Compact pulsators and δ Scuti stars from LAMOST spectra

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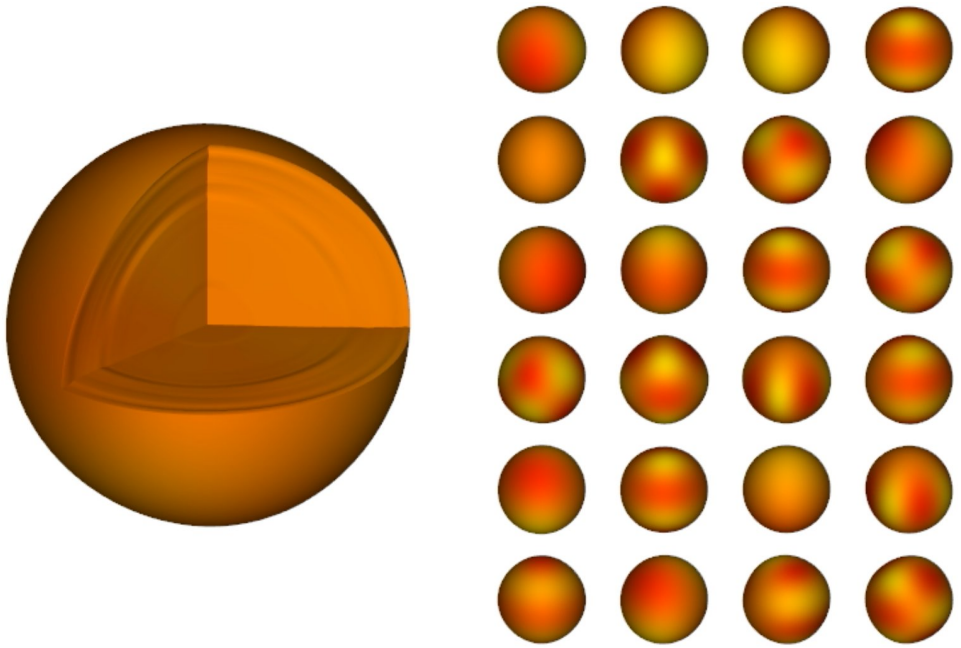
Stellar oscillation theory: Linear perturbation (Unno+ 1989)

- Some basic hydrodynamics: conservation of mass, momentum and energy
- The linear perturbations to describe oscillations
- Eigenvalues of oscillation modes can be distinguished by their quantum numbers:
  - n: the radial order
  - ℓ: the angular degree
  - m: the azimuthal number



In the linear domain, the oscillations can be represented as

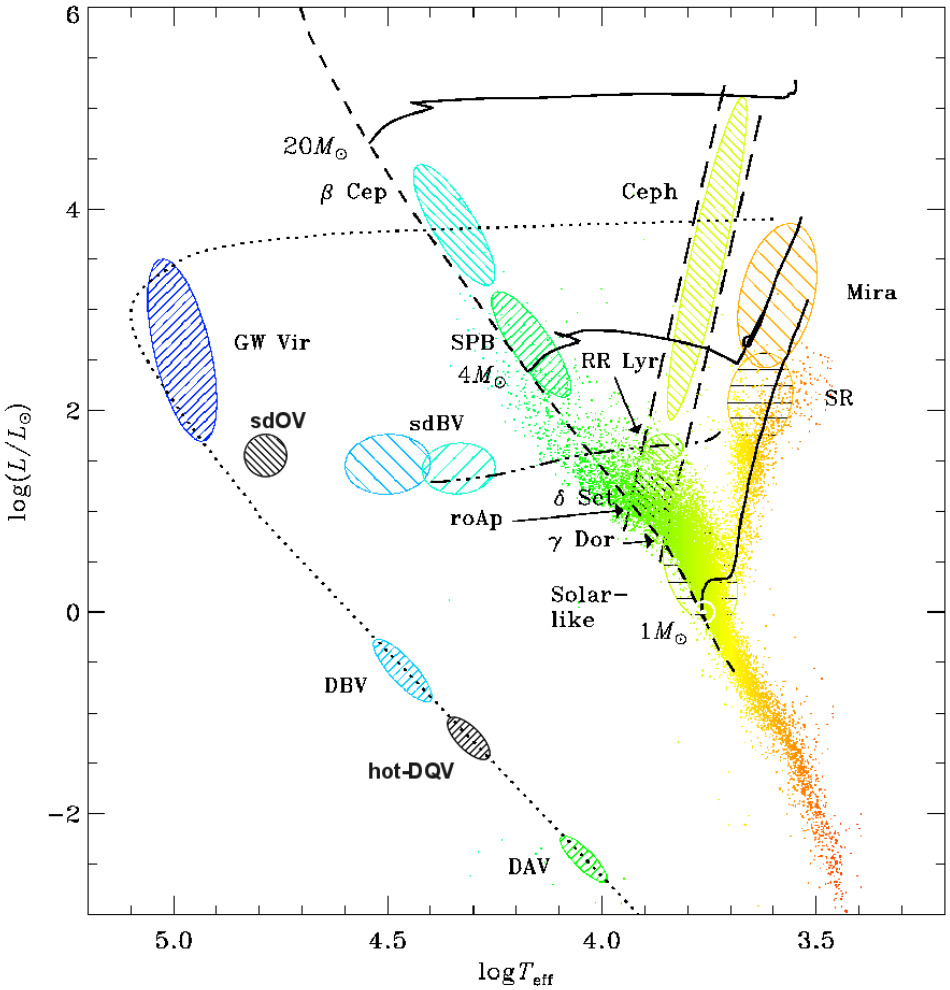
$$\mathbf{z} = \sum_j A_j \sin[2\pi(\omega_j t + \phi_j)]. \tag{1}$$

While, the stellar oscillations can be represented by temporal amplitudes (frequency) as

$$\mathbf{z} = \sum_j \frac{1}{2} A_j(t) e^{i\omega_j t} \mathbf{e}_j + \mathcal{C} + \mathcal{O}, \tag{2}$$

for nonlinear theory (Buchler+ 1995, 1997; Goupil+ 1994, 1998). Finally, we may have a general form of (Zong+ 2017, in prep.)

$$\mathbf{z} = \sum_j A_j(t) \sin\left[2\pi\left(\int_0^t \omega_j(\tau) d\tau + \phi_j(t)\right)\right]. \tag{3}$$



The pulsating stars including:

- ✔ δ Scuti stars
- ✔ pulsating white dwarf stars
- ✔ hot B subdwarf stars
- ✔ hot O subdwarf stars
- ✔ ... ...

Figure: A pulsation H–R diagram for pulsating stars.

