Unveiling the Evolutionary States of B Supergiant Stars

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ARTICLE

Physics of Extreme Massive Stars

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Introduction

Massive stars are the cornerstone for the chemical evolution of the interstellar medium through feedback from their winds and supernova explosions. To quantify this feedback, it is critical to understand massive stars and their winds in diverse evolutionary states. Our study focuses on blue supergiants (BSGs). This phase can be crossed twice in the evolution of massive stars, directly after the main sequence and after the red supergiant (RSG) state for stars with initially more than 20 solar masses. The chemical composition, number of excited pulsation modes and stellar mass loss of stars in these two groups of BSGs can be significantly different [1]. To establish a comprehensive picture of the two BSG populations, we combine asteroseismology, spectroscopy, and evolutionary models to unveil the evolutionary state of three Galactic BSGs: HD 42087 (PU Gem), HD 52089 (ϵ CMa), and HD 58350 (η CMa).

Time series and frequency analysis

We analyzed the frequency content in the 2 min cadence PDCSAP light curves from TESS, available for each star. HD 42087 was observed in one Sectors 43, 44 and 45; HD 52089 in Sectors 6, 7, 33 and 34; and HD 58350 in Sector 34. We adopted a S/N =5.037, 5.124 and 5.194 for the individual Sector and the 2 and 3 Sectors combined. The analysis of the combined Sectors allowed us to study the low-frequency variations.

