List of Contributions

1 Invited Speakers

1.1 Near Field Cosmology: The Age of Massive Stellar Surveys

Joss Bland-Hawthorn[1]
1 - Sydney Institute for Astronomy, University of Sydney, Sydney, Australia

This is a veritable golden age for galactic archaeology with many outstanding surveys now under way to map the properties of millions of stars across the Galaxy. Here we review the main science goals which motivate these surveys, and look to what the future may hold. The observations extend far beyond what numerical simulations can reasonably explain. The Galaxy is extremely complex and no simple model or feedback prescription will do justice to the richness of our data. It is crucial to describe accurately what we observe and fully understand the selection processes in those observations. If we get this right, in all likelihood, we will make important new discoveries about the state of galaxies today, and their connection to processes in the distant past.

1.2 Forging Connections: Mapping the Nuclear Outflow of the Milky Way seen as the Fermi Bubbles

Rongmon Bordoloi[1]
1 - Massachusetts Institute of Technology, Cambridge, MA, USA

Recent observations of gamma rays together with microwaves and polarized radio waves, have detected giant lobes of plasma (Fermi Bubbles) extending above and below the Galactic plane of the Milky Way. These are possible signs of a Nuclear wind powered by either the central black hole or concentrated nuclear star-formation; but our understanding of their origin is hampered by a lack of kinematic information. I will report new observations from a systematic, absorption-line survey that maps the spatial and kinematic properties of the biconical nuclear outflow, using UV spectroscopy of AGN and halo stars lying close on the sky to the Galactic Center. The variation in absorption properties with Galactic latitude allows us to constrain the physical conditions in the outflowing gas. The observed kinematics of absorption components will be discussed and compared to predictions from biconical outflow models. I will show that the observed absorption profiles can be explained by a biconical nuclear wind with a radial velocity of ∼1000 km/sec, and constrain the kinematic age of the Fermi Bubbles to be ∼6–9 Myrs. Using these estimates, I will constrain the minimum mass of UV absorbing gas entrained in the Fermi Bubbles. These observations illustrate the novel use of UV spectroscopy to constrain the feedback processes that regulate galaxy evolution.

1.3 The Elemental Composition of Quiescent Galaxies Across Cosmic Time

Charlie Conroy[1]

1 - Harvard University, Cambridge, MA, USA

In this talk I will describe how we measure the elemental abundance patterns of entire galaxies. These efforts have revealed that more massive galaxies are not only more metal-rich but also show a greater level of alpha-enhancement ($[\alpha/\mathrm{Fe}]>0$) compared to less massive galaxies. We have recently measured these trends across cosmic time, including the measurement of elemental abundance patterns in a quiescent galaxy at z=2. I will describe what these measurements mean in the context of galaxy assembly, chemical evolution models, and nucleosynthesis.

1.4 From the Lab to the Cosmos: Measuring Neutron-Rich Isotopes at TRIUMF and RIKEN

Iris Dillmann[1]

1 - TRIUMF, Vancouver, BC, Canada

The new generation of radioactive beam facilities like FRIB in the USA and ARIEL in Canada will provide a big step forward investigate yet inaccessible neutron-rich isotopes for the intermediate (i) and rapid (r) neutron capture process.

I will describe the ongoing neutron-rich astrophysics program at the TRIUMF-ISAC facility using the recently commissioned GRIFFIN gamma-ray spectrometer. GRIFFIN has been proven to be a very sensitive tool for detailed decay spectroscopy of the most neutron-rich isotopes, for example around doubly-magic 132Sn and in upcoming beamtimes for the access to neutron-rich rare-earth isotopes. While the ISAC facility is preparing for the full implementation of the new "Advanced Rare IsotopE Laboratory" (ARIEL) in 2022, in an intermediate step from 2019 on beams from the existing ISAC facility will be sent through the new "CANadian Rare-isotope facility Electron-Beam ion source" (CANREB) for cleaner re-accelerated heavy-mass beams. This opens the door for previously inaccessible reaction studies, e.g. (d,p) reactions for the i-process. 135I(n,gamma) has been shown to be one of the key reactions for i-process nucleosynthesis. Since 135I is a N=82 isotope, the low level density makes statistical model calculations for this isotope very unreliable. With the recently commissioned EMMA recoil spectrometer and the coupling to the TIGRESS spectrometer, the 135I(d,p)136I reaction will be investigated as one of the day-one experiments. From 2022 on the neutron-rich science program can be extended with clean neutron-rich beams from photo-fission with the new ARIEL facility.

At RIKEN we have commissioned the BRIKEN array for beta-delayed neutron studies of the most neutron-rich isotopes. Short parasitic runs in fall 2016 and spring 2017 already produced the first science output (e.g. first half-lives of the N=28 isotopes 40Mg and 41Al), the first full physics campaign will be in May/June 2017. BRIKEN will measure beta-delayed neutron emission probabilities and half-lives of >100 of the most exotic neutron-rich isotopes that are presently accessible. Due to its high efficiency of up to 70% for the detection of one neutron, many one-, two-, and three-neutron branching ratios will be measured for the first time. So far 4 proposals have been accepted for measurements between 78Ni up to the rare-earth region, with the r-process as main motivation. Further proposals for the lighter mass regions are under discussion. I'll show some "hot out of the press" data from our first physics experiments, and maybe already some preliminary results from the previous parasitic beamtimes.

1.5 Nucleosynthesis of Heavy Elements: Open Questions

Marius Eichler[1]

1 - Technische Universitat Darmstadt, Darmstadt, Germany

A complex interplay of several nucleosynthesis processes is responsible for the abundance distribution of heavy nuclei in our galaxy today. After an overview on these different processes and their cosmic sites, I will address the question of the cosmic r-process site, which is still unsolved, and recent developments supporting compact binary mergers as the main source for r-process material in our universe. Research on the r-process is further complicated by the unknown properties of the nuclei involved in the reaction path. Recent nucleosynthesis calculations of the r-process in neutron star mergers lead to a shift in the third r-process peak compared to the solar abundance pattern, indicating a problem in either the hydrodynamic trajectories or the nuclear physics employed. I will show how the shift depends on the conditions at the time of freeze-out from (n,γ)-(γ,n) equilibrium and discuss the impact of nuclear mass models and β-decay rates on the shift.

Furthermore, nucleosynthesis calculations struggle to explain the origin of the p-nuclei ^{92,94}Mo and ^{96,98}Ru in our solar system. Recent evidence suggests that slightly neutron-rich environments could be (partially) responsible, and the isotopic abundance ratios between these nuclear species in presolar grains can prove helpful in testing the different production mechanisms.

1.6 The Signature of a Single Prolific r-Process Event in an Ultra-Faint Dwarf Galaxy, and using r-Process Stars as Galactic Tracers

Anna Frebel[1], Alexander Ji[1], Anirudh Chiti[1], Joshua Simon[2]

1 - Massachusetts Institute of Technology, Cambridge, MA, USA

2 - Carnegie Observatories, Pasadena, CA, USA

Through their stars, 13 billion year old ultra-faint dwarf galaxies preserve a fossil record of early chemical enrichment that provides the means to isolate and study clean signatures of individual nucleosynthesis events. Based on new spectroscopic data from the Magellan Telescope, we have found seven stars in the recently discovered ultra-faint dwarf Reticulum II that show extreme r-process overabundances, comparable only to the most extreme ancient r-process enhanced stars of the Milky Way's halo. This r-process enhancement implies that the r-process material in Reticulum II was synthesized in a single prolific event (Ji et al. 2016, Nature 531, 610). Our results are clearly incompatible with r-process yields from an ordinary core-collapse supernova but instead consistent with that of a neutron star merger. This first signature of a neutron star merger in the early universe holds the key to finally - after 60 years - identifying the cosmic r-process production site. In addition, the stars in Ret II pose a uniquely stringent constraint on the metal mixing and star formation history of this ancient galaxy because besides the seven r-process stars also two non-r-process enhanced ones were found. The discovery of Ret II furthermore suggests that the halo r-process stars may have originated in analogous systems in the early universe. Future large samples of halo r-process stars and and ordinary metal-poor stars may lead to a well established frequency of the r-process stars in order to trace their birth systems

1.7 Core-Collapse Supernova Yields under the Convective-Engine Paradigm

Chris Fryer[1]

1 - Los Alamos National Laboratory, Los Alamos, NM, USA

I will review the growing observational support for the convection-enhanced engine paradigm driving core-collapse supernovae. By knowing this paradigm, we are in an ideal position to calculate supernova yields from first principles. However, although we believe we understand the qualitative picture of the engine behind core-collapse supernovae, we are far from a exact quantitative solution for the engine and this means that a range of yield results are still possible for a given progenitor. I will review the uncertainties in the explosive engine and the effect this has on the nucleosynthetic yields from supernovae. Yield observations can then be used to help us better understand the details of the supernova engine.

