

LA-UR-15-26498

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Intended for: International Astronomical Union Focus Meeting 17: Advances in Stellar Physics from Asteroseismology, 2015-08-12 (Honolulu, Hawaii, United States)

Issued: 2015-08-17

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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
August 12–14, 2015*

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.

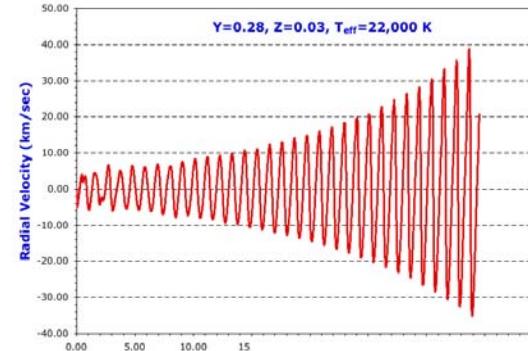
Why are pulsation amplitude (or frequency) variations unexpected?

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

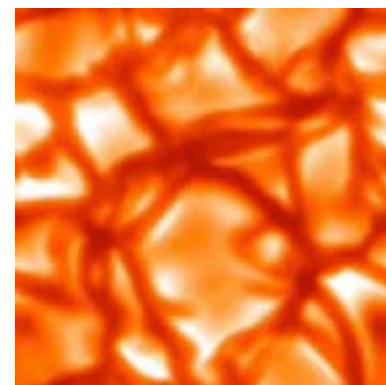
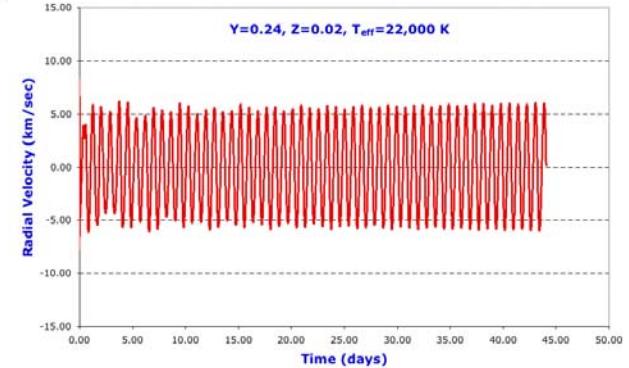
- ★ Pulsation properties are determined by structure of star, which changes very slowly over time via evolutionary processes (e.g., nucleosynthesis, cooling)
- ★ Timescales for evolutionary processes are hundreds to thousands of years rather than the timescales of hours to years over which we have photometric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



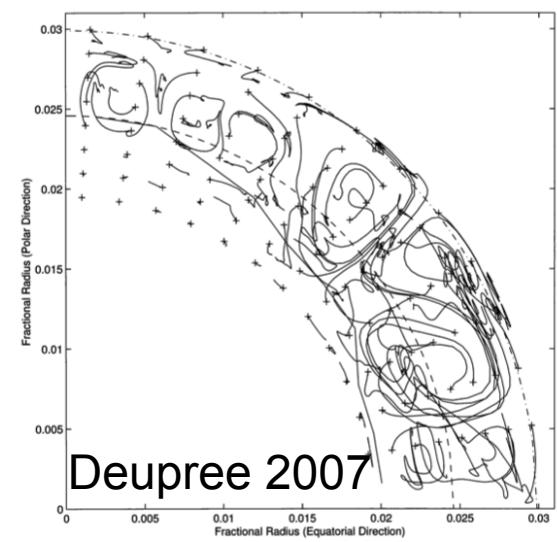
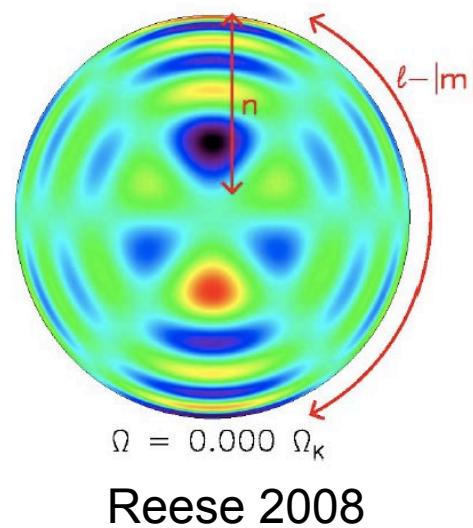
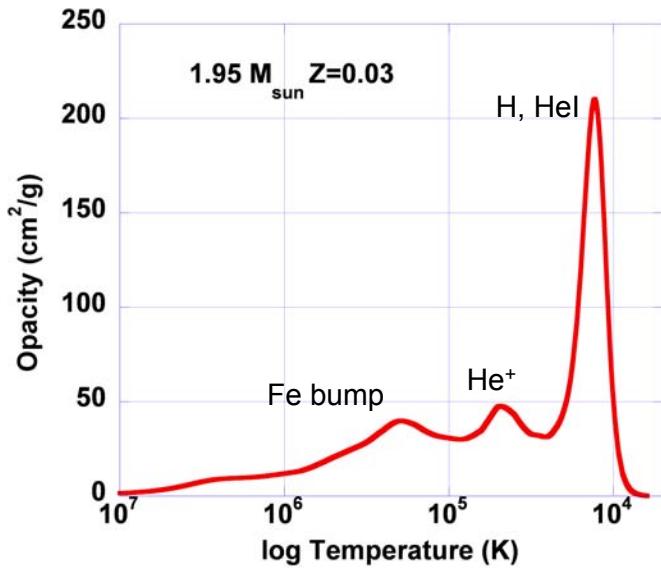
Radial B star pulsation simulation



Solar Convection Model (Stein 1998)

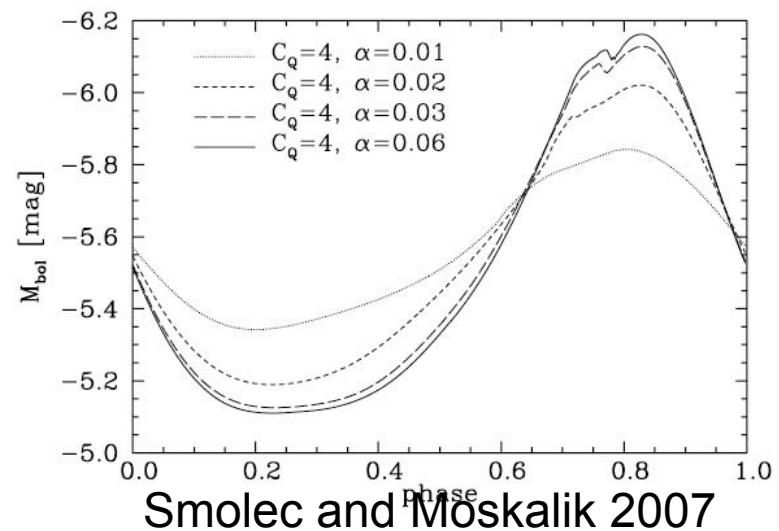
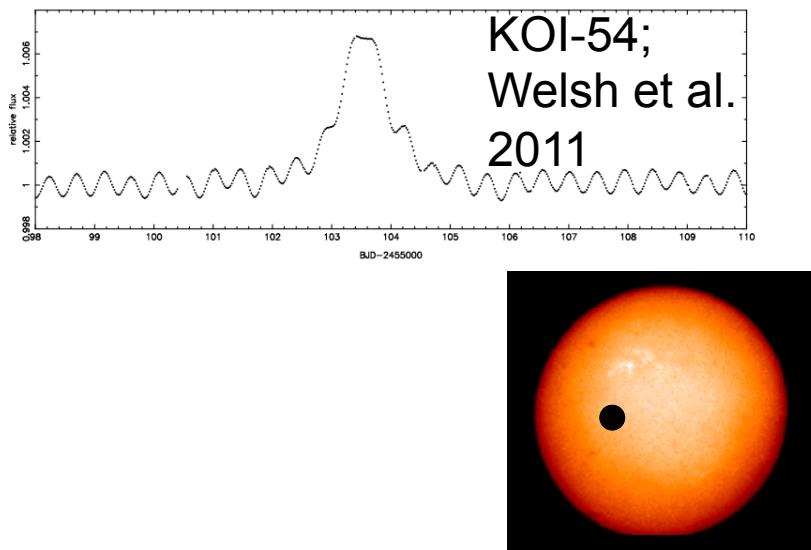
Why are amplitude (and frequency, phase) variations important?

