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Worlds Beyond Earth: TRAPPIST-1

Seven Planets, One Star

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Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

TRAPPIST-1 (also known as 2MASS J23062928-0502285 or SPECULOOS-1) is a red dwarf star with seven known exoplanets. It lies in the constellation Aquarius approximately 40.66 light-years (12.47 pc) away from Earth. An ultra-cool dwarf, it has a surface temperature of about 2,566 K (2,290 degrees C; 4,160 degrees F). Its radius is slightly larger than Jupiter's and it has a mass of about 9% of the Sun. It is estimated to be 7.6 billion years old, making it older than the Solar System.

The discovery of the star was first published in 2000. Observations in 2016 from TRAPPIST-South (Transiting Planets and Planetesimals Small Telescope project) at La Silla Observatory in Chile and other telescopes led to the discovery of two terrestrial planets in orbit around TRAPPIST-1. In 2017, further analysis of the original observations identified five more terrestrial planets. The seven planets take between 1.5 and 19 days to orbit the star in circular orbits.

They are all likely tidally locked to TRAPPIST-1, and it is believed that each planet is in permanent day on one side and permanent night on the other. Their masses are comparable to that of Earth and they all lie in the same plane; seen from Earth, they pass in front of the star. This placement allowed the planets to be detected: when they pass in front of the star, its apparent magnitude dims.

Up to four of the planets - designated d, e, f, and g - orbit at distances where temperatures are likely suitable for the existence of liquid water, and are thus potentially hospitable to life. There is no evidence of an atmosphere on any of the planets, and observations of TRAPPIST-1b have in particular ruled out the existence of an atmosphere. It is unclear whether radiation emissions from TRAPPIST-1 would allow for such atmospheres. The planets have low densities; they may consist of large amounts of volatile material.

The credit for finding its planets belongs to Michael Gillon's group at Belgium's University of Liege, working with a small robotic telescope of the same name on a Chilean mountaintop. Their 2015 campaign caught the faint, rhythmic dimmings of the star, and the Nature paper that followed in May 2016 announced the first three worlds; a larger follow-up, led by the Spitzer Space Telescope, soon raised the count to seven. What began as a modest survey of the smallest, coolest stars had produced the largest known family of Earth-sized planets, and the chapters that follow trace how it was found, what it is, and why it matters.

Chapter 01: The Discovery of TRAPPIST-1

TRAPPIST-1 is named after TRAPPIST (the Transiting Planets and Planetesimals Small Telescope project), which discovered the first two exoplanets around the star. Its planetary system was discovered by a team led by Michael Gillon, a Belgian astronomer at the University of Liege, in 2016 during observations made at the La Silla Observatory, Chile, using the TRAPPIST telescope. The discovery was based on anomalies in the light curves measured by the telescope in 2015.

These were initially interpreted as indicating the existence of three planets. In 2016, separate discoveries revealed that the third planet was in fact multiple planets. The telescopes and observatories involved were the Spitzer Space Telescope and the ground-based TRAPPIST-South, TRAPPIST-North in

Oukaimeden Observatory, Morocco, the South African Astronomical Observatory, and the Liverpool Telescopes and William Herschel Telescopes in Spain. The observations of TRAPPIST-1 are considered among the most important research findings of the Spitzer Space Telescope.

Complementing the findings were observations by the Himalayan Chandra Telescope, the United Kingdom Infrared Telescope and the Very Large Telescope. Since then, research has confirmed the existence of at least seven planets in the system, the orbits of which have been calculated using measurements from the Spitzer and Kepler telescopes.

Some news reports incorrectly attributed the discovery of the TRAPPIST-1 planets to NASA alone; in fact the TRAPPIST project that led to their discovery received funding from both NASA and the European Research Council of the European Union (EU). TRAPPIST-1 is in the constellation Aquarius, five degrees south of the celestial equator. It is a relatively close star located 40.66+/-0.04 light-years from Earth, with a large proper motion and no companion stars.

It is a red dwarf of spectral class M8.0+/-0.5, meaning it is relatively small and cold. With a radius 12% of that of the Sun, TRAPPIST-1 is only slightly larger than the planet Jupiter (though much more massive). Its mass is approximately 9% of that of the Sun, being just sufficient to allow nuclear fusion to take place. TRAPPIST-1's density is unusually low for a red dwarf.

It has a low effective temperature of 2,566 K (2,293 degrees C) making it, as of 2022, the coldest-known star to host planets. TRAPPIST-1 is cold enough for condensates to form in its photosphere; these have been detected through the polarisation they induce in its radiation during transits of its planets. Elements heavier than helium form compounds in its atmosphere, which display as

absorption lines in TRAPPIST-1's spectrum. There is no evidence that it has a stellar cycle.

