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EXCELENCIA
SEVERO
OCHOA
01-01-2023 A 31-12-2026

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

INSTITUTO DE ASTROFÍSICA
DE ANDALUCÍA (IAA)

EL IAA-CSIC OFRECE 10 CONTRATOS DE FORMACIÓN PARA REALIZAR LA TESIS DOCTORAL EN ASTROFÍSICA

El Instituto de Astrofísica de Andalucía (IAA-CSIC) busca 10 personas jóvenes interesadas en realizar su tesis doctoral con contratos financiados por el programa de formación de doctores de la Agencia Nacional de Investigación (AEI), en el marco de los proyectos susceptibles de ayudas para contratos predoctorales 2022 Severo Ochoa y María de Maeztu.

El Instituto de Astrofísica de Andalucía es un centro del Consejo Superior de Investigaciones Científicas (CSIC). Su misión es la de profundizar en el conocimiento del cosmos y acercar éste a la sociedad haciendo investigación Astrofísica y de Ciencia Espacial de vanguardia, fomentando el desarrollo tecnológico mediante la construcción de nueva instrumentación y diseminando nuestra investigación entre la comunidad científica y el público en general por medio de actividades divulgadoras.

Buscamos personas que deseen realizar su doctorado en un ambiente científico internacional, trabajando con investigadores líderes en las distintas disciplinas y en un ambiente dinámico y formativo.

OFRECEMOS:

- Contrato de 4 años orientado a la realización de la tesis doctoral, dentro de la convocatoria para la formación de doctores 2022 de la Agencia Estatal de Investigación enlace a la convocatoria de la AEI
- Formación complementaria de cursos y seminarios
- Seguimiento personalizado a través de un comité de doctorado
- Ambiente de trabajo dinámico, internacional, en temas frontera del conocimiento y de la tecnología, en un centro de excelencia Severo Ochoa (segunda acreditación)

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REQUISITOS:

Las personas interesadas en presentar candidatura deben cumplir los requisitos de la convocatoria (estar cursando un máster en el momento de la incorporación, entre otros). Por tanto, pueden presentar solicitudes para estos contratos quienes actualmente estén cursando un máster, o terminando el grado. Estos últimos deberán estar matriculados en el máster en el momento de incorporación que tendrá como fecha límite septiembre de 2024.

PLAZOS:

Presentación solicitudes en la AEI hasta el 26 de enero (14:00): https://www.aei.gob.es/convocatorias/buscador-convocatorias/ayudas-contratos-predoctorales-formacion-doctores-2022-0

CONSULTAS:

- Aspectos generales: severoochoa@iaa.es

- Cuestiones relacionadas con los proyectos ofertados: dirigirse a la persona supervisora del mismo.

Los PROYECTOS DE TESIS OFERTADOS Y las personas que los supervisarán se describen en las siguientes páginas.

Los proyectos de tesis asociados a las 10 FPI del IAA-CSIC, centro Severo Ochoa, y las personas que los supervisarán, son:

CEX2021-001131-S-20-1	Formation and evolution of planets around the nearest stars	Gabriela Gilli y Luisa M. Lara	gilli@iaa.es
CEX2021-001131-S-20-2	Atmospheres of planets and exoplanets	Manuel López Puertas y Alejandro Sánchez	puertas@iaa.es
CEX2021-001131-S-20-3	Star-planet interactions	Daniel Guirado y Carlos Carrasco	dani@iaa.es
CEX2021-001131-S-20-4	Our Sun and Solar System	David Orozco, José Carlos del Toro y Hanna Strecker	orozco@iaa.es
CEX2021-001131-S-20-5	The Galactic Center	Rainer Schoedel y Antxon Alberdi	rainer@iaa.es
CEX2021-001131-S-20-6	Black hole accretion in the context of galaxy evolution	Rubén López Coto	rlopezcoto@iaa.es
CEX2021-001131-S-20-7	Star formation in the context of galaxy evolution	José Manuel Vílchez y Ricardo Amorín	jvm@iaa.es
CEX2021-001131-S-20-8	Galaxy environment in the context of galaxy evolution	Francisco Prada	fprada@iaa.es
CEX2021-001131-S-20-9	Development of new instrumentation for state-of-the-art facilities	José Luis Ortiz y Jesús Aceituno	ortiz@iaa.es
CEX2021-001131-S-20-10	Development of new technologies for state-of-the-art facilities	Manuel Parra y Julián Garrido	mparra@iaa.es

Se ruega **contactar directamente con las personas supervisoras** (se incluye el correo).

El contenido de cada uno de los proyectos se da en las páginas siguientes.

CEX2021-001131-S-20-1
Formation and evolution of planets around the nearest stars

Gabriela Gilli y Luisa M. Lara gilli@iaa.es

PhD THESIS Project

Venus is in the spotlight of the public and scientific community after the selection of 3 missions: DAVINCI and VERITAS by NASA and EnVision by ESA/NASA. It remains an open question how Venus and the Earth started so similar but become such different worlds. Thus, studying Venus is essential for understanding the links between planetary evolution and habitability of terrestrial planets, including those outside our Solar System. Several Earth-sized exoplanets have been recently detected in short-period orbits of a few Earth days around low-mass stars. Those planets have stellar irradiation levels of several times that of the Earth, suggesting that a Venus-like climate is more likely than an Earth-like. Consequently, the atmosphere of our closest planet Venus represents a relevant case to address observational prospects of rocky close-in orbit exoplanets.

The successful candidate will be in particular involved in EnVision mission [1], notably he/she will join the international consortium of the high-resolution spectrographs VenSpec-H and VenSpec-U. She/he will use a sophisticated 3D model for Venus that has being developed since 2010 at LMD/IPSL in France, in the frame of a collaboration between different European institutions, included the IAA-CSIC, to analyze and identify potential physical, chemical, or dynamical processes driving the variability of trace gases above the cloud tops of Venus (70 km altitude, approximately). Heterogenous chemical processes will be implemented and studied, and the impact of complex cloud models and scenarios onto the water and sulphur species interpreted. These model developments will also contribute to the Venus Climate database (VCD), an on-line platform containing the meteorological fields derived from the Venus 3D Model and provides to the scientific community a climatology for many characteristics of the Venusian atmosphere from the surface to the exosphere.

In addition, a similar but simplified condensation cloud model will be implemented into a “Generic” 3D model, developed for exoplanets and paleoclimate studies, to simulate H_2SO_4-H_2O clouds “interactively” in the atmosphere of Venus-analogues around both Sun-like and M-dwarf stars, with the main goal of providing realistic predictions of future observations of cloudy rocky-exoplanets foreseen by the Webb Space Telescope and new generation instruments and facilities (e.g. ELT).

Foreseen Starting date: September/October 2023

PhD Advisors: G.Gilli and L. Lara

Gabriella Gilli

Research activity: covering a broad range of topics in Planetary Science in the last decade, from analysis of observations by Venus Express and Mars Express ESA missions, to atmosphere remote-sensing retrievals and simulations of terrestrial Solar System planets and exoplanet' atmospheres using sophisticated 3D models. More than 60 contributions including 22 SCI publications (one under review), with index H-13, leading 7 of them and being among the first 3 co-authors in 7, plus books' chapters, and a scientific Report (Redbook ARIEL).

