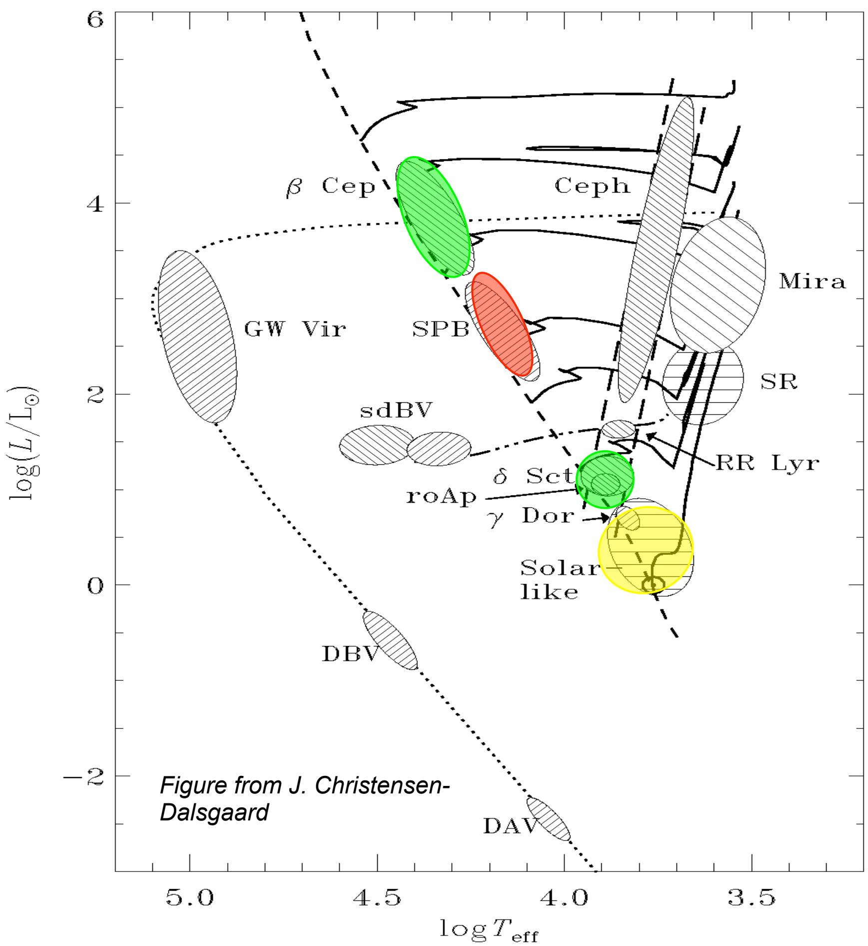
A-F star puzzles as revealed by the NASA Kepler spacecraft



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29th Annual NM Astronomy Symposium

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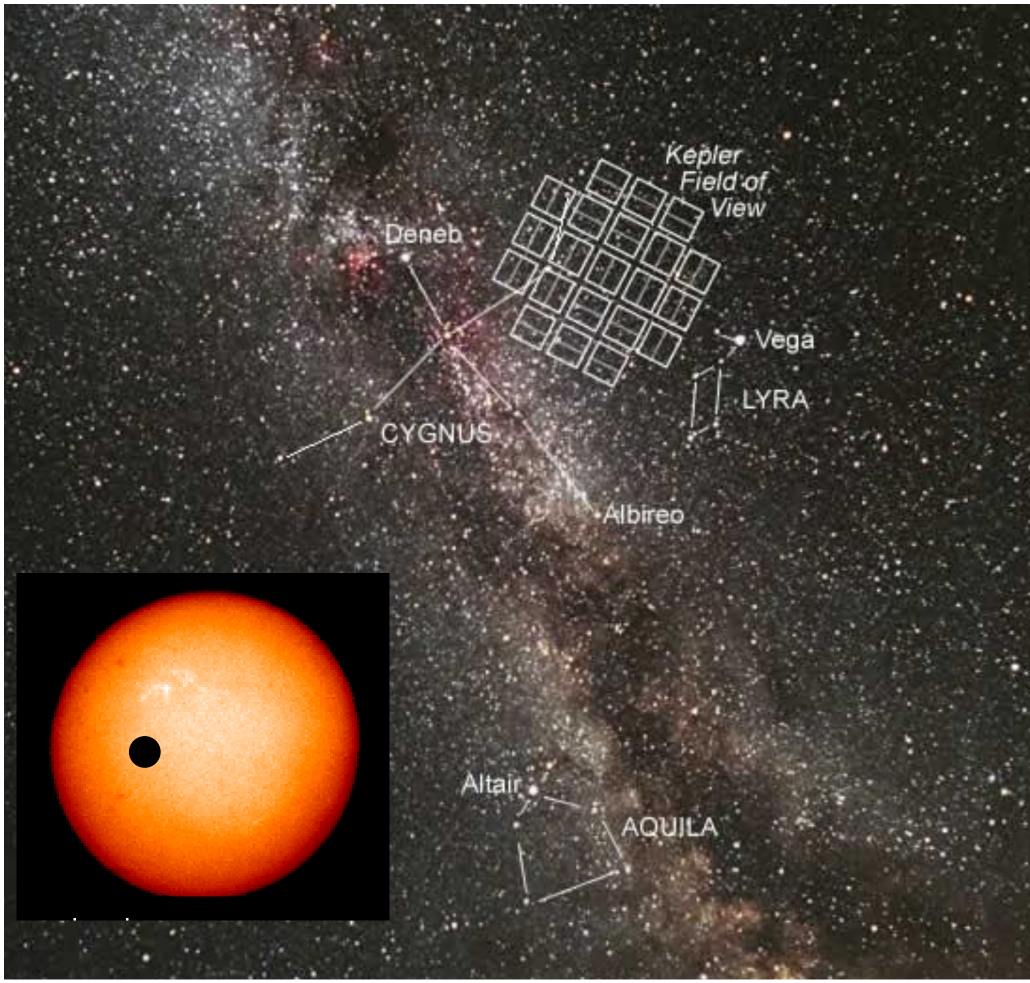
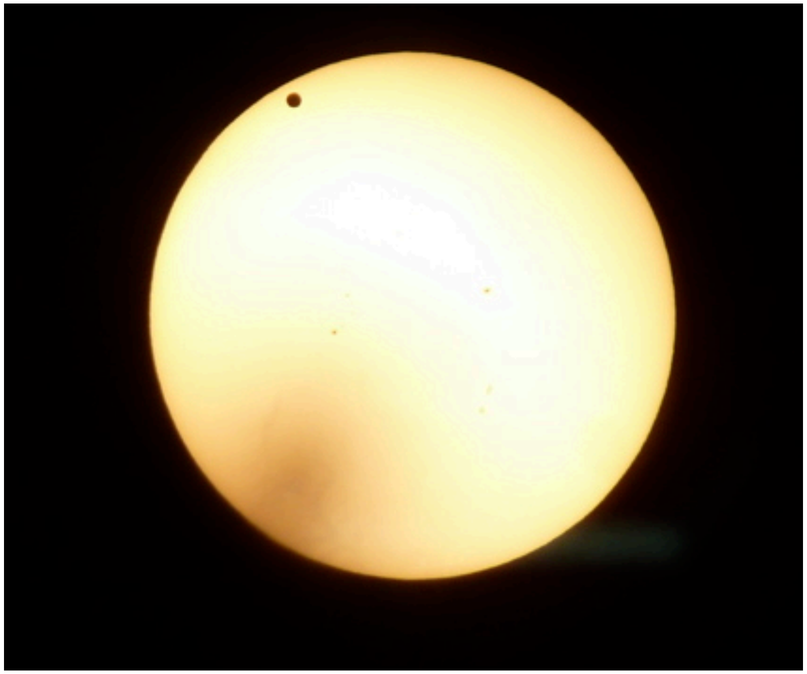
The NASA Kepler Mission

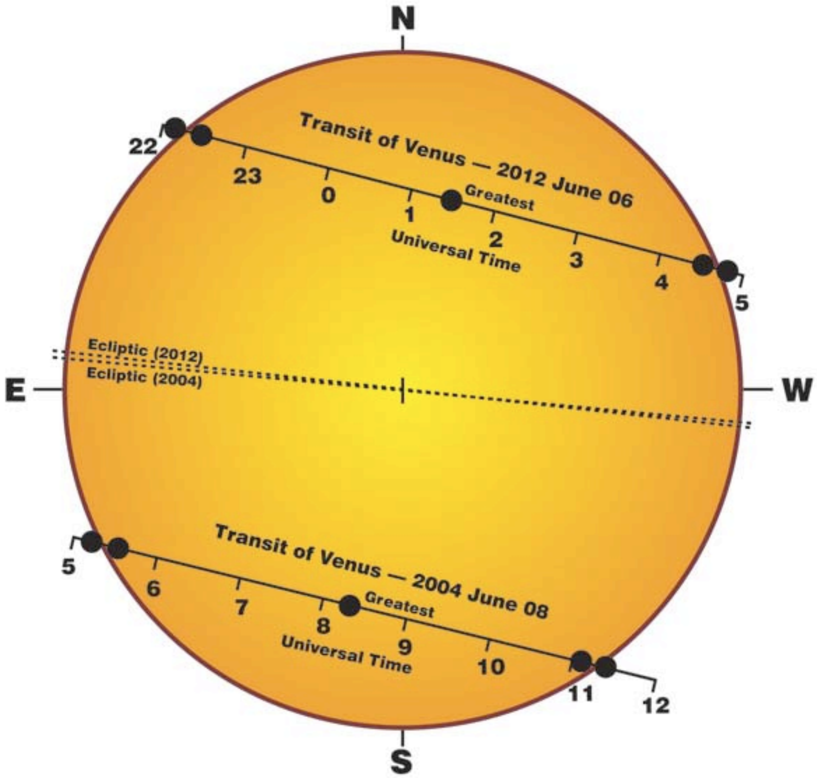


- Launched March 6, 2009
- Search for habitable planets
- High-precision CCD photometry to detect planetary transits
- Secondary mission to survey and monitor variability of stars for asteroseismology

