Confronting the "Extreme Planetary Systems" Claimed Around sdBVs

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KIC 05807616

LETTER

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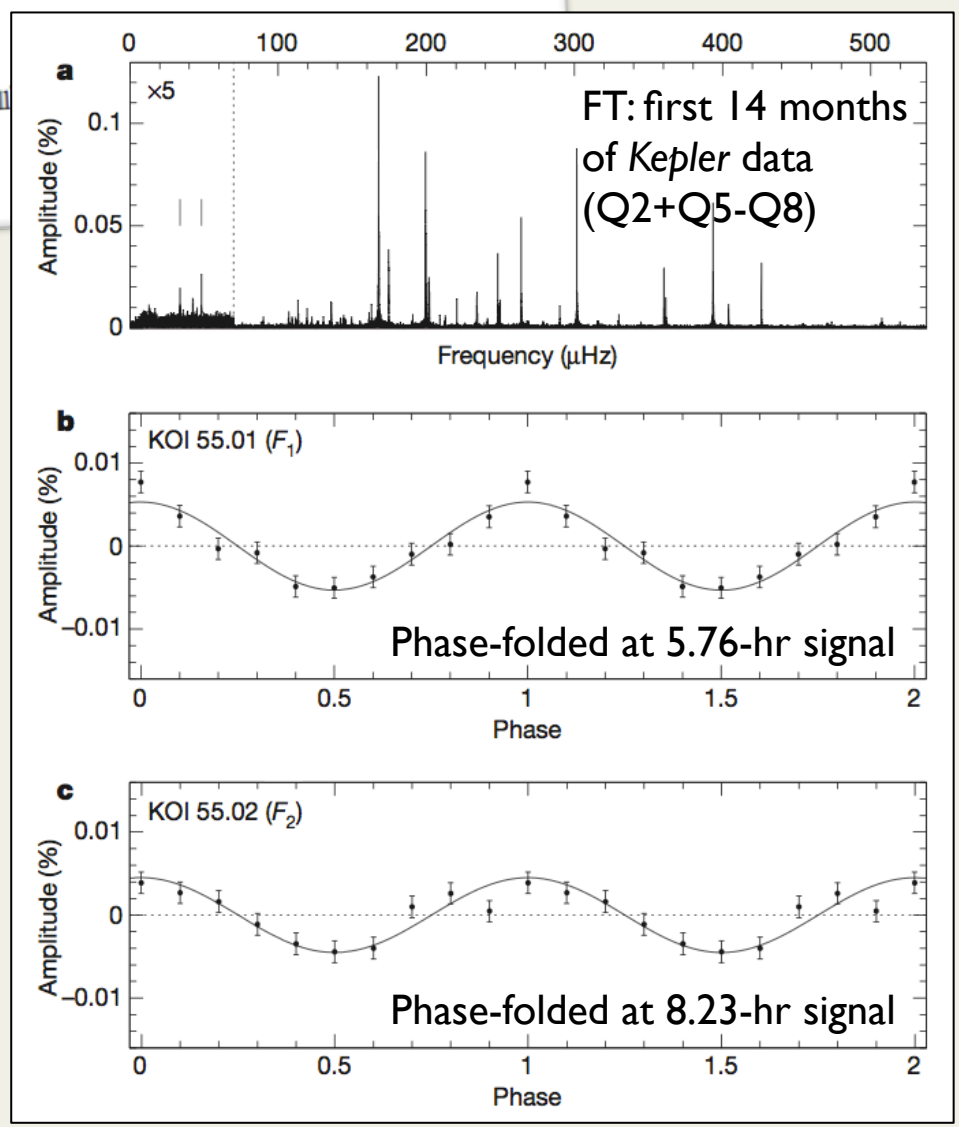
A compact system of small planets around a former red-giant star

S. Charpinet[1,2], G. Fontaine[3], P. Brassard[3], E. M. Green[4], V. Van Grootel[5,6], S. K. Randall
R. H. Østensen[11], S. D. Kawaler[10] & J. H. Telting[12]



KOI 55.01: P_{orb} = 5.7625 hr

(48.204 μHz)

~0.76 R_{Earth}

~0.44 M_{Earth}

a_{sep} = 1.290 $R_\odot$

KOI 55.02: P_{orb} = 8.2293 hr

(33.755 μHz)

~0.87 R_{Earth}

~0.66 M_{Earth}

a_{sep} = 1.636 $R_\odot$

a_{Roche} = 0.624 $R_\odot$

Charpinet et al. 2011, Nature, 480, 496

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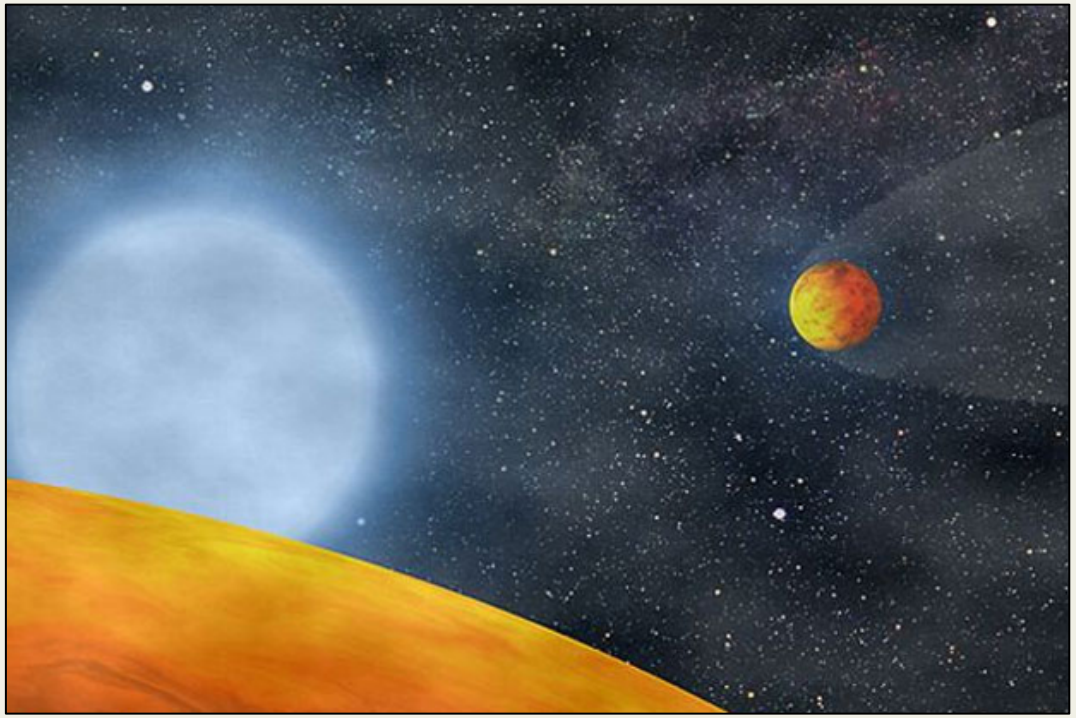
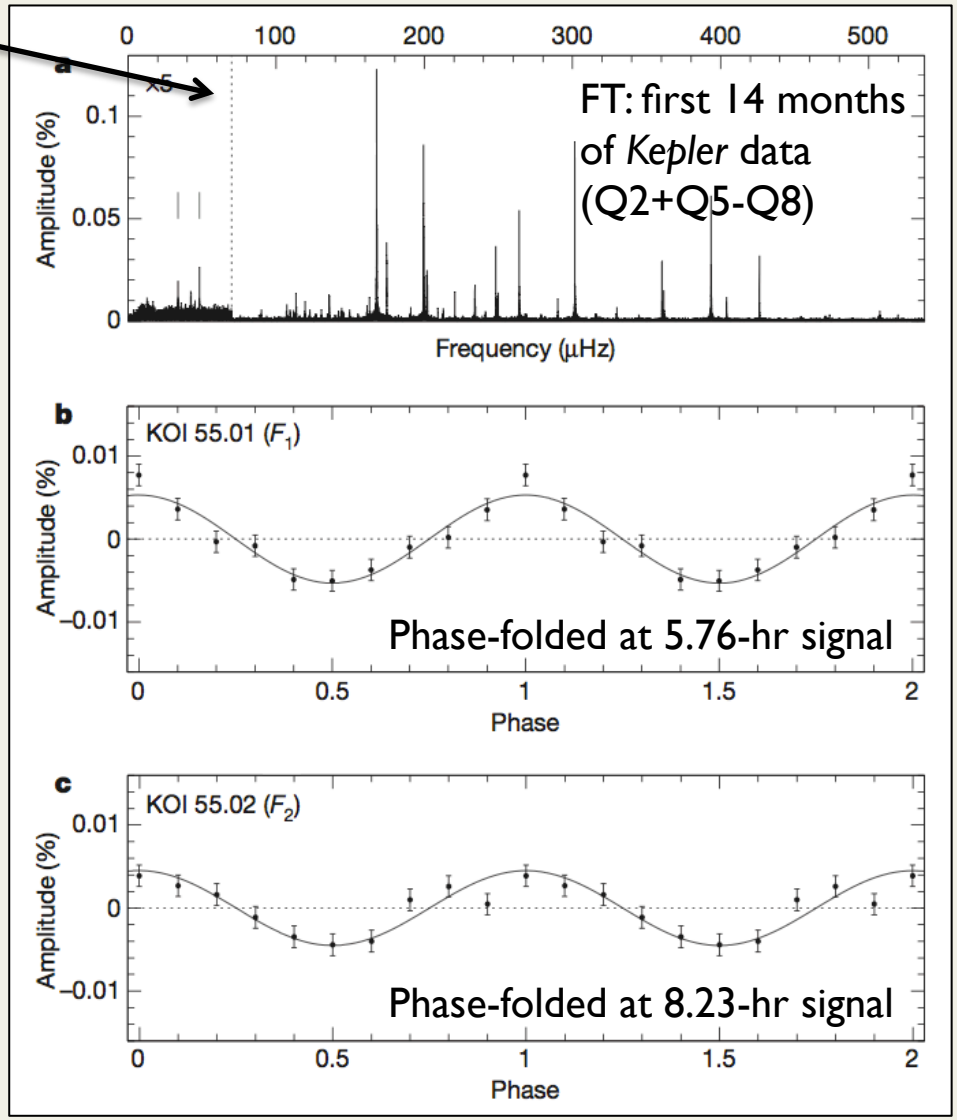
- *g*-modes (standing waves), must be reflected off surface
- <u>theoretical cutoff frequency</u> for ell=1 *g*-modes ~4.5 hr (61 μHz)
  (Hansen et al. 1985, ApJ, 297, 554)

"leaving orbital modulations … the most plausible interpretation."





