Evolutionary states of red giant stars

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Introduction

From its surface properties it can be difficult to determine whether a red-giant star is in its Helium-core-burning phase or only burning Hydrogen in a shell around an inert Helium core. Stars in either of these stage can have similar effective temperatures, radii and hence luminosities, i.e. they can be located at the same position in the Hertzsprung-Russell diagram.
Bedding et al. (2011) showed that with asteroseismic information from the stellar structure it is however possible to identify the evolutionary state of a red giant. For this technique one relies on the detection of the frequencies of mixed pressure-gravity modes. Resolving individual mixed modes is not always feasible in shorter timeseries data such as those of the K2 (Haas et al. 2014) and TESS (Ricker et al. 2015) missions.
Here we present two methods that do not rely on the detection of the individual mixed modes. These methods have been applied together with the methods by Kallinger et al. (2012) and Mosser et al. (2014) to the APOKASC stars (Pinsonnault et al. in prep; Elsworth et al. in prep) to provide consolidated evolutionary phases.

Method GBM

Within the asteroseismology community there is a general thought that for grid-based modelling (GBM) applied to red-giant stars it is important to know a priori the evolutionary phase, i.e., red-giant branch (RGB) or He-core burning phase, to avoid biases in the resulting stellar parameters, i.e., mass, radius etc. Here we follow this reasoning in the opposite direction and seek to answer the question **whether it is possible to determine the evolutionary phases of red-giant stars from grid-based modelling** using as input $\Delta\nu$ (large frequency spacing between oscillation modes of the same degree and consecutive orders), ν_{max} (frequency of maximum oscillation power), T_{eff} (effective temperature) and [Fe/H] (metallicity). In other words we want to **determine whether or not it is possible to find loci in this four dimensional space where RGB or He-core burning stars are uniquely defined, thereby allowing us to provide a reliable identification of the evolutionary phase**.

To achieve this we develop a support vector machine that we train in T_{eff}, $\Delta\nu/\nu_{max}$ and [Fe/H] space (see Fig. 1). For models of $0.75 \leq M \leq 1.75\ M_{\odot}$ we can show that the RGB and He-core burning are indeed uniquely defined, i.e., we find a training error of 0 in the ideal case without uncertainties. This cannot be achieved when treating $\Delta\nu$ and ν_{max} as separate parameters.

A preliminary estimate for the success rate of this method is of the order of 80 – 90%. As this method is applicable to relatively short asteroseismic timeseries, i.e., 30-80 days as obtained with the TESS and K2 missions for which only $\Delta\nu$ and ν_{max} can be extracted, this can be of significant added value.

