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Book of Abstracts

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The initial-final mass relation from carbon stars in open clusters

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Recently (Marigo et al. 2020-22), identified a kink in the initial-final mass relation around $M_i \simeq 1.65 - 2.10$ $M_\odot$, based on Gaia DR2 and EDR3 data for white dwarfs in open clusters aged 1.5-2.5 Gyr. Notably, wide dwarfs at this kink, all from NGC 7789, exhibit masses of $\simeq 0.70 - 0.74$ $M_\odot$, usually associated with stars of $M_i \simeq 3 - 4$ $M_\odot$. The above kink in the M_i mass range coincides with the theorerically acepted solar metallicity lowest-mass stars evolving into carbon stars during the AGB phase. According to our explanation, these carbon stars likely underwent shallow third dredge-up events, resulting in low photospheric C/O ratios and, as a consequence, midle stellar winds. Under such conditions, the AGB lifetime is prolonged allowing for greater core mass growth beyond typical predictions.

We have analyzed chemically a few carbon stars belonging to open clusters with the above cluster ages. Our chemical analysis confirms that the carbon stars found within the kink exhibit markedly low photospheric C/O ratios and stellar winds, and the typical chemical composition expected for carbon stars of near solar metallicity, thus validating our theoretical predictions. However, we also show that this conclusion is strongly dependent on the derived stellar luminosity of these carbon stars.

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The Role of the Third Dredge-up and Mass Loss in Shaping the Initial–Final Mass Relation of White Dwarfs

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The initial-final mass relation (IFMR) plays a crucial role in understanding stellar structure and evolution by linking a star's initial mass to the mass of the resulting white dwarf. This study explores the IFMR using full PARSEC evolutionary calculations supplemented with COLIBRI computations to complete the ejection of the envelope and obtain the final core mass. Recent works have shown that the supposed monotonicity of the IFMR is interrupted by a kink in the initial mass range $M_{\rm ini} \approx 1.65 - 2.10 M_\odot$, due to the interaction between recurrent dredge-up episodes and stellar winds in carbon stars evolving on the thermally-pulsing asymptotic giant branch phase. To reproduce the IFMR non-monotonic behavior we investigate the role of convective overshooting efficiency applied to the base of the convective envelope ($f_{\rm env}$) and to the borders of the pulse-driven convective zone ($f_{\rm pdcz}$), as well as its interplay with mass loss. We compare our models to observational data and find that $f_{\rm env}$ must vary with initial mass in order to accurately reproduce the IFMR's observed kink and slopes. We find some degeneracy between the overshooting parameters when only the IFMR information is used. Nonetheless, this analysis provides valuable insights into the internal mixing processes during the TP-AGB phase. Finally, we present chemical yields and ejecta calculated with our IFMR-calibrated models at solar metallicity.

AGB and beyond: learning from the advanced phases / 61

On the $^{17}O/^{18}O$ ratio of post-AGB sources: canonical and non-canonical populations

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Stellar evolution and nucleosynthesis models are fundamental tools to derive parameters of stars from elemental atomic and isotopic abundance ratios. For evolved stars, the C/O/N elemental ratios and the $^{12}C/^{13}C$ and $^{16}O/^{17}O/^{18}O$ isotopic ratios provide very significant constraints to the otherwise elusive initial mass of the stars. In the case of post-AGB sources, the chemical composition of their expanding circumstellar envelopes can be derived from sensitive observations of rotational lines of several molecular species in the millimetre and sub-millimetre radio domains. The initial mass of post-AGB sources is a fundamental parameter to establish correlations with the main properties of their post-AGB envelopes (mass, momentum, kinetic energy, shape) and progress in our knowledge of their formation and evolution. In these sources, the C/O ratio can be easily constrained from the detection of C-bearing and O-bearing molecules other than CO, while the $^{17}O/^{18}O$ ratio is also straightforwardly determined from the relative strength of the optically thin rotational lines of $C^{17}O$ and $C^{18}O$. However, the results obtained up to date are far from being clear.

In this presentation, we will review the status of the question, including new accurate $^{17}O/^{18}O$ ratio measurements for 13 targets, totalling 25 studied post-AGB envelopes: 15 O-rich sources (including the eight water fountains presented by Khouri *et al.* 2021) and 10 C-rich ones. Comparing the $^{17}O/^{18}O$ ratios and the C-rich/O-rich chemical composition with models for sources that have completed the AGB evolution, we find that for about 50% of the cases, observational data align with model predictions: these canonical sources include 50% of both O-rich and C-rich sources in the sample. As for the non-canonical sources, the O-rich ones, which present $^{17}O/^{18}O$ ratios above those expected for C/O < 1, can be explained by a premature interruption of their AGB evolution as a consequence of a quasi-explosive ejection of a large fraction of the initial mass. This hypothesis agrees with the suggestion that these envelopes form in the merging of common-envelope (or similar) events. The non-canonical C-rich sources, on the contrary, display $^{17}O/^{18}O$ ratios below the predictions for C/O > 1. We discuss possible explanations for this enigmatic behaviour, including the possibility that these sources are extrinsic C-rich stars, whose high C abundances result from previous mass accretion from a former higher mass C-rich AGB donor companion.

AGB stars in binary systems / 38

Multiwavelength study of circumbinary disks around evolved binary stars with SPHERE

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Circumstellar disks surrounding both single and binary stars have been extensively investigated in the context of young stellar objects. However, in this talk, we shift the focus to the late stages of stellar evolution where stable compact disks were discovered around low-mass dying binary stars, such as post-Asymptotic Giant Branch (post-AGB) binaries. Observational studies have shown that post-AGB circumbinary disks appear to be surprisingly similar to protoplanetary disks in terms of Keplerian rotation, IR excesses, dust disk mass, chemical depletion and dust mineralogy. However, a significant difference lies in the formation history and lifetime of post-AGB circumbinary disks, which persist for ~10^4-10^5 years compared to a few Myr lifetime of protoplanetary disks. In this talk, we present the results of the first polarimetric differential imaging survey of eight post-AGB binary systems with circumbinary disks. Using the state-of-the-art Spectro-Polarimetric High-contrast Exoplanet Research instrument (SPHERE) of the 8-meter Very Large Telescope (VLT) at the European Southern Observatory (ESO), we successfully resolved the complex morphologies of the circumbinary disks. One of the highlights of our study is the observation that certain post-AGB systems with lower metallicities exhibit smaller resolved disk sizes, potentially due to reduced levels of dust production during the AGB or RGB phase of the primary star. Moreover, our multiwavelength polarimetric study of IRAS 08544-4431 provided wavelength dependence of scattering and polarizing disk properties, shedding light on dust grain characteristics. These findings coupled with spectroscopic and interferometric studies establish post-AGB binary disks as invaluable laboratories for studying circumbinary disk evolution, including the potential formation of second-generation planets around evolved binary stars.

A variety of AGB stars: observational understandings / 76

A "Wonderful"Set of Mira Variables

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The conditions in Mira variable atmospheres make them wonderful laboratories to study a variety of stellar physics such as molecule+grain formation, dust production, shock chemistry, stellar winds, mass-loss, opacity driven pulsation, and shocks.

We are currently curating a Reference Set of 106 Mira variables based upon over a decade of synoptic observations made with the Palomar Testbed Interferometer (PTI). The Miras included in this dataset set include M-types, S-types, and C-types, and span a wide range of pulsation periods. PTI measured k-band angular sizes that when combined with a distance allow us to directly determine fundamental stellar parameters such as effective temperature, radial size, bolometric flux etc.

Supplementing observations with interferometric measurements of the stars opens the Mira laboratory to a wealth of different experiments. I will provide an example of combining PTI measurements with Spitzer IRS spectra of 13 M-type variables, which allowed us to fully characterize CO_2 gas in their atmospheres.

Nuclear reaction rates: news from laboratory measurements / 31

The ongoing deep underground measurement of 22Ne(a,n)25Mg at the Ion Beam Facility of the INFN-LNGS

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The reaction 22Ne(a,n)25Mg is a nuclear reaction of critical importance for a variety of astrophysical scenarios. While much effort has been devoted on the study of the low energy cross section through indirect measurements, direct cross section and resonance measurements have been severely hampered by the low event rate.
This problem is currently being approached at the Bellotti Ion Beam Facility of the Gran Sasso National laboratory (LNGS) in the framework of the ERC-funded project SHADES. A direct measurement in the ultra-low neutron background of the LNGS using a sensitive neutron detection array has recently begun its experimental campaign. We will report on the experiment and on the status and first results of the measurement.

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Exploring Evolved Stars Extended Atmospheres: New prospectives in observation

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Evolved asymptotic giant branch (AGB) stars undergo substantial mass loss, enriching the interstellar medium (ISM) with essential metals and dust crucial for the formation of future stars and planets. Presently, this mass loss is attributed to dust-driven winds emanating from the extended atmospheres of these stars. Nevertheless, our comprehension of AGB star atmospheres remains incomplete.

State-of-the-art simulations show that large convective cells play an important role, but recent observations at milliarcsecond resolution with ALMA have shown that the conditions in the extended atmospheres might be different than predicted by the models. Low-frequency observations of evolved stars with SKA and ngVLA will make it possible to study the critical outer regions of the extended atmospheres where dust forms and is accelerated in a novel way. With the high resolution and sensitivity of SKA and ngVLA, we can use the continuum emission to constrain atmospheric density and temperature structures at larger distances from the star. Also, simultaneous observations of SKA, ngVLA, and ALMA will produce wide-range multi-wavelength data for various radii of the extended atmosphere, enabling us to test and constrain theoretical models in a way that was not possible before. With the large field of view of ngVLA and SKA, we can study the temporal evolution of evolved star atmospheres and dust-forming regions.

In this presentation, I will share our recent results obtained from studying evolved star models, highlighting their practical significance and usefulness for future observational studies. Furthermore, I will discuss the potential for the SKA and ngVLA to revolutionize detailed observations in this field.

A variety of AGB stars: observational understandings / 59

Retrieving stellar parameters and dynamics of AGB stars with Gaia parallax measurements and radiative hydrodynamics simulations

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Asymptotic Giant Branch (AGB) undergo complex dynamics, including convection, pulsation and shockwaves. These processes trigger strong stellar winds, enriching the interstellar medium with various elements, and impact astronomical measurements, amplifying uncertainties in the determination of fundamental stellar parameters. Gaia Data Release 3 provides the parallax for about 2 million variable stars, including Mira stars showing extreme magnitude variations. Convection results in bright surface asymmetries and photocentre variability in the Gaia G band. Observations and three-dimensional radiative-hydrodynamics (RHD) simulations of stellar convection computed with CO5BOLD showed that convection substantially accounts for the parallax uncertainty measured by Gaia.
I will present AGB RHD simulations covering a large enough set of stellar parameters and derive analytical laws to retrieve the surface gravity, the radius, the temperature, and the pulsation period using the Gaia parallax uncertainty thanks to the use of photocentre variability of RHD simulations. The objective is to provide a systematic and statistical approach for quantitatively determining stellar parameters of AGB stars.

