AN ANALYSIS OF TYC 3413-242-1:

A RESEARCH PROJECT INVESTIGATING THE STAR'S PHOTOMETRIC PROPERTIES

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Time started with a flash of light, and with the energy from that light our universe was born. First, thanks must go to our Sun, which gives us everything we need to survive. The journey to create this research originated in September of 2020, at the suggestion of Dr. Kristen Miller, to whom I want to acknowledge her rock star status. Her leadership, patience, and her undeterred desire to help us by showing us her love for astrophysics. This document has inspired me and many in my immediate family and near-peer group to better understand the origins of our beginnings and continue my search for answers through the science of Astrophysics – Planetary Science. Thank you, Dr. Ed Albin, for your early belief in me, and to all my professors, particularly Dr. Nancy Taylor and Dr. Dmitri Bizyaev. Thank you to my four exceptional children for supporting me through the madness and countless hours mired in my research, and lastly, to my devoted partner in life, Siobhan, who often supports and lifts me through the downs and is quick to keep me grounded. Melanie Crowson, I cannot thank her enough for her advice and friendship, and the countless others whom I presume grew tired of hearing me say the often-shouted word, THESIS.

“*non est ad astra mollis e terris via*.” Seneca The Younger wrote in Hercules and translated it to “there is no easy way from the earth to the stars.”

AN ANALYSIS OF TYC 3413-242-1: A RESEARCH PROJECT INVESTIGATING THE STAR’S PHOTOMETRIC PROPERTIES

This study is a detailed observation of a star, TYC-3413-242-1, using the 60 cm Planewave telescope located at the American Public University campus in West Virginia using an L-Band filter. Several public data sources, including images from space telescopes Kepler, TESS, Gaia, and Hipparcos, helped identify a potential transit, in cooperation with numerous ground-based telescopes all contributed to the research. The goal here is to gather known optical data to identify and classify this star’s characteristics, identify a possible transit in its orbit or discern the possible characteristic pattern associated with either an eclipsing binary system, a variable star, an exoplanet and if, through additional observations, the study identifies, other potential types of transits. Research here used an astronomy software package to construct light curves, and the data was derived from sources mentioned earlier. Hundreds of observational images of TYC-3413-242-1 have been gathered through numerous observations, and all assisted in the work reported herein.

Prior observations were presented as incomplete or ambiguous, requiring multiple observational methodologies using optical, radio, and spectroscopic measurements. Data obtained will be used to build light curves, measuring any variability in the light emissivity of TYC-3413-242-1. A radio telescope used to observe this hyperactive star assisted in identifying the microwave fluctuations in the light ranging from .10 to 40 GHz. Data and observations are compared to other local target star’s light curves to determine the scaling of ingress and egress and the existence of a possible transiting exoplanet, or a binary star partner, or a fluctuating variable star. An astronomy software, AstroImageJ, is used here to develop qualitative evidence that assisted the research and findings.

Using light curves built through these observations and theoretical research, the arguments presented in this study showed one of three potential explanations for the resultant fluctuations. To narrow these findings and use the scientific method, it became more evident that the images must be high quality with as little noise as can be allowed, considering the telescope's location used in the original observation in April of 2020.

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Formula

[1.1] $Fp = [(t_2 - t_1) + (t_4 - t_3)]/(t_4 - t_1)$

Introduction

This research will present an overview of the main theoretical framework and rationale for exploring yet unidentified transitory objects using terrestrial-based telescope systems. The introductory chapter will present an overview of the research, the justification for the methodology applied, the work's principal aims, and objectives. The study is placed within the theoretical context of exoplanet and or eclipsing binary star exploration and the rationale for utilizing smaller-lens terrestrial telescopes to support this area of scientific discovery.

Overview and Rationale

Over recent years, the discovery of thousands of exoplanets, planets discovered outside this Solar System that are so physically and chemically different from the planets within the solar system represents possibly one of humankind's most significant technological advancements. The improvement of telescopic systems and spectrometers has allowed astronomers to discover more exoplanets each year and has also increased the potential of terrestrial-based telescopes to be more involved in that process. Although thousands of planets have been discovered and cataloged, thousands more planet candidates require confirmation (Seager and Bains, 2015). The composition of nebulae systems in the universe comprises a range of different planetary formations and system compositions. Several methods have been used to confirm these detections, including Doppler measurements, transit observations, microlensing, astronomy, and direct imaging (Fischer *et al.*, 2015). The conflagration of varying transits and the potential for false-positive identifiers lays bare in many research initiatives. This research looks at how small terrestrial-based telescopic systems contribute to exoplanet discovery, transit detection, and their confirmational analyses of these discoveries, which on its own expands the portfolio of known exoplanets and the competing eclipsing binary stars along with their physical characteristics.

Theoretical Background and Framework

Providing an initial overview of stellar exploration offers a rationale for the theoretical framework of this research and its significance in contemporary astrophysics. Historically, space exploration has been punctuated by periods of significant discoveries – opening new space areas to more detailed analysis of existing bodies and areas of the known universe that had otherwise not been explored. In the case of exoplanets, the Kepler Space Telescope, a space-based mission, revolutionized investigations into the existence of exoplanets and transitory movements around stars. The Kepler mission increased the number of known extra-solar planets, assisting researchers in determining if these transits are either variable stars or binary star systems by a factor of five. Furthermore, it is responsible for uncovering those systems with longer orbital periods and smaller planet radii than any other previous exoplanet surveys (Gautier *et al.*, 2012; Dressing & Charbonneau, 2013). Contemporary research evidence suggests that more than 4,300 exoplanets are confirmed in the visible universe (Samara *et al.,* 2021), and this portfolio of known exoplanets continues to expand. There is additional evidence that transiting binary star systems may exist in one out of every two stars. It becomes important here to define an eclipsing binary star, and according to the University of Iowa Astrophysics Department (2017):

> “Binary stars are often detected optically, in which case they are called visual binaries. Many visual binaries have long orbital periods of several centuries or millennia and therefore have orbits that are uncertain or poorly known. They

> may also be detected by indirect techniques, such as spectroscopy (spectroscopic binaries) or astrometry (astrometric binaries). If a binary star happens to orbit in a plane along our line of sight, its components will eclipse and transit each other; these pairs are called eclipsing binaries, or, as their changes in brightness detect them during eclipses and transits, photometric binaries."

The myriad of benefits of locating and confirming a binary system, particularly an eclipsing binary system, are numerous. Most importantly, these observations assist in establishing the distance to the binary, which helps in the decades-long challenge of determining the Hubble Constant, or as Albert Einstein referred to the variable, ʌ or Lambda, like the Cosmological Constant. (Einstein, V.A., 1917) Once researchers can determine distance, they focus on the star's mass or combined mass of two stars or more, such as orbital parameters, eccentricity, and perhaps radial velocity.

Historical References

1992 proved to be a significant year with the discovery of the first exoplanets, located by Alexander Wolszczan (22 April 1994) using the 305-meter Arecibo radio telescope. In the Journal Science, his team announced the discovery of two Earth-mass planets orbiting Pulsar PSR B1257 +12. Shortly after that, Mayor and Queloz (1995) discovered the first exoplanet in orbit around a main-sequence star, an important distinction. All this beginning only thirty-six years ago. Moreover, what was at the time a theoretical approach, using radial velocity measurements, or the redshift of light moving away from the observers' perspectives. The radial velocity measurements discovered the wobble caused by the perturbations of these planets working in tandem, and also a 3:2 resonance was determined statistically by Peale, S. J. (1976). Other approaches determining the existence of exoplanets, using astrometry charted the dimming of the light from the star Pegasi in the constellation Pegasus. Interestingly, the data showed that such planets are stable and estimate the magnitude of Classical Jeans evaporation, photodissociation and loss due to EUV radiation. Even over the primary lifetime, the companion planet would not have lost a significant fraction of its mass. (Guillot *et al.* 1995) In addition, Guillot *et al.* (1995) demonstrated that for the mass range quoted, such planets are well within their Roche lobes and that photometrically measuring such changes in the photoelectrons emitted from these stable stars is highly accurate.

The historical significance of discovering the first exoplanet orbiting a main-sequence star in 1995 proved that many other planets orbit around other stars. The discovery of 51 Peg (b) fostered those first steps using Doppler spectroscopy. (Guillot *et al.* 1995) Moreover beyond, there were other uses of different means of observations to determine the existence of exoplanets. In 1995, the technology to estimate an exoplanet's mass was not used, and science was simply a guess. Accordingly, with the theoretical advancements and opening of the minds of outstanding scientists who would then dedicate their lives to astrophysics and understanding all the components of planetary formations, exoplanet hunters emerged.

As more exoplanets are discovered and cataloged, creating more effective and complete databases to verify these discoveries and supplement existing research is becoming more critical. The methodology allows for networks of discovery to become more efficient, accessible, and contemporary. Cultivating a network of reliable and reputable exoplanet hunters is vital to continuing their search, and exploring their composition and significance. Noticeably, the false positives associated with exoplanet hunting and the confusion that eclipsing binary stars present when performing astrometry on the transits lead to significant aggravation. Creating valuable resources for these users to utilize terrestrial-based telescopes to confirm the findings of digital databases such as the Sloan Digital Sky Survey (SDSS), the NASA Exoplanet Catalogue, the American Association of Variable Star Observers, or AAVSO, and the Open Exoplanet Catalogue is vitally crucial in continuing the search and verifying the findings.

This search for extra-solar planets has recently been referenced as one of the ‘most vibrant fields in modern astrophysics’ (Curiel *et al.* 2020, p.1) and, with the continued developments of telescopic instrumentation and data analysis methodologies, exoplanet discoveries are becoming more frequent (Dressing & Charbonneau, 2013; Gillon *et al.* 2017). This list continues to expand as more planets are discovered and verified, with evident attention paid to those that may harbor life or those whose physical composition is like Earth. Analysis of many of these Earth-like exoplanets often targets atmospheric characterization to allow for more in-depth analysis of current and future astronomical facilities –with systems such as TRAPPEST-1 providing key target areas for space-based telescopes (Barstow *et al.* 2016; Gillion *et al.* 2017). Analysis of these exoplanets through these space-based systems allows for precise orbital configurations to be established. The proposed James Webb Space Telescope launch in October 2021 is thought to be the observational tool to ‘dramatically change our understanding of exoplanet atmospheres’ (Barstow *et al.*, 2016, p.L92). Despite this, strategies to improve the thousands of other existing and potential exoplanets need to consider how terrestrial-based telescopic contribute to these databases and confirm these thousands of space-based discoveries. Many anomalies surface in the analysis and confirmation of exoplanets, two of which are a variable star or an eclipsing binary star. Kirk *et al*. (2016) considered the number of potential eclipsing binaries (EBs) in the range of 2875, yet there is now a confirmed 13 through their analysis. There are estimates that one out of every two stars may be in a binary system. These findings often may prove to be what is termed false positives in determining if an exoplanet exists. Thus, the determination of the observation from ground-based photometric studies proves exceptionally challenging, with the variability of their timing, the length of their transit, and the other conditions that exist from atmospheric irregularities such as timing the location of the binary system, not including the variability of weather, and observing conditions.

Aims and Objectives

This work aims to prove that using a light curve, as described graphically in *Figure 1*, below can unequivocally assist in confirming transits and, more importantly, exoplanets. Establishing out the decrease in emissivity of a star to accurately detect a transit is a practical, scientifically accurate tool.

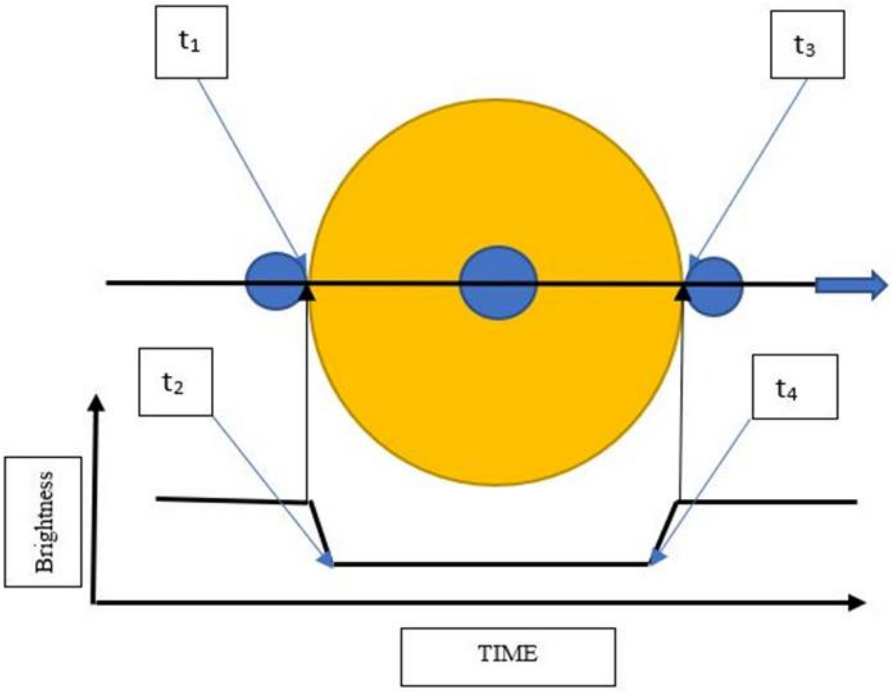


Figure 1: Example of a Transit
Source: Dennis Trevino/Dennis Conti, Ph.D., AAVSO – Exoplanet Section

The Figure above depicts a transit as it occurs across a star that assumes the view is on the same plane, at 90 degrees. The likelihood of a transit that occurs with the observation precisely at 90 degrees is low. However, the light curve generated will appear similar as the planet or object passes in front of the host star. Defined as Flux, or fluctuation of light, the decrease in the light is observable by means of using this formula,

$$Fp = [(t_2 - t_1) + (t_4 - t_3)]/(t_4 - t_1) \qquad [\,1.01]$$

Where Fp is the average rate of change of the Flux and t, 1thru 4 are time.

In the Caltech, IPAC, NASA Exoplanet archive, the methodology explaining charting and creating a typical light curve, described below, includes a seven-segment empirical fit represented by the following parameters as shown in *Figure 1* above.

- Zero-point offset
- t_1: Beginning of ingress - labeled 1.
- t_2: End of ingress - labeled 2.
- t_3: Beginning of egress - labeled 3.
- t_4: End of egress - labeled 4.
- L: length of transit from t_1 to t_4
- MD: mid-point of transit
- D: Transit depth at transit midpoint (MD)
- F_p: Partial transit fraction; $F_p = [(t_2-t_1) + (t_4-t_3)] / (t_4-t_1)$
- F_2: Fractional transit depth at t_2 (with respect to D)
- Temporal trend, i.e., slope of light curve without the transit [mmag/hour]
- Airmass trend [mmag/airmass]

The chart above is provided by Caltech, IPAC, and NASA Exoplanet Archive.

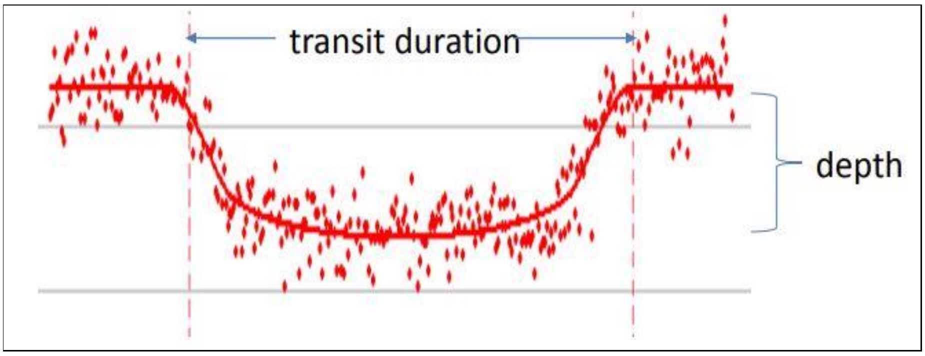


Figure 2: A representation of a Plot Chart of an Exoplanet.
Source: provided by Dennis Conti, Ph.D. AAVSO – Exoplanet Section

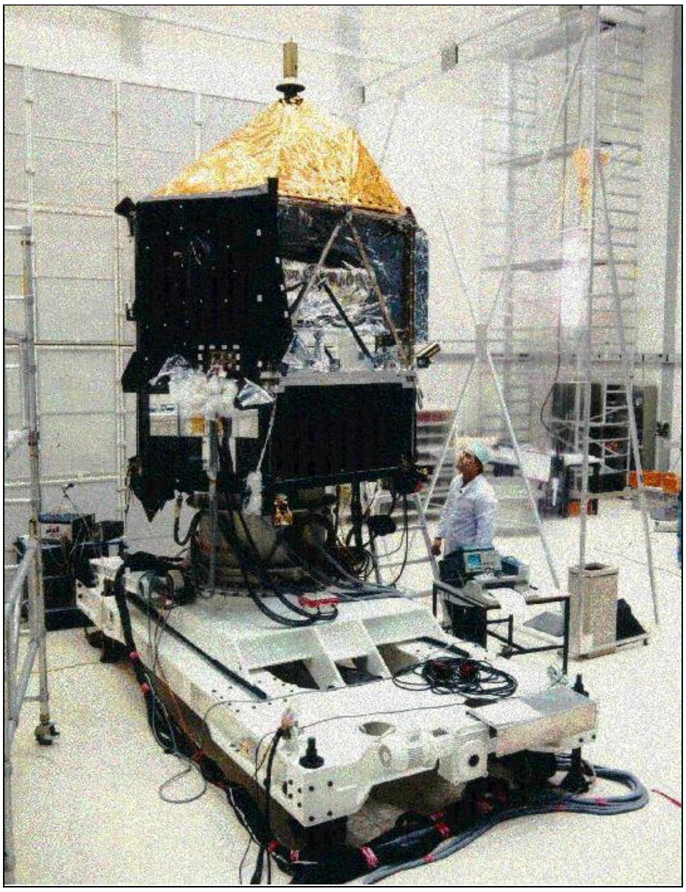
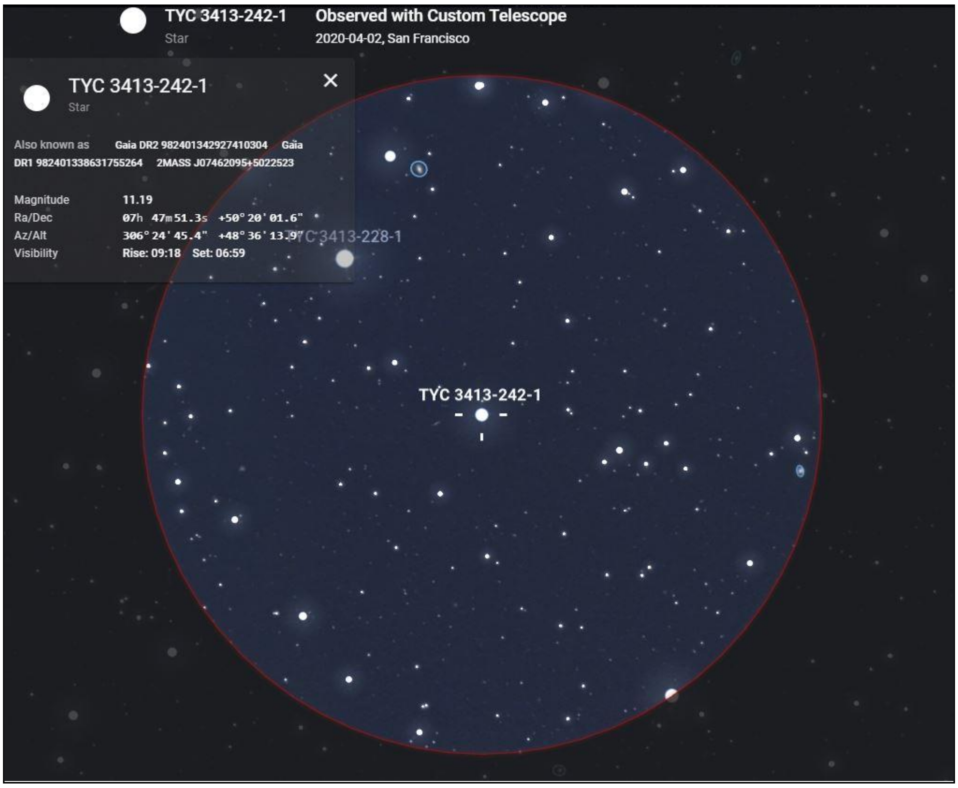


Figure 3: A 1989 Image of the First Star Mapper.
Source: European Space Agency



TYC 3413-242-1 Star

Observed with Custom Telescope
2020-04-02, San Francisco

TYC 3413-242-1
Star

Also known as Gaia DR2 982401342927410304 Gaia DR1 982401338631755264 2MASS J07462095+5022523

Magnitude 11.19
Ra/Dec 07h 47m51.3s +50°20'01.6"
Az/Alt 306°24'45.4" +48°36'13.9"
Visibility Rise: 09:18 Set: 06:59

Figure 4: STELLARIUM IMAGE on the Day of the observation.
Source: Stellarium Software, 2021

Furthermore, the methodology above offers reduction techniques that have improved the precision of the data and increased the total number of entries compared to the original Tycho database (ESA, 2021). Utilizing these databases allows for improved connectivity of the data obtained through the research and verification of the initial findings. The analysis herein highlights three essential research objectives:

1. To verify the findings of the exoplanet identified through the build of light curves from multiple imaging.

2. To investigate strategies to minimize the scale of uncertainty resulting from the use of terrestrial-based telescopes.