Its luminosity, emitted mostly as infrared radiation, is about 0.055% that of the Sun. Low-precision measurements from the XMM-Newton satellite and other facilities show that the star emits faint radiation at short wavelengths such as X-rays and UV radiation. There are no detectable radio wave emissions. Measurements of TRAPPIST-1's rotation have yielded a period of 3.3 days; earlier measurements of 1.4 days appear to have been caused by changes in the distribution of its starspots.

Its rotational axis may be slightly offset from that of its planets. Using a combination of techniques including composition and movements of the star, the age of TRAPPIST-1 has been estimated at about 7.6+/-2.2 billion years, making it older than the Solar System, which is about 4.5 billion years old.

It is expected to shine for ten trillion years - an interval some seven hundred times the current age of everything that exists - whereas the Sun will run out of hydrogen and leave the main sequence in a few billion years. Photospheric features have been detected on TRAPPIST-1 and probably make up a substantial part of the stellar surface. James Webb Space Telescope (JWST) observations indicate that cold starspots might cover up to one quarter of its photosphere.

The Kepler and Spitzer Space Telescopes have observed possible bright spots, which may be faculae, although some of these may be too large to qualify as such. Bright spots are correlated to the occurrence of some stellar flares.

Kepler K2 observations have shown that TRAPPIST-1 produces frequent flares (42 flares in 80 days), including large, complex flares that could alter nearby planetary atmospheres irreversibly and significantly, raising doubts of hosting life as we know it on Earth. The star has a strong magnetic field with a mean intensity of about 600 gauss which may be an underestimate. The magnetic field drives high chromospheric activity, and may be capable of trapping coronal mass ejections. According to Garraffo et al.

Dong et al. Simulations to estimate mass loss are complicated because, as of 2019, most of the parameters that govern TRAPPIST-1's stellar wind are not known from direct observation.

TRAPPIST-1 is orbited by seven planets, designated TRAPPIST-1b, 1c, 1d, 1e, 1f, 1g and 1h in alphabetic order going out from the star. These planets have orbital periods ranging from 1.5 to 19 days, at distances of 0.011-0.059 astronomical units (1.7-8.9 million km). All the planets are much closer to their star than Mercury is to the Sun, with the distance between TRAPPIST-1b and 1c

at syzygy being only twice that between the Earth and Moon, making the TRAPPIST-1 system very compact. Kral et al.

Due to the possibility of several of the planets being habitable, the system has drawn interest from researchers and has appeared in popular culture. The star known as TRAPPIST-1 was discovered in 1999 by astronomer John Gizis and colleagues during a survey of close-by ultra-cool dwarf stars. It appeared in sample C of the surveyed stars, which was obtained in June 1999. Publication of the discovery took place in 2000.

The star's name honors the TRAPPIST project, whose small telescopes bagged the first two planets found around it.

Observations with the Atacama Large Millimeter Array found no evidence of a circumstellar dust disk. The inclinations of planetary orbits relative to each other are less than 0.1 degrees, making TRAPPIST-1 the flattest planetary system in the NASA Exoplanet Archive.

The orbits are highly circular, with minimal eccentricities and are well aligned with the spin axis of TRAPPIST-1. The planets orbit in the same plane and, from the perspective of the Solar System, transit TRAPPIST-1 during their orbit and frequently pass in front of each other. The radii of the planets are estimated to range between 77.5+1.4-1.4% and 112.9+1.5-1.3% of Earth's radius. The planet/star mass ratio of the TRAPPIST-1 system resembles that of the moon/planet ratio of the Solar System's gas giants.

The TRAPPIST-1 planets are expected to have compositions that resemble each other as well as that of Earth.

The estimated densities of the planets are lower than Earth's which may imply that they have large amounts of volatile chemicals. Alternatively, their cores may be smaller than that of Earth and therefore they may be rocky planets with less iron than that of Earth, include large amounts of elements other than iron, or their iron may exist in an oxidised form rather than as a core.

Their densities are too low for a pure magnesium silicate composition, requiring the presence of lower-density compounds such as water. Planets b, d, f, g and h are expected to contain large quantities of volatile chemicals. The planets may have deep atmospheres and oceans, and contain vast amounts of ice. Subsurface oceans, buried under icy shells, would form in the colder planets. Several compositions are possible considering the large uncertainties in their densities.

The photospheric features of the star may introduce inaccuracies in measurements of the properties of TRAPPIST-1's planets, including their

densities being underestimated by 8+20 -7 per cent, and incorrect estimates of their water content. The planets are in orbital resonances. The durations of their orbits have ratios of 8:5, 5:3, 3:2, 3:2, 4:3 and 3:2 between neighbouring planet pairs, and each set of three is in a Laplace resonance.

Simulations have shown such resonances can remain stable over billions of years but that their stability is strongly dependent on initial conditions. Many configurations become unstable after less than a million years. The resonances enhance the exchange of angular momentum between the planets, resulting in measurable variations - earlier or later - in their transit times in front of TRAPPIST-1. These variations yield information on the planetary system, such as the masses of the planets, when other techniques are not available.

