Physical Parameters of Stars in NGC 6397 Using Full Spectrum Fitting

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1. Abstract

This project aims to determine the physical parameters—effective temperature (T_{eff}), surface gravity (log g), and metallicity ([Fe/H])—of stars in the globular cluster NGC 6397 using full-spectrum fitting techniques with the ULySS software. The spectra were obtained using the MUSE instrument at the VLT. Atmospheric parameters were estimated by fitting observed spectra with interpolated models from empirical spectral libraries like MILES and ELODIE. This project provides hands-on experience with astronomical data analysis and contributes to a better understanding of stellar populations in metal-poor globular clusters.

2. Introduction

The determination of stellar atmospheric parameters is essential in astrophysics. Such parameters help us trace stellar evolution, chemical enrichment, and the formation history of galaxies. Full-spectrum fitting (FSF) is an advanced technique used to extract these parameters from stellar spectra.

NGC 6397, one of the closest globular clusters to Earth at a distance of approximately 2.48 kpc, is a well-studied system known for its low metallicity and old stellar population. Studying its stars helps in understanding Population II stellar properties and the chemical evolution of the early Galaxy.

ULySS (University of Lyon Spectroscopic Analysis Software) is a versatile package for full-spectrum fitting. It allows parameter estimation by minimizing the residual between observed spectra and model interpolations from established libraries. Unlike machine learning-based interpolators, ULySS uses classical polynomial fitting, making it accessible and interpretable for undergraduate research.

3. Objectives

- To understand the principles of full-spectrum fitting in stellar spectroscopy.
- To analyze MUSE/VLT spectra of stars in NGC 6397.
- To estimate atmospheric parameters (T_{eff}, log g, [Fe/H]) using ULySS.
- To compare results with published literature.

4. Literature Review

Stellar spectral analysis is a fundamental tool in astronomy. Empirical spectral libraries such as MILES (Sánchez-Blázquez et al. 2006), ELODIE (Prugniel and Soubiran 2001), and the Indo-US library provide the basis for spectrum interpolation in tools like ULySS. These libraries contain observed stellar spectra with known parameters, covering a wide range of effective temperatures, surface gravities, and metallicities.

NGC 6397 has been the subject of many studies due to its proximity and simplicity. Husser et al. (2016) used MUSE data to extract over 18,000 spectra and published atmospheric parameters for more than 4000 stars. Baratella et al. (2022) performed spectral

fitting using FERRE and various synthetic libraries. Jain et al. (2020) used ULySS with ELODIE and MILES to rederive parameters, emphasizing the value of empirical libraries for such work.

Full-spectrum fitting differs from classical methods by utilizing the entire observed spectrum rather than individual lines, offering improved parameter accuracy. ULySS performs this using χ^2 minimization and polynomial corrections for flux mismatches. This method has been validated in numerous studies and is ideal for moderate-resolution spectra like those from MUSE.

5. Dataset Overview

5.1. Spectral Libraries

The fitting was performed using ULySS interpolators based on the MILES or ELODIE libraries. These cover:

- $T_{\rm eff}$ = 3000–8000 K
- log g = 0.0–5.0 dex

Fe/H = –3.0 to +1.0 dex

5.2. Observational Data: MUSE/VLT

- Source: Husser et al. (2016)
- Instrument: MUSE at the VLT
- Spectral Range: 480–930 nm
- Resolution: R $\approx$ 3000
- Dataset: 1587 spectra of 1063 stars with S/N $>$ 20

6. Methodology

1. Preprocessing: Spectra were selected based on S/N and wavelength coverage.
2. Initial Guesses: Used photometric estimates of $T_{\rm eff}$ and log g as inputs.
3. ULySS Fitting: Used the "uly_fit_spectra" routine to derive parameters.
4. Polynomial Adjustment: A multiplicative polynomial corrected flux calibration and extinction.
5. Visual Inspection: Residual plots and fit quality were assessed manually.

7. Results and Analysis

The parameters obtained were consistent with expectations for NGC 6397:

- Effective Temperatures: 4000 K – 6500 K
- Surface Gravity: 0.5 – 4.5 dex
- Metallicity: [Fe/H] around –2.0 dex

Fits showed close alignment between observed and model spectra, with low residuals. The results agree well with prior studies using different spectral fitting codes.

8. Conclusion

The ULySS software proved effective in determining atmospheric parameters from MUSE spectra using empirical spectral libraries. This project confirmed that classical full-spectrum fitting methods remain powerful tools in modern stellar spectroscopy, even without machine learning-based interpolation.

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