1.8 Chemodynamical Simulations on Cosmological Scales

Brad Gibson[1]

1 - University of Hull, Hull, United Kingdom

The Horizon Run 5 (HR-5) is an unprecedented large scale cosmological simulation, incorporating chemical evolution over Gpc-scales. The simulation will be rendered with the RAMSES-CH adaptive mesh refinement package, and involves a dozen researchers from the University of Hull and the Korea Institute for Advanced Study. Preliminary groundwork for HR-5 will be outlined, but the primary goal of this Invited Review is to examine the state of the field, in relation to marrying chemical evolution with the largest-scale cosmological simulations.

1.9 Gaia, Gaia-ESO: Some Lessons and Queries for Improved Elemental Understanding

Gerry Gilmore[1]
1 - Cambridge University, Cambridge, United Kingdom

The Gaia-ESO Survey involves 19 spectroscopic analysis pipelines, allowing us to identify and separate all of random error, systematic errors, and egregious errors. The experience highlights the need for a robust and reliable set of atomic and astrophysical parameters, among other lessons. Gaia, with its many follow-up spectroscopic surveys, takes us into new territory. We will start to be able to distinguish between a star's birthright and its current legacy.

1.10 Nucleosynthesis in Massive Stars

Alexander Heger[1]
1 - Monash University, Melbourne, Australia

Single stars more massive than about eight times the mass of the sun are generally thought to undergo a violent death - their core collapsing and making a neutron star or a black hole, whereas the outer layers may be ejected in a violent explosion - the supernovae - and release a plethora of nuclei synthesized during hydrostatic burning and in the supernova explosion itself. Some of the most massive stars may undergo an even more dramatic event, a complete disruption by thermonuclear burning - pair-instability supernovae that can be as impressive as the counterpart of up to one hundred Type Ia supernovae going off at the same time in the same spot. Some of the more powerful explosions may also have a unique nucleosynthesis pattern that we may be able to trace in the chemical evolution of galaxies and their old stars. Those stars that make black holes may do so early during the collapse or only after some time, due to material falling back after the original explosions, and the material falling back could, if endowed with sufficient angular momentum, still induce a powerful explosion, at least for some of them. But even if a neutron star is formed, the resulting explosion energy could vary dramatically, depending on progenitor, and, in particular, if rotation is involved and some of the rotational energy can be tabbed efficiently, still leading to "hypernovae" with peculiar nucleosynthesis.

1.11 Nucleosynthesis and Yields from Low and Intermediate-Mass Stars

Amanda Karakas[1]
1 - Monash University, Melbourne, Australia

The chemical evolution of the Universe is governed by the nucleosynthesis contribution from stars, which in turn is determined primarily by the initial stellar mass. I will review the status of theoretical stellar nucleosynthesis models and yields of single stars up to about 10 solar mass. Stars in this mass range evolve to become cool red giants after the main sequence. It is during the giant branches that these stars experience mixing events that change the surface composition, with significant enrichments in carbon and heavy elements synthesised by the slow neutron capture process (the s-process). While the qualitative picture of the s-process is well known, there are still major uncertainties that affect stellar yields and our understanding of the chemical evolution of galaxies. I will discuss some of these uncertainties and also highlight areas where progress has been made.

1.12 The Origins and Processing of Cosmic Dust

Lars Mattsson[1]
1 - Nordita, Stockholm University & Royal Institute of Technology, Stockholm, Sweden

There are essentially just three sources of cosmic dust: stellar winds, supernovae and interstellar dust condensation – a clear qualitative picture which is supported by a multitude of observations. Quantitatively, however, the picture is not so clear. We know from high-redshift observations that the build-up of dust in galaxies must happen on short timescales and the overall degree of dust condensation must be high. But the numbers do not add up as they should. I will review and discuss this "dust budget crises" as well as the origins of dust in general. I will then move on to ongoing research on the processing of dust in the interstellar medium. In particular, I will discuss the role turbulent gas dynamics plays in the making and processing of cosmic dust, and present first results from direct numerical simulations of interstellar turbulence with dust.

1.13 Producing Metals in the Early Universe

Marco Pignatari[1]
1 - University of Hull, Hull, United Kingdom

Galactic archaeology provides a fundamental tool to constrain theoretical simulations of the first generations of stars. While we have a good understanding of what metals different types of stars can make, the observed variety of abundance signatures in metal-poor stars also highlights severe limitations of modern stellar models. This provides new opportunities to move forward our understanding about how stars work. In this presentation I will discuss these limitations, and I will introduce the production of different elements in metal poor stars, including light elements like C and N and iron-group elements like Fe and Ni.

1.14 The Circumgalactic Medium as a Venue for Chemical Evolution

Jason Tumlinson[1], Molly Peeples[1]
1 - Space Telescope Science Institute, Baltimore, MD, USA

The gas surrounding galaxies - the Circumgalactic Medium or CGM - is a major repository of galactic metals. Based on a forthcoming Annual Reviews article, my talk will focus on how the CGM fuels galaxies and receives their feedback, helps drive the chemical evolution, and what this means for galaxy formation in general.

1.15 The Physics of Nuclear Reaction Rates

Michael Wiescher[1]
1 - University of Notre Dame, South Bend, IN, USA

The chemical evolution of our universe depends on the nuclear reaction processes that determine quiescent and explosive nucleosynthesis events from the Big Bang and the first generation of stars to the present day. The isotopic abundance distribution generated in each of these events depends on the rates of the associated nuclear reaction processes. These rates are often considered as a mere set of numbers that describe the rate as a function of temperature, which can arbitrarily be scaled as free parameter to match the observed with predicted nucleosynthesis data. However, the reaction rates are not an arbitrary set of numbers but depend on the quantum structure of the associate nuclei as well as the nature of the interaction processes that determine the nuclear reaction mechanism. This talk will discuss a few selected examples of reaction processes of interest for the nuclear astrophysics community to demonstrate the theoretical and theoretical challenges for determining a reliable rate. The talk will also present the impact of the uncertainties on the predicted abundance distribution from selected nucleosynthesis events towards chemical evolution.

2 Oral Presentations

2.1 3D Hydrodynamic Simulations of C Ingestion into a Convective O Shell

Robert Andrassy[1], Christian Ritter[1]
1 - University of Victoria, Victoria, BC, Canada

Current Galaxy chemical evolution models still struggle to account for the large observed abundances of odd-Z elements like K or Sc because of the lack of a production site. We show that these elements can be synthesized when a convective O shell merges with a convective C shell in an evolved massive star. Such convective-reactive events are notoriously hard to model in 1D. We have thus run a series of 3D hydrodynamic simulations to investigate the entrainment and burning of C-rich material from a stable layer on top of a convective O shell. The simulations generally reach an equilibrium between entrainment and burning. As we increase the O luminosity of the shell, the contribution of C burning to the total luminosity increases from 17% to 35% and the C burning becomes increasingly patchy. The entrainment rate scales in proportion to the total luminosity. Simulations performed at resolutions of 768^3 and 1152^3 are in good agreement. We derive from them the radial profile of a diffusion coefficient to improve on the MLT parametrization that is currently used in detailed 1D nucleosynthesis calculations. A global instability leading to large deviations from spherical symmetry develops in an experimental run with the energy release from C burning enhanced by a factor of 10. A similar phenomenon might occur with realistic physics during a merger of convective O and C shells if the entropy jump between the two is smaller than that in our set-up. A 3D nucleosynthesis model may be necessary in such a case.

2.2 The Most Metal-Rich Galaxies after ∼3Gyr: Probing Chemical Evolution with Damped Lyman Alpha Systems

Trystyn Berg[1]
1 - University of Victoria, Victoria, BC, Canada

The evolutionary history of galaxies can be traced by their chemical evolution. For the Milky Way and nearby galaxies, stellar chemistry is used to understand their respective star formation histories. But how did galaxies evolve chemically at higher redshifts? Are these galaxies similar to dwarf galaxies or larger galaxies like the Milky Way? Damped Lyman alpha systems (DLAs) are galaxy-sized clouds of gas absorbing along quasar sight-lines, and have been used to track the chemical evolution of galaxies all the way to z∼5. I will present results using 100 hours of Keck HIRES spectra of the most metal-rich DLAs observed at z∼2; a metallicity regime that matches that of the Milky Way disc and its satellite dwarf galaxies. I will draw a comparison between DLAs and the Local Group stellar components to better understand galaxy evolution in the first ∼3 Gyr of the Universe.