3. To analyze whether other measurement techniques can be used alongside light curves to improve the predictive capability of terrestrial-based telescope resources in exoplanet exploration.

The expansion of exoplanet research can create several exciting opportunities for discovery across a wide range of scientific disciplines. The findings of this study will provide original datasets to contribute to exoplanet discovery. Moreover, outline novel approaches using terrestrial-based telescoping systems to contribute to this search more effectively.

Hypothesis

The central hypothesis to be tested through this research relates to the benefits of using small (<1m diameter) terrestrial-based telescopes to correctly identify and confirm transient exoplanets, variable stars, or eclipsing binary stars. The analysis is given to predict that small terrestrial-based telescopes can and do ultimately contribute to the current exoplanet databases in tandem using astrometry software and the construction of light curves. There are three key hypotheses to be tested:

Null hypothesis: Identification and confirmation of known transits – either variable stars, eclipsing binary stars, or exoplanets can be achieved using terrestrial-based telescopes <1m in diameter through light curve analysis, as proved through this and other thorough studies of a potential transiting objects orbit around its host.

Directional hypothesis: small terrestrial-based telescopes can significantly contribute to identifying recently confirmed discovered variable stars, eclipsing binary stars and exoplanets when combined with astrometry light curve generating software.

Nondirectional hypothesis: The Earth's atmosphere of above >60km impacts a terrestrial-based telescopes' ability to identify most objects in outer space accurately with regularity, and the amount of time preferred for the verification process of terrestrial-based observations, versus those provided through space-based observations, prove out the considerations of additional space-based telescope developed technologies, yet the confirmation processes add considerably to the science.

Literature Review

A review is provided of contemporary published research literature, which presents an overview of current approaches to exoplanet exploration and the technologies used to identify these bodies.

Variable Stars

Variable stars remain a highly investigated stellar anomaly with the properties of a measurable increase and decrease in magnitude, allowing them to be defined as standard candles. In simple terms, a standard candle assists astrophysicists and astronomers in determining the distances and the heliophysics associated with determining star types.

Currently, three types of variable stars are studied, including Pulsating, Eclipsing, and Eruptive stars.

Pulsating Stars (Mira, SRs)

The variations are caused by the star physically pulsating, like a balloon blowing up and down, but only the outer layers are involved, with periods that range from hours to years, depending on the type, and a range in brightness from about 0.5 magnitudes to over 10. (Pickard, R., 2019)

Eclipsing Binary Stars (EBs)

Pickard, R. (2019) mentions that two stars cause variations in the line of sight as they physically revolve around each other, while those periods range from hours to many years. Any given night, observations of eclipsing binary stars might experience a single eclipse, or more than one eclipse, in a single observation.

Eruptive Stars can include Cataclysmic Variables or CVs, Novae, and or Supernovae. The interesting effect of these variable stars is that some can exhibit stable emissivity, and others might show significant instability, emitting explosions, or even supernovae. Again, Pickard, R., (2019) states that many CVs ('cataclysmic variables') are binary stars in which the eruptions are due to an exchange of material from one star to the other, often via an "accretion disc," with many subtypes of CVs, forming one of the most exciting areas of observing.

Exoplanet Exploration

Providing an initial overview of exoplanet exploration offers a rationale for the theoretical framework of this research and its significance in contemporary astrophysics. A review is provided of contemporary published research literature, which presents an overview of current approaches to exoplanet exploration and the technologies used to identify these bodies. Historically, space exploration has been punctuated by periods of significant discoveries – opening new areas of space to more detailed analysis of existing bodies and areas of the known universe that had otherwise not been explored. In the case of exoplanets, the *Kepler* space-based mission revolutionized investigations into the existence of exoplanets by increasing the number of known extra-solar planets by a factor of five – uncovering systems which longer orbital periods and smaller planet radii than any other previous exoplanet surveys (Gautier *et al.* 2012; Dressing & Charbonneau, 2013). Contemporary research evidence suggests that more than 4,300 exoplanets are confirmed in the visible universe (Samara *et al.,* 2021), and this portfolio of known exoplanets continues to expand.

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Both gas giant planets and brown dwarfs radiate away residual heat from their formation, cooling through a spectral type transition from L to T. This range encompasses the dissipation of ‘cloud opacity and the appearance of strong methane absorption’ (Skemer *et al.* 2016, p.1). Planets with sizes between Earth and Neptune are most commonly divided into those pure rocky bodies with negligible atmospheric contributions to their overall size and the larger gas-enveloped planets, which have optically thick atmospheres that can be viewed as a contributing factor to their overall size and dimensions (Dawson *et al.* 2015). The first directly imaged exoplanets were all in the L-type range. However, improved analytical and observational methods of known star systems provide new opportunities for detailed analysis of exoplanet atmospheres and potential surface properties (Skemer *et al.,* 2016). The science has been facilitated by recent improvements in the observational capabilities of many terrestrial-based telescopic systems, which have evolved to the point where potential terrestrial planets can now be more confidently predicted and detected around M-type dwarf stars (Samara *et al.* 2021).

Analysis of 1235 planet candidates by Howard *et al.* (2012) - building on the exoplanet catalog developed by Borucki *et al.* (2011) and the additional 1091 planet candidates presented by Batalha *et al.* (2013) as part of the Kepler database - has provided a good sample set for estimates of exoplanet occurrence rates, helping to improve the stellar parameters for many target stars (Dressing & Charbonneau, 2013). The results of the Kepler mission have ultimately helped to provide an improved understanding of the frequency and properties of planets in the Galaxy and provide more substantial constraints on models of planet formation (Boruki *et al.*, 2011; Ford *et al.,* 2011; Shlaufman & Laughlin, 2011).

Howard *et al.* (2012) also found evidence from analysis of 1235 planets observed as part of the Kepler mission that planets with orbital periods of <2 days are scarce, and more minor planets are seven times more abundant around cool stars (3600-4100 K) when compared to some of the hottest stars within this sample set (6600-7100 K). One of the exciting facts of the TYC 3413-242-1 star and the review of its ephemeris, the calculations show when measuring the peak to valley chart in the light curve produced in the TESS data a period (P) of < 2 days. It clocks in at 1.3 days. Reviewing these catalogs against the estimated temperatures, radii, and surface gravities from Kepler Input Catalogue (Brown *et al.* 2011) against the values which are predicted from the Yonsei-Yale evolutionary models (Dermarque *et al*. 2004) has revealed difficulties in characterizing some of these stars (particularly the coolest target stars) because starting points were often too far removed from actual space temperatures, radii and also the known surface gravities (Dressing & Charbonneau, 2013).

Recent research has found evidence suggesting that Kepler exoplanet host stars are preferentially metal-rich – confirming initial tentative hypotheses that there is an apparent correlation between the metallicity of low-mass stars and the association of low-mass and small-radius exoplanets (Schlaufman & Laughlin, 2011). Continued focus on spectroscopic classification of exoplanets has previously been deemed impractical because of the large numbers of stars that need to be examined across a big sky area for practical exoplanet analysis (Brown *et al.* 2011). Instead, methods such as broadband photometry augmented by custom filters to improve sensitivities to surface gravity and metallicity have been suggested as a more appropriate method for exoplanet analysis (Brown *et al.,* 2011). Higher signal-to-noise ratios have also been used to analyze brown dwarfs to improve understanding of potential exoplanet characteristics (Skemer *et al.* 2016) – with observations of the mid-infra-red wavelength are suggested as a potential mechanism to break the degeneracies in model parameters (Skemer *et al.* 2015). Despite this, there are difficulties in using predictive model approaches to exoplanet identification and maintaining an accurate database record of their properties (Dressing & Charbonneau, 2013).

Eclipsing Binary Stars

A known phenomenon, an eclipse, is a predictable transit in front or across a light source. In most cases, the reference is a planet or other object transiting in front of a star. Binary stars, as defined, represent the combination of two stars orbiting each other around a common barycentre. A barycenter represents the foci of the common combined mass of two objects. Below is the actual image of Charon in orbit around Pluto, and the wobble is apparent.

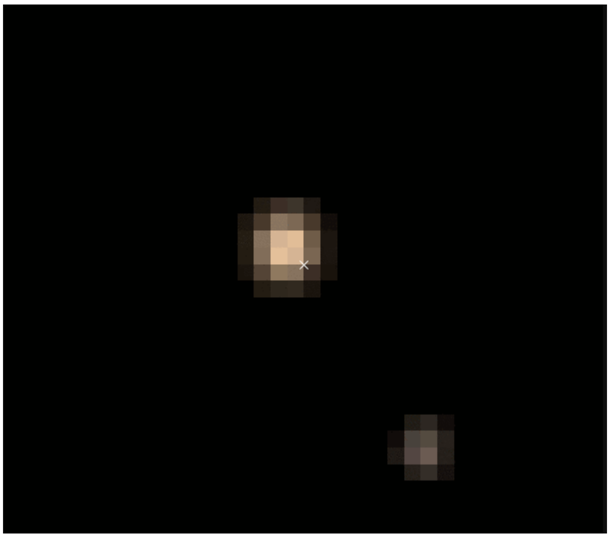


Figure 5: This short clip visually represents the actual wobble of Pluto as it is orbited by its moon Charon Source: JHUAPL, LLC. (2021)

The movie in *Figure 5* is barycentric, meaning that Pluto and Charon are shown in motion around the binary's barycenter – the shared center of gravity between the two bodies as they do a planetary jig. (JHUAPL, LLC., 2021) Because Pluto is much more massive than Charon, the barycenter (marked by a small “x” in the movie) is closer to Pluto than Charon. The illustration provides an evident wobble of Pluto, and that is an apparent and measurable change. The variance is noticeable in the GIF, now take that and encompass the same theory to a star system, and in the case of TYC 3413-242-1, there is the possibility that the stars, or the host’s planetary partner, a possible exoplanet, are astronomically close to each other, meaning there is no visible difference when viewed optically. Thus, the required photometry to best measure warrants further discussion to be covered more thoroughly in this paper.

Terrestrial-Based Telescopic Discovery

Numerous optical telescopes based terrestrially remain quite capable of discovering and classifying exoplanets. According to the European Southern Observatory, TRAPPIST South is a brilliant example of a highly successful terrestrial-based telescope, with multiple exoplanets discovered at hand. *Figure* ***6*** below shows one of many small aperture telescopes in use for exoplanet and transit discoveries.

FIGURE 6: TRAPPIST SOUTH
Credit: E. Jehin/ESO

The observatory experiences clear skies and still stable air in the high skies of the Atacama Desert. Since 2000 the Sloan Sky Digital Sky Survey (SDSS) uses a wide-field 2.5 m telescope at the Apache Point Observatory in Southern New Mexico. Using a 60-fiber interferometric spectrograph to measure the range of high-precision radial velocity stars, the SDSS moved into a new observation phase in 2012 – in the search for exoplanets and brown dwarfs (Ahn *et al.* 2014). Within the SDSS, the Apache Point Observatory Galactic Evolution Experiment (SDSS-III, 2010-2013) has been used as a near-infrared high-resolution method for analyzing significant Galactic stellar populations (Cunha *et al.*, 2017; Zasowski *et al.* 2013; Majewski *et al.*, 2017).

This has helped create the largest high-resolution (*R* ~ 22,500) spectroscopic map of the stars across the Milky Way, including many dust-obscured areas (Perez *et al.* 2006). Although the

AOPGEE line list has given comprehensive coverage of atomic and molecular H-band lines, it remains highly impacted by the apparent absence of direct measurements of *gf*-values under laboratory conditions (Wahlgren *et al.,* 2008). This absence has created a large number of uncertainties and impacted the accuracy of predictive values. Observational behaviors, therefore, have been highlighted in previous literature as an essential future research venture – particularly concerning observed behaviors, which are functions of stellar parameters and metallicity (Cunha *et al*., 2017).

Many small aperture telescopes provide tremendous and opportunistic observations. Location plays a significant role because smaller telescopes are as reliable as their larger counterparts related to their resolution of photons. Ultimately, the measurement of these photons occurs as they arrive at the telescope and is then calculated digitally, using a Charged Coupling Device, or CCD. Technological advancements of observational equipment, along with the ability to create optics with tremendous accuracy, enable photometry to measure the most subtle of changes in light and emissivity of a star, particularly as an object passes in front of and in between the line of sight of an observer and the object being studied.

In the pursuit of the study of this star, TYC 3413-242-1, *Figure 7* below

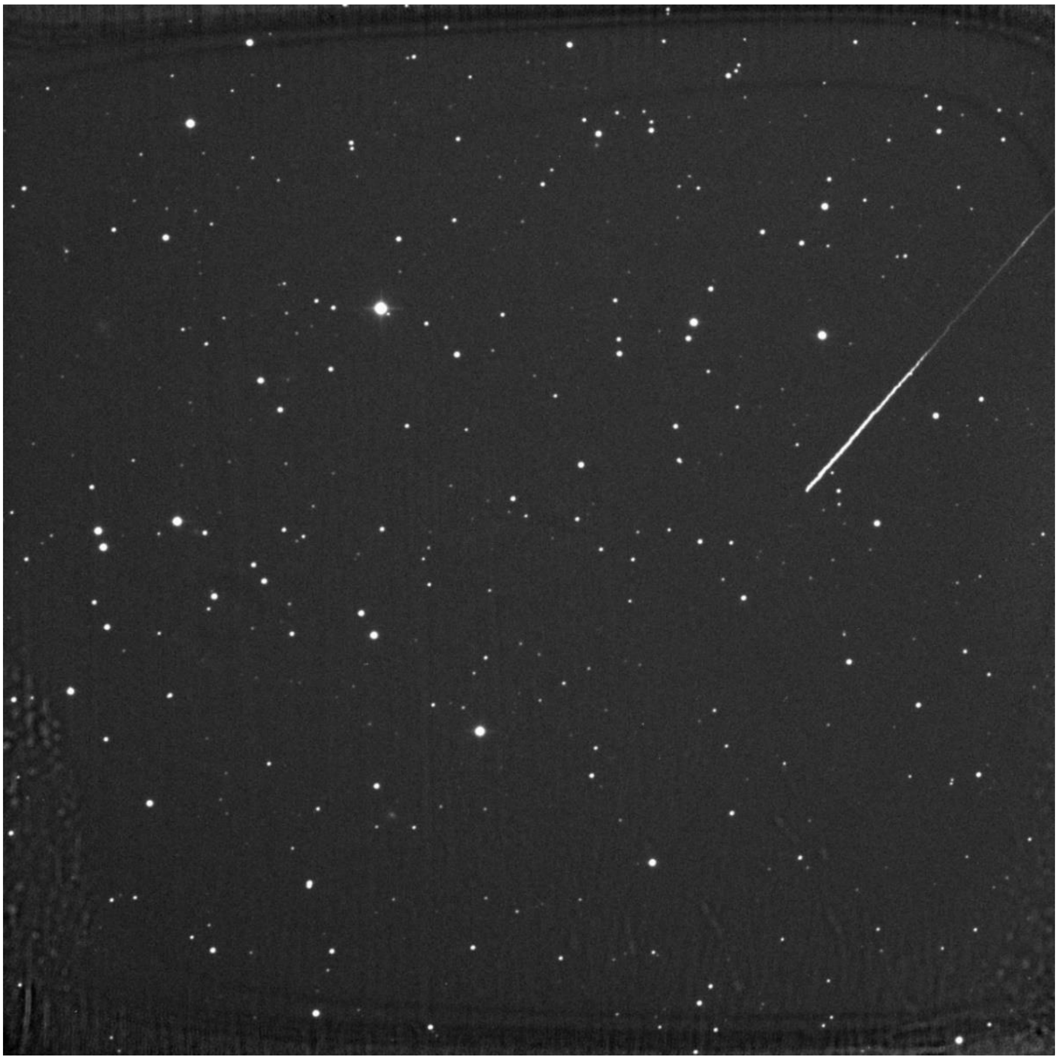


Figure 7: An actual Image Plate from the TYC 3413-242-1 image set produced by the APUS PlaneWave observatory, April 2020
Image Credit to Dr. Kristen Miller.

was produced using the American Public University System's telescope during an observation run by APUS Astronomer Dr. Kristen Miller on April 2 through April 3, 2020. *Figure 8* below is a photo of the APUS Telescope.

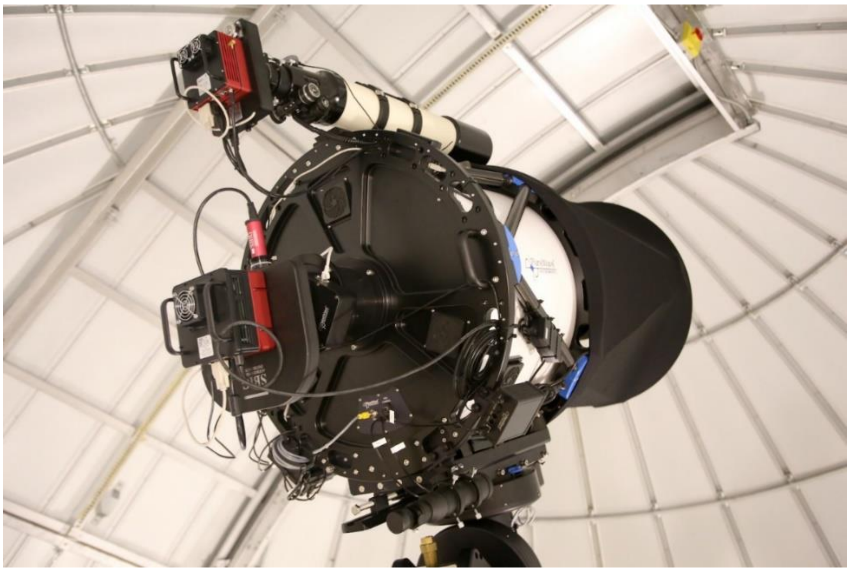


Figure 8: PlaneWave Telescope at APUS Observatory
Credit: PlaneWave Telescope Corporation

The observatory consists of the following equipment:

- Ash dome; 22.5′ diameter with hydraulic lower shutter and slip rings for continuous power to the dome.
- Dome automation system.
- PlaneWave Ascension 200 mount with eight (8) 40 lb. counterweights and one (1) 18 lb. counterweight.
- PlaneWave CDK24 (24″, 0.61 m) telescope with Hedrick focuser and Delta-T dew prevention system.
- Tele Vue NP127is (5″) refractor with Focusmaster motorized focuser and 1-micron fine indicator.
- SBIG STX-16803 camera with FW-7 seven-position filter wheel, Astrodon filters, Astrodon Off-Axis guider (MMOAG), and SBIG remote guide camera.

- SBIG STT-8300 camera with FW-8G eight filter wheel with internal guide camera and Astrodon filters.
- Remote power switches for the A200 mount and telescopes + accessories.
- Foscam webcam for monitoring activity inside the observatory.
- WeatherSTEM system for capturing weather information at the observatory.
- WeatherSTEM Cloud Camera for a general sky view at the observatory.
- Technical Innovations / AAG cloud sensor for monitoring sky conditions and controlling dome shutter automatic closure.
- SBIG All-Sky camera for detailed sky monitoring.