- ★ 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.



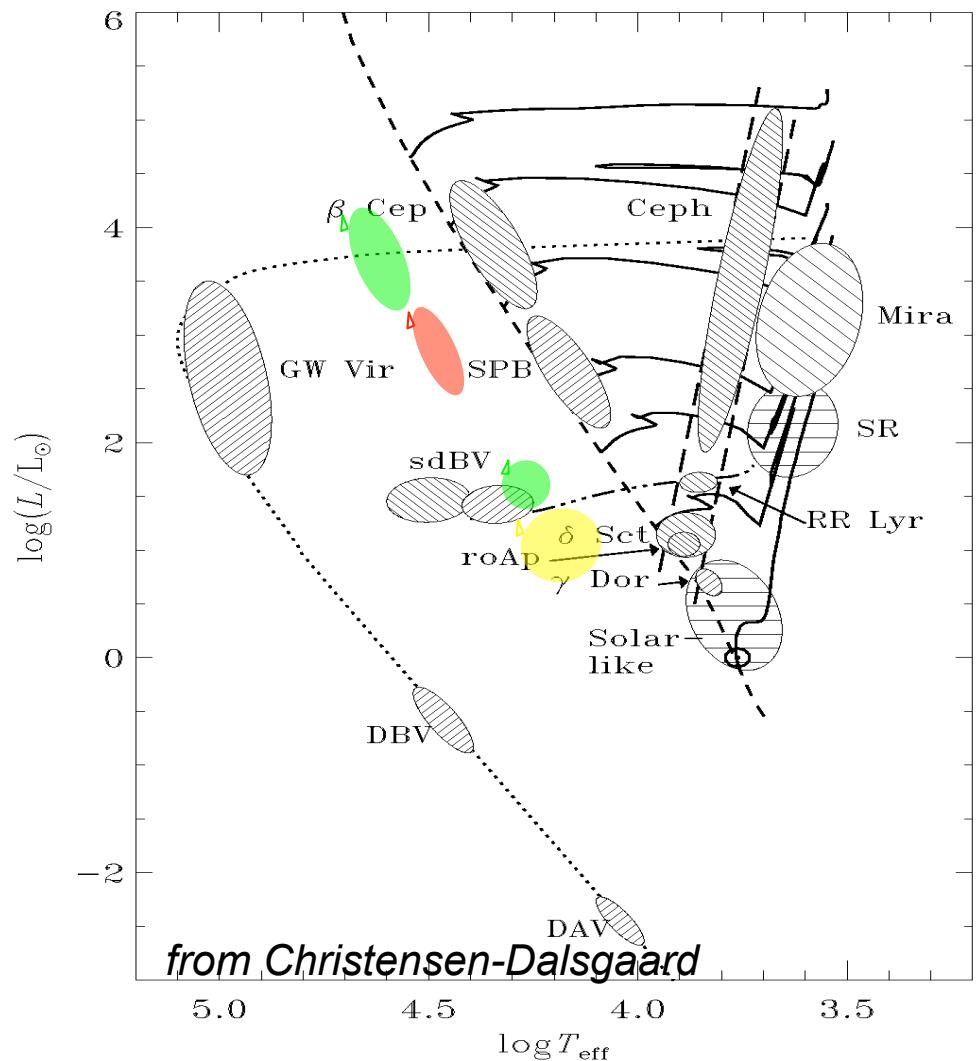
Why are amplitude (and frequency, phase) variations important?

- ★ 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

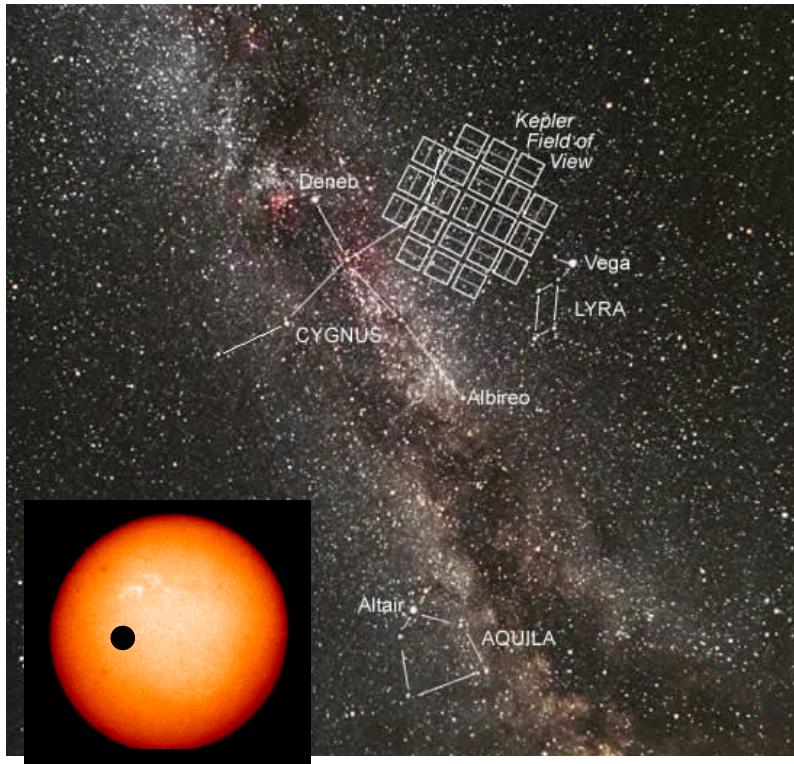
- ✿ *delta Sct, gamma Dor*
- ✿ *beta Cep*
- ✿ *roAp*
- ✿ High-amplitude classical pulsators: HADS, Cepheids, RR Lyrae, Mira, SGs
- ✿ DBV, DAV WDs; GW Vir
- ✿ sdBV
- ✿ Extreme helium subdwarf



Some proposed causes of amplitude variations

- ★ *Parametric instability (unstable high frequency mode $v1$ excites two lower frequency stable modes with $v2 + v3 = v1$)*
- ★ *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

