

Heartbeat Stars and the Ringing of Tidal Pulsations

Kelly Hambleton

Don Kurtz, Andrej Prša, Jim Fuller, Susan Thompson

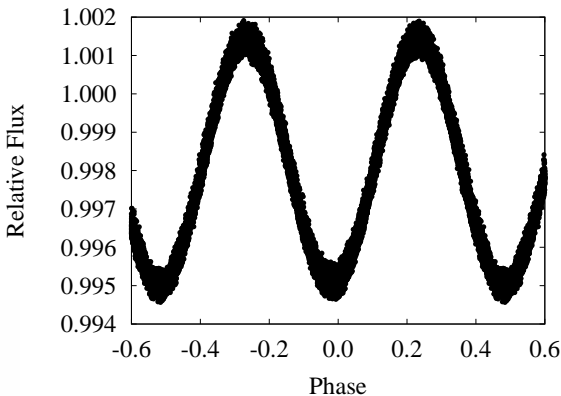
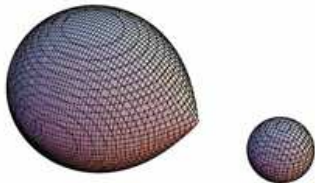
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July 10, 2014

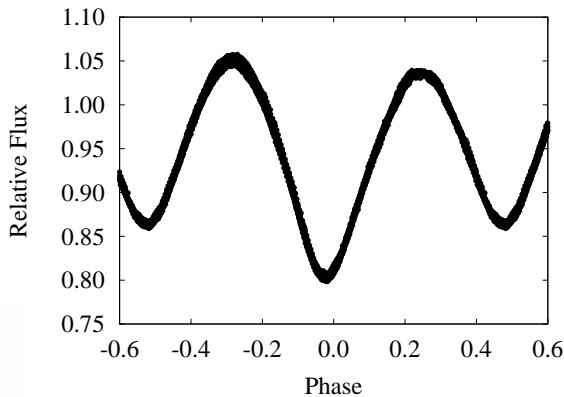
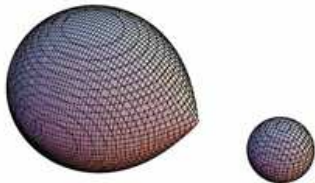
Ellipsoidal Variables

- Close binary stars
- Tidal Deformation
- Stellar rotation



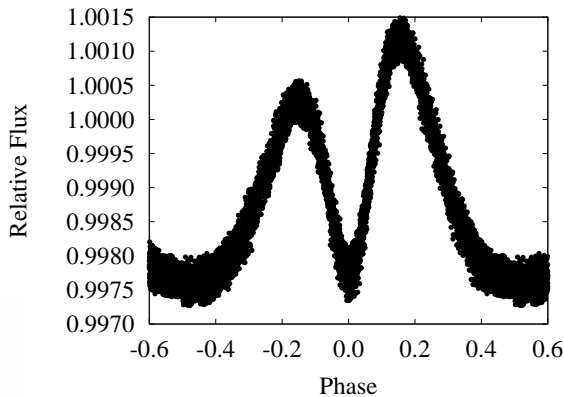
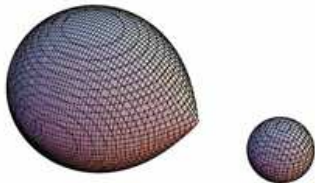
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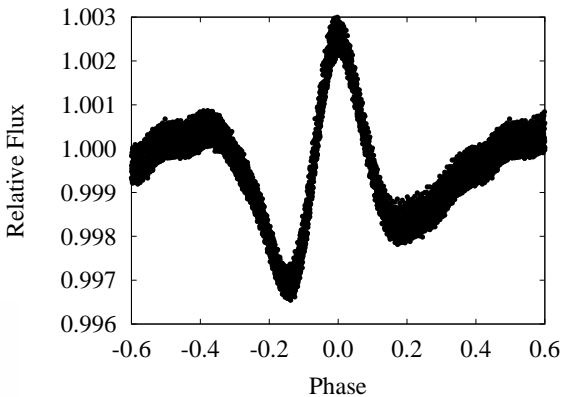
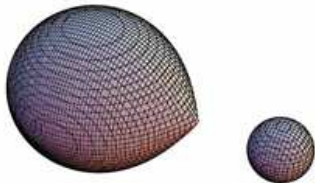
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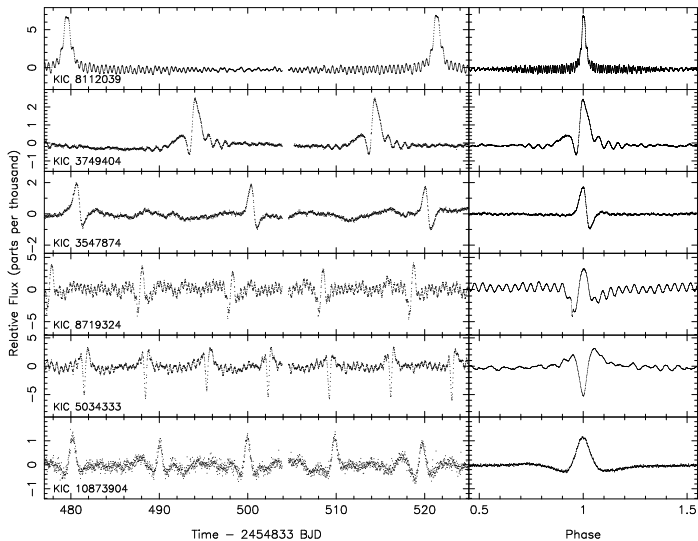