Spectroscopy

Integral field spectrographs remain essential technologies for exoplanet imaging as they can offer spectral analysis in high-contrast environments – helping to improve planet detection sensitivities through spectral differential imaging (Skemer et al., 2015). The ALES, Arizona Lenslets for Exoplanet Spectroscopy (ALES) is the world's first AO-fed thermal infrared integral field spectrograph, mounted inside the Large Binocular Telescope Interferometer (LBTI) on the LBT has been included in contemporary research as a new approach to fundamental field spectrograph analysis – demonstrating a capability of imaging exoplanets from the 3-5 micron wavelength range and ultimately extending the ability of researchers to characterize self-luminous exoplanets (Skemer et al. 2015).

When managing databases of exoplanet registration – key descriptive parameters must be addressed. The rapid improvements to data-processing methods have created more candidates for exoplanet status (Borucki *et al.*, 2011), so the consolidation and analysis of existing databases are essential. For example, previous research has demonstrated the importance of cerium in the study of solar metallicities – an element produced predominantly due to the slow capture of neutrons (s-process) during asymptotic giant branch star evolution' (Cunha *et al*. 2017, p.1). In observations of gas-enveloped planets, it has theorized as the main host planets for metal-rich stars – suggesting that host start metallicity can be used as a proxy for estimations of disk solid surface densities (Dawson *et al.*, 2015).

Understanding the limitations of existing theories and assumptions – mainly used in predictive analysis of potential exoplanet systems and stars – is essential in establishing robust terrestrial-based telescopic databases. For example, Curiel *et al.* (2020) cite the occurrences of giant planets around Ultracool Dwarfs (UCDs) as an essential observational constraint for planet formation theories. In observations of M-type dwarf stars, the active magnetism and common superflares produce vast coronal mass ejections (CMEs), observed in a series of previous research (Armstrong *et al.*, 2016; Vidotto *et al.*, 2011; Argioffi *et al.*, 2019). These CMEs can create direct threats to exoplanet atmospheric composition – a critical sustainability constraint to terrestrial exoplanets and potentially habitable zones (Samara *et al.*, 2021). However, these phenomena are difficult to observe due to the fainter magnitude of CMEs compared with the brighter solar photospheric disk (Samara *et al.* 2021) – with magnetic activity from stars up to x10 higher than the CMEs (Argioffi *et al.* 2019). CMEs make observational analysis using conventional terrestrial telescopic systems difficult.

Research has also shown that in single planetary systems, planetary-mass is independent of stellar metallicity (Gurumath *et al.*, 2017), which contradicts previous research that had emphasized the association of metallicity in low-mass stars and the association with low-mass, small-radii exoplanets (which had been discussed in Schlaufman & Laughlin, 2011). As a result, there is a requirement for researchers to continue to provide observational datasets to digital databases, to improve understanding of a range of planetary systems, and supplement existing research and established hypotheses. Utilizing photometry from Pan-STARRS 1 and 2MASS, Green *et al.* (2019) were able to present a new three-dimensional mapping of dust reddening, inclusive of *Gaia* parallaxes – improving the ability of researchers to estimate distances more accurately to nearby stars. Furthermore, helping support evidence for using terrestrial-based telescopic efforts to support the search for exoplanets and the digital databases that hold these datasets.

The accelerated rate of exoplanet discovery since the mid-1990s supports a range of terrestrial and space-based survey data (Pope *et al.* 2020). Despite this, until 2020, attempts to detect exoplanets and their host stars at radio frequencies (e.g., Murphy *et al.* 2015; Lynch *et al.* 2018; Bastian *et al.* 2018) had not provided possible – with non-flaring emissions proving too faint for most low-frequency telescopes van Haarlem *et al*. 2013; Curiel *et al.* 2020; Pope *et al.* 2020). However, over the last two years, advancements in observational methods have continued at pace, and significant developments have been made in facilitating more effective detection techniques at these lower frequencies. Curiel *et al.* (2020) introduced observational methods which facilitated the first astrometric detection of a planet at radio wavelengths. The theory supports the notion that exoplanets can be explored and identified utilizing existing terrestrial-based telescopic systems.

Reviewing this research provides evidence gaps across the current databases, particularly the observational record, which can be supported through databases such as the Sloan Digital Sky Survey, the NSASA Exoplanet Catalogue, and the Open Exoplanet Catalogue. The complexities of observational analysis of exoplanets continue to provide strong justification for the maintenance of digital databases. These databases are essential in providing the necessary collection, collation, organization, and scrutiny of exoplanet discoveries which continue to rise exponentially (Christiansen, 2018).

Exoplanet Exploration Catalogues

Analysis of 1235 planet candidates by Howard *et al.* (2012) - building on the exoplanet catalog developed by Borucki *et al.* (2011) and the additional 1091 planet candidates presented by Batalha *et al.* (2013) as part of the Kepler database - has provided a good sample set for estimates of exoplanet occurrence rates, helping to improve the stellar parameters for many target stars (Dressing & Charbonneau, 2013). The results of the Kepler mission have ultimately helped to provide an improved understanding of the frequency and properties of planets in the Galaxy and provide more substantial constraints on models of planet formation (Boruki *et al.*, 2011; Ford *et al.*, 2011; Shlaufman & Laughlin, 2011). Howard *et al.* (2012) also found evidence from analysis of 1235 planets observed as part of the Kepler mission that planets with orbital periods of <2 days are scarce, and more minor planets are x7 more abundant around cool stars (3600-4100 K) when compared to some of the hottest stars within this sample set (6600-7100 K). Reviewing these catalogs against the estimated temperatures, radii, and surface gravities from Kepler Input Catalogue (Brown *et al.* 2011) against the values which are predicted from the Yonsei-Yale evolutionary models (Dermarque *et al.* 2004) has revealed difficulties in characterizing some of these stars (particularly the coolest target stars) because starting points were often too far removed from actual space temperatures, radii and also the known surface gravities (Dressing & Charbonneau, 2013).

Both gas giant planets and brown dwarfs radiate away residual heat from their formation, cooling through a spectral type of transition from L to T. This range encompasses the dissipation of ‘cloud opacity and the appearance of strong methane absorption’ (Skemer *et al.* 2016, p.1). Planets with sizes between Earth and Neptune are most commonly divided into those pure rocky bodies with negligible atmospheric contributions to their overall size and the larger gas-enveloped planets, which have optically thick atmospheres that can be viewed as a contributing factor to their overall size and dimensions (Dawson *et al.* 2015). The first directly imaged exoplanets were all in the L-type range. However, improved analytical and observational methods of known star systems provide new opportunities for detailed analysis of exoplanet atmospheres and potential surface properties (Skemer *et al.*, 2016). Facilitated by recent improvements in the observational capabilities of many terrestrial-based telescopic systems evolved to the point where potential terrestrial planets can now be more confidently predicted and detected around M-type dwarf stars (Samara *et al.* 2021).

Recent research has found evidence that suggests that Kepler exoplanet host stars are preferentially metal-rich – confirming initial tentative hypotheses that there is an apparent correlation between the metallicity of low-mass stars and the association of low-mass and small-radius exoplanets (Schlaufman & Laughlin, 2011). Continued focus on spectroscopic classification of exoplanets has previously been deemed impractical because of the many stars that need examination across a large sky area for practical exoplanet analysis (Brown *et al.*, 2011). Instead, methods such as broadband photometry augmented by custom filters to improve sensitivities to surface gravity and metallicity have been suggested as a more appropriate method for exoplanet analysis (Brown *et al.*, 2011). Higher signal-to-noise ratios have also been used to analyze brown dwarfs to improve understanding of potential exoplanet characteristics (Skemer *et al.* 2016) – with observations of the mid-infra-red wavelength are suggested as a potential mechanism to break the degeneracies in model parameters (Skemer *et al.* 2015). Despite this, there are difficulties in using predictive model approaches to exoplanet identification and maintaining an accurate database record of their properties (Dressing & Charbonneau, 2013).

Light Curve Analysis

The discovery of transiting exoplanets has motivated considerable efforts to produce high-quality light curves that can be used to discover more about these systems (Maxted, 2016).

Light curves have been defined as the 'measurement of a celestial body's brightness at certain intervals over a given period' (NASA, 2017). These types of photometric observations of exoplanet transits can be used to derive information about exoplanets' orbital and physical parameters (Davoudi *et al.*, 2020) – and thus can make significant contributions to the initial verifications of these celestial bodies. Significant advancements in instrumentation, observational techniques, and a range of analytical methods to examine the data produced have ensured that eclipses with depths as small as 600 ppm on individual targets can now be detected with improved certainty (Delrez et al., 2015). Ground-based surveys utilizing light curves developed using telescopes such as WASP (Pollacco et al., 2006) and HATNet (Bakos et al., 2004) have been able to discover transiting exoplanets with eclipse depths of around 1% (Maxted, 2016). This continues to outline the potential of ground-based survey analysis to make significant contributions to exoplanet discovery.

The precision obtained shows that routine software analysis can be used to support follow-up investigations and produce observational results comparable to the values at the NASA

Exoplanet Archive (Davoudi *et al.*, 2020). High-quality light curves are now widely available, cataloging thousands of transiting exoplanets because of continued exoplanet and large-scale photometric surveys (Maxted, 2016). These curves have also helped identify many detached eclipsing binary stars (Maxted, 2016) – an important consideration when looking at the accurate identification and verification of new exoplanets.

Of the 2000 exoplanets in more than 1200 planetary systems, 100 are in binary-star systems, and over 20 are located in multiple-star systems (Schwartz et al., 2016). The number quoted here of 2000 is less than half of the now 4600 plus discovered exoplanets, of which most remain unconfirmed. Much of the observational evidence collected in these systems has indicated that many of these systems contain planet-forming circumstellar or circumbinary discs – with researchers suggesting that this provides strong evidence that planet formation is a common phenomenon around binary stars (Trilling et al., 2007). As a result, many research groups have examined planetary formations and evolution and dynamic stability in binary star systems (Mazari and Augereau, 2010; Andrade-Ines *et al.*, 2016).

Methodology

The methodology section outlines the theoretical approach for this research – outlining the main imaging techniques used, the telescopic system set up and subsequent analysis, and the software toolkits and imaging software used to verify the findings. An overview of the current cataloged data is provided to support the verification processes adopted in the research and an overview of the primary data analysis.

Theoretical Approach – Imaging

One of the critical aspects of the methodological approach was verifying the images obtained to establish if they could confirm the presence of the exoplanet. The data produced in previous surveys of transiting exoplanets has created a strong rationale for using terrestrial-based telescopic systems to analyze exoplanets, variable stars, and eclipsing binary stars. In some exoplanet verifications, years of images are cataloged to time the entry of a transiting exoplanet in front of its host star and exit. That simple data enables accurate estimates of a transiting planet's size if the host star’s radius is known. Doppler imaging has previously been used to produce 2D global maps of rotating objects using high-dispersion spectroscopy (Crossfield, 2014). When the Doppler analytical technique has been used to imagine brown dwarfs and extra-solar planets, several constraints were noticed related to global atmospheric dynamics and magnetic effects (Crossifeld, 2014). This research has looked to adopt analytical approaches that may overcome these limitations by utilizing software packages that have previously been demonstrated to identify and verify exoplanet discovery.

Telescopic System Set-Up and Analysis and Software Toolkit

One of the critical parameters in the methodological setup was in establishing the telescopic parameters. Setting clear parameters ensures the research is repeatable and more easily verified. Critically the lens through which exoplanetary systems are explored creates a known bias around the perimeter space that is visible. In previous research, Doppler and transit techniques have been used preferentially to detect planets that orbit close to their host stars or are more significant in mass or size, in contrast to the microlensing and direct imaging approaches, which are more commonly used when identifying planets in wider orbits (Fischer *et al*., 2015).

Discrete source images are unresolved at typical telescope resolutions (Perryman, 2010). In the specific domain of interest for exoplanet detection and discovery, the system (including the host start and the planet) acts as multiple lenses. A more distant star within the Galaxy can act as a source point (Perryman, 2010). The changing magnification of the sub-images due to the time-varying alignment of the observer-lens-background source has previously resulted in significant intensity variation (Perryman, 2010). This changing intensity of various temporal scales allows the event to be recognized as a microlensing event – providing a framework for the light curve analysis, which is conducted as these alignment changes over several hours (Perryman, 2010). Ultimately this microlensing process allows for the detection and characterization of planetary systems – however, it requires precise alignment of the observer, source, and lens (Perryman, 2010). The photometric detection of exoplanets using this approach has also been of particular interest in the discovery of eclipsing binaries (Schwartz *et al.*, 2016).

Within the analysis of exoplanets, photometric effects can be measured using the Doppler shift of stellar spectral lines (Maxted, 2016). Doppler imaging produces two-dimensional shapes of the rotating objects observed using high-resolution spectroscopy – exploiting the varying Doppler shifts across the rotating object (Perryman, 2010). The variation in the fluxes observed in previous studies has been attributed to Doppler boosting the light from different parts of rotating stars during an eclipse (Maxted, 2016). This Photometric R-M effect needs to be considered when analyzing the datasets produced. *Figure 9* below, The Rossiter McLaughlin Effect, represents a transit across the star, creating the signature radial velocity effect of the light as it transits in front of and then behind the star. *Figure 9* gives a graphical representation of the R-M Effect. (Triuad et al., 2018)

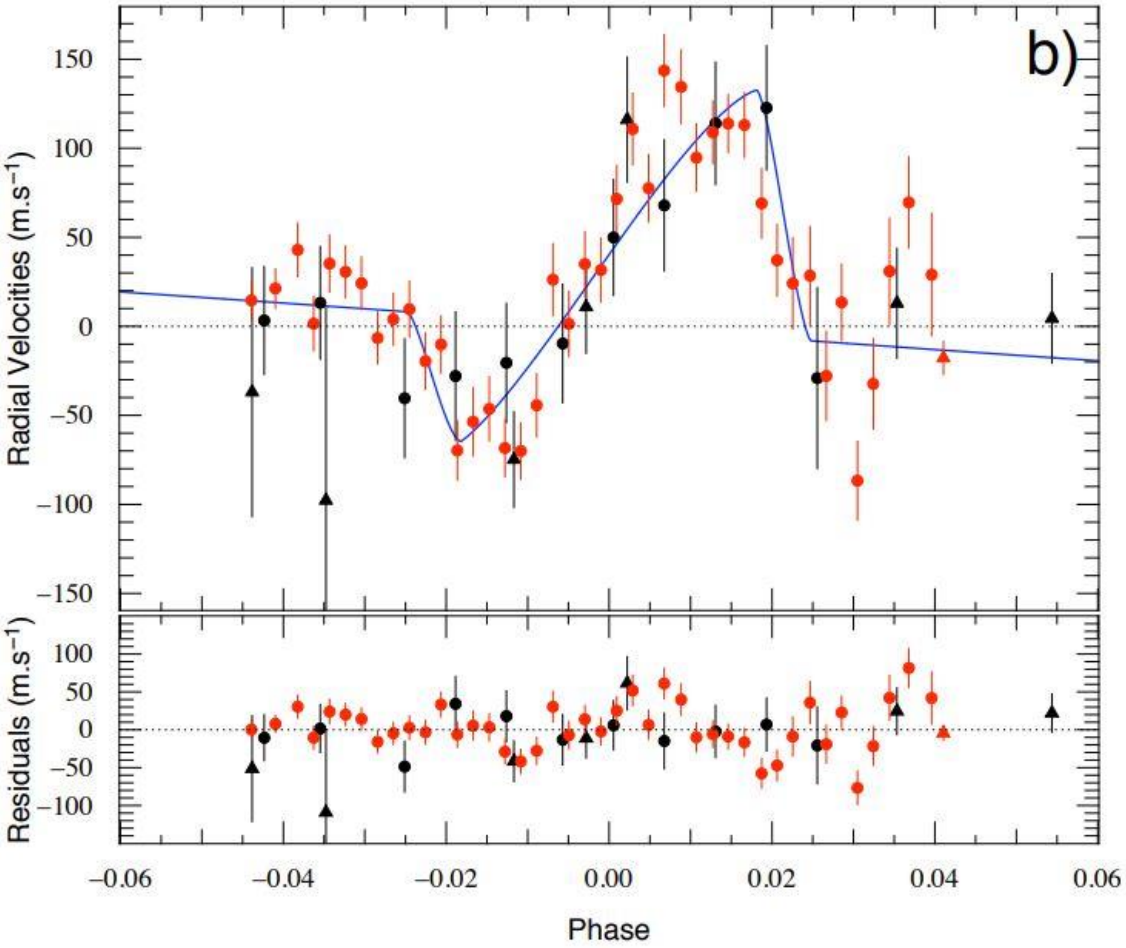


Figure 9: Example R-M Effect on WASP Star
Source, Tiuad, et al., 2018

Using a standard terrestrial-based telescope, a 60 cm Planewave CDK Telescope with a CCD, Charged Coupled Device allows for profound sky object observations. This telescopic system is relatively small compared to many other arrays which are used in exoplanet discovery. However, it is possible to confirm exoplanets using even smaller aperture telescopes, resolving photons from distant stars. Previous discoveries at the 60cm robotic telescopic system at La Silla Observatory in Chile have found three verified exoplanets orbiting a dwarf star just 40 light-years away using TRAPPIST datasets. The finding suggests that further research into using this size of the telescope to support the search for exoplanets further is valid. Further research should develop a more comprehensive catalog of small telescope-based search surveys for these types of objects.

The telescope used in this research uses a suite of software that allows for object identification and tracking. Astronomers studying exoplanets perform numerous observations of the same object over many hours. In some exoplanet verifications, years of images are cataloged to time the entry of a transiting exoplanet in front of its host star and exit. That simple data enables accurate estimates of a transiting planet's size if the host star’s radius is known. Based on the findings overall, it is presumed, as stated in Hypothesis, the data and research will show a significant advantage in using terrestrial telescopes less than one meter in width is an entirely reproducible endeavor. Of course, much relies on the timing of the transit, the telescope location, and, quite literally, the luck of good sky for precise observations.

Image Processing

Graphical user interfaces for the processing of telescope imagery are a fundamental part of creating a robust and replicable methodological framework. Previous research has used the AstroImageJ (AIJ) user interface (a Java-based software package) for general image processing in astronomy-based image display (Collins *et al.*, 2017). The AIJ software model was adopted within the research to identify all the data points accurately (within the standard deviation of <1 margin of error). Light curve analysis was a critical area of analysis within this research to enable an accurate analysis of the area of interest, particularly in determining the existence of a transient exoplanet from its host star. Measuring the decrease in emitted light from a host star as the shadow of the exoplanet is cast in the observer’s direction light curve analysis can help provide more definitive identification of a transient exoplanet. AIJ is a widely available software package using computational language parameters, enabling rapid data analysis by constructing light curves. Previous analysis of exoplanets using several transient light curves successfully demonstrated the precise values of these orbital and physical parameters using the AIJ (Davoudi *et al.*, 2020). The AIJ software demonstrated good capabilities in creating light curves for this research and helped overcome many of the prohibitive costs associated with the search for exoplanets and limiting the reliance on the use of larger array telescopes and facilities, which can significantly impact and reduce research time.

TYC 3413-242-1 – Cataloged Data

The use of a known method to locate and confirm exoplanets (transit photometry) has been detailed in previous research in discovering an exoplanet in orbit around a cataloged star (Fischer *et al.,* 2015). The focus of this research is to verify and catalog a potential exoplanet in the Lynx Constellation. TYC 3413-242-1 is a star originally cataloged in the Tyco-2 catalog using the Hipparcos Satellite (Hog *et al*. 2000); however, it has also more recently been added to the Gaia 2018 survey (Everall, 2018). TYC 3413-242-1 was observed using a 60 cm Planewave Telescope based in Charles Town, W. Virginia. It was initially discovered as part of the research designed to confirm a known exoplanet - XO-2b. (Fernandez, J. et al. 2009).

