CEMP Stars as Probes of First-Star Nucleosynthesis, the IMF, and Galactic Assembly

Sunday 8 September 2019 - Friday 13 September 2019

University of Geneva A100 Sciences II

Book of Abstracts

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Welcome from the LOC & SOC

Authors: Sylvia Ekström[1]; Raphael Hirschi[2]

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CEMP Stars –Past Perspectives and Future Objectives

Author: Timothy Beers[1]

[1] *University of Notre Dame*

It has been over a quarter century that the class of metal-poor stars known as carbon-enhanced metal-poor (CEMP) stars was first recognized. In that time, astronomers have recognized a number of sub-classes, apparently due to a variety of nucleosynthesis pathways. Most recently, the sub-class formerly referred to as CEMP-r/s has been shown to be due to the so-called intermediate neutron-capture process, one not appearing in the seminal work of B^2FH (1957) and Cameron (1957). After a brief review of our current state of understanding of the CEMP stars, I will comment on objectives for future study that are still required –- including understanding the effects of NLTE/3D corrections to the apparent frequency of CEMP stars as a function of declining metallicity, identification of the likely environments in which various sub-classes of CEMP stars formed, and identification of the progenitors (and binary nature) associated with each sub-class.

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Observations of very iron-poor stars

Author: Piercarlo Bonifacio[1]

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At the time of writing there are fourteen stars known to have an iron content below 3.16 e-5 that of the Sun. Twelve out of fourteen of these stars are extremely enhanced in carbon, so that their total metal content Z is larger than 1e-3 that of the Sun, although their iron content may be lower than 1.e-7 that of the Sun. I will summarize extant observations of these very iron poor stars. New radial velocity measurements, implying binarity in one of these stars, have revived the theoretical view that this extreme carbon enhancement is the result of mass transfer from a former AGB companion, in contrast with the more popular view, that it reflects the chemical composition of the gas cloud out of which the star was formed. I will also provide an outlook on how current and future surveys may provide us larger samples of these extremely rare objects.

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3D non-LTE chemical abundance measurements for CEMP stars

Author: anish amarsi[None]

Stellar abundance measurements are heavily model dependent, and for late-type stars, the accuracy is often limited by the use of one-dimensional (1D) hydrostatic model atmospheres and the assumption of local thermodynamic equilibrium (LTE). Systematic errors imparted by the use of 1D LTE modelling tend to grow towards lower metallicities, and are thus especially significant for CEMP stars. Recently it has become feasible to relax both assumptions simultaneously, by carrying out detailed 3D non-LTE radiative transfer post-processing of 3D hydrodynamic model stellar atmospheres. In this talk I shall present our new grids of 3D non-LTE abundance corrections, and the results of their application to CEMP stars.

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Accurate abundances at the lowest detected iron abundance: SMSS 1605-1443

Author: Thomas Nordlander[1]

[1] *Australian National University*

We recently announced the discovery of SMSS 1605-1443, which has the lowest detected iron abundance of any star at [Fe/H] = -6.2 (1D LTE). It is strongly carbon enhanced with [C/Fe] ˜ 4, but otherwise exhibits a perfectly normal halo star abundance pattern with no detection of neutron capture elements. Assuming a single enrichment event, we find good matches to predictions for Population III stars exploding in low-energy fallback-and-mixing supernovae (from Heger & Woosley 2010) assuming the progenitor star was just 10 solar mass.
I shall discuss recent results from follow-up UVES spectroscopy as well as accurate 3D NLTE spectrum synthesis calculations.

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Looking for the most metal-poor stars with large surveys

Author: David Aguado[1]

[1] *University of Cambridge, UK*

In the Big Bang Nucleosynthesis (BBN), hydrogen, helium, and small traces of lithium and beryllium, were produced. A few million years after BBN, the first stars were born. Important questions about star formation, galactic evolution, and the yields of the first supernovae can be answered from the study of these first stars and their descendants. The most chemically primitive stars in the Milky Way are invaluable to understand the early universe, but they are extremely rare and hard to find.

Over the past few years we have been digging in the SDSS and LAMOST spectroscopic surveys and identified tens of halo stars with estimated metallicities [Fe/H] < -3. We have obtained follow-up spectroscopic observations with the 4.2m William Herschel Telescope and the 10.4m Gran Telescopio Canarias, which were subsequently analyzed using the FERRE code. From this work, we have recently discovered two dwarf stars with extremely low iron content, SDSS J0815+4729 and SDSS J0023+0307, both at [Fe/H] < -5. In addition to it, in the context of the Pristine collaboration, we have selected and followed-up metal-poor candidates identified from narrow-band photometry. A brief description of the methodology used in all of these programs will be provided, summarizing the most important results.

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CEMP Stars as Probes of First-Star Nucleosynthesis, the IMF, and Galactic Assembly

Author: Starkenburg Else[1]

[1] *Heidelberg*

The lowest metallicity stars that still exist today probably carry the imprint of very few supernova. As such, they represent our best observational approach to understand the First Stars. In this talk I will review the early (chemical) evolution of the Milky Way system from both modeling and observational perspectives. In particular, I will present results of the Pristine survey, a Franco-Canadian photometric narrow-band survey designed to efficiently decompose the metallicity structure of the Milky Way halo. I will show how we use this discriminatory power to hunt for the very rare extremely metal-poor stars (bearers of the chemical imprint of the first stars), including CEMP stars, and greatly improve our study of metal-poor substructures in the halo.

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Tracing the formation of the Milky Way through UMP and EMP stars

Author: Federico Sestito[1]

Co-authors: Nicolas Martin [1]; Else Starkenburg [2]

[1] *Observatoire Astronomique de Strasbourg*

[2] *Leibniz-Institut für Astrophysik Potsdam*

I will present the results of a Bayesian derivation of stellar parameters, distances, and orbits for all ultra metal-poor stars (UMPs, [Fe/H] < -4) available in the literature, as well as for the extremely metal-poor stars (EMPs, [Fe/H]< -3) observed by Pristine survey, a unique spectrophotometric survey based on a narrow-band Ca H&K filter that aims to detect and analyse EMPs stars. The Pristine survey allows me to focus on a large and homogeneous EMPs dataset, from which it is possible to better study the spatial distribution and orbits of these stars around the Milky Way, especially when cross-matched with Gaia DR2 data. EMPs and UMPs are extremely rare objects located mainly in the Milky Way halo and because they are extremely metal poor, also relative to their neighbourhood, it is assumed that they formed in the relative pristine Galaxy short after the Big Bang. The inferred distances and orbital parameters are directly linked to the formation stages and building blocks of our Galaxy. I will show that, even though most UMP and EMP stars have properties that link them to the inner halo or the accreted halo, a strikingly large fraction of those stars follow disc-like orbits. I will discuss how this discovery affects the different scenarios of the formation of the proto-MW.

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The Metallicity Gradient in the Outer Halo of the Milky Way

Author: Sarah Dietz[None]

Co-authors: Jinmi Yoon ; Timothy Beers ; Vinicius Placco [1]; Young Sun Lee [2]

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[2] *Chungnam National University*

We present a study of the metallicity gradient in the outer halo component of the Milky Way's dual halo system, using metallicities from SDSS DR15 and several other datasets along with high-precision astrometry from Gaia DR2. It has previously been recognized that the outer halo has one of the most metal-poor stellar populations in our Galaxy (peaking around [Fe/H] = -2.2). In this work, we further explore this unique stellar population by examining variations in its metallicity as a function of kinematic and orbital parameters. Previous predictions have suggested that less massive, more metal-poor dwarf galaxy satellites do not sink very deeply into the potential well of our Galaxy during mergers, rather they remain on the outskirts and form the outermost regions of the halo. On this basis, we look for trends in metallicity in a variety of data samples to better understand the assembly history of the Milky Way. Our work aims to aid future efforts to expand the observational catalogue of [Fe/H] < -2 stars, which serve as important "fossils" of the first generation of stars.

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Observations of 200 New CEMP Stars from the South African Large Telescope

Authors: Kaitlin Rasmussen[1]; Vinicius Placco[1]; Timothy Beers[1]; Joseph Zepeda[1]; Éric Depagne[None]

[1] *University of Notre Dame*

Carbon-enhanced metal-poor stars belong to the second generation of stars to form in the Universe; as such, they are a valuable insight into nuclear processes and stellar environments that predate the formation of the Milky Way. At present, approximately one hundred and fifty CEMP stars have been studied via high-resolution spectroscopy. We have observed over 200 new CEMP stars at the South African Large Telescope and have analyzed a sizable subset of them thus far. We report the results of this analysis and discuss their implications for first star nucleosynthesis and Galactic chemical evolution.

