatory) to discover the Gliese 581 planetary system [ACL-4, 340, Mayor et al, A&A, submitted], which harbors the lightest exoplanets known so far and the first telluric planets located in the habitable zone of a star.

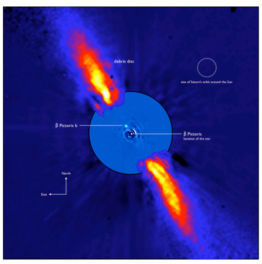
The planets orbiting A-F type stars are more difficult to detect, due in particular to the fast rotation of their host stars. We designed a new technique [ACL-19] to measure the radial velocity and separate the stellar from genuine exoplanet signatures, regardless of the stellar rotation. A detailed simulation of the stellar activity also showed the impact of stellar spots on the detection of exoplanets. This work may have some interaction with the study of stellar magnetism. A systematic search was initiated with HARPS [ACL-586]. This way we identified a few systems, like the system of HD 60532 which hosts two planets in probable 3:1 mean-motion resonance [ACL-430]. We often face multiple planetary systems. Fitting many planetary orbits in these systems is sometimes complex (Desort et al., submitted). This work was supported up until 2008 by an ANR grant (P.I. Lagrange).

We also look for planets in binary systems. A. Eggenberger conducts observing programs at VLT/NACO and PUEO/CHFT. It confirmed that there are less giant planets in binaries with separations <100 AU [ACL-311]. Statistically they seem to have shorter orbital periods than around single stars.

Direct detection: Imaging

(Chauvin, Lagrange, Mouillet, Beuzit, Ehrenreich, Bonnefoy)

Discovery of a giant planet candidate in the β Pictoris disk [ACL-601]



G. Chauvin and A.-M. Lagrange are P.I.s of two major surveys on NACO/VLT to directly image planets and low mass companions. This study led to the discovery of the first planetary mass companions ever imaged: 2M1207 [ACL-136], and AB Pic b [ACL-58], and recently a probable giant planet of ~8 M_J around β Pictoris [ACL-601]. Interestingly, in all three cases, these objects result from different formation mechanisms: The 2M1207 system is probably a brown dwarf binary which formed as such.

The companion of AB Pic (12 to 15 M_J) could have been formed by disk fragmentation. The planet of β Pic (8 AU projected distance) was predicted by various models. It likely formed by core accretion. The statistical analysis of the survey of 80 young stars allowed putting the first constraints on the frequency of giant planets in wide orbits (Chauvin et al. 2009, AA, accepted). These results are a clear example of the synergy between instrument designers, observers and modelers. These objects have been detected thanks to our knowledge of NACO which was built in LAOG in collaboration with GRIL.

Characterization of host stars

(Lagrange, Eggenberger, Bonfils, Beuzit, Meunier, Forveille, Desort, Delfosse, Chauvin)

The characterization of exoplanet host stars is important to investigate the impact of the stellar environment on the presence of planets. FOST is involved in this research in several ways, in relationship with the radial velocity surveys. A better knowledge of the host stars becomes essential for further radial velocity investigations. As we are now discovering telluric exoplanets, all stellar effects that can mimic radial velocity signatures need to be modeled. This topic is studied by A.-M Lagrange (bisectors method for A-F type stars), and by N. Meunier and X. Delfosse (indexes comparison in H_α and in calcium lines). The correlation between the indexes is highly variable among stars, and a detailed analysis of the solar case showed that it can vary during the cycle. We proposed an interpretation of this variability based on filaments (Meunier & Delfosse 2009, A&A, accepted).

We also aim at characterizing the chemical composition of the exoplanet host stars. It is well known that they are statistically more metallic. We investigate this issue for M dwarfs using a new technique: we select pairs of stars composed of one M dwarf and one solar-type star. We determine the metallicity of the latter and assume that the former shares the same. From a sample of 20 stars we proposed a first metallicity calibration for M dwarfs [ACL-15].

Characterization of the planets

(Chauvin, Bonnefoy, Delfosse, Beust, Ehrenreich, Lagrange,Desort)

The physical and chemical characterization of exoplanets was mentioned in our 2005 research plan as a long term objective. To fulfill this objective we recruited D. Ehrenreich as post-doc (ANR support, P.I. Lagrange). When an exoplanet transits in front of their host star, a radius measurement is possible. This provides basic information on its internal structure. Further investigation is now possible. The variation of the radius as a function of the wavelength enables to reconstruct a transmission spectrum. The observations in the visible and in the UV are made with HST, and the broadband spectrophotometry in the infrared with Spitzer. This provides information on the composition (Sodium, CO) of the atmosphere of transiting exoplanets [ACL-314, 477].

We also work at characterizing the planetary mass companions imaged by NACO. This work, associated with the use of 3D spectroscopy with VLT/SINFONI, recently allowed refining the properties of the planetary mass companion AB Pic b and of the young dynamical calibrator TWA22AB (Bonnefoy et al., A&A, 2009; coll. F. Allard, CRAL-Lyon). The program is also based on a collaboration with C. Ducourant (Bordeaux) to refine the parallaxes of these objects [ACL-529, 456].

The last aspect is the dynamical characterization of the planetary systems discovered. When an orbital solution involving several planets is found, we carry out a dynamical study of the system. This work is conducted by H. Beust using symplectic codes. For instance, we have studied the Gliese 581 system [ACL-524]. The system is stable, but only if it is viewed not too far from edge-on. This way we put upper limits to the masses of the planets, and proved that the smaller planets of Gliese 581 are telluric (Mayor et al. 2009, submitted). The same study was also conducted on HD 60532 [ACL-430] and Gliese 86, where we have combined constraints from radial velocities and astrometry [ACL-141].

12.2.3. Team publications

2005: 58 publications ACL- [1,2,3,4,8,10,11,12,13,15,19,20,25,26,27,29,30,31,32,34,36, 37,38,45,46,54,57,58,59,61,62,65,66,69,70,71,76,77,81,84,94,95,96,97,102, 103,121,123,125,126,127,128,130,131,132,133,136,138]

2006: 58 publications ACL [139,141,142,143,151,153,155,156,158,161,162,165,169,173, 178,179,180,184,185,189,192,193,194,196,200,201,209,211,212,214,216,219,221,224,229,233, 234,235,239,240,243,249,250,251,254,256,257,259,260,261,266,268,269,272, 273,277,278,280]

2007:88 publications ACL-[281,283,284,285,286,288,289,291,294,296,297,298,304,305, 306,307,308,309,310,311,312,314,315,316,318,320,321,322,324,327,330,333,334,335,339,340, 341,343,344,346,349,354,355,356,357,358,359,362,363,364,366,367,368,370,371,372,373,375,377,378,379,380,381,382,385,386,387,388,389,390,391,392,394,395,396,397,400,406,410,411,412,416,420,421,422,423,424,425]

2008: 63 publications ACL-[430,433,434,435,439,444,445,446,448,449,450,451,452,453,454,455,456,460,461,465,466,468,470, 471,472,473,474,475,476,477,478,480,483,487,488,489,490,492,493,494,497,501,502,505,506,507,508,509,512,513,514,515,518,521,522,523,524,525,529,532,533,537,541]

12.3. SHERPAS

12.3.1. General Presentation

The SHERPAS team is mainly working on theory and modeling of astrophysical plasmas, accretion and ejection processes and high energy phenomena. It interacts strongly with the theme of stellar formation through the problem of accretion discs and jets around YSOs, and also with instruments developed by GRIL, especially around optical interferometry. But it deals also with the most extreme objects of the Universe : pulsars, black holes, and gamma-ray bursts. The team is directed by a leader, who was formerly G. Pelletier, its funder. It is currently G. Henri. Both are Professors at University Joseph Fourier. Although it was orginally only composed of University lecturers, its composition is now well balanced between teachers (2 professors and 1 « maître de conférences » and CNRS researchers (4 « chargés de recherche »)), mainly thanks to the arrival of external CNRS (G. Dubus, after the venue of D. Fraix-Burnet and P.Y Longaretti), indicating a good attractivity. In the period 2005-2009, five PhD students have worked in the team, with four defences (C. Cabanac, G. Lesur, N. Bessolaz (codir. FOST) , T. Boutelier), B. Cerutti being in his second year. Two students (R. DeGuiran and A. Lamberts) should start their PhD in September 2009.

