# A Robotic Mission to Uranus Could Drive a Breakthrough in Extrasolar Planetary Studies

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## Abstract

The study of extrasolar planets is a young and growing field that has caught the attention of many astronomers and space scientists. The existence of other worlds many light years away in deep space is almost impossible to fathom. As technology advances, scientists are gaining the ability to locate and study these extrasolar planets in remarkable depth. Many of the extrasolar planets that scientists have discovered have proven to be of similar mass and density to the ice giants: Uranus and Neptune (Vision and Voyages 18). Unlike Jupiter and Saturn who have been studied by many spacecraft, these ice giants have only been studied by one spacecraft: Voyager 2. The ice giants are due for a revisit and a mission to Uranus presents as potentially more effective than a mission to Neptune. By studying Uranus in closer depth with advanced technology, astronomers can gain a better understanding of the characteristics of many of the extrasolar planets that have been discovered. Some of the instruments and methods used on the Jupiter and Saturn missions could inspire which instruments would prove most beneficial on a mission to Uranus. While the spacecraft is near the outer solar system, the instruments used on a mission to Uranus could also be used to study Uranus' rings and moons via a flyby mission. Astronomers have yet to fully understand the characteristics of the gaseous extrasolar planets that have been discovered, but studying Uranus could provide clarity regarding these distant, yet familiar bodies.

## Why Uranus?

Uranus is one of two ice giants which reside near the edge of the solar system, seldom explored by modern spacecraft. Voyager 2 was launched in 1977 and it remains as the only spacecraft that has observed Uranus up close (Stone and Miner 39). Voyager 2 has proven itself to be a highly successful mission, flying by Jupiter, Saturn, Uranus, and Neptune (Stone and Miner 39). While recognizing the success of Voyager 2, it is also important to note that this spacecraft was launched in the late 20th century which means that the technology aboard Voyager 2 that was used to study Uranus is only as good as it was in the late 20th century. The rings, atmosphere, and moons of Uranus have yet to be studied by the advanced telescopes that we are capable of launching today. While Uranus itself would be the primary focus of such a mission, the rings and moons of the planet could provide additional information. Additionally, Voyager 2 performed a flyby past Uranus meaning there is no chance of using Voyager 2 to recommence Uranian studies; Voyager 2 continues to traverse through interstellar space. Before leaving the solar system, Voyager 2 provided scientists with useful information about Uranus that has remained relevant since.

In regards to studying extrasolar planets, one of the primary steps to understanding their characteristics is by understanding their atmospheres. While we cannot yet directly study their atmospheres, “the Kepler mission and microlensing surveys have shown that many exoplanets are ice-giant size” which could imply that they have similar atmospheric compositions as the ice giants in our solar system (Vision and Voyages 271). There have also been discoveries of extrasolar planets called Super-Earths. Super-Earths are planets that are more massive than Earth, but less massive than the ice giants and seem to have ice-rock compositions (Vision and

Voyages 78). Hundreds of extrasolar planets have been discovered and many of these planets have been discovered via the Transiting Exoplanet Survey Satellite (TESS) (Ricker et al. qtd. in Kabath et al. 5956). Launched in 2018, the primary goal of the TESS mission is “to find planets with long orbital periods and low irradiation fluxes” using the transit method (Dalba et al. 2). With that being known, the next step is to discover whether these distant planets are composed of the same elements as Uranus. Modern technology is yet capable of informing scientists about the atmospheric compositions of distant extrasolar planets but considering their resemblance to Uranus, it is safe to assume that by studying Uranus’ atmosphere, scientists could potentially gain insight into the characteristics of composition of extrasolar ice giants. The studies that Voyager 2 conducted via radio astronomy and infrared spectroscopy revealed “estimates of the vertical temperature structure, the hydrogen-helium ratio, and the methane abundance” (Smith et al. 45). These estimates provide the best assumptions to date for what the compositions and characteristics of Uranian-like extrasolar planets may entail. A mission to Uranus would be highly demanding and NASA scientists have begun mapping out what such a mission would possibly look like.

