How are astronomical instruments helping us in locating Earth 2.0?

Extended Project Qualification

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13A

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Introduction

In 5.4 billion years from now, as the sun exits out of the main sequence of its lifespan, the outer envelope of the sun will expand as it goes from burning hydrogen fuel to burning only helium from starting its Red Giant phase of its evolution.[1] Based on the burning of fossil fuels by humans, the sun's ageing and the unpredictability of space - scientists have estimated (with 95% certainty) that humans will go extinct in 9000 years, in the worst case scenario, according to the average result from J. Richard Gott's and John Leslie's formulation of the controversial Doomsday argument.[2]

The topic of finding exoplanets within our reach to escape to in the event of a disaster or to even backup human DNA has become a duty for scientists since the beginning of space exploration.[3] In recent years, satellites have been released to take in data within the Earth's lower atmosphere and high-resolution photos at the Lagrange points. This generation is called the Artemis age and the research and discovery which we are doing now provides a stepping stone in the exploration of the unknown universe.[4]

Throughout the investigation of my project, I aim to discuss the different aspects of telescopes which make them effective at their role and how they can be manipulated to get a detailed picture of celestial bodies. Larger observatories follow the same procedures but can get much larger ranges and precision of the same celestial bodies which I aim to compare.

Methodology

The main research question I aim to answer by the end of this essay is "How are astronomical instruments helping us in locating Earth 2.0?". The focus is to not only highlight how different factors affect the use of astronomical instruments on Earth, but also how they are identified, stored, and manipulated to find different types of information.[5]

There are specific aims I wish to achieve by the end of my research, and they take the form of 2 separate independent variables which I investigated.

- The first variable being how different telescopes can affect the range that we see and therefore their ability to detect exoplanets.[6]
- The second variable being the area in the sky with most potential for habitable exoplanets.[7]

In my research about the detection of exoplanets, I will take photos of the moon with different types of lenses and sensors and see how they differ in terms of clarity and magnification. I specifically chose the moon as it is common within the useable time frame – with other objects the visibility changes often which makes the results unreproducible.[8]

[1] Abt, Helmut A. "What Happens to Am Stars After They Leave the Main Sequence?" Publications of the Astronomical Society of the Pacific, vol. 129, no. 974, 2017, pp. 1–4. JSTOR, https://www.jstor.org/stable/26660086. Accessed 12 Aug. 2022.

[2] Sober, Elliott. "An Empirical Critique of Two Versions of the Doomsday Argument: Gott's Line and Leslie's Wedge." Synthese, vol. 135, no. 3, 2003, pp. 415–30. JSTOR, http://www.jstor.org/stable/20117377. Accessed 31 Oct. 2022. Accessed 12 Aug. 2022.

[3] Bahcall, John N., and Lyman Spitzer. "The Space Telescope." Scientific American, vol. 247, no. 1, 1982, pp. 40–51. JSTOR, http://www.jstor.org/stable/24966634. Accessed 12 Aug. 2022.

[4] Sibeck, D. G., et al. "ARTEMIS science objectives." The ARTEMIS mission. Springer, New York, NY, 2011. 27-59.

[5] Schlesinger, Frank. "SOME NEW ASTRONOMICAL INSTRUMENTS." Publications of the Astronomical Society of the Pacific, vol. 14, no. 84, 1902, pp. 87–95. JSTOR, http://www.jstor.org/stable/40668241. Accessed 12 Aug. 2022.

[6] Pepe, Francesco, David Ehrenreich, and Michael R. Meyer. "Instrumentation for the detection and characterization of exoplanets." Nature 513.7518 (2014): 358-366.

[7] Martin, David V. "Populations of planets in multiple star systems." arXiv preprint arXiv:1802.08693 (2018).

[8] Bagenal, Fran, et al., eds. Jupiter: the planet, satellites and magnetosphere. Vol. 1. Cambridge University Press, 2007.

The criteria I will follow to assess the usefulness of Earth and Space based telescopes is focal length and diameter/aperture, magnification, mounting, editing required and cost. These criteria have been chosen wisely as they are a common element of all telescopes and will allow me to quantitatively analyse my sources.

In my research about the area in the night sky with the most potential I will look at different longitudes and latitudes and take various pictures of different star host systems and stand-alone stars and investigate their potential. Using Stellarium™ and Cambridge's guide to constellations[9] I can see different constellations to identify galaxies before taking a picture. Using a tripod at a specific location I can adjust the focus making sure the light is entering the Canon lens[10] correctly. In this procedure, I will take tens of photos so that in a stacking software (Sequator™). I can then layer the photos on top of one another to create one overall photo which has the combined information showing as many stars as possible. Although this process takes time, it is an accurate representation of what the JWST and the Hubble see.

The criteria I will follow to assess the area in the sky with the most potential for exoplanets are types of star systems located in the picture, the distance from the Earth, the possibility of a habitable planet being located, the magnification achieved, how many pictures taken to receive the picture, editing and the cost to make the photo. These criteria have also been chosen specifically as they assess the composition of the exoplanets in the frame and can help me to determine if they are even worth investigating.

The sources from which I compared the pictures are from astronomers with telescopes with focal ranges much higher than my own, as well as professional organisations like NASA and ESA.[11] But other sources I used are from private astronomers[12], so they won't be professionally recognised. Their data, however, follows the same trend as NASA so I am taking those sources as credible, and I will take groups which have been observing celestial bodies for decades rather than months to increase the reliability of my sources.

Literature Review

Through this literature review, I can know more about how telescopes work and how scientists analyse photos and data values before I fully analyse my findings. The reason I have followed this specific structure is that, in order to compare my photos with the James Webb, I need to understand the context behind my research much more.

Mathematically modelling of the Cosmos

Mathematics enables us to quantitatively describe the universe in a way which means we can understand it from a very small quantum scale to light-years. Early civilisations dating back to the Mesopotamians correctly identified they needed to use maths to determine their location, but very different when comparing with each other.[13] This was due to parallax.

[9] Bakich, Michael E. The Cambridge guide to the constellations. Cambridge University Press, 1995.

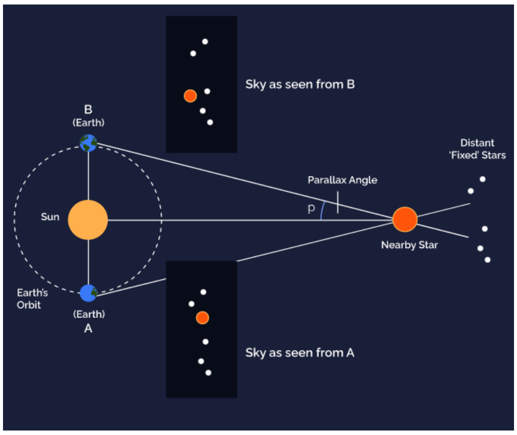
[10] The Canon DSLR used throughout this whole essay is the 2000D with several lens including the EFS 18-55mm and the EFS 24-105mm lens which both have manual focus capabilities.

[11] Kessler, Elizabeth A. Picturing the cosmos: Hubble Space Telescope images and the astronomical sublime. Minneapolis: University of Minnesota Press, 2012.

[12] The website from which I got the details and contacted was: https://www.ukastronomy.org/about_us.shtml

[13] Muhlestein, Kerry. "Encircling Astronomy and the Egyptians: An Approach to Abraham 3." Religious Educator: Perspectives on the Restored Gospel 10.1 (2009): 6.