As part of verifying the finding in TYC 3413-242-1, initial observations of XO-2S confirmed a transit of some type at 152.1 pc. The transit is approximately 1,300 light-years and was rediscovered using the AstroImageJ as a part of American Public University, APUS, to confirm exoplanets. Researchers were practicing using the software in the immediate vicinity of other stellar neighbors. The software is technically designed to see the variability of photons and their fluctuation, which works well in locating transiting planets and has significant ramifications in exoplanet research because their light curves can estimate their radii (Perryman, 2010). A small terrestrial-based telescope used to locate a very faint star and possibly an exoplanet in orbit suggests significant opportunities to expand the search for exoplanets beyond what was initially anticipated during the initial research framework. Refining this model for near-system exoplanet identification may improve understanding of how exoplanet discoveries can be widened using small terrestrial-based telescopes. The use of terrestrial telescopes has been a significant source of exoplanet detections, but the truth is the space-based telescopes are the primary source of initial discoveries. Verifying and validating these discoveries will create the fundamental component of this research. Do initial findings using the terrestrial-based telescopic system accurately identify an exoplanet and the possibility of other transiting occurrences, including variable stars or the existence of a previously undetected eclipsing binary star system? The answer lies within the use of data gathered systematically and without the aberrations of and contributory factors that prohibit findings and their confirmations.

Data Analysis and Results

Research is intended to adopt a single-source approach, including primary observation obtained from the APUS’s Telescope and secondary data sets of TYC 3413-242-1. The study's expectation covers possible exoplanet in orbit around the star, the significant Flux change related to a potential flaring variable star, or the existence of an eclipsing binary star. Much of the data available is from that of a known exoplanet nearby and comparing the light curve information of Star XO-2S. Fundamentally the hypotheses outlined require the primary data obtained through the observations produced using a small terrestrial telescope. The exoplanets identified as possible candidates within the viewing restrictions of the selected telescopes are to be verified and validated against a known exoplanet catalog and the knowledge that many eclipsing binary stars theoretically exist, yet only a few are confirmed. Eclipsing binary stars remain a terrific source of information. However, when compared against their nearby exoplanet neighbors, they often lead to false-positive identifications. Ideally, the detection of the Flux source encompasses the use of a terrestrial-based telescope. The intervening discussion then focuses on how the perceived limitations of these approaches overcame many of the factors to confirm the three potential findings.

Further analysis of closer stellar systems will be conducted to see if additional exoplanet identification is possible using the same telescopic setup. The examination will follow a mixed-method methodological framework that is inclusive of both qualitative and quantitative data analysis. This thorough examination includes discussions concerning the main theoretical background to existing findings and the quantification of current limitations and bias associated with the use of small terrestrial-based telescope systems.

Figure 10 below; image sets obtained from the APUS observation on April 2 thru 3, 2020, note a drop in Flux, when the data is aligned and charted in Microsoft Excel, through creating a light curve. Flux is defined as the number of photons reporting to the telescope’s CCD over time. The reduction can be one of three things, an exoplanet, a variable star, or an eclipsing binary star. Visually, the light curve constructed below represents another similar example of light curves generated from comparable stars nearby. One example is XO2S, a known exoplanet whose light curve is produced from the same image set and is available in **Error! Reference source not found.**. XO2S remains a well-validated discovery. There are surprising similarities, which lead to conclusions and outcomes that question what TYC 3413-242-1 is saying.

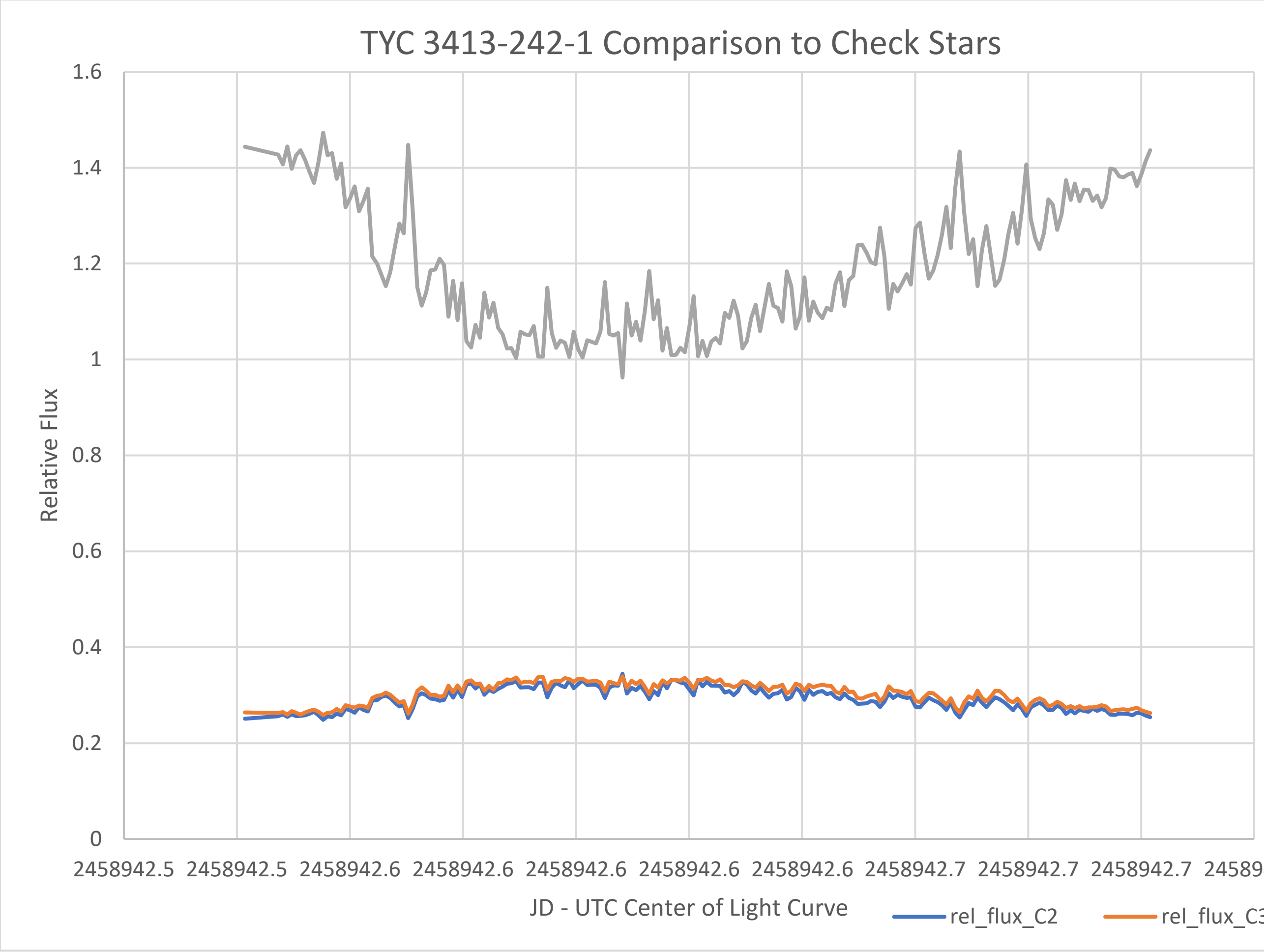


FIGURE 10: TYC COMPARISON TO CHECK STARS IN THE NEARBY FIELD OF VIEW.
Source: APUS Observations from April 2020.

There are some similarities to the light curves presented here, and in the below **Error! Reference source not found.**, the similar dip in Flux from the observations of XO2s and TYC 3413-242-1 is striking. Even the curve trends towards the egress or exit out of the star's emitted light are similar.

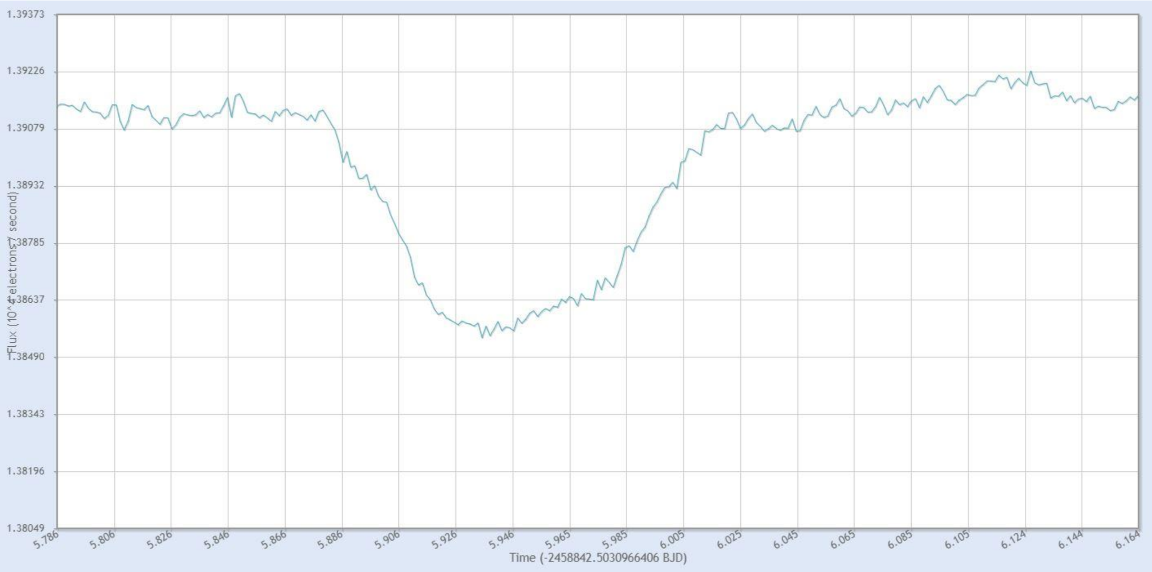


Figure 11: TESS Light Curve for XO-2b Exoplanet
Data Source: MAST Archive, Space Science Telescope Institute.

The effort to better understand the data as it visually represents itself, in *Figure 12: Revised light curve – Using AIJ Ver 3.2 Build 4* below, the apparent ingress and egress, shows that there is the possibility of a transit of an item across the star's disc that begins on the left of the field of view above the 90-degree intersection of the equatorial line on the star's disc and finishes or egresses below the 90-degree equatorial line of the disc. It is necessary to visualize the transit by building a light curve interpreting the change in Flux throughout the transit, allowing reasonably accurate measurement of the radius of an exoplanet. First, it is necessary to know the radius and estimate the mass of the stellar partner to interpret the radius of the transiting object accurately. Lastly, one of the interesting parameters that researchers possibly obtain from this observation is the proximity of the transiting object to its stellar host. The light curve built using these assumptions leads the author to firmly believe additional data will shed further detail on this fascinating star.

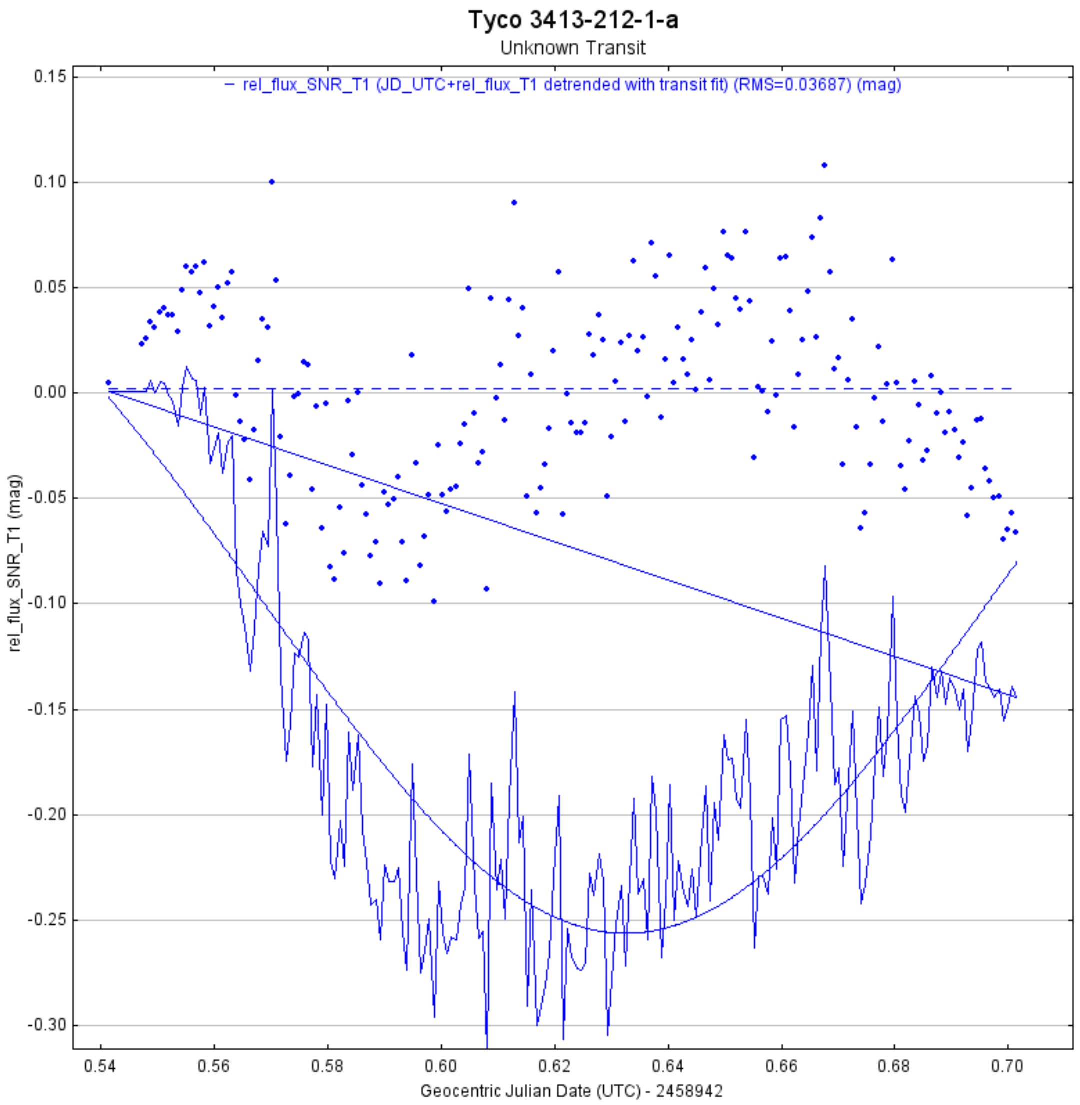


Figure 12: Revised light curve – Using AIJ Ver 3.2 Build 4
The curve here shows an ingress into the star's light decreasing, and the egress is out lower on the disc of the host star.

Further interest in this observation and the light curve produced is warranted. In Paul Wilson's graphical representation in *Figure 13*, the observer has the opportunity to resolve through technical observations the variability of the FLUX as an object transits in front of its stellar host, which may prove that several variables can be answered. Namely, the mass and, more importantly, the radius is determined with astonishing accuracy.

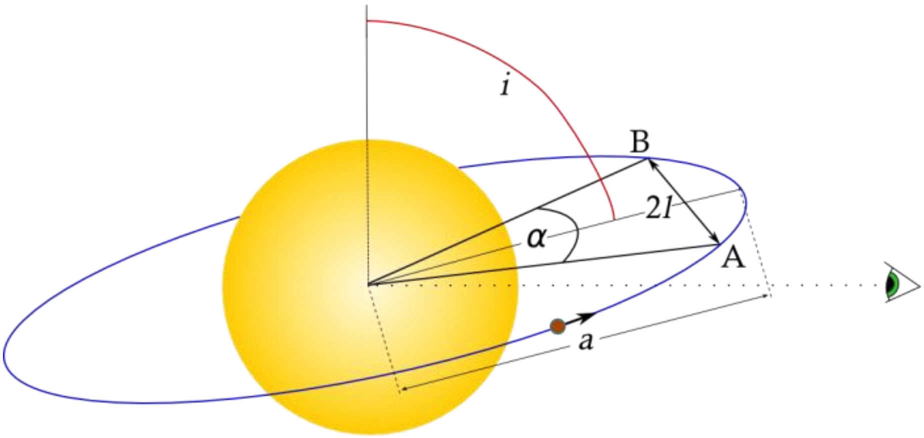


Figure 13: Representation of a transiting exoplanet at an oblique angle to the observer. Credit: Paul Anthony Wilson, at paulanthonywilson.com/exoplanets-detection-techniques

During an interview on 15 July 2020, with Dr. Dennis Conti, Exoplanet Section lead at American Association of Variable Star Observers, AAVSO, Dr. Conti opined, although inconclusively, that Tyco-3413-242-1 is with high probability an Eclipsing Binary star with a low mass stellar partner. (Conti, D., 2021) However, Triaud et al. believe a similar result is obtained with a close-in orbiting hot planet, likely a high mass Jupiter-like planet orbiting around a barycenter inside the Tyco-3413-242-1 Continuous Habitable Zone, also known as the CHZ.

The following Figure below, **Error! Reference source not found.**, is another compelling argument for the possibility of a hot (Hot is defined as close-in orbiting around its host star) Jupiter-mass planet inside the CHZ, creating the apparent wobble of the star, TYC 3413-242-1. *Figure 11* is a TESS Photometry measurement that made a light curve published in February 2020 from an observation produced over 120 days. Data were retrieved from the Space Science Telescope Institute’s Database managed by the Mikulski Archive for Space Telescopes. Interestingly, when the initial Flux/JD time charts were created, the light curves and photometric evidence shown the clear chance that there was a confirmed exoplanet similar to XO-2b and something very similar to an exoplanet light curve and an unknown transit around TYC 3413-242-1. The chart below in *Figure 14* represents the APUS observation from April 2020.

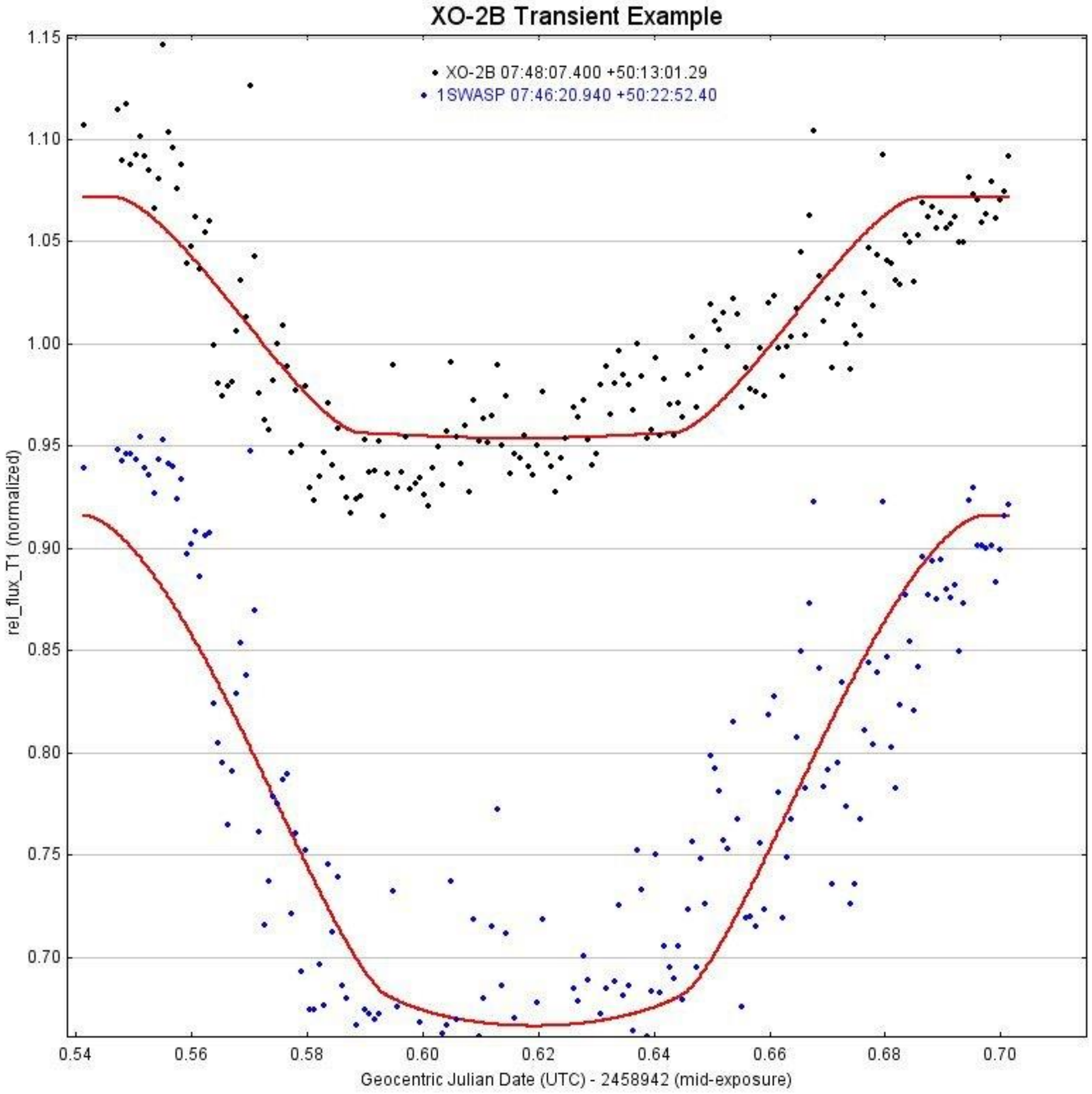


FIGURE 14: LIGHT CURVE PRODUCED FROM APUS OBSERVATIONS 2/3 APRIL 2020
Data Source and Credit: APUS Observatory – Image Created by APUS Student Astronomer - Jason Cushard.

