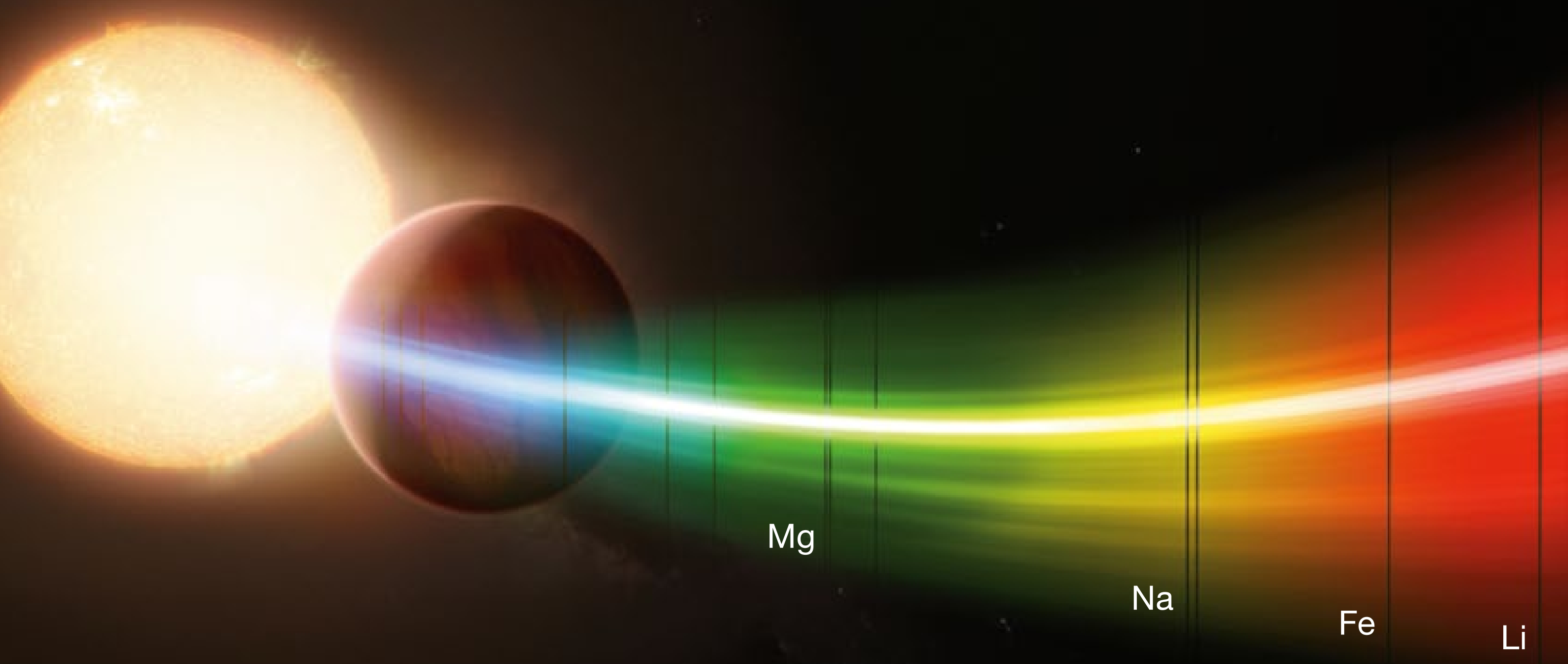
Charting the Future of Stellar and Exoplanet Spectroscopy

A conference in honour of Luca Pasquini

21–25 September 2026
Procchio, Elba Island (Italy)



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A general perspective on ESO instrumentation

A. Kaufer
ESO

ESO's scientific impact has always been driven by the close interplay between ambitious telescopes, innovative instrumentation, and the creativity of the astronomical community. Over the past four decades, successive generations of instruments have transformed ESO into one of the world's most productive observatories, enabling discoveries across virtually every field of astrophysics while continuously pushing the boundaries of observational capability.

Results and lessons learned from the Near Infra-Red Planet Searcher NIRPS

F. Bouchy
Geneva Observatory

The Near-InfraRed Planet Searcher (NIRPS) is a high-resolution, high-stability near-infrared spectrograph covering the YJH bands and coupled to an adaptive optic system. NIRPS joined HARPS on the ESO 3.6m telescope at La Silla in April 2023. Optimized for the detection and characterization of exoplanets around low-mass stars, NIRPS is the first nIR spectrograph to achieve radial-velocity precision below 1 m/s. In this presentation, we discuss the performance of NIRPS, the lessons learned, and the scientific results obtained over the past 3.5 years. We also present the planned extension NIRPS with a high-resolution K-band spectrograph fed by a single-mode fibre. Finally, we briefly describe how the NIRPS/HARPS tandem will be engaged in the radial-velocity follow-up of exoplanets candidates transiting M dwarfs that the ESA PLATO space mission should reveal as early as 2027.

First light of the NIGHT spectrograph at the 152cm telescope of OHP

C. Farret Jentink
University of Geneva

NIGHT is the first high-resolution spectrograph dedicated to surveying exoplanetary atmospheres through near-infrared helium triplet spectroscopy. Metastable helium serves as a sensitive probe of atmospheric mass loss processes that shape the close-in exoplanet population, such as the Neptunian Desert and

Radius Valley. As such, its 1083nm near-infrared triplet is one of the most sought-after tracers in exoplanet atmospheres. In addition, the same triplet of lines is an important tracer of stellar chromospheric activity and outflows. Focusing exclusively on these absorption lines, NIGHT employs a custom high-efficiency grating, achieving 90% throughput over a small spectral range of 1081-1085nm, enabling competitive science with smaller-class telescopes. This makes NIGHT the first instrument capable of conducting unbiased large-scale exoplanetary atmospheric surveys. From August 2025 to March 2026, NIGHT was installed on the 152cm telescope at Observatoire de Haute-Provence for a testing campaign. We present first-light results, including the achieved resolving power (R ~75,000), on-sky sensitivity, and initial transit observations. We demonstrate NIGHT's capability to characterize atmospheric escape across diverse planet types and stellar hosts, outline the path forward for NIGHT at the next telescope, and discuss the future of large-scale atmospheric and stellar surveys with dedicated instruments like NIGHT.

High Resolution Spectrographs

L. Sbordone
ESO-Chile

For many decades optical high resolution spectrographs - usually cross-dispersed echelle spectrographs - have been a mainstay of astronomical instrumentation, applied to all scales of astronomical research, from Solar System objects, to stars in the Milky Way and its satellites, to high-redshift absorption systems. They acquired multi-object capabilities, initially at expense of spectral coverage, a limitation that has been increasingly overcome in more recent years. They extended to the IR, opening an extremely productive window both to spectral features otherwise unavailable, and to more dust-obscured objects. And they are increasingly employed in large surveys of local stellar populations. In parallel, a family of high-precision, high-stability echelle spectrographs optimized for radial velocity determination has allowed the extremely fast expansion of the research on exoplanets and asteroseismology.
I will review the most representative types of high resolution optical-IR spectrographs currently "on the market", with a special emphasis on how the science cases they are designed for are in a feedback loop with the technological and observational constraints they have to deal with. I will then look at the instruments currently proposed or in a design / development phase, and I will try to provide element to a discussion of how the future needs of the community will shape the design of the upcoming generation of high resolution spectrographs.

Fundamental constants and ESO spectrographs

D. Milakovic
INAF – Astronomical Observatory of Trieste

Testing the constancy of fundamental constants offers a direct probe of new physics beyond the Standard Model, with profound implications for our understanding of dark energy and unification theories. Three ESO spectrographs – UVES, HARPS, and ESPRESSO – have been used to explore temporal and spatial variations of fundamental physical constants. Each one has pushed the boundaries of precision through innovation in instrument design, stability, and wavelength calibration accuracy.

In this talk, I will report on ongoing efforts to measure fundamental constants in the early universe from high resolution quasar spectra produced by VLT/ESPRESSO. Wavelength calibration procedures based on laser frequency comb minimises uncertainties from wavelength calibration, essentially removing a previously dominant systematic effect. The comb also provides crucial information about ESPRESSO's line-spread function, further increasing measurement robustness. The high quality ESPRESSO data were analysed using artificial intelligence methods designed to avoid bias.

High-fidelity extraction and calibration of high-resolution spectra for tests of fundamental physics

A. Ristea
Swinburne University of Technology

Improvements in the stability and wavelength calibration accuracy of high-resolution echelle spectrographs have enabled significant advancements in the study of exoplanets, stellar evolution, and tests of fundamental physics. One important science case that requires high-resolution spectroscopy is the redshift drift experiment, the only non-parametric observational test of cosmology. This test remains impractical even for the ESPRESSO spectrograph on the VLT, as it requires the detection of a tiny signal (<10 micro-angstroms in a decade). Our inability to detect this signal is heavily influenced by our spectral calibration accuracy. Although ESPRESSO can be calibrated using a laser frequency comb, current techniques for harnessing the comb signal to wavelength-calibrate the spectrograph still fall at least one order of magnitude short of the accuracy achievable using the comb. In this talk, I will present a novel implementation of Spectro-Perfectionism, a method of spectral extraction, which makes use of the true point-spread function of the instrument. Applying this method to ESPRESSO's frequency comb, I will show how it improves the current best calibration accuracy of ESPRESSO by up to an order of magnitude. Finally, I will discuss the prospect of implementing this technique on future spectrographs such as ANDES, its potential for reaching the accuracy required by the redshift drift experiment, and its advantages for other science cases.

Constraining Newtonian dynamics with Wide Binaries

R. Saglia
Max Planck Institute for Extraterrestrial Physics (MPE)

Dark matter halos are required to fit galaxy rotation curves under Newtonian dynamics. Wide stellar binaries probe the same range of accelerations as the outer regions of disk galaxies, with dark matter not playing any role. A failure of Newtonian dynamics to explain wide binaries kinematics would force a revision of our understanding of dynamics or gravity. I'll describe our recent efforts to measure and model the relative velocities of a sample of 65 carefully pruned, bona-fidae wide binaries. We combined their Gaia parallaxes and proper motions with accurate high-resolution radial velocities and applied corrections for gravitational redshift and convective motions. We find viable Newtonian orbits for all of them and derive the expected parameter distributions. We argue that four additional pairs labelled as binaries are in reality not bound. We are enlarging the sample of wide binaries to further 150 pairs using ESPRESSO at the VLT to complement Gaia data with radial velocities.

The intergalactic medium at high resolution: present results and future perspectives

V. D'Odorico
INAF – Osservatorio Astronomico di Trieste

The intergalactic medium (IGM) contains the majority of the Universe's baryons and plays a fundamental role in the formation and evolution of galaxies. It acts as both a reservoir of cold gas for star formation and a recipient of mechanical, thermal, ionizing, and chemical feedback. Furthermore, because the IGM represents matter in the linear regime, it serves as an excellent tracer of the underlying dark matter distribution and a powerful cosmological tool. IGM properties are primarily investigated using absorption spectra from bright background sources, such as high-redshift quasars. In this talk, I review recent results that utilize the IGM to shed light on key processes in cosmic history, including the epoch of reionization and early chemical enrichment. Finally, I will discuss the future of the field, specifically the transformative impact expected with the advent of the Extremely Large Telescope.

Chemical evolution of the light elements Li, Be, and B

R. Smiljanic
CAMK-PAN

In this contribution, I will review the chemical evolution of the light elements Li, Be, and B. The understanding of these elements touches on aspects of primordial nucleosynthesis, cosmic-ray physics, and stellar evolution. Of the three elements, Li is the most studied. The study of Be and B is more difficult, requiring ground near-UV or space UV stellar spectra. The evolution of Li is a puzzle that remains not fully solved, as Li can be produced and destroyed in a variety of environments. In the metal-poor regime, the Spite plateau remains a topic of discussion. The main source of the Galactic enrichment in Li is now strongly believed to be novae. At the metal-rich regime, stellar radial migration has been suggested as a factor to be taken into account to understand the Li abundances. Beryllium (9Be) and the isotope 10B are produced by cosmic-ray spallation in the interstellar medium. The second isotope of boron, 11B, is believed to result from neutrino interaction with carbon. Abundances of both Be and B show a linear relationship with metallicity, although a deviation from that may occur for Be at about [Fe/H] = -3.0. Moreover, the scatter observed in the relation between Be and Fe can be related to a mixture of in situ and accreted metal-poor stars. Future instrumentation targeting ground- and space UV wavelength ranges will help to increase the samples with abundances for these elements.

