



ASTROCHALLENGE 2024 SENIOR DATA ANALYSIS ROUND

Friday 12th April 2024

PLEASE READ THESE INSTRUCTIONS CAREFULLY.

This paper consists of **5** printed pages, including this cover page.

In this question, you will process a data set, analyse it, observe trends, and draw conclusions. **There are no right or wrong answers**; you will be marked solely on the quality of your analysis, even if your statistical methods are incorrect.

We **strongly** recommend you use industry-standard tools like Microsoft Excel™, RStudio, or various Python libraries to process the data.

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1 Instructions

1.1 Deliverables

You will need to submit the following items:

- an *Excel sheet* containing the results for each question in separate sheets, and
- a *PDF document* containing your answers for (c) and (d).

2 Data Analysis Question

In this question, we will explore the Kepler dataset with the objective of finding potential habitable exoplanets.

2.1 Introduction

The Kepler Space Telescope was launched by NASA in 2009 into an Earth-trailing heliocentric orbit. Its sole scientific instrument of a photometer that continuously monitored main-sequence stars in a specific region of the Milky Way. When a planet transits in front of an observed star, there will be an observable dip in brightness that Kepler will detect. This data is then sent down to Earth for processing, and candidate planets are entered into the Kepler Objects of Interest (KOI) list.

Kepler's mission was split into two parts — the original Kepler mission lasted until May 2013 when two of the spacecraft's four reaction wheels, providing the spacecraft attitude control, failed. The second part of the mission, named "K2", had the spacecraft use its two remaining reaction wheels and sunlight to balance the spacecraft to continue exoplanet hunting. This mission ended in October 2018 after Kepler used up all its fuel and the space telescope was retired.

2.2 Objectives

In this question, we will

- identify potential habitable exoplanets from a subset of the KOI list, and
- investigate the relationships between stellar temperature or gravity, and a star's radius.

2.3 Data [3 marks]

The data provided to you in `kepler_data.csv` is a subset of the KOI data we obtained from <https://exoplanetarchive.ipac.caltech.edu/> and datasets derived from literature (Chen and Kipping, 2017).

You have two options on how to proceed with this DAQ:

1. With reference to the **Appendix** and the dataset derived from literature `koi_planet_masses.csv`, you may attempt to prepare the full dataset (approximately 9000 objects).
2. Alternatively, you may choose to attempt this DAQ with the pre-prepared dataset (approximately 2500 objects) at `kepler_data.csv`. However, you will not be awarded the 3 marks allocated for data pipelining and preparation.

2.4 Data

2.4.1 Habitable Zone Calculation

Given the surface gravity g and the radius r from the KOI list, we can use this formula

$$g = \frac{GM}{r^2}$$

to calculate the mass M of the parent stars of the Kepler exoplanets. Use the value of the gravitational constant G given in the Formula Book.

- (a) **Compile the list of masses of the parent stars, with columns containing the KOI, stellar surface gravity, stellar radius, and the mass of the parent stars.** [2 marks]

To find habitable exoplanets, we need to find the habitable zone of the parent stars the exoplanets are orbiting. The *habitable zone* (also known as the Goldilock's zone) is defined as the region around a star at which liquid water can exist on orbiting planets' surfaces.

We can determine the radii of the inner boundary r_i and outer boundary r_o of the habitable zone with the equations

$$r_i = \sqrt{\frac{1}{1.1} \times \frac{L}{L_{\text{sun}}}} \quad \text{and} \quad r_o = \sqrt{\frac{1}{0.53} \times \frac{L}{L_{\text{sun}}}}.$$

However, this requires the luminosities L of the stars to be calculated using

$$\frac{L}{L_{\text{sun}}} = \left(\frac{R}{R_{\text{sun}}}\right)^2 \left(\frac{T}{T_{\text{sun}}}\right)^4$$

where R and T are the radii and temperatures of the stars respectively.

- (b) **Find the habitable zone of the parent stars, with columns containing the KOI, stellar mass, the luminosity, and the inner and outer radii of the habitable zone.** [2 marks]

2.4.2 Stellar Correlation Plotting

Using any data-processing software of your choice (we recommend Excel/R/Python), plot the following diagrams and include them along with your answers in a PDF.

“Plot A against B ” means put the values of A on the y -axis, and the values of B on the x -axis.

- (c) **Plot the overall stellar surface temperature against stellar radius.**

What can you say about the relationship between stellar surface temperature and stellar radius? [2 marks]

- (d) **Plot the overall stellar surface gravity against stellar radius.**

What can you say about the relationship between stellar surface gravity and stellar radius? [2 marks]

2.4.3 Identify Habitable Exoplanets

Having determined the habitable zone of the stars, we now need to find the orbital radii of the exoplanets.

