Absolute Relative Flux Calibration for the Dark Energy Survey

By: Sean Peete II

Abstract

This project delves into the realm of data analysis for photometric values, aiming to surpass the precision achieved by prior calibrated surveys. Its focal point is the enhancement of accuracy within the Dark Energy Survey, striving to narrow the uncertainty of absolute relative flux from 1% down to 0.5%. To accomplish this ambitious goal, our investigation concentrates on pure hydrogen white dwarfs (DA white dwarfs) and standard stars sourced from the Sloan Digital Sky Survey (SDSS). Employing the powerful capabilities of the Image Reduction and Analysis Facility (IRAF), we meticulously extract instrumental magnitudes from both the standard stars and DA white dwarfs. The pivotal role of the standard stars lies in quantifying the lost photons, which disperse through Earth's atmosphere, known as the extinction coefficient. Upon establishing this coefficient, we can then apply it to the DA white dwarfs, thus rendering their magnitudes standardized and comparable. Ensuring the integrity of our photometric values, we undertake an additional cross-validation technique known as synthetic photometry. This process leverages the spectral characteristics of the target star to compute an anticipated photometric magnitude. By scrutinizing the alignment between these computed values and our experimental data, we ascertain agreement and pinpoint any discrepancies, should they arise, in pursuit of a deeper understanding of their origins.

I. Absolute Relative Flux Photometry

The calibration process to determine the absolute relative flux [PSM1] of the Dark Energy Survey (Sevilla-Noarbe *et al.* 2021; DES) constitutes a significant advancement in achieving more precise and reliable data in the field of astrophysics. Absolute relative flux is the amount of light compared to a known source. The DES-has two distinct data collection modes, namely the time-based and wide-area surveys. These both play a significant role in unraveling the intricacies of the nature of Dark Energy and refining the constraints associated with its equation of state.

The primary objective of this research project is to substantially reduce the uncertainty associated with absolute flux measurements, achieved through a meticulous combination of photometric and synthetic photometric calculations. To achieve this, the study harnesses the powerful Sloan Digital Sky Survey (SDSS) filters, u, g, r, i, and z, for the purpose of leveraging external data. Notably, these filters operate within the wavelength range of approximately 300 nm (nanometers) to 1100 nm. For a more comprehensive understanding of the specific characteristics of the SDSS filter passbands see Fukugita *et al*. (1996).

The DES employs a slightly different set of filters, g, r, i, z, and Y, for imaging with the objective of minimizing the uncertainty of absolute relative flux for all DES filters to an ambitious threshold of 0.5%. However, it is noteworthy that the z and y filters exhibit marginally higher uncertainties. These DES filters operate within a slightly different wavelength range, spanning from 400 nm to 1000 nm. A deeper insight into the details of these passbands can be found in the comprehensive study conducted by Tucker and Allam (2022).

Undertaking the calibration of absolute relative flux for the DES using photometric and synthetic photometric calculations, represents an essential and formidable step towards obtaining more accurate and dependable data in the exploration of Dark Energy. As researchers seek to improve our comprehension of this cosmic phenomenon, advancements in calibration techniques are of utmost importance in advancing the frontiers of modern astrophysics.

II. What is the Dark Energy Survey

The DES represents a collaborative endeavor among multiple countries and institutions, stiving to refine the enigmatic Dark Energy Equation of State. Einstein's General Theory of Relativity proposed that mass and energy govern the curvature of space-time, influencing the movement of mass and energy itself. Per this theory, all matter in the universe should decelerate over time. However, a groundbreaking discovery in 1998 revealed that the expansion of the universe was actually accelerating, leading to the realization that either General Relativity required revision or there existed an unknown form of energy permeating the cosmos – this unknown energy is now known as dark energy.

Dark energy is the intrinsic energy present in the vacuum of space throughout the universe. The core mission of the DES is to explore and investigate this mysterious energy using two distinct surveys in the southern hemisphere. The first survey, the wide area survey, encompasses approximately 5000 square degrees of the sky. Its focus lies in gathering multiple images of distant objects through extended exposures. In contrast, the time-domain survey covers a smaller area of approximately 27 degrees. The goal of this survey is to capture an extensive number of images of selected patches of the sky, utilizing the DECam (camera on the telescope), which is attached to the 4-meter (shown in figure 1) Victor M. Blanco telescope at the Cerro Tololo Inter-American Observatory (CTIO) in the Chilean Andes. Equipped with 74 CCDs, the DECam probes the cosmos through four different methodologies.