Galactic Li evolution with correction from stellar evolution: Milky Way discs and Gaia-Sausage-Enceladus

C.T. Nguyen
University of Trieste

Lithium is the primary element of my current projects. I will present a chemical evolution model for Li, including the correction due to stellar evolution. In particularly, calculations of chemical evolution model predict the evolution of Li in the interstellar medium, which is then depleted due to the evolution of stars at different evolutionary phases. The model was then tested on the Galactic discs, Nguyen et al. (2025, A&A 703, A204), and currently on the GSE galaxy (paper is in submission process). In both works, the data is adopted from current big surveys such as GALAH and Gaia-ESO. In summary, the model computed with primordial Li abundance (A(Li)=2.7 dex), including stellar correction, reproduces the evolution of Li very well - from the Spite plateau to the enrichment branch in the solar vicinity. It also enables the study using early red-giant-branch stars, and successfully reproduces the eRGB Li plateau discovered in Mucciarelli et al. (2022). Moreover, novae contributions are also taken into account in the model to reproduce the Li enrichment evolution. Consistently, the model predicted Li nova yield is in good agreement with the mean value constrained from novae observations.

Abundances of Li in clusters

P. Bonifacio
Observatoire de Paris, CNRS

Taken individually stellar Clusters offer the possibility of studying a population of stars that have approximately the same age and the same chemical composition. This allows to highlight the effects of stellar evolution on the properties of the stars. In this context the fragile element lithium is a very good indicator of mixing that occurs as the star evolves, but also of less understood phenomena, like the appearance of lithium-rich stars. Taken collectively, stellar clusters span over two orders of magnitude in metallicity and and ages from extremely young to as old as the Universe. In this context the lithium abundances in stellar clusters are an interesting alternative to field stars to study the chemical evolution of Li. Having these aspects in mind I shall try to review our current understanding of Li in clusters, highlighting also the many important contributions of Luca Pasquini to this field.

Lithium-rich stars in globular clusters: a new perspective

A. Mucciarelli
Department of Physics & Astronomy, University of Bologna

The Li-rich stars are a class of rare objects with a surface lithium abundance, A(Li), that exceeds that of other stars in the same evolutionary stage. Their origin is still debated and valuable routes are the

Cameron-Fowler mechanism and a mass-transfer process in a binary system. Li-rich stars at metallicity below [Fe/H]~-1 are very rare and difficult to interpret invoking a Cameron-Fowler mechanism. Here we present the new results of an extended survey performed with the IFU MUSE@VLT for a sample of 26 Galactic globular clusters, detecting a large number of new candidate Li-rich stars and providing new insights to understand their origin.

Detectability of deuterium in spectra of A-type stars

V. Mitrokhina
Tartu Observatory

The primordial abundance of deuterium (D), set during Big Bang Nucleosynthesis at [D/H] = −4.59 ± 0.02 dex (Cyburt et al. 2016), is efficiently destroyed in stellar interiors through fusion. As a result, its presence in stellar atmospheres is not expected unless replenished by external accretion events. A-type stars, characterized by radiative envelopes, offer favorable conditions for temporarily preserving signatures of such events in their spectra. To investigate the detectability of D, we used synthetic spectra for stars with effective temperatures between 7500K and 12500K, computed with the ZEEMAN spectrum synthesis code, modified to include deuterium features. Initial tests used synthetic observations across a range of signal-to-noise ratios between 100 and 1000, and detection thresholds were quantified using a Markov Chain Monte Carlo framework. We then applied this method to observed spectra of the A9 star HD 32115 and the B9.5 star 21 Peg, and estimated upper limits of D detection at 99% confidence levels as being -5.53 dex and -4.89 dex respectively. Our results show that the Hα region provides a significantly more sensitive diagnostic of D than Hβ. The sensitivity of the method also depends on stellar effective temperature, cooler stars (~7500 K) give better constraints on D abundance. These results help to establish observational requirements for identifying deuterium in stellar atmospheres.

Exoplanets: in the prime of life, looking forward to a bright future

S. Udry
University of Geneva

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Laser Frequnecy Combs in Astronomy

G. Lo Curto
ESO-Chile

The first laser frequency comb in an astronomical spectrograph was tested in La Silla on HARPS in 2010. It was a bumpy road, but since then LFCs have become a standard tool for most spectrographs dedicated to precise radial velocity measurements.
On HARPS and ESPRESSO we are now routinely acquiring LFC calibration data daily. I will describe the benefits and the challenges of using a LFC on HARPS, what we have learned from the system, and how to move forward to fully exploit the science data with the existing daily LFC calibrations.

Calibrating spectrographs with laser frequency combs

E. Obrzud

Laser frequency combs provide spectra composed of a large set of laser lines equally spaced in frequency space, with each comb line frequency known with great precision. They have been recognised as an invaluable tool in astronomy, namely in astronomical spectrograph calibration, where they are referred to as 'astrocombs'. Precise and accurate spectrograph calibration is crucial in exoplanet detection and characterisation and determination of the fundamental physical constant variability, and imperative for the future direct measurements of the expansion rate of the Universe. The talk will concentrate on the latest LFC developments for calibrating the UV-VIS-NIR wavelength range as well as present an LFC able to calibrate spectrographs from a satellite.

Optimizing the HARPS LFC-based wavelength solutions for science use

S. Tavella
University of Geneva / ESO

The detection of an Earth 2.0 via the radial velocity (RV) method requires a 10 cm/s stability over several years. However, current state-of-the-art instruments are not there yet, with best-delivered results as low as 30–50 cm/s on M dwarfs (ESPRESSO). A key obstacle to long-term stability comes from wavelength calibration, as spectrographs broadly rely on hollow-cathode lamps (HCL) that exhibit a ~30-50 cm/s intrinsic jitter due to uncertainties on line positions and sparse wavelength coverage. In the last ~10 years, astronomical Laser Frequency Combs (LFCs) came to light to overcome HCL limitations, with a theoretical long-term stability of few cm/s over decades. However, current on-spectrograph LFC performances are still sub-optimal and demand a more thorough characterization before scientific use. On this line, we analyzed the benchmark LFC system on HARPS, started and operated by ESO since 2015, and with available high-cadence solar observations since 2018 (HELIOS). Confirmed that the LFC spectrum is intrinsically stable, we find that instrumental effects—such as component aging or overall flux and background variations—induce irregular wavelength shifts on the detector not observed with HCL calibrations. We thus developed an optimized method for LFC-based wavelength solutions, with background and CTI corrections and more accurate line fitting, to get rid of the spurious m/s-level offsets that we otherwise see in LFC-calibrated solar RVs, when not considering all effects.

Abundances and chemical evolution (modelling point of view)

C. Kobayashi
University of Hertfordshire

Explaining the origin of the elements is one of the scientific triumphs linking nuclear physics with astrophysics. During the Big Bang, only light elements such as hydrogen and helium were produced. Carbon and heavier elements are created inside stars and are ejected when they die. Iron-peak and neutron-capture elements are further produced by binaries - Type Ia supernovae and neutron star mergers, respectively. We included all of these processes in our cosmological, hydrodynamical simulations to trace inhomogeneous enrichment in the Milky Way. In the simulated galaxy, the bulge formed by the assembly of sub-galaxies at high redshifts, while the disk grow inside-out over Cosmic time. Stars on the disk tend to migrate outward following the cosmological growth of the disk. Because of the rapid production of Fe from Type Ia supernovae, our simulations produce the bimodality, or trimodality, for many elements. For example, in the alpha/Fe bimodality, the low-alpha stars tend to be rotating (high v/sigma). By comparing to these theoretical predictions, on-going and future observational surveys (with <0.1 dex accuracy) will reveal the formation and chemical enrichment histories of our Milky Way Galaxy.

Stellar elemental abundances: an observational view of the chemical revolution

D. Feuillet
Uppsala University

As this conference is designed to highlight, there has been a significant increase in the available datasets providing stellar elemental abundances, with ever larger surveys on the horizon. This wealth of data has facilitated a revolution in our understanding of galaxy evolution, planetary formation, and stellar nucleosynthesis. One field that has particularly benefitted is Galactic Archaeology. I will discuss the wealth of elemental abundance data available for stars across the Milky Way and Local Group, what we have learned from this data in the past decade about galaxy evolution, and what datasets are expected in the coming years. My perspective will focus on improvements to our understanding of the Milky Way disk, bulge, and halo possible thanks to large samples of stellar elemental abundances.

Chemical abundances as fossil records of dwarf galaxy evolution

D. de Brito Silva
Uppsala University

Chemical elements serve as powerful indicators for reconstructing the evolutionary history of the Milky Way and its satellites. Numerous studies have demonstrated that chemical abundance distributions differ among Milky Way components and satellite dwarf galaxies, indicating distinct evolutionary histories. Dwarf galaxies, in particular, are generally old and metal-poor systems, providing valuable parallels between high and low-redshift galaxy evolution, offering insights into the early universe. In this context, precise elemental abundances obtained through high-resolution stellar spectroscopy are essential for robust comparisons between observations and chemical evolution models, which is important to investigate the formation and evolution of dwarf galaxies. In this work, we used APOGEE chemical abundance data for six dwarf galaxies, including Sculptor and Fornax, to construct chemical evolution models and analyze their evolutionary histories. In this talk, I will discuss how the chemical evolution of these systems compares to that of the Milky Way, the importance of different chemical signatures as tracers of evolutionary history, and the role of outflows in shaping these galaxies. In the future, chemical evolution models will be crucial for interpreting data from forthcoming surveys such as 4MOST, which is expected to provide chemical abundances for approximately 100,000 stars in dwarf galaxies and to advance our understanding of galaxy formation and evolution.

Chemical decoding the Galactic halo with large-scale surveys

A. Mori
University of Florence

The Galactic stellar halo serves as fossil record of the Milky Way's hierarchical assembly, encoded in the phase-space and chemical properties of its stars. While dynamical mixing washes out the kinematic signatures a few Gyr after the merger, chemical abundances - which reflect the interstellar medium out of which the stars formed - are preserved during accretion. Thus, they can be used to trace stars that formed in the same progenitor system but are now dynamically decoupled. We show that high-precision chemical abundances provided by large-scale local surveys, namely Gaia EDR3 and SDSS-IV/APOGEE DR17, combined with a multi-dimensional, star-by-star analysis using Gaussian Mixture Models, can link accreted debris with common chemical characteristics that are currently dispersed in phase space. In particular, we find that several of known halo substructures are significantly ($>$ 50% of their stars) contaminated by the massive merger Gaia-Sausage-Enceladus, as well as by the in-situ kinematically-heated disc, and by other systems such as Sagittarius and ω Centauri. This approach proves to be a powerful method for reconnecting scattered stars to their original stellar streams and now-disrupted dwarf galaxies, as chemical information can recover accretion fossils otherwise obscured by phase mixing. It is particularly timely given the increasing volume and precision of forthcoming spectroscopic and astrometric data (e.g., from Gaia DR4, 4MOST, WEAVE and MOONS), and provides a robust framework for interpreting the complex structure of galactic haloes - even beyond our Galaxy, which is essential for reconstructing the formation history of the Milky Way and nearby galaxies.

Radial-velocity for exoplanet detection and stellar char-

acterisation

X. Dumusque
University of Geneva

Thirty years ago, the first exoplanet orbiting a solar-type star was discovered, using the radial-velocity technique. This was possible thanks to impressive technological improvements that brought RV precision from km/s to 10 m/s. But 51 Peg b was a Jupiter-mass exoplanet orbiting extremely close to its host star, an "easy case" by today's means. To discover a twin of the Earth, a precision of 10 cm/s must be reached over several years. This corresponds to measuring the shift of a stellar spectrum at a precision of 1/10000th of a detector pixel, which corresponds to approximatively 10 silicon atoms (1.5 nanometers). In this talk, I will review the major improvements over the last 30 years that allowed us to reach a few dozen of cm/s in RV precision. Those improvements include technological development, a better characterization of stars and complex data analysis methods. I will also discuss the remaining barriers toward the 10 cm/s precision and ideas on how to clear them.

Mitigation techniques for OH contamination in NIR radial velocities, applied to faint NIRPS targets

Y. Fensch
Instituto de Astrofísica e Ciências do Espaço

With the advent of high-resolution near-infrared spectroscopy, telluric contamination remains a key limitation for precise radial velocity (RV) measurements. While the Near Infra-Red Planet Searcher (NIRPS) reaches ~1 m/s precision for bright targets, observations of faint stars are still significantly affected by telluric emission lines, potentially inducing RV shifts of up to 250 m/s. We investigate mitigation strategies applied to NIRPS observations of faint M dwarfs, including: (i) removal of telluric-affected lines from the stellar masks used to compute the cross-correlation function (CCF), (ii) exclusion of contaminated spectral orders, (iii) modelling the CCF with a two-component Gaussian profile to account for telluric emission and stellar absorption, and (iv) excluding the telluric-affected region from the CCF. We compare the performance of these approaches and show that relatively simple methods can provide substantial improvements, with the exclusion of the telluric-affected regions emerging as a particularly effective and robust solution. Applied to two faint M dwarf targets, these strategies enable the recovery of RV signals consistent with their photometric transit detections. These results highlight methods to mitigate residual telluric emission contamination in the NIR regime, with relevance for current and future high-precision spectroscopic surveys targeting faint stars.