Ellipsoidal Variables

- Close binary stars
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Heartbeat Stars



SUSAN THOMPSON

Kelly Hambleton (UCLan)

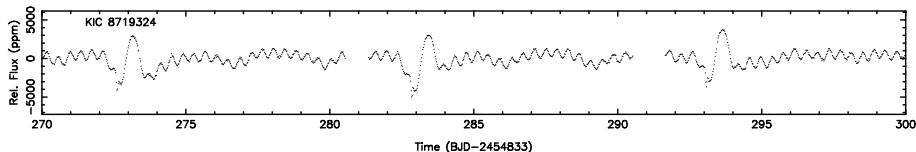
Heartbeat Stars

July 10, 2014

6 / 20

Tidally Induced Pulsations

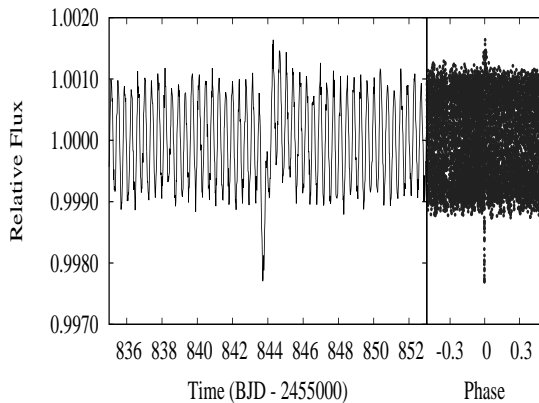
- Integer multiples of ν_{orb}
- $l=2$, $m = +2, 0, -2$
- Phase with the light curve
- Hypothesized by Zhan and Kumar - dynamical tide
- Amplitudes
- Phase dictated by azimuthal order



Resonance Locking

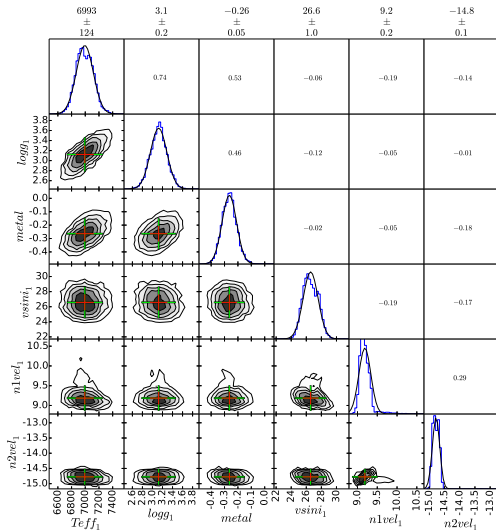
- Orbits evolve - exchange of angular momentum
- Stellar eigenfrequencies evolve as star spins faster
- Orbital period decreases as the orbit evolves
- Resonance locking:
 - 1 low frequency modes - travelling waves - damped
 - 2 high frequency modes - low mode energy
- KOI-54
- Another example coming up!

