The planet next door: an Earth mass planet orbiting Alpha Centauri B

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Alpha Centauri B (HD128621) is one of the best target to search for an habitable Earth-like planet. The brightness of the star (V = 1.3) allowing to reach a very high signal-to-noise ratio, its low activity, its spectral type (K1V) and the proximity of it have made of Alpha Centauri B the holy grail of exoplanet astronomy.

HARPS radial velocity (RV) measurements of Alpha Cen B show that the star is not as quiet as expected. Since 4 years, the activity level of the star has raised, increasing strongly the stellar jitter due to the presence of magnetic features on the stellar surface.

Due to a high frequency sampling (2 to 3 measurements per night every night) and the very high precision of the HARPS spectrograph (~80 cm.s^{-1}), it is possible to see the magnetic cycle and the day-by-day variation of the rotational activity induced signal. The high quality of these data allows us to correct RVs from these perturbing signals and to detect an Earth-mass planet only 4 light years away.

1 Contamination from Alpha Centauri A

- Due to the small separation between Alpha Centauri A and B, 7" in 2008, 5" in 2011, Alpha Centauri A will contaminate the spectrum of B when the seeing is poor. We estimate this contamination and remove measurements above a given seeing cutoff.

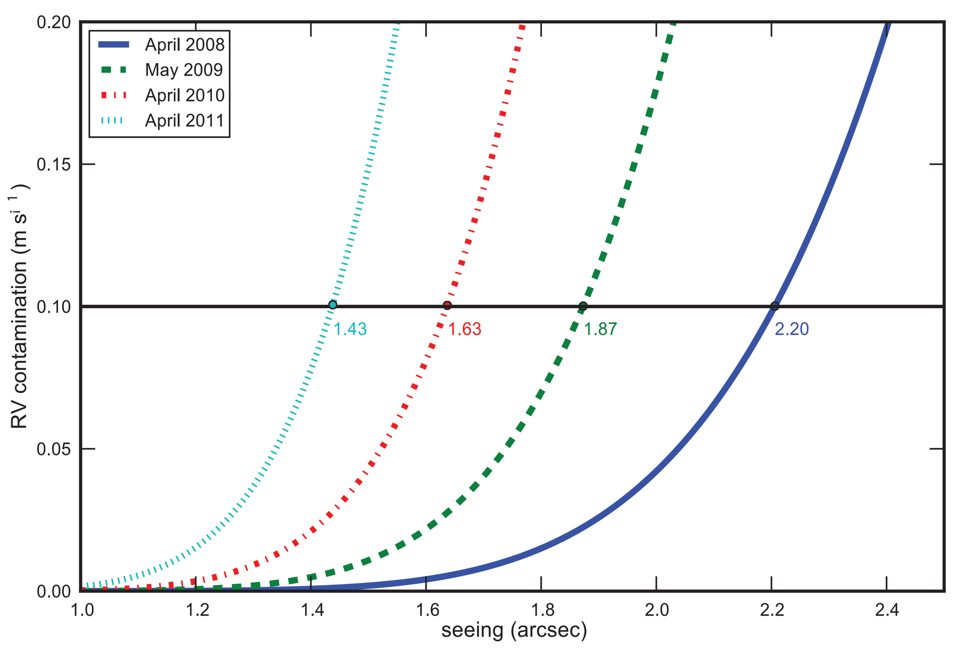


Fig 1: *RV contamination for each season and adopted seeing cutoff. The cutoff decreases because Alpha Centauri A is getting closer to Alpha Centauri B.*

2 Binary and magnetic cycle

- The effect of the binary and the magnetic cycle can be seen in the RVs of Alpha Centauri B. Once these signals are removed, the rotational period of the star and its harmonics are seen in the periodogram of the residuals, revealing the presence of rotational activity.

