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# ***Amplitude Variability in gamma Dor and delta Sct Stars Observed by Kepler***

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***IAU Focus Meeting 17  
Honolulu, Hawaii  
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# Abstract

- ★ The NASA *Kepler* spacecraft data revealed a large number of new multimode nonradially pulsating gamma Dor and delta Sct variable stars.
- ★ The *Kepler* high precision long time-series photometry makes it possible to study amplitude variations of the frequencies. We summarize recent literature on amplitude and frequency variations in nonradially pulsating variables.
- ★ We apply several methods, including those we have developed, and the wavelet technique of the VSTAR software (<http://www.aavso.org/vstar-overview>), to study amplitude variability in about a dozen gamma Doradus or delta Scuti candidate variable stars observed for several quarters as part of the *Kepler* Guest Observer program.
- ★ We discuss the magnitude and timescale of the amplitude variations, and the presence or absence of correlations between amplitude variations for different frequencies of a given star. We discuss proposed causes of amplitude spectrum variability that will require further investigation.

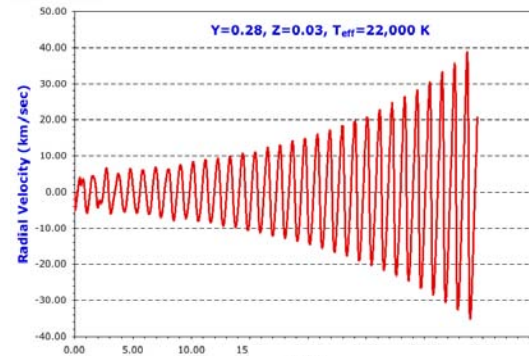
## ***Why are pulsation amplitude (or frequency) variations unexpected?***

For single stars with pulsations unstable to a driving mechanism such as the kappa mechanism:

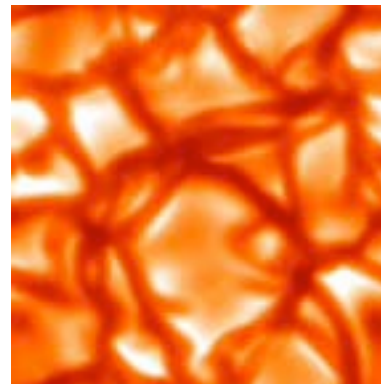
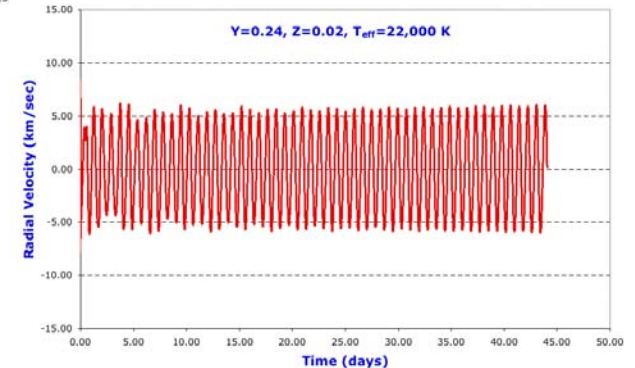
- ★ Pulsation properties are determined by structure of star, which changes very slowly over time via evolutionary processes (e.g., nucleosynthesis, cooling)
- ★ Timescales for evolutionary processes are hundreds to thousands of years rather than the timescales of hours to years over which we have photometric data and detect significant variations.

# *Why are pulsation amplitude (or frequency) variations unexpected?*

- ☀ Pulsation amplitudes should grow relatively quickly to reach a limiting amplitude
- ☀ On the other hand, stochastically excited pulsations, as found in solar-like and red giant stars, will be continuously excited and damped, so their amplitudes are expected to vary



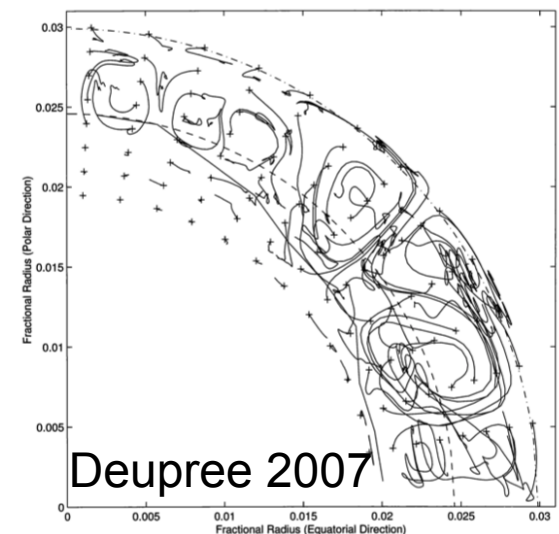
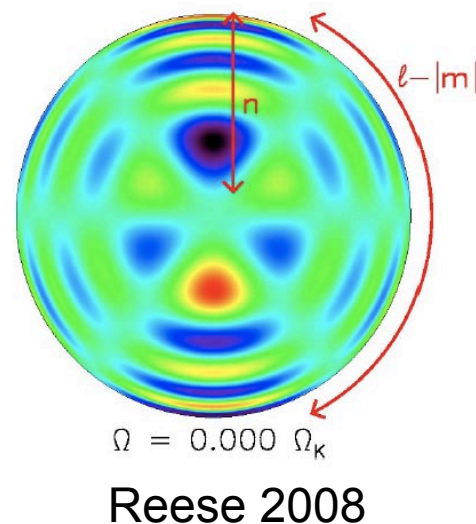
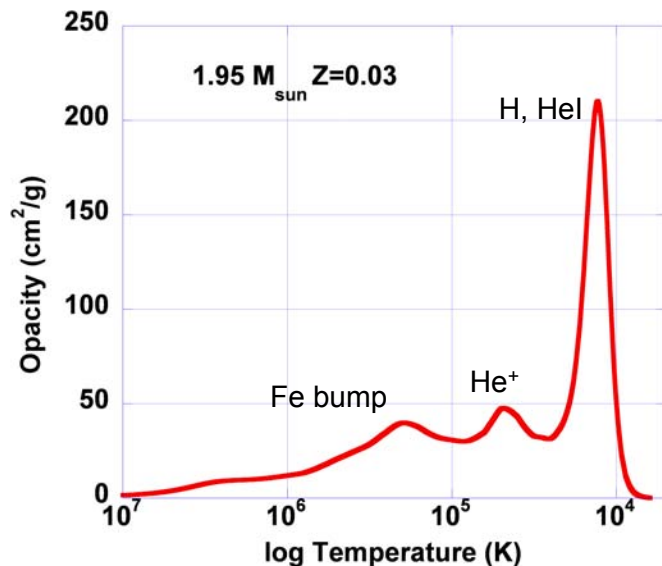
Radial B star  
pulsation  
simulation



Solar  
Convection  
Model (Stein  
1998)

