

Advancements in AI Technology and Their Impact on Exoplanet Discovery

By Joyce Liu

Author Biography

Joyce Liu is a high school junior at Choate Rosemary Hall, a private boarding school in Wallingford, Connecticut. Her academic areas of interest expand across multiple disciplines, including astrophysics, math, and chemistry, with particular topics in black holes, exoplanets, and nanotechnology. In her spare time, she enjoys music, specifically playing the violin, singing, and playing guitar.

Abstract

The continuous goal of discovering extraterrestrial life has driven scientific interest in exoplanets—celestial bodies orbiting stars outside our solar system. Traditional methods of exoplanet detection, reliant on manual analysis and prone to human error, presented unavoidable challenges given the vastness of the universe. This paper aims to discuss the benefits and limitations of AI within the exoplanet detection field, and determine whether the highly-regarded artificial intelligence is as beneficial to astronomical fields as we think. With the introduction of the first ever fully-robotic exoplanet detector which takes high-precision radial velocity measurements to measure the gravitational reflex motion, and advancing computer algorithms that avoid human errors in data analysis, modern advancements in artificial intelligence (AI) technology have not only transformed the efficiency and accuracy of exoplanet detection, but also extended our understanding of these distant worlds. While the use of AI does have its benefits, there are several drawbacks that could potentially hinder further advancement in the field of exoplanet detection.

Keywords: Exoplanet, Artificial Intelligence, Detector, Astronomy, Radial Velocity, Automated Planet Finder, Kepler Space Telescope, Image Classification, Habitability, Astronomy

Introduction

The fascination towards extraterrestrial life has been a driving force in the study of exoplanets, marking a crucial step in the exploration of the universe. However, the task of identifying exoplanets among billions of stars requires cutting-edge technology and innovative approaches to maximize efficiency. Traditional detection methods, reliant on human astronomers, were time-consuming and prone to error. In contrast, recent advancements in AI technology have brought forth a new era, significantly enhancing the efficacy of the exoplanet discovery process.

The collaboration between human expertise and the capabilities of machine learning algorithms has so far yielded impressive results in expanding the catalog of detected exoplanets. Human astronomers, through training and development of these algorithms, have not only improved their accuracy but also extended exoplanet detection to previously unattainable levels. The combination of human skill and artificial intelligence has allowed for the identification of subtle patterns and anomalies in vast datasets, contributing to a more comprehensive understanding of the exoplanetary landscape.

Furthermore, the introduction of a fully-robotic machine capable of autonomously taking high-precision radial velocity measurements has propelled the field into further technological innovation. This robotic machine is designed to measure the gravitational reflex motion of nearby stars induced by the orbiting of planets. The introduction of the first fully robotic exoplanet finder, the Automated Planet Finder (APF) telescope, has not only simplified the detection process, but has also pushed for the integration of robotic technologies in future astronomical research. This development reduces human intervention and paves the way for more efficient and consistent data collection.

Discovering exoplanets is crucial as it expands our understanding of planetary systems, and can potentially reveal Earth-like worlds that could maintain life, and address fundamental questions about our place in the universe. This knowledge will be able to benefit life on Earth by inspiring technological advancements and encouraging

international collaboration, inviting innovation in fields like space travel and environmental monitoring. Moreover, the study of exoplanets improves science by challenging existing theories, leading to breakthroughs in astrophysics, atmospheric science, and planetary formation, essentially expanding our understanding of the universe and the origins of life.

Technology holds great promise for revealing the mysteries of the universe and providing valuable insights into the characterization of the habitability of the vast worlds beyond Earth. The combination of AI-driven algorithms and robotic technologies not only enhances the precision of exoplanet detection, but also opens new opportunities for understanding the diverse compositions and conditions of distant celestial bodies.

Examples

1.1 Machine Learning Algorithms and the Transit Method

Modern AI technology, particularly machine learning algorithms, has become essential in revolutionizing the detection of exoplanets. These algorithms, designed to learn and improve from data, play a significant role in recognizing patterns and identifying potential exoplanet candidates. One notable example, NASA's Kepler Space Telescope, in 2017, employed a neural network—representative of AI algorithms—to autonomously discover Kepler-1705b, marking the first instance of an exoplanet found without human intervention (Brennan, 2022). As seen in Figure 1, the graph shows the discovery of 69 new exoplanets discovered by the implementation of machine learning algorithms. This proves the effectiveness and potential in the development of new algorithms to aid astronomers in their search for exoplanets.