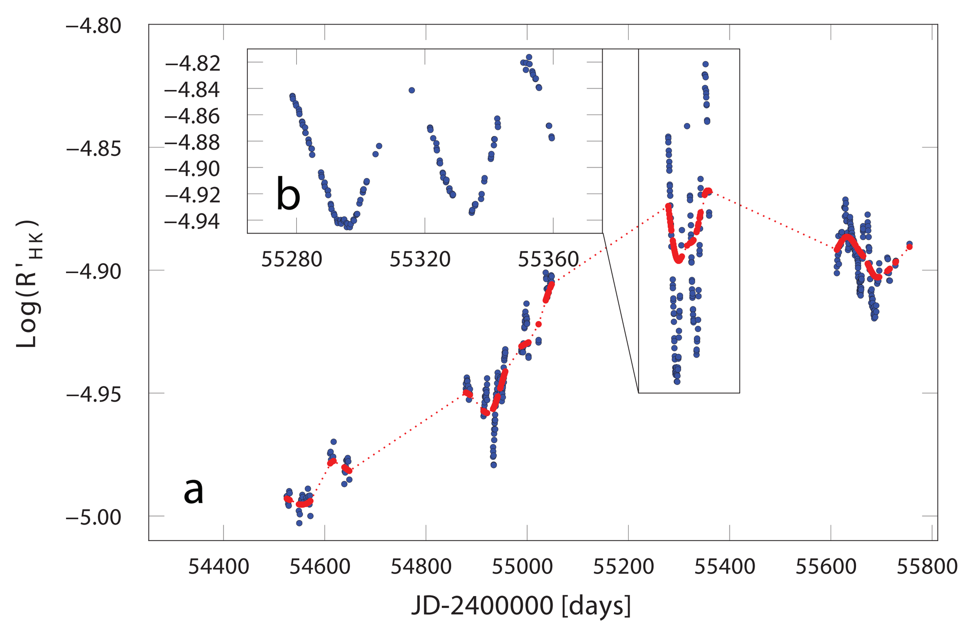


Fig 2: ***a*** *Magnetic cycle of Alpha Centauri B in blue and the same cycle low pass filtered in red.* ***b*** *The 3rd season highlights an important periodic activity variation. This is the signature of a magnetic feature on the stellar surface with a filling factor greater than 1%. The stellar rotational period of 37.2 days can be determined precisely.*