Charpinet et al. 2011, Nature, 480, 496

KIC 10001893

A&A 570, A130 (2014)
DOI: 10.1051/0004-6361/201424509

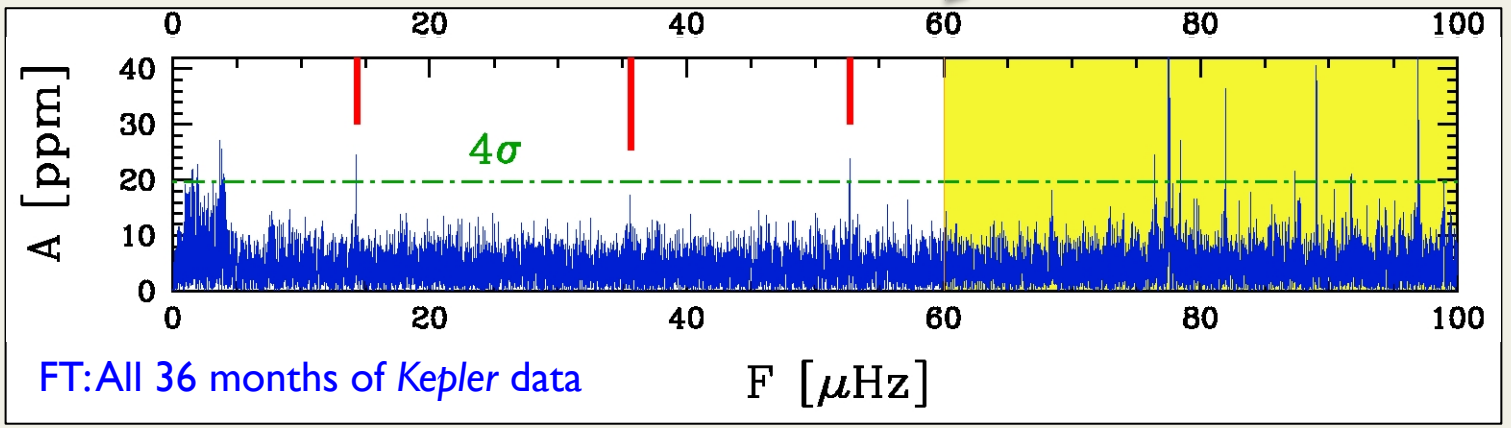
Astronomy & Astrophysics

Kepler detection of a new extreme planetary system orbiting the subdwarf-B pulsator KIC 10001893

R. Silvotti[1], S. Charpinet[2,3], E. Green[4], G. Fontaine[5], J. H. Telting[6], R. H. Østensen[7], V. Van Grootel[8], A. S. Baran[9], S. Schuh[10,11], and L. Fox Machado[12]

$P_1 = 5.273\ hr$
$(52.68\ \mu Hz)$
$P_2 = 7.807\ hr$
$(35.58\ \mu Hz)$
$P_3 = 19.48\ hr$
$(14.26\ \mu Hz)$

theoretical cutoff frequency for *ell*=1 *g*-modes: 60 muHz



FT: All 36 months of *Kepler* data

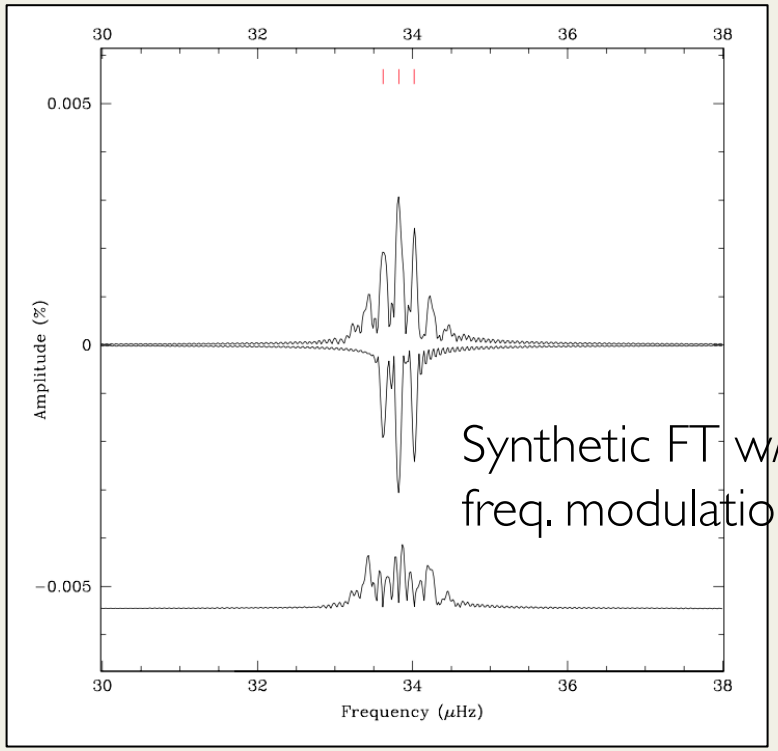
Silvotti et al. 2014, A&A, 570, A130

Issues Complicating the Planetary Hypothesis

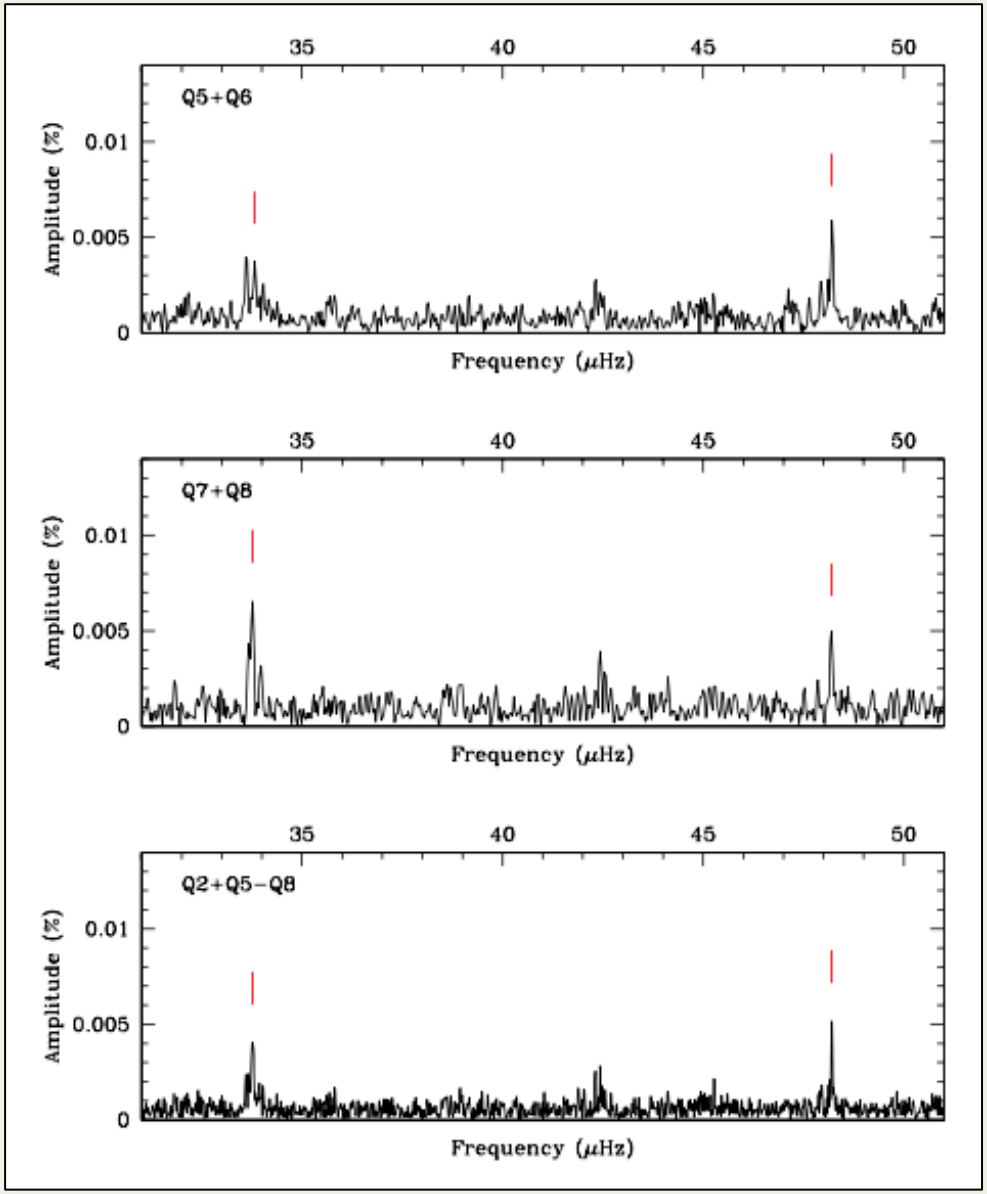
- Signals are unstable in frequency
- Signals are unstable in amplitude
- Some signals are in impossible planetary configurations