http://kepler.nasa.gov

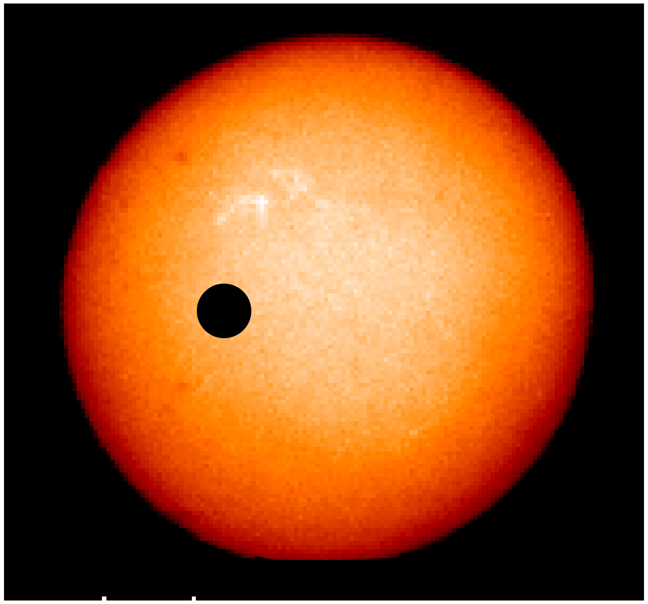
Venus Transit June 5, 2012

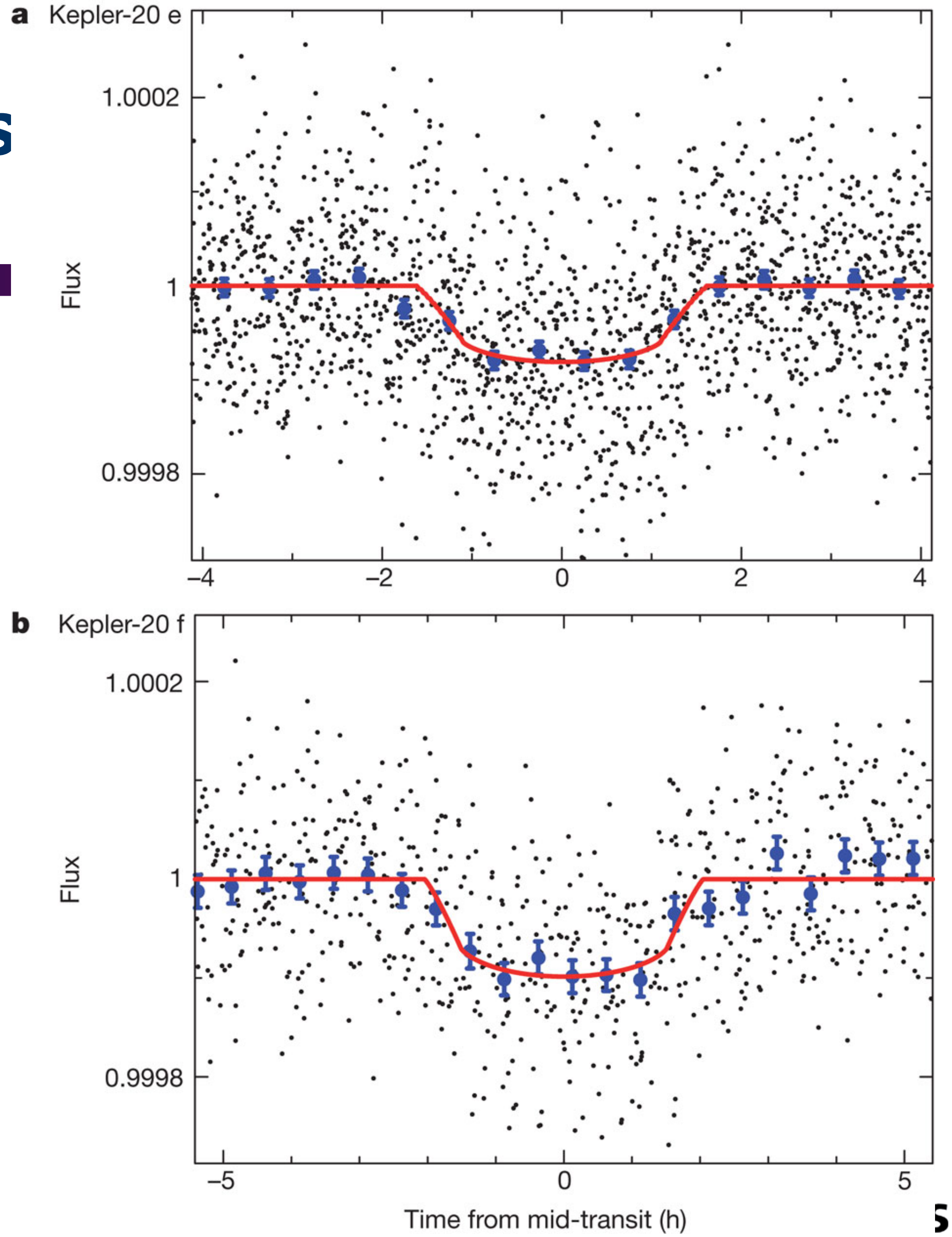




Kepler finds planets by transits

- 238 confirmed planets
- 3538 planet candidates





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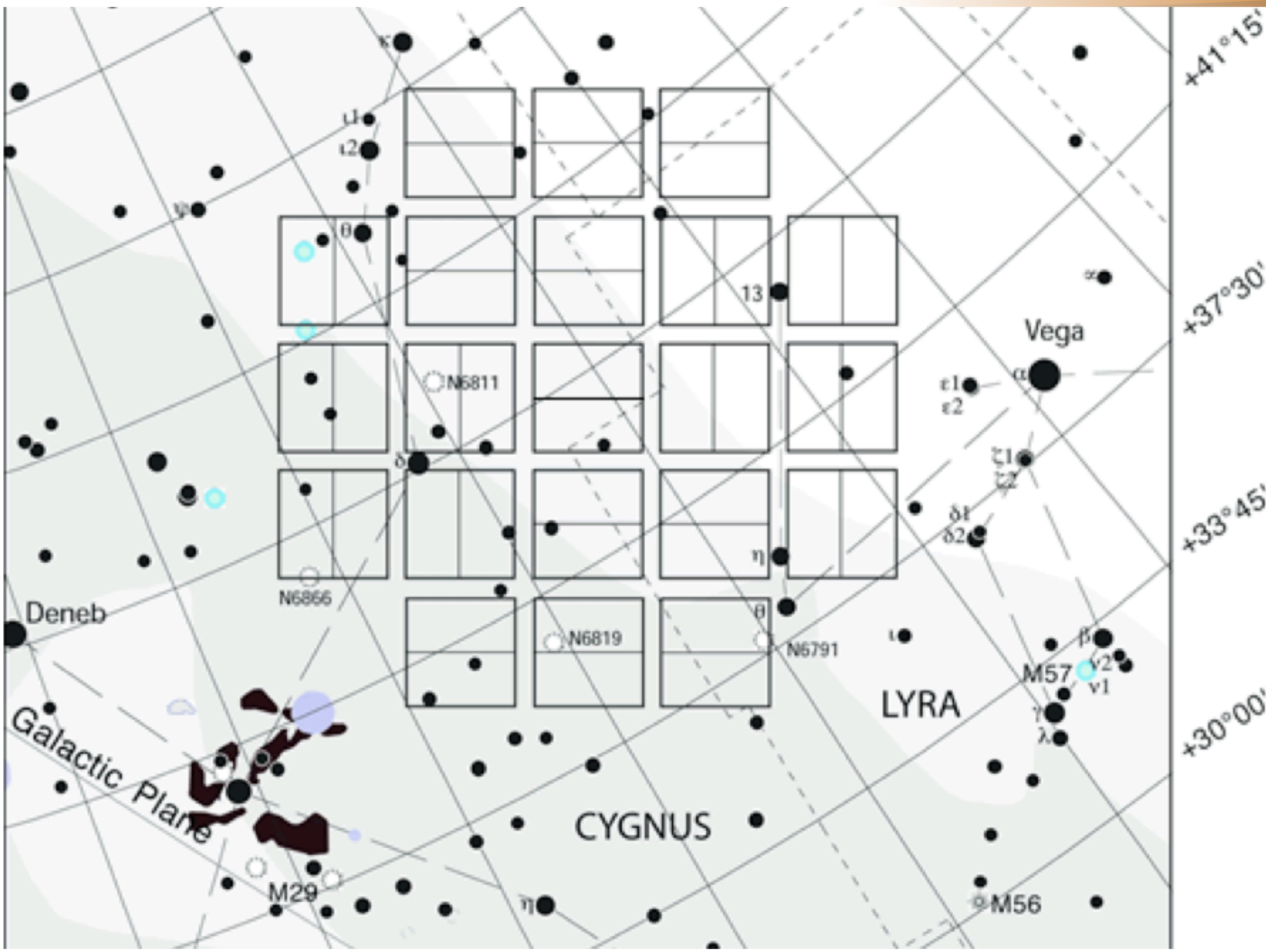
Kepler uses 21 CCD arrays to monitor 13+ million stars. 1 minute 'short cadence' or 30 minute 'long-cadence' integrations



Stars of nearly every evolutionary stage exhibit pulsations
This talk will focus on the region of γ Dor and δ Sct variables

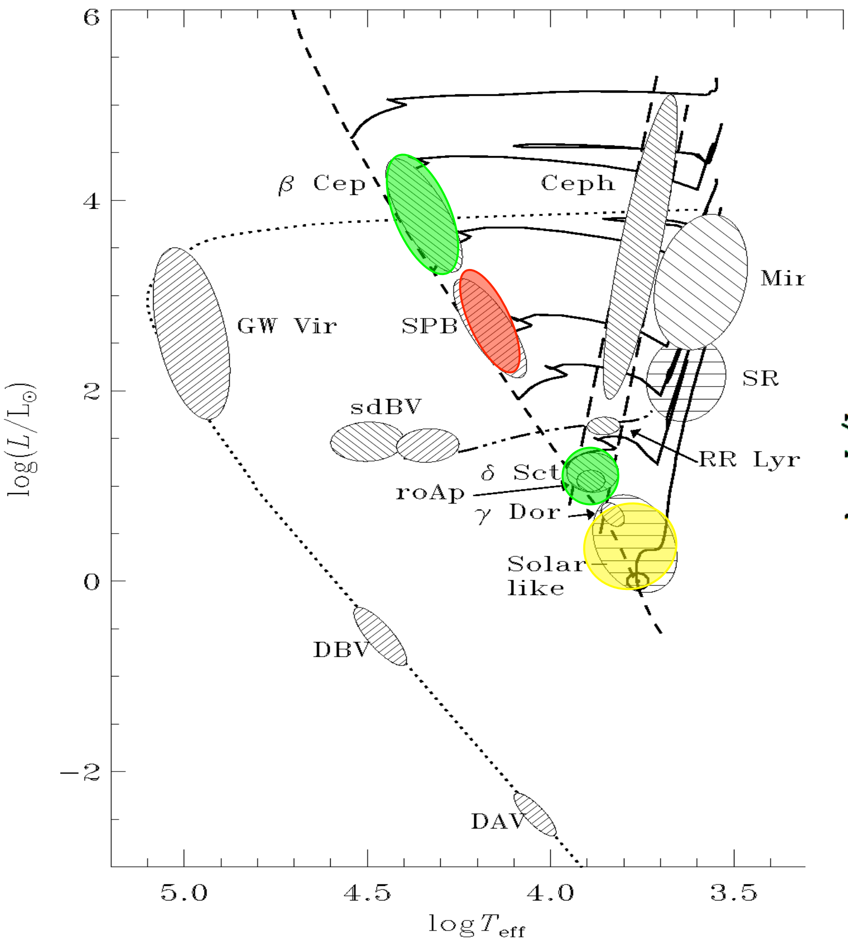
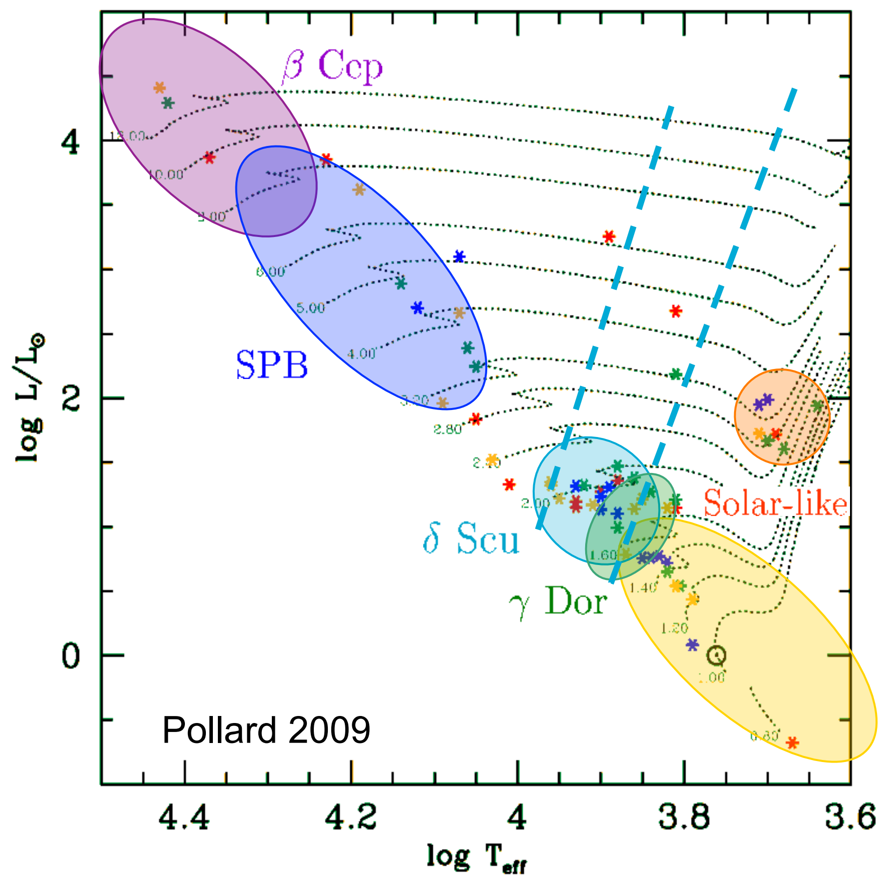


Figure from J. Christensen-Dalsgaard



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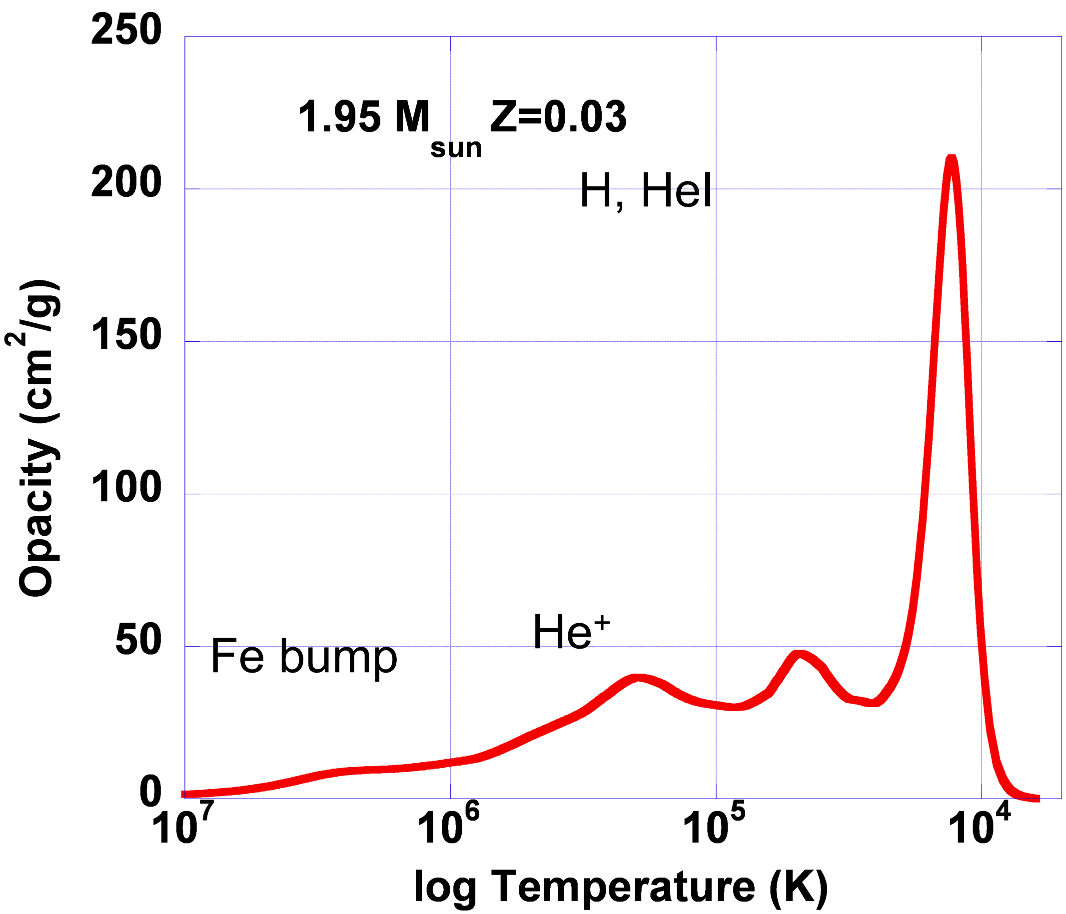
The δ Sct pulsations are driven by the κ effect from second ionization of He at about 50,000 K