The lecturers and professors have always been strongly involved in teaching and the administration of the University : G. Pelletier, G. Henri and now J. Ferreira (present) have all been director of the Master speciality « Astrophysique et Milieux Dilués » ; G . Henri is vice-director of the Physics Department (UFR de physique) for the teaching and responsible of the whole Master of Physics. He is also member of the UJF Board of Directors (Conseil d'Administration). On the national side, the team has been or is represented in CNRS section (G. Pelletier, now G. Dubus), CNU (G. Henri), various national programs (PCHE , PU : G. Dubus), etc…

SHERPAS is mainly involved in theoretical studies and numerical modelling, but it participates also in observations, either from individuals submitting proposals to ground-based (optical and radiotelescopes) and satellites (XMM, observatories) observatories, or by being associated with large international collaborations (HESS, Fermi). It has organized the fall collaboration HESS meeting, in September 2007.

Its funding comes partly from the general budget of the laboratory , but also from various grants : National GDR PCHE (2 or 3 applications/yr), Programme Particule Univers (formerly Astroparticules) through the HESS and CTA fundings (for the collaboration meetings and observation shifts), and also received a special grant form CNES concerning the participation in the SIMBOL-X collaboration. Besides the team has benefitted from an ANR « Jeune Chercheur » (PI : Pierre-Olivier Petrucci) on the numerical simulation of MHD structures, and G. Dubus has won an ERC grant in 2008, which recognizes the excellence of his research, and is very helpful to attract good young researchers in the group. Although it does not benefit from large instrumental projects funding, its numerous activities have insured a correct budget, but it must do choices for meetings and publications to define the most efficient and cheapest way of communicating its results. The team is coauthor of 233 rank A publications in the years 2005-2009, including 65 papers from the HESS collaboration.

To manage its scientific activities, the group organizes a weekly meeting where various administration and scientific problems are discussed (including the discussion around application of students and monitoring PhD and post-doc works). In addition, it organizes each year a meeting outside the laboratory (the « SHERPIADES »), to define the prospective for the coming year. The growing numbers of researchers and scientific themes has led us to organize several (this year, two) such internal workshops during the year, and we plan to maintain and generalize this way of working.

12.3.2. Scientific Results

We present here the main results obtained by the team in the different topics covered by its activity. The project for the current quadrennial plan was to amplify the activity in numerical simulations and the involvement in high energy observations and interpretation of data. As will be shown, these activities have been indeed very productive in the last years.

Fundamental hydrodynamical processes

after nearly four decades of research activity on the origin of anomalous transport in astrophysical disks, which is a central problem of all accretion processes studied in the laboratory, the turbulence, the leading candidate mechanism for accretion, remains poorly understood. In particular, neither is turbulent transport characterization well-established numerically nor is the dynamics underlying turbulent transport well-understood physically and analytically. On the first front, our group has produced a number of breakthroughs in the recent years. Various processes have been invoked to produce turbulence in disks, the most important ones over the years being subcritical hydrodynamic instabilities (i.e., finite amplitude instabilities in linearly stable disks) and baroclinic instabilities on the hydrodynamic side, and the magneto-rotational instability (MRI) on the MHD side. We have shown that subcritical turbulence is too inefficient in keplerian flows [ACL-6] and that the MRI-driven transport is highly dependent on microphysical dissipation processes, thereby invalidating the results on the efficiency of transport obtained in the last fifteen years[ACL-347]. We have also quantified the turbulent diffusion of magnetic field, and in this way given substance to the claim that accretion disks can launch jets which in turn can be responsible for most of the transport. We have finally shown that the (to date) only tentative approach to a dynamical understanding of transport through secondary instabilities of special linear and nonlinear solutions to the problem is not a viable option.

MHD global simulations

Most of the theoretical work on the accretion –ejection processes study the physics of magnetized accretion disc, where a large scale magnetic field is anchored in the disc and ensures both a magnetic torque leading to accretion and the extraction and collimation of a powerful jet. This activity has been developped in the recent years mainly through international collaboration (N. Bessolaz thesis, co-directed by SHERPAS (J. Ferreira) and FOST (J. Bouvier)) and the arrival of post-docs : Gareth Murphy thanks to the ANR contract (PI : P. O. Petrucci) and Claudio Zanni, also in collaboration with FOST, funded by the JETSET network. It is complementary to the fundamental studies above in the sense that it addresses the global structure of real astrophysical objects through heavy 2- to - 3D calculations , in order to check the results of semi analytical models and to better constrain the relevant values of physical parameters.

The physical conditions to drive cold jets from a Keplerian disc have been obtained through a general analysis, allowing to understand the outcome of self-similar solutions, namely the requirement of a near equipartition field. By investigating the angular momentum conservation of the disc and the wind, we were able to show that current X-wind models (Shu et al., 1994, The Astrophysical Journal, vol. 429, no. 2, pt. 1, p. 781) are inconsistent: the available power is too low for the assumed mass loss. This puts a severe constraint, comparable to that on stellar winds, and sheds doubts on such a model to explain jets around young stars. The longest (950 inner orbital periods) 2.5D simulation of accretion disc threaded by a large scale field has been performed. Many important results were found: (i) despite a very small magnetization, a super-fast-magnetosonic jet is launched from a finite radial extent of the disc; (ii) such a jet is made possible if the surface layers of the disc are heated and if a (dimensionless) magnetization parameter is not too small: it must reach at least unity at the disc surface, thanks to the decrease in density; (iii) it is proven that the inward transport of the magnetic field is due to the jet launching, while the outer parts are being depleted of the field (submitted to ApJ).

We have also addressed the problem of star-disc interaction ([ACL-533], [ACL-420]), which is another strong transversal theme developped with FOST. For the first time, we obtained a theoretical justification for the analytical estimate of the truncation radius of the disc. This was confirmed by the best numerical simulations to date, incorporating correct boundary conditions and a better description of the disc physics. The analysis of the torques shows that the disk locking paradigm cannot work unless a very efficient (ad-hoc) stellar wind is present. Concerning the stellar formation and the jets from YSOs, we have shown that, by reviewing all possible mechanisms of jet production around young stars and confronting them to up-to-date observations, it was possible to argue that there are most probably a multi-component wind: an inner stellar wind, a star-disc interaction (braking down the star) and a disk wind carrying most of the observed mass ([ACL-194]). The radial structure of Jet Emitting Disk (JED) has been obtained in the optically thick regime ([ACL-527]), providing the distributions that can be used for planet formation theories. It is also important to notice that a transition standard accretion disk (SAD) and a JED would allow to halt the migration of protoplanetary cores ([ACL-220]). The large ejection efficiency (xi of order 0.1) required in jets from young stars can be obtained if the disk surface layers are heated. Garcia et al show that UV and X irradiation by the star can provide such a heating in the inner disc regions.

High and very high energy gamma-ray astrophysics: LAOG, HESS, Fermi and CTA

The past years have seen remarkable progress in our knowledge of the gamma-ray sky at high (HE, > 100 MeV) and very high (VHE, > 100 GeV) energies. These photons are emitted when very high energy particles, typically electrons but also protons or possibly more exotic primaries (dark matter), interact with their environment: matter, radiation or magnetic fields. Gamma-rays provide clues on the acceleration processes through which their parent particles gained energy and on their importance relative to other dissipation mechanisms. Gamma-ray observations have revealed that a wide variety of astrophysical objects radiate energy principally via such non-thermal channels.