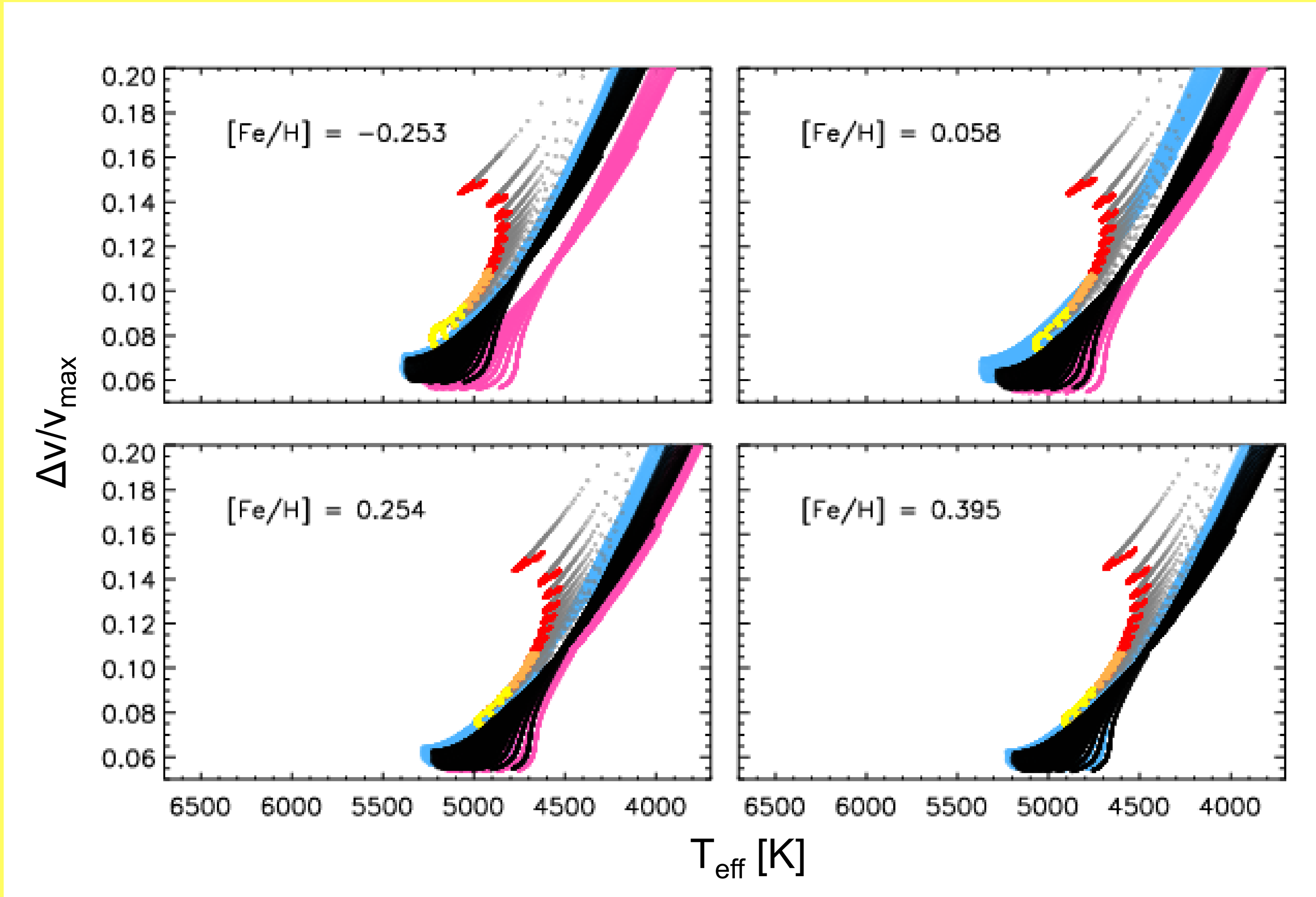

Figure 1: $\Delta\nu/\nu_{max}$ as a function of T_{eff} for different [Fe/H] values. RGB models are shown in black. He-core burning stars with He-core mass fraction > 0.1 are indicated in red, orange and yellow for models with masses < 1.5 $M_{\odot}$, masses between 1.5 and 2.0 $M_{\odot}$, and masses between 2.0 and 2.5 $M_{\odot}$, respectively. He-core burning stars with He-core mass fraction between 0.0 and 0.1 are shown in gray. The models in light blue (pink) indicate RGB models with lower (higher) metallicities in the grid.

