The Distribution of Cohesive Objects in the Universe: an Extended "Main Sequence"*

GABRIEL M STEWARD[1] AND MATTHEW HEDMAN[1]

[1] *University of Idaho, Moscow, Idaho 83844*

ABSTRACT

ABSTRACTION: this will be done last, as we need to know the end from the beginning to properly do it.

Keywords: KEYWORDS (111) — KEYWORDS (112)

1. INTRODUCTION

[NOTE: For major notes.]

For placeholder stuff and jotted notes.

The HR (Hertzsprung-Russel) diagram is a familiar sight to many. The relation of color temperature to luminosity sucinctely shows how a simple relation of two components can be used to identify, categorize, and explain objects in space. The success of the HR diagram is difficult to overstate, as it is a cornerstone of astronomy or astrophysics course.

In recent years, a similar endeavor has been undertaken for exoplanets. Now that we have over 5000 confirmed discoveries, mass/radius plots can be constructed that show distinct domains of planetary types (Chen & Kipping 2016; Müller et al. 2024). These graphs, while similar in purpose and scope to the HR diagram, are not yet as successful, but likely will be in the future. One can also find similar distribution graphs for asteroids, such as mass-density plots (Carry 2012).

One may be tempted to think that these three domains of stars, exoplanets, and asteroids are entirely unrelated. However, that is not the case; all of them share some simple, basic properties. All of them are cohsive objects with a particular mass and size, from which density and gravitational influence can be determined. This means that every one of these objects can be placed on the same plot so long as two of the aforementioned values were used.

In this paper, we present such a graph that plots the mass-density relation for all cohesive objects that we have decent measurements for, ranging from miniscule asteroids to supermassive black holes. The intention is that this plot will be shared readily among the community as a way to examine the overall distribution of objects in the universe, connecting many disciplines across astrophysics. Like the HR diagram, this distribution plot suggests many clear divisions by which to categorize objects, and even has an extended "main sequence" of sorts on which the vast majority of objects fall.

We begin with **Results** since the primary result of this paper is the driving force behind it. **Discussion** of the distributions come next, including classification implications, outlier examinations, and uncertainties. The **Conclusion** of our work comes next, though afterward we describe the **Methods** used to gather and pair down the data.

2. RESULTS

Figure 1 is our primary result, showing the relation of mass and density for asteroids, comets, trans-Neptunian objects, moons, planets, brown dwarfs, stars, neutron stars, and black holes. Every data point represents a real object in the scientific literature. The points are categorized by type via shape and color, the classification assigned based on the source they were found in. This draws attention to the inconsistent distinction between exoplanets and brown dwarfs, as well of the wide vareity in exoplanets and stars. Transparency represents the relative error associated with each object: low errors plot solid poitns, while high errors are almost transparent. The maximum relative error plotted is 0.5 for the mass or thrice the radius, whichever was larger. Direct radius relative error was not used as mass correlates with radius cubed, and so the error propogations differe between the two by a factor of 3. The largest errors are particualry noteworthy on outlier exoplanets, outlier asteroids, and particulary small objects.

No neutron stars have had their radii measured with any precision, but we do have fairly good ideas what they are from theory (). Thus, the range of neutron star masses and densities are plotted as a fat line, rather than individual points. Two black hole event horizon radii have been satisfactorily measured, and they are on the plot, but to put them in contaxt we opted to plot the theoretical mass-density relation for Schwarzchild black holes. Besides these two situations, every point is a real ojbect.