Currently four SHERPAS are HESS members (GP, GH, POP, GD) and three are affiliated Fermi scientists (GP, GH, GD). Several of the group's PhD students (L. Saugé, then T.Boutelier) and postdocs (A. Szostek, A. Hill) have been or are junior members of the collaborations. The SHERPAS group brings to HESS/Fermi its expertise in high-energy radiative processes, jet physics and particle acceleration. The group is regularly solicited to referee HESS papers internally before submission. The team has also a commitment to HESS of 25 days of observations per year and has performed several weeks of flare advocate duties for Fermi. Although primarily a theoretical group, SHERPAS are now involved in the analysis of HESS (A. Szostek) and Fermi (A. Hill) observations. There is a very active collaboration with the IN2P3 group at Laboratoire Leprince-Ringuet (with G. Dubus moving from LLR to LAOG in September 2006).

The group's scientific focus has been Active Galactic Nuclei (AGN) and compact binaries. G. Pelletier proposed some twenty years ago a new paradigm to explain relativistic ejections and high energy emission in AGN : the two-flow model; it assumes the presence of a dense, relativistic electron – positron beam travelling in the throat of a powerful MHD jet produced by the accretion disc. This model has been shown to explain successfully a number of observed features (gamma-ray spectra, relativistic jet Lorentz factors) and has been recently used to explain most recent VHE data. AGN studies have concerned mostly the blazar PKS 2155-304, one of the brightest VHE sources in the southern hemisphere. It is the first blazar to have been continuously detected in a 'low' VHE state. It was also detected in July 2007 in a flaring state, during which large amplitude variations were observed down to sub-minute timescales. SHERPAS have been involved in multi-wavelength campaigns ([ACL-18] , [ACL-550]) and in the timing analysis revealing power law variability behaviour during the VHE flare ([ACL-325]). We have successfully explained the light curve by the pair creation process, which is probably the most detailed time-dependant model available in the world ([ACL-459]) SHERPAS were also involved in modelling of the newly detected blazars H 2356-309 [ACL-181] and PKS 0548-322 (F. Aharonian et al. (H.E.S.S. collaboration), 2009, A&A, submitted). T. Boutelier is corresponding author of the PKS 0548-322 paper.

High energy gamma-ray emission from binaries is another recent strong point of the group. G. Dubus was corresponding author of the HESS paper in Science reporting the discovery of intense VHE emission from a neutron star or black hole in a 4 day orbit around a massive star, one of the four works cited in the European Community's 2006 Descartes prize awarded to the HESS collaboration ([ACL-135]). This attracted attention as this binary was presumed to be a microquasar, X-ray binaries in which accretion powers a relativistic jet emitting non-thermal radiation. Theoretical calculations showed pair production in the system should cause a VHE modulation, which was confirmed by HESS observations ([ACL-149]). A. Szostek is corresponding author of a coming HESS search for VHE emission from the microquasar GRS 1915+105 [(to be submitted) and A. Hill is corresponding author of the Fermi paper reporting the discovery of the first orbital modulation discovered in high-energy gamma-rays (submitted to ApJL).

X-ray astronomy : AGN and microquasars

In sharp contrast with the radio-loud AGs observed at very high energy, the radio quiet AGNs (Seyfert and QSOs) are not visible yet above the MeV range. Their spectral energy distributions are characterized by different components: a UV bump peaking in the UV range, and an X-ray powerlaw component extending up to at least 100 keV. As for all AGN, the basic paradigm supposes the existence of an accreting supermassive black hole. The gravitational energy released by the accreting gas is generally thought to be dissipated partly in the UV as thermal heating in an optically thick "cold" plasma and partly in X-rays in active blobs of optically thin "hot" plasma. Irradiation of the dense gas by hard X–rays produces also an X–ray reflection spectrum (dominated by a iron Kα emission line and a reflection bump peaking between 20-40 keV). The origin of the soft excess is still not clearly understood in this paradigm.

The activity in X-ray astronomy is mainly driven by P.O. Petrucci, who is the PI of observations on high energy satellites like XMM-Newton, INTEGRAL or Suzaku. Among other results, he has been closely involved in a detailed analysis of the high energy features (especially the iron line, soft excess and warm absorber) in the X-ray spectrum of the Seyfert 1 galaxy Mkn 841 ([ACL-276], [ACL-331]) which became famous thanks to its rapidly variable iron line complex. Another Seyfert galaxy, Mkn 509, known to harbor blueshifted absorption lines in its X-ray spectrum, was also studied with attention to probe its outflow dynamics ([ACL-561]). A very long (1.2 Ms) INTEGRAL program (PI: P.O. Petrucci) of 10 pointings, simultaneously with XMM, has been recently accepted on this source for the next AO (2009-2010) and should permit to bring new constrains in this respect. The high energy group of LAOG is also part of a international collaboration (FERO: Finding Extreme Relativistic Objects) to study in depth the presence of broad iron lines in a large sample of type 1 AGN.

Following the same kind of model succesfully applied to AGNs, we have also proposed a new framework to explain the spectral states and state transitions in X-ray binaries ([ACL-238]). It assumes the existence of a large scale magnetic field of bipolar topology in the innermost disc regions. For large enough magnetic/total disc pressure ratio (the magnetization), the production of a self-consistent and powerful MHD jet is possible and the disc transits from a standard accretion disc to a Jet Emitting Disc (JED). The transition between the standard disc and the JED appears also as an important parameters in the global structure. This framework is rich enough to explain all known spectral components as well as the hysteresis behavior observed in most XRB ([ACL-516]). The JED possesses also very interesting properties with the existence of different branches of thermal solutions, the hot one being of particular interest since it can play the role of the X-ray corona needed to explain the high energy emission in these objects (Petrucci et al. 2009 submitted). The production of broad band SED appears also very promising (Foellmi et al. in preparation 2009).

Gamma-ray bursts and relativistic shock acceleration

The environments of compact objects with their relativistic outflows are the sources of very high energy particles, through the conversion of a sizable fraction of the kinetic energy at strong shocks. The generation of suprathermal electrons is directly observed through the emission spectra in radio, X-rays and gamma rays bands; whereas the acceleration of high energy protons is supposed to nourrish the extragalactic component of the cosmic ray spectrum observed in ground observatories like Pierre Auger Observatory which is currently recording the Ultra High Energy events (beyond 10^{18}

eV). Relativistic shocks are considered as the most likely sites of acceleration of the highest energy particles, provided that the particles can wander back and forth the shock front, undergoing thus many “Fermi cycles” thanks to the scattering off magnetic irregularities. After promising results obtained at the turn of the century (Gallant, Y., et al., 1999, A&AS, 138, 549 ; Lemoine, M., & Pelletier, G., 2003, ApJL, 589, L73) where the formation of a power law energy spectrum with an universal index has been predicted with numerical and semi analytical works, some difficulties arised. In 2006, Polish group and M. Lemoine and G.Pelletier found out independently of one another, and with different methods, that an oblique magnetic mean field inhibits the Fermi cycles. Moreover we have shown that a turbulent cascade with a large scale correlation length had the same effect. Thus in order to make Fermi process operative at relativistic shocks we have shown that it is necessary that an intense turbulence be generated at short scale. Observations of Gamma Ray Bursts indicate that, like in Supernova Remnants, suprathermal electrons are accelerated to very high energies, that they display a power law energy distribution and that magnetic fluctuations are considerably amplified. We found the relevant instabilities that are able to produce the expected magnetic turbulence ([ACL-544], [ACL-588])

The full and definite answer to this issue will be obtained with large PIC (Particles in Cells) simulations, for which a collaboration is designed, especially with the great expert in France, B. Lambège, and hopefully 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 (Derishev, E., et al.; 1999, ApJ, 521, 640) is promising in this prospect.

