MSFR Research Training Network
Contributions from CEA/Saclay (DSM/DAPNIA/SAp)

We do not apply for the status of a Node in the network but whish to be associated to the Paris node via Saclay's CNRS unit (FRE 2591).

1 Applicants

Service d'Astrophysique staff members co-signing this proposal, in alphabetical order, are:

Pierre-Alain Duc Astronomer (CNRS) - `paduc@cea.fr`
holds a long record of investigations on the effect of gravitational interaction on the star forming properties of galaxies. He also studies the generation of new galaxies through interaction (the so-called galaxy recycling mechanism) through a wide variety of observational means.
Percentage of research time to be invested in project: TBD

David Elbaz Astronomer (CEA) - `delbaz@cea.fr`
focuses on the history of galaxy formation as revealed by infrared surveys. He studies the impact this violent star formation has on the global properties of galaxies, in order to find new star-formation tracers.
Percentage of research time to be invested in project: TBD

Suzanne Madden Astronomer (CEA) - `smadden@cea.fr`
is an expert on the properties of the interstellar medium in starburst galaxies, both metal rich and metal poor. Starburst galaxies are ideal objects in which to study energy tranfer mechanisms from newly-formed massive stars to the ISM, as well as feed-back mechanisms, in a wide variety of physical environments.
Percentage of research time to be invested in project: TBD

Felix Mirabel Astronomer (CEA) - `fmirabel@cea.fr`
his interest in the scope of this network would be the connection between ultraluminous X-ray sources dectected in growing numbers by XMM-Newton and Chandra and massive star formation. He is also an expert in starburst and ultraluminous infrared galaxies.
Percentage of research time to be invested in project: TBD

Frederique Motte Astronomer (CNRS) - `motte@discovery.saclay.cea.fr`
studies massive star formation and the origin of the initial mass function. Her preferred sources are in our Galaxy, thus providing a very important benchmark for validating starburst theories. The Galactic Center is, for instance, our closest example of a starburst region.
Percentage of research time to be invested in project: TBD

Marc Sauvage Astronomer (CEA) - `msauvage@cea.fr`
has a long experience of the infrared properties of galaxies. He is currently working on a category of dwarf galaxies that host super-star clusters embedded in large column densities of dust, i.e. possibly representing the first stages of super-star cluster evolution.
Percentage of research time to be invested in project: 40%

2 Project Objectives

CEA has a long tradition of infrared to millimeter astronomy. The projects we wish to develop in the context of this proposed RTN draw upon this tradition and expertise, and aim at preparing ourselves for the next major infrared European milestone: the Herschel/Planck satellites. During the period covered by the proposed RTN the infrared satellite SIRTF and the airborne telescope SOFIA will come into in operation. Combined with new and currently existing ground based MIR and submm/mm telescopes at our disposition, they will be used to obtain data needed by the projects highlighted here.

As the infrared to mm wavelength range is a domain where much of the processes involving massive star formation can be observed, sometimes with better accuracy than in any other domain, we will also provide our expertise in the preparation and interpretation of these observations to the RTN members.

2.1 heating and cooling processes in the ISM

Massive stars play a crucial part in the injection of energy in the interstellar medium, be it from mass-loss-related winds, from the strong and hard radiation they produce, or the extremely large amount of energy they release at the end of their life through supernova explosions cycling dust and gas in the ISM.

In the mid-infrared we have a number of physical tracers to follow this energy path: continuum emission from grains in or approaching thermal equilibrium follows the distribution of strong radiation sources, atomic fine structure lines provide clues on the density and strength of the radiation fields, almost unhindered by extinction, while solid-state features such as PAH bands allow to sample regions of smaller excitation further away from active star forming regions.

The FIR to mm wavelength range provides us well known atomic fine structure lines as well as valuable molecular tracers. Additionally, most of the energy of star formation is emitted in the FIR to mm. Including the cooling diagnostics from the FIR to mm in conjunction with photodissociation models, will provide a more coherent picture of the full cycle of energy transfer and feedback.

All of these very rich diagnostic tools can be combined in a study of how massive star formation affects the interstellar medium. Dwarf galaxies, where the starburst event is usually well isolated (in both space and time) from other star-forming sites, are very good laboratories to begin with for this study. We propose to combine the infrared data that we can extract from the ISO archive to optical information already available to other members of the RTN (France, Geneva, Germany). Detailed physical information can be extracted from this body of data using existing stellar evolution, photoionization and photodissociation codes, and refined with the Legacy tools proposed by the RTN, but more importantly, it can be used to validate models and introduce new physics in these models such as better relationships between photoelectric dust heating and gas cooling, or the competition between gas and dust for ionizing photons. In this respect, a fruitfull collaboration is expected with Mexico, Meudon and Geneva (inside the RTN). Our experience in modeling gas properties constrained by FIR to mm observations and photodissociation models, in collaboration with Bonn/Bochum collaborators, would enrich this modeling/observational aspect of the RTN.