LAMOST spectra of four new DAVs

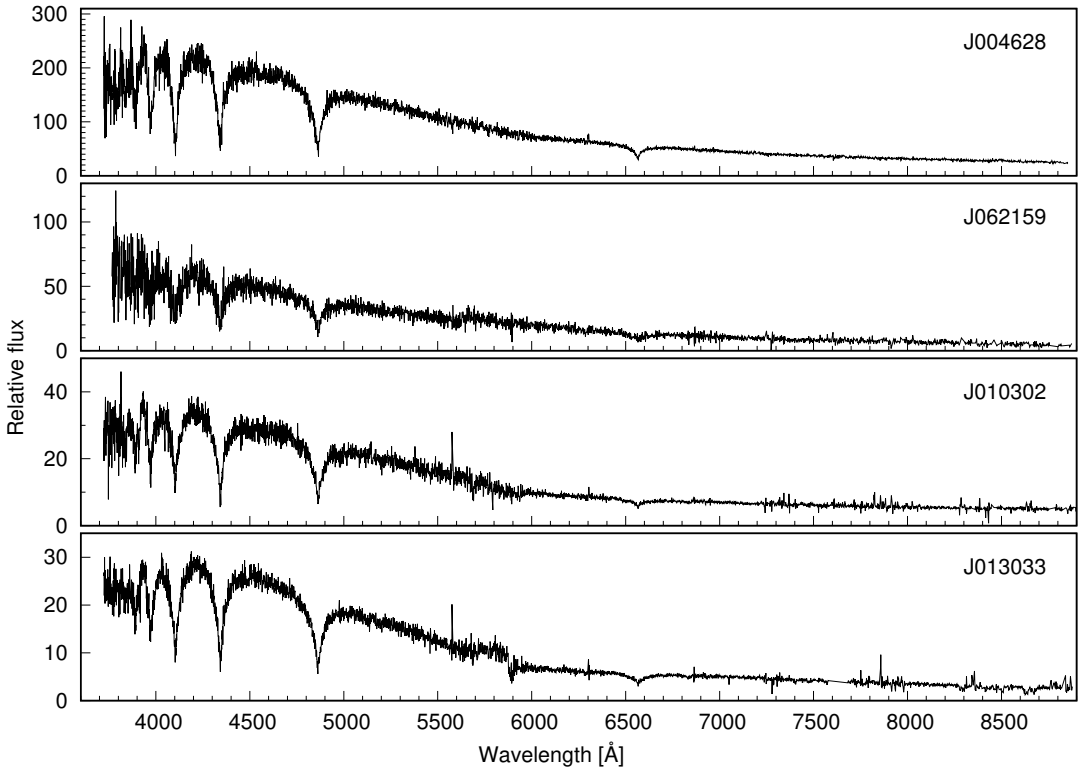


Figure: The LAMOST spectra of the four white dwarfs (Su+ 2017, under revision).

The atmospheric parameters:

① J0046: $\log g = 7.53$; $T_{\rm eff} = 11680$ K

② J0621: $\log g = 8.25$; $T_{\rm eff} = 11730$ K

③ J0103: $\log g = 7.89$; $T_{\rm eff} = 11750$ K

④ J0130: $\log g = 7.69$; $T_{\rm eff} = 14100$ K

Pulsating white dwarf stars: Light curves

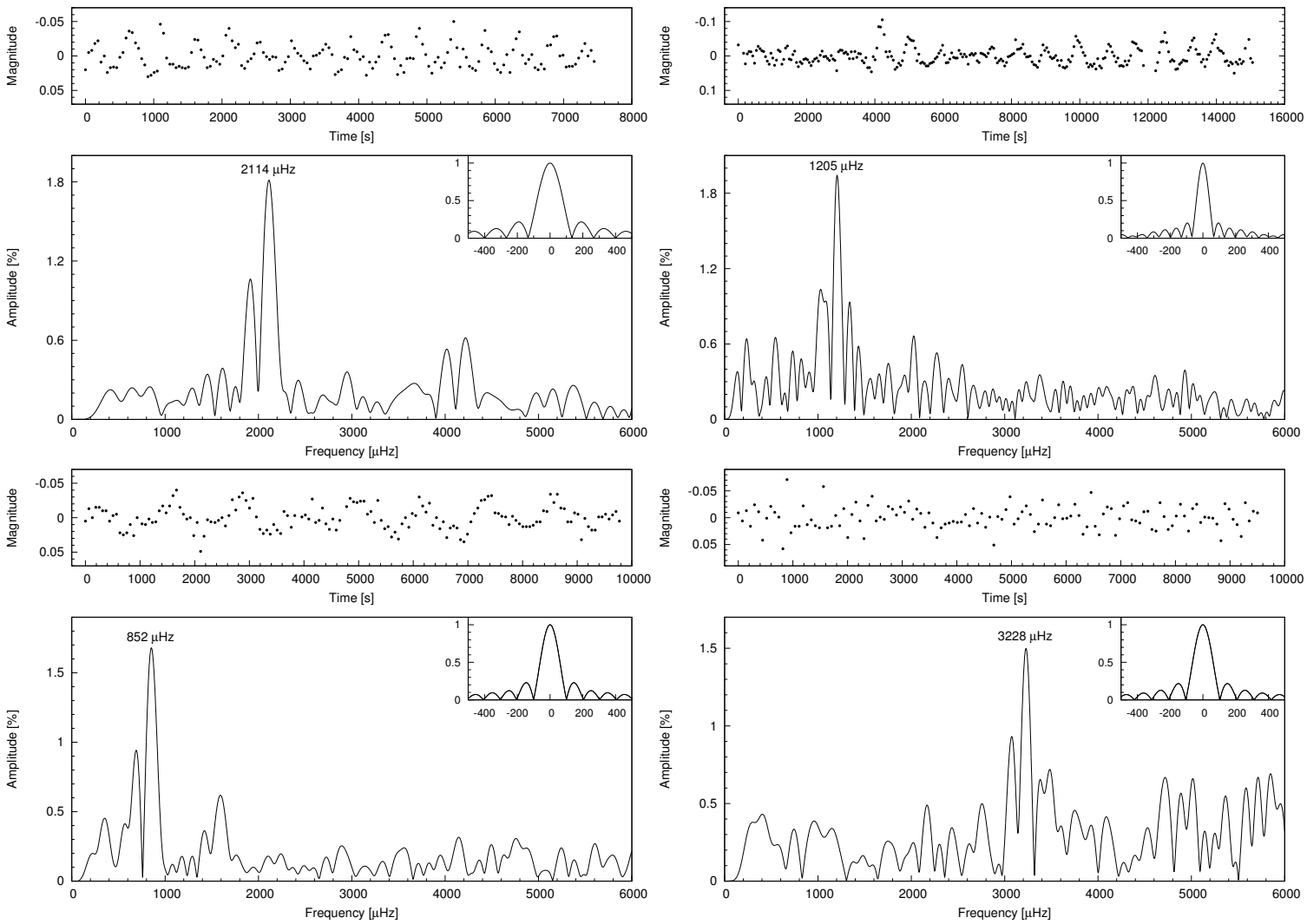


Figure: Light curves of these four LAMOST white dwarf stars.

The impacts of pulsation modes observed over long time baseline

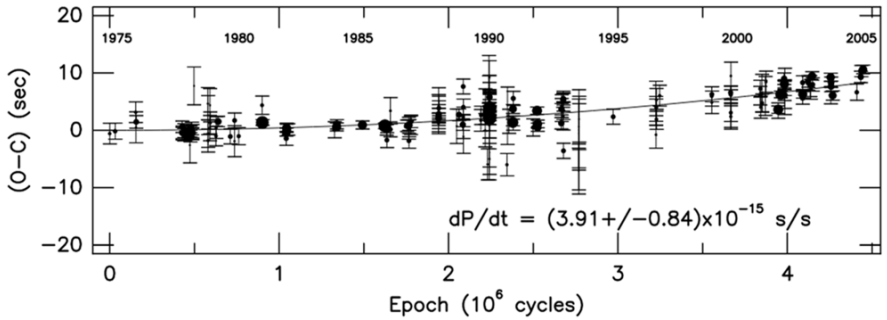


FIG. 1.—$(O - C)$ (observed minus calculated times of maxima) for the 215 s pulsation of G 117-B15A. The size of each point is proportional to its weight, i.e., inversely proportional to the uncertainty in the time of maxima squared. We show 2 σ error bars for each point, and the line shows our best-fit parabola to the data. The error bars plotted are those before adding the external uncertainty of 1 s quadratically, discussed in the text. The fact the line does not overlap these error bars demonstrates that they are underestimates. Note that as the period of pulsation is 215.197 s, the whole plot shows only $\pm 36^{\circ}$ in phase.