Astrocladistics

Initiated in 2001 by Didier Fraix-Burnet, astrocladistics is a methodology of multivariate analysis based on the evolving state of the descriptors of the objects of study. Cladistics is widely developed in evolutionary biology, with the involvement of mathematics, statistics and bioinformatics. Its application to astrophysics is totally new, and has proven to be quite suitable for studying the diversity of galaxies.

Since 2005, astrocladistics has undergone significant developments, which are reflected in particular by the first 3 articles published in 2006, and three other in 2009. It is important to note the very multidisciplinary field of research, since the articles are published in journals as diverse as Journal of Classification (mathematics), Evolutionary Biology (invited conference), Evolutionary Bioinformatics, in addition to A&A and MNRAS. The collaborations have widened: E. Douzery, P. Choler (evolutionary biology), E. Davoust, F. Lamareille, C. Charbonnel (astrophysics), A. & T. Chattopadhyay (astrostatistics), M. Thuillard (statistics/networks). The development of this new field of research, interdisciplinary, original and risky, is now successful. The laboratory, especially the Sherpas team, has always supported and encouraged this project. This support, combined with that of biologists and statisticians colleagues, has been invaluable, although the astrophysics community, including the national one, was more cautious, apart from financial support in 2007 of the National Galaxies (PNG).

12.3.3. Team publications

216 refereed publications over the 2005-2008 period : ACL-

-6, -7, 17, 18, 35, 40, 41, 42, 44, 72, 73, 74, 75, 79, 83, 85, 86, 89, 90, 92, 98, 99, 101, 106, 110, 112, 113, 114, 118, 119, 124, 135, 145, 146, 147, 148, 149, 150, 152, 160, 171, 172, 174, 181, 182, 183, 186, 188, 190, 197, 222, 223, 231, 232, 236, 238, 241, 242, 244, 245, 246, 252, 253, 255, 262, 263, 264, 270, 271, 274, 275, 276, 279, 295, 302, 317, 323, 325, 331, 338, 345, 346, 347, 348, 351, 352, 365, 369, 383, 384, 393, 398, 402, 408, 409, 413, 420, 429, 432, 438, 440, 457, 458, 459, 462, 463, 467, 469, 479, 482, 484, 491, 495, 496, 498, 510, 511, 516, 517, 519, 520, 527, 528, 530, 531, 539, 540, 543, 544.

12.4. GRIL

12.5. General Presentation

12.5.1. Main fields of activity and visibility

Since the 90's, LAOG has been deeply involved in high angular resolution techniques (adaptive optics and interferometry), a powerful mean for studying the conditions of stellar and planetary formation.

The main activities of GRIL are focused on high angular resolution and high dynamic imaging, spectroscopy and detection techniques, with three kinds of involvements:

- Study and manufacturing of instrumentation for large telescopes (ESO, CFHT)
- Associated or upstream R&T developments
- Study of new concepts

The GRIL team endeavors to maintain a good balance between these three complementary activities since this balance is an effective way of being involved in each generation of instruments and of being leader on innovative developments. As an illustration the detector R&T development led within the JRA2/FP6 framework (PI: P. Feautrier) is currently implemented for the wavefront sensor of the instrument SPHERE. This new ultra-fast developed camera can take 1500 finely exposed images per second even when observing extremely faint objects (ESO 22/09 and INSU/CNRS 17-06-2009 press releases). Another illustration lies on the fact that two engineers of GRIL defended HDR (E. le Coarer, P. Feautrier) and obtained an inter-ministry funding (Fond Unique Interministériel - FUI) each for developing micro-spectrograph and detector prototypes (see R&T sections). Two engineers have received the CNRS Cristal award (E. le Coarer, P. Kern) for their innovative works.

Indeed, since its creation, LAOG has been involved in precursors (in adaptive optics as well as in interferometry), then in the first-generation instruments (e.g. NAOS or AMBER) and is now leading the development of second-generation instruments (like SPHERE or VSI), as well as in conceptual studies for future instrumentations (for the E-ELT for instance).

Between 2005 and mid-2009, GRIL has published 142 papers in refereed journals. We have been involved in the organization (SOC, LOC) of several national and international conferences on high angular resolution techniques.

12.5.2. Organization

GRIL (Groupe de Réalisation et de Recherche du LAOG) has been established in 2004 to bring together researchers in instrumentation and technical staff with the aim at favoring fruitful exchanges between all experts in instrumentation. The team is composed of 9 researchers (most of them being also members of FOST), 26 engineers and technicians (included 3 staff on short-term contracts) and 10 students. A technical director (currently P. Puget) leads the technical staff and checks that LAOG fulfills his commitments on the various contracts. A researcher (currently K. Perraut) is in charge of the scientific steering of the team (organization of lectures by visitors or team members, thesis follow-up, coordination of R&T programs, management of the research budget, …). A group made of 6 members of GRIL (3 researchers, 2 engineers and the technical director) has been set-up to weekly study new research or project proposals, solve manpower conflicts between

projects, etc. This group is also the driving belt between the instrumentation team and the laboratory executive.
GRIL activities are partly funded by LAOG (for science steering and R&T support). Most of the budget comes from ASHRA, PNPS, UJF, CSAA, CNES supports, ESO contracts and ANR (2 senior grants during this quadrennial ; a junior one and a senior one in collaboration With ONERA in 2009).

12.5.3. Teaching and training achievements

GRIL includes 6 members of CNAP, 1 assistant professor and several engineers and technicians involved in teaching activities in physics, astrophysics, optics, electronics, etc., at UJF and IUT "Mesures Physiques", as well as in various engineering schools on the campus. In addition, several members have organized schools and workshops about high angular resolution techniques (VLTI school - Goutelas in June 2006; Adaptive optics school - Marseille in May 2009; Interferometric imaging - Goutelas in May 2009) and detection (Astrophysics detector workshop – Nice in November 2008).

12.5.4. Responsibilities in the community

Several members of GRIL took responsibilities in OSUG committees (chairman of the Research committee (J.P. Berger), participation in Observation committee) and in UJF organization (E. le Coarer – Vice-President ITA Human Ressources).
One of them (J.L. Beuzit) is the official representative of INSU for the Instrumentation. Several members participate in national committees (CSAA, CNES ad-hoc group, ASHRA, ASOV, PNPS, …). LAOG is also a very active contributor to the efforts made for the structuring of the French high angular resolution community, especially in bringing together both academic and industrial partners (PopSud, GIS Phase, Journées Recherche-Industrie de l'Optique Adaptative, …).
GRIL is also strongly involved in the European Community FP6 programs and will continue for the FP7, in particular in the fields of adaptive optics, low-noise high-speed detectors, interferometry and photonics.

12.6. Scientific Results

12.6.1. Study and manufacturing of instruments

The 2006-2010 period has been marked by the manufacturing of SPHERE, as well as by the beginning of the studies of the second-generation instruments for the VLTI.
LAOG took the responsibility of leading the project SPHERE (PI: J.-L. Beuzit, PS: D. Mouillet and PM: P. Puget), a second-generation VLT instrument dedicated to detect and characterize new giant extra-solar planets. The Final Design Review successfully passed in December 2008. Procurement is now underway. Integration and tests will begin mid-2009. Delivery to ESO is planned for early 2011 and the first light in June 2011. In 2009, about half of the technical staff has been involved in the manufacturing of various components and sub-systems for SPHERE (optics, mechanics, instrument control, detectors, etc).
LAOG joined the GRAVITY consortium (led by the Max-Planck Institute for Extraterrestrial Physics in Garching) in 2008. Gravity is a second-generation VLTI instrument dedicated to astrometry and imaging of the Galactic Center in the K-band. The LAOG contribution follows directly from our know-how in integrated-optics characterization (see R&T section) and our success in demonstrating their suitable performance for astronomical applications [ACL-69, 155, 179, 180, 200, 377, 473]. We are focused on the study, characterization and delivery of beam combiners in integrated optics at the

heart of both the scientific instrument and the fringe tracker. The Preliminary Design Review is planned in autumn 2009 and the delivery to ESO is due in 2012.