1. Signals are Unstable in Frequency

- 8.23-hr signal already showed frequency instability after first year
- Charpinet+ 2011 suggestion: Dynamical (orbital) perturbations from a third body (w/ period ~57 days)

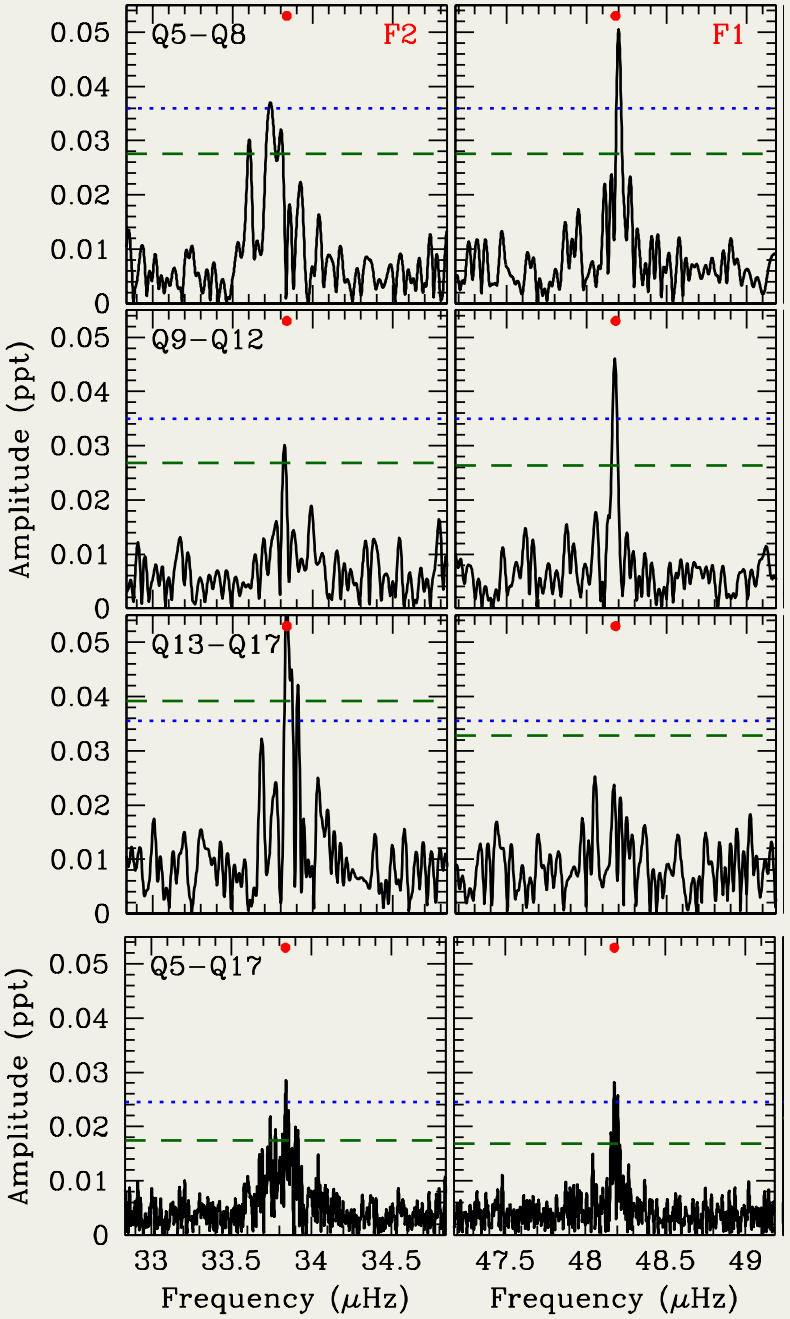


Synthetic FT w/ freq. modulation



Charpinet et al. 2011, Nature, 480, 496

1. Signals are Unstable in Frequency



Year 1:
All data used by Charpinet+ 2011

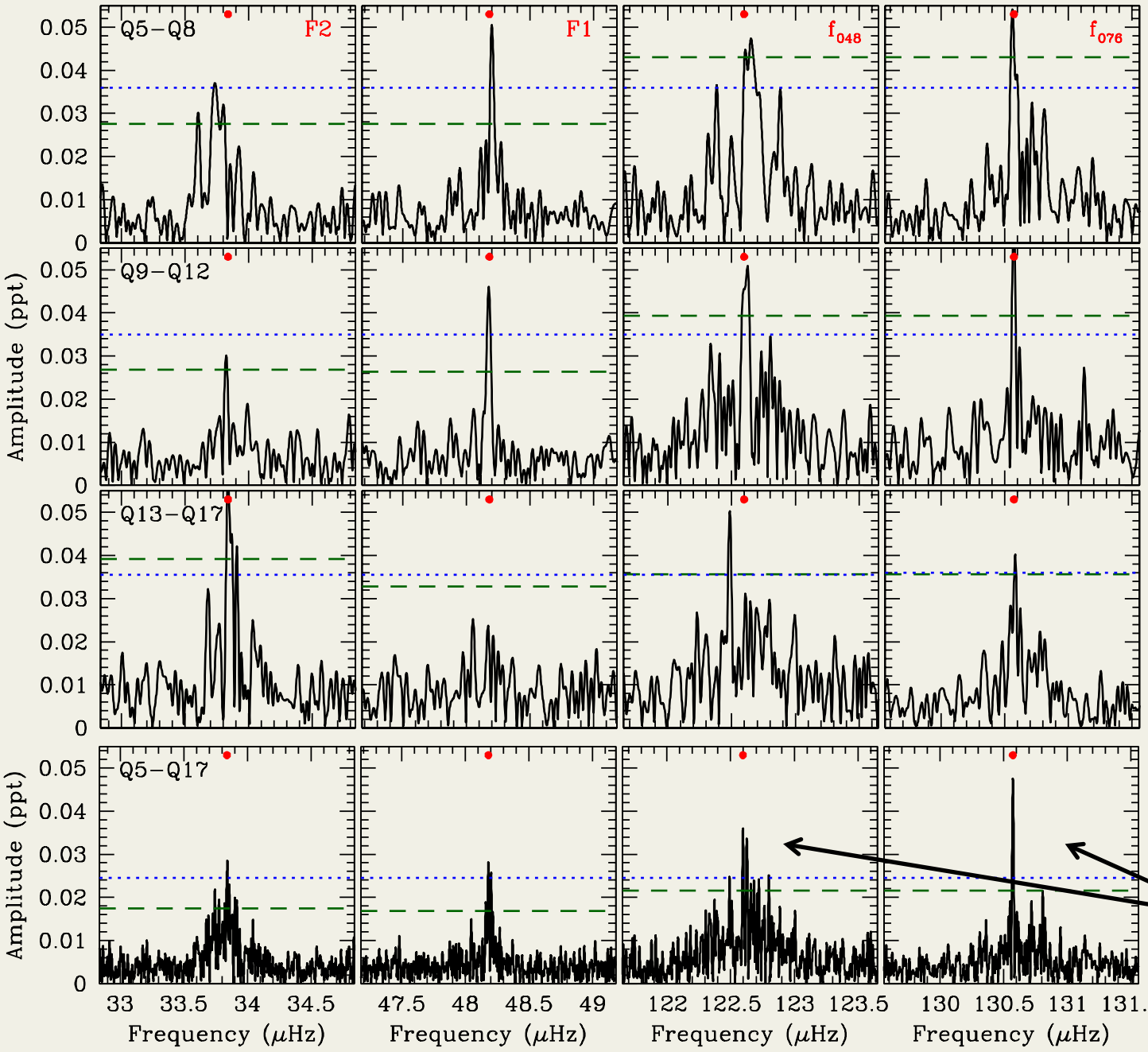
Year 2

Year 3

All *Kepler* data

- The frequency variability is <u>not long-term coherent</u>
- Why does it affect one mode and not the other? ("~3:2 resonance")

