Detection of exoplanet

PROJECT REPORT

Submitted in partial fulfillment of requirements fort award

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(Modell - computer applications)

Under the guidance

DEPARTMENT OF PHYSICS

BHARATA MATA COLLEGE THRIKKAKARA, KOCHI-21

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CERTIFICATE

Certificate that this document titled “ DETECTION OF EXOPLANET “ is bona-fide of the project report presented by RIYA BAIJU (University reg.no:200021039185) of sixth semester BSc physics, model Computer applications submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Science In Physics (Modell - Computer Applications) of the Mahatma Gandhi University, Kottayam during academic year 2020-2023.

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DETECTION OF EXOPLANET

Project submitted to the

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(2020-2023)

DECLARATION

I hereby declare that this project report entitled " DETECTION OF EXOPLANET " is based on the orginal work carried out by me under the supervision of Dr.Riju k Thomas in the department of physics, Bharat Mata College, Thrikkakara.

PLACE : THRIKKAKARA

DATE :

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The success and final outcome of this project report required a lot of guidance and assistance from many people and I am extremely fortunate to have got this all along the completion of my work. Whatever I have done is only due to such guidance and assistance and I would not forget to thank them.

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I would like to extend my sincere thanks to all my friends and family for their whole hearted support and encouragement

INDEX

CONCLUSION

5.1 SUMMARY

REFERENCES

ABSTRACT

Exoplanets are planets revolving around stars other than the sun in our universe. Radial velocity method is a method used to detect them based on the Doppler shifts of spectra of light emitted by their parent stars. In this Project, a standard Keplerian method was used as a model Radial Velocity(RV) data of stars to obtain the orbital parameters like time period (P), Semi-amplitude radial velocity (K), eccentricity (e) and argument of periastron (ω). The Radial velocity data was taken from NASA's exoplanet archive. Using the orbital parameters other properties like minimum mass of the exoplanet and semi major axis of the planet's orbit were determined. The results obtained compares well with the ones in the literature.

INTRODUCTION

CHAPTER 1

1.1 What is an exoplanet?

For tens of thousands of years, human beings have been fascinated by the stars in the night sky. This led them to formulating many theories and observations on stars, planets and other celestial bodies. One such quest was the concept of extrasolar planets or exoplanets i.e., planets outside solar system. The main interest of exoplanetary research is to find earthlike planets and extraterrestrial life, which helps scientists better understand how the solar system evolved and provide a more accurate picture of how the universe works.

Exoplanets are very hard to see directly through telescopes. They are hidden by the bright glare of the stars they orbit. So, astronomers use other ways to detect and study these distant planets. They search for exoplanets by looking at the effects these planets have on the stars they orbit. We use fundamental theories of physics to find them.

1.2 Brief history of exoplanets

The first confirmation of detection came in 1992, with the discovery of several terrestrial mass planets orbiting the pulsar PSR B1257+12. In 1995 Mayor and Queloz confirmed the existence of a Jupiter like planet with a four-day orbit around the nearby star 51 Pegasi. The HARPS (High Accuracy Radial Velocity Planet Searcher) introduced by European Space Organisation in 2002 discovered 134 exoplanets. The Kepler space telescope launched in 2009 discovered 715 exoplanets around 305 stars. As of 1 May 2022, a total of 5,017 exoplanets have been confirmed.

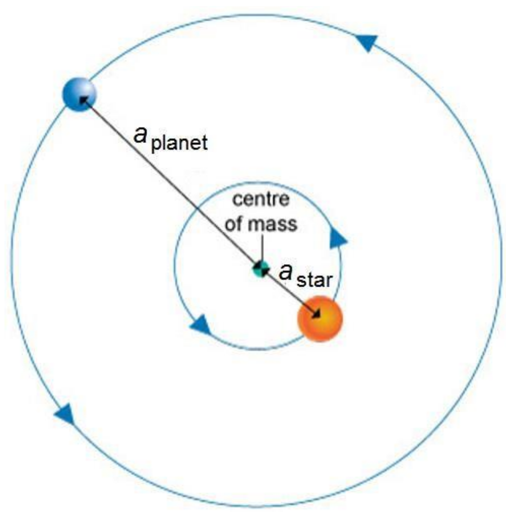
1.3Methods of detection of exoplanets

Several methods including transit photometry, radial velocity method, direct imaging, microlensing and astrometry are used for exoplanet detection. In Transit method, the exoplanetary parameters such as size etc. are found using the amount by which the star dims when the planet crosses infront of its parent star. This the most widely used method. Kepler used this method. Direct imaging is used to detect large exoplanets (more massive than Jupiter) and widely separated from parent star. When a certain star move along with its planet causes an increase in intensity producing a microlensing event. Astrometry consists of measuring a star's position and changes in position over a time. Measurements of the motion of host star around the centre of mass of star-planet system is taken and stellar parameters are calculated.