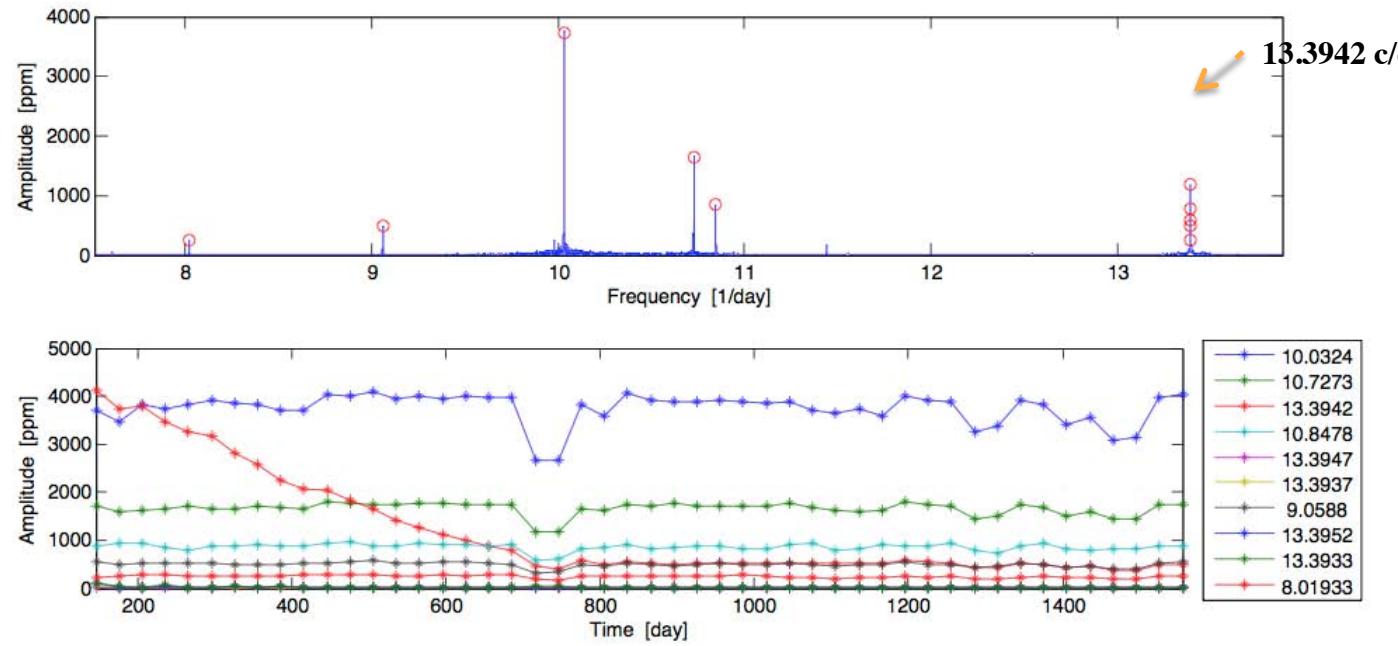
- ★ Kepler delta Sct/gamma Dor, . . .
- ★ CoRoT delta Sct/gamma Dor, . . .
- ★ ASAS (B stars)
- ★ WET (WD)
- ★ AAVSO (LPV, giants)
- ★ Need long-enough continuous time series, high precision

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

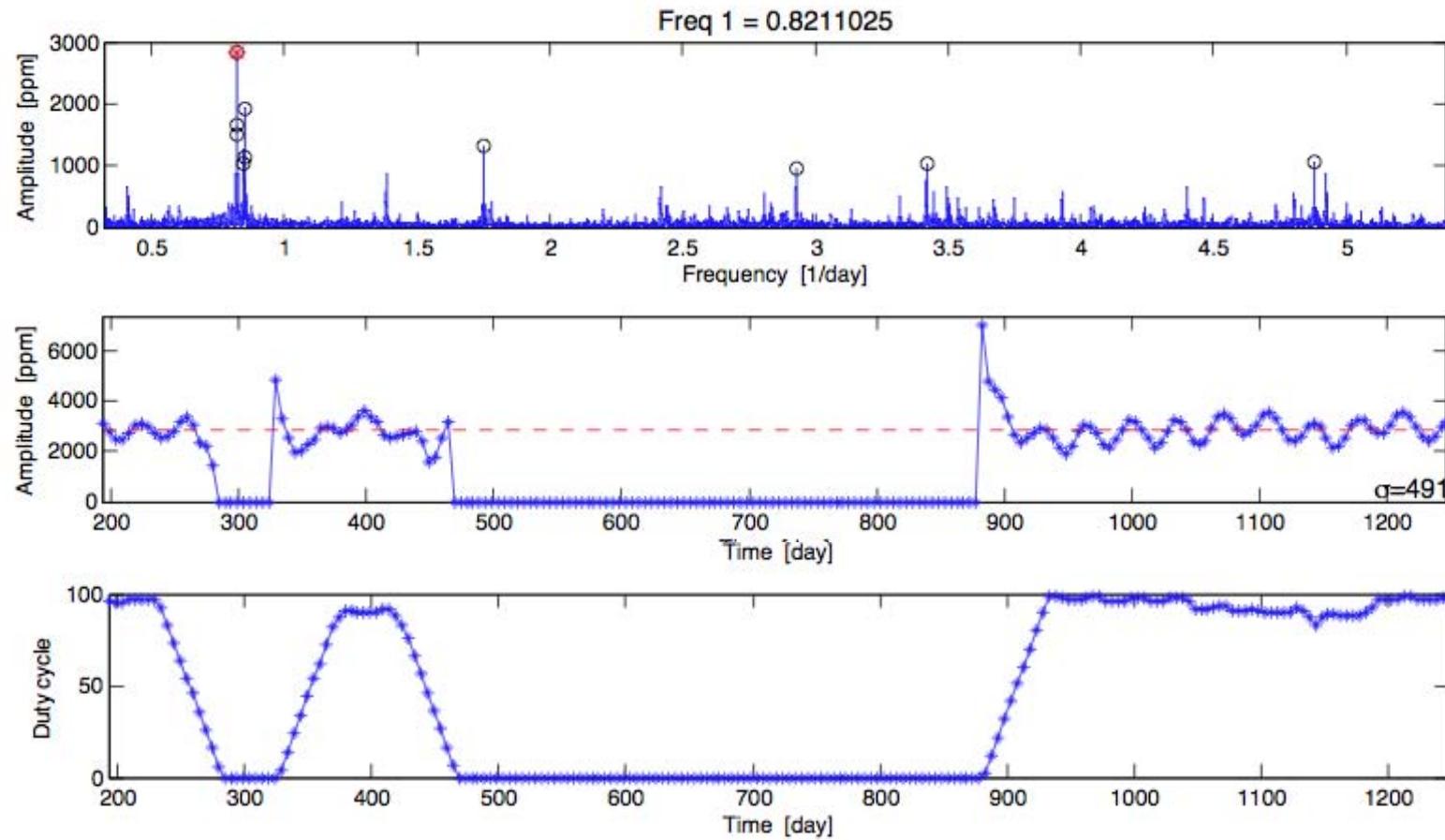
- ★ Long-cadence data from *Kepler* Guest Observer program Quarters 2 through 17
- ★ VSTAR software from American Association of Variable Star Observers (weighted wavelet z-transform, G. Foster, 1996, AJ, 112, 1709).
 - ~ 1000 data points per wavelet = $1000/ 48$ pts/day =
 ~ 20 -day windows
- ★ Wavelet 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)



