Orbital Period and Mass Measurement of 51 Pegasi B

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Abstract An exoplanet orbiting 51 Pegasi is detected using the radial velocity method and data collected by the ELODIE spectrograph between 1994 and 2004. The companion, designated 51 Pegasi B, is found to have an orbital period of $P = 4.2305$ d. Its minimum mass $M_{\rm p}\sin(i) = (0.50 \pm 0.05)\ M_{\rm Jup}$ is also determined, assuming a literature value of $M_* = (1.05 \pm 0.04)\ M_\odot$ for the stellar mass.

Keywords · (stars:) planetary systems · planets and satellites: detection · techniques: radial velocities · techniques: spectroscopy · methods: data analysis

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Introduction

The search for exoplanets is an important collective effort in astronomy. It helps us understand how planets form and evolve, and what are the properties of other stellar systems. Approximately 20% of all exoplanets have been first detected with the radial velocity method, including 51 Pegasi B, the first exoplanet discovered orbiting a main-sequence star. In this report, we reproduce some of the results and techniques that led to its discovery in 1995, such as Lomb-Scargle periodograms and spectrum analysis (Mayor & Queloz, 1995).

Methods

The ELODIE spectrograph was a 1.93 m reflector installed at the Observatoire de Haute-Provence in France. It could observe spectra in the 389.5–681.5 nm range with a resolution of up to 0.01 nm (Baranne et al., 1996). In this analysis, we used 168 spectra collected by ELODIE between September 1994 and December 2004.

A continuum estimate was obtained for each spectrum by linearly interpolating all NaN values and then applying a running percentile to the data. The window size used was 1500 pixels (75 nm), and the percentile value was 80%. Continuum normalized spectra were obtained by dividing the original spectra by their continuum estimates. After that, they were Doppler shifted to correct for the orbital motion of the Earth at the time of observation, which is provided by the telescope with the spectrum data.

To measure the radial velocity at each time, a continuum normalized spectroscopic template is used. This template, which represents the expected spectrum at rest, is then Doppler shifted by a range of velocities. Calculating the cross-correlation of the true spectrum and the Doppler shifted templates, we obtain the cross-correlation function (CCF). The CCF peak indicates the radial velocity of the spectrum. The measured radial velocity of each spectrum is taken as the mean of a Gaussian function fitted to the CCF.

Using *astropy*, the best fit period for the radial velocity variations was found through Lomb-Scargle with a frequency grid ranging $1/3750$–$5\ \mathrm{d}^{-1}$ and an interval of $1/18750\ \mathrm{d}^{-1}$. This method works by fitting a sinusoidal model to the data at a range of different periods, before choosing the frequency that maximizes the goodness of the fit. A phase-folded plot of all the measurements is shown in Figure 1. The false alarm probability (FAP) was also calculated using *astropy*.

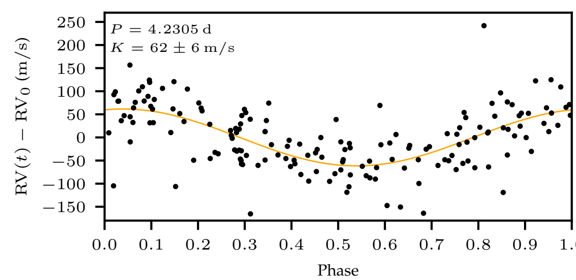

Figure 1: Phase-folded plot of radial velocities (RV) subtracted from the systemic radial velocity (RV_0). The best-fit sinusoidal model is shown in orange and modelled by $\mathrm{RV}(t) = \mathrm{RV}_0 + K\sin\left(\frac{2\pi t}{P} - \phi\right)$. P is the period previously calculated. RV_0, K, and ϕ are fit parameters.

Results

From Lomb-Scargle, we find the orbital period $P = 4.2305$ d and FAP $= 2.7 \cdot 10^{-17}$. The minimum mass measurement is done using the relationship between the star's semi-amplitude and other parameters of the system, as in Equation 1.

$$K = 203.255\ \mathrm{m\ s^{-1}} \left(\frac{1\ \mathrm{d}}{P}\right)^{1/3} \cdot \left(\frac{M_{\rm p}\sin i}{M_{\rm Jup}}\right)\left(\frac{M_\odot}{M_*}\right)^{2/3} \frac{1}{\sqrt{1-e^2}} \quad (1)$$

Where K is the semi-amplitude, P is the period, M_* is the mass of the star, and e is the eccentricity. In this case, e is assumed to be 0, and $M_* = (1.05 \pm 0.04)\ M_\odot$ is taken from the literature (Takeda et al., 2007), resulting in $K = 62 \pm 6$ m/s and $M_{\rm p}\sin(i) = (0.50 \pm 0.05)\ M_{\rm Jup}$. We conclude 51 Pegasi B is a hot Jupiter.

References

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