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Book of Abstracts

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Exploring the Origin of Light Heavy Elements: bridging experiments, theory, and observations

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The light heavy elements between strontium and silver, can be synthesized in a primary process in either neutron- (weak r-process) or proton-rich (νp-process) neutrino-driven outflows of explosive environments [1]. Constraining the nuclear physics uncertainties, for example the (α,xn) reaction rates in the weak r-process [2,3], allows us to investigate the conditions that create the light heavy elements, by comparing to the abundances of Galactic metal-poor stars. In addition, the study of presolar stardust grains (SiC) can also reveal signatures of neutrino-driven nucleosynthesis in the Galaxy [4]. We have used an extensive library of astrophysical conditions of both neutron- and proton-rich neutrino-driven outflows, as well as combinations of the two to reproduce the abundance patterns observed in metal poor stars with enhanced light neutron-capture element production, such as HD 122563 (Honda star)[5]. Our preliminary results suggest that there are specific combinations of astrophysical conditions that can reproduce the light heavy elemental abundances observed in such stars.

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The Photometric Revolution – Stellar Parameters and Elemental Abundances for over 50 Million Stars … and Counting

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Galactic Archaeologists are opening a revolutionary era for the determination of stellar parameters, such as effective temperature, surface gravity, metallicity, and ages, for a substantial fraction of the stars in the Milky Way, and eventually in dwarf galaxies and other nearby galaxies of the Local Group. The most recent surveys implement a combination of narrow- and intermediate-band filters that further enable measurements of a subset of the most important elements for probing stellar populations, in addition to [Fe/H], such as [C/Fe], [N/Fe], [Mg/Fe], and [Ca/Fe]. The recently (or nearly) completed surveys, including the SkyMapper Southern Survey (SMSS) and The Stellar Abundances for Galactic Exploration Survey (SAGES) in the North, have already contributed over 50 million stars with estimates of [Fe/H]. The ongoing Javalambre Photometric Local Universe Survey (J-PLUS) and the Southern Local Universe Survey (S-PLUS) will contribute another 25 million stars with additional elemental abundances over the next two years. For those who hunger for the most chemically primitive stars, we have already identified over 1 million Very Metal-Poor stars with [Fe/H] < -2.0, and over 50,000 Extremely Metal-Poor stars with [Fe/H] < -3.0. Extension of these techniques to other large-scale surveys in the future will also be discussed.

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The R-Process Alliance - mapping the r-process with stellar abundances

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How to make gold and silver? -The long-sought-after answer to this question remains one of the most challenging open problems that tie together nuclear physics with astronomy. Heavy elements like gold and silver are produced in the so-called rapid neutron-capture process (r-process). This process only occurs in rare explosive events in the Universe like supernovae (SNe) and neutron star mergers (NSMs), making it hard for astronomers to gather direct observations of the element creation. Likewise, it is difficult for nuclear physicists to recreate and study the nuclear process in the laboratory. These obstacles are why we today, six decades after the theoretical prediction of the r-process, still do not know how or at which astrophysical sites gold and silver are made. However, in 2016 the R-Process Alliance (RPA) initiated a successful new search to uncover bright metal-poor halo stars with r-process element enhancements. These stars are excellent laboratories for studying the r-process as the gas from which these stars formed was polluted by at most a few enrichment events — perhaps even a single explosion. To date, the RPA has collected spectra of ~2000 stars and discovered over 70 new highly r-process enhanced. I will report on RPA efforts over the past six years and plans for the future, including ways this stellar sample can help constrain the astrophysical site(s) of the r-process.

Stellar abundances and nucleosynthetic sources / **2**

Surface abundances of hot subdwarfs

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Hot subdwarfs are small, blue stars with unusual surface chemistries. Some have almost no hydrogen, and many have elevated heavy metal abundances. They are thought to form through binary interaction, with different formation channels enriching the end products with different species. I will describe helium-rich hot subdwarfs formed through white dwarf collision, which leads to nitrogen or carbon enriched products. I will also describe some of the mixing processes thought to affect the surface abundances of hot subdwarfs.

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Measurement of the bound-state beta decay of bare Thallium-205 ions and its nuclear astrophysical implications

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We present the results of the first-ever direct measurement of the bound-state beta decay [1] of $^{205}\mathrm{Tl}^{81+}$ ions, an exotic decay mode where an electron is directly created in one of the empty atomic orbitals instead of being emitted into the continuum. One of the most awaited and pioneering experiments was realized in the spring beamtime at GSI, Darmstadt in 2020, wherein the entire accelerator chain was employed. $^{205}\mathrm{Tl}^{81+}$ ions (completely devoid of electrons) were produced with the projectile fragmentation of a $^{206}\mathrm{Pb}$ primary beam on a $^{9}\mathrm{Be}$ target, separated in the FRagment Separator (FRS), accumulated, cooled, and stored for different storage times (up to 10 hours) in the Experimental Storage Ring (ESR). The experimentally measured half-life value [2] draws a significant deviation from the theoretically predicted values [3,4], which could influence our understanding of the abundance of chemical elements in the early universe. In this contribution, the authors aim to present the *s*-process motivation and a preliminary value of the $^{205}\mathrm{Tl}^{81+}$ half-life.