1. Signals are Unstable in Frequency



Year 1

Year 2

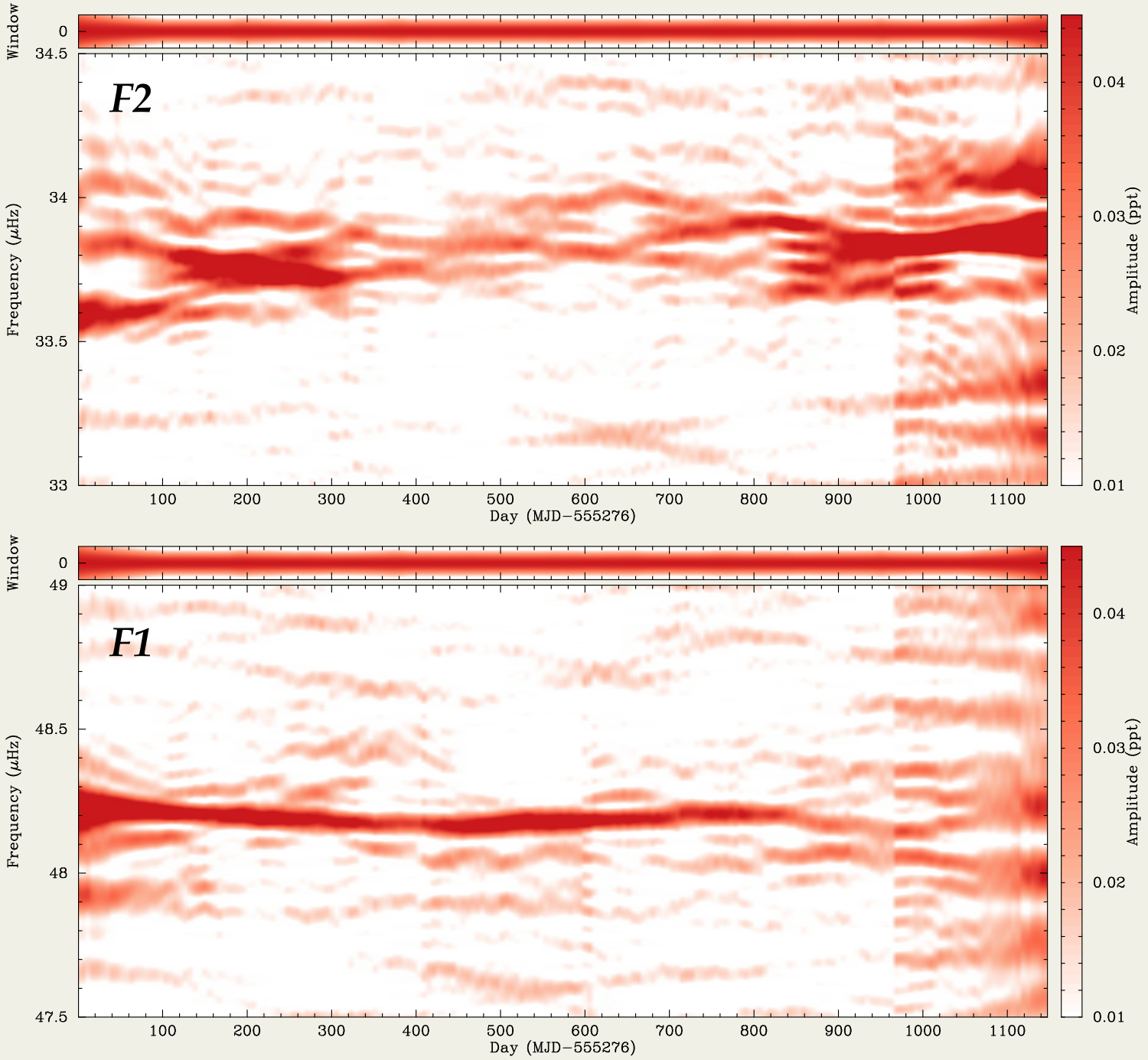
Year 3

All *Kepler* data

Right two panels are two random *g*-mode pulsations in the same star

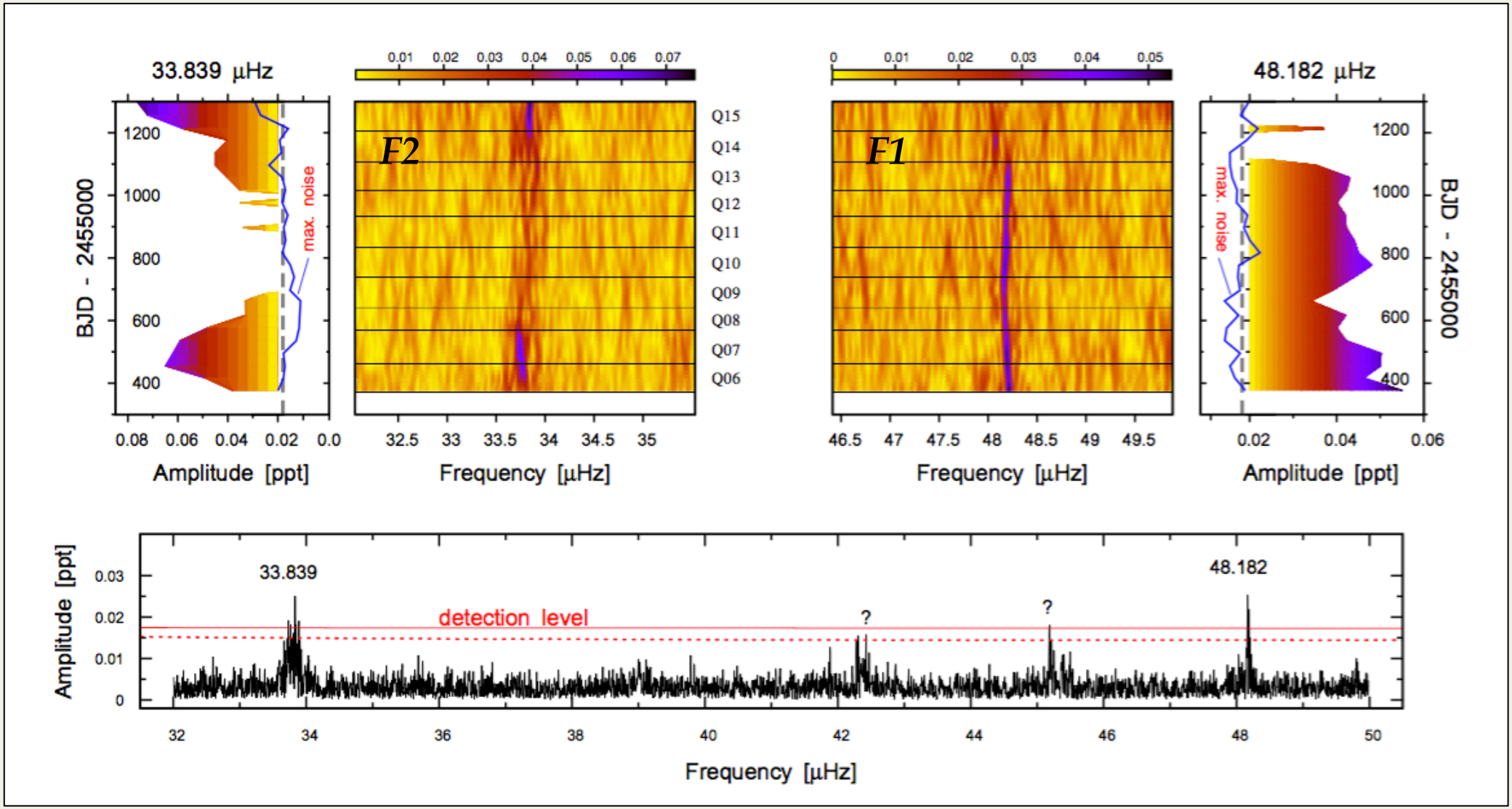
2. Signals are Unstable in Amplitude

(200-day sliding window, standard *Kepler* pipeline)



2. Signals are Unstable in Amplitude

(200-day sliding window, custom pixel mask)



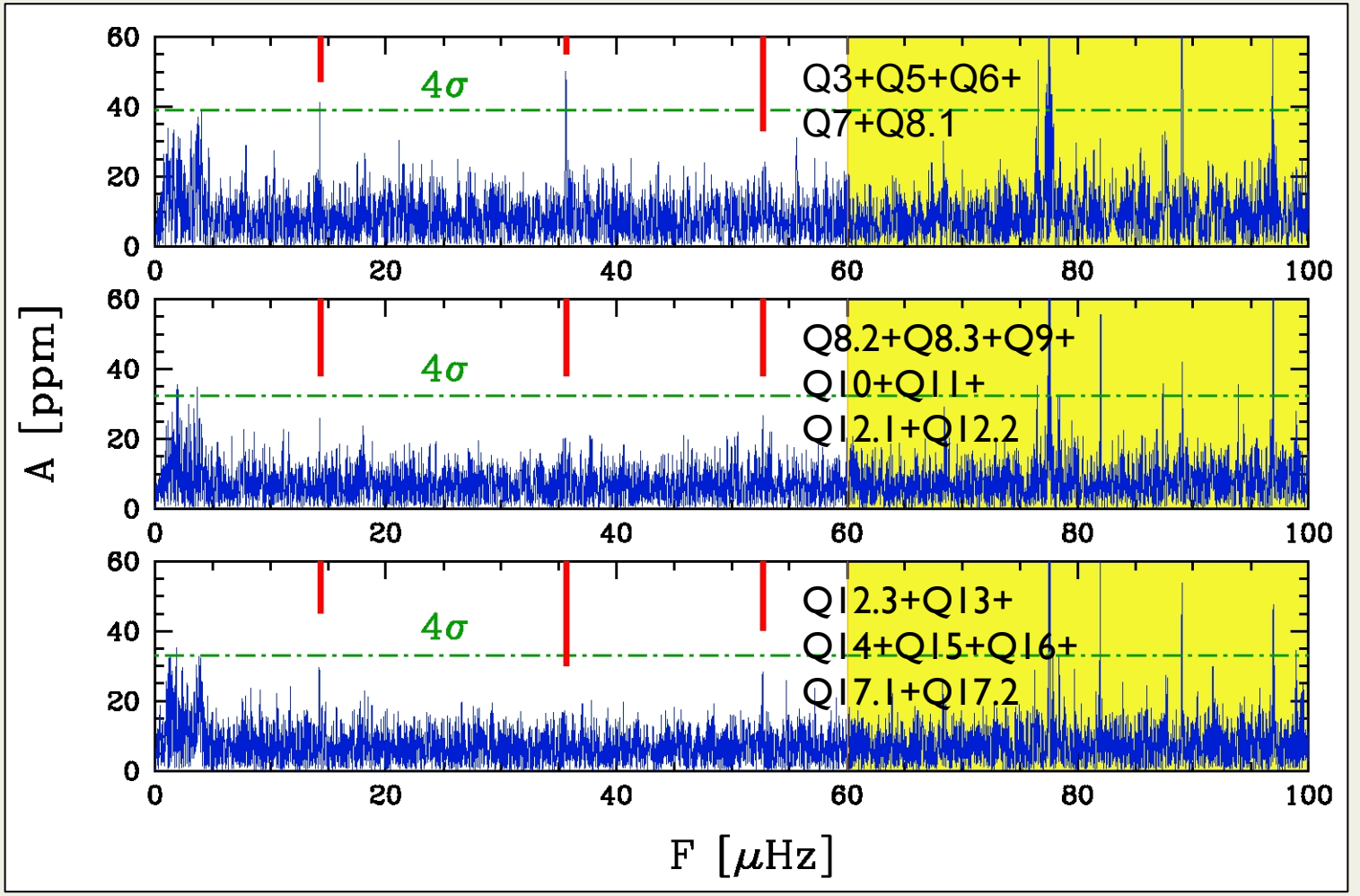
Jurek Krzesinski 2015, private communication

