Tidal Effects and Heartbeat Stars

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Heartbeat Light Curves

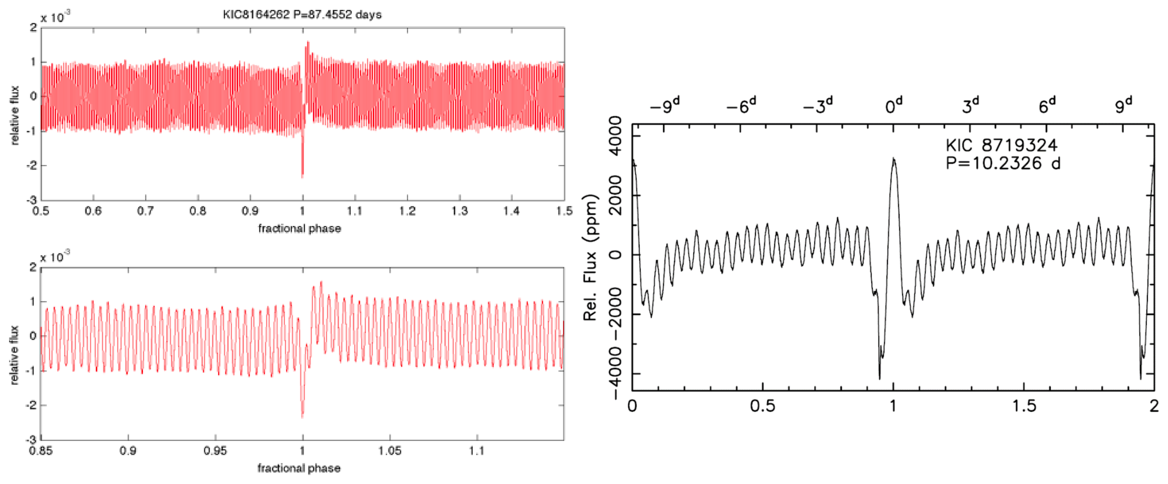

Figure 1: Folded light curves of two exemplary heartbeat stars. The distortion around $\phi = 1$ is due to reflection and tidal distortion effects near periastron. The continued "ringing" away from periastron is caused by tidally excited g-modes.

Mode Excitation

Heartbeat stars often continue to "ring" even away from periastron due to the tidal excitation of g-modes within the stars. However, the largest amplitude modes are difficult to explain with conventional tidal theory. Additional physics are required!

