The 13th Torino Workshop on AGB stars & the 3rd Perugia Workshop on Nuclear Astrophysics

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Book of Abstracts

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The neutron time-of-flight facility n_TOF at CERN

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Based on an idea by Carlo Rubbia, the n_TOF facility at CERN has been built and has been operating for over 20 years. It is a neutron spallation source, driven by the 20 GeV/c proton beam from the CERN PS accelerator. Neutrons in a very wide energy range (from GeV, down to sub-eV kinetic energy) are generated by a massive Lead spallation target feeding two experimental areas. EAR1, horizonal with respect to the proton beam direction is set at 185 meters from the spallation target. EAR2, on the vertical line from the spallation source, is placed at 20 m. Neutron energies for experiments are selected by the time-of-flight technique (hence the name n_TOF), while the long flight paths ensure a very good energy resolution.

Over one hundred experiments have been performed by the n_TOF Collaboration at CERN, with applications ranging from nuclear astrophysics (synthesis of the heavy elements in stars, big bang nucleosynthesis, nuclear cosmo-chronology), to advanced nuclear technologies (nuclear data for applications, nuclear safety) to basic nuclear science (structure and decay of highly excited compound states).

During the planned shutdown of the CERN accelerator complex between 2019 and 2021, the facility went through a substantial upgrade with a new target-moderator assembly, refurbishing of the neutron beam lines and experimental areas. An additional measuring and irradiation station (the NEAR Station) has been envisaged and its capabilities for performing material test studies and new physics opportunities are presently explored.

An overview of the facility and of the activities performed at CERN will be presented, with a particular emphasis on the most relevant experiments for nuclear astrophysics.

Session:

Experimental Nuclear Astrophysics

Nuclear Astrophysics / 39

Neutron capture and total cross measurements on ^{94,95,96}Mo at n_TOF and GELINA

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Molybdenum neutron cross section, especially capture cross section, has a role in many scientific fields from nuclear astrophysics to nuclear power plant safety. It is found as a pollutant in pre-solar silicon carbide grains, and it is important for the stellar nucleosynthesis of heavy elements in AGB stars. Moreover, molybdenum is present inside nuclear power plants as a fission product, and it can be used for new generation research reactor based on UMo fuel.
To improve the uncertainty on the neutron cross section of molybdenum a series of transmission and radiative capture measurements are ongoing at two neutron time-of-flight facilities: n_TOF (CERN) and GELINA (JRC-Geel). The measurements are performed with natural molybdenum and isotopically enriched samples in ^{94,95,96}Mo.
In this contribution I will show some of the results obtained so far.

Session:

Experimental Nuclear Astrophysics

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Experimental kT=28 keV Maxwell–Boltzmann-like neutron spectrum for Maxwellian averaged cross section measurement (R)

Authors: Elizabeth Musacchio Gonzalez[1]; Pierfrancesco Mastinu[2]

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To calculate the reaction rate in the neutron capture processes it is common to work with the Maxwellian Average Cross Section (MACS), defined as the reaction rate scaled by the most probable neutron velocity of the Maxwell- Boltzmann distribution. For the s-process mainly, the MACS directly describes the reaction rate inside the stars, for a given temperature and neutron density. Hence, the importance of determining the MACS with the least possible uncertainty. Before any MACS measurement, a characterized neutron beam with a spectrum as similar as possible to the stellar spectrum is mandatory, and this is the main purpose of this work. Mastinu et al. (2009), proposed a method to produce a high-quality Maxwell-Boltzmann neutron spectrum at different thermal temperatures (kT). The method is based on the idea of "shaping the proton beam energy distribution to shape the neutron energy beam to a desired distribution". In the experimental measurement, the ^{7}Li(p,n)^{7}Be nuclear reaction was employed as neutron source. To obtain a Maxwell-Boltzmann neutron spectrum with 28 keV of thermal temperature, an initial proton energy of 3170 keV and a 51 μm thickness aluminum (Al) foil, as proton energy shaper, were employed. Using a 600 kHz proton pulsed beam at the Van de Graaff accelerator of the Legnaro National Laboratory of the National Institute of Physics Nuclear (LNL-INFN), in Padua, Italy, the neutron time of flight spectrometry (TOF) was implemented to determine the neutron spectrum. Differential angular neutron energy distributions from 0 to 90 degrees in steps of 10° were measured to obtain the 0°-90° integrated

neutron spectra. The expected Maxwell-Boltzmann neutron spectrum has been measured and the obtained results will be presented.

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Experimental Nuclear Astrophysics

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Measurement of the 140Ce(n,γ) cross section at n_TOF

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Among the nucleosynthesis mechanism involving the heavy nuclei, the so-called slow (s-)process is responsible of about half of the element heavier than iron. Being one of the better known, many models were built in order to describe the process and the final element abundances.
The main component of the s-process take place in the outer layer of the AGB stars, where the heavy elements are produced through a succession of neutron captures and beta decays. In last decades great efforts have been undertaken in order to improve the quality of neutron cross section data, because of the strong implications on the s-process models accuracy.

An accurate measurement of the 140Ce(n,γ) energy dependent cross section has been performed at the n_TOF facility at CERN. This measurement was motivated by the significant discrepancy in the cerium abundance observed in the globular cluster M22 and the value predicted by theoretical stellar models[1]. This measurement was characterized by an unprecedented combination of the high energy resolution of the n_TOF neutron beam and a highly enriched 140Ce sample. The experimental apparatus was based on four gamma detectors based on C6D6 liquid scintillators, which are characterized by a very low neutron sensitivity.

In total, 81 resonances were measured and fitted. For each, the capture and neutron widths were determined, highlighting the large discrepancies respect to the major nuclear libraries. These new data allowed to calculate the 140Ce(n,γ) MACS with an uncertainty lower than 5%, significantly improving the experimental data available for the libraries update.

[1] O. Straniero, S. Cristallo, L. Piersanti. Heavy elements in globular clusters: the role of asymptotic giant branch stars, ApJ 785 (2014) 77.

Session:

Experimental Nuclear Astrophysics

Nuclear Astrophysics / 58

Neutron capture reactions in the stellar weak and main s-process regimes: AGa, ASe, AKr and ACe targets (R)

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The high-intensity quasi-Maxwellian neutron source based on the Soreq Applied Research Accelerator Facility (SARAF) [1] and the Liquid-Lithium Target (LiLiT) [2,3] were used to investigate neutron capture reactions in the weak and main $s-$process regimes. Experimental determinations of these reactions are important for helping to disentangle the different $s-, r-, p-$processes of nucleosynthesis and the characterization of their stellar sites. Our recently published value for the ^{71}Ga$(n,\gamma)^{72}$Ga Maxwellian averaged cross section [4] is smaller and with smaller uncertainty than the experimental recommended value, which may have implications in network calculations such as presented by Pignatari et al. [5]. The ^{A}Se and ^{A}Ce data are presently under final analysis and will be presented. Our ^{A}Kr(n,γ) cross sections [6] are shown to have a strong impact on calculated abundances of krypton isotopes and neighboring nuclides, in some cases improving agreement between theory and observations.
We gratefully acknowledge the collaboration of J. Zappala, T. Heftrich, W. Jiang, Z.-T. Lu, P. Müller, R. Purtschert, R. Reifarth, D. Veltum and M. Weigand in the Kr experiments. This work was supported in part by the Israel Science Foundation (Grant No. 1387/15), the Pazy Foundation (Israel), the German-Israeli Foundation (GIF No. I-1500-303.7/2019). M.P. acknowledges support by the European Union (ChETECINFRA,Project No. 101008324).

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[3] M. Paul, et al., Eur. Phys. J. A 55, 44 (2019)
[4] M. Tessler et al., Phys. Rev. C 105, 035801 (2022)
[5] M. Pignatari et al., Astrophys. J. 710, 1557 (2010)
[6] M. Tessler et al., Phys. Rev. C 104, 015806 (2021)

Session:

Experimental Nuclear Astrophysics

Nuclear Astrophysics / 29

Measurements of s process neutron source cross sections

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The slow neutron capture processes (”main”and ”weak”) build up elements heavier than iron through sequential neutron captures and β-decays, following the valley of stability from seed nuclei in the iron region. The neutron sources for these processes are the two reactions 13C(α,n)16O and 22Ne(α,n)25Mg. Their measurement is quite difficult due to the astrophysically relevant energy ranges being far below the Coulomb barrier. The neutron background on the surface of the earth has so far been a prohibitive factor for experiments trying to push the limit of cross section measurements further down in energy. By going deep underground one automatically

achieves a background reduction by 3-4 orders of magnitude, opening up possibilities to directly measure the low cross sections in the astrophysical range.
I will discuss the campaign to measure 13C(α,n)16O at the LUNA 400 and MV accelerators and present the status and an outlook of the ongoing project SHADES that aims at a measurement of 22Ne(α,n)25Mg at the LUNA MV accelerator in the Gran Sasso National Laboratory.

Session:

Experimental Nuclear Astrophysics

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The influence of electronic and nuclear correlation on weak decays

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We discuss our novel theoretical and computational method for calculating beta-decay rates of radioisotopes in astrophysical scenarios, which takes into account both nuclear end electronic degrees of freedom at the same level of theory. Within this framework, we analyze the 134Cs —-> 134Ba and 135Cs ——> 135Ba beta decays, which are crucial production channels for Ba isotopes in Asymptotic Giant Branch (AGB) stars. We find a significant increase (by more than a factor 3 for 134Cs) of the half-lives with respect to previous recommendations by Takahashi & Yokoi (TY). The major impact on half-lives comes from nuclear excited state decays, while including electronic temperatures yields a ~20% increase, at energies typical of low- and intermediate-mass AGB stars. Our predictions strongly modify branching ratios along the s-process path, and allow nucleosynthesis models to account well for the isotopic admixtures of Ba in presolar SiC grains.
We also present novel results concerning the weak decay of several other nuclei, such as 63Ni in presolar grains, and 129I to determine the Xe isotopic ratios. We compare them with TY87, finding large discrepancies. Finally, we also discuss the speculative application of our approach to the cosmic lithium problem.

Session:

Theoretical Nuclear Astrophysics

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Relativistic quantum theory and ab initio simulations of electroweak decay spectra in nuclei.

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In this presentation we introduce the theoretical methods and relevant computational approaches to calculate the electronic and nuclear structures within the mean-field approximation of the Dirac equation for many-particle systems. This model includes nuclear and electromagnetic correlations and the self-consistent numerical solutions are obtained by using either radial mesh or Gaussian basis sets. Furthermore, we describe the extension of our relativistic approach to deal with nuclear reactions driven by the weak force, such as the electron capture and β-decay, using the Fermi-Dirac statistics. The processes that we will analyze are in particular the C(14) —>N(14), the Be(10) —>B(10) and the Rb(87) —>Sr(87) β- decays.

Session:

Theoretical Nuclear Astrophysics

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Numerical virtual experiments for in-plasma nuclear beta-decay study in the framework of the PANDORA project

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Nuclear and atomic parameters both play a crucial role in constraining reaction rates of processes involved in several astrophysics domains. Reactions relevant for the s-process nucleosynthesis largely request for assessing yet open uncertainties on neutron capture cross sections and weak-interaction rates, for specific nuclear reactions, which branching ratio highly impacts on the final abundance pattern, as well as on a proper modelling of abundance-dependent mechanisms. In particular, the beta decay of radioisotopes is theoretically predicted to be largely influenced by the surrounding atomic environment, where strongly ionized plasma conditions can modify their half-life. The PANDORA (Plasmas for Astrophysics Nuclear Decays Observation and Radiation for Archaeometry) project can offer a unique experimental facility and approach aiming at measuring first-of-its-kind in-plasma beta-decay lifetimes as a function of thermodynamical conditions of the environment, namely a laboratory magnetized plasma able to mimic some stellar-like conditions. A direct correlation of the plasma environment and nuclear activity is possible via the gamma-rays tagging of excited daughter nuclei following the parent beta decay. A devoted multi-diagnostic system working synergically with a gamma-rays HPGe detection system will be capable to monitor plasma parameters, as well as to detect and discriminate photons emitted by the plasma from those emitted after the beta-decay. In view of the experimental measurements, numerical "virtual experimental runs"have been largely motivated by recent attempts to constrain atomic input for s-process branching ratios in models which try to reproduce isotopic admixtures of s-process elements in presolar SiC grains. Some specific radioisotopes, e.g., ^{134}Cs, ^{94}Nb, ^{176}Lu, have been investigated. Here, we present the numerical progresses done on the sensitivity of the designed experiment in PANDORA, based on the measurement time required in terms of 3σ-confidence-level for the decay-rates measurement. These estimates are based on calculations of reduced mean lifetime of ionized nuclei, considering the charge state distribution led by electron densities and energies typical of the plasma trap. Furthermore, an advanced estimate of the expected signal-to-noise ratio is here reported, including for the first time the simulated impact of short-lived radioisotopes'neutral depositions on the chamber walls of the plasma trap, being an additional source of background for the HPGe detectors array.

