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Asteroseismology as tool for stellar evolution models: the case of μ Herculis

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Abstract. For the first time the G5 IV Subgiant star μ Herculis has been observed as asteroseismologic target by our Group, using SARG at the Italian telescope TNG, Canary Islands. The analysis of its Power Spectrum (PS) has provided a value of the large separation in full agreement with the theoretical predictions. We present some considerations about the properties of this star on the basis of this analysis and making use of the teoretical relations. An interesting comparison could be done with β Hyi, a Subgiant star in the same evolutionary state of μ Her and which consequently shows similar asteroseismic properties.

Key words. Stellar Oscillations – Technique: Radial Velocities – Stars: μ Her

1. Introduction

Asteroseismology, based on the analysis of oscillation frequencies of non-radial pulsations, provides a tool to probe the interiors of stars, enabling us to study their internal structure, physical processes and the evolutionary state. As more widely discussed in Bonanno et al. 2007, we present the clear detection of solar-like oscillations in the G5 IV star μ Her, stressing the necessity to obtain a more precise estimate of its radius using interferometric techniques. This will help to put firm constraints in the evolutionary models of this star.

2. Observations and data analysis

μ Herculis (HD161797, HR6623) is a G5 IV Subgiant star, having $M = 1.1 M_{\odot}$, $T_{eff} = 5596 K$, $\log g = 3.93$ and $R = 1.77 R_{\odot}$ (Fuhrmann , 1998). This star has been observed for seven continuous nights in June 2006, using SARG (Gratton et al. , 2001), the high resolution spectrograph mounted at the Italian ”Telescopio Nazionale Galileo”. Making use of the iodine cell technique and processing the spectra with the AUSTRAL code (Endl et al. , 2000), we obtained very high precision radial velocities measurements, with an r.m.s. scatter of the time series of $\sigma = 2.53\ ms^{-1}$.

Figure 1 shows the power spectrum of μ Her where the excess of power, the clear signa-

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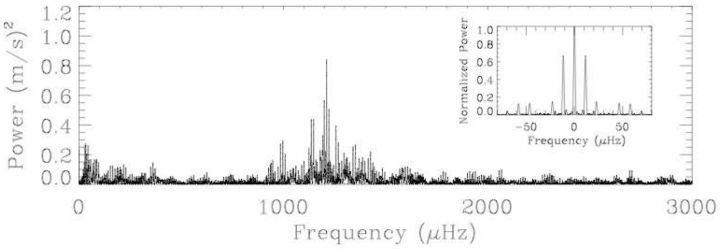

Fig. 1. The Power Spectrum of μ Her. The frequency for the maximum power is located at about 1.2 mHz.

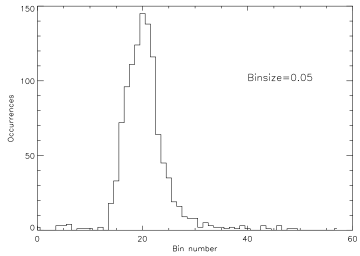

Fig. 2. Histogram of the errors in the radial velocities measurements of μ Her.

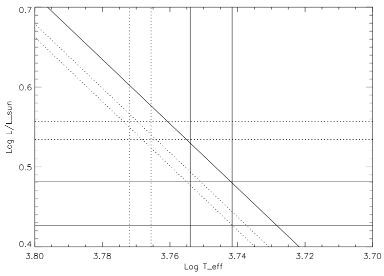

Fig. 3. Values of L, T_{eff} and radius (diagonal line) of β Hyi (dotted lines) and μ Her (solid lines) are reported in this plot within their uncertainties.

ture of the presence of solar-like oscillations, is evident. The histogram of the errors in the RV measurments (see Figure 2) is similar to a gaussian curve, demonstrating that the pulsations are excited by a purely stochastic process. Thanks to the Comb Response analysis we obtain the value of the large frequency separation: $\Delta\nu = 56.61 \pm 0.088$ μHz. Both the position of the main peak in the power spectrum, ν_{max}, and $\Delta\nu$ are in full agreement with the theoretical predictions of Kjeldsen and Bedding (1995). The large separation is bound to the mean properties of the star like the mean density, which in Bedding et al. (2007) is computed by scaling from the solar values:

$$\frac{\Delta\nu}{\Delta\nu_{\odot}} = \sqrt{\frac{\bar{\rho}}{\bar{\rho_{\odot}}}} \tag{1}$$

being $\Delta\nu_{\odot} = 134.81 \pm 0.09$ μHz. The computed mean density of μ Her is equal to 0.2486 ± 0.0018 g cm $^{-3}$. Once we have estimate the large frequency separation, it is possible to built the echelle diagram of the oscillation frequencies. Using both a standard and a modificated cleaning procedure of the PS (Bonanno et al. , 2007) we obtain a very good agreement between the observed frequencies and the expected frequencies by the asymptotic theory. The next step to achieve a deeper analysis of the solar-like oscillations in μ Her is a multi-site campaign. It will help to know the inner properties and to better understand the physical processes that are still not well defined.