She obtained her PhD in 2012 at IAA, Granada, and after about 3 years of postdoc at the *Laboratoire de Meteorologie Dynamique* (LMD), Paris, France, she was recipient of the EU selected Marie Sklodowska Curie Individual Fellowship (148653 €) (2019-2021) at the *Instituto de Astrofisica e Ciência do Espaço* (IA), Lisbon, Portugal, and also co-PI of project P-TUGA funded in 2018 by the Portuguese National Agency (228481 €) at IA, Portugal. In Dec. 2022 she was granted 4-year project within the program "EMERGIA" at IAA/CSIC, Granada (247000 €). Thesis 'supervision: 1 MSc, 2 PhD (on-going) and several undergraduate students. Selected to co-lead the ARIEL/ESA Working Group "Synergies with Solar System Planets" in Nov. 2019 and appointed by ESA in Oct. 2021 as member of the Science Study Team of Envision/ESA mission to Venus currently coordinating the WG "Aerobraking Science".

Luisa Lara

Research interests: Atmospheric physics and chemistry of planets and exoplanets. Time evolution of planetary atmospheres. Cometary science. Remote and in-situ exploration of the solar system bodies. Scientific instrumentation onboard interplanetary missions. Scientific career developed for 10 years in international scientific organisms and technology centers (Obs. Of Paris-Meudon FR, Max-Planck Institute for Aeronomie-MPG DE, European Space Technology Center-ESA NL). She has published 258 scientific papers accounting for 10355 citations (according to Scopus). The h-index is 55.

She has been involved in several space missions at various levels: Rosetta (ESA) OSIRIS Co-Investigator (Co-I); Herschel Space Observatory (ESA) HIFI Co-I and member of a Guaranteed Time Key Program; Bepi Colombo Laser Altimeter BeLA and SYMBIO-SYS (ESA-JAXA) Co-I; JANUS and GaLA Co-I of the JUICE (ESA) mission; CoCa, MANIaC, OPIC and Co-PI of EnVisS on board Comet Interceptor (ESAJAXA); co-PI of the VenSpec-H spectrometer and Co-I of the VenSpec suite of instruments for the EnVision mission (ESA-NASA). Member of the proposing team of the following international space missions: TandEM (ESA-NASA) to explore Titan and Enceladus, Marco Polo, and Marco Polo-R (ESAJAXA), Castalia (ESA), Comet Interceptor (ESA-JAXA) and Jupiter-Europa Mission (ESA-NASA). Principal Investigator of 15 I+D national and international projects representing the scientific and technological management of approx. 17 M€.

Research Group and collaborations:

Our group at IAA-CSIC holds the co-PI ship of one of the instruments on board EnVision, the high spectral resolution spectrograph VenSpec-H, and Co-I ship of the VenSpec suite (VenSpec-U and VenSpec-M). The technological responsibility is providing the power supply modules of VenSpec-H, VenSpec-U and of the Central Control Unit of the whole instrument. The candidate will also work in close collaboration with the group of the LMD and LAMTOS [3] in Paris, worldwide recognized for their leading work in planetary atmosphere climate models.

Current Funded I+D+i National Projects in the frame of the proposal:

PID2021-126365NB-C21 PIs: L. Lara and P. J. Gutierrez. 1/09/2022-30/09/2026
Programa EMERGIA: PI G. Gilli (01/03/2023-28/02/2027)

External links:

[1] https://envisionvenus.eu/envision/
[2] http://www-venus.lmd.jussieu.fr
[3] http://www-planets.lmd.jussieu.fr

Manuel López Puertas y Alejandro Sánchez puertas@iaa.es

Characterization of exoplanets' atmospheres through observations and modelling

Supervisors: Manuel López-Puertas and Alejandro Sánchez López

Scientific Groups: a) Group of Terrestrial and Planetary Atmospheres (GAPT); b) Low-Mass Stars & Exoplanets; and c) Stellar Variability

Founded projects: SO CEX2021-001131-S-20-2; Atmósfera y Clima de la Tierra y Exo-planetas (ACERO), Ref. PID2019-110689RB-I00/AEI/10.13039/501100011033.

1. Scientific background and objectives

The field of exoplanetary research is experiencing a revolutionary phase, moving beyond their detection and towards understanding their formation and evolution scenarios. Exo-atmospheric characterization has been at the forefront of such efforts, giving us clues about their composition, and temperature and, in turn, opening a window for probing biosignatures in the potentially habitable worlds [1, 2, 3].

Most of the planets are hot and ultra-hot gas-giant atmospheres, with a few Neptunes, sub-Neptunes, and Super-Earths. Observations of these atmospheres were mainly performed using low dispersion spectroscopy (e.g. HST, Spitzer), but more recently high-resolution spectrographs (R~100,000) in ground-based observatories have proven to be very useful for in-depth exo-atmospheric characterization.

In the last few years we have initiated a research line on exo-atmospheres at IAA about the detection, analysis and escape studies of gas giants [4, 6-13] and we are now pushing the boundaries of this field towards understanding sub-Neptune atmospheric loss and retention, of great debate in the field to explain the observational radius valley [14, 15]. To shed light on this problem, we propose a PhD project to address the **following questions**:

- To assess the presence of escape tracers (e.g. hydrogen and helium absorption features) in the atmospheres of ultra-hot planets, hot Jupiters, Neptunes and sub-Neptunes. By analyzing their absorptions we will constrain the temperature, composition and mass-loss rates of their upper atmospheres and advance our understanding of the role of the escape in shaping these envelopes.
- To study the composition of the lower atmospheric layers, which provides us with information about the atmospheric carbon-to-oxygen ratio, deeply linked to the

planet’s formation. Further, It has been proposed that, under the right conditions, sub-Neptunes can be habitable, with a detectable interplay between biospheres and atmospheres.

2. Methods.

We have available observations taken by CARMENES of a large variety of exoplanets as well as CRIRES+ sub-Neptune observations. In addition, we have submitted several proposals to CRIRES+. Further, we are Co-I of the JWST/ERS and JWST/GTO observing programs. On the modelling side, we count on a very fast 1D hydrodynamic spherically symmetric model, a radiative transfer modelling required for simulating the spectra, and a novel simulator of high-resolution observations.

Daniel Guirado y Carlos Carrasco dani@iaa.es

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Propuesta de proyecto de tesis FPI-SO 2023

TÍTULO: "Caracterización del polvo en discos protoplanetarios a través del modelado de sus propiedades de *scattering* y la comparación con observaciones en radio y NIR"

MOTIVACIÓN

El estudio del *light scattering* por partículas no esféricas constituye una potente herramienta de caracterización del polvo en entornos astrofísicos de nuestro sistema solar y más allá, ya que las propiedades de la luz dispersada dependen en parte de algunas características físicas del polvo que la dispers. El IAA-CSIC es líder en la vertiente experimental a través del Cosmic Dust Laboratory (CODULAB). Y el grupo de scattering asociado acumula décadas de experiencia también en el modelado de light scattering por partículas no esféricas, principalmente en atmósferas planetarias y cometas. Los estudios llevados a cabo por este grupo han servido para inferir propiedades del polvo del cometa 67P/Churimov-Gerasymenko a partir de las medidas realizadas por la cámara OSIRIS a bordo de la misión Rosetta. Este resultado contribuye al entendimiento de la evolución del disco protosolar y abre una vía natural para ampliar el estudio a discos protoplanetarios en torno a estrellas cercanas. Este proyecto de tesis propone precisamente un trabajo teórico y de modelado que abra el camino para esa ampliación.

