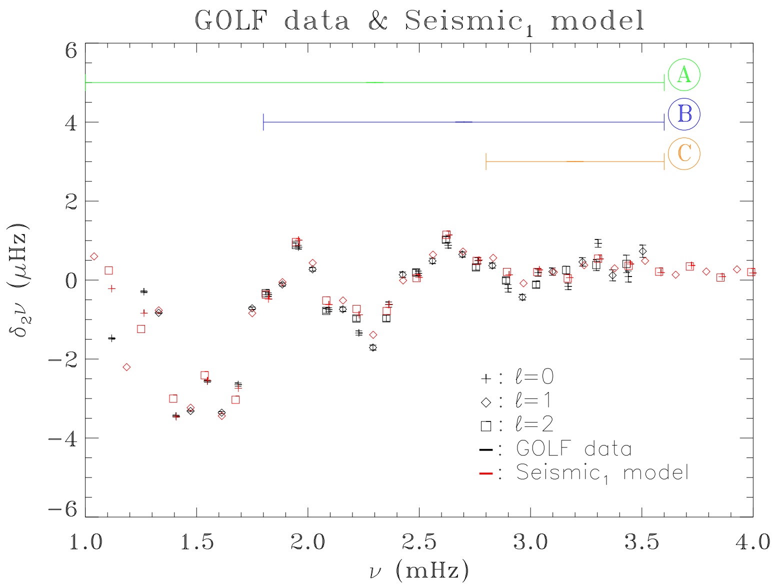
BCZ extraction: used method

- Sound-speed sudden variation (located at an acoustic depth τ_d) leads to oscillations in seismic observable parameters as

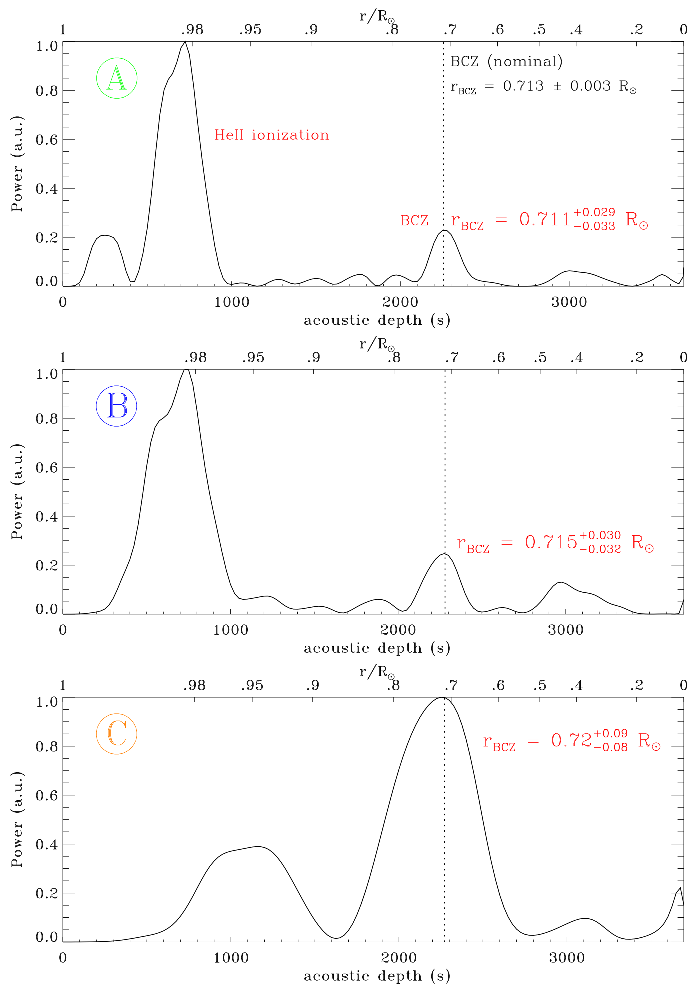
$$\propto \sin(2\tau_d\omega + \varphi)$$

- These oscillations can be found directly in the frequencies (Monteiro et al. 1994, 2000), large or second difference ($\Delta\nu$ & $\delta_2\nu$) (Gough 1990);
- The oscillation corresponding to the Base of the Convective Zone (BCZ) is found with a Fourier analysis (based on sine-wave fits) of the residue obtains by removing a smoothed curve to the choosen variable.
- $\delta_2\nu$ is noisier but the signal is larger too. In some cases (like the Sun) the expected signal-to-noise ratio in $\delta_2\nu$ is *not worse* than in the other magnitudes.
- Used $\delta_2\nu$ is robust, fast and easy to set up.