Figure 1 – Pictorial representation of the parallax error



Source from the OmniCalculator Organisation: https://www.omnicalculator.com/physics/parallax

Parallax, depicted in figure 1, shows the observed displacement caused by the change in the observer's point of view.[14] This makes a tremendous difference when calculating distances between them and distant stars like our sun. The real troubles arose when, instead of perceiving space as a two-dimensional plane, you look at the universe in three-dimensions which is where parallax distorts your view. This brought about trigonometry and its importance in this field.[15]

Every six months, the Earth is at a completely different point in the orbit around the sun, and it also changes displacement around the universe by three hundred million kilometres. This is where the intricate maths is needed, as there are vast distances to even the nearest stars, of which the uncertainty is extremely difficult to calculate.[16] Initially this method was used by the Greeks, who noticed this visible change from which our perspective of space was altered.[17] The ancient Greek astronomer Hipparchus used observations of a solar eclipse from two different locations to calculate the distance of the moon.[18] This later was manipulated by German astronomer Friedrich Bessel in 1838, from which began the long and tedious process of building the three-dimensional map of the universe. With the derivation of calculus by Newton, it made it much easier for Bessel to implement and join the findings so that it still followed classical physics.[19]

From here, the 19th century French mathematician Henri Poincaré made a massive impact in the field by solving "the three-body problem" using the idea of parallax in 1890. It states is there a configuration, in which three bodies could orbit each other, yet stay in the same position relative to each other. [20] The understanding of the solution helped us to discover the Lagrange points, in which the most powerful telescopes (such as the James Webb) orbit today.

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[14] Wu, Jianhua, et al. "The Research and Analysis of Parallax Error Decrease in Astronomical Navigation Positioning." 2013 the International Conference on Remote Sensing, Environment and Transportation Engineering (RSETE 2013). Atlantis Press, 2013.

[15] Makarov, Valeri V. "The Hipparcos (Hipparchus) Pleiades parallax error is also a proper motion error." arXiv preprint arXiv:2207.12975 (2022).

[16] Morrison, L. V., and Francis Richard Stephenson. "Historical eclipses and the variability of the Earth's rotation." Journal of geodynamics 32.1-2 (2001): 247-265.

[17] Goldstein, Bernard R., and Alan C. Bowen. "A new view of early Greek astronomy." Isis 74.3 (1983): 330-340.

[18] Toomer, Gerald J. "Hipparchus on the Distances of the Sun and Moon." Archive for History of Exact Sciences (1974): 126-142.

[19] Guicciardini, Niccolò. The development of Newtonian calculus in Britain 1700-1800. Cambridge: Cambridge University Press, 1989.

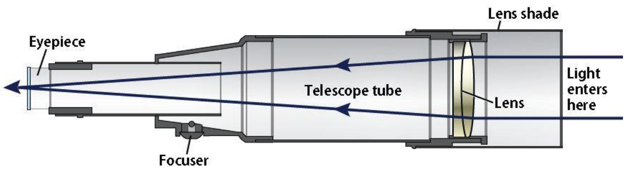
[20] Musielak, Zdzislaw E., and Billy Quarles. "The three-body problem." Reports on Progress in Physics 77.6 (2014): 065901.

Earth Based Telescopes

After the research of Galileo, refractor telescopes were widely used across the world to observe celestial objects. In the past, telescopes focussed the light using curved pieces of clear glass (lenses), however, nowadays telescopes use curved mirrors instead to gather the light before they are focussed. Although there is little difference in the structure, the images gathered are observed to be much more refined and you can also see a much larger angle of the sky.[21]

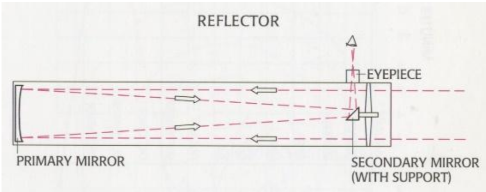
There are multiple research telescopes including Refractor, Reflector, Newtonian, Achromatic and many more.[22] All of them follow the same principles of operation, but are slightly modified in terms of focal length and diameter, so they can be used for various purposes. The most common are reflectors and refractors, which are used on Earth to observe objects in the sky.[23]

Figure 2 – cross-sectional view of a refractor telescope



Source from Tring Astronomy Centre LTD: https://www.tringastro.co.uk/refractors-89-c.asp

Figure 3 – cross-sectional view of a reflector telescope



Source from the University of Chicago: https://ecuip.lib.uchicago.edu/multiwavelength-astronomy/optical/history/04.html

As we can see in figure 2, refractors use a series of lens to bend the passing light. In large telescopes, very heavy, big, thick lenses are used to magnify objects more, but this also means they need to be cleaned regularly as flaws will change the image drastically.[24]

Reflectors, on the other hand, use mirrors and they bounce off concentrated light to the eyepiece to be observed as shown in figure 3. It is much easier to make a large, near-perfect mirror than to make a large, near-perfect lens. Also, since mirrors are one-sided, they are also easier than lenses to polish. Since they reflect light, the diameter they have is much larger so we can observe a larger angle of the sky.[25]

After being aligned, astrophotography is used to take detailed pictures of the sky over certain periods of time during the night (with high resolution cameras taking burst photographs).[26] Computers analyse these images using machine learning algorithms, which recognise patterns in pictures with high precision, filtering planets according to luminosity, size, supposed gravitational strengths etc.[27]

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[21] De Petris, Marco, Massimo Gervasi, and Fabrizio Liberati. "New far infrared and millimetric telescopes for differential measurements with a large chopping angle in the sky." Applied optics 28.10 (1989): 1785-1792.

[22] Kitchin, Christopher Robert. "Types of Telescopes." Telescopes and Techniques. Springer, New York, NY, 2013. 3-30.

[23] Miroshnikov, Mikhail M., Sergey V. Ljubarsky, and Yuri P. Khimitch. "Mirrors for optical telescopes." Optical Engineering 31. 4 (1992): 701-710.

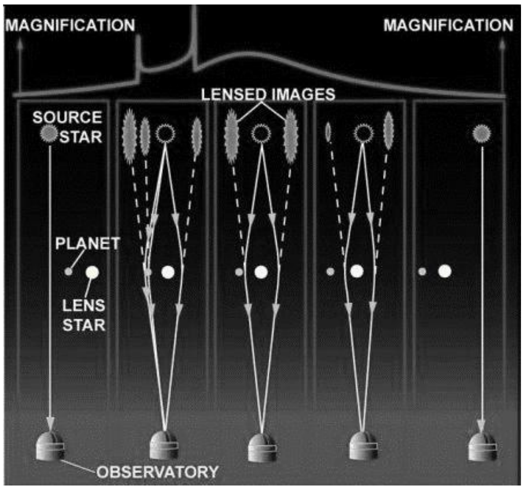
[24] DeVorkin, David H. "In the grip of the big telescope age." Experimental Astronomy 25.1 (2009): 63-77.

[25] Fath, Edward Arthur. "The Reflector—The Telescope of the Future." Scientific American, vol. 109, no. 2, 1913, pp. 30–30. JSTOR, http://www.jstor.org/stable/26019959. Accessed 12 Aug. 2022.

[26] White, Raymond E. American Scientist, vol. 75, no. 5, 1987, pp. 525–26. JSTOR, http://www.jstor.org/stable/27854803. Accessed 12 Aug. 2022.

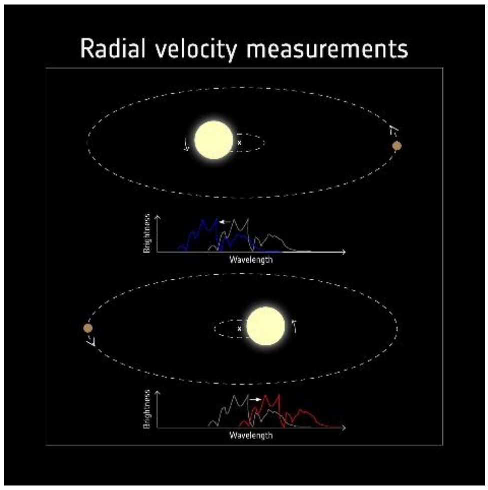
[27] Lu, Yijuan, et al. "Feature selection using principal feature analysis." Proceedings of the 15th ACM international conference on Multimedia. 2007.