El reciente desarrollo de instrumentación radioastronómica (ALMA y VLA), ha permitido realizar estudios muy detallados de la emisión de polvo en discos protoplanetarios por primera vez, y así estudiar las condiciones en que se forman nuevos sistemas planetarios. Aunque la mayoría de los análisis de las observaciones se han realizado asumiendo partículas esféricas y compactas, recientes investigaciones con modelos muy simplificados han demostrado que partículas de polvo porosas pueden explicar simultáneamente las observaciones de los perfiles de opacidad y polarización en función de la longitud de onda, mientras que con partículas compactas es imposible. Además de mejorar esos modelos para ajustarlos a las observaciones de los instrumentos actuales y futuros, queda por responder una importante cuestión: ¿son las partículas de polvo de los discos protoplanetarios fractales en todas las etapas de su evolución o en alguna etapa se conforman en partículas consolidadas ahuecadas, pero con porosidades más bajas? Esto conecta con el estudio polarimétrico de los cometas del sistema solar a través del polarímetro EnVisS a bordo de la misión Comet Interceptor, en el que participa en el grupo de scattering del IAA.

OBJETIVOS

1. Inferir las distribuciones de tamaños de partículas de polvo en discos protoplanetarios en distintas etapas evolutivas suponiendo partículas consolidadas.
2. Acotar la porosidad de estas partículas.
3. Determinar si las observaciones en flujo y polarización nos permiten discernir entre agregados fractales y partículas consolidadas porosas. En caso afirmativo, discernir el tipo de partículas que aparecen en distintas etapas evolutivas de los discos.
4. Identificar la etapa evolutiva correspondiente a las características del polvo de los cometas del Sistema Solar.

PASOS A SEGUIR Y CRONOLOGÍA

1. Generar partículas consolidadas con distintas porosidades y distribuciones de tamaño de los huecos.
2. Calcular las matrices de scattering y los coeficientes de scattering y absorción de estas partículas (método DDA).
3. Hacer públicas las tablas de opacidades, albedo e intensidad polarimétrica en función de la longitud de onda.
4. Utilizar las propiedades de scattering calculadas para crear perfiles modelo de opacidad y de intensidad de polarización de discos a partir de soluciones analíticas simplificadas 2D que ya existen.

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5. Comparar con observaciones reales de discos para inferir los tres objetivos de esta tesis: i) distribución de tamaño de las partículas, ii) porosidad y iii) carácter fractal o consolidado, si esto fuera discernible mediante flujo y polarización. Comprar modelos con características del polvo cometario del sistema solar.
6. Opcional: utilizar modelos Monte Carlo que consideran el espesor el espesor del disco (3D) y repetir los pasos 4 y 5. Este paso depende de los resultados de una colaboración previa entre el grupo de scattering del IAA y el grupo que desarrolla el modelo MCFOST. Su eliminación no compromete la viabilidad de esta tesis y la calidad e importancia de sus resultados.

- **Intenacionalización:** El trabajo en light scattering de esta tesis estaría concentrado en la primera mitad, con dirección del grupo del IAA. La dirección de la segunda parte sobre discos recaería principalmente sobre el grupo de discos del Instituto de Radioastronomía y Astrofísica (IRyA) de la UNAM en Morelia, México, liderado por el Dr. Carlos Carrasco González, que codirigiría la tesis. Están programadas dos estancias en el IRyA para trabajar *in situ* con aquel grupo, en el que participan investigadores de tres centros en tres países (México, Chile y Alemania). El paso opcional 6 implica la colaboración con el grupo liderado por el Dr. Francois Menard en la Universidad de Grenoble Alpes.
- **Conexión con grandes instalaciones:** El grupo mexicano tiene amplia experiencia en la observación con ALMA y VLA y una alta tasa de éxito en sus propuestas. En la actualidad disponen ya de un amplio conjunto de datos de alta calidad (múltiples longitudes de onda, alta resolución y sensibilidad) de discos protoplanetarios, así como modelos 2D para la interpretación de las observaciones. Podrán usarse los datos ya disponibles y además este grupo se compromete a la solicitud de tiempo de observación de nuevas fuentes con la nueva banda 1 de ALMA (7 mm). Los resultados de esta tesis podrían contribuir en el futuro a motivar observaciones de discos en alta resolución con ngVLA y SKA. El grupo mexicano está involucrado en la parte mexicana del consorcio de ngVLA mientras que desde el IAA se coordina la participación española en SKA. Las observaciones en NIR de discos por el JWST aportarían información a esta tesis sobre las partículas más pequeñas de los discos, que se encuentran en su superficie.

FECHA DE INICIO PROPUESTA: lo antes posible a partir del 1 de marzo de 2023.

CEX2021-001131-S-20-4
Our Sun and Solar System
David Orozco, José Carlos del Toro y Hanna Strecker orozco@iaa.es

Thesis title:

Impact of solar activity on the heliosphere: applications to space weather.

PhD thesis' objectives:

The presence and evolution of magnetic field activity on the Sun plays a key role in the accurate forecasting of the space environment. These forecasts, known as *space weather predictions*, are based on analysis and modeling of the past and present conditions of the solar magnetic activity. Solar photospheric magnetic fields establish the boundary conditions for modeling the uppermost layer of the Sun, the Corona, as well as the behavior of the slow and fast solar winds. These form what is known as the *heliosphere*, which reaches beyond the solar system limits. Nowadays, magnetic fields are constantly being monitored from the Earth point of view using ground-based and space-borne observatories. But these measurements only give us a partial view of solar activity, since the back of the Sun cannot be observed directly from the Earth. The "far-side" activity can only be predicted by helioseismology and Artificial Intelligence techniques. However, solar activity on the far side of the Sun can have implications for Earth's space environment. Complex active regions rotating into the field of view of Earth can emit X-ray flares (highly energetic radiation), while high energetic particles released in coronal mass ejections on the far side can impact Earth at any time.

The Polarimetric and Helioseismic Imager instrument on board ESA's Solar Orbiter mission (SO/PHI) is the first-ever instrument to provide measurements of solar magnetic fields from the far-side of the Sun. SO/PHI has opened up a window of opportunities for unique science and will allow making a breakthrough in space weather modeling and prediction. It is the first time that the surface activity over the entire surface of the Sun can be observed. The full disk telescope (FDT) of SO/PHI provides high sensitivity, full spectropolarimetric measurements almost routinely over the entire Solar Orbiter mission. These data will help to make global maps of the solar activity as never before. In addition, they will improve far side predictions and enable a better knowledge of the solar far side activity while no observational data is available. Combining SO/PHI FDT observations with those of other Solar Orbiter instruments will allow us to know the state of the heliosphere. Particularly useful will be the data from the METIS coronagraph, an instrument conceived to simultaneously image the visible and ultraviolet emission of the solar corona, the SPICE coronal imaging spectrometer that provides information about of the physical state and composition of the coronal plasma, and the Energy Particle Detector (EPD), which takes in-situ measurements of coronal electrons, protons, and ions from helium to iron.