This research has been conducted in the framework of the SPARC, ILIMA, LOREX, NucAR collaborations, experiment E121 of FAIR Phase-0 supported by GSI. The authors received support from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (Grant Agreement No. 682841 "ASTRUm").

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An Abundance Study of Faint Metal-Poor Stars in the R-Process Alliance observed by the GTC

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Several enigmatic questions have come up on the formation and chemical evolution of the Milky Way over the last decade. The detailed chemical abundances of the old, long-lived, metal-poor halo stars provide insights into the nature of the early chemical enrichment events leading to the formation of the metals as we see them now in the universe. In this talk, I will present a study on the detailed chemical abundances of very faint and extremely metal-poor stars from the R-process Alliance using the GTC. Here, we discuss the detailed abundances of light, alpha, Fe-peak and r-process elements of the faintest RPA sample of stars. The over-abundance of carbon for the most metal-poor stars indicates mixing and fallback type of supernova as the primary progenitor. We use the alpha elements to demonstrate that massive stars were the most likely progenitors at the lowest metallicities. We also identify stars of globular cluster origin at very low metallicities (Fe/H ~ -3.0) using the light element anticorrelation, which suggests further lowering the metallicity floor of GCs and revisiting the Galactic chemical evolutionary models. The neutron capture elements (Sr, Ba and Eu) could be measured, and several new R-process Enhanced stars have been identified for follow-up studies. We have also used the astrometric parameters from Gaia to obtain the kinematics of all the stars to understand the nature of their origin in the Galaxy. Thus we derive the complete chemo dynamical history of the stellar population in this study.

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Asteroseismology reveals a unique anchor point for calibrating interior rotation, mixing and angular momentum transport in massive stars

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Massive stars are progenitors of neutron stars and black holes, and through their winds and supernova explosions dictate the chemical and energetic feedback of galaxies. During the hydrogen-core burning phase the convective cores of massive stars act as engines that drive stellar evolution, but inferences of core masses are subject to unconstrained boundary mixing processes. Moreover, uncalibrated chemical and angular momentum transport mechanisms can lead to unwieldy mixing and rotation profiles. Ascertaining the efficiency of these transport mechanisms is challenging because of a lack of observational constraints. However, thanks to the ongoing TESS mission and our development of modern asteroseismic modelling techniques for massive stars, we deduce a precise convective core mass and robustly demonstrate non-rigid radial rotation in a supernova progenitor. In this talk, I present the results of combining TESS photometry, high-resolution spectroscopy, and Gaia astrometry for a main-sequence massive star pulsator. We measure its mass, core mass, and age to better than 15% precision which is unprecedented. Using asteroseismic modelling of rotational multiplets, we also infer its core to be rotating approximately 1.5 times faster than its envelope. This pulsating massive star represents a truly unique anchor point for calibrating the interior rotation, mixing and angular momentum transport processes within massive stars.

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Chemical abundance as a tracer of galaxy assembly and the star formation history of the Universe

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Metals are produced in galaxies as a result of processes associated with the stellar life cycle and will accumulate as galaxies assemble their stellar mass. The metal content of galaxies therefore provides a fossil record of the history of star formation, but also feedback and galaxy-scale gas flows. Measuring chemical abundances in galaxies are thus a powerful tracer of the assembly of stellar mass in the Universe across cosmic time.

However, chemical abundances are challenging to measure accurately. Historically these have largely been limited to galaxies at relatively low redshifts, sampling more recent cosmic history. Meanwhile, constraints have been very limited at early cosmic times when the first stars and galaxies are forming. With the advent of JWST, however, we can now make these measurements out to very large cosmic distances, probing to within a few hundred million years after the Big Bang. In this talk I will present the context into which these latest JWST results fit, as well as some of the early findings from chemical abundances studies with JWST.

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Simba-C: An updated chemical enrichment model for galactic and intragroup/cluster chemical evolution

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We introduce a new chemical enrichment and stellar feedback model into GIZMO, using the SIMBA sub-grid models as a base. Based on the state-of-the-art chemical evolution model of Kobayashi et al., SIMBA-C tracks 34 elements from H⟶Ge and removes SIMBA's instantaneous recycling approximation. Furthermore, we make some minor improvements to SIMBA's base feedback models. SIMBA-C provides significant improvements on key diagnostics such as the knee of the z = 0 galaxy stellar mass function, as well as providing a better match to recent observations of the mass-metallicity relation at z = 0,2. By not assuming instantaneous recycling, SIMBA-C provides a much better match to galactic abundance ratio measures such as [O/Fe] and [N/O]. Therefore, our new model allows for much more accurate galactic chemical evolution tracking through cosmic time in the simulation. We also demonstrate the impact that these newly created metals have on the global scaling relation of various X-ray properties (luminosity, temperature, mass, entropy, etc.) of different large-scale environments such as groups and clusters, and their evolution through cosmic time.