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CEMP-no and the early chemical enrichment of the Milky Way

Author: Cristina Chiappini[1]

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3D carbon and oxygen abundances in CEMP stars from molecular lines

Authors: A. Kučinskas[1]; E. Kolomiecas[1]; J. Klevas[1]; H.-G. Ludwig[2]; P. Bonifacio[3]

[1] *Vilnius University, Lithuania*

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Molecular lines are frequently the only available carbon and oxygen abundance indicators in CEMP stars. However, formation of molecular lines in the atmospheres of CEMP stars is prone to the influence of convection and NLTE. These effects have to be properly taken into account when aiming at reliable abundance estimates. In this contribution we present an overview of the current status in the studies of carbon and oxygen abundances in CEMP stars using molecular lines and 3D hydrodynamical model atmospheres. We focus on the progress made in this field during the recent years, discuss the outstanding problems and possible ways for tackling them in the future studies.

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Short poster presentations

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Very Iron-poor Stars and an Update of the SkyMapper Extremely Metal-Poor Star Program

Author: David Yong[1]

[1] *Australia*

The atmospheres of low-mass stars preserve information on the chemical and physical conditions of their birth gas clouds. Studying chemical abundances in the oldest, most metal-poor stars provides an observational window into the early Universe through which we can infer the properties and details of the earliest chemical enrichment events (e.g., supernovae, AGB stars).

The most metal-poor stars exhibit an enormous range in their relative chemical abundance ratios which demand a wide variety in the types of progenitors and their properties. I will present an overview and highlights of the chemical abundance patterns in metal-poor stars and the implications and insights into their progenitors as well as an update of our high-resolution spectroscopic follow-up of halo metal-poor star candidates from the SkyMapper Telescope.

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CEMP stars in dwarf galaxies

Author: Asa Skuladottir[1]

[1] *Heidelberg, Germany*

Dwarf galaxies are the most common type of galaxy in the Universe. The Local Group is the only place where we are able to obtain an unobscured view of early star formation and chemical enrichment in galaxies from abundance measurements in individual stars by using moderate- to high-resolution spectroscopy. Recent measurements of [Ce/Fe] in different dwarf spheroidal galaxies, suggest possible differences in the fraction and/or abundance patterns of CEMP stars based on the host galaxy. In this talk I will discuss the current status of CEMP observations in dwarf galaxies, as well as theoretical predictions of what is expected in such
systems.

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Abundances and Kinematics of CEMP stars - A new classification

Author: Camilla Juul Hansen[None]

Co-authors: Terese Hansen ; Andreas Koch ; Birgitta Nordström ; Tim Beers ; Daniel Singh ; Vinicuis Placco ; Johannes Andersen ; Henrique Reggiani ; Moritz Reichert

The elements locked up in old, metal-poor stars carry a wealth of information on the properties of the early Universe and how it evolved. Stellar abundances are fossil records of the physical conditions in the interstellar medium and of the progenitors that created the material the low-mass stars formed from. All heavy elements show a large star-to-star abundance scatter at low metallicities, which typically hides the fact that several processes and formation sites at early times created different amounts of a given element under different conditions. Using stellar abundances, we can explore the neutron-capture processes and learn about the origin of the heavy elements from a number of formation sites that host these processes. Meanwhile, kinematics will allow for an exploration of the CEMP occurrence in various Galactic components.
I will discuss abundances and kinematics of the old carbon enhanced metal-poor (CEMP) stars in which we have explored the behaviour of a large number of heavy elements. I will show how we can use Sr and Ba to classify them and how we can derive their metallicities in a new and faster way.

OBSERVATIONAL APPROACH: CEMP STARS, FIRST STARS, FIRST GALAXIES / 26

Binarity among CEMP-no stars: an indication of multiple formation pathways?

Author: Anke Arentsen[None]

Co-authors: Else Starkenburg ; Matthew Shetrone ; Kim Venn ; Éric Depagne ; Alan McConnachie

Understanding the origin of CEMP-no stars is crucial for our understanding of physical processes in the early universe. CEMP-no stars do not show any s-process enhancement and therefore cannot easily be explained by transfer of carbon and s-process elements from a binary AGB companion like the CEMP-s stars. This has been supported by the large radial velocity program by Hansen et al. (2016), finding a low binary fraction for CEMP-no stars. The abundance patterns of CEMP-no stars are therefore generally assumed to be direct probes of the first supernovae.

I will present here the results published in Arentsen et al. (2019). We have performed radial velocity monitoring of a sample of CEMP-no stars and we find four new binary CEMP-no stars based on their velocity variations. In our sample combined with the literature, we find a difference in binary fraction of CEMP-no stars that depends on the absolute carbon abundance. We find a binary fraction for CEMP-no stars in the Yoon et al. (2016) Groups I and III of almost 50%, while the binary fraction for stars in the less carbon-enhanced Group II is still low.

This might imply a relation between a high carbon abundance and the binarity of CEMP-no stars. Although binarity does not equate to mass transfer, there is a possibility that a CEMP-no star in a binary system has been polluted, and care has to be taken in the interpretation of their abundance patterns.

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Seeking the origin of CEMP-r/s stars

Authors: Birgitta Nordström[1]; Terese Thidemann Hansen[2]

[1] *Niels Bohr Institute, Copenhagen, denmark*

[2] *Texas University, USA*

The elemental abundances in many metal-poor stars show enhancements of carbon and as well neutron-capture elements: CEMP-s, CEMP-r and CEMP-r/s stars. In several radial velocity (RV) projects we have tried to uncover the origin of CEMP stars with enhancements of s- and/or r-process elements. The orbital elements of those that are binaries seem to give hints about the origin of the enhancements. Radial-velocity monitoring of CEMP-s stars has shown that these are primarily found in binary systems, and gained their s-process abundances via mass transfer as their companion evolved through the asymptotic giant branch phase. The source of neutron-capture elements of the CEMP-r/s stars is not well constrained. We now monitor a sample of CEMP-r/s stars for radial-velocity variations to determine the binary frequency of a sample of CEMP-r/s stars and determine orbital parameters for the binary systems.

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Multiplicity of the first stars from machine learning-based classification of stellar fossils

Author: Tilman Hartwig[1]

[1] *University of Tokyo*

We derive for the first time the multiplicity of the first stars from the abundance patterns of extremely metal-poor (EMP) stars in the Milky Way. Based on theoretical models of the chemical yields of the first supernovae, we train decision trees to classify EMP stars. This machine learning-based approach predicts if a certain abundance pattern is consistent with supernova enrichment by one or by several progenitor stars (mono- or multi-enriched). On a blind test sample, we achieve an accuracy of over 80% for individual EMP stars. By applying the trained random forest to actual observations, we find both mono- and multi-enriched EMP stars. Their relative fraction allow us to constrain the multiplicity and initial mass function of the first stars, which has significant consequences for the radiative and chemical signature of the first stars and galaxies.

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The binarity of dwarf carbon stars and their possible role as main sequence counterparts to CEMP stars

Author: Lewis Whitehouse[1]

[1] *University College London*

Contrary to expectations, the most abundant carbon stars in the Galaxy are long-lived, main-sequence stars. The origin of these dwarf carbon (dC) stars is an astrophysical curiosity that is 40 years(!) old, and the mechanisms for enhancing their observed C/O above unity are poorly constrained. Intriguingly, a significant fraction of the dC stars have clear halo kinematics, and are thus almost certainly related to the carbon enhanced, metal-poor (CEMP) stars observed in the Galactic halo.

We will present a search for evolved binary companions via radial velocity measurements of these chemically peculiar dwarf stars, all of which are currently in the solar neighbourhood. Over several years, we observed a few dozen dC stars with the ISIS spectrograph on the WHT, and 22 stars with sufficient data are consistent with a 100% binary fraction. We hypothesise these main-sequence stars are essentially CEMP-r or CEMP-s stars of relatively low mass, and are ancient and relatively pristine sites for stellar archaeology.

