Exploring AGB Dynamical Model Atmospheres By Using Infrared Spectra of 47 Tuc Stars

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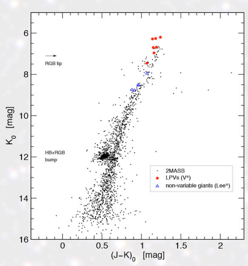
ABSTRACT

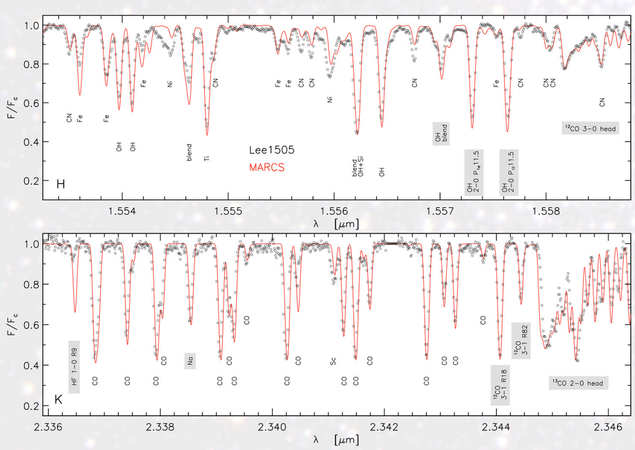
The rich globular cluster 47 Tuc presents a well defined sample of giant branch and AGB stars. A sample of 5 non-variable red giants and 7 variable AGB stars, including Mira variables, were observed at 1.555 and 2.341 μm with Phoenix at Gemini South. The spectra include molecular lines from ^{12}CO, ^{13}CO, OH, CN, and HF as well as a number of atomic lines. Stars in 47 Tuc have well-characterized mass, metallicity, and luminosity. We used the infrared features to investigate state-of-the-art dynamical stellar model atmospheres. C/O and $^{12}C/^{13}C$ abundances were derived for giant branch stars using standard hydrodynamic and LTE techniques. A set of dynamical model atmospheres were computed for the variable stars. Equivalent widths were computed using hydrostatic and dynamical model atmospheres. Assuming that the abundance pattern stays constant from the upper giant branch to the AGB in these low-mass stars, we used the results to gauge our ability to model dynamical stellar atmospheres.

INTRODUCTION

The evolution of low- and intermediate-mass stars along the red giant branch (RGB) and the asymptotic giant branch (AGB) is accompanied by major mixing events that change the elemental abundance pattern at the stellar surface. High resolution spectroscopy is the main tool for studying the abundances. For late-type stars molecules (CO, CN, and OH) provide the best tools for measuring the astrophysically important CNO abundance group. The variable AGB stars are at the end stage of mixing, returning a large fraction of their mass to the ISM. Ideally we would like to measure abundances in these pulsating stars.



Near-IR color-magnitude diagram of 47 Tuc showing the stars observed with Phoenix at Gemini South.



The observed spectrum of the non-variable 47 Tuc star Lee 1505 (circles) and a best-fitting synthetic spectrum calculated from a hydrostatic MARCS model (red line). The two spectral regions observed by Phoenix are shown and the major features identified. The grey shaded identifications were used to evaluate dynamic models. The fit was done to CNO group elements. Other species are at reduced solar abundances, [Fe/H] = -0.7.

Species	Transition	λ_{start}	λ_{end}	Note
OH	blend	15 568.6 Å	15 572.1 Å	1
OH	2-0 P_{1e}11.5	15 572.1 Å	15 574.8 Å	1
OH	2-0 P_{1f}11.5	15 574.9 Å	15 578.6 Å	1
^{12}CO	3-0 band head	15 581.1 Å	15 585.7 Å	1, 2
^{12}CO	4-1 P27	16 307.1 Å	16 309.1 Å	5
Na		23 383.6 Å	23 387.4 Å	4
^{12}CO	3-1 R18	23 438.5 Å	23 443.1 Å	3
^{12}CO	3-1 R82	23 443.1 Å	23 445.6 Å	3
^{13}CO	2-0 band head	23 447.1 Å	23 452.3 Å	2

List of individual features studied

Columns 3 and 4 give the borders of the spectral ranges applied to determine equivalent widths. The last column is a key for the use in our analysis: 1=C/O ratio, 2=$^{12}C/^{13}C$, 3=atmospheric structure, 4=[Na/Fe], 5=temporal change

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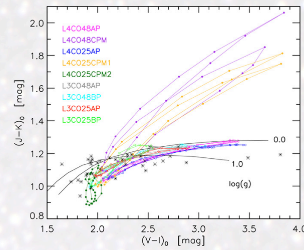
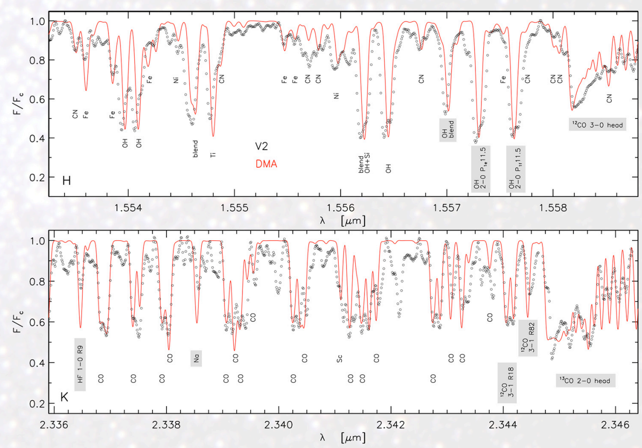
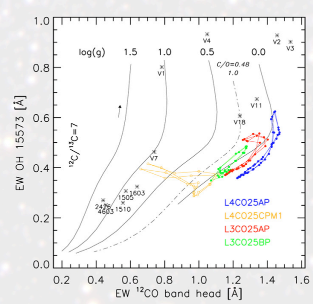


A number of dynamical model atmospheres were computed. These are shown here on a color-color diagram. Both the variable stars and the models undergo loops in color during the light cycle. There is not complete coverage for the individual stars over the entire light cycle but the available data give a good indication of the value of the models. The solid black lines are from temperature sequences of hydrostatic models at the log g shown.



Observed versus computed spectra for the 47 Tuc Mira V2. The fit uses a dynamical model with same abundances shown in the hydrostatic model fit to Lee 1505. The observed spectrum shows features, such as line doubling, that are well known to occur in Miras. While the dynamic model is a much better fit than hydrostatic models, there are significant problems with the fit. For instance the model that proved to be a best fit was not for the same phase as the observation.



Plotting two features strengths against each other allows a separation of the effects of effective temperature and gravity. Here the equivalent widths of an OH line are shown as a function of the ^{12}CO 3-0 band head. The black lines are hydrostatic model temperature sequences with the arrow showing decreasing temperature. Four dynamical models are shown with C/O = 0.25 unless indicated.

RESULTS

The equivalent widths measured in the variable stars strongly differ from the non-variable stars. We were not able to satisfactorily reproduced the observations with either hydrostatic or dynamical model atmospheres. Nevertheless, the dynamical models fit the observed spectra of long-period variables much better than any hydrostatic model. This material provides much needed input for improving dynamical calculations. For details see the published paper: Lebzelter et al. 2014 AA 567 A143.