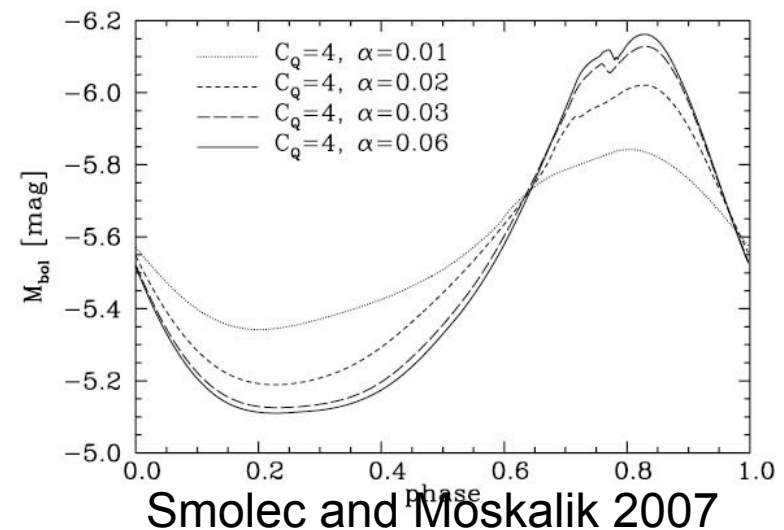
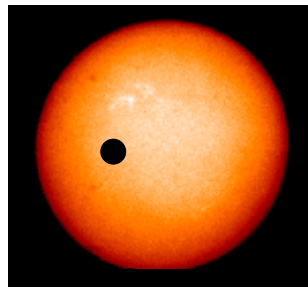
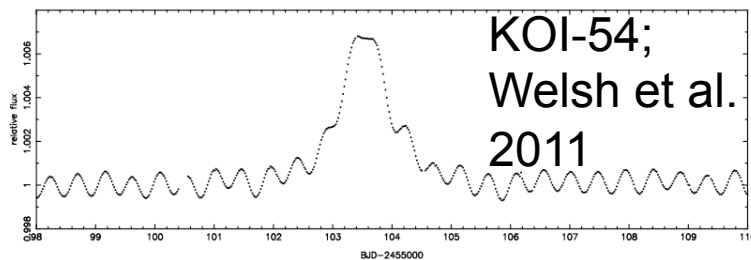
## *Why are amplitude (and frequency, phase) variations important?*

- ☀ May tell us something about energy partition/exchange between modes (some of higher degree / that more difficult to observe in photometry, internal gravity modes that aren't visible at surface).
- ☀ May tell us something about energy exchange with internal dynamical processes (convection, rotation, magnetic fields) or changes in ionization region that we cannot observe directly.



## ***Why are amplitude (and frequency, phase) variations important?***

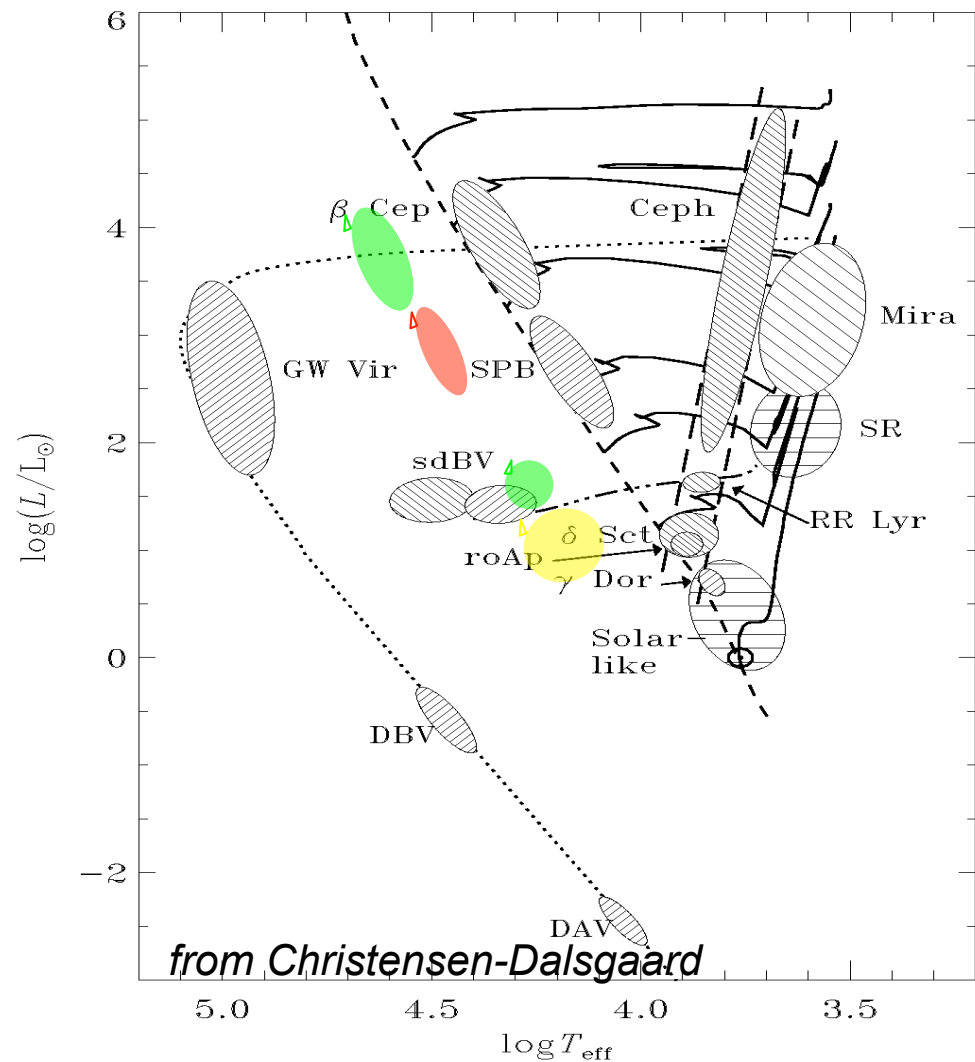
- ☀ May indicate interaction with external environment (accretion, tidal forces from binary or planet).
- ☀ Amplitude variations will help validate multidimensional nonlinear nonradial and nonadiabatic pulsation modeling.





# ***Amplitude/frequency variations have been found among nearly all types of non-stochastically excited pulsating variables***

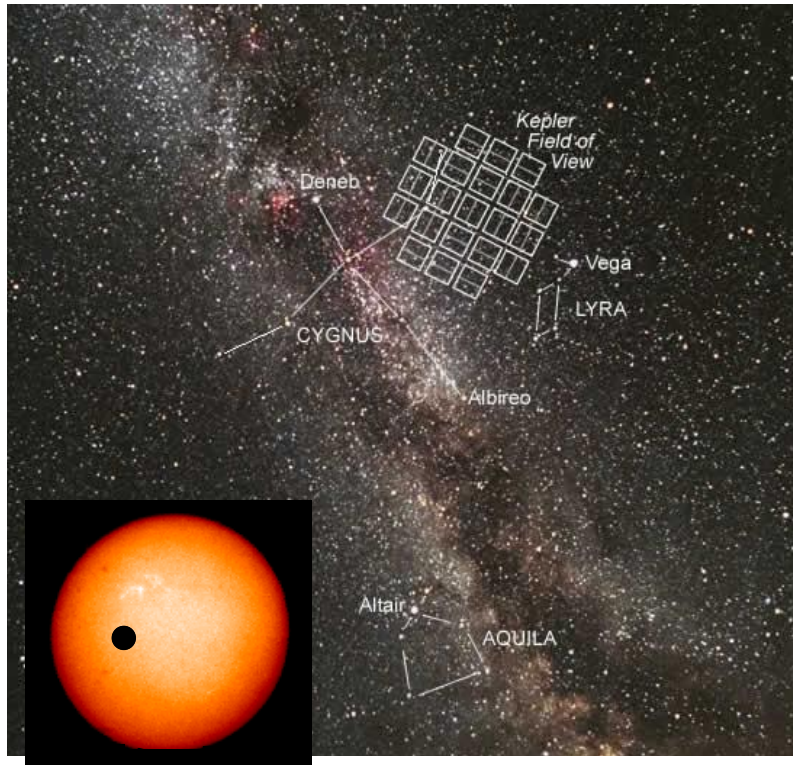
- ☀ *delta Sct*, *gamma Dor*
- ☀ *beta Cep*
- ☀ *roAp*
- ☀ High-amplitude classical pulsators: HADS, Cepheids, RR Lyrae, Mira, SGs
- ☀ DBV, DAV WDs; GW Vir
- ☀ sdBV
- ☀ Extreme helium subdwarf