Seeds and grains: AGB stars as dust factories in galaxies / 14

Laboratory Synthesis of Complex Nanocarbons detected in Carbon-rich Evolved Stars

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In the laboratory scale it is possible to produce most of the molecular species known (or suspected) to be formed in the evolution from AGBs to PN. These species can be produced through the carbon arc i.e. the electric arc struck between two graphite electrodes. The key reaction product of the carbon arc is the carbon vapor, derived from the sublimation of elemental carbon at T≥4000 K. Depending from the conditions selected, the carbon arc can produce polyynes (H-(C≡C)n-H), monocyanopolyynes (H-(C≡C)n-CN) and dicyanopolyynes (NC-(C≡C)n-CN). One key parameter to selectivity in the final products regards the arc regime. The selective production of fullerenes, requires a higher power carbon arc (3000 W) much higher than the 20 W arc needed to produce polyynes.
C60 and C70 fullerenes are readily reactive with atomic hydrogen yielding fulleranes the hydrogenated fullerenes. The fullerenes are so avid of hydrogen that the hydrogenation in the laboratory conditions leads directly to C60H18 and C60H36. Thus, it is completely reasonable to think that hydrogenated fullerenes may be present in space. For the time being, attempts to unambiguously detect hydrogenated fullerenes were unsuccessful.
Fullerenes were found in various space environments, sometime in conjunction with other complex molecules like PAHs or metals. Fullerenes are reactive with certain PAHs forming adducts. Examples of adducts are those with the acene series of PAHs and with indene. Indeed, our most recent works in fullerene adducts regard the reaction with C60 with the indene hydrocarbon and with CN radicals.
The Aromatic Infrared Bands (AIBs, sometimes referred as UIBs or UIRs) represent a series of discrete infrared emission bands detected in numerous and very different astrophysical objects including (proto-)PNe. The carriers of these infrared bands have not yet unambiguously identified. It has been proposed that the carriers of the AIBs could be described by an "average"chemical structure consisting of mixed aromatic-aliphatic organic nanoparticles (MAONs) and containing also heteroatoms such as N, S and O. We have shown through infrared spectroscopy that asphaltenes are matching quite well the MAONs model.

AGB stars as cosmic probes for clusters and galaxies evolution / 37

Chemical signatures of rotating massive stars dying in faint explosions

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We have recently investigated the origin of chemical signatures
observed in the oldest star of our Galaxy using a
stochastic chemical evolution model. The elements we have studied are
carbon, nitrogen, and oxygen, but also the neutron capture elements. We
have found that rotating massive stars are a promising way to explain
several signatures observed in these fossil stars. Analyzing the
chemical abundance characteristics of the extremely and ultra-metal-poor stars we also found that
our model can be improved if we consider
the presence of faint supernovae. These results seem to imply that
rotating massive stars and faint supernovae scenarios complement each other, and are both required
to match
the observed chemistry of the earliest phases of the chemical
enrichment of the Universe.

AGB structure, evolution and nucleosynthesis / 16

The intermediate neutron capture process in AGB stars

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The origin of trans-iron elements is not yet fully understood. In addition to the slow (s) and rapid (r) neutron capture processes, an intermediate neutron capture process (i-process) is thought to exist at neutron densities intermediate between the s- and r-processes. The chemical composition of the so-called r/s-stars support the existence of this process but the astrophysical site(s) hosting the i-process is (are) actively debated. The early asymptotic giant branch (AGB) phase of low-mass stars is a promising site. In this talk, I will focus on the development of the i-process in AGB stellar models of various masses and metallicities computed with the stellar evolution code STAREVOL. In particular, new results on the impact of overshooting and nuclear uncertainties will be discussed. The unique chemical fingerprint of these stars will also be presented and confronted with observations.

AGB structure, evolution and nucleosynthesis / 10

The effects of induced magnetic mixing in AGB stars.

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Asymptotic giant branch (AGB) stars synthesize half of the elements heavier than iron through the slow neutron capture process.
Despite the significant progresses in theory over the last few decades, many uncertainties still affect AGB models. The most notable example
is the mechanism responsible for the formation of the main neutron source in AGB stars, the so called 13C pocket.
Stringent constraints on the type and efficiency of mixing processes relevant to the s-process nucleosynthesis in AGB stars are provided by isotopic ratios in presolar grains, as well as from the latest spectroscopic observations of both intrinsic and extrinsic AGB stars.
We present recent results from AGB stellar models including the effects of mixing induced by magnetic fields. The comparison to extant observations suggests that magnetic instabilities may be at the origin of the 13C pocket in AGB stars, triggering future research aiming at better describing the physics governing these stars.

AGB structure, evolution and nucleosynthesis / 54

Exploring nucleosynthetic processes in a large sample of Barium stars using high resolution spectra

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Barium (Ba) stars belong to binary systems where a former asymptotic giant branch (AGB, now a white dwarf) star polluted the less evolved companion, which became enriched with material produced through the slow neutron capture process (s process). The currently observed Ba star preserves the abundance pattern of the AGB, allowing us to test the imprints of the s process. Comparing different AGB nucleosynthetic models and Ba star abundances based on high-resolution spectra, we are able to constrain, for example, the effect of the initial rotation velocity and the nature of the neutron source. When comparing AGB models to the extended list of heavy element abundances available for a large homogeneous observational sample of 169 Ba stars, we could confirm that the polluting AGBs are of low mass (< 4 MSun). However, approximately 25% of the sample stars show anomalous abundance patterns, mainly at the first s-process peak (with higher Nb, Mo and/or Ru than the models), along with high W. The high W value is comparable to some post-AGB stars, and might indicate that we can identify different subgroups among the Ba star sample. Additional measurements could reveal the cause for these overabundances and can help to identify the underlying processes.

AGB stars as cosmic probes for clusters and galaxies evolution / 43

News about the AGB scenario for Globular Clusters formation

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In the framework of the AGB model for the formation in Globular Clusters of a “second generation” of stars showing the sign of p-processing in the abundances of light elements, we present new ideas

and model results aimed at solving the discrepancies between observed and computed abundances. We focus on the problem of preserving a large Sodium abundance, while at the same time allowing anyway a stronger p-processing of Oxygen, Magnesium, Aluminum and Silicon. Comparisons are made with the prototype Globular Cluster NGC2808, whose stars display very large abundance variations of these elements.

AGB stars as cosmic probes for clusters and galaxies evolution / 9

Open Clusters as Gateways to Understanding the Evolution of Fluorine in the Galactic Disk

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Fluorine, an elusive yet crucial element in the field of galactic archaeology, has its significance masked by its rarity, complicating our understanding of chemical and stellar evolution. The debate over its origins is ongoing, with candidates ranging from massive stars and AGB stars to Wolf-Rayet stars and novae. In response, we've launched an ambitious project using the GIANO-B instrument on the TNG telescope to delve into the chemical evolution of fluorine across the Galactic disk, employing open clusters as pivotal indicators. This initiative stands to revolutionize our knowledge by providing detailed insights into fluorine abundance across different galactocentric distances and ages. This project is set to create the most comprehensive database of fluorine abundances in open clusters ever compiled. During my presentation, I will unveil our preliminary findings from this groundbreaking survey.

A variety of AGB stars: observational understandings / 21

Exploring the Galactic content in s-process elements with space and ground-based spectroscopic surveys

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The Galactic content in s-process neutron-capture elements is still poorly known and the chemical evolution of these species are frequently debated.
Fortunately, thanks to Gaia/GSP-spec cerium and neodynium abundances at the surface of thousands stars, the chemical content of the Galaxy in these two second peak s-elements has been recently explored.
This has been complemented by lead chemical abundances (third peak s-element) in several hundreds stars derived within the AMBRE Project.
The Galactic chemical trends of these heavy species will be presented as their interpretation thanks to chemical evolution models. We will also discuss the contribution of AGB stars to the chemical evolution of these s-process elements in the Milky Way.

AGB and beyond: learning from the advanced phases / 11

Jet formation in post-AGB binaries: Confronting cold MHD disk wind models with observations

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With about 100 Galactic candidates detected, Post-Asymptotic Giant Branch (post-AGB) binaries are now understood to be fairly commonly formed systems at the end of stellar evolution, displaying clear signs of ongoing re-accretion from their ubiquitous circumbinary disks. For ~ 35 of these systems, long-term, high-resolution spectral monitoring of the H_α line has revealed that this re-accretion has resulted in the launching of a jet from an accretion disk around the faint secondary star. I will first briefly describe the building blocks of post-AGB binaries, as well as how their jets are observed in H_α. Afterwards, I will show how modelling of the jet-related spectral signatures throughout the orbit can closely probe the jet-formation physics, accretion disk properties and re-accretion phenomena in these intriguing systems.

AGB stars as cosmic probes for clusters and galaxies evolution / 67

The GST (Gaia GSP-spec/TESS) catalogue: Exploring the Milky Way by coupling Gaia spectroscopic and TESS asteroseismic data

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The *Gaia* DR3 has parametrised 5.6 million stars based on their Radial Velocity Spectrometer (RVS) spectra (DPAC/GSP-spec module, Recio-Blanco et al., 2023). We have selected a sample of 153,544 GSP-spec stars with known spectroscopic atmospheric parameters, chemical abundances, and with asteroseismic TESS data. The asteroseismic and spectroscopic surface gravities are found to be in very good agreement: 80% and 21% of the whole ***GST*** sample have a gravity difference smaller than 0.2 dex and 0.05 dex, respectively. Those stars have been identified as RGB and RC stars, and we have analyzed their Galactic locations, chemical abundances, masses, ages and orbital energy distributions. This ***GST*** sample will be presented and its properties will be discussed within the context of Galactic Archaeology and Stellar Physics.

AGB structure, evolution and nucleosynthesis / 32

S-Process Nucleosynthesis in and from AGB Stars

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The nucleosynthetic slow neutron capture process (s-process) in AGB stars between ~ 1 – 6 $M_\odot$ is responsible for creating about half of the heavy elements in the universe. The s-process can be traced directly through AGBs, or indirectly through their binary companions (CEMP-s stars, Ba stars, CH stars), as thermally pulsing AGBs will dredge s-process material from the inter-shell to the surface. We present and study 10 AGB (intrinsic) stars and 10 (extrinsic) companions where mass transfer is important. Using high-resolution spectra, we derive atmospheric parameters and compute 1D LTE surface abundances, focusing on heavy elements created during the thermally pulsing AGB phase (C, N, Y, Zr, Nb, Mo, Ba, La, Ce, Nd, Pb), and the r-process element Eu. We compare our results to the FRUITY yields to constrain the masses of our AGB stars and their companions, and investigate correlations in abundance space using Gaussian mixture modelling. Through detailed stellar modelling, we constrain possible binary companion masses and other system parameters. This can help determine efficiencies of AGB wind mass transfer, and has implications for galactic chemical evolution as AGB stars deposit their material back into the ISM to seed further stellar generations.

