Introduction

These past years, there has been an increased interest in the outer space, as it is evident, not only from the successful launch of the Indian spacecraft near what is known as "the dark side of the moon", but also on potential high hopes in discovering exoplanets, which could be inhabitable by humans in the near future.

Exoplanets have been an interesting topic in recent years, a topic that many people curious about outer space keep up with. In this project, I have taken into account the 5 most known methods of planet detection, have analyzed their properties found through each method, and have tried to compare them to one another to see if there exists a certain method that generally captures only a planet with certain properties.

Definitions

Because this project deals with a completely separate field from most engineering and computer science courses, here is a list of all the parameters discussed throughout this report, and what they mean. The parameters (the ones used here, but not only) can be found under the *Metadata URL* provided for each data-source in this report and the project-plan. The methods themselves will be given a short definition at the beginning of each section under *Methods and Results*.

1. **Planet Mass (Earth / Jupiter)**: Amount of matter contained in a planet, measured in units of masses of Earth / Jupiter
2. **Planet Radius (Earth / Jupiter)**: Length of a line segment from the center of the planet to its surface, measured in units of radius of Earth / Jupiter
3. **Stellar Mass**: Amount of matter contained in the star, measured in units of masses of the Sun
4. **Stellar Radius**: Length of a line segment from the center of the star to its surface, measured in units of radius of the Sun
5. **Eccentricity**: Amount by which the orbit of the planet deviates from a perfect circle
6. **Inclination**: Angle of the plane of the orbit relative to the plane perpendicular to the line-of-sight from Earth to the object, measured in degrees
7. **Transit Depth**: The size of the relative flux decrement caused by the orbiting body transiting in front of the star, in percentage
8. **Transit Duration**: The length of time from the moment the planet begins to cross the stellar limb (curved edge of an apparent disk) to the moment the planet finishes crossing the stellar limb, in hours
9. **Right Ascension**: Celestial equivalent of a longitude, measured in degrees
10. **Declination**: Celestial equivalent of a latitude, measured in degrees
11. **Lens mass**: Host star mass
12. **Lens Distance**: Distance from the observer to the lens system, measured in parsecs
13. **Source Distance**: Distance from the observer to the source system, in parsecs

Methods and Results

Datasources

Planetary Systems

- Metadata URL
- Data URL
- Filtered Data URL

Direct Imaging

- Metadata URL
- Data URL
- Filtered Data URL

Microlensing

- Metadata URL
- Data URL
- Filtered Data URL

Transit

- Metadata URL
- Data URL
- Filtered Data URL

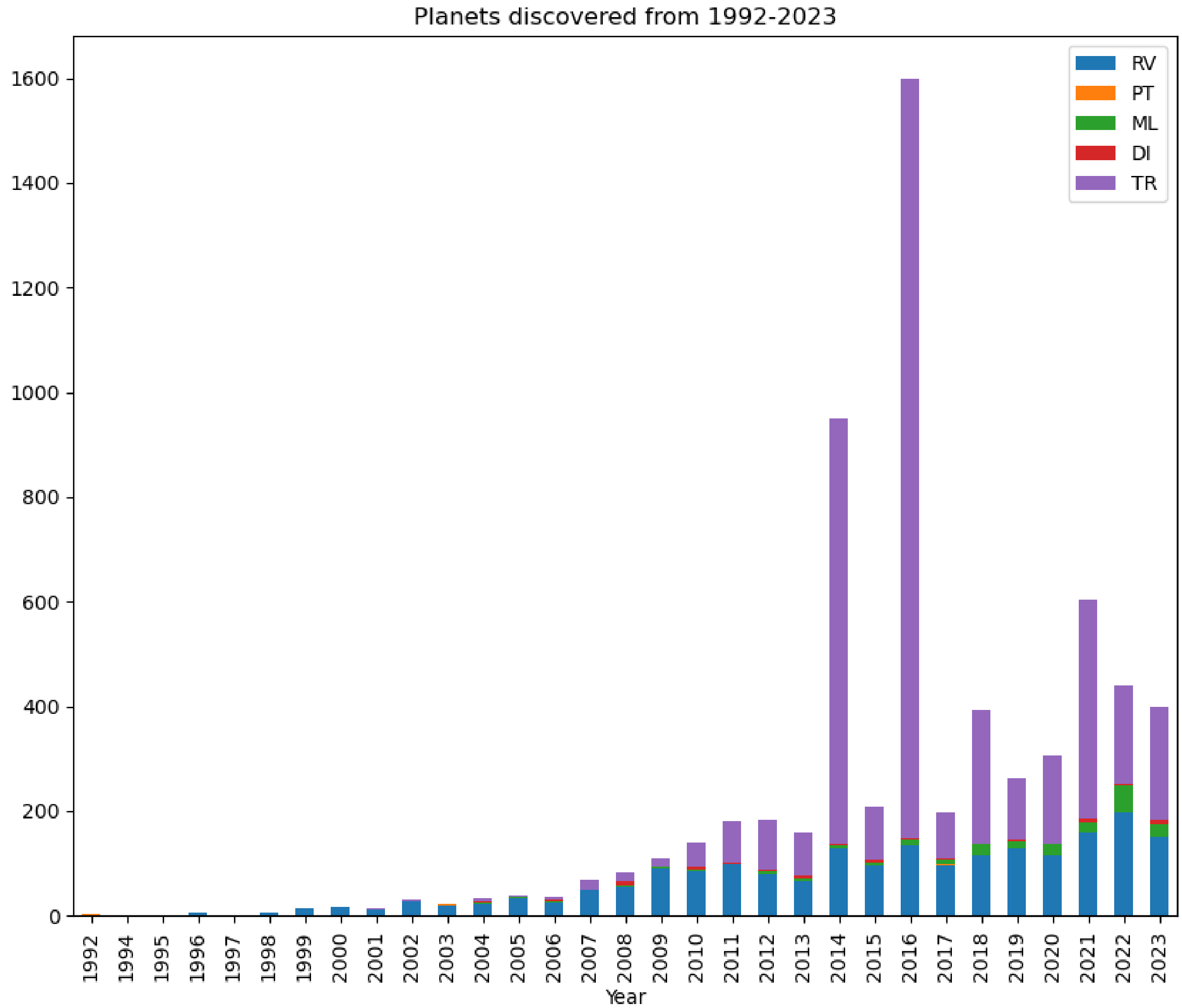
Data Transformation

The data transformation process can be found in the data pipeline Python file, where the afore mentioned data gets loaded from the internet, then further edited to only the properties needed for this project, and in the end the final tables are saved in an SQLite database.

The first table *planet_systems* contains the planet names and the methods used to discover each planet, which will be used as insight on which of the five methods was most used. The rest of the tables, beside planet names, contain other properties, such as, but not limited to, planet mass and radius, distance, right ascention and declination, and galactic longitude and latitude. To view all properties I've used, refer to the project plan.

General Overview of the Systems

Before starting the comparisons between the methods, I first wanted to check how many planets were detected using each method, and a total number of detected planets for each year.

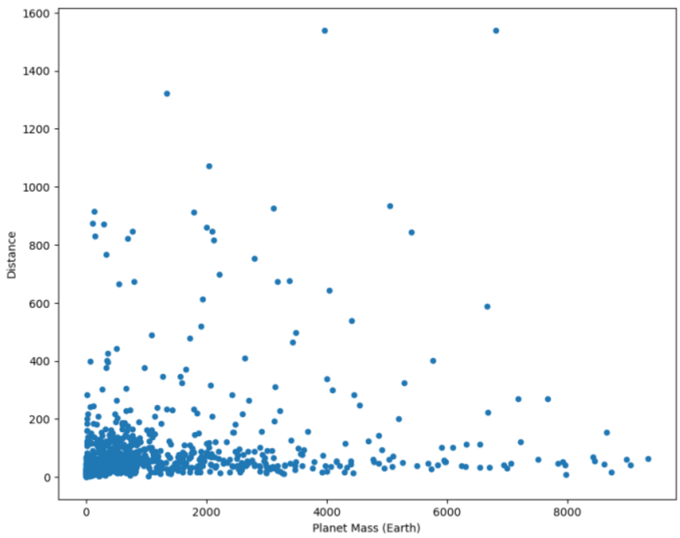


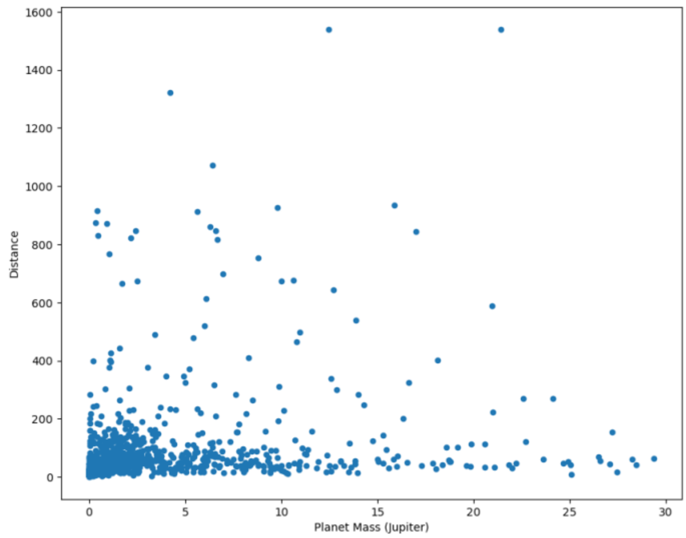
The graph was pulled from the first dataset, where I counted the flags used for each year. The end result was saved in a Pandas data frame, where then I plotted it to view the results as a stacked bar chart. From here, we can observe that in 2016 were detected the most planets, 1600 planets total, while the least were detected in 1994, 1995, and 1997, with 1 planet each. The code for this graph is under the *data exploration* file, along with all other graphs that are used in this report.