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Searching for a possible nuclear solution to the O-Na anti-correlation problem at LUNA

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Globular clusters (GC) constitute a rather unique probe of galactic and stellar evolution theory, but their formation and peculiar chemical patterns are still not completely understood.
The most striking feature is the presence of multiple stellar populations, showing strong star-to-star variations in light element abundances. The distribution of heavier elements is instead constant across different stellar generations, making a contribution to their formation from supernovae-processed material unlikely.
One of the strongest GC formation models suggests that new stars are produced from matter processed by nuclear burning cycles and slowly ejected during the AGB phase, while supernova explosions violently sweep nebulae out of the GC, hindering further star formation.
This model explains many GC observables, but fails in predicting the observed O depletion and Na enrichement, the so-called O-Na anti-correlation.
A possible nuclear solution to this long-standing issue could be a $^{23}\mathrm{Na}(\mathrm{p},\alpha)^{20}\mathrm{Ne}$ reaction rate a factor 2 to 5 lower than currently assumed.
This reaction is responsible for Na destruction and is dominated by a narrow resonance at E_{CM}=133 keV, never observed before.
Tentative upper limits for its strength have been placed depending on the unknown proton momentum transfer value I_p, carrying five orders of magnitude of uncertainty. After a first unsuccessful study, no attempts at direct measurement have been made, since the expected event rate is too low to be detectable on Earth's surface.
At LUNA (\textit{Laboratory for Underground Nuclear Astrophysics}), exploiting the combination of its known background reduction and the high proton beam intensities achievable, it will be possible to measure the strength of this resonance over a few months.
As part of the ELDAR project (UKRI ERC StG), a new array of silicon detectors has been specifically designed to detect charged particles at LUNA and its commissioning will begin in the next months. We are also exploring new production procedures for sodium targets, in collaboration with \textit{Laboratori Nazionali di Legnaro} (Italy), to reduce their sensitivity to humidity and improve their stability under beam bombardment.
The extensive experimental campaign will allow us to perform a deep study of the $^{23}\mathrm{Na}(\mathrm{p},\alpha)^{20}\mathrm{Ne}$, with a particular focus on the resonance that could possibly solve the GC puzzle.

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Stellar Abundances of the Center of Early Type Galaxies with Fine Structure

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Studies of the chemical evolution of stellar populations in distant galaxies have improved in the past decade with the advance of large galaxy surveys and telescopes that provide high signal-to-noise spectra that can then be analyzed with improved full-spectrum fitting techniques. Using high resolution spectra taken at the centers of elliptical galaxies, I obtain ages, central velocity dispersions, and abundance ratios relative to Fe of elements from various nucleosynthesis processes such as the CNO, α-elements (Mg, Si, Ca, Ti), Fe-peak elements (Cr, Mn, Co, Ni, Cu), and the neutron capture elements (Sr, Ba, and for the first time Eu). I apply full-spectrum fitting techniques to three early-type galaxies (ETGs) NGC 2865, NGC 3818, and NGC 4915, which belong to an interesting subset of elliptical galaxies that have distinct, stellar substructures that indicate late, major merger activity. In this talk I will discuss how, using the chemical abundances of the stellar populations that make up these ETGs, a range of galactic chemical evolution scenarios could emerge and be impacted by the major mergers. Additionally, I will highlight how the derived stellar abundances suggest that ETGs with fine structure can form via multiple pathways.

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Exploring High-Redshift Epochs with BEAGLE-AGN and JWST

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The first months of JWST science operations have brought forward multiple AGN candidates in the early universe. Acquiring high quality spectra across such epochs is imperative for constraining how early universe galaxy populations may have existed, and can help explore the nature of their stellar populations, in addition to AGN components if present. Dedicated study of such high-redshift sources yields opportunities to add to this picture, and may additionally contribute to discussions of AGN feedback in early Universe galaxies, as well as metal enrichment during the epoch of reionization.

One instance relating to these endeavours is the study of SMACS S06355, a galaxy at redshift z = 7.66 with potential NeIV emission (Brinchmann (2023)), which cannot be produced by star formation alone. This talk will present a further spectroscopic analysis on this galaxy, through use of spectral analysis and the SED fitting code BEAGLE-AGN (Vidal-García, Plat & Curtis-Lake et al. (2022)), the AGN extension of the code BEAGLE (BayEsian Analysis of GaLaxy sEds; Chevallard & Charlot (2016)). This tool is able to characterise Type II AGN by retrieving physical parameters of the narrow line region.

The application of this to SMACS S06355 therefore allows us to extract information about the galaxy in relation to its AGN based attributes as well as its star formation, in a simultaneous manner. These include both AGN and HII region metallicities, ionisation parameters and SFR. Paired with high-redshift sources, these methods present exciting opportunities to characterise AGN and star-forming components concurrently in some of the most pivotal epochs of the Universe's lifetime.