Figure: Measuring the Evolution of the Most Stable Optical Clock G 117-B15A (Kepler+ 2005).

The impacts of pulsation modes observed over long time baseline

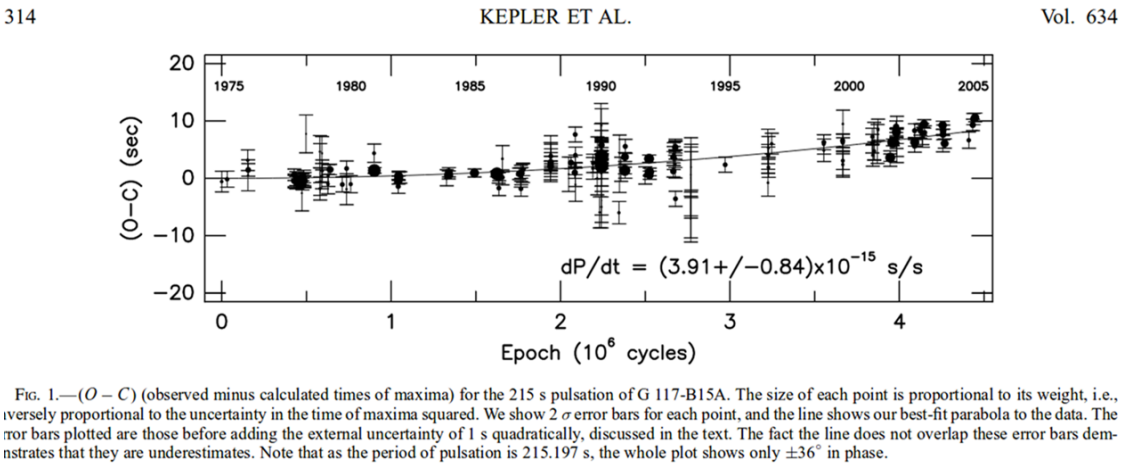


Figure: Measuring the Evolution of the Most Stable Optical Clock G 117-B15A (Kepler+ 2005).

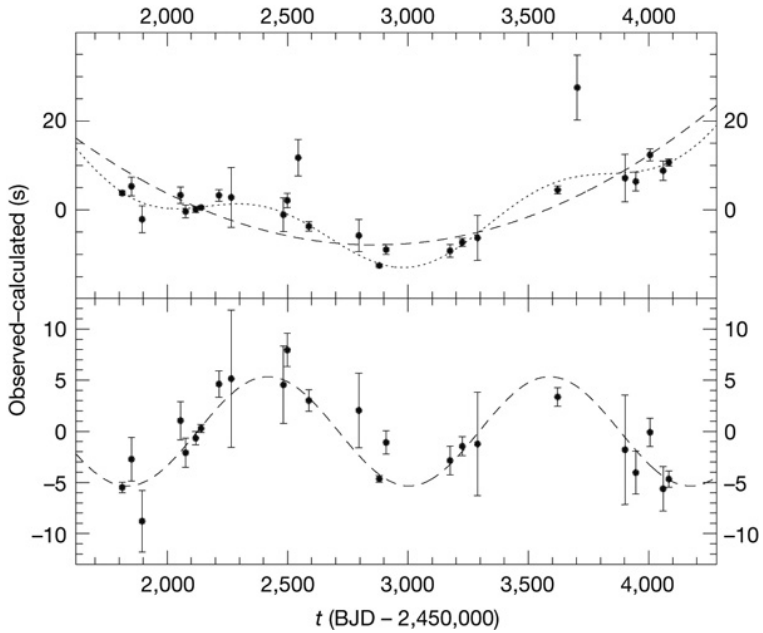
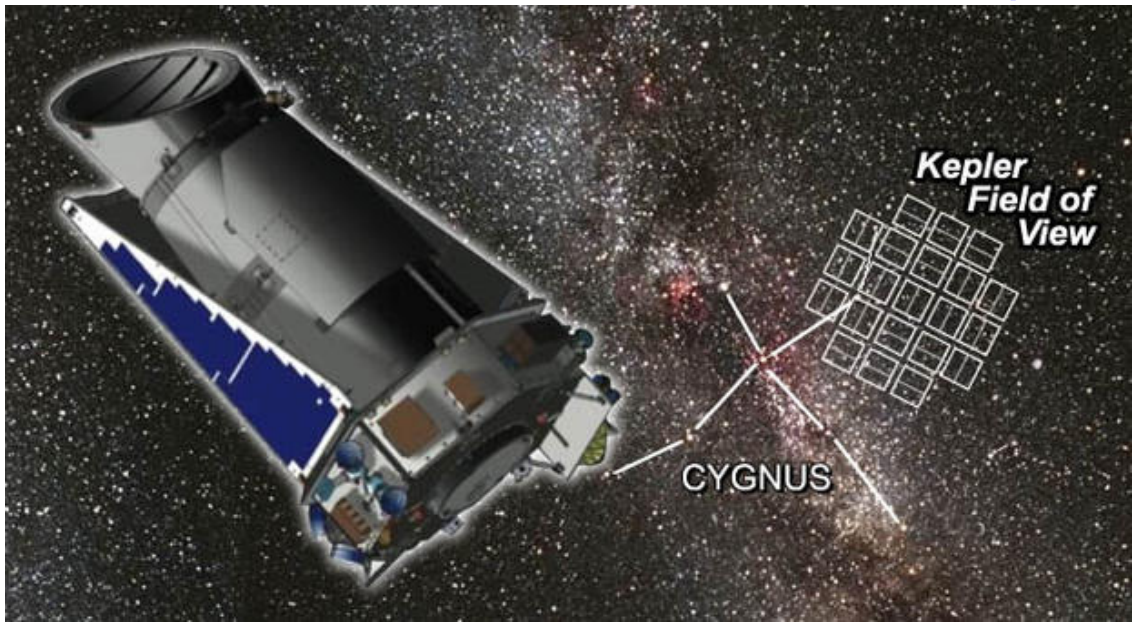
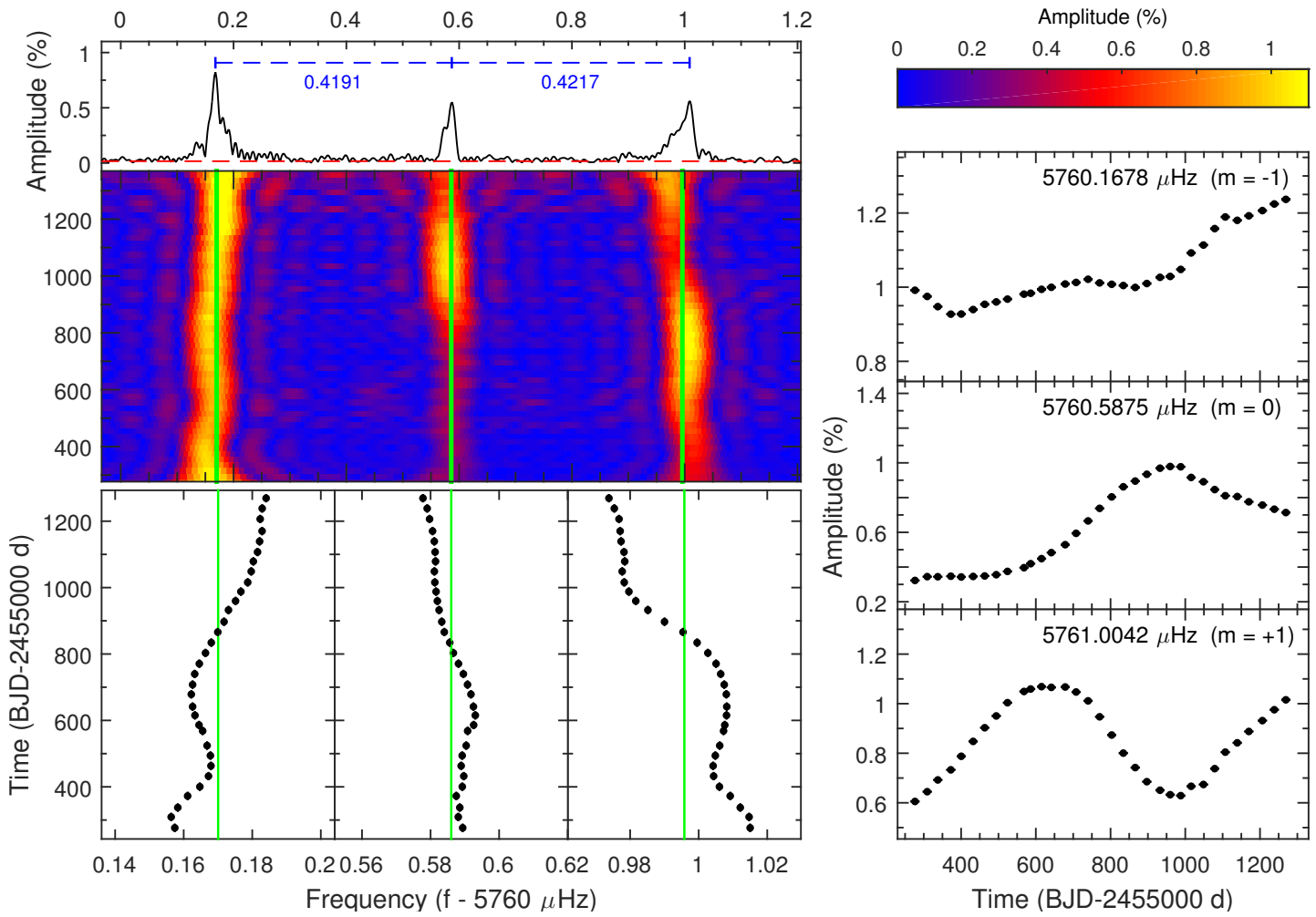


