

## Work visit of an Indian colleague to Belgium

(01/11/2024-30/11/2024)

During his one-month research visit to Brussels, [Muhammed Riyas Ankara](#) (UOC, India) worked closely with [Sophie Van Eck](#) (ULB, Belgium) and her team on a detailed spectroscopic analysis of Carbon-Enhanced Metal-Poor (CEMP) stars, focusing on the CEMP-rs subclass. The aim of this research was to better understand the role of the intermediate neutroncapture process (i-process) in producing extreme r-process elements and its broader implications for stellar and galactic chemical evolution.

### Background and Objectives

The origin of extreme r-process elements such as Os, Ir, Pt, Th, and U remains an open question in astrophysics. These elements, traditionally associated with the r-process in exotic astrophysical sites like neutron star mergers and certain types of supernovae, may also be produced in the i-process under specific conditions. This study specifically targeted the poorly explored link between the i-process and extreme r-process elements in CEMP-rs stars, which exhibit enrichments of both s- and r-process elements. The goals included:

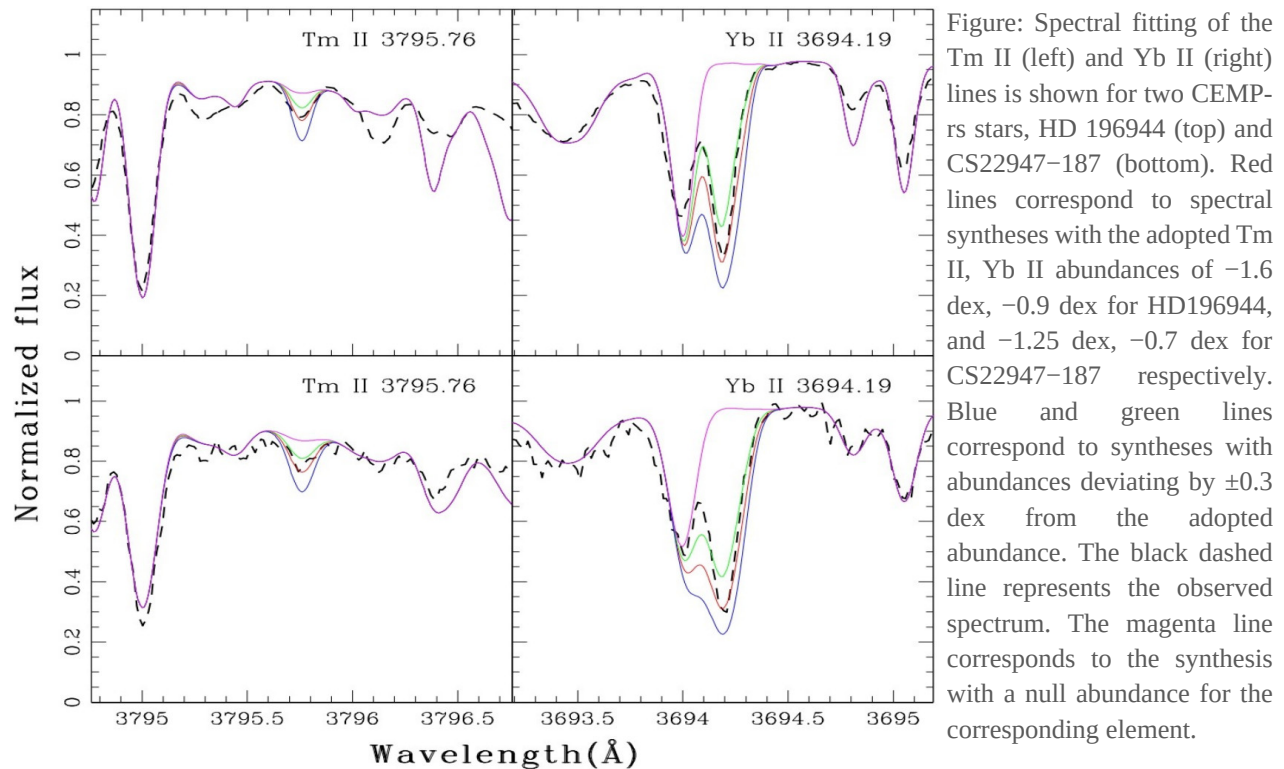
- Measuring heavy element abundances, particularly extreme r-process elements, in CEMP-rs stars using high-resolution UVES/VLT spectra.
- Comparing these observations with theoretical nucleosynthesis predictions to identify potential i-process contributions.
- Investigating the metallicity dependence of elemental enhancements and the implications for galactic chemical evolution.

