Project 1 - Radial Velocities

Part 1.

We want to explore the statistics of the exoplanets detected thus far using the NASA Exoplanet Archive `https://exoplanetarchive.ipac.caltech.edu`. Are we finding the same kind of planets with all methods? Before using the database to calculate the numbers try to briefly look at the questions and note down what you would expect based on your knowledge from the lecture. We will use the API to the database provided by the `astroquery` python package and implemented in the `Jupyter`-notebook provided. Jupyter notebooks are provided in the public git repository `https://github.com/seanjordan15/exoplanet_lecture_FS2025.git`. Follow the instructions on the Moodle to pull this git repository to your Jupyterhub.

1. Plot the mass (in units of mass of Jupiter) of detected exoplanets as a function of orbital semi-major axis (in AU). For now, only consider planets detected via radial velocity, transit, and direct imaging methods. Can you describe the general trends?

   Now only select the planets detected with RV.

2. Produce a histogram of the period distribution and find the main maxima and minima of this distribution (which orbital periods are most frequently found, which are less frequent). Try using logarithmic binning along the x-axis. Indicate the period range covering about 90% of the RV planets.

3. Which is the most frequently found RV semi-amplitude (K) for the planets discovered up until now? What is the lowest semi-amplitude detected so far? How does that compare to the semi-amplitude the Earth produces on the Sun?

4. What is, roughly, the fraction of planets with orbital eccentricity greater than 0.1? What about greater than 0.5? Why is that the case?

Part 2.

In this exercise we will explore the properties of exoplanet orbits and how the shape of the orbit influences the radial velocity signal of the star. To do so, we will simulate the movement of a planet and a host-star in a common inertial reference frame. This will result in both the planet and the star moving around their common center of mass (also called the Barycenter). For this, we are providing a small wrapper class to the `PyAstronomy` package, which solves the general two-body-problem using a numerical method by Markley (1995, CeMDA, 63, 101).

1. In the `Jupyter`-notebook we provided you with an example for the orbits of the exoplanet *HD 410004 Bb* around the star *HD 41004 B*. Assuming that

the observer is positioned along the x-axis of the given coordinate system, plot the radial velocity of the star that this observer would see. What is the amplitude of the RV-signal and how does it compare to literature[1]?

2. Current generation RV-instruments can typically measure RV-semi-amplitudes down to $0.5\,\mathrm{m\,s^{-1}}$. Is this sufficient to detect an Earth-twin around a sun-like star? What is the effect of inclination and eccentricity?

3. It is 1995 and you and your doctoral advisor have been performing stellar RV-measurements observations of *51 Pegasi* using one of the most modern available spectrographs ELODIE in France. After processing the data, you notice that there seems to be a systematic, periodic signal in the data. After having made sure that this signal is not some residual instrumental noise, you want to explore whether it could be created by a weird, unexpected type of exoplanet orbiting *51 Peg*. Use your RV-model from above and try to fit the provided RV-signal of *51 Peg* taken in the years 1995-96 by hand. What are the properties (mass, period, eccentricity) of your detection of the exoplanet *51 Peg b*?
Note: The mass of the star 51 Peg is one solar mass. Search in the period space from 3-5 days. Folding the RV-data by the period can help in identifying the correct fit.

Note *To receive feedback on your project work please use the answer-sheet provided and upload it as a PDF-file to the moodle-course. In case you have any questions, please contact Komal Bali (kobali@phys.ethz.ch), Janina Hansen (jahansen@ethz.ch), and Sean Jordan (jordans@ethz.ch).*

[1] use e.g., the NASA Exoplanet Archive by searching for the system name in the 'Explore the Archive' field on the main page