Figure 4 – process of microlensing to observe exoplanets



Source from a paper by Alka Mishra on the detection of exoplanets:https://www.lkouniv.ac.in/site/writereaddata/siteContent/202004261258144367alka_mishra_Methods_of_Detection_of_Exoplanets.pdf

Figure 5 – process of radial velocity



Source from the European Space Agency Archives:https://www.esa.int/ESA_Multimedia/Images/2019/02/Detecting_exoplanets_with_radial_velocity

Earth-based telescopes use microlensing and radial velocity to find the location of exoplanets.[28] Figure 4 shows microlensing, it uses the effects of gravitational fields of planetary systems and works on the principle of General Theory of Relativity. When one star in the sky appears to pass nearly in front of another, the light rays of the background source star become bent due to the gravitational "attraction" of the foreground star (lens star).[29] This star is then a virtual magnifying glass, amplifying the brightness of the background source star. The planets also act as lenses, from which they can provide a short deviation in the light. This means we can accurately determine the mass and separation of the star.[30] However, microlensing is not used as frequently, as exoplanet revolutions can take many decades and although accurate, it is defunct when compared to newer methods.[31]

Radial velocity, on the other hand, is more common, as it uses the principle that a star does not remain completely stationary when it is orbited by a planet as shown in figure 5. The slight movements correspond to the gravitational strength of the planet and changes the wavelength of light which corresponds to its mass and astronomical distance from Earth.[32] This is most accurate, and primarily used, for exoplanets within five astronomical units and gets less effective over greater

[28] Akeson, R. L., et al. "The NASA Exoplanet Archive: Data and Tools for Exoplanet Research." Publications of the Astronomical Society of the Pacific, vol. 125, no. 930, 2013, pp. 989–99. JSTOR, https://doi.org/10.1086/672273. Accessed 12 Aug. 2022.

[29] Gaudi, B. Scott. "Microlensing surveys for exoplanets." Annual Review of Astronomy and Astrophysics 50.411 (2012): 2012.

[30] Bennett, David P. "Detection of extrasolar planets by gravitational microlensing." Exoplanets (2008): 47-88.

[31] Tsapras, Yiannis. "Microlensing searches for exoplanets." Geosciences 8.10 (2018): 365.

[32] Lovis, Christophe, and Debra Fischer. "Radial velocity techniques for exoplanets." Exoplanets (2010): 27-53.

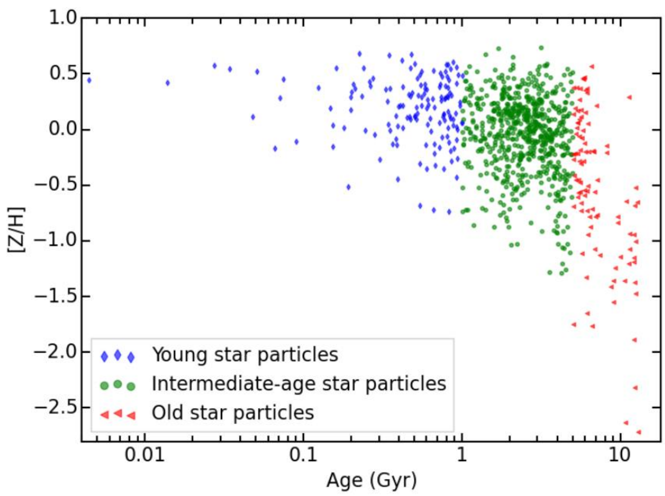
distances as the wavelength expands and contracts via redshift[33] and blueshift[34] respectively. This alters the value of amplitude which is utilised to find the mass.[35]

Development of Sensors

One major technological development which has contributed the most within the field of astronomy is the range of sensors being used.[36] Before 1995, our knowledge of exoplanets was mainly theoretical. The following years have proved these theories with high precision which made characterisation of these exoplanets much more efficient.[37]

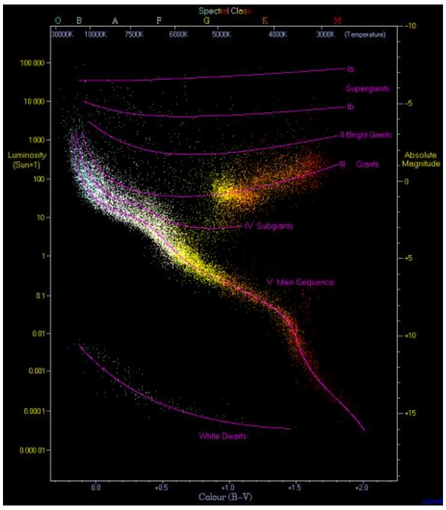
To understand the use of the sensors, we must understand what certain values mean in terms of the exoplanet and how certain factors guarantee habitability to categorise it as an Earth 2.0. To recognise habitability, we can compare data obtained about the Earth and use careful and precise uncertainties to determine the length of its suitability.[38] The main data points scientists utilise are – masses, relevant radii (orbital and planetary), density, flux (radiation emitted per unit time), planetary equilibrium temperature and orbital period.[39]

Figure 6 - Age-metallicity distribution for star particles



Source from the graph archive rich website, ResearchGate: https://www.researchgate.net/figure/Age-metallicity-relation-for-star-particles-divided-into-different-age-intervals-at_fig1_324886907

Figure 7 - H-R diagram of star magnitude against their temperature



Source from a Wikipedia article on the main sequence stars with full endnotes: https://en.wikipedia.org/wiki/Main_sequence

[33] When light from an astronomical object is displaced towards the longer wavelengths as the object moves away from the source of light. The waves from the source are bunched together and moves away with the expansion of the universe.

[34] Blueshift is the opposite of redshift – where the light that is bunched together is moving towards the Earth shortening the wavelength giving information to scientists as to how stars and galaxies are moving with respect to the Earth.

[35] Hatzes, Artie P. "The radial velocity method for the detection of exoplanets." Methods of Detecting Exoplanets. Springer, Cham, 2016. 3-86.

[36] Elachi, Charles, and Jakob J. Van Zyl. Introduction to the physics and techniques of remote sensing. John Wiley & Sons, 2021.

[37] Shi, Jinjun, et al. "Recent developments in nanomaterial optical sensors." TrAC Trends in Analytical Chemistry 23.5 (2004): 351-360.

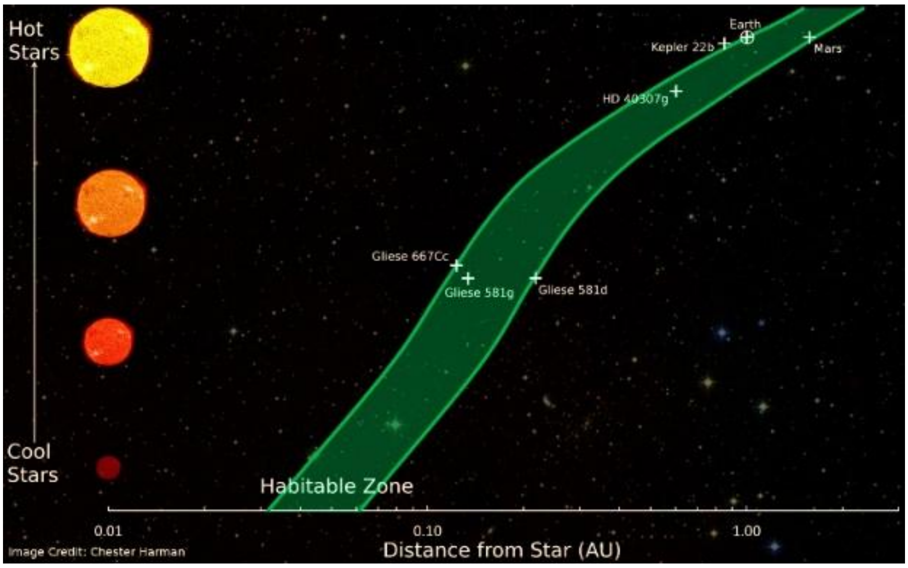
[38] Hogan, Jessica. Characterising the Potential for Planetary Habitability: A Study of the Temporal Evolution of Exoplanet Habitable Zones. No. EPSC2022-369. Copernicus Meetings, 2022.

