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ROCK OR GAS? WHICH MEASURED PARAMETERS REVEAL A ROCKY EXOPLANET IN THE NASA EXOPLANET ARCHIVE

Iltukov Aldiyar
School NIS, Aktobe, Kazakhstan

Iltukov Aldiyar — Grade 9 student, School NIS, Aktobe, Kazakhstan.

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Abstract: More than six thousand exoplanets are known, but for most of them it is not known whether they are made of rock or of gas. This study uses the 1,363 planets in the NASA Exoplanet Archive whose mass and radius are both well measured to ask which parameters best separate rocky planets from the rest. A planet was called rocky if its radius is no larger than that of a planet of the same mass with an Earth-like composition; 135 planets met this condition. Because this label is calculated from mass and radius, density separates the two groups almost perfectly (96% balanced accuracy) by construction. Among the parameters not used to define the label, the mass of the host star separates them best (69%), followed by the star's temperature and the orbital period, while the planet's temperature and the light it receives are close to chance. For giant planets above one Jupiter mass the radius hardly changes with mass, so density rises steeply with it (Spearman $\rho = 0.78$), and 27 of the 38 giants of 6-13 Jupiter masses are denser than the Earth. The author's expectation that density shows the type best holds only as a consequence of the definition, and his explanation of dense gas giants is consistent with the data.

Keywords: exoplanets, rocky planets, gas giants, density, mass-radius relation, NASA Exoplanet Archive

1. Introduction

Most known exoplanets were found by the dip in starlight when they pass in front of their star, which gives their radius, or by the wobble of the star, which gives their mass. When both are known, the average density of the planet can be calculated and compared with what different materials would give. Small planets with an Earth-like composition follow a known relation between mass and radius, and above about two Earth masses planets begin to keep envelopes of light volatile material [1]. Among small planets there is also a gap in sizes near 1.5-2 Earth radii that separates rocky planets from planets with gas envelopes [2].

The author has built his own program that classifies exoplanets as rocky or gaseous from NASA data. This study turns that idea into a test on the whole archive: which measured parameters actually show whether a planet is rocky, and which do not.

2. Hypothesis

Before this analysis, the author wrote (17 October 2026): "I assume that the main parameter is the density of the planet, because rocky planets consist mainly of heavy rocks and metals, while gas giants consist of light gases. Therefore rocky planets usually have a much higher density, and in my opinion it is this parameter that best helps to determine the type of a planet" (original in Russian).

3. Data and methods

The data are the Planetary Systems Composite Parameters table of the NASA Exoplanet Archive [3], queried on 21 October 2026 (6,378 planets). Planets were kept if both mass and radius are measured with uncertainties, are not upper limits, the mass is not calculated from the radius, the mass uncertainty is below 50% and the radius uncertainty below 20%. Objects heavier than 13 Jupiter masses, the usual boundary between planets and brown dwarfs, were removed (20), leaving 1,363 planets. The archive does not record whether a planet is rocky, so a label was calculated: a planet was called rocky if its radius R (in Earth radii) is no larger than 1.1·M^0.27, where M is its mass in Earth masses; R = M^(1/3.7) ≈ M^0.27 is the mass-radius relation of planets with an Earth-like composition [4], and the factor 1.1 allows for measurement error. Density was calculated from the same mass and radius (5.514·M/R^3 g/cm3), because the density column of the archive often comes from a different paper (108 kept planets differ from it by more than 15%). For each parameter, the best single threshold was found and its balanced accuracy (the average of the shares of rocky and non-rocky planets classified correctly) was calculated, so that 50% means chance. The distributions of the two groups were compared with the Mann-Whitney test. To see how much the parameters that are not used in the label can tell together, a logistic regression with orbital period, insolation, equilibrium temperature, star temperature, star mass and metallicity was checked by five-fold cross-validation.

4. Results

4.1. Which parameters separate rocky planets

Of the 1,363 planets, 135 are rocky by this definition; their median radius is 1.44 Earth radii and 68% of them are smaller than 1.6 Earth radii. Density separates them from the other planets with 95.5% balanced accuracy at a threshold of about 4.8 g/cm3, radius with 94.2% and mass with 83.8% (Table 1). These three are used to define the label, so their success is expected. Of the parameters that are not, the mass of the host star does best (69.1%): rocky planets orbit smaller stars (median 0.80 against 1.02 Sun masses). Star temperature, which is closely linked to star mass (Spearman ρ = 0.89), (66.1%), orbital period (65.0%) and metallicity (61.6%) follow, while insolation and equilibrium temperature (54.3% and 54.4%) are close to chance and their distributions do not differ between the groups (p = 0.96 and 0.30). Used together, the six independent parameters classify 71.4% correctly in cross-validation.

