Venus is not Earth's closest neighbor

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Abstract

Calculations and simulations confirm that on average, Mercury is the nearest planet to Earth—and to every other planet in the solar system.

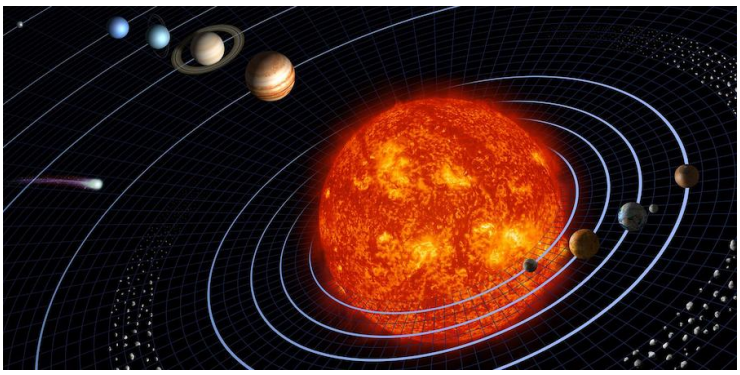


Figure 1: An illustration of the solar system. Credit: NASA

1 Introduction

Which planet is closest to Earth? Ask an astronomer or a search engine, and you'll probably hear that though the situation changes frequently, Venus is the closest when averaged over time. Several educational websites, such as The Planets and Space Dictionary, publish the distance between each pair of planets, and they all show that Venus is nearest to Earth on average. They're all wrong. NASA literature even tells us Venus is "our closest planetary neighbor," which is true if we are talking about which planet has the closest approach to Earth but not if we want to know which planet is closest on average.

As it turns out, by some phenomenon of carelessness, ambiguity, or groupthink, science popularizers have disseminated information based on a flawed assumption about the average distance between planets. Using a mathematical method that we devised, we determine that when averaged over time, Earth's nearest neighbor is in fact Mercury.

2 Simple but wrong

To calculate the average distance between two planets, The Planets and other websites assume the orbits are coplanar and subtract the average radius of the inner orbit, r_1, from the average radius of the outer orbit, r_2. The distance between Earth (1 astronomical unit from the Sun) and Venus (0.72 AU) comes out to 0.28 AU.

Although it feels intuitive that the average distance between every point on two concentric ellipses would be the difference in their radii, in reality that difference determines only the average distance of the ellipses' closest points.

3 A better approach

To more accurately capture the average distance between planets, we devised the point-circle method (PCM). The PCM treats the orbits of two objects as circular, concentric, and coplanar. An object in a circular orbit maintains constant velocity, which means that over a sufficiently long period, it is equally likely to be in any position in that orbit.

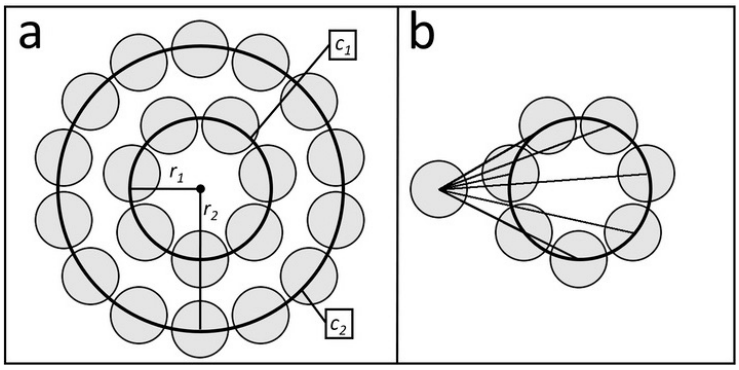


Figure 2: (a) The uniform probabilistic distribution of two circularly orbiting bodies, with orbital radii r_1 and r_2. (b) Radial symmetry is used to simplify the average distance between the distributions.

It can be determined by integrating the point-to-point distance around c_1, as simplified in the following equation, which defines the PCM:

$$\bar{d} = \frac{2}{\pi}(r_1 + r_2)E\left(\frac{2\sqrt{r_1 r_2}}{r_1 + r_2}\right) \tag{1}$$

where $E(x)$ is an elliptic integral of the second kind. The average distances between pairs of planets determined by the PCM are included in the table. Venus is on average 1.14 AU from Earth, but Mercury is a much closer 1.04 AU.