Session:

Experimental Nuclear Astrophysics

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Modelling Ion Population Kinetics in ECR Plasmas to Extract Inputs for In-Plasma β-Decay Rates

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Lifetimes of radioactive nuclei are known to be affected by the level configurations of their respective atomic shells. Immersing such isotopes in environments composed of energetic charged particles like stellar plasmas can result in β-decay rates orders of magnitude different from those measured terrestrially. Accurate knowledge of the relation between plasma parameters and nuclear decay rates are essential for reducing uncertainties in present nucleosynthesis models. Currently, the full effect of a charge state distribution (CSD) as exists in plasmas is only modelled theoretically but PANDORA (Plasmas for Astrophysics, Nuclear Decay Observations and Radiation for Archaeometry) aims to be the first experiment to verify these models by measuring β-decay rates of select isotopes diffused in electron cyclotron resonance (ECR) plasmas. We present here a comprehensive study of the inputs required by the model of Takahashi and Yokoi for calculating the perturbed decay rates, as well as a 3D ion dynamics model combining a quasi-stationary particle-in-cell (PIC) ion dynamics code with a Monte Carlo (MC) population kinetics routine to extract said data from the plasma. The simulation scheme is robust, comprehensive and makes few assumptions about the state of the plasma. While the method has been tested only on light ions till now, it has the potential to be extended to heavy nuclei of interest, including as many reactions as needed to populate the relevant atomic/ionic levels for precise estimation of the decay rates.

Session:

Experimental Nuclear Astrophysics

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Recent achievements of the ERNA Collaboration

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For more than two decades, the ERNA Collaboration has investigated nuclear processes of astrophysical interest through the direct measurement of cross sections or the identification of the nucleosynthesis effects. Measurements of cross-section of radiative capture reactions have been mainly conducted using the ERNA Recoil Mass Separator, and more recently with an array of charged particle detector telescopes designed for nuclear astrophysics measurements. Some results achieved with ERNA will be reviewed, with a focus on the results most relevant for nucleosynthesis in AGB and advanced burning phases.

Session:

Experimental Nuclear Astrophysics

Nuclear Astrophysics / **22**

Indirect Investigation for AGB Stellar Nucleosynthesis (R)

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Asymptotic Giant Branch (AGB) stars play a major role in determining the galactic chemical evolution being the production site of almost 50% of elements heavier than iron through the slow neutron capture process (the so-called s-process) [1,2].
From a pure nuclear point of view, several processes take part during this peculiar stage of stellar evolution thus requiring detailed experimental cross section measurements. Here, we report on the most recent results achieved via the application of the Trojan Horse Method (THM)[3] and Asymptotic Normalization Coefficient (ANC)[4] indirect techniques, discussing the details of the experimental procedure and the deduced reaction rates.
In particular, the indirect investigations of the low-energy cross sections of proton and neutron-induced reactions on 17O and on 18O will be discussed, as well as the measurements of the key reactions involved in the19F nucleosynthesis, 19F(p,α0)16O, and 19F(α,p)22Ne reactions [5].
In addition, we report also on the on-going studies of interest for AGB nucleosynthesis.

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Session:

Experimental Nuclear Astrophysics

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The $^{19}\mathrm{F}(\alpha,p)^{22}\mathrm{Ne}$ and $^{23}\mathrm{Na}(p,\alpha)^{20}\mathrm{Ne}$ reactions at energies of astrophysical interest via the Trojan Horse Method

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^{19}F has been clearly observed in AGB stars, and its abundance is strongly related to the physical conditions of stars. This element in fact can be destroyed via $^{19}\mathrm{F}(n,\gamma)^{20}\mathrm{F}$, $^{19}\mathrm{F}(p,\alpha)^{16}\mathrm{O}$, and $^{19}\mathrm{F}(\alpha,p)^{22}\mathrm{Ne}$, with α capture that is expected to dominate in the He-intershell region. Direct measurements for this reaction are nonetheless scarce and affected by large uncertainties at He-burning temperatures ($0.2 \leq \mathrm{T}_9 \leq 0.8$): the Gamow peak, in fact, lies between 0.2 and 1.2 MeV, while there are no direct measurements below 0.7 MeV. The Coulomb barrier effects strongly suppress such low energies reactions, and indirect methods such as the Trojan Horse Method (THM) can be a powerful tool to overcome the difficulties related to the presence of the Coulomb barrier itself.
As regard the $^{23}\mathrm{Na}(\mathrm{p},\alpha)^{20}\mathrm{Ne}$, this reaction is considered to have great importance in intermediate-mass AGB stars ($\mathrm{M} = 4 \div 8\ \mathrm{M}_{\odot}$), and could be strongly related to the wide known Na/O anticorrelation in globular clusters. This reaction also represents the turning point between the NeNa and MgAl cycles. $^{23}\mathrm{Na}(\mathrm{p},\alpha)^{20}\mathrm{Ne}$ has not been studied at astrophysical energies with direct methods in the energy range of astrophysical interest. Here the Gamow window lies between 50 keV and 200 keV, while the Coulomb barrier is at 2.57 MeV. Nonetheless, several states of $^{24}\mathrm{Mg}$ were studied, via transfer reaction, and two resonant states at 37 keV and 138 keV were found: the former had a too low cross section to be studied (but uncertainties were reduced by a factor of 515), and the latter is still the bigger source of uncertainties (approximately a factor of 12) in the temperature region near $\mathrm{T} \sim 70 \cdot 10^6$ K.
For the reasons above, in the recent years it has been decided to study such reactions using the Trojan Horse Method: the $^{19}\mathrm{F}(^6\mathrm{Li},p^{22}\mathrm{Ne})d$ and $d(^{23}\mathrm{Na},\alpha^{20}\mathrm{Ne})n$ have been used to explore the resonant cross section of the $^{19}\mathrm{F}(\alpha,p)^{22}\mathrm{Ne}$ and $^{23}\mathrm{Na}(p,\alpha)^{20}\mathrm{Ne}$ respectively in the Gamow region ov interest.
In this talk the cross section and reaction rate for the $^{19}\mathrm{F}(\alpha,p)^{22}\mathrm{Ne}$ reaction will be discussed, along with their impact on stellar nucleosinthesys. Also some preliminary results regarding the $^{23}\mathrm{Na}(p,\alpha)^{20}\mathrm{Ne}$ one will be presented.

Session:

Experimental Nuclear Astrophysics

Nuclear Astrophysics / 27

The measurements of nuclear reaction cross-sections relevant to AGB stars at LUNA: the case of the ^{17}O(p,γ)^{18}F reaction

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The study of Asymptotic Giant Branch star (AGB) nucleosynthesis is fundamental to understand the Galaxy chemical evolution. At the energies of interest for AGB stars direct measurements of the nuclear cross sections are challenging because of the extremely low count rate. A breakthrough in experimental nuclear astrophysics is represented by the Laboratory for Underground Nuclear Astrophysics (LUNA) in Gran Sasso, Italy. Over the last 30 years, the LUNA collaboration has provided cross section data directly at the relevant energies for AGB nucleosynthesis for a number of reactions. The talk provide a summary of the latest LUNA measurements and results with implications on AGB stellar evolution and nucleosynthesis.
Moreover the talk will focus on the more recent measurement performed at LUNA. The 17O(p,g)18F reaction play a key role in AGB nucleosynthesis whose footprint is the oxygen isotopic abundances observed in stellar spectra or in
pre-solar meteoritic grains. The rate of the ^{17}O(p,γ)^{18}F reaction t temperature of interest, 40-80 MK, is dominated by the poorly constrained 65 keV resonance. Only indirect measurement are reported with an evaluated resonance strength of $(1.6\pm0.3)\times10^{-11}$ eV. A new high sensitivity setup has been installed at LUNA, where a reduction of the cosmic ray background by several orders of magnitude is guaranteed by the underground location. The residual background was further reduced by a devoted shielding. The high detection efficiency of the 4π-BGO segmented detector was optimized by installing a devoted target chamber and holder. With more than 300 C accumulated on Ta_2O_5 targets with nominal ^{17}O enrichment of 90%, the LUNA collaboration has performed the first ever direct measurement of the 65 keV resonance strength.
In the talk details on the experimental setup and some preliminary results will be provided.

Session:

Experimental Nuclear Astrophysics

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Study of the 20Ne(p, γ)21Na reaction at LUNA

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The synthesis of Ne, Na, Mg, and Al isotopes is connected to the NeNa-MgAl cycles of stellar burning. The entire cycle speed is controlled by the $^{20}\mathrm{Ne}(\mathrm{p},\gamma)^{21}\mathrm{Na}$ ($Q = 2431.68$ keV) reaction, which is the first and slowest reaction of the whole NeNa cycle. At the state of the art, the uncertainty on the $^{20}\mathrm{Ne}(\mathrm{p},\gamma)^{21}\mathrm{Na}$ reaction rate affects the production of the elements in the NeNa cycle.
In the temperature range from 0.1 GK to 1 GK, the rate is mainly dominated by the 366 keV resonance, corresponding to the excited state of E_X = 2797.5 keV, and by the direct capture component. The present study focuses on the 366 keV resonance and on the direct capture below 400 keV. At LUNA (Laboratory for Underground Nuclear Astrophysics) the $^{20}\mathrm{Ne}(\mathrm{p},\gamma)^{21}\mathrm{Na}$ reaction has been measured using the intense proton beam delivered by the LUNA 400 kV accelerator and a windowless differential-pumping gas target. Two high-purity germanium detectors allow the detection of the products of the reaction.
The experimental details and preliminary results of the campaign will be shown, together with their possible impact on the $^{20}\mathrm{Ne}(\mathrm{p},\gamma)^{21}\mathrm{Na}$ reaction rate.

Session:

Experimental Nuclear Astrophysics

Stellar Evolution / 28

The initial-final mass relation of white dwarfs: breaking a paradigm, causes and consequences

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The initial-final mass relation of white dwarfs plays an important role across astrophysics. In a recent analysis of a few carbon-oxygen white dwarfs in intermediate-age open clusters of the Milky Way we identified a kink in the initial-final mass relation, located over a range of initial masses, 1.65 $\lesssim$ Mi/Msun $\lesssim$ 2.10, which unexpectedly interrupts the commonly assumed monotonic trend. The kink's peak in white dwarf mass of about 0.70-0.75 Msun is produced by stars with Mi ≈ 1.8-1.9 Msun, whereas these final masses are typically associated to Mi~3.0-3.5 Msun. We interpret the kink as the fingerprint of carbon star formation and the modest outflows produced as long the carbon excess remains too low to produce dust grains in sufficient amounts. Under these conditions the mass of the carbon-oxygen core can grow more than is generally predicted by stellar models. In a new systematic follow-up investigation, based on GAIA data, we examine the population of asymptotic giant branch stars, so far largely neglected, that appear in the fields of intermediate-age and young open star clusters. Thanks to GAIA, for the for the first time we identify 49 AGB star candidates, brighter than the tip of the red giant branch, with a good to high cluster membership probability. Among them, we find 19 TP-AGB stars with known spectral type: 4 M stars, 3 MS/S stars, and 12 C stars. By combining observations, stellar models, and radiative transfer calculations that include the effect of circumstellar dust, we characterize each star in terms of initial mass, luminosity, mass-loss rate, core mass, period, and mode of pulsation. The information collected helps us shed light on the TP-AGB evolution at solar-like metallicity, placing constraints on the third dredge-up process, the initial masses of carbon stars, stellar winds, pulsation, and the initial-final mass relation.