A mission to Uranus would be an expensive, challenging, and yet rewarding project that would require years of planning. As of today, a manned mission to Uranus would prove to be overly complicated and impractical for the amount of technology and knowledge that scientists possess today; humans have yet to make it to Mars. A robotic mission to Uranus would be more practical for what NASA and other space organizations are capable of today. NASA scientists have already begun organizing the aspects that a mission to Uranus would consist of. In the 2013-2022 Decadal Survey for Planetary Science, a flagship orbiter and probe mission to Uranus ranked third on the priority list (Vision and Voyages 18). Extrasolar planetary studies are currently near the top of NASA's priority list and a mission to Uranus will more than likely act as a catalyst to fuel those studies. The ice giants "serve as laboratories to understand [...] extrasolar planetary systems" and by understanding more about their history and characteristics, scientists can make more informed inferences about the history and characteristics of extrasolar planets (Vision and Voyages 11). While extrasolar planets continue to be discovered, the Uranus orbiter and probe mission may not happen until next decade. The most crucial projects to NASA scientists involve searching for ancient life and/or liquid water on the planets and moons in our solar system (Vision and Voyages 16, 17). Regardless, the data gathered from the prospective Uranus orbiter and probe mission have the potential to open many doors in extrasolar planet studies. Fortunately, NASA scientists have ample experience in studying the Jovian planets in our solar system using spacecraft; that experience will be useful in planning a mission to Uranus.

## Past Missions to the Jovian Planets

Scientists often refer to the two classes of planets as the terrestrial planets and the gas giants or Jovian planets. Jovian translates to "Jupiter-like" which typically refers specifically to Jupiter and Saturn; Uranus and Neptune are in a sub category called the ice giants. While commonly grouped into the same category, the Jovian planets are different from the ice giants. The ice giants reside near the outer edge of the solar system; they are colder than the Jovian planets and they are made up of heavier materials such as hydrogen, helium, and methane (Smith et al. 45). Scientists have experience in studying the Jovian planets up close by sending out spacecraft to flyby or orbit them. Unfortunately, the ice giants have not had nearly as many spacecraft travel out to them. Luckily, the gas giants are all primarily made up of dense, gaseous atmospheres. Similar equipment and techniques used to study the Jovian planets could be used to better study the ice giants, specifically Uranus. With the possession of previous knowledge about missions to the Jovian planets, scientists could build off of the knowledge to formulate a mission to Uranus without starting from scratch.

The Voyager missions 1 and 2 are two of the most well known space missions; they worked together to gather the most in depth information possible. Launched in the late 1970s, Voyager 1 and Voyager 2 possessed similar equipment. Specifically while studying Jupiter, anything that Voyager 1 found to be deemed scientifically interesting, such as hot spots on Jupiter, Voyager 2 would come behind and flyby to do more in depth research on it (Terrile 995). Voyager 2 was used to study planetary features more intensely because its equipment was higher quality than that of Voyager 1; its vidicons were 50 percent more sensitive than those on Voyager 1 (Bradford Smith 505). Both hot spots and bright areas were identified on Jupiter using an infrared interferometer spectrometer (IRIS) (Terrile 996). Voyager 2 also studied Saturn via a flyby. While Voyage 2 did not orbit Saturn, it was still able to capture useful information about the structure of Saturn. Using the data and images collected by Voyager 2, scientists were able to determine cloud structure, cloud depth, wind velocities, and latitudinal spacings of the zonal jets on Saturn (Bradford Smith 505). These characteristics aid scientists in understanding how the atmosphere of Saturn operates and what physics and chemistry is responsible for it. While flying by Saturn, Voyager 2 spent some time observing and gathering data about Saturn's largest moon, Titan (Lebreton et al. 758). Voyager 2 could not see the surface of Titan through Titan's thick atmosphere but Voyager 2 did reveal a rich organic chemistry on Titan and confirm that methane was the second most abundant gas in Titan's atmosphere (Lebreton et al. 758). The technology used on Voyager 2 to study Titan could also be used to study Uranus. Uranus has a much thicker atmosphere than Titan, but the equipment may prove beneficial.

