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Large Exomoon Likely Orbits a Faraway World

A team of astronomers has announced new evidence supporting the existence of an exomoon in orbit around a distant exoplanet.

"Within our solar system, satellites are abundant," said David Kipping, assistant professor of astronomy at Columbia University in New York. "We have long assumed that when it comes to exomoons, the question is not if they exist but, What are the physical properties of such a population?" Kipping, who has been hunting exomoons for nearly a decade, coauthored a *Science Advances* research paper that announced the discovery on 3 October (see http://bit.ly/teachey-exomoon).

Using the Hubble Space Telescope (HST), the team observed a Jupiter-sized planet as it transited its host star and blocked a fraction of the star's light. It found that the timing, shape, and strength of the planet's transit showed peculiarities that strongly suggest that it hosts a Neptune-sized moon.

"We are looking forward to the scrutiny of the scientific community on this work," said lead author Alex Teachey, "and we hope that we will have an opportunity to observe the target again before too long." Teachey is a graduate student in the Department of Astronomy at Columbia University.

If future observations validate this hypothesis, the exomoon candidate, tentatively dubbed Kepler-1625b-i, will be the first moon detected around a planet outside of our solar system.

Two Telescopes, One Target

The planet, called Kepler-1625b, first came to the researchers' attention as a possible exomoon host in 2017 after they analyzed data from the Kepler Space Telescope. Kepler observed three transits of the Jupiter-sized world during its primary mission. The planet, about 8,000 light-years from Earth, takes about a year to orbit an old star that is slightly larger and more massive than the Sun.

The Kepler data contained hints—subtle blips in the host star's emitted light that were slightly offset from the planet's signal—that an exomoon might be orbiting the planet. Kepler-1625b was the only planetary system out of nearly 300 viable targets that showed any hint of a moon.

The preliminary results from Kepler were tantalizing enough for the team to observe a fourth transit in October 2017 using HST. Hubble provided a fourfold improvement in precision over Kepler for this star and also made observations at infrared wavelengths. The team obtained about 40 hours of observing time on Hubble, then got to work meticulously scrutinizing the data.

Anomalies in Timing and Brightness

Teachey and Kipping found that two aspects of the transit data from Hubble were consistent with their exomoon hypothesis. First, the planet transited the star 1.25 hours earlier than expected on the basis of the orbital period measured by Kepler. "That is indicative of something gravitationally tugging on the planet" during this particular transit, Kipping explained.

If a moon did exist, he continued, the position of the moon in its orbit about the planet could help explain why the timing of the Hubble transit differed from that of the Kepler data. Imagine the influence of the moon to be like pushing someone on a swing: Depending on when you push, the direction of your push, and where you're standing when you do push, you (the moon) could make the swing (the planet) move faster or slower or not change speed at all.

Second, the Hubble observations of the host star's brightness showed two dips in brightness instead of just the one from the planet. "The location, shape, and depth of this event appear consistent with a Neptune-sized moon [also] transiting in front of the star," Kipping said. The team also saw this secondary dip in the star's light in some of the Kepler transits.

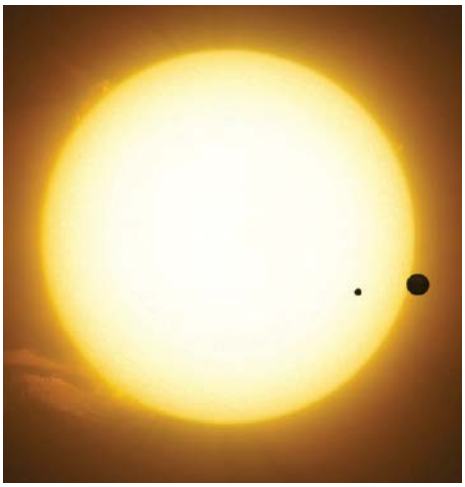
The team compared its data with outputs from a variety of transit models—some that included or excluded exomoons and some that included or excluded other exoplanets. "We have tried our best to rule out other possibilities such as spacecraft anomalies, other planets in the system, or stellar activity," Kipping said, "but we are unable to find any other single hypothesis that can explain all of the data that we have."

"The combination of Hubble data with the Kepler data is really an essential part of the moon search," Teachey said.

Moon of a Surprising Size

The exoplanet-exomoon system suggested by the new observations has mass and radius ratios similar to those of the Earth-Moon system but that are scaled up by a factor of 11. If you were on a spaceship flying through the planet's atmosphere, the exomoon would appear to be around twice as large in the sky as our Moon does, Teachey explained.

