Simulating Exoplanetary Composition Using ExoPlex

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April 16, 2025

Abstract

Simulating the internal composition of exoplanets provides valuable insights into the structure and formation of rocky planets. In this project, we utilize the ExoPlex software to model the interior structure of GJ-1132b, a known terrestrial exoplanet. By comparing its simulated composition to that of Earth, we assess differences in core, mantle, and crustal properties. Additionally, we place GJ-1132b's structure and composition in context by analyzing its predicted mineral properties alongside its orbital parameters, offering a comprehensive perspective on its internal composition.

1 Motivation

Throughout this course, we have discussed various ways in which to analyze planets, this helps us to determine which planets are Earth-like and, therefore, have a chance at supporting life. In this field our 'Earth-like' planets are primarily rocky planets of similar composition to Earth. In this project we identify Exo-Planet GJ 1132 b as our test planet, where we will determine through use of Exo-Plex, whether this planet is truly rocky, and if so, how rocky? With that are three goals to be accomplished in this project

1. Be able to use ExoPlex to calculate a planet's possible density and structure.
2. Calculate planet structures from mass-proportions and compare to stellar
3. Place the structure and composition in context of mineral proportions and orbital parameters

We will achieve these goals by completing the tasks of calculating molar ratios for various elements, placing the planet's size and orbital distance in the context of a likely rocky planet, using the likely refractory composition of the star to determine radius and density, and lastly, finding a structural model that explains both mass and radius.

2 Methodology

2.1 Warm-Up

To get familiar with the ExoPlex software, we were given a warm-up set in the code. We gave it different stellar planet masses to output their radii. For Earth, we got 0.999 $R_{\oplus}$. For Mars, we got 0.520 $R_{\oplus}$. For Mercury, we got 0.422 $R_{\oplus}$. After getting these values, we adjust our Iron in relation to Magnesium [Fe/Mg].

We do this many times with other elements like silicon and oxygen. We also calculate the mean fraction ratio of various variables as our final calibration.

Fe/Mg	$R_\oplus$	Core Mass Fraction
0.5	1.028	21.50
0.7	1.013	27.68
0.9	0.999	32.95
1.1	0.988	37.51
1.3	0.978	41.49
1.5	0.968	44.99

Table 1: Data from Iron adjustment

2.2 Initial Conditions

For the exoplanet GJ-1132, it has a mass of 1.66 $M_\oplus$, a radius of 1.15 $R_\oplus$, an orbital distance from the host star of 0.0153 au, and its host star has a stellar luminosity of 0.00436 $L_\odot$. We also start with some assumptions about composition. From the near-IR Spectrum, GJ 1132's composition: Fe/H = -0.12 $\pm$ 0.15 dex. Let's assume, Mg/H $\approx$ Fe/H and Si/H $\approx$ Fe/H. Fe/Mg = 0.9, Si/Mg = 0.9, Ca/Mg = 0.07, Al/Mg = 0.09.

We also calculate the bulk density, incident flux and equilibrium temperature of the exoplanet to confirm its rock planet characteristics. For bulk density we got 6.02 g/cm^3, for incident flux we got 18.63 Earth Flux (units of W/m^2), and equilibrium temperature of 529 K (with a bond albedo of 0.3). With the value for bulk density, we can confirm that this exoplanet is in fact a rocky planet and has a very irradiated environment.

3 Results

Our ExoPlex modeling results for GJ 1132 b demonstrate that the planet's observed mass and radius (1.66 $M_\oplus$, 1.15 $R_\oplus$) can be fully explained by a rocky interior with no significant atmosphere. The best-fit models were achieved with a Fe/Mg ratio between 0.90 and 1.00—close to solar—and a mantle FeO content near zero. This implies nearly all iron is concentrated in the core, resulting in a core mass fraction of approximately 33%.

Table 1 shows how variations in the Fe/Mg ratio affect planetary radius and core mass fraction. Our chosen model (Fe/Mg = 0.9) provides an excellent match to the observed radius of GJ 1132 b, with a predicted radius of 0.999 $R_\oplus$ in Earth units.

Comparing mantle compositions with Earth, we find GJ 1132 b's silicate mantle is significantly more magnesium- and silicon-rich and iron-poor. While Earth's mantle contains approximately 8% FeO by weight, our ExoPlex model for GJ 1132 b assumes 0% FeO in the mantle. This iron depletion shifts the silicate composition toward higher SiO_2 and MgO content: 52.6% SiO_2 and 39.2% MgO for GJ 1132 b, compared to Earth's 45% SiO_2 and 38% MgO. The minor oxides (CaO and Al_2O_3) are very similar between the two planets, with GJ 1132 b having 3.8% CaO and 4.5% Al_2O_3.

Additionally, the lack of an atmosphere in our best-fit model is significant. Unlike many super-Earths, GJ 1132 b does not require a gas envelope to explain its size, indicating that its dense, iron-rich rocky interior alone accounts for the observed radius. This finding is consistent with its high equilibrium temperature (529 K) and close orbital distance (0.0153 AU), both of which could inhibit atmospheric retention.

In summary, our ExoPlex simulations suggest that GJ 1132 b is a dense, rocky planet with a fully differentiated interior—featuring an iron-rich core and a magnesium- and silicon-rich mantle—and no significant atmosphere. Its structure can be understood as an Earth-analog composition with a more extreme iron partitioning, offering a compelling case for a terrestrial planet shaped by stellar abundances and intense stellar irradiation.

4 Conclusion

Our ExoPlex modeling of GJ 1132 b reveals that its observed mass and radius can be fully explained by a dense, rocky interior with no significant atmosphere. The best-fit model assumes a nearly solar Fe/Mg ratio (0.9–1.0), complete segregation of iron into the core (0% mantle FeO), and a resulting core mass fraction of 33%. Compared to Earth, GJ 1132 b's mantle is significantly more magnesium- and silicon-rich and iron-poor, with similar levels of CaO and Al_2O_3. These findings suggest a fully differentiated planet with a geochemistry shaped by both stellar composition and extreme proximity to its host star. The success of this model highlights the utility of ExoPlex in connecting bulk planetary properties with internal structure, providing valuable context for interpreting rocky exoplanets as we continue the search for Earth-like worlds.