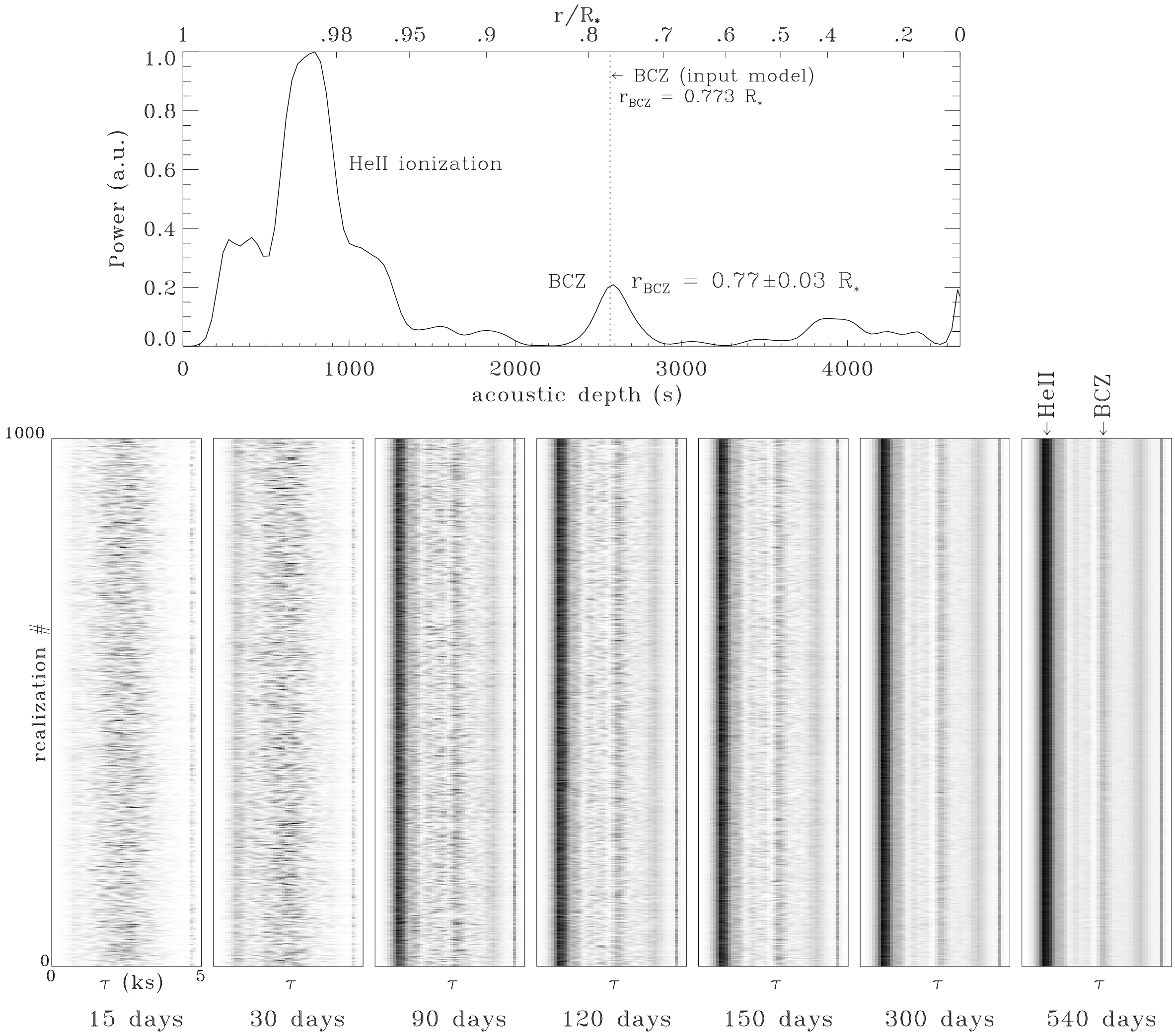
The Sun Case



Second difference for 5yr of GOLF data ($\ell < 3$) and Fourier analyses:



