Acoustic Glitches in 16 Cygni

(work in progress)

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July 18, 2013

Acoustic what?

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$$c^2 = \frac{\Gamma_1 P}{\rho}$$

Derivative wrt. acoustic depth

$$\frac{d \log c^2}{d\tau} = \frac{d \log \Gamma_1}{d\tau} + \frac{g}{c}\left[(\Gamma_1 - \gamma) + (\gamma - 1)\frac{\nabla}{\nabla_a}\right]$$

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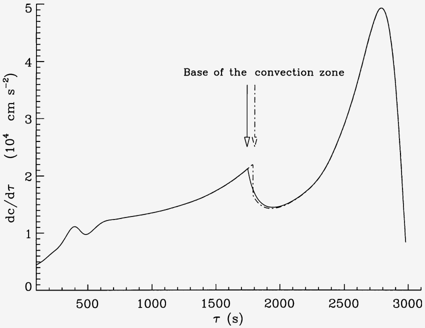

Monteiro & Thompson (2000)

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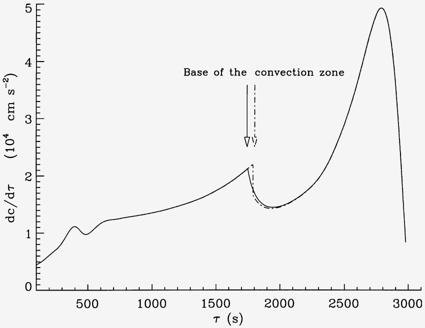

Monteiro & Thompson (2000)

- Base of the convection zone and second helium ionization region

Oscillatory signal

Each glitch causes a shift in the eigenfrequencies that is an oscillatory function of the frequency itself

- period: determined by acoustic depth of glitch
- amplitude: determined by "size" of glitch discontinuity

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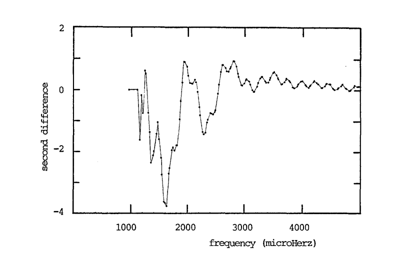
Signal will be present on frequencies and frequency combinations



Gough (1990)

$$\Delta_2\nu(n,\ell) = \nu(n-1,\ell) - 2\nu(n,\ell) + \nu(n+1,\ell)$$

How do we detect them?

Detection of the signal

- Need to fit an appropriate functional form...

$$\delta\nu \simeq \nu_{smooth} + \\ + A_{\text{BCZ}} \left(\frac{\nu_r}{\nu}\right)^2 \cos(4\pi\tau_{\text{BCZ}}\nu + 2\phi_{\text{BCZ}}) + \\ + A_{\text{HeIIZ}} \left(\frac{\nu_r}{\nu}\right) \sin^2(2\pi\beta_{\text{HeIIZ}}\nu) \cos(4\pi\tau_{\text{HeIIZ}}\nu + 2\phi_{\text{HeIIZ}})$$

$$\Delta_2\nu \simeq \sum_{k=0}^{3} c_k \nu^{-k} + \\ + \left(c_4/\nu^2\right) \sin\left(4\pi\nu\tau_{\text{BCZ}} + 2\phi_{\text{BCZ}}\right) + \\ + \left[c_5\, \nu\, \exp\left(-c_6\, \nu^2\right)\right] \sin\left(4\pi\nu\tau_{\text{HeIIZ}} + 2\phi_{\text{HeIIZ}}\right)$$