Method morphology

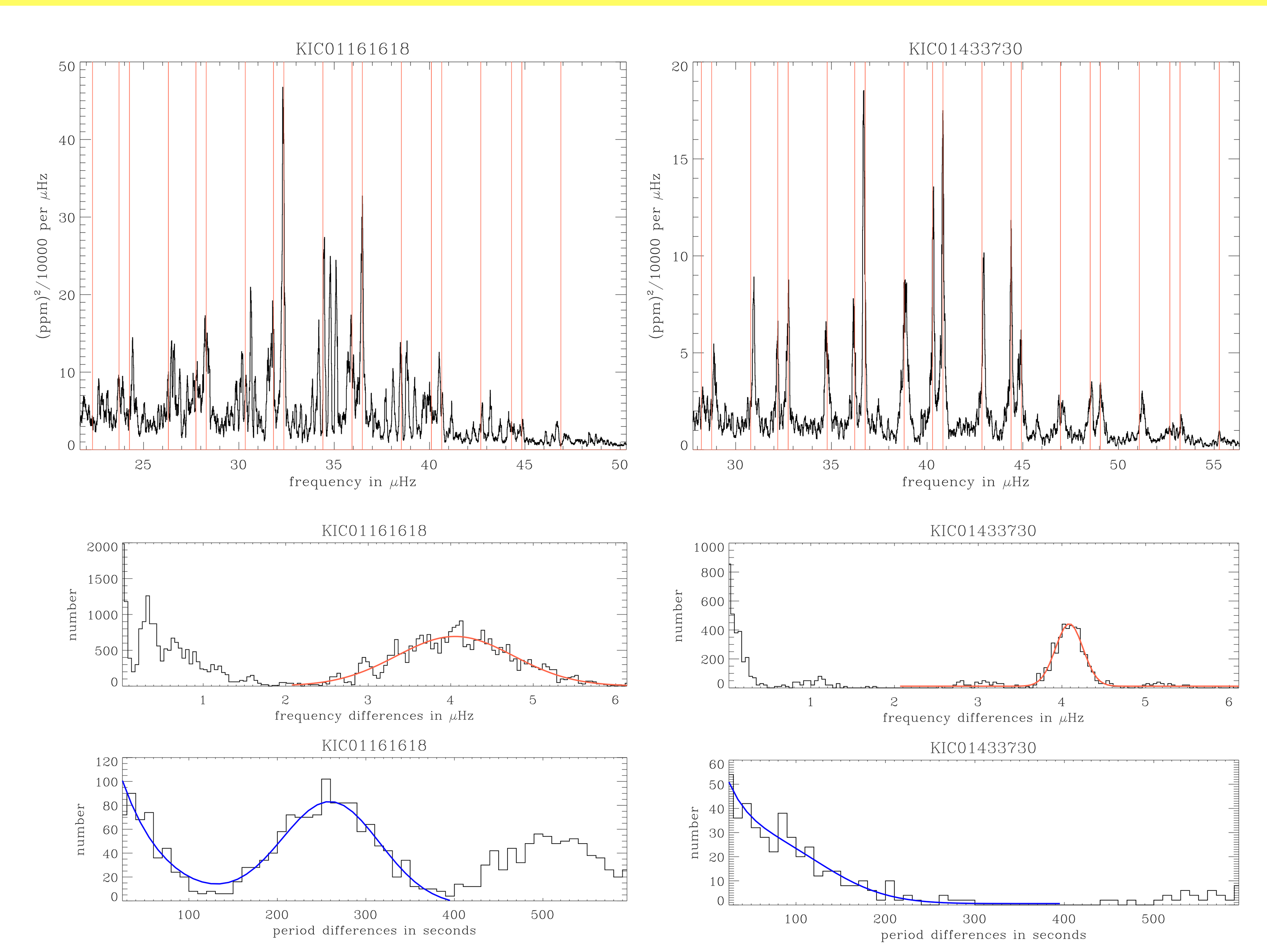

Figure 2: comparison of morphology of a red-clump star (KIC01161618, left) and a red-giant-branch star (KIC01433730, right). Top panels: smoothed spectrum (in black) and the aligned Universal Pattern (in red). Middle panels: histogram of the frequency differences between any one feature and all others. A Gaussian fit to the data in the vicinity of $\Delta\nu$ is shown in red. Bottom panels: histogram of the period differences between any one feature and all others. A multi-component fit is shown in blue.

With the help of the Universal Pattern (Mosser et al. 2011), we can divide the Fourier power spectrum into two zones, one of which contains the even-degree modes and the other the odd-degree modes. In each zone, we use statistical tests on the unsmoothed spectrum to pick out significant spikes. The significance threshold is set so as to exclude almost all the background noise, but to pick up small features in the spectrum. This is a frequentist approach that makes no assumptions about what will be present in the data. The result of the test is a set of frequencies at which spikes have been found.

If there were n features identified from the statistical tests there would be n(n-1) frequency differences. A histogram is formed from these frequency differences, which provides the number of occurrences of frequency differences. The features to be found in these histograms carry information about the features in the power spectrum.

The histogram of the frequency differences for the odd-degree zone shows the large frequency separation with features that are a consequence of the presence of mixed modes. In the central panels of Fig. 2 we show the frequency-difference histograms for the stars in the top panels of Fig. 2. **It is apparent that the width of the feature at a difference corresponding to $\Delta\nu$ is very different for the two stars.** A Gaussian function is fitted to the data around the initial value of $\Delta\nu$ in order to quantify the width of the distribution and is shown as the red line in the figures.
We divide the width of the Gaussian by the $\Delta\nu$ value for the star to produce a scaled frequency difference. For the whole cohort of stars considered here, we show this parameter as a function of ν_{max} in Fig. 3.