Chasing stellar noise in the quest for other Earths: the PoET approach

N. Santos
Instituto de Astrofísica e Ciências do Espaço/Universidad de Porto

The detection and characterisation of Earth-like planets is a major goal of modern astrophysics. However, this search is significantly hindered by astrophysical "noise" from host stars, which distorts the spectra used to detect and analyse these planets. Current methods to mitigate this issue have not yet achieved the necessary level of precision. In this talk I will briefly review the different challenges caused by stellar noise. I will then focus on the Paranal solar Espresso Telescope (PoET). Connected to the ESPRESSO spectrograph on the ESO-VLT, PoET provides both disk-resolved and disk-integrated ("Sun-as-a-star") observations of the Sun. This unique dataset, obtained in ultra-high resolution mode (R $>$ 200,000), will cover the full optical spectrum (380–780 nm) in a single observation. By using the Sun as a proxy for other solar-type stars, PoET will enable an unprecedented understanding of how different solar features contribute to spectral variability. This, in turn, will inform the best strategies for mitigating stellar "noise" in exoplanet research. Given its uniqueness, PoET data will further allow to tackle different unsolved problems in solar and stellar physics.

Using the Sun to benchmark stellar activity models for cm/s radial-velocity exoplanet detection

A. Barka
IA/FCUP

Advances in high-precision spectroscopy have pushed radial velocity (RV) measurements toward 10 cm/s precision. Stellar physical phenomena remain, however, a major source of noise, as they can mimic or obscure planetary signals. In this context, the Sun provides a unique benchmark to investigate these effects in detail. In this work, we model the RV variations induced by solar activity, specifically spots and faculae, using the SOAPv4 code. Active regions are identified from SDO/HMI and AIA images using different methods, and their impact is simulated and compared with Sun-as-a-star RV measurements from HARPS-N. After subtracting the modelled activity signals, the standard deviation of the RV residuals is reduced to 0.90 m/s over a timespan of 543 days, approaching the 80 cm/s granulation limit reported in literature. This precision is constrained by incomplete physical modelling, which, with further refinement, could enable the 10 cm/s precision needed to detect Earth-like exoplanets. We show that the choice of active-region identification method has a strong impact on the modelled RVs, leading to significantly different levels of activity correction. We also present preliminary results from a new implementation of SOAP in which active regions are treated at the pixel level. This new version will improve the modelling of active regions, enabling a more realistic representation of solar magnetic structures. The potential of future PoET data will be discussed.

Toward Earth Analog Detection: Constraining Granula-

tion Noise with Disk-Resolved Solar Spectroscopy

C. San Nicolas Martinez
Institute of Astrophysics and Space Sciences

Stellar surface inhomogeneities limit extreme-precision radial velocity (RV) measurements, with granulation driving short-timescale variability. Characterising these effects at the level of individual spectral lines is essential to reach the cm/s precision required to detect Earth-like planets around Sun-like stars. I present first results from the new PoET telescope (Santos et al. 2025), using disk-resolved solar observations to link photospheric structures with their spectroscopic signatures This provides a benchmark for understanding stellar noise in unresolved stellar observations. The analysis is performed with TILARA (San Nicolas et al. 2026), a line-by-line RV extraction code based on iterative multi-Gaussian modelling of individual absorption lines. This enables detailed control over line selection and the study of their differential sensitivity to granulation. I will present a set of spectral lines with distinct responses to granulation-driven RV variability, identifying those strongly affected and others more stable. I will also investigate centre-to-limb variations in line properties, including changes in depth, width, and asymmetry, to characterise how granulation imprints on spectral observables across the solar disk. These results show how disk-resolved solar spectroscopy and line-by-line analysis can optimise spectral line selection and mitigate stellar noise, improving RV precision in the search for Earth twins with current and future ultra-stable spectrographs.

Beyond the surface: Chemical signatures of internal transport processes in stars

N. Lagarde
Laboratoire d'Astrophysique de Bordeaux

The unprecedented combination of large spectroscopic surveys with asteroseismic and astrometric data is opening a new window on the interplay between stellar physics and Galactic evolution. However, the chemical properties of stars do not solely reflect their birth environment, as they are continuously modified by internal stellar transport processes. Chemical signatures observed in stars arise in part from such processes, including rotation and thermohaline mixing, which modify surface abundances throughout stellar evolution, depending on stellar mass and evolutionary stage.

The diffus(iv)e border between stellar atmospheres and stellar structure and evolution

A. Korn
Uppsala University

It is often assumed that sun-like stars preserve in their atmospheres the composition of the gas they were born from. To a large extent, this is a valid assumption. But as we push to ever more accurate abundances (0.1 dex and better), we see new chemical structures emerge. Two decades of detailed abundance studies on stars in globular and open clusters have revealed that, in fact, not a single element abundance (from H to U) is constant as stars evolve along and off the main sequence, with consequences ranging from the interpretation of the Spite plateau of lithium to age dating via isochrones. Progress has been made in understanding the physical effects that give rise to surface-abundance changes of ageing stars. Atomic diffusion, convective-boundary mixing and rotation are essential ingredients. In this talk, I will give an overview of where we stand and what aspects of stellar-physics modelling we need to develop further to sharpen our view of stellar abundances as tracers of stellar and Galactic evolution. [The starting point for my talk will be the bold exploration of lithium in NGC 6397 by Pasquini & Molaro (1996, A&A 307, 761) published 30 years ago!]

CNO abundances as probes of stellar and Galactic evolution

G. Tautvaišienė
Vilnius University

I will present the ongoing work on CNO abundances in the Galactic open cluster and field stars in the context of stellar evolution modelling and in developments of their usage as chemical clocks. Studying CNO abundances allows us to understand how stars generate energy as they play a central role in the CNO cycle. Their changes in surface abundances can reveal internal mixing processes that bring fusion products from the core to the surface. Carbon and its isotopes, as well as nitrogen, give. comprehensive information on thermohaline-, rotation-, or magnetically-induced material mixing during stellar evolution. CNO are among the most abundant elements produced in stars that give information on how galaxies chemically evolve over time.

Binary Stars as Laboratories for detailed Stellar Abundance Studies

L. Berni
INAF - Osservatorio Astrofisico di Arcetri

Binary stars are generally assumed to be co-natal and co-eval, sharing the same initial chemical composition due to their common origin. As such, they provide a unique laboratory for detecting subtle abundance differences induced by post-formation processes. One such process is planetary engulfment, which can alter the surface chemical composition of a star and produce characteristic abundance trends with elemental condensation temperature. High-resolution spectroscopy is essential for detecting these small chemical signatures. In this talk, we present a detailed differential abundance analysis of a sample of solar-type wide-binary stars observed at high spectral resolution with HARPS and ESPRESSO (see Pasquini et al. 2026 for details). Using carefully selected line lists and equivalent-width measurements, we perform a strictly differential analysis to maximize precision and minimize systematic uncertainties.

We investigate abundance trends with condensation temperature to assess the chemical homogeneity of binary systems and to identify signatures consistent with planetary engulfment. We also study these trends as a function of binary separation to explore the potential impact of the dynamical history of binaries on planet formation. Our results provide constraints on the detectability of engulfment events and offer insight into how planetary evolution can imprint measurable signatures on stellar atmospheres.

Time domain high-resolution spectroscopy: investigating the magnetic star-disk interaction in young stars

J. Bouvier
IPAG

I will review the results of several international campaigns aimed at investigating the star-disk interaction in young stars. These campaigns combine photometry, high resolution spectroscopy, spectropolarimetry, and interferometry to monitor low-mass pre-main sequence stars over several rotation periods (weeks). The analysis of the line profile variability, mostly HI and HeI lines in the optical and near-IR ranges, allows us to probe the structure and dynamics of the magnetospheric accretion flows connecting the inner disk edge to the central star and associated outflows. Magnetic field measurements and mass accretion rate estimates derived from the line profiles provide a direct estimate of the size of the magnetospheric cavity, which regulates the angular velocity of the central star and possibly halts the migration of inner planets at a distance of a few stellar radii.

The first high-resolution view of Type II Cepheids: from stellar properties to the distance scale

T. Sicignano
ESO-Garching

Type II Cepheids (T2Cs) are Population II pulsating stars that represent a promising but still under-exploited alternative to Classical Cepheids for distance scale studies. Despite their potential, their physical properties and evolutionary status remain less well constrained, largely due to the scarcity of high-resolution spectroscopic data. We present the first homogeneous high-resolution spectroscopic sample of 80 Galactic T2Cs. These data allow us to investigate in detail the chemical properties of T2Cs, providing new insight into their nature and their connection with other Population II tracers. By combining spectroscopic metallicities with Gaia parallaxes and optical–infrared photometry (including OGLE data), we derive fully empirical Period–Luminosity–Metallicity (PLZ) and Period–Wesenheit–Metallicity (PWZ) relations for Galactic T2Cs. Our primary goal is to assess the role of T2Cs as independent distance indicators in the context of the cosmic distance scale. The resulting calibrations yield distances to Local Group galaxies that are consistent with those obtained from Classical Cepheids and RR Lyrae stars, supporting the robustness of T2Cs as Population II standard candles. This work also lays the foundation for future comparisons with T2Cs in external systems. In particular, upcoming spectroscopic data from 4MOST will enable, for the first time, a direct comparison between Galactic and Magellanic Cloud T2Cs, opening a new window on population effects and systematics in distance scale studies.

The Gaia spectroscopic catalogue of exoplanet and host star parameters

P. de Laverny
Laboratoire Lagrange, Observatoire de la Côte d'Azur.

A new, large and homogeneous catalogue of precise exoplanet host star (EHS) and exoplanet properties will be presented. This catalogue has been build from the Gaia/GSPspec large spectroscopic survey complemented by Gaia astrometric and photometric data plus some ground-based spectroscopic survey informations. It contains the stellar atmospheric parameters, luminosity, radius, mass, Galactic kinematic and Galactic orbital properties for 2573 host stars. The mass and radius of 3556 exoplanets were then rescaled, fully consistently with the stellar data. This catalogue can be adopted to study individual planets, planet populations, and planet formation within their Galactic context. It is found that the EHS population is rather diverse in their chemical and Galactic properties, although they are all found in the Solar vicinity, close to the Local spiral arm. Most EHS belong to the thin disc, but some older thick disc and halo members have also been identified. Moreover, the stellar effective temperatures, luminosities, and radii are found to be more precise than literature values found in most used databases. For instance, the new stellar radii allow to reduce significantly the uncertainty on the planetary radii uncertainties, leading to a finer analysis of the planet evaporation valley around 1.8 R . Other planet properties were also explored as, for instance, the increase of the average planet radius with the metallicity of the host star. Finally, the future updates of this catalogue thanks to the Gaia/DR4 data will be discussed, including new results obtained on the chemical properties of the host stars.

Accurate, Precise, and Homogeneous Exoplanet Host Star Parameters and Elemental Abundances Contextualize the Formation and Time Evolution of Giant Planets

P. McCreery
The Johns Hopkins University

Homogeneous stellar parameters and elemental abundances are essential for interpreting extrasolar systems. Age is the most challenging stellar parameter to infer for field stars, especially for hot Jupiter hosts that may have experienced angular momentum exchange violating the assumptions of most age-rotation calibrations. Additionally, while accurate photospheric parameters and abundances are necessary for interpreting exoplanet atmospheres, systematic differences between spectroscopic analyses often exceed reported precisions, introducing biases in studies of the exoplanet population and their host stars. I present a comprehensive approach to host star characterization that addresses these challenges. By combining ground-based high-resolution spectroscopy with Gaia astrometry and multiwavelength photometry, I obtain accurate and precise stellar parameters and abundances for 98 solar-like exoplanet hosts observed by

JWST in Cycles 1 through 4. Crucially, stellar mean densities derived from JWST mid-infrared transit light curves yield age precisions an order of magnitude better than literature values – exceeding even those achieved by short-cadence Kepler asteroseismology. Over JWST's expected 10-year lifetime, this framework can be applied to hundreds of transiting giant planet systems, yielding homogeneous ages, parameters, and abundances that enable detailed studies of the formation pathways, migration histories, and time evolution of giant planets and their atmospheres.

Is lithium in planet-host stars affected by the presence of their planets?

M. Tsantaki
Osservatorio Astrofisico di Arcetri - INAF

Whether planet-host stars are systematically depleted in lithium compared to stars without detected planets remains an open question. Early studies suggested that solar-type stars hosting planets may exhibit Li depletion but later works showed that such claims may arise from biases in stellar age, mass or stellar parameters, all of which strongly affect lithium evolution. In this talk, I present a homogeneous analysis of lithium abundances for 350 FGK-type planet-host stars in the Ariel Mission Candidate Sample. Our aim is to show whether the presence of planets leaves a measurable imprint on the stellar Li content. We derived Li abundances from high-resolution, high-S/N spectra through spectral synthesis together with homogeneous stellar parameters from the Ariel Stellar Characterisation Working Group. The results are compared with a well-defined reference sample of stars without detected planets from the HARPS GTO survey. We show that the Li behavior of Ariel planet hosts is consistent with the expected trends driven by effective temperature, age, metallicity, mass, and rotational velocity. When planet hosts and non-host stars are compared within narrow stellar-parameter intervals, their Li distributions become statistically indistinguishable. We therefore find no compelling evidence for a systematic Li depletion associated with the presence of planets at the population level. These results support the view that previously reported Li differences are primarily the consequence of sample selection and underlying stellar-parameter correlations, rather than a direct signature of planet formation or star–planet interaction.

