IFPU Focus Week: Enigmatic first stars and where to find them

Report of Contributions

https://indico.ict.inaf.it/e/firststars

Contribution ID: **3** Type: **not specified**

Introduction and motivation for the meeting

Monday, 15 May 2023 14:30 (30 minutes)

Presenter: D'ODORICO, Valentina (INAF - Trieste)

Session Classification: Day 1 afternoon

Contribution ID: **4** Type: **not specified**

First stars in the first structures

Tuesday, 16 May 2023 09:00 (30 minutes)

Results from numerical simulations of primordial structure formation will be presented and their implications for early pristine population III stars and the transition to the following metal-enriched popII/I regimes will be discussed. A number of observables will be used to test different population III stellar models (in terms of mass and metal yields) and to rule out non performing ones, as well as to draw conclusions on the signatures of the first enrichment episodes in the infant Universe. By exploring the location within simulated galaxies of population III star formation episodes we will be able to assess whether they form preferentially in clustered environments or isolation, in the central regions or in the periphery.

Presenter: MAIO, Umberto (INAF - Trieste)

Session Classification: Day 2 morning

Contribution ID: **5** Type: **not specified**

Rotating First stars: a theoretician perspective

Monday, 15 May 2023 16:30 (30 minutes)

Presenter: EKSTRÖM, Sylvia (Univ. of Geneva)

Session Classification: Day 1 afternoon

Contribution ID: **6** Type: **not specified**

First stars, first galaxies: clues and links

Monday, 15 May 2023 15:00 (30 minutes)

I will outline some of the puzzles related to the connection between the first stars and the first galaxies in the light of new theoretical and observational (ALMA, JWST) findings.

Presenter: FERRARA, Andrea (Scuola Normale Superiore Pisa)

Session Classification: Day 1 afternoon

Contribution ID: **7** Type: **not specified**

Observational Signatures of the First Stars

Tuesday, 16 May 2023 10:00 (30 minutes)

Constraining the properties of the first generation of stars is one of the key motivations of the James Webb Space Telescope. I will discuss strategies for identifying genuine Pop III stellar populations, potential contaminants, and learnings from nearly one full year of JWST data.

Presenter: KATZ, Harley (Univ. of Oxford)

Session Classification: Day 2 morning

Contribution ID: **8** Type: **not specified**

First Galaxies with James Webb Space Telescope

Tuesday, 16 May 2023 11:00 (30 minutes)

In recent years observations of blank fields enabled us to detect galaxies as far as z~11. However, very little is known about those galaxies, and they are mostly the most luminous representatives. Observations with James Webb Space Telescope will revolutionize this field. In particular, grism spectrograph NIRISS provides observing modes for slitless spectroscopy, which will be unique in enabling unbiased selection of z > 7 galaxies in the grism data. Several clusters of galaxies, used as cosmic telescopes, will be observed. I will present results from the largest such survey CANUCS which identified new puzzles of star formation at z~7 and beyond.

Presenter: BRADAČ, Maruša (Univ. of Ljubljana)

Session Classification: Day 2 morning

Contribution ID: **9** Type: **not specified**

Constraining the chemistry of the first stars from the most metal-poor sub-damped Lyman alpha systems

Wednesday, 17 May 2023 11:30 (30 minutes)

Quasar absorption line systems are an excellent probe of chemical evolution across time. In absorption line systems associated with the interstellar and circumgalactic medium of galaxies, the column densities of gas are sufficiently high that detailed and accurate chemical abundance patterns can be obtained and compared to complimentary stellar abundance analyses. These detailed chemical abundance measurements of the most metal-poor absorbers have placed important constraints on the properties of the first stars. However, these studies of the most metal-poor absorbers have focused on damped Lyman alpha systems (DLAs; HI column densities of logN(HI)>=20.3), which are rare on the sky. Fortunately, high redshift (z>3.2) subDLAs (19.0<=logN(HI)<20.3) offer potentially larger samples as they are typically more metal-poor than DLAs and at least 5x more frequently observed towards quasars. In this talk I will highlight results from an ongoing survey of metal-poor subDLAs identified in XQ-100 legacy survey. In particular, I will share some of the initial results along with some of the challenges of using subDLAs to investigate the nature of the first stars.

