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Authors	Borin, Federico, PORETTI, Ennio, BORSA, Francesco, RAINER, Monica
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Observing exoplanets from the planet Earth: how our revolution around the Sun affects the detection of 1-year periods *

Federico Borin[1,2], Ennio Poretti[2], Francesco Borsa[2], and Monica Rainer[2]

[1] Dipartimento di Fisica G. Occhialini, Università di Milano Bicocca and INFN, Piazza della Scienza 3, 20123 Milano, Italy
[2] INAF-Osservatorio Astronomico di Brera, Via E. Bianchi 46, 23807 Merate, Italy

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Abstract. We analysed a selected sample of exoplanets with orbital periods close to 1 year to study the effects of the spectral window on the data, affected by the 1 y^{-1} aliasing due to the Earth motion around the Sun. We pointed out a few cases where a further observational effort would largely improve the reliability of the orbital solutions.

PACS. exoplanets: planets orbiting other stars – frequency analysis: spurious peaks in power spectra

1 Introduction

The search for extrasolar planets is not always a straightforward task. The recent case of α Cen B is an example of how stellar activity and data sampling can conspire in making the detection of a keplerian signal a controversial exercise. The planet α Cen Bb would have a mass of only 1.1±0.1 Earth masses, orbiting a sun-like star, at only 1.3 pc from the Solar System, with a period of P_b=3.24 d only. The signal detected in the radial velocity (RV) time series of α Cen B and ascribed to a keplerian motion has a semi-amplitude (K) of 0.51 $\mathrm{m\,s^{-1}}$ (Dumusque et al., 2012). However, the real nature of the signal was questioned and interpreted as a "ghost" signal due to α Cen B activity (Rajpaul, Aigrain, & Roberts, 2016). The signals due to the stellar activity artificially enhanced the peak at 3.24 d present in the spectral window of the data. Rajpaul et al. emphasized how crucial is the understanding of every component of a RV time series, including its spectral window.

There are other subtle examples of artificially induced signals. The HARPS spectrograph is very stable, close to the $\mathrm{m\,s^{-1}}$ level. However, the RV time series of some stars resulted to be contaminated by a spurious 1 year signal having an amplitude K of a few $\mathrm{m\,s^{-1}}$ (Dumusque et al., 2015). Its artificial nature was imprinted in the phase value, in opposition with the revolution of the Earth around the Sun. It has been explained by the deformation of spectral lines crossing block stitchings of the detectors. The spectrum of an observed star is alternatively blueshifted and redshifted due to the motion of Earth around the Sun. This annual perturbation can be suppressed *a priori* by either removing the affected spectral lines from the correlation mask or *a posteriori* by simply fitting a yearly sinusoid to the radial velocity data (Dumusque et al., 2015).

We also remind that the Doppler shifts measured from a ground-based observatory with respect to an internal calibration wavelength scale have to be transformed into those that would be measured in the barycenter of the Solar System. This transformation accounts for all the components of the Earth velocity in the direction of the target due to, e.g., daily rotation, Earth-Sun and Earth-Moon systems, ... However, we should also consider that high proper-motion stars show changing positions and radial velocities with respect to the Solar System barycenter and these small changes have to be carefully evaluated in the era of extremely precise measurements of Doppler shifts (e.g., Wright & Eastman, 2014).

2 Sample selection

The issues addressed above suggested us a simple project to verify the reliability of the detections of exoplanets having an orbital period of about 1 year and discovered with the Doppler spectroscopic technique. This technique is much more

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Send offprint requests to: E. Poretti

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Correspondence to: ennio.poretti@brera.inaf.it