Be and Li as tracers of stellar depletion and planet engulfment

A. Rathsam
Leibniz-Institut für Astrophysik Potsdam

The light elements Li and Be are powerful probes of stellar evolution. Since they are easily destroyed at different depths below the convective envelope of solar-type stars, and they are not produced by main sequence objects, the observed enrichment or depletion in stars can provide key clues regarding their past. To explore their use as tracers of evolutionary processes, we investigate their abundances in two stellar systems with distinct histories. The first is the star HD 65907, which has an isochronal age of 5 Gyr but shows alpha-element enhancement, strong Li depletion, and kinematics compatible with Pop. II stars, pointing to a past mass accretion episode. Its extremely low Li and Be abundances, combined with the lack of a detectable companion, suggest that HD 65907 is a blue straggler formed via merger. We also analyze the chemical abundance pattern of the system HD 129171/HD 129209, which, despite having similar atmospheric parameters, exhibits differences of ~0.12 dex in [Fe/H] and ~1 dex in Li content. As Li and Be are refractory elements, abundant in rocky planets, their enhanced photospheric abundances may indicate a planet engulfment event. We confirm that the chemical differences between both components of the pair are compatible with an engulfment model of 11.2 Earth masses of rocky material, highlighting Be as a sensitive diagnostic of engulfment events and, more broadly, the potential of Li and Be to trace diverse evolutionary pathways in solar-type stars.

Solar Twins: Probing Planetary Systems, Stellar Evolution, and Galactic Archaeology

J. Melendez
Universidade de Sao Paulo

I will discuss the importance of high-resolution, high-S/N spectroscopic studies of solar twins (stars with temperature, luminosity, and metallicity similar to our Sun) through differential line-by-line measurements, both by hand and with neural networks, with the aim of better understanding: (i) the formation and peculiarities of our Solar System; (ii) open problems in stellar astrophysics, particularly regarding rotation, stellar activity, and lithium depletion; and (iii) possible subpopulations in the solar neighborhood, radial migration, and the Sun's birthplace. Although neural networks have not yet reached the precision achieved by careful manual measurements, they show great promise for improving abundance precision in large stellar samples.

Revisiting r-process signatures with 3D non-LTE stellar spectroscopy

M. Racca
Stockholm University

The rapid neutron-capture process (r-process) produces about half of the elements heavier than iron, including Ag, Au, Th, and U. Despite its key role in cosmic chemical evolution, its astrophysical site remains uncertain. Metal-poor, r-process enhanced stars are ideal laboratories, as their surface abundances preserve the chemical signature of their birth gas. However, deriving reliable abundances from high-resolution spectra requires accurate atmospheric models and analysis techniques.

I present a new high-precision abundance analysis of the very metal-poor ([Fe/H] $\simeq -3.5$) and r-process enhanced star SMSS J200322.54$-$114203.3, previously studied in 1D LTE by Yong et al. (2021). Our study is based on high-resolution UVES spectroscopy combined with 3D hydrodynamical model atmospheres and (non-)local thermodynamic equilibrium (NLTE/LTE) radiative transfer. We derive full 3D NLTE abundances for Na, Mg, Al, Si, Ca, Cu, Ag, and Ba, and 3D LTE abundances for additional neutron-capture elements, allowing a direct assessment of biases in classical 1D LTE analyses.

We find large, element-dependent discrepancies with respect to previous results, with 3D NLTE corrections reaching ∼1 dex for some elements, notably Al. These revisions affect key abundance ratios used to compare with theoretical yields. While the 1D LTE abundances were consistent with magnetorotational hypernova models, our revised pattern alters this agreement, with important implications for the origin of the r-process and the early chemical evolution of the Milky Way.

Tracing Ba and Eu abundances across the Galactic disc from Gaia-ESO FLAMES/GIRAFFE spectra using the Cannon

P. B. Das
Macquarie University

Neutron-capture elements such as Barium (dominated by delayed s-process enrichment from asymptotic giant branch stars) and Europium (primarily an r-process tracer, with neutron-star mergers likely providing a major contribution) in Galactic-disc populations act as sensitive tracers of Galactic chemical evolution, revealing the interplay of enrichment channels across stellar populations. Yet deriving precise abundances at intermediate spectral resolution for large samples remains challenging, due to line blending, parameter covariances, and the large volume of spectra requiring analysis.

Here we incorporate “The Cannon” data-driven model, trained on ∼800 FLAMES/GIRAFFE HR15N spectra ($R \sim 19{,}000$) using reference stellar parameters and abundances from the Gaia-ESO DR5 catalogue, to derive atmospheric parameters (T_{meff}, $\log g$, $v \sin i$, [Fe/H]) and abundances A(Ba) and A(Eu) for ∼36,000 stars. Our analysis yields ∼21,000 reliable Ba measurements (median uncertainty ∼0.06 dex) and ∼400 reliable Eu measurements (∼0.02 dex), including ∼10,000 new Ba and ∼100 new Eu abundances beyond previous analyses.

The resulting catalogue, rich in open cluster observations spanning 10 Myr to 10 Gyr across Galactocentric radii of 6–20 kpc, enables robust exploration of age dependence of s- and r-process contributions across the Galactic disc. Importantly, this methodology can be directly adapted to the framework of upcoming massive spectroscopic surveys such as 4MOST and WEAVE.

Barium Isotope Fractions as Reliable Tracers of Nucleosynthesis Processes

R. Giribaldi
INAF – Osservatorio Astrofisico di Arcetri

Understanding the relative contributions of the slow (s) and rapid (r) neutron-capture processes is central to studies of stellar nucleosynthesis and Galactic chemical evolution. The abundance ratio [Ba/Eu] is commonly used for this purpose, but at very low metallicity ([Fe/H] < -2) both processes can produce significant amounts of barium, making this diagnostic ambiguous. An alternative approach exploits the isotopic composition of barium, which can be inferred from the detailed profiles of the Ba II resonance lines affected by hyperfine and isotopic splitting. In practice, however, the derived isotopic fractions can be strongly influenced by modelling assumptions and uncertainties in atomic data.

In this talk I present a systematic validation of the barium isotopic method using a sample of metal-poor benchmark stars together with several Ba-enhanced stars. We investigate the impact of different spectral modelling approaches—including 1D LTE, 1D non-LTE, and prototype 3D non-LTE calculations—combined with carefully tested atomic parameters. This analysis identifies the conditions under which reliable isotopic fractions can be obtained and reveals a characteristic signature in the [Ba/Eu]–[Ba/Fe] plane associated with s-process dominated enrichment.

As an application, we analyse a carbon-enhanced metal-poor (CEMP) star in detail. By combining isotopic barium fractions, elemental abundances, and nucleosynthesis modelling, we investigate the origin of its neutron-capture elements. The results favour a mixture of r- and s-process contributions: the r-process component is consistent with normal Galactic chemical evolution, while the s-process enrichment likely originates from mass transfer from an asymptotic giant branch (AGB) companion with initial 1.5 solar mass. The i-process scenario appears unlikely, as it predicts isotopic fractions incompatible with the observations, and requires extremely overshooting to reproduce the observational abundance pattern.

The r-process dominates neutron-capture elements production in the oldest SMC stars

L. Santarelli
DIFA Unibo & INAF Bologna

We present the chemical abundances of Fe, alpha, and neutron-capture elements in 12 metal-poor Small Magellanic Cloud (SMC) RGB stars, observed with the high-resolution spectrographs UVES/VLT and MIKE/Magellan. These stars are characterised by $-2.3 < m[Fe/H] < -1.4$ dex, with ten of them with [Fe/H] < -1.8 dex. According to theoretical age-metallicity relations for this galaxy, these stars were formed in the first Gyr of life of the SMC and represent the oldest SMC stars known so far.

The [alpha/Fe] abundance ratios are enhanced but at a lower level than MW metal-poor stars, as expected according to the slow star formation rate of the SMC. The sample exhibits a large star-to-star scatter in all the neutron-capture elements. The two r-process elements we measured (Eu and Sm) have abundance ratios from solar up to +1 dex, three of them with [Eu/Fe] $> +0.7$ dex and labelled as r-II stars. This [r/Fe] distribution indicates that the r-process in the SMC can be extremely efficient but is still largely affected by the stochastic nature of the main sites of production and the inefficient gas mixing in the early SMC evolution.

A similar scatter is observable also for the s-process elements (Y, Ba, La, Ce, and Nd), with the stars richest in Eu also being rich in these s-elements. Also, all the stars exhibit sub-solar [s/Eu] abundance ratios. At the metallicities of these stars, the production of neutron-capture elements is driven by the r-process because the low-mass AGB stars have not yet evolved and left their s-process signature in the interstellar medium.

Neutron-capture elements in Gaia-Sausage-Enceladus:

From Sr to Th

S. Jameela
Department of Physics and Astronomy, University of Florence

With the advent of the Gaia space missions, it has been undeniably and conclusively shown that the Milky Way halo hosted several accretion events in the past. The last major accretion event in the history of Milky Way happened 10 Gyrs ago, an encounter with a massive ($\sim$10% of the MW) dwarf galaxy named Gaia-Sausage-Enceladus (GSE) that brought a large amount of stars that can be identified through their unique chemical and kinematic signatures.

The first compelling evidence for the existence of a low-alpha population possibly coming from an accreted dwarf galaxy was presented in Nissen & Schuster (2010, NS10 hereafter). This low-alpha population has now been shown to largely correspond to the GSE. Chemical abundances of these low-alpha stars therefore provide valuable insights into the chemical evolution history of the GSE, thereby improving our understanding of accretion events and various nucleosynthesis processes.

In this work, we have performed a detailed high-precision chemical abundance analysis of neutron-capture elements such as Eu, Th, Ba, La, etc. for a sub-sample of 54 stars from NS10, covering the metallicity range $-0.4 \leq m[Fe/H] \leq -1.6$, including 26 GSE stars (low-alpha) and 28 high-alpha stars. The analysis is based on high-resolution ($R \geq 40{,}000$) and high S/N (> 80 pix^{-1} at 4000 Å) VLT/UVES spectra.

This is the most detailed r-process abundance analysis performed with high precision for a sample of stars outside the Galaxy (i.e., GSE). We have identified a clear separation between the accreted and in-situ populations in all r-process elements, highlighting the differences in the r-process enrichment histories of these two galaxies. Therefore, our work shows that understanding the complex origin of the r-process strongly relies on obtaining and accurately analysing high-resolution and high-S/N spectra in different galaxies and their various galactic components.

Tracing Cosmic Enrichment Through Metal-Poor Stars

P. Saraf
Physical Research Laboratory, Ahmedabad, Gujarat (India)

The oldest, most metal-poor stars in the Galactic halo and nearby dwarf galaxies preserve the chemical fingerprints of the early Universe in their atmospheres. Through “stellar archaeology”—combining chemical and dynamical properties with spectroscopy and orbit integration—we can address fundamental questions about cosmic origins.

I will present an overview of the Milky Way’s chemodynamic structure revealed by massive surveys such as APOGEE and Gaia, spanning from the bulge to the disk’s edge, and highlight the roles of enrichment, heating, migration, and mergers in shaping the Galaxy we see today. In the second part, I will focus on how high-resolution optical spectroscopy of chemically intriguing metal-poor stars probes the first stars and their supernovae, the nucleosynthesis processes that forged the elements, and the pathways of early star and galaxy formation.

I will share new results on chemically peculiar stars, including CEMP and r-process enhanced stars, observed with the Gran Telescopio Canarias, the Very Large Telescope, and India’s HESP-GOMPA survey. Using the powerful differential abundance technique, applied for the first time to RPE stars, we uncover evidence for multiple sites of element production. Our data-driven classification of RPE stars further suggests diluted populations and links with CEMP-r/s stars. Together, these findings open new perspectives on the origins of the elements and the complex pathways of cosmic enrichment.

Echoes of the Underdogs: unveiling the origin of the earliest Galactic disc stars with UVES

I. Gonzalez Rivera
Laboratoire d'Astrophysique de Bordeaux

The understanding of the Milky Way's assembly is crucial to probe the scenario of hierarchical galaxy formation on a large scale. Evidence supporting past accretion events can be observed in the form of substructures on the sky (e.g., stellar streams), or in phase space (e.g., the Gaia-Enceladus/Sausage merger), by studying the orbital and chemical properties of the most metal-poor stars ([Fe/H] < -2 dex).

Recently, several studies hinted at a population of metal-poor stars on disc-like orbits, i.e., planar and prograde with high angular momenta, pointing out the overall lack of consensus regarding the formation and potential origins of the Galactic disc. In González Rivera de La Vernhe et al. (2024), we highlighted the difficulty of relating this population to a halo or a disc component when solely relying on kinematics, especially at [Fe/H] < -1.7.