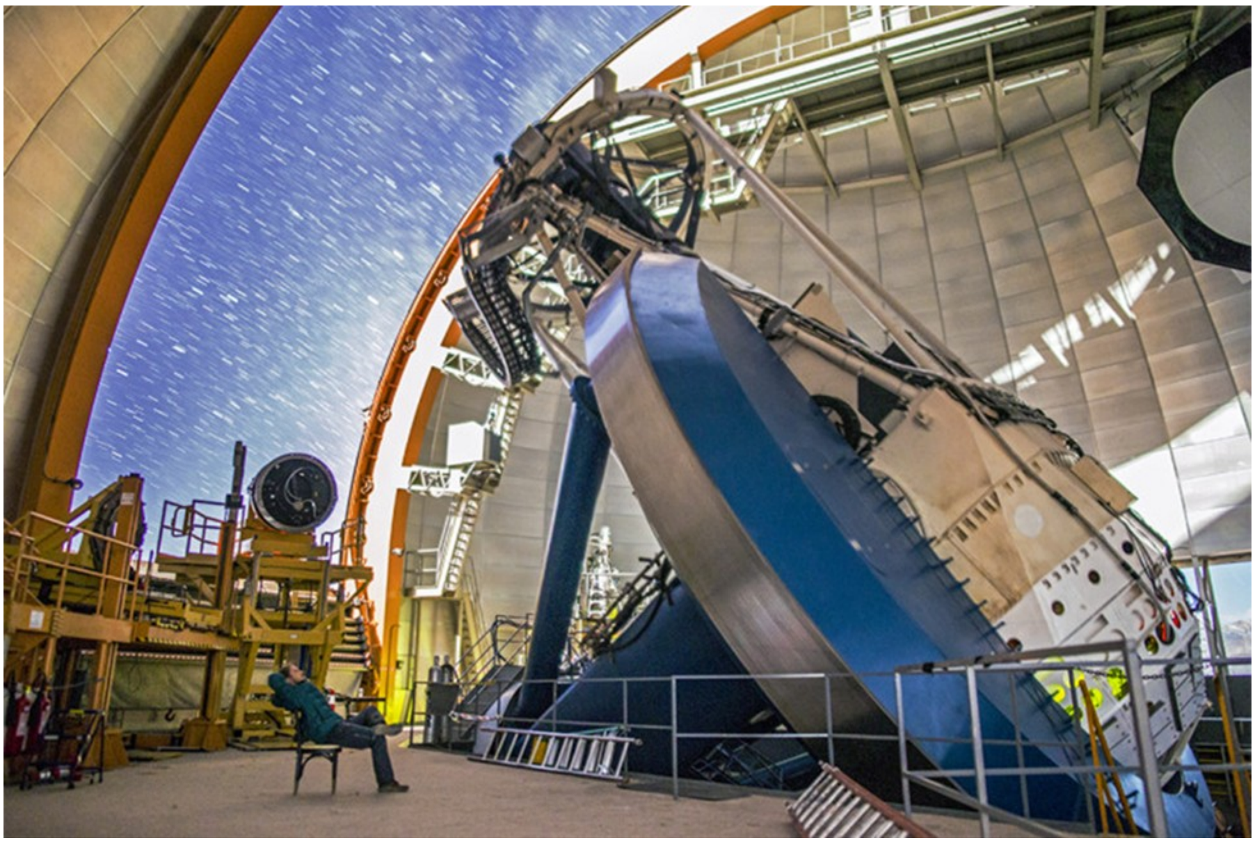

Figure 1: The 4- meter Telescope DECam in the Chilean Andes at CTIO

Firstly, supernovae serve as an excellent tool to determine the distance and acceleration of the universe, making them a focal point of DES observations. By observing a larger number of supernovae than any other survey, DES gains valuable insights into the expansion of the universe. Additionally, DECam employs weak gravitational lensing and galaxy clusters to gain a deeper understanding of structure formation and matter density throughout the cosmos. Gravitational lensing takes action on Einstein's theory of General Relativity. In this case massive objects cause spacetime to curve around such objects. This causes a distortion of light around such objects. This then bends the light in a way similar to a lens. This lets us see light from much further away therefore viewing the formation and the amount of matter throughout distant parts of the cosmos. Lastly, to comprehend the geometry of the universe, DES leverages Baryon Acoustic Oscillation (Bassett et al., 2009) as another vital element of its investigation.