Presenter: BERG, Trystyn (Univ. Milano Bicocca)

Session Classification: Day 3 morning

Contribution ID: **10** Type: **not specified**

The first chemical enrichment

Wednesday, 17 May 2023 09:00 (30 minutes)

I will give a brief summary on the origin of elements using Galactic chemical evolution with Pop II and Pop I stars. Then I will discuss the Pop III nucleosynthesis using extremely metal-poor stars in the Milky Way. Namely, I will present our new analysis with machine learning to find "the first stars were not alone". Finally, I will discuss the first chemical enrichment in the Universe, comparing our cosmological, chemodynamical simulations of galaxies to the observations such as with the James Webb Space Telescope.

Presenter: KOBAYASHI, Chiaki (Univ. of Hertfordshire)

Session Classification: Day 3 morning

Contribution ID: **11** Type: **not specified**

Searching for PopIII star complexes: an observational prospective

Tuesday, 16 May 2023 12:00 (30 minutes)

An efficient search for elusive PopIII sources/ stellar complexes at high redshift is a trade-off between different aspects related to (1) the available instrumentation (technical) and (2) the physical conditions which maximize their occurrence (physics). The necessity of reaching quite faint luminosity while keeping an elevated spatial contrast (both spectroscopy and photometry) seems the minimum condition, though the volume probed can't be very large. Contaminants must also be recognized. The necessity of using strong gravitational lensing is likely the best way to approach some of the aforementioned conditions. I'll briefly discuss these aspects and show a case recently observed with JWST.

Presenter: VANZELLA, Eros (INAF - OAS Bologna)

Session Classification: Day 2 morning

Contribution ID: **12** Type: **not specified**

A Study of Primordial Very Massive Star Evolution

Monday, 15 May 2023 17:00 (30 minutes)

We present new evolutionary models of primordial very massive stars, with initial masses ranging from 100 Msun to 1000 Msun, that extend from the main sequence until the onset of dynamical instability caused by the creation of electron-positron pairs during core C, Ne, or O burning, depending on the star's mass and metallicity.
Mass loss accounts for radiation-driven winds as well as pulsation-driven mass-loss on the main sequence and during the red supergiant phase. After examining the evolutionary properties, we focus on the final outcome of the models and associated compact remnants. Stars that avoid the pair-instability supernova channel, should produce black holes with masses ranging from ~40 Msun to ~1000 Msun. In particular, stars with initial masses of about 100 Msun could leave black holes of ~85-90 Msun, values consistent with the estimated primary black hole mass of the GW190521 merger event. Overall, these results may contribute to explain future data from next-generation gravitational-wave detectors, such as the Einstein Telescope and Cosmic Explorer, which will have access to as-yet unexplored BH mass range of ~10^2-10^4 Msun in the early universe.
Finally, some open questions about the evolution of primordial stars will be raised.

Presenter: VOLPATO, Guglielmo (Univ. of Padua)

Session Classification: Day 1 afternoon

Contribution ID: **13** Type: **not specified**

Can we detect the chemical signature of Pop III stars at z~6? A view from quasar absorption spectra

Wednesday, 17 May 2023 10:00 (30 minutes)

I will present the study of the abundances of the chemical elements present in the gas associated with cosmological structures at redshift ~6. The goal is to look for the nucleosynthetic traces of the Pop III stars and, more generally, to understand which generation of stars contributed to the enrichment of metals in the gas of galaxies at that time.
To determine these abundances, we studied the absorption spectra of 42 high redshift quasars (QSOs) from the literature and from the observing program called XQR-30. This program obtained 248 hours of observations with the VLT X-Shooter spectrograph, and collected optical and infrared spectra of 30 QSOs in the redshift interval 5.8<z<6.6.
Among all the detected absorption line systems, those with low ionization were selected, characterized by the presence of the neutral oxygen absorption line; this ion is present when there is a large amount of HI shielding the ionizing radiation and therefore these systems are probably associated with the interstellar medium of high redshift galaxies.
The relative abundances of most of the observed systems are in agreement with the average abundances of analogue systems observed at low redshift (2<z<4.5), and with those predicted in gas enriched by the explosion of Pop II stars in CCSN.