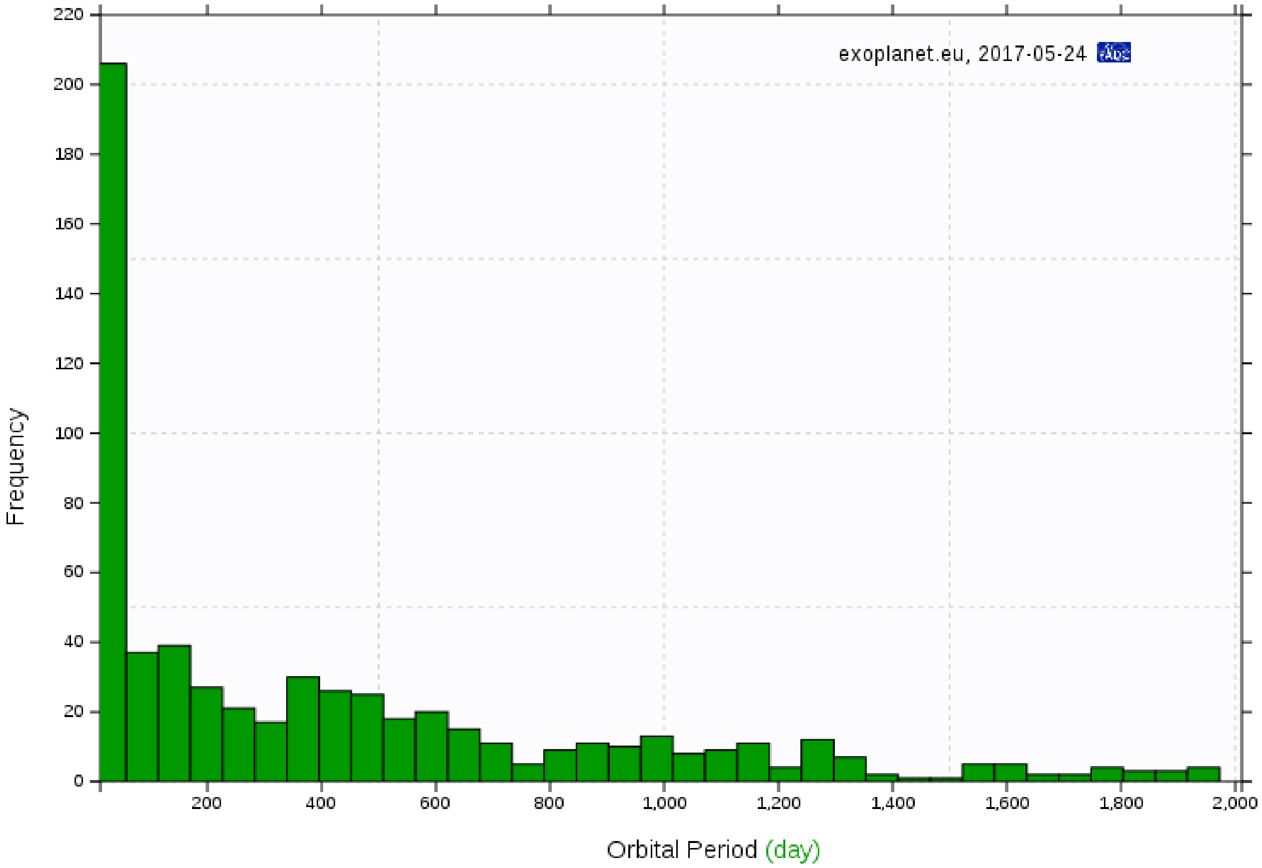

Fig. 1. Updated histogram of the orbital periods discovered with the Doppler spectroscopic technique. Note the small dip in the distribution around 360 d.

sensitive to the aliasing problems than the transit method. More than 3000 exoplanets were known when we started the project. A simple query using *The Extrasolar Planets Encyclopaedia*[1] found out 17 candidates with an orbital period in the range from 349.7 to 380.5 d (HD 142b, HD 192699b, HD 67087b, HD 159868c, HD 210702b, HD 4313b, μ Leo b, HD 63765b, HD 17092b, HD 4732b, HD 96063b, HD 38283b, HD 212771b, HD 73526c, BD+20 2457b, α Ari b, and HD 20868b). We note that the detection of exoplanets within this range is actually more difficult than in others: a clear dip is visible in the frequency distribution (Fig. 1).

The RV time series could be obtained from the discovery papers or, in a more useful way, from the NASA Exoplanet Archive[2]. Unfortunately, not all the discovery's authors put their time series in the paper or in the archive. We analysed all the available data and we discuss here the six cases able to provide a methodological feedback.

