

# The Massive Star Team at CAB-Torrejón

## Our Scientific Interests

Massive stars are fundamental agents of the Universe at galactic-scale. They are mighty sources that ionize and shape the interstellar medium. Their death as supernova can outshine entire galaxies and releases a wealth of metals synthesized in the stellar interior enriching the Universe. Either as basic ingredients or probes, massive stars are crucial to understand a variety of phenomena in Astrophysics.

The Centre for Astrobiology has assembled a team of experts on the field of massive stars. Using the most advanced available codes and extensive sets of spectroscopic observations across the electromagnetic spectrum, the team works to characterize different aspects of their physics and their impact on the interstellar medium and host galaxies.

One of the pivotal open questions of the field is to understand the role of metallicity in the evolution and physics of massive stars. In order to provide reliable answers, large stellar samples must be collected in a variety of metallicity environments. Our team is world-class referent on studies of metal-poor massive stars, extremely useful to study high redshift galaxies and to infer the physics of the first stars of the Universe. We are leading a unique effort to unveil hot massive stars in nearby dwarf irregular galaxies with poorer metal content than the Small Magellanic Cloud (SMC), and we are also part of international consortia to perform large spectroscopic surveys on both Magellanic Clouds. On the high-metallicity end, we have assembled our own collection of data from the Milky Way and M33. Our datasets span from metal-rich to extreme metal poor regimes, and were taken with different techniques, namely, multi-object and long-slit optical spectroscopy from 10m ground-based telescopes, integral field spectroscopy, and ultraviolet observations from space.

We have pioneered spectroscopic studies of massive stars at infrared (IR) wavelengths. We are working to unveil and characterize the population of massive stars in the disk of the Milky Way, which is obscured by heavy dust absorption, and use it to map the chemical composition of our Galaxy. From the quantitative IR study of the most massive clusters in the Galactic Center we are obtaining unique information of advanced stages of very massive stars, how these objects form, and the role that binaries may play in their birth and evolution. We have led HERSCHEL observing programs for massive stars in the far infrared and participated actively in the design of the SPICA mission, in a constant effort to identify diagnostics at the new spectroscopic windows opened by these space observatories. Understanding the atmospheres of massive stars from close modelling of spectral lines across the electromagnetic spectrum is also one of our main research lines.

Another focus of the massive star group at the CAB is on evolved massive stars, particularly in the red supergiant phase, which is the final evolutionary phase of massive stars before their explosion as supernova. In this area we are interested in the physical properties of red supergiant stars including their multiplicity properties and how binary interactions affect stellar endpoints. One of the key outstanding questions in this area is the so-called “Red Supergiant Problem”, which is a mismatch between the stars that we observe in the Local Universe and the mass distribution of the supernova that these stars supposedly produce. Our group at the CAB works towards solving this problem by studying red supergiant populations in external galaxies, particularly in the Magellanic Clouds.

Our technical, theoretical and observational expertise is balanced. Besides our past involvement in the SPICA-SAFARI instrument (F. Najarro was the national representative for Spain), we were members of the science teams supporting the construction of the WSO, MEGARA, MIRADAS and WEAVE instruments that just begun (or are about to begin) operations. At the moment, we work to define the technical specifications for the first generation of

instruments at the Extremely Large Telescope, HARMONI and MOSAIC. We are part of ESA and NASA consortia promoting the construction of a future large space telescope; these efforts materialized in international papers on the LUVOIR and HabEx mission concepts, and in our participation in two instrument science teams: LUMOS and POLLUX. We are also working to become involved in NASA's future flagship, the Habitable Worlds Observatory (HWO) as well as PRIMA, one of the candidates for the NASA FIR probe mission call. We handle the codes that currently provide the best description for the atmospheres of hot massive stars, with deep understanding of the physics, and keep working to improve them. Our observations include photometry and spectroscopy in the UV, optical and near-IR ranges, with some additional data in the far-IR and radio. This powerful database has been built from the successful proposals to large facilities (HST, HERSCHEL, VLT, GTC, VLA) led by our team members.