- A star and M dwarf
- $P = 87.4549(3) d$
- $e = 0.885(2)$
- $M_1 = 1.9(1) M_{\odot}$
- $M_2 = 0.21(7) M_{\odot}$
- $R_1 = 2.5(2) R_{\odot}$



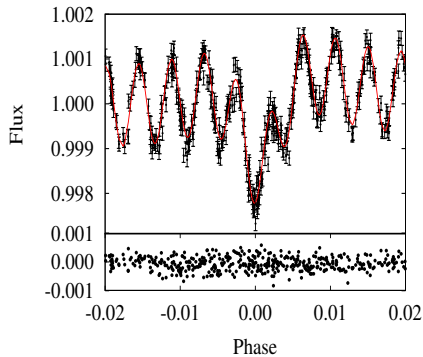
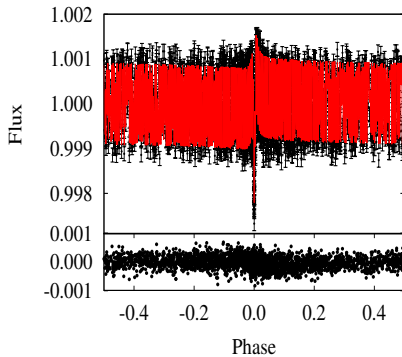
KIC 8164262: radial velocities

- 2 spectra - Kitt Peak
- TODCOR
- EMCEE: Markov chain Monte Carlo (MCMC)
- Grid of synthetic spectra
- Correlation coefficient
- Fundamental parameters and radial velocities simultaneously



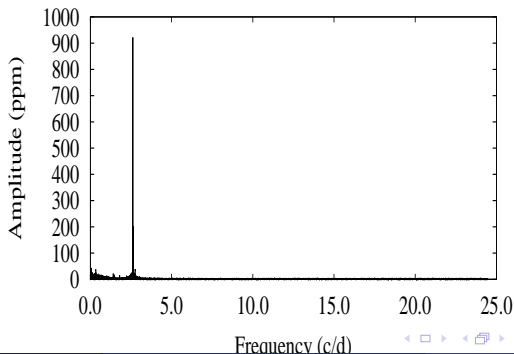
KIC 8164262: Model

- MCMC
- Pulsations, binarity and RVs modeled simultaneously
- Calculate phase shift, limb darkening and luminosity.



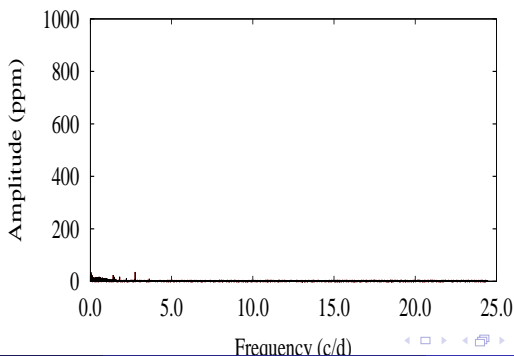
KIC 8164262: pulsations

- One prominent pulsation mode: $229 \times \nu_{orb}$
- Many modes at multiples of ν_{orb}
- Highest amplitude peak shows frequency modulation
- Independently determine the mass function
- Peaks indicative of rotation
- Suggests obliquity of $21 \pm 4^\circ$



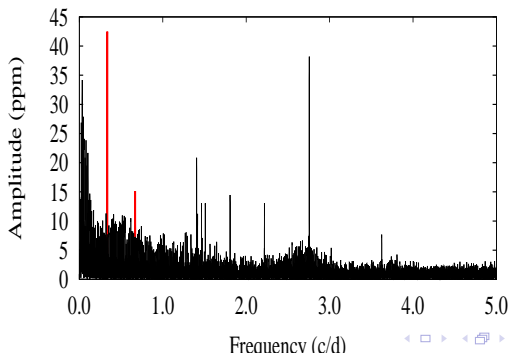
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- One prominent pulsation mode: $229 \times \nu_{orb}$
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- Peaks indicative of rotation
- Suggests differential rotation or obliquity of $21 \pm 4^\circ$