2. Signals are Unstable in Amplitude

First 13 months

Next 13 months

Last ~13 months

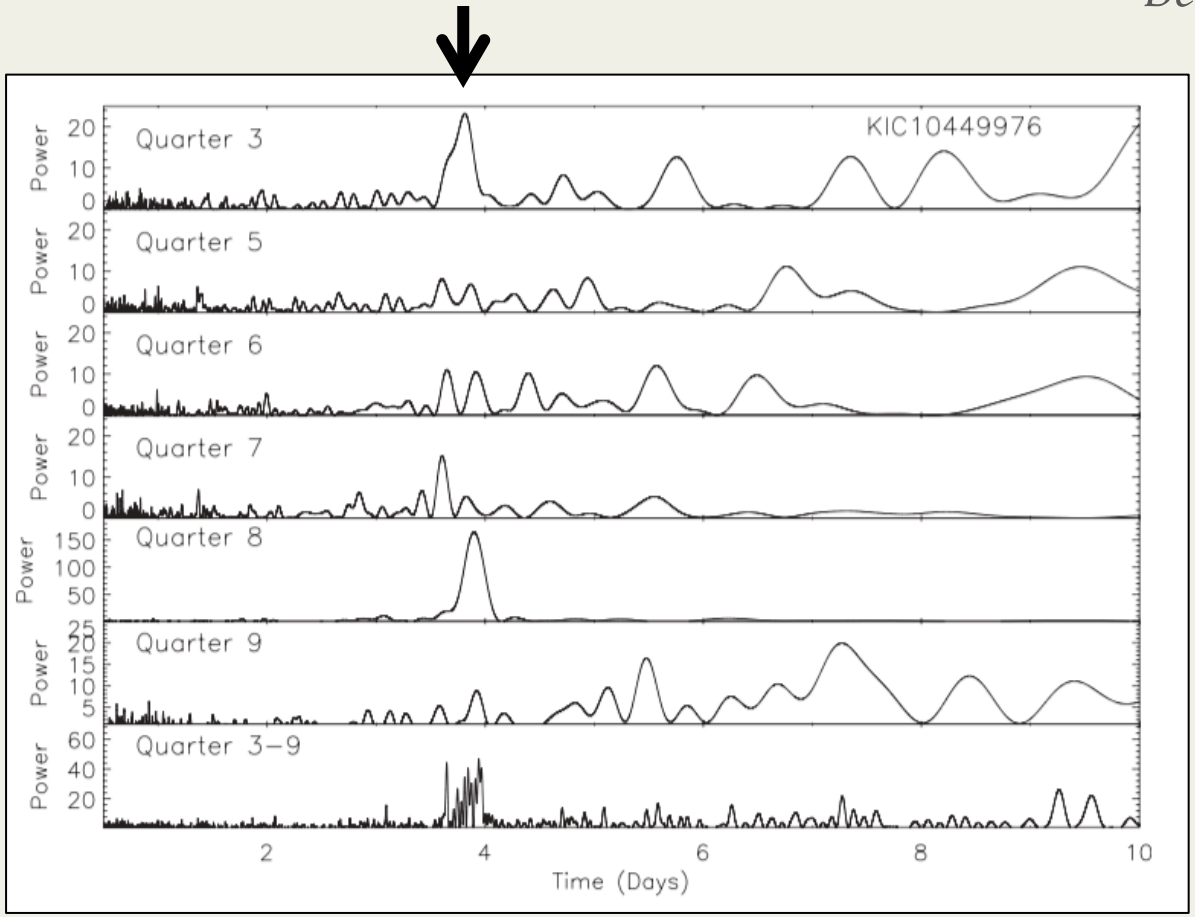


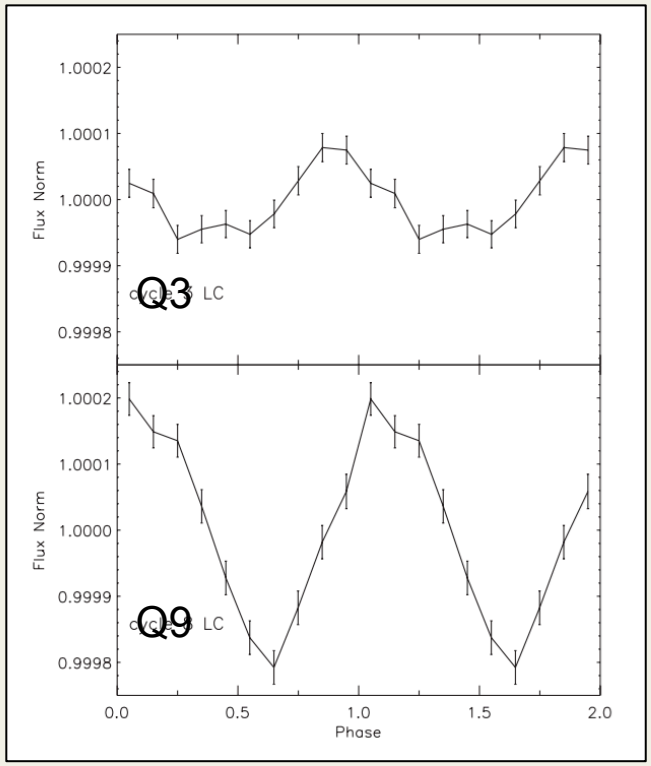
Silvotti et al. 2014, A&A, 570, A130

2. Signals are Unstable in Amplitude

- 40,000 K sdO KIC 10449976 shows unstable ~3.9 day variability
- "The stochastic variations in period and light amplitude are attributed to weather on … a tidally locked planet that is heated to ~5000 K by the UV radiation from the hot sdO star."

-- Bear & Soker 2014, MNRAS, 437, 1400

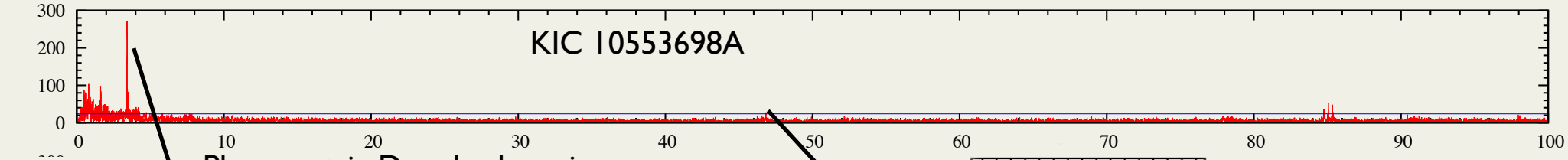




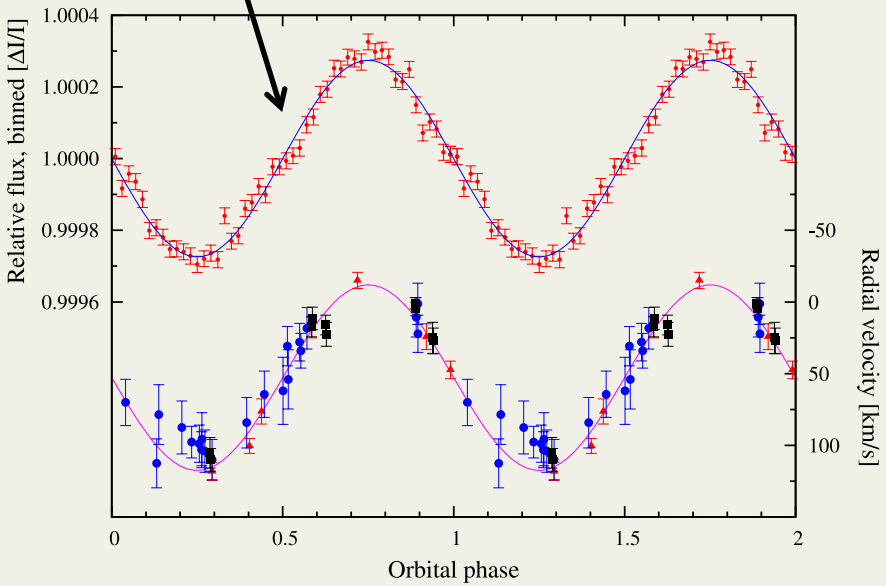
Jeffery et al. 2013, MNRAS, 429, 3207

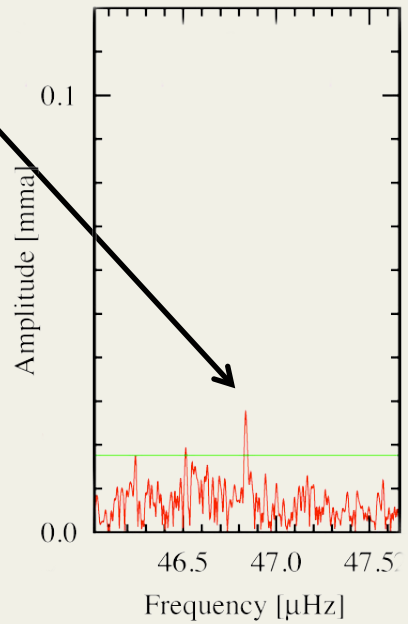
3. Signals Exist in Impossible Planetary Systems

- KIC 10553698A: sdBV in 3.4-day binary w/ ~0.6 $M_\odot$ WD
  - 5σ significant signal at 46.84 μHz (5.93 hr)
- KIC 11558725A: sdBV in 10-day orbit w/ >0.63 $M_\odot$ WD (Telting+ 2012)
  - Significant signals at 37.86 μHz (7.34 hr) and 49.78 μHz (5.58 hr)
- Dynamics don't allow for planet(s) to exist inside these **WD+sdBs**