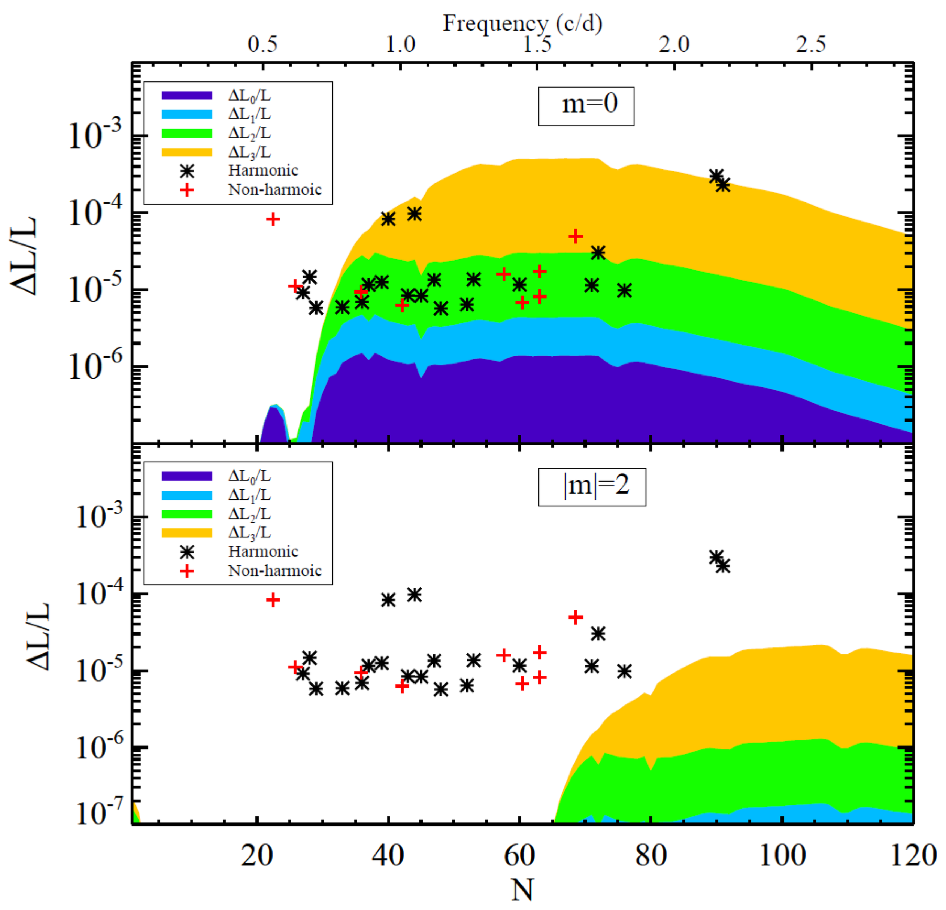

Figure 2: Luminosity fluctuations as a function of orbital harmonic N=ω/Ω for KOI-54. The points show the observed fluctuations, while the shaded regions represent the probability of each harmonic N having an amplitude in that range. For example, the yellow $\Delta L_3/L$ region indicates that observed pulsations in this range have amplitudes 2-3 σ above the expected amplitude. The N=90 and 91 modes are roughly 3-σ outliers, meaning that these modes should only be excited to this amplitude by chance 0.13% of the time. We conclude that these modes are probably not excited purely by chance, and that additional effects (see right poster column) are likely involved in mode excitation.

Abstract

The evolution of eccentric binary star systems is strongly influenced by stellar tidal processes, which remain poorly understood. Kepler is revolutionizing the study of tidal interactions by allowing for the direct observation of tidally excited stellar oscillations, which typically produce luminosity variations of $\Delta L/L \leq$ mmag with periods of several hours. These tidal effects are most pronounced in the growing class of eccentric binaries known as heartbeat stars, of which more than one hundred such systems have been identified in Kepler data. Some heartbeat stars appear to show evidence for complex tidal processes such as resonance locking and non-linear mode coupling. Under the right circumstances, these processes can greatly decrease tidal dissipation time scales in eccentric binaries. We develop techniques to determine which systems are likely to be involved in resonance locking and/or non-linear mode coupling, and we present results for a few interesting systems.

Make Your Own Heartbeat!

What would KOI-54 look like from a different angle? Use the program below to find out! Click and hold the right mouse button in the upper panel to drag the camera to a new position. Hold the control key and drag the left mouse button to zoom in and out of either panel.

Non-linear Effects

Many heartbeat stars exhibit signatures of non-linear mode coupling, which causes oscillation modes to interact with one another. Such interactions may enhance the visibilities of some modes while suppressing the visibilities of others. Non-linear effects can also increase the effective damping rates of tidally excited modes, causing enhanced tidal dissipation.