Cassini is one of the more recent missions designed to observe the Jovian planets. Cassini was a flyby mission that studied Jupiter. Cassini used various filters such as near-IR continuum, methane band, and ultraviolet to take images of Jupiter; each filter provides a different set of data (Barbara et al. 1). Through these images, Cassini collected data that gave scientists the insight necessary to “derive zonal wind profiles from the middle troposphere cloud tops to the lower stratosphere” of Jupiter (Barbara et al. 1). Cassini was also used to understand the nature of the gas and particles present in Jupiter's atmosphere by investigating their photometric properties (Barbara et al. 2). Even as a flyby mission, Cassini was capable of obtaining a large amount of scientific information about Jupiter’s atmosphere. Considering that the components of the Jovian planets are majority gas, gaining information about Jupiter’s atmosphere is likely the most useful form of data that Cassini could have obtained.

Saturn is the second of the Jovian planets and Cassini spent some time orbiting Saturn to collect data about it. The same camera filters that Cassini used to study Jupiter were also used to study Saturn; these filters range from near-IR to ultraviolet (Porco et al. 1243). Also similar to Jupiter, these cameras proved useful in studying “clouds and hazes at various altitudes and for monitoring winds, vortices, and evolving cloud structures” on Saturn (Porco et al. 1243). Cassini could inform scientists about what layers lie within Saturn’s atmosphere and how they differ from one another, whether that is in composition, movement patterns, density, temperature, etc. By making use of Cassini’s near-IR filter, scientists were able to analyze the temperature changes within Saturn's atmosphere which showed “an increase in temperature toward the south pole, which implies that the zonal winds decay with height” (Porco et al. 1245). Cassini was capable of determining a substantial amount of information about Saturn's atmosphere without use of a probe. Cassini did utilize a probe (the Huygens probe), but it was used to study Saturn's largest moon Titan (Lebreton et al. 758). The Huygens probe had many objectives in regards to studying Titan including determining atmospheric composition, studying aerosol properties and cloud physics, measuring winds and global temperatures, and investigating the upper atmosphere and ionosphere (Lebreton et al. 758). Similar objectives could be set in terms of studying other bodies in our solar system, specifically Uranus. Throughout their duration, Cassini and Huygens both significantly studied the atmospheres of Saturn and Titan which provided insight into the characteristics of those bodies and how to obtain information about them.

Juno is arguably the most famous spacecraft to have visited Jupiter. One area of study that Juno focused on was the cloud structure of Jupiter. Jupiter and the other Jovian planets are almost entirely composed of gaseous materials which essentially act as an extremely large and dense atmosphere. By gaining a stronger understanding of the characteristics of Jupiter's atmosphere, scientists will understand a large amount of what Jupiter has to offer. One significant piece of work done by Juno is that the gravitational measurements confirmed that "the cloud-level structure extends into Jupiter's interior" as opposed to the cloud-level structure being confined to Jupiter's surface (Kong et al. 8499). This newfound information implies that the layers of Jupiter's atmosphere that we see on the outside are the same as the inside. Without the use of a probe, Juno was able to determine the potential structure of Jupiter's interior. Some of Juno's gravitational measurements also support the shallow-layer concept which predicts Jupiter's wind patterns to go no deeper than the surface (Kong et al. 8500). With Juno's technology, it was difficult to tell a difference between whether Jupiter's cloud layers and patterns resided deeper than the surface level; figuring out the mystery will give scientists insight into the origins of Jupiter’s clouds and winds (Kong et al. 8503). The origins of Jupiter’s atmosphere will be different from those of Uranus but, with some precision upgrades, the same technology used on Juno to study Jupiter’s interior could potentially be used to study the interior of Uranus.