From the PCM, we noticed that the distance between two orbiting bodies is at a minimum when the inner orbit is at a minimum. That observation results in

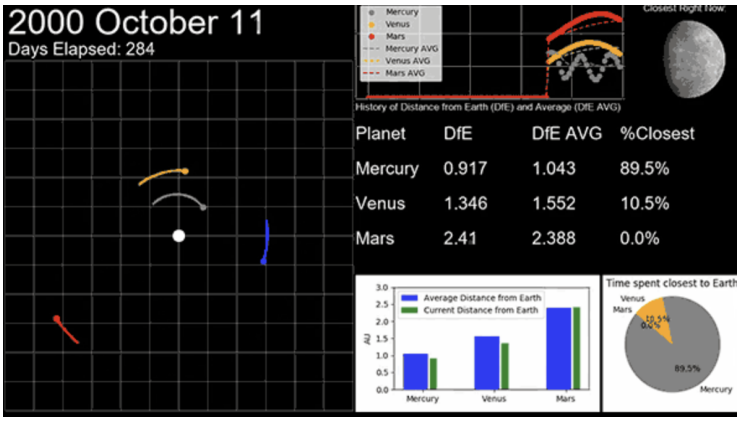


Figure 3: A simulation of an Earth year's worth of orbits by the terrestrial planets begins to reveal that Mercury (gray in orbital animation) has the smallest average distance from Earth (blue) and is most frequently Earth's nearest neighbor. A longer run of the simulation can be seen on YouTube. In addition, planetary geoscientist David Rothery ran a solar system simulation for the BBC radio program More or Less and came up with similar results.

what we call the whirly-dirly corollary (named after an episode of the cartoon Rick and Morty): For two bodies with roughly coplanar, concentric, circular orbits, the average distance between the two bodies decreases as the radius of the inner orbit decreases. It's clear from this corollary, and from the table, that Mercury (average orbital radius of 0.39 AU), not Venus (average radius of 0.72 AU), is the closest planet to Earth on average. In fact, Mercury is even the closest planet to Neptune. (And yes, to Pluto too: Though the corollary doesn't work as well for the dwarf planet, with its orbital inclination of 17° and eccentricity of 0.25, its nearest neighbor is also Mercury.)

4 Simulation validation

We ran a simulation to confirm the whirly-dirly corollary, using a Python library called PyEphem to chart the positions of all eight planets in the solar system for 10 000 years. An animation illustrating the simulation is shown in figure 2. After each 24 hours of simulated time, the program records the distances between each pair of planets.

In the table we list the average measured distances over the 10 millennia and compare them with the results from the PCM and the traditional method. The simulation results differ from the flawed numbers by up to 300 %, but they deviate from the PCM figures by less than 1 %. Figure 3 compares the results from both methods with the simulation of the average distance between Neptune and the seven other planets.