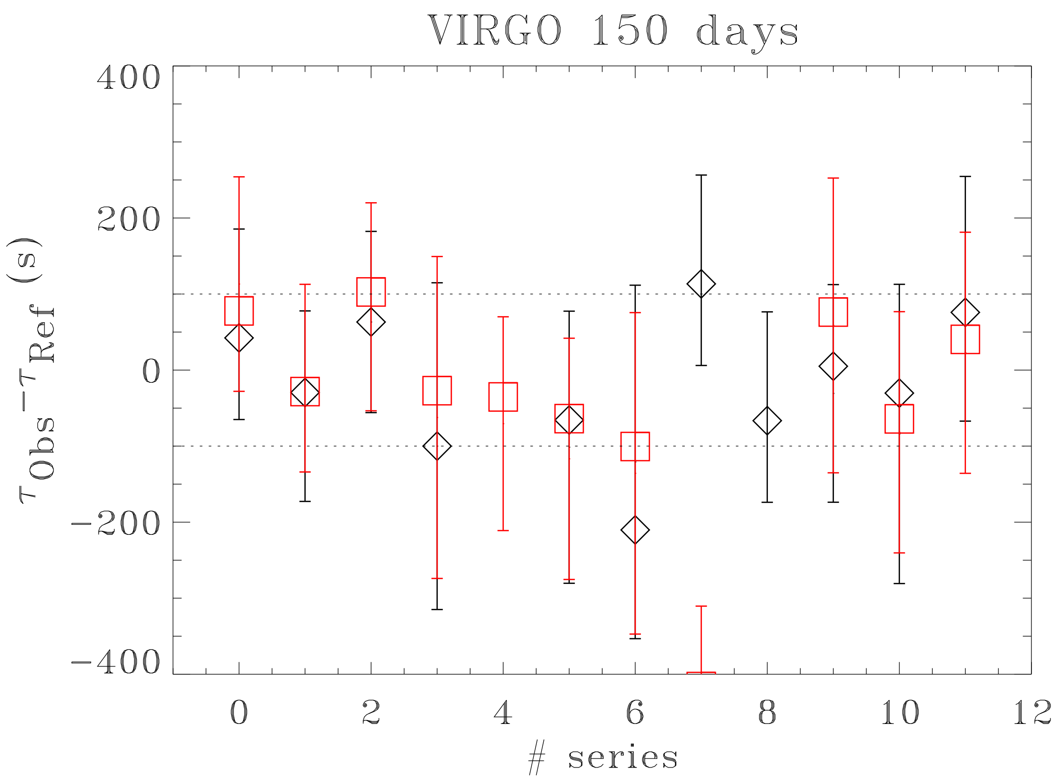
Simulated observations



- Eigenfrequencies from a model of α Cen A
- Monte-Carlo simulations of different observation lengths
- Error bars: $1/T_{\text{obs}}$
- 42 modes ($\ell = 0 - 2$) from 1.7 to 3.2 mHz
  - BCZ correctly derived:
    * 50% with 90 days
    * 75% with 120 days
    * 85% with 150 days

VIRGO 150 days

- 12 sets of 3-months solar data
- BCZ extraction with this method $\Rightarrow$ 8 cases out of 12 correctly derived
- Bad cases due to stochastic excitation



HD 45067: $\delta_2\nu$ analysis

- A smooth component is removed

  $\rightarrow$ linear fit $a_0 + a_1\omega + \frac{a_2}{\omega^2}$ (Basu, 1997)

- Different Fourier analyses are done

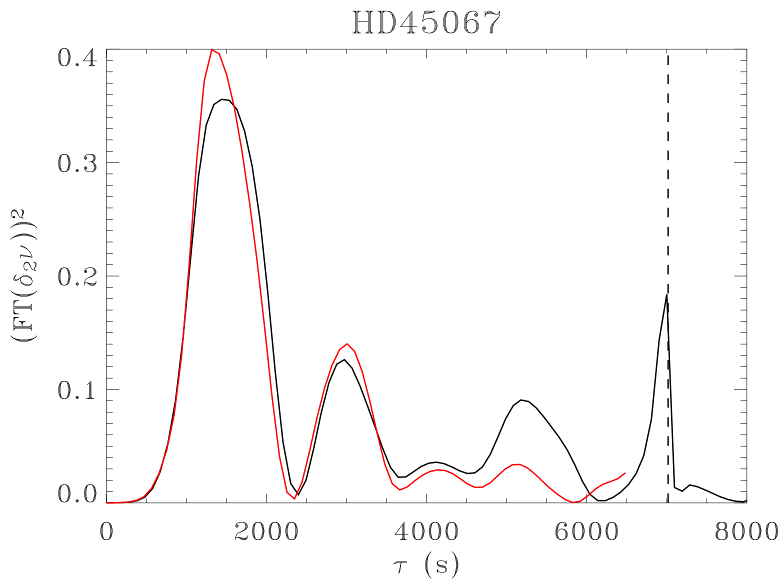
  $\rightarrow$ using only $\ell = 0, 1$ or $\ell = 0, 1, 2$