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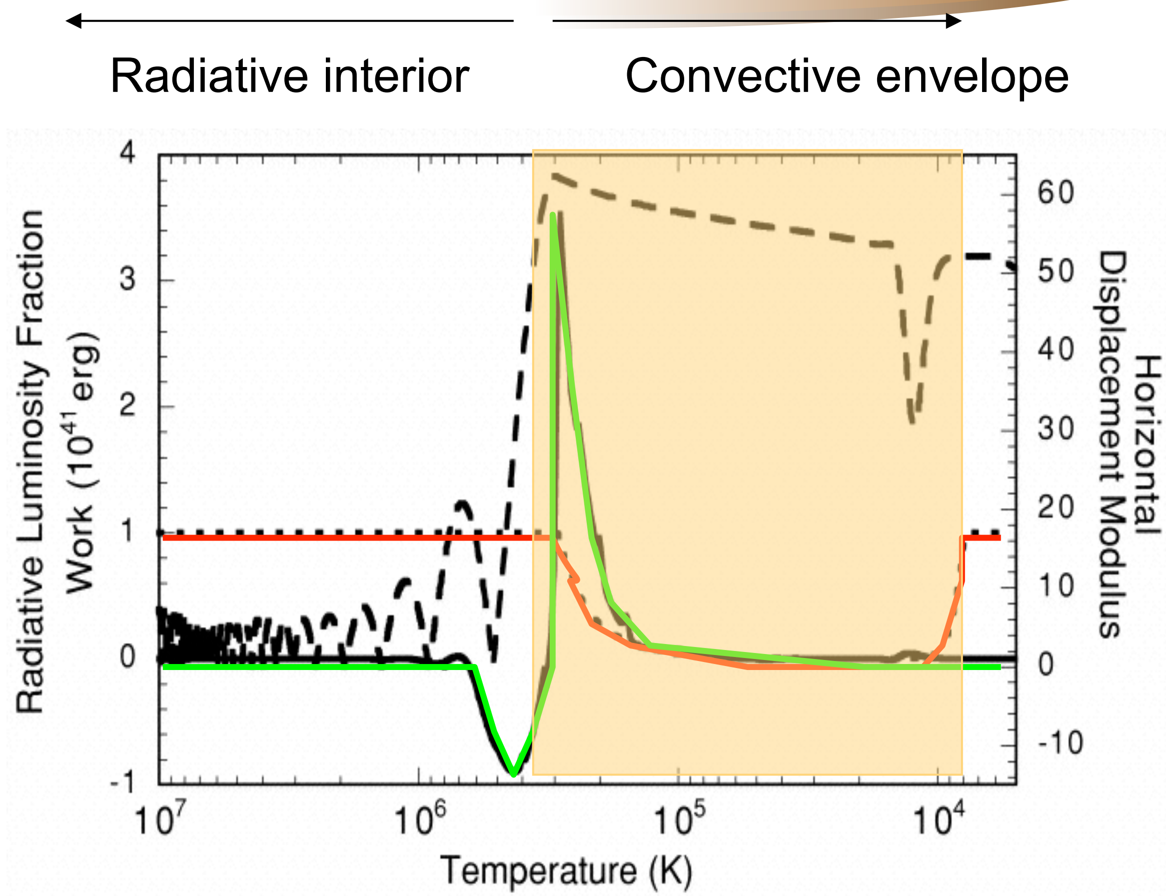
The γ Dor g modes can be driven by convective blocking at the base of the envelope convection zone

Luminosity fraction transported by radiation (red)

Work driving and damping (green)

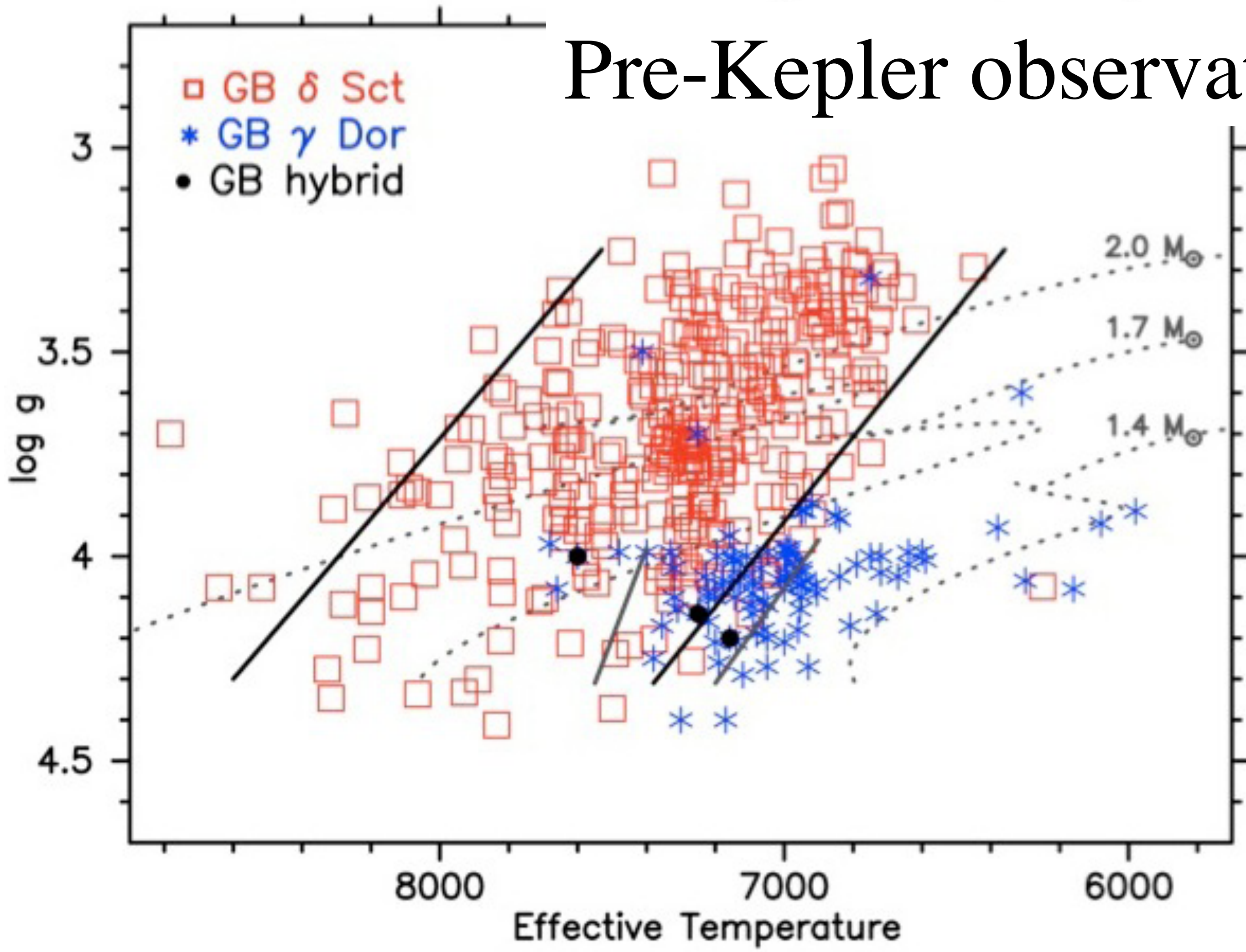
Horizontal displacement (dashed black line)



γ Dor g modes are driven best when T at convective envelope base is ~300,000 K

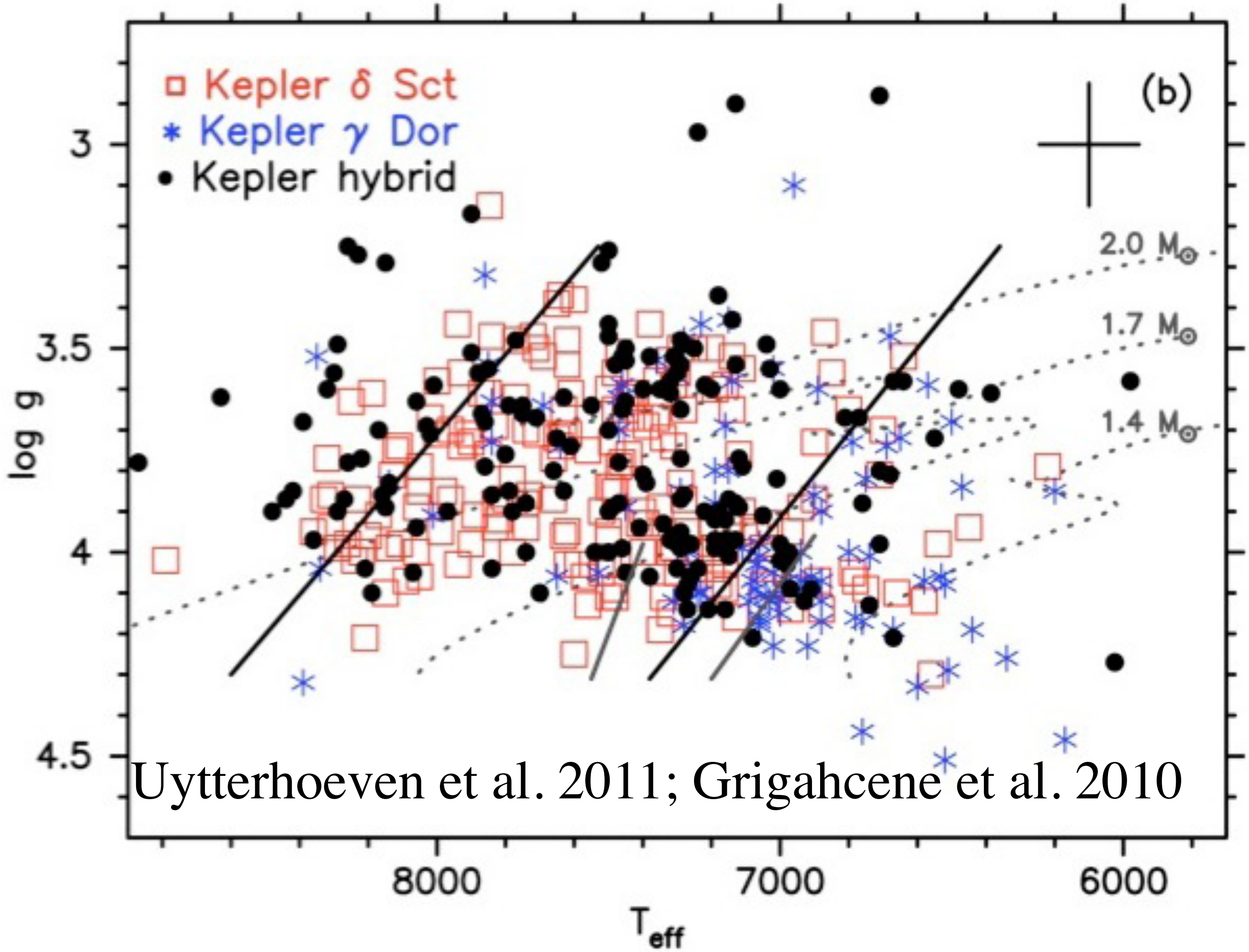
(Guzik et al. 2000; Dupret et al 2004, 2005)

Before Kepler, known gamma Dor and delta Sct stars mostly fit into expected instability regions



Grigahcene et al. 2010; Uytterhoeven et al. 2011

Analysis of bright stars observed by Kepler showed hybrid stars everywhere, and no clean separation by temperature



Uytterhoeven et al. 2011; Grigahcene et al. 2010

Kepler GO program target stars

- We examined data on the sample of 633 stars requested for *Kepler* Guest Observer Cycles 2 and 3, Quarters 6-13
- Selection criteria:
  - $6200 < T_{eff} < 8300$ K (Spectral types A-F
  - $3.6 < \log g < 4.7$ (near main sequence)
- These stars are relatively faint, with *Kepler* magnitudes 14-15.5
- Long-cadence data only (frequencies 0-24.4 cycles/day)
  - gamma Dor stars have frequencies of about 1 c/d
  - most delta Sct stars have frequencies of 10-20 c/d