## Team members

### Francisco Najarro de la Parra

Profesor de investigación de OPI

Francisco Najarro collaborates since 1990 in the development of CMFGEN, one of the most advanced codes to model the extended atmospheres of massive stars. He has led the pioneering infrared studies of the massive stars at the Galactic Center and metallicity maps using massive stars in clusters across the Galaxy. He is an expert on the complex atmospheres of massive stars across their lifetimes, from O stars to Wolf-Rayet and Luminous Blue Variables. His expertise extends to the UV, optical and radio ranges, and overall multi-wavelength quantitative spectroscopic studies of massive stars with CMFGEN. F. Najarro carried out the first spectroscopic analysis of a massive star beyond the Local Group. He was the Spanish Head of Nation within the SAFARI/SPICA consortium since 2005 and one of the two Co-PIs in 2009-2020, coordinating the Spanish participation in the mission. He was the Head of the Astrophysics department from October 2015 till August 2019 and since September 2019 he is Deputy Director of the Centro de Astrobiología.

### Miriam García García

Científico Titular de OPI

Vocal de la comisión de Estrellas Masivas de la Unión Astronómica Internacional (IAU-G2)

M. Garcia leads the efforts to unveil and study new metal-poor massive stars in nearby dwarf irregular galaxies with optical spectroscopic surveys. The principal focus is on IC1613 and Sextans-A, but she also discovered the first massive stars in the most metal-poor galaxy of the Local Group: the Sagittarius Dwarf Irregular. She is an expert on UV spectroscopy and obtained, for the first time, UV spectroscopy of metal-poor massive stars beyond the SMC with HST. She led white papers submitted to ESA and to the USA's National Academy of Science supporting the construction of a new large spaced-base mission past the JWST era. She participated in the definition of the specifications for the aspiring missions HabEx and LUVOIR. She is co-led the contribution of the field of massive stars to the LUMOS instrument, and also participating actively in the definition of POLLUX. On the IR side, M. García co-developed the code that ingests IR photometry and looks for clusters of massive stars for the MASGOMAS project. She and F. Najarro obtained the first of Milky Way massive stars with GTC-EMIR.

### Lee Patrick

Personal investigador doctor fijo

Lee Patrick focuses on determining the physical properties of evolved massive stars in the inner Galaxy and in Local Group galaxies. His principal focus in recent years is on the binary statistics of red supergiant stars, where he has discovered and characterised companions of red supergiant stars and is leading efforts to understanding these systems better using a range of observational tools, of which a particular highlight is HST UV spectroscopy. L. Patrick leads studies investigating the metal content of red supergiant stars in external galaxies using near-IR spectroscopy and, as part of the Science Team of the upcoming MOSAIC instrument on the European Extremely Large Telescope, will pioneer this research in the future. Combining his expertise in near-IR spectroscopy with determining the physical properties of red supergiants in external galaxies, L. Patrick is the lead on a JWST-NIRCam Cycle 2 proposal to study red supergiant stars beyond the Local Group of Galaxies.

### Tomer Shenar

Contratado Atracción de Talento de la Comunidad de Madrid (AT1)

Tomer Shenar's research revolves around massive stars, with focus on their evolved states and their final black-hole products, as well as on the impact of binary interactions on their lives across the metallicity axis. He collects and uses multi-wavelength spectroscopic, photometric, and interferometric data with the world's largest telescopes such as the Very Large Telescope and the Hubble Space Telescope to infer the observational properties of massive stars and binaries in the Local Group. He is the PI of an ESO Large Programme designed to characterize binaries among approx. 1000 massive stars in the SMC. Dr. Shenar develops and utilizes state-of-the-art model atmospheres and spectral disentangling algorithms to derive robust constraints on the progenitors of compact objects (Wolf-Rayet stars, OB-type stars, stripped stars), with the goal of advancing our understanding of the evolution of massive stars and binaries and the production of gravitational-wave sources. He is co-developer of the Potsdam Wolf-Rayet (PoWR) code, and a consortium member of 4MOST, MSE and E-ELT's MOSAIC.