[39] Kaspi, Yohai, and Adam P. Showman. "Atmospheric dynamics of terrestrial exoplanets over a wide range of orbital and atmospheric parameters." The Astrophysical Journal 804.1 (2015): 60.

But these values vary greatly based on star systems. Properties of single stars and stellar groups – like our own planetary system – vary greatly compared to a binary star system. From figure 6 you can see how single star systems can be classified and analysed to tell us the metallic composition and other age compared to the sun.[40] Using this we can quite accurately estimate the gravitational attraction and therefore timeline of the star itself. While a star is in the main sequence of its lifetime, they can be classified by mass into categories O, B, A, F, G, K and M. As shown in figure 7, stars with high mass have a greater luminosity but have a much shorter main sequence lifetime.[41] This tells us the current state of the star since we have to factor in the fact that the light arriving to the Earth will show the star in the past (as in the star's reference frame).[42]

Binary star systems are amongst a quarter of the data we have.[43] Techniques used in identification of different factors in binary star systems orbiting about a central point is much different as you observe little of the orbiting exoplanet and more about the equivalent star. Using data gathered orbital simulations are created to observe orbital eccentricity as well as axial tilt.[44]

Figure 8 - Habitable zone boundaries around stars



Source from Phys.org powered by the global organisation Science X Network: https://phys.org/news/2013-01-habitable-zones-star.html

Galactic habitable zones are another important factor which can only be analysed with the aid of sensors. The term "Goldilocks Zone" refers to the distance from a host star given its luminosity from which the conditions to sustain life are available.[45] This zone has minimal radiation and strong enough gravitational attraction so that it remains in the orbit which is why it is displayed as very narrow in figure 8.[46] Figure 9 clearly demonstrates the thin margin of the availability of habitable exoplanets and what scientists are primarily look for when analysing readings from telescopes. This

[40] Grand, Robert JJ, Daisuke Kawata, and Mark Cropper. "Impact of radial migration on stellar and gas radial metallicity distribution." Monthly Notices of the Royal Astronomical Society 447.4 (2015): 4018-4027.

[41] Valenti, Jeff A., and Debra A. Fischer. "Spectroscopic properties of cool stars (SPOCS). I. 1040 F, G, and K dwarfs from Keck, Lick, and AAT planet search programs." The Astrophysical Journal Supplement Series 159.1 (2005): 141.

[42] Zahnle, Kevin J., and James CG Walker. "The evolution of solar ultraviolet luminosity." Reviews of Geophysics 20.2 (1982): 280-292.

[43] Watanabe, Hiroshi, Toshiaki Sawada, and Yumi Matsumiya. "Constraint release in star/star blends and partial tube dilation in monodisperse star systems." Macromolecules 39.7 (2006): 2553-2561.

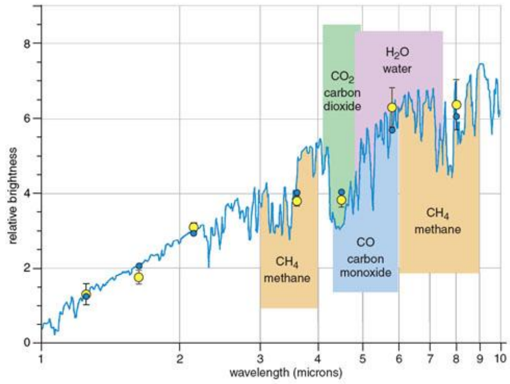
[44] Heppenheimer, T. A. "On the formation of planets in binary star systems." Astronomy and Astrophysics 65 (1978): 421-426.

[45] La Bella, Laura. The Goldilocks Zone: Conditions Necessary for Extraterrestrial Life. The Rosen Publishing Group, Inc, 2015.

[46] Jagannatha, Bindu. "Solar radiation pressure, drag and gravitational effects on a dust particle in Earth orbit." (2012).

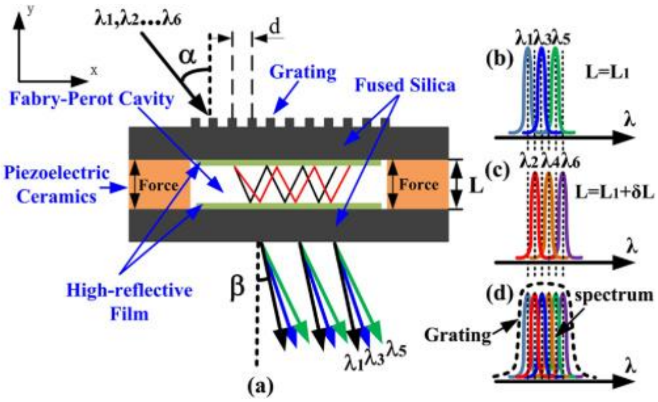
is not very easily observed by the naked eye, nor can it be analysed by computers to give an effective image which highlights the importance of spectroscopy in sensors.[47]

Figure 9 – relative climate on exoplanets based on the wavelength received



Source by leading article writer for science – Scientific America: https://www.americanscientist.org/article/the-study-of-climate-on-alien-worlds

Figure 10 – The work of Fabry-Perot filters in the Oxyometer to observe spectra of light



Source from research dissertation byZhendong Shi Et al. from the Institute of Optics and Electronics in the University of Chinese Academy of Sciences, Beijing : https://opg.optica.org/ao/abstract.cfm?uri=ao-53-1-76

To the topic of sensors, the most common technique used to analyse light received from exoplanets is Spectrometry.[48] As exoplanets orbit a host star, they reflect a certain amount of light out into space and the luminosity glare is captured, collimated and high-resolution spectroscopy can then disentangle and isolate the spectrum associated with the colours showing the different elements in figure 9.[49] The individual lines produced is different for each molecule and this can tell us compositions of the stars from which we can deduce the goldilocks zone radius, radiation emitted and size. For close-in planets the lines undergo Doppler Shifts[50] during the orbit of the planet, which can enable us to find the velocity separation of the planet.[51]

Apart from this, sensors such as the Oxyometer,[52] are added onto telescopes (Earth and Space) which use Fabry-Perot filters, working like figure 10, which allows simultaneous observation of narrow bands on, and off absorption lines received from certain spectrometers.[53] The concept of sensors for identifying exoplanets came from interferometers[54]. Providing the precision of the spectrums is accurate, this gives us the ability to then use computer algorithms to interpret and plot the data showing compositions of planets.[55]

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[47] Ditto, Thomas D., et al. Holographic Optical Method for Exoplanet Spectroscopy (HOMES). No. HQ-E-DAA-TN41345. 2017.

[48] Birkby, J. "Spectroscopic direct detection of exoplanets." (2018).