AGB stars in binary systems / 30

Revisiting 56 Ursae Majoris: Exit the barium star, enter the neutron-star companion

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56 Ursae Majoris is a long-period binary that was thought to contain a chemically peculiar red giant and a faint companion. The red giant was classified as a barium (Ba) star in the 70s. This classification would imply that the companion is a white dwarf, since Ba stars form when s-process rich Asymptotic Giant Branch (AGB) companions transfer mass to them. However, combining more than 50 years of radial velocity data with Hipparcos and Gaia astrometry, we measured 56UMa's orbital inclination for the first time, and we discovered that the faint companion was about 1.3 solar masses. Even if this were a white dwarf, nucleosynthesis models suggest that it would be too massive to be the progeny of an AGB star that could efficiently produce and dredge up s-process elements and then pollute a companion.

This puzzle motivated us to perform a full spectral analysis, re-investigate (and discard!) the Ba-star classification of the giant, and study the morphology of the interstellar gas in the vicinity. In my contribution, I will review the heavy metal abundance patterns obtained by different investigations, and I will discuss our findings, including the clear identification of a HI cavity around the system. The latter seems to indicate that a supernova exploded in the system several hundred thousand years ago, and that the faint companion is in fact a dormant neutron star. However, finding an evolutionary scenario that explains all these observables is not trivial, and I will discuss different possible configurations and their respective merits.

AGB and beyond: learning from the advanced phases / 62

Exploring the ionized core of the PPN CRL618 and its vicinity with ALMA

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The events that occur during the proto-planetary nebula (PPN) inter-phase are among the most stunning phenomena taking place during the evolution of solar and intermediate mass stars. PPNe comprise a dense circumstellar envelope that hide hot central stellar objects, which are frequently white dwarfs. PPNe usually display high velocity bipolar outflows that form close to the central stellar system and work their way through the ancient circumstellar envelope produced during the AGB phase. Extensive effort has been done to understand how the outflows are developed but there still are questions to be answered, mostly due to the lack of observational constraints.

One of the most paradigmatic PPN is CRL618, a C-rich PPN located at ~900pc from us with a set of bipolar outflows expanding at velocities up to ~200km/s. Its outflows are collimated by a dusty torus which makes difficult to observe the ionized core that host the stellar system and where the outflows are launched. Strong molecular emission is detected beyond the photodissociation shell that surrounds the ionized gas but this emission traces the neutral, low-velocity envelope and it is useless to describe the regions where the outflows form, for no molecule can survive inside the HII region. Nevertheless, it is possible to explore this region with the aid of recombination lines and free-free continuum emission in the mm range.

Based on high angular resolution observations (HPBW~30-50mas) of the H30alpha recombination line at ~1.3mm toward CRL618 carried out with ALMA, we have been able to resolve the ionized core of the envelope. The observed structure can be described as an elongated region along the E-W direction with a size of ~0.7"x0.4" and a perpendicular remarkable arc that connects two bright spots located to the N and S, which are separated by ~0.2". It resembles a cylinder tilted with respect to the plane of the sky with a bright, incomplete ring-like waist lacking its back side. The ionized gas is expanding toward the E and W with projected velocities up to ~45km/s and gradients of ~250km/s/arcsec. Apparently, there are not velocity gradients along the N-S direction but the velocity dispersion is as high as ~80km/s. We are currently modeling the continuum and H30alpha emission. Moreover, lines of CO, HC3N, HC5N, c-C3H2, and SiO among others have been detected in the observed spectral windows and their emission enclose the ionized gas in the bipolar outflows and the core, also describing the dense, expanding equatorial torus. In this talk, we will present our last advances on the analysis of these very rich high angular resolution data.

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SOFIA and HST Multiwavelength study of the Symbiotic Mira HM Sge

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We have compared new and archival observations of the symbiotic Mira HM Sge in the IR, optical, and UV to understand how the system has evolved on different scales after its 1975 nova-like outburst. With SOFIA we have probed the AGB dust and the gas kinematics of the dense circumstellar material, and with the Hubble Space Telescope we have mapped the gas in the inner nebula and probed the

shocked emission. In the IR, we have detected rovibrational water emission in a symbiotic system for the first time using new EXES high-spectral-resolution spectroscopy. The features, detected in emission, have velocities consistent with the systemic velocity but do not show any clear evidence of high-velocity outflows. Mid-infrared photometry and grism spectroscopy show that the oxygen-rich AGB dust and dust output have shown little to no change over the past 39 years. In the optical/UV, we detect three main nebular features in [N II] 6584Å emission that were detected 22 years ago. Two of these features show a small amount of movement, corresponding to average outflows speeds of 38 and 78 km/s since they were previously observed. New UV spectroscopy has shown that the nebular environment continues to steadily relax after the system's 1975 outburst. Our new and archival observations suggest that the evolution of the Mira after the outburst is swift with little to no major changes after a period of a couple of years.

AGB stars as cosmic probes for clusters and galaxies evolution / 13

The JAGB stars as distance indicator

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To investigate possible ways to resolve the Hubble tension other
distance indicators than cepheids, TRGB and SNIa and have seen a renewed
interest in the past years.
The Mira PL-relation is one of them, but in this contribution I want to
discuss the so-called JAGB stars that were introduced by Madore and Freedman in 2020. The name refers to the fact that the sample of interest are (carbon) stars located in region J of the classical 2MASS colour-magnitude diagram of the LMC by Weinberg and Nikolaev (2001)
and that the J-band magnitude is the magnitude of interest to provide the standard candle.
Some have advocated that the mean magnitude in a certain range in (J-K) colour is independent of metallicity and provides the standard candle. However, the situation is more complicated as pointed out in the literature.
Here I will give an introduction, and provide some new results on the SMC and LMC [that confirm results from the literature], and the Milky Wat and M31 as well.

Seeds and grains: AGB stars as dust factories in galaxies / 7

The Galactic chemical evolution of Mg-isotopic compositions inferred from presolar silicate grains

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Primitive Solar System materials contain small concentrations of presolar grains that formed in the winds of evolved stars and in the ejecta of stellar explosions [1]. These grains exhibit large isotopic abundance anomalies, the fingerprints of nucleosynthetic and mixing processes in their parent stars, and of Galactic chemical evolution (GCE). Silicates are the most abundant type of presolar grains. Based on O-isotopic compositions, O-rich presolar dust is divided into four distinct groups [2]. Most

abundant are Group 1 grains (ca. 80% of all presolar silicates) which are characterized by enrichments in 17O and close-to-solar 18O/16O ratios. About 60% of Group 1 silicates, called "normal"Group 1 grains, formed in the winds of low-mass asymptotic giant branch (AGB) stars, while the remaining 40% are likely from supernovae, supergiants and/or intermediate-mass (4-5 Msun) AGB stars with super-solar metallicities [3-5].

The surface Mg-isotopic compositions of low-mass AGB stars are predicted to change only little during stellar evolution [e.g., 6], i.e, initial Mg-isotopic compositions at stellar birth are largely preserved. In a Mg three-isotope-representation the normal Group 1 silicates [4,7] plot along a line with slope 0.84±0.05, called the Mg mainstream line, which is interpreted to represent GCE [4]. The slope of the Mg mainstream line is close to the slope of about 1 predicted by GCE models at around solar metallicity [8,9]. In a Si three-isotope representation normal Group 1 silicates [4,7] plot along a line with slope 1.34±0.09, called the "silicate Si mainstream line"[4], which is compatible with the slope inferred for presolar SiC mainstream grains (1.342±0.004 [10]). Magnesium-isotopic compositions of normal Group 1 silicates are correlated with Si-isotopic compositions and to some extent also with 18O/16O ratios, which supports the GCE interpretation of the Mg mainstream line.

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A variety of AGB stars: observational understandings / **46**

Variability of continuum radius and moleculer layers of R Car and VX Sgr using VLTI-GRAVITY

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Red giants and supergiants lose substantial fraction of their mass during their evolution and thus significantly contribute to the chemical enrichment of the interstellar medium. While the dust-driven wind coupled with pulsations can mostly explain the observed mass-loss rates of red giants on the asymptotic giant branch, this is not the case for red supergiants.

We obtained several epochs of Mira-type variable R Car and red supergiant VX Sgr, using spatially resolved near-infrared interferometry observations on VLTI-GRAVITY. We compare the observations with the state-of-the-art 1D and 3D models and archival data. This allows us to study regions close to stellar surface, where the mass-loss process is initiated, namely the continuum radius and the extended molecular layers, and also compare the structure and levitation of atmosphere between oxygen-rich Mira-type giants and red supergiants.

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Photospheres of red supergiants Betelgeuse, Antares and VX Sgr revealed by tomography

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Betelgeuse, a red supergiant star of semi-regular variability, reached a historical minimum brightness in February 2020, known as the Great Dimming. This event was likely caused by a surface mass ejection of material along our line of sight. This event suggests that the missing component to explain the mass-loss process in cool evolved stars may be the episodic mass-loss events.

We have obtained thousands of high-resolution spectra for Betelgeuse, Antares and VX Sgr. The spectra were taken across several years with STELLA robotic telescope, which is operated by Leibniz Institute for Astrophysics Potsdam. The tomographic method combined with this enormous dataset allows us to reveal variability of different layers in the stellar photosphere, for the first time in such a detail. We find phase shifts between photospheric layers and brightness variability, as well as powerful shocks that propagate through the photosphre and may be linked to the mass-loss events.

Specifically for Betelgeuse, we find many new insights regarding the Great Dimming, namely the discovery of yet unknown shock wave. This was followed by a subsequent rearrangement of the photosphere, when the timescale of variability was different between the inner and outer photospheric layers, while the first overtone has been excited.

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Binary stars in the Gaia DR3 era

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I will review some findings about binary stars recently achieved using Gaia DR3 data, and bearing some relationships with nucleosynthesis. More details may be given in the corresponding focused contributions (if accepted):
1/ The red giant 56 UMa, formerly classified as a barium star, probably hosts a (dormant) neutron-star companion of mass 1.3 Msun. Its abundances have been reviewed and not any longer tag the giant as a barium star (Escorza, Van Eck et al.);
2/ Several neutral-hydrogen cavities in the ISM, with fast-moving gas at their boundaries, are likely related to supernova explosions whose candidate progenitors have been searched among Gaia DR3 binaries possibly hosting a neutron-star companion, and likely candidates have been found (Escorza et al.);
3/ Samples of non-AGB Ce-rich and Ce-normal stars have been identified among the stars analysed in Gaia DR3, and it has been found that the frequency of binaries among Ce-rich is very significantly larger, because they were extrinsically-polluted by mass transfer from their (likely WD) companion

(Van Eck et al.);
4/ A full orbital (astrometric-spectroscopic) solution (with period 17.2+/-0.9 yr, i = 37.7+/-2°, M1 = 1.9 Msun, M2 = 2.6 Msun - to the best of our knowledge, the first orbit ever derived for a true AGB star) has been obtained for the carbon-star V Hya, exhibiting a jet and a dust clump obscuring the AGB star at each superior conjunction (Planquart et al.).