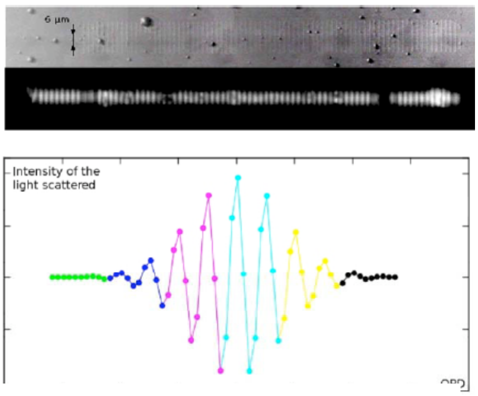
LAOG took the responsability of leading the project VSI (PI: F. Malbet and PM: P. Kern), a second-generation VLTI instrument dedicated to imaging at the milli-arcsecond scale in the near-infrared range. The concept is based on a 4 to 6-telescope combiner in integrated optics, providing a large number of visibility and phase measurements for image reconstruction of compact objects. The Phase A study of VSI has been achieved in 2008. A contract with ESO for the manufacturing of the instrument should be signed by 2010.

LAOG hosts the software team and headquarters of the Jean-Marie Mariotti Expertise Center (JMMC) in Interferometry (Director: A. Chelli, Science Director: G. Duvert), providing user support, software, service and education to the scientific community using ESO/VLTI (see Annex). Five astronomers of GRIL are involved in JMMC activities.

Finally, to be able to routinely obtain images at high angular resolution with the VLTI, we proposed to ESO in 2008 a near-infrared imager named PIONIER (PI: J.P. Berger, PM: G. Zins), to be developed and operated as a visitor instrument. The goal of this project is to install by mid-2010 an integrated optics 4-telescope beam combiner in front of a near-infrared camera to combine 4 telescopes of the VLTI.

12.6.2. R&T developments

R&T activities, whose impact on the team has been strengthened during the period 2006-2010, are linked to photon detection and oriented towards a better spectral resolution and a better sensitivity. For the following two projects, LAOG has been the initiator and is now the leader, being especially in charge of high level specifications for astronomical applications, integration, validation and tests of the prototypes.



MEB image of the first Swifts (up), recorded signal (middle) and corresponding reconstructed spectrum (down) [ACL-332].

a/ Swifts is a concept of miniature spectrometer operating over a large spectrum of wavelengths, as mentioned in the last report (based on patents registered in 2004-2005). The first prototypes have been manufactured during the last two years (Figure) and a large consortium centered on research laboratories and companies has been set-up to obtain an Inter-Ministry Funding (FUI). This financial support aims at developing a prototype for the spectral range [400 nm; 1000 nm]. All these activities are of strong interest for spectroscopy at high spectral resolution (goals: 40 000 at 1000 nm and 100 000 at 400 nm) for ground and space-based instrumentation (interest of CNES, thesis supported by EADS).

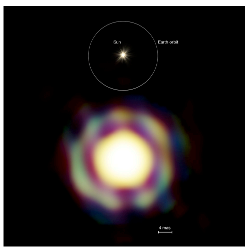
b/ RAPID : on the ground of LAOG expertise in the field of detectors for astronomy (detector delivery for various instruments, coordination of activities about detection in the FP6 [ACT-515] and FP7) and of unique technological skills available in Grenoble, another FUI has been obtained for developing matrices of infrared avalanche photodiodes targeted to both astronomical (like fringe tracking and wave front sensing) and medical applications. LAOG is particularly involved in the lab validation for fringe tracking applications, which is a challenging issue to be addressed in the context of interferometric imaging, to access faint objects.

- More than 70 magnetic mirrors have been manufactured and are currently in use worldwide. LAOG has also studied and developed a new concept for controlling the magnetic mirrors within the INOVEO (ANR) project. This new control electronics has passed the certification for use in medical instrumentation. LAOG has also coordinated the development of new mini deformable mirrors in preparation for the next generation of instruments on the VLT and E-ELT, within FP6 activities.
- Developments needed to progress towards <u>interferometric imaging</u> at the sub-milliarcsecond scale have been pursued along various axes:
    - <u>Beam combiners based on integrated optics</u> :
        - Design of components for combining more than 3 telescopes: conception and manufacturing of beam combiners for 4 telescopes in the H and K bands in close collaboration with CEA/LETI (Gravity, VSI) and design of combiners for 6 telescopes (VSI). Deep characterizations of multi-telescope combiners have been performed on prototypes [ACL-554].
        - Study, manufacturing and characterization of components operating at wavelengths above 2 µm, via several collaborations and the recruitment of a specialist in material properties in 2007. Within this context, several types of waveguides have been characterized in terms of throughput, spectroscopy, and (nulling) interferometry with dedicated workbenches available at LAOG. This research is also driven by the strong interest of FOST in the field of detection and characterization of exoplanets and exozodis. A summary of the suitable technologies for manufacturing single-mode waveguides in various spectral bands ([3 µm; 5 µm], [8 µm; 12 µm], and up to 15 or 20 µm) has been produced. We have chosen to put the effort on lithium niobate components for the L and M bands (a junior ANR support has been obtained in 2009 for 4 years).

      A strong connection exists between these developments in integrated optics and the Swifts project. In the long-term, the integration of the functions of combination, spectral dispersion and detection can be a powerful solution for (spectro-)imaging at high angular resolution (see the project document).

      Finally, LAOG holds a recognized position in this area of photonics for astronomy as revealed by the various collaboration proposals (received from the Gravity consortium but also from foreign colleagues for equipping interferometric arrays with integrated optics combiners) and by the invitations to write review papers ([ACL-581, ACL-595]) and give seminars on such topics (at St Andrews and Sydney universities for instance).

    - <u>Image reconstruction</u>: Collaborations on image reconstruction have been initiated with the CRAL (Observatoire de Lyon) in 2007 and a co-supervised thesis has started. LAOG has been associated to the first image of a complex object with the VLTI (Figure) and has organized a workshop dedicated to interferometric imaging in May 2009.



First image of T Lep with the VLTI ([ACL-572])

12.6.3. Involvement in system analysis

The period 2006-2010 has been marked by the decision to strengthen the involvement of the GRIL team in conceptual studies and system analysis. The hiring in 2008 of a research engineer with a background in system studies for adaptive optics has allowed to really kick-off these activities.

a/ The commissioning of AMBER has significantly benefited from the expertise in interferometry available at LAOG. In particular this has led to identify vibration issues within the VLTI in early 2006. LAOG has set up a task force (ATF) to pin down the last issues preventing AMBER for achieving its nominal performance. Meanwhile, AMBER has led to more than 30 referee papers, half of them submitted by astronomers from the consortium.

b/ LAOG is strongly involved in the Phase A study of EPICS for the E-ELT (System Engineer: C. Vérinaud, Co-PI: J.-L. Beuzit), in collaboration with ESO and several other European institutes. EPICS is an instrument designed to directly detect and characte-rize extrasolar planets. The concept is based on extreme adaptive optics and smart post-focal wavefront sensing techniques. The results of this study (concept analysis and compared performance) will be presented at ESO in December 2009. This study is in close relation to R&T activities (deformable micro-mirrors, low-noise detectors).

c/ LAOG is leading the POPS consortium (PI: P. Kern) in charge of a one-year feasibility study for a VLTI second-generation fringe tracker. Concepts based on integrated optics beam combiners are studied and their performance is compared for the cophasing of 4 and 6 telescopes. An end-to-end model is developed with the University of Liège to test the whole loop. A collaboration with the Department of Control Systems of the GIPSA-Lab (Grenoble) has been also initiated for studying the control loop. A PhD thesis focusing on these aspects is under discussion with ESO.

d/ LAOG has also been involved in the characterization and the science demonstration of the VEGA instrument (co-I: K. Perraut) in collaboration with OCA (PI: D. Mourard). This spectro-(polari)meter has been installed on the CHARA array (Mount Wilson) in September 2007 and its scientific validation has occurred in 2008.

