Convocatoria 2019 «Proyectos de I+D+i»

AVISO IMPORTANTE - La memoria no podrá exceder de 35 páginas. Para rellenar correctamente esta memoria, lea detenidamente las instrucciones disponibles en la web de la convocatoria. Es obligatorio rellenarla en inglés si se solicita más de 100.000,00 €.

IMPORTANT – The research proposal cannot exceed 35 pages. Instructions to fill this document are available in the website. If the project cost exceeds 100.000,00 €, this document must be filled in English.

TÍTULO DEL PROYECTO COORDINADO (ACRÓNIMO):

Estallidos de formación estelar a lo largo de la evolución del Universo (ESTALLIDOS 7.0)

TITLE OF THE COORDINATED PROJECT (ACRONYM):

Starbursts throughout the evolution of the Universe (ESTALLIDOS 7.0)

DATOS DE LOS SUBPROYECTOS - *SUBPROJECTS DATA*

SUBPROYECTO 1: nodo CIEMAT

IP 1 COORDINADOR 1 (Nombre y apellidos)**:** Mercedes Mollá Lorente

IP 2 COORDINADOR 2 (Nombre y apellidos)**:** --

TÍTULO - *TITLE*: Estallidos de formación estelar a lo largo de la evolución del Universo
Starbursts throughout the evolution of the Universe

SUBPROYECTO 2: nodo UAM

IP 1 (Nombre y apellidos)**:** Yago Ascasibar Sequeiros

IP 2 (Nombre y apellidos)**:** Ángeles I. Díaz Beltrán

TÍTULO - *TITLE*: Estallidos de formación estelar a lo largo de la evolución del Universo
Starbursts throughout the evolution of the Universe

SUBPROYECTO 3: nodo IAC

IP 1 (Nombre y apellidos)**:** Casiana Muñoz Tuñón

IP 2 (Nombre y apellidos)**:** Jorge Sánchez Almeida

TÍTULO - *TITLE*: Estallidos de formación estelar a lo largo de la historia del Universo
Starbursts throughout the history of the Universe

SUBPROYECTO 4: nodo IAA

IP 1 (Nombre y apellidos)**:** José M. Vílchez Medina

IP 2 (Nombre y apellidos)**:** Jorge Iglesias Páramo

TÍTULO - *TITLE*: Estallidos de formación estelar a lo largo de la evolución del Universo
Starbursts throughout the evolution of the Universe

1. JUSTIFICACIÓN DE LA COORDINACIÓN

The Estallidos team has a long experience in the analysis and interpretation of optical spectroscopic data, with significant presence in many international observational campaigns aimed to characterise galaxies in the local universe. The advent of large Integral-Field Spectroscopic (IFS) surveys has revolutionised the field over the past decade, and we now have detailed information about the properties (e.g. age, metallicity) of the stellar population, as well as the physical state (e.g. density, temperature, chemical composition) of the warm ionised gas, resolved on spatial scales of the order of kpc, for large samples of galaxies spanning a wide range in mass, morphology, and environment. On the other hand, cosmological surveys provide invaluable clues about the state of galaxies at different cosmic

epochs, helping us to disentangle the different processes that regulate star formation and chemical evolution throughout the history of the universe.

The ESTALLIDOS collaboration includes experts in observational astrophysics, numerical simulations and theoretical modelling. We have always played an active role in the development of the new tools and methodologies to analyse observational data, and we are at the forefront of the chemical evolution models that are necessary for their physical interpretation. Our group bases its strength on an effective coordination of their members in four different teams whose objectives are closely intertwined. The added value of this synergistic research stems from the combination of the expertise and specialisation of the scientists from the four nodes. Each group is particularly strong in a different aspect: UAM and CIEMAT lead the theoretical modelization of galaxy formation and evolution, whereas the expertise at IAA and IAC is more oriented towards astronomical observations and interpretation. Some members of the team are internationally recognised experts in specialised topics, such as gas accretion, environmental effects in galaxy clusters, circumnuclear star-forming regions, or galaxy formation in the early universe. The collaboration acts as a single group, and our working scheme has been optimised over the years in order to take maximum advantage of such a broad knowledge base. The objectives of the proposed work plan correspond to a purely scientific rationale, and often involve the participation of individual team members from different nodes.

The collaboration network is coordinated by a sound management structure that has proven extremely successful in past editions of the project. Since this structure has proven to be good, we will maintain it in this project, too, although some changes are implemented. The coordination scheme and management involves:

1. - Coordination Team (CT), formed by PIs and Co-PIs of the four nodes and seniors responsible for Objectives. At present these members (in alphabetic order by first names) are: Ángeles I. Díaz Beltrán, Carolina Kehrig, Casiana Muñoz Tuñón, Enrique Pérez Montero, Jorge Iglesias Páramo, Jorge Sánchez Almeida, José M. Vílchez Medina, J. Miguel Mas Hesse, José Miguel Rodríguez Espinosa, Martin Stulingher, Mercedes Mollá Lorente, Miguel Cerviño Saavedra and Yago Ascasibar Sequeiros.
Note: J. Miguel Mas Hesse has been active member in ESTALLIDOS since its beginning. He is part of our team even if they cannot be formally members due to bureaucratic reasons.
2. - Management and coordination meetings, to facilitate the monitoring of the day-to-day operation of the collaboration. These meetings can be held by teleconference among the PIs of the different subproject nodes. Then, operating strategies will be followed up and tuned when required. All CT members are invited to participate. From our previous experience we estimate that a frequency of 4/year is enough for taking decisions as needed. We believe that the video/telecon format is appropriate, saving travel time and unnecessary expenses.
3. - Review Meetings (1/year). The CT members will meet every year (presential/telecon) to supervise the correct scientific progress of the project and the foreseen achievements of each objective; the leaders of each objective, and the members of the CT, will attend these meetings. Whenever possible, each review meeting will follow a management meeting in order to optimize the time.
4. - Science Meetings: ESTALLIDOS Workshops and Specific Seminars. As part of the coordination of the project, an initial workshop (first year) and a final one will be organised. One of these meetings will be an international conference (International Symposium level). In addition, specific seminars (typically 20 participants) driven by the project objectives will be organised. In the last year of the previous Project, within ESTALLIDOS 6.0, we have organised the workshops: "*High energy processes in galaxies and clusters",* devoted to energy processes coming from SNRs, AGNs, Cosmic Rays, magnetic fields etc., which took place in Madrid (May) and "*EMIR y MEGARA en GTC: preparación de fase 2, tratamiento y reducción de datos",* organized as a RIA meeting in La Laguna. The last meeting will be *"XII Estallidos workshop: from PhD students to international partners"* and will take place in Almería (October 2019).

2. PROPUESTA CIENTÍFICA

Antecedentes y objetivos

ESTALLIDOS started formally as a coordinated team to study the formation and evolution of massive stars in starbursts in the Plan Nacional I+D back in 2001, continuing the activities of the GEFE (Grupo de Estudios de Formación Estelar) group. Thanks to the expertise we have gained during more than 18 years of working in collaboration, we are now a large, consolidated team, and an international reference in the field. Our distinctive traits are, on the one hand, the combination of observational and theoretical expertise, including the analysis of data at different wavelengths, and the development of new statistical, analytical and numerical techniques. On the other hand, we have always taken advantage of detailed studies in the local Universe to improve our comprehension of the starbursts that took place in the distant past and the early phases of the formation of galaxies and the production of chemical elements.

Star formation (SF) is probably the most important phenomenon in the Universe. It marks the ages of galaxies, and indeed defines the various types of galaxies. Over the last two decades, our group has made significant contributions to our understanding of starbursts and their impact on their host galaxies. In the past we have gained expertise about the massive SF processes and their consequences in the local Universe, by studying in great detail the massive star formation processes in the local objects (present time) from data obtained with good spatial and spectral resolution. In the meanwhile, in the last decade, observations at intermediate and high redshift have increased extraordinarily and, taken this into account, we initiated already in our last project, ways to apply our knowledge and techniques also to distant objects/galaxies. The improvement in the quantity of these data is large, decreasing extraordinarily the statistical errors. However, if the recipes used to interpret these data are simplistic, or not totally adequate, the systematic errors may be still very high, which might lead to erroneous evolutionary scenarios. In the present proposal, we are going a step forward, applying our techniques and knowledge obtained from the study of objects observed at zero redshift, to the excellent surveys that are also giving good quality data, at other epochs of their evolution. We think that in this way we will contribute significantly to the new sciencific advances, improving the quality of the interpretation of these observations, which are changing our view of the Universe.

Taking these arguments in mind, we, in the present edition, want to propose the next generic aims, described in the next section, which refer to these two scenarios: the **local Universe** and the **far Universe**.

Objetivos generales y específicos

Scientifically, our general aim is centered in the following open questions:

I. The study of structures within spiral galaxies.
II. Multi-wavelength constraints on star formation in nearby galaxies.
III. Star formation throughout the history of the Universe.
IV. Characterising ultra high-ionizing starbursts in the present and young Universe
V. Evolution of star-forming galaxies in dense environments near and far
VI. Advanced Intrumentation for extremely large telescopes

In what follows we will develop each of these wide aims, giving the state of the art and our own advances in the field for each one of them, and going into their specific objectives.

I. The study of structures within spiral galaxies (distribution of metals, the bar evolution, the bulge and the halo, the spiral wave, circumnuclear environment)**.**

Massive spiral galaxies of the local Universe show negative abundance radial gradients. This feature is related with the infall of gas to form disks. There is also a relationship between the mass of the galaxies and their average stellar metallicity. These facts were determined from azimuthally averaged elemental abundance measurements. With the advent of new instrumentation, it is possible to analyse in detail some structures of the spiral disks, as bars, bulges or spiral arms, and even the role of the stellar halo over the disk. It has been possible,

using IFU's data, to characterize the star formation and elemental abundances over the whole disk, spaxel by spaxel, not only by azimuthal averaged values such as CALIFA collaboration data have shown (Sánchez et al. 2012, 2014, González-Delgado 2014, 2015).

One of the usual tools to interpret the emission line intensities in terms of star formation rate and elemental abundances is a chemical evolution model. In the past years we have updated our 1D-MULCHEM model from Mollá & Díaz (2005) after analysing different sets of stellar yields combined with several Initial Mass Functions (IMF's), studying the possible infall rates of gas to form the disk for different dynamical masses of galaxies, and using new prescriptions to form molecular gas from the diffuse gas (this way eliminating a free parameter in our chemical evolution model). We have then calibrated this code with the Milky Way Galaxy (MWG) in Mollá et al. (2015, 2016, 2017a) and we have obtained the time evolution of the radial gradient of Oxygen abundances in our Galaxy (Mollá et al. 2017b, Mollá et al. 2019a) and other spirals (Mollá et al. 2017c), which results to be clearly dependent on the disk formation process. Thus, the radial gradient of the oxygen abundance turns out to be the same along the evolution when it is measured as a function of the effective radius of the disk. All galaxies show a similar behaviour, with slight differences depending on their dynamical mass: the gradient flattens rapidly after the early disk formation. The least massive galaxies suffer this flattening later in time, while in the most massive ones the gradient flattens very early. At the end, all galaxies have a very similar normalized radial gradient of oxygen, in agreement with observations (Díaz, 1989; Sánchez et al. 2014; Sánchez-Menguiano et al. 2016).

We have developed a new generation of 2D chemical evolution models, 2D-MULCHEM, extending the successful 1D-MULCHEM model to the MWG by considering a bidimensional density distribution with a spiral wave (Junqueira et al. 2013), including the spiral arm rotation in the evolution code (Mollá et al. 2019b, see Figure 1). A grid of chemical models in 2D, varying the spiral arm characteristics, will be computed and made publicly available through a dedicated web interface. The development of these models was the subject of a PhD thesis, co-supervised by MM and DSW, in collaboration with Kenya's astronomers.
Once the evolutionary models are developed, we will use them in comparison with data to interpret the observed galaxy in terms of evolution and formation. For that, we will take advantage of our collaborations with SIGNALS (see Section I.3) and MEGARA (see Section I.4). We have the following specific objectives within this main aim:

I.1. Models and simulations.
To develop models or simulations to predict the formation and evolution of structures as spiral arms, stellar bars and the own bulge and halo, within a spiral galaxy.

I.2. Realistic prescription to form stars.
We need to include a more realistic prescription about the process of creation of stars from molecular gas. In the past years, the inputs of our code MULCHEM have been updated: infall rate, stellar yields and initial mass function, formation of molecular clouds from diffuse gas.
However, we still use a free parameter in the conversion of molecular clouds to stars, which should be modified. We propose to implement a more elaborate treatment of this conversion into stars, which in turn requires following accurately the evolution of the dust phase (Vílchez et al. 2019). We will also improve our prescription for stellar feedback by taking into account cosmic rays, and by considering the effect of supernova explosions in different environments, that is a deep study of supernova remmant (SNR) evolution and their role on the feedback.