For all of these methods, their properties will be analyzed and then compared to one another, in order to answer the main question of the project.

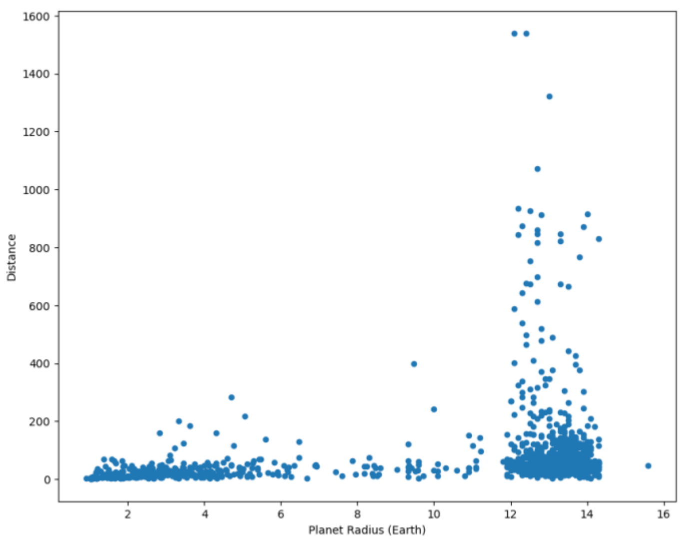
<u>The First Dataset</u>: *Radial Velocity*

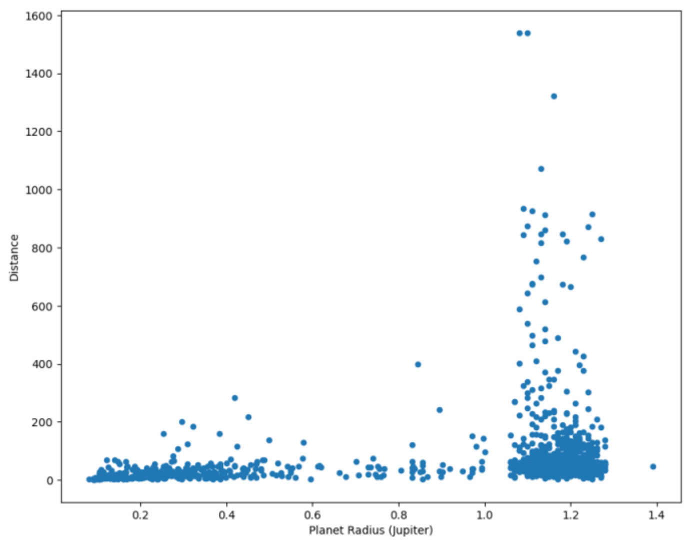
The first method to be analyzed is Radial Velocity. This method relies on the fact that a star does not remain completely stationary when it is orbited by a planet. The star moves, ever so slightly, in a small circle or ellipse, responding to the gravitational tug of its smaller companion.



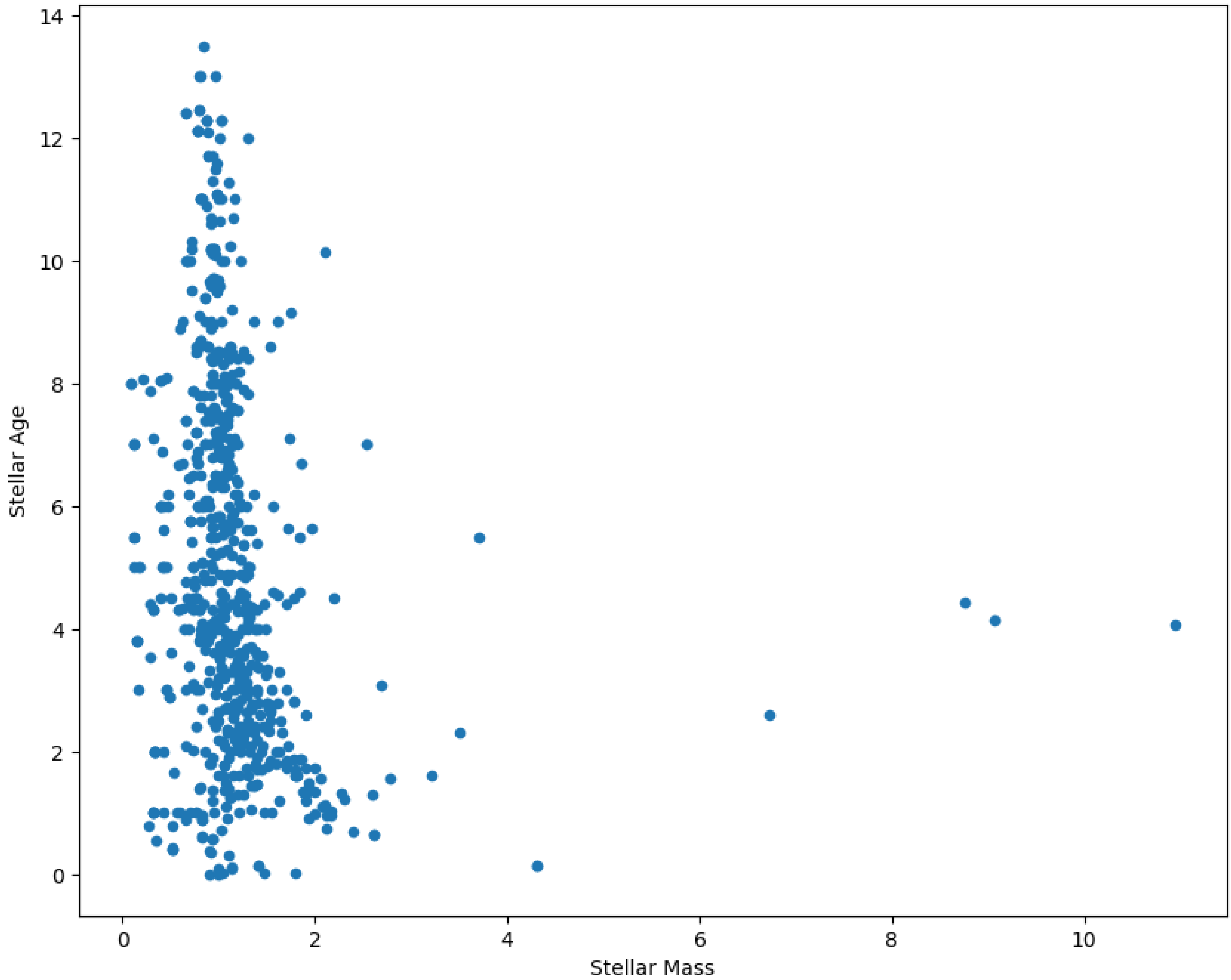


Here, a planet's mass with the distance to the system. From this, it can be noted that most planets detected through this method have a closer distance, lower than 200 parsecs, and the amount of mass, measured in the unit of masses of Earth and Jupiter respectively, are lower than 1000, which is where the density is located.