Artist's rendering of the Jupiter-sized exoplanet Kepler-1625b with its hypothesized Neptune-sized moon, Kepler-1625b-i. Credit: Dan Durda



Artist's impression of the exoplanet Kepler-1625b (larger black dot) and its potential exomoon (smaller black dot) transiting their host star. In this rendering, the planet and moon orbit the star from left to right. New data from HST first showed a dip in the star's brightness as the planet transited the face of the star. This dip was followed by a second, smaller dip, which the team attributed to a smaller exomoon. Credit: Dan Durda

The team was surprised that a Neptune-sized moon seemed to orbit a Jupiter-sized planet. Moons in our solar system formed as by-products of a collision (like our Moon), by the capture of asteroids or other objects (like the moons of Mars and Neptune), or as leftovers of planet formation (like Jupiter's Galilean moons). A Neptune-sized moon around a Jupiter-sized planet does not fit any of these formation scenarios, the team said.

"A moon like this is not necessarily readily explainable," said Teachey. However, "you certainly can't rule it out on those grounds, because nature makes all sorts of things that we are still struggling to explain," he said.

Cautious Optimism

The exomoon-hunting team received media attention in 2017 when its planned observations appeared on Hubble's public schedule. This sparked unsupported claims that the team was more confident in a Kepler-1625b moon than they had said.

With this paper, "we are urging caution here," Teachey said. "The first exomoon is obviously an extraordinary claim, and it requires extraordinary evidence." The researchers hope to observe the May 2019 transit of Kepler-1625b with HST to further test their exomoon hypothesis.

By **Kimberly M. S. Cartier** (@AstroKimCartier), Staff Writer

Heavy Air Pollution May Lower Cognitive Test Scores

Deteriorating air quality around the globe has long been linked to declines in physical health, including lung cancer, heart disease, stroke, and overall life expectancy. Now new research published in *Proceedings of the National Academy of Sciences of the United States of America* suggests that high levels of pollution can lead to a decline in cognitive ability too (see http://bit.ly/zhang-2018).

The study analyzed scores on cognition tests taken by nearly 32,000 participants across China, searching for demographic trends that may be associated with pollution levels. And it found them.

"Long-term exposure to air pollution impedes cognitive performance in verbal and math tests," Xiaobo Zhang, lead author on the study, told *Eos*. Zhang is a professor at the National School of Development at Peking University in Beijing and a senior research fellow at the International Food Policy Research Institute in Washington, D. C.

"The negative impact on verbal scores was more pronounced for men than women," he said. "The damage increases as people age."

The researchers note that most cities in developing nations, including China, fail to meet international air quality standards, so this study may have implications beyond China's borders.

"The damage to cognitive ability by air pollution also likely impedes the development of human capital," Zhang explained. "Therefore, a narrow focus on the negative effect on health may underestimate the total cost of air pollution."

Sifting Through Scores

Zhang's team mined cognition test results gathered in 2010 and 2014 by the China Family Panel Studies (CFPS), a national demographics survey conducted by Peking University. Among other questions, the survey included 24 standardized math questions and 34 word recognition questions of increasing difficulty. Responses to the survey, gathered from 162 counties spread over China, are representative of the Chinese population, according to CFPS.

Demographic data collected with the survey allowed researchers to group participants on the basis of personal factors like age, sex, and education level, which in China likely determine whether a person works predominantly outdoors and breathes unfiltered air. The data also supplied researchers with background information on test participants such as where they have lived and for how long.

By isolating these individual factors, the researchers could classify a benchmark value for each group. Assuming that a person's scores started at the benchmark when they were young, the researchers began to ponder the factors that could have led to changes in a person's cognition over time.

Given respondents' age distribution as well as the spatial distribution of scores over much of China, the factor the researchers kept circling back to was air pollution.

Pollution on the Brain

Personal experience led Zhang to consider the health effects of air pollution. Zhang told *Eos* that when he returned to China from the United States in 2012, he immediately began experiencing headaches and found it hard to concentrate on research on days when Beijing had heavy air pollution.

Past studies, the team notes in the paper, had looked at how air pollution affects children's test scores in school, so Zhang wondered whether the effects were the same for everyone. He became curious about how low air quality might affect different subpopulations in China. Do air pollution's effects differ for older populations, for men and women, or for those who work primarily outdoors?

So Zhang instructed his team to learn more about air pollution at the locations and times that the CFPS tests were administered. The survey fortuitously recorded the precise times and locations of the tests, which the researchers used to gather local air quality data for the testing period. Specifically, the team examined each location's air pollution index, a metric recorded by the Chinese Ministry of Ecology and Environment that accounts for levels of sulfur dioxide, nitrogen dioxide, and inhalable particulate matter smaller than 10 micrometers, such as smog, smoke, ash, and dust (see http://bit.ly/air-quality-index).

High Pollution, Low Scores

Several areas in China are hot spots of poor air quality as defined by the air pollution index. The country's northeastern coast from Shanghai to Beijing, in particular, has consistently been a source of unhealthily high pollution.

Most research into the cognitive impacts of air pollution "have focused on the U.S. or