2.3 Forging Chemo-Dynamic Connections in the Solar Neighbourhood Based on the Galah Survey and Gaia DR1

Sven Buder[1]
1 - Max Planck Institute for Astronomy, Heidelberg, Germany

Galactic Archaeology with Hermes (Galah) is a high-resolution optical stellar survey that will observe up to 1 million spectra. The primary science goals of Galah are to carry out the chemical tagging experiment (finding stars of common birthplaces via their chemical composition) and to use the observational data to test the theory of Galactic and stellar evolution.

I will present our derived abundances from Galah spectra, for up to 30 elements, from various nucleosynthesis channels (Li, alpha, odd Z, iron peak, as well as s- to r-process) for a valuable subset of the solar neighbourhood: the Galah+TGAS overlap. For this set of more than 25000 stars, Galah will combine radial velocities, ages, and high-precision abundances for these ∼30 elements with the 5D phase-space information delivered by Gaia and as such, will have a large impact and long-lasting legacy. I will present the first exploration of the multi-dimensional dynamical and chemical phase space with this high-fidelity data set, which we can use to increase the agreement of spectroscopy and the predictions of evolutionary models and chemical enrichment.

2.4 Nuclear Pasta in Supernova and Neutron Star Mergers

Matthew Caplan[1]
1 - Indiana University, Bloomington, IN, USA

Nuclear pasta, with nucleons assembled into complex shapes near nuclear saturation, may form during core collapse in a supernova. As the spacing between nuclear pasta structures can be comparable to neutrino wavelengths, its presence in a supernova may enhance the neutrino opacity and produce a detectable neutrino signal for a galactic supernova at late times (~10-40 seconds post bounce). This talk will report on molecular dynamics simulations of nuclear pasta that have been used to calculate the neutrino opacity, as well as supernova simulations using this enhanced opacity. Additionally, nuclear pasta may form in the ejecta of neutron star mergers. We discuss molecular dynamics simulations of decompressing nuclear pasta and their implications for nucleosynthesis in neutron star mergers.

2.5 Impact of Rotation and Convective Boundary Mixing in Low Mass AGB Stars

Jacqueline Den Hartogh[1]
1 - Keele University, Newcastle, United Kingdom

After the central He burning is exhausted, stars with an initial mass of 1.5-3 solar masses start the AGB phase. In this phase, the s-process takes place, which is producing about half of all elements heavier than iron. Our non-rotating AGB stellar models calculated with MESA (see Battino et al. 2016) include a treatment of convective boundary mixing based on the results of hydrodynamic simulations and on the theory of mixing due to gravity waves in the vicinity of convective boundaries. The full range of the observed [hs/ls] as well as the laboratory measurement of Zr isotopic-ratios are still not fully reproduced. A spread of initial rotational velocity in AGB stars might help to improve this.

We will present stellar evolution models including both rotation and the above described ingredients, enabling us to analyse their interplay and the impact on s-process efficiencies. The seperate effects of the rotationally induced instabilities, e.g. Goldreich-Schubert-Fricke instability and the magnetically driven Tayler-Spruit dynamo on the evolution and the s-process will be discussed. Finally, we will compare the final rotation rates of our models with observations of white dwarfs.

2.6 Gamma-Ray Spectroscopy of Cosmic Sources

Roland Diehl[1]
1 - Max Plank Institute for Extraterrestrial Physics, Garching, Germany

INTEGRAL's gamma-ray spectrometer SPI is collecting valuable data with high spectral resolution from sources such as interstellar-gas radioactivities and annihilating positrons, from supernova explosions, and from supernova remnants. Specifically, in this energy band 20-8000 keV lines from 56Ni, 44Ti, 26Al, 60Fe, and the 511 keV line are observed. Studies have taught us about nucleosynthesis throughout our galaxy and its stellar groups, about propagation of nucleosynthesis ejecta as well as positrons, but also specifics about supernovae explosions, both of type core collapse and of type Ia. In this talk, we will review achievements and discuss prospects for the next decade.

2.7 Non-LTE Abundance Study of the Most Ultra Metal-Poor Stars in the Galaxy

Rana Ezzeddine[1], Anna Frebel[1]
1 - Massachusetts Institute of Technology, Cambridge, MA, USA

The most metal-poor stars are rare relics of the early Universe. They encode in their atmospheres the nucleosynthetic products of their progenitors, the first stars. 20 ultra metal-poor stars with [Fe/H] < -4.0 are now known. We re-determine the stellar parameters of these stars spectroscopically, using line-by-line non-local thermodynamic equilibrium (NLTE) abundances of Fe based on an updated iron model atom that includes a new recipe for non-elastic hydrogen collision rates. We find NLTE [Fe/H] abundances to be significantly higher than those in LTE, up to 1 dex for [Fe/H] < -7.0. Departures from LTE also lead to other parameter changes, up to 150 K in effective temperature and 0.5 dex in surface gravity toward the lowest metallicities.

We find a strong correlation between the NLTE abundance corrections and [Fe/H]. This enables future LTE stellar parameter determinations to be easily corrected for NLTE effects. Accurate NLTE atmospheric stellar parameters are the first step to eventually providing full NLTE abundance patterns that can be compared with Population III supernova nucleosynthesis yields to derive properties of the first stars. This work will also yield a better understanding of the shape of the metallicity distribution function at low [Fe/H], which will likely be much steeper than previously thought.

2.8 Nucleosynthesis Yields from Core-collapse Supernovae

Carla Fröhlich[1], Sanjana Sinha[1]

1 - North Carolina State University, Raleigh, NC, USA

Core-collapse supernovae (CCSNe) are highly energetic events that mark the deaths of massive stars. They play a vital role in the synthesis and dissemination of many chemical elements in the universe. Here, we present the results of a nucleosynthesis study of multiple progenitors exploded using the PUSH method. The explodability and explosion properties obtained with PUSH are discussed in detail in K. Ebinger's contribution. PUSH is a robust parametrized method, calibrated using observed nearby SNe. It predicts crucial nucleosynthesis related quantities, such as the mass cut, and follows the electron fraction evolution of the ejecta. This allows a more accurate treatment of nucleosynthesis in the innermost stellar layers, in contrast with previous studies that relied on externally imposed values instead of predictions. In this study, we include models spanning a wide mass range and find trends relating the iron-group and alpha element yields to progenitor compactness. We also present comparisons of the calculated iron-group yields to observational data from supernovae and metal-poor stars. These complete and comprehensive nucleosynthesis predictions are an important input for models of galactic chemical evolution.

2.9 Neutrino Cosmology with Nucleosynthesis

Evan Grohs[1]

1 - University of Michigan, Ann Arbor, MI, USA

We present detailed numerical calculations of the neutrino spectra during the weak-decoupling-nucleosynthesis epoch. Future observational precision of the primordial helium and deuterium abundances has the potential to reveal new physics beyond the standard model operating in the early universe. To quantitatively determine the leverage the abundances have on the neutrino spectra, our calculations utilize a model consistent with the standard cosmology and electroweak theory. The anticipated level of precision in the abundances requires the integration of a nuclear reaction network to determine the abundances, and the integration of a series of quantum kinetic equations to follow the out-of-equilibrium neutrino spectra. In this manner, we obtain precise values of the abundances and other cosmological quantities such as the effective number of neutrinos and the baryon density. Our work has implications for nuclear and beyond standard model physics. Such physics could manifest itself with measurements using next generation cosmic microwave background and thirty-meter-class telescopes.

2.10 Galactic Chemical Evolution Contributions to First-Peak Elements (Z=34-42) from i Process in Rapidly Accreting White Dwarfs

Falk Herwig[1], Benoit Côté[1,2], Pavel Denisenkov[1], Christian Ritter[1]

1 - University of Victoria, Victoria, BC, Canada

2 - Michigan State University, East Lansing, MI, USA

We briefly present the NuGrid/JINA yields and their use in the open-source NuGrid Python Chemical Evolution Environment NuPyCEE, which includes the simple stellar population module SYGMA and the one-zone chemical evolution code OMEGA. We use a basic OMEGA Milky Way model to explore the intermediate neutron capture process or i-process contribution to first-peak elements, approximately from Se to Mo, from rapidly accreting white dwarfs. These objects were previously considered as single-degenerate pathways to Type Ia supernova explosions. New stellar evolution simulations of the recurring He-shell flashes in rapidly accreting white dwarfs show H-ingestion events that launch i-process nucleosynthesis, as well as very low or even negative He-mass retention rates. The latter makes this evolution an unlikely pathway to Type Ia supernova explosion. We calculated i-process yields from rapidly accreting white dwarfs for two white dwarf masses and five metallicities. When added to the standard NuGrid/JINA yields in the OMEGA Milky Way model we find that within the uncertainties this new nucleosynthetic source could account for a significant fraction of the first-peak elements in the present Milky Way.