## Payload of Uranus Orbiter and Probe

The scientific equipment aboard a spacecraft on a mission to Uranus would be one of the most crucial aspects of the journey. There are various types of equipment that serve specific functions to aid in these types of missions. For example, some equipment are designed to physically get the spacecraft to its destination while some are designed to perform experiments and collect data while the spacecraft is at its destination. In this case, the equipment that would be used to study Uranus is the focus. A mission to Uranus would be extensive and expensive, so it would be important to collect the most important information while the spacecraft is out near the edge of the solar system; it would not be practical to launch another mission if scientists forgot to collect certain necessary data. The focus is not on the engineering aspect of the spacecraft; assume all of the important equipment could be launched aboard the spacecraft regardless of its mass. Studying Uranus closely with an orbiter, probe, and various types of equipment will inform scientists about the origins and structure of Uranus. Specifically, the Uranus Orbiter with Solar‑Electric Propulsion and Probe is the assumed spacecraft in this case (Vision and Voyages 350). The data could potentially lead to a better understanding of the origins and structures of extrasolar planets that show similarities to the ice giants.

Uranus has a lot of research opportunities for astronomers, but not all of them can be listed as a top priority. In the 2013-2022 Decadal Survey for Planetary Science, NASA astronomers ranked the research opportunities that arise from a mission to Uranus by descending importance. The top five objectives are as follows: “1) Determine the atmospheric zonal winds, composition, and structure at high spatial resolution, as well as the temporal evolution of atmospheric dynamics; 2) Understand the basic structure of the planet’s magnetosphere as well as the high-order structure and temporal evolution of the planet’s interior dynamo; 3) Determine the noble gas abundances (helium, neon, argon, krypton, and xenon) and isotopic ratios of hydrogen, carbon, nitrogen, and oxygen in the planet’s atmosphere and the atmospheric structure at the probe descent location; 4) Determine internal mass distribution; 5) Determine the horizontal distribution of atmospheric thermal emission, as well as the upper-atmospheric thermal structure and changes with time and location at low resolution” (Vision and Voyages 206, 207). With the intent of learning more about the origins and characteristics of extrasolar planets, it is safe to assume that these objectives for studying Uranus are ranked by which ones will provide the most insight into understanding the features of extrasolar planets that resemble the ice giants.

The objective that is listed first in the 2013-2022 Decadal Survey for Planetary Science for studying Uranus is stated to be the top priority. In this case, the top priority is to “determine the atmospheric zonal winds, composition, and structure at high spatial resolution, as well as the temporal evolution of atmospheric dynamics” (Vision and Voyages 206). The most effective way to study these characteristics would be to send a probe down through Uranus’ atmosphere (Vision and Voyages 181). By using an entry probe, scientists could study Uranus’ atmosphere directly as opposed to a flyby which would likely not be as effective. Via the use of an entry probe, scientists could “determine the composition, cloud structures, and winds as a function of depth and location” on Uranus (Vision and Voyages 181). The Uranus entry probe would require multiple measurement tools to effectively collect data on each of the specific characteristics of Uranus’ structure. According to the 2013-2022 Decadal Survey for Planetary Science, NASA scientists predict the payload of the Uranus entry probe to consist of a mass spectrometer, an atmospheric structure instrument, a nephelometer, and an ultra‑stable oscillator (350). These instruments would work collectively to gather data on Uranus’ interior up until the intense pressure destroys the probe; the atmospheric pressure increases with depth. The Uranus entry probe would be destroyed relatively quickly, but it is suspected to provide scientists with a large amount of useful information about the structure of Uranus’ atmosphere.

