SAMPLE

Worlds Beyond Earth: Interstellar Objects

Visitors from Other Star Systems

Aira Astralis

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Conclusion

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

Introduction

An interstellar object is an astronomical object in interstellar space, not gravitationally bound to a star. The term is used for objects including some asteroids, some comets, and rogue planets, but not stars or stellar remnants. The interstellar objects were likely once bound to a host star and have become unbound since. Different processes can cause planets and smaller objects (planetesimals) to become unbound from their host star.

This term is also applied to an object that is on an interstellar trajectory but is temporarily passing close to a star, such as some asteroids and comets (that is, exoasteroids and exocomets). In this case the object may be called an interstellar interloper. Objects observed within the solar system are identified as interstellar interlopers due to possessing significant hyperbolic excess velocity, indicating they did not originate in the solar system.

The first interstellar objects discovered were rogue planets, ejected from their original stellar system (e.g., OTS 44 or Cha 110913-773444), though they are difficult to distinguish from sub-brown dwarfs, planet-mass objects that formed in interstellar space as stars do. As of 2025, three interstellar objects have been discovered traveling through the Solar System: 1I/Oumuamua in 2017, 2I/Borisov in 2019, and 3I/ATLAS in 2025. The prefix "1I" identifies the object as the first confirmed interstellar interloper, "2I" as the second, and so on.

There has been speculation that interstellar interlopers observed in the Solar System are extraterrestrial spacecraft, but there is currently no evidence for such claims to be plausible. Material from the Beta Pictoris debris disk is thought to be the dominant source of interstellar micrometeoroids in the Solar System. With the first discovery of an interstellar object in the Solar System, the IAU has proposed a new series of small-body designations for interstellar interlopers, the I numbers, similar to the comet numbering system.

The Minor Planet Center will assign the numbers. Provisional designations for interstellar objects will be handled using the C/ or A/ prefix (comet or asteroid), as appropriate. Astronomers estimate that several interstellar objects of extrasolar origin (like Oumuamua) pass inside the orbit of Earth each year, and that 10,000 are passing inside the orbit of Neptune on any given day.

Interstellar comets occasionally pass through the inner Solar System and approach with random velocities, mostly from the direction of the constellation Hercules because the Solar System is moving in that direction, called the solar apex. Until the discovery of Oumuamua, the fact that no comet with a speed greater than the Sun's escape velocity had been observed was used to place upper limits to their density in interstellar space.

A 1986 paper by Torbett indicated that the density was no more than 1013 (10 trillion) comets per cubic parsec. Other analyses, of data from LINEAR, set the upper limit at 4.5x10-4/AU3, or 1012 (1 trillion) comets per cubic parsec. A 2017 estimate by David C.

Both inbound and outbound, the object has an interstellar velocity (

A tail pointing away from the Sun is a common cometary feature that is formed when small dust particles are blown away by solar radiation pressure. The broad appearance of this tail suggests that small dust particles were ejected from 3I/ATLAS's surface at high speeds.

The estimated dust loss rate of 3I/ATLAS suggests that its nucleus is likely less than a kilometer in diameter, like 2I/Borisov. Observations by various interplanetary spacecraft have shown that 3I/ATLAS experienced significant non-gravitational acceleration that peaked up to (89.3+/-4.6)x10-9 AU/day2 one month before perihelion. If this non-gravitational acceleration is purely caused by outgassing, it would suggest that 3I/ATLAS's nucleus has a mass of roughly 4.4x1010 kg.

Another study published by Toni Santana-Ros and colleagues in August 2025 reported a similar (albeit shorter) rotation period of 16.16+/-0.01 hours, using observations by multiple different telescopes from 2 to 29 July. Santana-Ros and colleagues noted that the brightness variations of 3I/ATLAS had decreased from 0.3 to 0.2 magnitudes throughout July 2025, which likely indicates that 3I/ATLAS's nucleus became more obscured as it became more active.

It has a hyperbolic excess velocity (velocity at infinity,

Chapter 01: The Discovery of Interstellar Objects

Comets born around other stars drift through the inner Solar System from time to time, arriving on random paths that cluster toward Hercules, the patch of sky our system is traveling toward, a point called the solar apex. A 1986 calculation by Torbett capped the number at ten trillion comets per cubic parsec at most. LINEAR survey data later tightened that ceiling to a trillion comets per cubic parsec, an order of magnitude lower.