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Evidence and implications of enhanced O/Fe abundance ratios in high-redshift star-forming galaxies

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The growth of galaxies across cosmic time is regulated by a variety of processes, such as the formation of stars from the infall of new gas, the processing of gas into heavier elements within stars, and the release of this enriched material when stars die. By exploring the chemical content of galaxies at different cosmic epochs, we can constrain the mechanisms by which galaxies evolve. In addition, specific element abundance ratios can be used to constrain the rate of enrichment via different physical processes (e.g., CCSNe vs Typa Ia SNe), yielding insights into star-formation and chemical enrichment timescales. Previously, almost all observations at high redshifts (z>2) were sensitive only to the oxygen abundance (O/H). However, new developments in the analysis of deep UV spectra now enable the measurement of iron abundances (Fe/H) at these redshifts. In this talk, I will present measurements of the O/Fe ratio for star-forming galaxies at z=3.5. Our results show evidence for enhanced O/Fe ratios (relative to the solar value) as expected for young systems in the early Universe. I will also present a comparison between our observations at z=3.5 and stellar archaeology measurements of stars in the Milky Way. Finally, I will discuss the implications of our results with respect to modelling the stellar populations of galaxies at z > 2.

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Metallicities from nearby galaxies to the First galaxies

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Metallicity is a fundamental physical property that strongly constrains galaxy formation and evolution. The formation of stars in galaxies is highly impacted by metal production and energy release from supernova explosions, which suppresses star formation by generating outflows and evaporating star-forming clouds. However, this process - supernova feedback - is uncertain. We thus include different feedback methods and parameters by ejecting energy in thermal, kinetic, stochastic and mechanical forms into our state-of-the-art cosmological simulations. Our code (based on Gadget-3) includes the latest nucleosynthesis yields for all stellar mass ranges, Type Ia supernovae, and also the First stars so that our predicted abundances are comparable to the observations of the First galaxies. For each feedback scheme, we predict the evolution of stellar mass-metallicity relations for stars and interstellar medium. We aim to constrain the feedback method by comparing it with observational data from the James Web Space Telescope (JWST).

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Understanding the Chemical Abundance Patterns of nearby Star-Forming Galaxies with CLASSY

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Nebular emission lines are a powerful diagnostic tool for tracing the chemical evolution in star-forming galaxies (SFGs) across cosmic time. The COS Legacy Spectroscopy SurveY (CLASSY) is a treasury survey that comprises UV+optical spectra of 45 local SFGs covering a broad range of physical properties in terms of gas-phase metallicity, ionization parameter, star-formation rate, and stellar mass. In this study, we present an analysis of the abundance patterns of N/O, Ne/O, Cl/O, S/O, and Ar/O vs. O/H and their relationship with different galaxy properties (e.g., stellar mass and star-formation rate). We found that such abundance ratios show a constant trend with O/H as expected, except for Ne/O and Ar/O at high metallicities. We discuss the scatter involved in the N/O versus O/H relation and its connection with the different UV+optical observables. Finally, we compare the abundance patterns of CLASSY with the results of z > 6 galaxies observed with the JWST.

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iMaNGA: a virtual IFU survey based on Illustris hydro-dynamical simulations

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In the iMaNGA project we use a forward-modelling approach to directly compare predictions from hydro-dynamical cosmological simulations of galaxy formation with observations. We introduce a method to generate mock SDSS-IV/MaNGA integral-field spectroscopic galaxy observations from the simulations focusing on IllustrisTNG and TNG50. We generate a theoretical catalogue of 1,500 mock MaNGA galaxies for the direct comparison with observational results obtained with MaNGA data, investigating the dependence of radial gradients in age and metallicity on galaxy morphology, stellar mass, stellar surface mass density, and environmental density. The key point of our analysis is that the observational biases plaguing the interpretation of MaNGA data are emulated in the theoretical iMaNGA sample. It turns out that the cosmological simulations recover the basic stellar population properties, age and metallicity, well overall. We identify interesting differences between simulations and observations in some key aspects, however, that can inform further development of the simulations and their theoretical framework.

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Impact of newly measured 26Al(n, p)26Mg and 26Al(n, α)23Na reaction rates on the nucleosynthesis of 26Al in stars