Figure 1
Discovery of 69 New Exoplanets Using Machine Learning

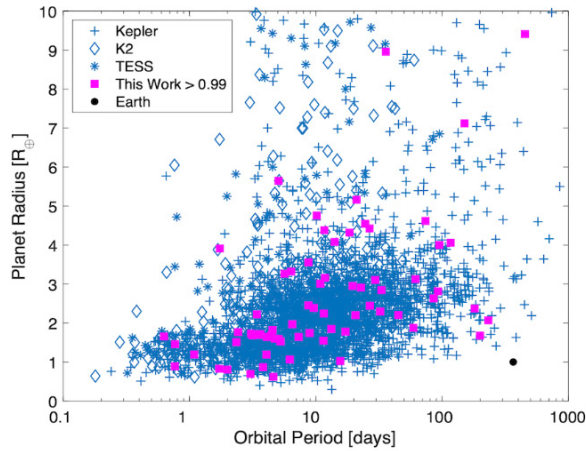
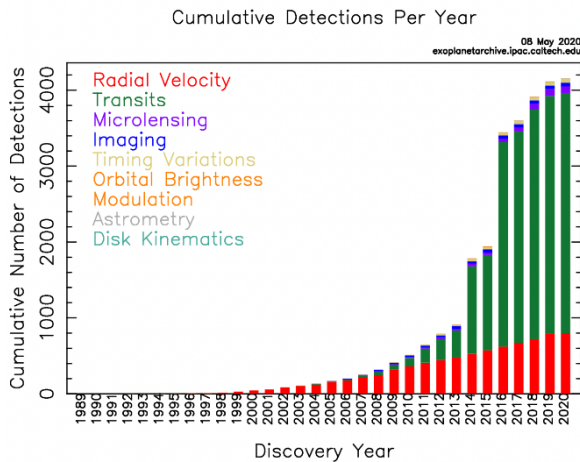


Figure 2
Cumulative Amount of Exoplanets Discovered by Method from 1989-2020

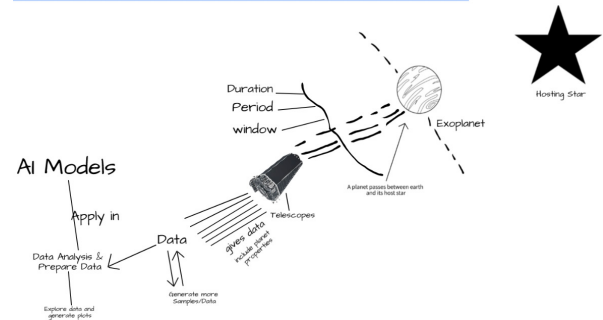


The significance of this method lies not only in the elimination of human intervention, but also in the efficiency and accuracy amplified by AI. The transit method, an essential part of exoplanet detection, involves observing the subtle dimming of starlight caused by a planet passing in front of its host star. Figure 2 highlights the increasing prevalence in the use of the Transit method in exoplanet detection, as shown by the increasing green bars above each new year. However, while important, this method presented challenges due to the complexities of planetary systems and their interactions, making the detection process difficult and time-consuming. In response to these challenges, a collaborative effort by astronomers

from the University of Geneva, the University of Bern, NCCR PlanetS Switzerland, and Disaitek utilized AI applied to image recognition.

This innovative approach, documented in Astronomy and Astrophysics, avoids the limitations of traditional methods by predicting the effects of planetary interactions. The AI-driven model, trained on extensive datasets, analyzes images to reveal previously undetectable exoplanets. The success of this method not only contributes significantly to the field of exoplanet detection, but also extends its implications to practical applications on Earth. The ability to predict and understand planetary interactions has led to the development of tools that could be employed to detect illegal waste dumps, demonstrating the broad applications of AI technology beyond astronomical exploration.

Figure 3
Diagram of Exoplanet Detection Process using Artificial Intelligence (AI)



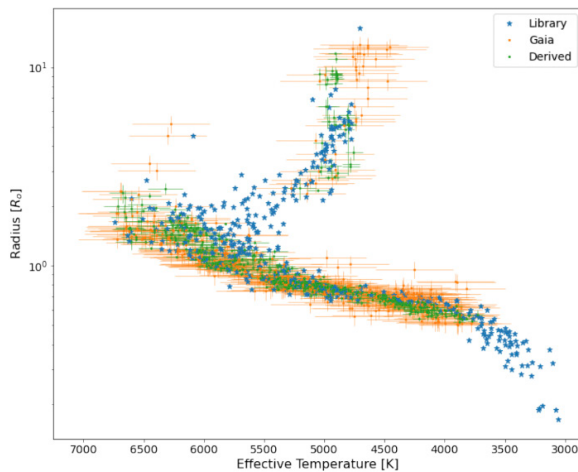
The integration of AI in exoplanet detection transcends the boundaries of traditional astronomy. As AI continues to evolve, it holds the potential not only to expand our understanding of the universe but also to contribute to solving pressing issues here on Earth, making it a transformative force in both astronomical research and practical problem-solving.