Presenter: SODINI, Alessio (INAF - Trieste)

Session Classification: Day 3 morning

Contribution ID: **14** Type: **not specified**

Massive binary black holes from Population III stars

Monday, 15 May 2023 17:30 (30 minutes)

Population III (Pop III) stars are almost metal-free stars, born from the primordial gas in the Universe. They have eluded any attempt of observation so far. Therefore, we must rely on predictions from the most advanced and detailed stellar evolutionary models to study them. The almost total absence of metals impacts their initial mass function distribution (predicted to be top-heavy), their evolutionary path, and their final fate. For example, Pop III stars are more compact and hotter than their metal-rich counterparts. Moreover, they lose a negligible fraction of their mass via stellar winds during their life. Such properties make them important ionising photon sources and ideal massive black hole progenitors.
In this talk, I will first present the new models of Pop III stars computed with the PARSEC stellar evolutionary code. Then, I will show the large sets of Pop III and Population II binary populations computed with the SEVN code used to study the formation channel of binary black hole mergers.

Presenter: COSTA, Guglielmo (Univ. of Lyon)

Session Classification: Day 1 afternoon

Contribution ID: **15** Type: **not specified**

Near-pristine DLAs: A window to the first stars

Wednesday, 17 May 2023 11:00 (30 minutes)

The properties of the first (Pop. III) stars remain a mystery. The chemistry of relic environments, enriched only by the supernovae of these first stars, offer an exciting avenue to study this population. Stellar relics are often found in the local Universe while gaseous relics probe the chemistry of low density structures at earlier epochs (z>2). I will discuss the complementary nature of these searches and how they can be used together to understand early chemical evolution and structure formation. Particularly, I will focus on the most metal-poor DLAs found at z~3 and the associated high-precision abundance determinations.

Presenter: WELSH, Louise (Univ. Milano Bicocca)

Session Classification: Day 3 morning

Contribution ID: **16** Type: **not specified**

Evolution, explosion and nucleosynthesis of PopIII massive stars

Monday, 15 May 2023 15:30 (30 minutes)

Presenter: LIMONGI, Marco (INAF - Rome)

Session Classification: Day 1 afternoon

Contribution ID: **18** Type: **not specified**

The first source(s) of neutron capture elements

Thursday, 18 May 2023 10:00 (30 minutes)

Presenter: CESCUTTI, Gabriele (Univ. of Trieste)

Session Classification: Day 4 morning

Contribution ID: **20** Type: **not specified**

Gravitational lensing of individual Population III stars in the early Universe

Tuesday, 16 May 2023 11:30 (30 minutes)

Individual stars are typically not detectable beyond the local Universe, but gravitational lensing by foreground galaxy clusters can in rare cases raise the brightness of extremely distant stars to detectable levels. More than a dozen lensed stars at z~1-3 have already been detected this way using HST and JWST, along with a smaller number of candidates at z~5-6 (including the current record holder "Earendel "at z=6.2). Individual, lensed Population III stars at redshifts up to z~15 may potentially also be detectable this way with JWST, which would allow for a unique opportunity to observationally constrain the SFRD(z) and stellar IMF of such stars. The methods used to interpret lensed-star observations are, however, still in their infancy and significant community efforts would be required to identify and characterize Population III candidates this way. In this talk, I will describe the current state of lensed-star observations, outline under what circumstances individual lensed Population III stars may be detectable with JWST, and describe what new challenges the Pop III community would need to face with in order to take full advantage of this observational technique.

Presenter: ZACKRISSON, Erik (Uppsala University)

Session Classification: Day 2 morning

Contribution ID: **21** Type: **not specified**

New avenues to indirectly study the nature of the first stars

Wednesday, 17 May 2023 12:00 (30 minutes)

The first stars were born from chemically pristine gas. They were likely massive and thus they rapidly exploded as supernovae, enriching the surrounding gas with heavy elements.
The nature of first stars can be studied locally, investigating the chemical properties of ancient metal-poor stars in the Milky Way halo and in Local Group dwarf galaxies. Indeed, here we observe low-mass, long-lived stars that provide an opportunity to explore the chemical and physical conditions of the earliest star-forming environments in the Universe in terms of first stars signatures. Complementarily to this approach, the investigation of high-redshift gaseous environments and their metal content, through direct observations against bright background sources, is a valuable diagnostic, which would help to catch first stars signatures.