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The cosmic production of the short-lived radioactive nuclide ^{26}Al is crucial for our understanding of the evolution of stars and galaxies. However, simulations of the stellar sites producing ^{26}Al are still weakened by significant nuclear uncertainties. We re-evaluate the ^{26}Al(n, p)^{26}Mg and ^{26}Al(n, α)^{23}Na ground state reactivities from 0.01 GK to 10 GK, based on the recent n_TOF measurement combined with theoretical predictions and a previous measurement at higher energies, and test their impact on stellar nucleosynthesis.
We computed the nucleosynthesis of low- and high-mass stars using the Monash nucleosynthesis code, the NuGrid mppnp code, and the FUNS stellar evolutionary code. Our low-mass stellar models cover the 2-3 $M_\odot$ mass range with metallicities between Z=0.01 and 0.02, their predicted ^{26}Al/^{27}Al ratios are compared to 62 meteoritic SiC grains. For high-mass stars, we test our reactivities on two 15 $M_\odot$ models with Z=0.006 and 0.02.
The new reactivities allow low-mass AGB stars to reproduce the full range of ^{26}Al/^{27}Al ratios measured in SiC grains. The final ^{26}Al abundance in high-mass stars, at the point of highest production, varies by a factor of 2.4 when adopting the upper, or lower, limit of our rates. However, stellar uncertainties still play an important role in both mass regimes.
The new reactivities visibly impact both low- and high-mass stars nucleosynthesis and allow a general improvement in the comparison between stardust SiC grains and low-mass star models. Concerning explosive nucleosynthesis, an improvement of the current uncertainties between T9∼0.3 and 2.5 is needed for future studies

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The differential cross section of the 13C(a,n) reaction

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Neutrons are naturally produced here on earth and in stellar environments through (α, n) reactions. During helium burning in massive stars, the slow neutron capture process (s-process) is fueled by (α, n) reactions on light nuclei like ^{13}C and ^{22}Ne, and may also be influenced by reactions on ^{17,18}O and ^{25,26}Mg. Here on earth, radioactive decays from long-lived actinides produce a constant source of α-particles, which then capture on ^{13}C and ^{17,18}O producing a constant source of neutrons. The flux is low, but is of a similar level that these neutrons are often significant background sources for ton scale neutrino, dark matter, and double β-decay experiments. In this talk I will focus on the study of the $^{13}\mathrm{C}(\alpha, n)^{16}\mathrm{O}$ reaction, where new experimental measurements have been reported at both the LUNA and JUNA underground facilities, reaching to unprecedentedly low energies. These measurements have been found to be consistent with past R-matrix extrapolations, constrained by transfer reaction determinations of the dominant subthreshold resonance strength, where the cross section were predicted to be lower than previous above ground measurements indicated. To further reduce the uncertainty, differential cross sections, spanning the laboratory α-particle energy range from 0.8 to 6.5~MeV were measured at the University of Notre Dame Nuclear Science laboratory. The measurements were made in approximately 10~keV energy steps at 18 angles between 0 and 160°, resulting in over 700 distinct angular distributions. These measurements are also the first differential measurements to extend below 1~MeV. We use these new data to augment the previous state-of-the-art R-matrix fit of the low energy $^{13}\mathrm{C}(\alpha, n)^{16}\mathrm{O}$ reaction and use Bayesian uncertainty estimation to demonstrate that the differential data decreases the uncertainty by a factor of two, from ≈10\% to ≈5\% over the energy region of astrophysical interest.

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Summing technique for γ-process nucleosynthesis

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The γ-process is a nucleosynthesis scenario that occurs during an explosion of a supernova and produces the proton-rich isotopes of elements between Se and Hg. The γ-process involves series of (γ,n), (γ,p) and (γ,α) reactions on pre-existing s-process seed nuclei. The reactions relevant for the γ-process can be studied in the laboratory via the inverse ones: the capture of protons or α-particles. For these measurements, the High EffCiency TOtal Absorption SpectrometeR (HECTOR) was developed at the University of Notre Dame.

HECTOR is a NaI(Tl) summing detector comprised of 16 separate NaI(Tl) crystals, each read by 2 photomultipliers. The array is designed for precision cross section measurements for (p,γ) and (α,γ) reactions across the γ-process Gamow window. The summing efficiency is a function of the total γ-ray energy and the average γ-ray multiplicity: for the ^{60}Co, source it is 52.7 (2.0)% and for typical cross section measurements it ranges between 20-30%.

Here, an overview of the recent results obtained with HECTOR for A~100 mass region will be presented. The experimental data will be compared to the Hauser-Feshbach model calculations using the Talys code and will be used to constrain the inputs for Talys to best reproduce the experimental data in the A~100 mass region.

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Nuclear reaction measurements at the CRYRING using CARME

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The CRYRING array for reaction measurements (CARME) is a charged particle detector array installed at the CRYRING storage ring designed to perform nuclear reaction measurements directly at stellar energies, and indirect studies of key nuclear properties. Heavy-ion beams are circulated around the ring and interact with an ultra-thin gas-jet target. The reaction products are detected by four, highly segmented, double-sided silicon detectors installed directly under XHV vacuum (10-12 mbar) with no pockets or windows. Measurements can be complex as the detectors are required to move in and out of the beam axis regularly to avoid un-cooled beam when it is first injected into the ring. In 2022, CARME was successfully commissioned and the experimental procedures for reaction measurements using this methodology have been developed. This measurement was the first use of the internal gas target, the first beam on target and the first observation of nuclear reactions at the CRYRING and acts as a launch pad for the exciting physics programme ahead.
In this talk, I will present the astrophysical motivation and experimental details of several of the measurements part of this future programme