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Studying the wind-driving region of nearby AGB stars with ALMA and SPHERE

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Despite many important advances in recent years, we are still unable to predict the dust formation process and the wind-driving mechanism in AGB stars remain impossible to predict from first principles. Particularly, the initial step of dust nucleation and the properties of the grains that drive the outflows in oxygen-rich environments have eluded empirical characterization for a long time.
In this talk, I will present high-angular-resolution observations of nearby AGB stars using ALMA and SPHERE/VLT which are used to constrain the distribution of gas and dust in the innermost regions of the circumstellar envelopes. These data allow us to probe the crucial region where the wind is being accelerated in unprecedented detail and to test the wind-driving paradigm for AGB stars. The maps of the molecular lines reveal the density, velocity, and temperature distributions of the gas, while the polarized-light data constrains the density distribution and sizes of the dust grains. By combining these two complementary datasets, we can determine the dust-to-gas ratio in the wind-acceleration regions. Moreover, we also investigate the radiation pressure force experienced by the dust, which directly relates to how efficiently grains can drive an outflow.

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Uncovering the connection between Observed and Intrinsic Galaxy properties using Machine Learning.

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Measuring a galaxy's stellar mass is essential for comparing it to simulations of galaxy formation and evolution. The most common method involves dynamical techniques, where we observe the velocity of tracer objects, like globular clusters, to recover the gravitational potential and thus the mass. My goal is connecting observed and intrinsic galaxy properties using Machine Learning techniques. We seek an explicit expression relating stellar mass to observables: u, g, r, i, z band magnitudes, redshift (z), and color (g-r). The challenge is creating an expression that works across broad range of redshifts. I test these methods on simulated universe generated using the GALFORM code, consisting of 475412 galaxies. Once we identify a model predicting stellar mass effectively based on observables, we will then apply it to real data for performance assessment. I use ML methods to predict mass values. Initially, a straightforward ML method provides stellar mass predictions as black-box process. We use this as a benchmark and subsequently employ symbolic methods to derive an explicit equation. The galaxies exhibits bi-modality in observer frame color, indicating differences in

star formation histories and dust extinction properties for red and blue galaxies. I apply SISSO, a Machine Learning approach used in Material Sciences, for the first time in astronomy. It automates feature engineering and selects a multi-dimensional expression with high covariance with the target variable, i.e. stellar mass, providing a simple feature-based equation with physical interpretation. I also explore techniques like Principal Component Analysis, Linear, Polynomial and Non-linear regression. We analyze scatter and bias plots between predicted and true stellar mass for these ML methods. So far, Polynomial Regression has produced the least scatter for red galaxies. Our findings provide insights into the complex relationship between galaxy properties and have the potential to establish a correlation between observed and intrinsic properties.

A variety of AGB stars: observational understandings / 69

Unlocking Galactic Mysteries: Machine Learning Analysis of Gaia DR3 Data Reveals New C-rich and O-rich AGB Stars

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AGB stars play a pivotal role in understanding galactic populations, producing essential elements such as carbon, oxygen, and nitrogen. Despite their significance, unresolved questions persist regarding their evolution, including the transition from oxygen-rich to carbon-rich states and the impact of mass loss. The recent release of Gaia DR3 presents a remarkable opportunity to expand the sample of C-rich and O-rich AGB stars. Leveraging machine learning, our study aims to classify AGB stars based on the Gaia DR3 XP spectra, enhancing our understanding of galactic systems. Our methodology involves a two-step process: firstly, identifying AGB stars similar to Galactic AGB sources using cosine similarity; followed by classifying them as either C-rich or O-rich. This analysis utilizes a dataset of 220 million Gaia DR3 XP spectra, integrating photometric and spectroscopic data. Our presentation will detail this methodology, showcasing how machine learning efficiently handles massive datasets like Gaia DR3. This approach not only enriches our understanding of AGB stars but also presents opportunities to broaden statistical samples of other celestial objects in the Milky Way.

Seeds and grains: AGB stars as dust factories in galaxies / 6

The Synthesis of Organic and Inorganic Compounds in Asymptotic Giant Branch Stars

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Infrared and millimeter-wave observations have identified many inorganic and organic molecules in the stellar winds of asymptotic giant branch (AGB) stars. Also synthesized in the outflows are solid-state minerals such as amorphous silicates and refractory oxides. The production of acetylene in extreme carbon stars leads to the formation of benzene and other aromatic and aliphatic compounds in the post-AGB phase. The formation of mixed aromatic/aliphatic nanoparticles (MAONs) and their ejection into the interstellar medium may have enriched the primordial Solar System with complex organics.

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Using Carbon-rich AGB stars as Standard Candles

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I will present the J-region asymptotic giant branch (JAGB) method, a new standard candle that leverages the constant luminosities of color-selected, carbon-rich AGB stars. Using NIR imaging of 11 galaxies collected from the Magellan Telescope, we find the mode of the carbon star luminosity function in the J band is an accurate and precise method for measuring distances that are independent of distances derived from Cepheids or the tip of the red giant branch. I will discuss the advantages and current uncertainties of the JAGB method; because the JAGB method is relatively new, JAGB stars are amenable to further theoretical understanding. However, preliminary tests show little to no dependence of the JAGB magnitude on the metallicity of the parent galaxy. Finally, I will show JWST NIRCam color magnitude diagrams of SN Ia host galaxies in which the JAGB populations are resolved at high signal-to-noise, illustrating the feasibility of using JWST and the JAGB method to measure the Hubble constant this year.

A variety of AGB stars: observational understandings / 53

Carbon stars in the Milky Way and beyond

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Carbon stars are crucial dust producers in the Universe.
These Asymptotic Giant Branch (AGB) stars play a significant role in the creation of a considerable portion of the molecules observed in the Interstellar Medium (ISM), contributing to the interstellar reddening not only within our Galaxy but also in other galaxies.
Despite their importance, a self-consistent estimation of the astrophysical parameters of Carbon Stars belonging to the Milky Way (MW) and the Magellanic Clouds (MCs) is still missing.
In this work, we provide a homogeneous and internally consistent analysis of stellar
and dust properties for a sample consisting of over 10,000 candidate Carbon Stars, belonging to both the MW and the MCs.
We conducted a comparison of photometric data obtained from SDSS, GAIA and other missions with a wide grid of synthethic Spectral Energy Distributions (SEDs), created using DUSTY in combination with the MARCS models.
Through this comparison, we derived various parameters for our stars, including the effective temperature, dust temperature, mass loss rate, and more.
In this talk the first results will be presented.

Seeds and grains: AGB stars as dust factories in galaxies / 57

The isotope distributions of presolar SiC grains from carbon-rich asymptotic giant branch stars

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Presolar grains, microscopic dust formed around various types of stars in their advanced evolutionary stages, recorded intricate details of nucleosynthesis and mixing within their parent stars, offering invaluable insights into diverse stellar processes (Nittler & Ciesla, 2016). Among these, silicon carbide (SiC) stands out as the most extensively studied presolar mineral phase, with the majority of SiC grains, including Types MS, Y, and Z, believed to have originated from carbon-rich asymptotic giant branch (AGB) stars.

However, existing studies have highlighted significant challenges. Firstly, the isotopic data of presolar SiC grains in the literature often suffered from terrestrial and/or asteroidal contamination, compromising the isotope data for elements such as N, Al, Sr, Mo, and Ba (Liu et al., 2015, 2021, 2022; Groopman et al. 2015). Secondly, there are a factor of two uncertainties in the inferred initial 26Al/27Al ratios for presolar SiC grains because of uncertainties in the relative sensitivity factor (RSF) of Mg/Al for secondary ion mass spectrometers (SIMS), the type of instrument used for Mg-Al isotope analysis of these grains (Hoppe et al., 2023).

In this study, we obtained new C, N, Mg-Al, and Si isotope data for a large number of presolar MS, Y, and Z SiC grains isolated from the CM2 Murchison meteorite. The grain data were obtained by adopting analytical procedures aimed at minimizing N and Al contamination (Liu et al., 2021). In addition, we inferred initial 26Al/27Al ratios using a recently reported SIMS Mg/Al RSF value with a ±6% error for SiC (Liu et al., 2024), which led to a factor of two increase in all the inferred initial 26Al/27Al ratios compared to the literature data. Our comprehensive dataset enabled a statistical analysis of isotope distributions, revealing several rare subtypes of AGB grains characterized by unique isotopic compositions. We will highlight a typical MS SiC grain with a 900 ‰ enrichment in 25Mg and a subgroup of MS grains with subsolar 14N/15N ratios and large 26Al-excesses (i.e., 26Al/27Al ratios of 0.01). These findings will be discussed within the framework of AGB stellar nucleosynthesis to constrain the properties of their parent AGB stars.

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Seeds and grains: AGB stars as dust factories in galaxies / 26

The impact of dust from AGB stars to the chemical evolution of the ISM

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Asymptotic giant branch (AGB) stars contribute to the chemical evolution of galaxies through the dust grains they release into the interstellar medium (ISM). The detection of pre-solar grains in meteorites shows that at least some of the dust from AGB stars survives the transition into the ISM. It is likely that these grains act as seeds for further dust-growth in the ISM leading to the final observed interstellar dust. I will present a detailed analysis of the dust emission observed with Herschel/PACS at 70 and 160 micron towards wind-ISM interaction regions around a sample of 22 carbon and oxygen-rich AGB stars. My results show that there is a tendency for the grains in the wind-ISM interaction regions to be relatively large (approx. 2 micron), while several uncertainties that affect commonly made basic assumptions on interstellar dust (e.g., composition and morphology) become obvious. This may have severe implications for our understanding of interstellar dust and their effect on the chemical evolution of the ISM, and hence the impact of AGB stars on the chemical evolution of galaxies. Further, the dust observed in the ISM is distinctly different from the dust observed in the circumstellar envelopes around evolved stars. The physical conditions in the regions where the stellar wind interacts with the ISM may lead to significant reprocessing of the grains, strongly affecting properties like the size, structure, geometry, and composition of the grains. Our lack of understanding affects our knowledge of the chemical feedback to the ISM from evolved stars, and the origin of the cycle of dust in the ISM. Our results show a path forward in investigating the origin of interstellar dust, the cycle of dust in galaxies, and the effect on the chemical evolution of the ISM.