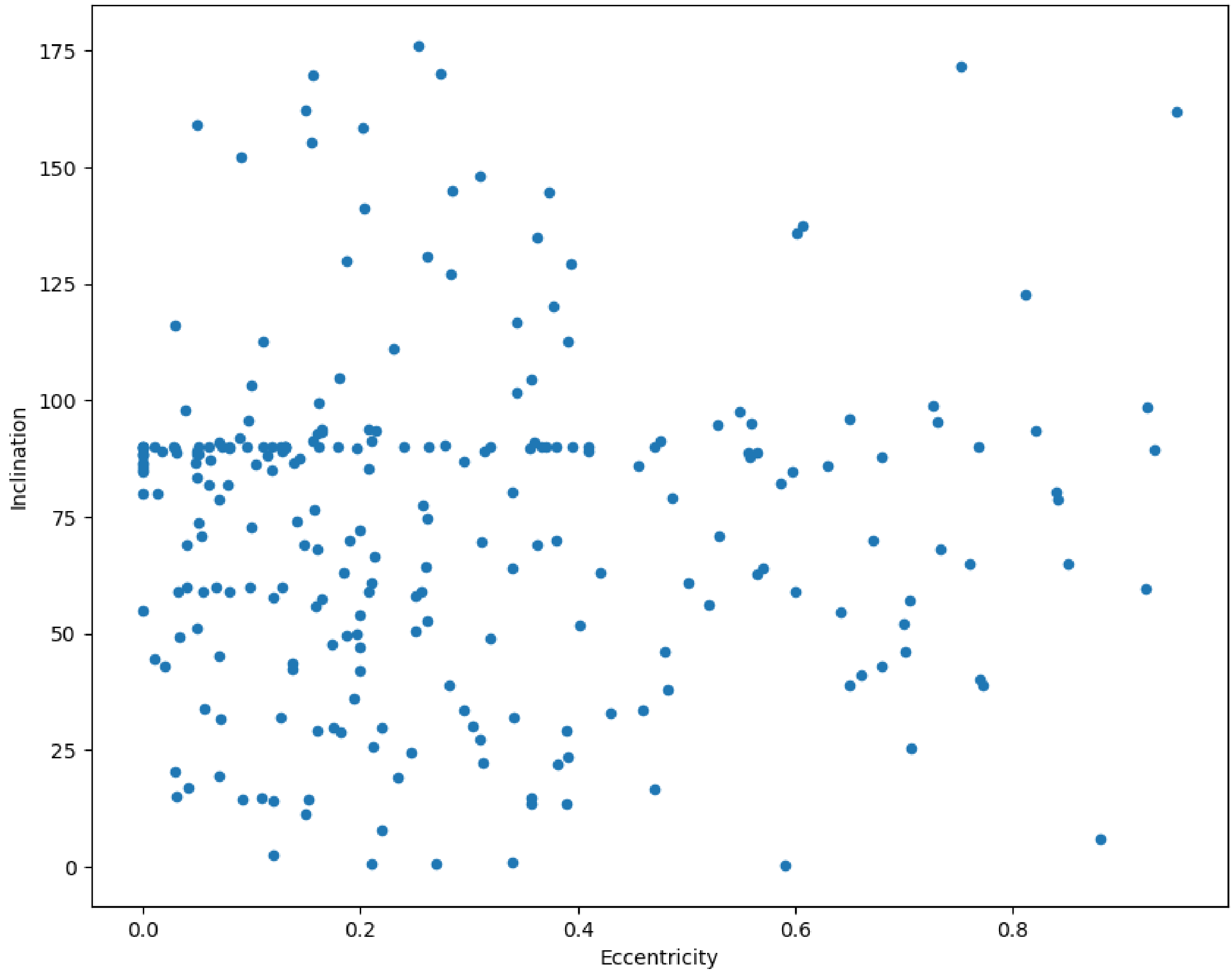




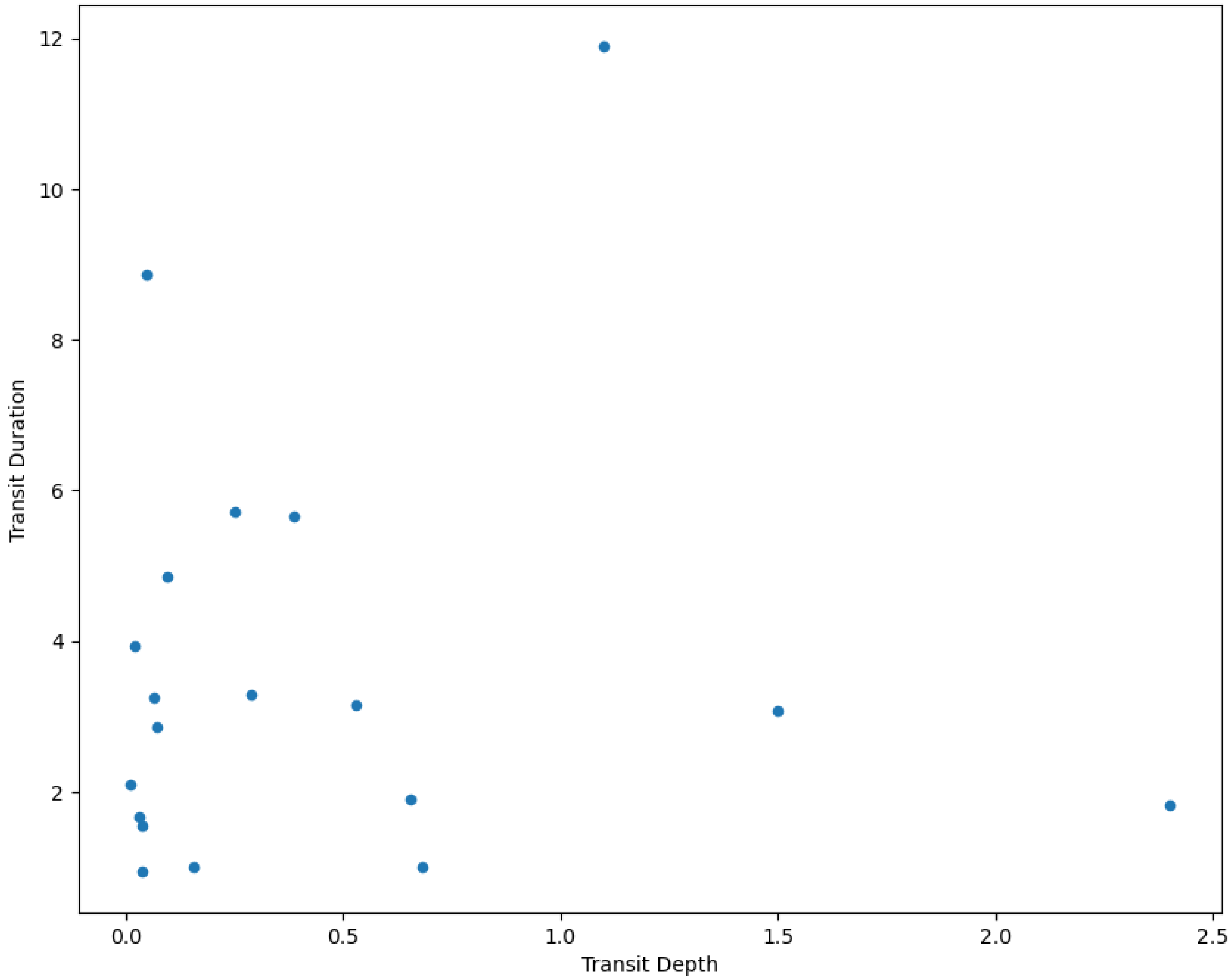
To affirm the previous find, here it can be observed that most planets that have a bigger estimated radius have a closer distance.



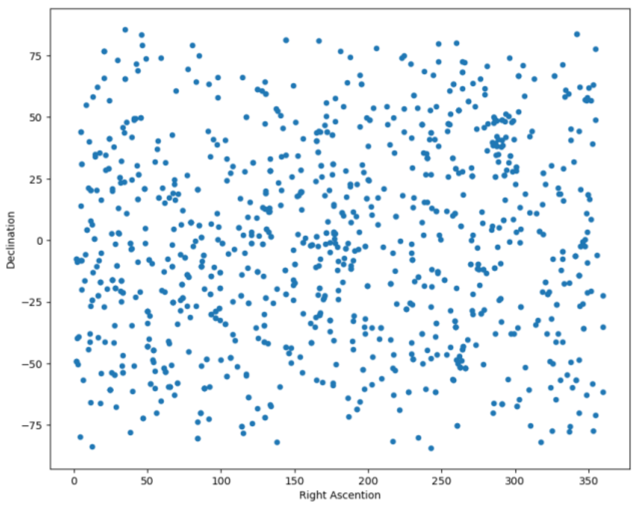
When analyzing the stellar mass with the stellar age, it can be noted that almost all the planets have a stellar mass lower than 2, while their ages go up to 13 gigayear.

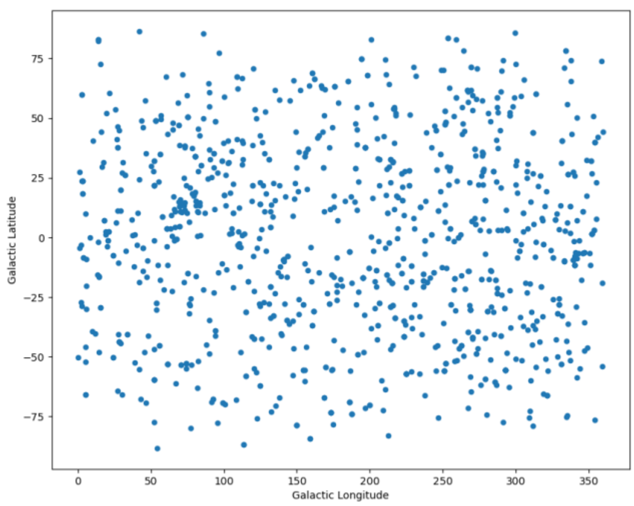


In this graph showcasing eccentricity with inclination, it can be noted that, while not much can be gathered, there seem to be planets ranging from 0 to 0.4 in terms of eccentricity, which have an inclination of approximately 87.5°. Most of the planets detected through this method are in the above measured range, when it comes to eccentricity.



For the transit depth and transit duration, data was not given for the majority of the planets, but from observing the information that it is provided, most planets have a depth ranging from 0% to a little lower than 0.75%, while the transit duration is generally lower than 4 hours.



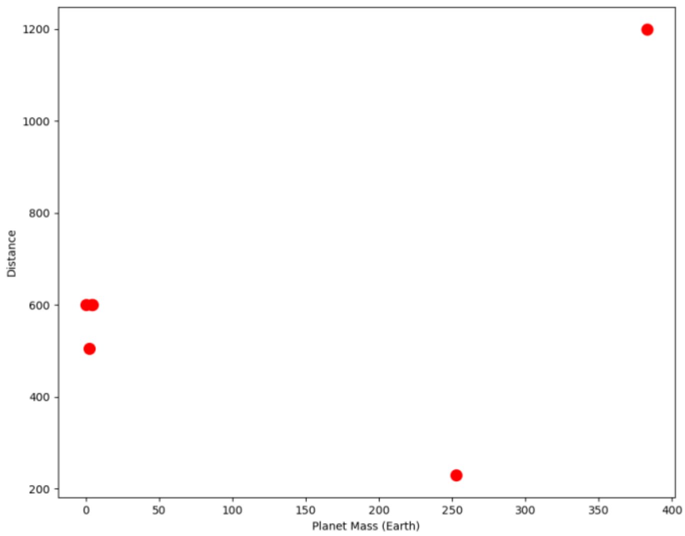


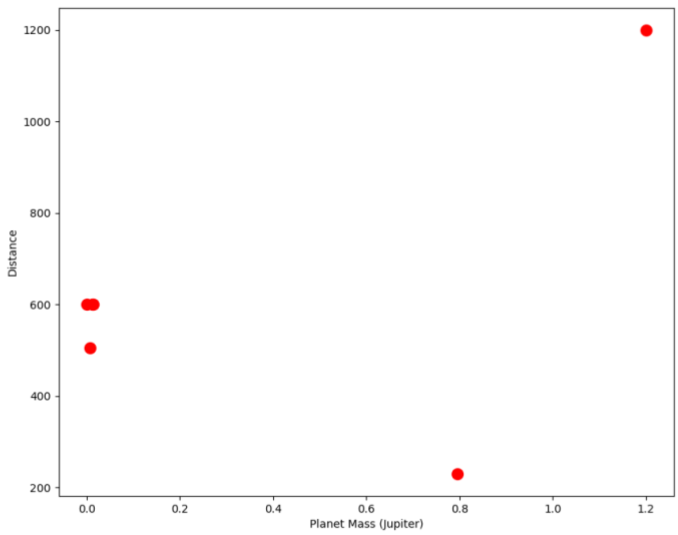
In these graphs, there seem to be no average number.