The main goal of the thesis is to use magnetic field data of SO/PHI-FDT of the solar far side and combine it with near Earth side observations to generate global models of the solar corona. These models will be then improved by comparing them with observations from co-temporal observations of METIS, SPICE, and EPD. These goals are of paramount importance for improving our current knowledge of solar magnetism and space weather, and for successfully exploiting the capabilities of SO/PHI in combination with other Solar Orbiter instruments and space missions. The SPG of IAA-CSIC has a high degree of responsibility in the scientific exploitation of the Solar Orbiter mission, since it is the co-PI institution of SO/PHI.

Methodology: The SO/PHI instrument is currently providing unprecedented spectropolarimetric data from the far side of the Sun, simultaneously with the other instruments of the mission. The student will first learn to use and manage data from SO/PHI and other instruments in Solar Orbiter. Later, the appointee will learn present techniques to generate far-side predictions and solar coronal global models using magnetic field data. The comparison of the models with METIS and SPICE co-temporal observations will allow the improvements of such models. In the end, the student will identify key solar and interplanetary parameters that are fundamental for space weather forecasting.

The IAA-CSIC Solar Physics Group co-leads the instrument operations and scientific data exploitation of SO/PHI, and hence it has guaranteed access to its data and the collaborations with the rest of the Solar Orbiter instrument teams involved in the project.

Expected Results:

Understanding the impact of the surface solar activity on the solar corona, solar wind and the heliosphere has strong implications for the modeling and prediction of what we know as space weather. Three out of the four top-level goals of the Solar Orbiter mission can be fully considered space weather goals, and hence the project contributes to the achievement of these objectives. In particular, the objectives of this PhD project greatly contribute to one of the Severo Ochoa - IAA pillars: Planetary systems and atmospheres, star-planet interactions. Understanding and predicting the state of the Sun, the interplanetary and the planetary environments (the heliosphere) allows us to model and understand space weather in other planetary systems. Hence, the PhD results will definitely not only produce added value to the knowledge, protection, and safety of our (space) environment, but it will help us now-cast space weather on exoplanet atmospheres. The project will consolidate the SPG solar physics and the IAA-CSIC in the forefront of space research.

Expected starting date: 1st April 2023

PhD's advisors and IAA-CSIC hosting group:

- Main thesis advisors will be Jose Carlos del Toro, David Orozco and Hanna Strecker
- Thesis advisors belong to the Grupo de Física Solar (departamento de sistema solar) del IAA-CSIC. Jose Carlos del Toro and David Orozco are the PIs of the "Física Solar Espacial y Tiempo Espacial" project of the Solar Physics Group (PID2021-125325OB-C51) funded by MICINN. Hanna Strecker is a Postdoc of the SPG group. Both researchers work in the operations and scientific exploitation of Solar Orbiter data.

CEX2021-001131-S-20-5
The Galactic Center

Rainer Schoedel y Antxon Alberdi rainer@iaa.es

Combined radio continuum and near-infrared observations of stars and their remnants in the Galactic Centre

Adviser : Rainer Schödel
Co-adviser: A. Alberdi

Proposed starting date: 1 September 2023 (as soon as possible)

Description of the project
The Galactic Centre is the only galaxy nucleus that we can resolve observationally on milli-parsec scales. It therefore plays a central role in the study of the properties of and interactions between the common building blocks of galaxy nuclei: massive black holes, nuclear star clusters and nuclear stellar discs. The Galactic Centre is also the most extreme environment in the Milky Way and its most prolific star-forming region. It can serve as a unique proxy to understand star-forming conditions in high-redshift star-forming galaxies. The Galactic Centre is a prime target for the most advanced existing and future telescopes, across the electromagnetic domain. This project focuses on constraining the properties of compact sources in the Galactic Centre: the winds of massive stars to better understand present-day star formation in this region and transients as tracers of the stellar remnant population to constrain past star formation.

Our objectives will be persecuted via a combined high angular resolution radio and infrared study of selected fields, in particular the environment of the Arches and Quintuplet clusters, two of the most massive ($\gtrsim 10^4$ $M_\odot$) young (2-5 Myr) clusters in the Milky Way, which are located at $\lesssim$ 30 pc in projection from the supermassive black hole Sagittarius A*. High angular resolution near-infrared studies have provided evidence that the IMF of these clusters is different than what is found in the Milky Way's disk: Their initial mass function (IMF) is either top-heavy or bottom light, which means there are relatively more massive stars or less light stars produced per unit mass than in the solar neighbourhood. This is also supported by theoretical considerations. We may also extend the radio IMF study to the central parsecs of the Milky Way.

Massive stars are radio sources due to their winds, that are either detected as thermal (free-free emission) or non-thermal (colliding winds) radiation. Pilot JVLA plus near-infrared studies by our group have found that the radio luminosity function of massive stars may provide independent evidence for a top-heavy (bottom-light) IMF in the Arches and Quintuplet clusters. Also, we have detected variability of the winds, either due to clumpiness, variable wind strength, or orbital motion in binaries (Gallego-Calvente et al. 2021, 2022). We have also found several candidates for stellar remnants (microquasars, pulsars, accreting white dwarfs…) in our target fields, in the form of transient sources or sources with no plausible stellar counterpart.

Objectives
We want to improve our constraints on the IMF from radio studies, to understand the frequency and strength of the variability of the winds from massive stars, and constrain the number density and properties of stellar remnants in the field. This project will build up on our previous work.

Methodology
1) Improved data reduction with less systematics and better signal-to-noise ratio, and inclusion of new X- and C-band data from JVLA observations acquired in 2022 to allow us to detect fainter sources and have longer timelines for the study of wind variability and transients. Inclusion of lower resolution JVLA data (to be proposed for) for multi-scale imaging.
2) Improved studies of the radio luminosity function from stellar evolutionary models, investigation of the role of binary stars.
3) Inclusion of near-infrared proper motions for membership probability of massive stars far from the core of the clusters.

4) Possibly inclusion of ALMA data (archive/to be proposed for), which will have a higher sensitivity to free-free radiation and thus can extend our study to smaller stellar masses.
5) Study of transient field sources with existing and future JVLA observations of the Arches and Quintuplet fields and control fields. Search for pulsars via their flux and spectral signature.
6) Use of near-infrared astrometry (and also proper motions) to search for potential infrared counterparts of transients and thus to constrain their nature.

Since the SKA will outperform the JVLA considerably in sensitivity and survey speed, **this work will prepare the ground for a large scale study of the Galactic Centre with SKA**.

Collaborations

The student will collaborate with the radio astronomy (A. Alberdi, J. Moldón, M.-A. Pérez Torres)) and Galactic Centre groups at the IAA. Outside collaborators will be F. Najarro (CAB-INTA/CSIC, expert on massive stars) and F. Yusef-Zadeh of Northwestern University (USA), an expert on radio interferometric continuum studies of the Galactic Centre.

Rubén López Coto rlopezcoto@iaa.es

Cosmic ray production and acceleration in star forming environments and its impact in galaxy evolution

Starting date: September 2023
PhD advisor: Rubén López Coto
Scientific group: Very High Energy Group for Astrophysics (VHEGA - https://vhega.iaa.es/)
Funded projects:
- PID2019-107847RB-C44. Astronomía de rayos gamma con MAGIC y CTA Norte - contribución del IAA-CSIC
- OTR08334 - RYC2020-028639-I. Proyecto intramural, Atracción al Talento 2020 (AT20-01)
- RYC2020-028639-I. Dotación adicional de contrato Ramón y Cajal de Rubén López Coto

Abstract:
The study of the non-thermal universe is a scientific domain in development that has been blooming in the last few years thanks to the arrival of very precise measurements. Cosmic Rays (CRs) are the ultrarelativistic charged particles that shape this field. Unsolved questions about their acceleration are therefore of paramount importance to understand the composition and evolution of galaxies.