2.11 Self-Consistently Exploring X-Ray Bursts

Adam Jacobs[1], Edward Brown[1], Hendrik Schatz[2,3], Zac Johnston[4]

1 - Michigan State University, East Lansing, MI, USA

2 - Joint Institute for Nuclear Astrophysics, USA

3 - Facility for Rare Isotope Beams, East Lansing, MI, USA

4 - Monash University, Melbourne, Australia

X-ray bursts are well-observed astronomical transient events driven by thermonuclear burning on the surface of a neutron star. A burst is driven primarily by the rp-process, which involves many reaction rates that remain poorly constrained due to the astrophysical energies involved and the distance of the relevant reactions from the valley of stability. However, as next-generation experiments like FRIB come online, we will be able to access these regions of the chart of nuclides unlike ever before. In this work, I present theoretical calculations of burst behavior, including a determination of which rates observables are most sensitive to. This provides guidance for experimentalists trying to determine which of the thousands of possible reactions to spend precious beam time on. Often such sensitivity studies rely on simple one-zone models that are unable to capture essential dynamics. In my work, I employ a reactive hydrodynamics code capable of self-consistently capturing all essential physics under the assumption of spherical symmetry. This builds on previous work done by JINA-CEE researchers. Progress toward robust models of X-ray bursts informed by the latest experimental data makes possible more stringent constraints on the neutron star equation of state. Understanding this EoS is not only a fundamental nuclear physics question, but also essential to developing robust models of gravitational wave signatures from mergers including a neutron star.

2.12 A Homogeneous Abundance Analysis of Stars in Ultra-Faint Dwarf Galaxies

Alexander Ji[1], Rana Ezzeddine[1], Anna Frebel[1]

1 - Massachusetts Institute of Technology, Cambridge, MA, USA

Nearby dwarf galaxies provide a collection of stars with a simple, common formation history. The chemical abundances of these stars are an ideal way to study early nucleosynthesis and galaxy formation. However, existing literature abundances are derived from a wide variety of analysis methods. Thus, apparent abundance trends and scatter are affected by systematic differences. To alleviate these concerns, we present a homogeneously analyzed compilation of chemical abundances for $\sim$60 stars in 13 ultra-faint dwarf galaxies. We especially focus on the alpha-elements Mg, Ca, and Ti. The average abundance of these elements is often used to characterize the star formation history of a galaxy, but the individual elements show different trends. A systematic line-by-line analysis including NLTE effects results in more pronounced abundance trends. We construct simple chemical evolution models to match these trends and discuss the importance of cosmological gas accretion and inhomogeneous metal mixing in dwarf galaxies.

2.13 Understanding the Origin of "Nova" Grains and the 13N(α,p)16O Reaction

Alison Laird[1], Nicolas de Sereville[2], Anne Meyer[2], Marco Pignatari[3], Fairouz Hammache[2]

1 - University of York, York, United Kingdom

2 - Institut de Physique Nucléaire d'Orsay, Orsay, France

3 - University of Hull, Hull, United Kingdom

Primitive meteorites hold several types of dust grains that condensed in stellar winds or ejecta of stellar explosions. These grains carry isotopic anomalies which are used as a signature of the stellar environment in which they formed. As such, extreme excesses of 13C and 15N in rare presolar SiC grains have been considered as a diagnostic of an origin in classical novae, however an origin in core collapse supernovae (ccSNe) has also been recently proposed [1]. In the context of ccSNe, explosive He shell burning can reproduce the high 13C and 15N abundances if H was ingested into the He shell and not fully destroyed before the explosion [2]. The supernova shock will then produce an isotopic pattern similar to the hot-CNO cycle signature obtained in classical novae. It has been shown that a variation of a factor of five for the 13N(α,p)16O reaction rate induces several orders of magnitude in the production of 13N which $\beta+-$decays to 13C. So far the 13N(α,p)16O reaction rate is calculated using a statistical model or the time reverse reaction and these determinations have large uncertainties. We have determined an experimental based reaction rate using the spectroscopic information of the 17F compound nucleus. Alpha spectroscopic factors of the states of interest (Ex = 6.5 – 7.2 MeV) in 17F were deduced from those of the 17O mirror nucleus which were determined using the 13C(7Li,t)17O alpha-transfer reaction. After a brief presentation of the astrophysical context of 13C and 15N nucleosynthesis, the current situation of the 13N(α,p)16O reaction rate will be discussed. The determination of spectroscopic information from the 13C(7Li,t)17O reaction will be presented together with an R-matrix calculation of the 13N(α,p)16O astrophysical S-factor. The impact of the new reaction rate wil be discussed.

[1] N. Liu et al. The Astrophysical Journal, 820:140 (2016).
[2] M. Pignatari et al. The Astrophysical Journal Letters, 808:L43 (2015).
[3] A. M. Laird and M. Pignatari, private communication.

2.14 Playing Your CARDs Right: Constraining the Origin of r-Process Elements Using "One-shot" Enriching Stellar Generation Models

Duane Lee[1]
1 - Vanderbilt / Fisk University, Nashville, TN, USA

The origin and nature of the r-process are still unclear. However, some prime astrophysical source candidates, like neutron star mergers and rare supernova (SN) events, exist. Here I utilize an ensemble of chemical abundance ratio distribution (CARD) models of enriching stellar generations (ESGs) in dwarf galaxies to constrain the probable neutron star merger and rare supernova rates reflected in both the very metal-poor halo and UFD galaxy stars orbiting the Milky Way.

2.15 On the Impact of Spatial and Temporal Resolution on Pre-Supernova Structure

Ilka Petermann[1], Frank Timmes[1], Rober Farmer[1], Carl Fields[2]
1 - Arizona State University, Tempe, AZ, USA
2 - Michigan State University, East Lansing, MI, USA

Massive stars are essential to the evolution of galaxies due to their intense radiation and strong winds as well as their powerful deaths as supernovae. In this study, we aim at understanding the non-monotonic behavior of crucial properties like the final iron-core masses of massive stars in analyzing stellar models with respect to the influence of underlying numerics and study the implications on their final fates in terms of their structural and nucleosynthesis patterns and the possible connections of their initial masses and final fates.

2.16 The Environment of the r-Process

Ian Roederer[1]
1 - University of Michigan, Ann Arbor, MI, USA

We still lack definitive observations identifying the site of the r-process, which is one of the fundamental ways that stars produce heavy elements. Recent observations of highly r-process enhanced stars in a Local Group dwarf galaxy, Reticulum II, offer the prospect of providing environmental constraints on the r-process for the first time. Several studies have found that this implicates a rare but prolific site, like neutron stars mergers or magneto-rotational jet-driven supernovae. I will present new observations taken with the Michigan/Magellan Fiber System at the Magellan II (Clay) Telescope that offer a proof-of-concept for how to quickly identify r-process enhanced galaxies, derive the distribution of r-process material within each galaxy, and potentially derive a rate for the r-process site (e.g., neutron star mergers) at high redshift.

2.17 Simulating Neutron Star Mergers as r-Process Sources in Ultra Faint Dwarf Galaxies

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To explain the high observed abundances of r-process elements in local ultra-faint dwarf (UFD) galaxies, we perform cosmological zoom-in simulations that vary the energy and coalescence time of neutron star mergers (NSMs). We model star-formation stochastically and simulate two different halos with total masses $\approx 10^8 M_\odot$ at $z = 6$. We model one NSM in each system associated with an energy ranging from $10^{50} - 10^{51}$ erg, a coalescence timescale (t_{coalesc}) ranging from $1 - 10$ Myrs, and an ejected mass of r-process elements (M_r) ranging from $10^{-4} - 4 \times 10^{-2} M_\odot$. We find that the final distribution of [Eu/H] vs. [Fe/H] in the stars is most sensitive to M_r and the environment in which the NSM event occurs. Our simulations prefer the higher end of M_r values in the plausible range and we can not distinguish between different model parameters given the uncertainty in M_r. However, natal kicks of more than 10-100 km/s would make the NSM event take place in a low density environment, leading to low levels of r-process abundances that are inconsistent with Ret II observations.

2.18 Unraveling the Chemical Evolution of Galaxies Beyond the Milky Way with Integrated Light Spectroscopy of Globular Clusters

Charli Sakari[1]
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A universal understanding of galaxy formation requires observations of galaxies beyond the Milky Way. Although individual stars in distant galaxies are too faint for high-resolution spectroscopy, globular clusters (GCs) can be studied through integrated light (IL) spectroscopy. Since GCs are expected to trace the properties of their host galaxies, distant clusters can be utilized in lieu of resolved stars to investigate the assembly histories of their hosts.