The First Dataset: *Pulsar Timing*

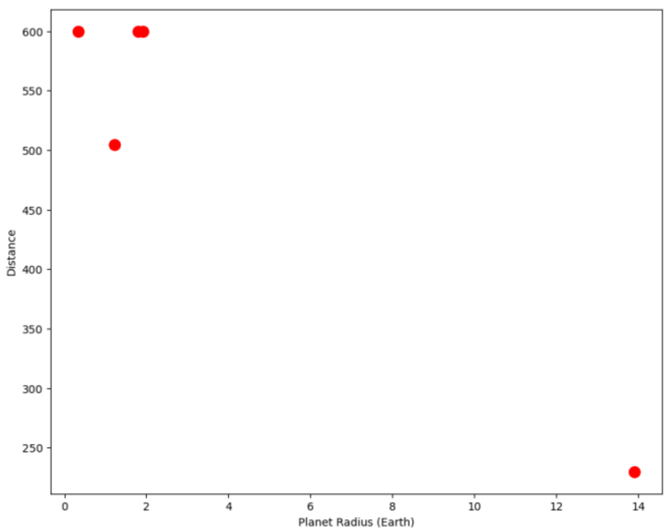
The second method to be analyzed is Pulsar Timing. Exoplanets detected through this method orbit a pulsar, which is a rapidly rotating neutron star. As they rotate, pulsars emit intense electromagnetic radiation that is detected on Earth as regular and precisely timed pulses, which are so regular they are more accurate than an atomic clock.

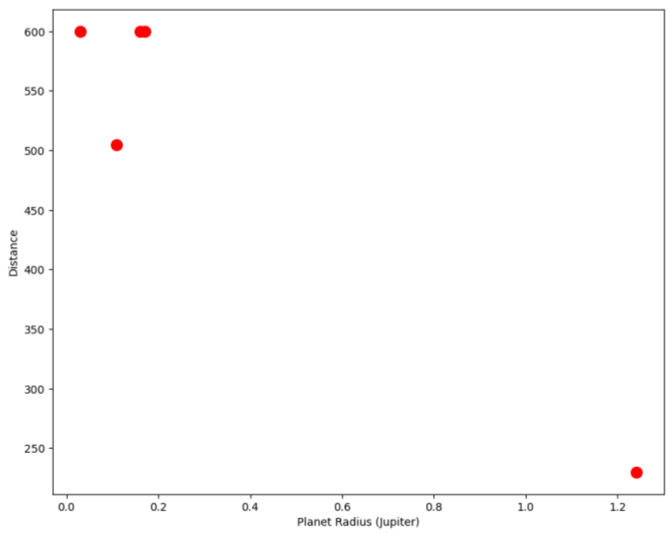
There is only a small amount of planets that have been detected using this method, thus the results might not be as insightful compared to the other data-frames.



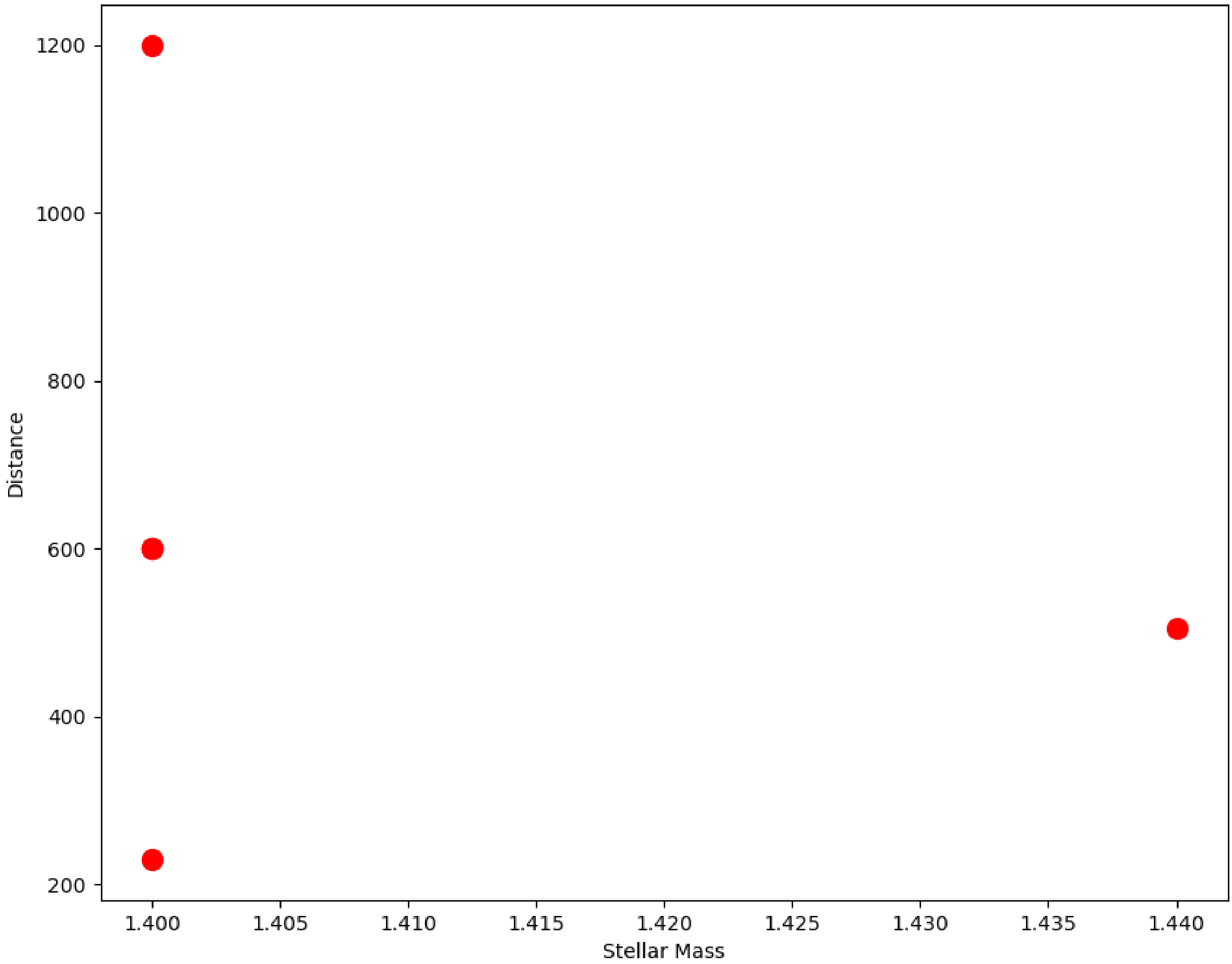


Here, the planet mass is analyzed against the distance from the planetary systems. From this graph, it can be observed that these planets have a greater distance, but a relatively smaller mass, compared to most of the planets that were detected through the Radial Velocity method.