Photometric Doppler beaming signal from ~0.6 $M_\odot$ companion



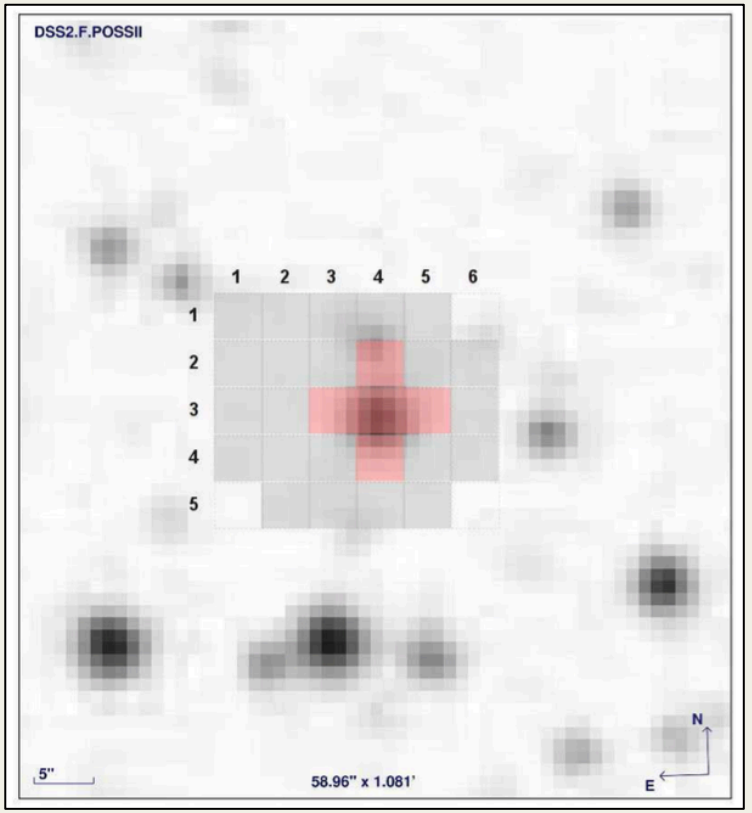


Significant signal at 46.84 μHz (5.93 hr)

Østensen et al. 2014, A&A, 569, 15

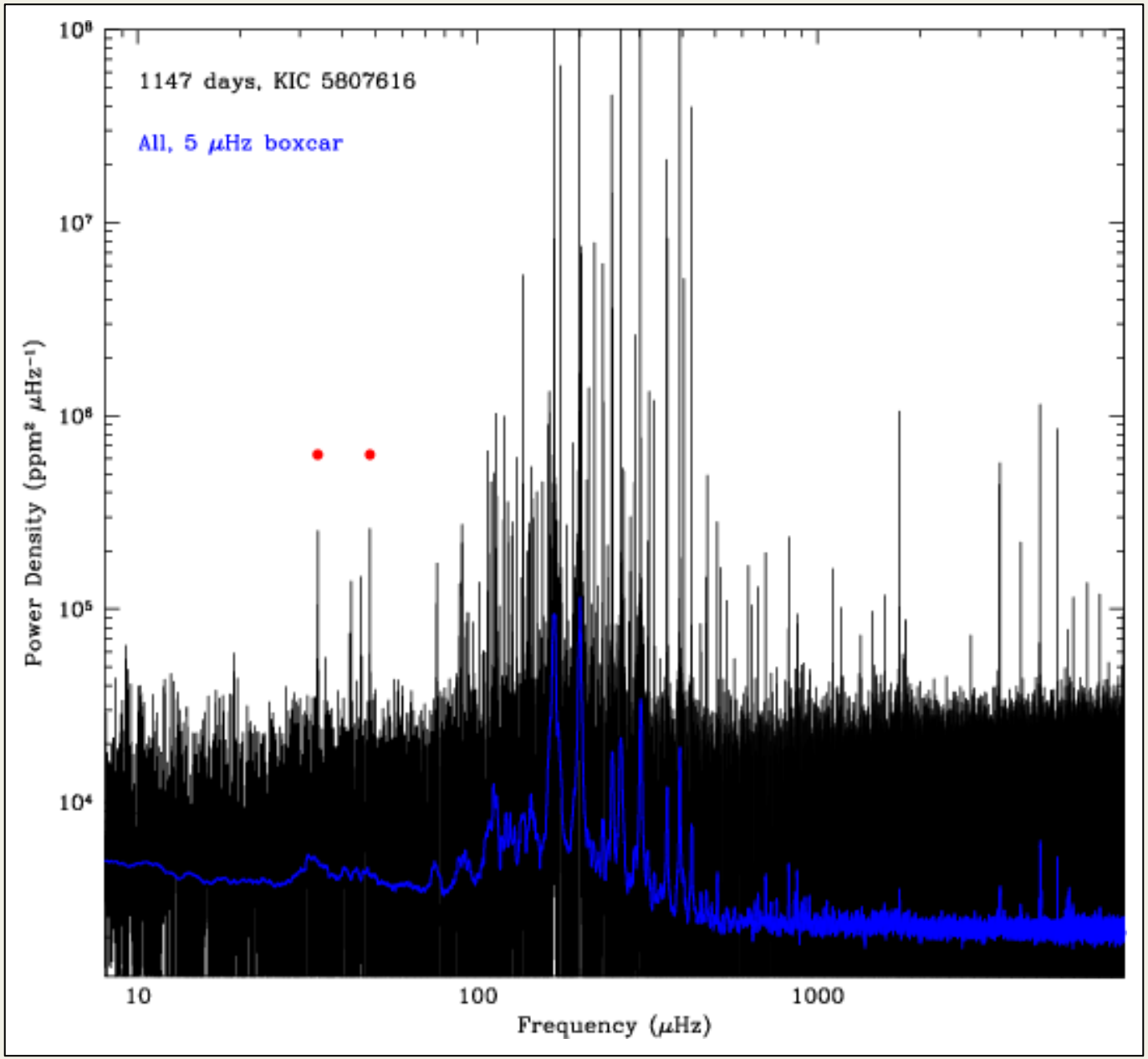
If Not Planets, then What?

- *Back to the drawing board:*
  - ~~*Contamination from a nearby star*~~
    - *Custom pixel masks*
  - ~~*Spurious Kepler frequencies*~~
    - *Not in Baran 2013 (arXiv: 1306.5472)*
  - ~~*Rotational modulations*~~
    - *p-mode splittings: P_{rot} ~ 40 days*
  - *Stellar pulsations*
    - *Cutoff frequency?*
  - *Nonlinear combination frequencies*
    - *Possible difference frequencies?*
  - ~~*Reflection off close-in planets*~~



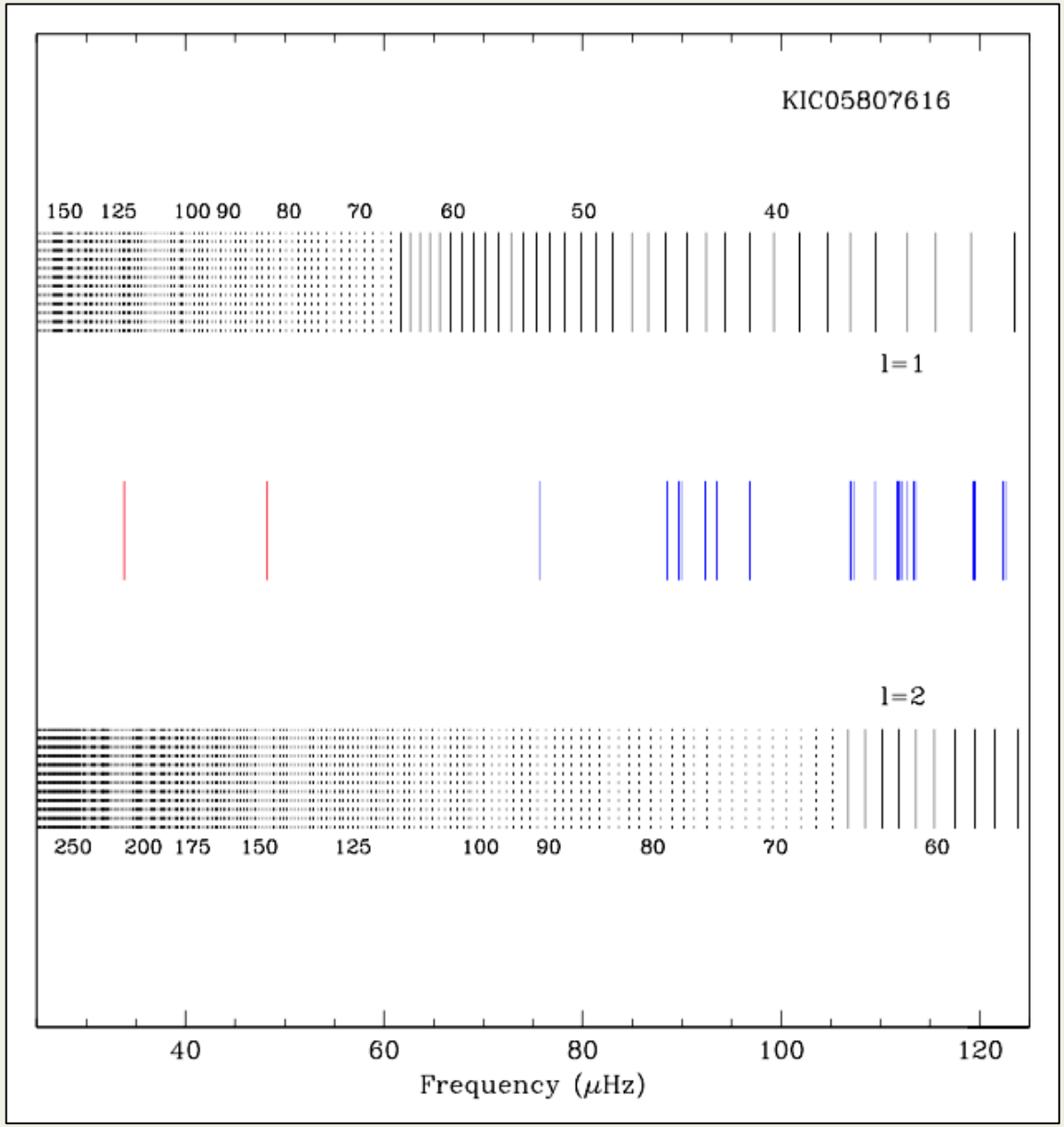
Revisiting the Theoretical Cutoff Frequency