Using the Pristine-Gaia synthetic catalog of photometric metallicities, we select 24 giant stars with $-3 < m[Fe/H] < -2$, to perform a high spectral resolution follow-up with UVES@VLT. To account for the diversity of targets, we implement a two-step pipeline that derives stellar parameters using both photometric and spectroscopic information. After carefully validating our sample, we investigate its chemical content in four main nucleosynthetic channels: alpha-process, neutron-capture, odd-Z, and Fe-peak, for a total of 25 chemical species.

Finally, we investigate the origin of the earliest disc stars, first in spaces such as [Mg/Mn]–[Al/Fe], then by comparing our data with the chemical trends of known in- and ex-situ populations from recent literature (e.g., GES, Loki, Sagittarius, bulge, …).

The oldest and most metal-poor stars in the Galactic disc: unveiling the Milky Way's chemo-dynamical evolution

F. Sestito
University of Hertfordshire

The most metal-poor stars (MMPs) are extremely rare objects located mainly in the Milky Way halo. It is assumed that they formed in the relatively pristine Galaxy shortly after the Big Bang, and they belong to the earliest generations of stars formed in the Universe. The study of stars at the lowest metallicities provides important tools to answer questions on the masses of the First stars, the origin of the elements, and the assembly and chemo-dynamical evolution of the Galaxy.

I will focus on the chemo-dynamical investigation of the MMPs using both observations and cosmological simulations. I will show that, at odds with pre-Gaia expectations, a fraction of the MMPs is inhabiting the Galactic plane, posing new questions on the formation of our Galaxy. This "planar" population, spanning several dex in metallicity, is preferring a prograde motion, as the more metal-rich Galactic disc.

The chemical properties, from an unprecedented high-resolution spectroscopic campaign, of a particular sample of stars in planar orbits suggest internal similarity and its separation from the bulk of the non-planar halo population. Their elemental abundances are similar to those that experienced a homogeneous chemical evolution akin to that of dwarf galaxies.

A plausible scenario, supported chemically and dynamically by cosmological zoom-in simulations (NIHAO and Aquarius), is the early accretion of a single system whose dynamical evolution produced stars on planar orbits. I will show how coming multi-object spectroscopic surveys are needed to better unveil the origin of this special population and, in general, how MOS surveys will revolutionise our understanding of Galactic assembly.

The impact of the first stars in two ultra-faint dwarf galaxies: Grus II and Tucana IV

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Università degli Studi di Firenze

The ultra-faint dwarf galaxies (UFDs) are predicted to host the descendants of the first stars (only H and He) that lit up in our Universe. No metal-free stars (Pop III) have been found to date, but the chemical abundances on the surfaces of carbon-enhanced metal-poor stars (CEMP-no, [C/Fe] $> +0.7$, [Fe/H] < -2) are believed to trace the products of low-energy ($E < 10^{51}$ erg) Pop III supernovae (SNe).

To search for Pop III descendants, we measured line-of-sight velocities, [Fe/H] and [C/Fe] in two recently discovered UFDs, Grus II and Tucana IV. We identified 13 members in Grus II and seven members in Tucana IV. Among the red giant branch stars in Grus II, we found three CEMP-no stars at [Fe/H] ≈ -3 and [C/Fe] $> +1$ and two CEMP-no stars at a slightly higher [Fe/H] and [C/Fe] $> +0.7$. In addition, we found one CEMP-no star in Tucana IV.

This results in a significantly higher fraction of CEMP-no stars derived in these two UFDs (60%) than the average UFD ($\sim$20%) or the Milky Way ($\sim$20%). Thus, the impact of the first low-energy SNe is particularly strong in these two very small UFDs ($M_\star \sim 10^3\,M_\odot$). This might indicate that the lowest-mass UFDs could be more strongly affected by the imprint of Pop III stars.

More data are needed, and fortunately there are many large spectroscopic surveys on the horizon. In particular, the 4DWARFS survey aims to target all UFDs in the Southern Hemisphere, and measure both radial velocities and chemical abundances. This will provide a large and homogeneous dataset furthering our understanding of the earliest chemical enrichment in these ancient and pristine systems.

Unveiling Oxygen's Past with Subaru/IRD: Oxygen Abundance of Very Metal-Poor Stars

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Determining oxygen abundances in very metal-poor (VMP) stars ([Fe/H] $= -4.0$ to -1.0) remains challenging, particularly at lower metallicities, due to the weakness and telluric contamination of the [O I] forbidden line—the most reliable oxygen indicator in the optical range. Oxygen, like carbon, is typically overabundant in VMP stars ([O/Fe] > 0.5); however, to identify and study stars with potentially lower oxygen abundances, alternative and reliable oxygen tracers are required.

In this study, we investigate the reliability of near-infrared OH vibration-rotation lines as oxygen abundance indicators in a metallicity regime where the [O I] line is unusable. Using high-resolution Subaru/IRD spectra ($R \sim 70{,}000$), covering numerous first-overtone OH lines in the H-band (1.5–1.7 μm), we determined oxygen abundances for 35 E/VMP stars (34 red giants and one dwarf).

To ensure consistency, we recalibrated the effective temperature, surface gravity, and iron abundance for all stars prior to determining oxygen abundances. Oxygen abundances were derived using 1D LTE models for all stars. For 21 of these stars, we also derived oxygen abundances from the [O I] 6300 Å line using archival Subaru/HDS and VLT/UVES spectra. This allows us to directly assess the consistency between OH and [O I] indicators.

Our results show that OH abundances are extremely sensitive to the derived temperature, but with carefully calibrated temperatures, we achieve abundance differences of < 0.2 dex for most of the stars. This study provides new observational constraints on oxygen abundance measurements in the VMP regime.

The new generation of MOS at ESO and the future of spectroscopic surveys

V. Mainieri
ESO-Garching

Multi-object spectroscopy has been a very powerful tool to enable science advancement in a very broad range of fields, from cosmology to stellar evolution. Looking ahead, this is a very interesting time, with multiple new MOS facilities recently starting operations or completing their surveys, e.g. DESI, PFS, WEAVE, and SDSS-5.

At ESO, two new major multi-object spectrographs are close to starting observations: 4MOST, a survey-dedicated facility at the 4-m VISTA telescope covering the optical bands at multiple spectral resolutions over a wide field of view, and MOONS, an optical/NIR MOS at the VLT. These two facilities will provide our community with unprecedented access to large spectroscopic samples.

I will describe the capabilities of these two MOS and some of their major science goals, as well as possible ways their scientific output can be further enhanced with new approaches to scheduling and data access. I will conclude by looking to the further future of spectroscopic surveys at ESO.

Towards Physically Realistic Stellar Spectroscopy across Cosmic Scales

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Accurate stellar parameters and chemical abundances underpin much of modern astrophysics, from the characterisation of exoplanet systems to the reconstruction of Galactic evolution. Yet, their inference from observed spectra remains limited by simplifying assumptions in spectral modelling, clouding our view of the cosmos with systematic biases.

In this talk, I present advances in physically realistic stellar spectroscopy, focusing on improved modelling of stellar atmospheres and line formation. I discuss how these developments impact the determination of stellar parameters and abundances across different stellar types and observational regimes, with emphasis on the consequences and opportunities for stellar, planetary, and Galactic astrophysics. These results highlight the importance of moving beyond simplified models towards a more consistent and physically grounded framework for stellar spectral analysis.

3D non-LTE Na Abundances for the 1 Million Stars of GALAH DR4

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Stockholm University/IAC

Sodium plays a crucial role in tracing Galactic chemical evolution, as seen in spectroscopic analyses of late-type stars across different Milky Way regions. Numerous studies have explored Na abundances in thin- and thick-disc stars, as well as in globular clusters, where the well-known [Na/O] anti-correlation is indicative of the presence of multiple stellar populations. Moreover, recently, Na has been useful as a population identifier in the halo field as well (Buder et al. 2022). However, traditional abundance determinations using hydrostatic one-dimensional (1D) local thermodynamic equilibrium (LTE) models can lead to significant overestimations—up to 0.5 dex for saturated lines in giant stars—due to the breakdown of LTE assumptions.

To overcome these limitations, we computed a state-of-the-art grid of 3D non-LTE synthetic spectra for FGK-type stars using 3D radiation-hydrodynamic atmospheres from the new, extended, and refined Stagger-grid (Rodriguez-Diaz et al. 2024). To achieve precise interpolations, we trained a Neural Network, outperforming standard methods such as linear and spline interpolation (Wang et al. 2021).

In this talk, I will present, for the first time, 3D non-LTE Na abundances for the one million stars in the recently released GALAH DR4 survey. Achieving a consistent and precise absolute Na abundance scale across different Galactic stellar populations requires the best physical models and a careful individual treatment of Na lines and their blends. We show that this is possible for a million-star survey like GALAH already today and, therefore, should be used for future larger-scale spectroscopic surveys like 4MOST and WEAVE, advancing our understanding of the Galactic chemical evolution of sodium.

Survey of Surveys: project status

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INAF – Osservatorio Astrofisico di Arcetri

The Survey of Surveys (SoS) project aims to place the main stellar spectroscopic surveys on a common scale and to build a homogeneous catalogue of stellar parameters and radial velocities. Although modern surveys provide measurements for millions of stars, differences in instrumental setup, spectral coverage, analysis pipelines, calibration, and target selection introduce systematic inconsistencies that limit their simultaneous usage. SoS addresses this problem through cross-survey calibration based on commonly observed stars.

In this contribution, we present an update on the current status of the project. We also present the SoS-ML, which extends the SoS framework beyond spectroscopy by estimating stellar parameters from photometric data. In this way, the homogeneous spectroscopic scale defined within SoS is used as a reference for machine-learning models that can be applied to broader samples not covered by the spectroscopic surveys alone.

Together, the SoS-Spectro catalogue and its photometric SoS-ML extension form a common framework for constructing larger and more consistent stellar samples for Galactic studies.

The Gaia benchmark stars

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The Gaia-ESO Survey demonstrated that calibrating automatic spectroscopic methods with the Sun only was not sufficient, and a larger set of reference stars with fundamental parameters was needed. The Gaia benchmark stars were built for that purpose, and became a legacy for validating automatic spectroscopic surveys in the post Gaia-ESO Survey era.

With more than a decade of work, we have provided not only accurate stellar parameters, but high-resolution spectral libraries and codes to perform spectroscopic analysis that help young researchers to initiate in spectroscopy. The sample has increased from 30 to 200 stars, and currently it is expanding towards lower metallicities, lower temperatures, as well as to infrared wavelength regions.

In this talk I will give an overview of this project that has been complementing the efforts of spectroscopic surveys across the globe and will discuss its future avenues.

Exoplanet meteorology: charting the climate of exoplanets with high-resolution spectroscopy

J. Seidel
Observatoire de la Côte d’Azur

Understanding the climates of exoplanets has entered a transformative era, where observations begin to resolve their structure, dynamics, and variability. In this talk, I will present how high-resolution spectroscopy has emerged as a powerful tool to probe the meteorology of exoplanets, enabling us to directly measure atmospheric winds, temperature gradients, and the chemical distribution of material in exoplanet atmospheres.

Focusing on close-in gas giants—particularly ultra-hot Jupiters—I will show how spectrally resolved line profiles of atomic species such as iron or sodium provide unique insights into atmospheric dynamics at extreme conditions. By resolving Doppler shifts at the sub-km/s level, we can map day-to-night winds, distinguish between morning and evening terminators, and constrain atmospheric mass loss.

Recent observations with instruments such as ESPRESSO have pushed these techniques to unprecedented precision, allowing us to move beyond bulk wind measurements toward a more nuanced view of atmospheric structure. I will present recent observational results that reveal altitude-dependent wind regimes, and follow-up modelling efforts to understand the complex interactions between radiation, chemistry, and dynamics.

These observations provide critical benchmarks for global circulation models, which are now being tested against increasingly detailed observational constraints. I will discuss how discrepancies between models and data at the population level point toward missing physics, including the interaction with the planetary magnetic field, which plays a crucial role in shaping exoplanet climates under extreme irradiation.

Looking ahead, I will outline how upcoming facilities, in particular the Extremely Large Telescope (ELT) and its high-resolution spectrograph ANDES, will revolutionise this field. With dramatically increased collecting area and spectral precision, we will be able to extend meteorological studies to smaller and cooler planets, probe temporal variability, and ultimately approach the regime of terrestrial exoplanets. High-resolution spectroscopy will thus serve as a cornerstone technique for the next decade, transforming our understanding of atmospheric physics beyond the Solar System. By placing atmospheric motion at the centre of exoplanet characterisation, exoplanet meteorology provides a new framework for interpreting these distant worlds—not as static atmospheres, but as dynamic, evolving climates.

Pushing the limits of high-resolution transmission spectroscopy with eccentric gas giants

B. Prinoth
ESO-Garching

Transmission spectroscopy has become a key tool for studying the atmospheres of close-in gas giants, allowing us to constrain their chemical composition, dynamics, and thermal structure. In the infrared, high-resolution instruments such as CRIRES+ have pushed this technique further, detecting molecules like CO and H_2O, extending atmospheric studies beyond the most strongly irradiated exoplanets.