[49] Aoki, Wako, et al. "High-resolution spectroscopy of extremely metal-poor stars from SDSS/SEGUE. I. Atmospheric parameters and chemical compositions." The Astronomical Journal 145.1 (2012): 13.

[50] Also known as the change in frequency due to the Doppler Effect – the change in wavelength or frequency of the waves with respect to the observer who is in motion relative to the wave source.

[51] Damiano, Mario, and Renyu Hu. "Reflected spectroscopy of small exoplanets I: determining the atmospheric composition of sub-Neptunes planets." The Astronomical Journal 162.5 (2021): 200.

[52] Baker, Ashley D., Cullen H. Blake, and Sam Halverson. "The Oxyometer." Publications of the Astronomical Society of the Pacific 131.1000 (2019): 1-22.

[53] Baker, Ashley D., Cullen H. Blake, and Sam Halverson. "The Oxyometer: A Novel Instrument Concept for Characterizing Exoplanet Atmospheres." Publications of the Astronomical Society of the Pacific 131.1000 (2019): 064402.

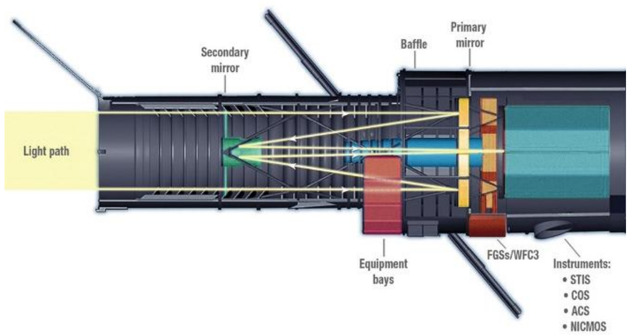
[54] Collection of sensors and semiconductors working together and combined to form a complete image of certain objects.

[55] Pearson, Kyle A., Leon Palafox, and Caitlin A. Griffith. "Searching for exoplanets using artificial intelligence." Monthly Notices of the Royal Astronomical Society 474.1 (2018): 478-491.

Space based Telescopes

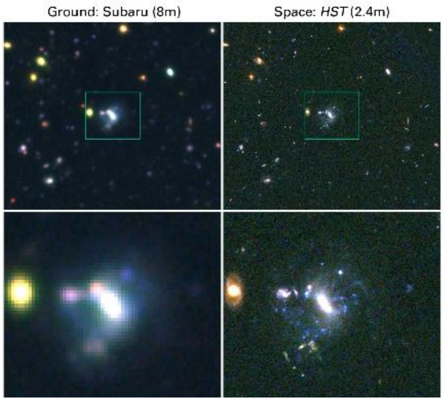
The first optical space telescope, OAO-2, was launched in 1968 and began a decade long operation to search the cosmos of exoplanets. The main reason for this was a telescope orbiting Earth was not subject to twinkling, light pollution nor the ability to have their angle changed due to Earth's motion so they can observe a full 360 ° field of view at whichever orientation making it very effective in locating exoplanets.[56] With such high angular resolution, aperture can be changed much more gradually to allow the most efficient viewing of celestial bodies. Space based telescopes primarily use the EM spectrum to navigate and map their location so once orbited twice can take accurate readings of the same point in space.[57] Communication is also more effective in space as they have in-built scientific instruments to analyse light levels so data can be then compared back when at Earth.[58]

Figure 11 – path of light through the Hubble telescope



Source by the leading scientists running the Hubble Telescope: https://hubblesite.org/contents/media/images/4520-Image.html?Topic=109-the-telescope

Figure 12 – comparison of ground-based telescopes against space telescopes



Source by the leading scientists running the Hubble Telescope:https://hubblesite.org/contents/media/images/2004/07/1461-Image.html?news=true

Telescopes, like the Hubble, were in operation since 1990 and focus light onto scientific instruments like cameras and spectrographs visible in figure 12.[59] The most important speciality of space-based telescopes is that their orbits don't have to be specific to capture images. The use of different distances from the Earth can heavily increase the clarity of images which can be distinctly seen in figure 12 as Earth naturally emits visible light and infrared radiation, this prevents the detection of distant galaxies.[60]

[56] Code, Arthur D. "Scientific results from the orbiting astronomical observatory (OAO-2)." Scientific results from the orbiting astronomical observatory (OAO-2). Vol. 310. 1972.

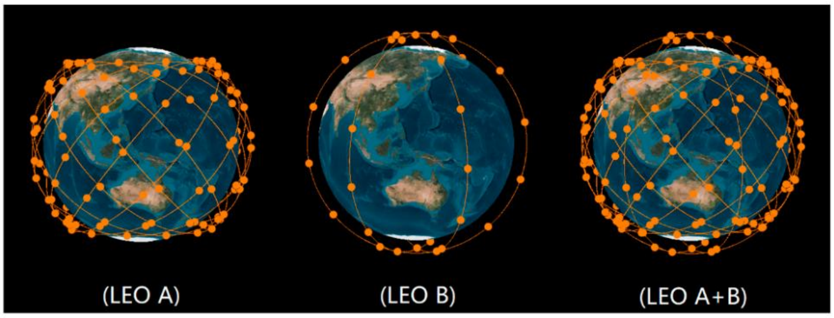
[57] Kirichenko, D. V., V. V. Kleimyonov, and E. V. Novikova. "Large optical space-based telescopes." Journal of Instrument Engineering 60.7 (2017): 589-602.

[58] Wang, Jianmin, et al. "Free-space laser communication system with rapid acquisition based on astronomical telescopes." Optics Express 23.16 (2015): 20655-20667.

[59] Scoville, Nick, et al. "COSMOS: Hubble space telescope observations." The Astrophysical Journal Supplement Series 172.1 (2007): 38.

[60] Deeg, H. J., et al. "Ground-based photometry of space-based transit detections: photometric follow-up of the CoRoT mission." Astronomy & Astrophysics 506.1 (2009): 343-352.

Figure 13 – revolutionary orbits around the Earth to capture different points in space-by-space telescopes



Source from dissertation paper by Zhixin Yang Et al. from GNSS Research Center, Wuhan University, Wuhan 430079, China: https://www.mdpi.com/2072-4292/12/12/2050/htm

The most common points of revolution are LEO (Low Earth Orbits) and L-points (Lagrange points). Satellites in LEO are relatively close to the Earth's surface, but the greatest advantage is that they do not always follow the same path around the Earth as exhibited in figure 13.[61] The ability to tilt the orbit allows for a much greater range of the sky you can view. The ISS mostly uses this orbit maneuverer around the Earth. Although this isn't used as much as there is severe light glare from the Earth as well as this the vast velocity travelled at this radius means telecommunication data such as navigation are much harder to track.[62] Within the span of a minute the degree radian travelled means failure could be catastrophic not only for the satellite itself, but neighbouring satellites or even debris which goes to MEO and SSO.[63]

The much more used Lagrange points are exclusive for space-based observatories and telescopes whose mission is to photograph deep, dark space. Lagrange points are over a million kilometres from Earth and don't even orbit Earth directly.[64] At specific points in space, the gravitational fields of Earth and the Sun combine in such a way that spacecraft that orbit them remain stable and can thus be 'anchored' relative to Earth. This point is very distinct, at other points spacecraft this far from Earth will naturally orbit the sun and end up at such a distance from Earth communication is impossible.[65]

[61] Barth, Janet L. "Space and atmospheric environments: from low earth orbits to deep space." Protection of materials and structures from space environment. Springer, Dordrecht, 2004. 7-29.