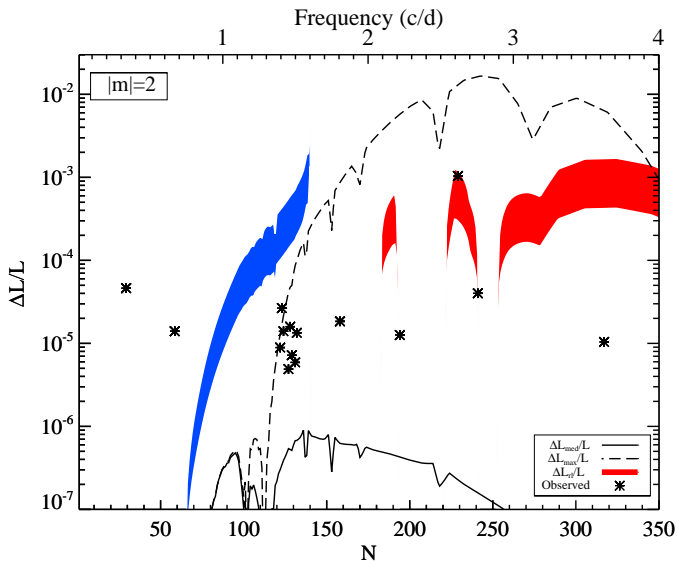


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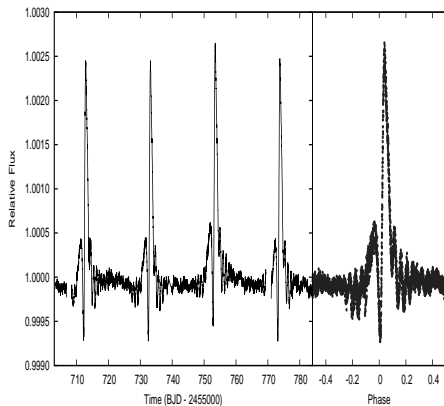
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KIC 8164262: resonance locking

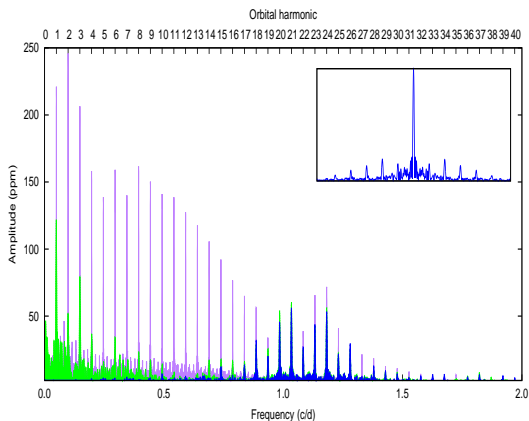


- All modes are tidally excited
- Tidal pulsations on the same time scale as orbital features
- Period = 20.30 d
- Late A and early F components
- highly eccentric
- Strong apsidal motion



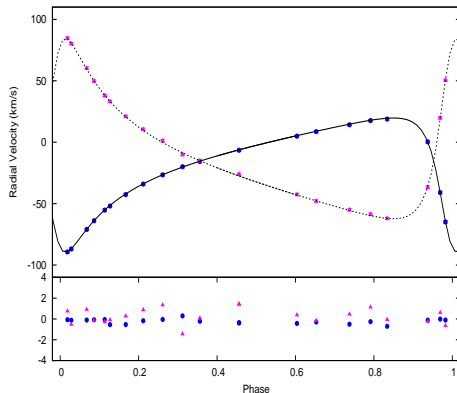
KIC 3749404: pulsations

- Fourier transform of residuals
- Low frequency peaks from binary features
- Second hump from pulsations
- All peaks are multiples of ν_{orb}

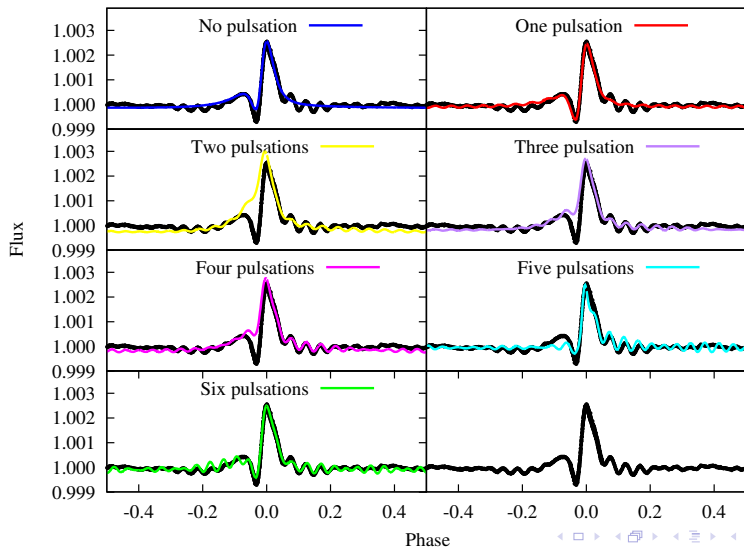


KIC 3749404: binary model

- Masses from RVs
- Temperatures from spectra
- Fit binarity and pulsations simultaneously
- MCMC



KIC 3749404: binary model



Heartbeat Stars

- Determine fundamental stellar parameters.
- Evidence suggests resonance locking causes high amplitude modes.
- Phases relative to periastron give information about the azimuthal order of a mode.
- Tidally induced modes appear to affect apsidal motion.
- Study orbital evolution and gravity darkening.