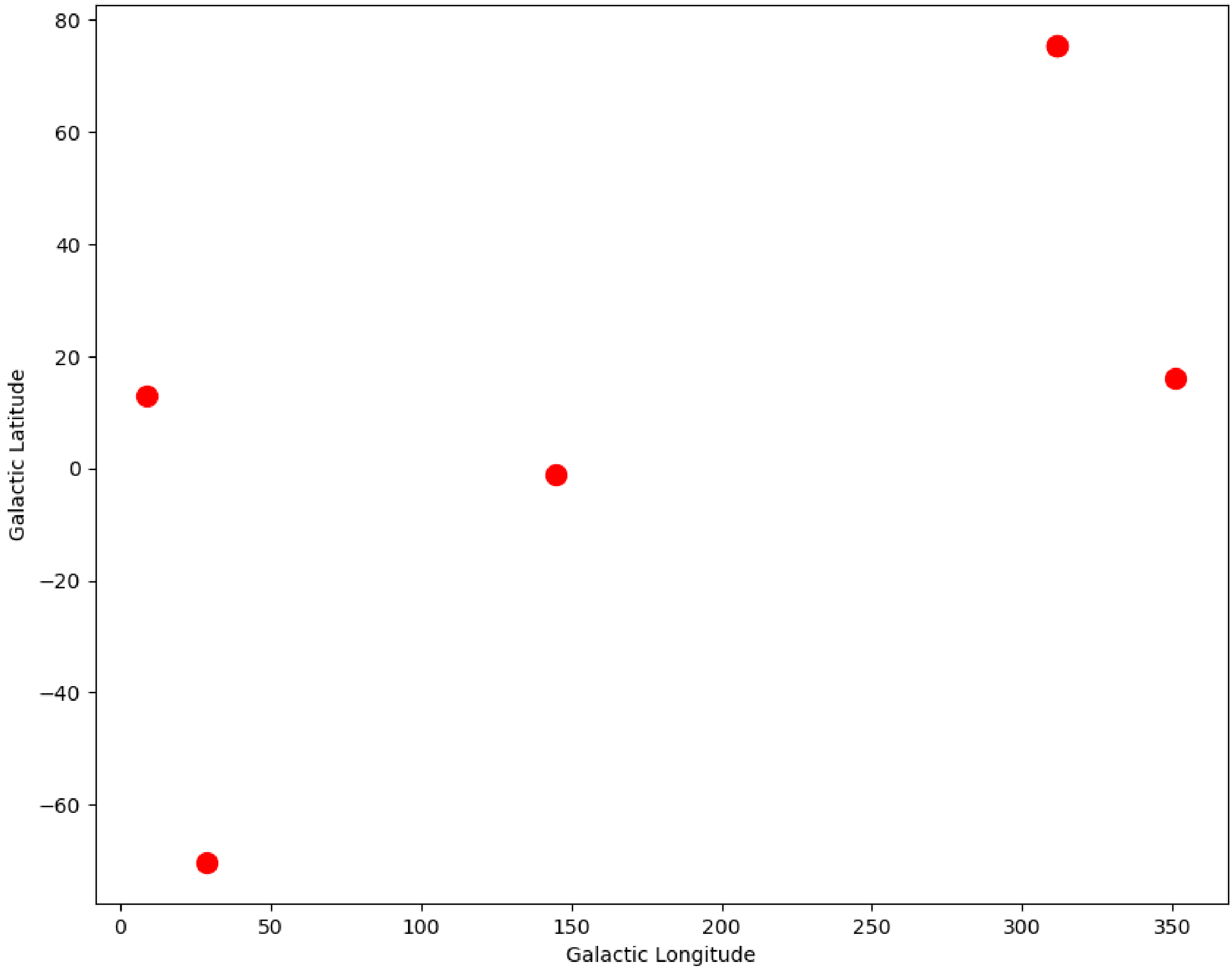




Here, the radius of the majority of the planets is ranging between 0 and 2.



Here, the stellar mass, measured in the units of masses of Sun, is analyzed with the distance. From the graph, it can be noted that most planets that have a stellar mass around 1400, while the distance goes up to 1200 parsecs. When compared to the Radial Velocity methods, the planets here have a higher stellar mass and have a bigger distance.

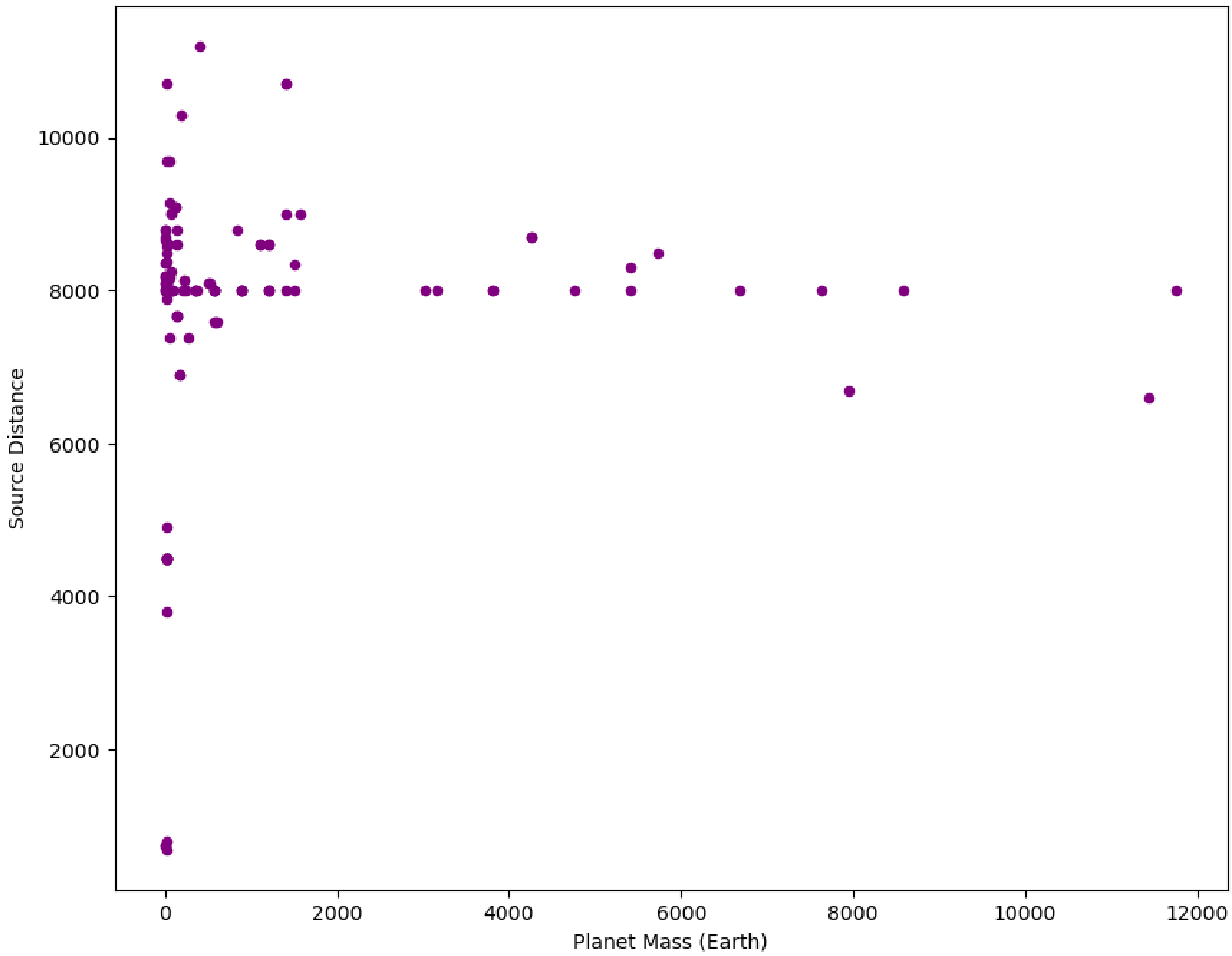


In this graph, there seem to be no average number for the galactic longitude and latitude.

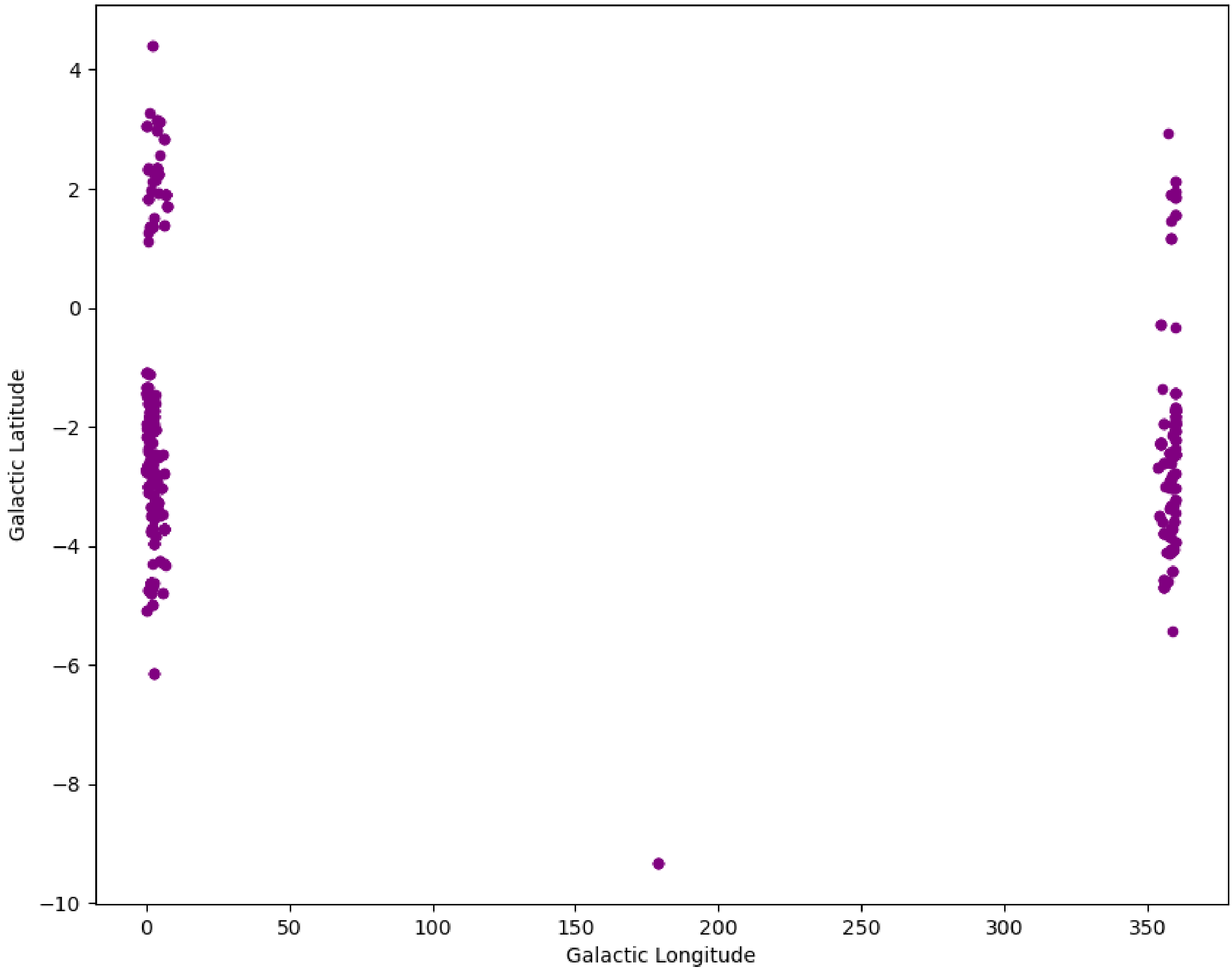
<u>The Second Dataset</u>: *Microlensing*

The third method to be analyzed is Microlensing. It is based on the gravitational lens effect. A massive object (the lens) will bend the light of a bright background object (the source). This can generate multiple distorted, magnified, and brightened images of the background source.