Session:

Stellar evolution

Stellar Evolution / 43

The role of AGB stars in stellar population models (R)

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With the recent advances in infrared instruments on large telescopes, such as X-shooter and KMOS, as well as NIRSpec on JWST, near-IR spectroscopic information of different types of unresolved galaxies in various environments will increase in quantity and in quality. Stellar spectral libraries and associated stellar population models need to keep up with the times. Near-IR spectra of intermediate-age and old stellar populations are sensitive to cool K and M giants. None of the previous empirical libraries has extensive coverage of the important stellar evolutionary stages needed for stellar population modelling in the near-IR. Furthermore, (O- and C-rich TP-)AGB and RGB stars are rarely segregated in stellar population modelling. We are presenting a new generation empirical stellar library –the X-shooter Spectral Library (XSL), and stellar population models. With 830 stellar spectra, this moderate-resolution near-UV to near-IR (R ~ 10 000, 300 –2480 nm) spectral library will cover the entire HR diagram, with an emphasis on M giants. We construct sequences of the average spectra of XSL static giants, variable O-rich giants, and C-rich giants to include in the stellar population models separately. The extended wavelength coverage and high resolution of the new XSL-based stellar populations models will help us to bridge the optical and the near-IR studies of the intermediate and old stellar populations, and clarify the role of evolved cool stars in stellar population synthesis.

Session:

Stellar evolution

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AGB Stars in Globular Clusters

Authors: Ernst Paunzen[1]; Tahereh Ramezani[2]

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We discuss three fundamental questions in AGB star research that can be addressed by results obtained from globular clusters (GCs):
(1) Period-luminosity relations derived for the long-period variables in four GCs show a similar splitting into two sequences but also differ in the maximum luminosity reached.
(2) C/O ratios measured in O-rich AGB stars in NGC 1846 prove the increase of C/O
with luminosity, but also reveal exceptions to the general trend.
(3) AGB stars in 47 Tuc reveal a remarkable change of mid-infrared dust features as the stars evolve up the AGB.
These three results illustrate the promising possibilities of using a homogeneous and well-defined sample of AGB stars, as can be found in GCs, for solving major questions in AGB star research.

Session:

Stellar evolution

Stellar Evolution / 63

Numerical methods for AGB evolution

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Asymptotic Giant Branch stars are of paramount importance in several fields of modern astrophysics. Their interiors are characterised by a rich nucleosynthesis, deeply connected to their surface via the recurring third dredge-up events. Nevertheless, full stellar evolution models in this phase are still plagued by uncertainties of both numeric and physics nature. The main processes that regulates the TP-AGB phase (convection, overshoot, stellar winds) are treated with parametrizations. These facts cause a wide heterogeneity of predictions across stellar models. In particular, full stellar evolution calculations of TP-AGB are known to be time consuming and often numerically unstable,

which prevents an extensive exploration and calibration of the input physics parameters. Even if modern computers are getting more powerful and faster, numerical methods aimed at increasing the computational speed may be the key to produce large sets of TP-AGB tracks without losing on the accuracy side. I will present results of a ongoing analysis, performed with the PAdova and tRieste Stellar Evolution Code (PARSEC), aimed to implement numerical techniques based on shell shifting, that allow to gain in computational agility during the interpulse periods. Timestep choice is a critical aspect: it will be investigated in a framework where the energy conservation is the basic constraint to be fulfilled. Alongside the numerical studies, I will discuss the stability of the methods against different overshooting prescriptions, mixing efficiency, and low-temperature opacities linked to the variations of hydrogen and CNO elements.

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Dissection of post-AGB binaries

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Binaries among post asymptotic giant branch stars (post-AGB) were historically serendipitously detected, but these turned out to have a common property: they all display a clear near-infrared excess, indicating that circumstellar dust must be close to the central star. It is now well established that this indicates the presence of a stable compact circumbinary disc. The luminous evolved post-AGB primary has likely an unevolved stellar companion with a minor contribution to the energy budget. In the Galaxy a sample of about 85 of these disc objects have been identified which turned out to be indeed binaries. In the Large
and Small Magellanic Clouds, disc sources represent about half of the population of optically bright post-AGB stars. In this presentation I will review the recent results on our attempts to dissect these systems. I will give an overview on the properties of all interacting components: the post-AGB primary, the main sequence component, the circumbinary dusty disc and the circum-companion accretion disc which launches a high-velocity jet. The interaction processes between these components govern the evolution of these systems and i will give an update on our sample studies. Our ultimate aim is to progress in our understanding of the late phases of binary evolution.

Session:

Stellar evolution

Stellar Evolution / 7

Shaping of AGB outflows by wind-companion interactions in eccentric binary and hierarchical triple systems

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At the end of their lives, low and intermediate mass stars scatter their envelope throughout the interstellar medium via a stellar wind. For decades, modelling endeavours of these outflows have assumed that these winds are spherically symmetric. However, recent high-spatial resolution observations reveal that the winds of evolved stars typically possess a high degree of complexity, from spirals, disks, clumps, and bi-conical outflows in the winds of AGB stars, to highly bi- or multi- polar structures around post-AGB stars and planetary nebulae. Sophisticated 3-dimensional hydro-dynamical modelling tools indicate that such structures can be formed by the gravitational interaction of a stellar or planetary companion with the AGB outflow, and the induced orbital motion of both components. Nevertheless, a number of observed targets posses complex-structured nebulae of which the morphological shape can still not be understood on the basis of the current set of theoretical models for such systems. To advance our insights on the origins of these complex nebulae, I present a comprehensive set of high-resolution models of (i) a stellar wind perturbed by a solar-mass companion in orbits of varying eccentricity, and (ii) a mass-loosing star in various hierarchical triple configurations. These models are constructed with the Smoothed-Particle-Hydrodynamics solver PHANTOM *(Price et al. 2018)*.
The ultimate goal of these sophisticated models is to compare them to high-resolution observations, to unravel how and by which binary/triple configuration the observed wind structures can be created. Therefore, we post-process our hydrodynamical models with the radiative transfer code MAGRITTE *(De Ceuster et al. 2019, 2020)* to create synthetic observations. Subsequently, we apply the primary ALMA data processing software CASA *(McMullin et al. 2007)* on the synthetic observations with various telescope configurations, and reveal the similarities with actual ALMA observations. These new simulations hence offer us a novel gateway for understanding the complex wind structures of evolved stars, and thus for constraining the fundamental stellar and wind parameters, key ingredients for predicting their further evolution.

Session:

Stellar evolution

Stellar Evolution / **17**

A Grid of Binary AGB Stars

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AGB stars are notoriously difficult to model with full stellar evolution codes, such as MESA, due to the various instabilities and convergence issues that arise during the thermal pulses. This makes the production of grids of AGB stars, with varying masses and metallicities, time consuming due to the large amount of human debugging required. This talk will summarise the various instabilities and convergence issues found using MESA and discuss ways to evolve past them, such that a grid of AGB models can be reliably run without intervention. The grid will, for the first time, contain stellar models with varying envelope to core mass ratios in order to cover the parameter space probed by binary systems that exchange mass. This will allow investigation of the third dredge-up parameter as a function of core mass in addition to total stellar mass and metallicity. From the full models, data will be extracted and transformed into a tabulated grid for use in the population synthesis code binary_c. Populations of stars can then be run through the AGB phase by interpolating parameters from the tabulated grid. These populations will have various uses including calculations of chemical yields and the ability to constrain stellar physics, such as convection, by comparison to observations.

Session:

Stellar evolution

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The Simmering phase of SNe Ia

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The stellar progenitors of SNe Ia are usually identified with CO WDs accreting matter in binary systems. Due to mass deposition C-burning is ignited at the center in highly degenerate physical conditions, determining the thermonuclear runaway. In this talk the interplay between weak processes and convection will be discussed and their effects on the physical and chemical properties at the explosion will be analized.

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Stellar evolution

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Evolution and nucleosynthetic gas yields of intermediate-mass primordial to extremely metal-poor stars

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In order to interpret the surface abundances of the most metal-poor stars detected, and infer the properties of the oldest stellar generations, it is crucial to develop models of stellar evolution and nucleosynthesis for primordial to extremely metal-poor (EMP) stars. Such models are also relevant in the context of Galactic Chemical evolution and Galactic structure formation.

We present models of intermediate-mass stars of initial masses Mini between primordial and EMP metallicity (Z=10-10, 10-8, 10-7, 10-6, and 10-5). Detailed evolution and nucleosynthesis (77 species) were computed till the late stages of the TP-(S)AGB phase.

Our models can be classified as follows, according to their evolution. The lowest mass cases (3 and 4 Msun) of Z=10-10 and 10-8, experience proton-ingestion episodes (PIEs) at the beginning of their TP-AGB. The high surface metal enrichment provided by such episodes allows them to undergo a 'normal'TP-AGB, and end their lives as CO-white dwarfs. Some models in a narrow mass and metallicity range (near 5 Msun and Zini ≤ 10-8) have an uncertain fate and might end their lives as SNeI1/2. Models of Mini ≥ 6 Msun, regardless of the initial metallicity within the considered range, and models of Mini ≥ 4 Msun for the Z=10 -7 and Z=10-8 cases, behave as normal TP-(S)AGB stars. SDU is particularly efficient for Mini above 6-7 Msun, and the base of the convective envelope reaches zones processed by He-burning (corrosive SDU).

The abundance pattern associated to the ejecta of our stars yields remarkably high CNO, with the characteristic [N/Fe]>[C/Fe]>[O/Fe]. The reasons for this pattern are the combined effects of SDU, efficient TDU, hot-bottom burning (HBB) and the activation of the NeNa-cycle and the MgAl-chains at the relatively high temperature nuclearly active regions of our models,

Our results differ substantially from other studies. Our analysis points to the treatment of convection as the main reason for these discrepancies and highlights the relevance of input physics uncertainties when considering the evolution of the most metal-poor stars.

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Stellar evolution

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Extremely Metal-Poor Asymptotic Giant Branch Stars

Authors: Luciano Piersanti[1]; Mario Cirillo[2]; Oscar Straniero[3]

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Little is known about the first stars, but hints on this stellar population can be derived from the peculiar chemical composition of the most metal-poor objects in the Milky Way and in resolved stellar populations of nearby galaxies. We review the evolution and nucleosynthesis of metal-poor and extremely metal-poor (EMP) stars with low and intermediate masses. In particular, new models of 6 $M_\odot$ with three different levels of metallicity, namely Z=10^{-4}, 10^{-6} and 10^{-10}, are presented. In addition, we illustrate the results obtained for a 2 $M_\odot$ Z=10^{-5} model. All these models have been computed by means of the latest version of the FuNS code. We adopted a fully coupled scheme of solutions for the complete set of differential equations describing the evolution of the physical structure and the chemical abundances, as modified by nuclear processes and convective mixing. The scarcity of CNO in the material from which these stars formed significantly affects their evolution, their final fate and their contribution to the chemical pollution of the ISM in primordial galaxies.

Session:

Stellar evolution

Stellar Evolution / **60**

On the reliability of stellar models used to probe new (and old) physics.

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The high temperature and density that develop within the cores of evolved stars, from red giants to supergiants, make them ideal sites to investigate deviations from the standard models describing the

behaviour of matter in extreme conditions. Note that these conditions are often not accessible by current laboratory experiments. A growing amount of scientific papers discuss various methods to investigate old physics (e.g., turbulence) or new physics (e.g., peculiar properties of standard and/or non-standard particles) by comparing stellar models predictions to several astronomical observables, among which surface composition of stars, stellar macroscopic properties (luminosity, effective temperature, age⋯.) or the frequencies of pulsation modes. However, the constraints obtained in this way are limited by the effective reliability of the stellar models that depends on the uncertainties of the adopted input physics (opacity, equation of state, nuclear reaction rates, and the like) and on the numerical method used to solve the differential equations describing the physical and the chemical structure of a star. In this talk I will discuss, how to evaluate the reliability of the theoretical predictions, the power and the limits of the methods employed to constrain new/old physics and possible (promising) future developments.