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Constraining the chemical evolution of AGB stars through detached shells

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The chemical evolution of asymptotic giant branch (AGB) stars is driven by repeated thermal pulses (TPs). Direct observations of TPs are unlikely. However, the CO detached shells that are formed as a result of a TP provide indirect constraints on the changes experienced by the star during the pulse. I will present observations of the 12CO(1-0) emission towards five AGB stars with ALMA. The observed CO emission separates into two sub-shells with an expanding coherent, bright outer shell and a more filamentary, faster inner shell. The observed spatial and kinematical splitting of the shells appears consistent with hydrodynamical models, provided the CO emission does not trace the H2 density distribution in the shell but rather traces the edges of the shells. Dissociation of CO in the shock inside the shell leading to the appearance of two shells in CO emission. The hydrodynamical models predict very different density profiles depending on the evolution of the shells and the different physical processes involved in the wind-wind interaction (e.g. heating and cooling processes). The CO observations for the first time directly probe this dynamical interaction directly in a sample of sources. Complementary observations of, e.g., CI as a dissociation product of CO would be necessary to understand the distribution of CO compared to H2, in addition to new detailed hydrodynamical models of the pre-pulse, pulse, and post-pulse wind. Only a comprehensive combination of observations and models will allow us to constrain the evolution of the shells and the changes in the star during the thermal-pulse cycle.

AGB stars as cosmic probes for clusters and galaxies evolution / 64

Unlocking Cosmic Distances with AGB Stars: The Potential of Mira Variables as Precision Distance Indicators

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Recently, Mira variables have gained renewed attention as a viable alternative to Cepheids for the initial step in the cosmological distance scale. Their advantages include being inherently brighter in the infrared spectrum, more prevalent, and found in diverse environments. Moreover, their evolutionary endpoint as white dwarfs links them to the progenitors of Type Ia supernovae, and as such they belong to the same population as the subsequent rung of the distance ladder. Replacing Cepheids with Miras has thus been proposed as an effective way to scrutinize Cepheids'distances and address the significance of the so-called "Hubble tension"—a discrepancy exceeding 5σ between the Hubble constant values derived from cosmic microwave background radiation analyses and those obtained via the cosmological distance scale, potentially hinting at undiscovered early universe physics.

In my presentation, I will delve into Mira variables' potential and limitations as precise distance indicators through their period-luminosity relationship. The intricate dynamics of Miras, especially as thermally pulsating AGB stars, introduce complexity to their period-luminosity relationship. Factors such as their alternating shell nuclear burning, surface composition alterations from dredge-up events, and reduction of their convective envelope due to mass loss —also responsible for shifting their emission from optical to infrared wavelengths —influence this relationship's accuracy. I will evaluate the inherent scatter in the period-luminosity relation stemming from these evolutionary processes, and introduce our latest work on empirically characterizing this relation with our data from NASA's Spitzer, Hubble and Webb telescopes.

Seeds and grains: AGB stars as dust factories in galaxies / 75

The intense production of silicates during the final phases of intermediate-mass AGB stars

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Silicate dust grains are an important player in the cosmic life cycle of matter and have been detected in a wide variety of environments. Although the intermediate mass stars are regarded as the most efficient manufacturers of silicates in the Universe, the formation process of this dust species in their winds is still highly debated. In this talk I will present our study on a sample of galactic, heavily obscured
AGB stars of intermediate mass, with the scope of assessing the efficiency of the dust formation mechanism in the circumstellar envelope of this class of objects and the amount of silicates that they release into the interstellar medium during their lifetime. The issues regarding the reliability of the predictions on the silicate yields from intermediate mass stars will also be discussed.

AGB structure, evolution and nucleosynthesis / 22

The impact of nuclear parameter and models uncertainties on the i-process nucleosynthesis in early AGB stars

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The observed surface abundance distribution of Carbon-enhanced metal-poor (CEMP) r/s-stars suggests that these stars have been polluted by an intermediate neutron-capture process (the so-called i-process) occurring at intermediate neutron densities between the r- and s-processes. Triggered by the ingestion of protons inside a convective He-burning zone, the i-process could be hosted in several sites, a promising one being the early AGB phase of low-mass low-metallicity stars. The i-process remains however affected by many uncertainties including those of nuclear origin since it involves hundreds of nuclei for which reaction rates have not yet been determined experimentally.

We investigate both the parameter and model uncertainties associated with theoretical nuclear reaction rates of relevance during the i-process and explore their impact on the i-process elemental production, and subsequently on the surface enrichment, for low-mass low-metallicity stars during the early AGB phase.

We use the TALYS reaction code (Koning et al. 2023) to estimate both the model and parameter uncertainties affecting the photon strength function and the nuclear level densities, hence the radiative neutron capture rates. The impact of correlated uncertainties is estimated by considering different nuclear models, as detailed in Goriely et al. 2022. In contrast, the uncorrelated uncertainties associated with local variation of model parameters are estimated using a variant of the backward-forward Monte Carlo method to constrain the parameter changes to experimentally known cross-sections before propagating them consistently to the neutron capture rates of nuclei of i-process interest.

On such a basis, the STAREVOL code (Siess et al. 2006) is used to determine the impact of nuclear uncertainties on the i-process nucleosynthesis in a 1 M⊠ [Fe/H] = - 2.5 model star during the proton ingestion event in the early AGB phase. A large nuclear network of 1160 species coherently coupled to the transport processes is solved to follow the i-process nucleosynthesis. This study allows us to quantify the relative importance of parameters versus model uncertainties with respect to the surface abundances in AGB stars and to identify the reaction rates that would need to be better constrained in the future in order to improve our understanding of the i-process.

AGB and beyond: learning from the advanced phases / 33

M 1-92: the death of an AGB star told by its isotopic ratios.

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Ongoing improvements in the sensitivity of sub-mm- and mm-range interferometers and single-dish radio telescopes allow the more and more detailed study of AGB and post-AGB objects in molecular species other than ^{12}CO and ^{13}CO. With a new update introduced in the modelling tool SHAPE+shapemol, we can now create morpho-kinematical models to reproduce observations of these shells in up to 10 different molecular species, allowing an accurate description of their physical features as well as their molecular abundances and isotopic ratios.
The pre-planetary nebula M1-92 (Minkowski's Footprint) is one of the most complex objects of this kind, with a wide range of physical conditions and more than 20 molecular species detected. We model this nebula, reproducing the observational data from IRAM-30m spectra and NOEMA interferometric maps, trying to understand the unusual evolution of its central star in the last phases of its life.

The results show interesting features that tell us the story of its death. A $^{17}O/^{18}O$ isotopic ratio of 1.6 indicates that the central star should have turned C-rich by the end of the AGB, as opposed to its O-rich nebula. The most plausible way of reconciling this discrepancy is that M1-92 resulted from a sudden massive ejection event, which also interrupted the AGB evolution of the central source, preventing its transformation into a C-rich star. We also detect different ratios of $^{12}C/^{13}C$ across the nebula, which is particularly relevant in the inner equatorial region traced by HCO^+ and $H^{13}CO^+$, indicating an isotopic ratio variation taking place at some point during the last 1200 yr.

AGB stars in binary systems / 45

Do Intrinsically s-process Enriched Evolved Binaries Exist?

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Binary stars can display a diverse range of chemical signatures arising from strong yet poorly understood interactions with their companions. In observational studies focusing on low to intermediate-mass ($0.8 - 8$ M$_\odot$) binary stars, such as Barium stars, Carbon Enhanced Metal-Poor (CEMP-*s*) stars, and extrinsic s-stars, the observed enrichments in carbon and slow neutron capture (*s*-process) elements have conventionally been attributed to interactions with their evolved companions, particularly white dwarfs (WDs), suggesting an extrinsic nature to the enrichment process. However, we have assembled a chemically peculiar sample of post-Asymptotic Giant Branch (post-AGB) binary stars, whose high-resolution optical spectra from VLT+UVES revealed a carbon and *s*-process enrichment, contrary to the commonly observed photospheric chemical depletion (reaccretion of pure gas onto the star, devoid of refractory elements) in post-AGB binaries. This occurrence, for the very first time, is more inclined towards intrinsic enrichment rather than the usual extrinsic enrichment. In this talk, I will present our detailed investigation as to how we ruled out the possibility of extrinsic enrichment (from a WD companion). This includes data from orbital parameter analyses and the study of the jets launched from the circum-companion (thorough spatio-kinematic and radiative transfer models). Additionally, we also exclude the inherited *s*-process enrichment from the host galaxy as a plausible explanation for the observed overabundances. To validate the intrinsic enrichment nature of our targets, we incorporate predictions from dedicated ATON stellar evolutionary models. I will showcase the exciting results uncovering the first potential of intrinsically enriched evolved binaries and discuss their implications on our current understanding of binary star evolution and nucleosynthesis.

Nuclear reaction rates: news from laboratory measurements / 27

22Ne(α,γ)26Mg with EASγ

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The reaction 22Ne(α,γ)26Mg is associated with several questions in nuclear astrophysics like the Mg isotope ratio in stellar atmospheres and its competition with the neutron source 22Ne(α,n)25Mg. Due to very low stellar energies and therefore very low cross section, direct experiments have been only able to provide upper limits below a strong resonance at 832 keV.

The purpose of the EASγ project is to perform the first direct measurement of the 22Ne(α,γ)26Mg in the range of astrophysical interest below 600-800 and the remeasurement of the 832 keV resonance. The measurement will be carried out using the new LUNA MV accelerator at Laboratori Nazionali del Gran Sasso, which provides a high and stable α particle current. Moreover, its position underground and additional passive shielding will reduce the γ-background. The γ-rays produced in the reaction will be detected by a NaI scintillator array surrounding a windowless, recirculating gas target.
Additional information on the excited state of 26Mg near the alpha threshold will be provided by an indirect measurement via 7Li(22Ne, t)26Mg in inverse kinematics, scheduled at the TRIUMF laboratory in Vancouver.
We present the current status of the project and an overview of the planned TRIUMF experiment.

AGB stars in binary systems / 63

Chemical depletion in evolved binaries with second-generation protoplanetary discs

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Binary interaction is known to affect the chemical composition of low- and intermediate-mass (LIM) stars. In particular, post-AGB/post-RGB binary stars with circumbinary discs display photospheric chemical depletion with a notable underabundance of refractory elements in the stellar photospheres (e.g., Al, Fe, Ti, s-process elements) relative to volatile elements (e.g., S, Zn, Na, K). The exact mechanism behind this depletion is not yet fully understood, but it is believed to result from the chemical fractionation of gas and dust in the circumbinary disc, followed by the re-accretion of clean gas onto the primary star. Recent observational studies have shown that these circumbinary discs are similar to the protoplanetary discs (PPDs) around young stars in terms of infrared excess, keplerian rotation, and dust mineralogy. Moreover, it was recently confirmed that a subset of post-AGB/post-RGB binary stars hosts "transition"discs that have large inner cavities similar to those observed in PPDs, which could reflect the presence of a giant planet carving a hole in the disc. To further investigate these targets, we carried out a detailed chemical abundance study of all 12 transition disc systems known to date in both the Galaxy and the LMC (characterised by moderate-to-high mid-infrared excess and significant depletion efficiency [S/Ti] > 1.3 dex). We used high-resolution optical spectra from HERMES/Mercator and UVES/VLT to study the elemental abundances as a function of parameters from both the binary (e.g., photometric, orbital, pulsational) and the disc (orientation, size, morphology). We confirmed that depletion efficiency in transition disc systems is higher than in other evolved binary stars. Additionally, we found that the derived chemical depletion patterns in our evolved binary systems are matching those observed in young planet-hosting stars and are mostly in line with those observed in interstellar medium. We also found that the pulsation period of our targets is strongly anti-correlated with the infrared luminosity produced by the circumbinary disc. In this talk, I will present these interesting highlights of our study and also the implications of our results on possible planet formation in evolved binary stars.