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Origin of CEMP-no morphology in the Milky Way halo

Author: Jinmi Yoon[None]

The last 30 years of galactic archaeological studies have provided many lines of evidence that CEMP-no stars are direct descendants of the very first stars. In particular, the last few years have been very thrilling because the recent observational studies have shown that there are likely multiple pathways to form CEMP-no stars based on distinctly different CEMP-no groups exhibited in the A(C)-[Fe/H] diagram (CEMP-no morphology). Also, the recent theoretical simulations have provided various possible mechanisms for the formation of these groups. In this talk, we will discuss the latest observational results regarding both the nucleosynthetic and accretion origins of CEMP-no group morphology in the A(C)-[Fe/H] diagram, based on the inference drawn from the similar A(C)-[Fe/H] morphological pattern from both the halo CEMP-no stars and that of stars found in the Milky Way satellite dwarf galaxies. Further, we present a kinematic analysis of the CEMP groups and carbon-normal stars and an exploration of the early Galactic chemical evolution of carbon for further understanding the origin of the distinct CEMP-no groups.

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Dynamical Relics with Chemically Peculiar Stars from Ancient Small Dwarf Galaxies

Author: Zhen Yuan[1]

Co-authors: Tadafumi Matsuno [2]; Kohei Hattori [3]; Haining Li [4]; Dmitrii Gudin [5]; Timothy Beers [6]

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[2] *NAOJ/SOKENDAI*

[3] *University of Michigan*

[4] *National Astronomical Observatory of China*

[5] *University of Notre Dame*

[6] *University of Notre Name*

Stellar halo of the Milky Way is believed to have formed through hierarchical mergers of small stellar systems such as dwarf galaxies. By studying the orbits and chemistry of very metal-poor halo stars, we can decipher the merger events of ancient galaxies, as well as their chemical properties. We applied a novel clustering method, StarGO, to the largest bright very metal-poor star catalog complied from the LAMOST DR3 VMP catalog and Gaia DR2. We found two significant substructures with retrograde orbits. Judging from their metallicities, these substructures are probably the remnants of tidally disrupted low-mass dwarf galaxies or ultra faint dwarf galaxies. One of the substructures, is confirmed to be dynamically associated with a well-studied strongly r-process element enhanced star (r-II star) and a CEMP-s star. Our finding favors the scenario that the progenitor is an ultra faint dwarf. High resolution spectroscopic studies will be undertaken to find more possible chemically peculiar stars in both of these substructures. It is the first attempt to study the birth environment of these stars from the relics of small dwarf galaxies.

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Chemodynamical Analysis of Six Low-Metallicity Stars in the Halo System of the Milky Way

Author: Mohammad Mardini[1]

[1] *National Astronomical Observatories of China*

In this work, we study the chemical compositions and kinematics of six metal-poor stars in the Galactic Halo. These stars were selected from the LAMOST survey and were followed up with high-resolution (R ∼˜110,000) with the Lick/APF. By investigating the chemical compositions and kinematics of this sample, we identified two carbon-enhanced metal-poor stars (J1630+0953 and J2216+0246) without enhancement in heavy elements (CEMP-no stars). By comparing the light-element abundances of these two stars with predicted yields from non-rotating zero-metallicity massive-star models, we find possible progenitors of J1630+0953 and J2216+0246 could be in the 13-25 $M_{\odot}$ mass range. In addition, there are no significant differences in the chemical abundances of light and heavy elements of the program stars when compared with data from the literature. We also present a kinematic analysis, which suggests most of our program stars are likely to belong to the inner-halo population, with orbits passing as close as ∼ 2.9 kpc from the Galactic center. The chemical and kinematic properties of this sample help place crucial constraints on the origin and evolution of low-metallicity stars in our Galaxy.

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Constraining nucleosynthesis in CEMP-s progenitors using Fluorine

Author: Aldo Mura Guzman[1]

Co-author: David Yong

[1] *Australian National University*

Carbon-Enhanced Metal-Poor (CEMP) stars are among the most important objects for constraining the formation and evolution of the first stellar populations in the Galaxy. CEMP stars with enhancements in slow neutron-capture process (s-process) elements (CEMP-s stars, objects with [Fe/H] < -2, [C/Fe] > 0.7 and [Ba/Fe] > 1) are a significant fraction (as high as 25%) of all metal-poor stars. Of the proposed formation channels for CEMP-s stars, mass transfer in a binary system from an AGB companion which is now an unseen white dwarf is the most widely accepted scenario.

Fluorine production at low metallicity is extremely sensitive to the physical conditions where produced and probably related to the same nucleosynthetic process responsible for s-process element production in AGB stars during the thermal-pulsating phase. Thus, Fluorine measurements in CEMP-s stars provide a direct test for CEMP-s formation scenarios, nucleosynthesis, and chemical enrichment mechanisms in the early beginnings of the Milky Way galaxy.

At low-metallicity, [Fe/H] < −2, Fluorine have been detected and measured in just 2 stars: HE 1305+0132 by Schuler et al. (2007) and HD 5223 by Lucatello et al. (2011). A handful of upper limits also exist.

We present Fluorine measurements in 2 CEMP-s stars along with a careful comparison with state-of-the-art nucleosynthesis predictions indicating some successes, and shortcomings, of the models.

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Chemical enrichment and ionizing escape fraction from observations of GRBs

Author: Nial Tanvir[1]

[1] *University of Leicester*

Gamma-ray bursts can be seen to very high redshifts, and the bright power-law continua of their afterglows provide ideal backlights for absorption lines studies. I will review what we have learnt from GRBs about evolving chemical abundances in the early universe; and consider the implications of the high HI column densities seen on the sight lines to GRBs for the escape fraction of ionizing radiation from massive stars. I will also review the importance of the kilonovae accompanying short-duration GRBs for the nucleosynthesis of heavy elements.

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The First Stars: Our Emerging Theoretical Framework

Author: Volker Bromm[1]

[1] *USA*

I will review the current standard model of how the first stars formed at the end of the cosmic dark ages, and how they impacted the subsequent history of the universe. The Population III formation process is intricately linked to the particle physics nature of dark matter, and can thus serve as an astrophysical laboratory to probe this elusive component of the cosmic matter-energy content. I will discuss select key observations that will soon test and constrain our theoretical ideas. Among them are campaigns to find and classify CEMP stars, providing important fossil evidence of the environment in which the first stars formed.

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Fragmentation Condition in a Primordial Accretion Disk

Authors: Wei-Ting Liao[1]; Matthew Turk[1]

[1] *University of Illinois at Urbana-Champaign*

The accretion disks around Population III (PopIII) stars are known to fragment under fast H_2 cooling. Based on the vertical disk structure, we study the optical depth for H_2 line cooling under an accretion disk geometry. With the physically motivated optical depth, we find that cooling in the inner disk with $r < 10$ AU is attenuated significantly due to the large surface density. PdV heating becomes more efficient than cooling, which prevents fragmentation in the inner disk. Yet, in the outer disk, cooling becomes dynamical. The fast cooling favors fragmentation. We thus argue that most of the fragments are initially at the outer disk.
In addition, any surviving fragment has to migrate slower than the photo-evaporation process. We found that fragments with $0.01 - 0.05\,M_\odot$ would survive under Type I migration if disk mass is less than 10% of the star's mass. For a fragment more massive than $0.1 M_\odot$, a gap would be opened up and migration would slow down. It increases the possibility for fragments encountering and merging with each other. The gravitational interaction between fragments would be crucial for mass growth of fragments, as well as the subsequent disk evolution.

THEORETICAL APPROACH TO CEMP STARS, FIRST STARS, AND FIRST GALAXIES / 56

Thermodynamics of H2 in the context of the First Stars

Author: Piyush Sharda[1]

Co-authors: Mark Krumholz [1]; Christoph Federrath [1]

[1] *Australian National University*

It is well known that the adiabatic index of H2 varies as its rovibrational modes are excited as a function of temperature. For the formation of the first stars at redshifts 20 and above, this variation can be significant because the primordial molecular clouds where the first stars form and the material present in accretion shocks near the first protostars can reach high temperatures where these modes can be excited. We build a statistical population of the first stars by performing a set of 80 3D gravito-hydrodynamic simulations of collapsing clouds with random seeds of sonic turbulence at high resolution (7.6 AU). We use the adaptive mesh refinement code FLASH with the primordial chemistry network KROME and follow all simulations till the time when 5 per cent of the initial cloud mass has been accreted by sink particles. The simulations are divided into two subsets - one where the adiabatic index of H2 is fixed to 7/5 (used in almost every 3D simulation of first stars), and another where it is calculated based on the temperature, ortho to para ratio and mass fraction of H2. The simulations result in the formation of 379 sink particles, implying that high fragmentation occurs in primordial clouds close to the primary sink. However, they also predict that there is a one-third chance that the massive primary might evolve in isolation, at least during its earliest stages. We find no significant differences in the mass distribution, clustering and multiplicity fraction of sinks in the two subsets. Thus, while it seems valid to treat H2 as a diatomic gas in these systems, the assumption may not stand if radiation feedback is included in simulations and followed to late times.

