Mass of Exoplanet Orbiting Star 51 Peg

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Abstract This paper applies radial velocity method on star 51 Peg to determine the mass of its exoplanet. Using spectral data obtained with ELODIE spectrograph, the variation in radial velocity of 51 Peg was found to have period P = 4.23 days and semi-amplitude $K_* = 51.38 \pm 2.29 ms^{-1}$. This gives the mass of its exoplanet $M_p sin(i) = 0.422 \pm 0.022 M_{jup}$.

Keywords · Exoplanet · Doppler Spectroscopy · 51 Pegasi ·
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Introduction Ever since the first confirmation of extra solar planet in 1992, more than 5000 exoplanets have been detected. One common method of detecting exoplanet is the radial velocity method, also known as Doppler spectroscopy. When a planet orbits a star, its gravitational pull will cause a subtle wobbling motion of the star. Such motion will produce a periodic variation in the spectrum of star, which is the Doppler shift. The radial velocity method measures the Doppler shift of stellar spectrum to determine the variation of its radial velocity, and hence properties of the planet orbiting it. This paper presents the application of radial velocity method on star 51 Peg, to determine the mass of the exoplanet orbiting it.

Methods The spectra used in this paper is obtained with ELODIE spectrograph. It measures spectrum with wavelength range from 3906 Å to 6811 Å. This paper focuses on the measurement of star 51 Peg.

The spectrum of 51 Peg is dominated by absorption lines. Thus, its continuum can be estimated by taking the average of 50 highest values of flux out of 500 nearby pixels for each pixels. The spectrum is then normalized by dividing it with the continuum.

The radial velocity of the star is determined by calculating the cross-correlation function (CCF) between the normalized spectrum and the spectrum template of G2 stars under different Doppler shifts. Before this calculation, NaN values in the spectrum are removed with linear interpolation, and a barycenter correction is applied to remove the intrinsic Doppler shift caused by Earth's motion around Sun. Also, a list of weight of each pixel is obtained by interpolating the mask onto the wavelength grid of observed spectrum.

To calculate CCF, a series of spectra were created by shifting the template with different radial velocities range from -45 km/s to -25 km/s. The cross-correlation between the normalized spectrum and each of these shifted spectrum are calculated by summing the product of the observed flux, the template flux, and the weight of each pixel. Plotting cross-correlations against shifted radial velocities, a Gaussian-shaped CCF is obtained. The radial velocity is determined by fitting a Gaussian function to the CCF and find its mean. The uncertainty of radial velocity is estimated by

$$\sigma_{RV} = \frac{500}{SNR_{550nm}} ms^{-1}, \tag{1}$$

where SNR is the signal to noise ratio.

Repeat these calculations for all 168 spectra of 51 Peg measured at different time, a time series plot of radial velocity can be obtained. Using the Lomb-Scargle method, the period of radial velocity variation of 51 Peg can be estimated. In this paper, the Lomb-Scargle method is applied with the 'LombScargle' function from astropy. With the estimated period, a phase-fold plot of sinusoidal shape can be obtained. This plot can be fitted with

$$RV(t) = RV_0 + K_* sin(\frac{2\pi t}{P} - \phi), \tag{2}$$

where K_* is the semi-amplitude of radial velocity variation, given by

$$K_* = 203.255 ms^{-1} (\frac{1d}{P})^{1/3} (\frac{M_p sin(i)}{M_{jup}}) (\frac{M_\odot}{M_*})^{2/3} \frac{1}{\sqrt{1-e^2}}. \tag{3}$$

In this equation, P is the period of radial velocity variation of star, M_p is the mass of planet, M_* is the mass of star, and $sin(i)$ is a correction factor from the unknown inclination of the star system.

Thus, the mass of the planet can be obtained by

$$\frac{M_p sin(i)}{M_{jup}} = \frac{K_*}{203.255 ms^{-1}} M_*^{2/3} P^{1/3} \sqrt{1-e^2} \tag{4}$$

Results The best-fit period of radial velocity variation of 51 Peg is 4.23 day. Fitting this period to the phase-fold plot results in a semi amplitude $K_* = 51.38 \pm 2.29 ms^{-1}$. For 51 Peg, $M_* = 1.05 \pm 0.04 M_\odot$, and $e = 0$. Plugging these values into Eq(4) gives $M_p sin(i) = 0.422 \pm 0.022 M_{jup}$.