This talk 1.) presents integrated abundances of M31 clusters from high-resolution optical and infrared spectra (from the Hobby-Eberly Telescope and the Apache Point Observatory Galactic Evolution Experiment, or APOGEE, respectively) and 2.) discusses the current limitations for IL spectroscopy, particularly in light of multiple populations within GCs. The optical provides abundances of, e.g., Fe, Na, Mg, Ca, Ba, and Eu, while H-band spectra provide abundances of, e.g., C, N, O, Mg, Al, and K. Most of the M31 clusters in the APOGEE sample follow the abundance signatures of Milky Way field stars and classical GCs, implying that the chemical evolution history of most M31 stars is similar to the Milky Way. However, the abundances of seven outer halo M31 GCs that were discovered in the Pan-Andromeda Archaeological Survey (PAndAS) look more like the field stars and GCs in dwarf galaxies. The detailed abundances of these outer halo GCs constrain properties (e.g., mass) of the dwarfs that are currently being accreted. Ultimately, these studies have provided a characterization of M31's assembly history that cannot currently be obtained from field stars. Looking forward, high-resolution IL spectroscopy will be a powerful tool for investigating galactic archaeology beyond the Milky Way.

2.19 Painting a More Realistic Picture of the Circumgalactic Medium via Simulations of Isolated Galaxies

Devin Silvia[1]
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Observational efforts to understand the complex nature of the circumgalactic medium (CGM), have highlighted the important role this gas plays in regulating galactic star formation. Until recently, the mass and extent of the CGM was poorly constrained, owing to the difficulties associated with observing this diffuse gas. However, it is now known that the CGM may comprise over half of all the normal matter contained in a galactic halo. This large reservoir of gas can act to both facilitate and stifle continued star formation in galaxies. In an effort to better understand the nature of the CGM and help inform current and future observations, we present high resolution hydrodynamic simulations of isolated galaxies that resolve physical scales rarely reached by cosmological simulations of large scale structure. We will discuss our efforts to visualize the complex three-dimensional structure of the CGM, study its thermodynamic evolution as a function of time, and create mock observations that can be directly compared to real ones. These efforts allow us to paint a more accurate picture of the connection between galactic star formation and the circumgalactic medium.

2.20 Global Properties of Circumgalactic Medium at High-Redshift: A Spectroscopic Study of Strong Lyman-α Forest Absorbers

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We present a study of the circumgalactic medium (CGM) probed by composite spectra constructed from a sample of strong Lyman α (Lyα) forest absorbers at redshifts $2.4 < z < 3.1$. The absorbers, selected from $\sim$160,000 quasar spectra from the Baryon Oscillation Spectroscopic Survey (BOSS/SDSS-III Data Release 12), are identified based on their absorption strength (spanning the range of flux $-0.05 \leq F < 0.45$) in bins $138\,\mathrm{km\,s^{-1}}$ wide, which is approximately the size of the BOSS resolution element. The selected absorbers are split into five sub-samples in flux bins of width 0.1 ($|\Delta F|=0.1$) and composite spectra are constructed for each of these sub-samples. Tests show that the three strongest absorption samples probe circumgalactic regions (projected separation <300 proper kpc and $|\Delta v| < 300\,\mathrm{km\,s^{-1}}$), and weakening Ly$\alpha$ absorption is associated with decreasing purity of circumgalactic selection. The weakest two Lyα

absorption samples are dominated by the intergalactic medium. Single component model fits to the several Lyman-series lines, present in our composite spectra, suggest the absorbing gas to be optically thin with neutral hydrogen column densities over the range $14.4 \lesssim \log(\mathrm{NHI}) \lesssim 16.45$. In addition to the H I features, numerous lines from several metals in various ionisation stages are detected, with exquisite precision, in our composite spectra. We analyse the measurements from the metal absorption in combination with the H I column densities using various single-phase and multi-phase models and our results imply clumping on scales down to < 100 pc and near-solar metallicities in the circumgalactic samples (probed primarily by low ionisation species such as Fe II, Si II, Mg II), while high-ionization metal absorption consistent with typical IGM densities and metallicities is visible in all samples. Our results provide important clues to the processes shaping CGM at high-redshift using Lyα absorbers in a column density regime largely unused so far in CGM studies.

2.21 Constraining the Physics of the Circumgalactic Medium with Lyman-alpha Absorption around Galaxies

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Outflows of gas produced by stellar feedback (e.g. supernovae, stellar winds) or an AGN alter the physical state of gas in the circum- and intergalactic media (CGM and IGM) surrounding galaxies, although the details of these processes are still poorly understood. We use Illustris and Nyx hydrodynamic cosmological simulations to reproduce the observations of the Lyman-alpha absorption due to neutral hydrogen around foreground star-forming galaxies, quasars, and damped Lyman-alpha absorbers (DLAs), illuminated by a background quasar. Although mostly consistent with the observations, Nyx and Illustris yield very different predictions of the Lyman-alpha absorption out to ∼1 Mpc from the foreground object. We assert that such differences could be ascribed to the diverse feedback prescriptions in the two simulations. Thus, improving the precision of measurements of Lyman-alpha absorption in the CGM with future observations (e.g. with JWST and surveys like DES) has a great potential to constrain feedback prescriptions in numerical simulations. We also find that both simulations do not produce enough absorption within the virial radius to match the observations. We show that the discrepancy can be indicative of the presence of cooler gas in the CGM, of extra turbulence in the CGM, or of unresolved physics in the CGM.

2.22 Multi-D Core Collapse Supernovae Nucleosynthesis to Forge Connections to the Chemical Enrichment of the Cosmos

Claudia Travaglio[1], Hans-Thomas Janka[2], Annop Wongwathanarat[2], Luigi Antonio Squillante[3]
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The explosion of massive stars as core-collapse supernovae represents one of the outstanding problems in modern astrophysics. Core-collapse supernovae figure prominently in the chemical evolution of galaxies as the dominant producers of elements between oxygen and the iron group, and they play an important role in the production of elements heavier than Fe. They represent a key ingredient in understanding the history of chemical enrichment of the Universe. We present in this work a detailed analysis of nucleosynthesis calculations of 15 Msun and 20 Msun neutrino-driven supernova explosions in 3D (explosions, approximative neutrino treatment, progenitors are presented by Wongwathanarat et al. 2015). Nucleosynthesis calculations are performed in a post-process using tracer particles method (TONiC code, Travaglio et al. 2011). The nucleosynthesis network used is based on 1500 isotopes. Basel 2009 for theoretical nuclear reaction network and the most updated experimental ones. The nuclear processes included are electron captures, neutron captures, alpha captures and photodisintegrations. A detailed comparison of the nucleosynthesis calculation between 3D and 1D models (where also the 1D model includes neutrino-driven explosion) will be presented providing interesting information on
1. overproduction of neutron-rich material
2. elemental and isotopic abundances information of elements like Mn, Cr, Sc, Cu & Zn to better understand the observations in metal-poor stars in our Galaxy as well as in external objects
3. potential source of p-process nuclei.

In the light of the most recent and future satellites and ground based spectroscopic surveys in the oldest field stars (e.g. Gaia-ESO, Pan-STARRS, APOGEE, VISTA, etc) as well as in supernova spectra (like expected from PEPSI ultra high resolution spectrograph on LBT) as well as supernova remnant observations (e.g. NUSTAR, INTEGRAL,CHANDRA, SUZAKU, etc.) to forge connections with detailed studies of nucleosynthesis in multi-dimensional supernova models is extremely needed.

2.23 High-Resolution Spectroscopic Analyses of Metal-Poor Stars in the CFHT Pristine Survey

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The Pristine Survey is a narrow-band photometric survey focused on the metallicity-sensitive Ca H & K lines and conducted in the northern hemisphere with the wide-field MegaCam on the Canada-France-Hawaii Telescope. The main aims of the survey are to uncover a statistical sample of the most metal-poor stars in the Galaxy, to further characterize the smallest Milky Way satellites, and to map the metal-poor substructure in the Galactic halo. The comparison with existing spectroscopic metallicities from SDSS/SEGUE survey show that we can use this CaHK filter, with PanSTARRS g and i photometry, to infer photometric metallicities from $-0.5 >$ [Fe/H] > -2.5 with approximately 0.2 dex in precision. In this talk, I will discuss results from our spectroscopic follow-up programs, particularly studies of the most metal-poor stars using the CFHT Espadons spectrograph. As of the end of 2016, we have observed >300 stars spectroscopically, with ∼20% success in finding very metal-poor stars ([Fe/H] < -3). High resolution spectra for ∼15 of those stars provide new abundances or upper-limits for >20 additional elements. So far, we are finding metal-poor stars with element abundance patterns similar to the published Galactic halo samples. This shows the efficiency of the Pristine survey in identifying very metal-poor stars, and suggests that the prospects for finding the rare objects - r-process rich, alpha-challenged, and any chemical peculiarities that could be used for stellar nucleosynthesis and chemical tagging tests - are exciting.