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Understanding post-RGB binaries through stable mass transfer

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Post-AGB binaries are binary star systems where the primary star has recently evolved past the AGB phase after having lost the majority of its envelope. Observed Galactic post-AGB binaries have orbital periods which are at odds with many binary population synthesis models. To investigate this, we compare these Galactic objects to detailed stable mass transfer models for low- and intermediate-mass binaries ranging from post-main sequence up to the first thermal pulse on the AGB. In particular, we focus on the regime below the RGB-tip luminosity, where we expect post-RGB binaries, the RGB analogue of post-AGB binaries, to reside. We determine a post-RGB binary luminosity-orbital period relation for a range of metallicities. We use this relation to estimate the orbital periods of post-RGB candidates in the Large Magellanic Cloud and Small Magellanic Cloud.

A variety of AGB stars: observational understandings / 29

Constraining the stellar mass-loss-rate evolution on the AGB (and slightly beyond)

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It is believed that stellar mass loss increases as a star evolves along the AGB, and that it is higher the more massive the star is. However, there is little evidence that supports these beliefs. In addition, it has been proposed, but not firmly established, that the MLR characteristics on the AGB are frequently (strongly) affected by the presence of a nearby companion. These are troublesome lacks of understanding since the mass-loss evolution of AGB stars is an important input parameter in population synthesis and galactic chemical evolution models, in which the mass-loss rates of AGB stars follow prescriptions based on the above expectations. It is therefore of great importance to empirically determine the mass-loss rate evolution for a large sample of AGB stars to improve the prescriptions. Of particular interest is the upper AGB and the early post-AGB where most of the stellar mass is expected to be lost.

We have assembled a sample of 77 OH/IR stars at the distance of the inner Galactic Bulge for a combined ALMA/APEX study to constrain their phase of strongest mass loss, and the sharp decline in mass loss expected to take place at the end of the AGB. It is a CO multi-transition study aimed at accurately estimating mass-loss-rate characteristics and stellar ^{12}C/^{13}C isotope ratios. This study will provide a much-needed and unprecedented empirical picture of the evolution of AGB gaseous mass loss at its most extreme phases.

AGB stars in binary systems / 23

The Influence of Binary Evolution on the Nucleosynthesis of AGB Stars

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Stars that evolve through the asymptotic giant branch (AGB) are vital to the chemical evolution of the universe as they produce a significant portion of the carbon, nitrogen, and elements heavier than iron. Most models studying the evolution and nucleosynthesis of AGB stars focus on single stars. However, at least half of these stars exist with a binary companion. In this study, we use the binary population synthesis code binary_c to investigate the influence of binary evolution on an AGB star's ability to contribute to the chemical enrichment of the universe. We simulate a stellar population of stars born with mass 0.8-8.5$M_\odot$ of varying binary fraction at solar metallicity. For a binary fraction of 0.7, we find a 15% decrease in the overall ejected carbon and a ~20% decrease in the ejected barium compared to our population of only single stars. Additionally, we compare our results to the Galactic planetary nebulae NGC3242 and NGC6537, which are difficult to fit with single-star models. Our binary models find reasonable agreement, with mismatches likely due to our assumptions of the initial abundances. Future work will extend this study to lower metallicities, allowing us to compare our results to a wider range of observations and gain a more complete picture of the influence of binary evolution on the stellar nucleosynthesis of AGB stars.

A variety of AGB stars: observational understandings / 35

Stellar surfaces through the looking-glass

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Stellar convection plays an important role in many astrophysical processes, including energy transport, pulsation, dynamos and winds on evolved stars. A direct characterization of convective structures in terms of size, contrast, and life-span is quite challenging because stars are still pretty far and convective patterns are small.
Most of our knowledge about stellar convection comes from studying the Sun. On the surface of our star a couple of millions of convective cells are observed, each one with a size of about 2000 km. Following predictions dating back to the '70, the surface of evolved stars (or a Sun at later evolutionary stage) is expected to be populated by only a few large convective cells several tens of thousand times the size of the solar ones. Such predictions were confirmed at the end of last decade by direct observations of the stellar surface of the low mass Asymptotic Giant Branch Stars pi1 Gruis. More recently the models are being challenged when it comes to more massive objects like the Red Supergiants.
In this talk I will review the recent results obtained using high angular resolution techniques to resolve the surface of stars, and I will discuss the various scenarios used to interpret the images. Are we really looking at convection?

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HD235858 revisited. Interpretation of a new spectral measurement for Pb.

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While AGB nucleosynthesis modelling is on average successful in explaining the observed abundances of s-process elements heavier than Sr in evolved low mass stars, either climbing along the AGB itself or belonging to connected stages (Busso et al. 2021), an inconsistency is found for the Pb abundances in post-AGB stars, so far available only as upper limits.
Aa an exploratory test on this problem, we present here new spectroscopic observations, made at the McDonald Observatory's 2.7m telescope, of the low metallicity ([Fe/H] = −0.77) post-AGB star HD235858. A high-resolution spectrum was taken in the spectral region λ ~ 400 − 900 nm. Spectral synthesis near the Pb I line at λ = 405.7807 nm showed that, among the huge number of lines, most are atomic, some are from CH, while CN lines are more difficult to see. The dominant contaminant of the Pb I line is the Mg I line, at λ = 405.751 nm. From the spectrum we can estimate the abundances for Mg and Pb: log epsilon(Mg) = +7.18, log epsilon(Pb) = +2.2, corresponding to [Pb/Fe] ~ 1.43.
We then tried to interpret our Pb abundance through an AGB nucleosynthesis model at low metallicity ([Fe/H] ~ −0.77) and low mass (M = 1.5 Msun), including magnetically-induced extra-mixing (Busso
et al. 2021) and updating the nuclear parameters (cross sections and decay rates) for the heaviest (A ≥ 140) nuclei.
Comparisons can be performed by combining our observations for Pb with abundances for other heavy elements by Reddy et al. (2002), by De Smedt et al. (2016), and by new determinations derived in this study. In so doing, our new Pb estimate confirms the existence of a large (0.7 dex) discrepancy on the Pb abundance with respect to model predictions that, on average, account well for the observations of the other s-process elements. Presence of this problem was already indicated also for other post-AGB stars (see e.g. De Smedt et al. 2016) on the basis of upper limits for the Pb abundance.
Reasons for the above discrepancy might be searched for, as an example, in some selective inclusion of Pb in circumstellar dust (Olofsson 2023). The occurrence of the i-process (invoked in other works) seems less likely in this low mass star, also due to the averagely good reproduction of other abundances with our pure s-process computations.

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AGB stars in binary systems / 20

A search of AGB binaries: the case of V Hydrae

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The presence of close-by companions is believed to be an essential ingredient to shape the outflow of the progenitor of bipolar planetary nebulae. However, only an handful of AGB binaries have been

detected so far and their orbital characteristics are not well constrained. Here, we target the well-known carbon-rich star V Hydrae (V Hya), known to exhibit a complex environment believed to be shaped by an unseen companion.

Using a multi-epoch and multi-instrumental study, combining spectroscopic monitoring (HERMES/Mercator spectrograph) and infrared interferometric imaging with VLTI/MATISSE (as part of the ESO-Large Program BINAGB), we disentangled the AGB orbital motion from its Mira-like pulsation, provided the complete set of orbital parameters and showed that a dust clump is associated with the close companion. This dust clump is responsible for the visual obscuration events occurring every 17 years. Based on spatio-kinematic modeling of a conical high-velocity outflow attached to the companion, we provide constraints on the gas and dust distribution.

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Mass transfer in AGB binaries revisited

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Barium stars and related systems, such as carbon-rich metal-poor stars, are the products of mass transfer from a binary companion during its thermally pulsing AGB phase. These systems are traditionally considered to result mostly from wind mass transfer, because Roche-lobe overflow (RLOF) from an AGB star is thought to be unstable and lead to a common envelope. Several recent theoretical insights are changing this picture. First, hydrodynamical simulations of AGB wind mass transfer show that the orbit may shrink rather than expand, bringing a larger number of systems into RLOF that would otherwise have avoided it. Second, detailed binary evolution modelling of mass transfer from evolved giant stars show that RLOF may be stable for a much wider range of initial mass ratios than has been assumed. In this contribution I will explore the consequences of the increased importance of stable RLOF in AGB binaries for our understanding of barium stars and their siblings.

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A Parameter Study of 1D Atmospheric Models of Pulsating AGB Stars

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Using the atmospheric pulsation code written by George Bowen, we have performed a parameter study, examining the effects of modifying various parameters of models of oxygen-rich AGB atmospheres pulsating in the fundamental and first-overtone modes. For each pulsation mode, we have examined the effects of adjusting the dust condensation temperature, dust condensation temperature range, pulsation amplitude, dust opacity, and metallicity. Our model grids are generated with the constraint that their luminosities are chosen to span the range of observed mass-loss rates at a

chosen mass. The dust condensation temperature, pulsation amplitude, and dust opacity have very strong effects on the ultimate location and shape of the final model grids. The parameter study shows that a moderate adjustment of the pulsation amplitude and amount of dust present in the stellar atmosphere can yield model grids consistent with observed limits in luminosity, pulsation period, and mass-loss rate.

The mass-loss rate evolution of the fundamental and first-overtone mode models show a significant difference in behavior. While the fundamental mode models exhibit the typically assumed power-law relation with mass and luminosity, the first-overtone mode models show significant non-power law behavior at observed mass-loss rates. Effectively, models in the first-overtone mode require somewhat higher luminosities to reach the same mass-loss rates seen in fundamental mode models of the same mass, consistent with observed AGB stars. This difference in behavior correlates well with differences in the acoustic cutoff periods of the models, suggesting differences in acoustic wave propagation is the source of this difference in behavior.

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Spectroscopy of a sample of RV Tauri stars with no IR excess

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We have observed high-resolution optical spectra of 11 stars that have been classified as RV Tauri type variables with no IR excess. Part of such objects are thought to be progenitors of AGB stars; therefore, enrichment in s-process elements could be expected. By using equivalent widths of absorption lines, as well as the method of spectral synthesis, photospheric parameters and chemical element abundances are estimated. We arrive at different abundance patterns, such as depletion and anomalous overabundance of sodium, which we discuss in the context of stellar evolution. We also discuss some of the stars being misclassified and provide evidence for some being binaries.

