Using Amateur Smartphone Photography to Calculate Luminosity and Temperature of Celestial Objects.

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Abstract

Exploration of space does not need to be the exclusive realm of multimillion dollar space telescopes and government funded agencies, the vastness of space and the absolute amount of potential discoveries presents opportunities for amateur astronomers to participate in space exploration. To provide valuable insights however, the data collected by amateurs needs to be correlative to the professional data. To that end; the goal of this project is to compare images of celestial objects captured by an amateur astronomer using an iPhone and a commercial telescope to images captured and reported by professional astronomers. Work presented here will demonstrate that amateur astronomers are capable of contributing to the world of astronomy. Analysis of three stars visible from the northern hemisphere demonstrated that an amateur astronomer could predict the temperature of a star within a 3-50% of the accepted value depending on the distance of the object. The accuracy of this analysis required the object to be reasonably close to Earth, as the further the star was from the Earth the less reliable the color-temperature analysis was. This work helps demonstrate that amateur astronomers are capable of contributing to the field of astronomy thus opening opportunities for the expansion of our understanding of celestial objects.

Introduction

The observable universe is vast, yet we have only looked and observed 5% [1] of the sky. A good analogy for this scale is if you imaged all of the water in all of the world's oceans representing the known universe then if you removed one glass of water, that water in the glass would represent the amount of the sky we have actually observed. Compounding the challenges further, 95% of the visible universe is devoid of observable matter (NASA (n.d).), making observations of stellar objects even more challenging. Even though the approximately 5% of physical matter feels like a small amount, the vastness of the universe is hard to comprehend. Another analogy to think of is that there are more stars in the universe than there are grains of sand in all of the beaches in the world. Considering there are limited professional astronomers and observatories, amateur astronomers are a valuable resource to help contribute to the field by cataloging and continually observing near Earth objects. This is valuable because amateur astronomers can record new objects along with potential changes in previously cataloged objects.

There are many different types of celestial objects such as planets, stars and galaxies just to name a few. All of these objects are possible to be observed from earth based observatories, depending on environmental factors such as light pollution, weather etc. Of all the celestial objects, local stars are the most accessible to amateur astronomers due to their luminosity. Luminosity is the total amount of electromagnetic energy emitted by a star and is directly correlated to the mass of the star itself represented by the Hertzsprung-Russell diagram. [2,3] For stars in the main sequence, the mass of a star is also directly correlated to the temperature of the star. [4] Since different temperatures correspond to different colors, the color of a celestial object can be used to determine the temperature, and therefore size and relative age of a star [5]. If an amateur astronomer can accurately determine the luminosity and color of a celestial object they would be able to predict the size and age of that star.

Common Smartphones on the U.S. market	Maximum pixel detection (MegaPixels)	Main camera aperture	Wide angle camera aperture	Average field of view
iPhone 16 Pro	48 MP	$f/1.78$	$f/2.2$	120°
iPhone 13*	12 MP	$f/1.6$	$f/2.4$	120°
Samsung Galaxy S24	50 MP	$f/1.8$	$f/2.2$	120°
Google Pixel 9 Pro	50 MP	$f/1.7$	$f/1.7$	123°

Table 1: *Camera characteristic for the three most common smartphones on the market. * Smartphone and camera used in this study.*

There are many bands of popular smartphones on the market today, many of which have professional quality digital camera optics. Table 1 lists the three most common smartphones [6] and a brief comparison of their camera technology along with an older model iPhone13 that was used in this study. Not only are smartphones a readily available technology, amateur telescopes are common in many American backyards. By coupling the smartphone and the telescope it is possible for amateur astronomers to document the night sky in greater detail than ever before. This report will demonstrate how the iPhone 13 and the Celestron NexStar 8C telescope were used to compare the luminosity of randomized celestial objects observable in the Northern hemisphere to each other and to the reported data of the object. Given the quality of digital cameras and telescopic optics it is anticipated that the data collected will be correlative to the published, accepted luminosity data. This report will demonstrate that amateur astronomical data can be relied upon to facilitate the cataloging and discovery of celestial objects.

Material and Methods

Equipment: A standard, unmodified iPhone13 was used as a camera for this study. The images were captured using the preinstalled camera application. The iPhone was paired with a commercially available Celestron NexStar 8C telescope. This telescope has an 8 inch visible light mirror as its main collection mirror and was paired with a Celestron 8-24mm 1.25 inch zoom ocular. The iPhone was aligned to the ocular using a camera mount specific for telescopes.