1.2 Automated Planet Finder (Apf): First Robotic Exoplanet Detection Telescope

The Automated Planet Finder (APF), positioned atop Mount Hamilton at the Lick Observatory, stands as a significant achievement in the field of exoplanet detection. This fully robotic 2.4-meter optical telescope represents a shift in astronomical exploration, particularly in its innovative approach to detecting rocky planets. Using high-

precision radial velocity measurements, the APF is specifically designed to identify planets within the mass range of five to twenty times that of Earth. Over the course of a decade, the APF studies 1,000 stars for potential planetary companions. The telescope's operational efficiency is highlighted by its examination of approximately 10 stars per night, a capability that positions the APF as an impressive tool in the quest for exoplanets. Figure 4 shows the stellar properties obtained from the search of the APF. Once the APF searches the sky, computer algorithms organize the data collected and create a plot of the stars found in the sky, classified by temperature and radius. While this graph somewhat resembles an HR diagram, it is important to note that the y-axis is a plot of radius instead of star luminosity.

Figure 4
Stellar Properties Derived from APF Spectra using SpecMatch-Emp Algorithm



The financial investment in the APF project, with an estimated cost of \$10 million and a total cost-to-completion of \$12.37 million, reflects a commitment to advancing astronomical research. This funding has enabled the telescope to meet its design goals successfully, achieving sensitivity comparable to other leading spectrometers such as HARPS and HIRES. The high-precision radial velocity measurements obtained by the APF produce invaluable data, enabling astronomers to detect subtle motions induced by the gravitational pull of orbiting planets. This precision places the APF at the top of exoplanet detection technology, marking a significant stride forward in our ability to explore distant worlds.

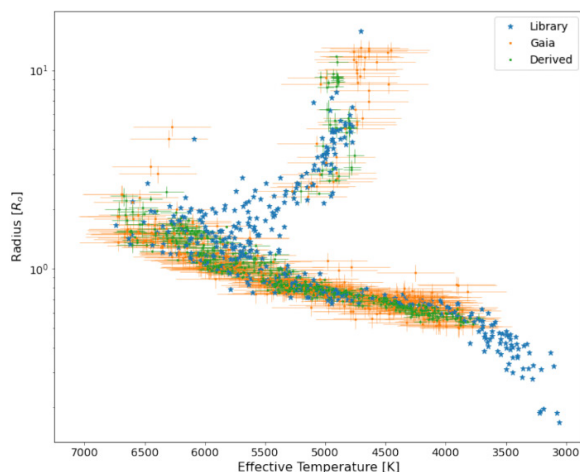
The APF's role as a fully robotic telescope not only enhances efficiency but also represents a significant shift toward automation in astronomical observation. The robotic nature of the APF reduces human intervention, allowing for consistent observations night after night. This autonomy not only pushes the exoplanet detection process forward, but also serves as a model for future robotic telescopes, potentially opening new opportunities for automated astronomical research.

As the APF continues its mission to evaluate nearby stars and their neighbors, its contributions to exoplanet detection stand as a testament to the power of technological innovation in advancing our understanding of the cosmos. The successful implementation of the APF reveals the importance of investing in cutting-edge astronomical equipment, paving the way for future discoveries that will shape our knowledge of the universe.

1.3 Other Uses/Roles of AI in the Detection Process

AI's impact on exoplanet detection transcends the area of direct identification, including a spectrum of methods that enhance the efficiency and depth of astronomical research. Telescopes like Kepler and the Transiting Exoplanet Survey Satellite (TESS) are mass-producing data generators, capturing intricate details of stellar brightness over extended periods. In this vast sea of data, AI algorithms emerge as valuable tools, playing an important role in discerning potential exoplanet candidates from the cosmic noise. By effectively using machine learning capabilities, AI aids astronomers in focusing their attention on the most promising leads, significantly reducing the time and resources required for manual analysis. Figure 5 shows the combination of real and synthetic data through a machine learning algorithm. Doing this improves exoplanet detection by training more developed models that can identify subtle patterns in noisy or incomplete data, which improves the number of discoveries and detection accuracy, thus expanding our understanding of planetary systems.