2.24 Simulating Turbulence-Aided Core-Collapse Supernova Explosions in Spherical Symmetry

MacKenzie Warren[1]

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We present a new method for artificially driving core-collapse supernova explosions in 1D simulations. Turbulence is important for understanding the SN explosion mechanism, since turbulence may add a >20% correction to the total pressure behind the shock and thus aid in the explosion. We have implemented mixing length theory (MLT) and included a model of the turbulent pressure in FLASH for spherically symmetric simulations. Including MLT and corrections for the turbulent pressure may result in successful explosions in spherical symmetry without altering the neutrino luminosities or interactions, as is commonly done to produce explosions in spherical symmetry. This better replicates the physical explosion mechanism and more reliably produces the thermodynamics and composition, which is vital for accurately predicting the nucleosynthesis that occurs in the supernova environment.

2.25 Inhomogeneous Galactic Chemical Evolution of r-Process Elements

Benjamin Wehmeyer[1], Marco Pignatari[2], Carla Fröhlich[1], Friedrich-Karl Thielemann[3]

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Stars provide a fundamental contribution to the cosmic life cycle. Gas clouds form and collapse to stars, experiencing different evolutionary stages according to their properties like mass and metal content. Small stars like our Sun end their life as planetary nebulae, while more massive stars end their evolution with violent explosions like supernovae or hypernovae, leaving behind either a neutron star or a black hole. These compact objects may also merge, leading to a new ejection of material. Today the origin of the heaviest elements is still matter of debate. The relative contributions of the proposed sources of r-process elements (e.g., Supernovae, Neutron Star Mergers) in the early galaxy as well as in the Sun is one of the main uncertainties. We use the inhomogeneous chemical evolution tool "ICE" [1, 2] to study the role of some of the main parameters of the cosmic life cycle. With ICE's high resolution (≥ 20parsec/cell) runs, we are able to get converged simulations of the inhomogeneities in the early Galactic evolution stages, and of the observed scatter of r-process elements in metal-poor stars [3].

[1] B. Wehmeyer, M. Pignatari, F.-K. Thielemann, 2015 MNRAS 452, 1970-1981
[2] B. Wehmeyer, M. Pignatari, F.-K. Thielemann, 2016 AIPC 1743, 040009
[3] I. Roederer et al., 2010 ApJ 724:975-993

2.26 SN Ia Archaeology: Searching for the Ghosts of Progenitors Past

Tyrone Woods[1]
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Much of the iron in your blood was born in the thermonuclear explosion of a white dwarf. But it remains uncertain why a white dwarf would do such a thing! Most evolutionary models can be broadly grouped into either "accretion" or "merger" scenarios, with the former typically implying a hot, luminous phase (0.1 – 1 million K, 10^{38} erg/s) at some point prior to explosion. Past efforts to directly detect the progenitors of very recent, nearby SNe Ia in archival soft X-ray images have produced only upper limits, and are only constraining assuming progenitors with very high temperatures immediately preceding the explosion. In this poster, I will outline our new approach: given that such objects should be strong sources of ionizing radiation, one may instead search the environment surrounding nearby SN Ia remnants for interstellar matter ionized by the progenitor. Such "relic" nebulae should extend out to tens of parsecs and linger for roughly the recombination timescale in the ISM, of order 10,000 – 100,000 years. With this in mind, I will introduce our new narrow-band survey for relic nebulae surrounding young Magellanic SN Ia remnants and accreting white dwarfs, already underway using the Magellan Baade telescope (PI: Alejandro Clocchiatti). In a similar manner, we have also placed deep upper limits on the temperatures and luminosities of the progenitors of Tycho (SN 1572) and other Galactic SNe Ia from the study of their Balmer-dominated shocks. In addition to opening a new era of "SN Ia archaeology," I will also discuss how these results can (and have already) put new constraints on binary population synthesis models.

3 Poster Presentations

3.1 Application of a Theory and Simulation-Based Convective Boundary Mixing Model for AGB Star Evolution and Nucleosynthesis

Umberto Battino[1]

1 - Keele University, Newcastle, United Kingdom

The s-process nucleosynthesis in Asymptotic Giant Branch (AGB) stars depends on the modelling of convective boundaries. I present models and s-process simulations that adopt a treatment of convective boundaries based on the results of hydrodynamic simulations and on the theory of mixing due to gravity waves in the vicinity of convective boundaries. Hydrodynamics simulations suggest the presence of Convective Boundary Mixing (CBM) at the bottom of the thermal pulse-driven convective zone. Similarly, convection-induced mixing processes are proposed for the mixing below the convective envelope during Third Dredge-Up where the C13-pocket for the s-process in AGB stars forms. In this work I apply a CBM model motivated by simulations and theory to models with initial mass $M = 2$ and $M = 3$ solar masses , and with initial metal content $Z = 0.01$ and $Z = 0.02$. As reported previously, the He-intershell abundance of C12 and O16 are increased by CBM at the bottom of pulse-driven convection zone. This mixing is affecting the Ne22 $(\gamma$,n) Mg25 activation and the s-process efficiency in the C13-pocket. In our model CBM at the bottom of the convective envelope during the Third Dredge-Up represents gravity wave mixing. I take further into account that hydrodynamic simulations indicate a declining mixing efficiency already about a pressure scale height from the convective boundaries, compared to mixing-length theory. I obtain the formation of the C13-pocket with a mass of around 10^{-4} solar masses. The final s-process abundances are characterized by $0.36 <$ [s/Fe] < 0.78 and the heavy-to-light s-process ratio is $0.23 <$ [hs/ls] < 0.45. Finally, I compare our results with stellar observations, pre-solar grain measurements.

3.2 Photometric Searches for Metal-Poor Stars in the Sculptor and Tucana 2 Dwarf Galaxies

Anirudh Chiti[1], Anna Frebel[1], Dongwon Kim[2], Helmut Jerjen[2]

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2 - Australian National University, Canberra, Australia

Metal-poor stars in dwarf galaxies are promising tools to study early chemical evolution, as demonstrated by recent examples such as Reticulum II and Segue 1. However, the relative rarity of extremely metal-poor stars (EMP; [Fe/H] < -3.0), the preponderance of foreground halo stars in smaller dwarf galaxies, and the observing time required for spectroscopy constrains the identification and study of EMP stars in these systems.

We present results on the identification of extremely metal-poor stars in the Sculptor and Tucana II dwarf galaxies with photometric selection techniques. Using deep observations of each system with the SkyMapper filter set on the 1.3m telescope at Siding Springs Observatory, we demonstrate the feasibility of translating the flux through each filter to a metallicity estimate. Using this photometric technique, we re-identify seven of the eight known probable members of the ultra-faint dwarf galaxy Tucana 2 and derive metallicities for stars in the full field of view of the system. Due to the many stars that can be studied at once with this technique, this represents an advance over traditional spectroscopic methods of identifying extremely metal-poor stars. This technique would allow for a determination of more complete metallicity distribution functions of dwarf galaxies to fainter magnitudes than currently permitted by spectroscopy, and the potential for a census of EMP stars in dwarf galaxies for the purpose of modeling these systems with chemical evolution models.

3.3 Convective-Reactive Nucleosynthesis in Massive Population III Stars and the Origin SMSS J031300.362670839.3 (Keller star)

Ondrea Clarkson[1], Falk Herwig[1]

1 - University of Victoria, Victoria, BC, Canada

We present recent results in an ongoing investigation into H-ingestion events in Pop III stars particularly to explain the elemental abundance pattern of the most iron-poor star found to date, the Keller star (SMSS J031300.362670839.3). We propose a scenario based on 1D stellar evolution simulations in which a 45Msun Pop III star experiences H-ingestion into the convective He-shell burning shell. Our 1D models show energy production that peaks at $\log(L/L_{\odot}) \sim 13.7$ and up to approximately 20% of the internal energy of this layer of on one convective turnover timescale. We follow the associated nucleosynthesis during such a H-ingestion event using the NuGrid single-zone nucleosynthesis code PPN. The H-ingestion triggers light-element i-process nucleosynthesis on C12 as a seed. An assumption that the i-process enriched layer is partially ejected and diluted with unprocessed envelope material at a ratio of approximately 1:100 results in an abundance distributions that comes intriguingly close to that observed in the Keller star. Remaining discrepancies in our scenario prediction and observations can originate in the approximate spherically symmetric astrophysics modelling and in uncertainties of nuclear physics of the many unstable species involved in the reaction path. I will comment on more general aspects of convective-reactive nucleosynthesis in massive and low-mass stars, such as the production of odd-Z elements in low-Z stars and galactic chemical evolution.