Figure: A giant planet orbiting the 'extreme horizontal branch' star V391 Pegasi (Silvotti+ 2007).

Kepler — a revolutionary mission on uncovering amplitude, frequency and phase modulations of oscillation modes in pulsating stars

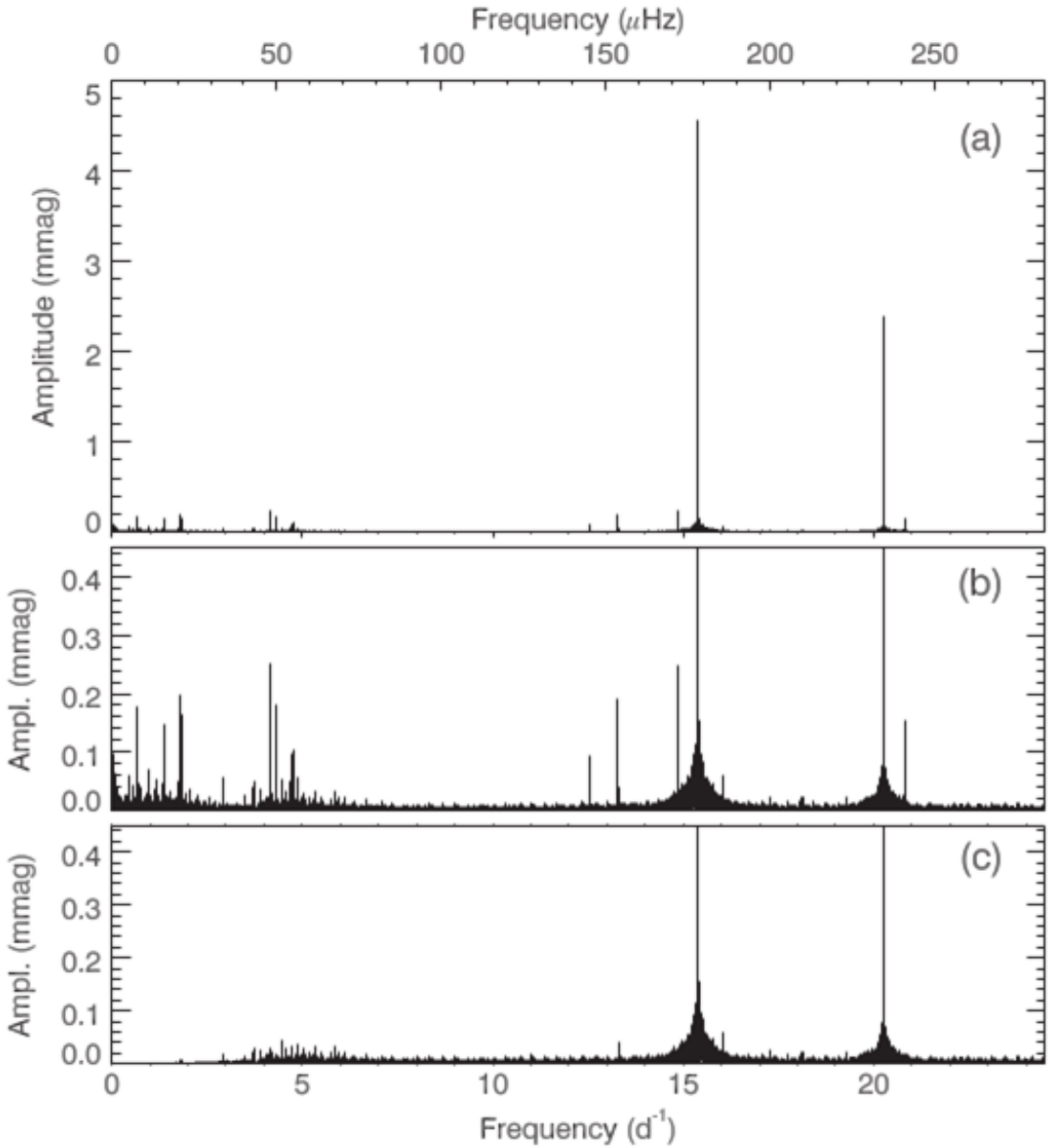


The hot B subdwarf star KIC 10139564: Amplitude and frequency modulations



Zong+ 2016

KIC 7917485: habitable zone planet harbour (Murphy+ 2016)