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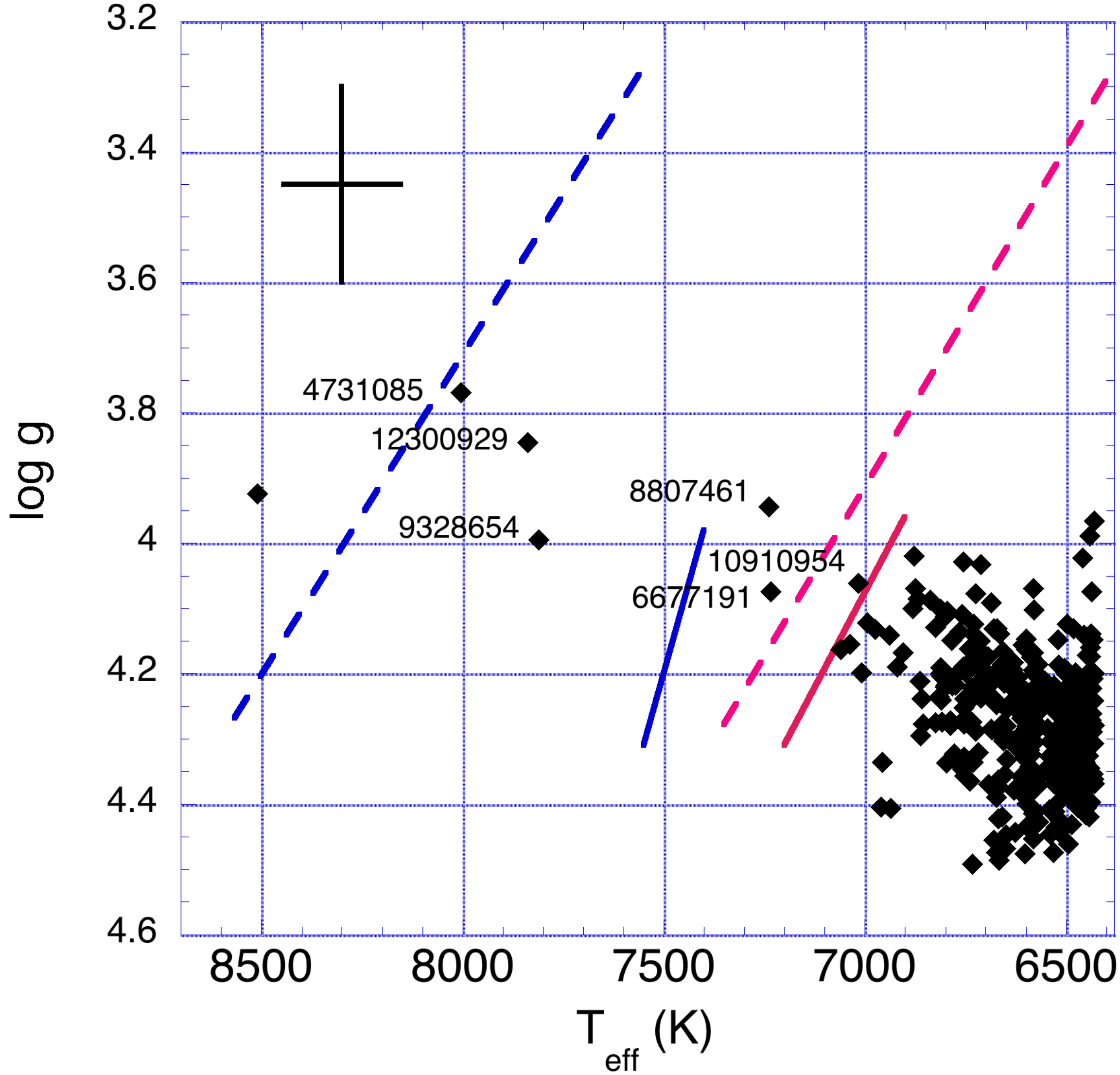
Data reduction and identification of 'constant' stars

- Used Matlab script (J. Jackiewicz, NMSU) to
  - remove outlier points and interpolate the light curves to an equidistant time grid
  - Fourier transform
- Flagged as 'constant' the stars with no power in the spectrum from 0.2 to 24.4 c/d above 20 ppm.
- We eliminated stars that appear to be eclipsing binaries (see Gaulme and Guzik, 2014)
- We applied a +229 K increase to the effective temperature given by the *Kepler* Input Catalog.
  - Offset from Sloan Digital Sky Survey- determined T_{eff}, Pinsonneault et al. (2012)

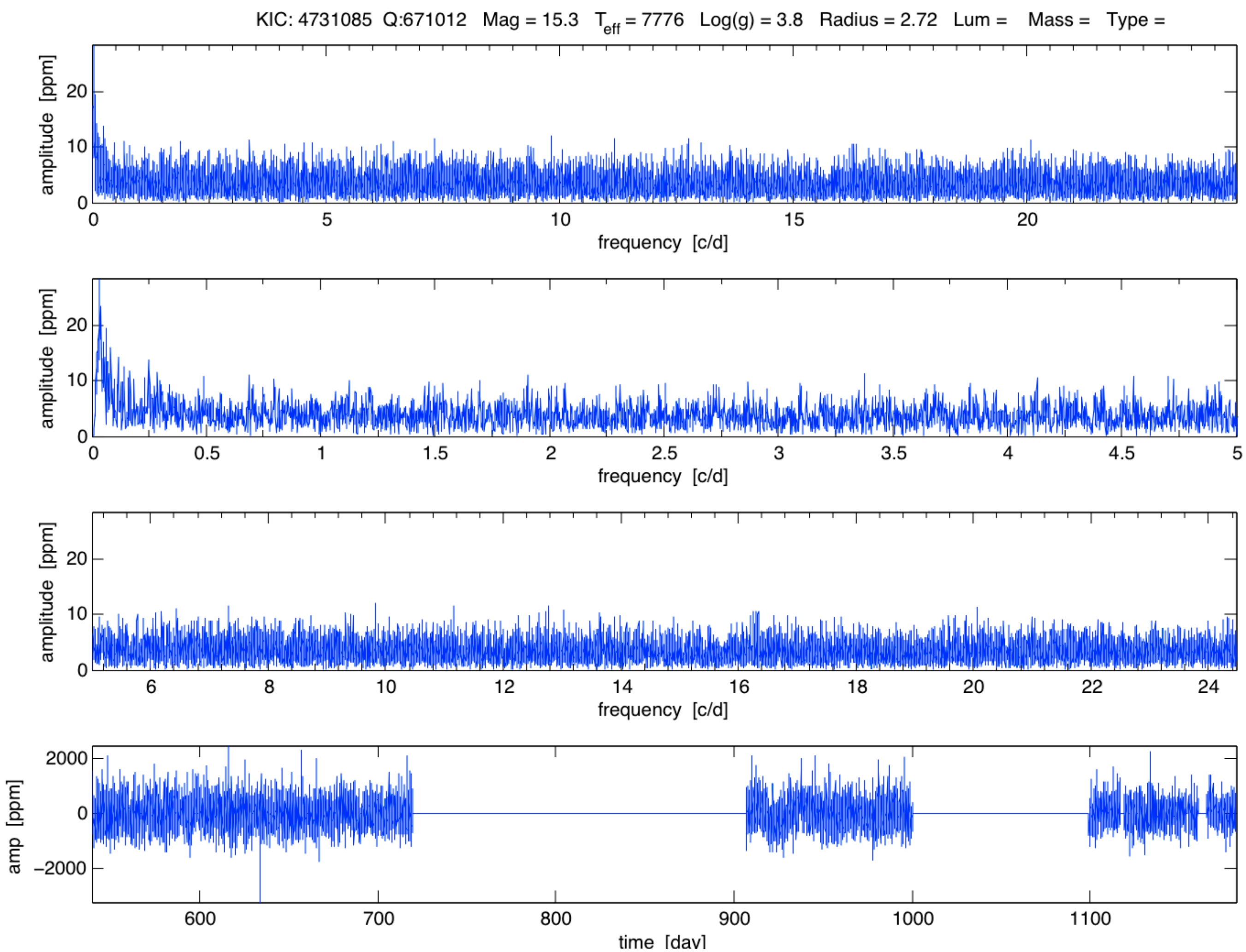
By these criteria, we find 359 'constant' stars out of the 633 stars in our sample, or roughly 60%

Location of our 359 faint 'constant' stars



Error bar:
290 K T_{eff}
0.3 log g from
Uytterhoeven
et al. 2011

KIC 4731085, Kp mag 15.3
Hottest ‘constant’ star, near delta Sct blue edge



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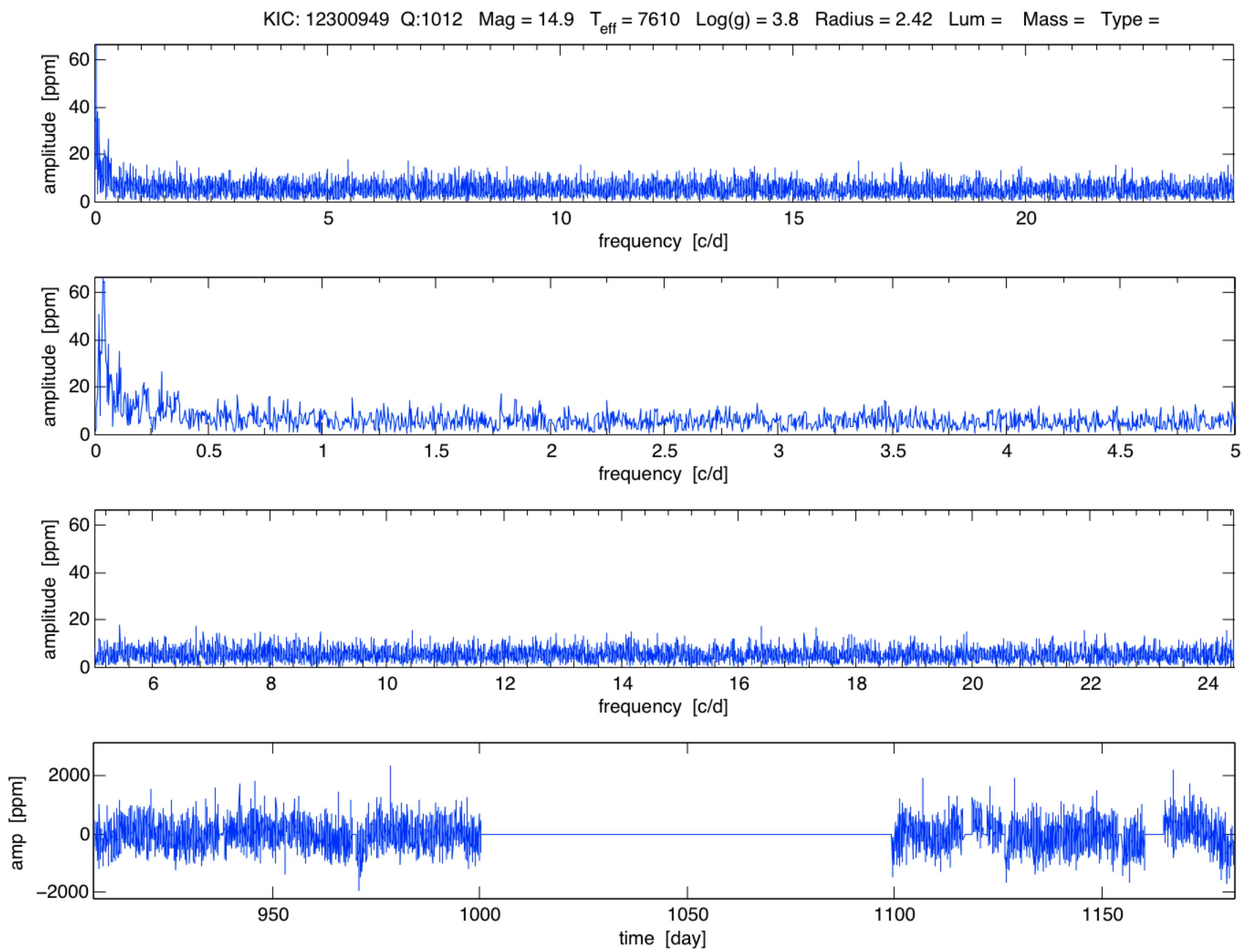
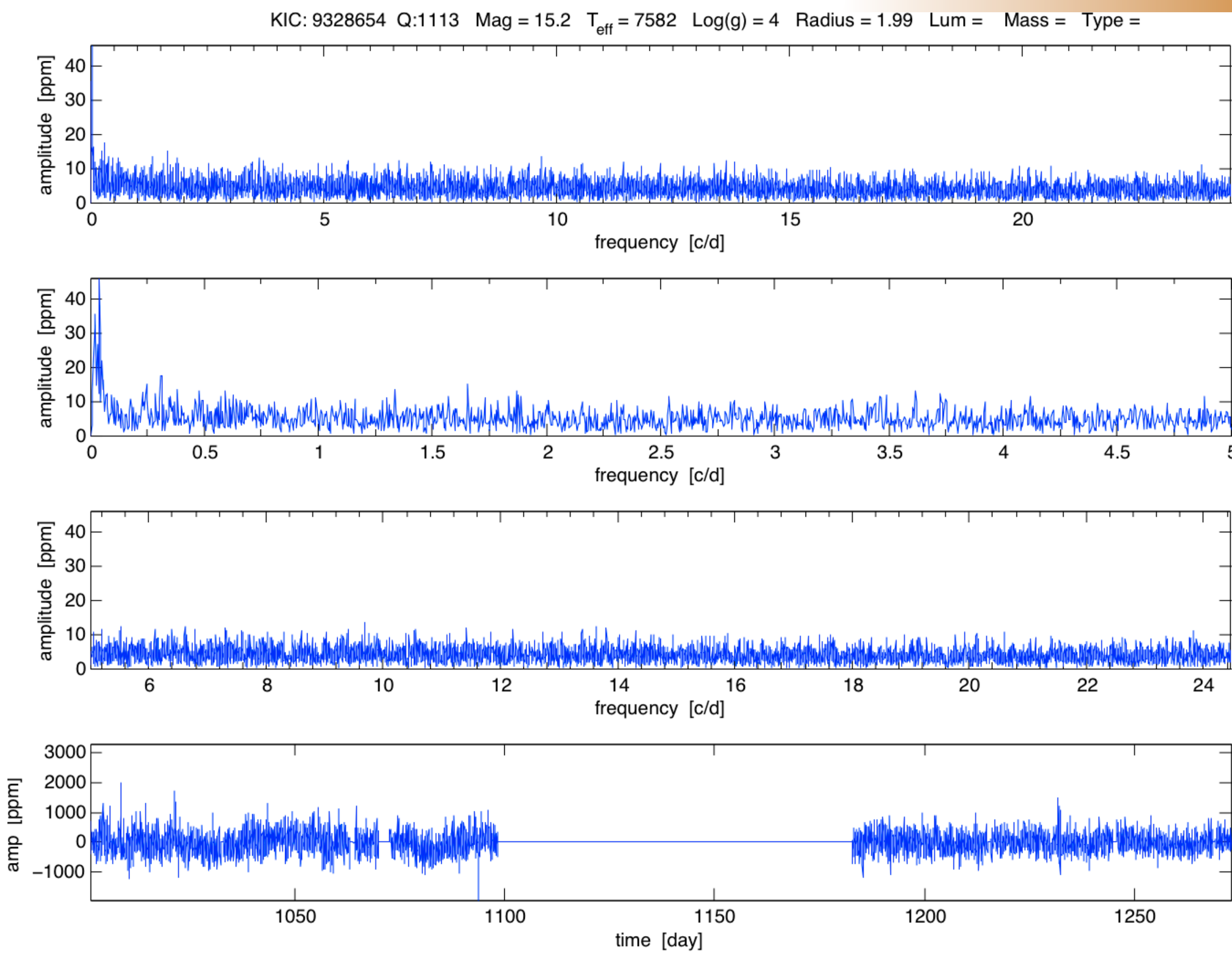
KIC 12300949, Kp mag 14.9, T_{eff} 7839 K, within delta Sct IS