According to Dr. Conti, the flat bottom of the curve for XO-2b indicates an exoplanet. The curve below XO-2b's curve in *Figure 14* above is less flat and thus more indicative of an eclipsing binary or a variable star. Both observations are unrecorded, having not been reported to the AAVSO, which is directly responsible for recording said variable stars, eclipsing stars, and only recently have they opened an exoplanet section.

The image provided in *Figure 15* below is the star investigated in this research and dotted. The star is located at the J2000 coordinates, Right Ascension 07:46:20.940, and Declination, +50:22:52.40. Using the Julian Date Epoch, J2000, an astronomical object's location is determined through the date of the equinox and the date of the epoch, as determined through the website, ascom-standards.org. (2010-2021). The TYC in star question is located near the known exoplanet, XO-2b, which as a part of the APUS Research Study Group undertaking deep learning of exoplanet's observation techniques presented in AstroImageJ and surveyed for confirmation when the possible eclipsing binary, variable star, or exoplanet was observed.

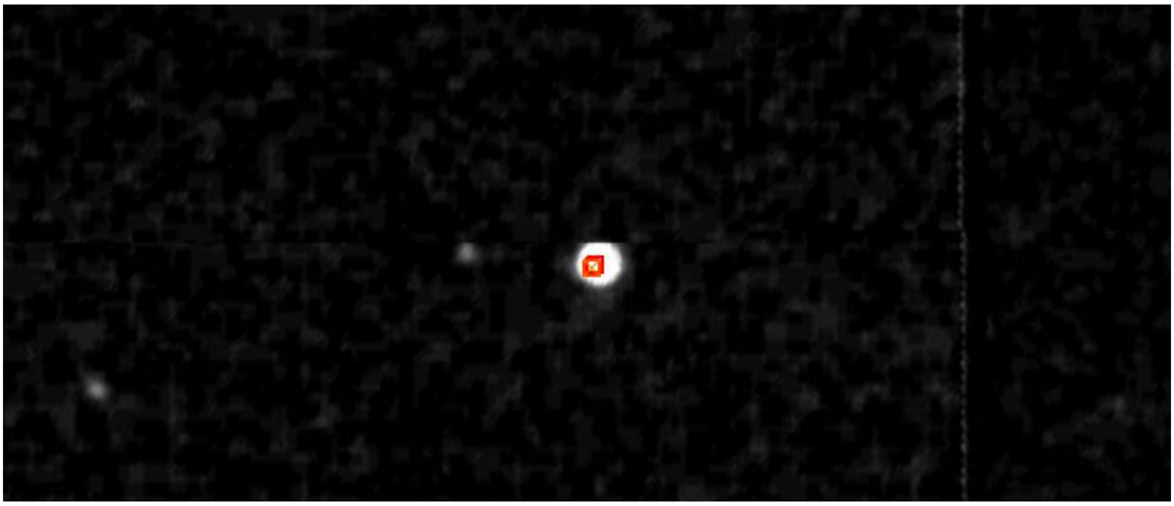


Figure 15: Actual image of TYC 3413-242-1 – Highlighted with the orange dot.
Source: The US Naval Observatory Archive.

Historical Data

A tremendous source of historical data can be found throughout the archives of NASA. But the most functional and perhaps the most frequently by exoplanet hunters and cosmologists. The data is powered by a partnership with the California Institute of Technology (CalTech) and Infrared Processing & Analysis Center" for *IRAS* -- the Infrared Astronomical Satellite, a joint project of the US, UK, and the Netherlands. (IPAC, 2021) It provides single-source access to numerous databases of space and ground-based telescopes. Place a single source right ascension and declination to gather the multi telescope data sources. The archive was used throughout the research on TYC 3413-242-1. The image above in *Figure 15* was sourced from the United States Naval Observatory archive. Again, the single-source information for this paper was drawn from IPAC and the NASA Exoplanet Archive. The exciting part of the data presented in *Figure 15* is that the source is an infrared image, allowing for greater detail of the signal to noise ratio and a more precise FLUX measurement. The noise in and around the photo makes the presentation a bit unclear. However, as faint as it is, the small star to the west of TYC presented a challenge in analyzing the photometry when placing the aperture over TYC. Nonetheless, the data is optimal to have as a source of determining what type of star it is believed TYC represents.

Stars fall into homogenous categories. Many billions of stars are yet to be sequenced, but many millions have been categorized. There are several characteristics of stars that appear identical. The significant part of the equation, in typing stellar properties, astrophysicists, those who understand the dynamics of a star and its inner workings, know a few basic details about a star well. For example, they determine the temperature and the mass of a star which assists scientists in knowing its chemical makeup—and knowing that chemical composition enables researchers to sequence stars knowledgeably based on their characteristics. The below **Error! Reference source not found.** highlights and defines a star's type graphically. The diagram was created independently around 1910 by Ejnar Hertzsprung and Henry Norris Russell and represented a significant step towards understanding stellar evolution. (Young, M., Sky, and Telescope – 2018)

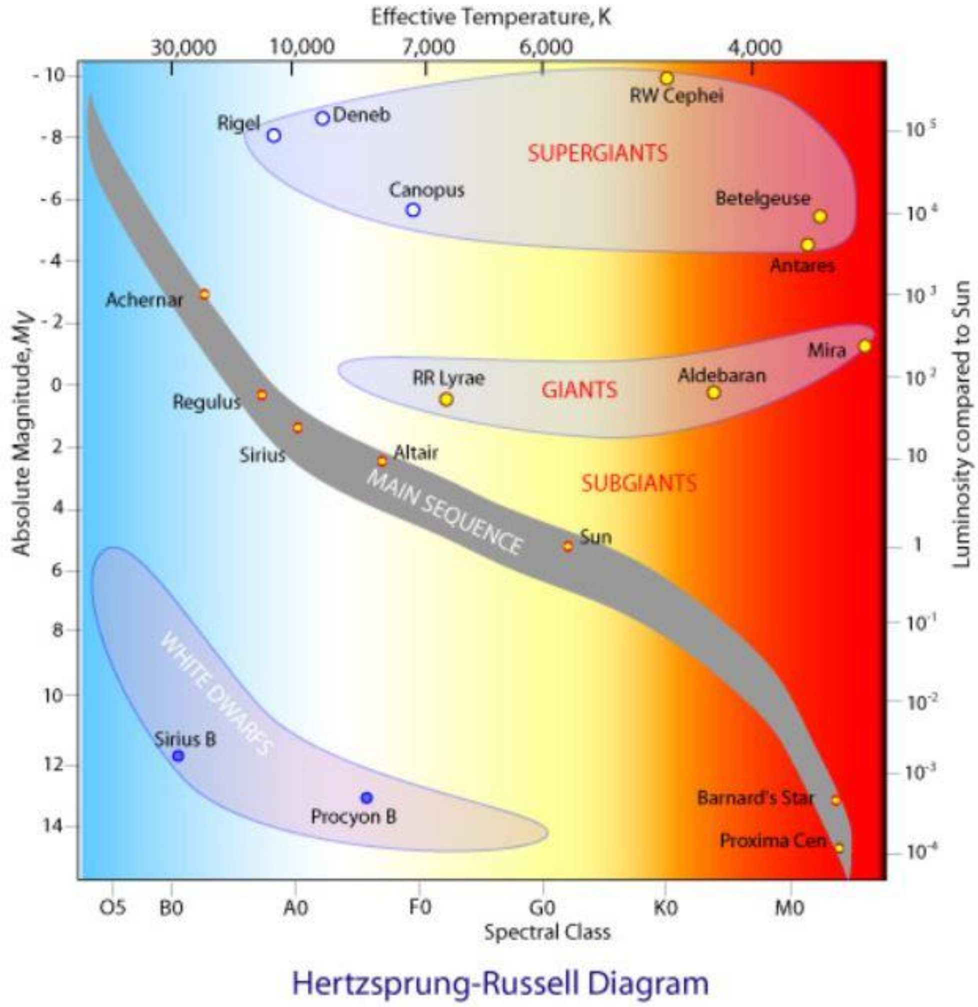


Figure 16: H-R Diagram Shows Estimates of Stars based on their sequencing. Credit: CSIRO The main groups of stars are shown on an H-R diagram.

The image and chart immediately below in *Figure 17* and *Figure 18* represent the actual observation of the star, and a light curve was created using the data drawn from 1SWASP, where the dips and increases in magnitude are evident.

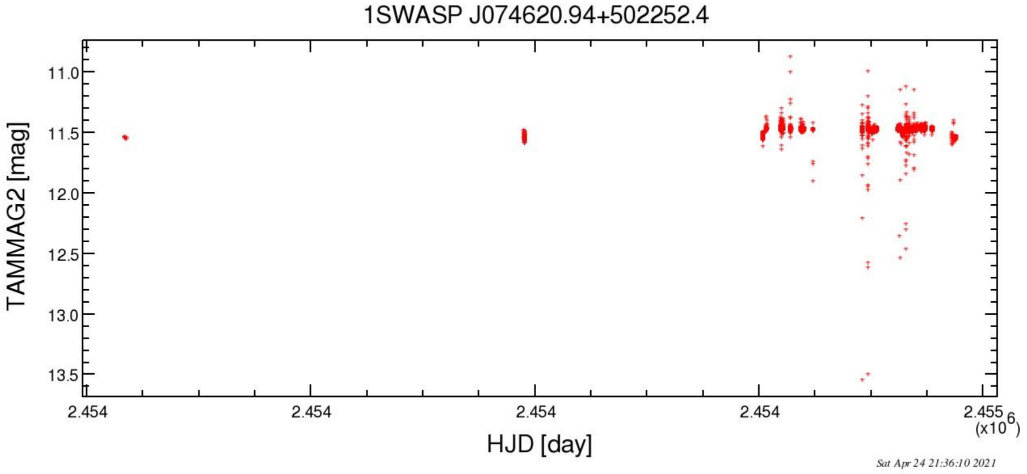


Figure 17: This is a longer-term light curve built over many months.
Source SWASP Data archives

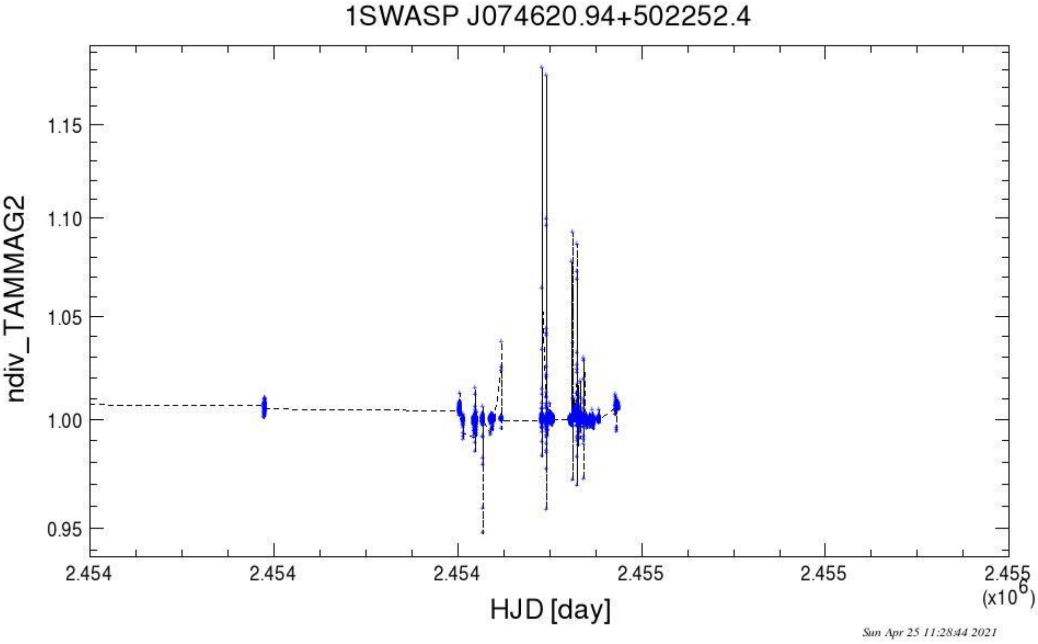


Figure 18: Represents a focused time frame providing a shorter period image of the same data.
Source: SWASP DATA Archive

The confirmation of the anomaly, aberration, or transit that appeared in the original observation of April 2020 continues to manifest itself in the multiple datapoints located in the various archives. *Figure 18*, a light curve developed using an exceptional terrestrial telescope, continued to assist in the process of confirming the data found in the IPAC archive using the telescope, known as the SWASP. SuperWASP is the UK's leading extra-solar planet detection program, comprised initially of a consortium of eight academic institutions. The consortia include many of the finest astrophysical universities in Europe, Cambridge University, the Instituto de Astrofisica de Canarias, the Isaac Newton Group of telescopes, Keele University, Leicester University, the Open University, Queen's University Belfast, and St. Andrews University (SuperWASP, 2021). The SuperWASP (2021) project is currently funded and operated by Warwick University and Keele University. (SuperWasp, 2021) consists of two robotic observatories is a series of observatories, each consist of eight wide-angle cameras that simultaneously monitor the sky for planetary transit events. Here in *Figure 19* below, find the SWASP telescope. The telescopes, designed to provide high-resolution photometry.

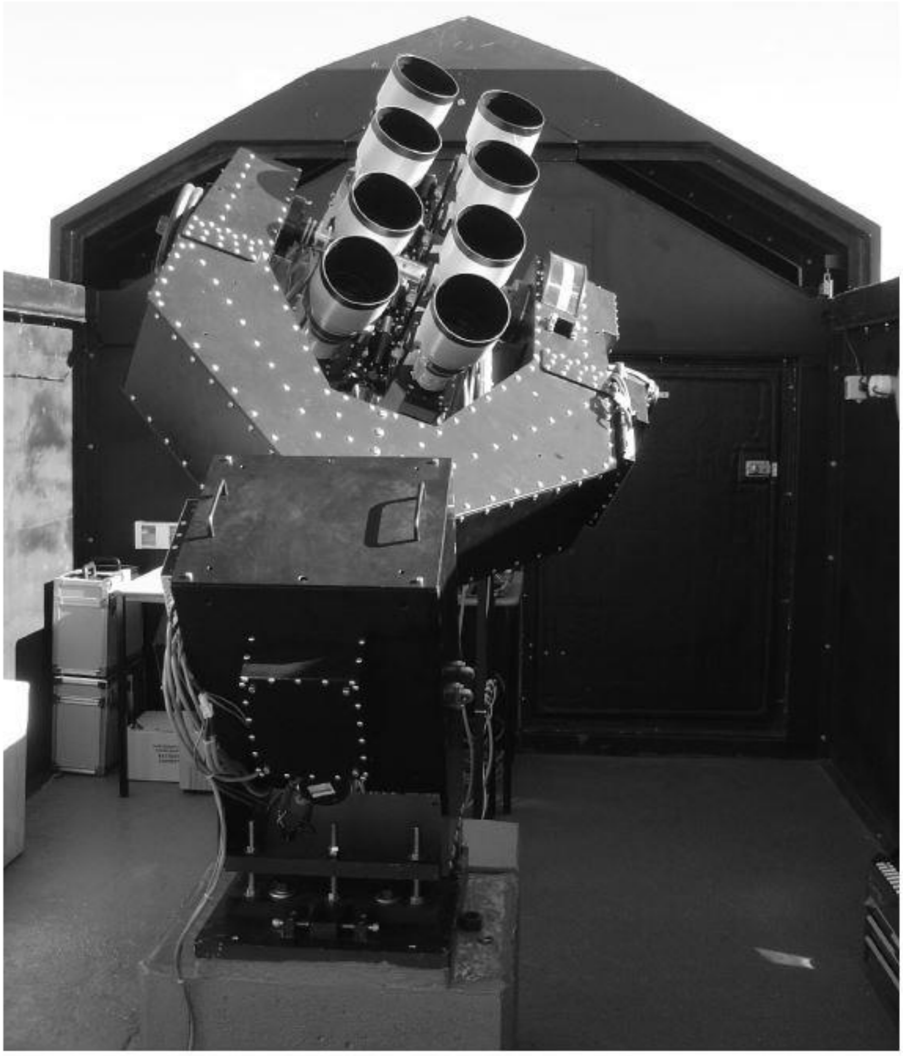


Figure 19: Actual 2017 image of the SWASP telescope.
Credit European Space Agency.

The detection of transiting extra-solar planets, asteroids, and transient events has become a collaboration of several universities, and the star that the SWASP covered, Tyco 3413-242-1, as a possible exoplanet and studied here in this document, was first reported in 2008, in a study by a satellite named Hipparcos. (Wright et al.,2003) The Wide-Angle Search for Planets (WASP) survey operates two installations, designated SuperWASP-N and SuperWASP-S, located in the Northern and Southern hemispheres. (Kane et al., 2008)

Figure 20 represents a clear image provided from the initial observations and indicates the evening of April 2/3, 2020, possessed exceptional viewing conditions, that the words of the professional astronomer and APUS observatory manager on staff at the time, Dr. Kristen Miller. The Images were taken over 198 minutes, using the Planewave 60 cm telescope, and each image is a 60-second observation. The following moves assist in creating a detailed image using dark bias and flat images, allowing for consistency of image quality, including moving the data into software developed to ready photons and the fluctuations, or FLUX. Minimal changes in the charged couple device or CCD image reader are evident and pronounced, appearing in the light curve detailed in **Error! Reference source not found.** and *Figure 14*.

Below, the CCD image shows a prominent star. All 198 images are stacked on each other to showing the variability of image pixelation and change in photons over the three-plus-hour period.