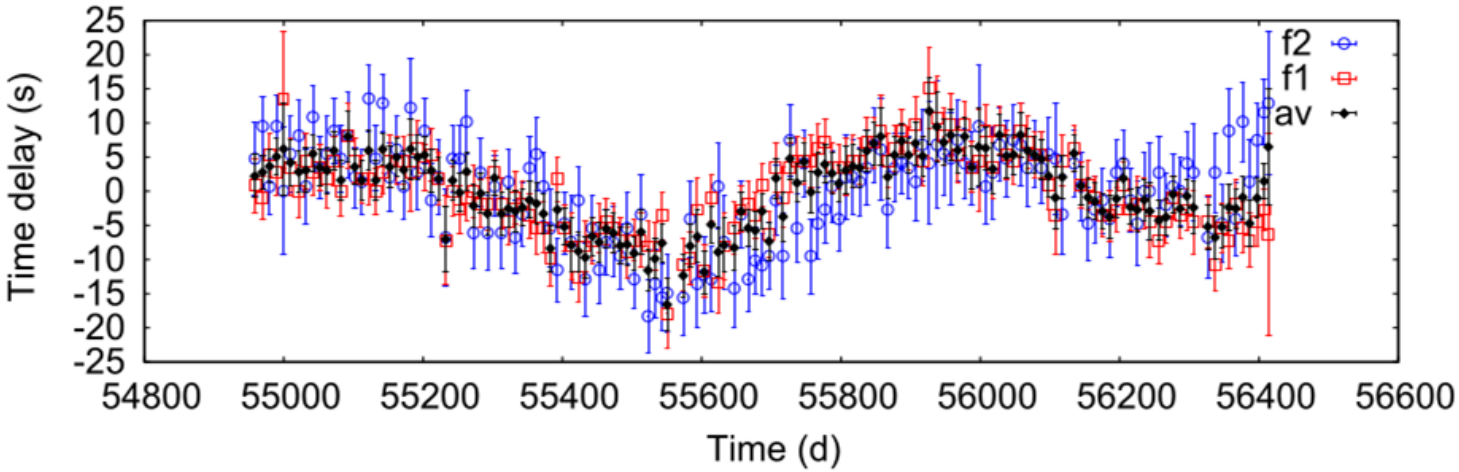
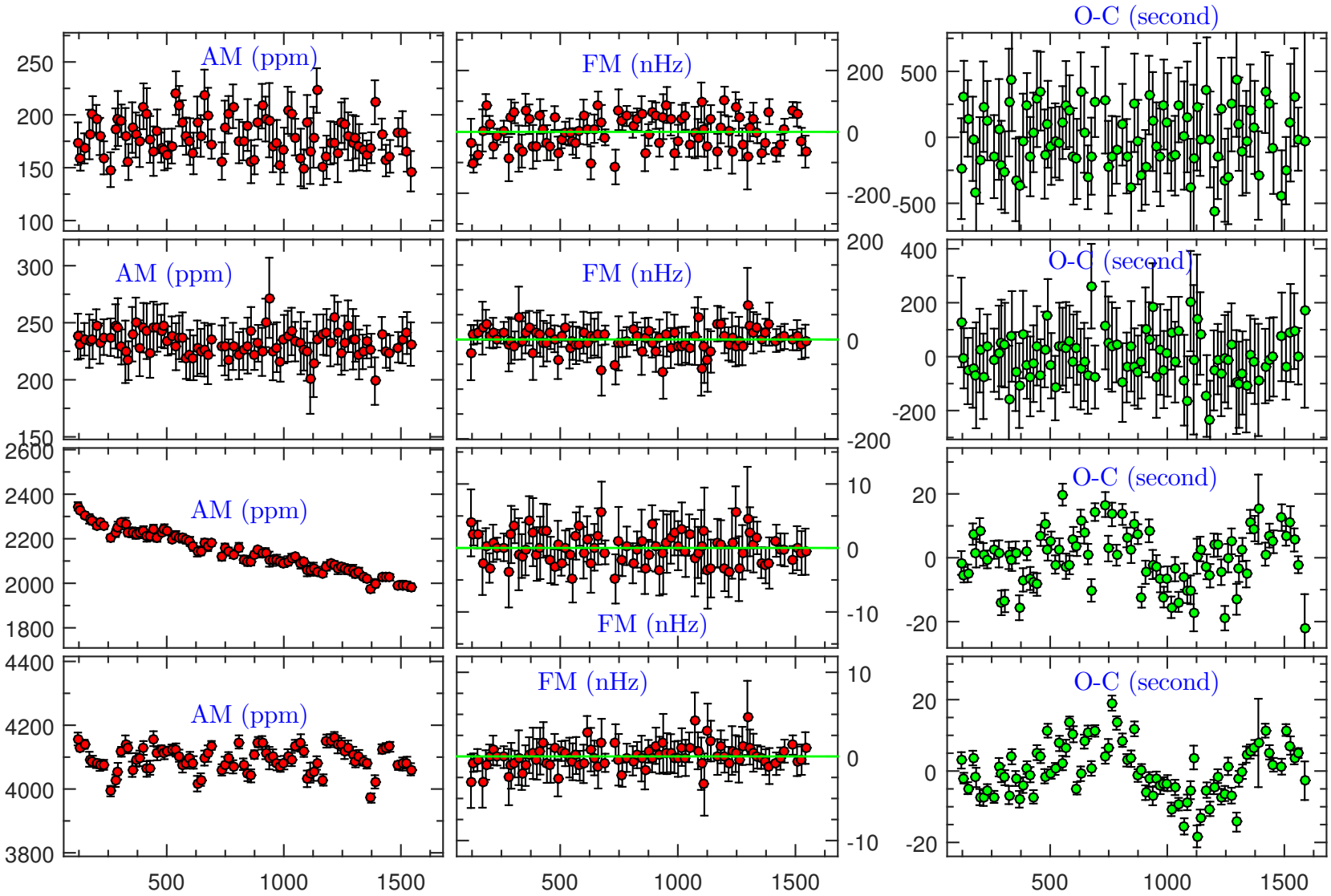
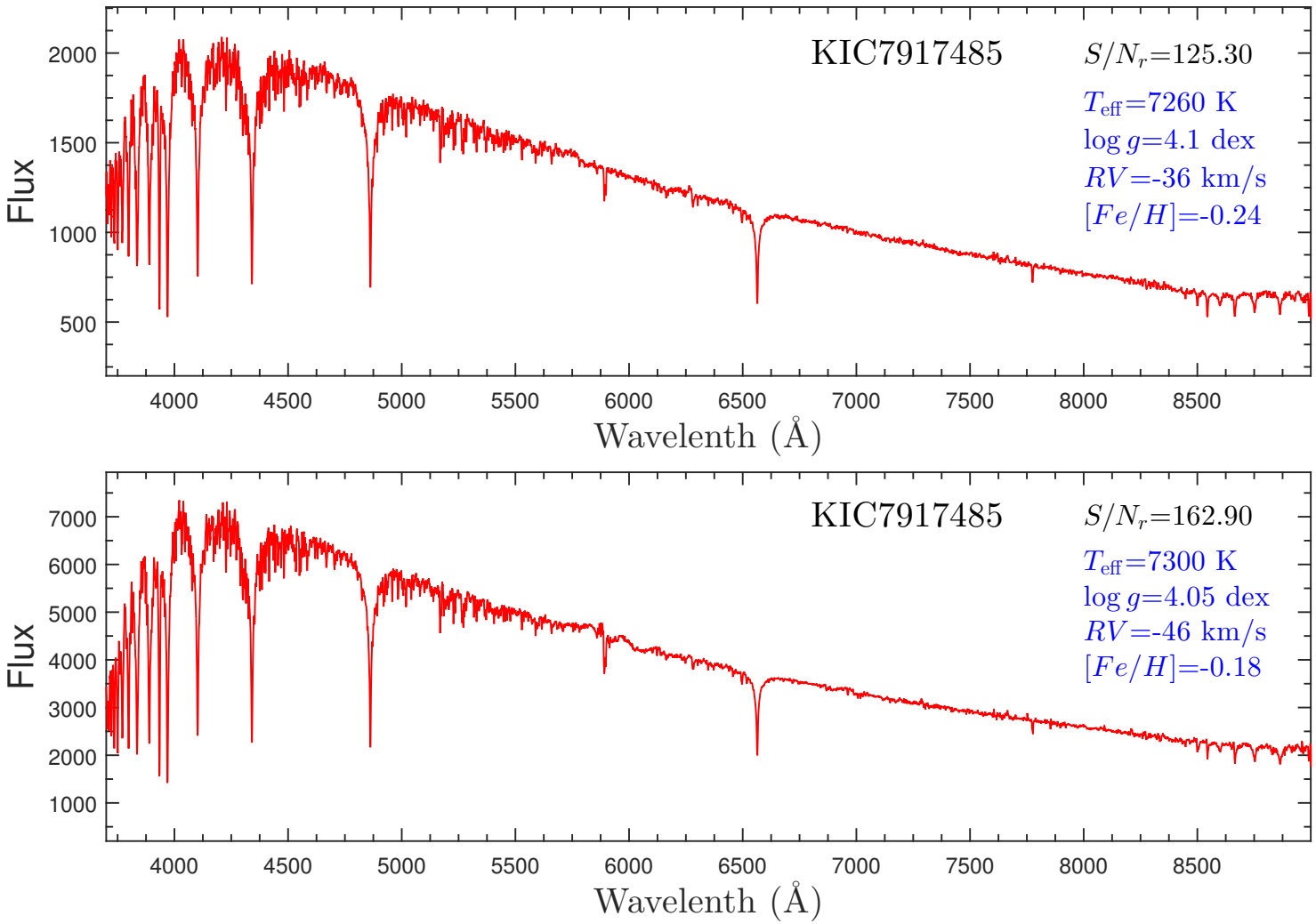