KIC 9328654, Kp mag 15.2, T_{eff} 7811 K, within delta Sct IS



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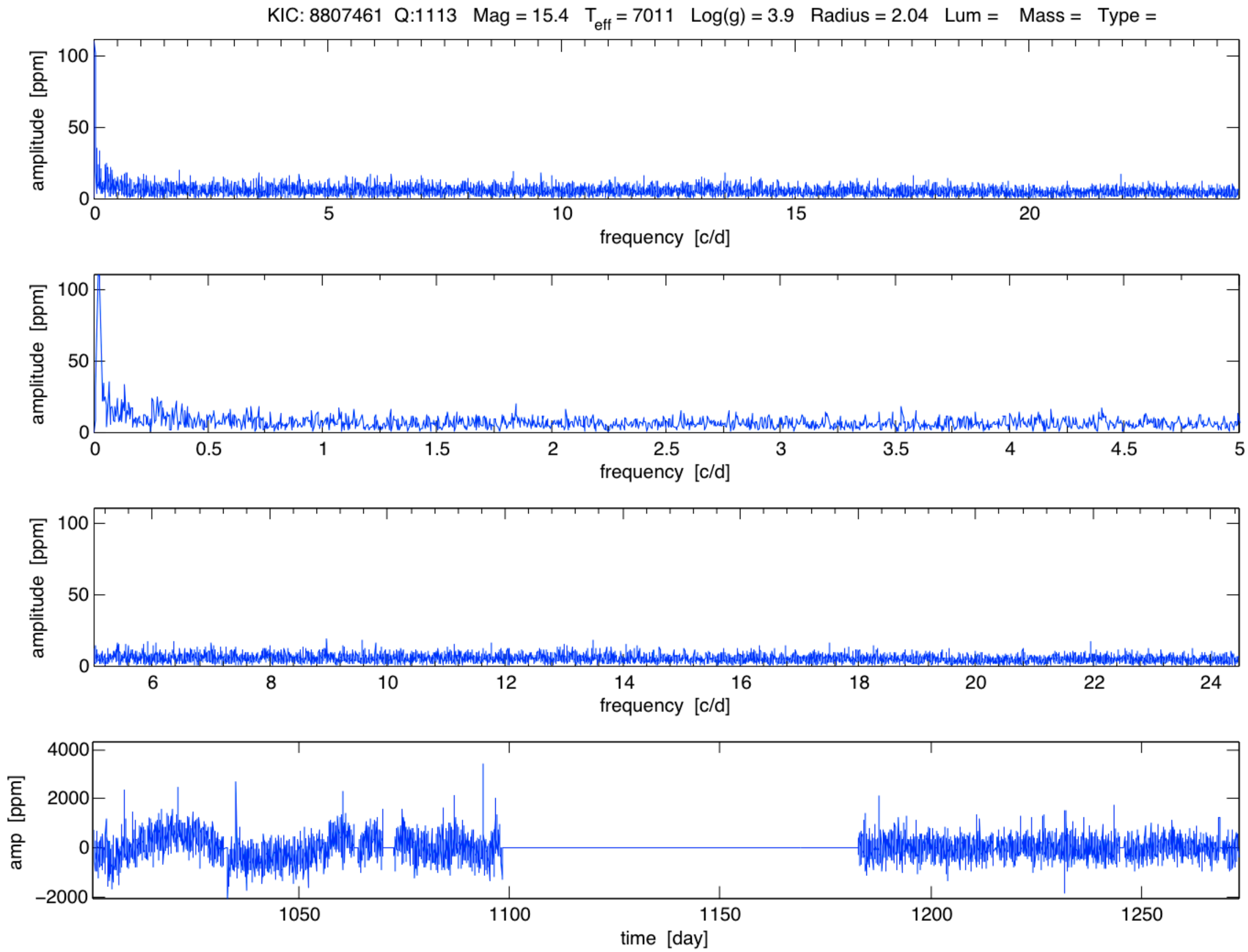
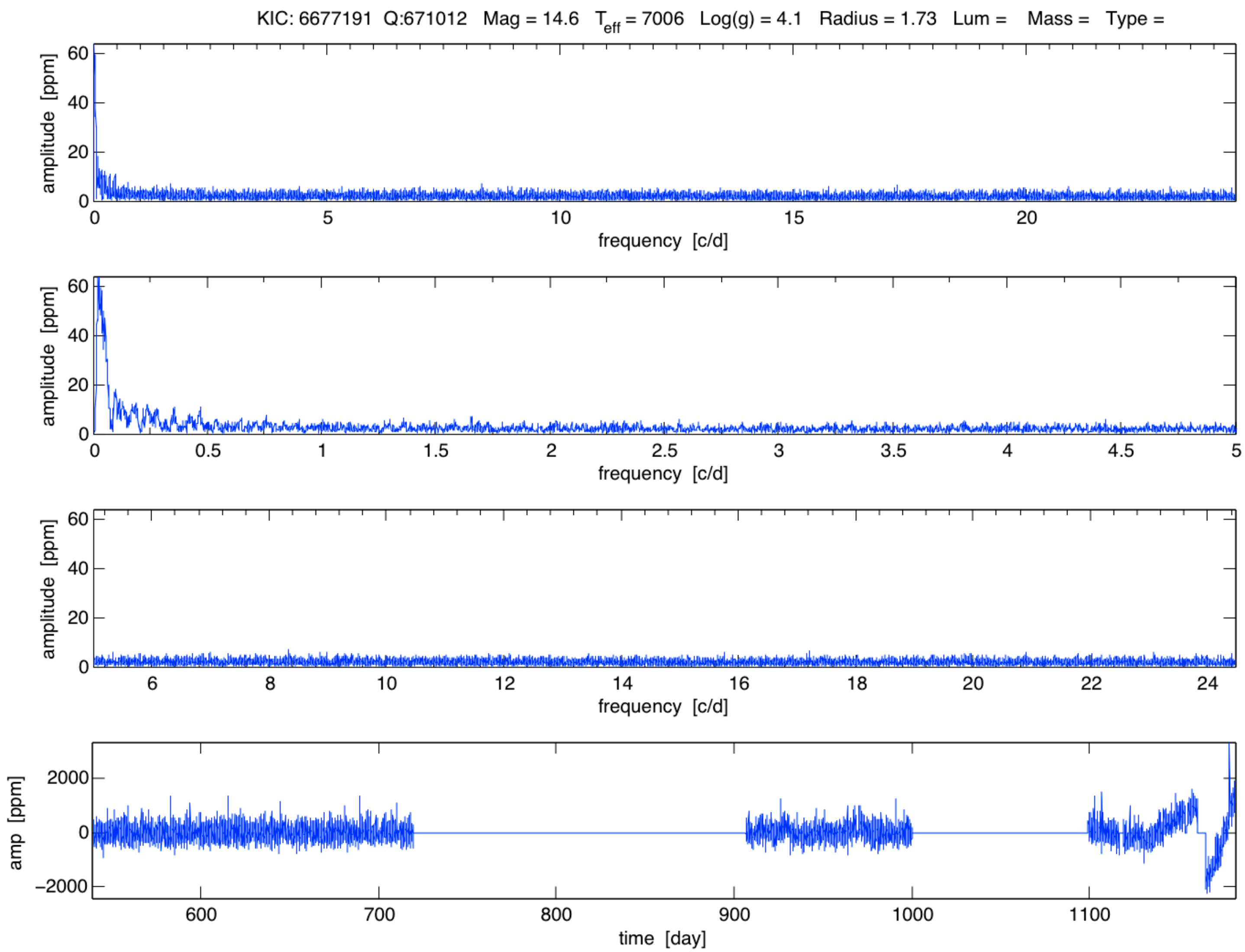
KIC 8807461, Kp mag 15.4, T_{eff} 7240 K, within hybrid delta Sct/gamma Dor region



KIC 6677191, Kp mag 14.6, T_{eff} 7234 K, within hybrid delta Sct/gamma Dor region



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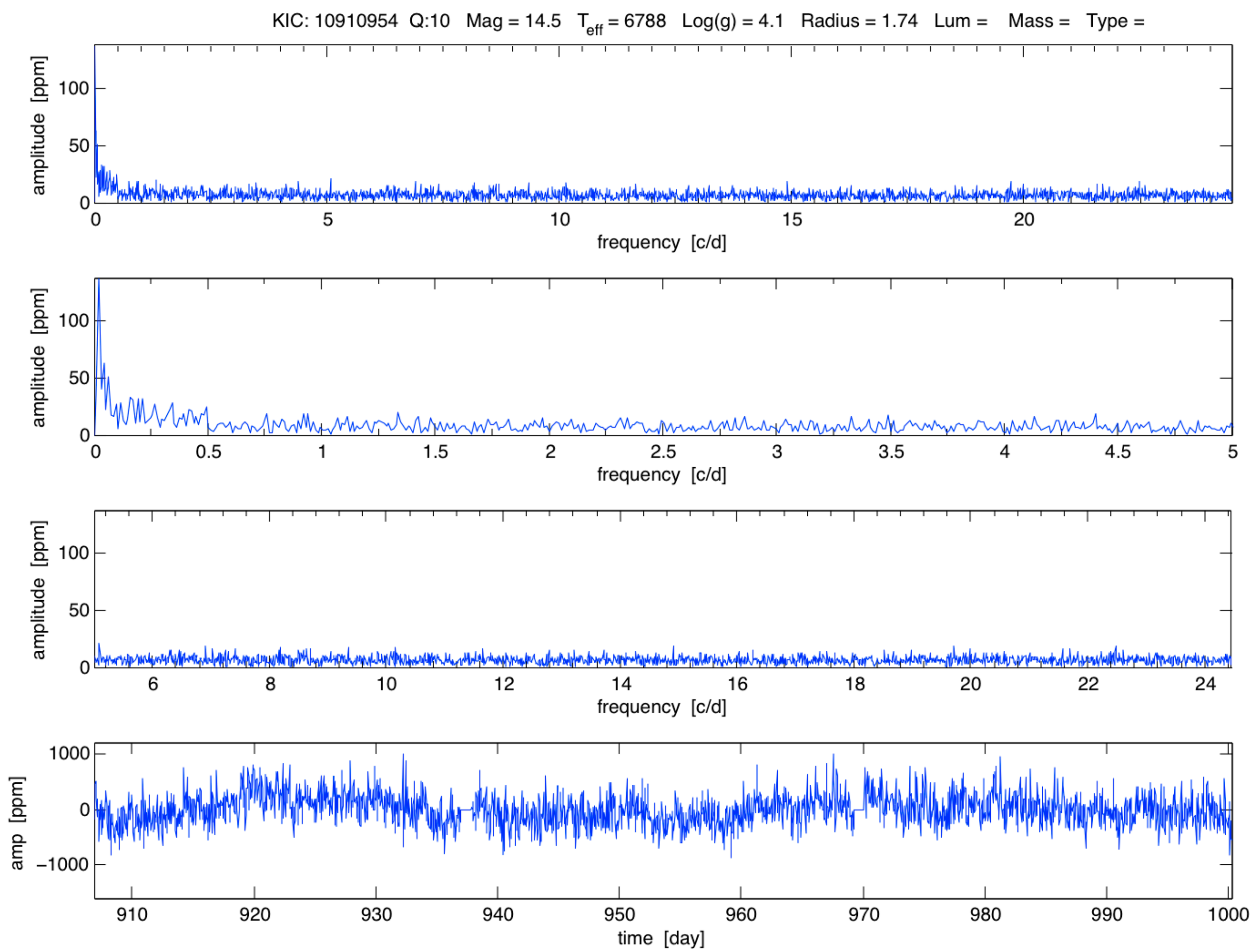
KIC 10910954, Kp mag 14.5, T_{eff} 7017 K, within gamma Dor instability region (Q10 only)