While the Uranus entry probe would play a significant role in data collection, the Uranus orbiter would possess its own set of objectives as well. In comparison to the Uranus entry probe, the Uranus orbiter would have a significantly longer life time. While the entry probe will likely be quickly destroyed by Uranus’ atmospheric pressure, the orbiter would continue to orbit around Uranus for 15.4 years (Vision and Voyages 350). During its many years orbiting around Uranus, the orbiter will be collecting data. The orbiter will be able to gather detailed information on Uranus’ characteristics because unlike the entry probe, the orbiter will be able to study the same characteristics multiple times as it continues to orbit. Statistically, the collected data would become more accurate the more times it is collected. The payload of the Uranus orbiter is predicted to consist of a wide‑ and narrow‑angle imagers, visible/near‑infrared mapping spectrometer, ultraviolet imaging spectrograph, mid‑infrared thermal detector, plasma instruments (2), magnetometer, ultra‑stable oscillator (Vision and Voyages 350). These instruments would be equipped to collect data from a distance; the orbiter would be close enough to gather accurate data while not descending through Uranus' atmosphere like the entry probe. The orbiter would "provide remote sensing of the cloud deck in infrared and visible light, as well as detailed gravitational measurements to constrain the interior structure" of Uranus (Vision and Voyages 198). These observations would contribute to satisfying the top priority objects of an orbiter and probe mission to Uranus. Along with measurement equipment, the Uranus orbiter would also be responsible for transporting the entry probe to Uranus and releasing it into the atmosphere (Vision and Voyages 198). Once the probe is delivered into Uranus' atmosphere, the orbiter will continue to orbit Uranus for many years collecting data on the planetary body itself, Uranus' rings, and its moons.

## Studying Uranus' Rings and Moons

The Uranian system has more to offer than just the planetary body; Uranus' has thin rings that have yet to be studied in depth. Uranus's primary rings are labeled as 6, 5, 4, α, β, η, γ , δ, and ∈ (Showalter 5). Uranus' rings are not as grand as Saturn's; the largest and most prominent of Uranus' rings is ring ∈, with a radial width varying between 20 kilometers and 96 kilometers and optical depths up to around 5 (Showalter 5). The other eight rings have radial widths varying from 1 kilometer to 10 kilometers and typical optical depths around 0.2 to 0.8 (Showalter 5). The size difference between ring ∈ and the other eight rings would make ring ∈ an easier target for study by default. By studying Uranus' rings, scientists can gain a better understanding of what the accretion process that formed the rings looked like. Uranus' rings also possess interesting characteristics in regards to their structure and form.

If a mission to Uranus' were to be launched, Uranus' rings would be worth studying with a spacecraft because of their unique characteristics. One of the interesting aspects about Uranus' rings is regarding the spacing between each ring. Each ring is suspected to maintain its narrow size and sharp edges via the newly proposed shepherding mechanism (Showalter 5). The shepherding mechanism creates sharp edges between Uranus' rings due to a torque balance from a nearby moon (Showalter 5). Uranus' rings would prove to be an interesting subject of study because in order for the shepherding mechanism to take place, the torque balance between the rings and the moons has to be quite precise. It is likely that factors such as the masses of the moons and the distances between the moons and the rings play into the torque balance. Assuming those factors are in fact necessary, scientists could potentially use that information to estimate where any undiscovered rings may reside. On that same note, Voyager 2 captured a singular image of an unusual ring around Uranus that is fainter and wider than the other rings; this ring is called ζ (Showalter 6). The features of ring ζ is an area of study that could inform scientists about the evolution of planetary rings and their compositions. Another interesting feature of Uranus' rings is that they have non-zero eccentricities; ring ∈ has the largest eccentricity of approximately 0.008, resulting in a difference of 800 kilometers between its pocentre and pericentre distances (Showalter 5). Seven of the other rings have eccentricities of approximately 0.001, except for ring η which is circular (Showalter 5). An orbiter spacecraft around Uranus would provide an opportunity for Uranus' rings to be studied up close for a long duration, resulting in ample data collection.