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Underground Measurements of the 16O(p,γ)17F Reaction at LUNA

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The 16O(p,γ)17F reaction is the slowest proton-induced reaction in the CNO cycle [1]. This is due to the fact that at energies of astrophysical interest it has no resonances, making it an example of a pure direct capture reaction [2]. The ratio of 16O/17O in stars depends strongly on the rate of this reaction. This ratio is an important probe of nucleosynthesis and mixing processes in the interior of stars, as it can be measured directly [3]. At astrophysical energies, i.e. centre of mass energies below around 500 keV, there is little experimental data for this reaction, and the data that exists tends to have relatively large uncertainties [4]. In addition, Bayesian estimations of the reaction s-factors carried out by Iliadis et al. in [4] do not closely match the low energy experimental data, particularly for direct capture to the ground state.
An experimental campaign has been carried out at the LUNA underground accelerator at Gran Sasso National Laboratory in Italy, aiming to measure the cross section for 16O(p, γ)17F. The very low background in the underground laboratory combined with lead shielding allows for direct measurements of this weak reaction to be carried out. Protons were accelerated onto a tantalum oxide target, and the resulting prompt gamma rays were detected using two cerium bromide scintillators and a high-purity germanium detector.
I will report on the characterisation of the setup and the data that has been taken.

[1] C. Iliadis, Nuclear Physics of Stars, 2007
[2] C. Iliadis et al., Phys. Rev. C 77 (2008) 045802
[3] T. Lebzelter et al., arXiv:1504.05377 [astro-ph.SR] (2015)
[4] C. Iliadis et al., Phys. Rev. C 106, 055802

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Retracing transient genealogies with BPASS

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One of the key sources of new elements in the Universe is the explosion of massive stars (core collapse supernovae) and their remnants (kilonovae). Understanding the stars that led to these explosions, and the evolutionary steps they must have followed, is essential to constructing a detailed picture of how our Universe was enriched over cosmic time. In this talk I will present two approaches by which this topic can be tackled using the results from the Binary Population And Spectral Synthesis (BPASS) code. First I will present the methods by which we can retrace the evolutionary steps of individual observed transients (e.g GW170817); secondly I will present recent results obtained from combining the BPASS data and cosmological simulations to obtain transient rate predictions across cosmic time. I will conclude with current challenges and necessary next steps required to push these research streams in the next few years

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3D Simulations of a Rotating, Magnetic Supernova Progenitor

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In recent years, it has become apparent that realistic, 3D progenitors can play an important role in the explosions of neutrino-driven core-collapse supernovae. While 3D shell convection simulations have been performed for a number of progenitors, thus far, tests haven't been done for magnetorotational supernova progenitors. These progenitors are expected to be very rapidly rotating and strongly magnetic, and are expected to end their lives in a hypernova explosions.
In this talk, I will present a first 3D magnetohydrodynamic (MHD) simulation of oxygen, neon and carbon shell burning in a rapidly rotating $16M_{\odot}$ core-collapse supernova progenitor. I will present key results of this work and discuss their implications on stellar evolution calculations as well as the subsequent supernova explosion.

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The survey of Planetary Nebulae in the Andromeda Galaxy: Constraints on the recent formation history of M31 from PN chemodynamics and GCE models

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Through the survey of Planetary Nebulae (PNe) in M31 with Megacam@CFHT, we identify ~5000 PNe in M31 with ~1200 having spectroscopic observations from Hecospec@MMT (~300 of which also have chemical abundance measurements). We find the kinematically and chemically distinct thin and thick discs of M31, as well as the kinematics of its inner-halo substructures. Of particular note, we find that the [Ar/H] vs [O/Ar] plane for emission line nebulae is analogous to the [Fe/H] vs [α/Fe] plane for stars, and exploration of the M31 PN population in this plane (with GCE models) allowed us to constrain the chemical enrichment and star formation history of the thin and thick disc in M 31 (that contrast that of the MW). Using PNe as chemodynamical probes and from GCE models, we infer that majority of the stellar population in the M31 disc was formed at very early times, and was disrupted by a wet major (mass ratio ~ 1:5) merger ~2.5-4 Gyr ago to form the thick disc while the thin disc was reformed in a burst (including relatively metal-poor gas brought in by the satellite) following the merger. We also obtain important constraints on the properties of the cannibalized satellite.

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Indirect Neutron-Capture Constraints for the Astrophysical i-Process

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Neutron-capture nucleosynthesis occurs via a variety of processes depending on the astrophysical sites and conditions. Recent observations and stellar evolution models of carbonenhanced metal poor stars (CEMP) and Rapidly Accreting White Dwarf stars (RAWDs) suggest that an intermediate process, known as the i-process, exists between the traditional s- and r-processes, and is necessary to explain observed abundances in these environments. i-process nucleosynthesis is impacted by various nuclear data inputs, of which the main source of uncertainty arises from neutron-capture reaction rates. Direct neutron-capture measurements are only feasible for long-lived nuclei, while for short-lived nuclei, indirect techniques are required. In this presentation, I will discuss indirect neutron-capture techniques that have been developed over the last few years, namely the β-Oslo method and the Surrogate Reaction method, and how they can be applied across the nuclear chart at radioactive beam facilities such as the Facility for Rare Isotope Beams, CARIBU at Argonne National Laboratory, and TRIUMF to address i-process nucleosynthesis and beyond.