I.3. Interpretation of IFS data.
The SIGNALS collaboration, lead by Université Laval, Québec, Canadá (Rousseau-Nepton et al. 2019), carries out a project to observe spiral galaxies with the SITELLE instrument in the Canada-France-Hawai Telescope. SITELLE is a Fourier-Transform spectrograph, which allows easily selecting the wavelength window to observe. The aim is measuring with high precision the intensities of the gas emission lines and thus determining the elemental abundances using many more HII regions in each spiral disk (see Figure 2). We will participate in the collaboration, firstly in estimating elemental abundances (see medios

materiales) and secondly, using our chemical evolution models for their interpretation. Since

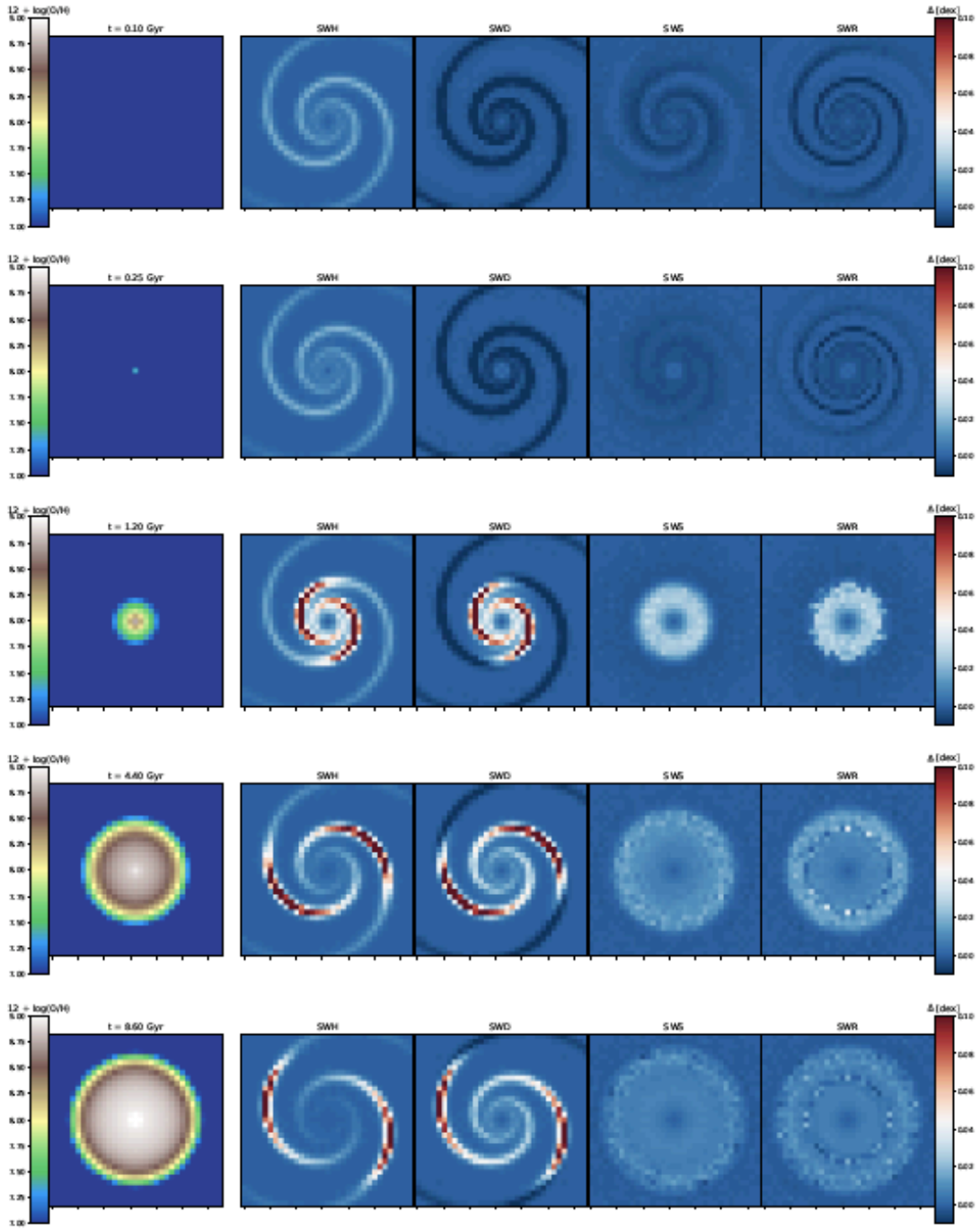


Figure 1. *Evolution along the time of the Oxygen abundance 12+log(O/H) (in a Milky Way type galaxy The left column shows the azimuthal symmetry model (AZ) results, with scale at the left side, while columns 2 to 5 show the resulting differences (residuals) with the AZ results, for four models including the spiral arm using different prescriptions. Each row represents a time from 0.10 Gyr until 8.60 Gyr as shown above of each AZ panel.*

we participate in the science group of OFIUCO, a similar instrument to be installed in San Pedro Mártir Observatory (México), the gained expertise will be applyed to this instrument.

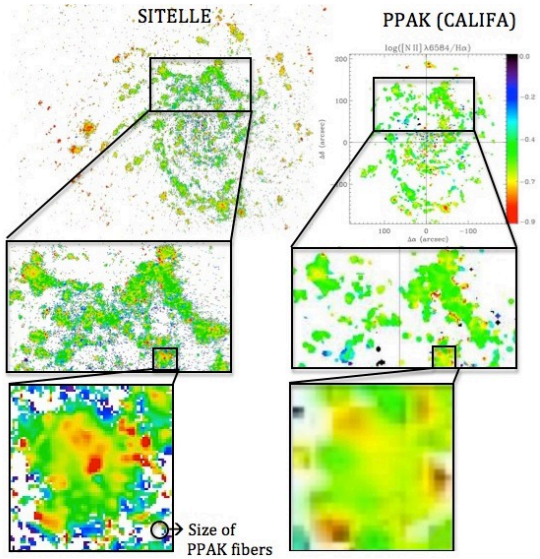


Figure 2. *Comparison of the SITELLE and CALIFA spatial resolutions and the filling factor impact on the measurements of the emission line ratios.*
The line ratio log([N II]λ6583/Hα) extracted from observations from SITELLE on NGC 628 is compared to PPAK's observations on the same area. The color scale is the same for both maps (upper-right corner).

I.4. Studies of low brighthness, low metallicity star forming galaxies with MEGARA

Star-Forming Galaxies (SFGs) have been proposed as the main contributors to the Universe reionisation after the Dark Ages, when the baryonic matter was neutral. However, the current number of detected SFGs is not enough to explain the reionisation at z~6 (Robertson et al. 2013) and several authors have pointed to the faint low-mass Compact Star Forming Galaxies (CSFGs), below the detection limit of most telescopes, as potential responsible for the escaping ionising radiation (Bouwens et al. 2015), with fractions over the whole ionising radiation (fescLyC) of the order of 10-20% (Robertson et al. 2015, Khaire et al. 2016). So far, the study of low-redshift SFGs has been proposed as the natural laboratory to test this hypothesis, but at low redshifts they are quite opaque to the ionising radiation (Grimes et al. 2009): only 4 low-redshift galaxies in the literature have been reported with fescLyC in the range 1-4.5% (Borthakur et al. 2014, Leitherer et al. 2014, 2016), being that by Borthakur et al. (2014) the only one confirmed with HST/COS observations as LyC leaker. Izotov et al. (2015, 2016), using SDSS data, selected ∼15000 CSFG at z < 1, finding that they use to be low-mass and low-metallicity galaxies, with stellar masses, star formation rates (SFR) and metallicities similar to those of high-redshift Lyman-alpha emitters (LAE) and Lyman-break galaxies (LBG) (Izotov et al. 2015). Many of these CSFG show high ratios of [OIII] to [OII] emission lines, O32 ≥ 5, and reaching values up to 60 in some galaxies (Stasinska et al. 2015). These HII regions of these galaxies colud be density-bounded, allowing to escape part of the ionising radiation to the IGM as suggested by Jaskot & Oey (2013), Nakajima & Ouchi (2014), Izotov, Thuan & Guseva (2017). Izotov et al. (2016a, 2016b), using HST/COS observations of five CSFGs at redshift z ∼ 0.3 and with O32 = 5–8, found that all these galaxies are leaking LyC radiation with an escape fraction from 6 to 13%. After this successful detection, they selected an additional sample with O32 > 10 detecting that the object J1154+2443 has fesc (LyC) as high as 46%, the highest value found so far in low-redshift CSFGs and one of the highest found in galaxies at any redshift (Izotov etal. 2018; Iz18 hereafter). This galaxy, found in the SDSS DR10 (Ahn etal. 2014) at a redshift of z = 0.3690, has O32= 11.5 and is the low-redshift LyC leaker with the lowest metallicity (12+logO/H=7.65±0.01). The compactness of these low-metallicity CSFGs is derived mostly tfrom SDSS images (with moderate exposure times) that have been the basis for long slit spectroscopy. More diffuse CSFG were proposed as candidates for low-metallicity in Izotov et al. (2019).

Our team has already started a study with MEGARA at the GTC using the central IFU and different gratings at medium to high resolution (resolving power between 6000 and 20000). The goal is to study the gas and stellar populations in low surface brightness low-metallicity CSFG. The program started during MEGARA commissioning in 2017 by observing two CSFG (J1608+3528 and J0159+0751) from a sub-sample from Izotov, Thuan and Geneva (2017, hereafter ITG17). Both galaxies showed a very extended gas region (much less

compact than expected) and no evidence for outflowing material. Ionisation and kinematical maps support the ionisation-bounded scenario.

Therefore, we want to answer to these two questions:
I. 4. 1 Is the ionizing radiation scaping from these CSFG? and
I. 4. 2 what is the quantitative definition of compact for these CSFG?

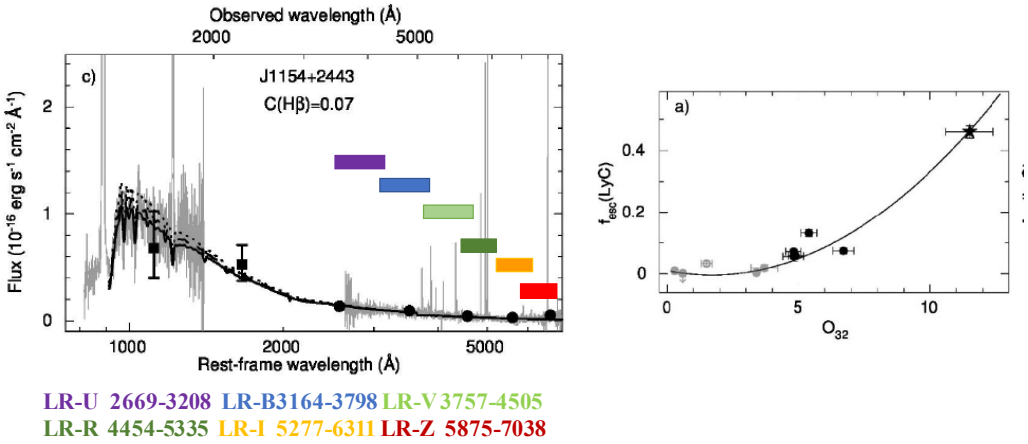


***Figure 3**. Left: SED fitting of the J1154+2443 optical spectrum (Yzotov et al. 2018). The grey line shows the rest-frame extinction-corrected SDSS spectrum. The stellar, ionized gas, and total modelled SEDs are shown by dashed, thin solid and thick solid lines, respectively. C(Hβ) = 0.07 is derived excluding Hα emission. We have over-plotted the MEGARA LR wavelength coverage. Right: Relationship between the Lyman continuum escape fraction fesc(LyC) and the O_{32} emission-line ratio for low-redshift LyC leaking galaxies observed with FUSE (grey) and HST/COS (black).*

II. Multi-wavelength constraints on star formation in nearby galaxies

Over the years, optical spectroscopy has provided invaluable insight on the physical properties of galaxies, and it has led to significant progress in our understanding of the physical processes that regulate star formation and chemical evolution. In particular, IFS data has extended our knowledge of the scaling relations between stellar and gas mass, as well as chemical composition and physical state, on spatially resolved scales (Ascasibar et al. 2015, Cano-Díaz et al. 2016, Zibetti et al. 2017). By comparing galaxies over a broad range of stellar mass, morphology, and environment, one may conclude that the evolution of most galaxies in the local Universe is dominated by the gradual conversion of gas into stars (Casado et al. 2015), and that the cold, atomic and molecular gas phases (as well as the associated phase transitions, such as photo-dissociation and ionisation) play a crucial role in the baryon cycle (Mollá et al. 2017a).

However, focusing on a narrow range of the spectrum leaves room for very different theoretical interpretations of the data. It is very hard to distinguish, for example, whether star formation expels a significant amount of gas outside the galaxy, or by the contrary it is simply there, in a hotter or colder phase (Gavilán et al. 2013). It makes also difficult to constrain the precise rate at which stellar winds, supernovae and AGN inject energy into the interstellar medium, and the fraction that is radiated away. In order to improve our understanding of these processes and their impact upon the internal structure and evolution of galaxies, as well as to break the degeneracy between the many free parameters of different theoretical scenarios, it is necessary to make accurate predictions of the expected spectral energy distribution and compare them across the broadest possible wavelength range.

Assembling a suitable sample of multi-wavelength observations is nonetheless far from trivial. Albeit relatively large galaxy surveys have been carried out in different spectral ranges, and many of these data are publicly available, the field of view, spatial resolution, and sensitivity of the respective instruments tend to bias the target lists towards objects of vastly different angular size, luminosity, distance, star formation, nuclear activity, and/or other physical properties. As a result, there is often very little overlap between surveys at different wavelengths, and the number of galaxies where all the required data are available is still very

limited. On the other hand, predicting the observable spectrum over a broad wavelength range requires a significant overhaul of our current theoretical models. In their current state, they have proven to successfully reproduce many of the observed spectrophotometric properties of the galaxy population in the optical regime, but a number of stellar populations, as well as the contribution of different gas phases, must be included in order to expand their current range of applicability. Reaching either extreme of the electromagnetic spectrum (radio and gamma-rays) requires, in addition, the implementation of a detailed treatment of relativistic particles and non-thermal processes. Given the recent advent of systematic surveys of the sky at these wavelengths, at unprecedented levels of spatial resolution and sensitivity, as well as our limited knowledge of the role that these particles and processes play in the regulation of star formation and the physical state of the interstellar medium, the importance of this task can hardly be overstated. The specific goals of this work package are:

II.1. Follow-up IFS observations of HI galaxies

Most of the fuel for star formation is in the form of atomic hydrogen (HI). Its total mass, derived from the luminosity of the 21-cm radio emission line, is certainly a useful constraint for any theoretical model, and the stellar-to-gas fraction, traced by HI, has been shown to provide a powerful indicator of the evolutionary state of a galaxy (Ascasibar et al. 2015). At these wavelengths, spatially resolved observations require radio interferometry over long integration times, and data are still scarce. The situation, however, is slowly changing, and there are now relatively large samples of galaxies in the local Universe. In the forthcoming future, the operation of the SKA and its pathfinder experiments will dramatically change the scene, as they scan a significant fraction of the sky. Our group is deeply involved in two large observational campaigns to carry out follow-up optical IFS observations of HI-selected targets: the WEAVE-APERTIF survey in the Northern hemisphere, and the HI-KIDS survey in the Southern sky. Apart from these dedicated observations, we will also make use of other IFS samples, as well as imaging and photometric catalogs available in the literature, in order to increase the statistical significance of our results and/or supplement our data set with relevant observations at other wavelengths. We will develop and test different techniques to derive possible evolutionary histories and detect particular sources (e.g. massive stars, supernova remnants or AGN) using these data.