In conclusion, the Dark Energy Survey's systematic exploration of dark energy through wide area and time-domain surveys, utilizing sophisticated observational techniques, holds the promise of unlocking fundamental secrets of the universe, accelerating expansion, and contributing to the forefront of cosmological research.

III. Photometry

Currently, I am engaged in the extraction of magnitudes from DA white dwarfs. DA white dwarfs in specific have a pure hydrogen atmosphere. We use these because the hydrogen spectrum is relatively simple to model as there is only one electron in the system. Fitting models of the spectra to the observations allows us to determine the effective temperatures and surface gravities of the white dwarfs. These quantities in turn affect the colors of the star. A color in the astronomical sense is the difference between two magnitudes (brightnesses) in the sense of shorter minus longer wavelengths. This is then later used in the process of synthetic photometry (explained later under IV.).

To extract the magnitude of DA white dwarfs, I employ the IRAF software suite, (Image Reduction and Analysis Facility) described in Tody (1986). Throughout this process, Figure 2 provides a visual representation of the various images involved.

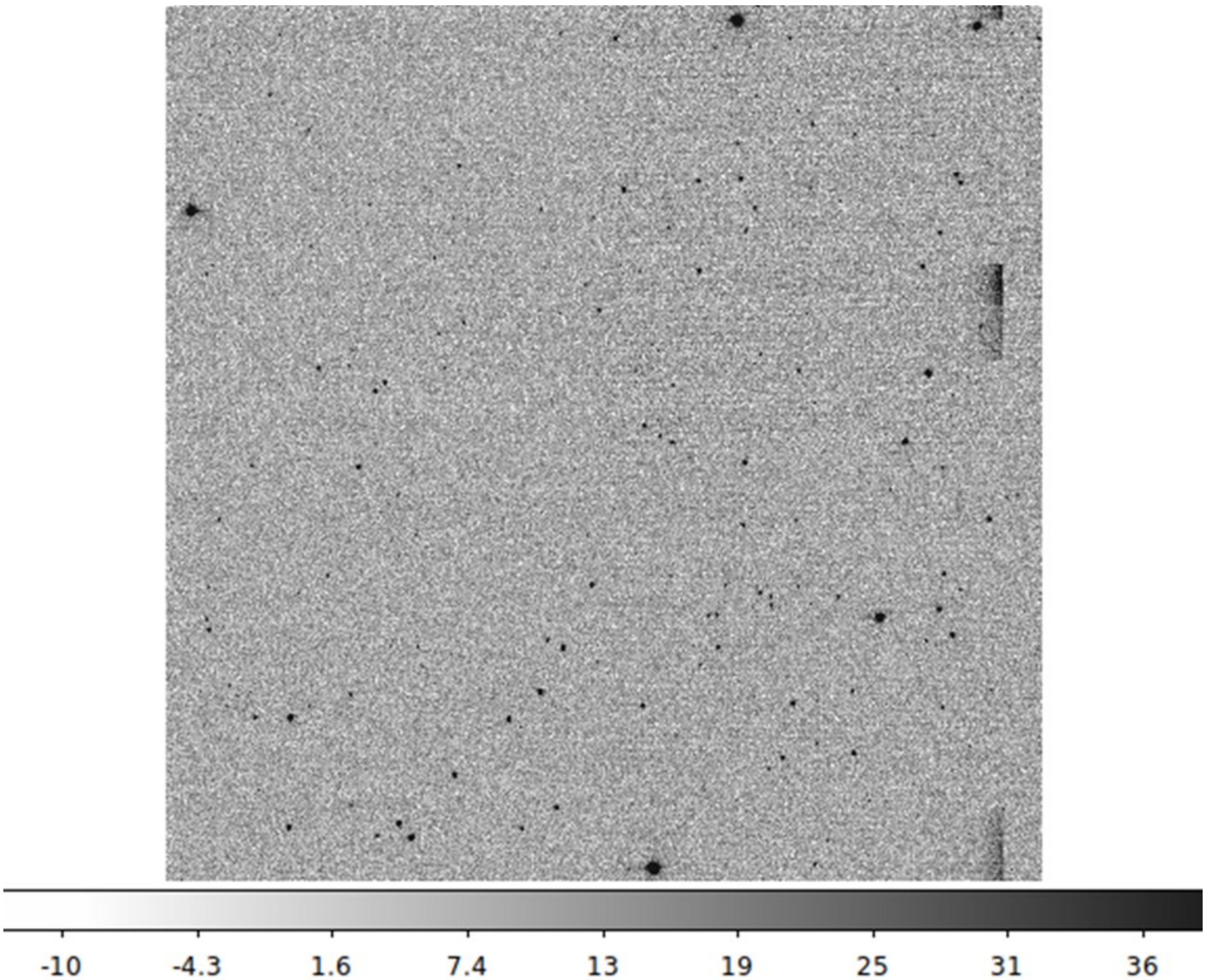

Figure 2: Image of standard star field J055950-595600

This project makes use of the Sloan Digital Sky Survey (SDSS) u,g,r,i,z (filters) standard star network, as established by Smith *et al.* (2002). The extraction aperture utilized for this system measures 14.86 arc seconds (Tucker et al. 2006) and to determine the specific aperture size (in pixels) for each telescope/detector combination used, we employ the plate scaling method. It is essential to customize the aperture to match the characteristics of the given telescope.

The foundation of this network is built upon the SDSS photometric system defined by Fukugita *et al.* (1996). In our analysis, we adhere to the AB magnitude system, which is a wideband variant of monochromatic flux. This system is based on BD+17:4708, distinguishing it from the Vega magnitude system. The AB magnitude system is a perfect fit for calibrating the absolute flux due to the system being a true flux derived system, whereas other magnitude systems are not.

By incorporating these methods and using the SDSS standard star network, we aim to extract precise and comprehensive magnitudes of DA white dwarfs with pure hydrogen atmospheres.

The use of IRAF and adherence to established photometric systems contribute to the reliability and scientific significance of our findings.

IV. Final Steps for Absolute Relative Flux Calibration

After obtaining the instrumental magnitudes, our next step involves the crucial calculation of extinction coefficient values. These values play a significant role in accounting for the dispersed light from the stars to the telescope. To achieve this, we rely on the data from standard stars, which allows us to determine the extinction coefficient. Once acquired, these coefficients are then applied to the DA white dwarfs, enabling us to obtain accurate magnitudes of these stars at the top of the atmosphere. The specific white dwarfs being used in our study are visually represented in Figure 3, offering a comprehensive view of our research subjects.