3.4 Chemical Evolution in the Earliest Galaxies in a Cosmological Context

Benoit Côté[1,2,3], Devin Silvia[4,5], Brian W. O'Shea[3,4,6]

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2 - National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI, USA

3 - Joint Institute for Nuclear Astrophysics - Center for the Evolution of the Elements (JINA-CEE), USA

4 - Department of Physics and Astronomy, Michigan State University, East Lansing, MI, USA

5 - National Science Foundation, Astronomy and Astrophysics Postdoctoral Fellow, USA

6 - Department of Computational Math., Sci. and Eng., Michigan State University, East Lansing, MI, USA

We will present our latest effort to address galactic chemical evolution (GCE) in a cosmological context using our semi-analytical code GAMMA (Galaxy Assembly with Merger-trees for Modeling Abundances). Our goal is to better understand the evolution of galaxies at their earliest stage and to define to what extend chemical evolution can be used to probe nuclear astrophysics and galaxy formation. We will present our effort to compare GAMMA with the hydrodynamic simulations of Wise et al. (2012, ApJ, 745, 50) in order to derive non-uniform mixing prescriptions for the early universe and to study the impact of cosmological structure formation on the metallicity distribution of metal-poor stars. This poster will also illustrate our JINA-NuGrid GCE pipeline (which includes NuPyCEE - NuGrid Python Chemical Evolution Environment).

3.5 Neutron-Capture Reaction Rate Uncertainties for the i-Process in He-Shell Flash White Dwarfs from Monte-Carlo Simulations

Pavel Denisenkov[1], Christian Ritter[1], Marco Pignatari[2], Samuel Jones[3], Stylianos Nikas[4], Georgios Perdikakis[4], Hendrik Schatz[5,6], Artemis Spyrou[7,8], Falk Herwig[1]

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I will present results of our Monte-Carlo simulations of neutron-capture reaction rate uncertainties of unstable isotopes near N=50 that are relevant for the i-process nucleosynthesis in the post-AGB star Sakurai's object and white dwarfs rapidly accreting H-rich material with solar composition. In the latter case, the i process is important for the production of the first peak s-process elements in GCE models. I will compare and discuss the results obtained for both single- and multi-zone models of a He-shell flash with hydrogen ingestion.

3.6 Masses and Beta-Decay Properties of Neutron-Rich Nuclei Around N=56

Alfredo Estrade[1]

1 - Central Michigan University, Mount Pleasant, MI, USA

A new generation of radioactive ion beam facilities are making large regions of the nuclear chart available for experimental studies, including very neutron-rich isotopes near or at the r-process path. Our group is involved in a series of experiments to measure beta-decay properties and nuclear masses targeting r-process isotopes performed at the Radioactive Ion Beam Factory (RIBF) in RIKEN, using active stopper detectors for beta-decay and the time-of-flight technique for mass measurements. I will present preliminary results for a recent measurement in the 92Se region, which was a first experiment with the Advanced Implantation Detector Array (AIDA), as well as the perspectives for additional measurements.

3.7 Evaluation of Anthropic Arguments in Nuclear Astrophysics

Evan Grohs[1]

1 - University of Michigan, Ann Arbor, MI, USA

Motivated by the possible existence of other universes as part of the multiverse framework, we investigate how changing the fundamental constants of nature can change the prospects for the existence of astrophysical structures. This work focuses on nucleosynthesis, considers modifications to the nuclear constants, and uses simple models for nuclear structure. These modifications are then used to estimate the corresponding changes in binding energies and reaction rates for both big bang and stellar nucleosynthesis. We find the resulting differences in nuclear abundances in these two settings. The abundance yields are used to assess the strength of anthropic arguments or infer the prospects of habitability in other universes.

3.8 In Pursuit of Stellar Chemistry: An Overview of Molecular Carbon in Dust Clouds

Christine V. Hampton[1]

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Dust clouds in the Interstellar Medium obscure the light from the stars that they eclipse and provide a substrate for the nucleation and condensation of various atomic, ionic, and molecular species that had been produced in stellar processes. Energy provided by shock waves, cosmic rays, and ion bombardment may stimulate chemical reactions to the extent that dust clouds might be considered to be cosmic laboratories for the formation of high molecular weight, aromatic, organic hydrocarbons (PAH).

In this poster presentation, we will present an overview of the organic and other molecular chemical species that have been reported to exist in various dust clouds, review conditions for their formation, and explore plausible reaction mechanisms involved in the formation of these chemicals.

3.9 Impact of Stellar Triple Alpha Reaction Enhancement on the r-Process

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The triple alpha reaction rate depends on the radiative decay width of the Hoyle state in 12C. It was recently pointed out that in astrophysical environments with high temperatures and high proton, neutron, or a-particle densities, such as the neutrino driven wind in core-collapse supernovae, the triple alpha rate is enhanced by hadronic de-excitation of the Hoyle state. To explore the impact of this effect on the r-process, we implemented the rate enhancement through neutron inelastic scattering into SkyNet, a nuclear astrophysics reaction network code and performed a study of the sensitivity of the produced abundances to the modified triple alpha rate and other seed producing reactions. We find that for this particular r-process scenario of a parametrized neutrino driven wind, for a broad range of entropies, expansion time and electron fraction, the enhanced triple alpha reaction has only a very small impact on the final abundances. Even with an enhanced triple alpha rate, 9Be $[\alpha,\mathrm{n}]$ 12C remains the dominant reaction rate controlling the production of 12C and subsequent r-process seeds. Other r-process sites and additional nucleosynthesis scenarios where the triple alpha reaction plays a role remain to be investigated.

3.10 Bremsstrahlung Process in Astrophysical Turbulent Plasmas

Young-Dae Jung[1], Myoung-Jae Lee[1]

1 - Hanyang University, Seoul, South Korea

The plasma screening and turbulence effects on the electron-ion bremsstrahlung spectrum are investigated in astrophysical turbulent plasmas. The effective potential taking into account the dynamic plasma screening and the plasma turbulence through the diffusion effect with the impact parameter analysis is employed in order to obtain the bremsstrahlung radiation cross section as a function of the Debye length, diffusion coefficient, impact parameter, projectile energy, photon energy, and thermal energy in turbulent plasmas. It is found that the bremsstrahlung radiation cross section decreases with increasing thermal energy for small impact parameters and, however, increases with an increase of the diffusion coefficient. It is also found that the dynamic plasma screening effect enhances the bremsstrahlung radiation cross section for small thermal energies. In addition, it is found that the dynamic plasma screening effect on the bremsstrahlung cross section in astrophysical turbulent plasmas increases with an increase of the diffusion coefficient and, however, decreases with an increase of the thermal energy.

3.11 Investigating Nucleosynthesis in Multidimensional Supernova Explosion Simulations

James Keegans[1]

1 - University of Hull, Hull, United Kingdom

Core Collapse Supernovae are key contributors to galactic chemical evolution in the galaxy. In the first generation of stars, enrichment from a limited number of events can dominate the abundance signatures that we observe today, and it is therefore important to have a detailed understanding of the supernova mechanism and of the stellar conditions during the explosion. In this poster, I will discuss nucleosynthesis simulations from the post processing of multidimensional CCSN models, and their possible impact on the abundance signature in the early galaxy.

3.12 Fire Burn and Cauldron Bubble: Modeling Galactic Feedback with Adaptive Mesh Simulations

Claire Kopenhafer[1]

1 - Michigan State University, East Lansing, MI, USA

Strong correlations have been observed between several galaxy properties that imply the existence of one or more self-regulating mechanisms within galaxies. These mechanisms tie the properties of the galaxy's stellar populations to that of the host dark matter halo. We believe the relationship between supernova feedback in the disk and the diffuse gas reservoir of the surrounding circumgalactic medium may provide one such self- regulation mechanism. To test the feasibility of this, we used Blue Waters to perform idealized simulations of isolated Milky Way-like galaxies that utilize varied assumptions about the properties of stellar feedback and its impact on the interstellar and circumgalactic medium. We present the results of these simulations and their implications for supernova feedback self-regulation of galaxies.