Image capture: All images were captured from a field in upstate New York located at 41° 15' 37.8072" N, 74° 21' 25.704" W. The telescope was aligned to the target objects using a laser mounted to the telescope. All images were taken with the exposures ranging from 5 seconds to 10 seconds. After the images were captured the target objects were identified using the freely available SkyView application [7].

Image processing: Images were captured using the built in iPhone camera application. Brightness levels were adjusted in order to make the image appear more isolated by increasing the presentation of the object of the image while at the same time decreasing the background objects. Other image attributes such as the exposure, the brilliance, the shadows, and the contrast were all adjusted as needed. Some of the edits adjust the space around the star, some adjust the star and others adjust both the star and the space around the star. Once the image was captured ImageJ was used to extract the red/green/blue values for the region that corresponded to my region of interest (ROI). I then used the RGB table [8] to determine the color that each set of RGB values corresponded to. Finally these colors were entered into the temperature-color converter algorithm [9] to predict the corresponding temperature.

Results showing the differences in visual magnitude

This project was designed to determine if a commercially available iPhone and intermediate amateur telescope can be employed to accurately acquire data about the nature of distant celestial objects such as stars. Image data from three stars was collected and used to determine the color characteristics of those objects. The color data was then extracted and used to determine the approximate temperature of the star. Compiling this information the characteristics of the star were compared to the scientifically agreed upon values of the star.

Vega is a star that is 25 light years away and has a visual magnitude of 0 and a predicted temperature of 9674 ^{0}K [10]. Figure 1 is a representative image of Vega as captured using the iPhone/NexStar 8C pair, in total 3 separate images of Vega were captured throughout the summer of 2023.

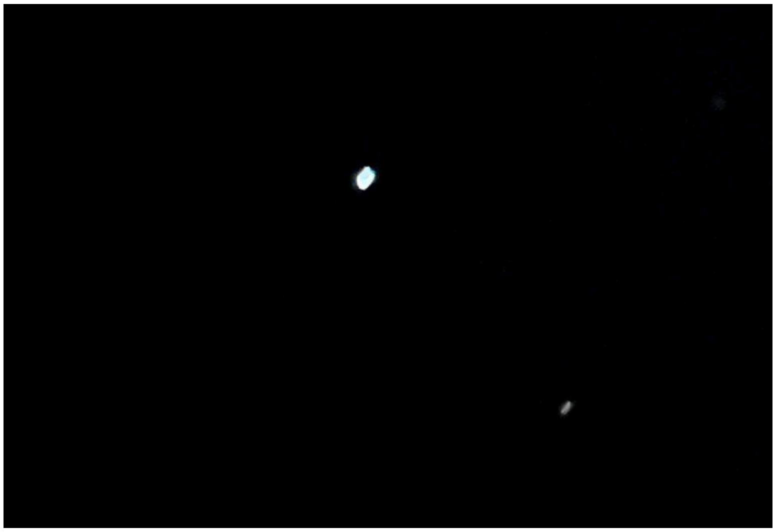

Figure 1. *Representative image captured of Vega, at center.*

Table 2 shows the image data extracted from Figure 1. The values of red/green/blue were determined by ImageJ for the ROI that corresponds to Vega. Images from multiple acquisitions were combined to calculate the average RGB values. These values were then entered into an RGB chart to determine the Hex# and corresponding color. For Vega the RGB values corresponded to CAD8DC or a light cyan color. Using the temperature-color converted algorithm CAD8DC corresponds to a temperature of approximately 10,023 °K. There is a +3.54% difference between the reported temperature of Vega and the value that I was able to calculate from my observations.

Star name	Red color value	Green color value	Blue color value	R+G+B	Predicted Color	Predicted Temperature in K
	224.167	231.763	235.135	167.906	E0E7EB	~ 7841
	180.004	201.399	205.166	160.167	B4C9CD	> 15000
Vega	202.0855	216.581	220.1505		CAD8DC - light cyan	~ 10023

Table 2: *Color and temperature data from my observations of Vega.*

Figure 2 is a representative image of Zeta Cygni, along with a galaxy in the distance. Zeta Cygni is 133 light years away from Earth, has a visual magnitude of 3.26 and a surface temperature of 4909 ^{0}K. [10] As shown in Table 3 zeta-Cygni the RGB values corresponded to D7D2AF or a light yellow color. Using the temperature-color converted algorithm D7D2AF corresponds to a temperature of approximately 8455 ^{0}K. There is a +50.07% difference between the reported temperature of zeta-Cygni and the value calculated from these observations.

