Low-Metallicity Stars in the Large Magellanic Cloud: Tracing the Early Conditions of Star Formation

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ANU welcomes access to telescopes at premier site | ANU College of Science

Agenda

- Nucleosynthesis and the r-Process
- What are Low-Metallicity/EMP Stars?
- High-Resolution Spectroscopic Study of Metal-Poor Stars in the Large Magellanic Cloud
- Sample Selection and Methods
- Results - Elemental Abundances and r-Process Enrichment
- Broader Implications for Galaxy Formation and Evolution
- Future Research Directions
- Conclusion

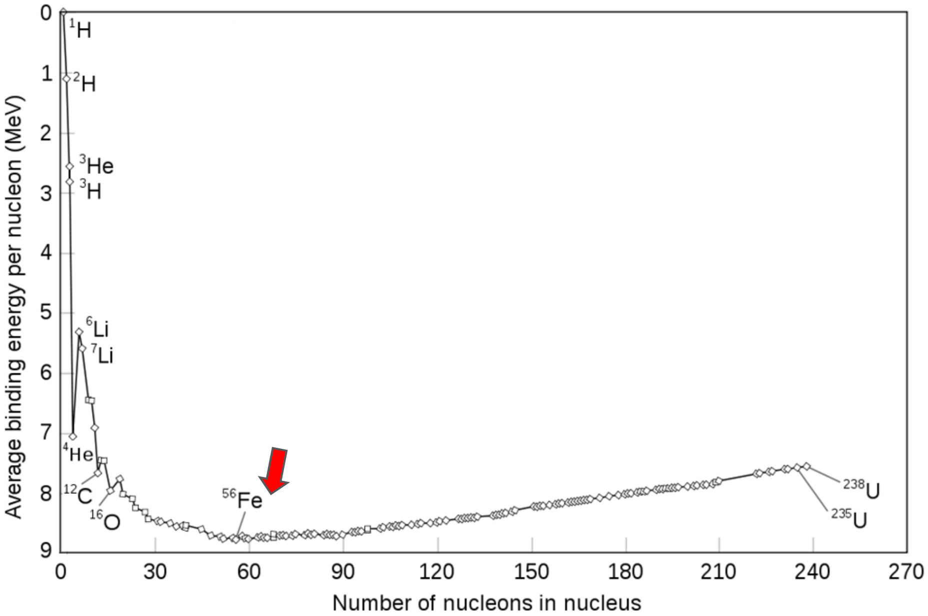
SkyMapper

Nucleosynthesis and the r-Process

The strong nuclear force beats out the coulomb force causing fusion

Fusion continues continues until ~ Fe or Ni

Fe and Ni have the lowest energy per nucleon



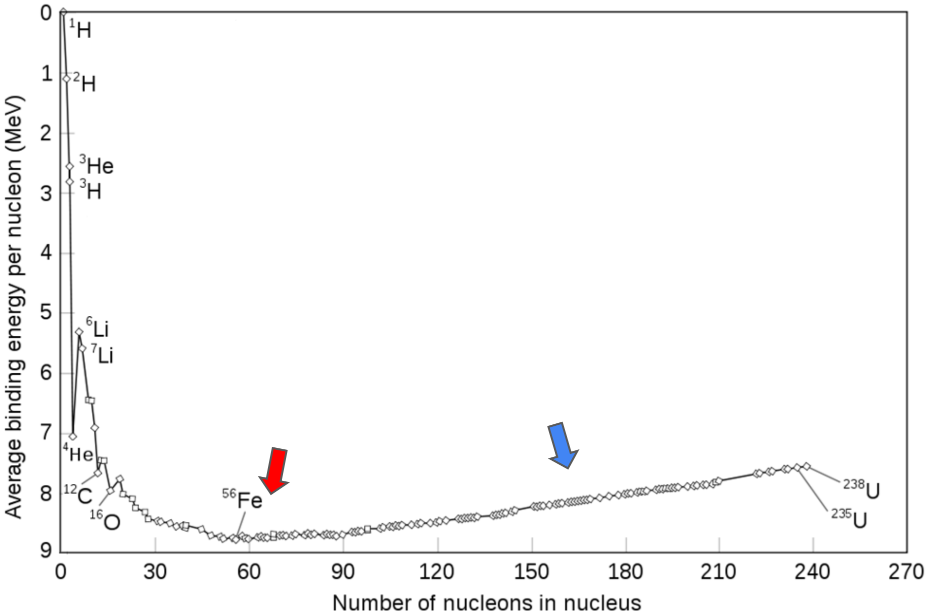
https://ch302.cm.utexas.edu/nuclear/nuclear-change/selector.php?name=binding-energy