* Sept, 17, 2024

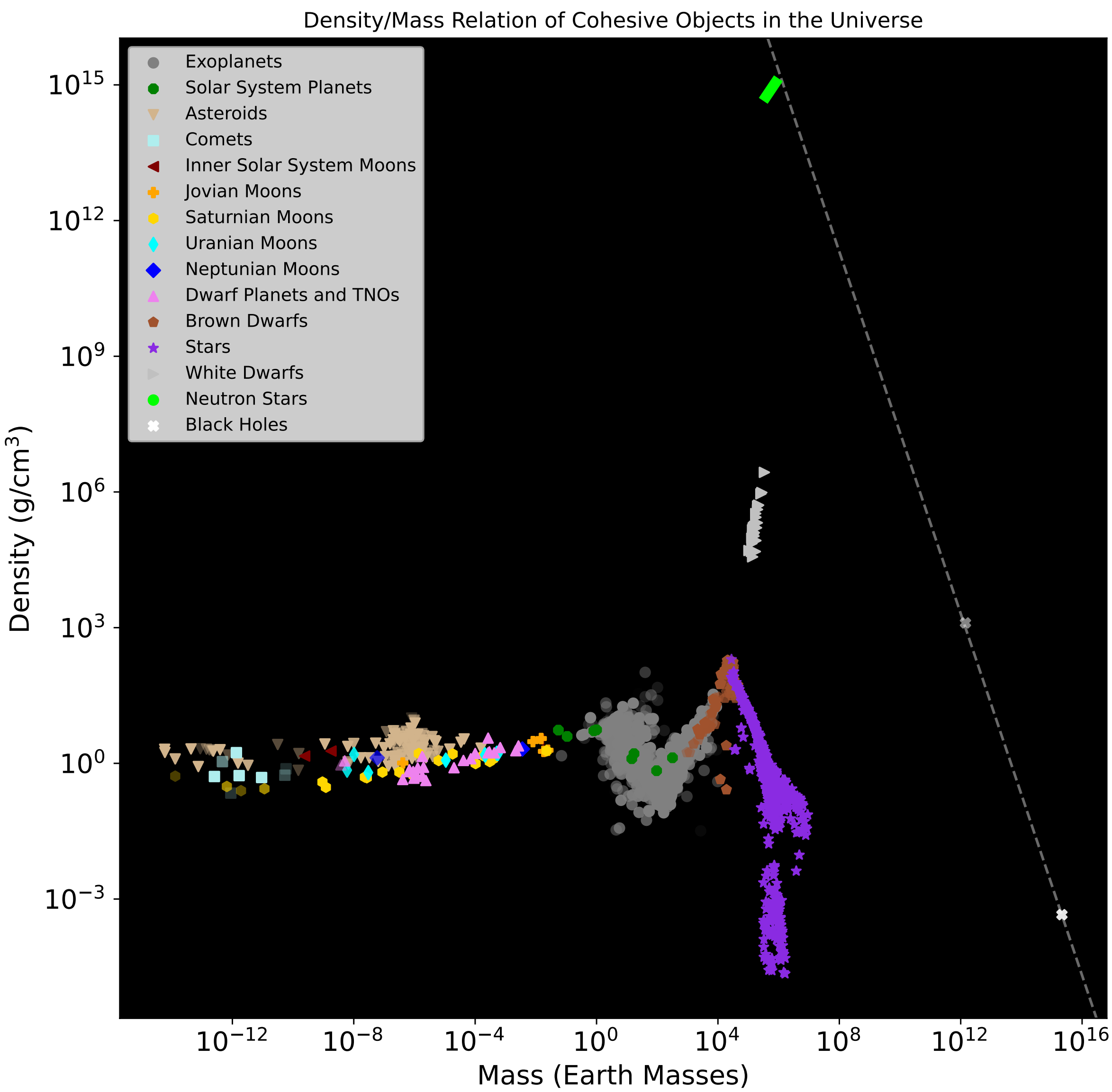

Figure 1. The relationship between density (in g/cm^3) and mass (in Earth masses) for cohesive objects in the universe on a log-log scale. Each kind of object is given a unique color and shape. The transparency of each point represents how large the errors are: solid objects have minimal errors while the more transparent ones have larger errors with a maximum relative permitted error of 0.5 in either mass or thrice the radius, whichever was larger for the object in question. As no neutron star radii have been measured to precision, the general area Neutron Stars occupy is given by a green line. The dashed line represents the black hole limit, any object that reaches this line should theoretically collapse into a black hole.

Expanded views of various sections of Figure 1 are shown in Figure 2, examing four different mass scales. These views make it possible to pick out individual objects among the otherwise dense clouds.

The actual data collected in our dataset are mass and radius, not mass and density. Mass and density were chosen for Figure 1 because it makes it easier to see distinct categories of objects, particuarly in the lower-mass regime of exoplanets. However, the mass-radius relation is not ignored; we have it plotted in FIGURE 3 alongside other combinations of mass, radius, density, and surface gravity.

3. DISCUSSION

DISCUSSION: Note the primary types of objects and their domains, what the "main sequence" is, what things are off of it, etc. Have a section about the outliers that survived inspection. Discuss how we can and cannot classify objects, overlaps, and questionable areas. Just have fun talking about it!

4. CONCLUSION

CONCLUSION: Discuss the major points, how the graph might be used, and what we can learn from it. Also note holes in the graph that could be filled in the future.