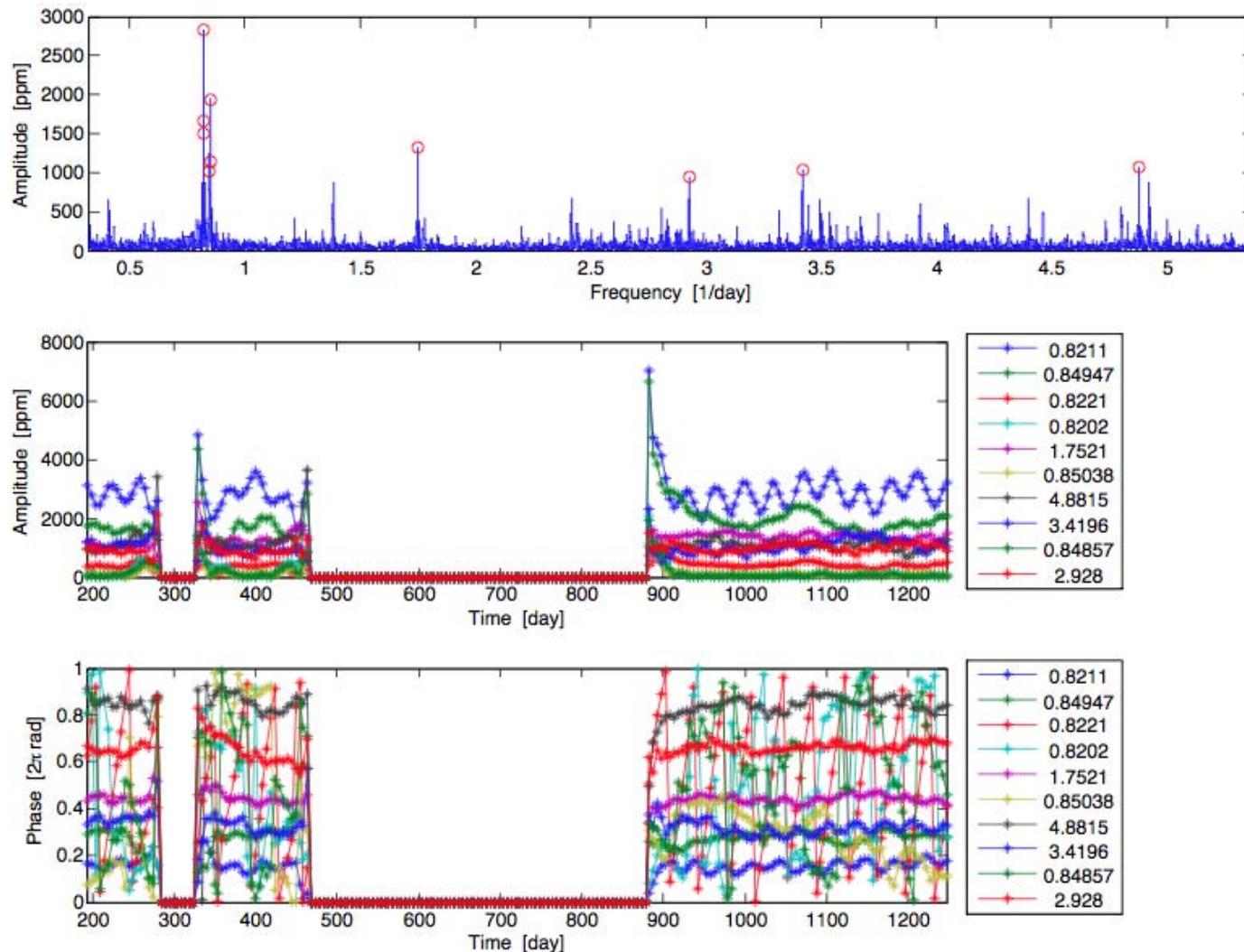
Amplitude decrease first reported by Bowman & Kurtz (2014) for 13.3942 c/d mode