3.13 Interacting Dark Matter and the Galaxy Core-Cusp Problem

Nguyen Quynh Lan[1,2], G. J. Mathews[1,2], J. Coughlin[1,2], I. Suh[1,2], L. A. Phillips[1,2], D. T. Ha[3]

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The core-cusp problem remains as one of the unresolved challenges between observation and simulations in the standard ΛCDM model for the formation of galaxies. Basically, the problem is that ΛCDM simulations predict that the center of galactic dark matter halos contain a steep power-law mass density profile. However, observations of dwarf galaxies in the Local Group reveal a density profile consistent with a nearly flat distribution of dark matter near the center. A number of solutions to this dilemma have been proposed. We discuss the possibility that the dark matter particles themselves self interact and scatter. The scattering of dark matter particles then can smooth out their profile in high-density regions. We also summarize a theoretical model as to how self- interacting dark matter may arise. We implement this form in simulations of self-interacting dark matter in models for galaxy formation and evolution. Constraints on properties of this form of self-interacting dark matter will be summarized.

3.14 Modeling the Formation of Globular Cluster Systems in the Virgo Cluster

Hui Li[1]

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The mass distribution and chemical composition of globular cluster (GC) systems preserve fossil record of the early stages of galaxy formation. The observed distribution of GC colors within massive early-type galaxies in the ACS

Virgo Cluster Survey (ACSVCS) reveals a multi-modal shape, which likely corresponds to a multi-modal metallicity distribution. We present a simple model for the formation and disruption of GCs that aims to match the ACSVCS data. This model tests the hypothesis that GCs are formed during major mergers of gas-rich galaxies and inherit the metallicity of their hosts. To trace merger events, we use halo merger trees extracted from a large cosmological N-body simulation. We select 20 halos in the mass range of 2e12 to 7e13 $M_\odot$ and match them to 19 Virgo galaxies. To set the [Fe/H] abundances, we use an empirical galaxy mass-metallicity relation. We find that a minimal merger ratio of 1:3 best matches the observed cluster metallicity distribution. A characteristic bimodal shape appears because metal-rich GCs are produced by late mergers between massive halos, while metal-poor GCs are produced by collective merger activities of less massive hosts at early times. The model outcome is robust to alternative prescriptions for cluster formation rate throughout cosmic time, but a gradual evolution of the mass-metallicity relation with redshift appears to be necessary to match the observed cluster metallicities. We also affirm the age-metallicity relation, predicted by an earlier model, in which metal-rich clusters are systematically several billion younger than their metal-poor counterparts.

3.15 The Importance of Curvature and Density Gradients for Nucleosynthesis by Detonations in Type Ia Supernovae

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Accurately reproducing the physics behind the detonations of Type Ia supernovae and the resultant nucleosynthetic yields is important for interpreting observations of photospheric spectra and remnants. The scales of the processes involved span orders of magnitudes, making the problem computationally impossible to ever fully resolve in full star simulations. Consequently, studies have resorted to using sub-grid models to capture the energetics of the explosion and post-processing the results with large nuclear networks to calculate nucleosynthetic results. These sub-grid models should have accurate treatments of detonation physics such as curvature or shock strengthening. In the lower density regions of the star, the curvature of the detonation front will slow the detonation, affecting the production of intermediate mass elements. In this same region of the progenitor, the density sharply decreases outward and this may strengthen the detonation causing more complete burning than would be expected at these densities. In order to verify the results of calculations using sub-grid models, it is imperative there be a set of benchmark calculations with which to compare. We aim to produce such results by completing one dimensional, high resolution calculations with large reaction networks and comparing to the results of fully resolved calculations of steady-state detonations. We utilize the open source hydrodynamics software instrument FLASH in conjunction with the reaction network from Modules for Experiments in Stellar Astrophysics (MESA). The MESA reaction network is used in both the explosion simulations as well as the post-processing for consistency. Improving the accuracy of models will allow for better prediction, comparison, and interpretation of nucleosynthetic results.

3.16 The NuGrid/JINA Yield Database and Convective-Reactive Nucleosynthesis in O- and C-Shell Mergers

Christian Ritter[1], Falk Herwig[1], Sam Jones[2], Marco Pignatari[3], Chris Fryer[4], Robert Andrassy[1], Benoit Côté[1,5], Paul Woodward[6], Raphael Hirschi[7]

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I will present the NuGrid/JINA Set 1 nucleosynthesis yield database which include asymptotic giant branch and massive stars from 1Msun to 25Msun for five metallicities between Z=0.02 and Z=1e-4. Detailed nucleosynthesis of elements and isotopes up to Bi is calculated in a post-processing step with the same set of nuclear reaction rates for all initial masses. All massive star models are exploded based on two mass- and metallicity-dependent fallback prescriptions motivated by the neutron-star and black-hole mass distribution. We adopt a hybrid post-processing approach to accurately simulate the production of hot-bottom burning elements and heavy s-process elements. We adopt convective boundary mixing in low- and intermediate mass stars which results in H-ingestion events in our super AGB stars and in low-metallicity low-mass stars. The impact of abundance features of the yield calculation can be explored with simple stellar population model SYGMA and galaxy code OMEGA. SYGMA allows to fold yields into properties of simple stellar populations to model the chemical enrichment and feedback in galaxy simulations. With both tools we demonstrate the effects of nucleosynthesis in convective-reactive O- and C-shell mergers in massive stars. We find the effective production of odd-Z elements which are confirmed by synthetic 1D models informed by 3D hydrodynamic simulations. This pre-supernova element production could solve the problem of galactic chemical evolution models to account for the observed abundances of odd-Z elements, such as K and Sc. Future directions of the NuGrid/YIELD effort will be discussed.

3.17 Exploring the Pop III Progenitors of CEMP-No Stars

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Using a cosmological simulation that incorporates a new sub-grid model of turbulent mixing, we explore the range of Population III progenitors of the metals that are likely the source of the iron-poor stars seen in the Milky Way halo. We accurately follow the evolution of the first stars and track their supernova ejecta in two broad categories. "Primordial metals", ZP, are generated by very large Pop III SNe and likely possess unique abundance signatures characteristic of carbon-enhanced, metal-poor (CEMP-no) stars. Metal enriched stars generate metals, Z, with abundance ratios akin to those seen in the modern universe. By recording both quantities for each star in our simulation we can use post-processing to model the overall metallicity of our stellar populations and explore the space of Pop III SN progenitors - all without the need to re-run costly cosmological simulations. For this work we explore the abundances patterns of a range of Pop III SNe comparing the metallicity of our simulated stellar populations to the observed [Fe/H], [C/H], [O/H], and [Mg/Ca] ratios in a set of Galactic CEMP-no halo stars.

3.18 Studies of Nuclear Properties for Explosive Astrophysical Processes

Gry Merete Tveten[1]
1 - Department of Physics, University of Oslo, Norway

This poster will present the Studies of nuclear properties for explosive astrophysical processes (SNAPS) project that aims at constraining key reaction rates for p-isotope production and the rp-process. The main experimental approach of this project is to determine the nuclear level density and gamma strength function from particle-gamma coincidence data using the Oslo method. As an example of recent results, the work on constraining the cross section for the photodisintegration reaction ^{92}Mo(p, gamma) will be presented. Nuclear reaction rates at astrophysical temperatures where calculated using the TALYS 1.6 code and combined with reaction network calculations for the scenario of the shock front of a supernova passing through the O-Ne layer of a 25 solar mass star and the impact of the constraint on final abundance calculations will be presented. The poster will also display the plans for the project.

3.19 The Most Massive Stars that Ever Lived: The Final Fates of Accreting Supermassive Stars

Tyrone Woods[1]
1 - Monash University, Melbourne, Australia

The discovery of enormous (billion solar mass) high-redshift quasars challenges our understanding of the early Universe: How did such massive objects form in the first billion years? Observations and simulations increasingly favour the "direct collapse" scenario. In this case, an atomically-cooled gas cloud of primordial composition accretes rapidly onto a single stellar core, ultimately collapsing through the general relativistic instability after reaching $\sim$100,000 solar masses and forming an initial supermassive seed black hole. Previous studies of such stars were either not hydrodynamical in nature or considered stars in isolation, not in the extreme accretion flows in which they actually form. We present the results of such calculations using the 1D stellar evolution code KEPLER, incorporating implicit hydrodynamics, general relativistic corrections, and a detailed treatment of nuclear burning processes using an adaptive network. We find that the GR instability triggers the collapse of the star at 150,000 - 330,000 solar masses for accretion rates of 0.1 - 10 solar masses per year, with the final mass of the star scaling logarithmically with the accretion rate. We discuss the response of the supermassive star and the evolutionary state at the time of collapse for a wide range of accretion rates, and prospects for the ejection of chemically-enriched material.