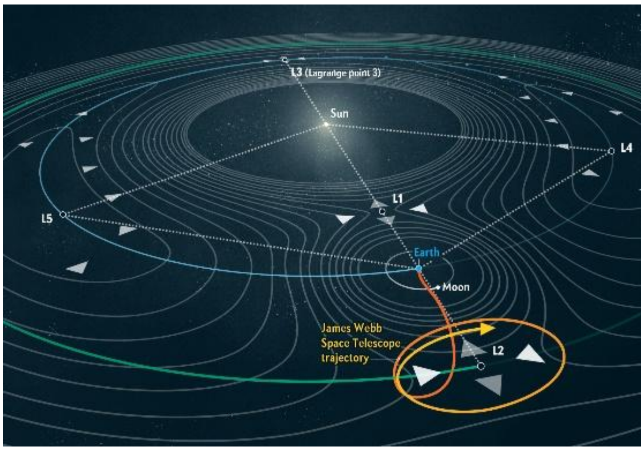
[62] Salmond, Wendy, Justin Walsh, and Alice Gorman. "Eternity in low Earth orbit: icons on the International Space Station." Religions 11.11 (2020): 611.

[63] Kallivayalil, Nitya, et al. "Third-epoch Magellanic Cloud proper motions. I. Hubble Space Telescope/WFC3 data and orbit implications." The Astrophysical Journal 764.2 (2013): 161.

[64] Bookless, John, and Colin McInnes. "Control of Lagrange point orbits using solar sail propulsion." Acta Astronautica 62.2-3 (2008): 159-176.

[65] Tang, Yuhua, et al. "Effect of orbital shadow at an Earth-Moon Lagrange point on relay communication mission." Science China Information Sciences 60.11 (2017): 1-10.

Figure 14 – Orbit of the James Webb and the positions of the Lagrange points relative to Earth depicting the three-body problem



Source by leading article writer for science – Scientific America: https://www.scientificamerican.com/article/what-is-a-lagrange-point/

The newly released James Webb telescope follows the L2 orbit (the halo orbit) which can be seen from figure 14 at approximately 1,500,000 km beyond Earth's orbit.[66] The James Webb is an infrared telescope meaning it uses IR radiation to detect objects, at the distance of normal space telescopes are limited as to how far they can see as the formation of stars hidden behind dust, this absorbs visible light. Despite this, infrared light emitted can penetrate this, revealing what's behind allowing us to observe the very first stars in the universe which is the principal reason of the Infrared Camera on the JWST.[67]

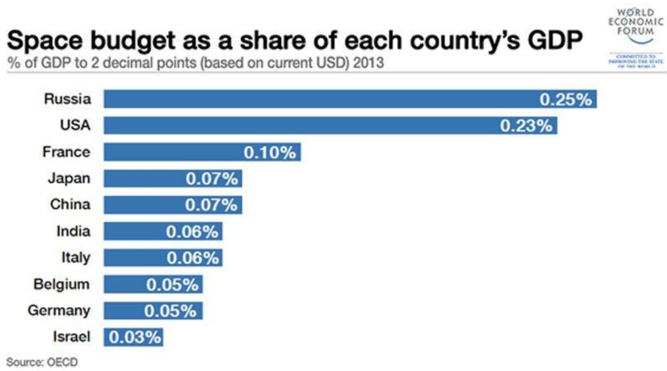
[66] Gardner, Jonathan P., et al. "The james webb space telescope." Space Science Reviews 123.4 (2006): 485-606.

[67] Rieke, Marcia J., Douglas M. Kelly, and Scott D. Horner. "Overview of James Webb Space Telescope and NIRCam's Role." Cryogenic Optical Systems and Instruments XI. Vol. 5904. SPIE, 2005.

Economic and environmental issues preventing development

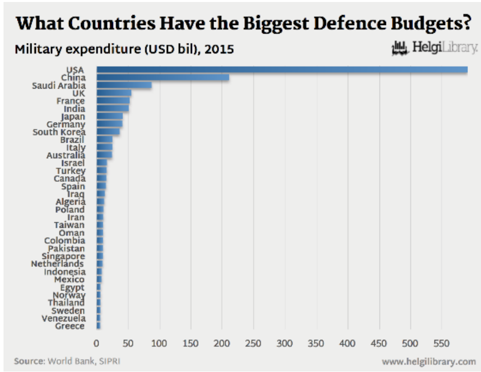
Although the rate of technological development is very high, many factors certainly limit the process of searching for exoplanets on a more resource frame of reference. Economically, the search for exoplanets uses many resources yearly as well as the team required to analyse the information received. Looking back from the point of NASAs inception to the present time, the US government aided nearly 650 billion dollars[68] for research, development and manufacture it is still quite limited in what it could be.[69] The percentage of the US budget going towards NASA is only 0.23%. In comparison with the military, which is 597.5 billion this year, this is shown as the combination of figure 15 and figure 16.[70] The sophistication of sensors, prototypes, and advancement in the field of optics can vastly be improved with the change in the budget which will rapidly increase the rate at which we find exoplanets.

Figure 15 – Space budgets as a share of GDP



Source by collective economists on World Economic Forum: https://www.weforum.org/agenda/2016/01/which-countries-spend-the-most-on-space-exploration/

Figure 16 – Defence budgets as of 2015 of nations



Source by Helgi Library – an extensive archive of data and reports: https://www.helgilibrary.com/charts/what-countries-had-the-biggest-defence-budget-in-2015/

Environmentally, there are certain arguments amongst the media that space exploration and addressing the many problems we have here on Earth are mutually exclusive, which does mean they can be solved quickly and independently of one another. One of the greatest benefits of the improvement of technology in this area is that there is the ability to study Earth from orbit. This has allowed us to learn an unprecedented amount about our planet's climate and weather systems, not to mention giving us the ability to measure these systems and the impact that human agency continues to have on them.[71]

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[68] All data points and figures are from the official NASA website which includes the budget documents, strategic plans and performance reports available to the public on the website: https://www.nasa.gov/news/budget/index.html

[69] Hamaker, Joseph W. "But what will it cost? The history of NASA cost estimating." Readings in Program Control 6103 (1994): 25.

[70] All data points and figures are from the official Worldbank website which includes the military expenditure over time as a percentage of the US GDP as well as starting from the correct time frame to just before the moon landing which is available to the public on the website: https://data.worldbank.org/indicator/MS.MIL.XPND.GD.ZS?locations=US

[71] Hartmann, William K. "Space exploration and environmental issues." Environmental Ethics 6.3 (1984): 227-239.

How are different telescopes being used to detect exoplanets?

My research strategy is to mainly follow the scientific method to see how telescopes influence the way we can see celestial bodies. I will take repeats of one magnification which can then be magnified later when I receive the pictures and edit them to increase sharpness and saturation and create higher resolution photos instead of many ranges of photos.[72]

To provide an insight into sensors and the use of different types of lenses I have used a flagship phone to capture the view based on the advancement of technology within that sector and my DSLR camera. A camera on a phone will have a constant focal length but the aperture and shutter speed can vary. DSLRs on the other hand house a variety of lenses with variable focal length and can be changed so I will use this to compare to show how it can affect the photos.[73]

The focal length used for both refractor and reflector are both the exact same which I will use as control variables as well as the moon phase, wind speed and light pollution. The moon phase is specifically important because the amount of light being reflected back is much higher during a full moon rather than a waxing/ wanning crescent.[74]

At the beginning of the investigation, my hypothesis was that the telescopes were going to have the greatest view of objects in space. However, after observing the capabilities of my DSLR, I believe that pictures from my DSLR will hold significant value, potentially more than telescopes.

Figure 17 – the Moon as seen from a refractor telescope

Figure 18 – the Moon taken from a DSLR camera

[72] Iachel, Gustavo, et al. "The assembling and usage of low-cost refractor telescopes as motivating experience in astronomy education." Revista Brasileira de Ensino de Física 31 (2009): 4502-4508.