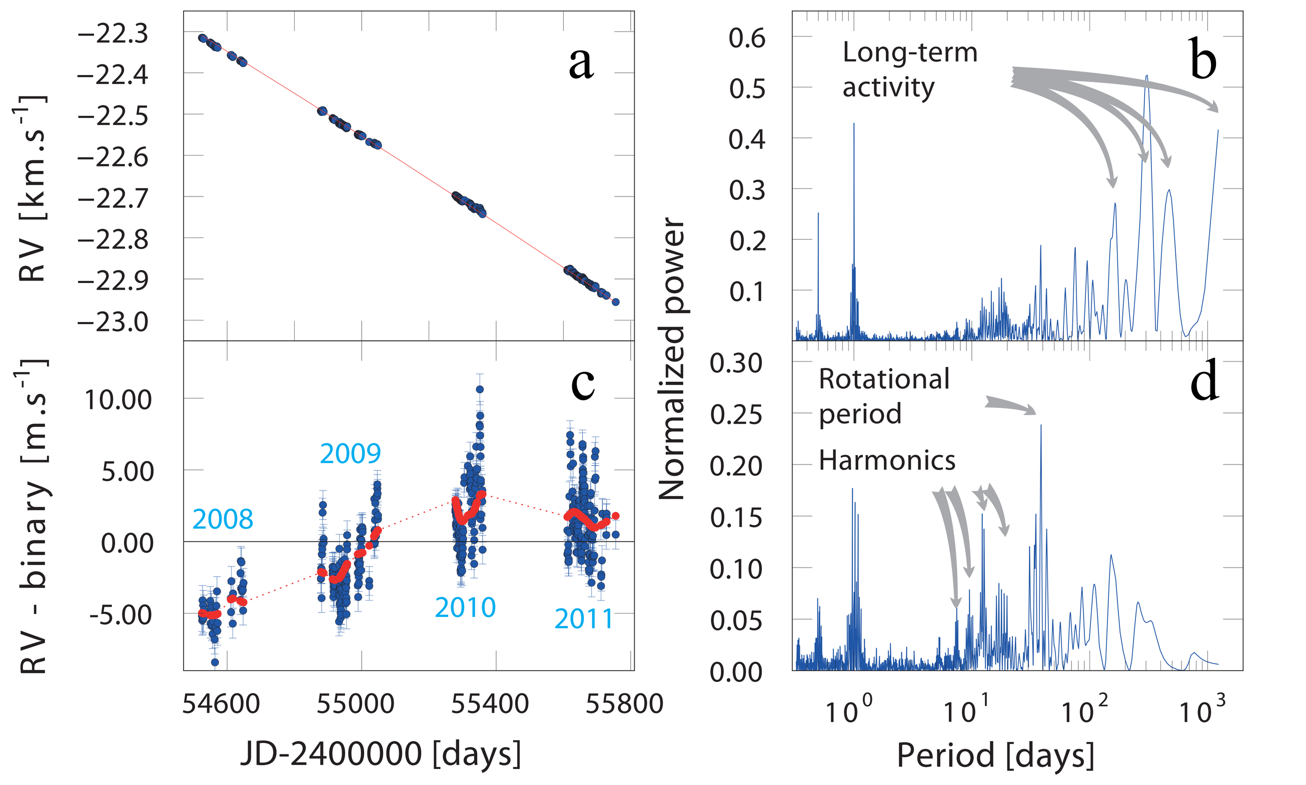


Fig 3: *Radial velocities of Alpha Centauri B and fitting the long-timescale stellar signals.* ***a*** *Raw RVs and the fit of the binary's signature (Alpha Centauri B orbiting A). In the residuals (**c**), signals at long period are visible. These signals, highlighted by grey arrows ('long-term activity') in periodogram **b**, correspond to the effect of the magnetic cycle. The red curve in **c** shows the variation of the low-frequency part of the activity index scaled to the radial-velocity variation (see Fig. 2). When these low-frequency perturbations are removed, signals induced by rotational activity, pointed out by grey arrows in periodogram **d**, can be seen at the rotation period of the star and its harmonics.*

3 Rotational activity

- Magnetic features are rotating with the star, therefore they will induce signal at the rotational period of the star and the corresponding harmonics (see Boisse et al. 2010).

- Because magnetic features evolve in size and appear-disappear on a few rotational periods, we divide our observations in 4 different seasons 2008, 2009, 2010 and 2011.

- For season 2008, no activity signal is observed because the star exhibits a low activity level (See Fig. 2).

- For the other seasons, sinusoids are fitted for the rotational period and the significant harmonics (1 harmonic for 2009 and 2 for 2010 and 2011).

- Modeling rotational activity allow us to reduce the RV rms from 2.0 to 1.2 m.s^{-1}.