Nucleosynthesis and the r-Process

Rapidly captures neutrons so nuclei are unable to decay

A high neutron/proton environment is important for this process

Where this process takes place is still an open discussion



https://ch302.cm.utexas.edu/nuclear/nuclear-change/selector.php?name=binding-energy

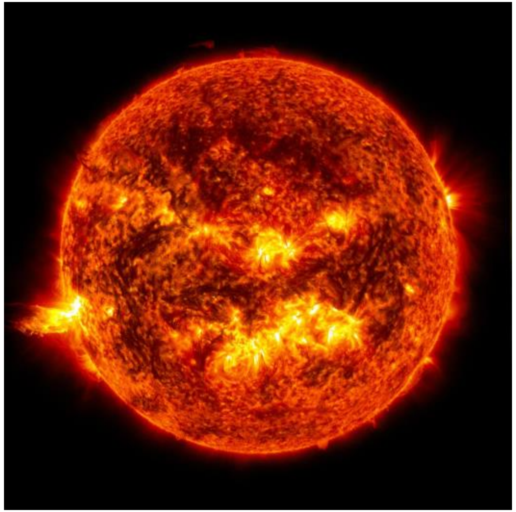
What are Low-Metallicity/EMP Stars?

Population **I**: "Young" with high metallicity found in galactic disk

Population **II**: Old with low metallicity found in galactic halo or globular clusters

Population **III**: Supermassive with virtually no metals - hypothetical

$$\left[\frac{\mathrm{Fe}}{\mathrm{H}}\right] = \log_{10}\left(\frac{N_{\mathrm{Fe}}}{N_{\mathrm{H}}}\right)_{\star} - \log_{10}\left(\frac{N_{\mathrm{Fe}}}{N_{\mathrm{H}}}\right)_{\odot}$$



Sun Emits a Solstice CME (nasa.gov)

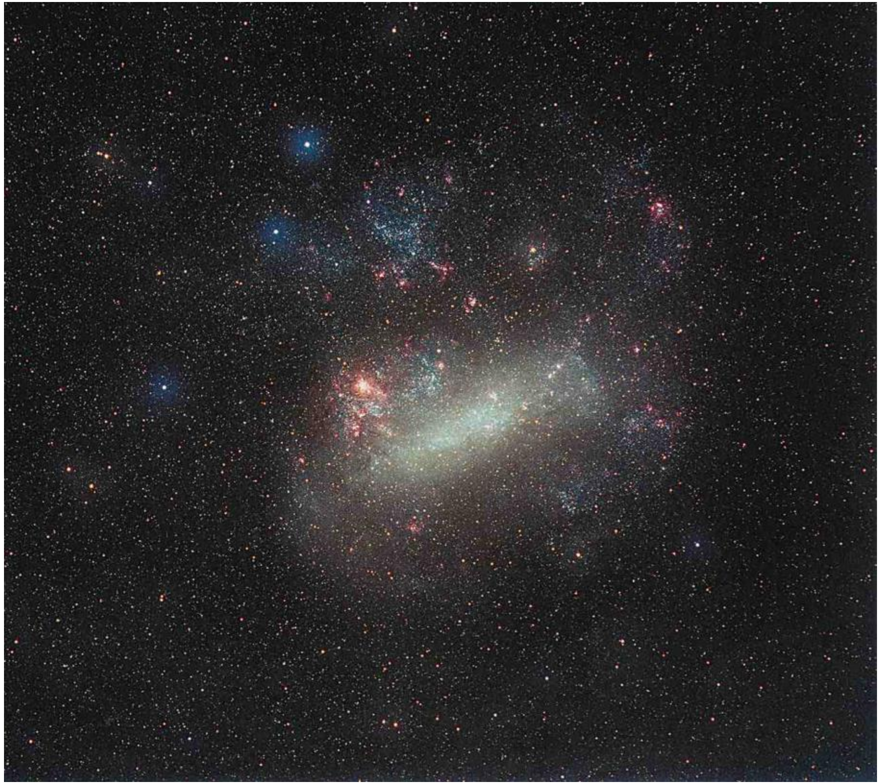
$$\left[\frac{\mathrm{Fe}}{\mathrm{H}}\right] = -3.0 \ldots -1.0$$

The Large Magellanic Cloud

The LMC is a MW satellite galaxy about 163,000 ly away

It offers insights into stellar evolution in low-metallicity environments

The LMC's variable stars are useful to calibrate cosmic distances



High-Resolution Spectroscopic Study of Metal-Poor Stars in the Large Magellanic Cloud

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https://rsaa.anu.edu.au/research/research-projects/skymapper-southern-sky-survey