Figure 3. Delays in the light arrival time for the independent oscillation frequencies f_1 (red squares) and f_2 (blue circles). Error bars are the formal least-squares uncertainties. Weighted averages of the two measurements in each 10-d segment are indicated as black diamonds.

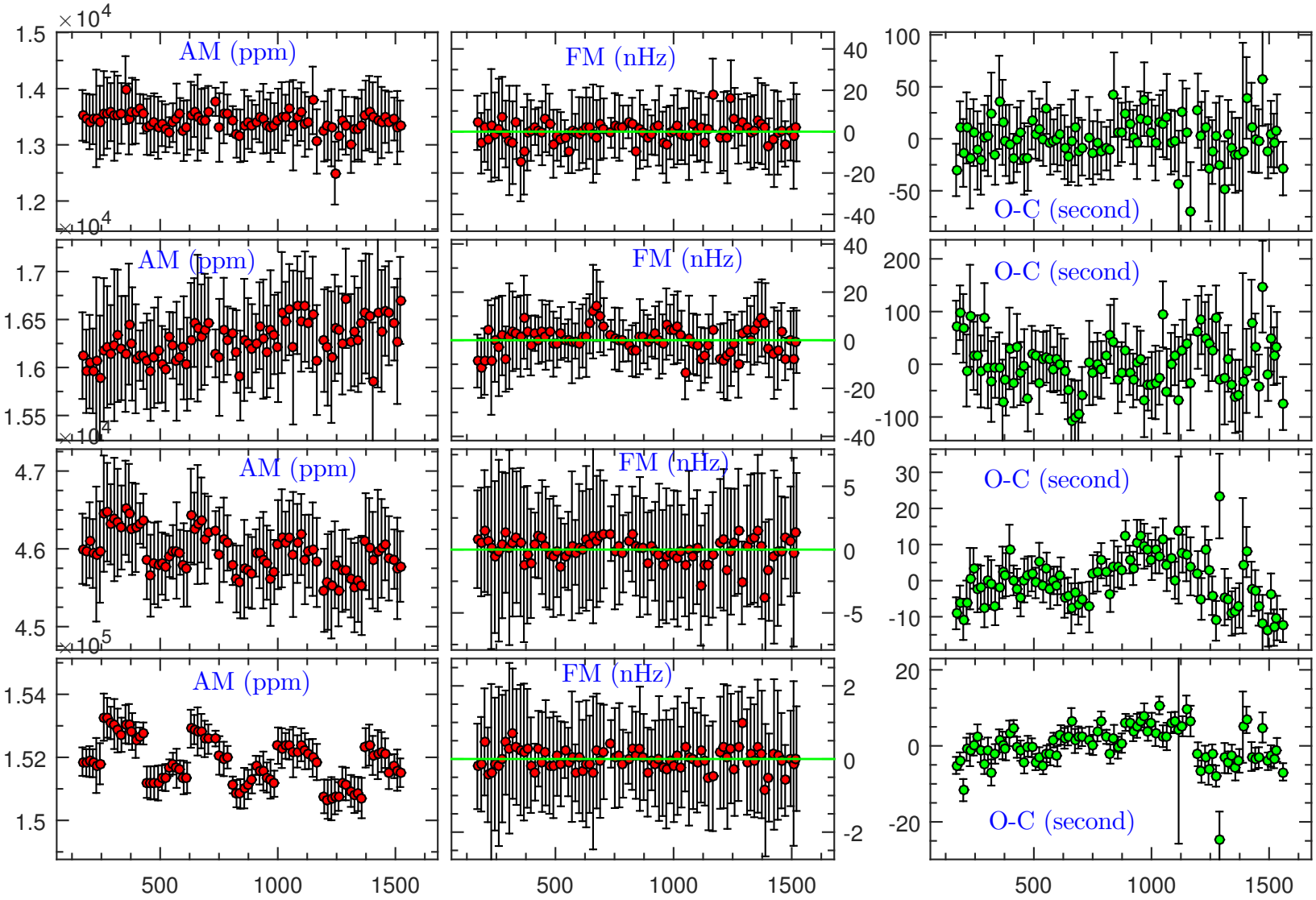
KIC 7917485: habitable zone planet harbour