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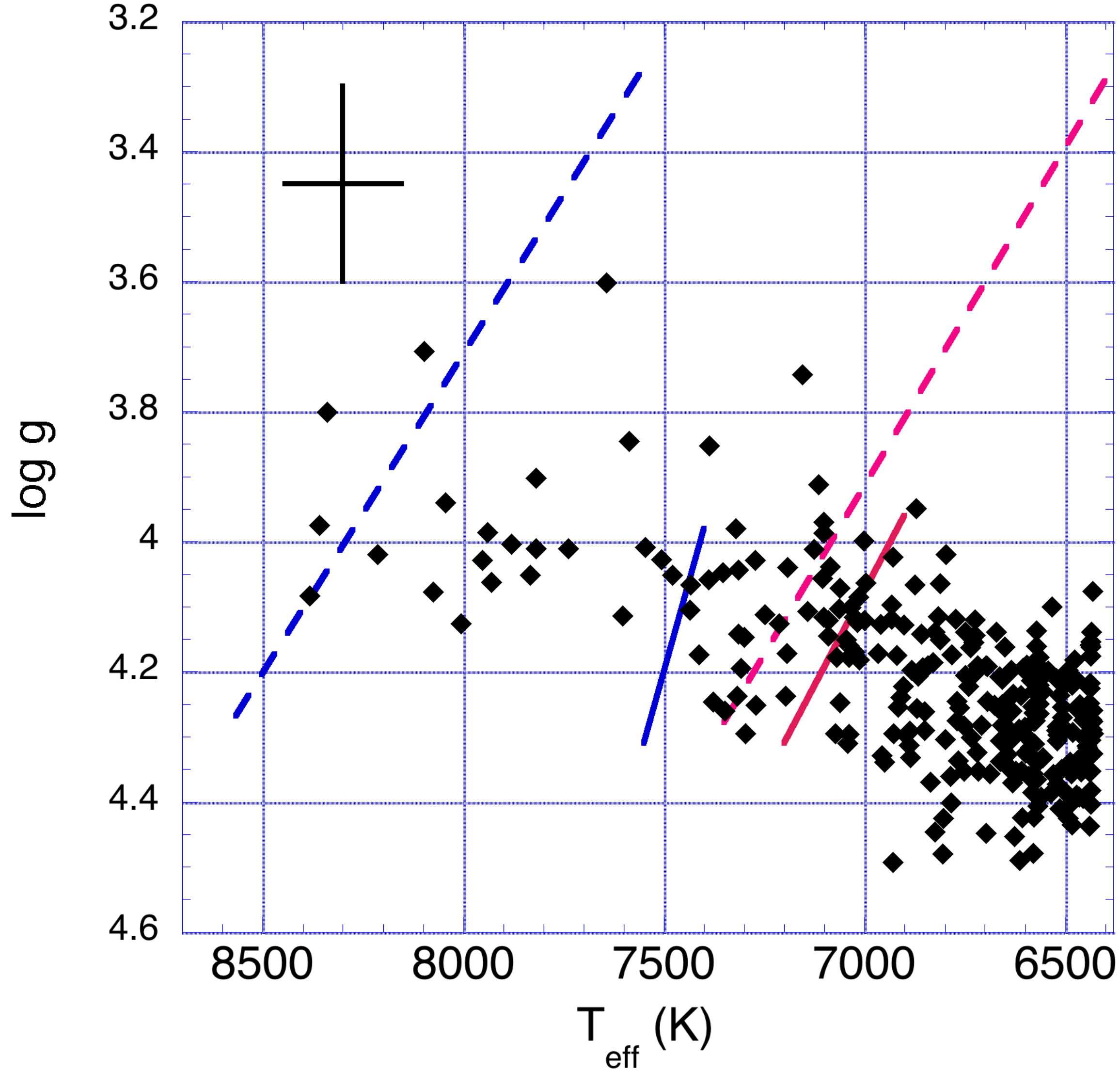
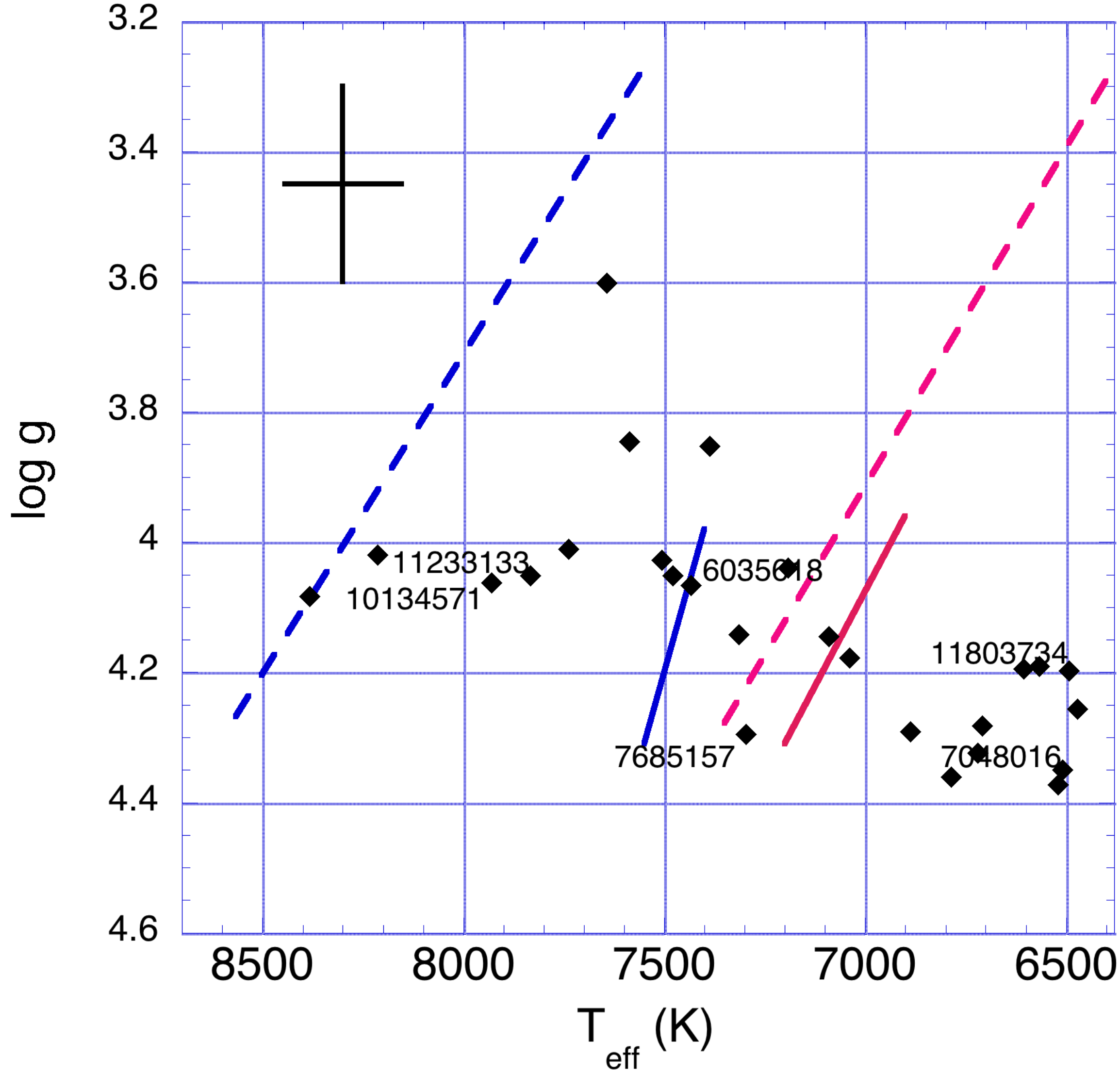
Possible explanations for 'constant' stars

- The stars are pulsating at delta Sct frequencies higher than 24.4 c/d
- The stars may be pulsating in higher spherical harmonic degree modes (e.g. degree > 0-3) that aren't easily detectable photometrically.
- The pulsation modes have amplitudes at or below the data noise level
- The log g or T_{eff} in these 'constant' stars may be in error, so that the stars are in reality outside the pulsation instability regions
- A physical mechanism is operating that inhibits pulsations
  - Diffusive helium settling might turn off delta Sct pulsations
  - Diffusion of metals in gamma Dor stars may cause the convection zone to become too shallow to enable the convective blocking mechanism for pulsation driving

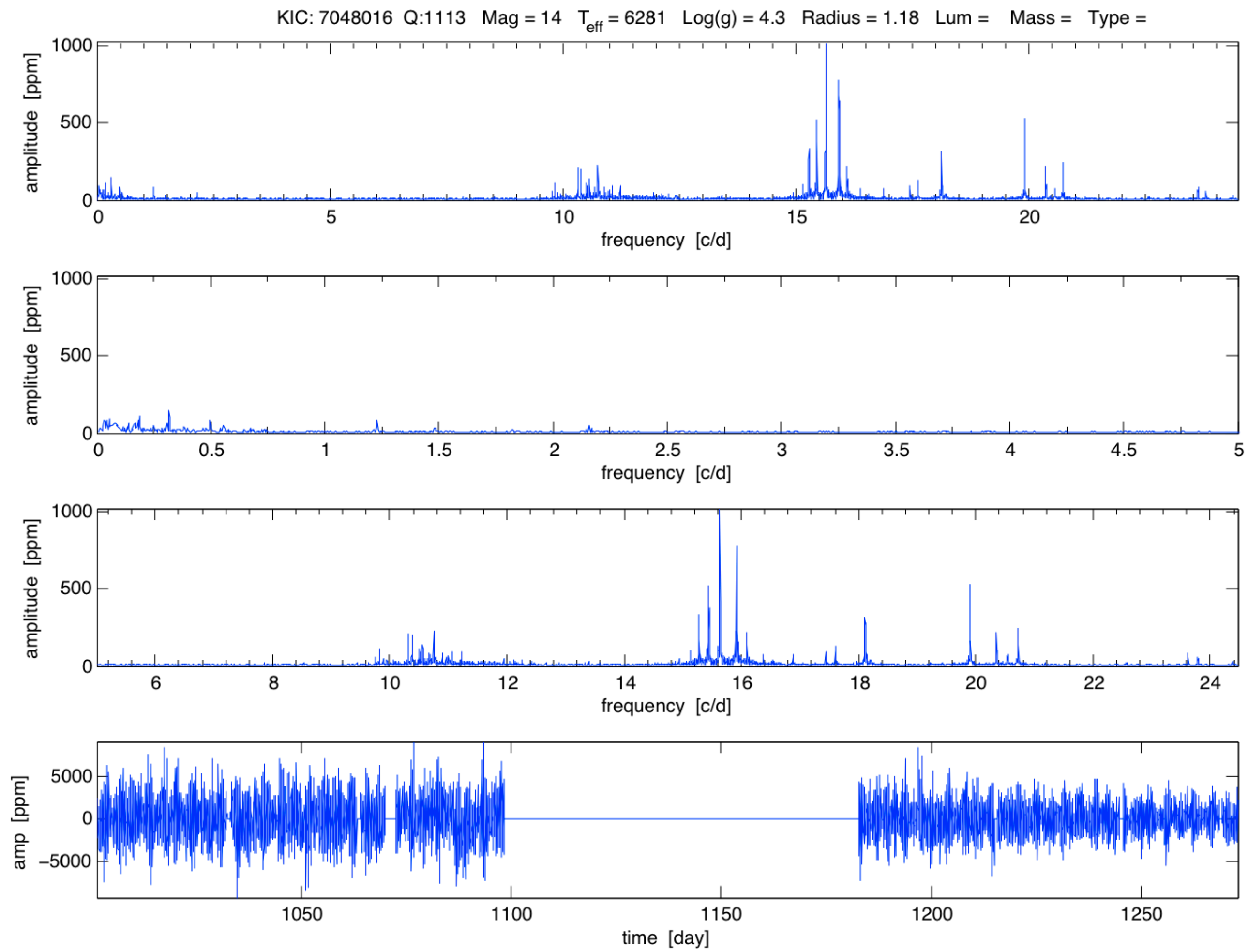
Distribution of 274 'non-constant' stars



26 obvious delta Sct or gamma Dor stars



KIC 7048016, hybrid gamma Dor/delta Sct candidate, T_{eff} = 6510, cooler than both IS regions



