AliasFinder: A Python script to search for the true planetary frequency within radial velocity data

Stephan Stock[1, 2] and Jonas Kemmer[1, 2]

1 Landessternwarte, Zentrum für Astronomie der Universität Heidelberg, Königstuhl 12, 69117 Heidelberg, Germany **2** Fellow of the International Max Planck Research School for Astronomy and Cosmic Physics at the University of Heidelberg (IMPRS-HD)

Summary

Planets around other stars, so called exoplanets, can be detected with the radial velocity (RV) method which uses high-resolution spectroscopy on the host star. The method transforms the measured Doppler-shift in a stellar spectrum to a radial velocity. This Doppler-shift is caused by the stellar reflex motion (wobbling), in particular the line of sight movement of the star, due to its gravitational interaction with the orbiting planet. By now the RV method is the second most successful method and the first one to find exoplanets. The detection of exoplanets by this method relies on finding periodic signals in noisy time-series data (RVs over time) using a periodogram analysis. However, gaps in the observations (e.g., stars can only be observed during night from the ground) can result in strong aliases, an effect where two signals are almost indistinguishable when sampled. Aliases normally occur at $f_{\mathsf{Alias}} = f_{\mathsf{True}} \pm m \cdot f_{\mathsf{Sampling}}$ where f_{True} is the true signal, f_{Sampling} the sampling frequency and m an integer value. This makes it difficult to assess the true period of the planet and has already led to incorrectly published orbital periods (see Dawson and Fabrcky 2010; Stock et al. in prep).

`AliasFinder` is a Python script which can help to identify the true signal within a time series data. The script is based on a method described in Dawson & Fabrycky (2010), however `AliasFinder` uses some improvements described in detail within Stock et al.(in prep.). To our knowledge, there are no other public packages to perform alias testing based on this methodology. The basic principle is to simulate an ensemble of noisy time-series based on the original data sampling and noise level and inject one of the signals observed within the original data into this time-series. `AliasFinder` will then plot the median GLS periodogram (Zechmeister & Kürster, 2009) from the simulations of the injected signal overplotted with the original data periodogram. From the comparison of the signal properties (signal power, frequency or phase) at the injected frequency and its aliases between these two periodograms one can then assess the true period of the signal. We show a straightforward example of such a plot in Fig. 1. where we test two possible true periods of a planet at either 2.64 d or 1.60 d which was analyzed by Trifonov et al. (2018). From the comparison of the simulated time series (in black) to the observed periodogram (in red) it is obvious that only the period of 2.64 d (f~0.38 1/d) is able to reproduce the data correctly.

`AliasFinder` is specifically written for Python 3 and should run with a standard Anaconda distribution with a few additional packages. The script is executed by passing a yaml parameter file with important information about the star, planetary system and the measured RV signals.

`AliasFinder` is developed to be used by astronomers that search for exoplanets in RV data. Nevertheless the software can in principle be used by anyone who needs to distinguish a possible signal from its aliases within any noisy time-series if the correct input format is respected. The script is already used within Stock et al. (in prep.) and will be used in further studies in the future. `AliasFinder` is designed to be fast (multi-core support), user-friendly and produce

high quality publication plots as in Fig. 1. This software will encourage the usage of alias testing within future scientific publications based on time-series data, in particular RV data, and result in less incorrectly published orbital periods for exoplanets.
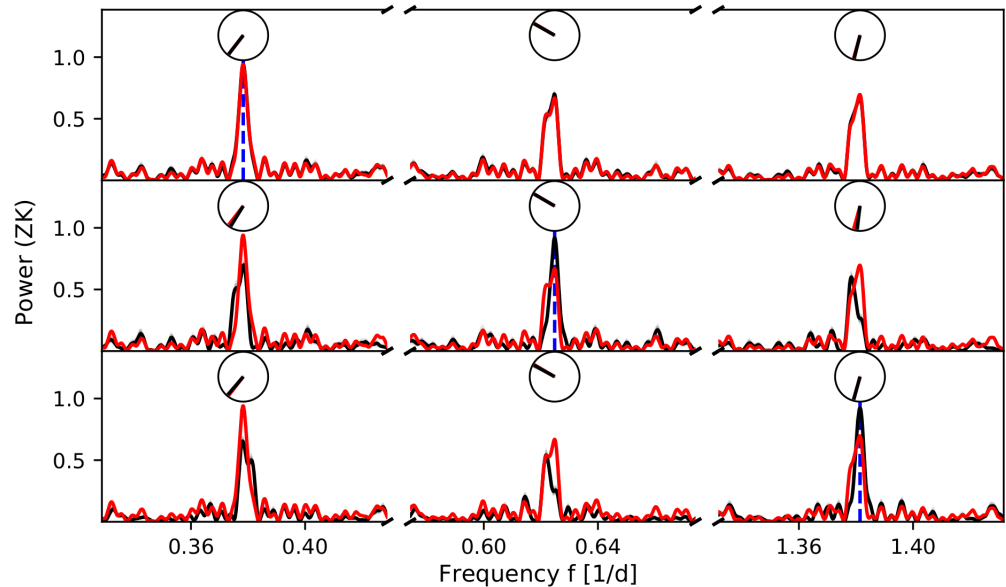
Figure 1: Example of a test for aliases. The top panel shows the resulting median periodogram (in black) derived from simulations of an ensemble of GLS periodograms where a signal of 2.64 d (marked with the vertical blue dashed line) was injected which was also observed within the original data periodogram (in red). The two lower panels show the simulated median periodogram where the first order aliases of 2.64 d, which are at 1.6 d and 0.72 d, are injected (also marked with the blue dashed line). The periodograms in each row are automatically plotted to regions that allow one to distinguish the true period from its first order aliases. The interquartile range and the range of 90% and 99% of the simulated periodograms are shown as the shaded grey area. The angular mean of the phase of each peak and its standard deviation are shown in the clock diagram (red: simulated; grey: data).

Acknowledgements

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