The resonances and the proximity to the host star have led to comparisons between the TRAPPIST-1 system and the Galilean moons of Jupiter. Kepler-223 is another exoplanet system with a TRAPPIST-1-like long resonance. The closeness of the planets to TRAPPIST-1 results in tidal interactions stronger than those on Earth. Models suggest all the planets may have reached an equilibrium with slow planetary rotations and tidal locking, which can lead to the synchronisation of a planet's rotation to its revolution around its star.

However, interactions among the planets could prevent them from reaching full synchronisation, which would have important implications for the planets' climates. These interactions could force periodic or episodic full rotations of the planets' surfaces with respect to the star on timescales of several Earth years. Vinson, Tamayo and Hansen (2019) found the planets TRAPPIST-1d, e and f likely have chaotic rotations due to mutual interactions, preventing them from becoming synchronised to their star. Lack of synchronisation potentially makes the planets more habitable.

Other processes that can prevent synchronous rotation are torques induced by stable triaxial deformation of the planets, which would allow them to enter 3:2 resonances. The planets are likely to undergo substantial tidal heating due to deformations arising from their orbital eccentricities and gravitational interactions with one another. Such heating would facilitate volcanism and degassing especially on the innermost planets, with degassing facilitating the establishment of atmospheres. According to Luger et al.

For the outer planets Quick et al. On the other hand, Thomas et al.

Tidal heating could influence temperatures of the night sides and cold areas where volatiles may be trapped, and gases are expected to accumulate; it would also influence the properties of any subsurface oceans where cryovolcanism, volcanism and hydrothermal venting could occur. It may

further be sufficient to melt the mantles of the four innermost planets, in whole or in part, potentially forming subsurface magma oceans.

This heat source is likely dominant over radioactive decay, both of which have substantial uncertainties and are considerably less than the stellar radiation received. Intense tides could fracture the planets' crusts even if they are not sufficiently strong to trigger the onset of plate tectonics. Tides can also occur in the planetary atmospheres.

Ignoring atmospheric effects, illumination would be orange-red. For TRAPPIST-1e, the central star would be four times as wide in the sky as the Sun in Earth's.

All of the planets would be visible from each other and would, in many cases, appear larger than Earth's Moon in the sky of Earth, and each would be recognisable as a planet rather than a star. They would undergo noticeable retrograde motions in the sky. Observers on TRAPPIST-1e, f and g, however, could never experience a total stellar eclipse.

Assuming the existence of atmospheres, the star's long-wavelength radiation would be absorbed to a greater degree by water and carbon dioxide than sunlight on Earth; it would also be scattered less by the atmosphere and less reflected by ice, although the development of highly reflective hydrohalite ice may negate this effect.

The same amount of radiation results in a warmer planet compared to Sun-like irradiation; more radiation would be absorbed by the planets' upper atmosphere than by the lower layers, making the atmosphere more stable and less prone to convection. For a dim star like TRAPPIST-1, the habitable zone is located closer to the star than for the Sun. Three or four planets might be located in the habitable zone; these include e, f and g; or d, e and f.

As of 2017, this is the largest-known number of planets within the habitable zone of any known star or star system. The presence of liquid water on any of the planets depends on several other factors, such as albedo (reflectivity), the presence of an atmosphere, and any greenhouse effect. Surface conditions are difficult to constrain without better knowledge of the planets' atmospheres.

A synchronously rotating planet might not entirely freeze over if it receives too little radiation from its star because the day-side could be sufficiently heated to halt the progress of glaciation. Other factors for the occurrence of liquid water include the presence of oceans and vegetation; the reflective properties of the land surface; the configuration of continents and oceans; the presence of clouds; and sea ice dynamics. The effects of volcanic activity may extend the system's habitable zone to TRAPPIST-1h.

But there's a new third planet, which has taken the d moniker, and what had looked like d before turned out to be glimpses of e, f, and g.

TRAPPIST-1f, probably rocky and fourth from the star, rides the habitable zone of this ultracool dwarf 40.7 light-years from Earth in Aquarius.

The Transiting Planets and Planetesimals Small Telescope (TRAPPIST) is the corporate name for a pair of Belgian optic robotic telescopes.

The planet was detected using the transit method, where a planet dims the host star's light as it passes in front of it. It was first announced on May 2, 2016, and later studies were able to refine its physical parameters. The planet is about 37% more massive than Earth and about 39% larger in volume; thus its density is very similar.

It is the innermost of seven planets orbiting TRAPPIST-1, all of which are terrestrial, but is too close to its star to be in the habitable zone. Observations by the James Webb Space Telescope announced between 2023 and 2024 suggest that it is either airless or has a hazy CO2-rich atmosphere. Its albedo is very low, making it dark in color. TRAPPIST-1b is very similar in both mass, radius, and gravity to Earth.

End of free sample. The full book is available at putrabooks.github.io

ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.