## ***Some proposed causes of amplitude variations***

- ✿ *Parametric instability (unstable high frequency mode  $\nu_1$  excites two lower frequency stable modes with  $\nu_2 + \nu_3 = \nu_1$ )*
- ✿ *Resonant mode coupling*
- ✿ *Modes are actually stochastically excited*
- ✿ Energy from modulated mode lost/gained somewhere, e.g. in convection zone, ionization region or magnetic field
- ✿ Weather from tidally locked planet
- ✿ Tidal effects from unseen binary or planetary companion
- ✿ Outbursts or accretion on star changing its structure
- ✿ Pulsations are sampling crystallization region (WD interior)
- ✿ Diffusive settling of helium
- ✿ Caught just at edge of evolutionary changes (e.g. at edge of instability strip, core contraction phase, . . . ).
- ✿ Very close frequencies not resolved
- ✿ Interruption in time series; artifact from temporal distribution of data

# *We now have many data sets that can be used to study such variations*



*Kepler* Field of View

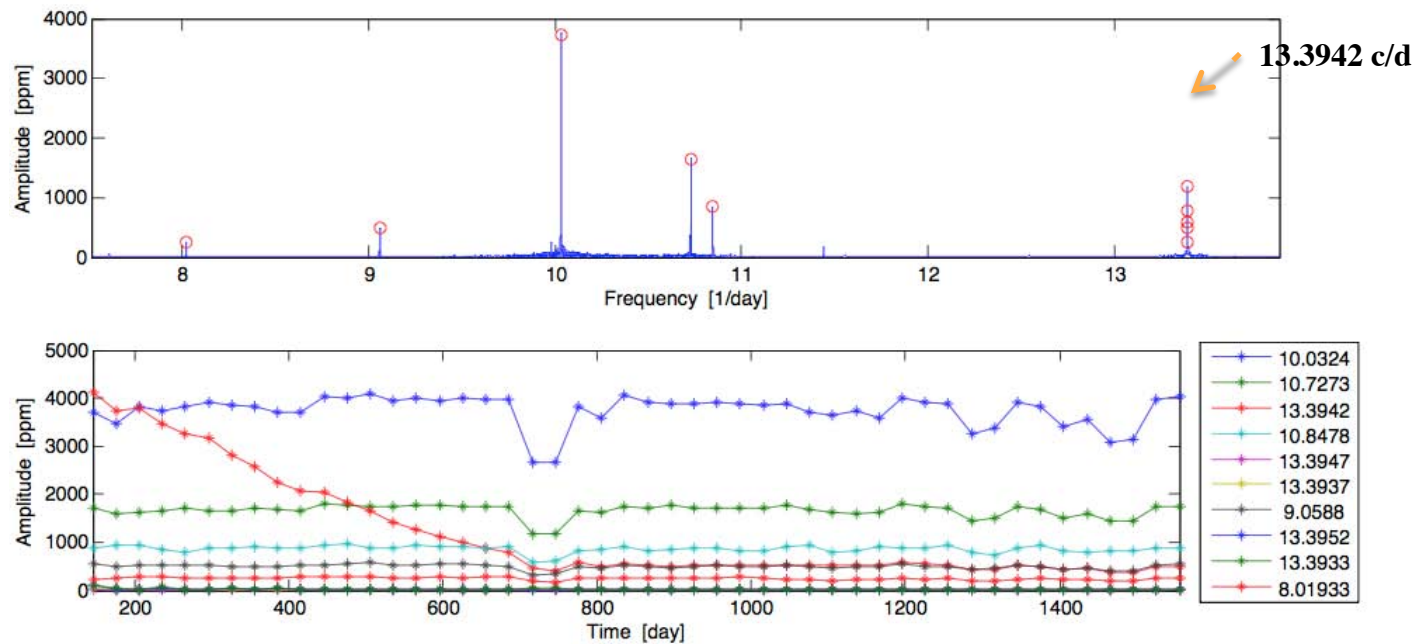
- ☀ *Kepler* delta Sct/gamma Dor, . .
- ☀ CoRoT delta Sct/gamma Dor, . .
- ☀ ASAS (B stars)
- ☀ WET (WD)
- ☀ AAVSO ( LPV, giants)
- ☀ Need long-enough continuous time series, high precision

*Kepler*—time series of months to years.  
Long cadence (30 min integrations) or  
Short cadence (1-minute integrations)  
Micromagnitude precision on amplitude  
spectrum

# ***Amplitude variation search***

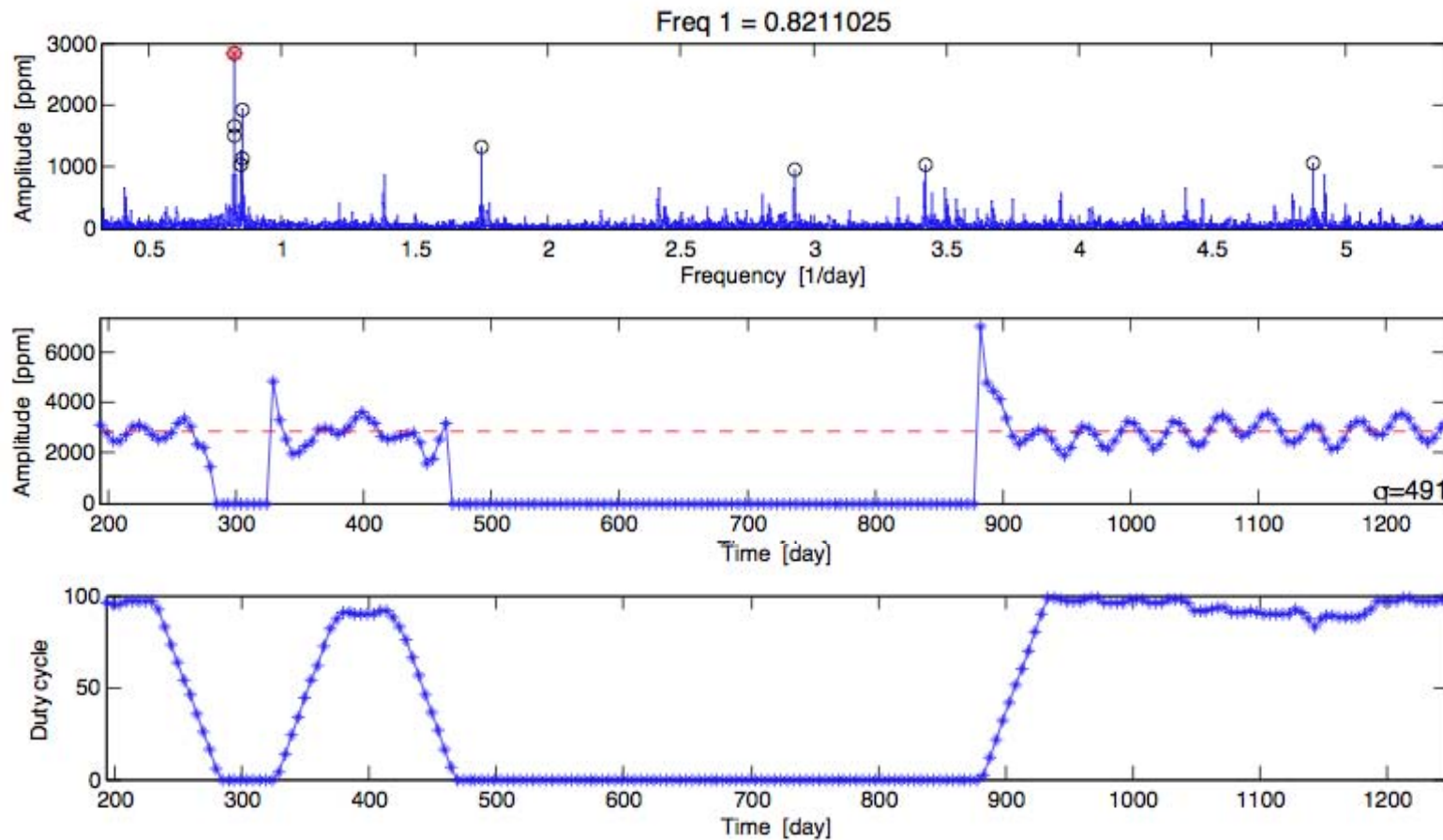
- ★ Long-cadence data from *Kepler* Guest Observer program Quarters 2 through 17
- ★ VSTAR software from American Association of Variable Star Observers (weighted wavelet z-transform, G. Foster, 1996, AJ, 112, 1709).
  - $\sim 1000$  data points per wavelet =  $1000 / 48 \text{ pts/day} = \sim 20\text{-day}$  windows
- ★ Wavelet analysis using Matlab scripts developed by J. Jackiewicz (NMSU)
  - 50 day wide “windows”, with 5-day or 10-day offsets