Detection of the signal

- ... to extract important parameters

$$\delta\nu \simeq \nu_{smooth} + $$
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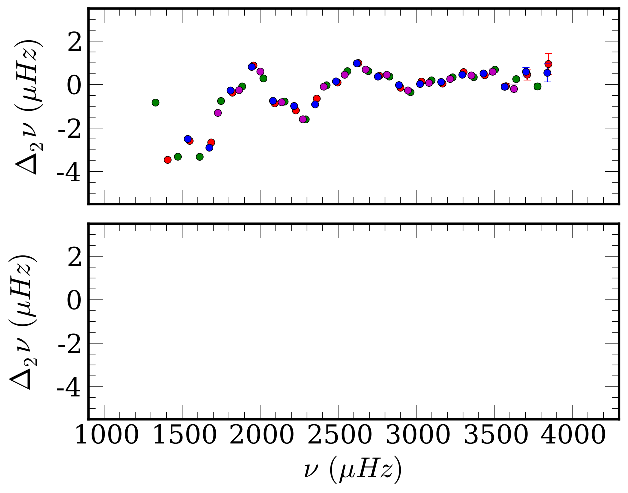
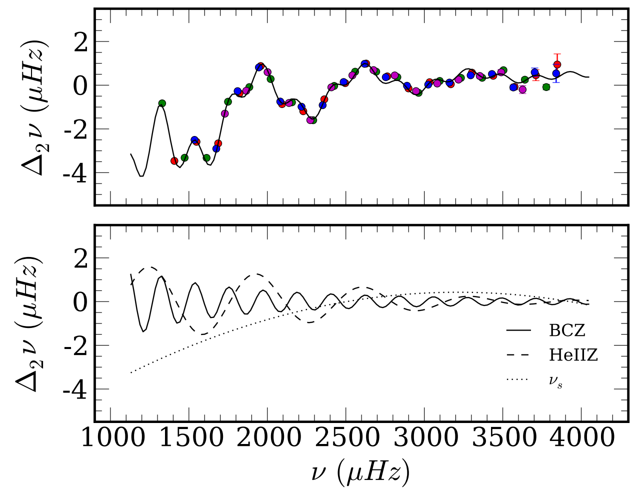


Detection of the signal



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Detection of the signal - improvements

- In the actual frequencies (Monteiro et al. 1994, Monteiro & Thompson 2000)
  - no assumptions on form of smooth component - difficult parameter λ ✗
  - can use every frequency
  - ~~may be less robust~~ global minimization (PIKAIA[1]) + IRLS ✓
  - BCZ and HeIIZ fitted ~~separately~~ together ✓
- In the second differences (Basu et al. 1994, Mazumdar & Antia 2001)
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  - increased errors
  - global minimization (PIKAIA) + IRLS ✓

[1] Charbonneau, P., 1995, ApJS, 101, 309

The data

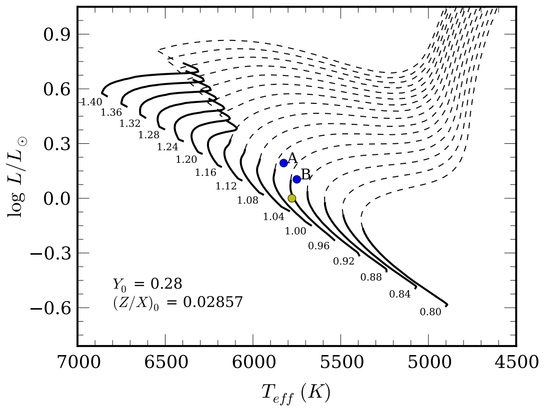
The 16 Cyg binary

- Evolved solar-type stars
- No dynamical masses
- On *Kepler* SC target list since Q7

$M_A \approx 1.11 M_\odot$
Age $\approx 6.9\,Gyr$

$M_B \approx 1.07 M_\odot$
Age $\approx 6.7\,Gyr$

Metcalfe et al. (2012)



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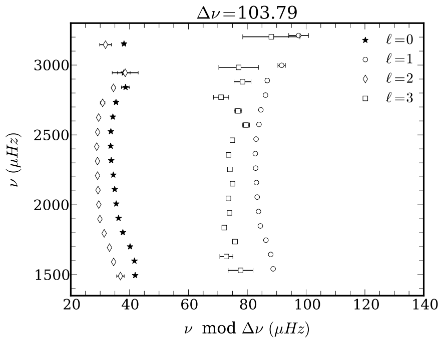
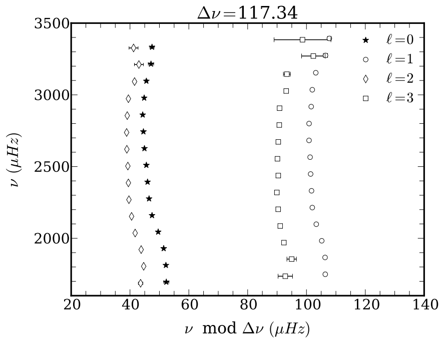