THEORETICAL APPROACH TO CEMP STARS, FIRST STARS, AND FIRST GALAXIES / 27

Surviving Pristine Stars and the Implications of their Non-detection Paper Number

Authors: Mattis Magg[1]; Ralf S. Klessen[2]; Simon C. O. Glover[2]; Haining Li[3]

[1] *Universität Heidelberg*

[2] *Institute for Theoretical Astrophysics, University of Heidelberg*

[3] *Key Lab of Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences*

As of now, the initial mass function (IMF) of metal-free stars is one of the key unsolved problems in the early Universe. Of particular interest is whether there are low-mass population III (Pop III) stars that survive until today. To determine how many such stars we should find in the Milky Way, we model Pop III star formation and feedback in the progenitors of Milky Way-like haloes. Assuming a typical top-heavy Pop III IMF that however still allows for such surviving stars, we find that about 4000 surviving metal-free stars should be present in the Milky Way. A simple estimate shows the incompatibility of this prediction with the lack of metal-free stars found during the search for extremely- and ultra-metal-poor stars. Thus, low-mass Pop III stars either have to be polluted by accretion during their life or form much more rarely than initially assumed. In the absence of pollution, constraints on the pristine IMF can be derived.

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The variety of CEMP-no abundances: back-and-forth mixing between H- and He-burning

Author: André Maeder[1]

[1] *Geneva University*

Stellar nucleosynthesis defines a sequence of abundances: - pure products of H-burning; - pure products of He-burning; - products of He-burning mixed into the H-burning region (class 2); - products of class 2 mixed in He-burning (class 3); - products of class 3 again mixed in H-burning zone (class

4). CEMP-no stars with enough observed data are distributed in classes 2, 3 and 4. Spinstars produce the abundances of classes 2-4 and account for CEMP-no enrichments, including some s-elements. The absence of anticorrelations Na-O and Mg- Al is discussed. Extreme class 4 abundances appear the closest ones to model predictions of GRB progenitors.

THEORETICAL APPROACH TO CEMP STARS, FIRST STARS, AND FIRST GALAXIES / 25

Probing the rotation of early massive stars from the abundances of metal-poor stars

Author: Arthur Choplin[1]

[1] *Konan University*

The study of the long-dead early generations of massive stars is crucial in order to obtain a complete picture of the chemical evolution of the Universe. The nature of these stars can be inferred indirectly by investigating the origin of the low-mass extremely metal-poor stars observed in our neighborhood, some of which are almost as old as the Universe. The material forming these low-mass metal-poor stars is generally thought to have been inherited from the ejecta of one or very few previous massive stars, called the source star(s). After introducing how rotation can impact the source star nucleosynthesis, I will discuss how the physics - especially rotation and nucleosynthetic processes - of the early generations of massive stars may be constrained by combining massive source star models including s-process and rotation with observations of metal-poor stars. A new detailed abundance fitting study of about 200 extremely metal-poor stars, carried out using massive stellar models computed at various initial rotation rates will be presented. From this analysis are guessed the characteristics of the best source stars, in particular their initial velocity distribution. It eventually provides hints on the nature of early massive stars.

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Mechanical mass loss in very metal poor massive stars

Author: Sébastien Martinet[1]

[1] *Geneva University*

Mass loss is expected to be very low at very low metallicities, even more for the first generations of stars. A lower mass loss induces a lower angular momentum lost during the main sequence, resulting in faster rotators. As the surface velocity increases, due to internal angular momentum transport from the core to the surface, the first stars reach critical velocity at their surface way easier than solar metallicities stars. The angular momentum excess is then needed to be lost through mechanical mass loss processes to remain subcritical. We discuss here the intensity of these mechanical mass loss rates for Pop III massive stars during the Main-Sequence phase and for very metal poor stars. We study how these mass loss rates may depend on the initial metallicity and also on the treatment of the angular momentum inside the stars. We also discuss some possible consequences of these mechanical mass losses on the evolution of very metal poor stars. Finally we study the cases of Be stars that may be stars losing masses by mechanical mass loss. However, reaching the critical limit may not be the key factor explaining the mass losses of these stars. Some other processes like pulsations may be important. To which extent these other processes may also play a role in Pop III and very metal poor stars is still an open question.

THEORETICAL APPROACH TO CEMP STARS, FIRST STARS, AND FIRST GALAXIES / 43

An Alternative Progenitor Scenario for the Most Iron-poor CEMP-no Stars.

Authors: Ondrea Clarkson[None]; Falk Herwig[1]; Paul Woodward[2]; Huaqing Mao[2]; Marco Pignatari[3]; Pavel Denissenkov[1]

[1] *University of Victoria*

[2] *University of Minnesota*

[3] *Hull University*

Understanding the nature of the first stars is essential to decipher the chemical abundance patterns in the most iron-poor CEMP stars. Due to their zero-metallicity nature, Pop III stars were structurally quite different than stars of higher metallicity. Namely, interactions between H- and He-burning layers have been recorded in the literature for both rotating and non-rotating stellar models. We recently showed that the intermediate neutron capture process (i-process; Nn=10ˆ13-16 cmˆ-1) can explain the lack of an odd-even effect in two of the most iron-poor CEMP-no stars, HE 0107-5240 and HE 1327-2326. We present results from a recent survey of Pop III stellar models where we investigated the occurrence and behaviour of interactions between H and He-layers. Simulations of massive Pop III stars from 15-140M_sun with various mixing prescriptions show that some form of interaction is present in 22/26 of our simulations. These interactions can vary in nature and result maximum H-burning luminosities from logL_H/L_sun ˜9-14. Higher luminosities typically coincide with energy generation around 25% of the binding energy of the H-He layer and could potentially expel a portion of the material enriched with i-process signatures. Motivated by the results seen in 1D simulations, we have calculated 3D hydrodynamic simulations of the events which shed new light on the mixing processes involved in the interiors of the first stars.

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The origin of CEMP-i stars - Results from a comprehensive multi-method simulations approach

Author: Falk Herwig[1]

Co-authors: Robo Andrassy ; Ondrea Clarkson ; Benoit Côté ; Pavel Denissenkov [1]; Huaqing Mao [2]; Marco Pignatari [3]; David Stephens [1]; Paul Woodward [2]

[1] *University of Victoria*

[2] *University of Minnesota*

[3] *Hull University*

Most C-enhanced metal poor stars show substantial enhancements of heavy n-capture elements, mostly of second-peak elements such as Ba, La and Eu. We report on a comprehensive simulation program involving 3D hydrodynamic simulations, 1D stellar evolution and nucleosynthesis simulations, galactic chemical evolution simulations as well as novel approaches to neutron-capture nucleosynthesis simulations. We start by introducing a classification of CEMP stars based on equilibrium neutron-density elemental ratio predictions that depend only on nuclear physics data, and are independent of any specific astrophysical site. Based on this approach we interpret the JINAbase databased of CEMP stars, and find that many stars labeled as CEMP-s cannot be reproduced by s-process neutron density models, but instead by the intermediate neutron density in the range 13 < log Nn < 16, demonstrating the importance of the i process for understanding the heavy-element patterns in CEMP stars. We will then present our current understanding of the i process as a prime example of a convective-reactive nuclear process that relies on the simultaneous coupling of hydrodynamic convective boundary mixing, entrainment and advection processes with detailed, heavy-element neutron-cature nucleosynthesis. I will present a brief survey of candidate stellar sites of the i proces, such as low-Z AGB and super-AGB stars, massive stars and post-AGB stars. The key ingredient of the convective-reactive i process is the H-ingestion into convective He-burning layers. However, the volatile nature of this process, as demonstrated through our 3D hydrodynamic simulations, poses also a great challenge to the viability of these sites. The new i-process site that we

discovered recently in rapidly accreting white dwarfs (RAWDs) is less volatile, and therefore promising in that regard. Our CEMP-i star abundance predictions for RAWDs are based on our new coupled 3D1D hydro-nucleosynthesis approach and reproduce the abundances of CEMP-i stars all the way from C to Pb remarkably well. We have also demonstrated through galactic chemical evolution simulatiopns, that i process in RAWDs may contribute substantially to some first-peak elements in the solar system. The important nuclear physics data impact on interpretations of CEMP stars will be demonstrated.