As we move toward the ELT era, the focus shifts to cooler, longer-period planets with weaker atmospheric signals. For these targets, the advantages of high-resolution spectroscopy start to break down: lower orbital velocities during transit reduce the radial-velocity separation between planetary, stellar, and telluric signals, making detections more challenging. Today, eccentric planets provide a way to explore this regime. Observed near periastron, their higher orbital velocities temporarily enhance the radial-velocity separation, allowing access to atmospheric signals.

I present results from a CRIRES+ survey of four transiting, eccentric Saturn-mass planets, constraining their atmospheric C/O ratios. While not unique, C/O adds context when combined with other system properties, linking planet formation, migration, and host-star chemistry.

These observations push high-resolution infrared transmission spectroscopy close to its limits. They provide a benchmark for ELT/ANDES and highlight that progress will depend not only on sensitivity, but timing, orbital geometry, and target selection.

Time-Resolved Stellar Contamination in High-Resolution Transmission Spectroscopy

E. Cristo
Instituto de Astrofísica e Ciências do Espaço @ CAUP

High-resolution transmission spectroscopy is transforming how we study exoplanet atmospheres, revealing their chemical fingerprints in remarkable detail. But as our ability to detect ever smaller planetary signals improves, a growing challenge emerges—the star itself. Even quiet stars show natural spectral variations across their surfaces due to rotation, viewing geometry, and line-of-sight effects. During transit, the planet sequentially hides regions with slightly different local spectra, introducing subtle, time-dependent distortions that can mimic or modify the planetary signature.

SOAPv4 was developed to address this challenge. It constructs a detailed model of the stellar disc, computing synthetic spectra for each surface element while accounting for effects such as centre-to-limb variation and local velocity shifts from rotation. By combining these spectra over time, SOAPv4 reproduces the full transit sequence, capturing the physically driven changes in stellar line profiles and tracing how they propagate into the observed transmission spectrum.

We will also present a new pipeline built upon SOAPv4 that extends these capabilities to time-series analysis, enabling the modelling and correction of stellar-induced distortions on exposure-by-exposure scales. Applications to benchmark systems such as HD 209458 highlight both the potential and current limitations of this approach. Together, these tools will be essential for interpreting high-resolution transmission spectra with future instruments such as ANDES@ELT.

Impact of stellar spots on high-resolution transmission spectra of an Earth-like planet around a Sun-like star

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High-resolution transmission spectroscopy provides detailed insights into exoplanetary atmospheres through individual atomic and molecular line profiles. While stellar activity is known to bias low-resolution spectra, its impact at high resolution, where atmospheric characterisation relies on subtle variations in line depth, shape, and asymmetry, remains poorly constrained. Variations in the host star due to magnetic activity, manifested in surface features such as spots and faculae, introduce stellar signals that can mimic or obscure planetary signals, representing a significant challenge for future high-precision observations. In this work, we present preliminary results from PoET (Paranal Solar ESPRESSO Telescope), a 60-cm telescope feeding the ESPRESSO spectrograph, capable of obtaining ultra-high-resolution ($R > 200,000$) disk-resolved and disk-integrated ("Sun-as-a-star") solar spectra. Using observations of the sun and active regions (spots), we investigate how stellar activity affects high-resolution transmission spectra of an Earth-like planet in the habitable zone of a Sun-like star. We simulate transits of a planet without an atmosphere to isolate signals induced by stellar activity and assess potential false positives in transmission spectra. This approach allows us to examine how parameters such as spot size and location impact the signatures of planetary atomic and molecular lines in transmission spectra. These first steps provide a framework for interpreting future high-resolution observations with instruments such as ANDES at the ELT and contribute to ongoing efforts to identify atmospheric signatures in Earth-like planets robustly.

Exoplanets in open clusters

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Università degli Studi di Padova

Stellar clusters, including open clusters and associations, are ideal laboratories for studying star formation and evolution, but their importance goes far beyond this. Because their stars are coeval and share a nearly homogeneous initial chemical composition, clusters provide crucial insight into the formation and dynamical, structural, and chemical evolution of the Galaxy. They also allow precise constraints on stellar masses, radii, ages, and kinematical properties.
In this context, the search for exoplanets around cluster members offers a unique way to investigate planet formation and evolution, and to test how the environment shapes these processes over time. By analyzing clusters across a wide range of ages and chemical compositions, we can constrain the history of planetary systems from protoplanetary disk dissipation to long-term dynamical stability, including orbital migration, tidal circularization, photoevaporation, and core-powered mass loss. Reconstructing cluster Galactic orbits reveals where planetary systems formed and their link to the environment.
Despite their importance, the number of planets in clusters is limited, mainly because of strong stellar activity, crowding, and distance. In this talk, I will review the main findings from photometric and spectroscopic surveys and discuss these results in the broader context of planetary evolution, with a particular focus on the correlations between host star-planet and on the environments in which these planets formed.

Beyond Na–O: What Li, Be and He Tell Us About Globular Cluster Formation

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Globular clusters are no longer regarded as simple stellar populations. Their variations in C, N, O, Na, Mg and Al reveal multiple populations, but these abundant elements alone have neither identified the stars responsible for the chemical processing nor reconstructed the conditions under which the enriched populations formed. Some of the strongest constraints come instead from far more elusive species: lithium, beryllium and helium.
In this talk I will review what these elements have taught us about globular-cluster formation, highlighting Luca Pasquini's pioneering contributions. Lithium in unevolved cluster stars, tied to the proton-capture patterns, constrains the dilution between pristine gas and processed material — and, where Li survives in stars that should have destroyed it, limits the polluters themselves. The first detections of beryllium in turn-off stars, in NGC 6397 and later NGC 6752, established Be as both a cosmochronometer for the earliest Galactic star formation and an independent tracer of the gas from which each population formed; the Be test remains one of the few measurements able to separate a genuine age difference between populations from pure chemical processing. And the direct comparison of the He I 10830 Å line

in chemically distinct giants of NGC 2808 gave the first spectroscopic evidence tying helium enrichment to the multiple-population phenomenon.
None of this was separable from instrumentation: the near-UV throughput of UVES made Be accessible at all, the multiplexing of FLAMES turned abundance work from single-star analyses into population surveys, CRIRES opened the near-IR helium diagnostic, and ESPRESSO now adds extreme stability and, in 4-UT mode, the collecting power of a 16 m telescope.
The way forward is not larger samples of the classical Na–O and Mg–Al patterns, but population-tagged, evolutionarily controlled measurements of Li, Be and He alongside the full proton-capture pattern. Combining the FLAMES and ESPRESSO legacies with the near-UV sensitivity of CUBES, the multiplexing of MOONS, and ultimately the ELT will turn these rare elements into quantitative tests of dilution, nucleosynthesis and formation timescales.

GLIMPSE-C01: A Galactic Relic Hidden in the Dust

A. Mura Guzmán
Mcquarie University

Star clusters in the Galaxy are typically either very young (open clusters, $t < 2$ Gyr) or as old as the Galaxy (globular clusters, $t > 10$ Gyr). Often described as “natural laboratories,” their formation conditions and stellar distances make them ideal for studying stellar and Galactic evolution. However, the Galaxy lacks intermediate-age ($\sim$2–8 Gyr) globular clusters (GC), although they are observed in nearby galaxies (e.g., Magellanic Clouds). GLIMPSE-C01 appears to be the only exception, and its chemical characterisation offers a unique opportunity to investigate its origin and implications for cluster formation in the Galaxy. However, severe dust extinction (AV = 14–22) makes it essentially invisible to optical wavelengths, requiring infrared observations to reveal its nature. We present stellar parameters and chemical abundances for 12 members of GLIMPSE-C01, derived from high-quality infrared spectra obtained with IGRINS@ Gemini South. The cluster shows near solar metallicity with no intrinsic iron spread. Star-to-star variation in [Na/Fe] indicates the presence of multiple stellar populations, and its steep O–Na relation is similar to other metal-rich bulge GCs. Si and Ca abundances follow the Galactic trends. Using nucleosynthesis models, we explore possible origins of the observed variations in light elements. Our findings place GLIMPSE-C01 as the most metal-rich known Galactic GC and support the presence of multiple stellar populations, providing new insight into the formation, evolution, and survival of globular clusters in the Milky Way. Is GLIMPSE-C01 alone in the Galaxy?

The Bulge Cluster Origin (BulCO) survey with CRIRES+ at the ESO-VLT: a chemical screening of the Globular Cluster NGC 6553

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The formation mechanisms of galaxy bulges are still highly debated and poorly constrained by observations, due to prohibitive observing conditions. Still, the Galactic bulge represents the first massive structure to have formed in our Galaxy. Therefore, the analysis of its stellar populations provides a unique opportunity to explore the formation and early evolutionary processes of the Milky Way Galaxy. In this talk, I will present the chemical screening of the stellar population belonging to the globular cluster NGC 6553 in the Galactic bulge, performed in the context of the Bulge Cluster Origin (BulCO) survey with CRIRES+ in the near-infrared domain. This survey is performing homogeneous high-resolution chemical screening of 17 stellar systems orbiting the Milky Way bulge, with the aim of unveiling their origin and true nature. I will introduce the survey and discuss the abundances of 18 elements produced via distinct nucleosynthetic channels for 14 red giant branch stars belonging to NGC 6553. We found a mean [Fe/H] = -0.20 ± 0.01 dex, and about solar-scaled iron-peak elements, confirming that this is one of the most metal-rich globular clusters in the Milky Way. We assess the presence of multiple populations typical of genuine globular clusters from the significant spreads in Na, N, and C, and an almost vertical Na–O anti-correlation. Finally, by using classical ([α/Fe] vs [Fe/H]) and newly defined ([V/Fe] and [Zn/Fe] vs [Fe/H]) ”chemical DNA tests”, we chemically confirm its in situ formation within the Galactic bulge.

HST+IGRINS synergy to characterise the newly discovered metal-rich bulge globular cluster Patchick 126

E.R. Garro
ESO-Chile

We present the first comprehensive spectroscopic and deep photometric study of the globular cluster candidate Patchick 126. The spectroscopic analysis is based on high-resolution near-infrared data obtained with the Immersion GRating INfrared Spectrometer (IGRINS) spectrograph, while the photometric analysis relies on Hubble Space Telescope (HST) observations from the Hubble Missing Globular Cluster Survey (MGCS). We derived abundances for α-(O, Mg, Si, Ca, Ti), light-(C, N), odd-Z (Na, Al), iron-peak (Fe, Co, Cr, Ni, Mn, V), and s-process elements (Ce) for four red giant stars observed in both the H and K bands. Our results yield a mean metallicity of [Fe/H] = -0.30 ± 0.03, with no evidence of intrinsic variation, and an α-enhancement of [α/Fe] = +0.19 ± 0.20. Mg, consistent with the trends of metal-rich Galactic globular clusters. We detect an intrinsic C–N anti-correlation, but no Na–O or Al–Mg anti-correlations, in agreement with expectations for low-mass, metal-rich clusters. From the HST photometry in the F606W and F814W bands, we constructed deep colour–magnitude diagrams extending $\sim$2–3 magnitudes below the main-sequence turn-off. This depth allowed us to provide the first robust age estimate for the cluster. Applying the methods developed within the Cluster Ages to Reconstruct the Milky Way Assembly (CARMA) project, we derive an age of 11.9-0.4+0.3 Gyr. Independently, we obtain a photometric metallicity of [Fe/H] = -0.28, in excellent agreement with the spectroscopic results. The colour excess we derived, E(B-V) = 1.08, confirms that Patchick 126 is a heavily reddened cluster, located at a heliocentric distance of 7.8 kpc. Finally, from the orbital parameters, including energy, vertical angular momentum, circularity, and maximum vertical height, we find that Patchick 126 closely follows a disc-like orbit. Taken together, these results confirm that Patchick 126 is an in situ, low-mass globular cluster of the Milky Way, exhibiting properties that lie at the boundary between old-open and globular clusters.

The Bulge Cluster Origin (BulCO) survey: results in Liller 1

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A variety of stellar systems are expected to populate galaxy bulges: genuine in situ and accreted globular clusters (GCs), the relics of nuclear star clusters of cannibalized galaxies, and even the fossil remnants of the proto-bulge formation process (the so-called “bulge fossil fragments”). The Galactic bulge is the only spheroid where individual stars can be observed in detail, and the signatures of its origin and evolution are imprinted in the kinematic, photometric, and chemical properties of its stellar systems. In particular, chemical tagging is a very powerful tool, since specific abundance patterns provide authentic “chemical DNA tests” univocally tracing the enrichment process, hence the environment, where the stellar population formed. In the contest, the BulCO (The Bulge Cluster Origin) survey, a spectroscopic survey with CRIRES+ at the ESO-VLT which is performing high-resolution chemical screening of the most massive stellar systems in the Galactic bulge. The abundances of about 20 iron and iron-peak, CNO, alpha-, other light elements (such as Al, Na) and a few neutron-capture elements are used to identify the polluters and the enrichment timescales of each system, providing crucial information on their nature and origin. In this talk I will present an overview of the BulCO survey, and the results obtained for Liller 1, one of the most extincted systems of the Galactic Bulge, which is suspected to be a bulge fossil fragment.