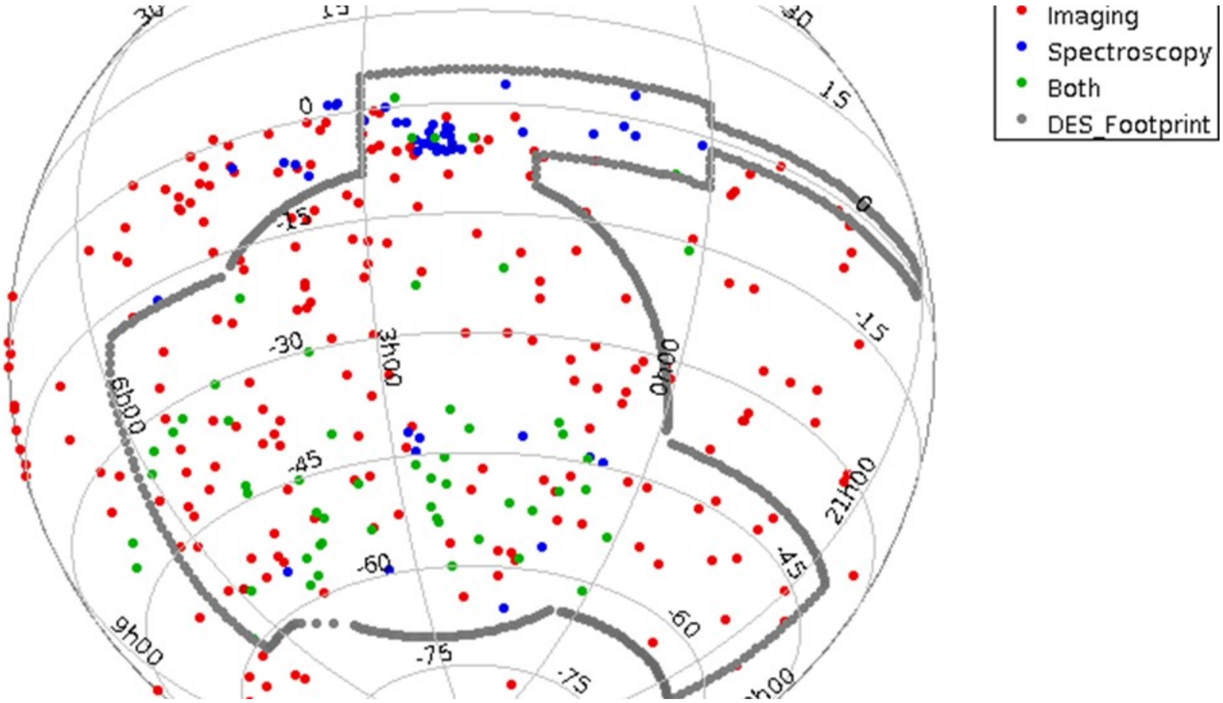

Figure 3: This graph shows the DA white dwarfs we have photometric and spectroscopic data of within the DES footprint

To ensure the reliability and precision of our magnitude measurements, we subject them to a thorough accuracy check through a process known as synthetic photometry. Synthetic photometry is a powerful technique that involves calculating magnitudes based on the spectroscopy of a star. In this scenario, we align the spectra with a model to attain the optimal fit. Simultaneously, the filter curves are convolved with the detector's quantum efficiency. Subsequently, the flux is integrated across the convolved filter curve and quantum efficiency profile. Through conducting a meticulous comparative analysis involving synthetic photometry and our calculated magnitudes, we can assuredly ascertain the precision and integrity of our outcomes. To evaluate the accuracy, we align the filter profiles with the spectra, enabling us to ascertain the expected magnitudes and compare them. This comparison can encompass diverse parameters, including unaccounted variables like cloud cover or noise interference.

The combination of calculating extinction coefficients and employing synthetic photometry strengthens the robustness of our research methodology, allowing us to make more informed and scientifically sound conclusions about the magnitudes of the observed DA white dwarfs. These intricate procedures contribute to the overall depth and integrity of our study, ensuring that the data we gather is of the highest quality and reliability, thereby advancing our understanding of these fascinating celestial objects.

V. Conclusion

In our research, we made use of the "worlds best telescope" 0.9m Small and Moderate Aperture Research Telescope System (SMARTS) situated at the Cerro Tololo Inter-American Observatory in Chile. This sophisticated telescope played a pivotal role in gathering the essential data for our study, particularly for Figures 5 and 6, which were acquired on October 20, 2018. To provide a glimpse of this impressive piece of technology, Figure 4 beautifully captures the essence of the SMARTS 0.9m telescope.