By understanding what fraction of the energy produced by massive stars gets stored in the ISM, and what fraction is dissipated, we will get important constraints on one fundamental, yet still crudely modeled, aspect of massive star formation: feed-back, i.e. the ability of the interstellar medium to control the star formation process. Additionally, the impact of galactic winds on the enrichment of the intergalactic medium has far reaching consequences (see for instance **??**). Investigating how galactic dust and gas properties, individually and in a coupling sense, effect this energy transfer mechanism, is fundamental in understanding the feedback cycle (collaborations with Bologne and Mexico).

2.2 Dust-enshrouded super-star clusters

Super-star clusters, clusters containing the equivalent of 1000+ young massive stars, are regularly produced by interacting or starburst galaxies, possibly indicating a distinct star formation process compared to normal disk galaxies. The formation conditions for these very massive ($\sim 10^6\,M_\odot$, very compact ($\sim$1-3 pc) assemblies of stars are still quite mysterious. Considering that (1) a significant fraction of star formation in starburst galaxies occurs through super-star clusters, and (2) the initial epoch of star formation in the universe likely lead to numerous starbursts, it becomes crucial to understand the initial conditions that lead to super-star cluster formation, as well as the evolution of these clusters.

This can be tackled by numerical simulations or it can be approached observationaly. Indeed quite recently, super-star clusters embedded in dust, sometimes up to the point of being undetectable in the optical, have been discovered, mostly in dwarf starburst galaxies where the problem of confusion with neighboring diffuse star-forming regions is reduced.

As dust obscuration has a strong impact on the optical light, these objects are best investigated in the infrared/mm. Starting from the ISO database, a sample of objects is now investigated from the ground in the $10\,\mu$m window with colleagues in Geneva (within the proposed RTN) as well as as with colleagues in Québec and Florence (outside of the proposed RTN). This observational study of the earliest stage of super-star cluster formation would largely benefit from (1) an extension at long wavelength such as offered by IRAM and soon, APEX and the possibility to access the mexican Large Millimeter Telescope (through our mexican colleagues inside the RTN), (2) the statistical study of more evolved super-star clusters developped in the UK (Cambridge & Sheffield, inside the RTN), and (3) a coupling with a more theoretical approach such as developed in Strasbourg (inside the RTN).

2.3 Stellar populations in tidal dwarf galaxies

On nearby systems of galaxies, it is recognized that the process of gravitational interaction is very efficient not only in trigerring star formation, but also in expelling large amount of interstellar matter in the intergalactic space, seeding it to possibly form “new galaxies”.

One often wonders if these new galaxies, also known as tidal dwarf galaxies, are really independent of their parent galaxies. We know now that it is quite likely the case as they host their own sites of star formation and they possess the classical phases of interstellar media (both atomic and molecular gas). However, we need to study in higher detail their complete stellar populations in order to understand how much of it originates in the parent system and how much was formed once the gas was expelled from the main system by the interaction. From the accurate knowledge of the stellar population, the star formation history of these galaxies can be derived. This can be compared to the modeled history of inteaction in the parent system, to place contraints on the influence of the environment on star formation.

A strong collaboration on this issue is already in place with Göttingen (inside the proposed RTN), both for the observational and theoretical part of the study.

2.4 Origin of the initial mass function

The IMF, or the probability distribution for stars of a given mass to be formed, is one of the longest standing mysteries in star formation. Where in the interstellar medium or at which moment of the star formation process is that mass function imprinted in the gas that is collapsing to form stars? Is it universal from galaxy to galaxy? These questions can be tackled through large scale mapping of protostellar cores in nearby star-forming clouds. Because of the very nature of the processes involved (large column densities, cold material), these studies can only be performed in the infrared and submillimeter. Our group has a vast experience of these wavelength domain and we note that the mexican node of the network will soon gain access to a very powerful instrument, the Large Millimeter Telescope, which, combined with existing european facilities (IRAM, APEX) allows for deep and high resolution searches for the first stages of star formation.

2.5 Ultraluminous X-ray sources and massive star formation

There is now mounting evidence that the ultraluminous X-ray sources that are detected in external galaxies are related to massive events of star formation. This offers the perspective of obtaining a new tracer of massive star formation, one which, tough likely biased in its own ways, would not suffer either from the extinction that strongly affects optically-based diagnostics or from the energy problem that can plague infrared diagnotics.

We wish to pursue the study of this new category of objects in order to ascertain their nature. This would be forstered by collaboration within the network with the Strasbourg observatory.