Introduction
CRs have different origin depending on their energy, being the ones above tens of gigaelectronvolt (GeV) and below PeV those accelerated in the *Milky Way*, outside the solar system. There have been many phenomenological attempts to pin down how these particles are accelerated, how they propagate and how they influence galaxy formation. CRs control for example the state of dense gas [1] and star formation [2]. Without understanding CRs, we will never be able to unveil the nature of dark matter through indirect searches or galaxy via CR outflows as predicted in the ΛCDM model [3]. At present time, it is clear that our understanding of the Universe will be incomplete until we have a deep comprehension of the non-thermal Universe [4, 5, 6]. Even though Supernova Remnants have historically been the primary candidates for the acceleration of the bulk of galactic CRs, it is now clear that they cannot provide their full energy budget and the maximum energy up to which they are accelerated. It has only been in the last few years in which star forming regions have become primary candidates to give a full answer to several of the problems of CRs such as their origin, acceleration up to PeV energies or the origin of structures so mystery as the Fermi Bubbles.

Precedents
Massive star clusters (MSCs) have recently been suggested as a new class of galactic CR accelerators [7]. This proposal is backed up by the detection of diffuse low energy γ-ray emission in objects such as Cygnus OB2 [8] and high energy gamma rays in regions such as Westerlund 1 [9] and several others, pointing to a hadronic origin in these star forming regions. The main engine behind MSCs are the powerful winds blown by massive stars hosted in the cluster core. In this scenario, particle acceleration can be achieved through the interaction of the winds of massive stars with different winds, shocks or media [10, 11, 12]. Morphological and spectral studies of the non-thermal emission of these regions and correlation with gas distributions can unveil the acceleration sites of CRs in these regions. Even though it has been performed in the past, analyses of extended sources and correlations with gas performed with pointing instruments such as Imaging Atmospheric Cherenkov Telescopes (IACTs) are challenging. This is the reason why a different strategy to search for CRs accelerated in this regions is to look for molecular clouds illuminated by the CRs escaping from them.

The Fermi bubbles are structures observed in gamma rays at GeV energies, emanating from the central region of our galaxy and extending up to 8.5 kpc above and below the galactic plane [13, 14]. The origin of these two plasma bubbles is still under debate, finding in the hadronic scenario, an origin explained by sustained **star formation** activity from the Central Molecular Zone which generates galactic winds that transport a population of CR protons (and heavier nuclei) into the Fermi bubbles. gamma rays are due to neutral pion decay which are themselves produced via pp-interaction, i.e. interaction between CR protons and ambient gas [15]. The power from nuclear

star formation matches the γ-ray luminosity of the steady state bubbles. While initial studies showed a flat brightness across the entire structure, more recent work found a brightening at the base that would imply different brightnesses at different latitudes, making it easier for the detection of a latitude-dependent brightness in gamma rays.

Proposal

In the following we show the tasks project we are making a twofold proposal to tackle the problem of CR acceleration in star-forming regions:

1) Usage of archival data from the LST-1, the first telescope of CTA, to study star forming regions and molecular clouds illuminated by CRs escaping from them. We will also consider the usage of MAGIC data taken simultaneously with LST-1 to improve the sensitivity of the observations. The student will perform studies of the correlation of gas tracers with γ-ray emission to pinpoint the regions in which high energy protons are accelerated and will tackle the problem of PeV acceleration in star forming regions.
2) Propose LST-1 and MAGIC observations of the base of the Fermi Bubbles. The objective of this sub-task is to study what is the maximum energy of the gamma rays observed in the Fermi Bubbles and distinguish if the hadronic, with a star-forming origin, scenario is the one that best fits the results. Data analysis, tool development for background calculation and interpretation of the results are the actions to achieve the goal of this sub-task. There will be the possibility of the improvement of the performance of the observations by adding observations of the subsequent LSTs (operative from December 2024 on).

The student will be hosted at IAA-CSIC in the VHEGA (Very High Energy Group for Astrophysics) Group (PIs: Iván Agudo & Rubén López-Coto), participating to CTA, LST and MAGIC. The group is specialized on studies of AGNs and galactic objects and their environments mainly through radio and Very High Energy gamma-ray observations. The VHEGA group produced in 2022 9 articles in very high impact journals (Nature/Science/Nature Astronomy), accounting for half of the production of the full IAA-CSIC. The student will join the group regular activities and is expected to attend collaboration meetings, data analysis schools and contribute with onsite observing shifts. The fellow will grow a state-of-the-art background in the fields of galactic physics, with focus on the VHE data analysis, on the exploitation of MWL data and on the theory-data comparison. This project will be developed in the context of top-class large international collaborations, a fertile and world-wide intellectual environment.

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CEX2021-001131-S-20-7
Star Formation in the context of Galaxy Evolution

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Proyecto de Tesis SO-IAA 2023

Título: ***Mass assembly and chemical enrichment of low-mass galaxies towards Cosmic Noon in the JWST era.***

Dirección: José M. Vílchez (IAA), Ricardo Amorín (U. La Serena, Chile). **Start date**. Preferred ***1st term of 2024.***

Executive summary. This project focuses on the ***study of the most active cosmic stages of evolution of the low mass (dwarf) galaxy population towards redshift z~2 (cosmic noon).*** These galaxies are in an early and significant stage of their growing and chemical enrichment processes, assembling a significant fraction of their mass and metals in short timescales. The paucity of spatially resolved imaging and [near-infrared, (NIR)] spectroscopy for these distant galaxies has resulted in significant limitations which we can witness now with first JWST data in hand. Main key questions remain open and in this project we aim at providing solid answers to main ones on the star formation history and the chemical enrichment process of low-mass systems.

This project will make use of ***unprecedented datasets*** collected from 8-10m class telescopes and from the Hubble and James Webb Space Telescopes. In particular, by the combination of deep imaging and spectroscopy we will: *i) observationally characterize the properties of this galaxy population, ii) analyze the star formation history of these galaxies and the physical mechanisms operating their rapid growth, such as massive gas accretion and interactions or mergers with nearby objects, and iii) constrain their chemical enrichment history and feedback processes via the combined study of their chemical abundances and gas kinematics (i.e. chemodynamics).*

The *high-level* **datasets** to be used are mostly ***public,*** obtained from the **HST and JWST** releases, **in addition to others *accessible to our group*** *from proprietary programs and/or large collaborations* in deep fields, such as those of JWST/CEERS, PRIMER, COSMOS-Webb and others from JWST Cycles1, 2) and HST (CANDELS, Frontier Fields). This will be *supplemented with proposals* for fields of interest *with large telescopes* (GTC, VLT) and IFU/multi-object spectroscopy (MEGARA, MUSE, MOONS). Objectives of the photometric analysis include the study of stellar populations (2D brightness and color profiles) together with the spectrophometric analysis to derive metallicities and 2D star formation histories, modelling the spectral energy distribution (SED) accounting for the contribution of ionized gas and dust in composite stellar population synthesis models available. This spectrophotometric analysis will provide detailed chemical abundances and will allow **tight constrains** to the *lower-mass end of* ***fundamental scaling relationships between mass, metallicity and size for the first time in this galaxy population***, exploring also the *dependence on the star formation history*.