For this method, unlike for the other three methods – excluding the Transit method, there has not been provided a distance for the planets, and thus, it cannot be compared to the rest of the datasets in this aspect.



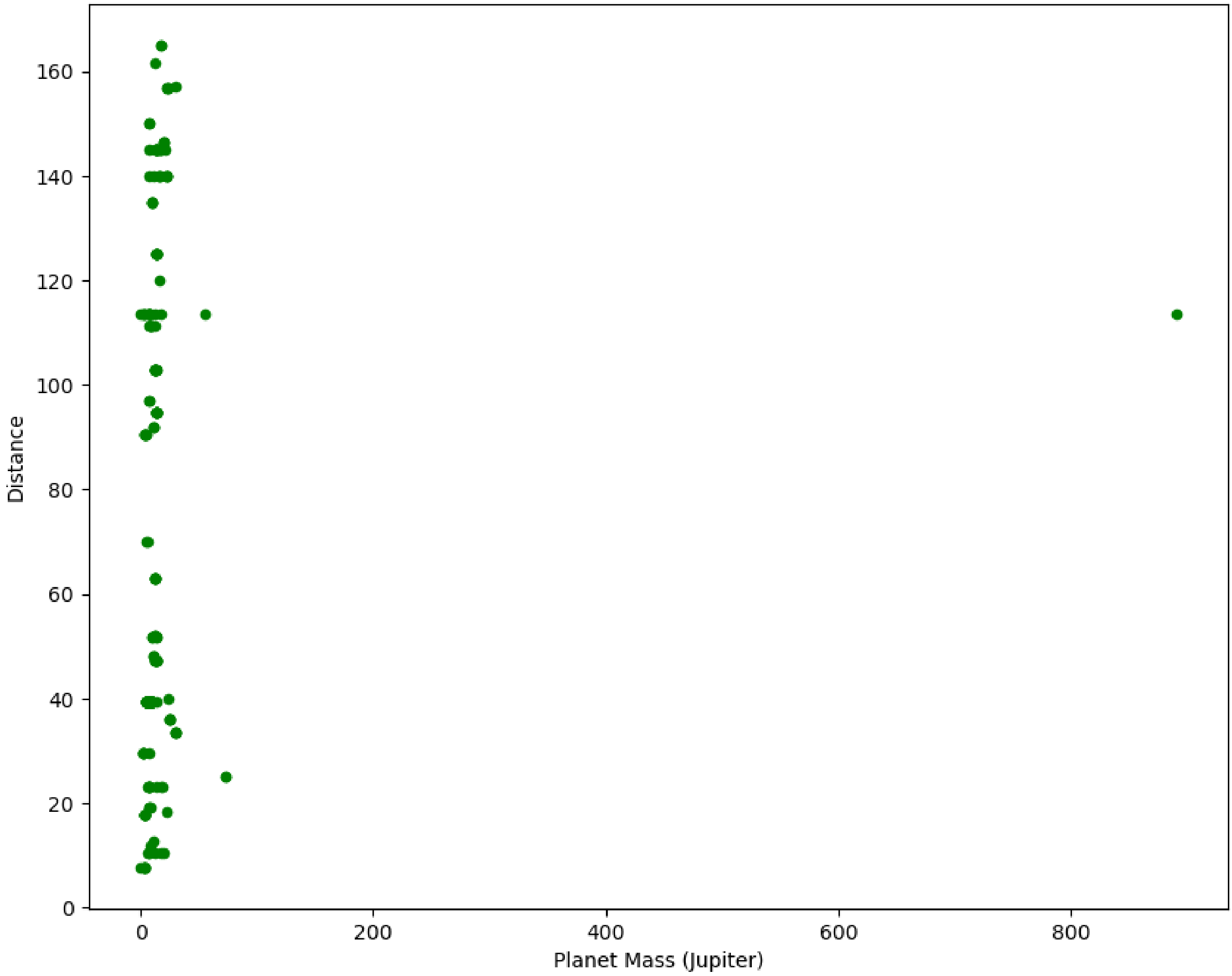
Here, the planet mass is compared to the source distance, rather than the distance from Earth. It can be observed that most planets have small masses, on par with the masses from planets detected through Pulsar Timing, and they have a rather large distance from the source.



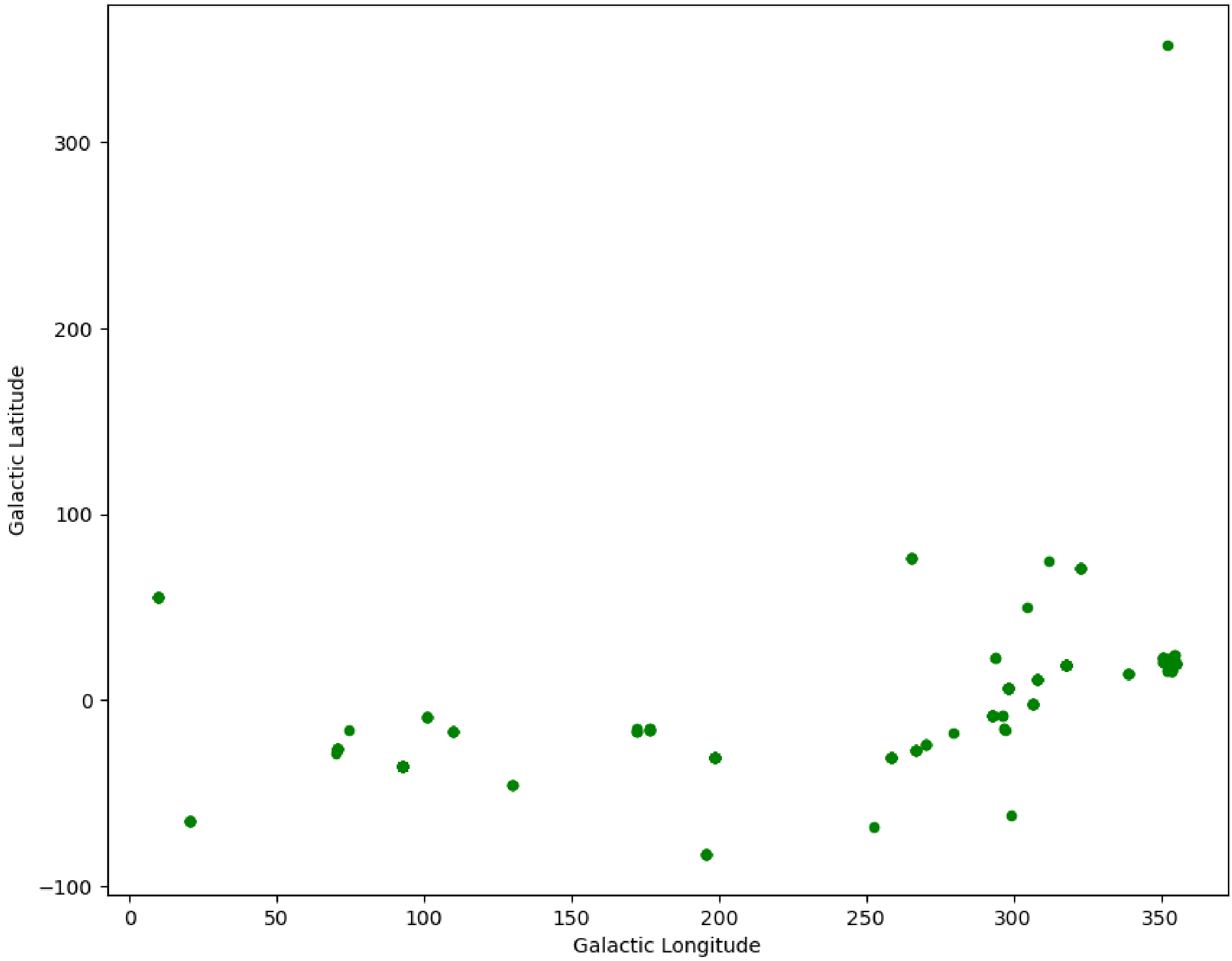
In this graph, galactic longitude and latitude are compared to one another. From it, it can be observed clearly that most of the planets either have degrees around 0 or around 350, while the latitude ranges from -6° to around -3°.