In addition to thin rings, the Uranian system is also composed of many satellites or moons residing within the rings. Uranus has 18 inner satellites, most of which were discovered by the Voyager 2 flyby (Showalter 2). A mission to Uranus would be extremely expensive and it would take years of planning. With that, it would be necessary for a mission to Uranus to be as efficient as possible. In addition to studying Uranus itself, the spacecraft would have the opportunity to study Uranus' moons in more detail. One of the interesting qualities about Uranus' moons is that the orbits of Uranus' moons are unstable and catastrophic collisions are expected to happen within the next $10^6$ years (Showalter 4). Sending a spacecraft out to study these moons up close would allow scientists to better understand the gravitational interactions between the moons in the Uranian system and observe their orbital patterns and history. Some scientists believe that orbital migration may have played a role in the positions and orbital patterns of Uranus' moons (Showalter 4). With the use of an orbiter spacecraft, scientists would have the opportunity to study Uranus' inner moons up close and Uranus' outer moons at the closest distance since Voyage 2.

While each of Uranus' moons are unique, one of Uranus' largest moons, Miranda, appears to have a particularly fascinating history. Miranda's unique geological structure implies that it may have a history of significant internal tectonic activity (Avramchuk et al. 187). Miranda is heavily cratered, as are Uranus' other moons, but Miranda's cratered surface possesses "long deep canyons" that cross through them (Avramchuk et al. 187). Between these features are large, crater-free flat regions that are described to resemble plowed fields; they are called coronas (Avramchuk et al. 187). According to the law of superposition, the canyons and coronas are both younger than Miranda's cratered surface i.e. Miranda's surface was cratered before the canyons formed (Kravitz 692). Knowing this, planetary geologists could make inferences about how old Miranda is and when each prominent geological feature formed. Scientists have only been able to study Miranda's surface briefly using Voyager 2 (Avramchuk et al. 187). Modern spacecraft technology could surface new discoveries regarding Miranda's rock formations and why there is an apparent discontinuity in the ages and features. The leading theory for the cause of Miranda's unique geology is that "the internal tension of the surface due to tidal forces from Uranus" essentially triggered extensive tectonic activity (Avramchuk et al. 187). A Uranus orbiter would have ample time to study many of Uranus' inner and outer satellites. Specific research targeted to understanding Miranda's history and interactions with Uranus would prove beneficial in understanding how Miranda, and other satellites in our solar system or elsewhere, interact with their host planets. The same research could also potentially be applied to exoplanets orbiting their host stars.

## Conclusion

The field of extrasolar planetary studies is rapidly advancing. Distant extrasolar planets are constantly being discovered and studied by space scientists. While scientists have yet to possess the technology necessary to study these extrasolar planets in detail, via space telescopes, many extrasolar planets have been found to have similar masses and densities to those of the ice giants (Vision and Voyages 18). Using that information as a lead, scientists predict that a mission to Uranus would prove valuable to the understanding of extrasolar planets. Science is fueled by searching for similarities and patterns and using those as a guide to the next breakthrough. There is currently no confirmation that the extrasolar planets that have been discovered have the same composition or origin as Uranus; they could be vastly different. At the least, a mission to Uranus would provide insight into the origin and structure of Uranus whether it is similar to some extrasolar planets or not. Uranus was last visited by Voyager 2 and has yet to be studied by modern day spacecraft. Using specific and advanced equipment on a spacecraft designed to study

Uranus, scientists can study detailed characteristics of Uranus and gather more in depth information than what was gained via Voyager 2. Extensive data on the structure, origins, rings, moons, etc. could be obtained using a modern spacecraft to study Uranus. By following the notion that many exoplanets are similar to the ice giants, specifically Uranus, scientists have the potential to gain insight on the characteristics of extrasolar planets using advanced spacecraft while staying within the comfort of the solar system.

Scientists have only scratched the surface in regards to learning about extrasolar planets. Ideally, future advancements in space technology will allow scientists to eventually study features of extrasolar planets that modern technology cannot. Future technological advancements could also allow scientists to discover extrasolar planets that are too small or too distant from their host star to be detected by current planet detecting equipment. The field of extrasolar planetary studies is young and full of potential. While modern technology may have a limit to how much information it can gather about extrasolar planets, scientists can potentially gather some of that information with current technology by studying Uranus and applying the findings to relevant extrasolar planets.

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