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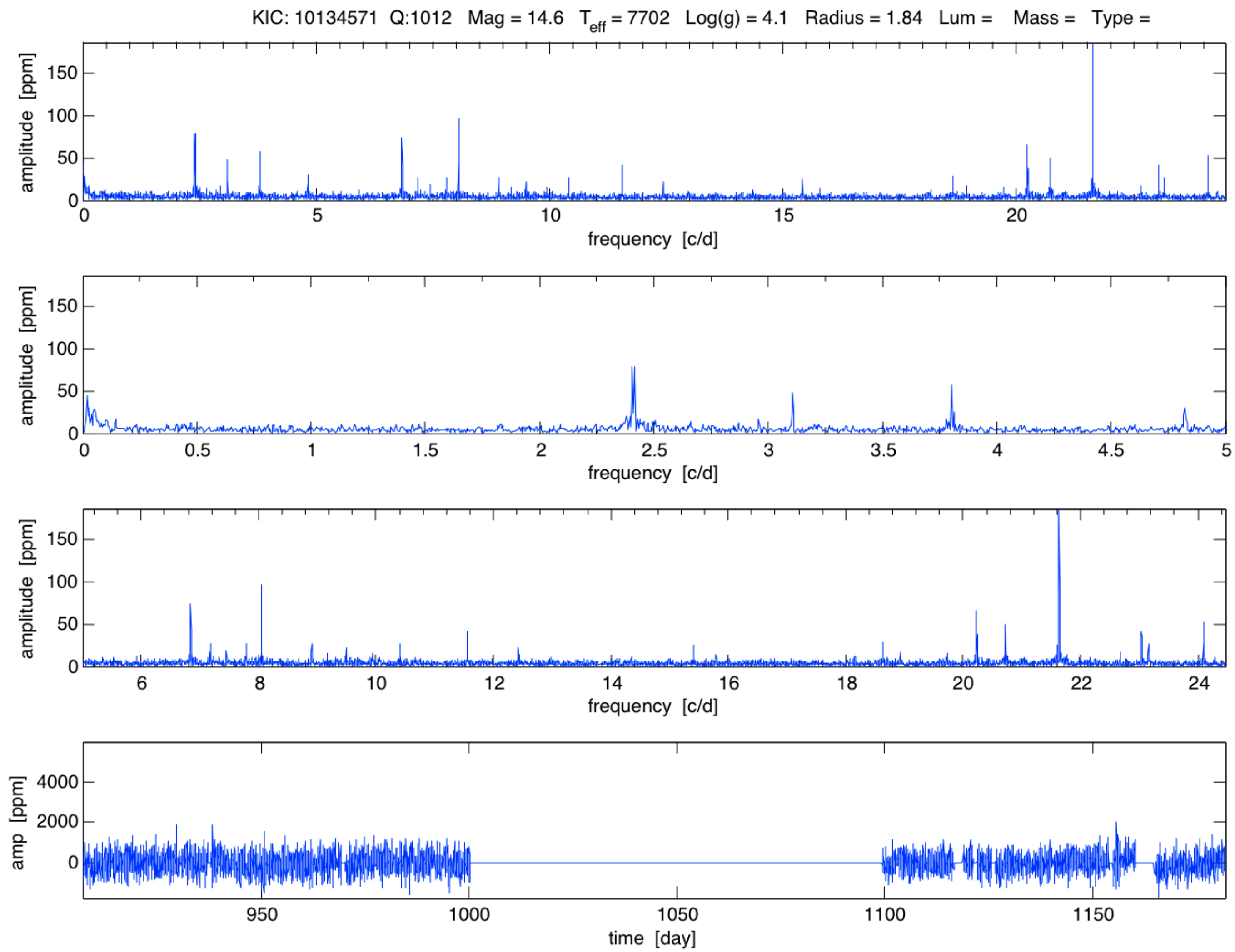
KIC 10134571, hybrid gamma Dor/delta Sct candidate, T_{eff} = 7931, outside of hybrid region



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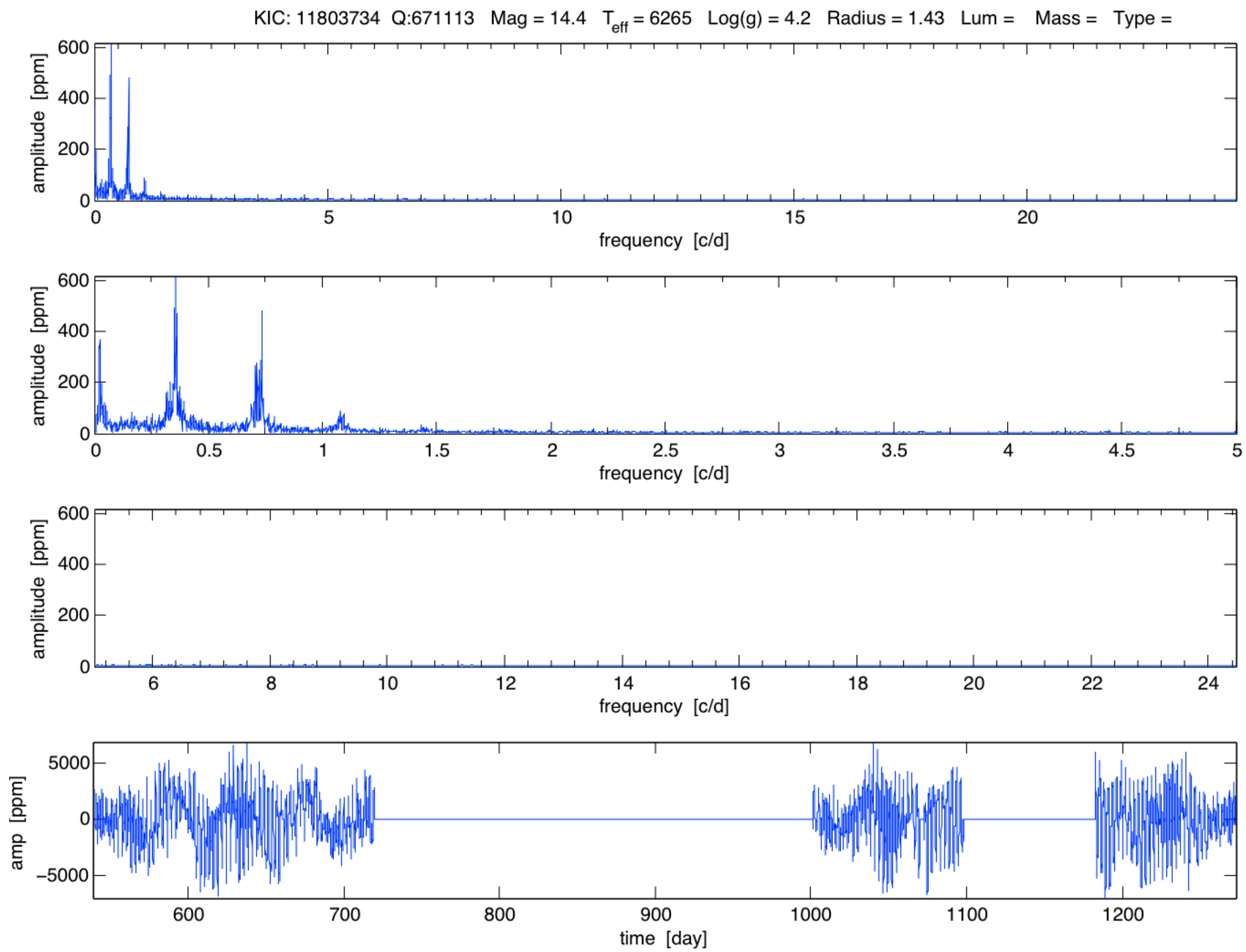
KIC 11803734, gamma Dor candidate, T_{eff} = 6494 K, outside of gamma Dor IS region



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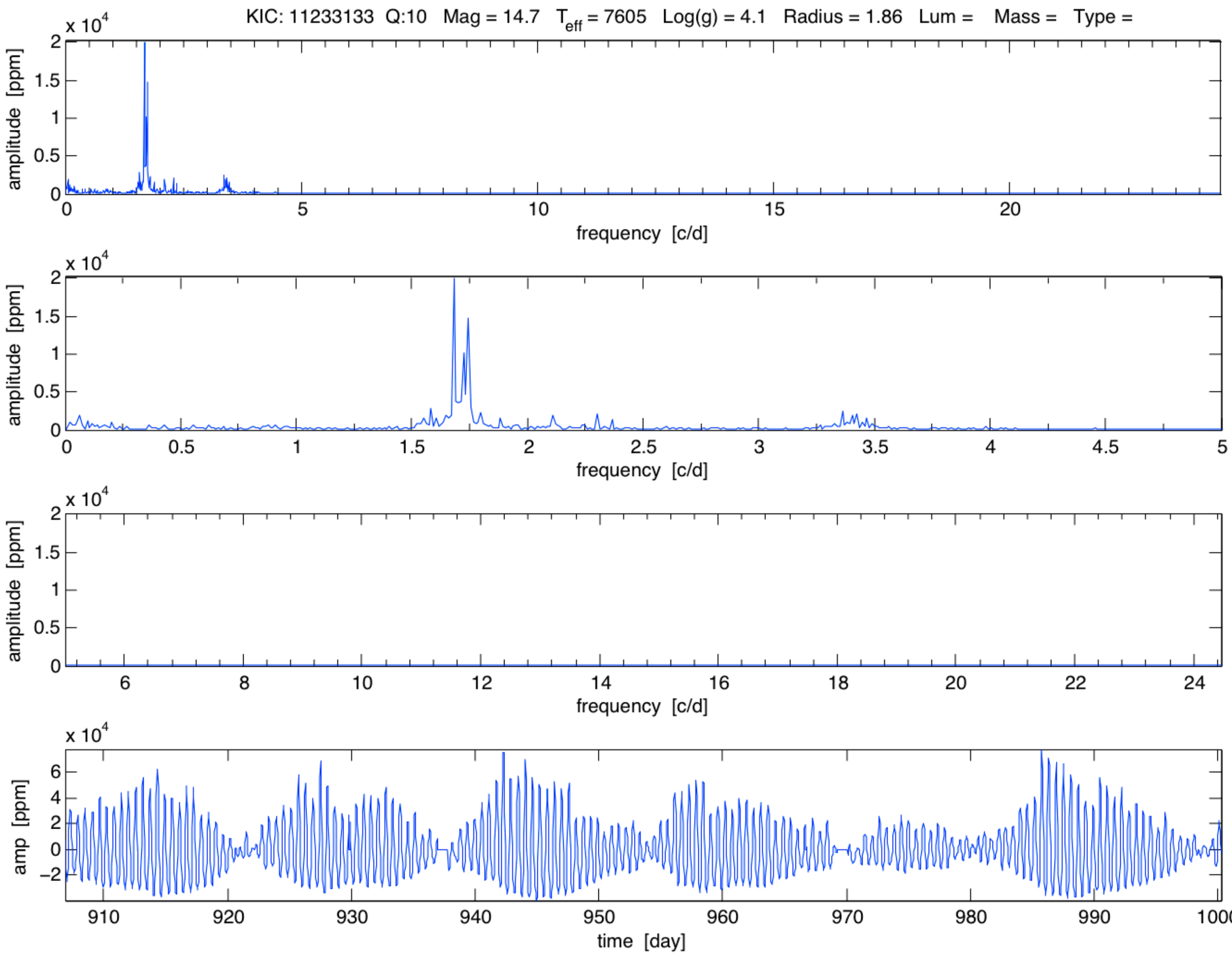
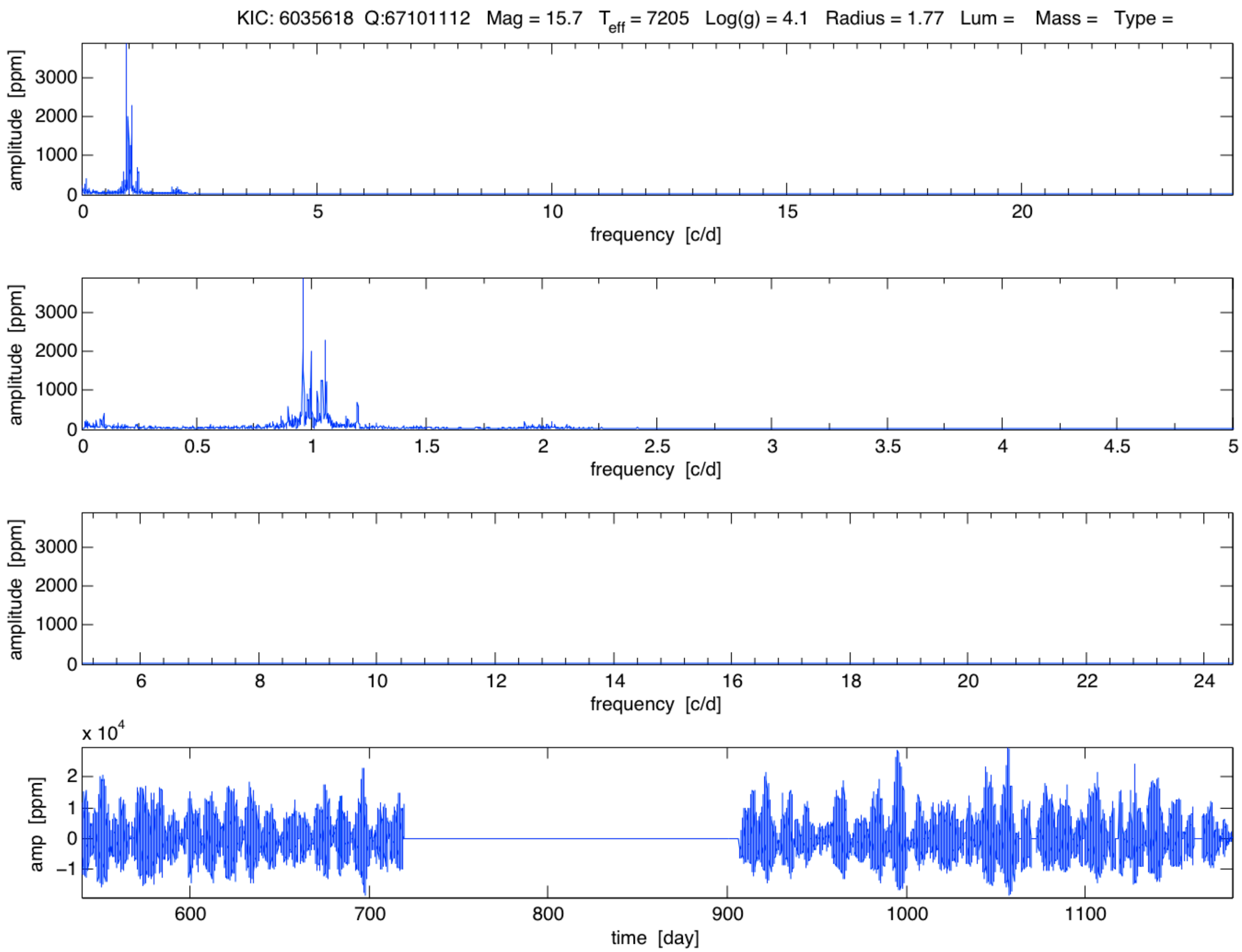
KIC 11233133, gamma Dor candidate, T_{eff} = 7833 K, outside of gamma Dor IS region