II.2. Upgrading our population synthesis models

The improvement in the quantity and quality of our observational database must necessarily be paralleled by a similar improvement in our ability to predict the spectral energy distribution of our theoretical models. First, we will update our spectral synthesis code POPSTAR (Mollá et al. 2009) with new, high-resolution stellar spectra. In order to extend its range of applicability towards the high-energy regime, we will include additional stellar population components that are extremely relevant for the emission at ultraviolet and X-ray wavelengths. Of course, computing the panchromatic spectra of galaxies requires including detailed predictions for the continuum and line emission from diffuse gas and dust at very different densities and temperatures, either through detailed physical modelling of radiative transfer and thermal equilibrium or by resorting to simple phenomenological prescriptions. In order to achieve a meaningful comparison with current and forthcoming observational data, we will carry out detailed simulations mimicking the technical characteristics of specific instruments.

II.3. Non-thermal processes in galaxies

In addition to thermal processes, galaxies contain a small fraction of relativistic particles that are far away from the Maxwell Boltzmann distribution. Most of these cosmic rays are thought to originate in astrophysical shocks, and they drift and diffuse through the galaxies as dictated by the ordered and random components of the magnetic field. Within our Galaxy, supernova remnants are able to accelerate protons and electrons in the interstellar medium up to GeV energies, and model predictions are fully consistent with the observed spectrum. The situation at higher energies is far less clear, and a different source must be responsible for the proton, antiproton, electron, and (most notably) positron spectra between 100 GeV and 1 TeV (Aguilar et al. 2014, 2015, 2016).

We will explore the origin of these particles in the Milky Way, as well as the possibility of building the first detailed models of cosmic ray propagation for other galaxies. Depending on

the injection and propagation parameters, heating (Ascasibar 2007, Iwanus et al. 2019) and pressure (Wechakama & Ascasibar 2011) from these particles may have a sizable impact on galaxy formation and evolution. We will carry out a detailed assessment of the cosmic-ray pressure, heating, and ionisation rate in our Galaxy and explore the possibility of including an approximate treatment of these particles and the associated emission of radio and gamma-ray wavelengths within our chemical evolution models (I.2). In external galaxies, active galactic nuclei (AGN) are often invoked to explain the low specific star formation rate of massive galaxies, although the exact physical mechanism(s) ar yet unidentified. We will investigate the correlation between the optical classification of the galactic nucleus and the star formation history of the nuclear region, including the circumnuclear star-forming regions that are often observed within the central kpc (Díaz et al. 2000, Álvarez-Álvarez et al. 2015), as well as the galaxy as a whole. Optical identification of AGN is, however, far from optimal, and we will use our multi-wavelength database to make use of more reliable criteria.

III. Star formation throughout the history of the Universe

Galaxies are engines that transform gas into stars; therefore, the process of SF is central to understand the universe as a whole. It is a multi-face phenomenon evolving with time, thus, it is important to approach SF from several angles, and throughout the history of the Universe. The Universe was originally neutral, hence the line emission of the first stars and galaxies is difficult to observe. The Lyman α (Lyα) line is absorbed by neutral Hydrogen unless the emitting sources are either very powerful to ionise a big bubble around them (possibly AGN) or they are triggered in groups. Eventually, the Universe became re-ionised, but it is not clear how this happened and which sources were responsible for the re-ionisation.

SF can indeed be followed from the early Universe until today. Photometric surveys are ideal to identify and characterise star forming galaxies, and to follow those galaxies in time. The SHARDS survey (Perez-González et al. 2013) is an excellent tool to search for star formation sources from low redshift up to z=6, using characteristic patterns in the spectral lines and continuum breaks. The COSMOS Survey includes the peak of star formation at z~2.5 and reaches till today. Our idea is to follow the SF process from z~0 to z~6.5, to comprehend how the SFR increased so fast to then decline by z~0. This is a measure of the availability of neutral Hydrogen gas through time.

A consequence of SF is feedback. The study of negative feedback in SF is recognised to be one of the central issues regarding galaxy formation (Dekel & Silk 1986, Scannapieco et al. 2002, Ferreras et al. 2002, Hopkins et al. 2004). The large UV photon output from massive stars and their violently deposited mechanical energy make them major players in the dynamics of the interstellar medium (ISM). They limit and stop star formation (Tenorio-Tagle and Bodenheimer 1988, Elmegreen 1999a, 1999b). However, as shown by Tenorio-Tagle et al. (2005, 2007), for the case of massive and compact young clusters, the stellar feedback may, in extreme cases, become positive. State-of-the-art models of galaxy formation only match the observations by including AGN & SN negative feedback (Silk & Mamon 2012). Massive stars, which produce photons and mechanical energy, drive super galactic winds (SGW). SGWs remove the material from the galaxy and inhibit further SF (Heckman et al. 1990, Tenorio-Tagle & Muñoz-Tuñón 1997, Tenorio-Tagle & Muñoz-Tuñón 1998).

Numerical simulations predict that accretion of cosmic web gas drives SF in disk galaxies (Dekel et al. 2009; Silk & Mamon 2012). The process is more important in low mass dark matter haloes ($< 10^{12}$ $M_{\odot}$, Dekel et al. 2013), hence in the early universe, when most galaxies had low mass, but also in the local universe around isolated dwarf galaxies. The accreted gas is predicted to be tenuous and patchy, with low-metallicity (van de Voort & Schaye 2012). In low mass haloes, the cosmological accretion comes together with intense outflows produced by stellar feedback, i.e., by the collective effects of stellar winds and SN explosions from short-lived stars. Inflows are comparable to outflows; therefore, the gas that ends up in stars is just a small fraction of the total gas involved in large-scale gas flows (Dave et al. 2012, Shen et al. 2012). This picture has been difficult to confirm observationally (Sánchez Almeida et al. 2014). There is an ongoing quest for the cosmic gas that must be falling in, with only partial and/or indirect success. Among the most compelling evidence, we found metallicity drops associated to enhanced SF in extremely metal poor galaxies (XMPs),

as expected if the gas forming stars in XMPs had cosmological origin (Sánchez Almeida et al. 2015). Recently, Wisotzki et al. (2018) discovered how the whole universe between redshift 3 and 6 emits in Lyα, which opens up a gateway to study the gas in the intergalactic medium (IGM) through such emission. Our project will contribute to understand the process of cosmological gas accretion and to characterise the elusive gas feeding SF. This issue is also treated in Objective I.

III.1. Studying the gas feeding star formation at different redshifts

Our project will contribute to the detection and characterisation of the elusive gas feeding star formation in three different but complementary ways: (1) The cosmic gas shows up in Lyα at a surface brightness of 10^{-19} erg/s/cm^2/arcsec^2, which is routinely achieved by MUSE-VLT (https://www.eso.org/sci/facilities/develop/instruments/muse.html). These Lyα photons are mostly produced by recombination therefore Hα and the other H recombination lines are generated together with Lyα. They can be used to detect the gas around galaxies in the local Universe, where Lyα is not easily detectable. The publicly available 'MUSE-Wide Survey' optical spectra will be used to show the existence of a halo of metal-poor gas around galaxies forming stars in the local Universe. There are thousands targets to be studied (Urrutia et al. 2019). (2) Chemical inhomogeneities associated with enhanced star formation trace cosmic gas accretion intermingled with gas mixing processes in galaxy disks. The chemical inhomogeneities have been recently proved to exist in virtually all star-forming galaxies of the local Universe (Sánchez-Menguiano et al. 2019, Sánchez Almeida and Sánchez-Menguiano 2019). They remain to be fully characterized. (3) The need for cosmological accretion to drive star formation was originated as a theoretical construction. Numerical simulations provide a generic framework to understand the growth of low mass galaxies; however, we still lack of a proper set of specific predictions to be compared with the observations mentioned in the two previous items. Thus, our specific objectives are:

III.1.1. Gas around local galaxies in emission lines. By using either haloes of individual galaxies or stacked spectra, we will detect and constrain the metallicity (Pérez-Montero 2017) and motion of the metal-poor gas around galaxies. Tailored HST observations of a few selected targets are underway with a similar scientific purpose (Elmegreen et al. 2019).

III.1.2. Local correlation between metallicity other physical parameters. We will determine whether the chemical inhomogeneities found in all star-forming galaxies are also associated with local changes in stellar age and gas mass, as expected (Sánchez Almeida and Sánchez-Menguiano 2019).

III.1.3. Analysis of numerical simulations. Supported by out past experience with such kind of comparisons (Ceverino et al. 2016, Sánchez Almeida and Dalla Vecchia 2018, see Figure 4), we will analyse one of the state-of-the-art numerical simulations, EAGLE (Schaye et al. 2015), to develop the physical intuition needed to interpret observations

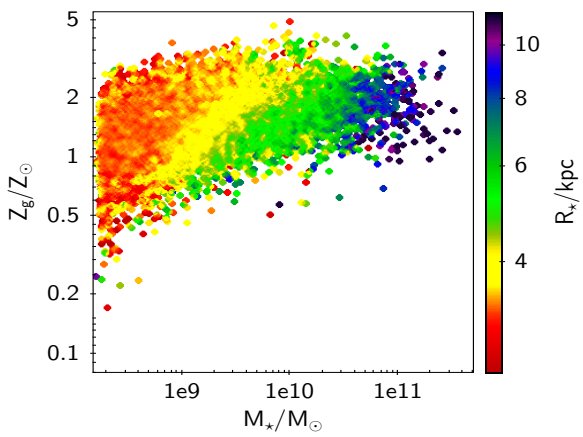


Figure 4. *Gas-phase metallicity versus stellar mass relation color-coded according to the galaxy radius, (data taken from the EAGLE numerical simulation, Schaye et al. 2015). As observed (Ellison et al 2008), galaxies of the same mass are more metallic when they are smaller. The agreement between simulations and observations allows us to identify the physical cause the correlation, namely, cosmological gas accretion (Sánchez Almeida & Dalla Vecchia 2018).*

III.2 Understanding star formation at different z, from multi-λ photometric information.
In the quest for understanding SF at different redshifts, we will apply what we did with SHARDS to larger surveys spanning redshifts from z~0 to z~7. With SHARDS, we characterised the population of both LAEs and LBGs with a special detection technique. We will apply a similar technique to the PAU Survey to which we have access. An advantage of using this survey is that it is much larger, 100 squared degrees versus 135 arc-minutes for the SHARDS survey and almost free from cosmic variance. The wide field implies that the exploration would be done on more than 3 millions sources detected with excellent redshifts. Our specific objectives for this point are:

III.2.1 Detect both LAEs & LBGs in the PAU Survey.
III.2.2 Characterise the sources found in terms of SFR, Mass density Functions, clustering.
III.2.3 Use machine learning algorithms to detect classes in this larger sample.

III. 3. Quantifying the SF feedback
ESTALLIDOS 6 dealt with Emission Line galaxies from SHARDS (GOODSN) up z=1. We also managed the COSMOS-SHARDS database. As a result, we have a sample of low mass emission line galaxies at z<1 (3000 galaxias). Besides, we have a high luminosity catalogue in a wider field from the COSMOS survey. The studies carried out so far provide detailed photometric information about the sources. We propose to study the feedback by adding spectroscopic information, and study, in particular, the emission line profiles. This will be done with high spectral resolution spectroscopy using WEAVE and MEGARA and theoretical models in collaboration with our colleagues in Mexico and the Check Republic. Our specific objectives are:

III.3.1 Quantify the feedback balance (winds from stars and SN) in starbursts in the Universe up to z<1.
III.3.2 Relate the results with the underlying structure of the host galaxies.
III.3.3 Evaluate the importance of the positive feedback and its impact on the chemical evolution of galaxies.

III.4. Star Formation in the Epoch of Re-ionisation
The re-ionisation of the Universe is a key topic of modern astrophysics. We know that the re-ionisation process was carried out by low luminosity star forming galaxies (Ouchi et al. 2019, Robertson et al. 2015, Bouwens et al. 2010). These galaxies, however, would not be seen unless they are clustered, so that they produce an ionised bubble large enough for ionising photons to get redshifted when they leave the bubble. This way, they are able to escape the resonant gas (Dayal & Ferrara 2018, Calvi et al. 2019). This allows us to study not only the star forming sources, but also their clustering properties. But, how was the Universe re-ionised? One way of probing the number of ionising photons is by deriving the LyC photons escape fraction in starbursts at high z. In particular, we will look for double peak Lyα emitters. The double peak has been interpreted as produced by a bubble of ionised gas. We have a large sample of sources where to look for. The idea would be to find out how and when star forming galaxies allow LyC photons to escape. We have recently characterised one such bubbles, powered by a proto-cluster of galaxies (Calvi et al. 2019, Rodríguez-Espinosa et al. 2019). Also Dayal and Ferrara (2018), have claimed that re-ionisation was very likely achieved by galaxies in groups. So, the pressing topic here is to find the sources that produce the LyC photons and their census. With this in mind we define the following specific objectives:

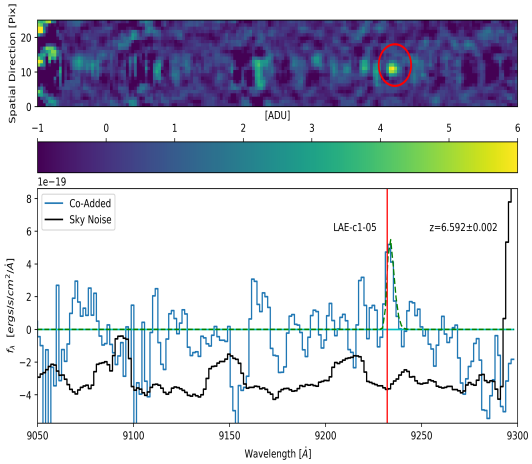


Figure 5*. Note the faintness of the high-z galaxias, difficult to disentangle from the sky lines*

III.4.1 Reduce the data as soon as they are observed.
III.4.2 Check the percentage of LyC leakers.
II.4.3 Study their output, in terms of Lyman Continuum photons.
III.4.4. Measure the ionised bubbles if present.