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Stellar evolution

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Core-Collapse Supernovae: the connection between explosion and progenitor structure

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The explosion mechanism of core-collapse supernovae has been a longstanding problem in nuclear astrophysics. In the last decade, important steps towards a thorough understanding of what causes supernovae to explode have been made, thanks to the development of very detailed three-dimensional simulations. However, a lot of work still needs to be done. In this talk, I will focus on the connection between the thermodynamic and compositional structure of the progenitor star and its subsequent explosion. I will use spherically symmetric simulations (where neutrino-driven convection is included via a mixing length approach) to simulate the collapse and shock revival of stars with different initial masses. I will highlight how discontinuities in the density profile at the onset of collapse can be used to predict the outcome of the explosion. Specifically, two types of explosions can be identified. The first is triggered at early times after bounce (< 500 ms) and is predominantly caused by an early accretion of sharp density gradients, which significantly decreases the ram pressure that is preventing further expansion of the shock. The second one happens at late times after bounce (> 500 ms), and it does not involve the accretion of sharp density gradients. In this case, it is the strength of neutrino-driven convection that determines the onset of the explosion. Finally, I will comment on the differences between stellar evolution codes and reaction rates and how they can significantly change the explodability pattern of supernovae.

Session:

Stellar evolution

Stellar Evolution / **11**

Modified gravity in the interior of population II stars (R)

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We study the effects of a beyond-Horndeski theory of modified gravity in the interior of a population II star. We consider a simple phenomenological model of a 1.1M star that has left the main sequence, has a thin Hydrogen burning shell with a partially degenerate isothermal core, surrounded by a radiative envelope having two regions of distinct opacities. Using suitable matching conditions at the two internal boundaries, a numerical analysis of the resulting stellar equations in modified gravity is carried out. While overall, gravity may be weakened, resulting in a decrease of the luminosity and an increase of the radius of the star, some of these effects are reversed near the core. It is suggested how the model, within its limitations, can yield a bound on the modified gravity parameter.

Session:

Stellar nucleosynthesis

Dust and presolar grains / **57**

Light and Heavy-element Isotopic Compositions of Presolar SiC Grains from Low-mass AGB Stars (R)

Author: Nan Liu[1]

Co-authors: Conel Alexander [2]; Andrew Davis ; Diego Vescovi [3]; Maurizio Maria Busso [4]; Sergio Cristallo [5]; Larry Nittler [2]; Sara Palmerini [4]; Thomas Stephan [6]

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Presolar grains are microscopic dust grains that formed in the gas outflows or explosions of ancient stars that died before the formation of the solar system. The majority (~90% in number) of presolar SiC grains, including Types mainstream (MS), Y, and Z, came from low-mass C-rich asymptotic giant branch (AGB) stars, which is supported by the ubiquitous presence of SiC dust observed in the circumstellar envelope of AGB stars and the signatures of the slow neutron-capture process (s-process) preserved in these grains.

We report NanoSIMS Si and Mg–Al isotopic data (and C, N, and Ti isotopic data, when available) for 62 new MS and Y grains from the CM2 Murchison meteorite. The MS and Y grain data demonstrate that (1) C and N contamination mainly appears as surface contamination, and sufficient presputtering is needed to expose a clean grain surface for obtaining intrinsic C and N signals, and (2) Mg and Al contamination appears as adjacent grains and rims, and high-resolution imaging and the choice

of small regions of interest during data reduction together are effective in suppressing the contamination. Our results strongly indicate that previous studies of presolar SiC grains could have sampled differing degrees of contamination for C, N, Mg, and Al. Compared to the literature data, our new MS and Y grains are in better agreement with carbon star observations for both the C and N isotopic ratios. By comparing our new, tighter distributions of 12C/13C, 14N/15N, and initial 26Al/27Al ratios for MS and Y grains with FRUITY low-mass asymptotic giant branch (AGB) stellar models, we provide more stringent constraints on the occurrence of cool bottom processing and the production of 26Al in N-type carbon stars, which are classical AGB stars.

In addition, we report Sr and Ba isotopic compositions of 18 presolar SiC grains of types Y (11) and Z (7), rare types commonly argued to have formed in lower-than-solar metallicity asymptotic giant branch (AGB) stars. The Y and Z grains show Sr and Ba isotopic compositions similar to MS grains, which challenges their proposed low-metallicity AGB stellar origins especially given that 88Sr/87Sr is expected to increase linearly with decreasing initial stellar metallicity based on AGB stellar nucleosynthesis models and stellar observations. We find that the Si, Sr, and Ba isotopic compositions of our Y and Z grains can be consistently explained if the amount of 13C in the 13C pocket is reduced by a factor of 4.0–7.8 in Torino AGB models for a 0.3 Z8 AGB star with respect to that required by MS grains for a 1.0 Z8 AGB star. This scenario is in line with the previous finding based on Ti isotopes, but it fails to explain (1) the indistinguishable Mo isotopic compositions of MS, Y, and Z grains and (2) the lack of SiC grains in the presolar SiC grain inventory from low metallicity AGB stars.

Session:

Dust and presolar grains

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CHILI: What's next?

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The Chicago Instrument for Laser Ionization (CHILI), a microbeam laser resonance ionization mass spectrometer, has measured the isotopic compositions of Fe, Ni, Sr, Zr, Mo, Ru, and Ba in presolar SiC and graphite grains, revealing much about *s*-process nucleosynthesis in AGB stars. In CHILI, atoms are removed from samples by sputtering with Ga^+ ions or ablating with a 351 nm laser. Both sampling methods are well-suited to presolar grains, but each have their specific limitations.
The Ga^+ ion gun produces a maximum DC beam current of 15 nA, but the beam current must be lowered when focusing to ≤1 μm. When operating at 1 kHz with 100 ns pulses, this corresponds to a maximum of 10^4 incident Ga^+ ions per shot. Sputter yields for 30 kV Ga^+ ions depend on the target material, but ~10 secondary particles are sputtered per primary ion. Thus, a maximum of 10^5 atoms per pulse can be desorbed, and elements at concentrations below one part in 10^4, or 100 ppm, will not be collected at the maximum count rate of the detector. Trace element concentrations in presolar grains are usually well below 100 ppm.
With CHILI's current 20 ns desorption laser, volatilization of neutral atoms occurs by surface heating. Successful samples must have strong absorption at 351 nm, and sample heating must not cause undesired internal diffusion. Most silicates and oxides are transparent at 351 nm. Even on well-behaved presolar SiC, small changes in laser pulse energy or sample absorbance can lead to large changes in signal, as vapor pressure is exponential in temperature. Fluctuating ion signals hamper high precision, since dead time correction relies on constant count rates.
We are currently installing a Light Conversion PHAROS femtosecond ablation laser with outputs at 1030, 515, or 343 nm. Pulse duration can be adjusted from 190 fs to 10 ps at 1030 nm and is fixed at 190 fs at the other two wavelengths. Short-pulse laser ablation has several advantages: (1)

at fluences appropriate for CHILI, it is practically athermal; (2) it ablates materials irrespective of their optical properties; and (3) desorption yield is linear in pulse energy rather than exponential, allowing effective deadtime correction. The new laser will allow CHILI to expand its range of target materials to include presolar silicates and oxides, a wide variety of early Solar System materials, and will allow for more effective depth-profiling of presolar SiC, graphite, and other samples.

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Dust and presolar grains

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Molybdenum, ruthenium, and barium isotopes in presolar silicon carbide and graphite

Author: Thomas Stephan[1]

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We have measured Mo, Ru, and Ba isotopes in 49 presolar SiC and 11 high-density graphite grains from the Murchison meteorite with the Chicago Instrument for Laser Ionization (CHILI), a microbeam laser resonance ionization mass spectrometer. Each of these elements has seven stable isotopes, which allow study of *s*-, *r*-, and *p*-process products. Correlated nucleosynthetic effects observed for several elements in single grains can provide tighter constraints for modeling of their parent stars.
All SiC grains were classified using C, N, and Si isotopic measurements with the NanoSIMS at MPIC. Of the 49 grains, 40 were mainstream (M), three Y, one Z, one X1, and four AB (one AB1 and three AB2). Only six of the graphite grains had NanoSIMS C and N isotope data available.
CHILI's six tunable Ti:sapphire lasers allow simultaneous analysis of three elements, each with independent two-photon resonance ionization schemes. Molybdenum and Ru isobars were separated by firing respective ionization lasers on alternate desorption laser shots. Barium ionization lasers were fired together with the Ru lasers.
Molybdenum was detected in all 49 SiC grains, confirming previously reported trends for SiC grain types, except for the AB1 grain, which showed slight *r*- and *p*-process isotope enrichments. Ruthenium was detected in 38 SiC grains (30 M, three Y, one Z, and four AB) and showed *s*-process-dominated isotope patterns for all grains except the AB1 grain, which showed similar slight *r*- and *p*-process enrichments for Ru. The Ru and Mo *s*-process isotope enrichments for all other grains are strongly correlated. At least some Ba isotopes were detected in 23 of the SiC grains (20 M, one X1, and two AB2), also confirming previously observed trends. The X1 grain showed a neutron burst isotopic signature for Mo and a strong enrichment of ^{138}Ba, as has been observed in X grains before.
The graphite grains suffered from strong surface contamination with terrestrial or solar Mo, and the majority had no detectable Ru and Ba. We suspect the Mo contamination is related to the reagents used during separation of the grains from the host meteorite. Only one graphite grain showed clear *s*-process signatures in Mo, Ru, and Ba.
The correlated *s*-process enrichments of Mo, Ru, and Ba in presolar grains link these grains to low-mass asymptotic giant branch (AGB) stars. Subtle differences between individual grains, especially in Mo, point towards variations in relative *s*-process yields for individual isotopes.

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Dust and presolar grains

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The ^{26}Al/^{27}Al isotopic ratio in stellar grains and the stars of the asymptotic giant branch

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Stellar grains are solid samples of stars that were trapped in the interior of primitive meteorites. Lewis et al. first identified stellar grains in 1987. The complex origins of stellar grains have been the topic of research since then. One of the important markers of their origin is a short-lived radioactive nucleus, the ^{26}Al ($t_{1/2}$=0.717 Myr). The strength of the conclusions drawn from the ^{26}Al /^{27}Al isotopic ratio is weakened by uncertainty in nuclear physics. C. Lederer-Woods et al. (2021a, 2021b) remeasured two of the reactions, which consume ^{26}Al (^{26}Al(n,p)^{26}Mg and ^{26}Al(n,α)^{23}Na), they performed their measurements at CERN with the n_TOF instrument. The new reaction rates are lower than previous measurements, and their effects have been examined with the Monash post-processing nucleosynthesis model code. The used models cover the 2-5 solar mass range with Z=0.014 or 0.030. The outcome of the models has been compared with 62 stellar grains from Groopman et al. (2015) and Liu et al. (2021). All the grains are SiC grains, but they belong to separate subclasses. The majority of the included grains are "mainstream"(M or MS) SiC grains (56/62), which category build up most of the SiC grain population. The six other included grains are from the Z and Y subclass, which probably come from low-metallicity stars.
The new reaction rates produce models with a higher ^{26}Al /^{27}Al ratio, but the consequences are not entirely clear since grains from Groopman et al. (2015) tend to have a higher ^{26}Al /^{27}Al ratio than grains from Liu et al. (2021).

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Dust and presolar grains

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Dust production around carbon-rich stars: the role of metallicity

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Most of the stars in the Universe will end their evolution by losing their envelope during the thermally pulsing asymptotic giant branch (TP-AGB) phase, enriching the interstellar medium of galaxies with heavy elements, partially condensed into dust grains formed in their extended envelopes. Among these stars, carbon-rich TP-AGB stars (C-stars) are particularly relevant for the chemical enrichment of the local and high-redshift galaxies.
We have investigated the role of the metallicity in the dust formation process from a theoretical viewpoint by coupling an up to date description of dust growth and dust-driven wind, including the time-averaged effect of shocks propagating into the circumstellar envelope, with the stellar evolutionary tracks computed with the FUNS code. We compare our predictions with observations of

C-stars in our Galaxy, in the Magellanic Clouds and in the Galactic Halo, characterised by metallicity between solar and 1/10 of solar.
Our calculations explain the variation of acetylene molecules in the gas phase and dust content around C-stars derived from the IRS Spitzer spectra as a function of the metallicity. The wind speed of the C-stars observed at varying metallicity is fairly well reproduced by our description.
We predict the properties of the circumstellar envelope, including the wind speed, down to metallicities of 1/10 solar for different stellar masses, representative of diverse environments, including metal-poor star-forming dwarf galaxies. The model predictions can be tested with future observations performed by the Atacama Large Millimeter Array (ALMA) and the James Webb Space Telescope (JWST).