For several instruments (AMBER, VSI, etc.) and R&T developments (Swifts), LAOG has been responsible for a part or for the whole data processing package, either within the GRIL team or in the framework of the JMMC (see Annex).

12.7. Publications

2005 : 29 publications in refereed journals [ACL 4, 8, 19, 22, 32, 36, 37, 43, 45, 46, 53, 58, 64, 65, 67, 69, 70, 78, 88, 91, 94, 95, 100, 121, 129, 130, 132, 133, 136]

2006 : 33 publications in refereed journals [ACL 143, 153, 155, 162, 167, 173, 175, 176, 179, 180, 187, 200, 201, 205, 209, 210, 211, 218, 219, 224, 225, 226, 228, 229, 233, 235, 247, 248, 249, 259, 265, 272, 277]

2007 : 34 publications in refereed journals [ACL 281, 284, 285, 294, 298, 301, 303, 306, 307, 308, 309, 311, 326, 332, 337, 349, 366, 377, 381, 385, 386, 387, 388, 389, 390, 391, 392, 395, 396, 397, 414, 419, 426, 427]

2008 : 26 publications in refereed journals [ACL 442, 444, 445, 454, 460, 461, 464, 466, 468, 470, 472, 473, 483, 489, 492, 493, 497, 507, 509, 512, 521, 526, 532, 535, 538, 542]

13. The Astrochemistry PPF

Plan Pluri-Formation (PPF) « Astrochemistry and Star Formation with the HERSCHEL Space Observatory HSO » was organized between three laboratories L3AB in Bordeaux and CESR in Toulouse, and LAOG (Astromol) in Grenoble, under the coordination of the latter. The goal of the PPF was to prepare the scientific exploitation of HSO, the realization of which France is strongly involved in. Launched in May 2009, HSO will allow us to understand the processes involved in the molecular complexity observed in our solar system and to bring definite answers to the dynamical processes which govern the gravitational collapse of interstellar matter to form stars, which are closely linked with the chemical evolution of protostellar gas.

The main motivation of the three PPF teams was to prepare the tools of spectroscopic and astrophysical analysis permitting an optimum exploitation of the data to be collected by HSO, especially in the guaranteed time Key Project HS3F. This project, led under the responsibility of members of the PPF (220hrs; PI : C. Ceccarelli), is dedicated to unbiased spectral surveys of Star Forming Regions, in collaboration with other groups in Europe and in the US (Arcetri, Italy; CAB, Spain; Bonn, Germany; Caltech, USA). An important aspect is the complementarity of the expertise developed by the 3 partners of PPF, in terms of astrophysical observations, chemical and astrophysical modeling, molecular spectroscopy, and molecular physics. The adopted approach was fourfold : 1) collection of data with the best suited ground-based telescopes, 2) development of astrophysical models, 3) developments of numerical codes and theory on molecular physics, to calculate the properties of molecular species observed or intervening in 4) the interpretation of the observations.

The actions undertaken in the frame of PPF aim at exploring the molecular complexity of the low-mass sources of the HS3F spectral survey (one prestellar core, solar-type protostar IRAS16293, one protostellar shock region), from ground-based observations in the millimeter and submillimeter domains. These complementary data obtained have been used to model the sample sources and make observational diagnostics for the instruments PACS and HIFI onboard HSO. Particular emphasis was put on the analysis of a spectral survey of the protostar IRAS16293, carried out at the IRAM 30m telescope and the JCMT in the range 72- 372 GHz. For many species of interest like e.g. H_2CO and CH_3OH, the many transitions detected in the mm and submm bands (up to several tens) were used to model the molecular abundance profile in the envelope, from the outer cold protostellar regions, where molecules can deplet on dust grain mantles, to the inner central regions, where mantles sublimate and a high temperature chemistry develops.

Missions of collaboration between members and with external collaborators (Spain, USA) on the tasks defined in the working plan were organized on a regular basis; a meeting between the three teams was held every semester to check the evolution of the program, and to undertake new actions if necessary. A workshop dedicated to analysis tools for spectral surveys, like CASSIS, with special attention to PhD students training was organized in Toulouse in May 2009, jointly with the team in charge of the guaranteed time Key Project HEXOS on high-mass star forming regions. Three PhD thesis (3 in Grenoble, 1 in Toulouse) are / have been conducted within PPF. In addition to the many articles published by the PPF team in journals with refereeing comittee, oral communications in conferences (see REFERENCE?), we have developed a tool of analysis and modeling of molecular lines (GRAPES) to study the flux distributions obtained from spectral surveys. GRAPES represents a first step towards an authentic simulation tool able to combine astrophysical models and molecular databases in order to produce synthetic spectra that can be compared with observations.

The strong collaboration forged in the PPF will continue beyond 2011, to exploit the second part of the HSO mission and prepare for the arrival of ALMA. The PPF has allowed to strengthen two lines of investigation in the field of planet and star formation, especially important in the perspective of ALMA and NOEMA : the chemistry of protoplanetary disks and the physics of protostellar jets and shocks.

14. Jean Marie Mariotti Center (JMMC)

14.1. Aims of the JMMC

The "Centre Jean-Marie Mariotti (JMMC[4])" is a network of 6 laboratories, provided with a software realization center located at LAOG. It was created by INSU in 2000 in order to optimize the use of optical interferometers, particularly the VLTI. Its missions:

- develop, produce, document and maintain the software, services and databases, needed to ease the use of interferometric instruments by the French community, and boost their scientific return.
- stimulate academic training.

The Laboratories components of the JMMC: CRAL, FIZEAU, IAS, LAOG, LESIA, ONERA. The JMMC community includes all high angular resolution aspects: ASHRA, PNPS, PNP, PNCG.

14.2. Software Realization Center (LAOG)

The headquarters of JMMC and its Software Center are located at LAOG. The Software Center supports the daily management of the website and the web services, together with the financial, human and organizational management. With 2 engineers working full-time, it is the provider of half of the JMMC projects and most than often the kingpin of their achievement.

5 CNAP of LAOG perform their observing service at JMMC. Beside leading the JMMC, they participate in the management of the JMMC projects, group facilitation, training, user assistance for each project and, naturally, R&D for the community benefit.

14.3. National/International implication

Since 2003 and until the end of 2010, the JMMC is the GdR # 2596 of the CNRS. Agencies involved: CNRS, ESA, ESO, FP6 (Europe).

- From 2004 to 2008, the JMMC was a prime contractor for the Joint Research Activity # 4 (JRA4, interferometry) in the framework of the OPTICON FP6 project.
- In 2006, JMMC (CRAL/FIZEAU/IAS/ONERA) won in collaboration with Alcatel Space the ESA call for tender for the development of a data processing software for the DARWIN instrument (2006-2008).
- In 2007, the JMMC established a cooperation agreement with ESO for the provision of software for the VLTI. An ESO/JMMC group is currently working on an evolution of the SearchCal software developed by the JMMC that will be interoperable by ESO.