KIC2167444 shows high-frequency amplitude modulation of about 28 days

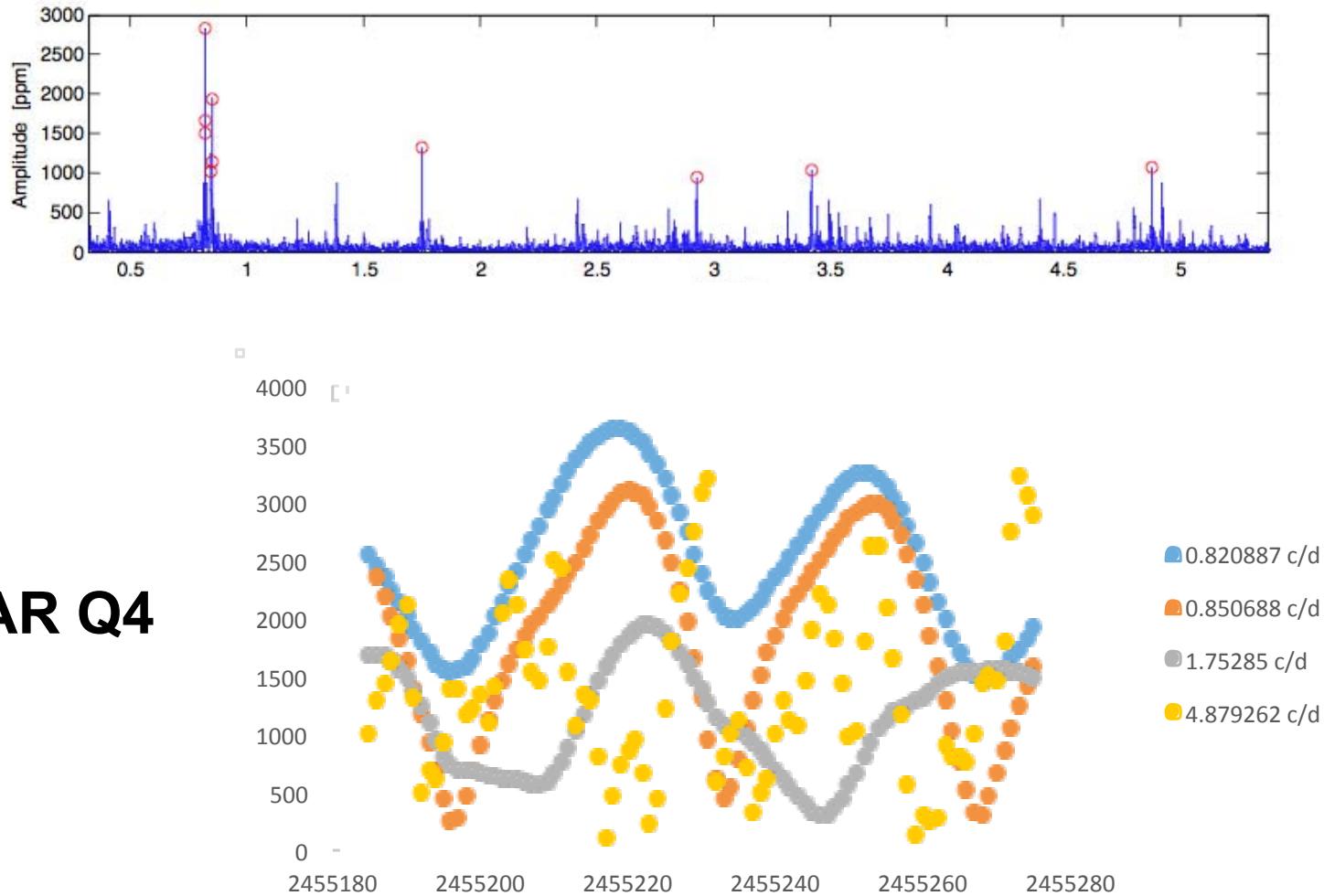


Kepler mag 14.1, Q2, 4, 10-13

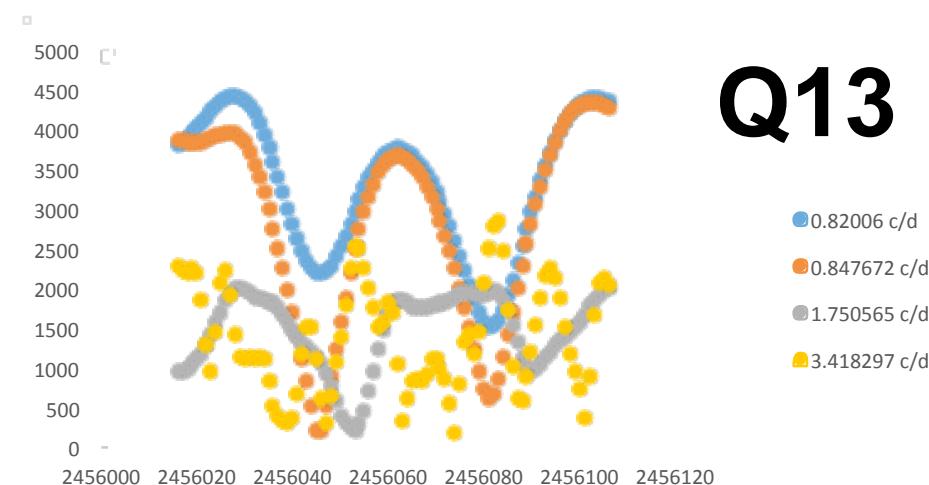
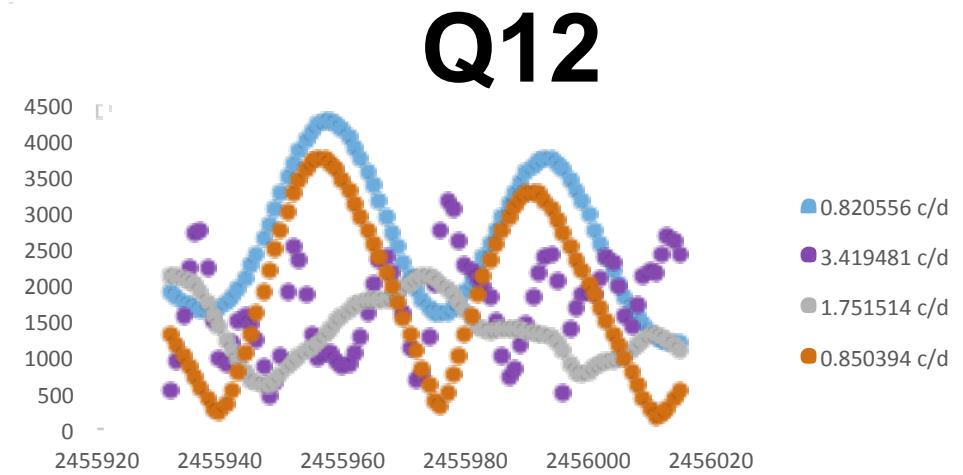
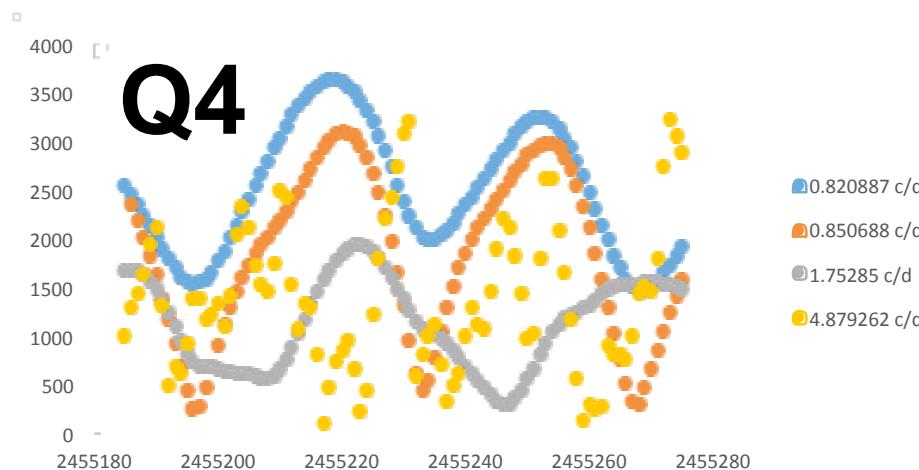
Other 2167444 modes also show amplitude (and phase) variation



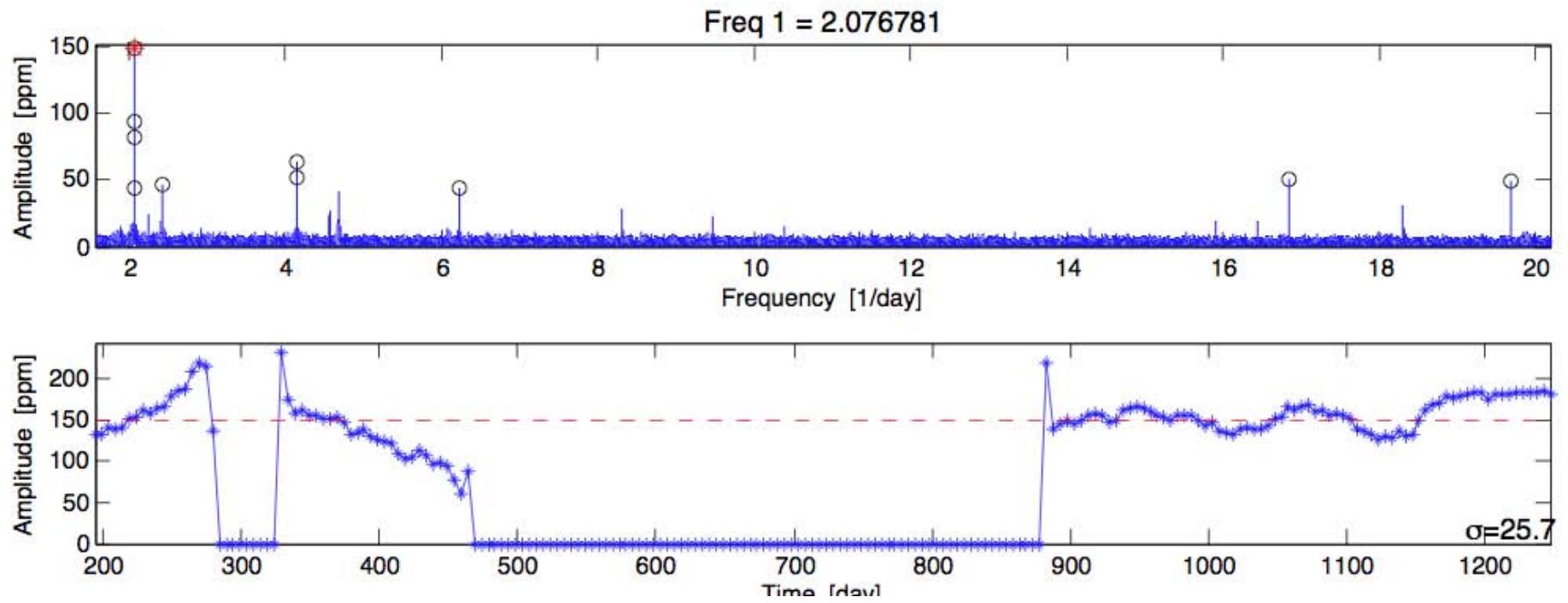
VSTAR wavelet analysis of 2167444 also shows 28-day variation