In this talk I will report new results on this last approach. In particular I will show a recent work (A. Saccardi, S. Salvadori, V. D'Odorico et al. in press) on the signatures of first stars in high-redshift absorbers. Through the analysis of the spectra of QSO lines of sight, we detected 3 very metal-poor, carbon-enhanced systems, at redshift z~3-4. These absorption systems reveal an overabundance with respect to Fe of all the analyzed chemical elements such as C, O, Mg, Al, and Si. The distribution of the relative abundances with respect to [Fe/H] perfectly matches those of the local very metal-poor stars. Consequently, these absorbers, likely imprinted by the chemical yields of the first stars, suggest that the signature of the first stars survives in optically thick, relatively diffuse absorbers, not sufficiently dense to sustain star formation and hence, not dominated by the chemical products of normal stars.

Presenter: SACCARDI, Andrea (Observatoire de Paris)

Session Classification: Day 3 morning

Contribution ID: **22** Type: **not specified**

GRBs as tools to probe the first stars

Wednesday, 17 May 2023 09:30 (30 minutes)

GRB are produced by massive stars. Several studies considered the possibility of PoPIII stars as GRB progenitors and predicted the GRB properties. Furthermore GRB afterglows are bright at any redshift and can be used as background sources to study the absorbing gas in their host galaxies and along GRB lines of sight up to the highest redshift, looking for signatures of pristine gas or gas enriched by first stars. Such studies are currently limited mostly by the characteristics of the satellites detecting GRBs. I will introduce the use of GRBs as tools to probe the first stars, and discuss the needed future capabilities to exploit GRBs at best for this kind of research.

Presenter: VERGANI, Susanna (Observatoire de Paris)

Session Classification: Day 3 morning

Contribution ID: **23** Type: **not specified**

Chasing the Most Metal-Poor Stars

Thursday, 18 May 2023 11:00 (30 minutes)

During Big Bang Nucleosynthesis, hydrogen, helium, and small traces of lithium and beryllium were produced. A few million years after BBN, the first stars were formed out of this primordial material. 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. We will review main efforts in this regard and key results on the comprehensive study of these fossil records.

Presenter: AGUADO, David (Instituto de Astrofisica de Canarias)

Session Classification: Day 4 morning

Contribution ID: **24** Type: **not specified**

Tracing Pop~III supernovae with extreme energies

Thursday, 18 May 2023 12:00 (30 minutes)

The Sculptor dwarf spheroidal galaxy is old and metal-poor, making it ideal to study the earliest chemical enrichment in the Local Group. We followed up the most metal-poor star known in this (or any external) galaxy, AS0039, with high-resolution ESO VLT/UVES spectra. Our new analysis confirmed its low metallicity, [Fe/H]=-3.90, and that it is extremely C-poor, with [C/Fe]=-0.33. This adds to the evidence of Sculptor being intrinsically C-poor at low [Fe/H]. A re-analysis of known extremely metal-poor stars in Sculptor, shows clearly that these peculiarities in Sculptor reach beyond carbon. This unique abundance pattern in Sculptor indicates an enrichment from a Pop~III star with high explosion energy, solidifying this galaxy as one of the benchmarks for understanding the energy distribution of the first supernova in the Universe.

Presenter: SKULADOTTIR, Asa (University of Florence)

Session Classification: Day 4 morning

Contribution ID: **25** Type: **not specified**

The effects of the population III stars on the chemical evolution of the Milky Way

Thursday, 18 May 2023 09:00 (30 minutes)

I will review results on the effects of population III stars on the chemical abundances of the population II stars. Some of the unsolved problems related to this topics will be discussed.

Presenter: MATTEUCCI, Francesca (University of Trieste)

Session Classification: Day 4 morning

Contribution ID: **26** Type: **not specified**

First stars and first galaxies: how to constrain their nature

Thursday, 18 May 2023 09:30 (30 minutes)

Presenter: SALVADORI, Stefania (University of Florence)

Session Classification: Day 4 morning

Contribution ID: **27** Type: **not specified**

ESPRESSO observations of very metal poor stars

Thursday, 18 May 2023 11:30 (30 minutes)

Presenter: MOLARO, Paolo (IFPU/ INAF OATs)

Session Classification: Day 4 morning

Contribution ID: **28** Type: **not specified**

Simulations of very high-redshift galaxies

Tuesday, 16 May 2023 09:30 (30 minutes)

Presenter: PALLOTTINI, Andrea (SNS Pisa)

Session Classification: Day 2 morning

Contribution ID: **29** Type: **not specified**

Wrap up

Presenter: PARTICIPANTS, All

Session Classification: Day 5 morning