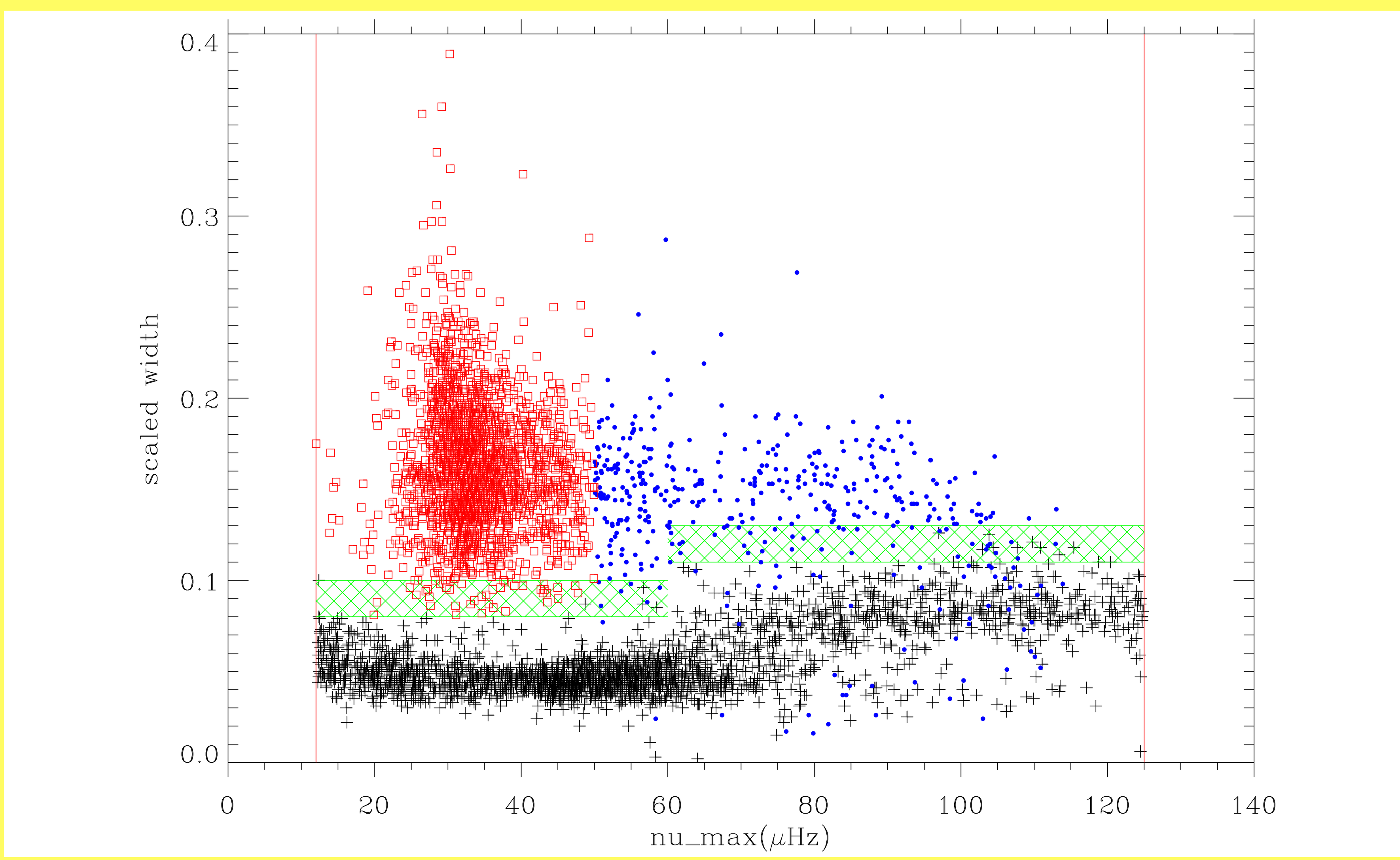

Figure 3 (on the right): scaled width of the odd-mode frequency differences, i.e. width of Gaussian fit shown in the central panels of Fig. 2 divided by $\Delta\nu$, as a function of ν_{max}. This provides the evolutionary categorisation of individual stars based on the morphology in the power spectrum where black is RGB, red is red clump and blue is secondary clump. The ambiguous zone is shown cross hatched in green.

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