- (e) Use Kepler's Third Law to find the orbital radii of the exoplanets in astronomical units (AU), with columns containing the KOI and the orbital radius. [3 marks]

Now that the orbital radius of the exoplanets have been calculated, we can now determine if the exoplanets discovered by Kepler Space Telescope to be habitable.

- (f) Write down the list of exoplanets in the habitable zone. [2 marks]

Warning: No marks will be awarded for if ANY non-habitable planets are not omitted from the list.

2.4.4 Size Categorisation

Now that we have determined the list of habitable planets, it's time to categorize them. First, we need to find the mass of the exoplanets. In this exercise, we will assume the orbits are circular to simplify calculations. However, do note that in actual calculations, the calculations are much more complex.

- (g) Assume the exoplanet orbits are circular.

Refer to Table 1. Classify each of the planets into the following types: Asteroids, Mercurians, Sub-earth, Earth, Super Earth, Neptunians, Jovians. [2 marks]

Planet Type	Mass (Earth Units)	Radius (Earth Units)
Asteroids	0 - 0.00001	0 - 0.03
Mercurians	0.00001 - 0.1	0.03 - 0.7
Sub-earth	0.1 - 0.5	0.5 - 1.2
Earth	0.5 - 2	0.8 - 1.9
Super Earth	2 - 10	1.3 - 3.3
Neptunians	10 - 50	2.1 - 5.7
Jovians	50 - 5000	3.5 - 27

Table 1: Mass classification for solar and extrasolar planets

Appendix

How to Use the Kepler Objects of Interest (KOI) Catalogue

1. Go to NASA Exoplanet Archive (<https://exoplanetarchive.ipac.caltech.edu/>),
2. Hover over “Data”, then under “Kepler”, select “KOI Data (Cumulative List)”,
3. Give the website some time to load as the dataset is very large, then under “Download Table”, select “Download All Columns” and “Download All Rows” before pressing “Download Table”.

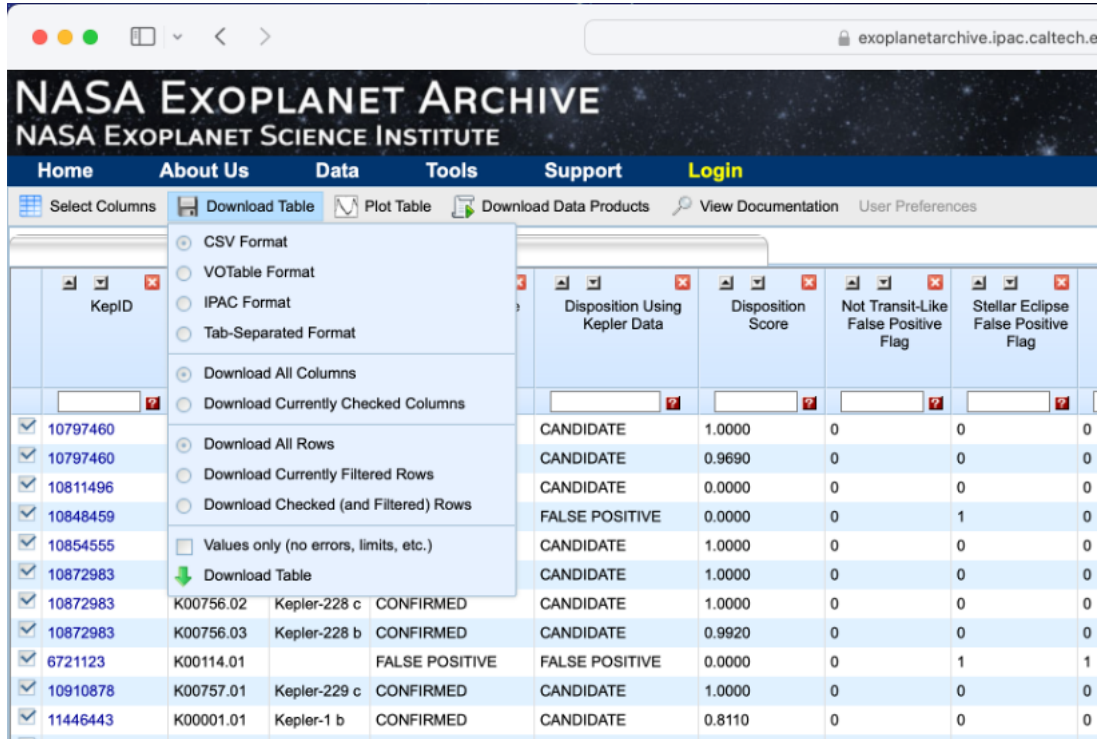


Figure 1: KOI List download options

Before you start working, ensure that you filter out false positives from the dataset. This can be achieved by checking for a “Kepler-” name prefix or by the column ‘*Disposition Using Kepler Data*’, where only objects with the “Candidate” status should be considered. Additionally, you can refer to the exoplanet archive *Dispositions*, where both “Confirmed” and “Candidate” statuses indicate reliable data points.