3 Research projects for PhD students and postdoctoral fellows

Note pour Daniel: comme tu peux le voir, le projet dont on parle ici n'est pas aussi détaillé, en termes d'étapes, que celui de Starsbourg par exemple. La raison principale c'est qu'on ne sait pas si à l'intérieur du noeud parisien il y aura la "place" pour un projet (thèse ou post-doc) par institut. Il faudra peut-être fusionner les projets pour faire une demande réaliste. On met donc dans cette section la partie d'un projet qu'on pourrait éventuellement lancer.

The network proposes to deliver a set of Legacy tools to the community to analyze and understand the properties of massive star populations. Though a large part of this effort deals with theoretical modeling and integration large sets of model predictions, an observational effort has to be made, in order to verify and validate the Legacy tools predictions.

Saclay proposes to be part of this observational effort by developing real-world test-benches for the tools. In this respect we wish to develop a project within the framework, that is fit for a PhD student or a post-doc. Our proposal also allows for a new dimension to be added to the Legacy tools: the training one. As these tools would be put to use immediately to analyze the stellar properties of our targets, PhD students and post-docs would get a strong and valuable training in stellar astronomy.

Given the project interests developped above, we envision a project (PhD or postdoc) level centered around the impact of massive star formation on the interstellar medium in starburst galaxies. We would start from a sample of dwarf galaxies with known super-star cluster population, both embedded and visible. For this project, Saclay would provide a unique environment with respect to the expertise on dust and insterstellar medium while the inclusion in the proposed network would ensure that the optimum information can be extractd from the stellar and nebular data available on the galaxies.

The problems we wish to tackle all deal with the response of the interstellar medium to a strong and compact burst of star formation. This requires a comprehensive study of the stellar properties of the galaxies, to understand their star formation history. It also implies that the interstellar medium tracers are well understood. This is where we think that Saclay could provide very valuable additions to the network. As mentionned before, the infrared to millimeter domain hosts a large variety of tracers related to massive star formation.

A number of them are already identified, i.e. fine structure lines, ionic or atomic, but our long experience with ISO has revealed a number of new ones, which we propose to exploit here (the PAH bands for the photodissociation regions, silicate grains emission in regions of extreme radiation density). Understanding correctly these tracers will require detailed dust modeling and fully consistent radiation transfer computations, for which we propose our already quite comprehensive experience.

The benefit of such a study for the proposed network and astronomical community at large is manyfold. First it opens an area of star formation diagnostics that will be covered by many future European experiment (e.g. Herschel or Planck) and this represents a valuable career asset for a PhD or Post-Doc. Second it will enhance the quality of the Legacy tools envisioned by the proposed network by allowing them to operate in environments where the column density can be very high. Third, it will forster progress in our understanding of dust properties, its formation and destruction processes, which are dearly needed now that our telescopes reveal that dust was already present in sources at the highest redshift known.

4 CEA/Saclay as a host for network trainees

4.1 Environment

The Service d'Astrophysique is part of the Particle Physics, Nuclear Physics and Astrophysics Department (DAPNIA) of the CEA, itself a research institute of 15000+ people. DAPNIA is involved in a large number of fundamental research projects thus providing to its students and visitor and environment of high scientific standards.

The Service is connected to other french research bodies through two units that it hosts within its walls: the national centre for scientific research (CNRS) that focuses on extragalactic and cosmological studies, and the university with the Paris 7 Gamma-Gravitation group, working, as the name implies, on high-energy astrophysics and newtonian gravitation problems. Through this unit, the Service also participates in the content definition for the master degree level courses in the Paris area. As the Service is also heavily involved in the preparation and development of space experiment, it provides of broad mix of scientific cultures, from the engineer-oriented to the fundamental reseach one.

4.2 Astrophysical Research

Service d'Astrophysique of CEA saclay has a long tradition of participation in forefront space astronomy, from the early rocket days of high energy experiments, to the latest ESA cornerstone missions such as ISO, XMM, or Integral. SAp is currently a major partner in the construction of Herschel, the next IR-submillimeter space telescope from ESA. SAp has two wavelength domains of preference, the infrared and the high energy parts of the electromagnetic spectrum. It specializes in black hole and neutron star physics, star formation studies in our galaxy, galaxy surveys at high redshift, and galaxy clusters.

4.3 Management experience

CEA regularly participates in large networks. SAp was a participant in the ELAIS, AstroPlamas-Physics, and the "formation and evolution of young stellar clusters" network of the 5th Framework Programme. SAp is also involved in large european consortia to build instruments for ESA's space missions. SAp was also recently involved in the organisation of the 3-event Euroconference. Through these we have acquired a substantial experience of handling and managing large collaboration programs. SAp has a strong PhD and post-doc program in a variety of research field. Each year an average number of 10 PhDs and 5-10 post-docs, sponsored either directly by CEA or through space agency or the European Community. CEA also has a dedicated structure aimed at handling EC-sponsored projects according to EC management rules.