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How a stellar companion influences the dust-gas chemistry within AGB outflows and beyond (R)

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Spherically symmetric AGB outflows are the exception rather than the rule: both small-scale asymmetries (e.g., clumps) and large-scale asymmetries (e.g., spirals and disks) are widely observed. Binary interaction, either with a stellar or a planetary companion, has been proposed as the driving mechanism behind the large-scale asymmetries.

Recently, we found a stellar companion can strongly influence the gas-phase chemistry throughout the entire outflow. Its impact depends on the intensity of the stellar UV radiation and on the extinction it experiences as it radiates outward through the envelope. Photodissociation can now occur in the dense, inner regions of the outflow, altering the nature and products of chemical reactions which affect the entire circumstellar envelope. The outcome of the chemistry depends on the balance between two-body reactions, which build up complexity, and photoreactions, which destroy this.

Motivated by these findings, we now include stellar companion photons in our unique comprehensive dust-gas chemical network. Our previous work shows that dust-gas interactions have a strong influence on the gas-phase composition of higher-density outflows, depleting gas-phase species onto the dust, building up an icy mantles around the dust grains. In our latest work on dust-gas chemistry, we included the photoprocessing of volatile complex ices into inert refractory organic material. Such a refractory organic mantle is necessary to explain the properties of dust in the ISM and thought to be formed in diffuse clouds. When allowing photoprocessing to occur within the AGB outflow, we find that dust in high-density, carbon-rich outflows can have a refractory coverage of up to 22%. This is too low to have a significant impact on the ISM.

The presence of a close stellar companion, especially in an asymmetrical outflow, could significantly influence the dust-gas chemistry within AGB outflows and beyond. Here, we present our initial findings on the effects on the gas-phase chemistry throughout the outflow (i.e. depletion and formation of gas-phase species), on the complex chemistry on the grain surface, and on the refractory organic coverage of the dust as it enters the ISM.

Session:

Dust and presolar grains

Dust and presolar grains / 46

Are the extremely red asymptotic giant branch stars hiding a close companion?

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Asymptotic giant branch stars are major sources for carbon dust in galaxies. The analysis of these objects in the Large Magellanic Clouds unearthed a group of stars, called "Extremely Red Objects" (EROs). The analysis of EROs spectral energy distribution suggests the presence of large quantities of dust in their surroundings, which demands gas densities in the outflow significantly higher than expected from theoretical modelling of single stars. In this talk I will discuss the possibility that EROs are part of interacting binary systems where the presence of a common envelope would favor a conspicuous dust formation.

Session:

Dust and presolar grains

Dust and presolar grains / 50

Studying the Post-AGB stars in Magellanic Clouds as a probe for dust production and mass-loss mechanisms

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The asymptotic giant branch (AGB) phase modelling is made uncertain by the poor knowledge of some physical mechanisms that play a crucial role on the internal structure and the late evolution of low- and intermediate-mass stars. On the contrary, the post-AGB phase is only marginally affected by the uncertainties mentioned and spectra can be more easily analyzed to derive the chemical composition and to characterize the dust in their surroundings. By exploiting these characteristics of

the post-AGB stars, it is also possible to retrieve crucial information regarding the mass-loss process experienced by stars during the transition from the AGB to the post-AGB phase. To this purpose, we interpreted the spectral energy distribution of 14 post-AGB stars in the Magellanic Clouds to derive information about the luminosity, the dust content, and the surface chemical composition of the individual sources. In this talk I will present the results of this analysis from which we are able to infer information regarding the optical depth and the mass loss rate necessary to link the post-AGB phase to the previous one.

Session:

Stellar evolution

Poster presentation / 40

Carbon stars in the L-band: update on ongoing work

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We report on ongoing projects related to observations of prominent Carbon stars in the L-band. This wavelength region is of particular interest as it covers a strong band of C_2H_2 a building block of Carbon dust. The instruments used are MATISSE at the VLT Interferometer and ALES at LBTI.

Session:

Stellar observations (photometry and spectrometry)

Poster presentation / 79

PARSEC V2.0: Stellar tracks and isochrones of low and intermediate mass stars with rotation

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We present a new comprehensive collection of stellar evolutionary tracks and isochrones for rotating low- and intermediate-mass stars assembled with the updated version of PARSECV2.0. The recent calibration of the extra mixing from overshooting and rotation is included, as well as several improvements in nuclear reaction network, treatment of convective zones, mass loss and other physical input parameters. The initial mass that we present are from 0.09 Msun to 14 Msun, for six sets of initial metallicity from Z=0.004 to 0.017. Rotation is considered only above about 1 Msun, with a smooth transition between non rotating and extremely fast-rotating models, based on the initial mass. Above about 1.3 Msun the full range of rotation from low to the critical, is considered. The solar-scaled chemical mixture by Caffau et al. is adopted with Zsun = 0.01524. All the evolutionary phases from the pre-main-sequence to the first few thermal-pulses on the asymptotic-giant-branch

(TP-AGB) or central C exhaustion.
The corresponding theoretical isochrones are derived with TRILEGAL code and are converted into several photometric systems with the accounting for different inclination angles due to rotational effects.
The new collection is fully integrated in a user friendly WEB interface for the benefit of easily performing stellar population studies and will be provided.

Session:

Stellar observations (photometry and spectrometry)

Poster presentation / **54**

Uncovering the hidden population of symbiotic stars

Author: Manica Perko[None]

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Symbiotic stars are interacting binary systems consisting of a companion star, usually a white dwarf, and a primary star, usually a red giant. In general, there are two phases of symbiotic stars: accreting-only and burning-type. There are several hundred known symbiotic systems, most of which are in the burning phase, but that is due to an observational bias. In the burning-type case, we observe a strong nebular continuum and a rich emission line spectrum, so systems in this phase can be easily detected at optical wavelengths. In order to determine the significance of symbiotic stars, we need to characterize and quantify the entire population in the Galaxy. Furthermore, we assume that symbiotic stars spend most of their lives in the accreting-only phase. These systems are difficult to detect because the optical spectrum is dominated by the red giant and there are no or only very weak emission lines present.

One of our goals is to separate symbiotic stars which contain AGB or RGB giant as a primary star. The most promising approach we tried is looking for IR excess. We think we found a good independent indication of AGB versus RGB in the form of a W3-W4 color index. We are interested in light curve deviations in IR which can be a consequence of heated dust around a star. A similar kind of IR excess can be seen in AGB stars which lost a lot of mass due to their evolution. We are exploring ways of connecting photometric detection of AGB stars with their spectra. If we are successful we will be able to search for AGB and RGB distinction based on their spectra from large surveys such as GALAH, Gaia-ESO and in the future 4MOST.

We will extend our research to other color indices and first use an unsupervised machine learning technique for clustering, e.g. t-distributed stochastic neighbor embedding (tSNE), which is a dimensionality reduction technique. This provides a larger training set for a supervised machine learning method, e.g. Random Forest, which can be used in future identifications of such systems (see also Akras et al, 2019).

The accretion of stellar wind from the red giant onto the surface of the white dwarf makes symbiotic stars a promising Type Ia supernova progenitor. Because of the novae outbursts, they are considered to be one of the candidates responsible for the enrichment of the interstellar medium with lithium.

Session:

Stellar observations (photometry and spectrometry)

Poster presentation / **48**

Upgrading the dppn45 post-processing nucleosynthesis code

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Decay rates have a significant effect on the abundance of branching point elements and short-lived nuclei. Thus, a correct description of the decay rates is essential for the accurate study of the s-process in AGB stars. The dppns45 post-processing nucleosynthesis code calculates the changes in the abundances of isotopes due to mixing and nuclear burning after the detailed stellar structure was calculated by a stellar structure evolution code. The nuclear reaction network of dppns45 is originally based on the reaclib formula (Thielemann et al., 1987). The JINA reaclib libraries have several advantages, however, they do not include temperature and density dependence of decay rates. To remedy this shortcoming, a new version of the code includes a routine that allows using tabulated values of decay rates instead of the reaclib fit. During this work, I expand the reaction network to account for the temperature and density dependence of the radioactive decay and electron captures. The tables were created based on the NEXTGEN (Xu et al., 2013) database, and new rates are currently being tested on a model with M = 3 solar masses and z = 0.014 metallicity. The purpose of the testing process is to determine whether the use of tabulated rates instead of reaclib fit causes a significant difference in the final surface abundances. According to the results so far, it can be assumed that the new version of the dppns45 code works, there are significant differences between the tabulated and the reaclib rates, especially for the 152Gd, whose surface abundance is greatly influenced by three (151Sm-›151Eu, 152Eu-›152Sm and 152Eu-›152Gd) new rates.

Session:

Stellar nucleosynthesis

Poster presentation / 64

The recent achievements of the RockStar Group of the Perugia University on astrophysical modeling and pallasite geochemistry.

Author: Lisa Ricci[1]

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Here, we summarize the first achievements of the RockStar Group of the Department of Physics and Geology (at the University of Perugia, Italy). The group was created on the initiative of Maurizio Busso and consists of a close collaboration between Physicists and Geologists on astrophysical and planetological studies. Astrophysical modeling takes significant advantage of geochemical investigations on meteorites, since they store information about the early Solar System and its evolution.

On the other hand, geochemical and structural studies of minerals, crystals, and quasi-crystals can provide the basis for modeling the formation and the physical evolution of meteorites and planetary bodies. In agreement with these premises, the RockStar Group acts on two research lines: (i) astrophysical modeling and (ii) mineralogical and geochemical studies of meteorites. With regard to astrophysical modeling, our recent studies focused on nucleosynthesis models and mixing processes in AGB stars. Latest models, that consider the activation of the 13C neutron source in AGB stars as a by-product of magnetically-induced mixing episodes, were shown to explain several observational constraints on s-processing. In particular, magnetic models for low-mass stars with close-to-solar metallicity can reproduce the peculiar isotopic ratios of trace heavy elements measured in presolar SiC coming from ancient AGB stars. Concerning meteorites, our recent studies focused on the Mineo pallasite, a unique sample hosted by the Meteorite Collection of University of Perugia. The new geochemical and mineralogical data constrain the Mineo meteorite among the Main Group Pallasites and support the hypothesis of the "early giant impact"formation.

Session:

Galactic Chemical Evolution

Dust and presolar grains / 14

Mixed metal oxides as primary dust condensates

Author: David Gobrecht[None]

Metal oxides are promising candidates as a primary dust condensate in the atmospheres of oxygen-rich evolved stars. Typically, Al2O3 and TiO2 are considered as they represent the most prominent case studies. However, also mixed metal oxides, containing more than one metal, represent realistic alternatives to Al2O3 and TiO2 as a first solid in the rich gas mixture of
stellar atmospheres. Their related nano-sized metal oxide clusters, often referred to as seed particles, trigger the onset of stellar dust formation and the mass return into the interstellar medium.
However, the nature and the formation of these clusters are not well understood.
Nano-sized clusters are fundamentally different from crystalline bulk material.
As a result of their finite size and quantum interactions clusters exhibit a wide range of different structures and potential energies. The most favourable structures with the lowest potential energies are typically not spherical and can generally not be extrapolated from the bulk.
We aim to shed light on the initial steps of cosmic dust formation (i.e. nucleation) in oxygen-rich environments by a quantum-chemical bottom-up approach. Therefore, we study different metal oxide clusters containing Mg, Al, Si, Ti, and Ca, including various combinations and stoichiometries.
Starting with an elemental gas-phase composition including radioactive isotopes, we construct a detailed chemical-kinetic network describing the formation and destruction of molecules and dust-forming clusters up to the size of 16 atoms.
The reaction rates are derived from their potential energy surfaces using global optimisation techniques and transition state theory. Owing to the increasing computational complexity the subsequent coagulation of clusters with more than 16 atoms is calculated using accurate thermo-chemical data.
The resulting extensive network is applied to two model stars, representing a semi-regular variable and a Mira-type AGB star, and to different circumstellar gas trajectories including a non-pulsating outflow and a pulsating model.
We provide energies, bond characteristics, electrostatic properties and vibrational spectra of the clusters as a function of their size, oxygen content, and temperature.
Our preliminary model results predict temperature- and density dependent abundances of molecules and clusters, dust compositions and sizes, IR spectra, and chemical timescales that are compared to recent observations as well as to grain properties of meteoritic stardust.