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The impact of binary stars on the dust and metal evolution of galaxies

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At the BRIDGCE meeting last year, I presented the technical implementation of the binary stellar evolution (BSE) code, BINARY_C, into the cosmological-scale galaxy evolution simulation, L-GALAXIES. This implementation is now fully complete, providing us with a set of comprehensive final results describing the impact of binary stars on the dust and metal evolution of galaxies (Yates et al., submitted), which I will present in this talk.

First, I will present the effect of BSE on the key scaling relations for galaxies. We have found that binaries have a negligible impact on the stellar mass function, HI mass function, and star formation rates of galaxies, iff the total mass ejected by massive stars is unchanged. This is because massive stars determine the strength of supernova feedback, which in turn regulates galaxy growth. Binaries do noticably enhance the enrichment of carbon and nitrogen through common envelope ejection, although heavier alpha elements are more affected by the choice of SN-II yields than binary effects.

Second, I will show how this new L-GALAXIES simulation reproduces the observed dust-to-metal (DTM) and dust-to-gas (DTG) ratios for galaxies back to z ~ 4, especially with binaries included and unlike many other cosmological-scale simulations. This is chiefly due to shorter dust accretion timescales in dust-rich environments. Dust masses are still under-predicted at z > 4 in L-GALAXIES however, as in most other simulations, highlighting the need for enhanced dust production at early times.

Third, on sub-galactic scales, we find very good agreement between L-GALAXIES and observed dust and metal radial profiles in galaxies at z = 0. A drop in DTM and DTG ratios is also found in diffuse, low-metallicity regions, contradicting the common assumption of universal values.

I will finish by highlighting the wide range of future avenues of investigation that are opened-up by the inclusion of BSE into cosmological-scale simulations. These include precisely tracking rare transient events, s- and r-process element production, and the complex chemistry of the Milky Way disc and stellar halo.

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Close Hierarchical Triples and Tertiary Tides

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In recent years, close hierarchical triples have been shown to be increasingly important when it comes to understanding many astrophysical phenomena, including but not limited to SNe Ia and BBHs. However, our understanding of them is yet incomplete. This talk will focus on a recently-discovered tidal process that is active in these systems, and its implications on stellar evolution will be discussed.

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Stellar Wind Yields of Very Massive Stars

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The most massive stars provide an essential source of recycled material for young clusters and galaxies. While very massive stars (VMS, M>100 M⊠) are relatively rare compared to O stars, they lose disproportionately large amounts of mass already from the onset of core H-burning. VMS have optically thick winds with elevated mass-loss rates in comparison to optically thin standard O-star winds. We compute wind yields and ejected masses on the main sequence, and we compare enhanced mass-loss rates to standard ones. We calculate solar metallicity wind yields from MESA stellar evolution models in the range 50 – 500 M⊠, including a large nuclear network of 92 isotopes, investigating not only the CNO-cycle, but also the Ne-Na and Mg-Al cycles. VMS with enhanced winds eject 5-10 times more H-processed elements (N, Ne, Na, Al) on the main sequence in comparison to standard winds, with possible consequences for observed anti-correlations, such as C-N and Na-O, in globular clusters. We find that for VMS 95% of the total wind yields is produced on the main sequence, while only ~ 5% is supplied by the post-main sequence. This implies that VMS with enhanced winds are the primary source of 26Al, contrasting previous works where classical Wolf-Rayet winds had been suggested to be responsible for Galactic 26Al enrichment. Finally, 200 M⊠ stars eject 100 times more of each heavy element in their winds than 50 M⊠ stars, and even when weighted by an IMF their wind contribution is still an order of magnitude higher than that of 50 M⊠ stars.

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Stellar Evolution in the PI Gap

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Traditionally, the lower edge of the Pair Instability (PI) mass gap was firmly established to occur at masses of 50 $M_\odot$. This assumption has been questioned with recent Gravitational Wave (GW) observations, which has shown that there are black holes (BHs) present above the 50 $M_\odot$ limit, prompting questions on how this occurs. We present stellar evolution models for massive single stars which retain a large Hydrogen envelope at low (10-3 - ZSMC) metallicity and can remain dynamically stable without PI. Using these models, we produce fits for the core mass and final mass, and find that the maximum BH mass before PI is ~ 90 $M_\odot$. Additionally, we independently calculate critical core mass values using the Γ1 criterion. Finally, we use the aforementioned fits to produce a small population synthesis and show that we should expect to see many more BHs towards the lower edge of the traditional PI gap due in part to the Initial Mass Function (IMF), but also the same stellar interior physics which sets the maximum.

