SUB-JUPITER RADIUS OCCURRENCE RATE ANOMALY

JOE RENAUD

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

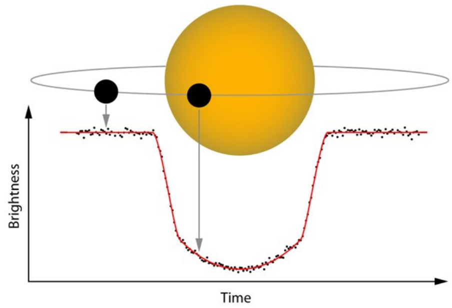

Figure 1: Cartoon of a transiting exoplanet, image taken from NASA exoplanet database

1 INTRODUCTION

Since the first confirmation of an extra-solar planet in 1992[10], the field of exoplanet research has exploded with nearly 1800 planets currently confirmed (as of May 6th, 2014[7]). Since the early 90's the detection techniques employed to discover these exoplanets relied heavily upon tracking the Doppler shift in a host star's spectrum. Such a shift could arise from a large, short period, exoplanet. The radial velocity technique formed the majority of exoplanet confirmations well into the late 2000's[3]. During this time the transit technique started to gain prevalence.

1.1 Transit Technique and NASA's Kepler Mission

Exoplanet transiting refers to the event when a exoplanet passes into the line of sight of the observer to the host star. A host star's light can be monitored over a certain time span; when compared to the light output of similar stars in the same frame - a exoplanet detection can be easily picked out (see figure 1). These light curves allow researchers to determine certain characteristics of the transiting planet. Specifically from one transit one can find the ratio of the radius of the planet compared to the host star. Multiple transits will provide orbital information[9]. The early days of transit discoveries found only large radius planets as these required the least sensitive equipment, and from the fact that the signal to noise ratio of an exoplanet discovery is described by equations 1 and 2.

$$\frac{S}{N} \approx \sqrt{N_t}\frac{\delta}{\sigma} \tag{1}$$

$$\delta = \left(\frac{R_p}{R_*}\right)^2 \tag{2}$$

The radius of the planet R_p and the radius of the star R_* greatly impacts the S/N, as does the photometric precision σ[1]. Thus, these early discoveries had limited (and small) photometric precision. Therefore, the only planets that had a decent signal to noise ratio were those with large radii. This can be seen in the histogram of radii for all exoplanets discovered by the transit technique up to 2008 (Figure 3 on page 4). Jupiter size planets and larger were common discoveries for the transit technique. It was not until NASA's Kepler mission was launched in 2009[6] that photometric precision was increased to the point that sub-Jupiter planets could be detected[8]. Once Kepler's data began getting published it became clear that not only could

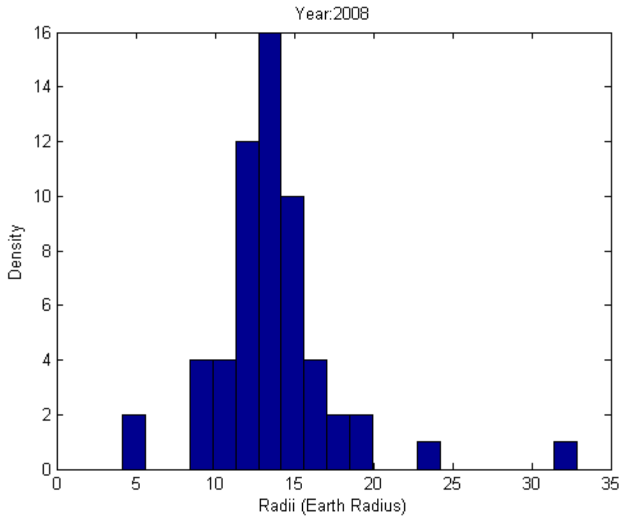

Figure 2: Exoplanet discoveries made by the transiting technique from 1990 to 2008. The radii are measured in Earth Radii, with 10 Earth Radius being roughly the size of Jupiter.

Kepler detect planets down to the sub-Earth size, but it was also able to find planets much more quickly - increasing the exoplanet database size dramatically (Figure 3 on the following page). There are over 1700 exoplanets discovered through the transit, and other techniques (last checked on May 10th 2014[7]). All of these planets provide a good sampling of the potential exoplanets within our galaxy. There has been a number of studies that examine properties of the currently discovered exoplanets (e.g: [2, 5, 4]). This project examines an anomaly in the distribution of exoplanet radii in transiting exoplanets.

1.2 Radii of Discovered Planets

We are specifically curious what the distribution of exoplanet radius has been changing since the introduction of the Kepler mission. Since radius is a primary variable of only the transit technique: most of the analysis will be based upon planets discovered by transiting. However, some planets originally discovered by radial velocity, or other techniques, have been reexamined by telescopes using the transit technique. This allows some analysis of radii of radial velocity exoplanets.