Chapter 2

2.1 Radial Velocity method

The motion of a single planet in orbit around a star causes the star to undergo reflex motion (wobbling) about the star-planet barycentre (centre of mass). The edge on system is needed to obtain the spectra showing shift in wavelength. The observed spectral lines make red and blue shift as the star moves away and towards the observer respectively. The amount of shift is related to the velocity of star. From RV method , the mass of exoplanet, orbital radius of exoplanet (semi-major axis), and a guess at temperature can be obtained.



The star and planet moving about a common centre of mass

2.2 Radial Velocity Equations

A star planet system may comprise of either a single planet revolving around a star or many planets moving around the star. For simplicity we can take single companion stars for modelling. The Keplerian model is based on the oscillatory nature of the radial velocity of the parent star (due to the periodic motion of p arent star). Here terms like eccentricity (e) and argument of periapsis (ω) are incorporated into the model. The Keplerian model for fitting is given by equation shown below

$$\mathbf{V(t) = c + K\cos(\omega + \theta(t)) + K e \cos(\omega)}$$

Here, V(t) is the radial velocity of the star, c is the offset radial velocity, K is the RV semi-amplitude, ω is the argument of periapsis and θ is the true anomaly of the planet. The radial velocity offset (c) is obtained by fitting the radial velocity data with a constant c. From the fit, it can be seen that the radial velocity data is averaged around the offset value c. True anomaly is the angle between the line connecting star and the planet to the semi major axis of the planet's orbit. We can't directly get true anomaly form the radial velocity data. The true anomaly for a circular orbit can be easily found using the expression $\theta = (2\pi/P)t$, where, P is the period and t is the time of observation. Finding the true anomaly for an elliptical orbit is a tedious process

MODELLING THE RADIAL VELOCITY DATA

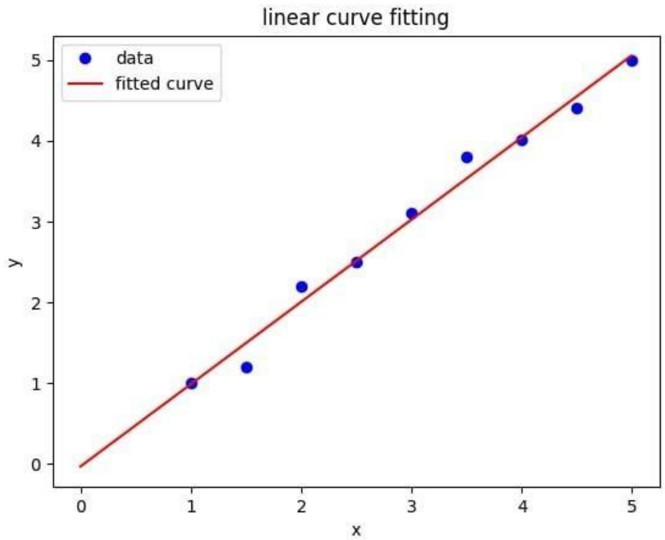
CHAPTER 3

3.1 About curve fitting

Curve fitting is the process of constructing a curve or mathematical function that has the best fit to a series of data points. Fitted curves can be used as an aid for data visualisation to infer values of a function where no data are available and to summarize the relationships among to or more variables.

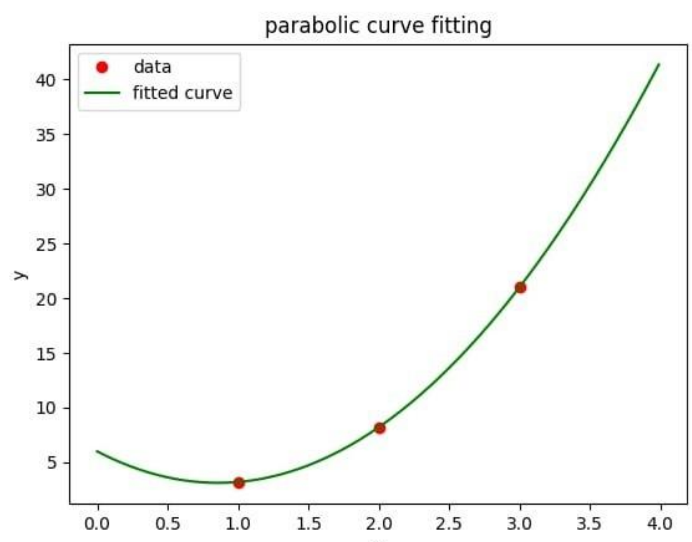
Most commonly one fits a function of form $y=f(x)$

The first degree polynomial equation $y=ax+b$ is a line with slope a and y intercept b.



If the order of the equation is increased to a second degree polynomial, the following results, $y=ax^2+bx+c$

This will exactly fit a simple curve to three points



3.2 The Radial Velocity Data

In this section we present some observational data of the star HD 142 and analyse it for its companion called, HD 142 b. It belongs to the phoenix which is at a distance of 85.5 light years away from earth. HD 142 is a F type main sequence star with surface temperature of 6338 K. It was discovered in 2001 by the Anglo-Australian Planet Search team.

Here we present the observational data of HD 142 b produced using 3.92 m Anglo- Australian Telescope (AAT), the University College of London Echelle Spectrograph (UCLES) and an I2 absorption cell in Tab 1. The RV data was taken from the freely accessible NASA's exoplanet archive.