4 Jean-Marie Mariotti Centre

14.4. Products supplied by JMMC

The JMMC produces services and softwares available to all French research laboratories in astrophysics as well as to the community of European astronomers, either by downloading or by setting up web services. The JMMC also provides user assistance, tutorials, servers documentation, competitive development tools, configuration management and collaborative work spaces for the community.

Software provided to the community (see http://jmmc.fr)

- ASPRO: software preparation of interferometric observations.
- ASPRO-VLTI: specialized in the preparation of observations with AMBER and MIDI instruments of the VLTI (software updated each semester).
- SEARCHCAL: software "virtual observatory" to search for calibration stars.
- DRS AMBER_V3.0: optimized software for data processing of the AMBER instrument.
- LITPro: model fitting software for interferometric reduced data.
- WISARD: image reconstruction software.
- OIVAL: OI-FITS files validator.
- SOFTWARE XMLGui, Client-Server GUI for web applications.
- JMCS and MCS: library services for applications in interferometry, signal processing and interferometric data visualization.

Organization of distributed services

Production and maintenance of software in the JMMC collaborative framework is based on a gallery of services settled at the software realization center :

- Application server ASPRO and SearchCal,
- Server for downloading applications,
- CVS and backup server (LAOG coll.)
- Documentation server
- JMMC (http://jmmc.fr) and JRA4 (http://eii-jra4.ujf-grenoble.fr) web servers, (col. OSUG UMS)
- Mailing list server (coll. CRIP / UJF),
- Collaborative working platforms for teams of JMMC partners laboratories and European teams
  JRA4 Opticon project.

Catalogs

- catalog of calibrators for the PRIMA instrument (in preparation)
- database of "bad calibrator" interferometers (coll. ESO)
- database of stellar diameters

14.5. Organization of Schools

During the quadrennial period, the JMMC organized or participated in the organization of several schools in interferometry:

- Workshop "Data reduction with AMBER: amdlib", Grenoble, November 2005, 3 days, 20 p.
- European School "Observations and Data Reduction with the VLTI" Goutelas (France), June 2006, 2 weeks 60 p.
- Workshop "Data reduction with AMBER, Grenoble, February 2007, 3 days, 30 p.

- European School VLTI Porto (Portugal), June 2007, 2 weeks, 60 p.
- VLTI European School of Torun (Poland), August 2007, 2 weeks, 40p.
- Ecole de formation continue des personnels CNRS, Porquerolles, Sept. 2007, 1 week, 20p.
- European School of VLTI Keszthely (Hungary), June 2008, 2 weeks, 60 p.
- School WII09, Chateau de Goutelas, Boën, France, May 2009, 1 week, 45 p.

14.6. Desired developments and prospects in the years ahead

The JMMC will loose his status as a GdR at the end of 2010. There is a need for a substitute structure enabling the permanency of the current services, as well as a support for future developments and R&D.

14.6.1. Scientific Prospective

JMMC prospective is due for 2010 and is underway at the Scientific Council level. Today's main axes are:

- Signal processing for 2nd generation VLTI instruments (VLTI2)
- New service for calibrators, aimed at the data reduction level.
- Image reconstruction for VLTI2
- Polychromatism in image reconstruction
- Support for Phase Referencing
- Pupil masking
- Differential Astrometry
- Support for non-VLTI interferometers in use by the community (ex: CHARA/VEGA)
- Interoperability of Optical Interferometry Observations: databases, Virtual Observatory techniques…
- Post-VLTI interferometers (2020 horizon)

14.6.2. Permanency of the JMMC

The JMMC whishes to be maintained as a permanent structure established by INSU and provided with equivalent financial support. The structure should continue the activities and responsibilities of the LAOG headquarters and software centre, and provide support for the networks of inter-laboratories cooperation that together make the JMMC.

15. Publications and productions

15.1. Honors and Awards

2005 : F. Malbet Nomination prix de l'Ingénieur année 2004 (instrument AMBER)

2005 : P. Kern Cristal du CNRS

2005 : A.-M. Lagrange : Prix académie des sciences "Cino Del Duca"

2006 : C. Ceccarelli : Prix Irène Joliot-Curie 2006 ``Femme Scientifique de l'année'', du Ministère délègue à l'enseignement supérieur et à la recherche.

2007 : F.-X. Désert : nomination de la Section 17 du CNRS pour la médaille d'argent du CNRS

Membres de l'IUF : G. Henri de 1998 à 2003, G. Pelletier de 1996 à 2006, JL Monin de 1997 à 2002.

2006 : prix européen Descartes attribué à la la collaboration HESS qui comprend 3 membres permanents du LAOG.

2008 : G. Dubus, financement ERC jeune chercheur.

15.2. National & International meetings organisations

2005 "Critical Stability of Few-Body Quantum Systems", 2005 : Wiesenfeld.
2005 PLANETS network meeting, Nov. 2005, Augereau (SOC)
2005 Multiple Stars across the HRD, Jul.05, Garching : Bouvier (SOC)
2005 Protostars and Planets V, Hawaii, Nov.2005 : Bouvier (SOC)
2005, sept : Ecole Aussois, "Interactions dans les systèmes composites : étoiles, disques et planètes" : Bouvier (SOC)
2005 Co-éditeur du colloque ESO « The power of optical/IR Interferometry. Recent scientific results and second generation instrumentation » : A. Chelli
2006 Ecole de Goutelas, juin 2006 (vltischool.obs.ujf-grenoble.fr): Malbet
2006 Congrès National du Programme National PCMI, Grenoble : Wiesenfeld
2006 Ecole JETSET, Villard de Lans, janvier 2006, "Jets from young stars, models & constraints", Dougados, Ferreira
2006 Ecole JETSET d'Elba (Septembre 2006) "High Angular resolution observations", Dougados, Ferreira
"High performance computing in astrophysics": Dougados (SOC)
2006 Cool Stars 14, Pasadena, nov. 2006 : Bouvier (SOC)
2006 Ecole de Cargese "Observing the X- and Gamma-ray sky", summer school : P.O. Petrucci (SOC)
2007 Symposium IAU 234 "Star-Disk Interactions in Young Stars", Grenoble, juillet 2007 : Bouvier, Chalabaev, Malbet (SOC + LOC).
2007 Semaine de l'Astrophysique", SF2A, Grenoble, juin 2007 : Bouvier, Malbet, Petrucci.
2007 Colloque SFP, Grenoble, juillet 2007 : Duchêne (LOC)
2007 JENAM 2007, Arménie : Bouvier (SOC)
2007 Colloque Suivi de Projets ANR "Systemes Planetaires et Climat", Dec.07, Grenoble : Bouvier (Chair)
2007 Meeting de collaboration HESS, Novembre 2007 : LOC : G. Dubus, P.O. Petrucci, G. Henri.
2007 Congrès de la Société Française d'Optique (Juillet 2007) : Kern (SOC)
2008 Perraut - SPIE "Optical and Infrared interferometry"
2008 Kern - Astrophysics detector workshop
2008 Feautrier - Astrophysics detector workshop

15.3. National and international responsabilities

15.3.1. Local Committees 2005-2008 :

Augereau Membre de la commission recherche de l'OSUG
Berger Président de la commission de recherche de l'OSUG
Bouvier Coordinateur Scientifique du Pole SMIng de l'UJF
Cecilia Ceccarelli [2008-] Responsable de la filière Licence L3 « Diffusion des Savoirs ».
Claudine Kahane, direction DLST,2003-2007
Claudine Kahane, membre CNESR 2007-
Delfosse Conseil scientifique UJF 2006-2008
Delfosse Membre de la commission pole Tunes
Ferreira Commissions de spécialistes 34e observatoire de Lyon 2005-2007