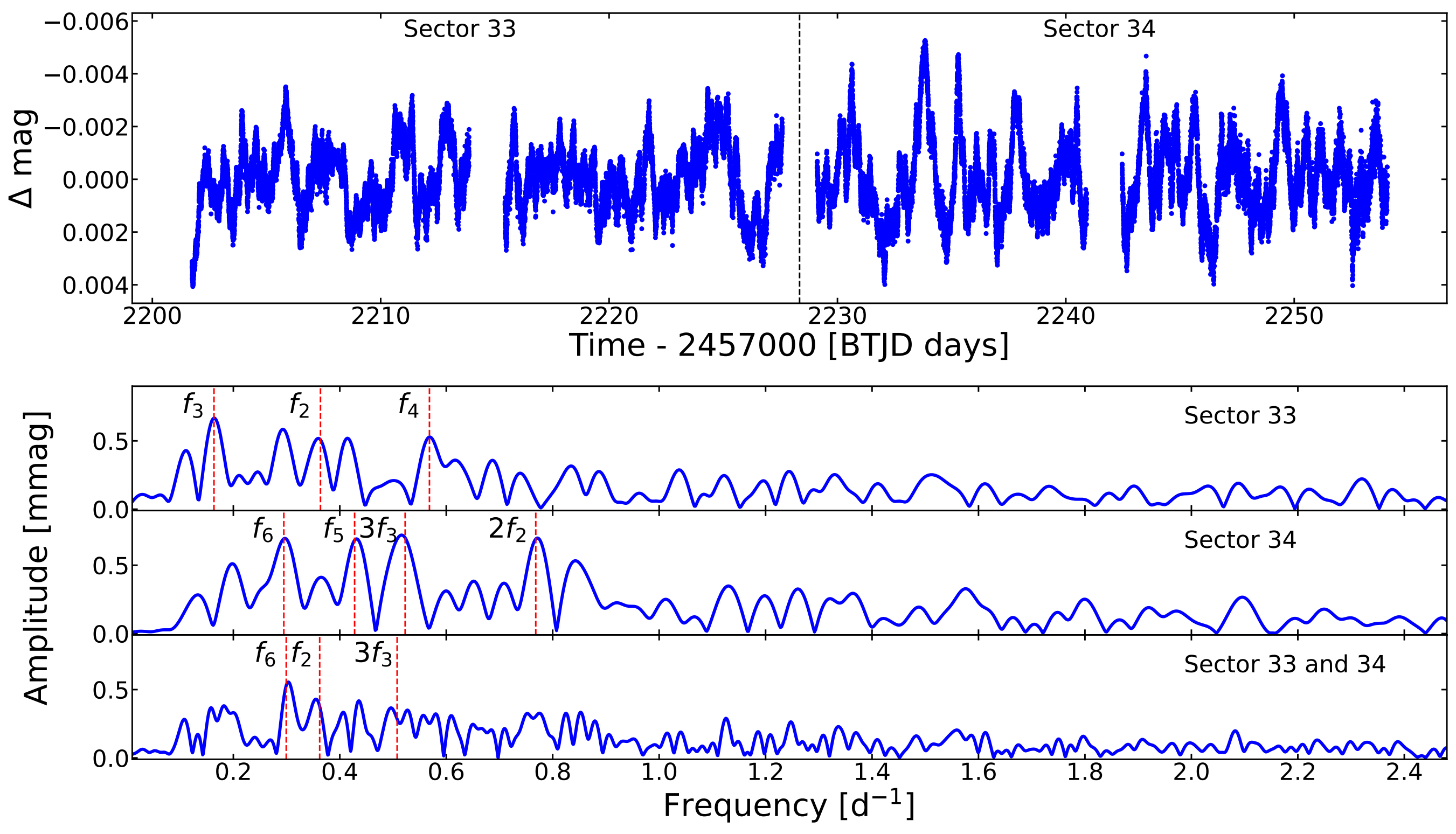

Figure 1: Example of our analysis results for the star HD 52089.*Top panel:* light curve in the two consecutive sectors. *Bottom panel:* Amplitude spectra of the individual sectors and the combined light curve with the identified frequencies marked.

Spectral modeling with CMFGEN

We obtained new spectroscopic observations at the CASLEO observatory and applied non-LTE radiative transfer models calculated with CMFGEN to derive the stellar and wind parameters. CMFGEN models were included in the iterative spectral analysis pipeline XTGRID to determine the surface parameters using a robust atomic setting including heavy elements as Fe and Ni. The spectral modeling was limited to changing only the effective temperature, surface gravity, CNO abundances, and mass-loss rates.