Chemical abundances and chemical evolution of the Galactic Center from high-resolution near-IR spectra

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Abundance trends as a function of metallicity for different stellar populations in the Galactic Center provide new insights that complement other studies. Since various elements trace distinct nucleosynthetic channels with unique evolutionary timescales, these trends can vary depending on factors such as the star formation rate and gas inflow, thereby revealing differences between stellar populations. I will present a project in which we have succeeded in measuring detailed abundances of nearly two dozen elements for stars in the Galactic Center structures. We find predominantly metal-rich stars, with abundance trends consistent with those of the inner bulge, suggesting similar evolutionary histories. However, we identify a significant and unexplained enhancement in Na abundances. Further studies are required to determine possible evolutionary links to the complex stellar system Liller 1 and metal-rich globular clusters. We find no evidence of typical globular cluster abundance signatures in our Nuclear Stellar Disk stars with sub-solar metallicities.

Uncovering the Milky Way bulge's neutron-capture dimension

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Universidad de Santiago de Chile

Spectroscopic surveys have been pivotal to our understanding of the formation and evolution of the Milky Way bulge. In fact, the availability of large stellar samples from multi-object optical and near-infrared spectroscopy have provided the means to tackle the statistical sampling of the bulge's resolved stellar populations. From the exploitation and combination of these different datasets a state-of-the art observational picture of the bulge has emerged: the bulge is a very complex region of the Galaxy, with the concurrence of at least two different components, and with observational properties suggesting a complex formation and evolutionary history. These efforts have been largely based on the analysis of alpha- and iron-peak elements. On the other hand the study of the distribution of neutron-capture elements in bulge stars has been studied in rather limited terms so far. These group of elements are of great importance as they provide an independent assessment of the star formation history of a stellar population. We have started a FLAMES follow-up campaign of bulge stars from the Gaia-ESO survey with the aim of producing the first large scale study of heavy elements, securing precision from the joint analysis of Gaia-ESO and the new available data. In this talk I will overview the observational and analysis strategy of this campaign and I will present some preliminary results.

Investigating the Milky Way's Origins: A Spectroscopic Survey of the Galactic Bulge

G. Anacleto
University of São Paulo

The Galactic Bulge preserves fundamental traces of the Milky Way's origins. Therefore, the detailed study of its chemical evolution is essential to understand the formation and evolution of the oldest stellar populations. However, identifying these ancestral survivors is a major challenge, as they are statistically drowned out by the dominant metal-rich populations ([Fe/H] > -0.5) and obscured by severe crowding and variable extinction in the inner Galaxy.

In this work, we analyze a sample of approximately 500 stars observed with the VLT/FLAMES-GIRAFFE spectrograph ($R \sim 22{,}000$), strategically selected in fields surrounding key globular clusters (HP 1, NGC 6522, NGC 6558, Palomar 6, AL 3, and NGC 6355). From these spectra, we derive precise atmospheric parameters and detailed chemical abundances (C, N, O, Fe-peak, neutron-capture elements) that allow us to chemically differentiate these groups. By analyzing abundance ratios, the project aims to reconstruct the chemical enrichment history of the early Galaxy and investigate the nucleosynthesis of the first supernovae in the bulge.

Furthermore, this work serves as a strategic preparatory study for future multi-object spectroscopy with the MOSAIC instrument on the Extremely Large Telescope (ELT). The reduction and analysis techniques for crowded fields refined here will be directly applied to the development of the spectrograph. We therefore present the first results of this survey, characterizing the oldest components of the Galactic core.

First observations of dwarf galaxies with 4MOST

R. Lucchesi
University of Florence

We present the first science results obtained with 4MOST on metal-poor stars in dwarf galaxies.

Following a successful commissioning phase, the first science observations were carried out during the Survey Programme Validation (SPV). The 4DWARFS survey (S14) aims to observe dwarf galaxies and stellar streams visible from the southern hemisphere over the five-year duration of the 4MOST survey.

As part of the validation process, we observed two dwarf spheroidal galaxies as a test case in order to assess our observing strategy and verify that the main science goals can be achieved. We obtained up to two thousand stellar spectra in the magnitude range $G = 16$ to 20, covering a wide spatial extent of these systems.

We explore the radial velocities, metallicities, and some of the chemical abundances derived from these data, such as carbon and alpha-elements. We estimate the associated uncertainties as a function of stellar magnitude and observing time, and evaluate the overall data quality. We also compare our results with measurements available in the literature from other instruments, in order to assess consistency and performance.

These first results highlight the potential of 4MOST to significantly increase the number of spectroscopically analysed member stars in dwarf galaxies, in some cases by several orders of magnitude. These large and homogeneous datasets will provide new insight into the chemical enrichment and dynamical properties of metal-poor stellar populations within dwarf galaxies, and will help to trace their formation and evolution.

Instrumentation panorama (beyond ESO)

R. Bernstein
GMTO / Carnegie Observatories

A significant challenge in realizing the promise of the ELTs is the design and construction of spectrographs capable of delivering the data we expect. This is particularly true for high-resolution and wide-field instruments. In the transition from 4 m- to 8 m-class telescopes, instruments could largely be “scaled up”; their designs did not need to change significantly to achieve the expected gains in sensitivity with increased telescope area. In the leap to 30 m-class telescopes, however, instrument designs cannot simply be scaled up. In many ways, the ESO community has led the way with innovative designs in anticipation of these challenges. In this talk, I will discuss some of the instrument solutions adopted by GMT and other telescopes.

CUBES: a UV spectrograph for the future

S. Covino
INAF / Brera Astronomical Observatory

In spite of the advent of extremely large telescopes in the UV/optical/NIR range, the current generation of 8–10 m facilities is likely to remain competitive at ground-UV wavelengths for the foreseeable future. The Cassegrain U-Band Efficient Spectrograph (CUBES) has been designed to provide high-efficiency observations in the near UV at a spectral resolving power of $R > 20{,}000$, although a lower-resolution, sky-limited mode of $R \sim 7{,}000$ is also planned.

CUBES will offer new possibilities in many fields of astrophysics, providing access to key lines of stellar spectra: a tremendous diversity of iron-peak and heavy elements, lighter elements (in particular Beryllium) and light-element molecules (CO, CN, OH), as well as Balmer lines and the Balmer jump (particularly important for young stellar objects).

The UV range is also critical in extragalactic studies: the circumgalactic medium of distant galaxies, the contribution of different types of sources to the cosmic UV background, the measurement of H_2 and primordial Deuterium in a regime of relatively transparent intergalactic medium, and follow-up of explosive transients. We propose to briefly describe the CUBES project development and goals, the main science cases, the instrument design and the project organization and management.

Small-ELF: A prototype telescope for future exoplanet life detection

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We present the current status and near-term scientific outlook of the Small ExoLife Finder (SELF), a technological and scientific pathfinder for the ExoLife Finder (ELF), a proposed 30–50 m class ground-based facility aimed at the direct detection and characterisation of nearby exoplanets, including the search for biosignatures. The project is led by the Laboratory for Innovation in Opto-Mechanics (LIOM) at the Instituto de Astrofisica de Canarias (IAC) in Tenerife and supported by the European Union through the ERA Chair programme, combining advanced opto-mechanical design, optics, photonics, and machine learning techniques.

As of 2026, the mechanical structure SELF is fully assembled at IACTEC (La Laguna, Tenerife), with its telescope base and dome installed at the Teide Observatory, where on-sky commissioning is planned for 2028. SELF is designed as a 3.5 m diameter, 15 sub-aperture nulling Fizeau interferometer. The instrument is designed to demonstrate key technologies required for future ground-based high-contrast observations, including nulling interferometry, light mirrors, active wavefront control using multi-mode and photonic fibres in combination with machine learning approaches.

SELF will target bright, nearby systems hosting well-separated exoplanets and substellar companions, providing a unique testbed for the extraction of weak astrophysical signals in the presence of overwhelming stellar flux. In this context, SELF directly addresses challenges that are increasingly central to modern exoplanet astrophysics: extreme calibration stability, control of systematics, and high-angular-resolution techniques.

By placing SELF in the broader landscape of current and forthcoming facilities (ESPRESSO, 4MOST, MOONS, ELT instrumentation), we discuss how pathfinder experiments like SELF can inform the design of future large telescopes and high-precision instruments, particularly for the characterisation of exoplanet atmospheres. SELF thus represents a concrete step toward extending the legacy of ESO into the high-contrast, exoplanet-focused domain that will define the coming decades.

Discovery of a Beryllium Anomaly in the Accreted Galaxy Thamnos-2

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Thamnos is an accreted Galactic substructure, possibly associated with the Sequoia merger event, in which the Be-rich star BPM3066 was first identified by Monaco et al. (2025). In a new survey, we identify four additional members of Thamnos-2 exhibiting significant beryllium overabundances. Moreover, the two previously known Be-rich stars, HD 106038 and HD 132475, whose origin has remained unexplained, are also found to have kinematics consistent with membership in Thamnos-2. Thus, all currently known stars with anomalous beryllium abundances appear to be associated with this accreted structure.

No comparable population of Be-rich stars is known elsewhere in the Galaxy, pointing to a rare and localized enrichment event. The observed excess A(Be)/A(Li) ratio bears the signature of spallation reactions, indicating a highly energetic event in which fast CNO nuclei fragmented through collisions with the surrounding medium. The beryllium enhancement is accompanied by elevated silicon abundances, and we also detect a correlation between beryllium and neutron-capture elements. The silicon enhancement is likewise consistent with enrichment by a hypernova. Such an event could have rapidly enriched the surrounding gas to [Fe/H] ≈ -1.5, naturally explaining the relatively high metallicities of stars that formed from this material despite their old ages ($\approx$13 Gyr). We discuss this scenario in the context of recent models of hypernova-driven nucleosynthesis (more in Molaro, Bonifacio, Caffau, Monaco, Cescutti, 2026, AA in press, arXiv:2607.08179).

Heavy Elements with HRMOS: Constraining Stellar Ages and Nucleosynthesis in the High-Resolution Era

L. Magrini
INAF – Osservatorio Astrofisico di Arcetri

The High-Resolution Multi-Object Spectrograph (HRMOS) proposed for the VLT will provide an unprecedented combination of very high spectral resolution, stability, and multiplexing capability. In this contribution I will focus on the instrument's potential to measure abundances of heavy elements in large stellar samples with high precision. These elements are crucial both for determining the ages of the oldest stellar populations through nucleocosmochronology and for constraining the astrophysical sites responsible for their production, including neutron-capture processes associated with compact-object mergers.

I will also discuss the scientific opportunities offered by extending HRMOS observations into the near-ultraviolet (NUV), where several key heavy-element transitions are located. Access to this spectral window would enable the measurement of elements that are otherwise inaccessible at longer wavelengths, providing unique constraints on nucleosynthesis processes and on the chemical evolution of oldest stellar populations.

Perspectives

L. Pasquini

Luca’s highlights and future perspectives.

Abstracts of e-posters

Preparing for Mira spectra in Gaia DR4: Improving the GSP-Spec pipeline in the cold giants domain

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The Gaia mission provides powerful astrometric precision, spectro-photometric observations in the visible, and medium resolution (R$\sim$11500) spectroscopy (by the Radial Velocity Spectrograph, RVS) around the infrared calcium triplet. The RVS spectra allows for the derivation of stellar radial velocities and, through the analysis of the GSP-Spec module, the estimation of effective temperatures (Teff), surface gravities (log g), and chemical abundances. The Gaia DR3 GSP-Spec all-sky catalogue provided these parameters for $\sim$5.6 millions stars, using their mean RVS spectra. Furthermore, the Gaia DR4 will include all epoch RVS spectra for these stars.
Access to these parameters for a large sample of Mira pulsating stars, as bright intermediate-age standard candles, would allow for a detailed chemical and dynamical study of the Galaxy's intermediate-age stellar populations far beyond the solar neighborhood. However, due to the cold temperatures (Teff $\leq$ 3500 K) in these stars' atmospheres, their RVS spectra are dominated by molecular lines which replace the continuum with a pseudo-continuum and complicate their parametrization.
We are working on improving GSP-Spec's performance for the cold giants domain, with the goal of reliably characterizing RVS epoch spectra of Mira variables, opening new paths for a large scale chemical cartography of the Milky Way and its satellites. In this talk, the results of this analysis with public RVS mean spectra of M-type giants will be presented.