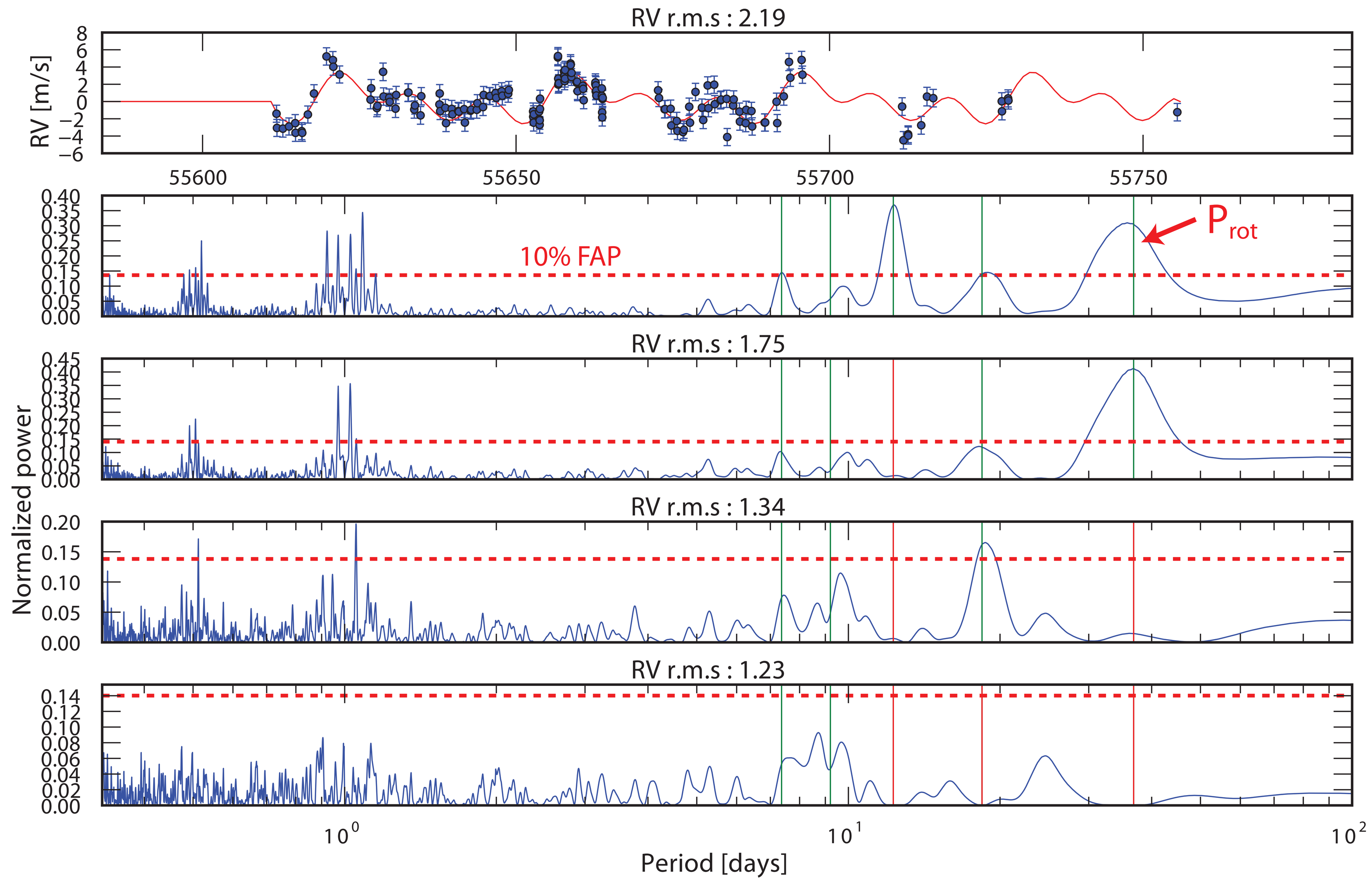