We have developed sophisticated tools for spectroscopic analysis, such as *LiMe* (Fernández+2022; https://lime-stable.readthedocs.io), which will be extensively used with the different datasets to derive galaxies' *chemodynamics* (Amorin+ 2012). Comparison with predictions from numerical simulations, photoionization and chemical evolution models (e.g. *MulChem*, Molla+ 2014) available to the *Estallidos* group are planned.

During this Thesis project, the student will be able to join our international collaborations, enjoy learning during working stays abroad, and attending specialized workshops and conferences.

I. Theoretical background. The formation and early evolution of galaxies remain one of the greatest challenges in astrophysics. The current picture remains incomplete and when trying to fit a physical scenario, the agreement between observations and theoretical predictions is still inconclusive, particularly in the early stages of the galaxy growth process. While the current paradigm is that of the hierarchical growth of structures in a ΛCDM Universe, the dominant role and interaction between the different physical processes in each cosmological stage is not yet well established.

The growth of stellar mass in galaxies is related to the mass of the dark matter halos and is sustained by star formation fueled by existing or accreted gas from the intergalactic medium and through major or minor mergers (Keres+ 2005, Dekel+ 2009, de Lucia+ 2020). This in turn is modulated by feedback processes, which contribute to the loss of gas and metals through the injection of radiative and mechanical energy (superwinds) both from active nuclei (AGN) and from the joint action of winds from massive stars and supernovae. In low-mass galaxies ($M_* < 10^9$ Msun) stellar feedback appears as the main regulator of the growth and chemical enrichment of galaxies -modulo environmental effects (Peng+ 2012, Oppenheimer & Davé 2012).

This PhD project is aimed at ***contributing to the following main challenges:***

➔ ***Dwarf galaxies and their star formation history in the current cosmological paradigm.***

Low-mass star-forming galaxies in the the local universe are mostly discs with continuous and moderate star formation. However, a fraction show bursts of star formation (or starbursts), separated by long periods of quiescence (eg Martín-Manjón+ 2012). Cosmological simulations (e.g. Governato+2015, Benítez-Llambay+ 2015) and various observational evidence, e.g. stellar mass versus star formation rate (SFR, Brinchmann+ 2004, Atek et al. 2014; Duarte-Puertas, Vilchez+ 2017; 2022) and the evolution of the specific star formation rate (sSFR=SFR/M*) towards higher values at higher redshift (Salmon+ 2015, Tasca+ 2015), suggest that this mode of star formation is more common in the early universe, in good agreement with predictions of cold gas accretion models (e.g. Dekel+ 2009). Their unique properties make dwarfs ideal laboratories for studying starbursts in low metallicity environments, similar to young galaxies in the universe at high redshift (z>2-9; e.g. Amorín+ 2017, Trump+ 2022).

➔ ***Galaxy formation mechanisms in late cosmological epochs: deciphering downsizing.***

Various pieces of evidence show that the cosmic star formation history shows a steep decline in the last 8 billion years (Madau & Dickinson 2014). During this decline, massive galaxies are already fully assembled, evolving secularly in sparse environments or through mergers. However, low-mass galaxies, continue to grow by accreting gas of cosmological origin or merging with other more massive central or satellite galaxies (downsizing, Cowie+ 1996). It is expected that a significant fraction of dwarf galaxies at z<2 are still forming and evolving towards the low to intermediate-mass galaxies today.

The observational identification of this population of young dwarfish galaxies is challenging due to their faintness and small size. However, they host strong bursts of star formation detectable using ionized gas emission lines with high contrast (e.g. Halpha, [OIII]5007; Amorin+ 2010; Iglesias-Páramo+ 2022; Breda+ 2022). **Such population of youngest galaxies can be traced up to z~1** using rest-optical (Amorín+ 2015; Calabrò+ 2017**) and up to z~9 with NIR JWST data** (e.g. Llerena, Amorin+ 202, Trump+ 2022, Brinchmann 2022, Matthee+ 2022; Kartaltepe+ 2022).

➔ ***The population of dwarf galaxies at intermediate redshift.***

This project will study the physical properties, star formation histories and metallicities of dwarf galaxies at the low luminosity/mass end towards Cosmic Noon. We will use the experience gained from similar studies carried out in deep cosmological fields (Amorín+ 2015; Calabrò+ 2017; Iglesias-Páramo+ 2022), mostly limited to relatively bright objects (continuum magnitudes m_i <22 mag). However, due to their fainter magnitudes these samples are missing the bulk of star-forming dwarfs, which **are now detectable (and resolved) by JWST.** Thus, this project has been designed to expand towards the extreme of low mass and lowest metallicity, by searching for the youngest and most compact objects detectable in that redshift range, reaching up to at least 5 magnitudes weaker (up to m_i <27 mag).

II. Main goals: i) characterize the properties of the dwarf galaxy population; ii) analyze the 2D star formation history of dwarf galaxies and the physical mechanisms operating their rapid growth, including massive gas accretion, interactions or mergers; iii) constrain the 2D chemical enrichment history and feedback processes of low mass galaxies via the combined study of chemical abundances and gas kinematics (*chemodynamics*); iv) comparison with the predictions from theoretical models (e.g. De Lucia+ 2020; Torrey+ 2017), and from the photoionization (HII-CHI-mistry code) and chemical evolution models available to our *Estallidos network*.

III. Data and methodology. This project will make use of public and proprietary data from the near-UV to mid-IR (imaging-NIRCam; spectroscopy in optical and NIR-NIRSpec) taking advantage of our participation in large collaborations (e.g. JWST/CEERS; ASTRODEEP HST/CANDELS and Frontier Fields), in order to find and characterize strong emission line dwarf galaxies in deep cosmological fields. Many of them have IFU (470nm-1000nm) MUSE spectroscopy available publicly. Important note: all these catalogs and high-level data products are ready to produce science. All methods, codes, programs and models necessary for this Thesis are available to our group (e.g. *LiMe* https://lime-stable.readthedocs.io ; MulChem; FADO, among others).

IV.Science Groups. 1. IAA: i) *Estallidos* (PI J.M. Vílchez); ii) Advanced instrumentation for large telescopes: *ELT-MOSAIC, CAHA-TARSIS (*PI J. Iglesias). *Projects:* PID2019-107408GB-C44; P18-FR-2664 (J.A.); CAHA, FEDER. **2. U. La Serena**, Chile (PI R. Amorín).

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Director de la Tesis Doctoral: Francisco Prada

Proyecto de la Tesis Doctoral:

MEDIDA DE LOS PARÁMETROS COSMOLÓGICOS CON LA ESTADÍSTICA DE VACIOS EN LA ESTRUCTURA A GRAN ESCALA DEL UNIVERSO

El grupo de Cosmología y Física de Astropartículas del Instituto de Astrofísica de Andalucía (IAA-CSIC; http://fprada.iaa.es) ofrece al candidato o a la candidata la posibilidad de desarrollar un proyecto en el campo de la cosmología y la estructura a gran escala del universo con el objetivo de investigar la naturaleza de la energía oscura. Se tendrá la oportunidad de analizar simulaciones cosmológicas y catálogos virtuales de galaxias de última generación creados por nuestro grupo (http://www.skiesanduniverses.org/Simulations/Uchuu/), y comparar con los catálogos de galaxias observadas por el proyecto DESI (https://www.desi.lbl.gov). A fecha de hoy DESI ya ha completado el 30% de las observaciones de sus cinco años de duración, estando ya disponible los datos para poder llevar a cabo el proyecto propuesto para esta tesis doctoral. El objetivo principal del proyecto consiste en estudiar las propiedades estadísticas de los vacíos en la distribución a gran escala de las galaxias de DESI para medir con precisión los parámetros cosmológicos y la ecuación de estado de la energía oscura.