*We easily detect the large amplitude decrease of mode in KIC 7106205 ( $K_p$  mag = 11.455)*



Amplitude decrease first reported by **Bowman & Kurtz (2014)** for 13.3942 c/d mode

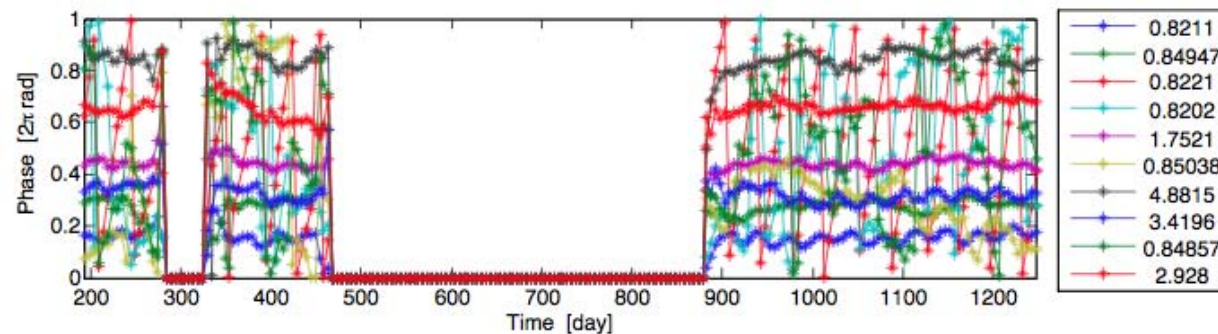
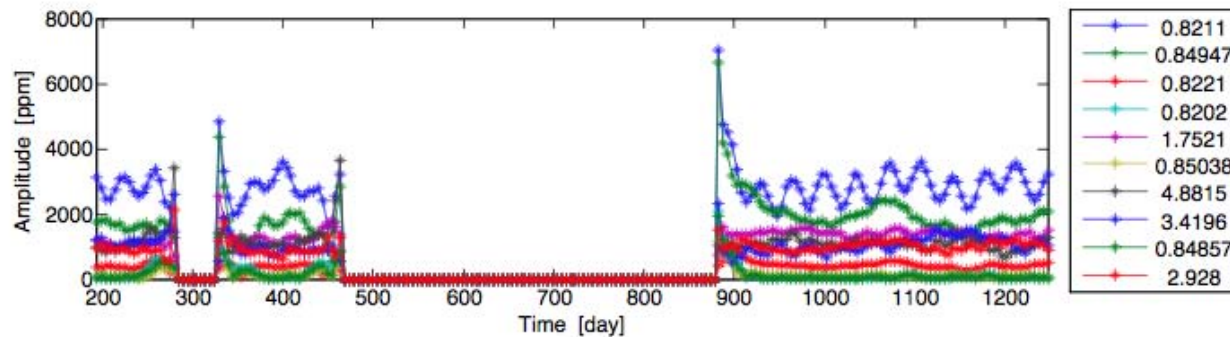
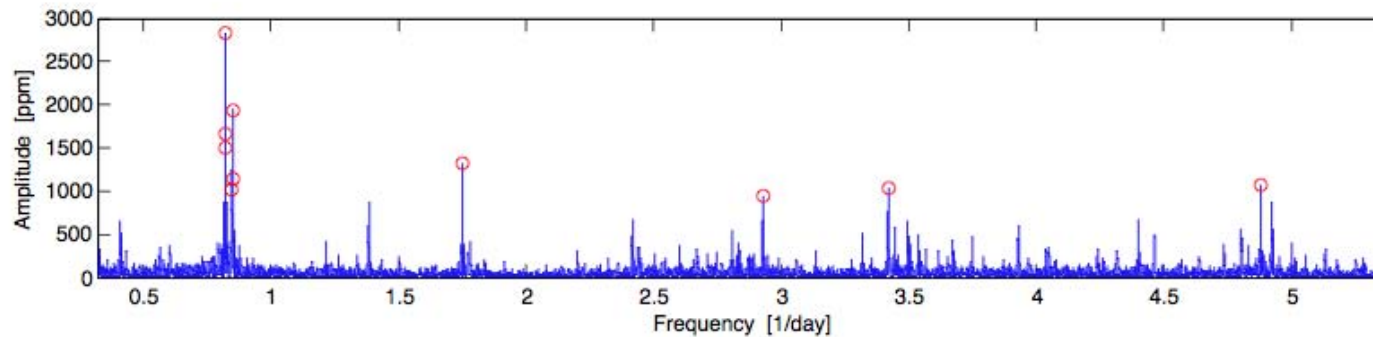
# ***KIC2167444 shows high-frequency amplitude modulation of about 28 days***