## Publications

Our publications are compiled in the following ADS library

<https://ui.adsabs.harvard.edu/public-libraries/Rj1GAjbeTS-aOITUF04CgQ>

## Our current PhD students

- Marta Lorenzo González: *Sextans A, a Rosetta Stone for massive star formation and evolution at low metallicity*. Universidad Autónoma de Madrid. Expected June 2024.
- Raúl Castellanos Sánchez: *Estrellas Masivas como Motores del Universo: Estudios en el IR-cercano*. Universidad Autónoma de Madrid. Expected June 2025.

## Most recent Master students

- Jana Markovic: *Dissecting the 30 Doradus analog in Sextans A with VLT-MUSE*. Universidad Autónoma de Madrid. Defended in September 2023

- Juan Martínez García: Estrellas supergigantes rojas en las nubes de Magallanes. Defended in June 2023

## Participation in international and national collaborations and consortia

### International Consortia

- Future space missions: PRIMA, HWO
- Future ground-based instruments: ELT-HARMONI, ELT-MOSAIC, GTC-MIRADAS, VLT-BlueMUSE, TARSIS
- High resolution optical spectroscopy of massive stars in the 30 Doradus region of the Large Magellanic Cloud: VFTS (PI C.J. Evans, <https://www.roe.ac.uk/~cje/tarantula/>).
- ULLYSES: Ultraviolet spectroscopy of metal-poor massive stars: LMC, SMC and dwarf irregular galaxies of the Local Group (<https://ullyses.stsci.edu/index.html>). M. Garcia was part of the Science Advisory Committee.
- XSHOOTU: Optical follow-up of ULLYSES targets with VLT-XSHOOTER. (<https://massivestars.org/xshootu/>)
- International science teams of EMIR (<http://www.iac.es/proyecto/emir/pages/general-description/science-goya-east.php>) and MEGARA (<https://guaix.fis.ucm.es/megara/scienceTeam.html>), respectively, both developed for the Gran Telescopio Canarias.
- Spanish coordinated massive stars team (Grupo español de estrellas masivas, GEEMAS).
- MASGOMAS team, a project to execute IR spectroscopy to discover new clusters of massive stars hidden by dust in the Milky Way
- 4MOST survey, 1001 Magellanic Clouds Survey
- WEAVE survey, Stellar, Circumstellar and Interstellar Physics (SCIP) survey

### Closest collaborators

- Artemio Herrero and Sergio Simón-Díaz, Instituto de Astrofísica de Canarias
- Amparo Marco and Ignacio Negueruela, Universidad de Alicante
- Rainer Schödel, Instituto de Astrofísica de Andalucía
- Miguel Cerviño and Jesús Maíz Apellániz, Centro de Astrobiología – Villafranca, Spain
- Joachim Puls, Universitäts-Sternwarte München, Germany
- Don F. Figer, Rochester Institute of Technology, USA
- Tom R. Geballe, Gemini North Observatory, USA
- Daniel J. Lennon, Instituto de Astrofísica de Canarias
- Frank Tramper, KU Leuven, Belgium
- Norbert Przybilla and Miguel A. Urbaneja Pérez, Universität Innsbruck, Austria
- Christopher J. Evans, ESA delegate at Space Telescope Science Institute, USA

- Martin Roth and Norberto Castro Rodríguez, Leibniz-Institut für Astrophysik Potsdam (AIP), Germany
- Marcus Lohr, The Open University, UK
- John D. Hillier, University of Pittsburgh , USA
- Alex W. Fullerton, Space Telescope Science Institute, USA
- Aida Wofford, Universidad Nacional Autónoma de México, Ensenada, Mexico
- Jean-Claude Bouret, Laboratoire d'Astrophysique de Marseille, France
- Jura Borissova, Millennium Institute of Astrophysics and Universidad de Valparaíso, Chile
- Sebastián Ramírez-Alegría, Centro de Astronomía, Universidad de Antofagasta, Chile
- Luis J. Corral Escobedo, Universidad de Guadalajara, Mexico
- Andreas Sander, University of Heidelberg, Germany
- Sylvia Ekström, University of Geneva, Switzerland
- Fabrice Martins, University of Montpellier, France
- Jean Claude Bouret, Laboratoire d'Astrophysique de Marseille, France