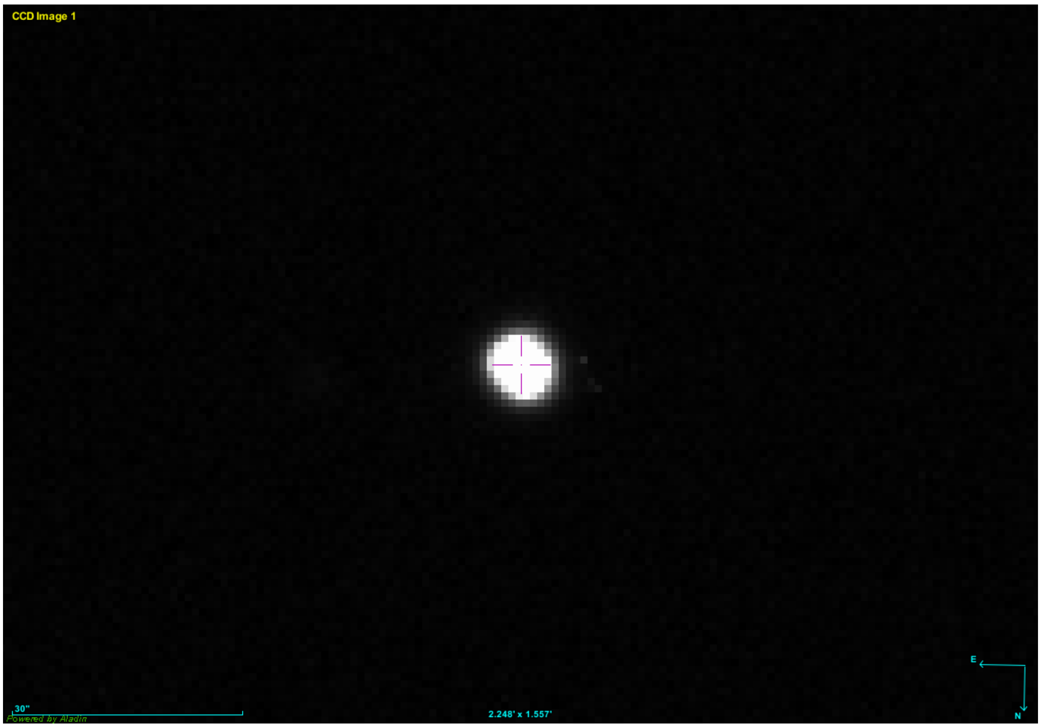
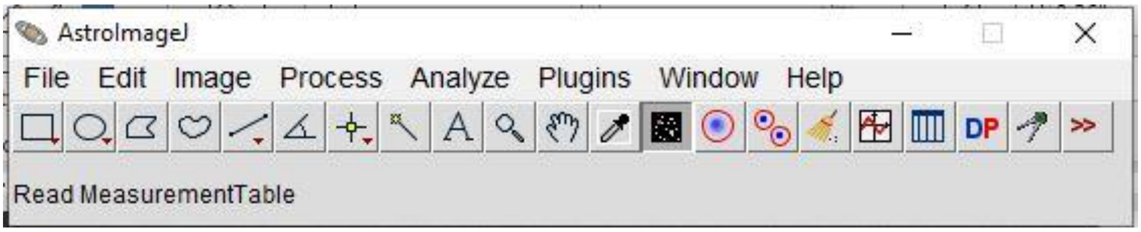


Figure 20: This is the actual image of TYC 3413-242-1 at 1800 light-years, produced by Dr. Kristen Miller – April 2020.
Credit APUS Observatory

AstroImageJ

AstroImageJ is a photometry tool developed in consideration of exoplanet detections. The software is a simple and functional tool that reads photometry increases and decreases in photons that strike a CCD, Charged Couple Device, attached to a telescope, and used to digitize the imagery produced. The below *Figure 21*, *Figure 22, and Figure 23* map out the general distribution of the processes as they begin when building the light curve of a transitory object. In *Figure 22*, key data parameters are added to assist in allowing for the determination of the radius and ultimately the mass of the transiting object



Read MeasurementTable

Figure 21: Represents the header and command panel of the software are used in the production of data-solving light curves.
Credit: AstroImageJ Karen Collins University of Louisville, KY.

rel_flux_T1

User Specified Parameters (not fitted)

Orbital Parameters

Period (days)	Cir	Ecc	ω (deg)
27.99	☑	0.0	0.0

Host Star Parameters (enter one)

Sp.T.	Teff (K)	J-K	R* (Rsun)	M* (Msun)	ρ* (cgs)
M0V	3800	0.840	0.600	0.510	3.150

Transit Parameters

☑ Enable Transit Fit

☑ Auto Update Priors

Extract Prior Center Values From Light Curve, Orbit, and Fit Markers

Parameter	Best Fit	Lock	Prior Center	Use	Prior Width	Cust	StepSize
Baseline Flux (Raw)	0.668255812	☐	0.651816105	☐	0.130363221	☐	0.1
$(R_p / R_*)^2$	0.046362663	☐	0.010524601	☐	0.005262301	☐	0.010524601
a / R_*	57.119684144	☐	49.121695512	☐	7.0	☐	1.0
T_C	2458942.631185462	☐	2458942.6	☐	0.015	☐	0.01
Inclination (deg)	89.329060043	☐	89.4	☐	15.0	☐	1.0
Linear LD u1	0.300000000	☑	0.3	☐	1.0	☐	0.1
Quad LD u2	0.676897018	☐	0.3	☐	1.0	☐	0.1

	b	t14 (d)	t14 (hms)	t23 (d)	tau (d)	ρ* (cgs)	(e)SpT	Rp (Rjup)
Calculated from model	0.669	0.158292	03:47:56	0.064003	0.047144	4.4959	M0V	1.26

Detrend Parameters

Use	Parameter	Best Fit	Lock	Prior Center	Use	Prior Width	Cust	StepSize
☐	Source_SNR_T1		☐	0.0	☐	1.0	☐	0.1
☐			☐	0.0	☐	1.0	☐	0.1
☐			☐	0.0	☐	1.0	☐	0.1

Fit Statistics

	RMS (raw)	chi²/dof	BIC	dof	chi²
Fit Statistics	0.008502	28.747618	5457.4348	192	5519.5426

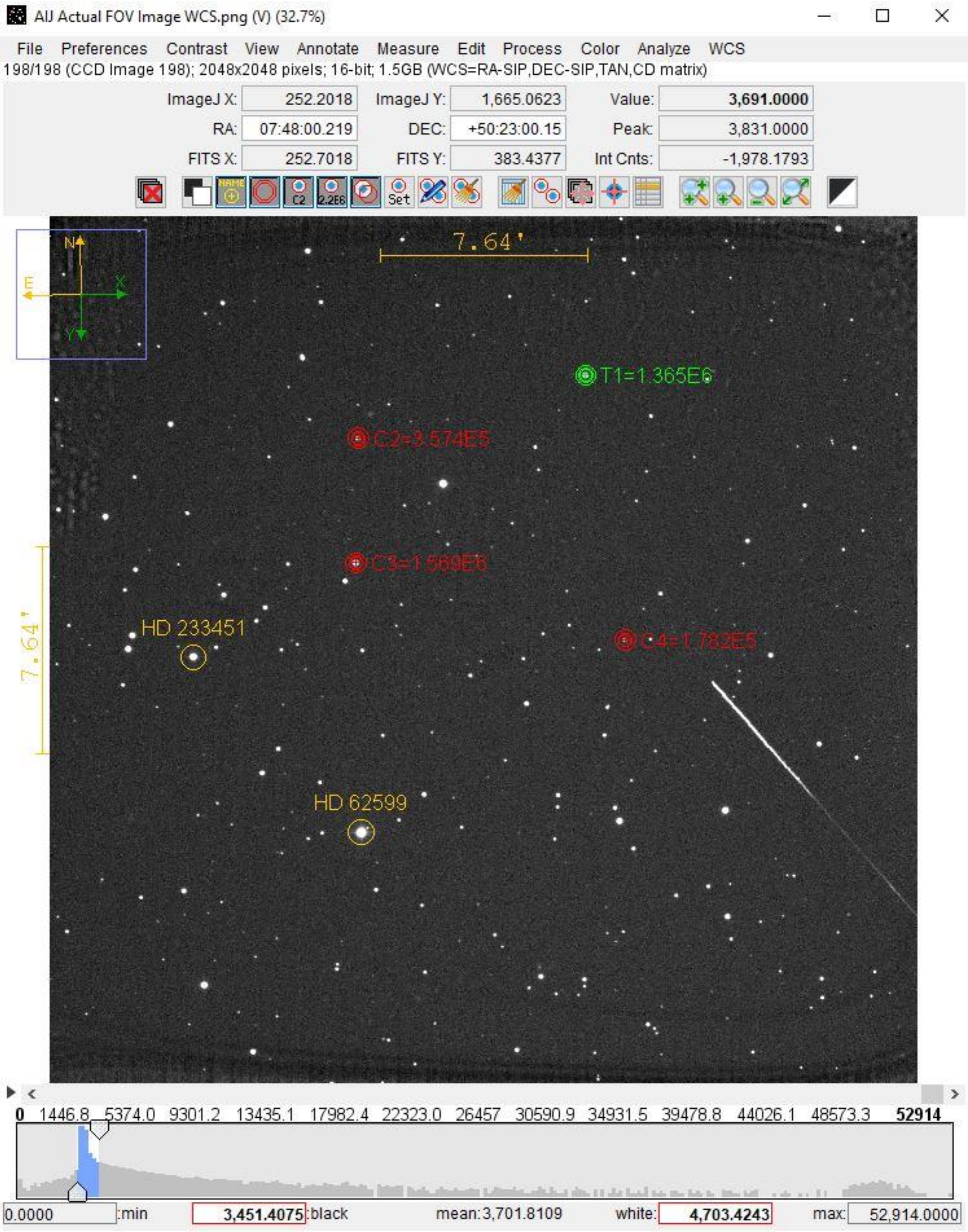
Plot Settings

		Line Color	Line Width	Symbol	Symbol Color	Shift
☑ Show Model	☑ Show in legend	blue	1			
☐ Show Residuals	☑ Show in legend ☐ Show Error	blue	1	dot	blue	0.0

Fit Control

	Fit Update Options		Fit Tolerance	Max Allowed Steps	Steps Taken
Fit Control	☑ Auto Update Fit	Update Fit Now	1.0E-10	20,000	1988

Figure 22: The TYC 3413-242-1 Source Star Data.
Credit AstroImageJ Software, Karen Collins University of Louisville, KY.



AIJ Actual FOV Image WCS.png (V) (32.7%)

198/198 (CCD Image 198); 2048x2048 pixels; 16-bit; 1.5GB (WCS=RA-SIP,DEC-SIP,TAN,CD matrix)

ImageJ X: 252.2018 ImageJ Y: 1,665.0623 Value: 3,691.0000

RA: 07:48:00.219 DEC: +50:23:00.15 Peak: 3,831.0000

FITS X: 252.7018 FITS Y: 383.4377 Int Cnts: -1,978.1793

0.0000 :min 3,451.4075 :black mean: 3,701.8109 white: 4,703.4243 max: 52,914.0000

Figure 23: The above Figure represents image #198.
This is a FOV image used to determine the flux changes of the star TYC which is circled and labeled as T-1 with an estimate of the number of pixels or light electrons collected from the star.

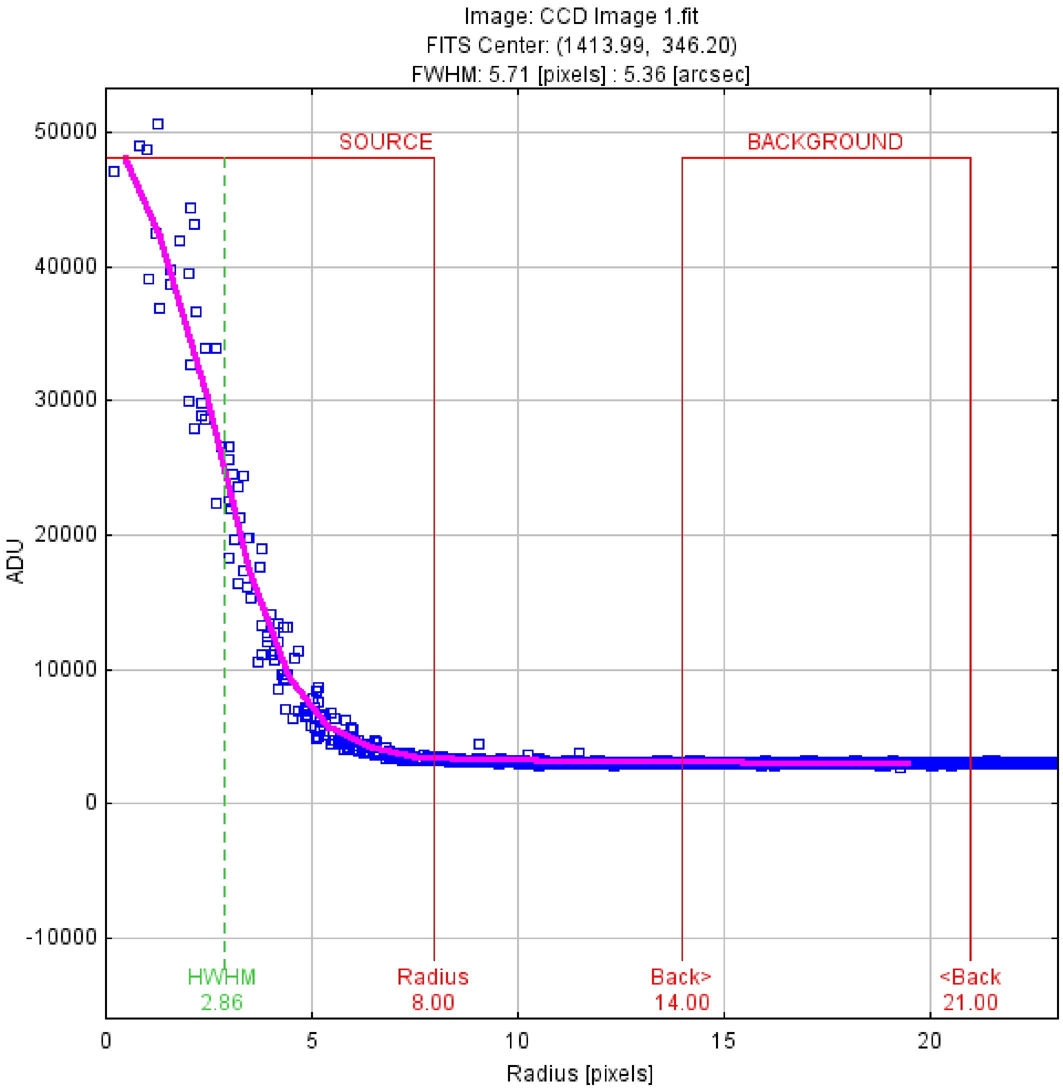


Figure 24: The Figure above details the entire image set reading the quality of the pixilation. The image shows an accurate decrease in pixilation and a linear progression inside the radius of the aperture used to measure the number of pixels counted.

The software package used to create the light curve in *Figure 14*, AstroImageJ, or also known as AIJ, performs sensitive data analysis that builds affirming light curves modeling the ingress, entrance of the transiting object into the electrons emitted by its host star, and the egress of the transiting object, or its exit out of the light. Stacking the 198 images taken on April 2020 in a 9’x6’ Field of View, or FOV of the immediate vicinity around TYC 3413-242-1, allows the generated light curve to assist researchers in telling the story of this star. It allows for the prediction of the transiting object's mass and perhaps its radius. Some of the steps performed to produce the light curve are pre-programmed, and a part of the software package and is perhaps one of the most critical elements in determining that all 198 plates are usable in the image set.

Once the target star, in this case, TYC 3413-242-1, is selected, the work begins. Moreover, in the case of AstroImageJ, that early work is critical in gathering the most accurate reading possible. As shown below in Table 1, the system defines the procedures of operating a CCD Camera attached to a telescope. The guidelines are produced by Teledyne Photometrics and include calculating the gain, assuring the readings are free from unwanted noise, which can skew the images' photon measurements.

Table 2

A simple method to calculate the system gain is shown below:

1. Collect a bias image (zero-integration dark image) and label it "bias."
2. Collect two even-illumination images and label them "flat1" and "flat2".
3. Calculate a difference image: diff = flat2 – flat1.
4. Calculate the standard deviation of the central 100 x 100 pixels in the difference image.
5. Calculate the variance by squaring the standard deviation and dividing by 2 (variance adds per image, so the variance of the difference image is the sum of the variance of flat1 and flat2).
6. Calculate a bias-corrected image by subtracting the bias from one of the flat images and label it corr: corr = flat1 – bias.
7. Obtain the mean illumination level by calculating the mean of the central 100 x 100 region of the corr image.
8. The mean divided by the variance equals the gain: gain = mean /variance.

Table Source. Photometrics.com/learn/imaging-topics/gain

After performing the above procedures, the ADU, the measurement of the number of electrons/ (analog-to-digital units) ADU, shows a reading in line with standard models of light curve formations. The next step creates the light curve, calibrating the output of the information to assure the research is clear, unbiased, and free from anomalies.

Figure 25 is a graph created from a radio observation using the Pari 12-Meter Radio Telescope and data gathered on TYC 3413-242-1 observed by the author. The readings were performed, then recorded on July 1, 2021. In the review of the information gathered, the raw data was then fed into an Excel spreadsheet, parsed, and then a chart created, using the readings of the Neutral Hydrogen. TYC 3413-242-1, the subject star, moved East to West, and as the star crossed into the cone of the radio telescope, measuring the radio waves of neutral hydrogen, which reports in at the spectroscopic hydrogen line (1420.40575 MHz) and is the precession frequency of neutral hydrogen atoms, the most abundant substance in space. The first measurement, in the central region of the graph, is hydrogen intensity levels on the Y-axis as the object's surface brightness, or the flux density per unit solid angle, and units of Watts per Hz per square meter per steradian (Marr; Snell; Kurtz, 2016), and the second axis, the X-axis, is the time in minutes. Together this graph forms a picture of the fluctuations of hydrogen intensity. The data happens to fall in the quietest part of the radio spectrum.

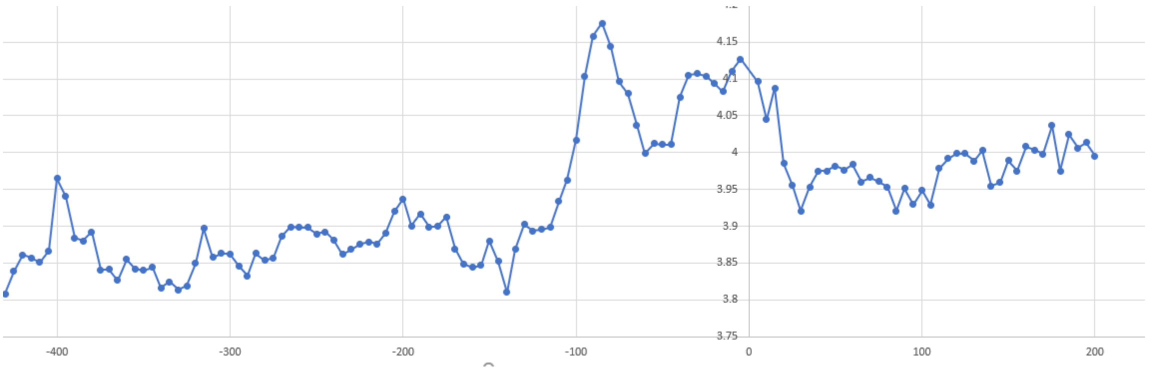


Figure 25: The above Figure represents Radio Measurements of TYC 3413-242-1.
These measurements were used to create the above graph from data obtained during a July observation in the Neutral Hydrogen frequency range, data observed by the Author using the 12-meter Pari Radio Telescope.

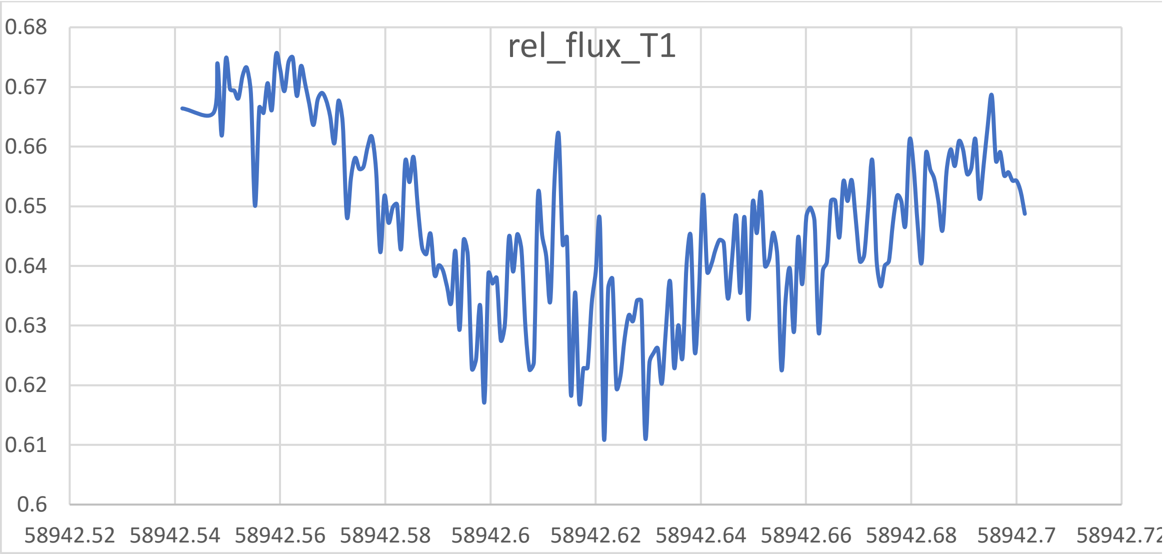


Figure 26: Light curve produced in Excel.
Credit: data from April 2/3, 2020, Observation.