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A new grid of Geneva stellar evolution models for Population-III stars

Author: Laura Murphy[1]

Co-authors: Jose Groh [1]; Sylvia Ekström [2]; Georges Meynet [2]; Cyril Georgy [2]

[1] *Trinity College Dublin*

[2] *Université de Genève*

Understanding the nature of the first stars and their explosive deaths is key to understanding the early universe and the evolution of high-redshift galaxies. With new facilities such as JWST we may soon have the first observations of the earliest stellar populations, but to understand these observations we will require detailed theoretical models. Using the Geneva stellar evolution code, we have developed a new grid of zero-metallicity models for a range of initial masses from 9 to 120 solar masses. We have produced three sets of models, one non-rotating, and two rotating at 20% and 40% of critical velocity. We analyse the evolution of the interior structure, energy generation, angular momentum transport, as well as the surface properties, identifying unique features of Population-III evolution. Key findings so far include the significant expansion of the stellar envelope at late evolutionary stages in rotating models, and the spin-up of very massive models leading to episodic mass-loss events at critical rotation. This research sheds new light on the behaviour of the first stars and how they may have impacted their environments, particularly in relation to their final fates.

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Low-mass primordial stars: i-process nucleosynthesis during core-flash proton ingestion episodes?

Authors: Simon Campbell[1]; Carolyn Doherty[2]

[1] *Monash University*

[2] *Konkoly Observatory Budapest*

Models of zero metallicity and extremely metal-poor stars show that they evolve differently to their more metal-rich counterparts. In particular they suffer violent proton-ingestion episodes (PIEs) that lead to extreme carbon enrichment at the surface. The fresh carbon has a fundamental effect on their further evolution, and can be transferred to binary companions, producing CEMP stars. As first suggested by Fujimoto et al. (1990), the carbon enrichment may also be accompanied by s-process products produced during the PIEs, thus making the stars intrinsic CEMP-s stars. More recent models have shown that the neutron densities can become high enough to trigger the i-process. In this talk I will describe the evolution of a primordial star from the main sequence through to the thermally-pulsing asymptotic branch phase, with a particular focus on our new calculations of the i-process nucleosynthesis that occurs during the core helium flash proton ingestion episode. I will also briefly present a summary of the evolutionary outcomes we have found in our grid of zero metallicity and

extremely metal-poor models. We have calculated the nucleosynthetic yields for these stars, with the caveat that they suffer from many uncertainties.

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Observational Evidence for Aspherical Jet-Like Population III Supernova Explosion

Author: Rana Ezzeddine[1]

[1] *Massachusetts Institute of Technology*

Theoretical investigations have long indicated that supernovae of the first stars would explode in an asymmetric fashion, mainly driven by their fast rotations. However, insufficient observational evidence has prevented in-depth studies. Ultra metal-poor stars ([Fe/H]<-5) encode information about their First progenitor star, such as the explosion mechanism, through the relative abundances of heavy elements like Cr, Co, and, most importantly, Zn. In this talk, I will report on the first detection and determination of a Zn abundance in the UV spectrum of the hyper metal-poor star, HE 1327−2326. Zn is found to be highly enhanced relative to Fe. I will show that this amount of Zn can only be produced in a high-entropy explosion environment, such as an aspherical supernova explosion with bipolar outflows. I will then reflect on the implications that such explosions of the First stars could have on our understanding of the chemical enrichment across the early universe, and formation of the second-generation of stars.

THEORETICAL APPROACH TO CEMP STARS, FIRST STARS, AND FIRST GALAXIES / 57

CEMP star formation from faint supernova explosions

Authors: Gen Chiaki[None]; John Wise[1]; Stefania Marassi[None]; Raffaella Schneider[None]

[1] *Georgia Institute of Technology*

Large observation campaigns of metal-poor stars in Galactic halo and dwarf galaxies have revealed that there are stars with higher carbon abundance relative to the solar one ([C/Fe] > 0.7; carbon-enhanced metal-poor [CEMP] stars). It has been considered that long-lived or low-mass CEMP stars form through fragmentation of their parent clouds induced by gas cooling of carbon grains. Carbon grains can be supplied by faint supernovae (FSNe), where iron-rich inner layer of the ejecta falls back into the remnant and mainly carbon-rich gas is ejected. We numerically follow enrichment process of a minihalo (MH) which hosts a first primordial (Pop III) star exploding as a FSN. In a cosmological simulation with a simulation box size of 300 comoving kpc, a Pop III star forms in a MH with 10^6 $\mathrm{M}_\odot$ at redshift 12. We then run three simulations in three cases with progenitor masses of $M_{\mathrm{PopIII}} = 13$, 50, and 80 $\mathrm{M}_\odot$. The metal and dust abundances are consistently given by the nucleosynthesis and dust formation models of FSNe. In this talk we will present the metallicity range of enriched region and discuss the condition of cloud fragmentation induced by gas cooling owing to carbon dust grains.

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Simulating and Observing the First Galaxies

Author: John Wise[1]

[1] *Georgia Institute of Technology*

JWST will uncover a vast population of low-luminosity galaxies at Cosmic Dawn that is responsible for most of reionization. We present predictions on this high-redshift population, focusing on their physical properties and role during reionization. We use two suites of high-resolution cosmological simulations – the Renaissance Simulations and the Tempest Simulations – that sample different large-scale environments. Using a sample of over 3,000 resolved galaxies along with the formation of 10,000 massive Population III stars, we show that the luminosity function flattens above a UV magnitude of -14, and the faintest galaxies may be the ancestors of ultra-faint dwarfs. Metals from Population III supernova are the primary source of metals in a fraction of the most metal-poor galaxies. Star formation in low-luminosity galaxies is extremely bursty as the gas reservoir is easily disrupted by internal feedback, resulting in a large spread in galaxy relationships, such as the mass-metallicity, SFR-stellar mass, and stellar mass-halo mass relations. This inefficient star formation ultimately leads to high mass-to-light ratios, similar to local ultra-faint dwarfs, even at high redshifts.

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Building-up Pop III IMF in the Milky Way-like galaxies

Author: Shingo Hirano[1]

[1] *Kyushu University*

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First star mass distribution: empirical constraints

Author: Salvadori Stefania[1]

[1] *University of Florence, Italy*

The Local Group holds the living fossils of the first stars and galaxies. Still, these precious relics are extremely rare, and hence very difficult to catch. In this talk I will discuss the most recent observational findings and theoretical predictions for present-day metal-poor stars, underlying the links with the properties of the first stars. In particular, I will show that chemical abundance studies of metal-poor stars in both the stellar halo and in nearby dwarf galaxies are key observations to study the early metal enrichment and to constrain the mass distribution of the first stars.

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Connecting the first galaxies with ultra faint dwarfs in the Local Group

Author: Jeon Myoungwon[1]

[1] *Korea*

We investigate the star formation histories and chemical evolution of isolated analogs of Local Group untra-faint dwarf galaxies (UFDs) and gas-rich, low-mass dwarfs. We perform a suite of cosmological hydrodynamic zoom-in simulations to follow their evolution from the era of the first generation of stars down to z = 0. We confirm that reionization, combined with supernova (SN) feedback, is

primarily responsible for the truncated star formation in UFDs.
In this talk, we will show the importance of Population III stars, with their intrinsically high Carbon yields and the external metal enrichment, in producing low-metallicity stars and carbon-enhanced metal-poor (CEMP) stars. We will also discuss whether the progenitors of local, gas-rich dwarf galaxies (M_star ˜ 10ˆ6 solar mass) could possibly be detected as Damped Lyman-alpha Absorbers (DLAs) over cosmic time. Specifically, since we explicitly consider the contribution of heavy element enrichment from the first stars to the build-up of metals in dwarf galaxies, we can test the scenario that very metal-poor DLAs could contain the unique signature of Pop˜III nucleosynthesis.

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Exploring the stellar ionising continuum of galaxies in the context of cosmic reionisation

Authors: Anne Verhamme[1]; Charlotte Simmonds[1]

[1] *UNIGE*

Cosmic reionization corresponds to the period in the history of the Universe during which the predominantly neutral intergalactic medium was ionised by the emergence of the first luminous sources. I will first briefly describe what we know about cosmic reionisation from observations, and explain the actual limitations/challenges of state-of-the art simulations of this phenomenon.
In particular, the nature of the sources of reionisation is one of the main unknowns of reionization studies. Young stars in primeval galaxies may be the sources of reionization, if the ionising radiation, called Lyman continuum (LyC), that they produce can escape their interstellar medium. The strength and shape of this stellar ionising continuum is vastly unknown. I will describe direct and indirect ways to probe the shape of the stellar ionising spectrum of galaxies, and to put constraints on the nature of the sources powering it.