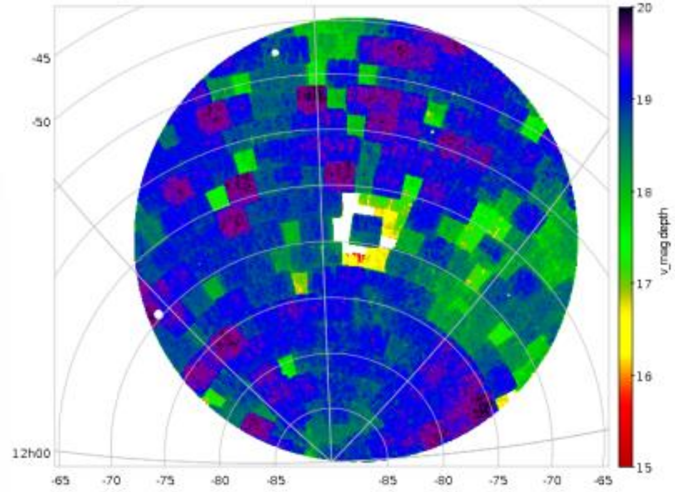
Sample Selection and Methods

Selection Process:

SkyMapper photometry was used to identify identify LMC low metallicity stars

The ANU 2.3m telescope was used to confirm the stars’ metallicity using low-resolution spectroscopy

Only stars with [Fe/H] ≤ -2.75 were included in the final sample



The SkyMapper DR3 v-filter coverage in the vicinity of the LMC(20◦ radius). The darker patches show areas with deeper coverage.

Sample Selection and Methods

High-Resolution Spectroscopy:

After selection, stars were observed using the UVES on the VLT

This data was analyzed to determine several different stellar parameters

The blue arm of the spectrograph covered a wavelength range of 3289-4525 Å

The red arm of the spectrograph covered a range of 4780-6801 Å

Data was reduced using the UVES pipeline

https://www.britannica.com/topic/Very-Large-Telescope

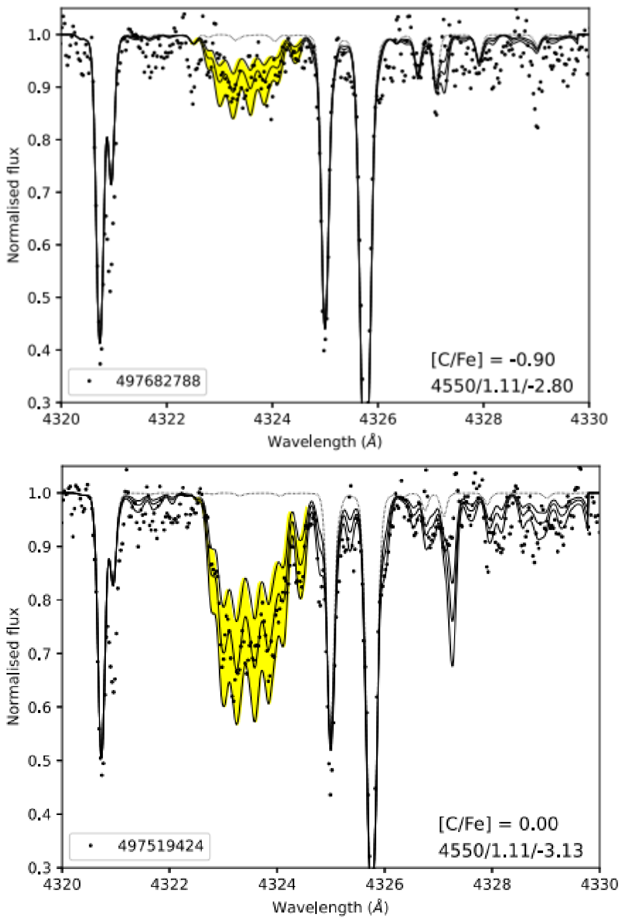
Sample Selection and Methods

Spectroscopic Analysis:

Abundances of 24 elements were determined using MOOG stellar line analysis

Most element abundances were determined using equivalent widths

Other elements abundances were confirmed using synthetic spectra



Results - Elemental Abundances and r-Process Enrichment

Light and “Iron Peak” Elements:

