

Osservatorio Astronomico di Trieste Astronomical Observatory of Trieste



Revealing the Nature of the First Stars the point of view of neutron capture elements

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4MOST – 4m Multi-Object Spectroscopic Telescope

erc



LXI SAIt Conference - 12/09/17

BRIDGCE UK Network

First Stars



"Understanding these first sources is critical, since they greatly influenced the formation of later objects such as galaxies."

"The chemical elements of life were first produced in the first generation of stars after the Big Bang. We are here today because of them – and we want to better understand how that came to be!" John Mather

Quest for future telescopes

James Webb Space Telescope (JWST)

European Extremely Large Telescope (E-ELT)

Simulations of the First Stars



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The theoretical challenge: Total dynamical range 10¹² !







Discovery Channel

Simulations of the First Stars



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The First Star within it

The First Supernova

Discovery Channel



Start with a stadium and then focus on a single atom within a stadium!

The oldest stars in our Galaxy formed from the gas ejected by the first stellar generations:

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Massive Stars – short lifetimes



First polluters in the Universe

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Core collapse Supernova

First polluters in the Universe

The oldest stars in our Galaxy formed from the gas ejected by the first stellar generations:

Massive Stars – short lifetimes

Low mass stars – long lifetimes

Core collapse Supernova

First polluters in the Universe

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The Sun

Imprints of the first stars

Where are the oldest fossil stars in the MW?







Spiral arms



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Where are the oldest fossil stars in the MW?







Spiral arms



dwarf spheroidal galaxies



Why neutron capture elements?

Mg: alpha-element

Sr: neutron capture element



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Sneden+08

Nucleosynthesis of neutron capture elements

from Truran 1981 to ~6 years ago



Magneto Rotationally Driven SN scenario (MRD)

(Winteler+12, Nishimura+15)

The progenitors of MRD SNe are believed to be rare: only a small percentage of the massive stars (\sim 1–5%)

We have results for 5% and for an higher value (10%).

This percentage is not well constrained, in particular for the early Universe.



r-process

pattern in r-process rich stars



Stochastic chemical evolution models

Problem:

Neutron capture elements present a spread alpha elements do not





Bonifacio+09

Stochastic chemical evolution models



Bonifacio+09

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Problem: Neutron capture elements present a spread alpha elements do not



Solution:

The volumes in which the ISM is well mixed are discrete. Assuming a SNe bubble as typical volume with a low regime of star formation the IMF is not fully sampled. This promotes spread among different volumes if nucleosynthesis of the element is is different among different SNe,

Stochastic chemical evolution models



Stochastic model for Ba in the Galactic halo

We run the stochastic model (based on Cescutti 08) with these prescriptions for the Ba:

10% of all the massive stars produce 8 10⁻⁶ Msun



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Puzzling result for the "heavy to light" n.c. element ratio

For Sr yields: scaled Ba yields according to the r-process signature of the solar system (Sneden et al '08)





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Another ingredient (process) is needed to explain the neutron capture elements in the Early Universe!

[Fe/H]

Possible solution? Fast rotating massive stars in the early Universe

In the Early Universe

Low metals: stars rotate faster (more compact)

Rotation



Ejected matter will be rich in¹⁴N,¹³C, ¹²C, & s-process?

Massive stars rotate in the Local Universe



Signatures in the Galactic Halo

- Large amounts of N (Chiappini+06 A&A)
- Increase of the C/O ratio (as above)
- Large amounts of ¹³C(Chiappini+08)
- Early production of Be & B by cosmic ray spallation (Prantzos 12)

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Test the production of neutron capture elements from rotating massive stars! (Cescutti+13)



Low metallicity and fast rotating massive stars

Frischknecht et al. 2012, 2016 (self-consistent models with reaction network including 613 isotopes up to Bi)



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Fast rotating massive stars can contribute to s-process elements!



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Can they explain the puzzles for Sr and Ba in halo?

Neutron capture elements

from Chiappini+11



S-process from fast rotating massive stars + an r-process site (the 2 productions are not coupled!)

Cescutti et al. (2013) Cescutti & Chiappini (2014)

s-process from fast rotating massive stars

+ an r-process site (the 2 productions are not coupled!)



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A s-process (from fast rotating massive stars) and an r-process (from rare events) can reproduce the neutron capture elements in the Early Universe

Fast rotating massive stars

Fast rotating massive stars

(1)

(2)

(3)

Solution for 4 signatures in the early Universe

Large amounts of N in the early Universe (Chiappini et al. 2006 A&A Letters) Increase in the C/O ratio in the early Universe Large amounts of ¹³C in the early Universe (Chiappini et al. 2008 A&A Letters) Early production of Be and B by cosmic ray spallation (Prantzos 2010)

Models predict an enhanced s-process

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First stars: fast rotating massive stars