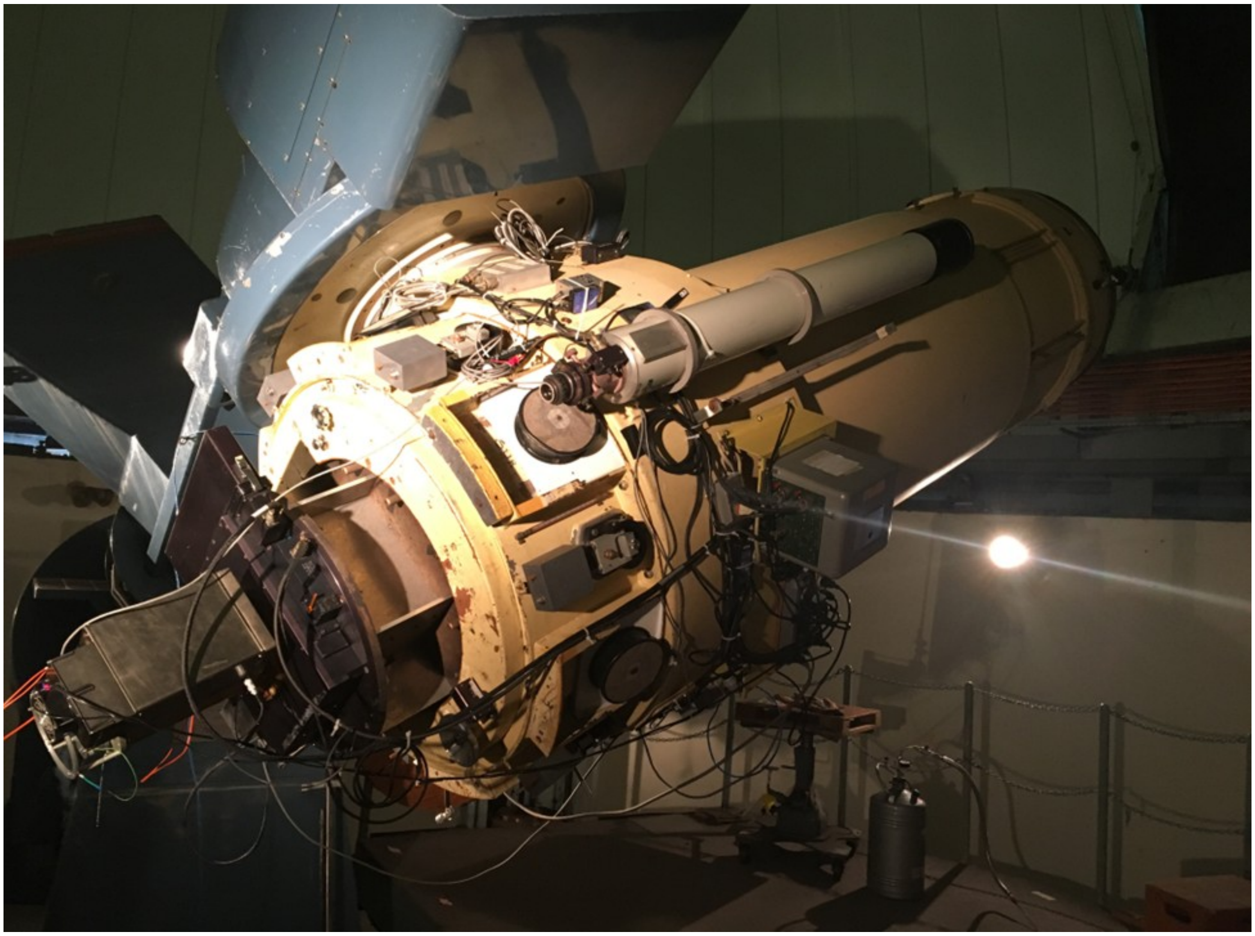

Figure 4: SMARTS 0.9-meter (m) telescope on Cerro Tololo in Chile. Photo credit J.A. Smith.

Figure 5 showcases a compelling example of the extinction coefficient, derived from a comprehensive analysis involving the slope, zero point, and color transformation. The extinction coefficient plays a crucial role in our research, accounting for the dispersion of light from stars to the telescope, thus contributing to the accuracy and precision of our measurements.

