INTERPRETING VOLCANISM ON EXTRASOLAR PLANETS

Team 487
Problem: A

With computational modeling, we can project the volcanic activity on extrasolar planets or super-earths by creating a relationship between the local planets in our own solar system and that of an external solar system. We take a relational compatibility between the volcanic activity of shield volcanoes on Earth and Venus. The data is model fitted with functions in a math suite software and then the model is used to predict the behavior of volcanic activity on planets that are not local to our own solar system. To side note, we have plotted different compatible models that could later be augmented for more accurate use in astronomical modeling of exoplanetary volcanic activity. By taking into account the age of our solar system and the current amount of active shield volcanoes and the fact that when a planet has zero activity when time is zero, we can approximate the variation of volcanic activity over time. The planets and satellite objects within our solar system take longer to cool and therefore have a longer period of volcanic activity and the inverse for planets with a smaller mass.

I. INTRODUCTION

In recent times, astronomers have discovered an array of extrasolar planets or super-earths. The discovery of extrasolar planets has raised speculation as to how similar or dissimilar they are in comparison to the planets contained by our own solar system. Within our solar system, evidence of volcanism is present on various planetary and satellite objects.

Based on our current understanding of volcanism, the surfaces of Venus and Earth host active volcanoes. There are many factors that play a role in volcanism, one of which is the age of the Solar System. The age of our solar system is generally accepted to be 4.6 billion years old. In the duration of 4.6 billion years, the core of the Moon and Mercury has cooled, meaning that their lower crust and upper mantle are no longer molten to the point of initiating volcanic activity [1]. However, Venus and the Earth still exhibit volcanic activity, which brings to reason that the time span of these celestial objects isn't the only contributing factor of active volcanism.

Most noticeably are the mass sizes of Venus and the Earth in comparison to the Moon and Mercury. Since the mass size of Venus and Earth are significantly larger than the mass size of Mercury and the Moon, it takes Venus and Earth significantly longer for their pockets of molten rock within the lower crust and mantle to solidify and eventually mitigate volcanic activity. Astronomers are capable of estimating the masses of the extrasolar planets in question and have ranged them anywhere from 0.5 to 3 times the mass of the Earth. Given then approximated mass sizes of these extrasolar planets and what we know to be true of Venus' and Earth's volcanic activity, we can speculate the volcanic activity level on super-earths.

II. THEORETICAL MODEL

Assuming that astronomers have found a population of extrasolar planets exhibiting earth-like qualities and with masses that range from 0.5 to 3 times the mass of earth ($M_\oplus$), we are able to calculate their projected volcanic activity and how it varies over time. Based off of the variation in volcanic activity over time for Earth, Venus, the Moon, and Mercury, we know that the larger the mass of a planetary or satellite object, the longer it remains volcanically active. For this theoretical experiment, we will be using the data collected for shield volcanoes. Evidence for shield volcanoes is found on Venus, Mercury, and the Moon where horizontal plate movement does not take place, as well as on Earth which demonstrates plate tectonics allowing for another type of volcano called a composite volcano. A planet or satellite object without horizontal plate tectonics may have shield volcanoes, but it may not have composite volcanoes.

Our theoretical model of volcanism on extrasolar planets consists of two parts: calculating the number of active shield volcanoes of an extrasolar planet at present time, 4.6 billion years and calculating the variation of active volcanism over time.

ACTIVE SHIELD VOLCANOES

In order to find the mass in comparison to the mass of Earth we used equation (1) to find the mass multiplierρ, where $M_\rho$is the mass of the extrasolar planet in question.

$$\rho = \frac{M_\rho}{M_\oplus} \tag{1}$$

With that in mind, we were able to create an equation that will predict the number of active shield volcanoes on an earth-like planet based on its mass in comparison to the mass of Earth:

$$\Upsilon(\rho) = \rho^2 \bar{A}\,(1.570125\rho - 0.570125) \tag{2}$$

where $\bar{A}$ represents the mean number of active shield volcanoes. We used Mathematica to model fit the data to a compatible equation. We plotted a variety of equations as seen in FIG. 1 and determined that equation (2) fit best., represented by the thick blue line.

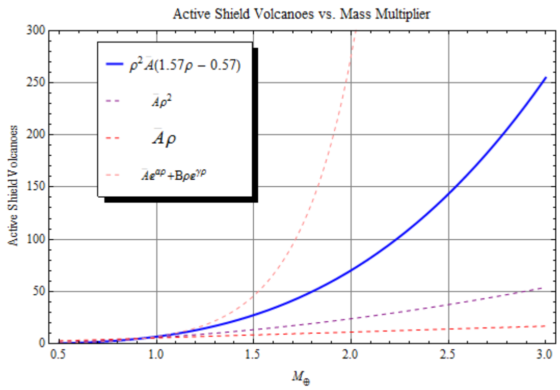

FIG. 1. Tested equations. The equations plotted shown give more weight to the choice of model that we approved to use with our data.