<u>The Third Dataset</u>: *Direct Imaging*

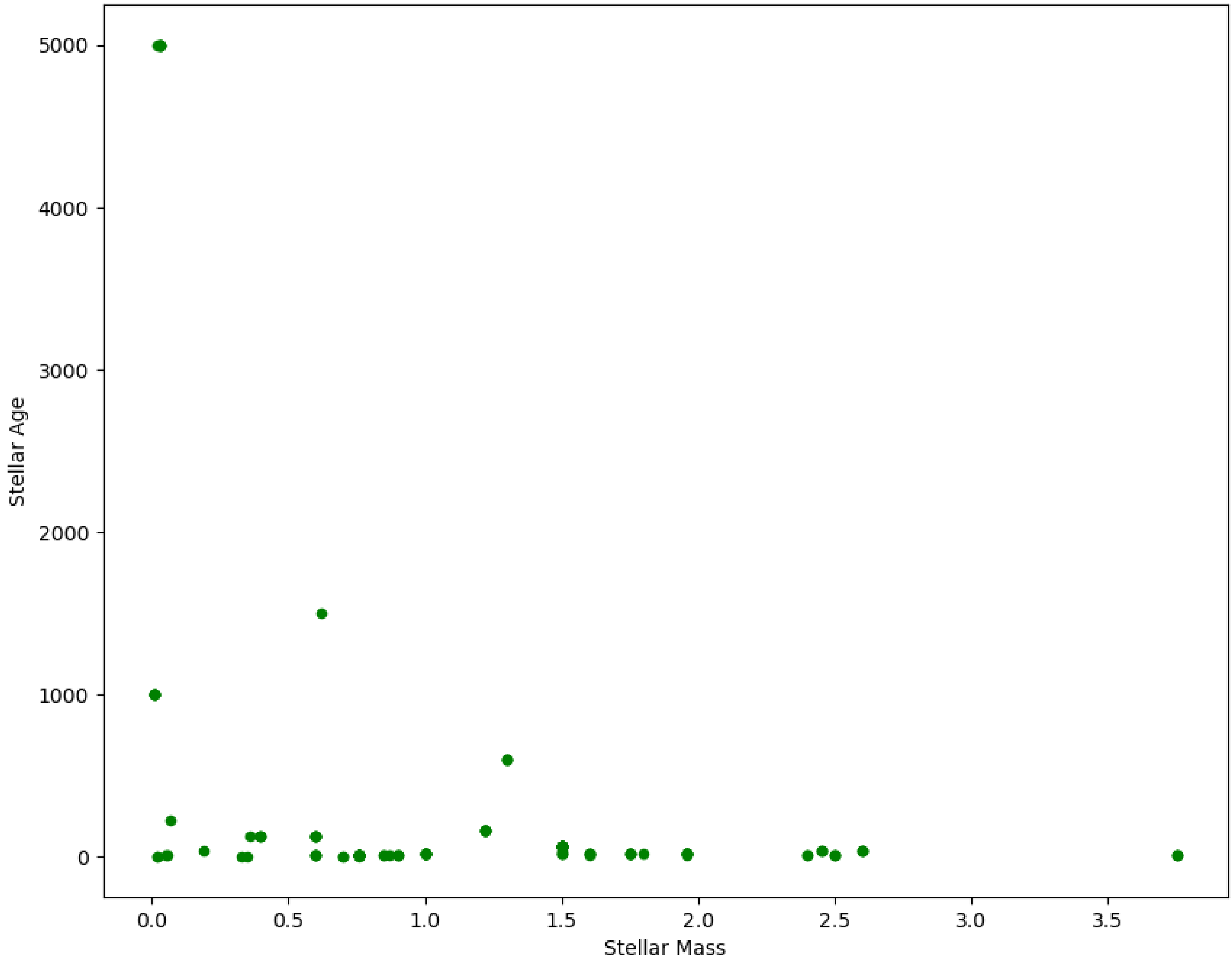
The fourth method to be analyzed is Direct Imaging. This method consists of capturing images of exoplanets directly, which is possible by searching for the light reflected from a planet's atmosphere at infrared wavelengths.



Here, the planet mass using the units of planet Jupiter is analyzed with the distance. It can be noted that almost all planets, except one, have a mass close to 0, which is quite similar to other planets' mass, detected from the previous methods.



Here, the galactic longitude and latitude are compared. From the graph, it can be noticed that most of the planets have a longitude between 250° and 350°, which differs from planets detected through Microlensing, where the majority of them had a longitude close to 0°. The latitude differs here as well, which is much larger than those planets ranging from around -100° to around -50°.

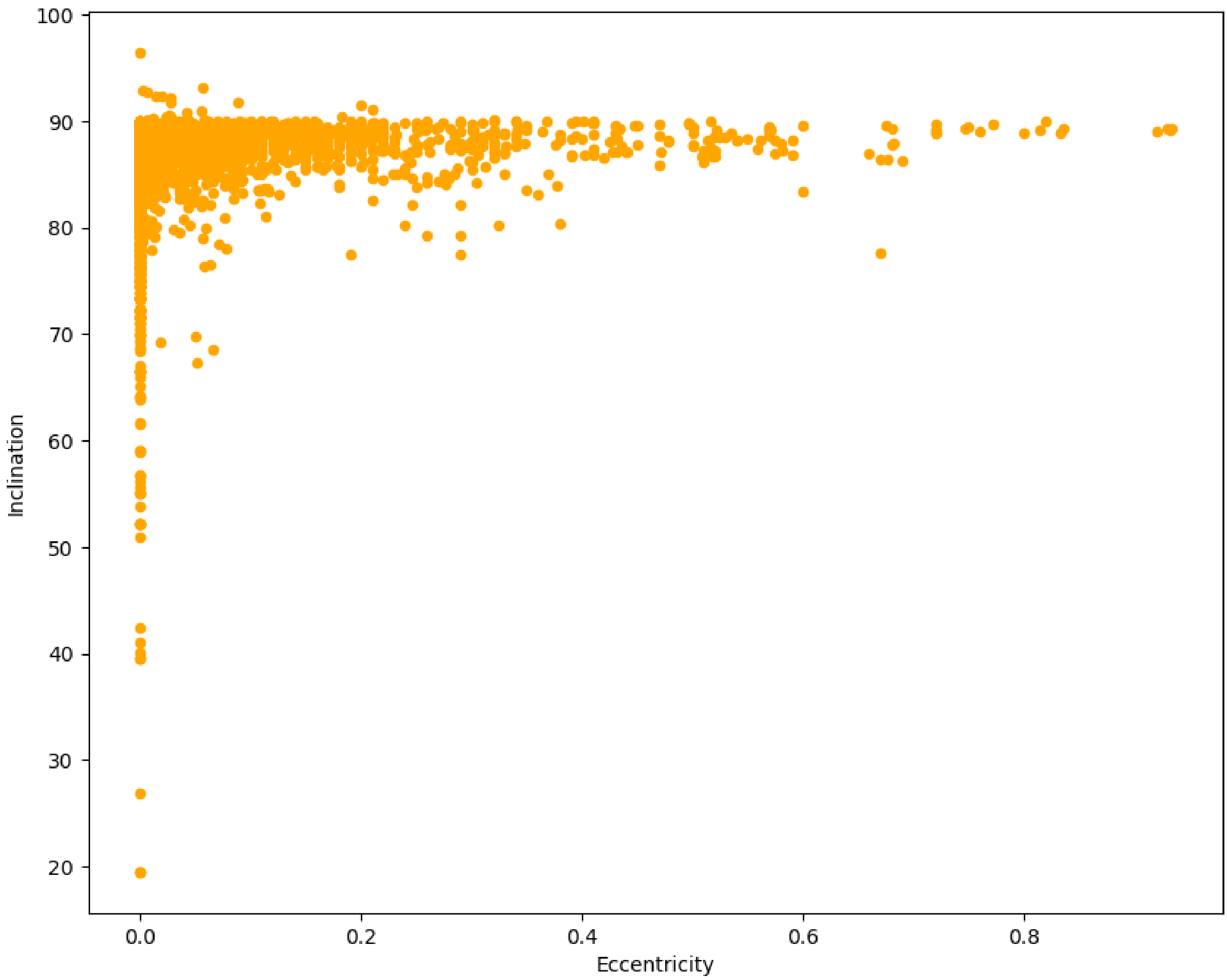


When comparing stellar age of a planet with its stellar mass, it is worth noting that, unlike the planets detected from Radial Velocity, almost all of these planets have a stellar age closer to 0 gigayear, while the stellar mass ranges from 0 to 3.5. The planets here, in comparison the Radial Velocity detected planets, have a much larger age, ranging up to 5000 gigayear.

