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Supporting Online Material for

Kepler-Detected Gravity-Mode Period Spacings in a Red Giant Star

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This PDF file includes:

Supporting On-line Material

Material and Methods

- Data treatment

For this analysis, we used 320 days of consecutive measurements in the long-cadence mode (one measurement every ~30 minutes) obtained with the Kepler satellite (*S1*). The photometric band-pass is roughly equivalent to a very broad combination of the V- and R-bands of the Johnson system. We computed the Fourier-transform of these photometric time series and extracted the mode information from fitting Lorentzian profiles to the power spectrum, as described in the next section.

- Extraction of mode parameters and mode identification

Solar-like oscillations are stochastically driven by convective motions and are therefore constantly damped and re-excited. This leads to a finite lifetime of the peaks, and a broadening of the mode in the power spectrum. To extract the mode parameters, we fit a series of Lorentzian profiles

$$P_{(\nu)} = \sum_{n=1}^{M} \left(\frac{H_n}{1 + \left(\frac{2(\nu - \nu_n)}{\Gamma_n} \right)^2} \right) + B$$

to the modes in a given frequency range, where H_n is the height in power of the Lorentzian profile, ν_n is the oscillation frequency of the mode, and Γ_n is the mode line-width. The granulation background B has been treated as constant white noise in this analysis, as its variation over the inspected frequency range is negligible. The line-width Γ_n is inversely proportional to the mode lifetime. This procedure was followed in the current analysis for individual and multiple peaks.

For a seismic analysis to be successful, knowledge of the spherical degree ℓ of a mode is mandatory. In the case of solar-like oscillations, this can be derived from a so-called échelle diagram. For pure short-lived acoustic modes, the frequency spectrum is very regular and well understood in terms of the so-called large separation $\Delta\nu$, which represents the approximate scale of the comb-like structure (*S2,S3*). When plotting the power spectrum folded with the large separation, the mode degree is derived from the frequency separations of the ridges.

For KIC 6928997, the comb-like structure has a characteristic spacing of $\Delta\nu$=10.05±0.09μHz and is centered on the frequency ν_{max}=120±1μHz. In the échelle diagram, the modes of degree ℓ=1 do not follow the comb-like pattern of acoustic modes, but we clearly see the fine structure of these modes ℓ=1 (Fig. S1).

We determined the mean width of the three center dipole modes with the highest signal-to-noise ratios to be 0.056 μHz, which translates into a mean lifetime of about 65 days. This value is larger than the mean lifetime of 35 days we find for the pure acoustic radial modes (ℓ=0). This is consistent with the ℓ=1 modes being mixed, as a higher mode inertia leads to longer lifetimes. We further find that the mode lifetimes of the dipole modes increase towards the wings of the dipole fine structure in agreement with the modes having increased g-mode content. The current dataset implies a limit of detectable lifetimes well below 100 days.

- Comparison with model spacings

Theoretical period separations were computed for a representative stellar model (1.5 Msol, 2.44 Gyr and solar metallicity). To correct for the small systematic offset introduced by surface effects, the model frequencies were shifted by 3 μHz (*S4*). Note that for this model only modes with a period spacing below the maximum value of about 70 seconds (cf. Fig. 1 C) are expected to have observable amplitudes.

Figure S2 shows the square root of the energy density normalized at the surface of three consecutive mixed modes distributed over the dipole fine structure. Starting from the center of the structure at 117.7 μHz towards lower frequencies, the changing color from yellow to red illustrates the effect of the varying level of importance of the acoustic versus gravity nature of the modes.

The mode at 112.3 μHz (shown in gray) has considerable energy in the core and is not observable, while the mode at 117.7 μHz has only a small amplitude in the core and predominately a p-mode character. These functions are contrasted with the eigenfunction of a pure acoustic radial mode (ℓ=0, dashed blue line) at 112.9 μHz, which has no energy in the core.