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More realistic 1D classical-nova models

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Classical-nova outbursts are thermonuclear explosions in the accreted envelope of a white dwarf in a close, mass-transferring binary system. Three-dimensional nova studies show that temperature fluctuations during the explosions cause dredge up of white-dwarf material that enriches nova ejecta up to about 60% metals. Conventionally, white-dwarf-envelope interface mixing is not modelled in 1D simulations of novae. Instead, pre-mixed material is accreted resulting in a less-massive envelope at explosion. In this talk I will present an imposed-diffusive mixing method of WD-envelope mixing during a nova's thermonuclear runaway, as developed for MESA by Arman Aryaeipour in his PhD.

With this method, Solar-composition material is accreted then mixing is parameterized based on 3D hydrodynamics. We construct a parameter space of nova outbursts to investigate the impact of WD mass, composition and mixing on key nova features and nucleosynthetic yields. We show that realistic multiple outbursts differ from individual explosions, and that our novae eject 1-2 orders of magnitude less beryllium-7, hence less lithium-7, than predicted in the literature, disagreeing with idea that novae make much Galactic lithium. The uncertainties are large but now quantifiable, with variable accretion rates and chemical diffusion at the white-dwarf-envelope interface leading to a wide range of ejected metallicities, sometimes up to 50%, much of which can be lithium-7.

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Investigating Potential Observational Signatures of Type Ia Supernovae through Monte Carlo Radiative Transfer Simulations

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Type Ia supernovae (SNe Ia) play a key role in cosmic nucleosynthesis and serve as cosmological distance indicators. There is consensus that SNe Ia originate from the thermonuclear explosions of white dwarfs (WDs) but the explosion mechanism(s) that produce them are still not understood. In this talk I will focus on potential observational signatures for two different SNe Ia explosion scenarios, which provide a critical test for whether these scenarios should be supported or ruled out as explanations for SNe Ia. I will first discuss the pure deflagrations scenario for Chandrasekhar mass carbon-oxygen (CO) WDs, suggested as the most promising explanation for the most numerous, peculiar sub-class of SNe Ia, known as type Iax supernovae (SNe Iax). Many pure deflagration models do not fully unbind the WD leaving behind a remnant polluted with a significant amount of ^{56}Ni, which is therefore expected to be luminous. Such a luminous remnant has also been suggested to have been observed for multiple SNe Iax. Previous studies of pure deflagration models have not however accounted for luminous remnants in early time radiative transfer simulations, possibly explaining why the model light curves decline significantly too quickly after peak compared to observed SNe Iax. In this talk I will present radiative transfer simulations for a selection of models from our pure deflagration sequence in which the contribution from a luminous remnant is included. I will comment on how the inclusion of a luminous remnant impacts comparisons with observed SNe Iax and the implications of including this potential observational signature of pure deflagration models on their case as the explanation for the SNe Iax sub-class. Another leading theoretical model for SNe Ia is the "double-detonation" scenario in which the explosion of a CO WD is triggered by ignition of a surface layer of helium. Recent simulations have demonstrated that double detonation models have the promise to account for SNe Ia across a range of luminosities including normal and peculiar SNe Ia (but not SNe Iax). Additionally, several observed SNe Ia have been suggested to arise from this

scenario. A defining property of double detonation models is unburnt helium in their outer ejecta – determining whether this helium should produce observable signatures is therefore a critical test of this scenario. Our group recently published results from a radiative transfer simulation of a double detonation model in which a full NLTE treatment of the plasma conditions was utilised, enabling potential helium features to be accurately simulated. I will summarise the key findings of this study, in particular commenting on the helium features predicted by the simulations, their comparisons with observations and the potential of helium spectral features as a possible observational signature of the double detonation scenario.

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Vote of Thanks and Explosive Closing Remarks

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Neutrons / 18

Indirect Neutron-Capture Constraints for the Astrophysical i-Process

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Neutron-capture nucleosynthesis occurs via a variety of processes depending on the astrophysical sites and conditions. Recent observations and stellar evolution models of carbonenhanced metal poor stars (CEMP) and Rapidly Accreting White Dwarf stars (RAWDs) suggest that an intermediate process, known as the i-process, exists between the traditional s- and r-processes, and is necessary to explain observed abundances in these environments. i-process nucleosynthesis is impacted by various nuclear data inputs, of which the main source of uncertainty arises from neutron-capture reaction rates. Direct neutron-capture measurements are only feasible for long-lived nuclei, while for short-lived nuclei, indirect techniques are required. In this presentation, I will discuss indirect neutron-capture techniques that have been developed over the last few years, namely the β-Oslo method and the Surrogate Reaction method, and how they can be applied across the nuclear chart at radioactive beam facilities such as the Facility for Rare Isotope Beams, CARIBU at Argonne National Laboratory, and TRIUMF to address i-process nucleosynthesis and beyond.

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