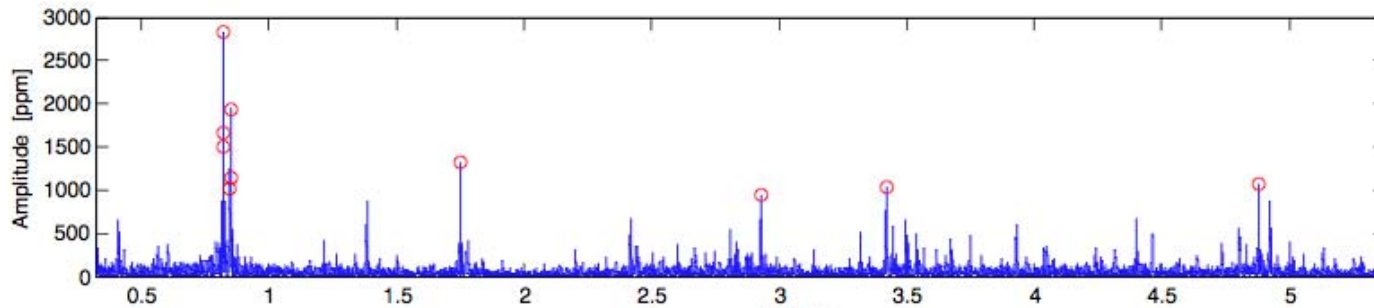
*Kepler* mag 14.1, Q2, 4, 10-13



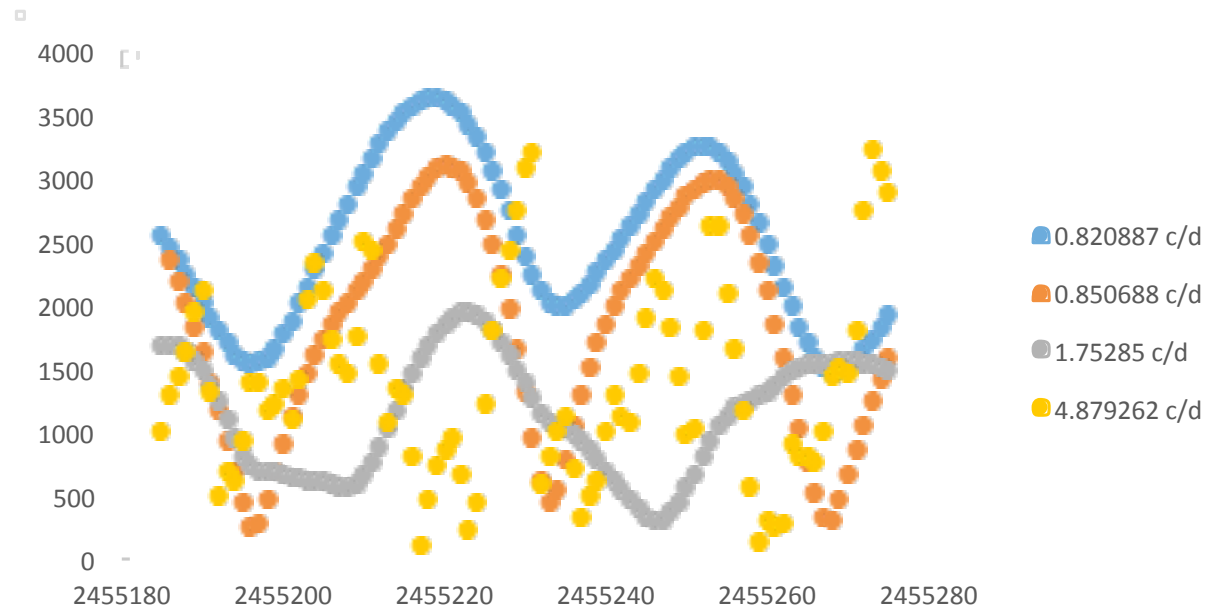
# *Other 2167444 modes also show amplitude (and phase) variation*



# ***VSTAR wavelet analysis of 2167444 also shows 28-day variation***

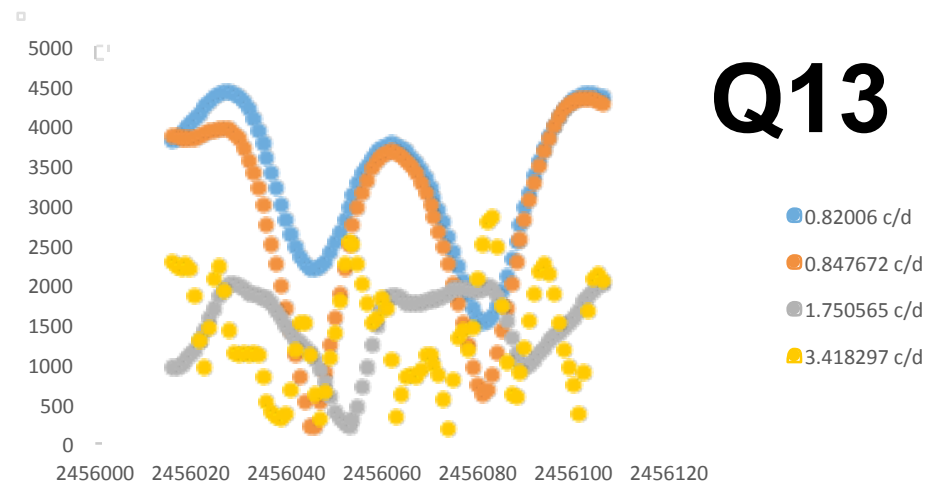
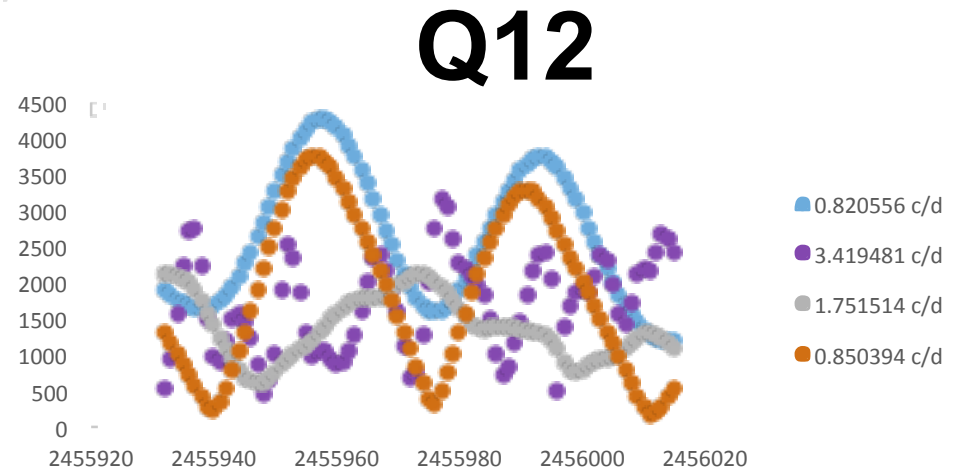
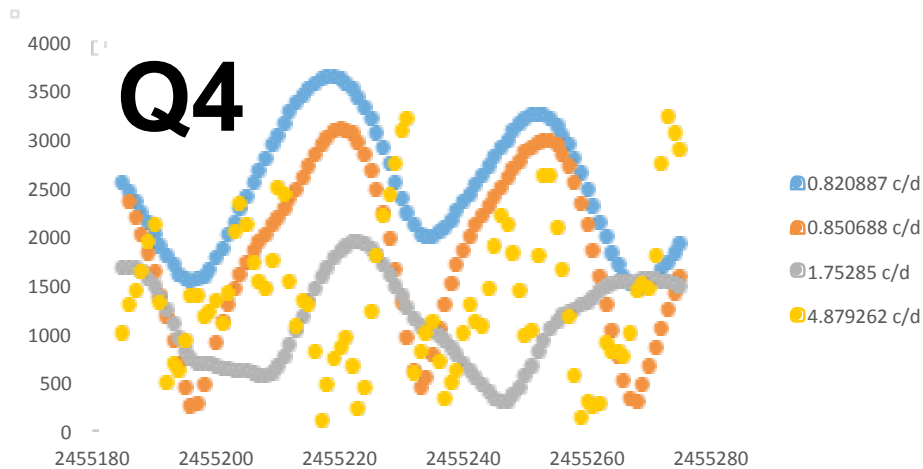