Session:

Dust and presolar grains

Dust and presolar grains / 5

The stellar sources of presolar silicates revisited - New insights from magnesium isotopic compositions

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Primitive Solar System materials contain small amounts 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 with stellar origins. Based on O-isotopic compositions, O-rich presolar dust was divided into four distinct groups [2]. Most abundant are Group 1 grains (about 80% of all presolar silicates) which are characterized by enrichments in 17O and close-to-solar 18O/16O ratios. For a long time it was believed that the vast majority of Group 1 silicates formed in the winds of low-mass asymptotic giant branch (AGB) stars. However, recently conducted high-resolution in-situ Mg isotope measurements on presolar silicates, facilitated by technical advancements on the NanoSIMS ion probe, have changed this view considerably [3-5].

The surface Mg-isotopic compositions of low-mass AGB stars are predicted to change only marginally during stellar evolution [e.g., 6], i.e, initial Mg-isotopic compositions at stellar birth are largely preserved. In a Mg three-isotope-representation about 60% of Group 1 silicates plot along a line with slope 1, interpreted to represent GCE [5]. The O-, Mg-, and Si-isotopic compositions of these grains are compatible with origins in low-mass AGB stars. About 25% of Group 1 silicates show strong enrichments in 25Mg of up to a factor of 2 or more, along with typically 4-5 times smaller 26Mg/24Mg anomalies. Type II supernovae (SNe) and intermediate-mass (4-5 Msun) AGB stars with super-solar metallicities have been proposed as most likely stellar sources of 25Mg-rich Group 1 silicates [3, 5]. The remaining 15% of Group 1 silicates are 26Mg-rich and might have formed in the winds of supergiants or in the ejecta of SN explosions [5]. Similarly, Group 2 silicates (a few percent of all presolar silicates) might have formed in intermediate-mass AGB stars, super-AGB (8-10 Msun) stars, supergiants, and SNe [4, 5].

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Session:

Dust and presolar grains

Dust and presolar grains / 19

Dust Changes in Sakurai's Object: PAHs, SiC and carbonates (not melilites)

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Sakurai's Object (V4334 Sgr) is a low mass post-AGB star that has been forming dust in an eruptive event since 1996. We have been analysing 6-14 µm Spitzer spectra obtained at 6 epochs between 2005 April and 2008 October to determine temporal changes in the dust features. An initially rapid mid-infrared flux decrease stalled after 2008 April 21. Optically thin emission due to nanometre-sized SiC grains reached a minimum in 2007 October, increased rapidly between 2008 April 21-30 and more slowly to 2008 October. 6.3-µm absorption due to PAHs with an underlying broad component increased throughout the observing period. The broad component was initially assigned to melilite silicates (Bowey 2021). However Bowey & Hofmeister (2022) reassigned the broad component to carbonate because the original laboratory data for melilites were dominated by a very low (<0.1 % by mass) component of carbonate in the sample which was undetected at other wavelengths. Mass estimates based on the optically thick emission (Evans 2020) agree with those in the absorption features if the large SiC grains formed before 1999 May and PAHs formed in 1999 April-June. Some of the submicron-sized silicates responsible for a weak 10 µm absorption feature are probably located in Sakurai's local environment because its optical depth decreased between 2007 October and 2008 October. With magnesite (MgCO3), the abundance of 20-micron-sized SiC grains is increased by 10 - 50 per cent and well-constrained. The mass of carbonate dust is similar to the mass of PAH dust. Experimental work on carbonate formation is required because a similarly broad 6.9-µm absorption feature is common in molecular clouds and YSOs.

Session:

Dust and presolar grains

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Flecks of extraterrestrial dust, all over the roof - The story of their cosmic makeup (R)

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After decades of failures and misunderstandings, scientists have solved a cosmic riddle —what happens to the tons of dust particles that hit the Earth every day but seldom if ever get discovered in the places that humans know best, like buildings and parking lots, sidewalks and park benches. The answer? Nothing. Look harder. The tiny flecks are everywhere, all over the roof. The morphology of these flecks - micrometeorites - is a first hint of their extraterrestrial origin, the determination of their chemical makeup is the decisive making body. But how is that cosmic dust formed? What important clues on stellar evolution are hidden in these extraterrestrial flecks? What do these microscopic samples supported by astronomical observations tell us about the future evolution of our own Sun, and how life on Earth might change in a few billion years from now? In this talk, I will discuss how interdisciplinary research linking astronomy and chemistry –'astrochemistry'–can reveal the true formation pathways of these little grains, thereby combining the four fundamental axes of (astro)physical research: theory, observations, numerical models, and laboratory experiments. During this talk, I will specifically highlight the crucial role of ALMA observations in disclosing the nucleation histories of ageing Sun-like stars.

Session:

Dust and presolar grains

Dust and presolar grains / 13

Production of light trans-Fe elements in neutrino-driven winds

of core-collapse supernovae: Implications from presolar SiC-X grains

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In a large-scale nucleosynthesis parameter study, we have extended the initial ideas of Hoffman et al. [1], who showed that light p-nuclei can be produced in the neutrino-driven winds of core-collapse supernovae (cc-SNe). Our project began about a decay ago, based on the r-process model of Farouqi et al. [2], where we found that in the low-entropy (S) charged-particle component of moderately neutron-rich wind ejecta of cc-SNe, in addition to the classical light „p-only"isotopes, the „s-only "and „r-only"nuclei between Zn (Z = 30) and Pd (Z = 46) can also be co-produced [3,4]. In the present contribution, we focus on a recent update to the nucleosynthetic interpretation of the anomalous isotopic compositions of Zr (Z = 40; 5 stable isotopes), Mo (Z = 42; 7 stable isotopes) and Ru (Z= 44; 7 stable isotopes) reported in the rare presolar SiC-X grains discovered by the Argonne/Chicago group [5]. In contrast to the dominant class of AGB (s-process) grains, very few SiC-X grains were identified and qualitatively interpreted to originate from explosive nucleosynthesis scenarios. We show that these meteoritic observations do not represent the signatures of a „clean"stellar scenario, but rather are mixtures of an exotic nucleosynthesis component with different fractions of Solar System material [6,7]. The co-production of these isotopes through a rapid „primary"production mode provides further means to revise the abundance estimates of the light trans-Fe elements from so far favoured „secondary"nucleosynthesis scenarios like Type Ia SNe (see, e.g. [8]) or neutron-bursts in exploding massive stars [9]. Finally, we point out that from the isotopic abundance patterns of the SiC-X grains, we obtain better electron fraction - entropy ($Y_e - S$) constraints for nucleosynthesis in regular cc-SNe nucleosynthesis than we do from the elemental abundances of metal-poor halo stars [10].

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Session:

Dust and presolar grains

Stellar Nucleosynthesis / 74

How important are Asymptotic Giant Branch Star in Astrophysics? (R)

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Asymptotic giant branch stars (AGB) represent an important phase in stellar evolution, because of the important physical processes involved in describing their internal structure and evolution. About half of the heavy elements beyond iron were produced during their peculiar evolutionary phases. Furthermore, the diversity of the nuclear processes determining the nucleosynthesis in these stars have initiated experimental activities to measure relevant reaction rates needed to determine the nuclear energy production and nucleosynthesis. The present contribution is primarily aimed at appreciating the effort and contribution of Prof. Maruzio Busso and collaborators that helped developing this exciting subject in astrophysics. After a short description of the basic characteristics of the AGB stars, a list of essential nucleosyntheses processes will be highlighted.

Session:

Stellar nucleosynthesis

Stellar Nucleosynthesis / 18

The NuGrid AGB Evolution and Nucleosynthesis Data Set

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Asymptotic Giant Branch (AGB) stars play a key role in the chemical evolution of galaxies. These stars are the fundamental stellar site for the production of light elements such as C, N and F, and half of the elements heavier than Fe via the slow neutron capture process (s-process). Hence, detailed computational models of AGB stars'evolution and nucleosynthesis are essential for galactic chemical evolution.
In this work, we discuss the progress in updating the NuGrid data set of AGB stellar models and abundance yields. All stellar models have been computed using the MESA stellar evolution code, coupled with the post-processing mppnp code to calculate the full nucleosynthesis. The final data set will include the initial masses M_{ini} /$M_{\odot}$= 1, 1.65, 2, 3, 4, 5, 6 and 7 for initial metallicities Z = 0.0001, 0.001, 0.006, 0.01, 0.02 and 0.03. Observed s-process abundances on the surfaces of evolved stars as well as the typical light elements in the composition of H-deficient post-AGB stars are reproduced. Additionally, we discuss our new nucleosynthesis results with the inclusion of new nuclear reaction rate, in particular documenting the impact of new ^{22}Ne+α rates on presolar grains, where the description is improved. A key short-term goal is to complete and expand the AGB stars data set for the full metallicity range. Ejected chemical yield tables are provided for the available models.

Session:

Stellar nucleosynthesis

Stellar Nucleosynthesis / 16

Mixing by internal gravity waves and its possible roles in the origin of the Li-rich red-clump stars and formation of the ^{13}C pocket

in AGB stars

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The observed evolutionary decrease of the $^{12}C/^{13}C$ isotopic ratio, Li and C abundances, accompanied by the increase of the N abundance, in low-mass stars on the upper RGB is caused by extra mixing in their radiative zones. Multi-dimensional hydrodynamic simulations of thermohaline convection have demonstrated that its rate of mixing is almost two orders of magnitude as low as what is required to reproduce the observational data. Therefore, the search for an alternative mechanism of the RGB extra mixing still continues. To simultaneously explain the observed Li depletion on the lower part of the upper RGB followed by a presumed fast Li enhancement in the vicinity of the RGB tip, we consider a model of RGB extra mixing in which the diffusion coefficient strongly increases with the luminosity. With analytical prescriptions for the rates of mixing by internal gravity waves (IGWs) generated by turbulent convection in the envelopes of RGB stars, that are partly supported by our 3D hydrodynamical simulations, we can reproduce the high Li abundances recently revealed in red-clump stars. The results of our simulations also support the hypothesis that the ^{13}C pocket in thermally-pulsing AGB stars, necessary for the main s process to occur under radiative conditions, could be formed as a result of proton ingestion by IGW mixing.

Session:

Stellar evolution

Stellar Nucleosynthesis / 20

Magnetic mixing and s-processing in AGB stars

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Asymptotic giant branch stars are major sources of heavy elements in the Universe.
Despite the huge progress made in the last decades in the theoretical modeling of these objects, mixing processes occurring in their interiors are quite uncertain, especially the physical mechanism leading to the formation of the ^{13}C pocket. Here, I will present recent results from the new generation of FRUITY models, including the effects of mixing triggered by magnetic fields. I will show comparisons with available observational constraints provided by isotope ratios of heavy elements in presolar grains and spectroscopic observations of carbon AGB stars and Galactic open clusters.

Session:

Stellar nucleosynthesis

Stellar Nucleosynthesis / **55**

Barium stars as tracers of s-process nucleosynthesis in AGB stars (R)

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The Barium (Ba) star phenomenon is unmissable from the study and understanding of nucleosynthetic processes occuring in AGB stars. Ba stars belong to binary systems, where the former AGB polluted the companion, a less evolved star, which became enriched with material produced through the slow neutron capture process (s process). While the AGB has evolved to a white dwarf, 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, we are able to constrain the effect of the initial rotation velocity or the neutron source in the interior of the AGB star. Additionally to the large, homogeneous observational sample of Ba stars of de Castro et al. (2016) an extended list of heavy element abundances was published by Roriz et al. (2021a,b), including Sr, Mo, Ru and re-determined La values. Here I will present the results for individual Ba stars using a simplified method of normalising the models to the determined [Ce/Fe] abundances and calculating dilution factors for each star and model. The results of the comparison of models with initial AGB masses from an independent source and the analysis of 28 Ba giant star abundances confirm that the polluting AGBs are of low mass (< 4 MSun). There is a good agreement between the models and the abundance pattern for most of the stars, with some peculiarities at the first s-process peak. Nb, Mo and Ru values higher than the model predictions indicate the operation of a different nucleosynthesis path, which needs further investigation. The dilution factor distribution and the binary orbital parameters suggest that systems with shorter orbital periods needed higher mass transfer efficiency in the past.