2 DATA

The data for this study is obtained from NASA Confirmed Exoplanet Database and NASA Exoplanet Candidate Database. This data is updated continuously by the scientific community and managed by NASA, making it a very reliable source. The specific type of data that can be pulled from this source includes publication date, Planetary properties (mass, radius, period, etc), Stellar properties (mass, radius, galactic location, etc), and detection information. A number of planets detected by the transit method up to the current date can be found on figure 3 on the next page. To ensure reliabil-

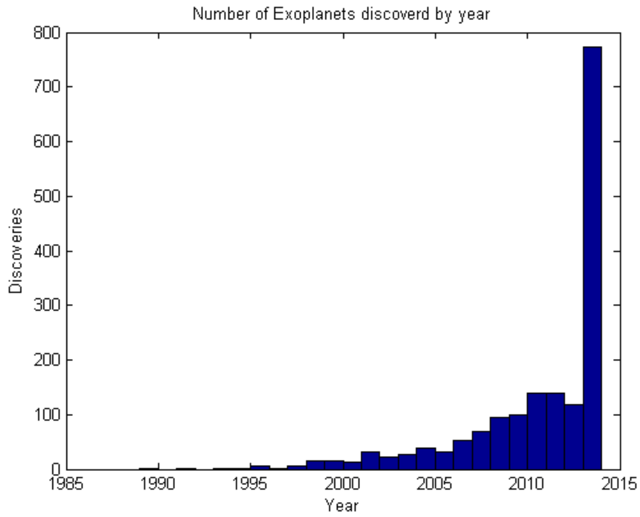

Figure 3: Transit technique discoveries up to April 25th 2014. It is clear that since Kepler's launch in 2009, the exoplanet database has grown substantially.

ity of data: any exoplanet that was examined was first cross referenced on a different, but still well cited, exoplanet database - Exoplanets.eu. Specifically, planet radii were confirmed to be the same across both databases. Any planet that had a significant variation across the sources was neglected from the study.

Issues with this data is that the date listed does not necessarily correspond to the date when technology was sufficient enough to detect said planet, but rather when enough research and/or follow-ups were preformed to make a publication regarding its discovery. This means that the capability of discovering does not scale with publication year. This means that predictions as to when technology will be sufficient enough to detect a planet of a certain radius ($P(R) \propto R^n$) can not be easily extrapolated.

3 METHODS

Reference to Figure 4 on the following page.

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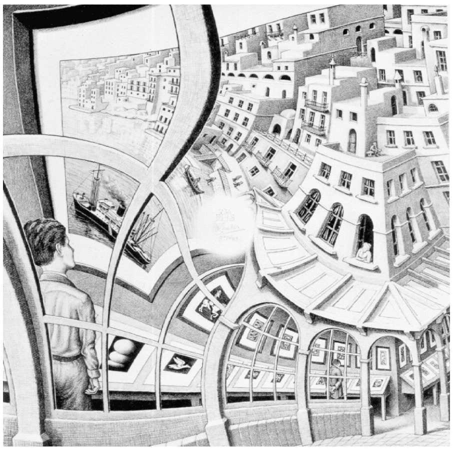

Figure 4: An example of a floating figure (a reproduction from the *Gallery of prints*, M. Escher, from `http://www.mcescher.com/`).

3.1 Paragraphs

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3.2 Math

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$$\cos^3\theta = \frac{1}{4}\cos\theta + \frac{3}{4}\cos 3\theta \tag{3}$$

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Definition 1 (Gauss)**.** To a mathematician it is obvious that $\int_{-\infty}^{+\infty} e^{-x^2}\,dx = \sqrt{\pi}$.

Theorem 1 (Pythagoras)**.** *The square of the hypotenuse (the side opposite the right angle) is equal to the sum of the squares of the other two sides.*

Proof. We have that $\log(1)^2 = 2\log(1)$. But we also have that $\log(-1)^2 = \log(1) = 0$. Then $2\log(-1) = 0$, from which the proof. $\square$

4 RESULTS AND DISCUSSION

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4.1 Subsection

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4.1.1 *Subsubsection*

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WORD Definition

CONCEPT Explanation

IDEA Text

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4.1.2 *Table*

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Table 1: Table of Grades

Name		
First name	Last Name	Grade
John	Doe	7.5
Richard	Miles	2

Reference to Table 1.

4.2 Figure Composed of Subfigures

Reference the figure composed of multiple subfigures as Figure 5 on the following page. Reference one of the subfigures as Figure 5b on the next page.

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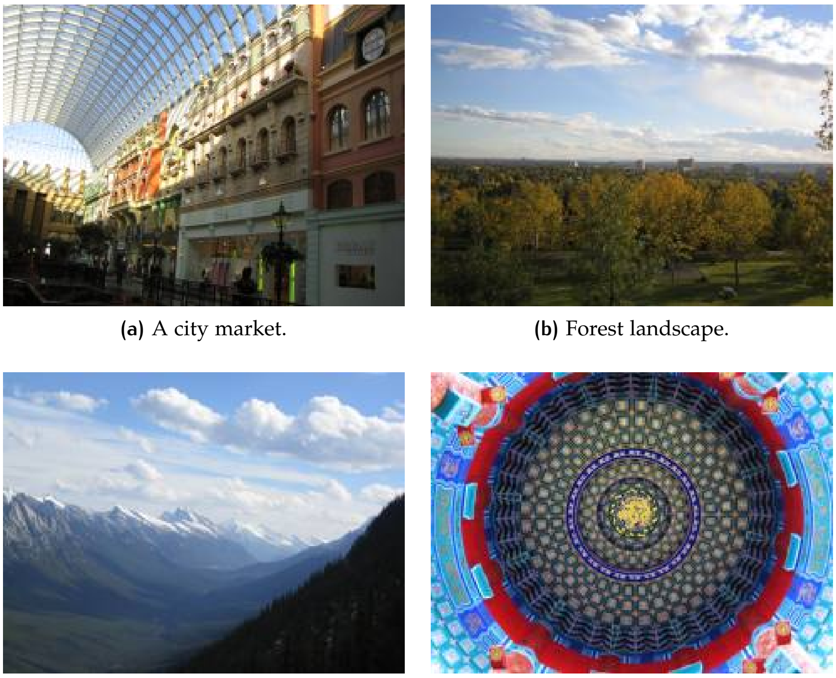

(a) A city market.

(b) Forest landscape.

(c) Mountain landscape.

(d) A tile decoration.

Figure 5: A number of pictures with no common theme.

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