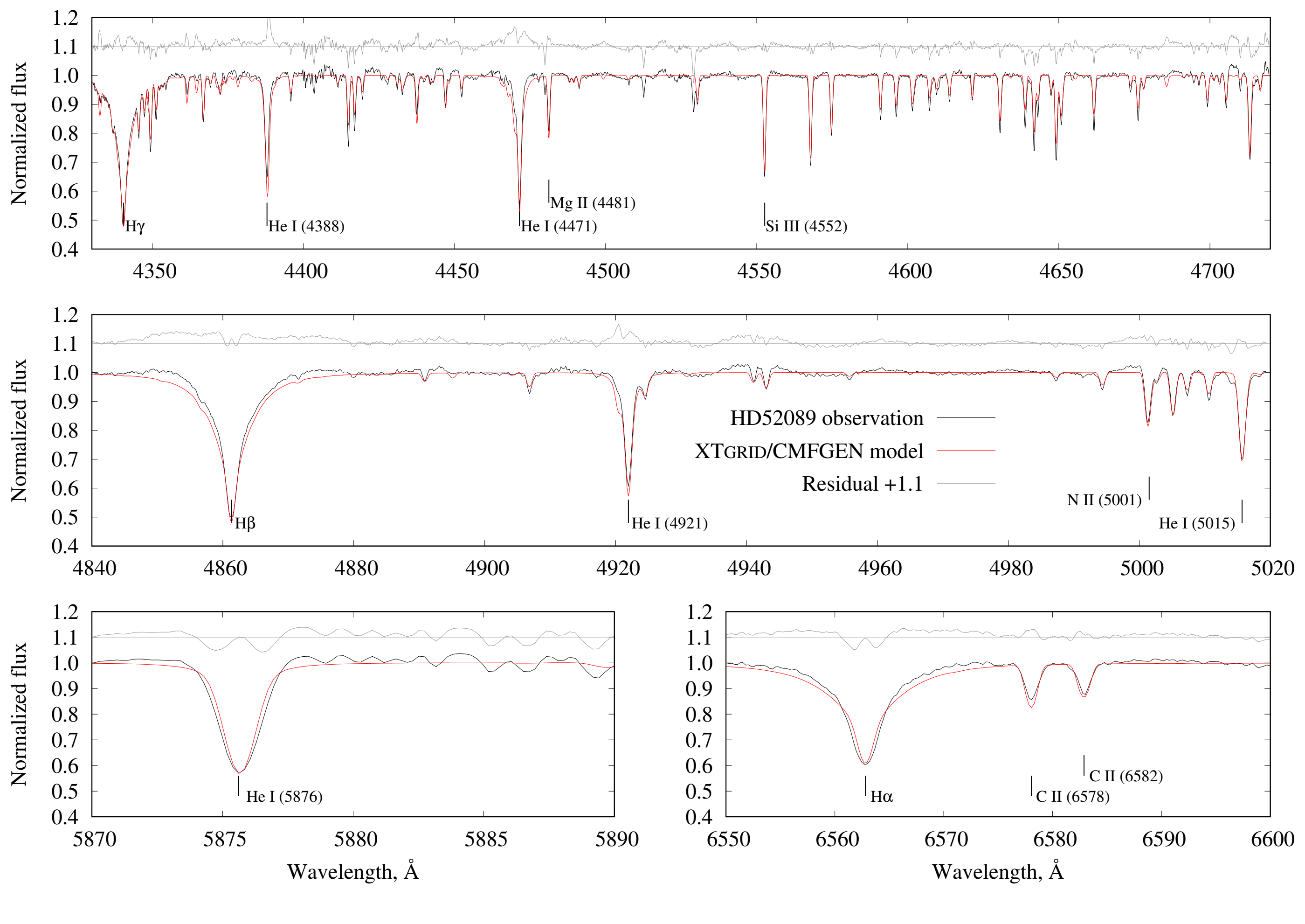

Figure 2: Best-fit XTGRID/CMFGEN model for HD 52089. In each panel, the CASLEO observation is in *grey*, the CMFGEN model in *black*, and the residuals, shifted by +1.1 for clarity, are in *red*.

The best-fit CMFGEN model is then used to predict the spectral energy distribution which was compared to observed broad-band data.