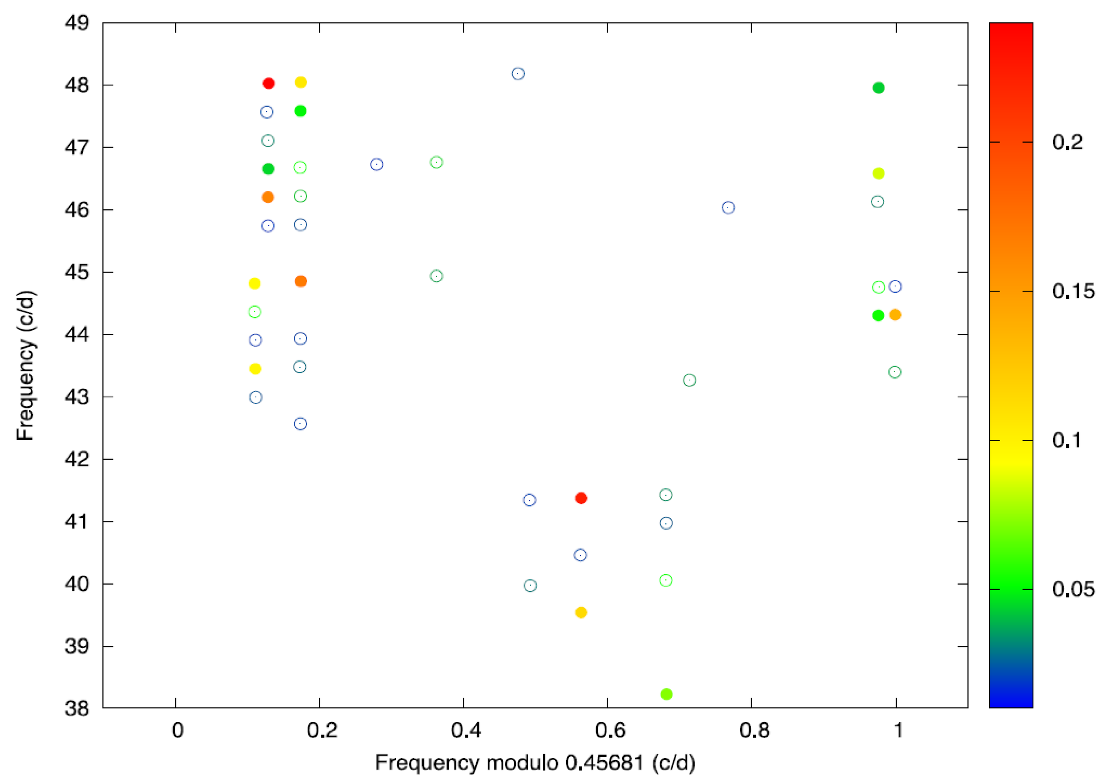

Figure 3: Observed p-mode frequencies in KIC 4544587, with points colored based on their relative flux amplitudes (in units of 10^{-3}). The x-axis is the frequency modulo the orbital frequency of the system. The vertical columns result from modes whose frequencies are spaced by multiples of the orbital frequency. These spacings are indicative of non-linear coupling with tidally excited g-modes.

Resonance Locking

As the stellar structures and orbital motions of heartbeat stars evolve, the systems will pass through resonances in which a stellar g-mode frequency is an exact multiple of the orbital frequency. Under the right circumstances, the system may become trapped in the resonant configuration, causing the g-mode to be excited to large amplitudes. An observable signature of resonance locking is a tidally excited mode (with observed frequency equal to a multiple of the orbital frequency) whose amplitude is much larger than the other tidally excited g-modes.

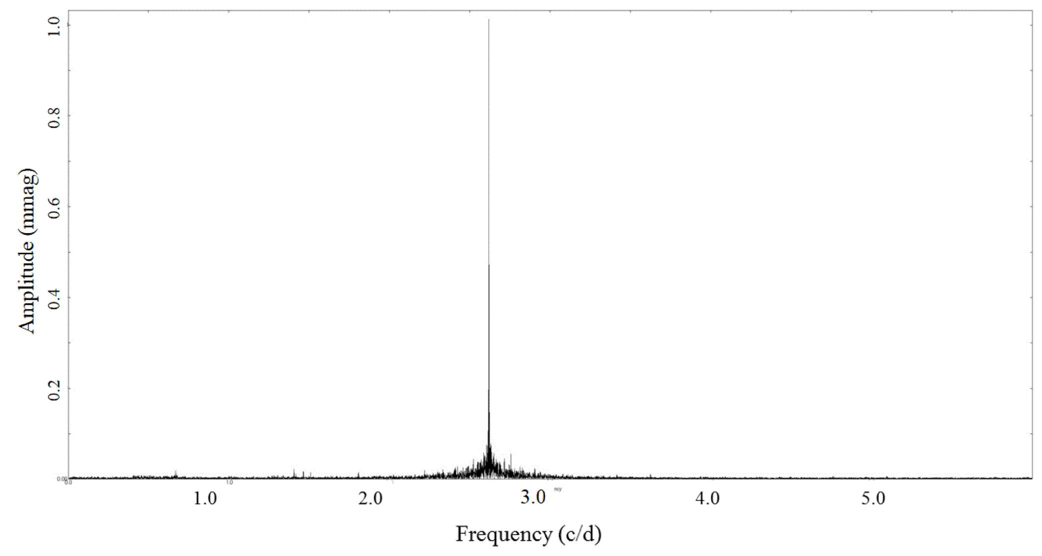

Figure 4: Power spectrum of KIC 8164262. The largest amplitude mode has a frequency of exactly $\omega = 229\Omega$. Its amplitude is over 30 times greater than any other tidally-exited g-mode, possibly indicating it is locked in resonance.