  $\rightarrow$ and using different frequency ranges

$\nu \in [0.8; 1.3]$ mHz

$\ell = 0, 1, 2$: Black line; $\ell = 0, 1$: Red line

dotted line: $\frac{1}{<2\Delta\nu>}$



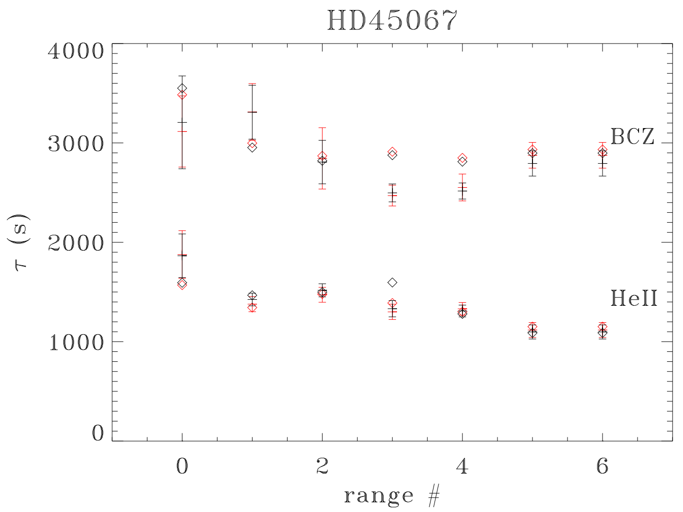
- 1st peak ($\sim$ 1500 s): HeII ionization
- 2nd peak ($\sim$ 3000 s): BCZ (?)
- 3rd peak ($\sim$ 5500 s): alias of the 1st one.

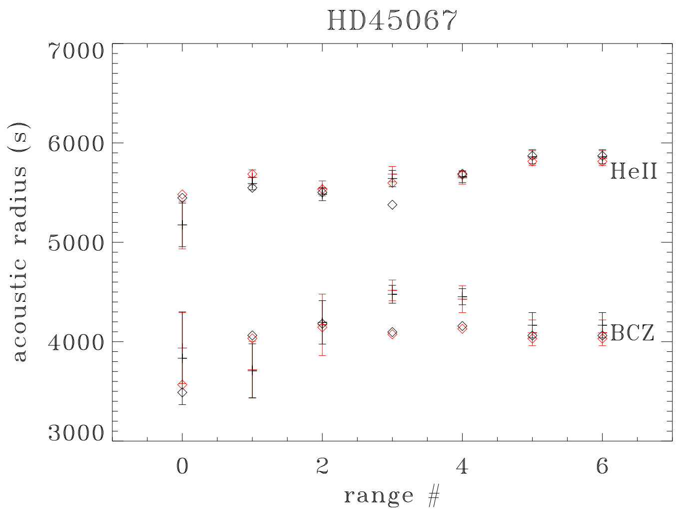
HD 45067: $\delta_2\nu$ analysis (2)

- Found $\tau_{\rm He}$ and $\tau_{\rm BCZ}$ are used as guess to fit the *non-linear* expression: $(a_0 + \frac{a_1}{\omega^2})\sin(2\tau_{\rm He}\omega + \varphi_{\rm He}) + (b_0 + \frac{b_1}{\omega^2})\sin(2\tau_{\rm BCZ}\omega + \varphi_{\rm BCZ})$ (Basu, 1997)
  Note: Without good guess, no fit...
- acoustic depth: from where ?
- acoustic radius: $\sim \frac{1}{<2\Delta\nu>} - \tau$

Results for different frequency ranges:

Red: $\ell = 0, 1$; Black: $\ell = 0, 2$
Diamonds: TF results; error bars: fit results
Range: $\nu \in [0.8; 1.2 + 0.1 \times i]$ mHz





Extracted BCZ acoustic radius :$\sim$ 4060 s ($\pm$150 s)

Conclusion

- This method is robust and easy to use
- We will be very happy to see the results obtained with more refined methods.
- Our frequency sets are available...
  Email: `jballot@cea.fr`

Acknowledgments: We would like to thank the VIRGO group for giving the data.