**VSTAR Q4**

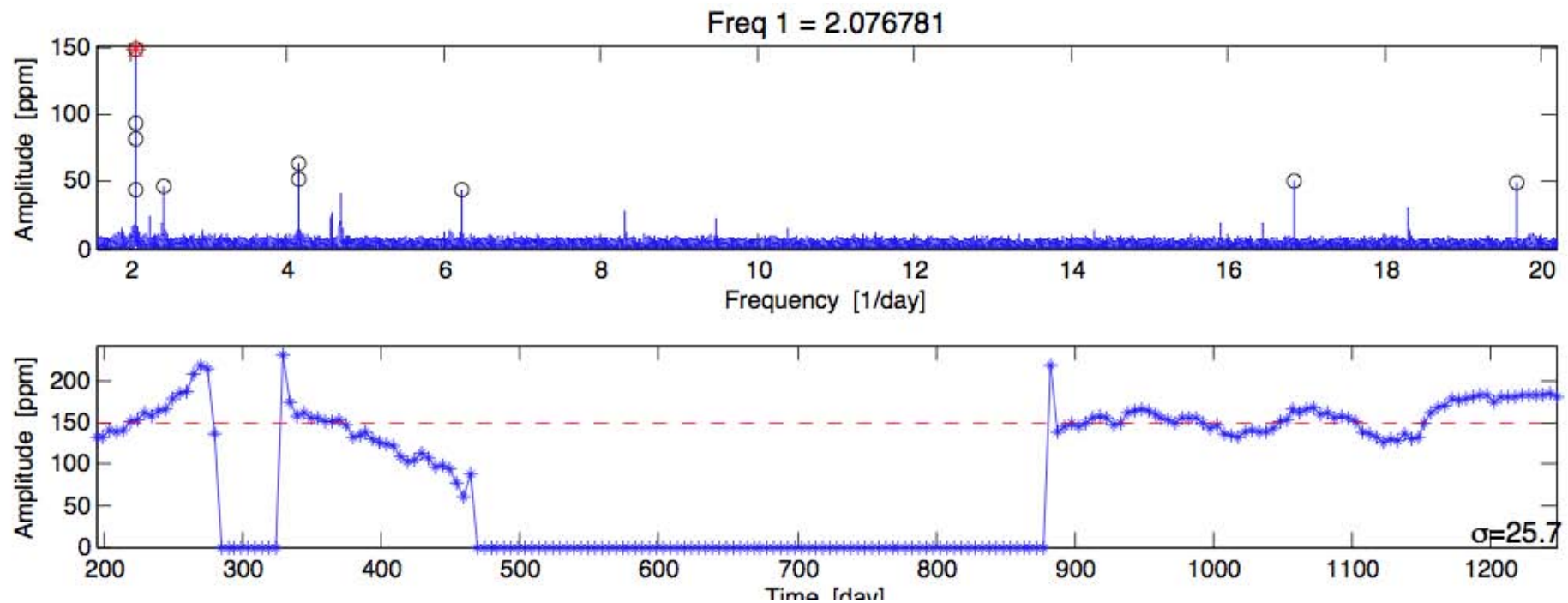




# ***VSTAR results show different behavior from quarter to quarter***



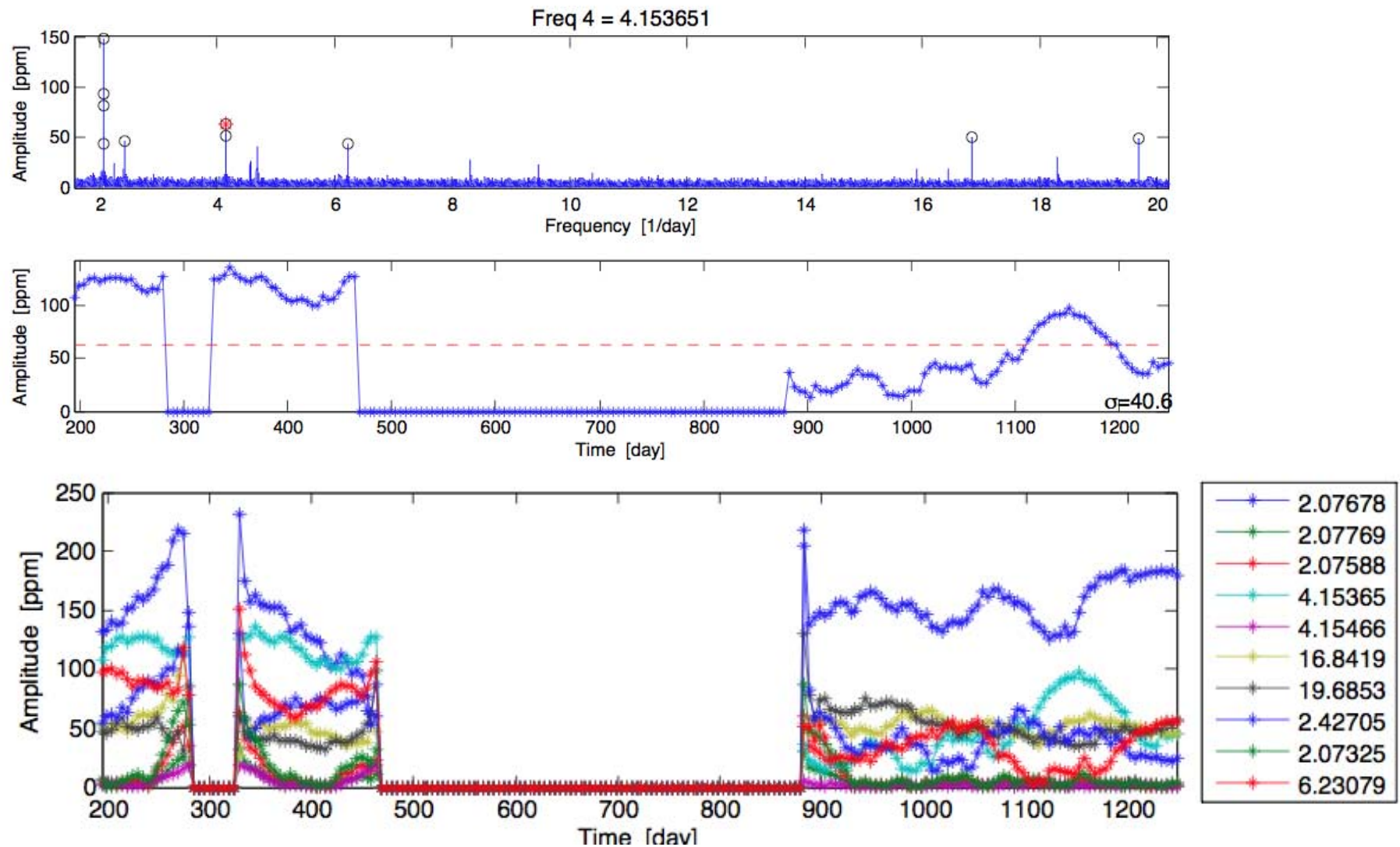
***KIC2301163 shows significant variations,  
even though signal/noise is low***