- Critical frequency delineating standing/running waves
- "Surface reflection condition"
- Charpinet+ 2011 used full seismic models, found $\nu_{crit,l=1} = 61.0$ μHz *(Hansen et al. 1985, ApJ, 297, 554)*



Revisiting the Theoretical Cutoff Frequency

- Not an energy barrier, just an energy sink: Amplitudes shrink but not necessarily to 0
- Really want to compare <u>energy leakage</u> e-folding timescale to <u>intrinsic driving</u> e-folding timescale
- Truly a non-adiabatic problem, but adiabatic approx. should be decent
- $\nu_{crit,l=1} = 61.0\ \mu Hz$
- $\nu_{crit,l=2} = 105.7\ \mu Hz$

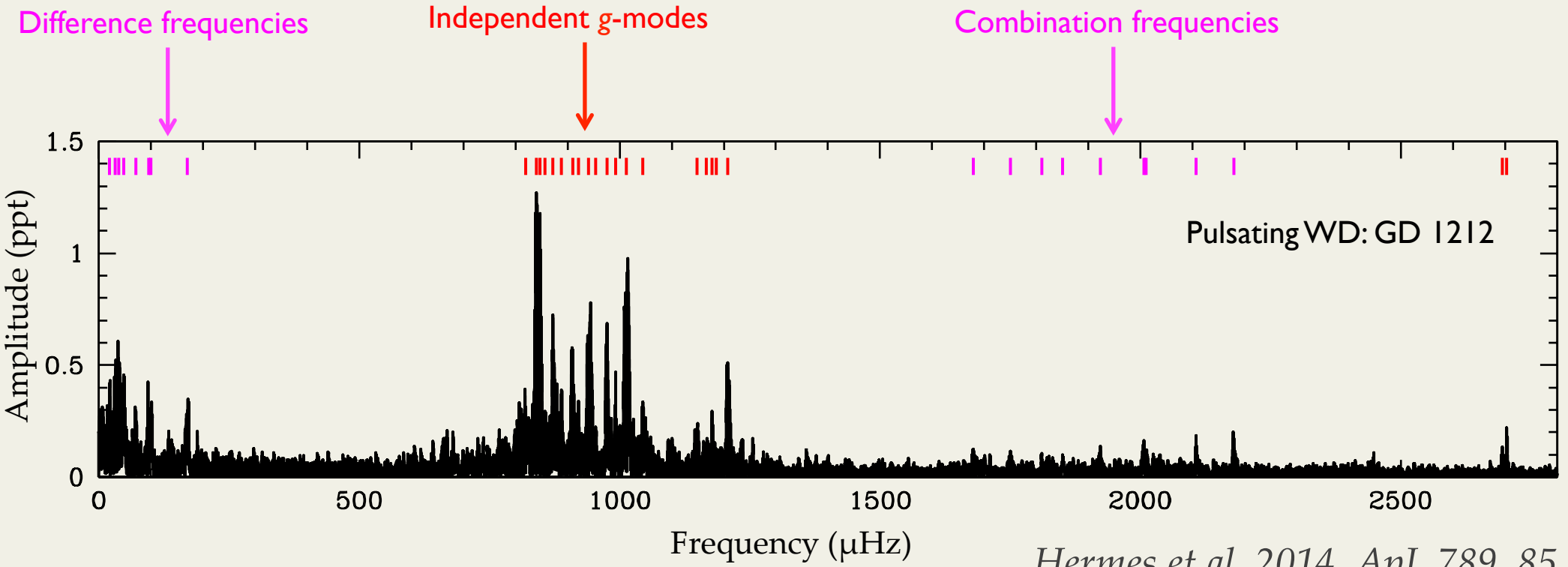


Charpinet et al. 2011, Nature, 480, 496

Nonlinear Combination Frequencies?

e.g., $f_1 + f_2 = f_3$ or $f_1 - f_2 = f_3$

- 14.5 hr signal in *K2* run on white dwarf GD 1212: $f_{10} - f_8$



Hermes et al. 2014, ApJ, 789, 85

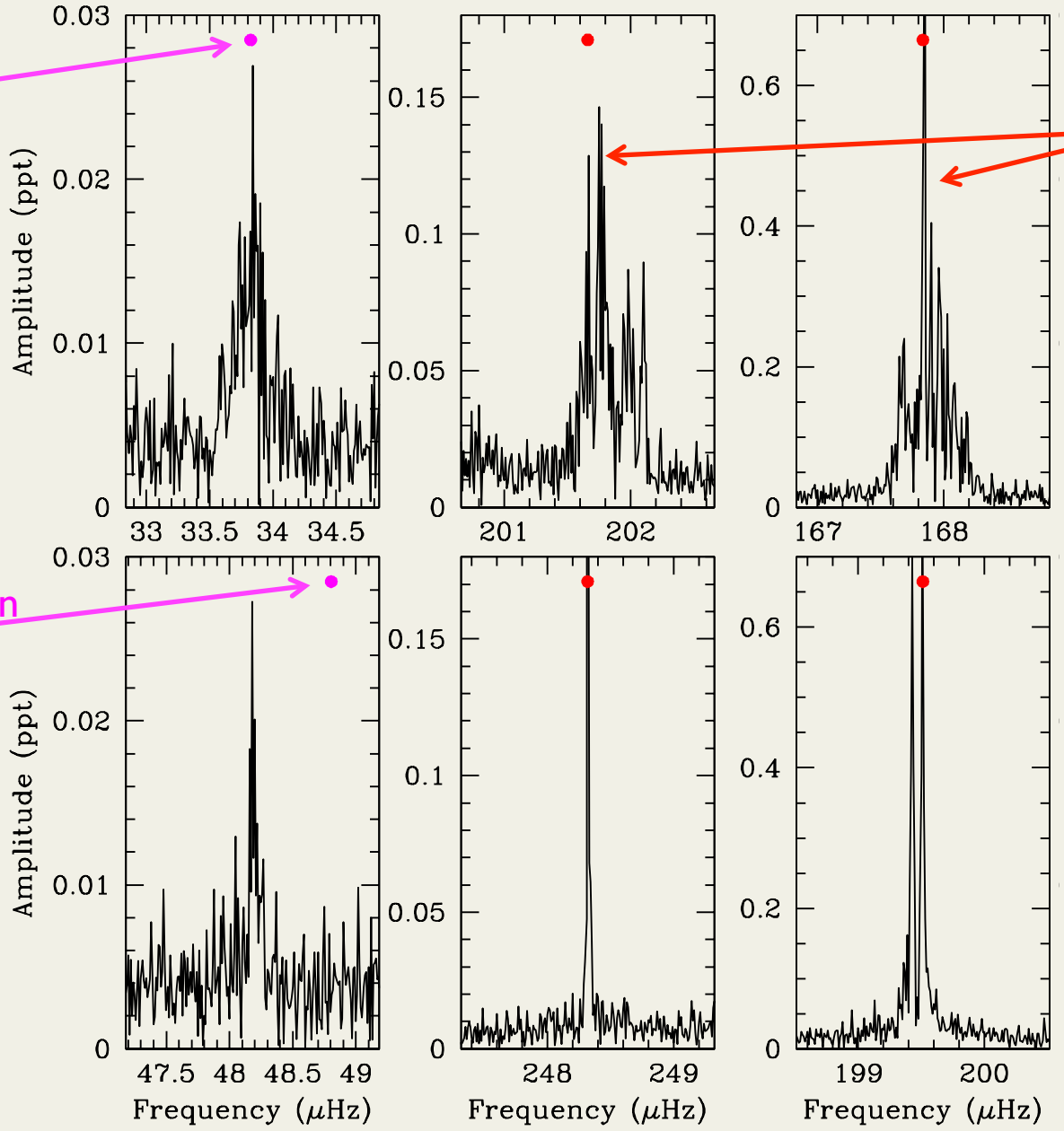
Nonlinear Combination Frequencies?