VSTAR results show different behavior from quarter to quarter

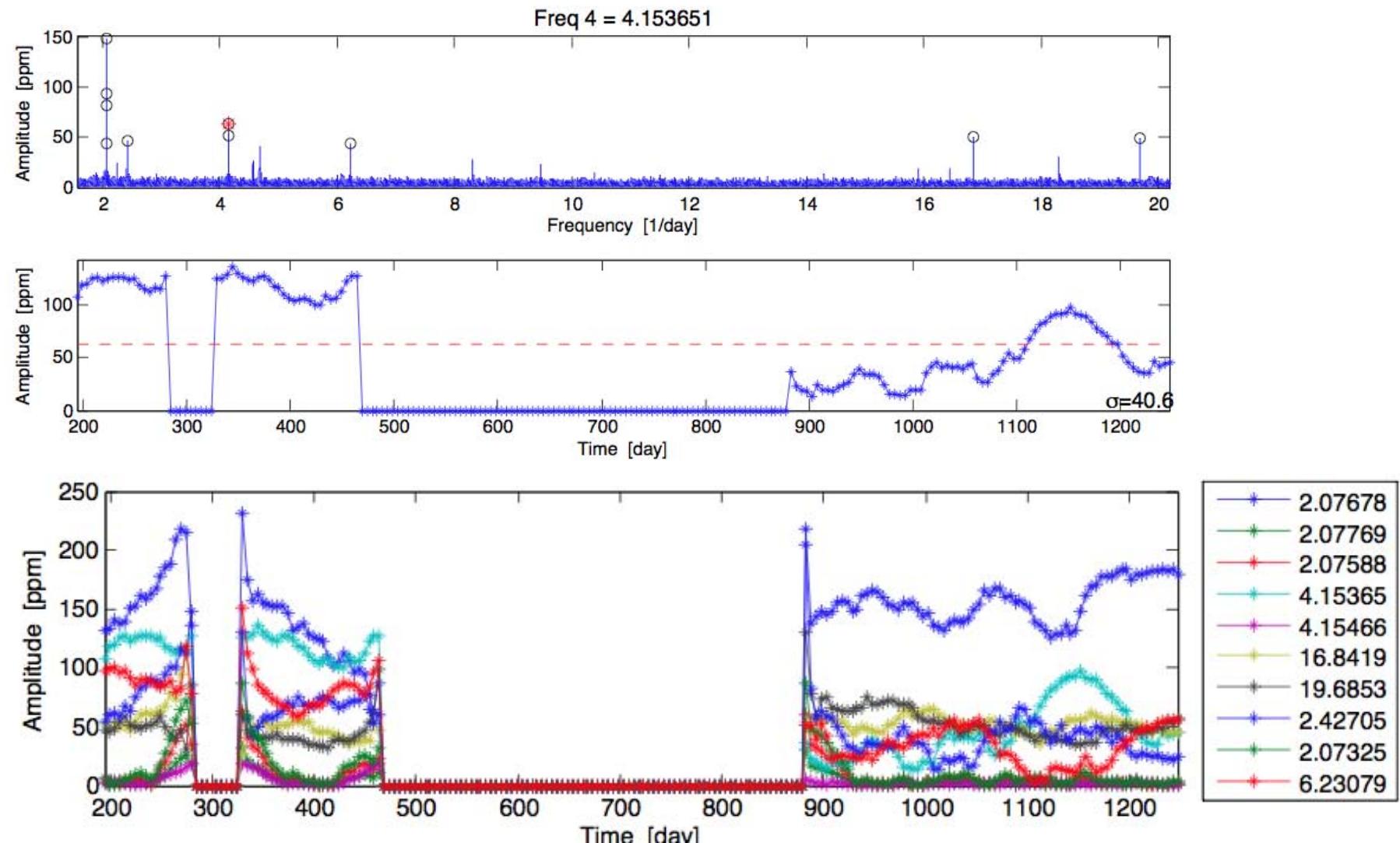


KIC2301163 shows significant variations, even though signal/noise is low

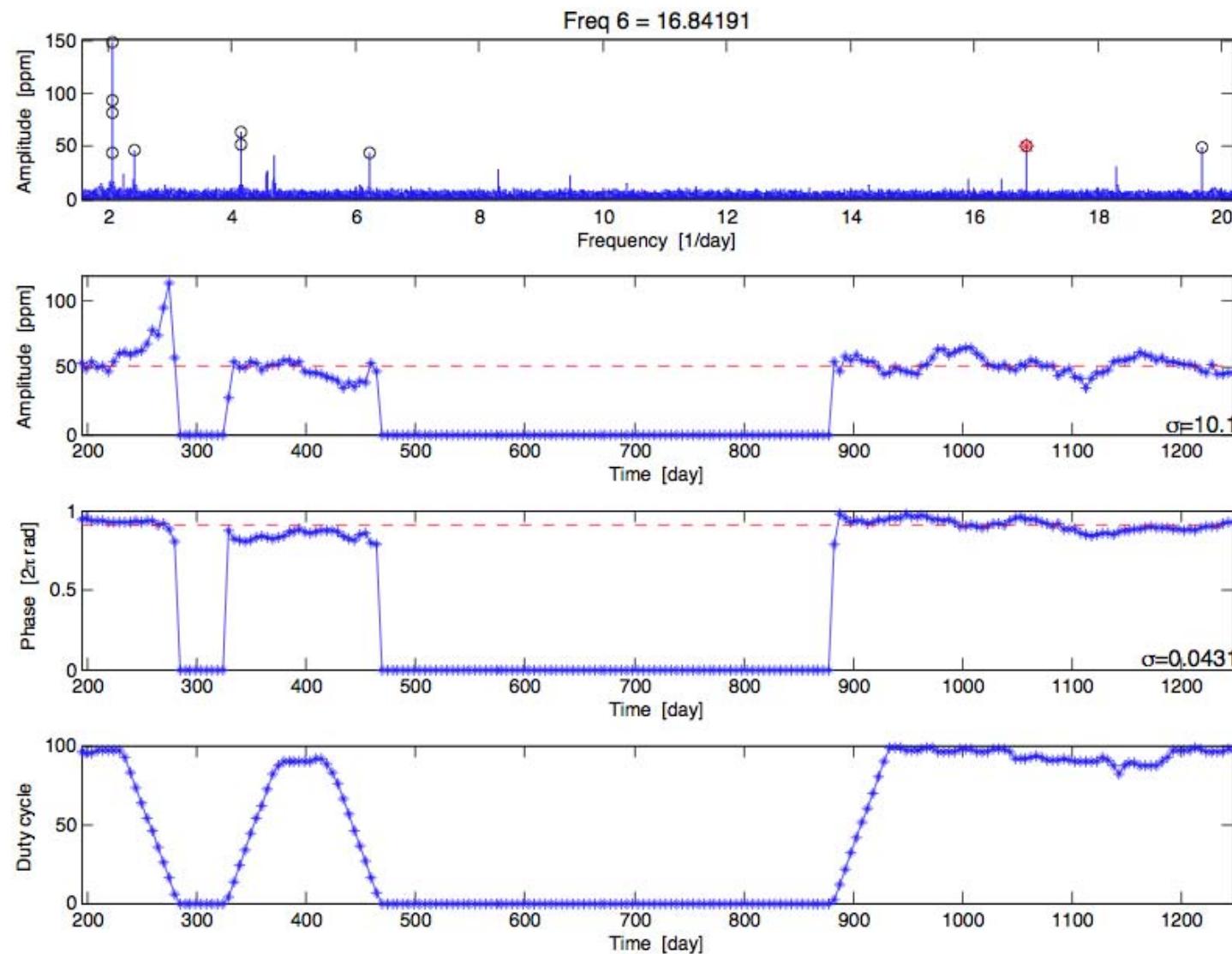


K_p magnitude 14.1
Kepler Quarter 2,4, 10-13 data

KIC2301163 shows different behavior for frequency at $\sim 2x$ 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

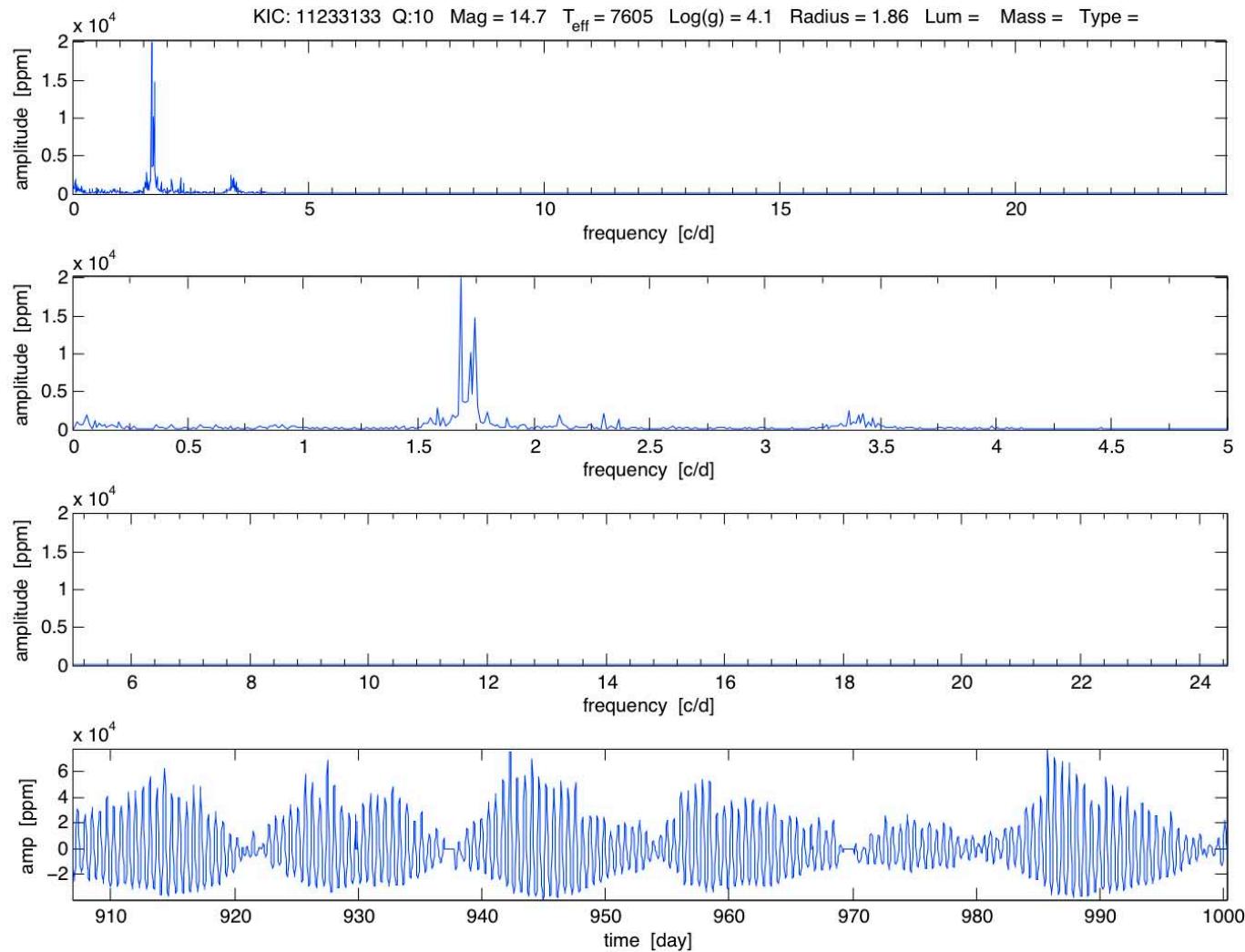
- ★ Bowman, D. and Kurtz, D. “Pulsational Frequency and Amplitude Modulation in the δ Sct star KIC 7106205,” MNRAS 444, 209 (2014)
- ★ Breger, M. and Montgomery, M., “Evidence of resonant mode coupling and the relationship between low and high frequencies in a rapidly rotating A star,” ApJ 783, 89 (2014)
- ★ Forteza, B., Michel, E., Roca Cortez, T., and Garcia, R.A., “Evidence of amplitude modulation due to Resonant Mode Coupling in the δ 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