Anglo Australian Telescope(AAT)

The first column of Tab 1 represents the time in Julian days. The Julian day is like a normal day which has been continuously counted from the beginning of Julian period (BC 4713). It was widely used by astronomers to know the elapsed time during astronomical observations. The modern day softwares also use Julian days to know the time elapsed. The second column represents the Doppler shift of HD 142 w.r.t the solar system barycentre by reducing the relative motion of both barycenters and the last column depicts the uncertainty in each measurement in ms^-

Tab 1.Radial velocity data for HD124

Julian date (-2450000)	RV (ms^-1)	Uncertainty (ms^-1)
830.9587.........	-13.1	7.50
1121.0194.......	-16.0	7.50
1385.3105.......	42.6	14.50
1411.2025.......	13.0	15.80
1473.0850.......	-15.2	7.90
1683.3314.......	36.1	8.10
1743.2765.......	41.0	7.50
1745.2642.......	24.0	10.40
1767.2699.......	0.1	9.00
1768.2542.......	1.3	7.10
1828.0607.......	-16.4	8.90
1856.0643.......	-5.9	10.70
1856.9250.......	-12.5	12.90
1918.9407.......	-4.1	9.30
2061.2963.......	32.7	8.00
2092.2683.......	19.8	7.50
2093.2876.......	11.4	8.10
2127.2230.......	-20.0	9.40
2128.1545.......	-4.0	9.00
2130.2433.......	-16.0	8.00

2151.2113.......	-21.9	7.40
2152.0786.......	-12.0	7.80
2154.1541.......	-29.5	6.90
2187.1000.......	-15.2	7.00
2188.0360.......	-9.4	7.20
2189.0199.......	-23.9	7.00
2190.0032.......	-12.0	6.40

3.3 Fitting the Radial Velocity data

The special package called SciPy curvefit in Python was used for modelling the radial velocity data. In curve-fit package one needs to provide a basis function upon which the given data points are optimised and fitted based on least square fitting. Here, the initial parameters or guesses are provided. For modelling the RV data one needs to provide initial guess parameters. Here, the parameters are Time Period (P), c (RV offset), RV semi amplitude (K), eccentricity (e), argument of periapsis (ω). The radial velocity offset (c) is taken by fitting a constant c to the data points.

RESULTS

4.1 HD 142 b

The fitted RV curve of HD 142 is as follows,

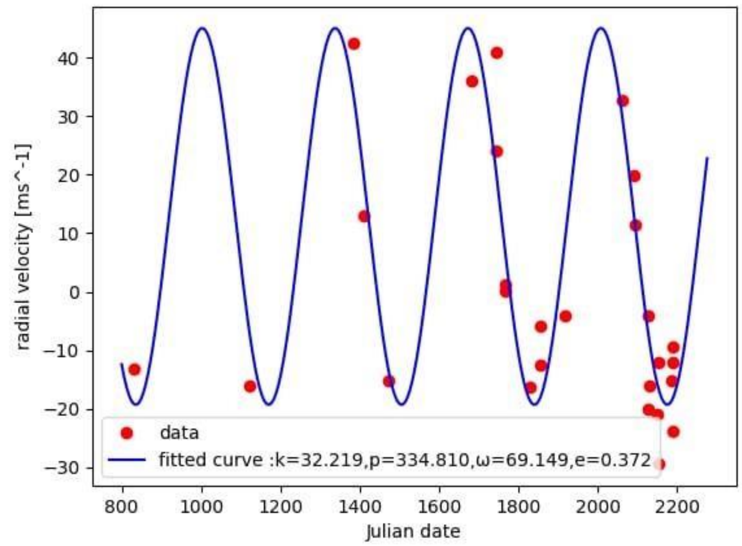


Figure 4.1.1 Keplerian model fitted to the RV data points of HD 142

From our model, the parameters obtained were as follows:

Parameters	**From our model**	**From literature**
Orbital period,P(days)	334.810	339 ± 6
Velocity amp. (ms^-1)	32.291	29.6 ± 5
Eccentricity (e)	0.372	0.37 ±
0.1 ω (deg)	69.149	71 ±
	36	

Table 5.1.1 Comparison of parameters of HD 142b

CONCLUSION

5.1 SUMMARY

The main aim of this work was to detect and characterize exoplanets. The observational data was obtained from NASA's exoplanet archive and the modelling was done using python.

I decided to take planets with sufficient number of data points. Because it was observed that when there are limited data points and small period, it was difficult to model the data. Thus the star HD 142 was chosen for modelling. HD 142 is a G type star (Temp.= 6180 K) belonging to the constellation Phoenix. A slight idea about K and P of both the stars were obtained by seeing the data plot. A best fit was generated by giving proper initial guesses. The results obtained are depicted in Table 5.1.1. The obtained results are in agreement with the theoretical values. Here, radial velocity jitter due to star spots and other surface activities weren't considered for the fit. A much better and accurate fit can be obtained by incorporating jitter to each data point.