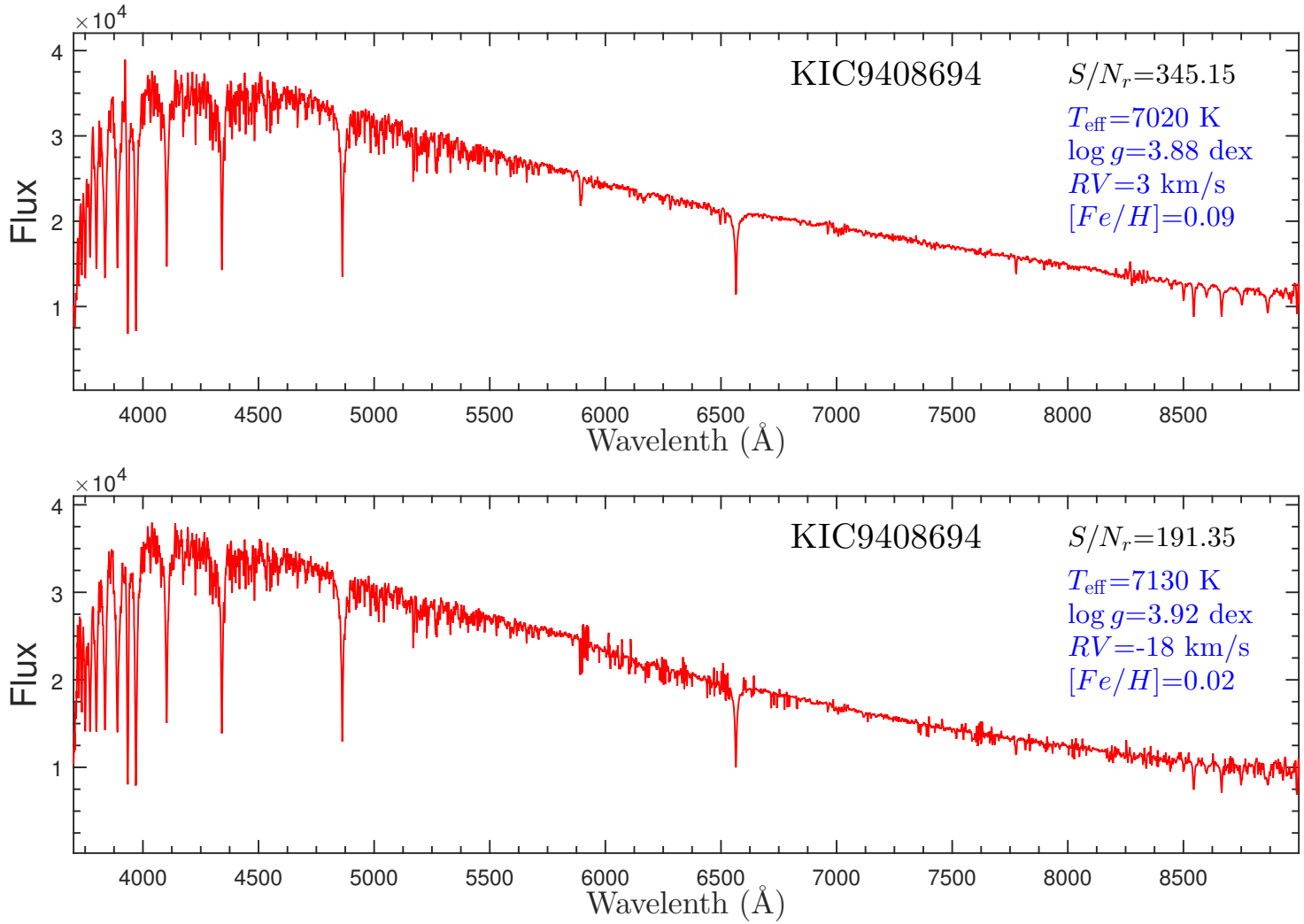
KIC 7917458: habitable zone planet harbour



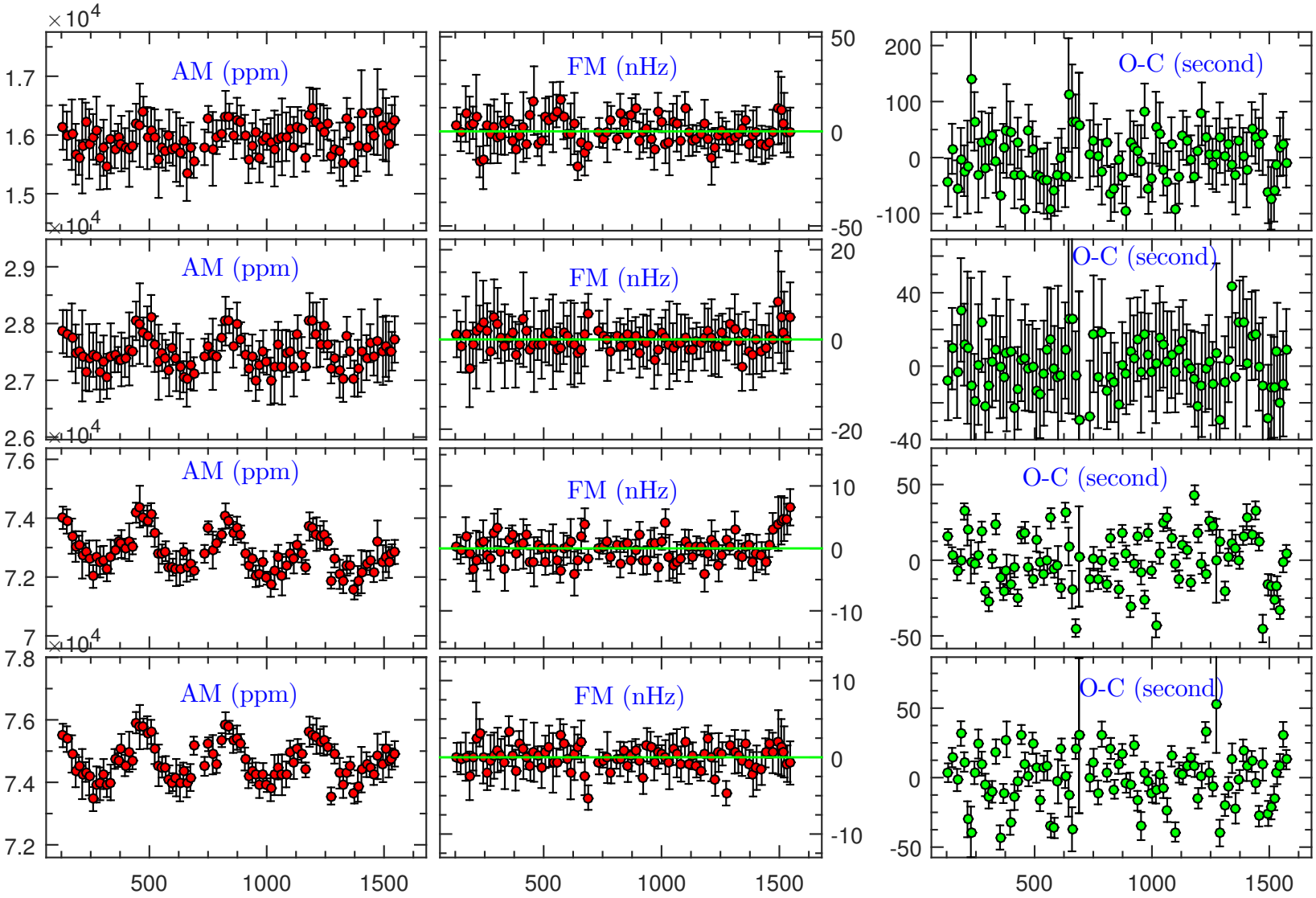
KIC 9408694: HZ planet? brown dwarf? or stellar companion? or noise??