VOLCANIC ACTIVITY VARYING OVER TIME

Thenceforth, we created a function to determine how the volcanic activity of a planet with mass M_ρ varies over time:

$$\psi(\rho, t) = \Upsilon(\rho)\frac{te^{\beta - t}}{\beta} \tag{3}$$

where t is time in billion years, ρ is the planetary mass multiplier, and β is the current age of the solar system $\beta = 4.6$. In FIG. 2 we plot the contour graph of equation (3) which shows that planets with greater mass will start off with more volcanic activity and the activity will take longer to diminish over time.

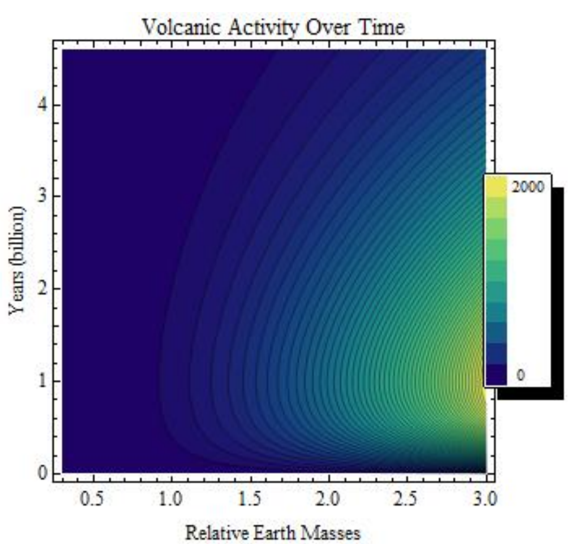

FIG. 2. This contour graph plots equation (3). The lighter color depicts a greater amount of volcanic activity and the darker color represents minimal volcanic activity.

The equations 1, 2, and 3 give us an approximation on the volcanic activity varying over time for distant extrasolar, super-earth planets.

III. FURTHER ANALYSIS

On researching the volcanic activity present on Earth (approximately 60 to 70 active per year), we found it was an unfair addition to volcanic activity that wasn't present on Venus nor other rocky planets or satellites. Doing more research [3] we found that there are currently 3 to 4 active shield volcanoes on the surface of Venus and taking the shield data collected for Earth [4] for the previous 3 decades, we averaged around 6 to 7 active shield type. The lack of horizontal plate movement restricts the possibility of composite volcanoes. Shield volcanoes are a shared volcanic feature on both planets. For this reason, we excluded the volcanoes cause from the tectonics leaving only shield systems to be compared. Technology at this time cannot tell us whether or not an extrasolar planet will have horizontal plate movement.

In equation (3), we used the age of our solar system, 4.6 billion years to determine the variance of volcanic activity over time [1] and assumed it to be true for the extrasolar planets in question. If given the age of the solar system in which the extrasolar planets are located, we could approximate the volcanic activity even more.

IV. RESULTS

In using our theoretical equations, we were able to determine that extrasolar planets with masses ranging from $0.5M_\oplus$ to $3M_\oplus$. Our model shows that extrasolar planets with masses less than $1M_\oplus$ will not only start off with less volcanic activity, but they will also become less active over time. The extrasolar planets with masses greater than $1M_\oplus$ will start off with more active shield volcanoes and will remain active for a much longer duration of time.

V. DISCUSSION OF RESULTS

Due to the low amount of data that was available to us, the approximations are very vague. It was hard to project an accurate amount of volcanic activity on an extrasolar planet over time, because it is mostly theoretical. The initial volcanic activity for shield volcanoes on Earth, Venus, Mercury, and the Moon is unknown. Being that volcanism and the total volcanic activity on both Earth and Venus is still not entirely understood [1][3], we cannot accurately determine the amount of volcanic activity

VI. CONCLUSIONS

Detecting the volcanic activity of extrasolar planets is currently beyond the reach of our modern day technology. However, with the geophysical data collected within our own solar system we can theorize a general approximation of volcanism on earth-like extrasolar planets. The equations (2) and (3) take into account the volcanic activity on Earth and Venus at the current age of the solar system.

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[1] M. A. Seeds D. and E Backman, *Astronomy: The Solar system and Beyond*, sixth Edition. (Brooks/Cole , Belmont CA, 2010).

[2] *Astronomy Encyclopedia* (Oxford University Press, New York, 2002)

[3] Volcanoes on Venus, Oregon State University. http://volcano.oregonstate.edu/oldroot/volcanoes/planet_volcano/venus/intro.html

[4] *Global Volcanism Program (GVP)*, Smithsonian Nation Museum ofNatural History http://www.volcano.si.edu/index.cfm