Figure 2: *Representative image of zeta-Cygni, at center with a distant galaxy above.*

Star name	Red color value	Green color value	Blue color value	R+G+B	Predicted Color	Predicted Temperature in K
	198.364	194.38	163.337	183.598	C6C2A3	10632
	217.476	213.369	184.383	174.231	D9D5B8	8307
	228.903	221.708	178.439	179.651	E5DEB2	7523
zeta-Cygni	214.9143333	209.819	175.3863333	179.16	D7D2AF - light yellow	~ 8455

Table 3: *Color and temperature data obtained from observations of zeta-Cygni.*

Figure 3 shows a representative image of Deneb. Deneb is 2,616 light years away and the farthest star that was able to be imaged and identified. Deneb has a visual magnitude of 1.25 and a temperature of 8524 ^{0}K [10]. As shown in Table 4, Deneb has RGB values that correspond to B4C6C7 or a bright cyan color. Using the temperature-color converted algorithm B4C6C7 corresponds to a temperature of greater than 15000 ^{0}K. The color value that was calculated for Deneb was outside of the color-temperature conversion algorithm that was run. There is a +55.06% difference between the reported temperature of Deneb and the value that was calculated from these observations.

Figure 3: *Representative image of the distant star Deneb.*

Star name	Red color value	Green color value	Blue color value	R+G+B	Predicted Color	Predicted Temperature in K
Deneb	175.657	200.819	202.423	144.715	B0C9CA	> 15000
	184.166	195.577	195.584	141.06	B8C4C3	13750
	179.9115	198.198	199.0035	142.8875	B4C6C7 - medium light cyan	> 15000

Table 4: *Color and temperature data obtained from observations of Deneb.*

Conclusions

This project was designed to determine if amateur astronomers could produce data that could aid in the advancement of our understanding of the cosmos. Since so many celestial objects in the night sky are undocumented it is important to expand our abilities to accurately describe celestial objects. Amateur astronomers are one resource that could be used to accomplish this. Results reported here have shown that an intermediate level telescope and an iPhone are capable of accurately describing the temperature of nearby stars. Analysis of images and colorimetric data of Vega was within 4% of the professionally described temperature. If the color-temperature algorithm is optimized this error could be reduced.

Further analysis of the data does demonstrate one limitation of this approach and that is as the distance between the Earth and the celestial object being observed increases, the predictive value of the data decreases. Imaging Vega, which is 25 light years away, resulted in only 4% error while images of zeta-cygni, which is 133 light years away resulted in 50% error when compared to the known temperature of the star. Interestingly Deneb, which is 2,616 light years away also resulted in 50% error, suggesting that 50% error might be the top end of the error possible. Since there were no objects that are between 25 and 100 light years away analyzed, investigation into these objects will further our understanding of the capabilities and limitations of this study as the prediction of luminosity-temperature error correlates with distance. Understanding this characteristic could help in the refinement of this type of color-temperature analysis.

Another challenge that many amateur astronomers will encounter is light pollution. The location where these images were taken from was nearby New York City. The lights from the city resulted in background light that made stars appear dimmer and more difficult to image. The artificial brightness according to the Bortle scale, the sky brightness of my area is 504 ucd/m^2, where the artificial brightness of a truly dark sky is 0 ucd/m^2 [11]. The lower the value of artificial brightness the darker the observable sky appears. Artificial brightness is caused by man made sources of light and is a continual challenge for amateur and professional astronomers alike. Most artificial brightness is localized around large metropolitan areas and decreases as you move into more unpopulated areas. Most dark sky areas in the continental United States are in uninhabited wilderness areas far from major cities.

The work presented here could be used to help catalog the night sky. To untrained sky watchers all stars could look the same and people may think they are observing an uncatalogued object by mistake. It is also useful to compare images captured using an iPhone with images captured using professional equipment. Amateur astronomers can use this information to understand the differences between high quality and low quality images of stars. Professional astronomers could understand how well the next generation of astronomers is progressing and can use their images to further understand the observable universe.

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