# Modelling Kepler Red Giants in Eclipsing Binaries

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# Introduction

Kepler offers a great opportunity to calibrate model parameters for evolved stars like red giants. Using Kepler, the group led by Li, Tanda introduced a new method for identifying the oscillation modes inside red giants. This asteroseismology allows for identifying the convective mixing-length parameter and the correlated surface parameters.

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6. The coefficients in the surface correction expression increase greatly with evolution due to growth of mode inertia

# Red Giants

Stars chosen for modeling were detached-companion eclipsing binaries

- Eclipsing binaries are easy to determine masses and radii
- Detached companions have reached neither Roche lobes and can be modeled as single stars
- Helium core and Hydrogen shell allow well-defined parameter tuning from asteroseismology
  - mixed p and g modes probe core properties
  - p mode probes convective shell
- Use mixing-length approximation to model convective shell

# Mixing Length

Mixing length is the distance traveled by a convective envelope before dispersing. We parameterize it as a ratio of the characteristic length to the scale height

$$\alpha \equiv l/H_p \tag{1}$$

This mainly correlates with the total radius and structure of the envelope in low-mass giants

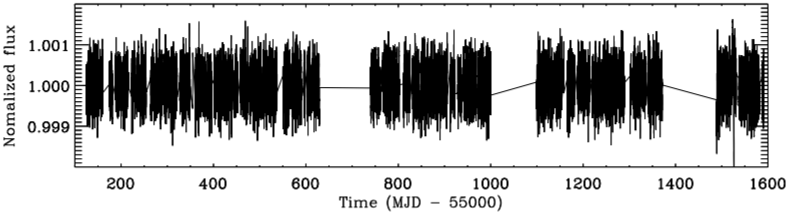
# Surface Term

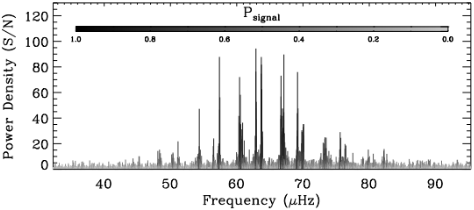
Poor modeling of near-surface layers causes discrepancies between models and observations. This is corrected via a 'surface term'

- Originally it was a ratio of interior structure parameters
- Turned into a power law
- Added proportionality to mode inertia $(\nu^{-1}/I, \nu^{3}/I)$
- Strongly correlated to surface properties.

Li et. al. therefore does not assume the solar surface term should be applied to other stars.

# Data




6 red giants with high S/N ratios were observed by Kepler over four years and were shown to have solar-like oscillations. Raw Kepler data was reduced and then combined into a power spectrum.

# Peak-Bagging

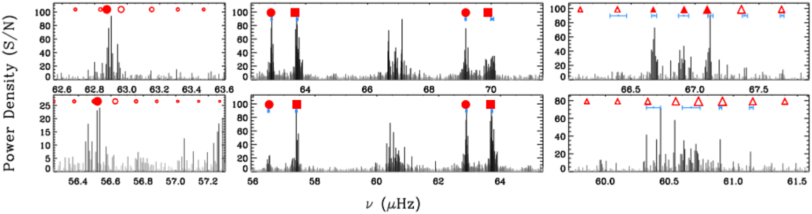
Mode frequency approximation

$$\nu_{nl} \approx \Delta\nu \left( n + \frac{l}{2} + \epsilon \right) - \delta_{nl} \tag{2}$$

- $l$ is mode degree
- $n$ is radial order
- $\epsilon$ is stellar surface feature parameter
- $\delta_{nl}$ is small separation

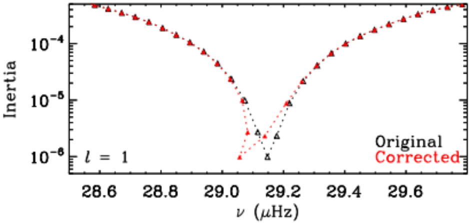
In the analysis, the modes $l = 0$ were determined to be radial nodes and $l = 1, 2$ were most p-like and $l = 1$ was individual mixed-mode

