The exoplanet-host star $\mu$ Arae: A new seismic analysis

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Abstract. We present here the detailed modelling of the exoplanet-host star $\mu$ Arae, which is known to harbour a four-planets system. This star presents a metallicity excess compared to stars without detected planets. Asteroseismology can help determining precisely its internal structure. $\mu$ Arae was observed with the HARPS spectrograph at La Silla Observatory in June 2004, and 43 p-modes were identified. Using the external parameters provided by spectroscopy and the seismic constraints, we computed new stellar models, in a wider range and more precisely than [1], with various assumptions (overmetallic or accretion scenario, overshooting or not, $\nu$ enriched with metals or $\nu$ fixed to its solar value). We tried to find which ones give the best fit to the observations.

1. Introduction

$\mu$ Arae (HD 160691) is a G3 IV-V type star with a visual magnitude $V = 5.15$ and a parallax $\pi = 65.46 \pm 0.80$ mas. It is the central star of a system of 4 planets [9].

Like most exoplanet-host stars, $\mu$ Arae presents a metallicity excess compared to stars without planets. This overmetallicity may be of primordial origin or it could be due to accretion. This star has been observed in June 2004 with the HARPS spectrograph at La Silla Observatory. 43 p-modes oscillations were identified with degrees $\ell = 0$ to $\ell = 3$.

We computed evolutionary tracks with the TGEC code [10] [5], and the adiabatic oscillation frequencies with the PULSE code [4].

2. Stellar parameters

2.1. Observational constraints

Five groups of observers have derived from spectroscopy the external parameters of $\mu$ Arae: $T_{\text{eff}}$, log g and [Fe/H]. The average value for effective temperature is $T_{\text{eff}} = 5800 \pm 100$K. With the tables of [7], we obtained $BC = -0.085 \pm 0.01$ for the bolometric correction, and so the luminosity is $\log(L/L_\odot) = 0.24 \pm 0.03$.

Contrary to [1], we do not use the luminosity as a constraint, we prefer to fit our models to the “triplets” ([Fe/H], log g, log $T_{\text{eff}}$) determined consistently by spectroscopists.

2.2. Seismic constraints

Solar-like oscillations have been detected by [3] with the HARPS spectrograph. 43 p-modes were identified between 1.3 and 2.5 mHz with a mean large separation of 90 $\mu$Hz and a mean small
Figure 1. Evolutionary tracks for overmetallic models of 1.06 (red), 1.08 (grey), 1.10 (blue), 1.12 (pink), 1.14 (green), 1.16 (yellow), 1.18 (magenta), and 1.20 (cyan) $M_\odot$. The five error boxes shown are from: [2] (asterisks), [11] (diamonds), [12] (triangles), [8] (crosses), [6] (black triangles).

Figure 2. Echelle diagram for an overmetallic model ([Fe/H]=0.32) of 1.10 $M_\odot$, 6.318 Gyr, without overshooting. The lines represent the theoretical frequencies and the symbols their observational counterpart: solid line and diamonds are for $\ell = 0$, dotted line and triangles for $\ell = 1$, dashed line and crosses for $\ell = 2$, dotted-dashed line and asterisks for $\ell = 3$.

3. Modelling

We computed evolutionary tracks for overmetallic and accretion models, for the two values of [Fe/H] given by the groups of observers: [Fe/H]=0.29 and 0.32 (FIG.1), with and without overshooting, with a solar helium abundance and with $Y$ increasing with metals. We then computed the adiabatic oscillations frequencies for a large number of models along the evolutionary tracks. The only acceptable models are those that have a mean large separation of exactly 90 $\mu$Hz and that can fit the observed small separations and echelle diagram. So we computes on each log $g$-log $T_{eff}$ diagram, an iso-$\Delta \nu$ 90$\mu$Hz line. The models that can give the best fit to the observations are at the crossing of the evolutionary track and the iso-$\Delta \nu$ line.
4. Results
We found that, even if all the models are in agreement with the observable \((\log g \text{ and [Fe/H]})\) and seismic \((\Delta \nu = 90 \mu Hz)\) constraints, some models do not fit the observed small separations and echelle diagram.

We also noticed that none of the models cross the [8] and [11] error boxes, which correspond to high values of \(\log g\).

We present here the two models that give the best fit to the observations:

- An overmetallic model of \(1.10 \, M_\odot\), 6,318 Gyr, with a metallicity [Fe/H]=0.32 (cf. FIG. 2). The mean small separation is 6.621 \(\mu\)Hz.
- An accretion model of \(1.05 \, M_\odot\), 7,182 Gyr, with a metallicity [Fe/H]=0.29 (cf. FIG. 3) and a mean small separation of 6.619 \(\mu\)Hz.

In these models, we assumed that the helium abundance increases with metals, according to the law found for galaxies.

These two models correspond to stars on the subgiant branch, with a helium-rich core.

Their luminosities are larger than that derived from the Hipparcos parallax.

4.1. The effect of overshooting
In the TGEC code, overshooting is computed by increasing the convective core by a zone with a width of \(\alpha_{ov} H_P\), where \(H_P\) is the pressure height scale, and \(\alpha_{ov}\) the overshooting parameter (ranging from 0.19 to 0.22).

We have tested the effect of adding overshooting in overmetallic and accretion models. For most models (at the end of the main sequence), with a helium-rich convective core, we found negative small separations, so that the lines \(\ell = 0\) and \(\ell = 2\) cross on the echelle diagram (cf. FIG. 4).

These models do not agree with the observations as well as those without overshooting. More work is being done on the subject.

5. Conclusion
\(\mu\) Arae is a G3 IV-V type star with a system of four planets. Solar-like oscillations were detected and a first seismic analysis of this star was achieved by [1].

Here we performed a new analysis of \(\mu\) Arae, in a more precise and complete way. We computed new stellar models, taking into account the external parameters \((\log g, \log T_{eff}, \text{and})\)
Figure 4. Echelle diagram for an overmetallic model ([Fe/H]=0.29) with overshooting ($\alpha_{ov} = 0.20$), 1.05 M$_\odot$, and 8.948 Gyr. The symbols are the same as in FIG.2.

[Fe/H]) given by several groups of spectroscopists and the seismic constraints derived from the HARPS observations. We have tested various computation assumptions and we found other models which give the best fit to the observations.

6. References

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