2.1 HD 142

The periods of the two planets orbiting HD 142 ($T_{\rm eff}$=6025 K, G1IV, M=1.15 $M_\odot$) are very intriguing. The planet *b* ($M_p \sin\ i$=1.21 $M_{\rm Jup}$) has a period P_b=351.1 d, the planet *c* ($M_p \sin\ i$=5.5 $M_{\rm Jup}$) a period P_c=7900 d (Wittenmyer et al., 2012). We performed a careful analysis of the spectral window, since the authors do not report on it and the two frequencies (f_b=0.0028 d^{-1} and f_c=0.0001 d^{-1}) are separated exactly by 1 y^{-1}. We were made suspicious by the fact that one period is the alias of the other and by the regular structure of the peaks at low frequencies (Fig. 2, panel *a*). First harmonics of f_b and f_c are also detected due to the eccentric orbits. Note that the peak at 0.033 d^{-1} is an alias, being reproduced by the spectral window.

The amplitudes involved here (K_b=31.6 m s^{-1}, K_c=52.6 m s^{-1}) ruled out the possibility of a misidentification or of an instrumental effect. Indeed, Wittenmyer et al. report a very convincing RV curve over 5000 d and clear phase-folded RV curves on the two periods. We just note that the coverage of the P_b orbit was not completed, a fundamental step to definitely discard the hypothesis of a long-term variability due to an activity cycle.

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[1] `http://exoplanet.eu/`

[2] `https://exoplanetarchive.ipac.caltech.edu/`

We also remind the reader that the planets were discovered around the star HD 142A, but there is a faint stellar companion (HD 142B, V=11.5), with similar high proper motion. We noticed that the gravitational bounding of the two stars has not been taken into account in the evaluation of the long-term variation of the radial velocity. Moreover, the high proper motion of HD 142A can also affect the long-term behaviour of the radial velocity.

2.2 HD 4732

The presence of a planet around the high proper-motion star HD 4732 ($T_{\rm eff}$=4959 K, K0IV, M=1.74 $M_\odot$) was suspected by analysing a RV time series obtained at the Okayama Astrophysical Observatory. A continuous increase ranging 100 $\mathrm{m\,s^{-1}}$ was observed, without a clear definition of the extrema. Therefore, other RV measurements were performed at the 3.9 m Anglo-Australian Telescope and a period P_b=360 d (K_b=47.3±3.5 $\mathrm{m\,s^{-1}}$) could be inferred (Sato et al., 2013). On the basis of five years of monitoring, Sato et al. also detected a second planet with a period P_c=2732 d (K_c=24.4±2.2 $\mathrm{m\,s^{-1}}$).

This case is less convincing than the HD 142 one, since the power spectrum is more noisy (Fig. 2, panel *b*). We verified that none of the two datasets is providing a clear solution when analysed separately from the other. When combining them, large parts of the folded RV curve of planet *b* remain uncovered (few points on the steep descending branch).

2.3 μ Leo

A planet around the giant star μ Leo (V=3.88, K2 III) was detected by means of 103 RV measurements spanning about 10 years (Lee et al., 2014). The resulting period is P_b=357.8±1.2 d. The massive planet (K=52.0±5.4 $\mathrm{m\,s^{-1}}$and hence $M_p \sin\ i$=2.4 $M_{\rm Jup}$) is orbiting at only 1.1 AU from the giant star, whose radii is 16.2 $R_\odot$, i.e., 0.07 AU. Therefore, the planet is exposed to a large irradiation.

The spectroscopic data do not cover the RV curve in a satisfactory way, in particular at the minimum. A special effort was made in the last observing season to cover this part of the RV curve, providing a good confirmation of the planetary fit. The peaks at f_b=0.0028 $\mathrm{d^{-1}}$ and at the first harmonic value $2f_n$ (eccentric orbit, e=0.09±0.06) stand out above the noise, but the power spectrum shows a general increase of the noise level for f <0.01 $\mathrm{d^{-1}}$, due to the poor spectral window (Fig. 2, panel *c*).