IV. Characterising ultra high-ionizing starbursts in the present and young Universe.
The cosmic dawn ($6 < z < 10$) marks a major phase transition of the universe, during which the "first light" metal-free stars (or the so-called PopIII-stars) and the subsequent formation of low mass, metal-poor galaxies appeared putting an end to the dark ages. Apart from being the main candidates for explaining the Universe's reionisation, PopIII-stars and their hosts play a key role in the chemical evolution of the universe. Despite much observational and theoretical effort, the sources of reionisation are completely unconstrained at present (e.g. Bromm 2013).

There is growing evidence from observations that high-excitation SF galaxies are usual at high-redshift indicating that extreme radiation fields characterise reionisation-era systems (e.g., Stark et al. 2016). Therefore, high-ionisation emission lines (e.g., HeII) represent our best probe to detect and characterise the most distant galaxies that we will observe in the coming years. However, knowing the mechanisms responsible for the production and transmission of these high-energy ionising photons is far from being a settled matter (e.g., Kehrig et al. 2018, Berg et al. 2019). An important aspect is that we know very little about the extreme UV ionising continuum of massive stars, poorly constrained specially at low metallicity (e.g., Crowther et al. 2002, Kubatova et al. 2019). First-class facilities (e.g., JWST, ELT) will improve the statistics of galaxies at $z > 6$, and will study the integrated properties of the sources identified at this epoch. At $z \geq 6$, however, observing the UV photons gets progressively more difficult due to the increasing opacity of the IGM (e.g., Dijkstra et al. 2011). This way, direct studies of $z \geq 6$ galaxies responsible for the reionisation will remain prohibitive, and all that we can currently learn about these newly forming galaxies comes from indirect evidence.

All the above mentioned urges detailed spectroscopic studies of ultra high-ionising starbursts at somewhat lower redshifts, which will shed some light on the properties of primordial galaxies, and are fundamental to interpret data of $z > 7$ galaxies in a physically meaningful manner. We thus plan to unveil the prominent metal-poor, strongly star-forming galaxies, with high ionisation which mimic the predicted first galaxies. We will perform a detailed galaxy-by-galaxy study of the gas properties and ionising sources necessary and sufficient to power high-energy ionising emission. The specific targets we will study are: LyC emitters, HeII emitters, metal-poor Wolf-Rayet (WR) galaxies, and extreme EW ([OIII]5007) emitters. A new search for these sources applying data science techniques to the JPAS survey will be performed using our guaranteed access. Our main objectives in this area are:

IV.1. Understanding the strongest LyC leaker emitters nearby.
We are working with a selected sample of galaxies LyC emitters which present likely the highest LyC escape fractions ever observed in relatively nearby galaxies ($z \sim 0.3 - 0.4$). Constraining the ionisation and chemodynamics of the gas in these strong leakers is of paramount importance (Schaerer et al. 2016; see also sect. III.4); they have been recently discovered, and their absolute escape fractions, obtained from observations, range from 2 to 70% (see Izotov et al. 2016). Our team is in a unique position to carry out a detailed study of the physical conditions and kinematics behind the strongest leakers, in collaboration with our main partners at U. Geneve (D. Schaerer, CH), U. La Serena (R. Amorin, Chile) and M.A.O (Y. Izotov, Ukraine). The key parameters of the ionisation structure and the chemo-dynamical properties of the ionised gas will be derived from their obtained spectra. This will help us to understand not only the transmission channels of LyC leakers, but also their fotoionisation, complex kinematics and structure.

IV.2. The ionising sources of HeII emitters.
Nearly metal-free ($Z < Z_{\odot}/100$) and PopIII stars are predicted to produce many HeII-ionising photons ($E > 54$eV), and so the high-ionisation HeII line has been considered one of the best

signatures to single out candidates for the elusive PopIII-hosting galaxies. For many years, hot WR stars have been suggested to be the main responsible for the HeII excitation (e.g., Schaerer 1996). However, there are many cases, both locally and in the distant Universe, where the nebular HeII is not associated with WRs (detectable via broad emission bumps at ~ 4650 Å and 5808 Å, e.g., Kehrig et al. 2011, 2013). The HeII origin is still mysterious, especially at low metallicities (e.g., Cassata et al. 2013; Kehrig et al. 2015; Senchyna et al. 2019). In-depth studies of the ISM properties and ionising sources of metal-poor HeII emitters (see e.g., Kehrig et al. 2018) is of paramount importance to better understand the excitation mechanisms prevailing at the primordial universe, and to possibly constrain sources responsible for the H and HeII reionization epochs.

IV.3. Extremely high EW ([OIII] 5007) emitters. These very compact, high ionisation galaxies present extreme equivalent widths of [OIII] 5007 Å, EW([OIII]5007), larger than 1000 Å. Green Pea galaxies are a paradigmatic sub-class of such objects, found typically at z ~ 0.1-0.3 (e.g, Amorin et al. 2010). Many questions remain to be answered on the formation and evolution of these galaxies, especially those related to the role played by massive gas inflows/outflows in their evolution, which must be linked to their gas chemodynamics (Bosch et al. 2019).

V. Evolution of star-forming galaxies in dense environments near and far

The role of the environment on the evolution of galaxies has been largely discussed in the literature (e.g. Dressler et al. 1980). Several fundamental processes, acting on different components of the galaxies, have revealed to be at the basis of this differential evolution: e.g. ram pressure stripping (Gunn & Gott 1972), harassment (Moore 1996), and starvation (Larson et al. 1980). The overall observational effect seen in the *local universe* is that, as the density of galaxies increases, the fraction of spirals and star forming galaxies decreases and the metallicity of the galaxies increases, although the relative predominance of each of these effects has not been fully established yet (e.g. works from our group at IAA: Petropoulou et al. 2011, 2012; Hernández-Fernández et al. 2012a, 2012b; Duarte Puertas et al. 2019, see Figure 6.



Stephan's Quintet complex 3D Hα strands uncovered with SITELLE
(Duarte Puertas, S., et al., 2019, A&A, 629, A102)

Figure 6. Three color composite image of Stephan's Quintet with SITELLE SN1, SN2, SN3 filters. Regions with detected Halpha emission are shown. From Duarte Puertas et al. 2019, A&A cover page.

At *higher redshifts* the situation is less clear. Although these relations seem to reverse at z>=1 (e.g. Elbaz et al. 2007; Tran et al. 2015; Wang et al. 2016), other studies report that these relations hold at such high redshifts (e.g. Quadri et al. 2012; Andreon et al. 2014). Moreover, it is not yet well established whether this effect is due to environment or stellar mass, and which is the redshift at which (a) these two mechanisms become dominant with respect to each other, and (b) the scaling relations between SFR and stellar mass or metallicity are defined (see Lee et al. 2015; Wagner et al. 2017; Lagana & Ulmer 2018). Our main interest in this topic is twofold:

V.1. The final fate of the interstellar gas: we will study the interplay of the SF with the ISM by means of the combination of optical and radio observations that trace the stellar, neutral and molecular gas in galaxies. To achieve this goal, we will make use of integral field spectroscopy and archival radio data of selected galaxies in a selected sample of nearby clusters. The combination of these data will allow to answer key questions like: (a) when and where is SF quenched as galaxies fall into the clusters?; (b) which is the impact of stripping in the chemical evolution of galaxies?; (c) which is the impact of shocks in the interstellar

medium?; (d) are strong starbursts produced in galaxies infalling to clusters, and how this affects the different components of the interstellar medium (ionised, neutral, molecular)?

V.2. Is there a break in the evolution of cluster galaxies?
We are interested in studying the evolution of the SF in cluster galaxies at higher redshifts; in particular we aim at verifying the epoch of the Universe at which the "star formation – density" relation observed in clusters of the local Universe appears. Linked to this, we will also investigate the role played by the environment in shaping the galaxy ST main sequence (e.g. Wang et al. 2018). This aspect is of fundamental relevance for a complete understanding of the mass-metallicity relation of galaxies. Some differences have been shown to exist for star forming dwarfs: their present star formation activity and/or their metal content could have been affected as a result of pre-processing, or by quenching associated to their close environment. In order to carry out these objectives, we plan to perform a study of a sample of clusters at redshifts $1.35<z<1.65$ obtaining H-band spectra (centered at the Hα line) of galaxies at different cluster centric distances to ensure membership to the cluster, and to estimate the SFR. The redshift range of our sample properly covers the critical range where both normal star formation-density relation (as in the local Universe) and the opposite have been reported. Thus, this will allow performing a coherent study with a homogeneous sample.

Metodología y plan de trabajo

In order to facilitate progress monitoring and ensure that all the proposed goals are achieved, the work to be carried out within each specific objective is organised into individual tasks:

I. The study of structures within spiral galaxies

I.1.Models and simulations: Realistic models to simulate the structures within galaxies
Team: MM, AID, JMG, OC, BKG, ER-CIEMAT1, PhD-CIEMAT

I.1.1 Relation of the radial gradient of abundances with the formation of the disk. We will use our 1D-MULCHEM models to study the evolution of the radial gradient of abundances in different types of galaxies and also the dependence on the stellar mass. This is a work in advanced state (Molla et al. 2017c, 2018). Now, we would need a precise comparison with intermediate and high redshift observations of galaxies. (MM, JMV, BG, AID, YA).

I.1.2 Studies of bulges. We have also worked from the observational point of view (Cavichia et al. 2018) as well as at computational level (Cavichia et al. 2017, Cavichia & Mollá 2019) in the evolution of the bulge of the MWG and its relation with the disk, as in the bar role. We will continue with this fruitful collaboration with the Brazil group with realistic models to simulate the evolution of bulges and stellar bars in spiral galaxies and to mainly analyze in detail the possible radial gradient of the abundances within the bulge. (MM,OC).

I.1.3 Studies of stellar haloes. Once task I.1.2 is finished, we will be able to apply the same technique to the stellar halo, dividing it into concentric rings to obtain radial gradients in R and in z for abundances and ages. The large number of data coming from GAIA, PAN-STARRS, GALEX and even the SDSS spectroscopic sample (see Whitten et al. 2019 and references therein), for the Milky Way Galaxy allows now to do the comparison between models and observations for this component. (MM, OC, BKG).

I.1.4 Hydrodynamical simulations with a spiral wave. We have developed the 2D-MULCHEM code to study the role of the spiral wave in a MWG type galaxy (Mollá et al. 2019b). However, we need to go a step further by including the dynamic and movement of stars and gas from one spaxel to the closer ones, and the corresponding chemical evolution. These calculations are bound to be intricate considering the nature of our model and the many integrated features. Therefore, we would need to compute these models as hydrodynamical simulations with a code as the one used by the BKG group. This migth be the subject of a PhD, in collaboration with the group of BKG, and it may imply a stay in UK(University of Hull) for some months. (MM, BKG and a new FPI)

I.2. Realistic prescriptions to form stars
Team: MM, YA, AID, JMV, ER-CIEMAT2, ER-UAM1, IMY, MR, AC,MCS
More elaborate modelling -- including turbulence, cosmic rays and magnetic fields – must be computed. We know that actually the process of stellar formation is complex, since it implies several phases of formation and destruction of molecular clouds due to interactions with cosmic rays, γ rays, magnetic fields and other feedback mechanism from the supernova explosions, with their injection of energy and heating and cooling mechanisms. It is, therefore, necessary to study in detail the creation of new stars, including non-thermal processes, taking into account the role of these diffrent ingredients. This could be the work for a post-doc researcher in collaboration with the CTA group in CIEMAT. The task may be split in the next steps:

I.2.1.The role of the dust. Our objective consists on the design and numerical implementation of a detailed treatment of the formation and evolution of dust grains, as well as their effects on the observable properties of our model galaxies. Apart from their production as end products of different stellar types, as well as their growth and destruction in the interstellar medium due to a variety of processes, we will thoroughly consider the absorption and scattering of ultraviolet and optical light (see II.2), the energy exchange with the gas, chemical reactions, and thermal emission in the far infrared. A large grid of self-consistent models will be generated in order to cover the full parameter space, and a Bayesian framework will be developed to compare them with the observational data compiled in II.1.

I.2.2.Supernovae and SNR. We will refine our estimation of the supernova rate from the star formation history, as well as the prediction of detectable signatures of supernova remnants in different environmental conditions. First, we will make a statistical comparison between the predicted and observed supernova rates in nearby galaxies to constrain the delay time distribution of different supernova types; and second we will run numerical simulations of the evolution of SNR in different environments, in order to better characterise the amount of energy and momentum injected to the surrounding medium as a function of the local physical conditions of the gas. We will make detailed predictions of the observable signatures at different stages of the evolution of the remnant, and compare them with IFS data of very nearby galaxies, where individual remnants are spatially resolved, as well as large galaxy samples, amenable to a statistical study. The observational characterisation of supernova remnants, prior to its inclusion in the models, constitutes an important part of the Ph.D. thesis of AC.

I.2.3 Cosmic rays. We will include the production and propagation of cosmic rays, the associated emission at radio and γ-ray frequencies, and possible feedback effects (e.g. heating, ionisation) on the physical state of the interstellar medium. Once the previous objectives are reached, it will be the time to include the results in our code 1D or 2D-MULCHEM.