$f_{15} - f_1 = 33.82$ μHz $f_{15} = 201.66$ μHz $f_1 = 167.84$ μHz

Exact nonlinear combination (can explain F2 as $f_{15} - f_1$)

Independent *g*-modes in KIC 5807616

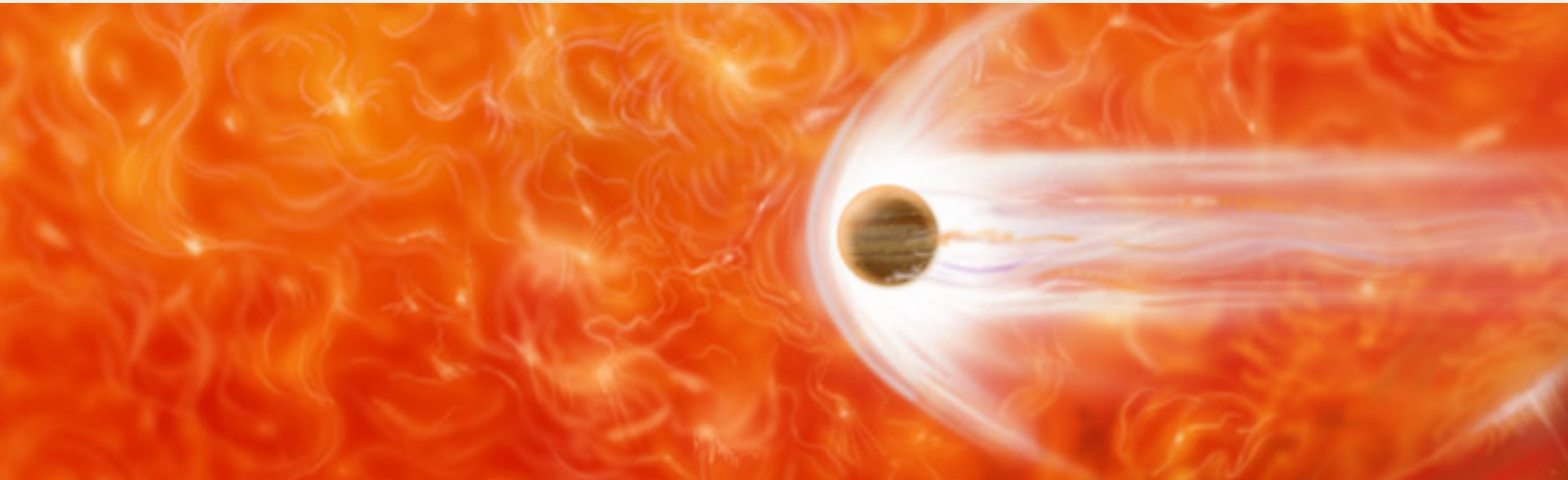
Close but inexact nonlinear combination (cannot readily explain F1, possibly f_{11}-f_2?)

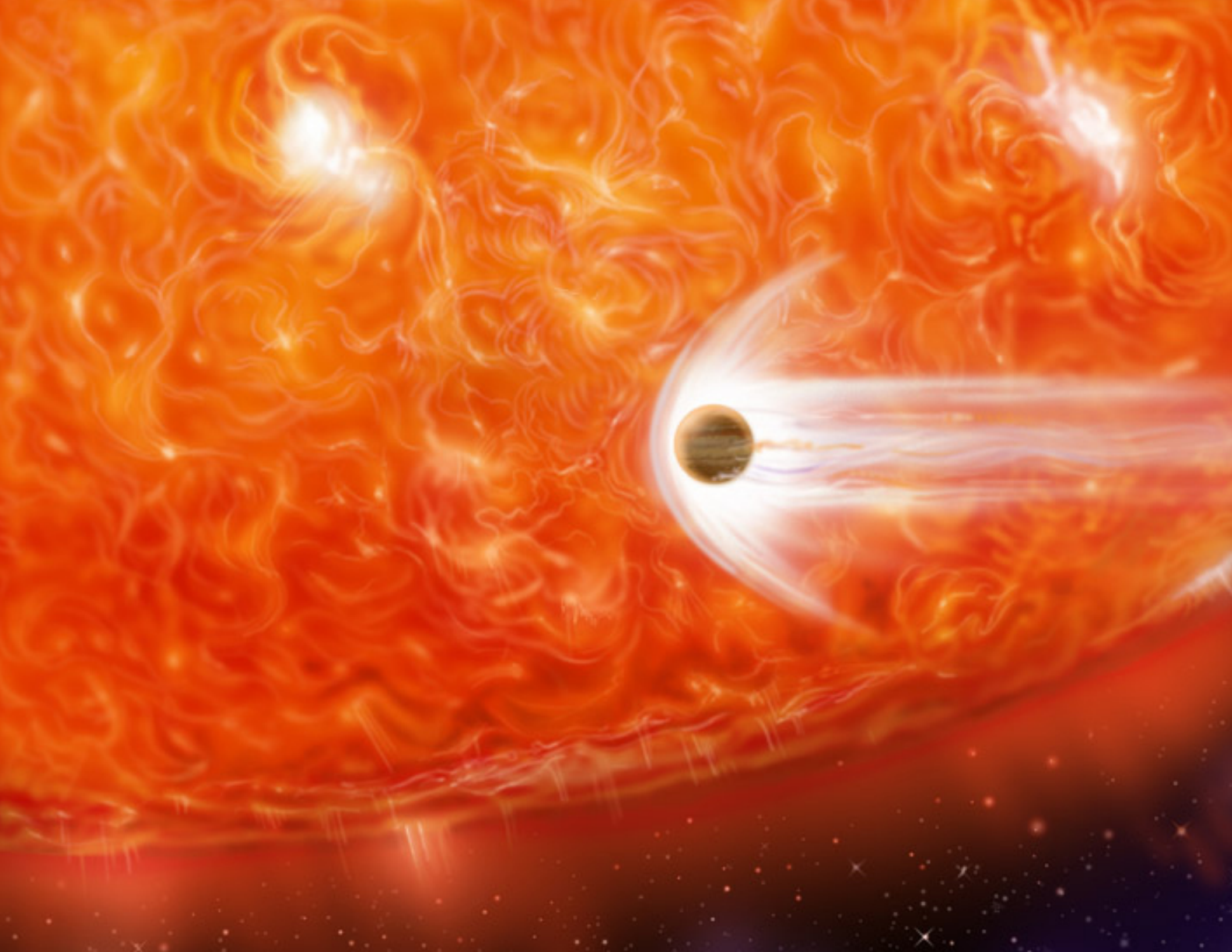


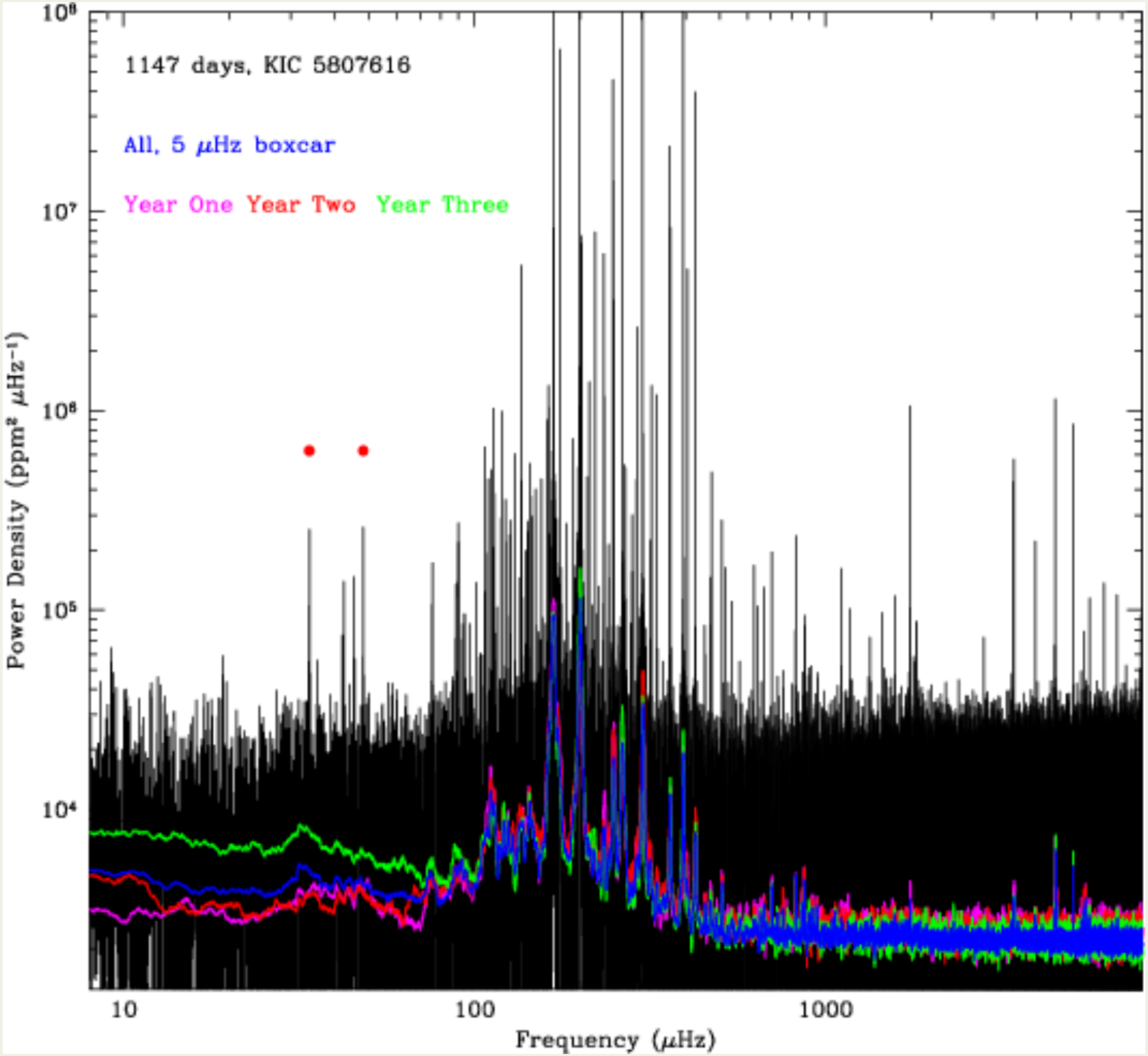
$f_{11} - f_2 = 48.81$ μHz $f_{11} = 248.32$ μHz $f_2 = 199.51$ μHz

Conclusion: Major Flaws w/ 'Extreme sdB Planets'

- At least **four** sdBVs in *Kepler* show significant 5-9 hr variability
- Major complications to these being reflections off close-in planets:
  - Signals are **unstable in frequency**
  - Signals are **unstable in amplitude**
  - Some signals are in **impossible planetary configurations**
- A **connection with pulsations** is the most plausible explanation, but several interesting questions remain






1147 days, KIC 5807616
All, 5 μHz boxcar
Year One Year Two Year Three
Power Density (ppm² μHz⁻¹)
10⁸
10⁷
10⁶
10⁵
10⁴
10
100
1000
Frequency (μHz)