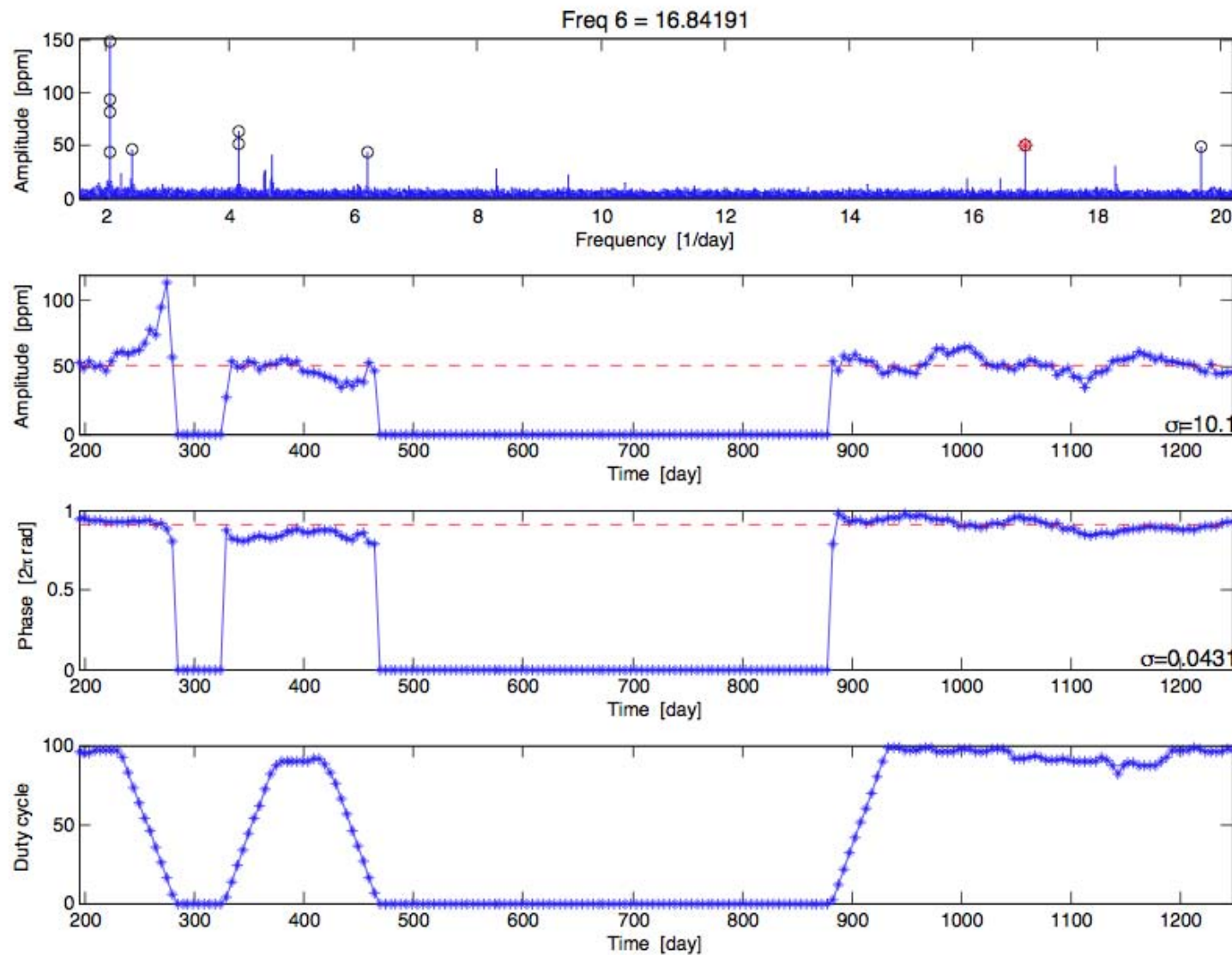
$K_p$  magnitude 14.1

*Kepler* Quarter 2,4, 10-13 data

# *KIC2301163 shows different behavior for frequency at ~2x that of highest amplitude mode*



***KIC2301163 also has delta Sct modes that do not show significant amplitude variation***



# ***Conclusions***

- ✱ Amplitude variations may be detectable using *Kepler* data even for stars with *Kepler* mag > 14 with low-amplitude frequencies >150 ppm using only one or a few quarters of LC data.
- ✱ Amplitude variations for different frequencies are sometimes correlated.
- ✱ Nearby peaks around main peak often show large phase variations
- ✱ It seems that the *Kepler* data requires one or more papers per star to investigate possible amplitude/frequency variations.

## ***A few recent interesting papers discussing causes of amplitude and frequency variations***

- ✶ Bowman, D. and Kurtz, D. “Pulsational Frequency and Amplitude Modulation in the  $\delta$  Sct star KIC 7106205,” MNRAS 444, 209 (2014)
- ✶ Breger, M. and Montgomery, M., “Evidence of resonant mode coupling and the relationship between low and high frequencies in a rapidly rotating A star,” ApJ 783, 89 (2014)
- ✶ Forteza, B., Michel, E., Roca Cortez, T., and Garcia, R.A., “Evidence of amplitude modulation due to Resonant Mode Coupling in the  $\delta$  Scuti star KIC 5892969; a particular or general case?”, A&A, arXiv:1506.00543v1, June 2015
- ✶ Holdsworth, D.L., et al., KIC 7582608: a new Kepler roAp star with frequency variability,” MNRAS 443, 2049 (2014)
- ✶ Percy, J.R. and Khatu, V.C., “Amplitude Variations in Pulsating Red Supergiants,” JAAVSO, 42, 1 (2014)

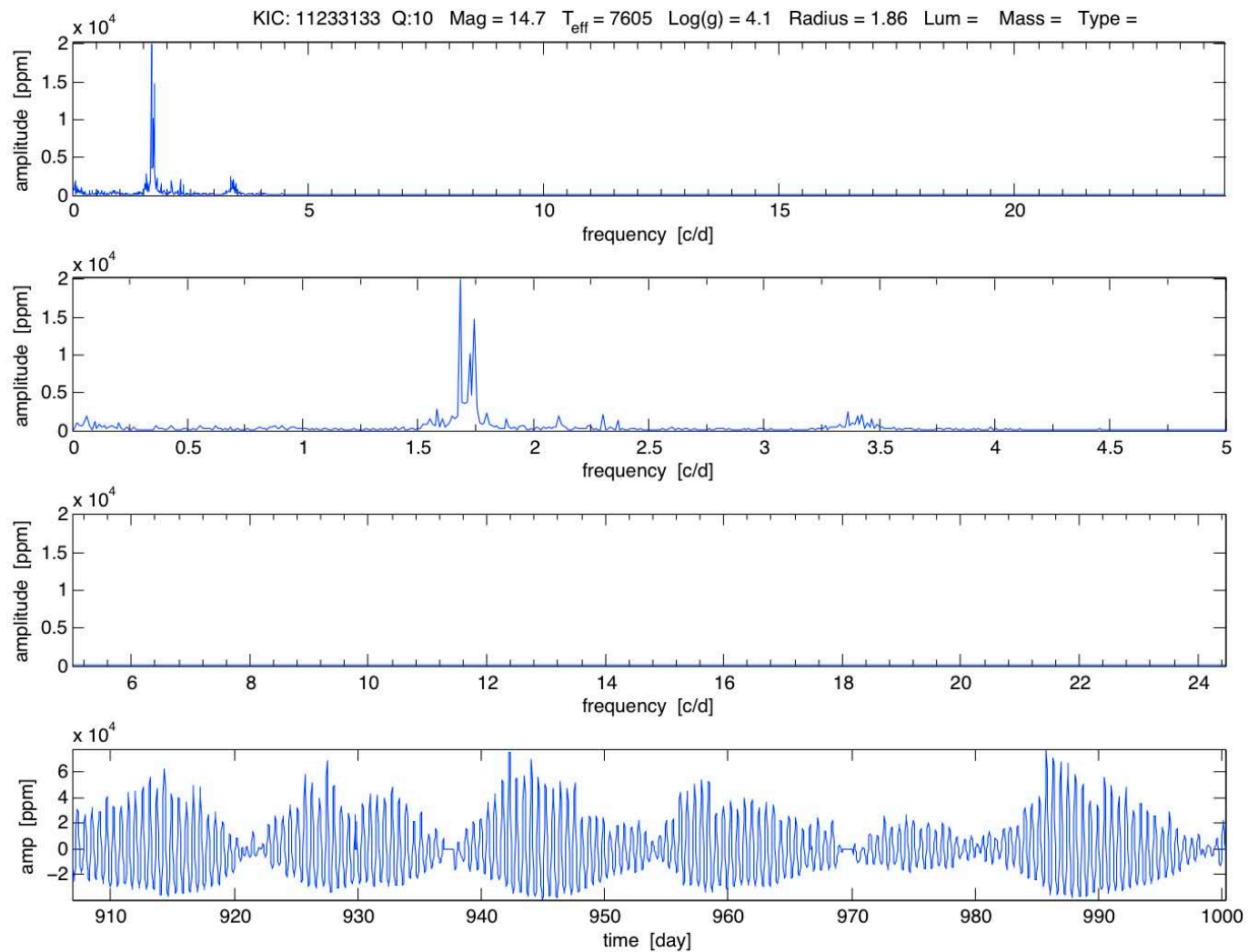
# ***Acknowledgments***

- ✪ NASA Kepler Guest Observer Program
- ✪ DOE Science Undergraduate Laboratory Internship program
- ✪ Los Alamos National Laboratory