I.3. Interpretation of IFS data
Team: JIP, MM, IMY, JMV, LD, EPM, YA, MCS, MGV, SPD

Participation in the SIGNALS collaboration. SIGNALS will provide us a large set of data, with which we may estimate the abundances using the photoionisation code (see VI) and then to interpret with our 2D-MULCHEM model. The work with these data needs different methods specifically developed. Moreover, the collaboration also needs tools to subtract the stellar contribution in which we are working with our code HR-Py-POPSTAR (see next subsection). Learning these techniques will be an advantage when the instrument OFIUCO, which will be installed in the San Pedro Mártir observatory, will be available. We are also involved in this last project through our collaboration with the INAOE (Puebla, México). The main tasks within this collaboration, besides adapting the new HR-PyPOPSTAR (see II.2) for the specific windows of wavelength ranges of SITELLE, OFIUCO and MEGARA, will be:
I.3.1.To estimate the elemental abundances from the emission line intensities by our photoionisation models --see **medios materiales/material resources.**
I.3.2 To interpret the data in terms of evolutionary galaxy models

I.4 Studies of low brighthness low metallicity star forming galaxies with MEGARA.
Team: MM, MGV, JMG, MCS, JIP

I.4.1 Is the ionising radiation scaping from CSFG? The answer to this question needs a deep study of these objects to be able to discriminate between matter bounded and ionisation bounded scenarios, which requires detailed 2D spectroscopy from which we can derive emission line maps and interpret them with the use of photoionisation models. This needs an instrument that allows us to detect the low surface brightness galaxies to measure its gas distribution and kinematics with enough spatial and spectral resolution. The instrument MEGARA at the GTC, and in particular the large central Integral Field Unit, IFU, is perfect to deal with this challenge.
As a first program we propose to carry out a detailed 3D (spatial + kinematics) study at R ~ 6000 of some of these objects, and specifically J1154+2443, for which we (García Vargas, Mollá) have already requested Open Telescope Time to observe it with GTC and MEGARA. We will derive maps of the gas and stellar kinematics as well as the source "compactness" and a detailed abundance determination. We propose to limit the study to detect Hβ,[OIII]5007Å and Hα respectively (gratings LR-R ad LR-Z of MEGARA) and then extend the observations to other setups if we find positive results from the first runs. Also to extend the sample to lower metallicities and determine whether this extended emission is the rule or the exception and to model its impact on the fesc(LyC) values derived. In a second phase we will aim at the detection of Mg II interstellar medium lines (with MEGARA, LR-U) to check if this is correlated with the reported Lyα escape as has been suggested in recent papers (Henry et al. 2018). This work will be carried out with the participation of the other nodes and with the MEGARA collaboration.

I.4.2 What is the quantitative definition of "compact" for CSFG?
The galaxy J1608+3528 was observed at a resolution R=6000 over the whole wavelength range and with excellent seeing conditions. The observations of J0159+0751 were not completed due to bad weather. However, the two setups observed: MR-G and MR-RI, centered in Hβ and Hα respectively showed promising results. ITG17 had reported one of the broadest Hα emission line among the galaxies of their sample, what we confirmed with the MEGARA+GTC commissioning observations. This indicates a fast-dynamical process in the nebulae whose origin is unknown: ITG17 did not find WR bumps at 4650 Å or 5800 Å, which would discard the association with stellar winds. We were awarded by the CAT in 2019A time to obtain complementary observations of J0159+0751 to look for the presence of WR, in the blue, and/or CaT or Pa series lines, in the near-IR, to constrain the age of the stellar population throughout the overall region. Through the collaboration with INAOE and the MEGARA Guaranteed Time, we have also observed two of the lowest metallicity galaxies known: Leoncino galaxy (AGC 198691), whose data have been released, and Little Cab (observations in progress), both around Hβ and [OIII] and Hα. Three more objects are on the list to be observed.
With the evolutionary synthesis code PopStar, combined with photoionisation models as CLOUDY (Ferland et al. 1998) and with chemical evolution models, we may produce self-consistent scenarios for star formation (PopStar II, III) *to try to reproduce the distribution and kinematics of the gas ionised by the young stellar clusters.* This opens a new window of opportunity to boost the discoveries associated to CSFG – compactness, kinematics, Lyα leakage problem, distribution of diffuse gas around the nucleus and a precise ionised-gas' mass and metallicity determination by single spectral lines.

II. Multi-wavelength constraints on star formation in nearby galaxies

II.1. Follow-up IFS observations of HI galaxies
Team: YA, MSL, PRP, MM, AID, ER-UAM2, ALS, LG, AC, PC, JFB

II.1.1. HI-KIDS
The HI KOALA IFS Dwarf Galaxy Survey (HI-KIDS), carried out with the KOALA instrument at the Anglo-Australian Telescope, targets dwarf galaxies extracted from the Local Volume HI Survey (Koribalski et al. 2018) as well as other interferometric data sets. It covers a range of stellar and atomic hydrogen mass between 10^6 and 10^{10} solar masses, metallicity from 0.1 to 0.5 solar, and SFR from 10^{-3} to several solar masses per year. These observations will

reveal a detailed picture of the local and global properties of the stellar population and the warm ionised gas, such as kinematics, chemical abundances, ionization structure, etc. On the other hand, the spatially-resolved intensity and kinematics of the HI line provide information about the cold gas reservoir, constraining the total amount of gas available to form new stars, as well as possible flows into and out from the disk. On larger scales, they also trace the mass of the dark matter halo and the possible interaction with neighbouring galaxies. A large set of data on about 70 galaxies has already been taken, and they are currently being reduced. Our team is playing a leading role in the process, and has already contributed to improve the official pipeline of the instrument. We will also be deeply involved in the scientific analysis (in particular, the interpretation in terms of chemical and spectrophotometric models), which will constitute the basis of the Ph.D. thesis of PC, supervised by YA and ALS.

II.1.2. WEAVE-APERTIF

The WEAVE-APERTIF survey will obtain intermediate resolution (R=2500) data from 3600 to 9500 Angstrom for about 400 galaxies over a 7-year period, as well as high spectral resolution (R=10000) observations in the spectral ranges 4000-5000 and 6000-7000 for approximately 100 of these objects, using the WEAVE IFU at the William Herschel Telescope in La Palma. Our targets will be selected from the APERTIF Shallow and Deep imaging surveys carried out with the upgraded receivers of the WRST telescope, which is expected to yield of the order of 10^4 galaxies with resolved HI data. Our optical selection criteria will ensure an adequate coverage of the colour-magnitude diagram with sufficient signal-to-noise to carry out exquisitely detailed studies of the stellar and gas components, especially for the sub-sample observed at high spectral resolution. The larger sample, on the other hand, will make possible to carry out a systematic study of the physical processes regulating star formation as a function of HI morphology (regular, lopsided, or disturbed), stellar mass, specific star formation rate, and local environment (in terms of galaxy number density). We are currently taking part in the definition of the survey strategy, the sample characterisation, and the quality control of the data. We will also take an active part during the commissioning and science verification phases when the WEAVE instrument sees its first light (foreseen for 2020) and then in the scientific exploitation of the survey.

II.1.3 Archival data

We will supplement our IFS data set with additional, publicly-available observations from different sources, such as e.g. CALIFA, MaNGA, SAMI, AMUSING, and the ESO archive of MUSE observations. We have already compiled a sample of more than eight hundred galaxies and analysed them with a common pipeline based on Pipe3D (Sánchez et al. 2016a, 2016b) to build a homogeneous data set. Optical observations will be cross-correlated with different catalogs in the radio (e.g. NVSS, VLASS, LOTSS, ALFALFA), infrared (2MASS, WISE), ultraviolet (XMM, GALEX) and X-ray (XMM, Chandra) bands. We will first make a statistical analysis of these data, trying to derive robust constraints on the star formation activity of galaxies in the nearby universe and the relation with their local and global properties. We will also refine our current methodology to derive the star formation history, taking into account multi-wavelength data, and explore different parametrisations to better characterise ageing and quenching processes. The observations with highest spatial resolution will be used to study individual supernova remnants in detail and calibrate a method to identify these objects in galaxies farther away from us. Finally, our multi-wavelength sample compiled here will be instrumental in order to classify nuclear activity in objective III.3.

II.2. Upgrading our population synthesis models

Team: MM, YA, PRP, MGV, MCS, MSL, JMG, PP, ALS, IMY, MR, PC, AID, SDP, JI, LD

II.2.1. Update of HR-PyPOPSTAR code

We are currently rewriting our population synthesis code POPSTAR in the Python language, with a modular structure that facilitates the modification of each individual component of the external input required by the algorithm (Millán-Irigoyen et al. in preparation). This update of our model will extend the stellar population synthesis towards the high-energy (UV and X-ray) regime, and make detailed predictions for the continuum and line emission arising from

the cold (radio), warm (optical), and hot (X-ray) gas phases, mimicking the technical characteristics of specific instruments. We will take into account the population of high- and low-mass X-ray binaries (Cerviño et al. 1997, Cerviño & Mas-Hesse 1999, Lehmer et al. 2010) as well as systems undergoing a cataclysmic variable phase (Knigge et al. 2011). This is an important part of IMY's Ph.D. thesis (MM, YA), due in 2022.

II.2.2 Fine tuning for SIGNALS and OFIUCO.
We will do a fine tuning of the resulting HR-PyPOPSTAR to be applied to the spectra obtained by SIGNALS and OFIUCO collaborations, in order to interpret the evolution and stellar populations of galaxies observed at very high spatial and spectral resolution. We will also make changes to the wavelength range and resolution so that they can be easily adaptable to other instruments.

II.2.3 Develop HR-POPSTAR-MEGARA.
We will do a fine tuning to also use empirical stellar libraries that will be updated to the new high-resolution spectra to be obtained with MEGARA; we have been already compiling spectra for a stellar library or catalogue. Our main aim is to produce evolutionary synthesis models with an empirical library of stellar spectra also observed with MEGARA, instead using atmosphere models. The proposed work more the first spectra are shown in García-Vargas et al. (2019). We are obtaining data with GTC-MEGARA through a filler-type program in telescope scratch time in HR-R and HR-I (R ~ 20000) setups. We have been awarded time in the past three calls, through programs GTC22/18B, GTC37/19A and GTC33/19B with a total granted of 175 hours (50+50+75) in filler-type GTC time, from which we have received up to date 76 hours (64 + 12 + 0). We have just asked for more time for next semester 2020A. Up to date we have a total of 192 complete OBs (in HR-R and HR-I). We have reduced all these 384 MEGARA spectra, which we would like to publish in the near future (Carrasco et al. in preparation). We still need a set of hot stars spectra before modifying HR-POPSTAR for computing the evolution of single stellar populations spectra in these two particular bands of HR-R and HR-I. This part is the one included within the objectives of the present Project.

II.2.4 Diffuse gas
In order to take into account the emission of the diffuse gas in the different phases of the interstellar medium, as well as the thermal emission of dust in the infrared, we will start from a grid of photoionisation models (see **Medios materiales/Material Resources**) based on the Cloudy code, extending it in wavelength towards the radio and X-ray bands, and adding models appropriate for a shocked gas. To guide our modelling, we will look for empirical correlations between the star formation history and the luminosity at different wavelengths, and test a physically motivated prescription where the temperature of the different phases is self-consistently determined from the stellar radiation field returned by POPSTAR.

II.2.5 Specific instruments
We will extend our current formalism to simulate the performance of specific instruments in the optical (Guidi et al. 2018) to account for the main characteristics of current and forthcoming facilities, such as the SKA and its pathfinder experiments (e.g. APERTIF, WALLABY) in the radio band; Chandra, XMM, eROSITA or Athena in the X-ray regime; or Fermi and CTA in the gamma-ray regime.

II.2.6 Analysis of galaxies with FADO.

Within our collaboration with the Oporto group (JMG), as part of the PhD work from IMY, we will make use of the SED from HR-PyPOPSTAR. This task aims to apply them to intermediate/high-redshift galaxy spectra from VLT/MOONS (Cirasuolo et al. 2014). MOONS is a multi-object spectrograph with ~1000 fibres deployable over a FoV of ~500 square arcminutes. The total wavelength range goes from 0.6 to 1.8 microns. The instrument will have two modes, a low to medium resolution mode (R~4,000-6,000) and a high-resolution mode: one around the CaII triplet (at R~9,000) and a second at R~20,000 in the H-band. This data will allow us to observe early time galaxies thus providing a view of the evolutionary path of these objects. This subproject can be subdivided into two parts:

i) Simulate realistic mock-galaxies using the HR-PyPOPSTAR evolutionary synthesis models to test the reliability for recovering the physical and observed parameters of galaxies (e.g. mean stellar age, mean stellar metallicity, and abundances). These synthetic SEDs will be created using different SFHs with simple SFH parametrizations (e.g., continuous star formation at a constant star-formation rate SFR, exponentially declining SFR with an e-folding timescale between 0.1 and 10 Gyr or even delayed SFR functions) or non-analytical function of the SFHs for random bursts or adopted from post-treatment of cosmological simulations.
ii) Use HR-PyPOPSTAR as inputs to the population spectral synthesis code FADO (Gomes & Papaderos 2018) to estimate non-parametrically the star formation and chemical enrichment histories of several thousands of galaxies from MOONS.

II.3. Non-thermal processes in galaxies
Team: YA, AID, MSL, NL, MS, ER-UAM1, MASC, DG, SZ

II.3.1 Milky Way Galaxy
Taking into account the propagation of cosmic rays and the associated radiation represents a major improvement to our theoretical modelling. We will use specialised software (DRAGON) to predict the spectrum of relativistic particles and address their effect in the context of galaxy formation and evolution. More precisely, we will first consider a standard model of the Milky Way galaxy, well calibrated against radio and gamma-ray observations (Gaggero et al. 2015, Albert et al. 2018), and compute the heating and ionisation rates in different regions of the Galaxy, as well as the pressure gradient and its effect on the rotation curve and scale height of the disk. Then, we will constrain the properties (injection rate, spectral energy distribution) of the additional sources that would be necessary to explain the anomalies observed in the high-energy range; in particular, the electron and positron spectrum at high energies.

II.3.2 AGN
Here we will start by investigating the effect active galactic nuclei from a phenomenological point of view. Based on our compilation of multi-wavelength data (II.1.3), we will carry out a thorough statistical analysis of the correlations between star formation, AGN activity, and the luminosity at different wavebands. We will then combine this information with the grid of theoretical models developed in I.2 to provide the necessary astrophysical input (gas densities, supernova rates, etc.) to build a realistic model of cosmic-ray propagation in different kinds (star-forming, passive, AGN) of galaxies in the nearby Universe.

II.3.2 CNSFR
Independently of AGN activity, it is not uncommon to find rings of vigorous star formation within the circumnuclear regions of spiral galaxies. We will use different spectral signatures in order to estimate the dynamical mass of the circumnuclear star-forming regions (CNSFR) and their chemical abundances, as well as to constrain the properties of the stellar population and the ionising radiation field. We will also try to detect and characterise the flow of gas in the nuclear region. Special attention will be devoted to disentangle the emission arising from CNSFR, diffuse gas, and AGN. Multi-wavelength observations will be used to calibrate a theoretical interpretation in terms of energy balance. The work in this task will be carried out in the context of SZ's Ph.D. thesis.