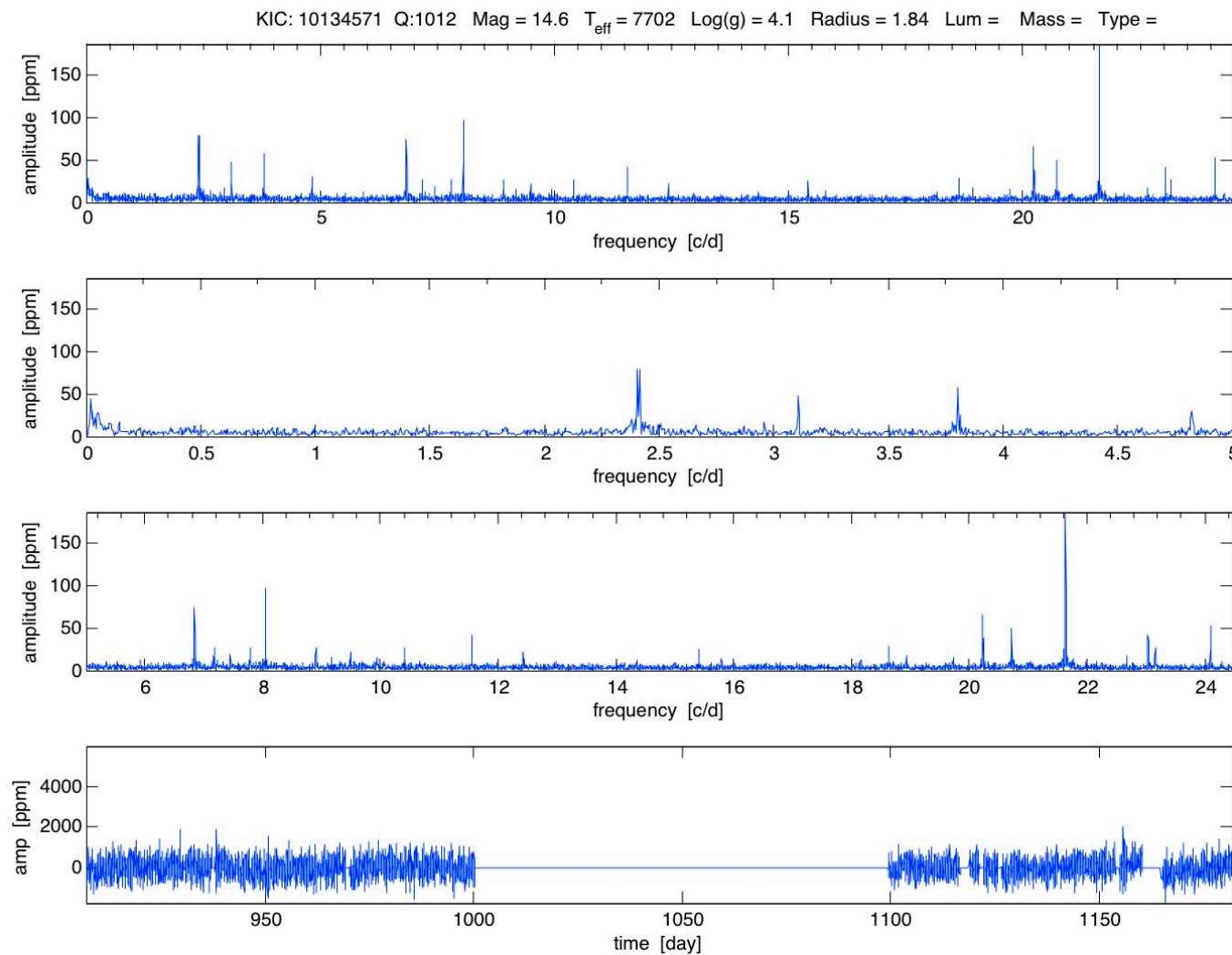
gamma Dor candidate KIC 11233133

Q10 data, mag 14.7

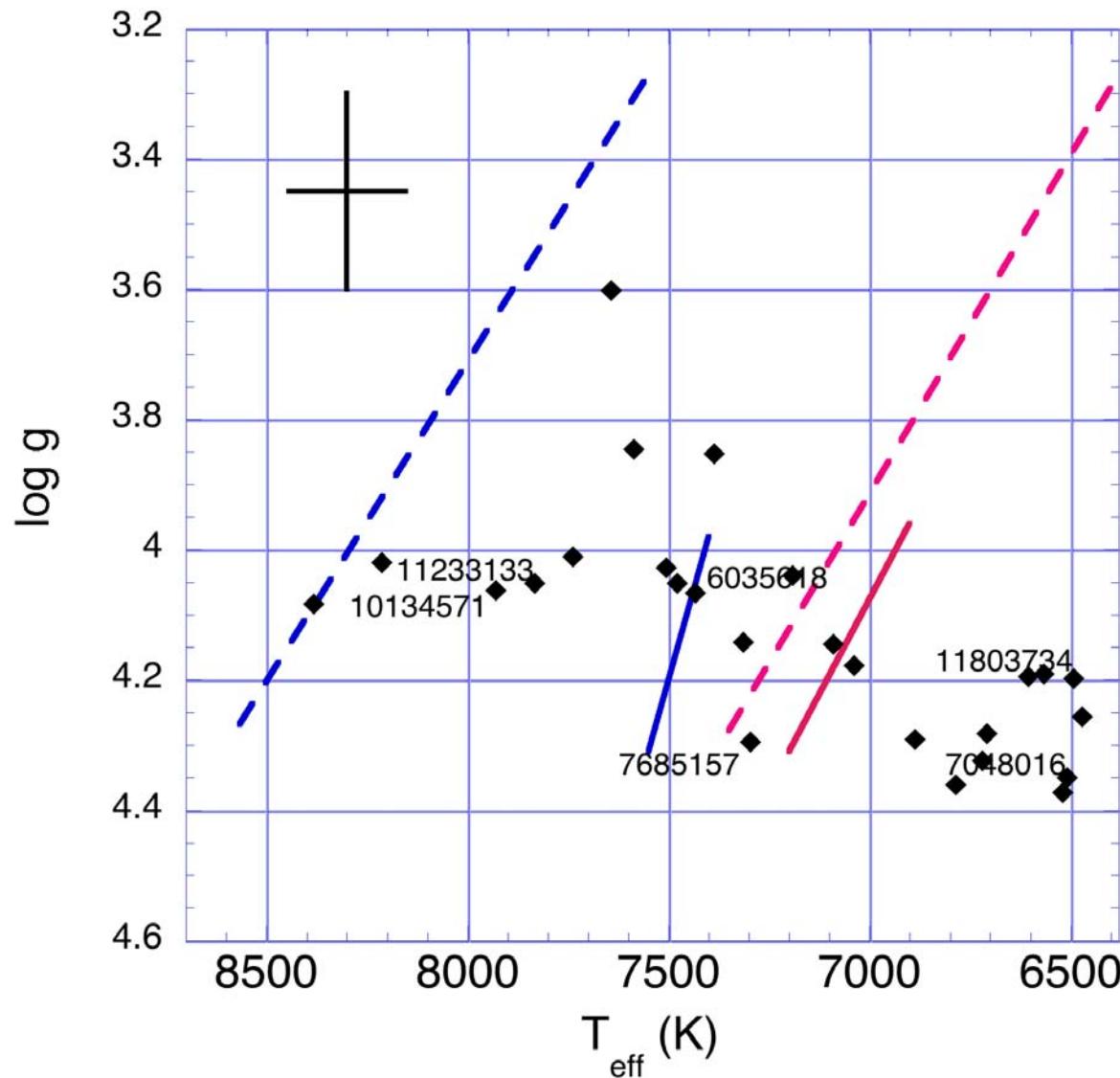


Hybrid gamma Dor/delta Sct candidate KIC 10134571

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