# ***gamma Dor candidate KIC 11233133***

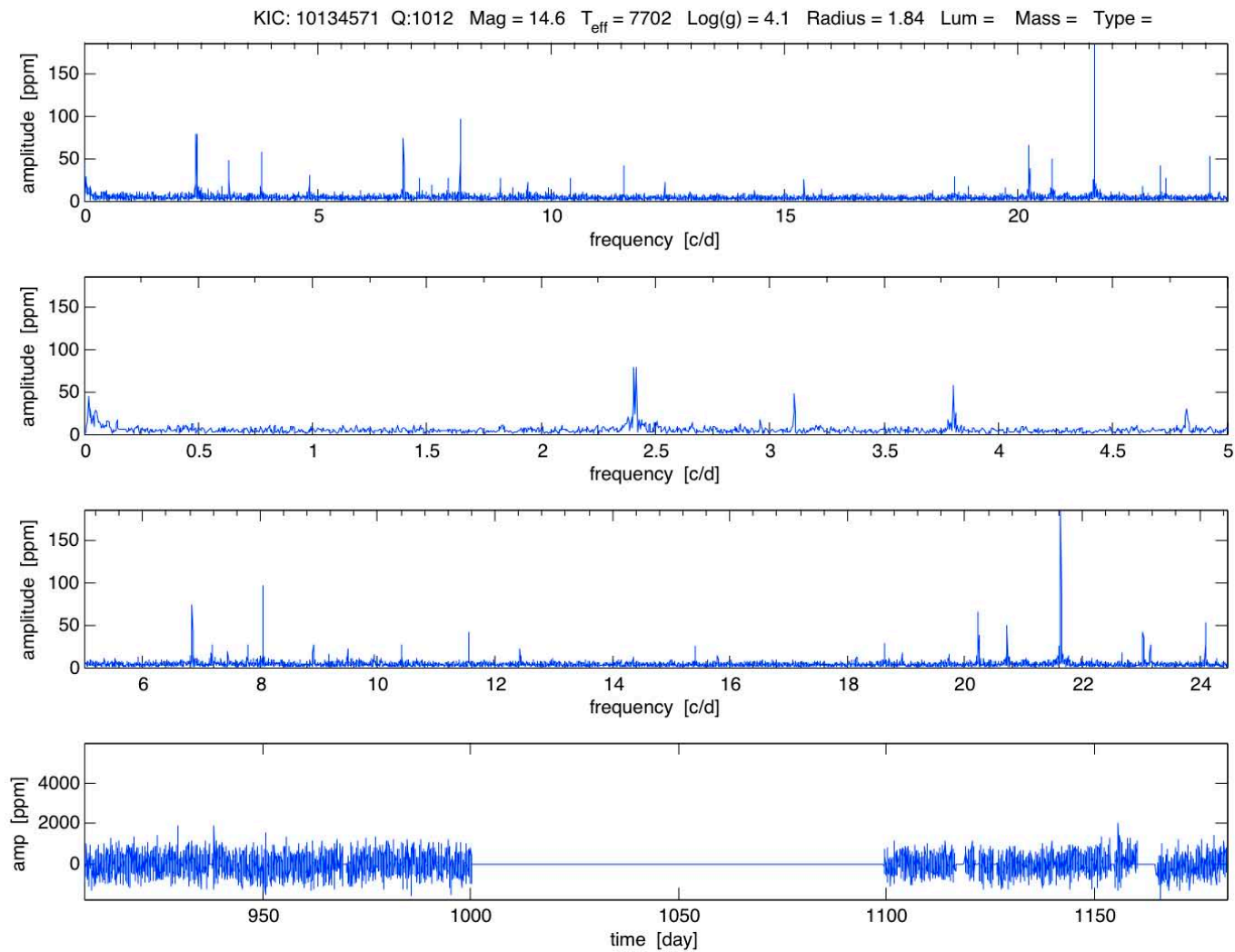
## ***Q10 data, mag 14.7***



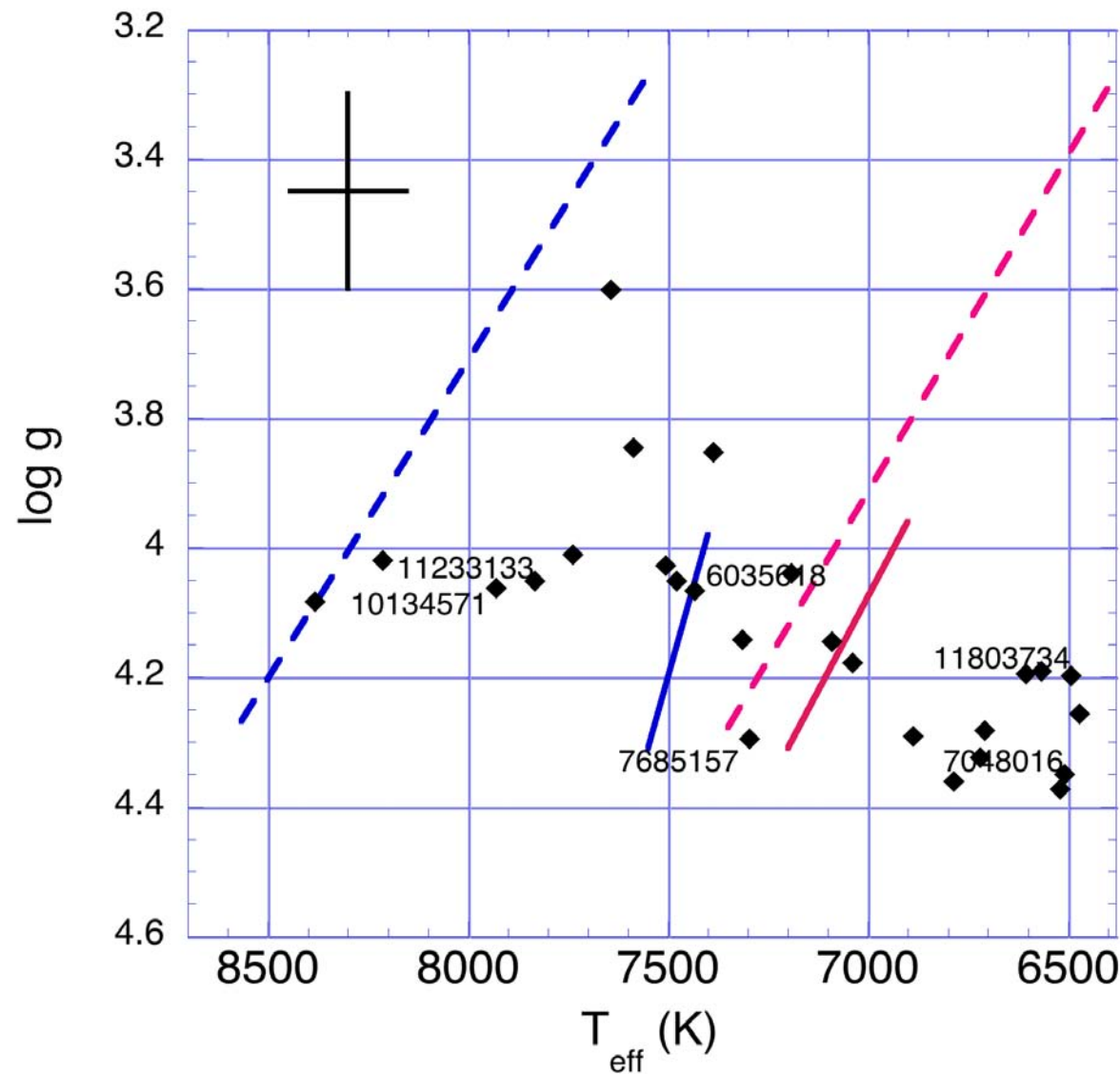


# Hybrid gamma Dor/delta Sct candidate KIC 10134571

## Q10 and 12 data, $K_p$ mag 14.6



# *Some faint Kepler delta Sct or gamma Dor candidates plotted against ground-based instability boundaries*



From Guzik et al.,  
Astronomical  
Review, 2015