



Exoplanet Atmosphere Spectroscopy with Future Space Telescopes

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DESCRIPTION

The exploration of exoplanet atmospheres has been a captivating work in the field of astronomy. Over the past few decades, astronomers have made remarkable progress in characterizing these distant worlds, which explain on their composition, structure, and potential habitability. One of the important tool in this work is spectroscopy, a technique that dissects the light from exoplanet-hosting stars to reveal the chemical makeup and physical properties of exoplanet atmospheres. The pioneering work began with ground-based observations and early space missions, such as the Hubble Space Telescope, which provided important insights into exoplanet atmospheres. These observations were often limited to giant, close-in exoplanets, commonly referred to as "hot Jupiters."

As technology advanced and our understanding of exoplanets deepened, the field expanded to include smaller, potentially more Earth-like exoplanets. Space telescopes like Kepler and Spitzer contributed to the discovery and initial characterization of numerous exoplanets, while ground-based observatories continued to play a significant role. However, one of the most innovative developments came with the launch of the Kepler Space Telescope, which used the transit method to detect exoplanets by measuring the periodic dimming of their host stars as planets passed in front of them. This method allowed for the discovery of thousands of exoplanets, including many in the habitable zone-regions where conditions might be right for liquid water and, potentially, life.

While transit observations were instrumental in identifying exoplanets, they provided limited information about their atmospheres. Enter spectroscopy, a technique that analyzes the light passing through or reflecting off an exoplanet's atmosphere. Spectroscopic observations reveal the chemical composition, temperature, pressure, and even the presence of clouds in an exoplanet's atmosphere. Traditionally, spectroscopic studies were constrained to a select few exoplanets, mostly those with large atmospheres and favorable geometries for observations.

However, recent advances in technology and instrumentation have expanded the reach of exoplanet atmosphere spectroscopy, and the future holds even more potential.

Several future space telescopes are poised to revolutionize exoplanet atmosphere spectroscopy. Let's explore some of these game-changing missions and their potential impact on our understanding of exoplanets. The James Webb Space Telescope, often dubbed JWST or Webb, is one of the most highly anticipated space missions in recent history. Scheduled for launch, it boasts capabilities that will significantly enhance our ability to study exoplanet atmospheres. Webb's primary instrument, the Near Infrared Spectrograph (NIRSpec), will enable high-resolution spectroscopy in the infrared range. This is important for studying exoplanet atmospheres because many key molecular signatures, such as water vapor, methane, and carbon dioxide, are most accessible in the infrared. Webb's sensitivity and spectral range will allow us to probe a wide variety of exoplanets, including those in the habitable zone.

The Atmospheric Remote-sensing Infrared Exoplanet Large-survey (ARIEL) mission, led by the European Space Agency (ESA), is designed specifically for exoplanet atmosphere spectroscopy. ARIEL aims to observe hundreds of exoplanets across a broad range of sizes, temperatures, and orbital distances. By collecting data in the infrared and visible wavelengths, it will provide insights into the diversity of exoplanetary atmospheres. The Large UV/Optical/IR (LUVUIR) telescope is a concept for a future flagship space observatory that could be a game-changer for exoplanet studies. LUVUIR's large aperture and advanced instrumentation would enable high-resolution spectroscopy across a wide range of wavelengths. This telescope could investigate the atmospheres of Earth-like exoplanets, search for biosignatures, and explore a vast array of planetary systems.

The Origins Space Telescope, another ambitious concept, would focus on the far-infrared spectrum. While its primary goal is to study the origins of stars and galaxies, it would also have applications in exoplanet atmosphere spectroscopy. By probing the far-infrared, it could provide information on the colder and

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more distant exoplanets. Despite the potential of these future space telescopes, exoplanet atmosphere spectroscopy still faces several challenges. Choosing the right exoplanet targets is important. Researchers are developing algorithms and techniques to prioritize exoplanets based on their scientific potential, ensuring that valuable telescope time is used efficiently.

Spectroscopic observations are sensitive and can be affected by various sources of noise. Advanced data processing and analysis techniques are being developed to reduce noise and improve the accuracy of spectroscopic measurements. Exoplanets come in all shapes and sizes. To address this diversity, scientists are developing spectroscopic models that can be applied to different types of exoplanets, from hot Jupiters to rocky worlds. One of the ultimate goals of exoplanet atmosphere spectroscopy is to

detect biosignatures—indicators of life in the atmospheres of distant planets. This involves the identification of specific chemical compounds associated with life, such as oxygen and methane. Future missions will play a vital role in this search.

With the launch of space telescopes like JWST, ARIEL, LUVOIR, and others on the horizon, they are on the cusp of a new era in our understanding of exoplanets. These missions will allow us to explore a diverse range of exoplanetary atmospheres, from scorching gas giants to potentially habitable Earth-like worlds. As technology continues to advance, the field of exoplanet atmosphere spectroscopy will continue to evolve. The answers to age-old questions about the potential for life beyond Earth and the diversity of planetary environments are within reach, waiting to be unveiled by the powerful instruments of the future.