[73] Ignatov, Andrey, et al. "Dslr-quality photos on mobile devices with deep convolutional networks." Proceedings of the IEEE International Conference on Computer Vision. 2017.

[74] Bond, G. P. "On the light of the Sun, Moon, Jupiter, and Venus." Monthly Notices of the Royal Astronomical Society 21 (1861): 197.

Figure 19 – the Moon as seen from a reflector telescope Figure 20 – the Moon from a phone

Figure 21 – Picture of the Moon as taken from NASA's Hubble telescope

Source by the Massachusetts Institute of Technology Department of Astrophysics: https://news.mit.edu/2012/moon-dynamo-0127

To start the analysis with focal length, both the telescopes consisted of the same focal length of 900mm which tells me that the angle of view will be smaller but have a much higher magnification which can be seen from figure 18 and 20. With a larger angle of view from the flagship phone and the camera in figures 19 and 21 show a much more open-ended photo of the whole moon. But looking at figure 20 the magnification and detailed captured is incomparable to the other photos which shows the power of the reflector telescope in capturing details of near celestial objects. Included in this the focal diameter plays a vital role in the visibility of the moon. The refractor telescope has a focal diameter of 60mm and from figure 18 you can see it quite magnified but compared to the reflector in figure 20 with 90mm which is a small difference but effective especially with the specific lens the magnification is remarkable visually. Both figure 19 and 21 had a manual zoom and with the focal lens being small it was effective this way as the DSLR only had a 58mm focal diameter and the one on the phone quite small.

Going to magnification the reflector and refractor were both tested with different levels of magnification. But the reflector paired with the specific focal length and diameter made it so that the level of magnification needed did not have to be as high to capture as much detail. This however is different to the DSLR and phone as they both have lens to magnify to a certain extent but afterwards the image then can be zoomed further – although the resolution decreases not to such a high extent, so the image is still visible.

Both the reflector and refractor were on an equatorial mount which meant that they can be changed precisely which does go in their favour as the others had a normal strand which shows if the stand is sturdy, it does not make a huge difference in the image. Both the phone and DSLR had photos edited for exposure and hue to create a more accurate one – the one on the telescopes did not have to be which does show their superiority in this category, they already had significant colour which makes then stand out and still look natural.

Finally, looking into cost figure 22 was from the Hubble telescope which did cost millions but has significant other uses. Both the reflector and refractor were £100 which is very reasonable especially with the detail captured in the photos and since this is the primary purpose the craters visible has incredible detail. However, the DSLR and phone are much more significantly priced the detailed captured but them were also significant. Figure 19 clearly shows a much wider view of the moon the detail close up but is not as great as the reflector visible in figure 20 for the significant price increase.

My data can be repeated every fortnight because the lunar cycle repeats so if I were to take the pictures again – they will be very similar to the original as the sun's luminosity does not change immensely which does not affect the moon's ability to reflect the light drastically.[75] This would mean I would get very similar results even for long periods of time delay the moon's axis tilts so I have taken the readings several times and layered them to give the average of all the pictures.

Since, I am using somewhat subjective approach to this specific question, the validity of my research could differ based on reader, but I feel like the data set forth follows a basic trend which can be easily picked up on.

<u>SUB-CONCLUSION:</u>

At the end of this investigation of inspecting the moon – the different uses of telescopes have become very apparent to me, and I have seen that the use of reflector telescopes (when looked at it as a whole) is the most efficient telescope. The other telescopes like the DSLR camera have benefits over the reflector but not significant when looking for exoplanets as there must be great magnification, resolution so you can classify specific locations on the photograph.

[75] Coates, Robert J. "Note: Lunar Brightness Variations with Phase at 4.3-MM Wave Length." The Astrophysical Journal 133 (1961): 723.

Areas with the most potential of habitable exoplanets within the night sky

The second variable considers the different positions within the night sky and using different apps and maps of the sky from NASA can determine which area within the sky has the most potential to host the next potential Earth.

With having done background research I can see how the different places in the sky can be observed to hold much more value than others which can vary depending on hemisphere. So, I aim to use my DSLR to capture as much light as possible whilst keeping a high field of view.[76]

The parameters on my DSLR which I can change is aperture, shutter speed and ISO. ISO is light sensitivity relative to the subject and this needs to be as large as possible so that as much light can be captured as possible. Shutter speed quantifies the length of time the camera shutter is open while the camera takes a photo. When the shutter is open, light hits the camera sensor; therefore, the shorter the shutter speed, the more light the sensor receives. Finally, there is also aperture which controls the brightness of the image that passes through the lens and falls on the image sensor. All the other changeable factors such as zoom, and white balance will be kept constant as control variables so that there can be a unified picture which reflects the best.

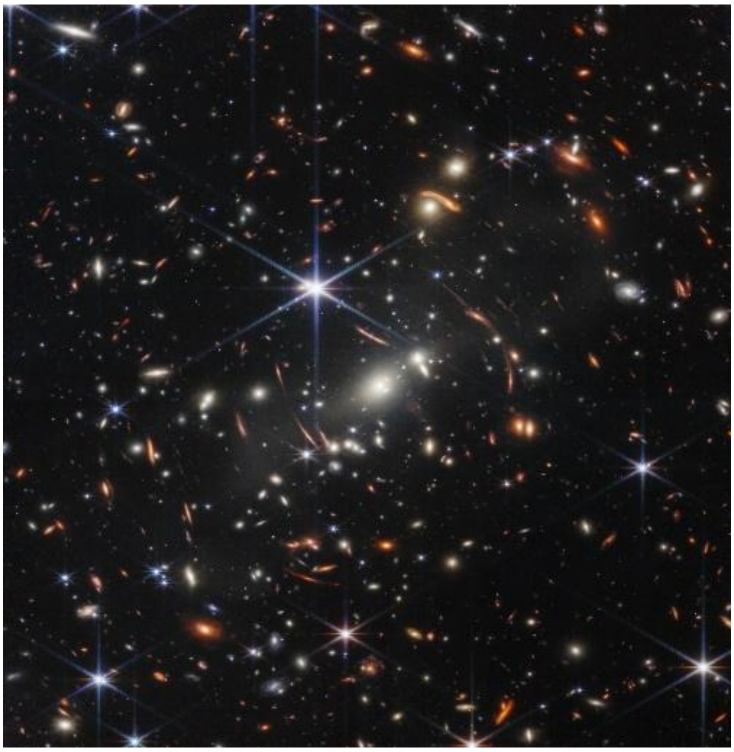
At the beginning of the investigation, I was convinced that the lowest shutter speed, lowest aperture, and higher ISO would get the most informative photo of the Andromeda (057 degrees longitude and +028 degrees latitude), as a hypothesis. I also looked at a different area of the sky – where the Vega star system is located as that too has high potential of habitable exoplanets.

Figure 22 – the view of the Vega constellation (circled red)

[76] Hoot, John E. "Photometry with DSLR cameras." Society for Astronomical Sciences Annual Symposium. Vol. 26. 2007.

