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High-resolution spectroscopy of "hump and spike" stars

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Abstract

We used data collected with the High Efficiency and Resolution Mercator Échelle Spectrograph (HERMES). We determined the spectral type of these stars and obtained the atmospheric stellar parameters such as effective temperatures, surface gravities, projected rotational, microturbulent and radial velocities. We also performed a detailed individual chemical abundance analysis for each target. We confirmed KIC 3459226 (kA2hF0mF3) and KIC 6266219 (kA3hA7mF1) as Am stars, KIC 9349245 as a marginal Am star, while KIC 4567097, KIC 4818496, KIC 5524045, KIC 5650229, KIC 7667560, and KIC 9272082 are non-Am stars. Using the MESA evolution code, the evaluation of the transport processes indicates that radiative diffusion, combined with turbulent mixing, thermohaline convection, and slow to moderate rotation can account for most of the chemical peculiarities found in Am stars. The differences in abundances suggest that there are other mechanisms at work, which are currently unknown, that contribute to the chemical anomalies identified in Am stars.

1 Introduction

Recently, many space missions were lauched, such as Microvariability and Oscillations of Stars (MOST), Convection, Rotation and planetary Transits (CoRoT), *Kepler*, and TESS, which are mainly searching for exo-planets and performing asteroseismology of pulsating stars. More projects like PLAnetary Transits and Oscillations of stars (PLATO) and Wide Field Infrared Survey Telescope (WFIRST) will be launched in the near future. The space-based mission provided high-precision photometric data. Using these data, interesting phenomena such as pulsations, spots, and "hump and spike" features were observed among some normal A and metallic lined A stars (Am stars). The observations in

Am stars somewhat deviate from the current predictions of diffusion theory of Am stars. In order to understand this discrepancy, its important to obtain ground-based high-resolution spectroscopic data to determine the fundamental parameters and individual chemical abundances and compare results with theory.

2 Data

The high-resolution spectroscopic observatiions were made on the nights of 02, 06 and 07 November 2018, using the HERMES spectrograph mounted at the Cassegrain focus of the 1.2-m Mercator telescope located at La Palma, Spain. In a single exposure, this spectrograph records optical spectra in the wavelength (λ) range 377 to 900 nm across the 55 spectral orders. The resolving power of this instrument in the high-resolution mode is 85 000 with radial velocity stability of about $50\,\mathrm{m\,s^{-1}}$, and excellent throughput (Raskin et al., 2011). The spectra were reduced using a dedicated HERMES pipeline and corrected for barycentric motion. Normalisation of all the spectra to the local continuum was performed manually using the *continuum* task of the IRAF package.

3 Atmospheric parameters and abundances

Prior to the determination of atmospheric parameters and chemical abundances, we performed a spectral classification analysis of the targets on the MK classification system using MKCLASS. We determined atmospheric parameters (T_{eff}, $\log g$, and $v \sin i$) by comparing the observed spectra with a grid of synthetic spectra, pre-computed with plane-parallel ATLAS9 model atmospheres. This comparison was performed with a least-square method based on the MINUIT minimization package used by the GIRFIT package (Frémat et al., 2006). The input physics was estimated from photometry and fitting the spectral energy distribution using VOSA (Bayo et al., 2008). We uniquely obtained ξ by fitting iron lines using the MOOG radiative transfer code, ATLAS9 model atmospheres, the Vienna Atomic Line Database (VALD) line-list and Asplund et al. (2009) solar abundances.