High-precision abundance analysis of a unique CEMP-no star in Sculptor

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The Carbon-Enhanced Metal-Poor stars not enhanced in neutron capture elements (CEMP-no) are commonly accepted as the direct descendants of those Population III (Pop III) stars which ended their lives as supernovae (SNe) with relatively low explosion energy (10^{51} erg). While CEMP-no stars are common in the Milky Way (MW) and Ultra-Faint Dwarf galaxies (UFDs), they are surprisingly rare in Dwarf Spheroidal galaxies (dSphs). The reason behind this remains uncertain, which makes the study of CEMP-no stars discovered within dSphs even more crucial. This insight could help determine whether and how the chemical enrichment by Pop III stars is influenced by the environment in which they formed.

In the Sculptor dSph, a survey conducted with VLT/FLAMES led to the identification of a new CEMP-no star, DR20080, at [Fe/H] $<$ –3. Here I will present a new high-resolution VLT/UVES spectral analysis, including 17 elemental abundances and 4 upper limits. To further refine the results, state-of-the-art corrections for Non-Local Thermodynamic Equilibrium effects were applied to the measurements. This star is extremely metal-poor, [Fe/H] = –3.08, and clearly enhanced in Carbon, [C/Fe] = $+1.42$ (after correcting for internal mixing). Moreover, its CEMP-no nature is verified by the low abundances of Barium ([Ba/Fe] = -1.25) and Europium ([Eu/Fe] $< +0.3$).
Comparison with the average abundances of CEMP-no stars observed in the MW revealed that DR20080 has an unusually high abundance of Oxygen, while the Iron-peak elements are significantly under-abundant. Finally, the abundance pattern of DR20080 was compared to theoretical yield predictions of Pop III SNe to infer the properties of its Pop III progenitor(s). The best fit points toward a double Pop III progenitor scenario, with the major contributor being a Pop III faint SN with mass m_{PopIII} = 43 M_{sun} and explosion energy E_{SN} = 0.6x10^{51} erg, while the minor contributor is a Pop III hypernova of m_{PopIII} = 19.4 M_{sun} and E_{SN} = 10x10^{51} erg. However, the fitting procedure revealed how crucial it is to have high-quality spectra to break the degeneracy of the solutions. Without a high number of elements measured with good precision, it would not have been possible to constrain the progenitors of DR20080.
These new high-quality spectra reveal that DR20080 possesses unique characteristics, never before observed in Sculptor or any other environment within the local Universe. This highlights the importance of dedicated high-resolution follow-up of the descendants of Pop III stars. With future efforts, we can expect more such unique stars providing crucial insights into the diverse properties of the earliest SN nucleosynthesis that took place in the Universe.

Tracing Early Oxygen Enrichment with Metal-Poor stars with VLT-UVES

H. Ernandes
CAMK-PAN

The next generation of spectroscopic and astrometric surveys, including Euclid, DESI, and 4MOST, will provide an unprecedented view of the chemo-dynamical structure of the Milky Way and nearby galaxies. Fully exploiting these datasets requires abundance measurements placed on a consistent and precise scale across different instruments, pipelines, and surveys. In this context, we are developing a homogeneous, high-precision standard for carbon, nitrogen, and oxygen (CNO) abundance analysis, based on high-resolution UVES archival spectra of metal-poor stars ([Fe/H] < –2.0).
This carefully curated dataset, comprising both halo field stars and globular cluster members, serves as a benchmark for defining robust methodologies, calibrating stellar parameters, and quantifying systematic effects in CNO determinations. After hydrogen and helium, CNO are the most abundant elements in the Universe, and they provide essential constraints on early galactic chemical enrichment, as highlighted by recent JWST observations of N/O-enhanced galaxies. Using this reference framework, we aim to recalibrate and homogenise CNO abundances from large spectroscopic surveys, establishing a common abundance scale applicable to current (e.g., APOGEE, GALAH) and upcoming datasets, including 4MOST. By anchoring survey data to a well-characterised high-resolution standard, we can reduce inter-survey systematics, enable reliable comparisons of chemical patterns across Galactic components, and strengthen studies of first-star archaeology, chemo-dynamical tagging of stellar streams and dwarf galaxy debris, and near-field cosmology as a precision probe of galaxy assembly and early chemical evolution.

Gaia FGK Benchmark Stars: Impact of Spectral Resolution on Stellar Abundances

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ESO-Chile

Large spectroscopic surveys such as GALAH, MOONs, WEAVE, and SDSS-V will provide accurate stellar parameters and abundances for millions of stars. Calibrating and standardizing these measurements is crucial to obtain new insights into stellar evolution, nucleosynthesis, and Galactic archaeology. The Gaia Benchmark Stars (GBS) are essential reference points characterized by well-defined parameters derived from fundamental relations independent of spectroscopy. In this work, I will show how spectral resolution impacts the determination of stellar parameters and metal abundances for a sample of 30 GBS, by comparing resolutions of R$\sim$190 000 (R190), R$\sim$42 000 (R42), R$\sim$28 000 (R28), and R190 degraded to R28 (R190-R28), as well as a new list of spectral lines suitable for both metal-poor and metal-rich stars (Hernández-Araya et al. 2026, submitted). Our comparative analysis between R28 and R190-R28 reveals that gaps in wavelength coverage can lead to discrepancies in the derived stellar parameters, particularly in $\log g$. These effects are not primarily driven by spectral resolution, but rather by the limited spectral coverage and line availability. Overall, our results show that high spectral resolution is not always required for reliable abundance measurements. We provide practical guidelines for upcoming large spectroscopic surveys aiming to place stellar abundances on a homogeneous scale and reconstruct the chemical history of the Milky Way.

VIPER: High-precision radial velocities from optical to infrared

J. Köhler
TLS Tautenburg

In recent years, Radial Velocities (RVs) have become an admired tool for the discovery and study of exoplanets, coming along with a number of new instruments and software codes. One of these codes is the Velocity and IP EstimatoR (viper), a publicly available and user-friendly code, which is able to process data from various spectographs. viper is based on the method described in Butler et al. (1996), which uses imprinted cell lines for the wavelength calibration. To enable RV calculation in the NIR, which is strongly contaminated by telluric lines, viper is able to model imprinted telluric lines and to create telluric-free stellar templates. Furthermore, these tellurics can serve as an additional wavelength calibration. To show the efficiency of viper, I will present recent results from the NIR spectograph CRIRES+, where we have achieved an RV accuracy of 3 m/s in the K-band over a period of 2.5 years using a gas cell.

Direct Imaging of Exoplanets using Coronagraphy

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Faculty of Sciences Semlalia, Cadi Ayyad University

Direct imaging is a powerful technique for exploring exoplanets, yet it remains one of the most challenging methods in observational astronomy. Two major obstacles limit its performance: the extreme brightness contrast between a star and its orbiting planet, and the very small angular separation that makes them difficult to distinguish. Coronagraphy addresses these challenges by suppressing starlight and enhancing image contrast. This work presents an overview of the main coronagraph types such as Lyot, phase mask, and vortex designs and explains how each contributes to improving contrast and enabling the detection of faint exoplanets. The poster summarizes their principles, strengths, and current technical limitations to provide a clear understanding of how coronagraphs advance direct imaging capabilities.

Tracing cosmic helium abundances using K-dwarfs

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K-dwarf stars offer a unique window into the formation and chemical evolution of the Milky Way. Their slow evolution and long lifetimes allow them to retain the chemical signatures of their birth material, making them useful tracers of the Galaxy's enrichment history. In this work, we present a study using 25,000 K-dwarfs from the GALAH DR4 survey to achieve two key goals: (1) to improve the precision of fundamental stellar parameters (Teff, $\log g$, [Fe/H]) using a differential approach, and (2) to constrain the helium-to-metal enrichment ratio ($\Delta Y/\Delta Z$), which has implications for stellar evolution, galactic chemical evolution, and big bang nucleosynthesis. We apply the EPIC code – previously used tested for G-dwarfs – to our K-dwarf sample, employing a differential equivalent width analysis that leverages the existing GALAH stellar parameters. This differential approach with EPIC significantly improves the internal precision of stellar parameter estimates while minimizing systematic errors. With precise metallicities and bolometric luminosities derived from Gaia DR3 parallaxes, we then fit GARSTEC stellar evolution models across a grid of helium and metal abundances to infer individual helium mass fractions (Y) for K-dwarfs. This allows us to estimate the $\Delta Y/\Delta Z$ ratio and extrapolate to $Z = 0$ to determine the primordial helium abundance (Y). Our results will provide new observational constraints on both stellar evolution theory and cosmological predictions of Big Bang Nucleosynthesis.

Chemically Peculiar Stars in the Open Cluster Melotte 111

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Open clusters provide a unique laboratory for studying stellar physics under well-constrained age and chemical composition. In this work, we present a spectroscopic analysis of chemically peculiar stars in the open cluster Melotte 111. Using high-resolution spectra, we determine atmospheric parameters and detailed chemical abundances. The homogeneous age and distance of cluster members allow us to investigate how chemical peculiarity develops in stars of similar evolutionary stage and initial composition. In addition, we analyse photometric and spectroscopic variability to explore the role of rotation, surface abundance inhomogeneities, and possible pulsational behaviour. By combining atmospheric modelling, abundance analysis, and variability diagnostics, we aim to better understand the interplay between diffusion, rotation, and stellar evolution in chemically peculiar stars.

Where is Scandium? A Spectroscopic Probe of Diffusion in AmFm Stars

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Chemically peculiar AmFm (CP1) stars exhibit characteristic underabundances of Ca and Sc accompanied by overabundances of heavier elements, commonly attributed to atomic diffusion processes. Among these, scandium is a key diagnostic element, as its behaviour is highly sensitive to the interplay between gravitational settling, radiative acceleration, turbulent mixing, and mass loss.

Current theoretical models predict a complex evolution of scandium, including a short-lived phase of overabundance, but observational constraints remain limited and are largely restricted to a few open clusters. In particular, a significant gap exists in the 100–500 Myr age range, preventing robust tests of diffusion scenarios and mixing processes.

We present a homogeneous spectroscopic study of AmFm in a few open clusters younger than 600 Myr, targeting this unexplored age domain. Atmospheric parameters (effective temperature, surface gravity, microturbulence, and rotational velocity) are derived using Balmer-line fitting and metal-line analysis, while chemical abundances are obtained through comparisons with synthetic spectra computed using ATLAS9 and SYNTHE. Special emphasis is placed on scandium, using selected Sc I and Sc II lines, and on radial-velocity measurements to assess binarity. This study will help to provide new constraints on diffusion and mixing processes in intermediate-mass stars.

The early chemical evolution of the Sagittarius dwarf galaxy

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The Sagittarius (Sgr) dwarf galaxy experienced its first in-fall into the Milky Way (MW) about 5 Gyr ago. As it is being tidally stripped by the MW, its core and two stellar streams are now visible in the Sky, as well as various associated globular clusters. Given its proximity, it is an ideal test-bed for galactic chemo-dynamical models. So far, studies have typically focussed on metal-rich and relatively young stars,

given that they are the prevalent population. Further complicating the study of the oldest/metal-poor stars is the strong overlap in the colour-magnitude diagram between the Milky Way bulge population and stars in Sgr. However, the most metal-poor stars are key to understand the early chemical evolution of Sgr.
My talk will focus on the nucleosynthetic channels that are responsible for the production of s-, i- and r-process elements in Sgr, especially during its early chemical evolution. I will present the most extensive chemical abundance analysis at the lowest metallicities and connect it to the more studied metal-rich regime, also providing a complete panoramic of the system's chemical evolution. I will show that the interstellar medium of Sgr may have retained yields from more energetic Population III and II supernovae than those imprinted in the stars accreted from the Milky Way's building block. Additionally, the lack of a particular population of Carbon-enhanced stars, linked to the first supernovae, would suggest the need for a new definition for this class of stars, which should be calibrated on the average [C/Fe] of a given system. I will show how coming multi-object spectroscopic surveys are needed to better study the oldest stars in the Local Group.

Chemically Peculiar Stars in the Era of Large Spectroscopic Surveys

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Large spectroscopic surveys have transformed our understanding of the Milky Way and its stellar populations, providing homogeneous stellar parameters and detailed chemical abundances for millions of stars. Yet, while these surveys excel in the “normal” regime, their performance for chemically peculiar objects remains largely unexplored. In particular, stars enriched by the slow neutron-capture (s-) process, such as Barium, CH, and CEMP-s stars, pose significant challenges to automated pipelines. These binary systems, polluted by former AGB companions, display extreme heavy-element enhancements that can push abundance analyses beyond the training limits of data-driven methods.
Using GALAH DR4, complemented by a targeted high-resolution follow-up campaign with UVES and HERMES (PI: Ana Escorza), we assess how large surveys characterise s-process-enhanced stars and construct a homogeneous catalogue of s-process polluted systems across the full parameter space of the survey. By relying on multiple s-process elements rather than Ba alone, we define robust abundance thresholds and build a pure sample of s-process-polluted stars. Such validation is essential in the current data-rich era, where precision and scale must be matched by reliability across all chemical regimes. Our results strengthen Galactic archaeology and binary evolution studies, addressing key challenges in next-generation spectroscopic facilities, calibration, abundance homogeneity, and pipeline robustness.