16 Cyg A

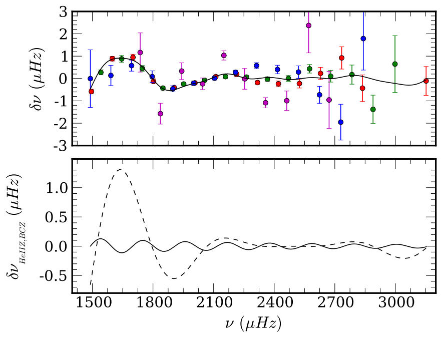


16 Cyg B

Results

Results - frequencies

- 9 months data from *Kepler*



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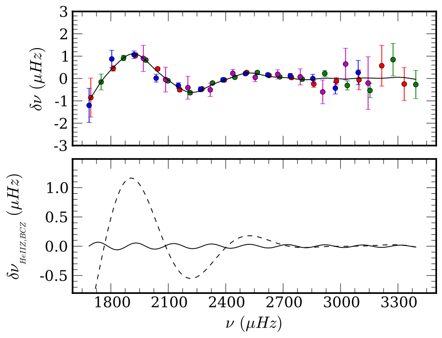
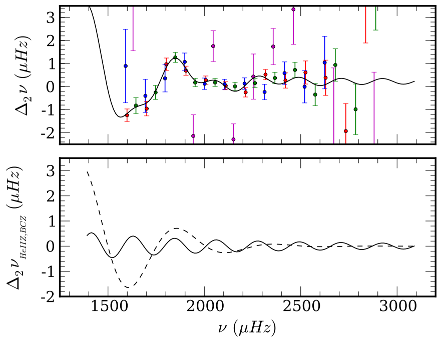


16 Cyg B

Results - second differences

- 9 months data from *Kepler*



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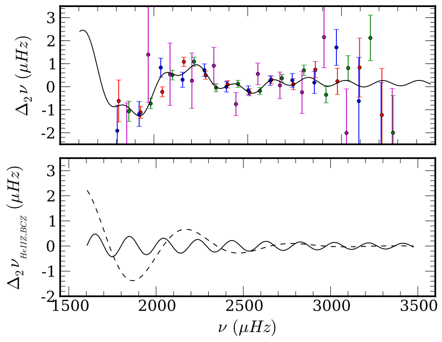


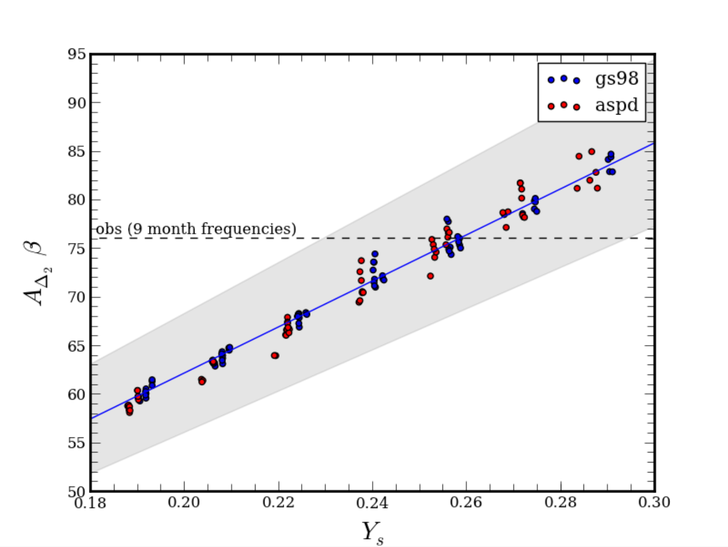
16 Cyg B

Results - comparison

	16 Cyg A		16 Cyg B	
	τ_{BCZ}	τ_{HeIIZ}	τ_{BCZ}	τ_{HeIIZ}
$\delta\nu$	2407.22 ± 133	915.03 ± 8	2577.48 ± 141	777.08 ± 16
$\Delta_2\nu$	2328.23 ± 249	967.38 ± 67	2511.74 ± 255	857.42 ± 35

Is this useful?

Results - Helium abundance (16 Cyg A)



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Thank you!