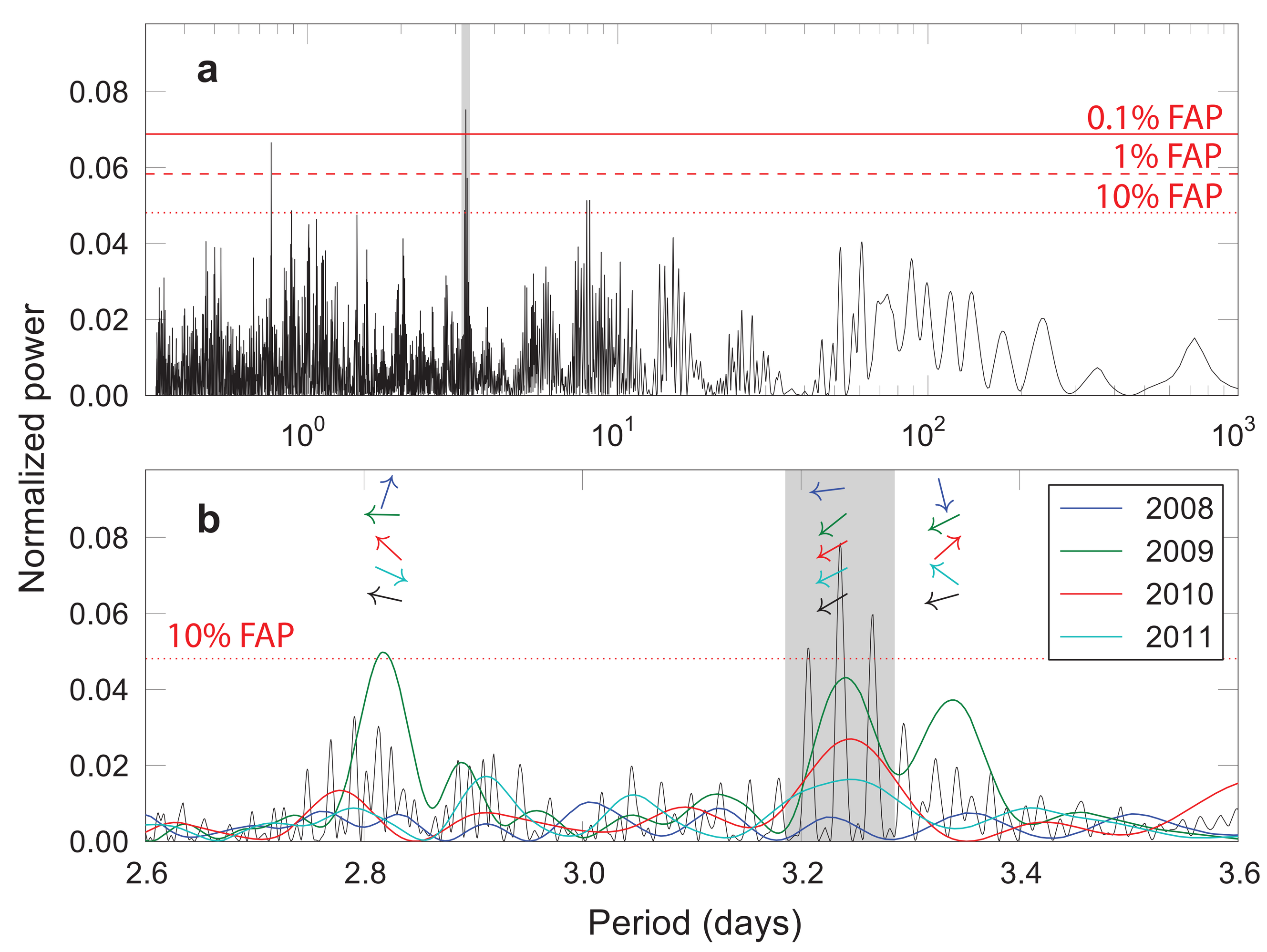