It is noteworthy that an independent spectroscopic survey aimed at detected pulsation in μ Leo did not revealed any trace of RV variability (Hekker et al., 2006). However, the phase coverage of these RV data was poor on the period very close to 1 year discovered by Lee et al. and this could explain the non-detection. The possibility that μ Leo is a pulsating variable was ruled out by HIPPARCOS photometry (Lee et al., 2014). Finally, we note that μ Leo is another high proper-motion star.

2.4 HD 96063

Fourteen RV measurements spanning 1400 days suggested the presence of a planet orbiting the subgiant star HD 96063 (V=8.37, G6) with a period P_b=361.1±9.9 d and K_b=25.9±3.5 $\mathrm{m\,s^{-1}}$ (Johnson et al., 2011). Such a sampling is prone to annual systematic errors and actually Johnson et al. carefully verified if the barycentric correction was a possible error source. No correlation was found and no similar signal was detected in other targets. The few measurements per year make the power spectrum a bit noisy, with large structures (Fig. 2, panel *d*). The phase coverage is also very poor.

2.5 HD 73526

The real existence of the 2:1 resonant exoplanetary system (P_b =187.5 d, P_c=376.9 d) around HD 73526 (V=4.1, G6V) has not been easy to ascertain (Tinney et al., 2006), but there now is a good theoretical background supporting it (Wittenmyer et al., 2014). The fact that the second period is close to 1 year did not help in securing a good phase coverage. The power spectrum clearly detects the highest peak at f_b=0.0054 $\mathrm{d^{-1}}$, while the peak at 1 $\mathrm{y^{-1}}$ is much lower (Fig. 2, panel *e*).

Both spectroscopic orbits have large amplitudes (K_b=83.0 $\mathrm{m\,s^{-1}}$ and K_c=62 $\mathrm{m\,s^{-1}}$). We notice that the orbital solution could be improved by planning new measurements covering the extrema: in few occasions only the highest maxima and the lowest minima have been observed, and almost all times with few measurements (Fig. 1 in Wittenmyer et al., 2014). This weakens the reliability of the periods, as demonstrated by the changes in the values of the parameters in the solutions proposed first by Tinney et al. (2006) and then by Wittenmyer et al. (2014).