5. METHODS

METHODS: In the back discuss the nitty-gritty deatils of where the data was gathered from, how it was trimmed down, and what the requirements were. Also discuss outlier handling. This is mainly where a ton of citaitons are going to go.

Insert ACK here.

Data availability? Would like to make it clear that we'll give all the information after just being asked...

[Not sure who needs to be put here who won't be put on the author list. Though there is going to be funding recongition here.]

APPENDIX

A. APPENDIX?

Appendix!

REFERENCES

Carry, B. 2012, 73, 98, doi: 10.1016/j.pss.2012.03.009

Chen, J., & Kipping, D. 2016, 834, doi: 10.3847/1538-4357/834/1/17

Müller, S., Baron, J., Helled, R., Bouchy, F., & Parc, L. 2024, 868, doi: 10.1051/0004-6361/202348690

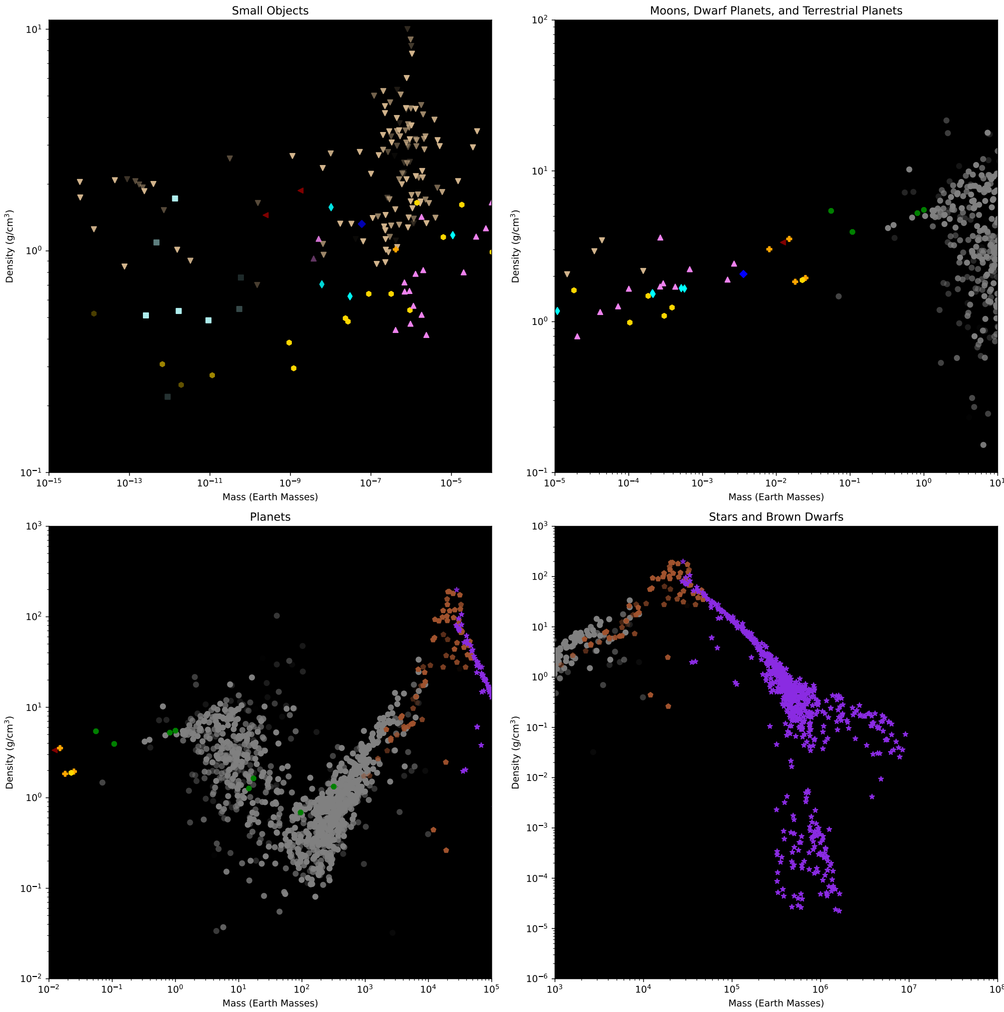

Figure 2. Zoomed in views of Figure 1 using the same colors and shapes. No view for white dwarfs or other extreme objects, as there is not much detail present in those ranges to begin with.