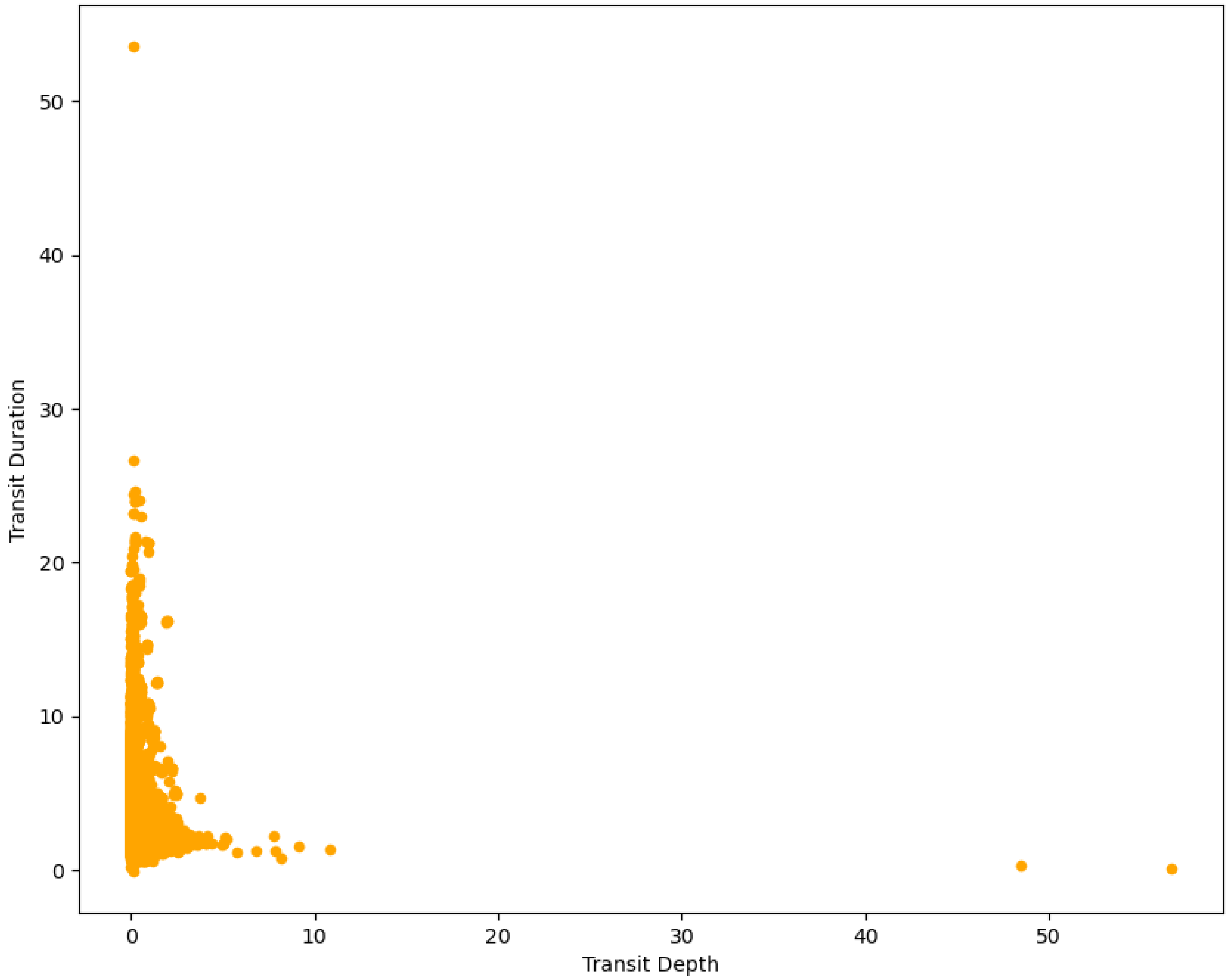
<u>The fourth Dataset</u>: *Transit*

The fifth and final method is Transit. This method only works for star-planet systems that have orbits aligned in such a way that, as seen from Earth, the planet travels between us and the star and temporarily blocks some of the light from the star once every orbit.

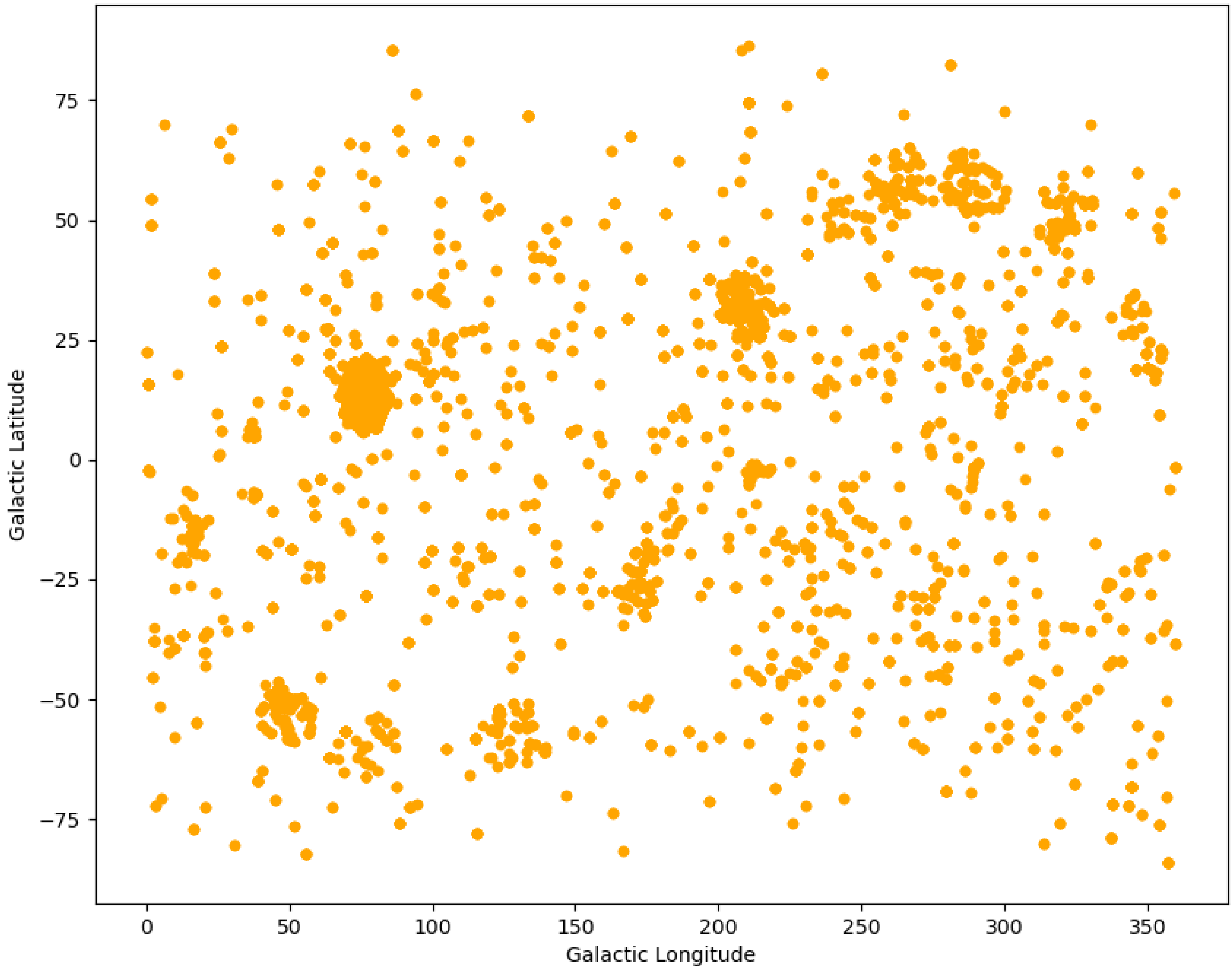
For this method, unlike for the other three methods – excluding the Microlensing method, there has not been provided a distance from Earth for the planets, and thus, it cannot be compared to the rest of the datasets in this aspect.



When analyzing the inclination with eccentricity, it can be noted that most of the planets have a relatively small eccentricity, ranging from 0 to 0.2, and an inclination ranging from around 80° to 90°. Compared to the Radial Velocity detected planets, not much of a difference is noticed between the planets, but the inclination here is relatively higher.



Here, transit depth and transit duration are analyzed, and it can be observed that the majority of the planets have an almost 0% depth, with a duration, ranging from 0 hours to around 5 hours.



In this graph, there seem to be no average number for the galactic longitude and latitude.

Conclusion

In this project, a look was taken into the detection methods used for exoplanet detection. Below I have made comparisons between all the parameters shown here in the form of graphs.

	PLANET MASS (JUPITER)	DISTANCE
RADIAL VELOCITY	0 – 5	0 – 200 parsecs
PULSAR TIMING	0	600 parsecs
DIRECT IMAGING	0	5 – 160 parsecs

From this table, it is noted that some Radial Velocity detected planets have a bigger planet mass compared to the planets detected by the other methods, while Pulsar Timing detected planets have a much larger distance compared to the other planets.

	PLANET RADIUS (JUPITER)	DISTANCE
RADIAL VELOCITY	1 – 1.3	0 – 200 parsecs
PULSAR TIMING	0 – 2	600 parsecs

From this table, it is observed that, in similar way to the previous table, Pulsar Timing detected planets not only have a larger distance compared to other planets, but some of these planets have in general a bigger radius.

	STELLAR MASS	STELLAR AGE
RADIAL VELOCITY	0 – 2	0 – 14 gigayear
DIRECT IMAGING	0	0 – 2.5 gigayear

From this table, it is worth noting, that planets detected through Radial Velocity, not only have a larger stellar mass, but also have a bigger stellar age.

	ECCENTRICITY	INCLINATION
RADIAL VELOCITY	0 – 0.4	0° – 87.5°
TRANSIT	0 – 0.2	80° – 90°

From this table, it can be observed that some planets detected through Radial Velocity may have a bigger eccentricity, but the Transit detected planets have a relatively larger inclination, but not by a big margin.

	TRANSIT DEPTH	TRANSIT DURATION
RADIAL VELOCITY	0% – 0.6%	0.5 – 6 hours
TRANSIT	0 – 5%	0 – 25 hours

From this table, it can be noticed that, not only some planets detected through the Transit method reach a bigger depth compared to other planets, but also their transit duration is way higher.

	GALACTIC LONGITUDE	GALACTIC LATITUDE
RADIAL VELOCITY	0° – 350°	-75° – 75°
PULSAR TIMING	0° – 350°	-70° – 75°
MICROLENSING	0°, 350°	-5° – 3°
DIRECT IMAGING	250° – 350°	-20° – 10°
TRANSIT	0° – 350°	-75° – 75°

From this table, it can be observed that, while all other methods have detected planets with a galactic longitude of around 0°, Direct Imaging detected planets fall under the 250° up to 350°, but in contrary with other planets, their latitude is rather small. Planets detected through Radial Velocity, Pulsar Timing, and Transit have a bigger range when it comes to the galactic latitude, and some of these planets can reach up to 75°.

To answer the main question of *"Are certain methods of detection able to capture only certain exoplanets?"*, I think that ultimately a planet's properties have minor significance on the methods that detect them, although this project has shown some interesting insight. It seems that, compared to other methods, there's more data on the Radial Velocity method, where I personally saw the most insights; the planets detected through this method appear to have large properties compared to the rest, with a rather close distance from Earth, while Pulsar Timing has detected planets way further from Earth.

Although I obtained some insight on these planetary systems, I would say a limitation of this project would be missing data, and because I am not a NASA scientist, I cannot say for certain how much or little work goes into gathering and preparing this data. However, a lot of properties were unique to each method and most of the time, there could not be found a property that all methods possessed, which would have made the analysis more complete, and, ultimately, better.