THEORETICAL APPROACH TO CEMP STARS, FIRST STARS, AND FIRST GALAXIES / 24

CEMP stars: their origin and connection with stars that reionized the Universe

Author: Mahavir Sharma[None]

The carbon enhanced metal poor (CEMP) stars are of immense importance as they likely carry signatures of first few generations of stars in the Universe. At the observational front there has been a tremendous advance in our ours understanding of CEMP stars, and recently theoretical studies have provided new insights. Nevertheless, the origin of CEMP stars, and in particular that of their subtypes (e.g. CEMP-no, -r) remains under debate. Our investigation into the origin of CEMP stars and their sub-groups with the EAGLE cosmological hydrodynamical simulation show that the galaxy building processes e.g. the feedback plays a crucial role in the formation of CEMP stars by creating a poorly mixed interstellar medium. In this picture, various groups of CEMP-stars form during different temporal stages of the bursty star formation in first galaxies. Our predicted spatial distribution of CEMP stars in the Milky Way is in good agreement with the existing data. We also claim that the CEMP-no stars are the siblings of the first stars that reionized the Universe.

FUTURE PERSPECTIVES, CHEMICAL EVOLUTION, LARGE SURVEYS / 51

Multi-dimensional modelling of stellar interiors

Author: Raphael Hirschi[1]

[1] *Keele University*

Stars are complex three-dimensional (3D) objects involving many physical processes: convection, rotation, magnetic fields. In this talk, I will review the efforts to constrain the physical ingredients of 1D stellar evolution models of the first stars using multi-D (magneto-)hydrodynamic simulations.

FUTURE PERSPECTIVES, CHEMICAL EVOLUTION, LARGE SURVEYS / 78

Asteroseismology and transport processes in stellar interiors

Author: Patrick Eggenberger[1]

[1] *Geneva University*

Thanks to space missions, measurements of solar-like oscillations are now available for a large sample of stars. This has led to the precise characterization of the global and internal properties of these stars, and in particular of their internal rotation. In this talk, we will first discuss how these asteroseismic measurements can help us progress in the modelling of angular momentum transport processes in stellar interiors. We will then describe the impact of these transport mechanisms on the evolution of stars, with a peculiar emphasis on the modelling of CEMP stars.

FUTURE PERSPECTIVES, CHEMICAL EVOLUTION, LARGE SURVEYS / 36

Asteroseismology and high-resolution spectroscopy of halo stars

Author: Tadafumi Matsuno[None]

Co-authors: Masao Takata [1]; Wako Aoki [2]; Luca Casagrande ; Jianrong Shi [3]; Maosheng Xiang [4]; Gang Zhao [3]; Miho, N. Ishigaki [5]

[1] *University of Tokyo*

[2] *National Astronomical Observatory of Japan*

[3] *NAOC*

[4] *MPIA*

[5] *Tohoku University*

We derive stellar masses and precise chemical abundances for 26 halo red giants, among which 5 and 17 turned out to be [Fe/H]<-2 and <-1, respectively, by combining high-resolution spectroscopy and asteroseismology. We selected the 26 stars in the Kepler field based on radial velocity and metallicity estimated from spectroscopic surveys and confirmed that they show halo-like kinematics using the Gaia DR2. The stellar masses are estimated through the scaling relations of asteroseismology with a theoretical correction factor and with updated spectroscopic parameters, temperature and metallicity. The typical estimated mass is around 1.0 Msun with 10% relative uncertainty, suggesting that asteroseismology systematically overestimates masses for low metallicity stars even with the correction factor. We find no correlation between mass and chemical abundance; the chemical abundance of halo stars might not be a clear indicator of stellar age.

Although our sample is the largest sample of halo stars that have asteroseimic information and precise chemical abundances, it is still small and does not contain any CEMP stars. I will present future prospects on the use of asteroseismology to study halo stars, including CEMP stars.

FUTURE PERSPECTIVES, CHEMICAL EVOLUTION, LARGE SURVEYS / 54

New light on the Sun: Updates on helioseismology and the Solar modelling problem

Author: Gaël Buldgen[1]

Co-authors: Patrick Eggenberger [1]; Sébastien Salmon [2]; Arlette Noels [2]

[1] *Université de Genève*

[2] *Université de Liège*

The Sun holds a special place in stellar astrophysics, we use it as reference for the determination of the chemical abundances of all stars in the Milky Way. Since 1962, the field of helioseismology has provided unprecedented ways of testing the internal structure of solar models. Soon after the discovery of neutrino-oscillation and the end of the solar neutrino problem, the revision of the solar abundances by Asplund and collaborators lead to strong disagreements between solar standard models and helioseismic inferences. This now 15 year old tedious issue is called the solar modelling problem and crystallizes the strong dependencies of stellar models on fundamental physics. In this talk, I will present the current state of solar modelling,the current questions surrounding the solar abundances and how new seismic inferences can help shed new light on the limitations of solar models and possible solutions to the solar modelling problem.

FUTURE PERSPECTIVES, CHEMICAL EVOLUTION, LARGE SURVEYS / 95

Probing the early Universe with black hole binaries

Author: Tassos Fragos[None]

Binary stellar systems are unique astrophysical laboratories for the study of black holes (BHs). Accretion of matter from a binary companion gives rise to X-ray emission, bringing them to the X-ray binary phase and making them visible on Gpc scales, while the recent gravitational wave observations enabled us to witness the last few seconds of the lives of coalescing binary BHs. X-ray binaries and coalescing binary BHs have a lot of common threads. In fact, some types of high-mass X-ray binaries are considered as the potential immediate progenitors of gravitational-wave sources. In this talk, I will review the potential formation channels of BH binaries, focusing on the effect that metallicity has on their properties. I will discuss the constraints that current and upcoming X-ray and gravitational-wave observations can put on the properties of BH binaries in the early Universe. Finally, I will comment on the potential role that population-III stars may have in shaping these BH binary populations.

FUTURE PERSPECTIVES, CHEMICAL EVOLUTION, LARGE SURVEYS / 55

Life and death of supermassive stars

Author: Lionel Haemmerlé[1]

[1] *Université de Genève*

Supermassive stars (SMSs) are candidates for being the progenitors of the most massive quasars discovered recently at high redshift. The viability of this formation channel (direct collapse) depends on the properties of the progenitor, whose evolution is dominated by rapid accretion. I will present the most recent models of SMSs, that include accretion and rotation, and discuss their implications regarding the direct collapse scenario and the possible observational signatures of these stellar Titans.

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General discussion

Possible themes:
- The hunt for EMP stars: new strategies, new methods of analysis
- What is the helium content of EMP? How to know? What to expect?
- Multi-messenger astrophysics for the study of the first stars
- Possible links and differences between EMP and stars in globular clusters?

FUTURE PERSPECTIVES, CHEMICAL EVOLUTION, LARGE SURVEYS / 87

Modeling the first stages of galaxy formation

Author: Pascale Jablonka[1]

[1] *EPFL - EPF Lausanne*

I will review (some of) the latest developments in chemo-dynamical numerical simulations of galaxies, particularly focusing on the early formation stages.