Supplementary Figures

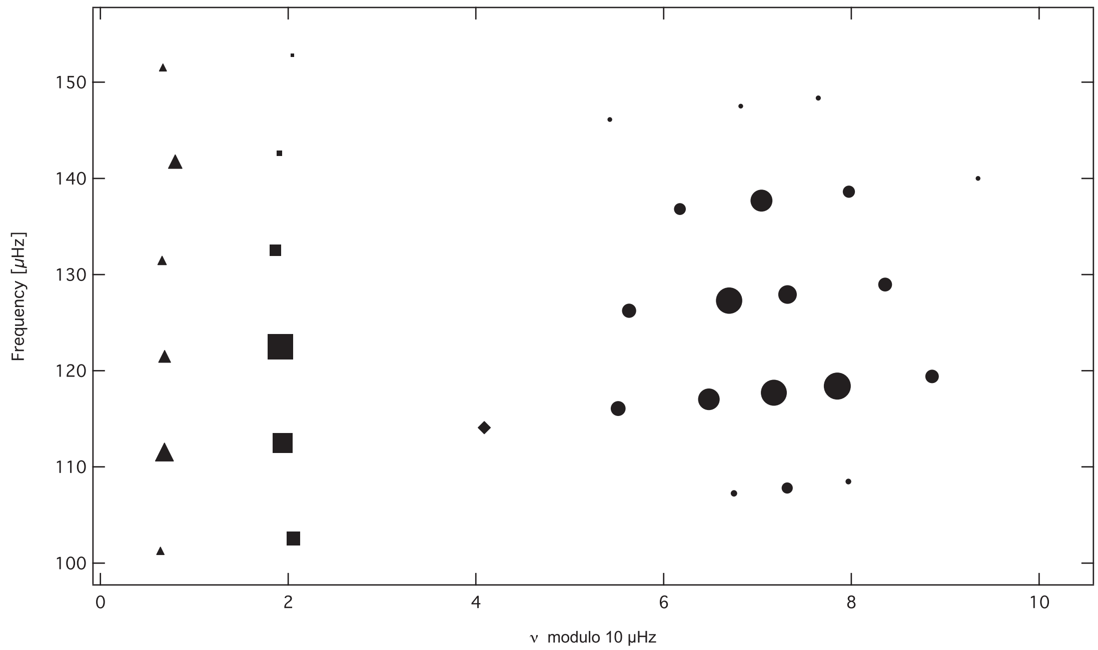

Fig. S1. The échelle diagram for KIC 6928997. The size of the symbols corresponds to the height of the individual modes in the power spectrum. Modes of the degree ℓ=0, ℓ=1, ℓ=2 and ℓ=3 are marked by squares, circles, triangles and a diamond, respectively.

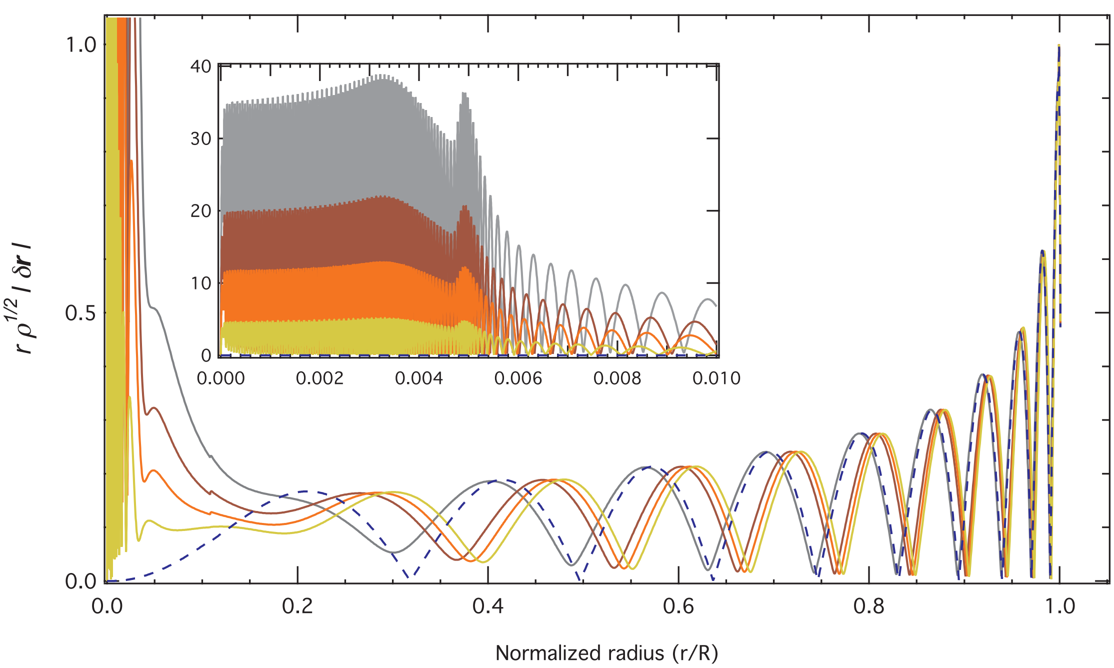

Fig. S2. Theoretical eigenfunctions with frequencies around 117μHz in KIC 6928997, normalized at the surface, for dipole modes (yellow, orange, red) and a radial mode (blue). The predominant g-mode is marked in gray. See section 'Material and Methods' for a detailed explanation.

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