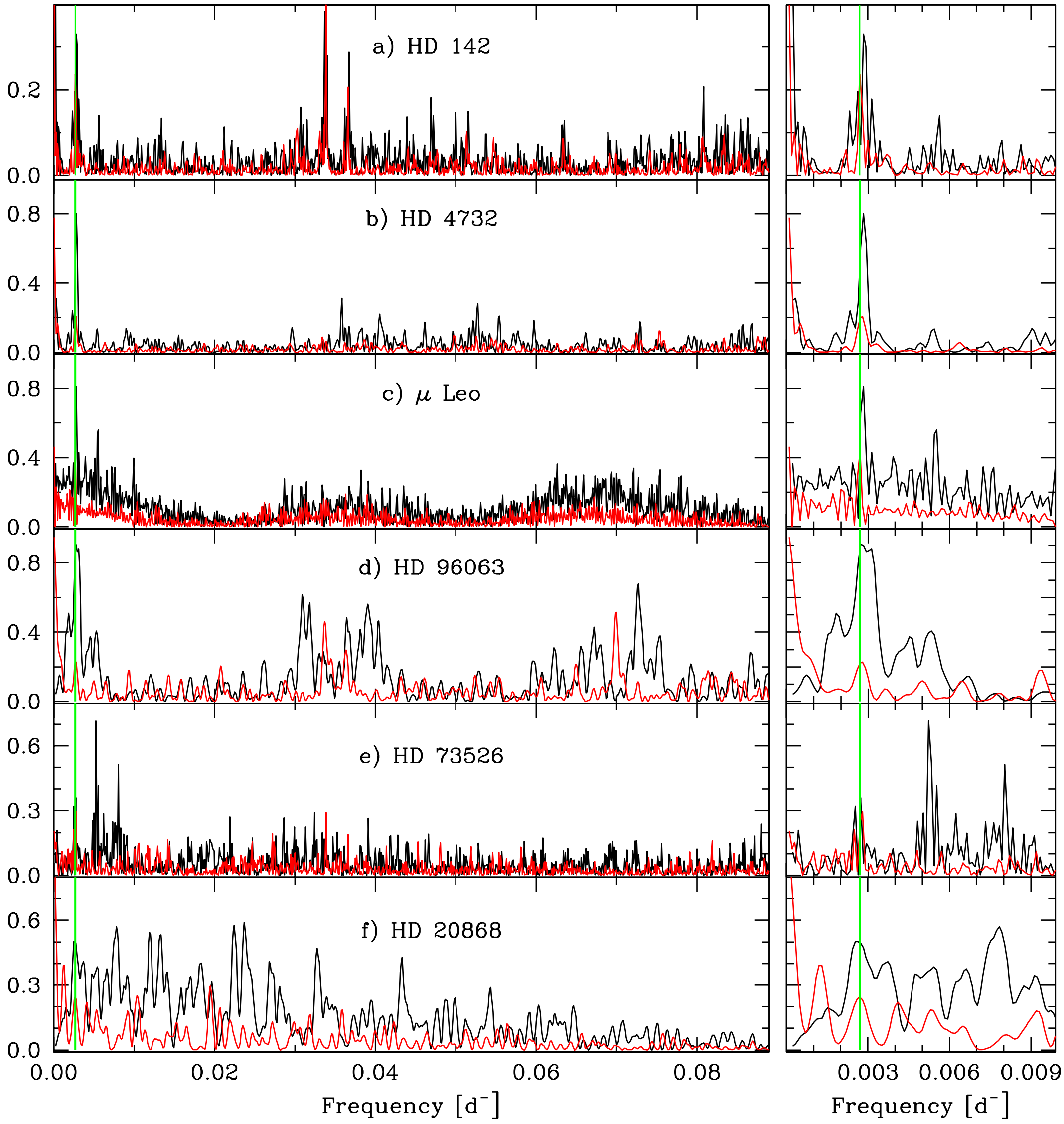

Fig. 2. Power spectra (y-axis in arbitrary units) of the time series of the six exoplanetary systems discussed in the paper. In each panel the power spectrum is in black, the spectral window in red, and a vertical green line shows the position of the 1 y^{-1} peak. The different widths of the peaks in the power spectra are due to the different time lengths of the time series. The panels on the right side are a zoomed version of those on the left side. They emphasize how power spectra and spectral windows are often well superimposed around the 1 y^{-1} frequency.

2.6 HD 20868

The detection of the planet orbiting HD 20868 (Moutou et al., 2009) is clearly unquestionable. Despite a period close to 1 year (P_b=380.85 d, the longest in our sample) and a very eccentric orbit (e=0.75), the HARPS measurements covers the RV abrupt changes around the periastron in a very satisfactory way. The maximum RV values and the amplitude (K_b=100.34±0.42 $\mathrm{m\,s^{-1}}$) are also well constrained by the dense monitoring secured during the last passage at the periastron. The resulting power spectrum (Fig. 2, panel f) shows the complex structure due to the several harmonics (not observed in the spectral window) we have to consider to fit the non-sinusoidal RV curve.

3 Conclusions

Our analysis of the exoplanets with orbital periods of about 1 y did not revealed any spurious results, but just a few cases (HD 4732b, HD 4732c, μ Leo b, HD 96063b) deserving more observations. All the stars are quite bright and the requested time sampling should try to cover the largest part of the year as possible, with a cadence of 2-3 measurements per month. Such a task can be accomplished by long-term programs, like the *Global Architecture of Planetary Systems* (GAPS) with HARPS-N at the Telescopio Nazionale Galileo (Poretti et al., 2016). However, the scheduling should take care to limit the months without data acquisitions to those with the targets in close conjunction with the Sun. This is the gold rule to minimize the 1 y^{-1} alias and to ensure an almost perfect satisfactory coverage of the folded RV curves.

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