Los vacíos cósmicos son grandes regiones del universo que contienen una baja densidad de materia, por lo que están menos afectados por los efectos gravitacionales no lineales. Por lo tanto, los vacíos son trazadores ideales de la formación de las estructuras cómicas y del campo de densidad de la materia subyacente, lo cual permite una medida precisa de los parámetros cosmológicos. Entre otros, se pretende medir el parámetro cosmológico σ_8, el cual mide la amplitud del espectro de potencia (lineal) en escalas de 8 Mpc/h. Se pretende estimar la densidad numérica de los vacíos cósmicos, en función del radio de los mismos, a partir de los catálogos de galaxias de DESI y de los catálogos virtuales con distintas cosmologías generados con nuestras simulaciones Uchuu, con el objetivo de resolver la tensión reportada en la literatura para el valor de σ_8. El valor que se obtiene para este parámetro cosmológico de las medidas del fondo cósmico de microondas difiere del derivado a partir de las medidas del agrupamiento de las galaxias y lentes gravitacionales. La inferencia de los parámetros cosmológicos a partir de las estadísticas de vacíos en DESI nos permitirá también medir la ecuación de estado de la energía oscura.

Se utilizará C/C++ y Python como lenguajes de programación para el análisis y las estadísticas apropiadas para el estudio de los vacíos en la estructura a gran escala de las galaxias. El proyecto abarcará todo el periodo de la explotación científica de DESI, y el candidato o la candidata tendrá acceso a todos los datos de DESI generados en los cinco años de observaciones, y tendrá acceso a los recursos necesarios de computación para el análisis de los datos y de las simulaciones.

Grupo y Colaboradores:

Somos un grupo cohesionado de científicos, tecnólogos y socios industriales involucrados en grandes desafíos en los campos de la Cosmología y la Física de Astropartículas. Nuestras actividades de investigación incluyen el análisis de las medidas del agrupamiento de las galaxias a gran escala, la producción de simulaciones cosmológicas y catálogos virtuales de galaxias, el desarrollo de instrumentación e infraestructura de Big-Data para los grandes cartografiados de galaxias. La experiencia de nuestro grupo y red de colaboradores proporciona una interpretación detallada de la explotación científica de dichos cartografiados y nuevos conocimientos sobre la física del cosmos y la naturaleza de la energía oscura. Para lograr nuestros objetivos, aprovechamos nuestra participación en los proyectos BOSS, eBOSS, Euclid, MAAT, Uchuu y DESI. También trabajamos en el campo de la física de astropartículas, centrando nuestros esfuerzos principalmente en la cosmología de rayos gamma. Colaboramos en proyectos transdisciplinares en los campos de la Neurociencia y la Biomedicina. El candidato o la candidata tendrá la oportunidad de trabajar con nuestros colaboradores en el campo de las simulaciones cosmológicas (el Prof. Anatoly Klypin de la Universidad de Virginia, USA, y el Prof. Tomoaki Ishiyama de la Universidad de Chiba, Japón), la estructura a gran escala (el Prof. Juan Betancort-Rijo del Instituto de Astrofísica de Canarias), la doctoranda Julia Ferrer Ereza que realiza su tesis doctoral en nuestro grupo en el estudio del agrupamiento de las galaxias luminosas rojas de DESI, y los miembros de la Colaboración DESI a través de sus dos reuniones anuales y las frecuentes reuniones virtuales de los diferentes grupos de trabajo.

Financiación:

El proyecto propuesto se enmarca dentro de los objetivos principales del Proyecto Tests de modelos cosmológicos con las medidas de BAO y H_0 realizadas con DESI y MAAT (Ref. PID2021-126086NB-I00). A este proyecto no se le asigno una FPI. La doctoranda Julia Ferrer Ereza, que realiza su tesis doctoral en nuestro grupo, está en su tercer año.

Fecha de incorporación:

Se propone iniciar el contrato FPI en septiembre de 2024.

CEX2021-001131-S-20-9

Development of new instrumentation for state-of-the-art facilities

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In the past half-century, a new generation of successively ever larger and more sophisticated telescopes and instruments have ushered in a golden age of remarkable results in astronomy. This road is taking us to the age of the extremely large telescopes (ELTs). In this sense, we have developed and currently lead the efforts on a new concept of telescope optimized for high resolution spectroscopy and for high dynamic range imaging in wide fields at subarcsecond resolution. We call this the MARCOT concept.

The main scientific goal pursued by MARCOT project is the search for Earth-like exo-planets and the characterization of their atmospheric features, for a large sample of stars. To achieve these goals, a high-resolution spectrograph that operates simultaneously in the visible and infrared wavelength range is necessary. Within this proposal, the existing spectrograph CARMENES, located at Calar Alto observatory, will be adapted to collect the light from this new facility, together with the 3.5m telescope. Therefore, there is currently a huge interest within the CARMENES consortium to go ahead with the MARCOT concept.

The new development will be more survey-oriented than a general, multipurpose observatory and would become a key facility for research areas in Astrophysics such as exoplanetary sciences. This concept can be a game changer in several research areas, especially in exoplanetary science where IAA is playing a key role internationally with the CARMENES survey and the CARMENES instrument, developed by MPIA and IAA and currently at the Calar Alto observatory.

We have built two prototypes of MARCOT. The best prototype is currently located at Calar Alto observatory which is called MARCOT-pathfinder and consists of seven units of 40cm in aperture, resulting in a telescope of 1.1m in aperture. It is currently under commissioning phase and results are very promising.

The PhD student will work on two different phases. First, he/she will perform the integration of all the subsystems and in the development of the software needed for most of the tasks, and will be in charge of doing the scientific commissioning with different test programs that will be evaluated for the MARCOT-pathfinder. Secondly, he/she advance the details of the conceptual design of a larger aperture installation based on the repetition of several modules in cascade where each module contains multiple optical tubes to reach an equivalent aperture of 15m.

The work will be supervised by J. L. Ortiz and J. Aceituno, who will be their PhD thesis advisors, with some support from P. Amado, F. Pozuelos and Stefan Cikota. The student will also closely interact with our international partners, mainly the IAP in Potsdam but also the members of CARMENES and the university of Liege.

CEX2021-001131-S-20-10
Development of new technologies for state-of-the-art facilities
Manuel Jesús Parra y Julián Garrido mparra@iaa.es

Brokering of Cloud Computing services in SKA Regional Centres Network and in Open Science infrastructures

Estimated date to start this FPI contract: September-December 2023.