The individual chemical abundances were determined based on direct fitting of the theoretical profiles of individual spectral lines. We used the SYNTHV_NLTE code (Tsymbal et al., 2019) and a grid of atmosphere models pre-computed with the LLmodels code (Shulyak et al., 2004). This was implemented through an IDL visualization program, BINMAG6 (Kochukhov, 2018). During spectral synthesis, local thermodynamic equillibrium (LTE) was assumed. We adopted spectral line lists and atomic parameters from the 3D release of the Vienna Atomic Line Database (VALD3; Ryabchikova et al. 2015). We divided each spectrum into several intervals, each ≈ 5 nm wide, and derived the abundances in each interval by performing a χ^2 minimization of the difference between the

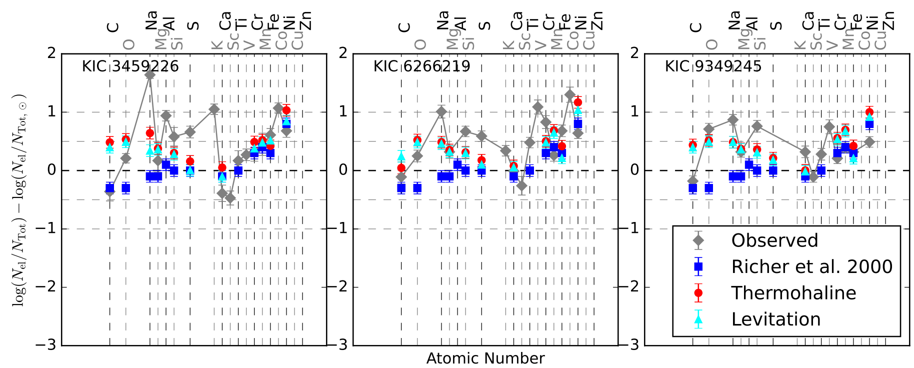

Figure 1: The individual chemical abundances for the three Am stars relative to the solar values.

observed and synthetic spectrum. The average individual chemical abundances were then computed (Trust et al., 2021).

4 Model

In the modelling procedure, stellar mass and age are also essential constraints for the evolutionary models. Using the spectroscopic $T_{\rm eff}$ and the $\log(L_\star/L_\odot)$ computed from the GAIA parallaxes, stellar mass and age were determined by interpolating the PARSEC 1.2 evolutionary tracks and isochrones (Bressan et al., 2012), respectively. We used MESA version 12778. The basic input physics used in all the models includes the 2005 updated version of the OPAL equation of state (Rogers & Nayfonov, 2002). The only elements and isotopes that were followed are ^{1}H, ^{12}C, ^{16}O, ^{23}Na, ^{24}Mg, ^{28}Si, ^{32}S, ^{40}Ca, ^{48}Cr, ^{51}Mn, ^{56}Fe, and ^{58}Ni. An initial metallicity Z of 0.02, a fixed mixing-length parameter, $\alpha_{\rm MLT}$ of 1.8, and a helium-to-heavy element enrichment ratio of 1.33 were assumed. Thermohaline convection and levitation were considered in addition to atomic diffusion and rotation. To visualise the effect of turbulence on chemical abundances, the theoretical predictions by Richer et al. (2000) were used and results are presented in Figure 1.

5 Conclusions

Based on the spectral classification analysis and the resulting chemical abundance pattern, KIC 6266219 was reclassified as an Am star (kA3hA7mF1) while KIC 9272082 as chemically normal. Therefore, it is concluded that sample contains two Am stars (KIC 3459226 and KIC 6266219) and one marginal Am star (KIC 9349245), and six targets that are considered as non-Am stars (KIC 4567097,

KIC 4818496, KIC 5524045, KIC 5650229, KIC 7667560, and KIC 9272082). We determined theoretical chemical abundances for the three Am stars in which atomic diffusion, rotation, thermohaline convection, and levitation were accounted for. The results were also compared with the predictions based on diffusion models with turbulent mixing by Richer et al. (2000). An excellent agreement, within the errors, was obtained for a significant number of the elements in common. This study indicates that radiative diffusion, combined with turbulent mixing, thermohaline convection, and slow to moderate rotation can account for most of the chemical peculiarities found in Am stars. However, discrepancies in a number of abundances also imply that there are other processes, currently unknown, which contribute to the observed chemical peculiarities in Am stars.

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