Forveille vice-président CSE de physique, UJF (section 28-29-30-34)
Henri Commissions de spécialistes 34e ENSL 2006-2007
Henri Commissions de spécialistes 34e observatoire de Lyon 2006-2007
Henri Membre élu du CNU 34e section 2005-2007
Henri Membre élu au Conseil d'Administration de l'UJF 2005-2007
Monin Directeur Adjoint LAOG 2003-2006
Monin Directeur LAOG 2007- present
Montmerle Directeur LAOG 2003-2006
Pelletier Commissions de spécialistes 34e UJF 2004-2007
Laurent Wiesenfeld Membre (élu) CS, Université Joseph-Fourier 2006-8
Laurent Wiesenfeld Membre (élu) CA, Université Joseph-Fourier 2008-2011
Claudine Kahane Membre (élu) CA Université Joseph-Fourier 2003-6
Claudine Kahane, Membre (élu) CEVU, Université Joseph-Fourier 2006-8

15.3.2. National Committees 2005-2008 :

Berger CS action spécifique HRS 2007- present
Beust CS PNP 2007-2010
Beuzit CNAP 2004-2007
Beuzit CS A&A INSU 2007-present
Beuzit CS Observatoire Marseille Provence 2007-present
Beuzit: Charge de mission aupres du DSA INSU depuis janvier 2009
Beuzit : coordinateur du groupe de travail R&D et moyens instrumentaux pour la prospective INSU.
Bouvier CS INSU 2004-2007
Bouvier CS A&A INSU 2006-
Bouvier Membre nomme CSD6 ``Univers et Geo-environnement'' ANR
Bouvier Coordinateur Scientifique CSD6 Unite Support ANR (USAR)
Bouvier Membre élu conseil SF2A
Bouvier Membre CES Universites Lyon, Montpellier
Castets Direction de l'Observatoire de Bordeaux 2003-2006
Castets Délégué scientifique aupres de l'INSU 2007-
Ceccarelli Rapporteur ANR ; rapporteur programme national CNRS
Chelli Directeur du JMMC (GdR 2596)-> 2010]
Chelli Représentant de la France au CS de l'EII 2008-
Delfosse CS Astrophysique Marseille
Desert CS Programme National de Cosmologie 2005-present
Dougados CNAP 2004-2007
Dubus CS GDR PCHE
Dubus CS Programme Particules et Univers 2007-present
Duvert Dir. Tech. et Sci. du GDR JMMC 2002-present
Duvert CS action spécifique OV 2004-present
Duvert P.I. 'WorkPackage 2' JRA4 OPTICON 2003-2007
Henri Conseil Scientifique INSU 2004-2007
Henri Conseil Scientifique LPSC Grenoble 2004-2006

Henri Conseil Scientifique INSU
Henri Expertise ANR 2006-2007
Henri Commission attribution PEDR 2007
Henri Commission attribution Post Docs CNRS IN2P3 2004-2006
Faure CS centres de calculs nationaux (IDRIS, CINES) 2004-present
Forveille CS A&A INSU 2006-present
Kahane : Membre élu du CNESER 2007-present
Kern : Coordinateur du groupe de travail Valorisation pour la prospective INSU 2009.
Lagrange Dir. Sci. Adjoint INSU 2002-2006
Le Coarer Vice-Président Ressources Humaines (ITAs) UJF 2007-present
Lefloch CS Programme National PCMI 2003-present
Lefloch CNU UJF 2003-present
Lefloch CNU Universite Aix-Marseille 2003-present
Lefloch Conseil SF2A
Malbet CS PNPS 2003-2008
Malbet Membre du groupe ad-hoc ´ Astronomie ª du CNES 2007-present
Malbet CS Centre d'Expertise JMMC 2008-
Menard CNRS Section 17 2005-2008
Menard Comité d'évaluation du GEPI, CRAL, l'USR TBL, LAM 2005-2006
Menard CS PNPS 2006-2010
Menard CS OPV 2006-2010
Menard CS action spécifique ALMA 2008-present
Meunier CNRS Section 17 2005-2008
Meunier CNAP 2007-2010
Monin Rapporteur ANR 2005-present
Monin Expert AERES 2007-2009
Monin Membre CNU 34 2003-2007
Montmerle Expertise ANR
Montmerle CS AERES
Moraux CNU 2008-2011
Pelletier Présidence du conseil scientifique APC 2003-2006
Pelletier CS GDR PCHE
Pelletier Jury IUF Senior 2007
Perraut CS Physique de l'UJF 2004-2008
Puget : Membre de l'observatoire des metiers INSU.
Valiron Président CSA de l'INSU 2007
Valiron Membre du CS du Département MPPU du CNRS
Valiron Expertise ANR
Laurent Wiesenfeld, referee bourses régionales Ile de France

15.3.3. International Committees 2005-2008 :

Augereau Rapporteur pour l'agence STFC (ex-PPARC) (UK)
Beust Rapporteur NSERC (Canada)

Beust Rapporteur pour l'agence STFC (ex-PPARC) (UK)
Beuzit CS Canada-France-Hawaii-Telescope 2000-2005
Beuzit Responsable Scientifique du JRA1 OPTICON (FP6)
Beuzit Rapporteur NSF (USA), NSERC NRC (Canada) et PSTF (Portugal)
Bouvier Responsable noeud LAOG RTN FP5 ``Young Stellar Clusters''
Bouvier Responsable noeud LAOG RTN FP6 ``Constellation''
Bouvier Reponsable programme ECONET-EGIDE France-Ouzbekistan
Ceccarelli : Rapporteur NASA NSF ;
Cecilia Ceccarelli [2009] Membre du panel « External review of the School of Cosmic Physics of the Dublin University ».
Responsabilités d'Enseignement :
Cecilia Ceccarelli referee pour l'attribution des « Early Grants » donnes par l'European Research Council (ERC) de la European Community dans le cadre FP7.
Cecilia Ceccarelli Membre du Comité pour l'attribution des « Advanced Grants » donnes par l'European Research Council (ERC) de la European Community dans le cadre FP7 en 2008 (et jusqu'à 2012), les bourses prestigieuses données aux chercheurs européens affirmés (senjor).
Ceccarelli Expertise Green Bank Telescope, USA ; JWST
Chelli PI du JRA4 d'Opticon
Désert Comité des programmes de l'IRAM 2005-2008
Dougados Membre du comité exécutif du réseau européen JETSET 2005-2009
Dougados Responsable workpackage et des activités de training
Faure Co-responsable noeud LAOG RTN FP5 "Molecular Universe'' 2004-2008
Feautrier Coordinateur JRA2 ´ Détecteurs ª OPTICON (FP6)
Ferreira Expertise pour la NWO (Pays-Bas) 2005
Ferreira Expertise programme de recherche chilien 2006
Ferreira WP manager programme de JETSET
Forveille Membre de l'OPC de l'ESO
Forveille : Editeur "astronomy & Astrophysics"
Henri Expertise Fonds de la Recherche Portugaise
Henri Expertise pour la FCT (Portugal) 2006
Kern CS Action Spécifique HRA 2004
Kern Membre du réseau Key technologies OPTICON (FP6)
Lefloch Comité des programmes de l'IRAM 2007-present
Malbet Rapporteur NFS (USA) et INAF (Italie)
Ménard Rapporteur DFG (Allemagne), CNRC (Canada), PPARC (UK)
Monin Rapporteur DFG (Allemagne) 2005-2008, ApJ, A&A
Montmerle CS IAU Division XI (High-Energy Astrophysics) 2007-present
Montmerle Editorial Board of Astronomische Nachtrichten 2007-present
Montmerle CS Observatoire de Potsdam, RFA 2007
Montmerle CS Centre d'Astrophysique de Porto, Portugal 2006
Montmerle ESO Observations Program Committee 2002-2005
Perrier Représentant français à l'OPC de l'ESO 2003-2004

Perrier CS Euro-Interferometry Initiative 2003-2006
Valiron Responsable noeud LAOG RTN FP5 "Molecular Universe'' 2004-2008