Nuclear reaction rates: news from laboratory measurements / 8

^{17}O destruction rate

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When stars approach the red giant branch, a deep convective envelope develops and the products of the CNO cycle appear at the stellar surface. In particular, the ^{17}O is enhanced in RGB and AGB stars. Then, spectroscopic analyses of O isotopic ratios of these stars provide a powerful tool to investigate the efficiency of deep mixing processes, such as those powered by convective overshoot, rotation, thermohaline instability, gravity wave and magnetic field. However, this method requires a precise knowledge of the reaction rates that determine the ^{17}O abundance in a H-burning shell, among which the $^{17}\mathrm{O}(\mathrm{p},\gamma)^{18}\mathrm{F}$ and the $^{17}\mathrm{O}(\mathrm{p},\alpha)^{14}\mathrm{N}$ reactions are the more relevant. Since the last release of rates compilations (see the JINA reaclib database) a number of experiments have updated the reaction rates, incorporating new low-energy cross-section measurements. To provide up-to-date input to the astrophysics community, we performed simultaneous multi-channel and Monte

Carlo R–matrix analyses of the two reactions including all newly available data, resulting in realistic uncertainty ranges for the rates.

AGB structure, evolution and nucleosynthesis / 47

Stellar evolution and nucleosynthesis in 3D hydrodynamic models of stars

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Our understanding of stellar evolution and nucleosynthesis is limited by the uncertainties coming from the complex multi-dimensional processes in stellar interiors, such as convection and nuclear burning. 3D stellar models can improve this knowledge by studying realistic multi-D processes for a short timerange (minutes or hours). Recent advances in computing resources have enabled 3D stellar models to reproduce longer timescales and include nuclear reactions, making the simulations more realistic and allowing to study explicit nucleosynthesis.
In this talk, I will present results from 3D stellar simulations that include an explicit nuclear network for different burning phases in advanced massive stars. I will introduce the methods and limitations of multi-D stellar modelling, and describe the effects on the evolution of the stellar structure, discussing also the implications for stellar evolution, nucleosynthesis, and convection theory.

AGB structure, evolution and nucleosynthesis / 17

Evolution and final fate of stars in the transition between AGB and Massive Stars

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According to a standard initial mass function, stars in the range 7-12 Msun constitute $\sim 50\%$ (by number) of the stars more massive than 7 Msun. Despite this, their evolutionary properties, particularly their final fate, remain mostly understudied. In this talk I will present some of the results published in our recent paper, where we discussed in details the evolutionary properties of solar metallicity, non rotating, stars in the range 7-15 Msun, from the pre-main sequence up to the presupernova stage or up to an advanced stage of the thermally pulsing phase, depending on the initial mass. Our findings revealed several key points: (1) the 7.00 Msun develops a degenerate CO core and evolves as a classical AGB star; (2) stars with initial mass M $\geq$ 9.22 Msun end their life as core collapse supernovae; (3) stars in the range 7.50 $<$M/Msun $<$ 9.20 develop a degenerate ONe core and evolve through the thermally pulsing SAGB phase; 4) stars in the mass range 7.50 $\leq$ M/Msun $\leq$ 8.00 end their life as hybrid CO/ONe- or ONe-WD; (5) stars with initial mass in the range 8.50 $\leq$ M/ Msun $\leq$ 9.20 most likely achieve the central densities in excess of the threshold value for the activation of the electron capture on 20Ne before losing the entire H-rich envelope and therefore may potentially explode as electron capture supernovae.

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Steps towards disentangling asymmetric AGB winds using MATISSE: the case of X TrA

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Severe mass-loss is the reason behind the ending of the asymptotic giant branch (AGB) stellar evolutionary stage, this phase having a high importance for the recycling of heavy elements within the interstellar medium. A very intricate process, many clues regarding the formation and evolution of AGB winds are still hidden in the close and extended environments of AGB stars. Believed to form from ejected AGB atmospheres, planetary nebulae (PNe) provide extra constraints on the mass-loss picture. One such aspect is the ratio of observed asymmetric PNe to AGB stars that have a companion, which does not not match that well. Observationally, symmetry also appears to be affected by the chemical type of the star, carbon-rich stars showing more asymmetric features in their envelopes than their oxygen-rich counterparts. As part of an ESO Large Program, VLTI/MATISSE is used to observe a sample of different (chemical type and companionship status) AGB stars as a means of investigating the problems mentioned above. Covered here will be X TrA, a non-binary carbon star from this sample for which previous studies have found some extended infrared ring morphology along with SiC dust features. The focus will lie on the image reconstruction and modelling process, followed by any potential implications regarding previous results and the asymmetries observed in carbon-rich AGB winds.

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ALMA observations of Titanium and Aluminium bearing species in Mira

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Asymptotic giant branch (AGB) stars stand out as prominent contributors to the production of dust within our Galaxy. However, the intricate process of inorganic dust grain condensation in the outflows of AGB stars remains uncertain. Theoretical investigations, rooted in chemical and thermal equilibrium, have pinpointed aluminium oxides, titanium oxides, and silicon oxides as the primary contenders for serving as the nuclei around which dust particles coalesce in M-type AGB stars. Nevertheless, the mechanisms responsible for the remarkably efficient coagulation of molecules into dust grains remain poorly understood. In this study, our objective is to probe the formation of dust surrounding the nearby M-type AGB star, Mira, using finely resolved observations from the Atacama Large Millimeter/submillimeter Array (ALMA) across Bands 6, 7, and 8. Our analysis has successfully identified multiple spectral lines, including 46TiO, 48TiO, 49TiO, 50TiO, 46TiO2, 47TiO2, 48TiO2, 49TiO2, 50TiO2, AlO, AlCl, AlF, SO2, SO, SO2, SiO, and SiS. We have estimated the column density and abundance of the majority of these detected species. We aim to provide a more precise characterization of the aluminum and titanium budgets within the inner outflow region of Mira, with the ultimate goal of shedding light on the intricate processes governing dust formation in Mira's inner outflow.

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Do Technetium-rich M stars pose a challenge to our understanding of third dredge-up physics?

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The technetium-rich (Tc-rich) M stars reported in the literature (Little-Marenin & Little 1979; Uttenthaler et al. 2013; Shetye et al. 2022) are puzzling objects since no isotope of technetium has a half-life longer than a few million years. Hence, 99Tc, the longest-lived isotope along the s-process path, is expected to be detected only in thermally-pulsing stars enriched with other s-process elements (like zirconium). The anomaly deepens as carbon enrichment is anticipated in tandem with zirconium, following each thermal pulse on the asymptotic giant branch (AGB). Surprisingly, the Tc-rich M stars lack significant zirconium enhancement (which would categorise them as S-type stars) and display no substantial carbon overabundance (which would label them as carbon stars).
In my talk, I'll present a high-resolution study of a large sample of Tc-rich M stars. I'll delve into the challenges associated with determining their atmospheric parameters and propose effective solutions. Additionally, I'll present their s-process element abundance analysis, accompanied by a comparison of their location on the HR diagram with Tc-rich S-type stars. Lastly, I will discuss the role of Tc-rich M stars as the potential tracer of the onset of the third dredge-up.

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Dusty common envelope evolution

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We will present recent SPH simulations of common envelope evolution including the formation of dust. Our calculations indicate that radiative acceleration on dust grains has a weak impact on the dynamics of the gas. However, dust formation can significantly alter the observational properties of the object.

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Temporal changes in the infrared molecular spectrum of a Magellanic carbon star

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The mid-infrared spectrum of a carbon star in the Large Magellanic Cloud (LMC) has changed substantially between a recent observation with the Medium-Resolution Spectrometer (MRS) on the Mid-Infrared Instrument aboard JWST and a spectrum obtained over 18 years ago with the Infrared Spectrograph on the Spitzer Space Telescope. The JWST observation is part of a program to capitalize on the spectral resolution of the MRS to study the molecular absorption bands in nine carbon

stars in the LMC. The sample spans a range of colors and includes relatively dust-free semi-regular variables and more dust-enshrouded Mira variables. The two spectra obtained so far straddle the boundary between these two groups, and the semi-regular variable looks much as it did when observed with Spitzer. In the Mira, however, the acetylene band at 7.5 um has nearly vanished, the CO at 5 um is weaker, and a new band stretching from 8.5 to 11.5 um has appeared. We have not yet identified this band (at the time we submitted this abstract), but it is real. The overall brightness of the star in the mid-infrared remains approximately the same. This change raises a host of questions about the evolution of carbon stars and underscores the importance of spectroscopic monitoring to better understand their behavior over time scales of decades.

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Multiwavelength Variability in Nearby Evolved Stars

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I will present results from our recent work on collecting and analysing multiwavelength light curves for targets from the Nearby Evolved Stars Survey (NESS; Scicluna et al. 2022). The NESS collaboration is studying ≈800 asymptotic giant branch (AGB) and red supergiant (RSG) stars in the Solar Neighbourhood (d
$lesssim$ 3 kpc) in order to obtain a robust understanding of the mass-loss process and its connection to the content, distribution, and properties of the circumstellar gas and dust. These nearby, bright AGB/RSG stars are long-period pulsators for which variability data exists in many all-sky surveys across a large range of wavelengths. A systematic study of multiwavelength light curves is required to connect photospheric variability to changes in the circumstellar emission. We have performed such a study for the first time for a large, nearby sample of evolved stars by combining light curves in over 20 photometric filters from optical, near-infrared, and mid-infrared surveys resulting more than 5000 light curves for over 700 NESS targets.

We extract periods, amplitudes, and mean magnitudes from these light curves using the Python Gaussian processes for MUltiwavelength Variability Inference (PGMUVI; Scicluna et al. 2023) code. We reproduce the general trends seen in the literature between these parameters and with other properties such as mass-loss rates. Our analysis provides robust constraints on the properties of evolved stars in the Solar Neighbourhood –previous studies have typically either focussed on small samples or a narrower range of wavelengths.

A small fraction (~5%) of the AGB stellar population dominates (>75%) the dust production in nearby galaxies. Of these, the dustiest can only be detected at near- and mid-infrared wavelengths; however, in the absence of mid-infrared spectra, they are impossible to distinguish from young stellar objects. One application of our work is the analysis of mid-infrared light curves for identifying such stars, which might reveal extreme carbon stars and/or massive AGB/super-AGB candidates in nearby galaxies. I will discuss one such interesting sample.