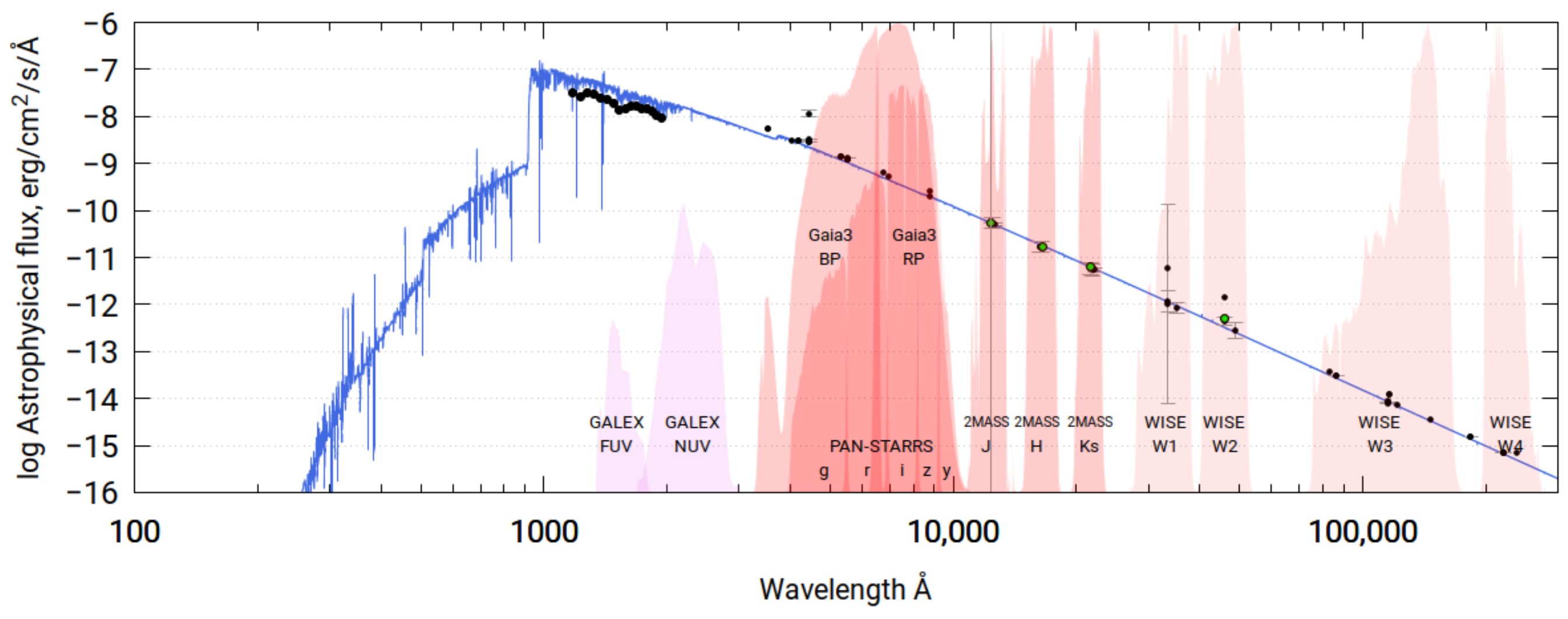

Figure 3: SED of HD 52089. All data points were taken from the VizieR Photometry Viewer service. The photometric data were de-reddened using $E(B-V)$ = 0.005 mag. The green points were used to match the slope of the passband convolved CMFGEN fluxes to the observations and the model was normalized to the observed SED in the 2MASS/J band. The binned IUE spectrum is included with black dots.

Comparisons with evolution models

Finally, we compared the derived $T_{\rm eff}$, L, M with predictions from Geneva stellar evolution models and previous and metal abundances determinations for the samples of BSGs [2, 3] and main sequence stars [4] as a reference.