### Sample and Data Analysis

The study analyzed a sample of 17 CEMP stars, including 12 from [Karinkuzhi et al. \(2021, "Low-mass low-metallicity AGB stars as an efficient i-process site explaining CEMP-rs stars", \*Astronomy & Astrophysics\* 645, A61\)](#) and five identified from the literature. These stars were selected to include both CEMP-s and CEMP-rs subclasses for a comparative analysis. High-resolution spectra were obtained using the UVES spectrograph on the VLT, covering a wavelength range of 328.0–683.5 nm at a resolution of 47 000. The data included archival spectra and observations from previous observing runs.

### Methodology

1. *Atmospheric Parameters:* Stellar atmospheric parameters (effective temperature, surface gravity, metallicity, and microturbulence velocity) were derived using BACCHUS code [[Masseron et al. 2016, "BACCHUS: Brussels Automatic Code for Characterizing High accuracy Spectra", \*Astrophysics Source Code Library, record ascl:1605.004\*](#)] in semi-automated mode.
2. *Line Selection:* For key heavy elements (e.g., Gd, Dy, Ho, Er, Ta, and Tm), they carefully selected clean spectral lines in the UV and optical regions to ensure reliable abundance measurements. NLTE corrections were applied where necessary.
3. *Spectral Fitting:* Synthesized spectra were fitted to the observed spectra for each star, ensuring robust measurements of elemental abundances. Special attention was given to elements with few measurable lines, such as Tb and Tm.
4. *Theoretical Comparisons:* Observed abundance patterns were compared with predictions from nucleosynthesis models of low-mass, low-metallicity AGB stars, computed using the STAREVOL code. Both s- and i-process contributions were evaluated.



## Key Results

1. *Abundance Patterns:* CEMP-rs stars showed significant enhancement of extreme r-process elements compared to CEMP-s stars. The enhancement increased with decreasing metallicity, suggesting a strong link between the i-process and these elements.
2. *Element-Specific Insights:*
  - Gd and Dy: Measurements from multiple lines showed consistent enhancement across most CEMP-rs stars.
  - Ho and Er: These elements were enhanced in CEMP-rs stars but showed lower levels in some CEMP-s stars, underscoring differences in their enrichment histories.
  - Tm and Yb: These elements provided critical insights into the relative contributions of the s- and r-process in CEMP-rs stars.
3. *Model Comparisons:* Observations agreed well with i-process nucleosynthesis models for low-mass AGB stars, supporting the hypothesis that the i-process contributes to extreme r-process element production. However, some stars, such as CS 30322-023, exhibited abundance patterns not fully explained by current models, indicating the need for further investigation.

## Conclusions and Implications

This study highlighted the significant role of the i-process in producing extreme r-process elements, challenging the traditional view that such elements are solely the product of exotic r-process sites. The findings suggest that low-mass stars contribute more to the chemical enrichment of galaxies than previously thought. Additionally, this research underscores the need to revisit the i-process's contribution to the Solar System's chemical evolution.

The collaboration with [Sophie Van Eck](#) was pivotal in refining analytical techniques, particularly in spectral fitting and abundance determination. This visit has not only advanced the PhD research of [Muhammed Riyas Ankara](#) but also laid the groundwork for future publications and collaborations in this field.