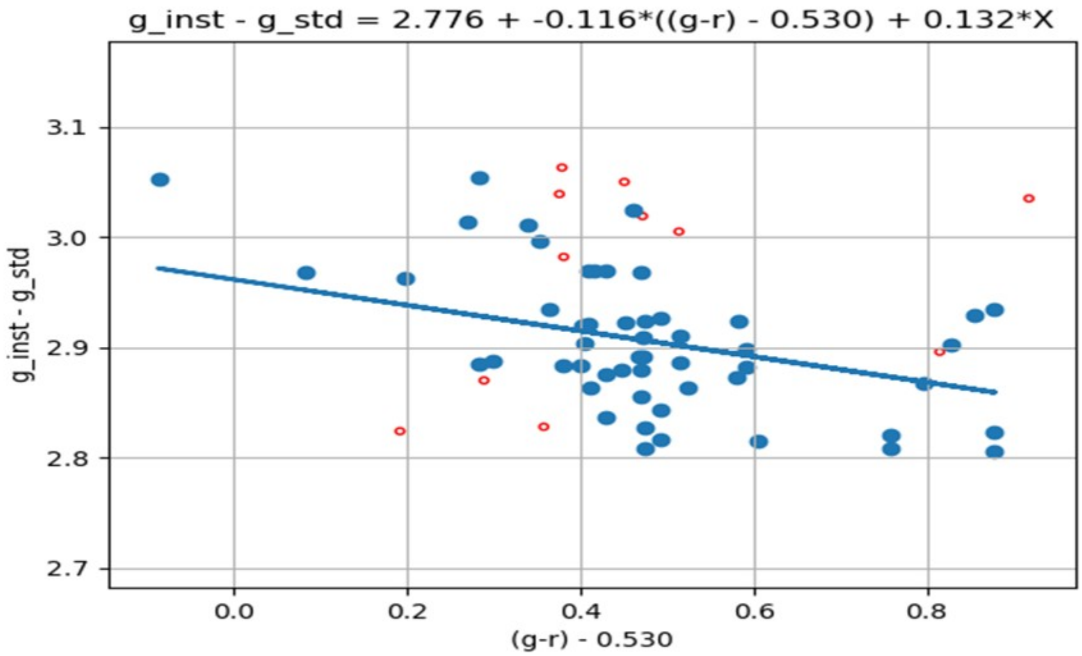

Figure 5: This graph shows the difference of instrumental magnitude and standard magnitude plotted against air mass to result in the slop being the extinction coefficient.

In Figure 6, we present the color term, which significantly influences the results displayed in Figure 5. This term, extracted from careful observations and meticulous calculations, plays a vital role in our analysis, ensuring the reliability and relevance of our findings.

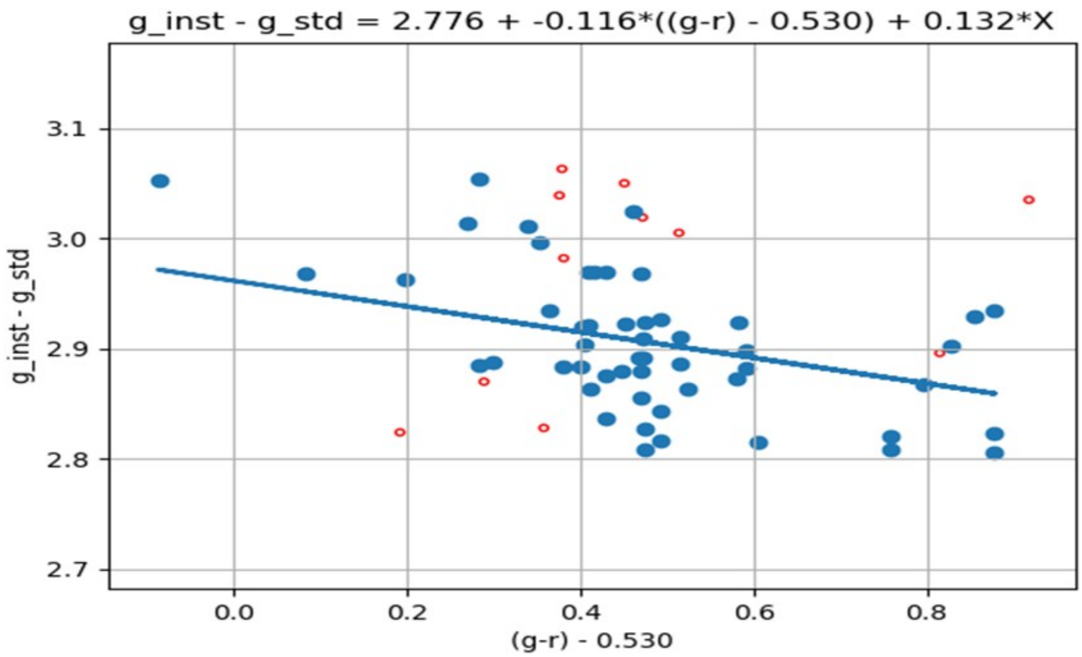

Figure 6: : This graph shows the difference of instrumental magnitude and standard magnitude plotted against the observed color minus cosmic color. From this graph you derive the color transformation of the g filter.

However, despite the robustness of our research methodology and the advanced capabilities of the SMARTS 0.9m telescope, we encountered an intriguing outcome on the night of October 20, 2018. Specifically, this night displayed higher residuals from the standard stars than we initially expected, leading to a somewhat elevated level of uncertainty in our measurements. This unexpected result opens up new avenues for further investigation and underscores the complexity of the celestial phenomena we are exploring.

In conclusion, the combination of cutting-edge technology, such as the SMARTS 0.9m telescope, and the intricate analyses of Figures 5 and 6 provide valuable insights into the behavior of extinction coefficients and color terms. Despite encountering higher uncertainties on the particular night in question, this discovery serves as an exciting opportunity for future research and a deeper understanding of the universe's intricacies. Our commitment to scientific rigor and exploration drives us to uncover even more captivating revelations about the cosmos and its celestial wonders.

VI. References

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- Figure 1 taken from Dark Energy Survey, instrument, webpage.

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