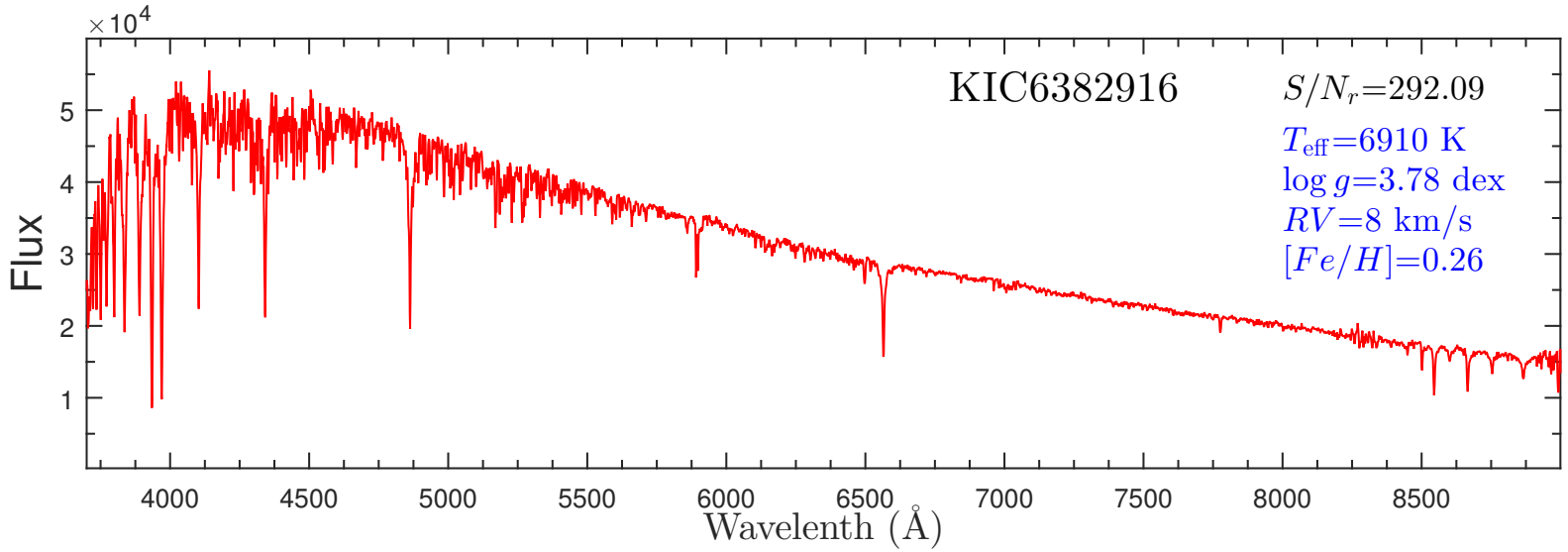
KIC 9408694: habitable zone planet harbour?



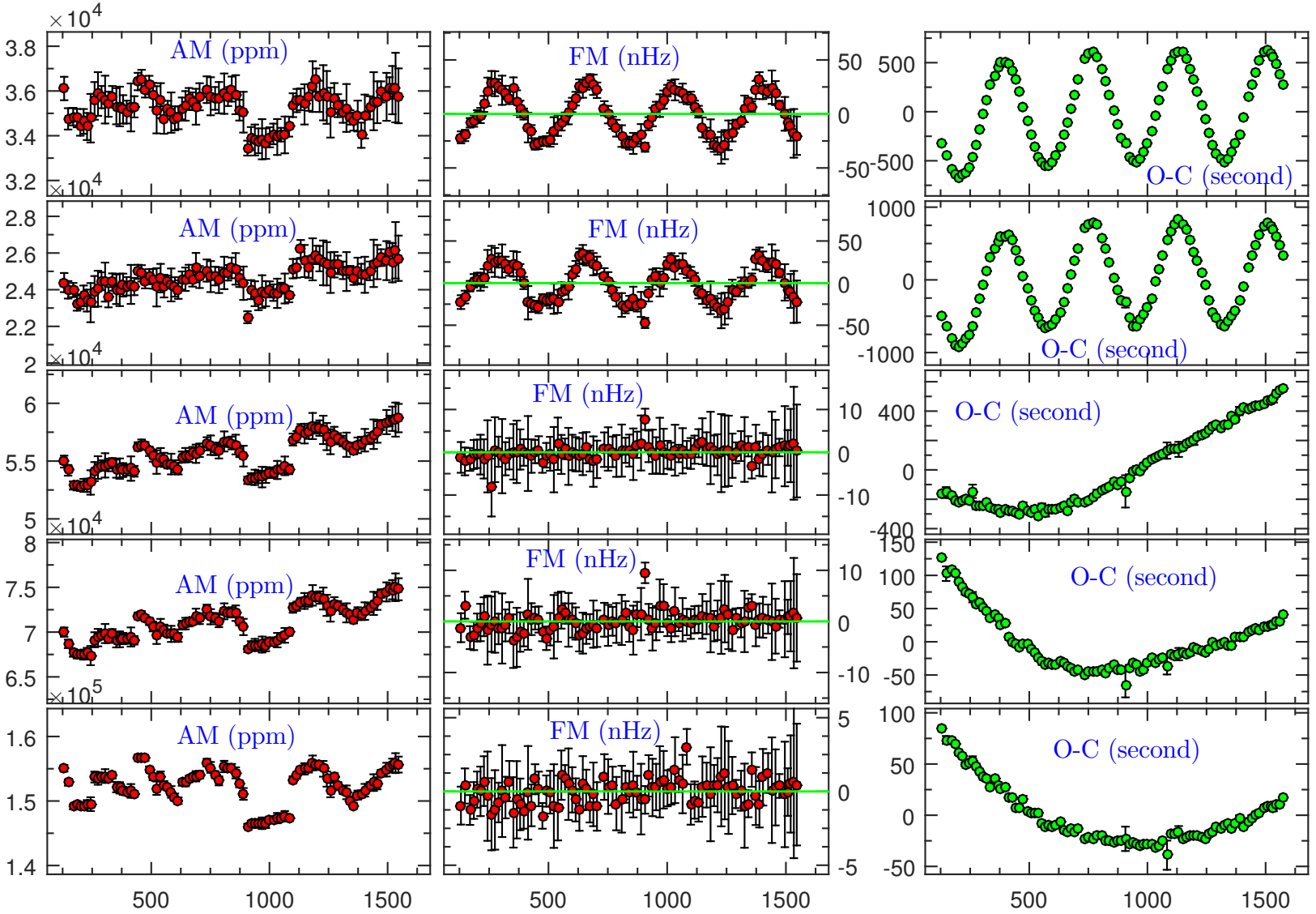
KIC 6382916


AM (ppm)
FM (nHz)
O-C (second)
×10^4
1.7
1.6
1.5
50
0
-50
200
100
0
-100
2.9
2.8
2.7
2.6
20
-20
40
-40
7.6
7.4
7.2
7
10
-10
50
-50
7.8
7.6
7.4
7.2
500
1000
1500

KIC 6382916


×10^4
Flux
KIC6382916
S/N_r=292.09
$T_{\rm eff}$=6910 K
log g=3.78 dex
RV=8 km/s
$[Fe/H]$=0.26
Wavelenth (Å)

KIC 5950759



General summary

- Part (1) Four LAMOST white dwarf stars have been identified as pulsating white dwarfs so far
- Part (2) Three δ Scuti stars had been observed by LAMOST
- Part (2) Another new planet around a δ Scuti star?
- Part (2) One δ Scuti star in a wide binary system.

Further works

- The faint *Kepler* sdB and white dwarf stars are very few observed by LAMOST
- The following LAMOST observations can provide constraints on the orbital parameters pulsating stars in binary systems or planetary system
- The follow-up photometric observations to complete a entire cycle of KIC 5950795


Thank you!