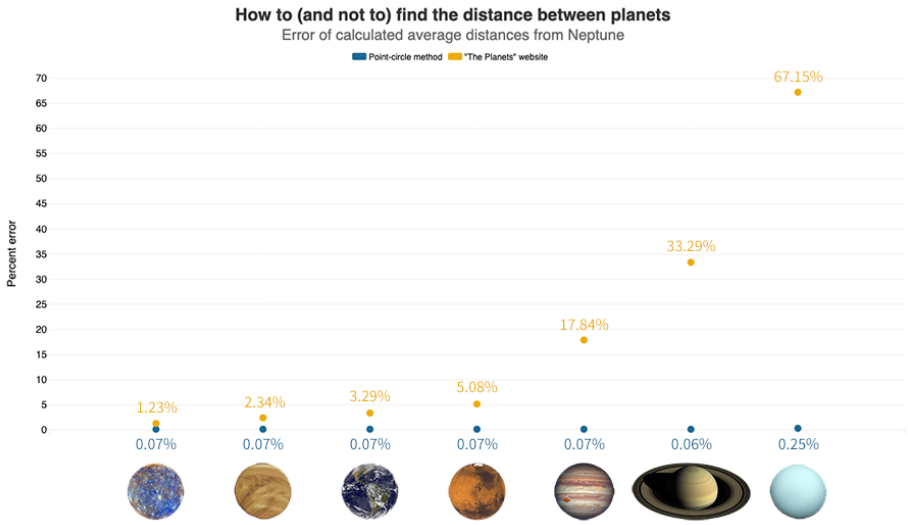


Figure 4: The point-circle method (blue points) calculates the average distance from Neptune to the other seven planets far more accurately than the method used by websites such as The Planets (yellow). The values are compared with those obtained from the 10000-year solar system simulation. Credit: Greg Stasiewicz and Flourish

5 Conclusion

As best we can tell, no one has come up with a concept like PCM to compare orbits. With the right assumptions, PCM could possibly be used to get a quick estimate of the average distance between any set of orbiting bodies. Perhaps it can be useful for quickly estimating satellite communication relays, for which signal strength falls off with the square of distance. In any case, at least we know now that Venus is not our closest neighbor—and that Mercury is everybody's.

	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	
Mercury	0.0	0.779	1.039	1.557	5.215	9.550	19.214	30.071	Simulation
		0.776	*1.038*	*1.548*	*5.212*	*9.586*	*19.203*	*30.049*	*PCM*
		0.34	*0.61*	*1.14*	*4.82*	*9.14*	*18.82*	*29.70*	*Old Method*
Venus	0.779	0.0	1.136	1.618	5.236	9.563	19.218	30.074	Simulation
	0.776		*1.136*	*1.611*	*5.230*	*9.596*	*19.208*	*30.052*	*PCM*
	0.34		*0.28*	*0.80*	*4.48*	*8.80*	*18.49*	*29.37*	*Old Method*
Earth	1.039	1.136	0.0	1.701	5.259	9.575	19.224	30.078	Simulation
	1.038	*1.136*		*1.693*	*5.253*	*9.608*	*19.214*	*30.056*	*PCM*
	0.61	*0.28*		*0.52*	*4.20*	*8.52*	*18.21*	*29.09*	*Old Method*
Mars	1.557	1.618	1.701	0.0	5.314	9.616	19.252	30.089	Simulation
	1.548	*1.611*	*1.693*		*5.317*	*9.643*	*19.231*	*30.067*	*PCM*
	1.14	*0.80*	*0.52*		*3.68*	*7.99*	*17.69*	*28.56*	*Old Method*
Jupiter	5.215	5.236	5.259	5.314	0.0	10.276	19.583	30.295	Simulation
	5.212	*5.230*	*5.253*	*5.317*		*10.303*	*19.556*	*30.273*	*PCM*
	4.82	*4.48*	*4.20*	*3.68*		*4.32*	*14.01*	*24.89*	*Old Method*
Saturn	9.550	9.563	9.575	9.616	10.276	0.0	20.421	30.834	Simulation
	9.586	*9.596*	*9.608*	*9.643*	*10.303*		*20.417*	*30.816*	*PCM*
	9.14	*8.80*	*8.52*	*7.99*	*4.32*		*9.70*	*20.57*	*Old Method*
Uranus	19.214	19.218	19.224	19.252	19.583	20.421	0.0	33.119	Simulation
	19.203	*19.208*	*19.214*	*19.231*	*19.556*	*20.417*		*33.203*	*PCM*
	18.82	*18.49*	*18.21*	*17.69*	*14.01*	*9.70*		*10.88*	*Old Method*
Neptune	30.071	30.074	30.078	30.089	30.295	30.834	33.119	0.0	Simulation
	30.049	*30.052*	*30.056*	*30.067*	*30.273*	*30.816*	*33.203*		*PCM*
	29.70	*29.37*	*29.09*	*28.56*	*24.89*	*20.57*	*10.88*		*Old Method*

Figure 5: A comparison of the average distances (in astronomical units) between planets, as obtained via simulation, the point-circle method, and the common method used by various educational websites. The PCM results are far closer to those from the simulation, correctly demonstrating that Mercury is every other planet's closest neighbor.