Figure 23 – the view of the Andromeda Galaxy

Figure 24 – the Deep Field photo taken by the James Webb Space Telescope which captures galaxies from just some hundred millions of years before the Big Bang



Source by scientists who worked on the James Webb:https://webbtelescope.org/contents/media/images/2022/035/01G7DCWB7137MYJ05CSH1Q5Z1Z?news=true

Located in Figure 23 on the Lyra constellation is the Vega star system being the 5th brightest star[77] in the night sky but surrounding this the neighbouring stars within the constellation include the Zeta Lyrae as well as Beta Lyrae ("Sheliak") and Gamma Lyrae. Most of the stars located in the picture are the same as our sun being individual, but parts of this light source even form a binary and triple star system which is why it is so visible even for such little exposure time and to the naked eye. [78] Comparing Figure 23 with 24 the major celestial object visible other than some other individual and binary star systems is the closest galaxy to the Milky Way the Messier 31 or the most common name of Andromeda. The blue tinge suggests there is blue shift when the wavelength of light gets shorter and frequency larger meaning it is moving towards us. Although at a slow speed, with equivalent mass at 1 trillion solar masses the collision will form a lenticular galaxy with a combined mass.[79] Figure 25 also known as the Webb's first deep field photograph shows the galaxy cluster SMACS 0723 as it appeared 4.6 billion years ago.[80] The combined mass of this galaxy cluster acts as a gravitational lens, magnifying much more distant galaxies behind it.[81]

Vega sits roughly 25 light years, but many binary and triple star systems sit thousands of lightyears away like the Beta Lyrae B which sits at 1085 lightyears this would also mean this star is much farther beyond our reach.[82] Looking at Andromeda being 2.5 million lightyears away consisting of millions of binaries, triples, and even individual star systems the venture across this specific galaxy would lead to thousands of possible exoplanets.[83] This is heavily contradicted by the James Webb which proposed that one of the galaxies in the image could have a redshift of greater than 7.5, suggesting a distance of around an incredible 13 billion light years away.[84]

Vega is an A-type star with the rotation, size and age is much different to the one of ours. Vega has a much faster rotation, at 16 hours as opposed to our sun's 27 days, being 2.5 times larger and being only 400 million years old. This knowledge predicts the elements are burning much faster leading to any orbits of planets deadly found by the radial velocity meaning the goldilocks zone is narrow so the chance of any habitable planet at all is very slim.[85] In Figure 24 considering the drake equation by gives us a number around the billions taking basic statistical values like the fraction of star systems which have planetary systems.[86] The JWST, however, shows a legion of galaxies and it has proposed due to the fact that the goldilocks zones are so vast and cold it is actually impossible to find any within each one.[87] But insightful information is still given as to the level of intelligent species which could have lived to suggest the next stages of new habitable exoplanets.

The magnification used in both Figure 23 and 24 was identical to 85 mm, but the JWST as a stunning 6.5m capturing more energetic phenomena including forming proto-stars and building a more

77 Artymowicz, Pawel. "Vega-type systems." The Role of Dust in the Formation of Stars (1996): 137-148.
78 Kuiper, Gerard P. "On the Interpretation of beta Lyrae and Other Close Binaries." The Astrophysical Journal 93 (1941): 133.
79 Hodge, Paul. The Andromeda Galaxy. Vol. 176. Springer Science & Business Media, 2013.
80 Ferreira, Leonardo, et al. "Panic! At the Disks: First Rest-frame Optical Observations of Galaxy Structure at $ z> 3$ with JWST in the SMACS 0723 Field." arXiv preprint arXiv:2207.09428 (2022).
81 Connolly, A. J., et al. "The Evolution of the global star formation history as measured from the Hubble deep field." The Astrophysical Journal 486.1 (1997): L11.
82 Linnell, Albert P., Paul DeStefano, and Ivan Hubeny. "Binary Star Synthetic Photometry and Distance Determination Using BINSYN." The Astronomical Journal 146.3 (2013): 68.
83 Vilardell, Francesc, et al. "The distance to the Andromeda galaxy from eclipsing binaries." Astronomy & Astrophysics 509 (2010): A70.
84 Kalirai, Jason. "Scientific discovery with the James Webb space telescope." *Contemporary Physics* 59.3 (2018): 251-290.
85 Song, Inseok, et al. "Ages of late spectral type Vega-like stars." The Astrophysical Journal 533.1 (2000): L41.
86 Efremov, Yu N., G. R. Ivanov, and N. S. Nikolov. "Star complexes and associations in the Andromeda galaxy." Astrophysics and space science 135.1 (1987): 119-130.
87 Pascale, Massimo, et al. "Unscrambling the lensed galaxies in JWST images behind SMACS0723." arXiv preprint arXiv:2207.07102 (2022).

complete picture of the astrophysical universe. The comparison in magnification shows us its importance rather than the zoom in editing although very high the pictures gained is immensely powerful and worth the cost.

Although Figure 24 was magnified and sharpened greatly in the editing stage due to its shape and tiny lack of visibility to a lens camera in the night sky. On Sequator™ 80 photos were layered on top with 20 dark and vignetting frames to reduce noise. On Figure 24 the use of 100 photos layered with the same length of dark and vignetting frames which gives the correct ratio to observe several galaxies with increased resolution.[88] Figure 25 has a very long exposure of 12.5 hours in total including more than 150 million pixels from nearly 1,000 individual photographs. The level of precision and its comparison with the photo taken by the Hubble shows it is worth the time given the level of information we have about the early universe.

The only type of editing which is done on Figure 23 and 24 was changing the sharpness and the contrast along with saturation which changes light from distant stars who are in the same phase of their lifecycle which makes it distinct. This greatly contrasts Figure 25 where literally no editing is done but the original colours picked up by the sensors giving us a marvellous in-depth view. Finally, looking into cost although the James Webb Space Telescope is worth 10 billion US dollars compared to the cost of a DSLR, the picture received, however, can date right back the beginning of the universe. This is impossible with a DSLR only looking back at a couple of hundreds of thousands of years, nevertheless, the information received from even this picture is immensely powerful and gives us a great insight into habitable planets.

SUB-CONCLUSION:

In conclusion, at the end of this investigation of inspecting the cosmos, the area within the night sky with the highest potential given the amount of research and its precision would be the Messier 31 galaxy or in other words the Andromeda. Given the rate of technological advancement and power of the JWST pictures of the Andromeda will give immense information about the types of star systems and their previous owners if any. As well as this the area visible has very close links to other neighbouring galaxies and star systems which could allow homo sapiens in the future to expand the colony in search of more exoplanets.

[88] Parimucha, S., and M. Vanko. "Photometry of the variable stars using CCD detectors. I. Photometric reduction." Contributions of the Astronomical Observatory Skalnate Pleso 35 (2005): 35-44.

Conclusion

To conclude, based on the literature available, humanity has made dynamic leaps in the field of astronomy from very early on in history. Mathematics and optics have allowed us to magnify celestial objects on Earth and in space. From this we discovered different methods to identify distant planets, i.e. microlensing and radial velocity, which allowed us to categorise the exoplanets we discovered. Telescopes play an immense role in making the search more efficient as we can manipulate lenses to identify different properties of exoplanets which is crucial in finding specific data points to categorise exoplanets. Additionally, sensors have given us a way to categorise the data in which computers helping us store and analyse the millions of photos taken and investigate each area in the sky very thoroughly.

Within the literature there is no great disagreement as every way of research is valid given the technology and scientists at the time of advancement have just built upon the fundamental ideas. This means as we improve the astronomical instruments we use, the more we understand about the universe and the closer we can get to understanding time through the universe.

Finally, to answer the base question, astronomical instruments like lenses are helping us locate an Earth 2.0 by joining together and being in very precise locations around the globe, allowing us to understand where we are in the universe. The astronomical instruments in question do not only refer to telescopes or DSLR cameras and sensors, but anything which helps us pinpoint where we are and help create a map so that we can proceed in the next steps to evolve humanity. This has been developed from the ancient Mesopotamians to technology today. This highlights the importance of human curiosity and innovation skill in the search for exoplanets making it – I believe – the most important instrument of them all to understanding the whole universe.

Word Count: 6000 (excluding footnotes etc.)

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