# Peak-Bagging Result



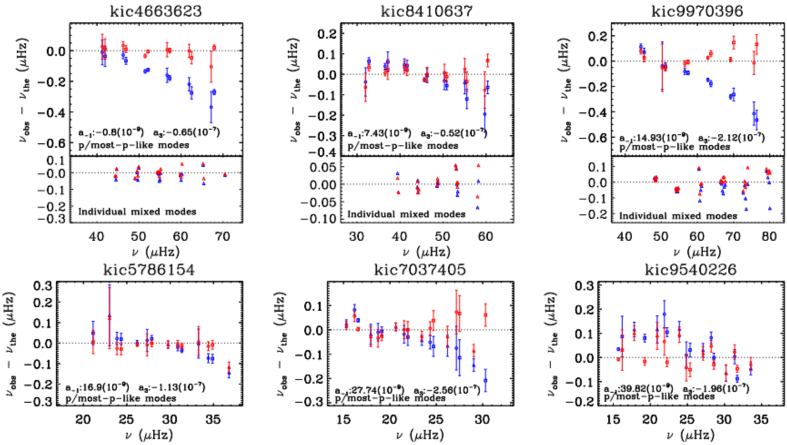

Red symbols show where certain modes would be in a best-fitting model of the spectrum. Left frame is primarily g-modes, middle is mixed modes, right is primarily p-modes.

# Effects of Surface Correction on Wave Modes

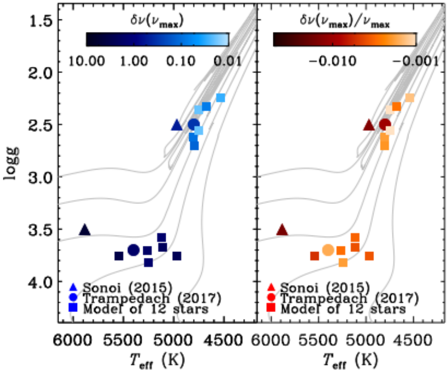



Correction for $l = 1$ mixed modes due to surface parameter.

# Surface Correction Effect

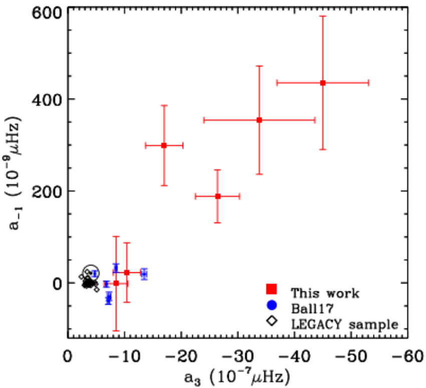


# Surface Correction Correlation




Surface correction is dependent on surface parameters like $T_{eff}$ and $\log g$.

# Surface Correction Coefficient Correlation




Linear correlation of $a_{-1}$ and $a_3$.

# Stellar Models

MESA models:

- $Y_0 = 0.249$
- $Y_{init} = Y_0 + \frac{\Delta Y}{\Delta Z} Z_{init}$
- $X + Y + Z = 1$

Overshoot mixing diffusion:

$$D_{OV} = D_{conv,0} \exp\left(\frac{-2z}{fH_p}\right)$$

Surface correction:

$$\delta_\nu = \frac{a_{-1}(\nu/\nu_{ac})^{-1} + a_3(\nu/\nu_{ac})^3}{I}$$

Acoustic cutoff:

$$\frac{\nu_{ac}}{\nu_{ac,\odot}} \approx \frac{g}{g_\odot}\left(\frac{T_{eff}}{T_{eff,\odot}}\right)^{-1/2}$$

# Model Parameters Results

| Star | $\alpha$ | $a_{-1}$ [$10^{-9}\mu$Hz] | $a_3$ [$10^{-7}\mu$Hz] |
|---|---|---|---|
| Sun | 1.92 | 1.73 | -2.25 |
| KIC 4663623 | 2.23±0.12 | 22.50±64.74 | -10.4±2.4 |
| KIC 5786154 | 2.29±0.10 | 298.9±87.0 | -16.9±3.3 |
| KIC 7037405 | 2.01±0.07 | 435.0±145.1 | -45.0±8.1 |
| KIC 8410637 | 2.25±0.10 | -1.6±102.7 | -8.5±2.1 |
| KIC 9540226 | 2.28±0.10 | 354.0±117.7 | -33.8±9.8 |
| KIC 9970396 | 2.21±0.23 | 188.3±57.5 | -26.4 ±3.9 |

Model parameters were fit with a (beautiful) bayesian analysis. The parameters determined are show clearly that the mixing length parameter is larger in these red giants than the sun and that the surface correction coefficients are not solar. This mixing length is also 16% higher than 3D hydrodynamical simulations.

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