FUTURE PERSPECTIVES, CHEMICAL EVOLUTION, LARGE SURVEYS / 65

Formation and Evolution of Milky Way Galaxy: Abundance trends of stable and short-lived nuclides

Authors: Tejpreet Kaur[1]; Sandeep Sahijpal[1]

[1] *Department of Physics, Panjab University, Chandigarh*

To understand the formation and evolution of Milky Way galaxy, Galactic Chemical Evolution (GCE) simulations are performed using N-body Monte Carlo technique. Our GCE models predict the elemental abundance gradients of C, N, O, Mg, Si, Ca, Ti, Fe, and Zn using the revised solar abundance of value 0.0143. The galaxy is radially divided into eight annular rings of 2 kpc width each at a distance of 2-18 kpc from the center of the galaxy. We ran models using three infall and two infall accretion models to gradually form halo, thick disc and thin disc. An ensemble of stars in the mass range 0.1-100 M⊠ is formed and evolved over the galactic time scale. The process of star formation is mainly controlled by Star Formation Rate (SFR) and Initial Mass function (IMF). The nucleosynthetic yields ejected from stars of various generations enrich the Interstellar gas. Further, next generation of stars form out of enriched gas with higher metallicity. The predicted normalized abundance gradients are compared with the observational data from various sources. The effect of radial gas mixing and gas inflows on the predicted abundance gradients is also explored in these simulations.
In these models the formation of solar system takes place ˜ 4.56 Gyr ago in the fourth annular ring from the galactic center. At that instant, the values for metallicity and [Fe/H] are assumed to be ˜0.0143 and 0 respectively. In the present work, three infall GCE model is further developed to explain the abundance trends of Short lived radio nuclides (SLRs), 26Al, 36Cl, 41Ca, 53Mn and 60Fe in the galaxy and solar neighbourhood. The homogeneous GCE models predict the abundance trends of SLRs for the entire galaxy. In addition, heterogeneous GCE simulation are performed by dividing the solar annular ring into independent grids of size in the range of 0.1-1 kpc2 to consider the homogenization of stellar ejecta in localized region. In case of heterogeneous models the formation of various stellar clusters/associations are simulated in the solar annular ring ˜4.56 Gyr ago. The birth of solar system is likely to occur within one of these stellar clusters. In these simulations, mainly massive stars in the clusters contribute SLRs in the early solar system. This contribution is scaled by parameterizing the homogenization spatial scale in a specific grid to obtain the canonical values of SLRs, 26Al, 36Cl, 41Ca, 53Mn and 60Fe observed in the early solar system.

FUTURE PERSPECTIVES, CHEMICAL EVOLUTION, LARGE SURVEYS / 68

The Galactic bulge and old stellar populations

Author: Beatriz Barbuy[None]

We present observations and theoretical models regarding the formation of the Galactic bulge. Our main interest concerns the blue horizontal branch and moderately metal-poor globular clusters, that might be among the oldest objects in the Galaxy. We also present abundances, in particular of heavy elements, that could provide evidence for early s-process nucleosynthesis in early rotating massive stars.

FUTURE PERSPECTIVES, CHEMICAL EVOLUTION, LARGE SURVEYS / 74

Extremely metal-poor stars in the next generation large surveys

Author: Vanessa Hill[1]

[1] *France*

TBD

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Concluding discussion

Each participant will be asked to answer in a few written lines the two following questions:
1) What is the most interesting thing she/he has learnt during the conference?
2)What non-answered question(s) she/he would like to study in the coming years about CEMP stars?

The answers will be collected and a SOC member will prepare a small presentation to share the results with the audience.

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A new stellar cluster Gaia 2

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Stellar clusters are the key for understanding of galaxy formation and evolution because they host number of old stars. We determine the atmospheric parameters of two members of a new stellar cluster Gaia 2. The low resolution spectra of the stars were obtained at TÜBİTAK National Observatory, using the RTT150 telescope (with 1.5 m). We announce the first results in the present study.

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The Pristine Survey: High-resolution spectroscopy and kinematics of new extremely metal-poor stars

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Extremely metal-poor stars (EMPs, [Fe/H] < -3) are excellent tools for Galactic archaeologists to study the first stars and the early formation history of the Milky Way. A great diversity has been seen in the EMP stars, both in the medley of their chemical abundance ratios, as well as in their kinematics; a diversity suggestive of the variety of their nucleosynthetic origins and formation sites. Here we present the first results from the high-resolution spectroscopic follow-up of 21 new EMP stars found in the Pristine survey. We observed these stars with the Gemini Remote Access to CFHT ESPaDOnS Spectrograph (GRACES) at Gemini-N and have determined precision chemical abundances for key elements including the alpha (Mg, Ca), odd- Z (Na, Al, Sc, Mn, Zn), and the neutron capture elements (Y, Sr, Ba, Eu). These element abundances are necessary to identify rare classes of chemically peculiar stars, such as CEMP-no, alpha-challenged, and r-process rich stars, and also enable new constraints on supernova yields with respect to progenitor mass, rotation rates, explosion energies, mixing/fallback models, explosion symmetries, and progenitor binarity. Furthermore, we infer distances, kinematics, and orbits for our sample by combining Gaia DR2 astrometric and photometric data with isochrones and radial velocities measured from the GRACES spectra. We find a majority of our stars are confined to the Galactic halo, however we additionally identify a group of stars with prograde "disk-like" orbits ($z_{max} < 3$ kpc, $J_z < 100$km s−1 kpc). The unique kinematics of these "disk-like" stars have an assortment of possible explanations, most notably the ancient accretion event(s) responsible for the formation of the proto-Milky Way disk. These data are part on an ongoing Gemini Large and Long Program which aims to increase the number of known EMP stars with detailed abundance analyses by ˜30%.

FUTURE PERSPECTIVES, CHEMICAL EVOLUTION, LARGE SURVEYS / 30

Chemical signatures of rotating massive stars dying in faint explosions

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

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CNO abundances in the early Galaxy

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Carbon-enhanced metal-poor (CEMP) stars contribute to about 20% of the metal-poor stars below [Fe/H] < -2.0. The origin of carbon in these stars could be due to AGB mass transfer in a binary system. These class of objects (CEMP-s) also show enhancement of s-process elements, and most of them show radial velocity variations indicating the presence of a companion. However, the class of CEMP stars that do not show s-process enhancements, that are more dominant at much lower metallicities ([Fe/H] < -3.5), are thought to be true first low mass stars that received contributions from winds of rotating very massive star (spinars) or faint supernovae. C, N, O abundances of these objects are crucial to understand the contributions of C, N, O from these massive stars. Carbon and nitrogen abundances can be derived from the C_2, CH, CN and NH bands. However, obtaining oxygen abundance is very time-consuming and difficult in CEMP stars due to the weak 6300 [OI] line and crowded C2 and CN lines in cool-CEMP stars that require high resolution, high S/N optical spectra. Hence, we use NIR CO rovibrational bands in the NIR region, to derive oxygen abundances. For a carbon-enhanced star, the CO lines are sensitive to change in oxygen abundances. We also derived C, N, O abundances from optical wavelengths to calibrate the C, N, O abundances from NIR CO lines for a subset of CEMP stars. Here, we report CNO measurements of 10 CEMP stars from high-resolution optical spectra and low-resolution NIR spectra and compare them. This is the first time such comparison of CNO abundance over optical and NIR wavelength done in CEMP stars. We also present a detailed abundance of alpha, Fe-peak, and n-capture elements as well to understand the origin of CNO.

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r-Process Sites, their Ejecta Composition, and their Imprint in Galactic Chemical Evolution

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From low metallicity stars and the presence of radioactive isotopes in deep-sea sediments we know that the main r-process, producing the heaviest elements, is a rare event. The question remains whether neutron star mergers, via GW170817 the only proven r-process site, are the only contributors or also (a rare class of) supernovae, hypernovae/collapsars, as well as neutron star - black hole mergers qualify as candidates. Early galactic evolution as well as variations in nucleosynthesis signatures, e.g. actinide boost stars, might indicate the need for such other sites. We discuss and present the possible options (a) with respect to possible differences in ejecta amount and composition, and (b) in terms of their timing (onset and frequency) during galactic evolution.

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Metal poor stars in Gaia

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The study of the oldest and most metal-poor stars in our Galaxy promotes our understanding of the cosmic chemical evolution and the beginning of Galaxy and star formation. However, they are notoriously difficult to find, with only 5 stars of [Fe/H]<-5 having been detected to date. Thus, the spectrophotometric data of ˜1 billion stars which will become available with the third Gaia Data Release, comprise a very promising set for the identification of candidate metal-poor stars.

In this talk I shall present preliminary results of our candidate selection method in development, based on combinations of flux-ratios from BP/RP (Blue Photometer/Red Photometer) Gaia spectra. I shall demonstrate that these data do in fact contain enough information to identify iron-deficient stars, despite their very low spectral resolution. The method presented here can therefore soon be used to help populate the poorly constrained tail of the metallicity distribution function of the stellar halo of the Galaxy.

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Detailed abundance analysis of new CEMP stars from HESP-GOMPA survey

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The aim of this work is to study the chemical abundances of Milky Way halo stars which belong to the oldest stellar population of the Galaxy and detailed Chemical analysis of these populations can address several intriguing problems in the area of galaxy formation. For our present study, we have carried out high resolution spectroscopic survey using the Hanle Echelle Spectrograph (HESP) at 2m Himalayan Chandra telescope. Till date, we have carried out a detailed abundances analysis of about 60 metal poor stars at resolutions of R=30000 and R=60000 which resulted into the HESP-GOMPA (Galactic survey Of Metal Poor stArs) survey. The current study in high resolution is limited to selected stars from SDSS MARVELS pre-survey with Vmag = 8 - 13, that primarily targets the low latitudes for exoplanet studies.