A 2017 estimate by David C. Jewitt and colleagues, following the detection of Oumuamua, predicts that "The steady-state population of similar, ~100 m scale interstellar objects inside the orbit of Neptune is ~1x104, each with a residence time of ~10 years." Current models of Oort cloud formation predict that more comets are ejected into interstellar space than are retained in the Oort cloud, with estimates varying from 3 to 100 times as many. Other simulations suggest that 90-99% of comets are ejected.

There is no reason to believe comets formed in other star systems would not be similarly scattered. Amir Siraj and Avi Loeb demonstrated that the Oort Cloud could have been formed from ejected planetesimals from other stars in the Sun's birth cluster. Both researchers proposed a search for Oumuamua-like objects which are trapped in the Solar System as a result of losing orbital energy through a close encounter with Jupiter.

It is possible for objects orbiting a star to be ejected due to interaction with a third massive body, thereby becoming interstellar objects. Such a process was initiated in the early 1980s when C/1980 E1, initially gravitationally bound to the Sun, passed near Jupiter and was accelerated sufficiently to reach escape velocity from the Solar System. This changed its orbit from elliptical to hyperbolic and made it the most eccentric known object at the time, with an eccentricity of 1.057.

It is heading for interstellar space.Due to present observational difficulties, an interstellar object can usually only be detected if it passes through the Solar System, where it can be distinguished by its strongly hyperbolic trajectory and hyperbolic excess velocity of more than a few km/s, proving that it is not gravitationally bound to the Sun. In contrast, gravitationally bound objects follow elliptic orbits around the Sun.

Computer simulations show that Jupiter is the only planet massive enough to capture one, and that this can be expected to occur once every sixty million years. Comets Machholz 1 and Hyakutake C/1996 B2 are possible examples of

such comets.

They have atypical chemical makeups for comets in the Solar System. Research published in 2018 suggests that asteroid 514107 Kaepaokaawela may be a former interstellar object, captured some 4.5 billion years ago, as evidenced by its co-orbital motion with Jupiter and its retrograde orbit around the Sun. In addition, comet C/2018 V1 (Machholz-Fujikawa-Iwamoto) has a significant probability (72.6%) of having an extrasolar provenance although an origin in the Oort cloud cannot be excluded.

Harvard astronomers suggest that matter, and potentially dormant spores, can be exchanged across vast distances. The detection of Oumuamua crossing the inner Solar System confirms the possibility of a material link with exoplanetary systems. Interstellar visitors in the Solar System cover the whole range of sizes - from kilometer large objects down to submicron particles. Also, interstellar dust and meteoroids carry with them valuable information from their parent systems. Detection of these objects along the continuum of sizes is, however, not evident (see Figure).

The smallest interstellar dust particles are filtered out of the Solar System by electromagnetic forces, while the largest ones are too sparse to obtain good statistics from in situ spacecraft detectors. Discrimination between interstellar and interplanetary populations can be a challenge for intermediate (0.1-1 micrometer) sizes. These can vary widely in velocity and directionality. The identification of interstellar meteoroids, observed in the Earth's atmosphere as meteors, is highly challenging and requires high accuracy measurements and appropriate error examinations.

Otherwise, measurement errors can transfer near-parabolic orbits over the parabolic limit and create an artificial population of hyperbolic particles, often interpreted as of interstellar origin. Large interstellar visitors like asteroids and comets were detected the first time in the solar system in 2017 (1I/ Oumuamua) and 2019 (2I/Borisov) and are expected to be detected more frequently with new telescopes, e.g. Amir Siraj and Avi Loeb have predicted that the Vera C.

Rubin Observatory will be capable of detecting an anisotropy in the distribution of interstellar objects due to the Sun's motion relative to the Local Standard of Rest and identify the characteristic ejection speed of interstellar objects from their parent stars. In May 2023, astronomers reported the possible capture of other interstellar objects in Near Earth Orbit (NEO) over the years. A dim object was discovered on 19 October 2017, by the Pan-STARRS telescope, at an apparent magnitude of 20.

Mainstream Oort cloud models suggest that interstellar space holds three to a hundred times more ejected comets than the cloud itself ever kept.

An interstellar comet can probably, on rare occasions, be captured into a heliocentric orbit while passing through the Solar System.

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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.