3. Comparison with β Hydri

For the G2 IV Subgiant star β Hydri (Bedding et al. 2007) asteroseismic observations have provided constraints to the evolutionary mod-

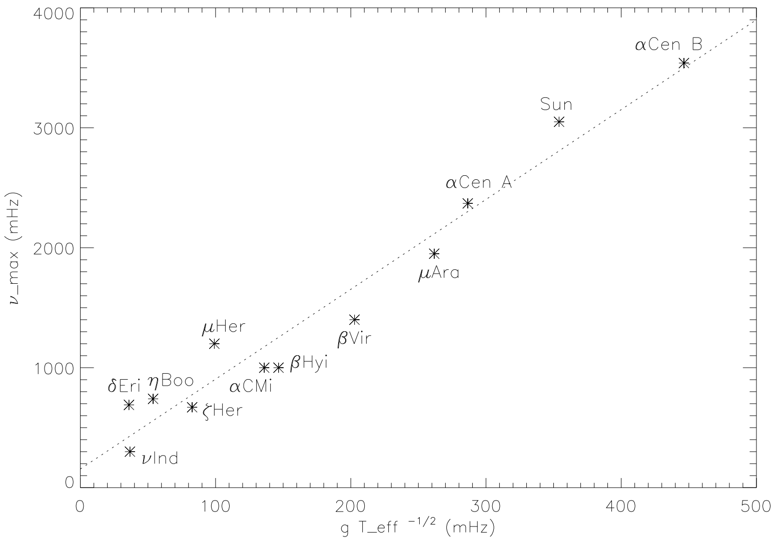

Fig. 4. Observed frequency of maximum power, ν_{max}, versus the ratio $g \cdot T_{eff}^{-1/2}$. The stars μ Her and α CMi (Claudi et al. , 2005) are asteroseismological targets of SARG.

els (Fernandes & Monteiro , 2003). This star is quite similar to μ Her, being in the same evolutionary phase, with a slightly greater mass. Recent interferometric observations provide a very good measurement of β Hyi radius (North et al. , 2007). This allow them, using the uncertainties of the parameters, to built a $\log \frac{L}{L_\odot}$ versus $\log T_{eff}$ diagram, where the location of β Hyi is well defined. We try to reproduce the same kind of plot for μ Her, taking values from Fuhrmann (1998), together with β Hyi estimates. It is clear from Figure 3 that μ Her values are affected by greater uncertainties. The most problematic question concerns the radius of μ Her, which has an uncertainty that goes beyond the limits of the plot (we give only the mean value). Interferometric observations are then required to obtain accurate measurements of μ Her properties like radius and so the mass. The avoided crossing phenomenon (Aizenman et al. , 1977) is clearly visible in β Hyi echelle diagram (Bedding et al. , 2007), where some frequencies depart from the asymptotic prediction. This feature, characteristic for the evolved stars, is not present in our echelle diagram for μ Her.

4. Confirmation of the theory

Asteroseismology has demonstrate its diagnostic power in the last years. The asteroseismological observations performed until now have shown a very good agreement with the theoretical expectations suggested by Kjeldsen & Bedding (1995). The maximum peak in the PS is proportional to the product $g \cdot T_{eff}^{-1/2}$. Figure 4 shows the actual linear correlation between the measured ν_{max} and the expected. A better estimate of ν_{max} is provided by :

$$\nu_{max} = \frac{M/M_\odot}{(R/R_\odot)^2 (T_{eff}/T_{eff\odot})^{1/2}} \nu_{max\odot} \qquad (2)$$

(Kjeldsen & Bedding 1995), being $\nu_{max\odot} = 3.05$ mHz, which provide the plot in Figure 5. The straight line has a slope equal to one.

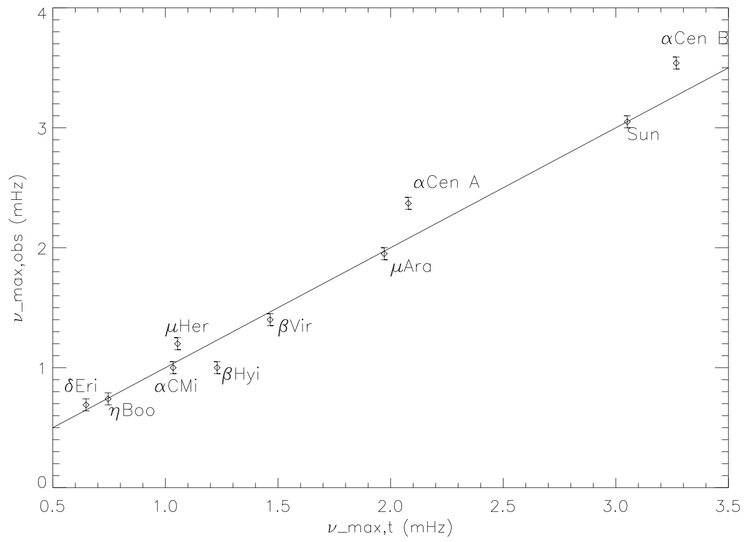

Fig. 5. Observed ν_{max} versus the predicted value.

5. Conclusions

To confirm the detection of the solar-like pulsations in μ Her will be necessary multisite coordinate observations. Furthermore, lower errors acquired with interferometric technique in stellar radius measurements, together with the astereosismic determination of the average stellar density allow a very accurate measurement of the stellar mass. Such a finest determination of stellar parameters could put tight experimental constraints on theoretical evolutionary model for μ Her.

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