III. Star formation throughout the history of the Universe.
III. 1. Studying the gas feeding star formation at different redshifts

III.1.1. Gas around local galaxies in emission lines.
Team: JSA, CMT and ER-IAC1

The study will be based on existing IFU data, complemented with GTC observations of selected targets. The MUSE data are already available, including galaxy catalogues (Urrutia et al. 2019). Techniques to extract faint emission lines from the MUSE cubes are ready (e.g. Akhlaghi and Takashi 2015). Once the signals are detected (either in individual galaxies or by stacking), we will apply conventional diagnostic techniques to derive metallicities (Pérez-Montero 2017) and Doppler shifts. (One advantage of using the optical lines is the availability of well-tested diagnostic techniques.)

III.1.2. Local correlation between metallicity other physical parameters.
Team: LSM, JSA, CMT, BGE, DME, AB, MM

The MANGA data cubes are already available. The IAC is a 'Participating Institution of the SDSS Coll.', thus, we have privileged access to the data. We do have the know-how to extract 2D maps of physical parameters (Sánchez-Menguiano et al. 2019), hence exploring correlations between SFR and other parameters should be straightforward. We will apply Machine Learning techniques to obtain the relative importance of the parameters characterising the gas (Sánchez-Almeida et al. 2010, Garcia-Dias et al. 2019).

III.1.3. Analysis of Numerical simulations
Team: JSA, CDV, CMT, AVP and LSM

To develop physical intuition on the cosmological gas accretion process. Realistic numerical simulations are publicly available (Schaye et al. 2015). We already have experience with them (Ceverino et al. 2016, Sánchez-Almeida & Dalla-Vecchia 2018, see Figure 4). We will continue this line of work to link observables with key parameters of the model.

III.2. Understanding star formation at different z, from multi-λ photometric information.
Team: CMT, MMH, JRE, JMA, NC, DS, ER-IAC1

The work done in SHARDS can be applied to the much larger PAU survey. This will give us a larger field, which will achieve much more general results, free from cosmic variance. In particular Luminosity Functions, Star Formation Rates, Mass Density Functions, clustering trends, classes of sources with machine learning, etc. will be derived for a larger survey such as the PAU survey.

III.3. Quantifying SF feedback.
Team: CMT, JMA, CF, JRE, JSA, GTT, SS

As shown by Tenorio-Tagle et al. (2005, 2007), Wunsch et al. (2008) and Silich et al. (2010), the assembly of massive galaxies may evolve in a positive star formation feedback mode. Theoretical models have shown that three different hydro-dynamic regimes may happen: (1) quasi-adiabatic super-galactic winds; (2) bimodal flows, with mass accumulation in the central region and gas expulsion from the outer zones of the assembling galaxy; and (3) the gravitationally bound regime. Which of the three possible solutions takes place depends on the mass of the star-forming region, its mechanical luminosity (or star formation rate), and its size (Silich et al. 2010, Tenorio-Tagle et al. 2010, Muñoz-Tuñon et al. 2013). For stellar clusters evolving under case (2) the value of the stagnation radius defines the volume in which the reprocessed material is retained. Outside the stagnation radius, the classical adiabatic wind solution holds (Chevalier & Clegg 1985). These different regimes can be distinguished by accurately measuring the different components of the emission lines. More specifically, the bimodal stage would be distinguished by the presence of broad, mildly intense, emission lines at the same velocity.
We will use long slit HR spectra taken at the INT and WHT with IDS and ISIS of a parent sample of ELG in COSMOS (Hinojosa-Goñi et al. 2016) and Extremely Metal Poor galaxies (XMP, Morales-Luís et al. 2011). The emission lines will show 1) presence of multiple components, and 2) presence of broad and narrow line components at the same velocity. We will also implement Deep Learning algorithms to classify the emission line profiles.

III.3.1. We will apply for WEAVE observing time in its mIFU mode with HSR for the sample of ELG at $z < 1$ in SHARDS (Lumbreras-Calle et al. 2019a).
III.3.2. We will use the TKRS (Wirth et al. 2004) long-slit data already available for a subsample of ELGs in GOODS-N. The spectroscopic data will be complemented with the HST images to identify the clump(s) in each galaxy responsible for the emission.
III.3.3 The SED of the clumps will be used to derive mass following Lumbreras-Calle et al. (2019a). The line emission will provide a dynamical mass, assuming virialization. The

agreement/discrepancies will be further analysed in the context of the SF feedback from our theoretical studies.
III.3.4 The structure of the host galaxies will also be considered in the analysis. For that we will use the results and algorithms already developed in Estallidos 6 (Lumbreras-Calle et al. 2019b; Putko et al. 2019).
III.3.5 Other parameters like the relative location clumps in the galaxy and their metallicity will also be considered (Muñoz-Tuñon et al. 2014, Sánchez Almeida et al. 2013, 2016).
The samples were obtained during the PhD works of four former PhD students. The topic is important, the database available and the observations planned feasible. The needed development and analysis makes it ideal for a PhD Thesis. We ask for a pre-Doctoral grant.

III.4. Star Formation in the Epoch of Re-ionisation.
Team: JRE, MMH, CMT, DS, AB, ER-IAC1

We have been granted GTC time to observe a sample of Lyman Alpha Emitters (LAEs) with very large equivalent widths. We expect these sources to be Lyman Continuum (LyC) leakers. The double Peak has been interpreted as produced by a bubble of ionised gas. The size of this bubble can be determined by the separation of the peaks. Moreover, the relative intensity of the peaks is related to the LyC leakage. Indeed, if Lymanα can escape, LyC photons must also be able to escape (Shapley et al. 2003). Thus, characterising these double peak galaxies we will be in a position to ascertain the number of LyC photons and compare them with those required to re-ionise the Universe.

IV. Characterising ultra high-ionizing starbursts in the present and young Universe
IV.1. Deciphering the physics of the strongest LyC leakers.
Team: JMV, JIP, PhD-IAA, EPM, RAB, SDP, LSP, RMM, AAP

This objective is already ongoing: two observing proposals with XSHOOTER/VLT and MEGARA/GTC have been awarded observing time; XSHOOTER data provide integrated spectra at intermediate spectral resolution for our southern targets, in a wide spectral range (optical+NIR). MEGARA is used to obtain deep IFS of our northern targets with high spatial and spectral resolution, sampling from [OII]3727 Å to [NII]6584 Å with the available VPHs. First data for 6 targets of our LyC leakers sample have been already collected with XSHOOTER and MEGARA. Kinematics, physical conditions, and ionization structure of their ionized gas will be derived from the emission lines in the spectra.

IV.1.1**.** We will complete the observations in 2020, so two observing proposals will be resubmitted next year. Now reduction has started for the first data and the analysis will proceed in 2020-21. Hopefully new data will come during 2020, so this year the data reduction should be completed.
IV.1.2 Some MEGARA runs were obtained in 2019 in service without optimal observing conditions and they will be repeated by GTC. During 2021 full analysis of the observations will be achieved and the first publications will be already in place.
IV.1.3 In 2021-22 tailored photoionisation models and abundance analysis will be done (HII-CHI-mistry) to explain the gas physical-chemical properties and fraction of escaping photons, plus the publication of this work.

IV.2. The origin of the nebular HeII emission.
Team: CK, PhD-IAA, JMV, EPM, JIP, SDP, AAP, LSP, RMM

We have already initiated a project with MEGARA/GTC to observe local and intermediate-redshift HeII-emitters. The data cube for PHL293B, a z~0 highly SF HeII-emitting galaxy, are already in hand; we were awarded 12.42 hrs to observe IZw18 – one of the most meta-poor HeII-emitters known in the local Universe; 27.1 hrs are allocated from MEGARA GT to observe HeII-emitters at z~2-3 selected from VUDS (Tasca et al. 2017). Similar methods to those used for us (Kehrig et al. 2015, 2018) will be employed. By adding all the HeII-emitting spaxels, we will derive the total HeII-ionizing photon flux (Q(HeII) free from aperture effects thanks to the IFS. Next, we will compare the observed Q(HeII) with state of the art stellar models which take into account key ingredients in the evolution and content of massive stars,

specially at low metallicties (e.g., binarity, rotation, top-heavy IMF; Yoon et al. 2012; Szecsi et al. 2015; Eldridge et al. 2017). This will allow us to put strong constrains on the ionising sources, and metal-poor stellar models, an essential step to better understand the physics behind the HeII ionization in low metallicity nebulae. The following actions will be done:

IV.2.1 In 2020, the work on PHL293B will be published and the data reduction of IZw18 and of the VUDS HeII-emitters data cubes will be started.
IV.2.2. In 2021, we will analyse the MEGARA data cubes obtained, and submit observing IFS proposals (MEGARA, PMAS, MUSE) in order to study the new candidates which will be found, using data science tools (RMM is Dr. in data science), from our guaranteed (IAA is institutional partner) access to JPAS survey (http://www.j-pas.org/survey/survey) on which we are deeply involved.
IV.2.3. In 2022 we will complete the described work and submit several publications based on the analysed data.

IV.3. Characterizing extreme EW([OIII]5007)-emitters.
Team: JMV, RAB, PhD-IAA, EPM, JIP, CK, SDP, AAP, LSP, RMM

Our team has published several seminal papers on these sources (e.g. Amorin et. 2010, 2012, 2015). In this goal we will study ionised gas chemo-dynamics deriving the physical properties and chemical abundances for each one of the different velocity gas components, associated to the expected massive (in/out) flows (Bosch et al. 2019).

IV.3.1 Spectroscopy (GEMINI, MEGARA, EMIR) of a sample of extreme targets selected from available catalogues (SDSS, zCOSMOS, VVDS) is being obtained in 2020 with our collaborators (U. La Serena, Chile; U. La Plata, Argentina; CAUP, Porto). First GEMINI data were in hand and the first paper has been already published (Bosch et al. 2019).
IV.3.2. In 2020, the reduction of new coming data will be performed, and observations of new candidates from the JPAS survey will be obtained; these activities will continue in 2021.
IV.3.3 In 2022 the follow-up IFS of the entire sample of new EW([OIII]5007) emitters, and their chemo-dynamics study will be completed.

The content of items IV.1, IV.2 and IV.3 above, and their objectives, constitute the thesis program of the PhD student we request in this application for the subproject of IAA-CSIC**.**

V. Evolution of star-forming galaxies in dense environments near and far
V.1. The final fate of interstellar gas.
Team: JMV, ER-IAA, JIP, JAC, EPM, PP, SDP, AFM, DRP, LSP, RMM

This objective starts with an observing proposal already accepted by the TAC of the Calar Alto Observatory (with PPAK at 3.5m telescope) to cover the first cluster of our sample: A1367. These observations will provide spectral information with 100% spatial coverage of the sample galaxies in A1367; this will make possible a detailed analysis of the spatial distribution and the chemical evolution of the star formation regions (using the emission lines Hα, Hβ, [OII]3727Å, [OIII]4363Å, [OIII]5007Å, [NII]6583Å, [SII]6717,6731Å). In addition to this, we will relate the ionised gas content (from PPAK data), with their neutral (HI) and molecular (H_2) content (data already in hand). This way, we will extract information about the physical mechanisms altering the gaseous content of galaxies suffering from environmental effects in dense environments, and at which stage of their infall they do act. The following specific objectives are defined:

V.1.1 Given that the HI and H_2 data of our sample galaxies are already available, we will focus on the reduction and analysis of the PPAK data as soon as they start arriving. Data reduction will make use of the CALIFA pipe-line (most members of the IAA scientific team were part of the CALIFA team).
V.1.2. We will also use the FADO code (http://www.spectralsynthesis.org) to decompose and fit the stellar and gaseous contributions of the observed spectra. This will be carried out with our collaborators from Porto University CAUP (also members of the PPAK proposal). **The work of the postdoctoral experienced researcher, ER, we request is much needed**

here.The final phase of interpretation and paper production will need a strong interaction between both teams (IAA – Porto Univ.), so some meetings in Granada and/or Porto are expected in 2020 – 2022. We expect the first publications starting 2021, and during 2022.

V.2. Is there a break point in the evolution of cluster galaxies?
Team: JIP, ER-IAA, JMV, CMT, SDP, DRP, JAC, LSP

This goal is related to a recent observing proposal already submitted for the multi-object spectrograph EMIR @ GTC for the scientific verification phase of the instrument. The first observations should come soon, and we plan to resubmit the full proposal to the next calls to get a complete sample of clusters. The data will provide the Hα emission line of the cluster galaxies, so that we will be able to ascertain the membership of the galaxies to the clusters, as well as the star formation intensity and an estimation of their metallicity from the [NII]6583Å line close to Hα. This research has the following specific objectives:

V.2.1 Depending on the success of the proposal in the Time Allocation Committees, we plan to submit it from 2020 to 2022 (until we get the complete sample of clusters to carry out the project). We hope to have the first observations to arrive starting 2020, so that year would be dedicated to data reduction (depending on the complexity of the data, this phase could extend out to 2021).
V.2.2. From 2021 on we will perform the analysis of the data for this sample with the help of the postdoctoral researcher ER, and then prepare the first publications.

The complexity of the EMIR data reduction, and subsequent analysis (mainly in the MOS mode), to be carried out (see V.2) together with the front-line work to be performed with the application of the FADO code for the complete survey of cluster galaxies (see V.1), **requires to contract one experienced postdoctoral researcher ER** for the subproject at IAA-CSIC in order to achieve these necessary tasks.

VI. Advanced Intrumentation for extremely large telescopes

This is a transversal action of this project involving the previously described objectives. During the last years our team *Estallidos-IAA* has invested great efforts in the development of instrumentation for large telescopes; in particular, the multi-object spectrograph MEGARA for the 10.2m GTC. This instrument is working since summer 2017, and it is now producing good-quality data, a great achievement for our team, which benefits of GT observations.