Fig 4: ***Top*** Fit of the rotational activity signal for season 2011. The fit is composed of 3 sinusoids at the rotational period and the 2 first harmonics. ***Bottom*** Periodograms highlighting rotational activity for season 2011. The vertical green lines represent the stellar rotational period fitted and the first four harmonics. The 2nd graph starting from the top shows the residuals after removing the binary andthe magnetic cycle. The plots below show the periodograms of the RV residuals after fitting the signal corresponding to the red vertical lines. The improvement brought by the fit is shown by the decrease of the RV r.m.s shown in the plot titles (in m.s^{-1}). For this season, the rotational period and the 2 first harmonics are fitted.

4 An Earth-mass planet



- After removing the contaminated points, the effects of the binary, the magnetic cycle and the rotational activity, a signal at 3.2 days is revealed with 1 chance over 5000 to be due to noise (FAP = 0.02%). The amplitude of this signal is 51 cm/s.

- For each year of observation, the peak at 3.236 days conserves the same phase, which is expected for a planetary signal. On the contrary, the peak at 2.8 days and its alias at 3.35 days do not keep the same phase and are therefore associated to noise.

- This signal corresponds to an Earth-mass planet orbiting in 3.2 days around Alpha Centauri B.

Fig 5: ***a***, *The periodogram of the RVs after correction for stellar effects. The highest peak, at 3.236 days inside the shaded region, has an FAP of 0.02%.* ***b***, *Zoom of the periodogram around the planet signal. The periodogram for all seasons is shown in black, and the yearly periodograms for each observational period (2008, 2009, 2010 and 2011) are shown in different colours. The phase of the most important peaks is shown (arrows); the direction of the arrow gives the phase between 0 and 2pi.*

5 Skepticism about the planet

- Hatzes reanalyzed the data and did not find significantly the planetary signal (2013, ApJ, 770, 133). Using pre-whitening, he found a FAP of 7% for the planetary signal. Using Local Trend Filtering, the planet can only be found in special conditions.

- Performing pre-whitening season by season (because magnetic features on the stellar surface change) and removing only peaks that correspond to a physical signal (peaks at the rotational period and harmonics), we were able to recover the planetary signal with a FAP of 0.05%, similar to our analysis (0.02%).

- 10 nights of continuous observation with HARPS and a search for the transit with HST will help us to increase the detection significance.

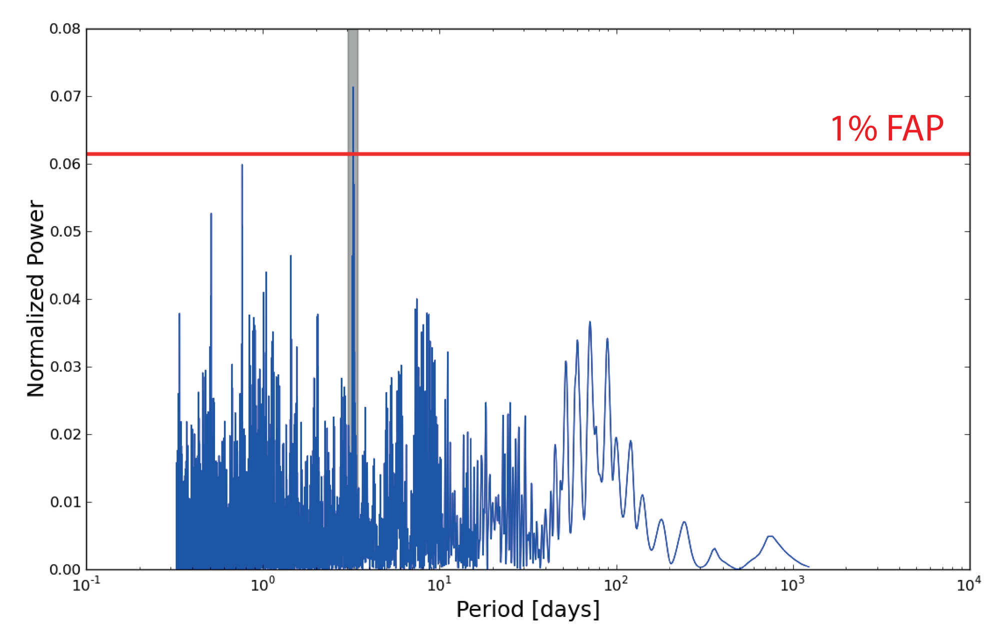


Fig 6: *Periodogram showing the planet signal after pre-whitening the data season by season, and removing only physical signals (at the rotational period of the star and its harmonics)*

Conclusion

- Correcting for stellar signal is mandatory to find small amplitude planetary signal with RVs.

- High-frequency sampling is crucial to correct for rotational activity signal.

- We have found an Earth-mass planet orbiting the second closest star.