Session:

Stellar nucleosynthesis

Stellar Nucleosynthesis / **53**

Finding the polluter AGB properties of a Barium stars with machine learning

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The use of machine learning techniques in astronomy is becoming more and more widespread. Here I present our results on using machine learning (ML) methods for the comparison of observed Barium (Ba) star abundances and the predictions of AGB nucleosynthesis codes. This way, we can provide an estimate of the progenitor mass and metallicity of the former polluter AGB star that in the past enriched the composition of a currently observed Barium (Ba) star via accretion.

For this task, we use the largest, homogeneous sample of Ba star abundances from de Castro et al. (2016), Roriz et al. (2021a,b) and the two most extended AGB nucleosynthesis models in the literature, the Monash and FRUITY models.

Cseh et al. (2022) published a method for this problem, where the dilution factor (namely the fraction of AGB material in the Ba star envelope) for each model was calculated based on the [Ce/Fe] value. However, the mass range of the models was selected manually using independent AGB mass estimates as initial values, which is available only for 28 stars out of the whole sample.
As an upgrade, we considered the dilution factor as a free parameter and used three differents classificators for this much more complex task –a neural network, a random forest and an analytical method based on the closeness of derived abundances to the models –to identify the pattern of polluter AGBs in the whole sample of Ba star spectra.

This approach allows us to have an insight to the behaviour of each element in each star, as well as to build statistics for the differences in the abundance patterns of all stars. We found that the mass distribution of the optimal polluter AGBs fall into the low-mass range and do not exceed 4 $M_{\odot}$, as expected by previous results. Also, a systematic underestimation occurs at some of the first s-process peak elements when comparing the model predictions to the observations –this may indicate a possible missing nucleosynthesis path from the models.

Session:

Stellar nucleosynthesis

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The intermediate neutron capture process in AGB stars

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Despite considerable progresses over the past few decades, 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 existence of this process is supported by the observation of metal-poor stars whose chemical compositions are intermediate between the s- and r-processes (the so called r/s-stars). The i-process is triggered when protons are mixed in a convective helium-burning zone (proton ingestion event or PIE). The astrophysical site(s) hosting PIEs and thus the i-process is (are) actively debated. Among the various possible sites, the early AGB phase of low-mass stars is a promising one. In this presentation, I will focus on the development of the i-process in state-of-the-art AGB stellar models of various masses and metallicities computed with the STAREVOL code. I will first show how the AGB evolution of models suffering a PIE can be dramatically altered. Then, I will discuss the i-process nucleosynthesis accompanying a PIE, identify key reaction rates, highlight the chemical fingerprint of these stars, present i-process yields as a function of mass and metallicity and eventually discuss the implication on galactic chemical evolution.

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Neutron capture nucleosynthesis in zero and very low metallicity rotating massive stars

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In the last years observations of Fe-poor stars have made possible to have detailed measurements of their surface chemical composition. These objects are the perfect laboratories in which is possible to investigate the differences among the possible astrophysical sites of element production, from the lightest ones to the neutron capture elements. In fact, iron poor stars probably formed during the very early epochs of the evolution of the Universe, hence the study of their abundance patterns may help to constrain the nucleosynthetic yields of the first supernova explosions. A number of Fe-poor stars shows not negligible abundances of neutron capture elements relative to iron, which are produced in stars through the slow neutron capture (s-process) nucleosynthesis. Since the efficiency of this process scales with the initial metallicity, no production of elements heavier than Zn is obtained in classical models of low metallicity massive stars. A possible scenario which aims to explain this unexpected chemical composition is that iron poor stars formed out from gas clouds polluted by the supernova yields of rotating massive progenitors. Rotation at low metallicity, in fact, can considerably boost the neutron capture nucleosynthesis in massive stars through an efficient activation of the neutron sources. In this talk, I will discuss the effect that rotation introduces in the yields of two typical massive stars, a 15 and 25 $M_{\odot}$ stars, at zero and very low metallicity, with a particular focus to the nucleosynthesis of heavy nuclei.

Session:

Stellar nucleosynthesis

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Characterization of Galactic carbon stars from Gaia EDR3

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The third early Gaia data release (EDR3) has improved the accuracy of the astrometric parameters of numerous long-period variables (LPVs) stars. Many of these stars are on the Asymptotic Giant Branch (AGB), showing either a C-rich or O-rich envelope and are characterised by high luminosity, changing surface composition, and intense mass loss, that make them very useful for stellar studies. In a previous investigation we used Gaia DR2 astrometry to derive the luminosity function, kinematic properties and stellar population membership of a flux limited sample of carbon stars in the solar neighbourhood of different spectral types. Here, we extend this initial study to more ample and recent surveys of Galactic carbon stars and related stars by adopting the more accurate EDR3 astrometry measurements. Thanks to a much larger statistics, we confirm that N- and SC-type carbon stars share a very similar luminosity function, while the J-type stars show luminosities (Mbol) fainter by half a magnitude in average. The carbon stars of R-hot type show luminosities all along the RGB, which favours the hypothesis of an external origin for their carbon enhancement. Moreover, a significant fraction of the R-hot stars have kinematics properties compatible with the thick disk population, in contrast with that of N-, SC-type stars which would belong mostly to the thin disk. We also derive the luminosity function of a large number of Galactic extrinsic and intrinsic (O-rich) S-stars and show that the latter have luminosities typically higher than the predicted onset of the third dredge-up (TDU) during the AGB for solar metallicity. This result is consistent with these stars being genuine thermal pulsing (TP) AGB stars. On the other hand, using the so-called Gaia-2MASS diagram we show that the overwhelming majority of the carbon stars identified in the LAMOST survey as AGB stars, are probably R-hot and/or CH-type stars. Finally, we report the identification of ~ 2660 new AGB carbon stars candidates, identified thanks to their 2MASS photometry, their Gaia astrometry, and their location in the Gaia-2MASS diagram.

Session:

Stellar observations (photometry and spectrometry)

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[C I] in the circumstellar envelope of IRC+10216

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IRC+10216 is the archetypal carbon-rich AGB star situated at a mere distance of 130 pc. The star exhibits a high mass loss rate of 2 –4 x 10-5 M⊙ / yr. Until now ~90 molecular species are found in the circumstellar envelope (CSE) of this star alone. The carbonaceous atmosphere around the star shows intense emission of the CO molecule. Guelin et al. (2018) mapped this environment successfully in the CO (2-1) line with ALMA, SMA and IRAM PdB, where they revealed a pattern of concentric shells of extended emission. But the distribution of atomic carbon in the envelope is seldom studied towards this star. Keene et al. (1993) performed observations at various offsets from the central position of the star and inferred that the [C I] line is present in the form of shells in the envelope of the star. There is no atomic carbon present at the 0" position, but the line appears at 15" and at 45" away from the star, which was confirmed by van der Veen et al. (1998). Following this, we performed observations with the APEX telescope targeting the fine structure line at 9 different offsets, with an increment of ~6.5"from the star, in the R.A. and Dec directions to get a precise position of the presence of the shell. We further modeled the spectral lines using the RATRAN radiative transfer tool to get constraints on the physical distribution of the [C I] line in this star.

Session:

Stellar observations (photometry and spectrometry)

Stellar Observations / 3

The complex behaviour of the s-process element abundances at young ages

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Open clusters appear as simple objects in many aspects, with a high degree of homogeneity in their (initial) chemical composition, and the typical solar-scaled abundance pattern for the majority of the chemical species. The striking singularity is represented by heavy elements produced from the slow neutron-capture process reactions. In particular, young open clusters (ages less than a few hundred Myr) exhibit extreme and atypical enhancement in their [Be/Fe] ratios (~0.6-0.7 dex) which is not followed by the other s-process elements, as lanthanum or cerium. This is labelled as the Barium Puzzle. The definite explanation for such a peculiar trend is still wanting (and missing), as many solutions have been envisaged. In this talk, I will review the status of this field and present the new results obtained by our group on young open clusters and the pre-main sequence star RZ Piscium.

Session:

Stellar observations (photometry and spectrometry)

Stellar Observations / 47

New clues for heavy element nucleosynthesis (R)

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The foundations of stellar nucleosynthesis have been established more than 70 years ago and since then, many progresses have taken place, in particular concerning the heavy-element nucleosynthesis in late stages of the evolution of solar-mass stars. Targeting key-elements, including radio-isotopes, in both intrinsic and extrinsic stars, the latter constituting "cold cases" and useful probes of a past nucleosynthesis, allows to better understand chemical element production by stars with masses as low as 1 Msun during their evolved phases. Given their numerical importance, these stars are major contributors to the chemical evolution of the Galaxy. New aspects, such as evidences for the i-process operation at close-to-solar metallicities, will be discussed.

Session:

Stellar observations (photometry and spectrometry)

Stellar Observations / 65

Post-AGB stars as tracers of the origin of elements and isotopes in the Universe.

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The chemical evolution of galaxies is governed by the chemical yields from stars, especially from Asymptotic Giant Branch (AGB) stars. Post-AGB stars are exquisite probes of AGB nucleosynthesis. Photospheric chemical studies of single post-AGB stars in the Galaxy and the Magellanic Clouds have shown an intriguing chemical diversity that ranges from stars that are extremely enriched in carbon and s-process elements to the discovery of the post-AGB stars with no traces of carbon nor s-process elements. For the Galactic post-AGB objects, the previous lack of accurate distances (luminosities and initial masses) jeopardised comparison with theoretical AGB models. However, the Gaia Early Data Release 3 (Gaia EDR3) astrometric data has allowed for a breakthrough in this research landscape: derivation of accurate luminosities (and hence initial masses) of the Galactic post-AGB stars. We found that while most known objects are in the post-AGB phase of evolution, we found a subset of low-luminosity objects likely to be in the post-horizontal branch phase of evolution, similar to AGB-manque objects found in globular clusters. We also investigated the observed bi-modality in the s-process enrichment of Galactic post-AGB single stars of similar Teff and metallicities. We found that the two populations: the s-process enriched and non-enriched, have similar luminosities (and hence initial masses), revealing an intriguing chemical diversity. For a given initial mass and metallicity, AGB nucleosynthesis appears inhomogeneous and sensitive to other factors, which could be mass-loss, along with convective and non-convective mixing mechanisms. We have developed new post-AGB models tailored to the individual objects to investigate which parameters and processes dominate the photospheric chemical enrichment in these stars. In this contribution, I will present our research highlights and the updates in the field of post-AGB stars as tracers of AGB nucleosynthesis.

Session:

Stellar nucleosynthesis

Stellar Observations / 9

Technetium in and Mass-Loss from Miras

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Not predicted by stellar evolution theory, observations find that Miras without the 3DUP indicator technetium (Tc) in their atmospheres have a *higher* near-to-mid IR colours than their Tc-rich siblings (Uttenthaler 2013, A&A 556, A38). Since a near-to-mid IR colour such as K-WISE4 is an indicator of the mass-loss rate of AGB stars, this suggests that the mass-loss rate from post-3DUP Miras is lower than from pre-3DUP Miras. This is unexpected also because stars with 3DUP activity are thought to be more evolved than Tc-poor Miras, and mass loss is thought to increase along the evolution on the AGB. Different explanations for this result are discussed. One of them is that the radioactive decay of unstable isotopes, foremost ^{26}Al, could impact the formation of dust in the stellar atmosphere and thereby the acceleration of the stellar wind (Uttenthaler et al. 2019, A&A 622, A120). We present new observational results in support of this hypothesis. In particular, we show new results involving measurements of the gas mass-loss rate (Uttenthaler et al., in preparation).

More work, in particular on the role of radioactive isotopes in stellar atmospheres, is required to better understand this intriguing phenomenon.

Session:

Stellar observations (photometry and spectrometry)

Stellar Observations / 10

Nucleosynthesis and binarity in AGB stars: the Barium star perspective

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A rich zoo of peculiar objects forms when evolved stars with extended and loosely-bound convective envelopes, such as Asymptotic Giant Branch (AGB) stars, undergo gravitational interaction with a binary companion. The stellar, chemical and orbital properties of these peculiar products of binary interactions are essential to understanding the interaction history in such systems and to constraining many physical and chemical mechanisms that concern their giant progenitors.