This success encourages us to continue on this working line, and presently we belong to one of the working groups for the development of the multi-object spectrograph MOSAIC (http://www.mosaic-elt.eu), that is expected to be delivered in 2027 to the 39m ELT (Extremely Large Telescope); without doubt this is the largest future telescope in the world. When completed, this spectrograph will enrich our research on the physics of the youngest galaxies in the universe (http://www.mosaic-elt.eu/index.php/science/46-science-team). The goals of this task are mainly (but not only) related to the technological development in itself: our team in the IAA is involved in the **Electronics and Instrument Control System working group**, so an important part of the work will be done in close contact with engineers and researchers of this institute; but we will also work with researchers of other institutes members of the MOSAIC consortium. In addition, our science team is responsible of the definition of the challenging science case presented for the AGT. Once the instrument is finished (2027), **our Estallidos team will profit from the agreed guaranteed time** (AGT) to pursue research on the evolution of youngest galaxies in the Universe. The participation in the development of MOSAIC represents a new technological challenge for our team. Given that the scientific exploitation of the data is far from now (2027), currently we are mainly focused on the technological aspects; without forgetting the preparation of the future science case, though.

Working plan: Our team will be in charge of this technical goal (lead: JIP, JIM, HMM; **control of cryogenic mechanisms in the NIR spectrographs);** our science team will keep working in the definition of the challenging science case for the AGT. During the 2020-2022

period, we will be engaged in the definition and construction of a prototype, according to ESO-consortium standards; and a number of working meetings (in Granada, Toulouse, and several other places) are expected.

Medios materiales/material resources

All the nodes can make use of the facilities that each institution makes available to them, including computing facilities, access to the different databases and archival data and supercomputer facilities (UAM: Centro de Computación Científica). All the researchers at the different nodes can apply for observing time at the different national ICTS on a competitive basis as well as to ESA and ESO time and other infrastructures in open access regime. All the nodes possess the necessary software to reduce and analyse the secured data.

Photoionisation models.

We have also tools already developed that all members of the collaboration can use as the photoionisation models. These models constitute an important tool to interpret the observed emission-line spectra observed in many star-forming galaxies. Our group has extensively used this computational technique to derive both physical properties and chemical abundances in different types of environments adapting it to various observational techniques including long-slit spectra and integral field unit observations.

The code HII-CHI-mistry (Pérez-Montero, 2014) leads to the derivation of the chemical abundances of oxygen and nitrogen, which are tracers of the past chemical evolution of an object, and of the ionisation parameter, that is indicative of the relative density of radiation and particles in the ionised gas. This program consists of a bayesian-like comparison among all the results from large grid of models with the measurements of the relative emission-line intensities from the gas and it is totally consistent with the so-called direct method, that is the most precise methodology to derive abundances using the optical emission-line spectrum. However, the direct method has the disadvantage that relies on the measurement of distinct weak emission lines not always detectable in low-surface brightness regions of galaxies or in metal-rich environments, when the gas is usually cold and has very low emissivity, so the use of an alternative method is mandatory in cases when only strong-lines are detectable. This code has been applied to different sets of observations and surveys, such as) SDSS (Florido et al 2015) for integrated galaxies, and also in the case of different pointings of IFS such as CALIFA (Pérez-Montero et al. 2016) or MUSE observations (Kumari et al. 2018).

A version of the code in the ultraviolet part of the spectrum (Pérez-Montero & Amorín 2017) for high-redshift galaxies also leads to precise determinations of oxygen and carbon abundances, which are the main tracers of the chemical evolution that can be derived using this spectral range. This has been already applied to samples such as the VIMOS Ultra Deep Survey for a redshift $2.4 < z < 3.5$ (Amorín et al. 2017). Other extensions of the same project include the application of a similar version of it to derive other functional parameters, such as the effective temperature of the incident field of radiation (Pérez-Montero et al. 2019a), or the application of the code to derive chemical abundances in objects ionised by non-thermal radiation sources, such as Narrow-Line Regions in Seyfert 2 galaxies (Pérez-Montero et al. 2019b).

Among others, we may use it to study *Galaxy disk abundances:*

- *Consistent determination of total oxygen and nitrogen-to-oxygen* abundance ratios from bright and weak emission-lines using the code HII-CHI-mistry to depict a whole picture of the spatial radial and azimuthal galactic variations to serve as input in the chemical evolution models. (EPM, JVM).
- Design of tailor-made photoionization models and bayesian-like comparison between large grids of photoionization models and the integrated most prominent emission-lines in the rest-frame ultraviolet part of the observed sample to quantify the fraction of escaping photons, the nature of the ionizing radiation and the carbon-to-oxygen and the total oxygen abundance (EPM, JMV, CK, PhD1, LSP, RAB).

Contratación de personal

Subproject CIEMAT is requesting for two post-doctoral contracts (ER-CIEMAT1 and ER-CIEMAT2) to do some of the tasks already described.

The first contract, ER-CIEMAT1, refers to the adequate extraction of information of a grid of chemical evolution models and the comparison of results for a set of theoretical galaxies of different masses and morphological type with observational data and other cosmological hydrodynamic simulations. Therefore, she/he would also need to produce a catalogue of all type of data: abundances, stellar populations, infall rates, gas and stellar densities, SFR, colors, etc, which is now feasible but hardly due to the large number of IFU projects with available data. This will need the coordination with members of the IAA and UAM, and also with our collaborator in Australia (ALS), to analyze and complete a data base for low mass galaxies compiling observations from the HI-KIDS survey and other sources. We, therefore, need finantial support for a postdoctoral post for three years.

The second one, ER-CIEMAT2, will be devoted to modify the prescriptions for the star formation so that it starts from first principles, and thus we transform the molecular clouds into stars in a realistic way. The life cycle of dust grains, the energy and momentum injection by supernova remnants, and novel ingredients such as cosmic rays, magnetic fields, and high-energy radiation, must be taken into account when in order to follow the cooling of the gas and the SF process. The contract will be CIEMAT and the selected postdoc will have to work also in connection with other projects of the department, (in particular the CTA working group). They will contribute with their expertise in γ-ray astronomy and cosmic rays astrophysics, to his/her training, providing substantial added value to the project and enhancing its competitiveness (in both training and scientific terms) by including this transversal vision.

Subproject UAM requests funding for two experienced researchers (ER-UAM1 and ER-UAM2).

ER-UAM1 will play a major role in our investigation of non-thermal processes (II.3.1 and II.3.2), and therefore a strong background in high-energy astrophysics, (astro-) particle physics, and ideally cosmic ray propagation will be required. The work will be carried out in close collaboration with the members of the *Instituto de Física Teórica* UAM-CSIC involved in this project and the CTA group at the CIEMAT. Depending on the candidate's background, complementary training in astrophysics or particle physics will be provided. This multidisciplinary work, which is a groundbeaking aspect of the project, will be carried out in close collaboration with the members of the *Instituto de Física Teórica* UAM-CSIC recently incorporated to the team as well as with the CTA group at the CIEMAT.

ER-UAM2 will have an observational profile, and most of their work will be devoted to the scientific exploitation of optical integral-field spectroscopic data, mostly from PMAS/PPAK, MUSE, KOALA and WEAVE instruments, in Objective II.1. Experience with this kind of observations (and/or multiobject spectroscopy) in the context of large galaxy surveys will therefore be required. The tasks assigned to both ER-UAM offer ample opportunities for co-supervision of graduate and undergraduate students, and the candidate will be strongly encouraged to take advantage from them.

The Ph.D. thesis of AC, supervised by YA and AID since February 2019, focuses on the characterisation of supernovae and supernova remnants using IFS data. The first results on the delay time distribution of different supernova types are about to be submitted for publication, and will be used in the prediction of supernova rates in the chemical evolution models (I.2) and the studies of cosmic-ray propagation in nearby galaxies (II.3.2). Collaboration in the compilation and analysis of additional data (II.1.3) will take place from the very start of the project, and the results related to resolved supernova remnants in individual galaxies, as well as the identification of unresolved candidates in the whole sample, will constitute the basis of his Ph.D. thesis, due in February 2022.

The early-stage researcher PC will carry out a Ph.D. thesis within the context of the HI-KIDS survey (II.1), starting in February 2020. He will receive training and be responsible for the reduction and analysis of the data that we have already gathered, as well as help with additional observations and the development of the pipeline of the KOALA instrument. Scientifically, the main goal of the Ph.D. thesis is to investigate the mechanisms that regulate the conversion of gas into stars. YA and ALS supervise him in the framework of the Cotutelle programme of Macquarie University, who has already signed an institutional agreement with the UAM in this respect. The researcher will be considered both an Australian and a Spanish Ph.D. candidate to all effects and will obtain to a title in each university. The doctoral period will be split evenly between both institutions, and financial support is only requested for the 18 months that it will be carried out at the UAM.

Subproject IAA. The IAA node is requesting one esperienced researcher postdoc, ER-IAA, and one PhD student, PhD-IAA. The justification for the PhD student is given in Capacidad formativa. One experienced postdoctoral (3 years) contract (ER-IAA) is requested to carry out the tasks of objective V leaded by this subproject. This objective includes the study of the interstellar medium of cluster galaxies in the local Universe (V.1), and the evolution of cluster galaxies from high to low redshifts (V.2). According to the methodology and working plan described for this item, the requested ER-IAA will dedicate the time to both taskes (50% to each of them). Regarding V.1, the main duties will be: i) to analyze the optical spectra of the galaxies observed with PMAS/PPAK, ii) operate as the interface with the Univ. Porto group, developing all the work of spectral decomposition to be done with FADO, iii) combine the multiwavelength information of the galaxies available, and complete the analysis including optical/radio data. Concerning V.2, the main duties associated to the ER will be: iv) carry out the data reduction and the analysis of the data observed with EMIR @ GTC, v) complete the compilation of the observed galaxies and the derivation of their main properties. It is expected that this postdoc will actively contribute to the discussion and to the writting of the papers issued from both topics.

The required profile must include: (i) experience in the field of galaxy evolution; (ii) experience in the physics and properties of galaxies located in dense environments; (iii) solid experience in observational Astronomy, mainly optical and NIR spectroscopy, since this will be absolutely necessary during all phases of the contract.

Subproject IAC is requesting two PostDocs, ER-IAC1 and ER-IAC2, and two PhD students. PhD-IAC1, PhD-IAC2. The justification for the students is given in **'Capacidad Formativa'**.

ER-IAC1 will be responsible for completing Objective III.1.1.The data are already available, but we need someone with the expertise and independence to used them for the science purpose. It is a project for someone with a solid formation in galaxy astrophysics, even though the work will be carried out in close collaboration with JSA and CMT. The know-how of BGE and DME for interpretation of results will be fundamental. We do not have manpower to complete this objective without her/his workforce.

ER-IAC2 will be responsible for completing Objective III.4. She/he will be responsible of the data analysis of the GTC spectra granted to our team to observe a sample of LAEs with very large equivalent widths. We expect these sources to be LyC leakers and, thus, we will be in a position to ascertain whether these are the sources that re-ionised the Universe. She/he will work in collaboration and under the supervision of JRE, CMT and MMH. We do not have manpower to complete this objective without her/his workforce.

3. IMPACTO ESPERADO DE LOS RESULTADOS - *EXPECTED RESULTS IMPACT*

ESTALLIDOS and its members have been always characterised by their compromise with a continuous transfer of both skills and knowledge to the members of the group, and to the rest of the community, by means of their participation in other astronomical collaborations devoted to new facilities or scientific goals, and the immediate publication of the acquired results and methodologies. The four nodes (IAC-IAA-UAM-CIEMAT) of ESTALLIDOS keep a

commitment to disseminate the main results arising from our scientific activities, following the main guidelines of this diffusion plan.

We will focus on the diffusion of our results among the members of the scientific community. Our findings will be published, as we always do, in top impact journals (e.g. MNRAS, A&A, ApJ, AJ, etc.), therefore the results visibility is high in the international scientific community. Also, the members of ESTALLIDOS will attend the most straightforward scientific meetings and workshops to present our results, whenever possible in the form of review or invited contributions. In addition, as we know of the importance of becoming a world-leading group in our research area, we plan to participate at the highest level in the organisation of international collaborations and networks, and to become members of advisory panels of institutes, journals, facilities (telescopes/instruments), etc. An international conference organized (mostly) by ESTALLIDOS members will be proposed for the last year of the duration of the project. We have started to organize a conference as part of an EWASS meeting or an IAU symposium. Press releases will be done for special relevance results.

The results of simulations, observations, new codes, etc. will be publicly available by the adequate interfaces, such as the Virtual Observatory, webpages of the corresponding journals, or other resources created "ad-hoc". In particular, we are preparing SPiCE, a GIT-HUB page that will include our updated chemical and spectrophotometric models. The code will be prepared with modules, each one computing a different part of the whole galaxy or region evolution. The idea is to create a platform with an *open source code* to do *open science*: our calculation methods may be available for everybody in the astronomical community.

We will continue organizing public outreach conferences, mainly during the workshops of the collaboration. Other activities that we will continue doing are related with the participation in the institutional activities: events and sessions that all our institutions will organize along the year. We consider that the transmission of the results of our research must be shared with the society at all the possible levels. For that, we use as main tool, our web page with a section devoted to our outreach activities. (http://estallidos.iac.es/estallidos/).

4. CAPACIDAD FORMATIVA - *TRAINING CAPACITY*

Subproject CIEMAT

The CIEMAT requests one predoctoral contract, PhD-CIEMAT, in order to work on task related with the 2D-MULCHEM model and its implementation in a hydrodynamical simulation code. This will form part of a new PhD Project, co-supervised by MM and YA. Furthermore, the student will have the possibility to work partially in the University of Hull with BKG's group.

In the last 10 years, 3 Ph.D. theses have been completed:

- 05/2009 Evolución de galaxias enanas aisladas
  Marta Gavilán Bouzas (AID & MM)
  External collaborator, UAM
- 05/2009 Emission-Line Star-forming Dwarf Galaxies: Self-consistent Evolutionary Models
  Mariluz Martín Manjón (AID & MM)
  Consultant at Digital Strategy (Banco Bilbao Vizcaya Argentaria),
- 07/2016 Study of the relation between the SNIa luminosity with host galaxy metallicity
  Manuel Emilio Moreno Raya (MM & ALS)
  Secondary school teacher
- In process: Evolutionary Models of galaxies: spectral energy distributions, star formation and the relation with the high energy emission
  Iker Millán Irigoyen (MM & YA)

Subproject UAM

The Astrophysics group at the UAM provides an excellent environment, encouraging collaboration between researchers of different fields and nationalities, and former students have been fully integrated in large international collaborations and profited from different research exchange programmes to visit foreign institutions. In the context of the previous

project, a new predoctoral post started to work in his Ph.D. thesis, being co-supervised by YA and MM, who has acquired a strong theoretical background, both analytic (e.g. turbulence, atomic and molecular physics) and numeric (cosmological hydrodynamic simulations), as well as an understanding of the observational data needed to provide a meaningful interpretation of the results. A FPI was obtained leading to a Ph.D. thesis supervised by AID and YA, about the connection between circumnuclear SF and activity in galaxies, updating the stellar population models to quantify the different contributions to both star forming regions and the AGN to the X-ray and gamma-ray spectrum, confronting the predictions with observations and computing the energy balance in as much as possible.