Context and description of the PhD thesis project

The SKA observatory (SKAO) will be supported by a global network of SKA Regional Centres (SRCs) distributed around the world. In this context where SRCs work as a collaborative ecosystem, the SRC Network (SRCNet), will have the ability to interoperate and support a paradigm where users and their workflows are sent "to-the-data" to avoid data movement bottlenecks wherever possible. This paradigm, which some authors call "software-to-the-data", is not very widespread because of the challenges with current technology and services, and it is still under research. Advances in communication networks have allowed the development of computing infrastructures distributed all over the world and the use of these infrastructures as if they were a local service in which the user does not have to worry about where his data is located or where his services and applications are running. However, the technologies interoperating these infrastructures reach their limits when the volume of data sets exceeds the terabyte (TB) scale and the transfer of data over intercontinental networks requires hours or days. In these cases it is not possible to send the data and software to the compute node available for execution, nor is it efficient to replicate the data to all nodes that make up the global infrastructure. The development of the SRCNet faces this challenge: the volume of SKA datasets easily reach several tens of TB per data product and in aggregate would amount to ~700 TB per year, making it almost impossible to replicate across all nodes in the network. Several elements are being investigated to address this challenge and support the software-to-the-data paradigm, such as Data Lakes, which allow storage systems based on heterogeneous and globally distributed technologies to interoperate and offer a single namespace, providing a file system that supports Exa-bytes, also information systems, capable of gathering the status of all infrastructures, and brokerage services capable of selecting the compute node where it is most efficient to execute a given workflow, taking into account multiple parameters (data location, infrastructure status, and energy consumption, among other metrics).

The applied research work of this PhD focuses on brokering services where we propose to explore innovative solutions for accessing and processing SKA data close to the Exa-Scale through an enabling layer of a Cloud Service Broker platform for Open Science, framed within the prototyping activities of an international team led by the SPSRC. A cloud broker is a third-party intermediary service that acts as a liaison between an organisation and one or more cloud service providers (i.e. SRCNet nodes), managing the complexity of multiple cloud services and providers, as well as providing a single point of access for the cloud needs of the entire organisation. For this research, we want to address this problem from a modelling perspective that explores interoperability and intelligence capabilities, thus coherently facilitating the brokering of scientific services, a key piece to glue together the SKA Regional Centres as it will allow to a) optimise access between them, so that it can intelligently decide where to run science services (i.e, CARTA, notebooks, astrophysic workflows, etc.), where to take the data, or even where to move the computation, b) homogenise the model to implement SKA common science services for astrophysics in different SRC nodes (i.e. a scientist needs a notebook to work with SKA data, then the broker takes care of abstracting the different infrastructures of the nodes, to provide a common interface), and c) manage the efficiency in the use of computing and data resources by using artificial intelligence, (i.e. at the level of computing, data and infrastructures, the broker will use metrics to query the status of the SRCNet and to decide which pattern to use or what is the suboptimal procedure to deliver compute and data services).

Within this context, SKA precursors MeerKAT and ASKAP are anticipating the new Data Science Challenges that SKA will bring to the community. The applicants are co-authors of a granted MeerKAT PI proposal (on key science for the SO Program), participation in the ASKAP Wallaby Large Programme, and development of an SRC in Spain. From this perspective we identified that new research approaches on the interoperability of the SRC platforms, resources and science services are of high interest for the international community (see support letter from Jesús Salgado - SKAO SRCNet Architect) to enable collaborative science and to reduce the SRCNet enviromental footprint. This constitutes the motivation of this PhD work.

Aims

This thesis aims to perform applied research to explore how a cloud broker platform can provide advanced resource management, automated service discovery, cost optimization, self-service provisioning and better performance, based on artificial intelligence. It will help SKA and SRCNet to manage their cloud resources more efficiently, securely and cost-effectively, while also providing a model of centralised interface for accessing and managing those resources. It can also predict the future needs of the SKA telescope and pre-allocate resources for precursors already in operation, to ensure that the right resources are always available at the lowest energy cost and with the greatest efficiency.

Methods

This applied research will be cross-disciplinary, so together with scientific and technical team members the candidate will:

- Review the state of the art of protocols/services for the model of a cloud science service broker.

Brokering of Cloud Computing services in SKA Regional Centres Network and in Open Science infrastructures

- Research on selected protocols for service brokering, as well as resource definition of computing and storage within the SRCNet infrastructures (DOI: 10.1109/TSC.2020.2966607). The candidate will document the selected specification for the definition of these capabilities within the SRCNet as well as on existing Open Science Cloud (OSC) Infrastructures and Open Science initiatives (EOSC and UNESCO collaboration).
- Study the interoperability layer within the broker and interaction with the SRCs endpoints and OSCs, to allocate resources and interoperate services across the SRCNet as well as deliver science services for the SKA community and precursor telescopes. The candidate will study the cutting-edge federated computing platforms for it.
- Design within a service broker prototype, the intelligent engine based on machine learning, which will allow the selection of the sub-optimal available options for service requests, based on workload prediction, workflow features, monitoring, energy profiling, topography of distributed data/resources, SLA or QoS among others.

The supervisors will be Dr. M.J. Parra-Royón (advisor of 6 MSc, mentored a total 10 people) and Dr. J. Garrido Sánchez (advisor 1 PhDs, 5 MSc, mentored a total of 12 people). M.J. Parra has a strong industry track record background and he is expert in Cloud Computing, Big Data and AI and in the software design of distributed architectures, as well as working on the research of scalable science services. M.J. Parra coordinates an international team (UK, Sweden, Switzerland, Spain) of scientists and engineers working on the different prototypes of the SRCNet. J. Garrido is an expert on Computer Science and has a strong background in Open Science and interoperability in astronomy. Both are members of the “Conexiones CSIC AI-Hub” (for artificial intelligence) and PTI+ CSIC Digital Science Platform, as well as the UNESCO Open Science Infraestructures Working Group. The AMIGA team is composed of 9 women and 10 men, maintaining parity at all levels, with members from 6 countries, and with continuous interactions. The team is involved in the coordination of the Spanish participation in the SKA, in the development of the SPSRC and in SKA precursors and pathfinders scientific activities. The team complements fundamental science with applied e-Science research, aiming to improve the scientific work and the Open Science.

Scientific groups with which we will collaborate

This PhD will involve direct collaboration with the SKAO and the SRC network including, United Kingdom SRC (University of Manchester), Swedish SRC (Chalmers University), Swiss SRC (École polytechnique fédérale de Lausanne) and AusSRC (CSIRO). As well as direct interaction with experts in science services for astrophysics and architect of the SRCNet. In addition, the candidate will collaborate with the groups hosting the most demanding scientific projects at the SPSRC, of special relevance to support preparation for SKA Key Science Projects.

Funded projects and on-going grants directly related with the proposed PhD

“TED4SKA. A Sustainable approach to Data centres of the SKA Big Data infrastructure: the Spanish prototype SKA Regional Centre. (TED2021-130231B-I00)” Ministerio de Ciencia e Innovación, Plan Estatal de Investigación Científica, Técnica y de Innovación. 01/12/22 – 01/12/24. L. Verdes-Montenegro and Julián Garrido.

“AMIGA8. Exploring galaxy evolution at the extremes modulated by their large scale environment with SKA precursors. New technologies for SKA and its Regional Centre Network. (PID2021-123930OB-C21)”. PGC del Plan Estatal de Investigación Científica, Técnica y de Innovación 2021-2023. 1/09/2022 – 30/08/2025. PI and coordinator: L. Verdes-Montenegro, K. M. Hess.