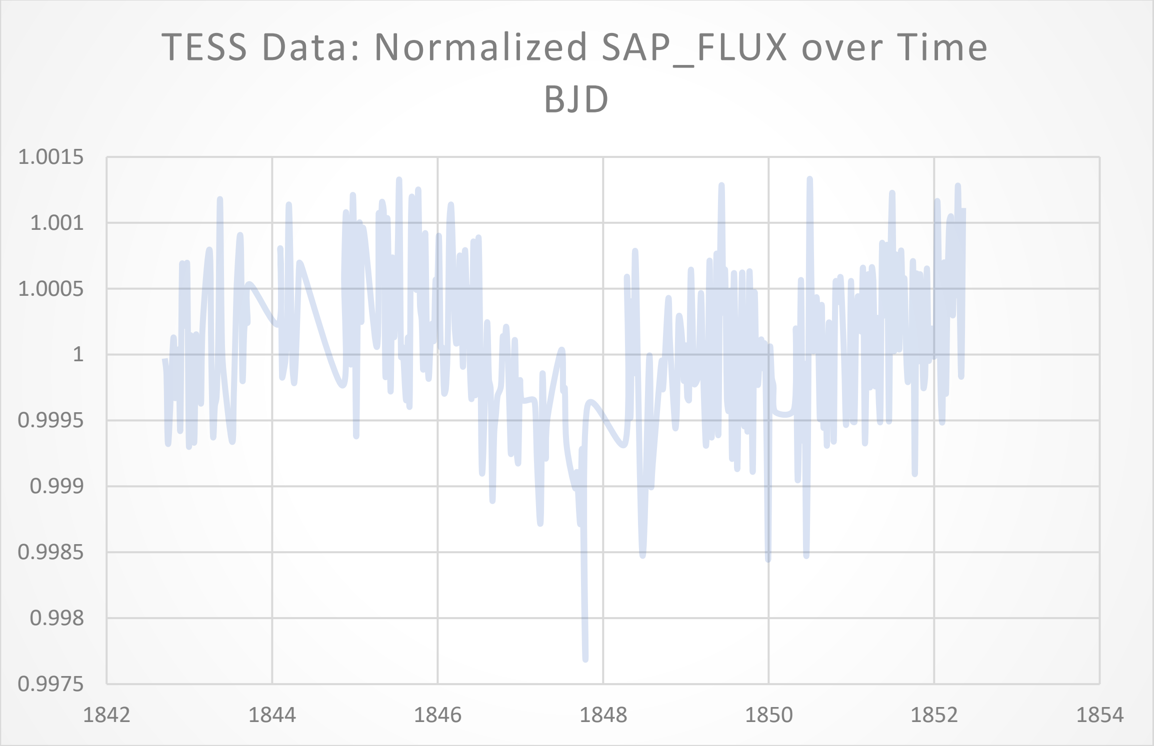
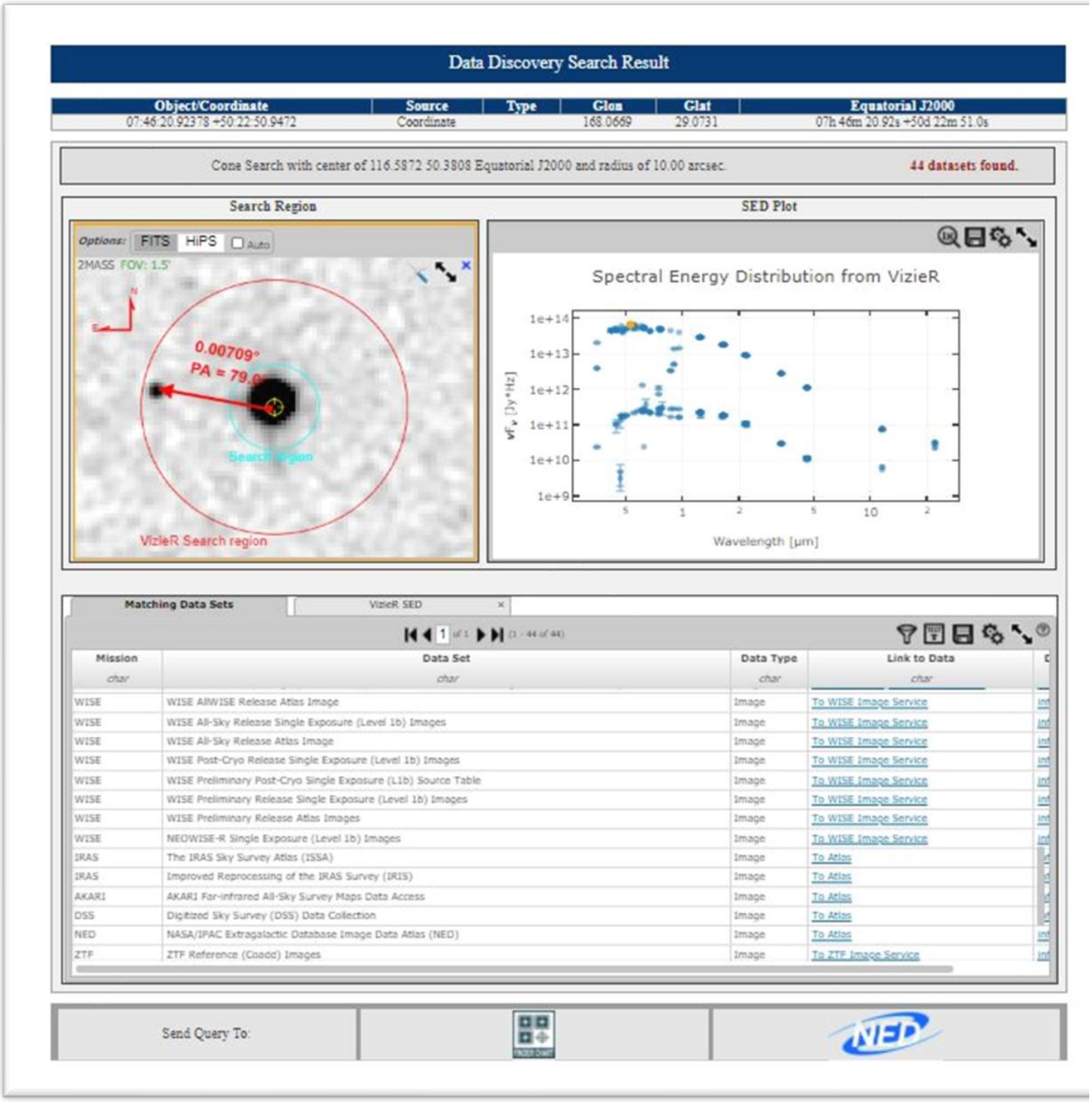


Figure 27: A light curve was generated through the TESS Space Observatory.
Source: Tess Data - MAST – Space Science Telescope Institute

Above in *Figure 27*, the light curve generated through the TESS observations shows a dramatic change in FLUX, which is generally accepted as the star's magnitude. The raw image data was obtained over 180 days, but for the presentation here in the document, research included in the data set detail was shortened to just under 50 days.



Object/Coordinate	Source	Type	Glon	Glat	Equatorial J2000
07:46:20.92378 +50:22:50.9472	Coordinate		168.0669	29.0731	07h 46m 20.92s +50d 22m 51.0s

Cone Search with center of 116.5872 50.3808 Equatorial J2000 and radius of 10.00 arcsec.

44 datasets found.

Mission char	Data Set char	Data Type char	Link to Data char
WISE	WISE AllWISE Release Atlas Image	Image	To WISE Image Service
WISE	WISE All-Sky Release Single Exposure (Level 1b) Images	Image	To WISE Image Service
WISE	WISE All-Sky Release Atlas Image	Image	To WISE Image Service
WISE	WISE Post-Cryo Release Single Exposure (Level 1b) Images	Image	To WISE Image Service
WISE	WISE Preliminary Post-Cryo Single Exposure (L1b) Source Table	Image	To WISE Image Service
WISE	WISE Preliminary Release Single Exposure (Level 1b) Images	Image	To WISE Image Service
WISE	WISE Preliminary Release Atlas Images	Image	To WISE Image Service
WISE	NEOWISE-R Single Exposure (Level 1b) Images	Image	To WISE Image Service
IRAS	The IRAS Sky Survey Atlas (ISSA)	Image	To Atlas
IRAS	Improved Reprocessing of the IRAS Survey (IRIS)	Image	To Atlas
AKARI	AKARI Far-infrared All-Sky Survey Maps Data Access	Image	To Atlas
DSS	Digitized Sky Survey (DSS) Data Collection	Image	To Atlas
NED	NASA/IPAC Extragalactic Database Image Data Atlas (NED)	Image	To Atlas
ZTF	ZTF Reference (Coadd) Images	Image	To ZTF Image Service

Figure 28: 2MASS Light Curve and Observation of TYC 3413-242-1

Data catalogs throughout the NASA Exoplanet Archives maintain significant resources on various stars, and here TYC 3413-242-1 is no exception. The 2MASS project collaborates with The University of Massachusetts and the Infrared Processing and Analysis Center (JPL/ Caltech). Funding is provided primarily by NASA and the NSF. The University of Massachusetts constructed and maintained the observatory facilities and operated the survey. (Caltech.edu/2mass, 2006) The mission operations were from the Spring of 1997 to the Spring of 2001. The data release took place in 2003 and was released into the NASA Exoplanet Archive in 2009. The image in *Figure 28* above is in infrared and shows a limited data light curve yet delineates a significant variability in FLUX over a relatively large range in wavelength.

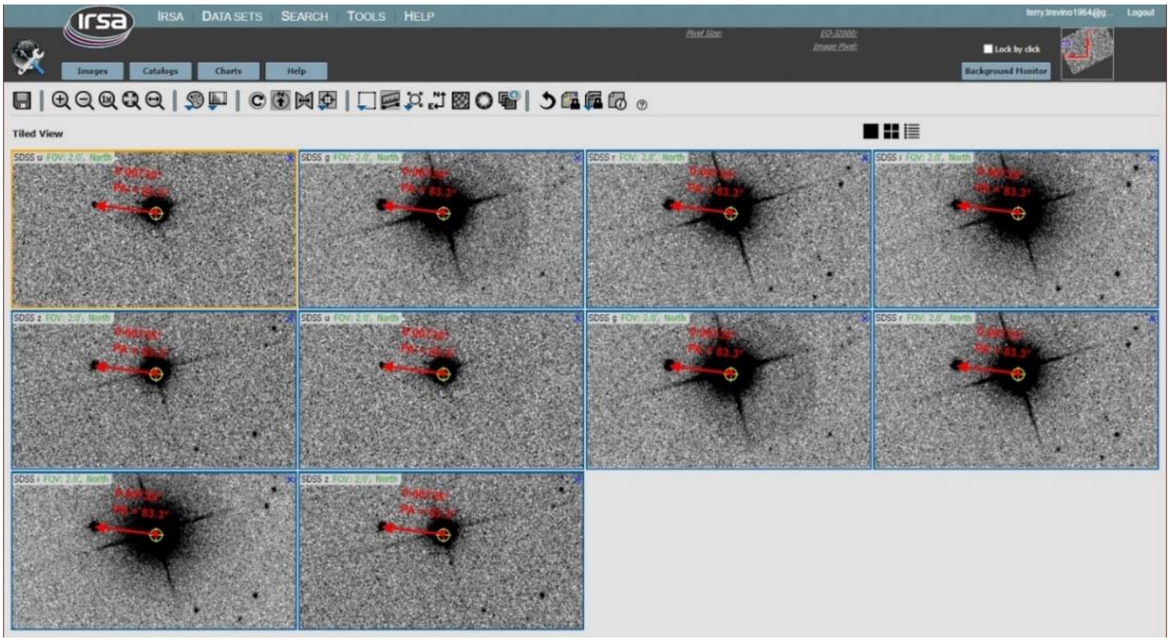
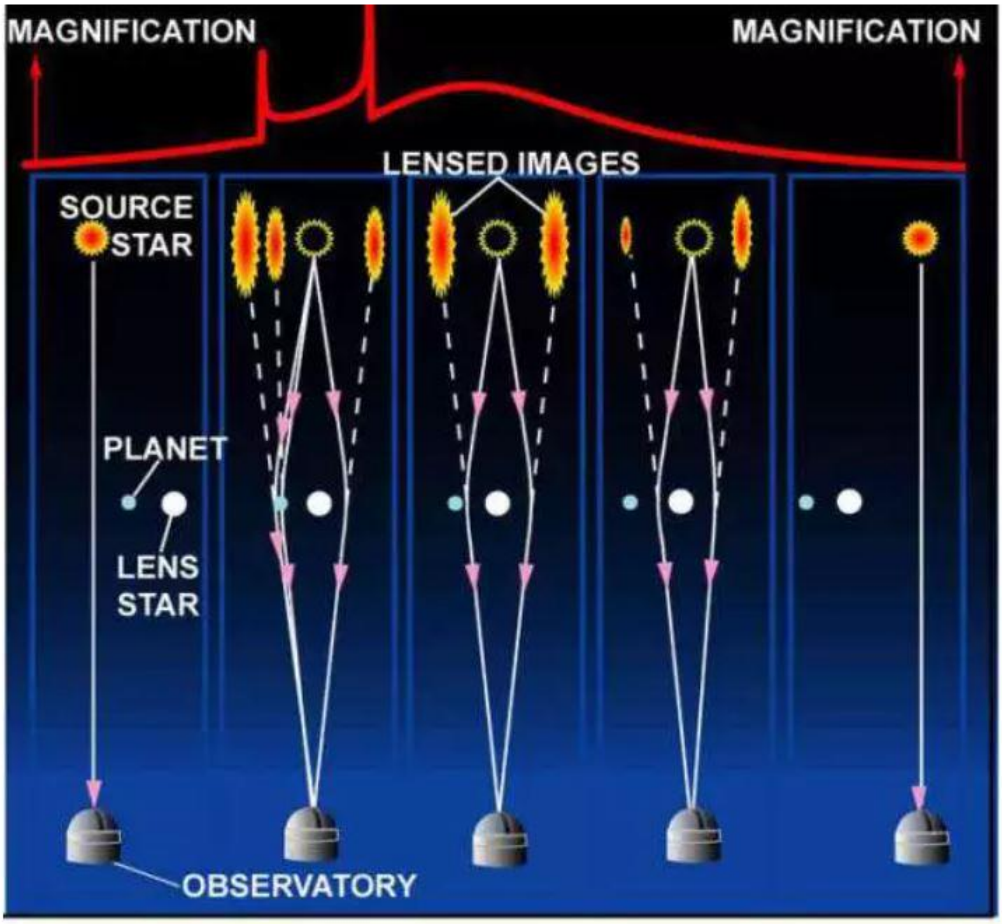


Figure 29: SDSS-III Data from Multiple Observations.
CREDIT: SDSS APOGEE

The SDSS-III data presented above in *Figure 29* proves no further clarity on the possibility of an exoplanet in orbit. However, the variability of the light measured from the star is significant, as is demonstrated in this Figure. These image sets typically do not prove the existence of an unknown yet-to-be charted exoplanet, and the evidence leaves a slightly open door of the possibility of a transit. Since 2000, the Sloan Sky Digital Sky Survey (SDSS) uses a wide-field 2.5 m telescope at the Apache Point Observatory in Southern New Mexico. The telescope is enormously capable of multiple discoveries in using a 60-fiber interferometric spectrograph to measure the range of high-precision radial velocity stars, intending to map the entire sky spectroscopically. (SDSS-III, 2010-2013)

An interesting thought experiment and the soon-to-be-launched James Webb Space Telescope, or JWST, is an upcoming mission undertaking the challenge to measure photons that reflect off the atmosphere of a nearby exoplanet using sophisticated near-infrared cameras. Furthermore, as is the case in our planet-stellar relationship, these photons reflect off the planet's atmosphere in orbit around a host star. However, the required resolution to observe these photons is not available in mainstream technology using terrestrial-based telescopes. There are telescope systems with the ability to manipulate their lens in such a way as to remove the aberrations that manifest when viewing through significant atmospheres.

Few other methodologies enable the confirmation of exoplanets or other transits. One terrific example of an observational technique to locate the optical change of light as it travels to the observer is Radial Velocity (Meriam-Webster, 2021), defined as the velocity of relative approach or recession of an observer and a celestial body or other sources of radiation in the line connecting the two: speed in the line of sight. The physics of radial velocity brought about an exoplanet discovery in 1995, orbiting a nearby star and won a shared Nobel Prize in Physics, awarded to two of these exoplanet explorers, Michel Mayor and Didier Queloz. (Winn, J., 2019) Gravitational lensing did the same when the technique was initially proposed by astronomers Mao, S., & Paczyñski, B. (1991) as a means of looking for binary companions to pulsating stars. Andy Gould and Abraham Loeb refined their proposal in 1992 as a method of detecting exoplanets. This method is most effective when looking for planets towards the center of the Galaxy, as the galactic bulge provides many background stars, and the theoretical development of the Optical Gravitational Lensing Experiment, known as OGLE, was born. (Udalski *et al.* 1994) The primary purpose of Udalski *et al.* (1994) and their work was to experimentally view the Magellanic Cloud and peer beyond the center of the Milky Way Galaxy. The theory allowed Mao, S., & Paczyñski, B. (1991) to practically explore how microlensing light curves if the lensing star has a binary companion or one or more exoplanets. *Figure 30* provides a clear example of how the physics of microlensing works as a "naturally occurring" telescope. Conventionally the original concept of gravitational lenses has been credited to the work of Albert Einstein in his work of 1911 when he used Newtonian mechanics to derive the deflection of light by a massive body and used that theory to work with Sir Arthur Eddington (1920) to use gravitational lensing to see the actual curvature of light around an eclipsing Sun. However, the theory's roots begin at least 220 years before this, in the famous work 'Optiks' by Isaac Newton. (Newton, I., 1704)



PLANET DETECTION THROUGH MICROLENSING The microlensing process in stages, from right to left. The lensing star (white) moves in front of the source star (yellow) magnifying its image and creating a microlensing event. In the fourth image from the right the planet adds its own microlensing effect, creating the two characteristic spikes in the light curve. *Image: OGLE*

Figure 30:Gravitational Lensing - Image Credit - OGLE Experiment.

Discussion

Over a dozen data sources proved the hypothesis that ground-based telescopes remain a dependable means to confirm transiting objects in the past several months. Variable stars aside, an eclipsing binary star and the option that an exoplanet transiting in front of TYC 3413-242-1 remains a strong possibility. The results herein, however, show that the choice remains; TYC is a variable star. Numerous conclusions often provide innumerable interpretations. Dr. Dennis

Conti of the AAVSO Exoplanet Section, who is knowledgeable on the usage of AstroImageJ as a tool in interpreting photometric analyses of the plates provided by the April 2020 observations of TYC 3413-242-1, remains convinced the light curve produced shows a high probability that the star is an eclipsing binary star. Outside of this professional opinion, the images set from those observations were apparent, and the visualizing of the star at close range shows no evidence of an eclipsing binary star. However, the possibility remains that the binary partner is intimate in eclipsing star, meaning the period of the rotation of the binary star is very fast.

Should data be obtained using radial velocity measurements, research may ascertain if there are the possibilities of a close-in binary star or, perhaps, an exoplanet. Those two types of transits would show a decrease in light emitted from the host star, which could then be mistaken for a variable star. The next step in that confirmation is to determine the variability of the star. TYC shows significant variability in the 10ths of magnitude, and the shape of the light curve is not indicative of an exoplanet. If there are regular intervals of the decrease in light and the importance of the stars are to decrease predictably. Yes, there is the possibility of an eclipsing binary star or an exoplanet. In TYC 3413-242-1, the star shows irregular increases and decreases in its magnitude in the TESS measurements and typically indicates a variable star. The rises and falls in importance are not sharp and appear in a regular pattern, even in the TESS image. The light curves generated, other than the very first light curve, show irregularities. The first AIJ light curve produced, as depicted in *Figure 12*, used an overlay that is a model of an exoplanet, and fit into the model very cleanly. Figure 9 also shows an exoplanet with a statistically predictable decrease in Flux and an immediate increase.