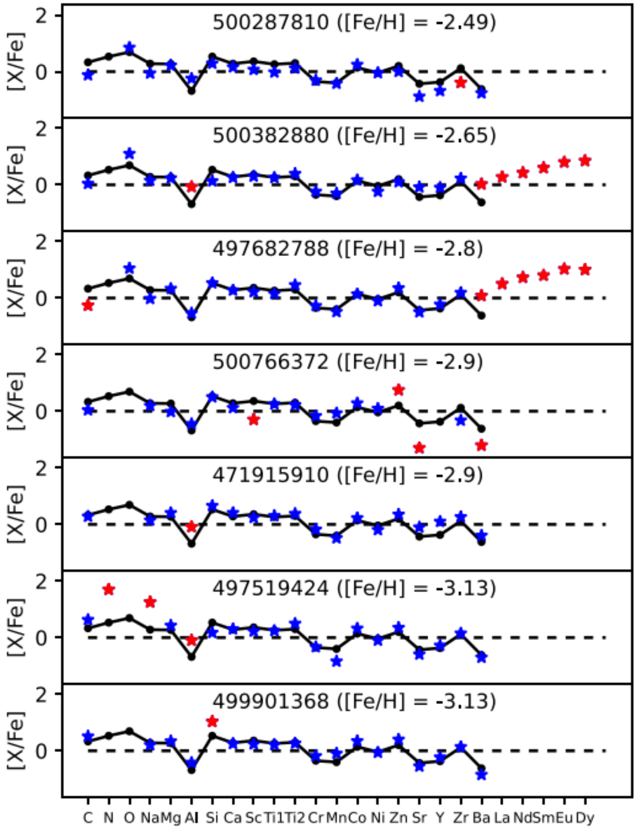
C abundances were lower than those in MW stars

497519424 classified as the first NEMP star in the LMC

O abundances were only measurable for three stars due to spectra contamination

Sc, Cr, and Mn were consistent with Milky Way stars

No significant Ba abundances were observed



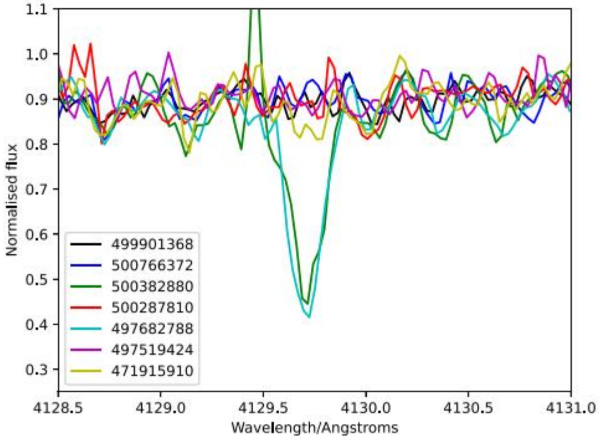
Results - Elemental Abundances and r-Process Enrichment

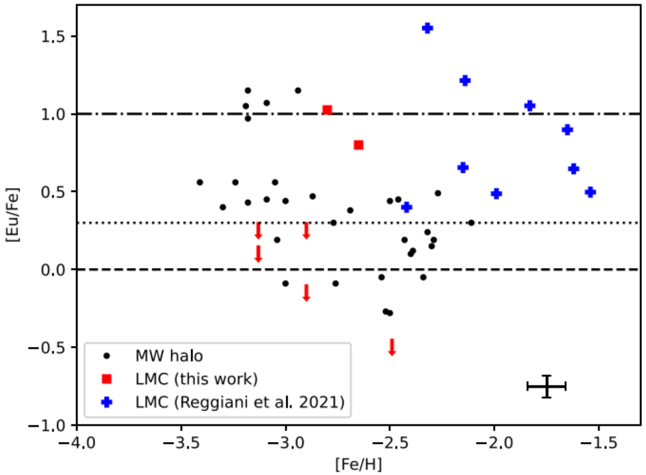
r-Process Elements and Enrichment:

Star (497682788) is classified as an r-II star, with [Eu/Fe] > 1.0.

Star (500382880) is classified as an r-1 star, with moderate enrichment([Eu/Fe] between 0.3 and 1.0)

The frequency of r-process enhanced stars was found to be statistically similar to the Milky Way halo