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Advances in stellar and galactic evolution with the population of the progenitors of planetary nebulae from the APOGEE DR17 survey

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Planetary nebulae (PNe) are the ejected gas and dust shells of Asymptotic Giant Branch (AGB) stars. We present an abundance comparison between PNe and their progenitors to disclose their similarities and differences since such a comparison has been rarely, and not recently, done in the Milky Way. While we expected similarities in most of the alpha-element distributions across the two populations, given their limited evolution in LIMS, differences in Fe and S abundances allow us to determine their depletion due to grain condensation in the post-AGB phases. Differences in N and C between PNe and their progenitors set new limits to the LIMS contributions to these elements. Radial metallicity gradients from RGs and PNe and Gaia-calibrated distances constrain galactic evolution evolution in the framework of the current chemical evolutionary models.

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Dust Production from Metal-Poor AGB Stars: JWST Results from Sextans A

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Dust formed through the winds from stars on the Asymptotic Giant Branch (AGB) can have a substantial contribution to the overall dust budget in a galaxy. However, it is uncertain how metallicity impacts AGB dust production because model predictions vary and observational constraints are scarce at low metallicity. Quantifying the dust production from very metal poor AGB stars has profound implications for identifying the dominant dust producers in the early universe. We present new JWST imaging and spectroscopy of Sextans A, a distant member of the Local Group with 7% Solar metallicity. With NIRCam and MIRI photometry, we identify AGB stars and classify them as oxygen- or carbon-rich. We then fit their mid-infrared SEDs to calculate their dust production rates (DPR) and compare those rates to AGB stars in the Magellanic Clouds and other nearby galaxies. Mid-infrared spectroscopy of five carbon-rich stars reveals they are embedded in carbon-rich dust shells, confirming the previous photometric identification of dusty carbon stars in this very metal-poor environment. One of the sources shows a tentative detection of SiC dust emission at 11.3 μm. The origin of this SiC dust in Sextans A is a mystery that has strong implications for the dust production and mineralogy in nearby and high redshift metal-poor systems.

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Insight on AGB mass-loss and dust production from PNe

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Low-mass stars lose a significant fraction of their mass during the final stages of the asymptotic giant branch (AGB) phase, resulting in the production of a substantial mass fraction of dust. The

mass loss process influences the timescales of the transition from the AGB to the planetary nebulae (PNe) phase, while the residual dust contributes to the spectral energy distribution of the PNe. Our latest research endeavors aim to establish a link between what is currently observed in the PNe and the evolution of their progenitor stars in previous phases, thereby improving our understanding of the mechanisms behind dust production and mass loss during the final AGB phase.
In this talk, I will present an investigation of PNe likely originating from single stars, observed from both the Magellanic Clouds and the Milky Way. By comparing the observed spectral energy distribution with that obtained from photoionization modeling, we can discern crucial details such as the luminosity and effective temperature of the central star, the mass of the gaseous nebula, and the amount and composition of dust present. The physical and chemical properties of the central stars are then compared with predictions from ATON evolutionary tracks to constrain the mass of the PN progenitor. The determination of these parameters enables allows us to infer crucial insights into the processes of mass loss and dust formation experienced occurred during the final thermal pulses of the AGB phase.

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Tackling an ALMA-ACA volume-complete sample of AGB stars

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Mass-loss from asymptotic giant branch and red supergiant stars drive local galactic chemical evolution, but one of the main uncertainties in quantifying this process is the spatial and temporal variations in mass-loss across the evolved star population. A large sample of sources is needed to recover the statistical mass-loss rate, and variation thereof, as a function of observable stellar parameters.

We will describe a volume-limited sample of nearby evolved stars that the Nearby Evolved Stars Survey (NESS) team is building. The program started with initial data from a James Clerk Maxwell telescope (JCMT) large program, where CO 3-2 and 2-1 observations were obtained for all known AGB stars in the Solar Neighborhood, within a radius of 2 kpc.

We will focus on the current efforts being done using the group's interferometric observations from the Atacama Large Millimeter/submillimeter Array (ALMA). The data is bringing the ability of the JCMT at the largest angular scales with those of the angular resolution of ALMA's Atacama Compact Array (ACA) to probe their circumstellar envelopes. We are interested in the mass-loss histories, geometries, and 12C/13C and dust-to-gas ratios in order to make predictive estimates for stellar evolution models and quantify the dust and molecular inventory AGB stars return to the interstellar medium. In this talk we will present preliminary results based on roughly half of the ACA observations available, including detection rates of the CO lines, angular extensions of the envelopes, and general statistical properties of the sample's data. We will also present physical parameters, including mass loss rates, that can be obtained from the observations.

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Infrared Period-Luminosity Relations of Galactic Miras based on Multi-Epoch Photometry and the Gaia Parallax Precision

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Till date, period-luminosity relations of Galactic Miras are scarce in the literature because their distances were poorly known. This has changed with the advent of Gaia parallaxes. A further limitation is the lack of multi-epoch IR photometry for significant samples of Miras; single-epoch 2MASS photometry results in large scatter because of the stars' large amplitude variability. We combined several sources of data to improve on this: 3.6 years of observations with the COBE/DIRBE instrument in four IR photometric bands, multi-epoch observations with the WISE space observatory in two bands, and hand-picked pulsation periods based on visual AAVSO light curves of the stars. We present period-luminosity relations of Galactic Miras in these photometric bands and use the scatter around them to assess the precision of Gaia parallaxes of AGB stars. We find that they must be more precise than often reported in the literature.

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From the s-process to the i-process: A new perspective on the chemical enrichment of extrinsic stars

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Recently, there have been hints that an increasing number of extrinsic stars (barium, CH and CEMP) could be enriched in chemical elements produced by the i-process (characterised by neutron densities $N_n \sim 10^{14-15}$ cm^{-3}) rather than by the s-process ($N_n \sim 10^8$ cm^{-3}) .
Different isotopic mixtures are predicted for the s-process on the one hand, and for the r- or i-processes on the other. After a brief review of previous isotopic composition determinations, we report on our investigation, based on high-resolution, high signal-to-noise HERMES and UVES spectra and non-LTE line synthesis, of the barium isotopic composition of extrinsic stars enriched in heavy elements.
We also report on a sample of extrinsic stars uncovered in Gaia DR3. We discuss their properties in terms of chemical abundances and binarity, as well as the overlap with existing catalogues of extrinsic stars.

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15 years of High Resolution Spectral monitoring of evolved stars with HERMES at the 1.2m Mercator telescope

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HERMES is the high resolution optical spectrograph of the 1.2m Mercator telescope at the Roque de los Muchachos observatory at La Palma, Spain. After commissioning we started a long-term monitoring programme of evolved stars and focused on detecting and/or monitoring binaries with

an evolved stellar component. The latter is either a post-AGB star or a white dwarf. Now, 15 years later I will review the unique datasets and highlight the most important scientific results of this monitoring programme.

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Molecular gas after the AGB: the cases of V Hydrae and KJPN 8

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Post-AGB stars play a significant role in enriching and advancing the chemical complexity of the Universe. During the late stages of low-to-intermediate mass stellar evolution, substantial outflows of dust and gas are injected into the interstellar medium (ISM). Post-AGB stars undergo significant intrinsic changes, and, in a notable proportion, they also experience changes induced by companions, disrupting their AGB circumstellar envelopes and activating complex chemistry. These changes include stellar evolution towards the white dwarf phase, which enhances the emission of UV photons from the central star, and shocks due to interactions with binary companions. These factors lead to an enhancement of photo-induced processes and shocks, which can dissociate and ionize material, and form structures such as disks, tori, and elongated gas and dust outflows.

In this presentation, I will discuss the latest results from our post-AGB studies of the molecular outflow of V Hydrae and the disk of KJPN 8, using data from APEX and the IRAM 30m telescope, respectively. The complete molecular inventory of V Hydrae remains unknown, which biases our interpretation of the chemical richness of evolved stars, particularly towards AGB sources. Our observations of V Hydrae have revealed the presence of CO, SiC2, HC3N, SiS, and CCH, among other typical molecules and isotopologues found in carbon-rich post-AGB sources. KJPN 8 is surrounded by a molecular disk displaying the characteristic content of a young Planetary Nebula (PNe): CO, HCN, HNC, CN, and HCO+, including several isotopologues. Additionally, we have detected marginal emission of CS. Our analysis of the data obtained thus far has yielded intriguing results. By examining isotopic ratios and species ratios such as HCN:HNC, we aim to constrain the progenitor nature of KJPN 8, which remains unclear.

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The extended atmosphere of CW Leo seen by ALMA at stellar resolution

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During their thermally pulsing phase, AGB stars expel material, forming extended dusty envelopes. Previous studies have revealed inhomogeneous molecular gas and clumpy dust clouds in the close vicinity around oxygen-rich AGB stars. Nevertheless, the distribution of molecular gas in carbon-rich AGB extended atmospheres and the mechanisms governing the mass loss remains incompletely understood due to limitations in spatial resolution.

Our work presents stellar-size ALMA observations of dust and molecular gas in the atmosphere of CW Leo, a prototypical carbon AGB star. These observations unveil complex anisotropic structures within the extended atmosphere of the star, indicating distinct regions of HCN, SiS, and SiC2 emission at different radii. These findings suggest the presence of large convective cells influencing the stellar wind formation. The interaction between these convective cells and pulsations generates anisotropies that shape the circumstellar envelope (CSE), alongside companions. This research sheds light on the intricate dynamics and morphology of CSEs of AGB stars, particularly carbon stars, contributing to a deeper understanding of stellar evolution during the late AGB phase. The results have been published in Nature (Velilla-Prieto et al., 2023, Nature, Volume 617, Issue 7962, p.696-700).

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Barium stars: Systematic deviations from the AGB models

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Barium (Ba) stars are peculiarly enriched in *s*-process elements, even though they have not yet reached the AGB evolutionary phase. This enrichment can be explained by contamination from a companion star when that was an AGB star. Ba stars preserve this material for a long time and are easy to derive their high-resolution spectra, making them objects ideal for testing models of AGB star nucleosynthesis. We had developed a method with which we could identify the best-matching polluter AGB model for each Ba star abundances.

By comparing the identified AGB models with the Ba star abundances, our aim was to derive systematic deviations between the observations and models. We found that there is a systematic underproduction of some elements in the AGB models compared to the observations: in particular for Nb, Mo and Ru, which are just beyond the first *s*-process peak. This may imply that there is a neutron capture process (e.g. the *i* process) not yet included in the AGB models, which contributes to the abundance of these elements.

We investigated the correlations between the abundances, the residuals between the observationally derived and modelled abundances and the metallicity of the stars. Some correlations may be noted between the residuals of these elements, indicating a common source for the inability to fit with the models. There is a weak dependence on metallicity, which is the strongest for Nb, Mo and Ru. The offset of these three elements are also increasing with higher s-process abundances.

We have also examined the relation between the Zr and Nb abundances of these stars, since this can be used as a thermometer for the *s* process, assuming local nuclear equilibrium. However, the vast majority of stars would require a temperature higher than 400 MK to explain their abundances within this framework - this may also indicate that Zr itself is not produced solely in the steady-state *s* process.