Earth-Based Telescopes and Their Discoveries

There are few confirmed observational telescopic discoveries of exoplanets. The difficulty of performing observations at the consistencies required of a scientific method is practically impossible unless, of course, time is no obstacle, with a few exceptions, largest telescopes and those telescopes on orbit outside of Earth's atmosphere. Yes, atmospheric conditions and the timing of the weather patterns prove to be a significant challenge. These issues call into question any findings or, by definition, discoveries, as confirmation is time-consuming. Considering the orbital paths of these exoplanets can often fall into years versus days, as is the case for Tyco-3413-242-1. It is estimated that this star's unknown object orbits every 27.99 days based on the data from the SWASP light curve. There are many variables yet to be confirmed with this observation. Ultimately, it is beginning to feel that the only answer to the riddle is more data and more confirmations.

Perfecting the equipment is equivalent to creating experiments that produce repeatable results. In TYC 3413-242-1, the simple fact remains, there are possibly three results to consider, a variable star, a binary star, or an exoplanet. How does a researcher best unlock these obstacles, force science to refine their instrumentation, perfect the observational requirements, and ask more profound data questions? Perfecting the instrumentation seemed to play often into the equation on how best to continue the accurate confirmation of possible discoveries. Perfecting the software shows a rapid positive movement in detection perfection.

Summary and Conclusions

Numerous examples prove that statistically, a small terrestrial-based telescope performs admirably when used in ideal conditions. There were numerous observations performed over several months, through the use of radio observations, through optically generated images, and several sources of space-based observations were located identified and confirmed, TYC 3413-242-1 possess as a statistically significant aberration or anomaly. Most notably, there is no clear-cut answer to the significant change in FLUX, and a theoretical guess is not warranted. There will come a time soon as the galaxy rises in the East, high enough for other observation to train their sensitive instruments to TYC 3413-242-1.

The data presented herein prove additional findings and further research required to unequivocally determine the possibility that the small Plane Wave telescope at the American Public University in West Virginia discovered an exoplanet, variable star, or a binary star system in orbit around a star in the Lynx Constellation, Star Tyco -3413-242-1, in April of 2020. Confirming the fact that something was discovered took the better part of 6 months. The following steps must include further confirmations by other researchers. The discovery of an exoplanet using a terrestrial located telescope is rare compared to the daily discoveries by the space-based telescopes that have operated over the past 15 years. Discovering and confirming an Eclipsing Binary star proves much more a challenge for a small terrestrial-based telescope. Fewer than a handful of these exoplanets have been found, and even fewer eclipsing binary stars. Those exoplanets located and confirmed with these terrestrial telescopes number less than 20. Perhaps, it will be unambiguously determined to be an exoplanet after a thorough vetting of the new data, which is expected with further scheduled observations in the early Winter 2021 through early Spring of 2022.

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Appendix

The Following files represent a small percentage of the data retrieved and obtained from numerous sources for the research provided herein.

Python Codec

Document 1: Pages 67 through 71, are the document attached below and is the actual Python Code used to obtain the MAST Archive Data from the Space Science Telescope Institute. The code was provided through a GitHub, a public software repository. The corresponding script is written in a universal well shared software language known as Python and all the codec is attached here, was built over several iterations, to verify that data on TYC 3413-242-1 was locked in the larger data set of over 200000 million stars in the database. The actual details are a part of a larger privately funded study through MIT and a High Level Science Project, or HLSP, performed by a team of astrophysicists led by Chelsea X. Huang. Data here proved that the HLSP did detect an anomaly, either a Variable Star, an Eclipsing Binary Star or an Exoplanet. HLSPs such as these are the precursor studies pointing out the possible transit. Thereafter, researchers must work to verify these findings and narrow the discovery, which was a part of the project here, analyzing TYC 3413-242-1. The images attached in the programming code are a means of confirming the star in question is correctly identified for the researcher’s purpose, and includes the Right Ascension and Declination, which are on the X and Y axis accordingly.

```
In [1]:  pip
```

```
Note: you may need to restart the kernel to use updated packages.
Usage:
  C:\Users\terry\anaconda3\python.exe -m pip <command> [options]

Commands:
  install                     Install packages.
  download                    Download packages.
  uninstall                   Uninstall packages.
  freeze                      Output installed packages in requirements format.
  list                        List installed packages.
  show                        Show information about installed packages.
  check                       Verify installed packages have compatible dependencies.
  config                      Manage local and global configuration.
  search                      Search PyPI for packages.
  cache                       Inspect and manage pip's wheel cache.
  wheel                       Build wheels from your requirements.
  hash                        Compute hashes of package archives.
  completion                  A helper command used for command completion.
  debug                       Show information useful for debugging.
  help                        Show help for commands.

General Options:
  -h, --help                  Show help.
  --isolated                  Run pip in an isolated mode, ignoring
                              environment variables and user configuration.
  -v, --verbose               Give more output. Option is additive, and can be
                              used up to 3 times.
  -V, --version               Show version and exit.
  -q, --quiet                 Give less output. Option is additive, and can be
                              used up to 3 times (corresponding to WARNING,
                              ERROR, and CRITICAL logging levels).
  --log <path>                Path to a verbose appending log.
  --no-input                  Disable prompting for input.
  --proxy <proxy>             Specify a proxy in the form
                              [user:passwd@]proxy.server:port.
  --retries <retries>         Maximum number of retries each connection should
                              attempt (default 5 times).
  --timeout <sec>             Set the socket timeout (default 15 seconds).
  --exists-action <action>    Default action when a path already exists:
                              (s)witch, (i)gnore, (w)ipe, (b)ackup, (a)bort.
  --trusted-host <hostname>   Mark this host or host:port pair as trusted,
                              even though it does not have valid or any HTTPS.
  --cert <path>               Path to alternate CA bundle.
  --client-cert <path>        Path to SSL client certificate, a single file
                              containing the private key and the certificate
                              in PEM format.
  --cache-dir <dir>           Store the cache data in <dir>.
  --no-cache-dir              Disable the cache.
  --disable-pip-version-check
                              Don't periodically check PyPI to determine
                              whether a new version of pip is available for
                              download. Implied with --no-index.
  --no-color                  Suppress colored output.
  --no-python-version-warning
                              Silence deprecation warnings for upcoming
                              unsupported Pythons.
  --use-feature <feature>     Enable new functionality, that may be backward
                              incompatible.
  --use-deprecated <feature>  Enable deprecated functionality, that will be
                              removed in the future.
```

In [2]:

```
import numpy as np
from astropy.io import fits
import requests
from astroquery.mast import Catalogs
import zipfile
from astropy.wcs import WCS
import matplotlib.pyplot as plt

%matplotlib inline

urlroot = "https://mast.stsci.edu/tesscut/api/v0.1"
```

In [3]:

```
ticid = 309635035

starName = "TIC " + str(ticid)
radSearch = 5 / 60 # radius in degrees

catalogData = Catalogs.query_object(starName, radius = radSearch, catalog = "TIC")
Ra = catalogData[0]['ra']
Dec = catalogData[0]['dec']

# Print out the first five rows in the table
print( catalogData[:5]['ID', 'Tmag', 'Jmag', 'ra', 'dec', 'objType'] )
```

```
    ID      Tmag   Jmag         ra               dec         objType
--------- ------- ------ ---------------- ---------------- -------
309635035 10.8561 10.296 116.587324519841 50.3812150731683    STAR
309635034 16.4141 15.572 116.598807856659 50.3818605431911    STAR
742731988  19.458    nan 116.568549501007 50.3735719665074    STAR
742731989 19.7464    nan 116.565044537554 50.3863227700955    STAR
742731982 19.3133    nan 116.600866342202 50.3976873386107    STAR
```

In [4]:

```
bright = catalogData['Tmag'] < 14
```

In [5]:

```
# Make it a list of Ra, Dec pairs of the bright ones. So this is now a list of nearby b
nearbyStars = list( map( lambda x,y:[x,y], catalogData[bright]['ra'], catalogData[brigh
len(nearbyStars)
```

Out[5]:

```
7
```

In [11]:

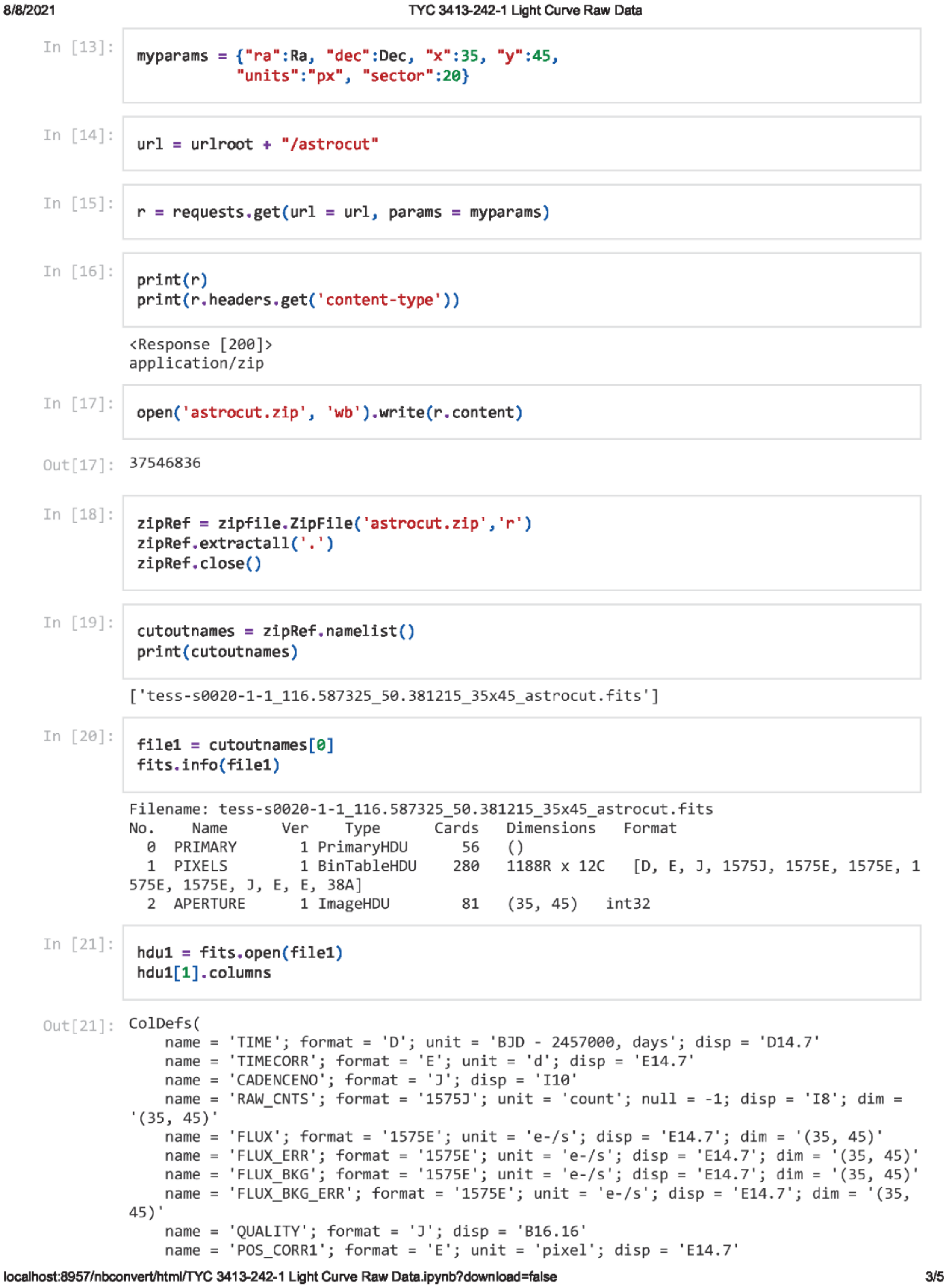
```
url = urlroot + "/sector"

myparams = {"ra":Ra, "dec":Dec, "radius":"0m"}

requestData = requests.get(url = url, params = myparams)

print(requestData.headers.get('content-type'))
```

```
application/json
```

In [12]:

```
sectors = requestData.json()['results']
print(sectors)
```

```
[{'sectorName': 'tess-s0020-1-1', 'sector': '0020', 'camera': '1', 'ccd': '1'}]
```



In [13]:
```
myparams = {"ra":Ra, "dec":Dec, "x":35, "y":45,
            "units":"px", "sector":20}
```

In [14]:
```
url = urlroot + "/astrocut"
```

In [15]:
```
r = requests.get(url = url, params = myparams)
```

In [16]:
```
print(r)
print(r.headers.get('content-type'))
```

```
<Response [200]>
application/zip
```

In [17]:
```
open('astrocut.zip', 'wb').write(r.content)
```

Out[17]:
```
37546836
```

In [18]:
```
zipRef = zipfile.ZipFile('astrocut.zip','r')
zipRef.extractall('.')
zipRef.close()
```

In [19]:
```
cutoutnames = zipRef.namelist()
print(cutoutnames)
```

```
['tess-s0020-1-1_116.587325_50.381215_35x45_astrocut.fits']
```

In [20]:
```
file1 = cutoutnames[0]
fits.info(file1)
```

```
Filename: tess-s0020-1-1_116.587325_50.381215_35x45_astrocut.fits
No.    Name      Ver    Type      Cards   Dimensions   Format
  0  PRIMARY       1 PrimaryHDU      56   ()
  1  PIXELS        1 BinTableHDU    280   1188R x 12C   [D, E, J, 1575J, 1575E, 1575E, 1
575E, 1575E, J, E, E, 38A]
  2  APERTURE      1 ImageHDU        81   (35, 45)   int32
```

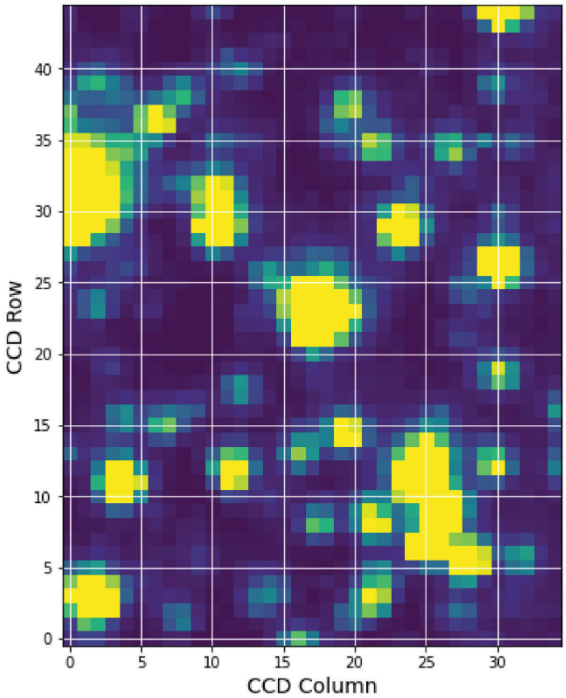
In [21]:
```
hdu1 = fits.open(file1)
hdu1[1].columns
```

Out[21]:
```
ColDefs(
    name = 'TIME'; format = 'D'; unit = 'BJD - 2457000, days'; disp = 'D14.7'
    name = 'TIMECORR'; format = 'E'; unit = 'd'; disp = 'E14.7'
    name = 'CADENCENO'; format = 'J'; disp = 'I10'
    name = 'RAW_CNTS'; format = '1575J'; unit = 'count'; null = -1; disp = 'I8'; dim =
'(35, 45)'
    name = 'FLUX'; format = '1575E'; unit = 'e-/s'; disp = 'E14.7'; dim = '(35, 45)'
    name = 'FLUX_ERR'; format = '1575E'; unit = 'e-/s'; disp = 'E14.7'; dim = '(35, 45)'
    name = 'FLUX_BKG'; format = '1575E'; unit = 'e-/s'; disp = 'E14.7'; dim = '(35, 45)'
    name = 'FLUX_BKG_ERR'; format = '1575E'; unit = 'e-/s'; disp = 'E14.7'; dim = '(35,
45)'
    name = 'QUALITY'; format = 'J'; disp = 'B16.16'
    name = 'POS_CORR1'; format = 'E'; unit = 'pixel'; disp = 'E14.7'
```

```
    name = 'POS_CORR2'; format = 'E'; unit = 'pixel'; disp = 'E14.7'
    name = 'FFI_FILE'; format = '38A'; unit = 'pixel'
)
```

In [22]:

```
firstImage = hdu1[1].data['FLUX'][0]
fig = plt.figure(figsize=(8,8))
plt.imshow(firstImage, origin = 'lower', cmap = plt.cm.viridis, \
           vmax = np.percentile(firstImage,92), vmin = np.percentile(firstImage,5))
plt.xlabel('CCD Column', fontsize = 14)
plt.ylabel('CCD Row', fontsize = 14)
plt.grid(axis = 'both', color = 'white', ls = 'solid')
```

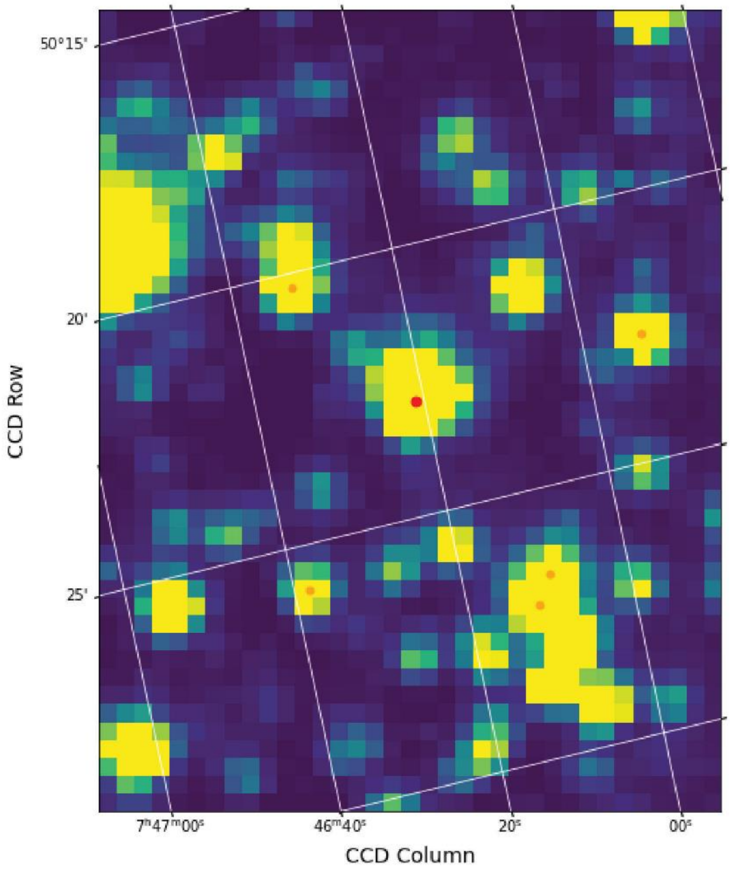


In [23]:

```
wcs = WCS(hdu1[2].header)

fig = plt.figure(figsize = (10,10))
fig.add_subplot(111, projection = wcs)
plt.imshow(firstImage, origin = 'lower', cmap = plt.cm.viridis, vmax = np.percentile(fi
           vmin = np.percentile(firstImage,5))

plt.xlabel('CCD Column', fontsize = 14)
plt.ylabel('CCD Row', fontsize = 14)
plt.grid(axis = 'both', color = 'white', ls = 'solid')

starLoc = wcs.all_world2pix([[Ra,Dec]],0)  #Second is origin
plt.scatter(starLoc[0,0], starLoc[0,1], s = 45, color = 'red')

# Plot nearby stars as well, which we created using our Catalog call above.
```

```
nearbyLoc = wcs.all_world2pix(nearbyStars[1:], 0)
plt.scatter(nearbyLoc[1:,0], nearbyLoc[1:,1], s = 25, color = 'orange')
```

```
Out[23]: <matplotlib.collections.PathCollection at 0x10d724882b0>
```



```
In [ ]:
```