In the last few years, the combination of long-term radial-velocity monitoring programmes, high-resolution spectroscopy, high-quality Gaia distances, and state-of-the-art stellar models has proven to be very powerful to learn about evolved long-period binaries. During my contribution, I will present the latest observational constraints that we obtained for a family of chemically peculiar stars known as Barium (Ba) stars. These main-sequence and red-giant stars accreted mass from the outflows of a former AGB companion, which is now a dim white dwarf (WD), polluting their atmospheres with material rich in heavy metals. The orbital properties of Ba stars can help us constrain the exact mass-transfer mechanism through which they formed, and their chemical abundances are a tracer of the nucleosynthesis processes that took place inside the former AGB companion.

Additionally, including Hipparcos and Gaia astrometric information in our recipe, we recently determined absolute masses for the invisible WD companions of many Ba stars, obtaining direct information about their AGB progenitors via initial-final mass relationships. I will discuss the orbital parameters of Ba star systems in the context of binary interactions in systems with AGB-star components and the WD masses in the context of AGB nucleosynthesis. Neither binary evolution models nor nucleosynthesis models fully reproduce the orbital and chemical properties of Ba stars, which represents a gap in our knowledge about AGB stars, their outflows, and their interactions with binary companions.

Session:

Stellar observations (photometry and spectrometry)

Stellar Observations / 25

The Active Chromospheres of Lithium-Rich Red Giant Stars (R)

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We have discovered an unexpected observational feature of the rare lithium-rich G-K red giants: many have very strong neutral helium 10830 A absorption transitions in their spectra. While over 90% of normal lithium-poor giants have weak He I absorption lines, more than half of the lithium-rich stars have deep, very broad 10830 features. The noble gas helium cannot generate detectable spectroscopic absorption in the photospheres of cool red giants; any 10830 A feature must arise in hot, disturbed outer chromospheres of these stars. Almost all lithium-rich, helium-active giants appear to be red clump objects; very few seem to be on the first-ascent red giant branch. The Li-He combination most probably results from lithium generation and envelope mixing during the otherwise unobservable helium flash. The Li-rich, He-strong stars are ones who must have experienced this internal cataclysm relatively recently. They probably are "young" helium-burning horizontal branch stars whose outer envelopes are trying to recover from the helium flash.

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Stellar observations (photometry and spectrometry)

Stellar Observations / 71

The peculiar abundances of fluorine in hydrogen-deficient stars (R)

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The production of the observed cosmic fluorine (F), a highly volatile element, is still shrouded in mystery. While debates rage between the Wolf Rayet stars and the AGBs being the possible sites of F production, a small group of peculiar stars show extreme F overabundances in their atmospheres, further deepening this mystery. These peculiar stars with F overabundances are a group of hydrogen-deficient stars, which are thought to result from a merger of two low mass double-degenerate white dwarves.
In this talk, I review the status of F abundances observed in various groups of H-deficient stars and how F abundance connects or disconnects them in a common evolutionary sequence. From the spectroscopic observational evidence and available theoretical calculations in literature, we also discuss that the low mass DD-merger events are also slowly gaining ground in explaining the F production among the well-accepted F formation scenarios.

Session:

Stellar observations (photometry and spectrometry)

Galactic Chemical Evolution / 62

Yields from AGB stars with a minimum of ad-hoc assumptions and free parameters, and the origin of carbon in the Galactic disk (R)

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The modelling of the chemical evolution and nucleosynhesis in galaxies is depending on a number of uncertainties, concerning stellar evolution with mixing in stars, stellar mass loss, galactic evolution with star-formation rates, mixing of populations, infall of pristine gas, etc.
These uncertainties are often handled by introducing free parameters which are varied in order to fit observations, in particular of abundance ratios and ages of solar-type stars.

More empirical approaches are explored in attempts to minimize the use of ad-hoc assumptions and parametrization. The methods are applied to the problem of the origin of carbon in the Galactic disk.

Session:

Stellar observations (photometry and spectrometry)

Galactic Chemical Evolution / **23**

The abundance of s-process elements: temporal and spatial trends from open cluster observations

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Spectroscopic observations of stars belonging to open clusters, with well-determined ages and distances, are a unique tool for constraining stellar evolution, nucleosynthesis, mixing processes, and ultimately galactic chemical evolution. Abundances of slow (s) process neutron capture elements in stars that retain their initial surface composition open a window into the processes that generated them. In particular, they give us information on their main site of production, i.e. the low- and intermediate-mass Asymptotic Giant Branch (AGB) stars.
In this contribution, I will review some observational results obtained during the last decade that contributed to a better understanding of the AGB phase: the growth of s-process abundances at recent epochs, i.e., in the youngest stellar populations; the different relations between age and [s/Fe] in distinct regions of the disc; and finally the use of s-process abundances combined with those of α elements, [s/α], to estimate stellar ages.
I will revise some implications that these observations had both on stellar and Galactic evolution, and our ability to infer stellar ages.

Session:

Stellar observations (photometry and spectrometry)

Galactic Chemical Evolution / **45**

Cerium in the Kepler and TESS fields

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In the era of Gaia and large spectroscopic surveys, an important missing ingredient to complete the Galactic archaeology is provided by stellar ages. A powerful method to infer precise age for field giant stars is obtained exploiting asteroseismic datasets collected by space missions such as Kepler/K2 and TESS. Thanks to these unprecedented constraints from asteroseismology, we can explore the orthogonal constraints offered by age and chemistry to infer the Milky Way formation and evolution.

In this talk, I will show the correlation of the only slow neutron capture element present in the APOGEE DR17 survey, Cerium, with the seismic ages from Kepler and TESS missions for a sample of red giant stars.I will also investigate the [Ce/α] ratios as chemical clocks, in order to maximise the correlation of these abundance ratios with age.

Finally, I will present the comparison between the observed age-chemical-composition trends and predictions from chemical evolution models, discussing how these novel observational constraints help us to understand the Cerium production in our Galaxy.

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Stellar observations (photometry and spectrometry)

Galactic Chemical Evolution / **33**

Galactic Archaeology with neutron capture elements

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The s-process nucleosynthesis in asymptotic giant branch stars impacts the enrichment of heavy elements. However, since Truran 1981, we know that the entire picture comprehends other actors, such as r-process events.
The electromagnetic counterpart of GW170817 has shown that neutron star mergers host an r-process production of neutron-capture elements, but are neutron star mergers the only events playing this role? At present, we have a poor understanding of the precise composition of the ejecta and the rate of these events.
We can find the answer to these questions in the fossil records provided by the spectra of the ancient stars of our Galaxy and its satellites. These observations coupled with chemical evolution models can improve the constraints on the nature of the first sources of neutron-capture elements, the r-process events and the first massive stars. Our findings support a scenario where at least a fraction of r-process events has exploded in a very short timescale.

Session:

Galactic Chemical Evolution

Galactic Chemical Evolution / **31**

Chemical enrichment in local galaxies as probed by star-formation driven outflows

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Galactic feedback driven by massive stars and active galactic nuclei (AGNs) plays a fundamental role in regulating galaxy evolution. Galaxies are filled with chemical elements and dust, released in their interstellar medium through different channels, e.g., supernova explosions, stellar winds. However, intense starburst episodes could generate strong outflows able to suppress star formation (SF) and to expel large amount of dust and metals out of the galaxies, enriching their circum (or even inter) galactic media. Therefore, the balance between the production and removal of such galactic components is of key importance to determine the fate of a galaxy. Although galactic outflows are common in high-redshift star-forming galaxies (SFGs) and quasars, local dwarf galaxies are particularly sensitive to feedback processes and offer a unique opportunity to study these phenomena in great details. Furthermore, efficient outflows are predicted by state-of-the-art chemical evolution models in such galaxies, in order to reproduce their observational properties. To test these expectations, we looked at outflow signatures in a sample of ~ 30 local dwarf SFGs as part of the Dwarf Galaxy Survey. We made use of spectroscopic Herschel/PACS archival data to search for atomic outflows in the broad wings of observed [CII]158 μm line profiles. We found that SF-driven outflows are typically less efficient than those from local AGNs, with mass-loading factors (i.e., the ratio between the outflow mass and star formation rate) slightly greater than unity. However, these findings could be underestimated up to a factor ~ 3 when accounting for the molecular and ionized gas phases. Direct constraints on the outflow efficiency in removing dust and metals from these sources are fundamental for a correct tuning of chemical models, in order to obtain new insights on the processes ruling the dust and metals growth and destruction in the interstellar medium of galaxies.

Session:

Galactic Chemical Evolution

Galactic Chemical Evolution / **36**

Chemistry around AGB stars: a theoretical sensitivity study (R)

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The outflows of AGB stars are rich astrochemical laboratories, with close to a 100 chemical species and some 15 newly formed dust grains detected so far. They host interesting and unique chemical regimes thanks to the large gradients in temperature and density throughout the outflow. Moreover, chemistry and dynamics are closely linked throughout the outflow, making the study of molecules especially interesting to retrieve the specific physical conditions within AGB outflows.

In this talk I will present the results of the first sensitivity study of chemistry in AGB outflows, using a 1D chemical kinetics framework. More specifically, we investigated the effect of the dynamics of the outflow, given by its density and temperature profile, on the chemistry of both C-rich and O-rich environments. I will focus on the envelope extents of parent species and compare to relations from

the literature resulting from observational studies. We find that specific combinations of chemical species can help constrain the temperature profile throughout the AGB outflow in observations, an often uncertain parameter.

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Galactic Chemical Evolution

Galactic Chemical Evolution / 44

Nucleosynthesis from massive-star groups (R)

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Massive stars are among the most-significant drivers of stellar feedback and chemical evolution, due to their short evolutionary time scale. Occurring typically in groups, their nucleosynthesis ashes are distributed in an interstellar surroundings that has been shaped by massive-star feedback. We will discuss what 26Al gamma-ray observations and related studies have taught us, and which questions remain to be addressed.

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Beyond Iron: Numerical models of s- and r-processes elements distribution

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We present here the results of high resolution (M_gas= 2.4x10^4 M_sun) Galactic Chemical Evolution (GCE) models of Milky-Way type galaxies. We restrict ourselves to "monolithic" models where the galaxy forms and evolves in isolation, i.e. we do not include any mergers nor tidal fields from neighboring galaxies. All our models start from redshift z=8 and we assume a flat CDM cosmology (Omega_lambda=0.71, Omega:m=0.29, h=0.69)
Using the results of more recent calculations of the enrichment of neutron-capture elements in low and intermediate mass stars, we predict the evolution of the distribution of s- and r-processes elements, particularly Barium and Europium.
We use a customized version of GIZMO, a very stable, numerically sophisticated code which has been recently tested in a wide variety of GCE projects. We discuss our customization of the public version of the code, which has mostly touched the inclusion of the yields for elements heavier than Fe, and of the contributions from Type II SNe's and neutron stars merging. Few critical issues have emerged from the treatment of the initial enrichment, a phase for which input from direct observations are absent.
We select two types of envionments from the numerical experiments: solar-neighborhood sites and

open clusters, the latter using an algorithm which selects regions based on local clustering inof disk stellar particles. We show that the final slope of the Eu and Ba distributions, like that of lighter species like Oxygen and Fe, is consistent with observations from surveys (APOGEE and Gaia), but the normalization is highly dependent on the initial enrichment. The enrichment history for solar neighborhood regions is highly affected by radial migration of stellar particles, up to redshift z~0.35, after which it tends to get stable.

Session:

Galactic Chemical Evolution

Nuclear Astrophysics / **2**

Unstable Isotopes of s-Process Origin: from very short-life to very long-life

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The s-process path involves unstable isotopes for each element.
After the discovery of live Tc-99 in the Red Giant RCor Bor star by Paul
Merrill in 1952, several have been found alive in meteorites, or through their extinct daughters trapped in microscopic Silicon Carbide grains.
We will dwell on the short-live Ca-41, Nb-92, Pd-107, Hf-182.
Then we will the origin of the stable isotope In-115 and on the s-only pair Lu176/Hf176, with Lu176 thermometer of the main s-process in AGB Stars, not a chronometer as believed before. Nuclear spectroscopy analysis by Franz Kaeppeler has been crucial.

Session:

Stellar nucleosynthesis