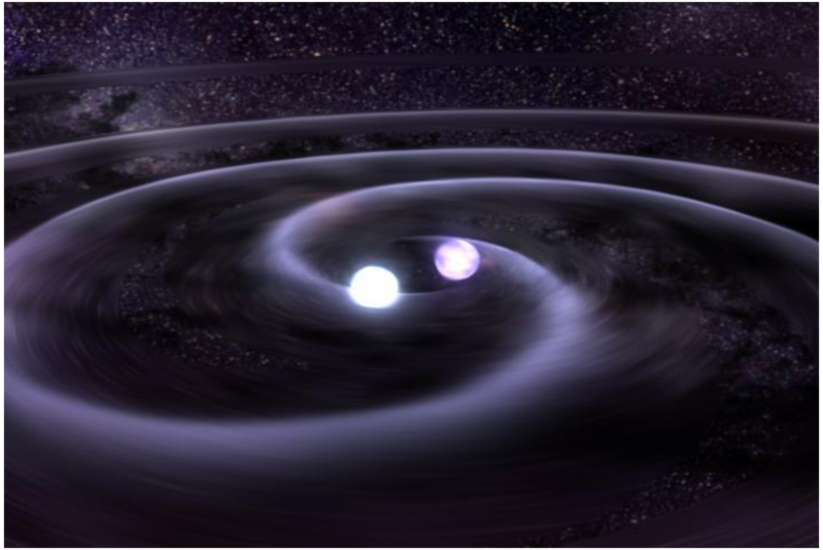
Results - Elemental Abundances and r-Process Enrichment

Nucleosynthesis Timing:

Presence of r-process enhanced stars suggests r-process nucleosynthesis occured after a long time delay

NS-mergers are likely sites for r-process nucleosynthesis

Observations of r-process elements like Eu suggest that the r-process contribution was non-uniform



NASA SVS | Neutron Star Merge

Broader Implications for Galaxy Formation and Evolution

EMP stars Confirm the LMC formed it's first stars early in its history

The low metallicity environment suggests early star formation took place in a low metallicity environment

Delay may be required to turn ON the r-process

Stellar metallicities may reach < - 2.5 before r-process enhancement

Explore the Large Magellanic Cloud (thoughtco.com)

APOD: 2008 January 4 - The Milky Way at 5000 Meters (nasa.gov)

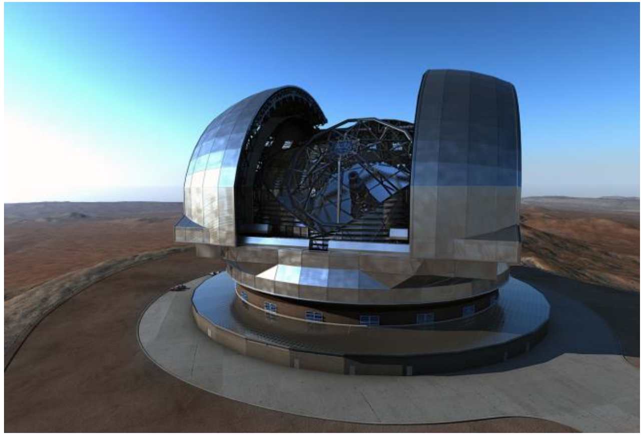
Future Research Directions

Expanding the Sample Size

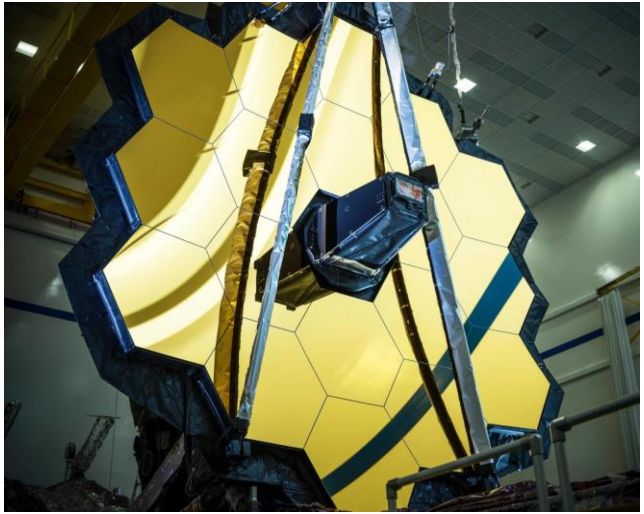
Detailed Analysis of r-Process Enriched Stars

Investigating the presence of NEMP Stars and the absence of CEMP stars in the LMC

Connecting EMP stars to Early Stellar Populations in Other Dwarf Galaxies



Artist’s impression of the European Extremely Large Telescope (E-ELT) | ESO



https://scitechdaily.com/nasas-10-billion-james-webb-space-telescope-completes-final-functional-tests-to-prepare-for-launch/

Conclusion

Abundance results, based on high-resolution spectra, were presented of seven metal-poor stars present in the LMC

Although their abundances/ abundance ratios resemble those found in the MW halo, there were several key differences

The absence of r-process enhancement in low-metallicity stars suggest a minimum time delay ~100Myr for NS mergers to generate substantial enhancement

The occurrence rates of r-I and r-II stars are statistically indistinguishable in the very and extremely metal poor stars in this LMC sample and the MW halo

Ultimately, these results provide valuable insights into the earliest stages of star formation in the LMC