KIC 6035618, gamma Dor candidate, T_{eff} = 7433 K, at blue edge of gamma Dor IS region



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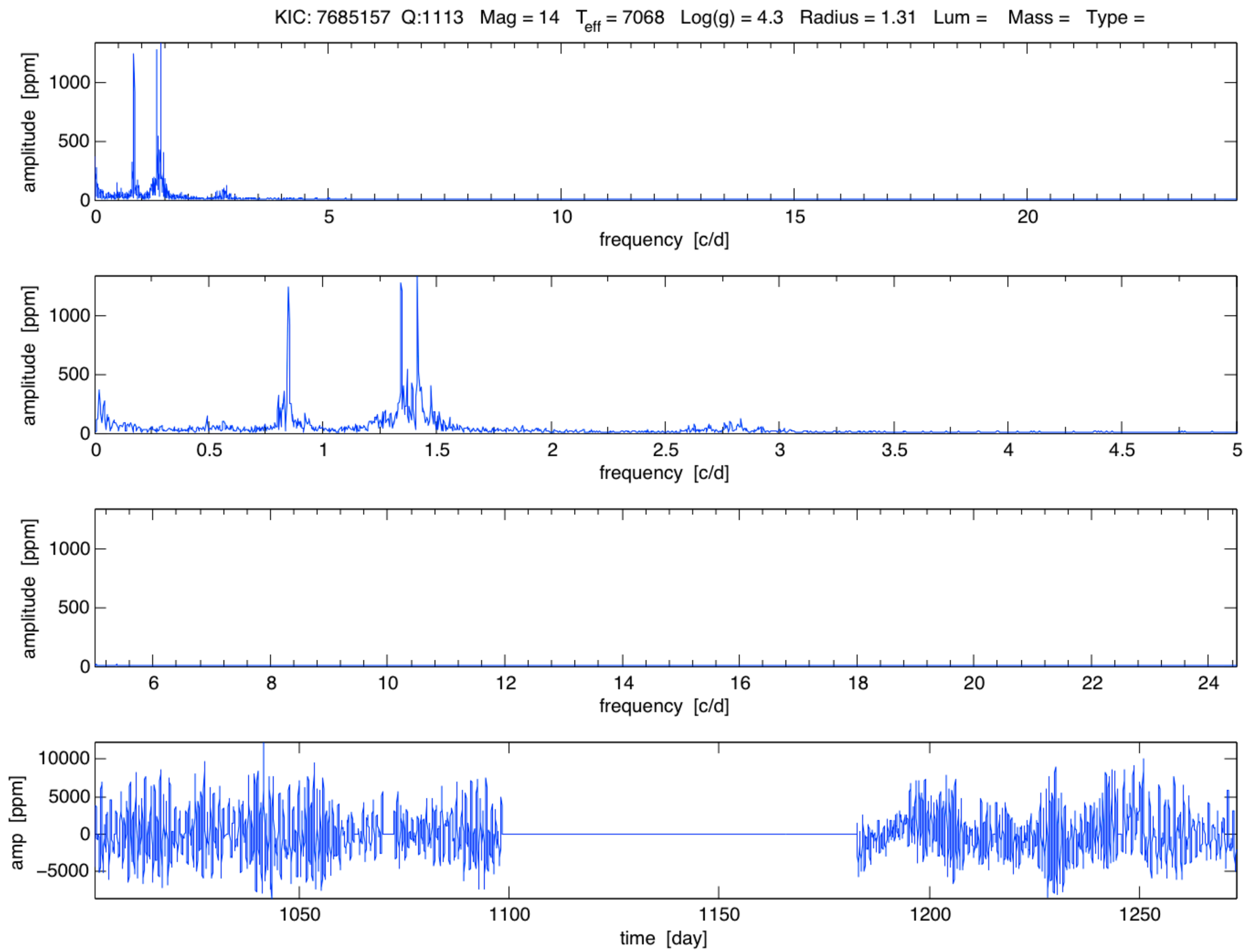
KIC 7685157, gamma Dor candidate, T_{eff} = 7297 K, actually within gamma Dor IS region



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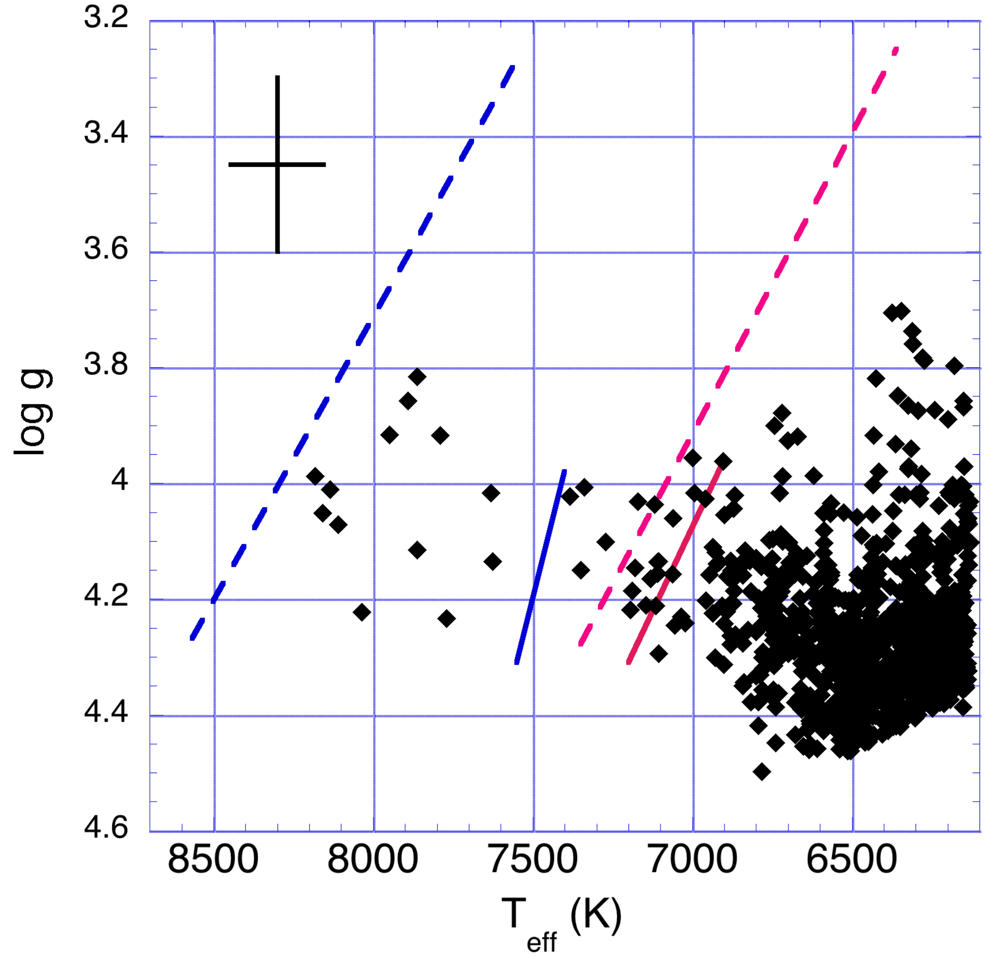
Results from Q14-17 Kepler Guest Observer Data

- Additional *2152* stars
- Sample not unbiased, selected for variability from full-frame images
- Find 997 out of *2152* stars 'constant' (46%)
- 34 out of 997 'constant' stars (3.4%) within IS region boundaries



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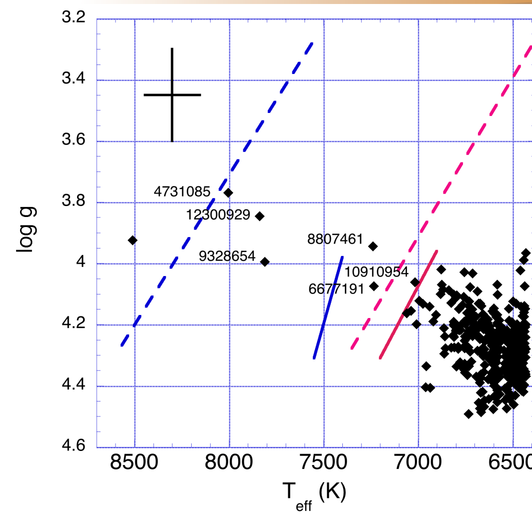
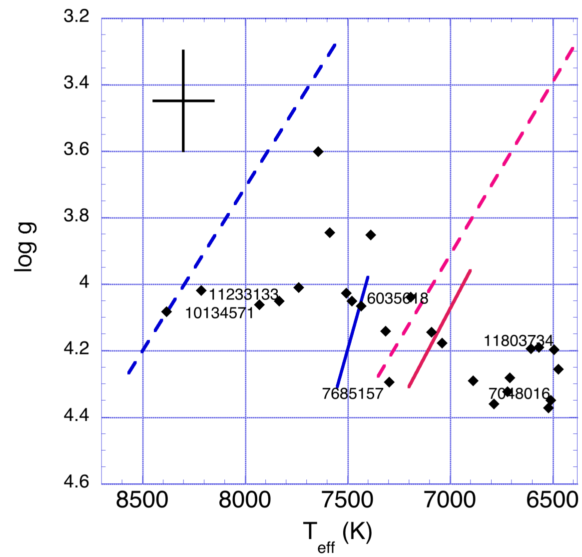
Future work

- Use stellar modeling to determine how much diffusive settling is possible and necessary to eliminate pulsations in gamma Dor or delta Sct stars
- Explore alternate pulsation driving mechanisms to explain stars that show pulsations at unexpected frequencies or lie outside of predicted instability boundaries



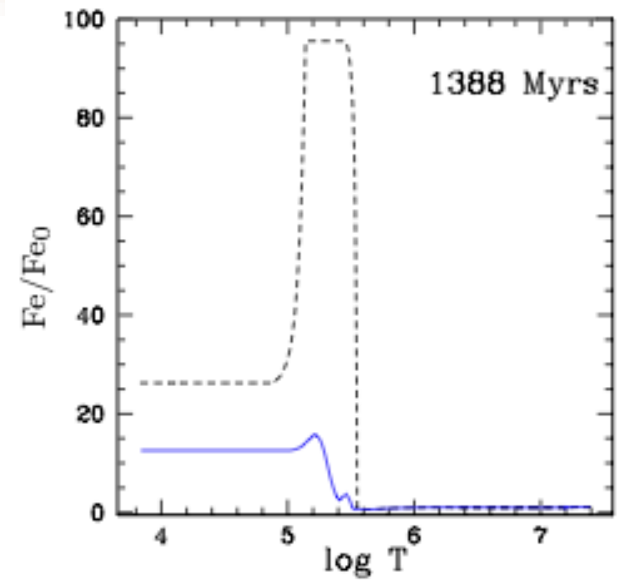


Abstract

The NASA *Kepler* mission was launched in 2009 to search for planets around sun-like stars via planetary transits. In addition, Kepler observed thousands of stars with high-precision photometry, discovering many pulsating stars including core hydrogen burning gamma Doradus and delta Scuti variables. Before *Kepler*, the known variables appeared to fit within the pulsation instability regions expected from theory/simulation. However, *Kepler* has found stars pulsating in one or both types outside of their expected instability regions, as well as apparently non-pulsating stars within the instability regions. I will discuss possibilities to explain these observations, and implications for stellar physics.

Are there other pulsation driving mechanisms that produce gamma Dor or delta Sct frequencies?

- Convective driving at top of envelope convection zone, as in DA ZZ Ceti white dwarfs (Wu & Goldreich; Goldreich & Wu 1999; Brickhill 1991)
- κ-effect from Fe concentration due to settling and levitation, as in subdwarf O/B stars (see Turcotte et al. and Kaye et al. (2000); Richard et al. 2001 ApJ 558, 377; Theado & Vauclair 2009)
- Interaction and phase offset between Fe and He ionization κ effect (Gautschy & Loeffler 1996 DSN 10,13; Loeffler 1999 proceedings)
- Stochastic excitation (Pereira et al. 2011; Antoci et al. 2011) as in solar-like stars and red giants
- Tidal forcing (KOI-54, Welsh et al. 2011)



Fe concentration in 1.7 M_{sun} model (Theado and Vauclair 2009)

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Summary

- 633 A-F main-sequence stars observed by *Kepler* Q6-13
- 359 stars, or about 60%, were found to be ‘constant’, defined as showing no frequencies above 20 ppm in their light curves between 0.2 and 24.4 c/d.
- Only six photometrically non-varying stars within gamma Dor and delta Sct pulsation instability regions established from pre-*Kepler* ground-based observations. However, the lack of variability in these several stars requires explanation.
- 26 stars in entire sample, or about 10%, are obvious gamma Dor or delta Sct variable star candidates. However, many of these stars do not lie within their expected instability regions, and their behavior also requires explanation.
- Additional 2152 stars observed Q14-17
- Selection for Q14-17 biased toward variability based on full-frame images
- 46% ‘constant’ stars; 34 ‘constant’ stars within instability region
- Many new gamma Dor/delta Sct candidates