The results include discovery of more than 10 new EMP and CEMP stars which are useful for further detailed isotopic abundances and key waiting point nuclei to probe the nucleosynthesis sites. We compare the elemental abundances derived for these classes of stars along with other carbon-enhanced metal-poor (CEMP) and EMP stars, in order to understand the nature of their parent supernovae. We find that CEMP-no stars and EMP dwarfs exhibit very similar trends in their lithium abundances at various metallicities. We have also conducted a comparative study of CEMP-no and EMP stars using their heavy element enrichment. We also find indications that CEMP-no stars have larger abundances of Cr and Co at a given metallicity, compared to EMP stars. The spectra were obtained over a span of 6-24 months, and indicate that some of the stars could be members of binary systems. One of the CEMP-s stars in this study ([Fe/H] = -2.3, [C/Fe] = 0.87) shows a very peculiar chemical abundance which could be of significant interest for stellar modelling. It shows a rather unusually high abundance of certain n-capture elements ([Ba/Fe] = 1.62, [Sr/Fe] = 1.18) alongside low abundances for other elements like Y, Zr, Ce, Nd, Sm, Eu and Dy.

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An Extended Empirical Library for Metal-Poor Stars Recognition and Parameterization

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We present an extended empirical stellar spectra library created using spectra from the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) DR5 and the Sloan Digital Sky Survey's extended Baryon Oscillation Spectroscopic Survey (eBOSS). Using more spectra of Metal-poor stars observed by both LAMOST and SDSS, we generated denser low-metallicity templates to fill in data missing from the pre-constructed empirical spectral library using only LAMOST spectra (Bing Du, et al. 2019, ApJS, 240, 10). The extended library covers the parameter space, temperatures of 3750 K through 8500 K, metallicity from −2.5 dex to +1.0 dex, and log g from 0 dex to 5.0 dex, with grid steps of $\sim$ 150 K, 0.15dex, and 0.25 dex for $T_{\rm eff}$, [Fe/H], and log g, respectively. The spectra in the library have resolutions R $\sim$1800, with well–calibrated fluxes and rest-framed wavelengths. we confirmed that the density of the library and the quality of the associated stellar parameters enable the stellar parameter measurements from this library to achieve precisions of about 125 K in $T_{\rm eff}$, 0.1 dex in [Fe/H] and 0.20 dex in log g. For metal-poor stars, owing to the limited number and the limited S/Ns of the observational spectra, the co-added templates are very limited in this parameter space. More spectra of metal-poor stars should be assembled to create more complete empirical templates with spectra of higher quality.

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Current Results of the New Metallicity Calibration Method for EMP Stars

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The aim of the proposed study is to present the current results of a freshly developed photometric metallicity calibration method for the discovery of new EMP stars ([Fe/H] < -2.5). Different from others, this system is theoretically formed by a narrow band filter (CaK) centered on Ca II K line (3933Å) together with the broad band SDSS (Sloan Digital Sky Survey) filters (ugr). Our calibration has been obtained from the u'g'r'CaK observations of around 100 giant calibration stars, made at Turkish National Observatory between April 2016 and August 2018. With this method, the metallicity of a star, whose u, g, and r band observation data have already been acquired, will be determined by observing the star only in the CaK filter without the need of any spectroscopic information.

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SALT CEMP Stars Survey

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CEMP stars have increasingly been shown to be important for understanding Pop III stars, early chemical enrichment, and many neutron capture nucleosynthetic processes. However, currently there are only approximately 150 CEMP stars that have been studied in high resolution. While this number is sufficient for statistic of a single population of stars, CEMP stars exist in many varied subgroups of which larger samples are needed to produce reliable statistics. In this survey we have observed 200 stars CEMP stars. The stars were observed using the high resolution spectrograph on the South African Large Telescope (SALT) with a resolution of 40,000 and a signal to noise ranging

from 30-50. I will present the results of this survey and discuss their implications for the first stars, chemical evolution, and the r, s, and i-processes.

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Putting CEMP-s stars into context: the swan songs of stars as recorded by their binary companions

Author: Pierre North[1]

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CEMP-s stars are thought to be the EMP equivalents of Pop. I barium stars or of Pop. ii CH stars, owing their chemical peculiarities to binary evolution. Their present-day companion is a CO white dwarf that had been the core of an AGB stars. We review the observations of different types of chemically peculiar stars originating from binary evolution, including those presumably polluted by a core-collapse SN event. We discuss some possible ways to detect them.

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Searching the Metal-poor Star with Deep Learning Method

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Searching for the rare metal-poor stars requires fast and effective analysis methods on the vast spectral survey data. Here, we develop a deep learning network to search for metal-poor and carbon-enhanced metal-poor (CEMP) stars in low-resolution spectra. We train a deep convolutional neural network (CNN) on a synthesized stellar spectra grid with Teff ranging from 5000K to 7500K, log g ranging from 0 dex to 5 dex, and [Fe/H] ranging from -5 dex to 0.5 dex. The deep CNN also employs the spectral absorption-line indices and intrinsic colors for all the spectra to measure the three fundamental parameters and to identify the metal-poor stellar spectra. The tests on synthesized spectra at different noise levels show that the deep CNN have the efficiency of the metal-poor recognition and good accuracy of parameterization.

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IMF of the first enrichment sources and their contribution to galaxy evolution

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First I will show the initial mass function (IMF) of the first enrichment sources obtained with our abundance fitting analysis. We compare the elemental abundance patterns of about 200 extremely metal-poor (EMP) stars to our nucleosynthesis yields of primordial supernovae. As a result, the IMF spans 13-100 Msun with a peak at 25 Msun with a large fraction of hypernovae. The majority of the primordial supernovae have ejected 0.01-0.1 Msun of 56Ni, leaving behind a compact remnant (either a neutron star or a black hole), with a mass in the range of ˜1.5-5 Msun. The masses of the first stars responsible for the first metal enrichment are predominantly <40 Msun. This implies that the

higher-mass first stars were either less abundant, directly collapsed into a black hole without ejecting heavy elements, or a supernova explosion of a higher-mass first star inhibits the formation of the next generation of low-mass stars at [Fe/H]<-3. I will then focus the stars fitted with 13M sun or 100 Msun models, which have relatively low alpha/Fe ratios, connecting super-luminous supernovae. Finally, I will predict galactic chemical evolution with these first supernovae, which can be tested with future observations with JWST.

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Iron-peak elements Sc, V, Mn, Cu, and Zn in Galactic bulge globular clusters

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Globular clusters are tracers of the history of star formation and chemical enrichment in the early Galaxy. Their abundance pattern can help understanding their chemical enrichment processes. In particular, the iron-peak elements have been relatively little studied so far in the Galactic bulge.
Methods. The main aim of this work is to verify the strength of abundances of iron-peak elements for chemical tagging in view of identifying different stellar populations. Besides, the nucleosynthesis processes that build these elements are complex, therefore observational data can help constraining theoretical models, as well as give suggestions as to the kinds of supernovae that enriched the gas before these stars formed.
The abundances of iron-peak elements are derived for the sample clusters, and compared with bulge field, and thick disk stars. We derived abundances of the iron-peak elements Sc, V, Mn, Cu, and Zn in individual stars of five bulge globular clusters (NGC 6528, NGC 6553, NGC 6522, NGC 6558, HP 1), and of the reference thick disk/or inner halo cluster 47 Tucanae (NGC 104). High resolution spectra were obtained with the UVES spectrograph at the Very Large Telescope over the years. Conclusions. The sample globular clusters studied span metallicities in the range -1.2<~[Fe/H]<~0.0. V and Sc appear to vary in lockstep with Fe, indicating that they are produced in the same supernovae as Fe. We find that Mn is deficient in metal-poor stars, confirming that it is underproduced in massive stars; Mn-over-Fe steadily increases at the higher metallicities due to a metallicity-dependent enrichment by supernovae of type Ia. Cu behaves as a secondary element, indicating its production in a weak-s process in massive stars. Zn has an alpha-like behaviour at low metallicities, which can be explained in terms of nucleosynthesis in hypernovae. At the metal-rich end, Zn decreases with increasing metallicity, similarly to the alpha-elements.