Figure 5
Combining Real and Synthetic Data Through Machine Learning to Aid Exoplanet Detection



One notable strength of AI in exoplanet detection lies in its ability to identify celestial bodies that defy conventional detection methods. Exoplanets with irregular orbits or unique characteristics are often neglected through traditional techniques, presenting challenges for astronomers. AI algorithms, however, excel in recognizing unconventional patterns, expanding the scope of exoplanetary diversity. This adaptability increases the likelihood of discovering habitable worlds and contributes to a more nuanced understanding of the universe.

Beyond simple detection, AI's significance extends to the more complicated but important task of characterizing these exoplanets. The analysis of light spectra, a complex process requiring precision, is made more efficient and accurate through the application of AI algorithms. By examining intricate details in the spectra, AI contributes crucial information for assessing the composition and atmospheric conditions of exoplanets. This characterization is pivotal in determining the potential habitability of these distant worlds and evaluating the likelihood of extraterrestrial life.

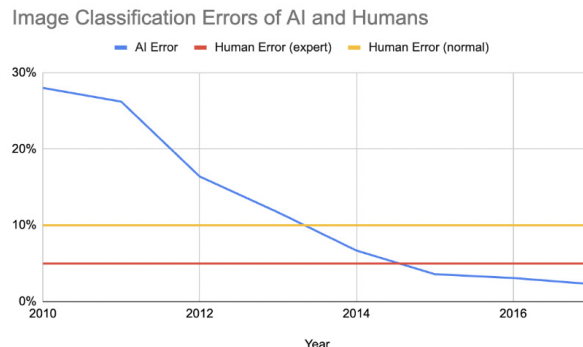
As AI technologies continue to evolve, their role in the exoplanet detection process is undoubtedly going to deepen, offering astronomers an increasingly sophisticated and effective toolkit for research. The already diverse roles of AI—from data analysis and candidate identification to the characterization

of exoplanetary atmospheres—underscores its transformative impact on the field of astronomy, helping us obtain a more comprehensive understanding of the unknown and vast universe.

1.4 Drawbacks of Using AI for Detection

Although the implementation of AI for detection of exoplanets has been more and more common, there are several negative consequences that could be introduced by the excessive use of AI.

Figure 6
Comparison of Image Classification Error in AI and Humans (expert and normal)



As seen in Figure 6, the error in image classification that AI yields has decreased to levels below that of even expert humans, showing that they are both more efficient and accurate. Although this may seem like an advancement, it also has its drawbacks. The upgrading of AI machines has led to more scientists unable to follow along. While AI keeps being enhanced, human skill is not able to catch up, therefore leading to a mystery of how to move forward in the field of research. As robots begin to gain more knowledge, it becomes difficult for humans to continue programming AI for the better, as they are unable to figure out what is needed for further enhancement. This leads the field into a dead end, as AI has overcome the ability of scientists, and is an unnerving situation for not only the astronomical field, but across all fields related to the use of artificial intelligence.

Conclusion

In summary, the introduction of AI technology into the realm of exoplanet detection has not merely upgraded existing processes; it has transformed our methods for understanding the universe and, in particular, the continuous question of extraterrestrial life. Uses of machine learning algorithms, as showcased in the transit method, stand as a representation of the efficacy and precision that AI provides, significantly enhancing the efficiency and accuracy of exoplanet detection. Technology has pushed us beyond the traditional boundaries of human analysis, allowing us to navigate the vast universe with previously unachievable speed and accuracy. However, this also creates a problem: how do we navigate AI once it surpasses our skill and knowledge? The answer is undefined but we can argue that it becomes more and more difficult. As AI advances, humans will find it challenging to maintain pace of growth or even catch up, and this creates a hindrance in exoplanet detection. Even though AI can provide us with more potential in our findings, it could also pose more threat than benefit, so we need to acknowledge the potential pitfalls and monitor/manage the advancement of AI at a pace. This way, we can maximize benefits from implementing AI into our detection methods.

Discovering exoplanets is essential for expanding our knowledge of planetary systems and potentially finding Earth-like worlds that could maintain life. Additionally, the study of exoplanets challenges existing scientific theories, leading to developments in astrophysics, atmospheric science, and planetary formation, essentially enriching our understanding of the universe and the origins of life. As AI continues to appear in increasing areas of astronomical research, its potential holds great promise. In a time of rapid technological advancement, the age-old question “are we alone?” is not just a simple question; it is a tool guiding us towards higher levels, where the fusion of human and artificial intelligence unlock secrets of the universe in ways we have yet to imagine.

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