Both PIs of the UAM node have significant experience in training students and early-stage researchers. YA has co-supervised 2 Ph.D. thesis, 10 M.Sc. theses, and 15 B.Sc. Theses whereas AID has supervised 18 Ph.D. students over her career, as well as 19 M.Sc. Theses, often in collaboration with other members of the research team, both at the UAM node as well as CIEMAT and INAOE. Over the past 10 years, thse Ph.D. thesis have been defended:

- 05/2009 Evolución de galaxias enanas aisladas
  Marta Gavilán Bouzas (AID & MM)
  External collaborator at the UAM
- 05/2009 Emission-Line Star-forming Dwarf Galaxies: Self-consistent Evolutionary Models
  Mariluz Martín Manjón (AID & MM)
  Consultant at Digital Strategy (Banco Bilbao Vizcaya Argentaria)
- 08/2009 A Spatially Resolved Study of Ionized Regions in Galaxies at Different Scales
  Rubén García Benito (AID)
  Postdoctoral researcher at IAA (Granada)
- 09/2010 Gas altamente ionizado en galaxias seyfert 1: interpretación de sus marcas en espectros de rayos X de alta resolución
  Mónica Cardaci (AID, MSL)
  Lecturer Universidad de La Plata (Argentina)
- 08/2013 Astrophysical signatures of dark matter
  Maneenate Wechakama (YA & Volker Müller, U. Potsdam, Germany)
  Lecturer at U. Kasetstat (Thailand)
- 09/2015 Submillimetric study of nearby galaxies
  Ilhuiyolitzin Villicaña Pedraza (Jesús Martín Pintado, CAB-CSIC & AID)
  Postdoc at New Mexico State University, New Mexico, USA
- 11/2016 A new perspective on the evolution of galaxies: from global to local scales
  Javier Casado (YA, AID)
  Data Scientist and Senior Consultant at MHP (Germany)
- 09/2018 Primordial helium abundance determination via the spectral analysis of hii galaxies
  Vital Fernández Gutiérrez (ET, AID)
  Instituto de Astrofísica, Óptica y Electrónica (INAOE), México
- 03/2019 A differential study of the massive star formation process in circumnuclear and outer disk regions of nearby spiral galaxies
  Marina Rodríguez Baras (AID, FRO)
  Universidad Autónoma de Madrid
- 07/2019 Spatially resolved photometric study on H II galaxies with different morphology
  Ana P. Torres Licastro (ET, AID)
  Instituto de Astrofísica, Óptica y Electrónica (INAOE), México

At the time of writing, the following Ph.D. theses are in progress (the date provided indicates the start of the Ph.D. thesis):

- 02/2017 Analytical and numerical models of self-regulation of the star formation activity in galaxies
  Mario Romero (YA, MM)
- 02/2018 A comprehensive study of star formation processes in the circumnuclear environment of galaxies
  Sandra Zamora (AID, YA)

- 02/2019 Extragalactic supernovae and supernova remnants in integral-field spectroscopy surveys
  Asier Castrillo (YA, AID)

Subproject IAC

The IAC node has proven experience supervising students. During the last 10 years, we have supervised 12 PhD theses and a similar number of master theses. The students formed under our guidance have significant chances of pursuing a career in astronomy or related fields; 4 of the 12 PhD students we supervised already have permanent positions (see below). Please note that the last two 2PhD students will defend their PhD theses by the end of this year (2019). The time is ripe for the group to accept new students; therefore, we are requesting two FPI grants.

Theses defended at the University of la Laguna during the last 10 years, supervised by members of the team (all of them awarded with cum laude):

- 06/2009 Calibracion Espectrofotometrica del GTC
  M.A. Di Cesare
- 07/2009 Morfología y formación estelar en Galaxias en Cúmulos cercanos
  Ruben Sánchez Janssen
  Staff at UK Astronomy Technology Centre, Edinburgh, UK.
- 07/2009 Impacto de la formación estelar en galaxias compactas azules
  Ismael Martínez Delgado
  FRACTAL SLNE
- 07/2009 Actividad nuclear y formación estelar en galaxias
  C. Ramos Almeida
  Ramon y Cajal, IAC
- 10/2009 La Galaxia Anfitriona de las Galaxias Compactas Azules
  R. Amorin Barbieri
  Staff, Departamento de Astronomia, Universidad de La Serena, Chile
- 04/2014 Search and characterization of Galaxies with the lowest metallicity
  A.B. Morales
- 05/2015 Observational properties of fossil galaxy systems from the FOGO project
  S. Zarattini
- 03/2016 Search and characterization of starbursts in the survey of COSMOS
  R. Hinojosa Goñi
  Support astronomer at Gemini observatory
- 07/2019 Precipitable Water Vapor al the Canary Island Astronomical Observatories
  J. Castro Almazán
  IAC sky characterization team
- 07/2019 Cold-Flows in the local Universe
  A. del Olmo García
- 11/2019 (expected) El papel de los estallidos de formacion estelar en laformación y evolución de galaxias
  A.Lumbreras
- 11/2019 (expected) Searching and characterisation of the high-z star-forming galaxy population in the early Universe
  P. Arrabal

Subproject IAA

To carry out the research proposed the subproject at IAA request one Ph.D. position. PhD-IAA. The IAA node is prepared to offer an atractive program for the predoctoral formation of this PhD student; the IAA presents ideal conditions for new PhD students since it offers an international research atmosphere enhanced with the traditional close links with the University of Granada. In addition, the IAA is *Centro de Excellencia Severo Ochoa* and within this framework it has created a specific commission in charge of the production and supervision of a complete program of formation activities for our students (schools, seminars, and colloquia, among others).

The PhD program for the new student to follow will be based in the physics described in objective IV: the characterization of highly ionising metal-poor galaxies; including compact objects as extreme [OIII]- and HeII emitters, and strong LyC leakers, using existing IFU data vailable to us (MEGARA/GTC, MUSE, PPAK/PMAS, SITELLE). He/she will take benefit of: i) the use of our new MEGARA/GTC observations, obtained in the science verification and guaranteed time within the framework of our participation in the construction of MEGARA; and ii) the new data already coming from JPAS (fully operational in 2020), thanks to our guaranteed access to this survey.

All the tools, communication, networks and the necessary software packages for data reduction and analysis of astronomical data (optical, IR and radio) are made available. The easy access to the telescopes of the observatories at Calar Alto and, especially, Sierra Nevada (30 mins by car), also offers a fantastic training school for the new PhD astronomers – its optical/IR telescopes together with the nearby 30m IRAM instrument, allow our students a close contact with complementary wavelength ranges-, in addition to IAA's own students training program which include advanced software programming and technology. The group in Granada has 4 senior researchers with proven experience in the formation of students at various academic levels. JMV has supervised/cosupervised 11 PhD theses, plus one ongoing, several master theses and DEAs. He is a professor of the master of Physics at the Univ. of Granada, as well as a member of the PhD program "Physics and Astronomy", and a former fellow of the Fisymat program. JIP has supervised/cosupervised four PhD theses, plus one ongoing. In addition, JIP has been responsible for several graduate students final research works at Univ. of La Laguna and also at the Granada universty, where he is a professor at the Master f Physics. EPM has co-supervised one PhD Thesis defended at University of Granada, and several master theses at the Universidad Internacional de Valencia. JAC has supervised two master thesis at University of Granada.

Below, we list the PhD Thesis since 2009 performed by former members of the IAA node, including a short summary of their positions held and current activity.

2011 Galaxy Evolution in Clusters of Galaxies with Databases of GALEX & SDSS
Jonathan Hernández Fernández (FPI)
Postdoctoral researcher, I.A.G. of University of Sao Paulo (Brasil).
since 2018+ Jonathan is a data science consultant at *Globalia group* (Palma de Mallorca, Spain).

2012 Star Formation in nearby clusters of galaxies: spectroscopic properties and metal enrichment
Vasiliki Petropoulou (FPU. Doctor Europeus).
Postdoctoral researcher at the Osservatorio Astronomico di Brera, Milano (Italy).
Since 2017+ she is a postdoc at University of Padova (Italy).

2013 Estructura de ionización y composición química de nebulosas galácticas
Alba Fernández Martín (FPI)
2014 Postdoctoral researcher at IRYA of UNAM, Morelia (Mexico).
2018+ Currently Alba is staff astronomer at CAHA, (Calar Alto Observatory).

2019 Star formation and chemical evolution of galaxies in different environments
Salvador Duarte Puertas (FPI. International Doctorate. Defence expected mid November)

Ongoing Exploring the population of emission line galaxies in the JPAS survey
Antonio Arroyo Polonio (FPI Severo Ochoa)

CRONOGRAM

Task	Lead	Team	2020				2021				2022			
			T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
I														
I.1														
I.1.1	MM	ERCIEMAT1, PSB,AID	■				■	■	■	■	■	■	■	■
I.1.2	MM	OC	■	■	■	■								
I.1.3	MM	BKG		■	■	■	■	■						
I.1.4	MM	BKG,PhD-CIEMAT					■	■	■	■	■	■	■	■
I.2														
I.2.1	MM	YA, IMY, JMV,MCS	■	■	■	■	■	■						
I.2.2	YA	MM,AID,AC, MR	■	■	■	■	■	■	■	■				
I.2.3	MM	ERCIEMAT2, YA, MS,MCS			■	■	■	■	■	■	■	■	■	■
I.3														
I.3.1	EPM	JI, JMV, SDP,MM,LD				■	■	■	■	■	■	■	■	■
I.3.2	MM	JMG,MCS,JI, LD,SDP,MGV						■	■	■	■	■	■	■
I.4	MM	MGV,JMG,MCS,JIP	■	■	■	■	■	■	■	■	■	■	■	■
II														
II.1														
II.1.1	YA	MM, ALS, LG, PC,NL,ER-UAM2	■	■	■	■	■	■	■	■	■	■	■	■
II.1.2	YA	PSB,JFB,ER-UAM2	■	■	■	■	■	■	■	■	■	■	■	■
II.1.3	YA	AID, MSL, PRP, AC, PC,NL	■	■	■	■								
II.2														
II.2.1	MM	YA,IMY,MCS, MGV	■	■	■									
II.2.2	MM	IMY,SDP,JI,LD		■	■	■								
II.2.3	MM	MGV,MCS				■	■	■	■	■	■	■	■	■
II.2.4	YA	MSL,MM,MR	■	■	■	■								
II.2.5	YA	PRP,ALS,PC					■	■	■	■	■	■	■	■
II.2.6	MM	YA,JMG,PP,IMY			■	■	■	■	■					
II.3														
II.3.1	YA	ER-UAM1,MASC, DG,MM			■	■	■	■	■	■	■	■	■	■
II.3.2	YA	ER-UAM1,NL,MS	■	■	■	■	■	■						
II.3.3	AID	MSL,SZ	■	■	■	■	■	■	■	■	■	■	■	■
III														
III.1	JSA													
III.1.1		CMT,ER-IAC1	■	■	■	■	■	■	■	■	■	■	■	■
III.1.2		LSM,CMT, BGE,DME,AB,MM	■	■	■	■	■	■	■					
III.1.3		CDV,CMT,LSM,AVP	■	■	■		■	■	■		■	■	■	
III.2	JRE	CMP, MMH, JMA, DS, NC, ER-IAC2												
III.2.1			■	■	■	■	■							
III.2.2					■	■	■	■						
III.2.3								■	■	■	■	■	■	■

III.3	CMT	JMA, CF, JRE, GTT, SS, JSA												
III.3.1														
III.3.2														
III.3.3														
III.4	JRE	JRE, MMH, DS, AB, ER-IAC2												
IV														
IV.1	JMV	JIP, PhD-IAA, EPM, RAB, SDP, LSP, RMM, AAP												
IV.1.1														
IV.1.2														
IV.1.3														
IV.2	JMV	CK, PhD-IAA, EPM, JIP, SDP, AAP, LSP, RMM												
IV.2.1														
IV.2.2														
IV.2.3														
IV.3	JMV	RAB, PhD-IAA, EPM, JIP, CK, SDP, AAP, LSP, RMM												
IV.3.1														
IV.3.2														
IV.3.3														
V														
V.1	JIP	JMV, ER-IAA, JAC, EPM, PP, SDP, AFM, DRP, LSP, RMM												
V.1.1														
V.1.2														
V.2	JIP	ER-IAA, JMV, CMT, SDP, DRP, JAC, LSP												
V.2.1														
V.2.2														
VI	JIP	JIM,HMM												

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MGV Marisa García-Vargas

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RMM Rafael Morales Muñoz
CK Carolina Kehrig
AAP Antonio Arroyo Polonio
SDP Salvador Duarte Puertas
AFM Alba Fernández Martín (CAHA)
DRP Daniel Reverte Payá (GTC)
RAB Ricardo Amorín Barbieri (Chile)
LSP Leonid S. Pilyugin (UKraine)
PP Polychronis Papaderos (Portugal)

ACRÓNIMOS/ACRONYMS:

- AGN: Active Galactic Nuclei
- CALIFA: Calar Alto Legacy Integral Field Area Survey
- CGM: circum galactic médium
- GTC: Gran Telescopio Canarias
- ER: Experienced researcher (Postdoc)
- FOV: Filed of view
- FWHM: Full width at half maximum
- HST: Hubble Space Telescope
- IFU: Integral Field Units
- IGM: Inter galactic medium
- ISM: inter stellar medium
- MEGARA: Multi-Espectrógrafo en GTC de Alta Resolución para Astronomía
- MWG Milky Way Galaxy
- MUSE: Multi Unit Spectroscopic Explorer
- PNe: Planetary nebulae
- QSO: Quasi Stellar Object
- SF: star formation
- XMP: Extremely metal poor galaxies

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