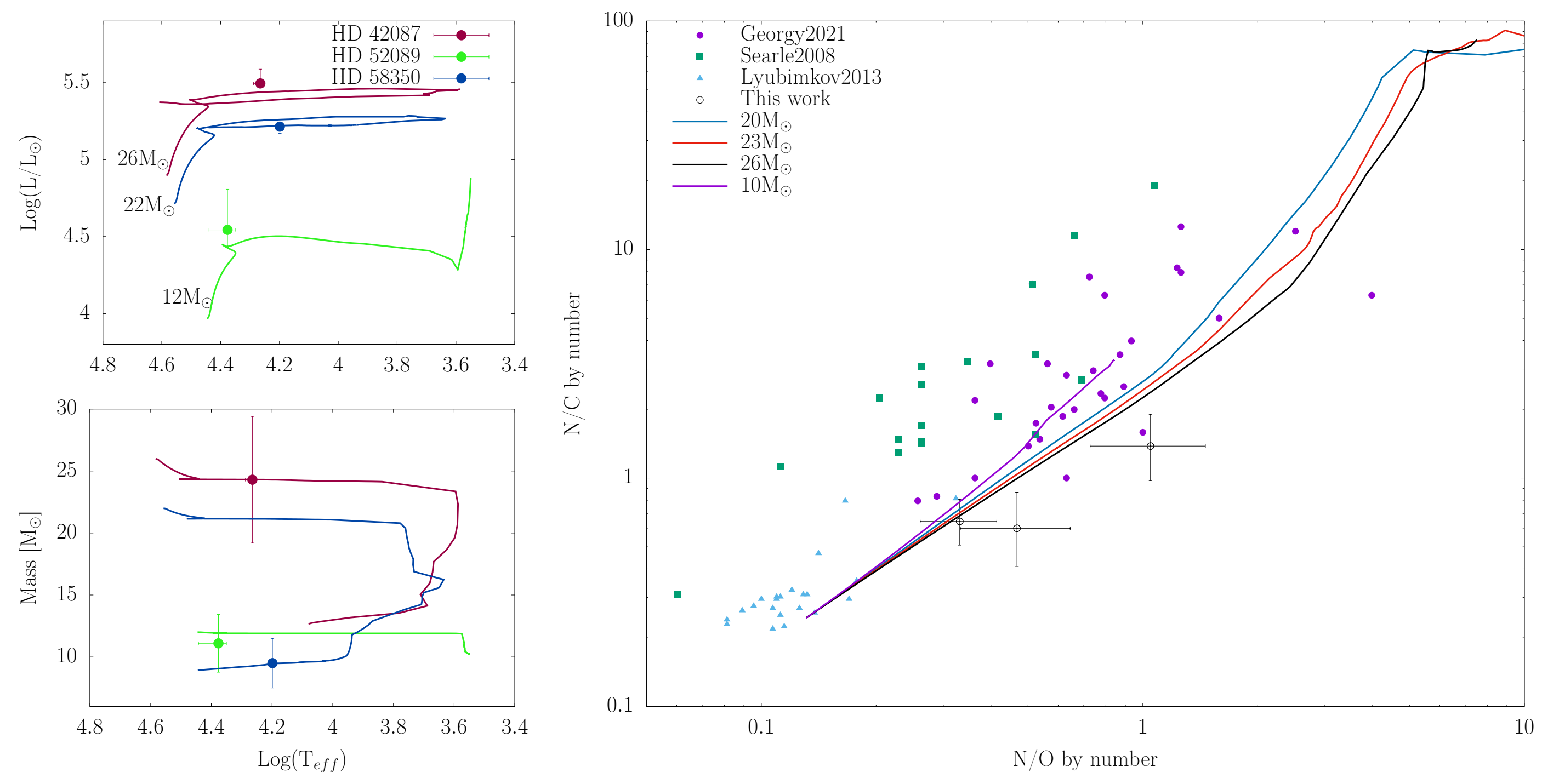

Figure 4: *Left panels:* Position of the three studied objects in the HR diagram (top) in comparison with stellar evolutionary tracks of stars with initially 12, 22, and 26 solar masses with solar metallicity and $\Omega/\Omega_{crit} = 0.568$. The derived evolutionary masses (bottom) suggest HD 58350 is a post-RSG and the other two pre-RSGs. *Right panel:* Measured surface abundance ratios of B-type main sequence stars (triangles) and BSGs (colored symbols) compared to theoretical predictions along evolutionary tracks with $\Omega/\Omega_{crit} = 0.4$. The clear discrepancy in the post-main sequence evolution implies a significant lack of knowledge of the physical processes inside these objects.

Results

The frequency spectra of all three stars show stochastic oscillations, possibly related to wind variabilities and indications of one nonradial strange mode, $f_r = 0.09321\,d^{-1}$ in HD 42087, consistent with its value $L/M = 4.1$, and a rotational splitting centred in $f_2 = 0.36366\,d^{-1}$ in HD 52089.

The spectral analysis confirmed gradual changes in the mass-loss rates when compared to literature values [5], and the derived CNO abundances comply with the values reported in the literature. However, the spectroscopic surface abundances turned out to be inconsistent with the theoretical predictions. The stars show N enrichment, typical for CNO cycle processed material, but the abundance ratios did not reflect the associated levels of C and O depletion. Based on the abundance ratio alone, we found that all our stars are more consistent with a pre-RSG stage. However, stellar evolution models confirm this stage only for HD 42087 and HD 52089 considering their derived $T_{\rm eff}$, L and M, while predicting HD 58350 to be at the post-RSG stage.

Conclusions

The results underscore the need to study large samples of B supergiants homogeneously and to review processes involved during the evolution of massive stars, such as mass loss via stellar oscillations, in particular strange modes. Detailed internal structure and pulsation models are needed to revise the chemical evolution of massive stars. Further efforts are required for a more efficient spectral fitting due to the high computational cost of the radiative transfer calculations. The synergy of the three different research methodologies helps better understand supergiant stars and by confronting them one can improve the models and reduce limitations.

References

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