Table 1. How well each parameter separates rocky from other planets, 1,363 planets [3]. * Used to define the label

Parameter	Balanced accuracy, %	Median, rocky	Median, other	Unit
Density *	95.5	7.28	1.07	g/cm3
Radius *	94.2	1.44	10.97	Earth radii
Mass *	83.8	4.14	147.15	Earth masses
Star mass	69.1	0.80	1.02	Sun masses
Star temperature	66.1	4974	5668.5	K
Orbital period	65.0	3.07	4.88	days
Star metallicity	61.6	0.00	0.09	dex
Insolation	54.3	236.17	231.2	Earth = 1
Equilibrium temperature	54.4	1009	1090	K

4.2. Dense gas giants

55 planets that are not rocky are nevertheless denser than the Earth (5.5 g/cm3). 18 of them are small planets below 30 Earth masses that lie just above the rocky boundary, 36 are giants heavier than Jupiter, and 1 lies in between. For the 351 planets above one Jupiter mass, the radius barely depends on mass (median 1.19 Jupiter radii; Spearman ρ between mass and radius -0.11), so density grows almost in proportion to mass (ρ = 0.78). The median density is 1.13 g/cm3 for planets of 1-3 Jupiter masses, 3.1 for 3-6 and 6.93 for 6-13, while the median radius stays between 1.11 and

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1.21 Jupiter radii (Table 2). Only 1 of the 253 giants of 1-3 Jupiter masses is denser than the Earth, against 8 of 60 at 3-6 and 27 of 38 at 6-13 Jupiter masses.

Table 2. Radius and density of giant planets by mass [3]

Mass, Jupiter masses	Planets	Median radius, Jupiter radii	Median density, g/cm3	Denser than Earth
1-3	253	1.21	1.13	1
3-6	60	1.15	3.10	8
6-13	38	1.11	6.93	27

5. Discussion

The author expected density to show the type best, and in these data it does, but this result cannot count as a confirmation: the archive does not record the type, and the label used here is calculated from mass and radius, which is exactly what density is made of. The real information is in the other parameters. Rocky planets are found around smaller, cooler stars and on shorter orbits. Part of this is likely a selection effect, because a small planet blocks a larger share of a small star's light and is easier to detect on a short orbit, and part may be real: giant planets are known to be more common around metal-rich stars [5], and here the median metallicity of the stars of rocky planets is 0.00, against 0.09 for the others. The temperature of a planet and the light it receives tell almost nothing about its composition.

When he saw that some gas planets are denser than the Earth, the author explained (24 October 2026) that "heavy gas giants can be denser than the Earth because of the enormous force of gravity, which compresses the matter inside the planet. As the mass increases, the gas becomes so strongly compressed that the average density of the planet can exceed that of the Earth, despite its mainly gaseous composition. Therefore high density does not always mean that a planet is rocky" (original in Russian). The data are consistent with this: above one Jupiter mass, adding mass hardly increases the radius, so the extra mass is packed into the same volume, and the heaviest giants end up denser than the Earth. The mass-radius relations of [1] show the same flattening for giant planets. The data cannot show the physics inside the planets, only this pattern.

Limitations. The rocky label is a simple threshold, and planets near it, such as water-rich planets, may be misclassified; the relation of [4] was derived for planets up to about eight Earth masses, and 25 of the planets labelled rocky are heavier, up to 73 Earth masses. Star mass is also used when planet masses and radii are measured, so it is not fully independent of the label. The planets with well-measured masses and radii are not a random sample of all planets: they are biased towards large planets on short orbits around bright stars. The thresholds were chosen on the same data that they are tested on, which flatters the single-parameter accuracies slightly; the combined model was tested by cross-validation.

6. Conclusion

In the NASA Exoplanet Archive, density, radius and mass separate rocky planets from the rest almost perfectly, but only because rockiness is defined from them. Of the parameters measured independently, the host star's mass and temperature and the orbital period carry some information, and the planet's temperature carries almost none. High density alone does not prove a planet is rocky: the radius of giant planets barely grows with mass, so most giants above six Jupiter masses are denser than the Earth.

Data availability

The NASA Exoplanet Archive data are public [3]. The planet table and the analysis script are available from the author or his mentoring team on request.

Author contributions and use of AI tools

The author built the exoplanet classification program on which the research question is based, proposed the hypothesis quoted in Section 2 before this analysis, and proposed the explanation discussed in Section 5. The data were analysed and the text was drafted by his mentor

with the help of a generative AI assistant (Claude, Anthropic). Every number was computed by the analysis script from the archive data.

Conflicts of interest

The author declares no conflicts of interest. No funding was received for this study.

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