

# Final Report: ICTP PWF Physics for Bangladesh Online Internship Program (July 15 – October 15, 2025)

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Supervised by Dr. Syeda Lammim Ahad

## Introduction

The ICTP PWF Physics for Bangladesh online internship program gave me the opportunity to experience what real research work feels like under the helpful supervision of Dr. Syeda Lammim Ahad. Throughout the internship period, I explored a broad range of topics in cosmology and astrophysics starting with the theoretical foundations on galaxy formation and evolution before eventually focusing on astrophysical K-corrections which deals with converting observed magnitudes of galaxies to their rest-frame magnitudes. Studying the K-correction is essential in helping astronomers account for the redshift of distant galaxies and compare their true colors and luminosities across different cosmic times.

At first, I was mostly focused on reading and trying to understand the theoretical ideas behind cosmology and galaxy evolution. Gradually, the internship moved toward something much more hands-on, involving computational work and analysis of real survey data. For me, this shift from theory to data-driven research was one of the most exciting (and challenging) parts of the entire experience. I also learned to handle large-scale datasets and modern Python-based analysis tools, which was a completely new experience for me as a third year undergraduate physics student.

My supervisor was particularly helpful especially with the amount of freedom she gave me helped me explore tons of topics in astrophysics early on in the internship.

## Early Weeks: Cosmology and Galaxy Evolution

The first few weeks (weeks 1–3) were devoted to understanding basic cosmological ideas and how galaxies evolve in different environments. A major starting point was the paper by [Ahad et al. \(2021\)](#) *The stellar mass function and evolution of the density profile of galaxy clusters from the Hydrangea simulations at redshift 0-1.5*. This paper compared the Hydrangea hydrodynamical simulations with real observational data to study galaxy cluster evolution. It introduced me to simulation-based astrophysics, galaxy halo mass function and statistical comparison between theory and observation. But as a third year undergraduate whose sole exposure to astrophysics had been an ongoing introductory course, I needed to first familiarize myself with the physics of galaxy formation and evolution. I used texts like *Galaxies in the Universe: An Introduction* by [Sparke & Gallagher \(2007\)](#) and *Galaxy Formation and Evolution* by [Mo, van den Bosch, & White \(2020\)](#). During these early stages, I also briefly went through foundational cosmology books such as *Introduction to Modern Cosmology* by [Liddle \(2015\)](#) and several papers on gravitational lensing and cosmological simulations, notably the [Narayan & Bartelmann \(1996\)](#) paper *Lectures on Gravitational Lensing*. These readings shaped my early understanding of galaxy environments and the methods used to probe them.

## Transition Toward K-correction Studies

By mid-August (weeks 3–5), my supervisor introduced me to the topic of **K-corrections** through [Hogg et al. \(2002\)](#)'s pedagogical paper *The K-correction* which promptly and concisely defines K-correction mathematically i.e.,

$$m_R = M_Q + DM + K_{QR} \quad (1)$$

where:

- $m_R$  is the apparent magnitude of the object observed through the filter  $R$ ,
- $M_Q$  is the absolute magnitude the object would have if observed through the rest-frame filter  $Q$ ,
- $DM$  is the distance modulus, defined as  $DM = 5 \log_{10} \left( \frac{D_L}{10 \text{ pc}} \right)$ , with  $D_L$  being the luminosity distance,
- $K_{QR}$  is the K-correction, accounting for the effect of redshift on the observed magnitude.

The paper explains how observed and rest-frame magnitudes relate through redshift and filter sensitivity. The dependence of K-correction on redshift is defined as the following messy integral over all wavelengths:

$$K_{QR} = -2.5 \log_{10} \left[ (1+z) \frac{\int \frac{d\nu_o}{\nu_o} f_\nu(\nu_o) R(\nu_o) \int \frac{d\nu_e}{\nu_e} g_\nu^Q(\nu_e) Q(\nu_e)}{\int \frac{d\nu_o}{\nu_o} g_\nu^R(\nu_o) R(\nu_o) \int \frac{d\nu_e}{\nu_e} f_\nu\left(\frac{\nu_e}{1+z}\right) Q(\nu_e)} \right] \quad (2)$$

where:

- $f_\nu(\nu_o)$  is the observed spectral flux density per unit frequency,
- $g_\nu^R$  and  $g_\nu^Q$  are the flux densities of the standard sources used to define the zero-points of filters  $R$  and  $Q$ ,
- $R(\nu_o)$  and  $Q(\nu_e)$  are the response functions of the observer and rest-frame filters,
- and  $z$  is the redshift.

This work laid the theoretical foundation for everything that followed. However, the brute-force methodology of calculating K-correction in the paper is usually not practical to use directly for large-scale galaxy K-corrections unless one happens to have the galaxy's fully calibrated spectral energy distribution (SED). The focus of this project was to explore a couple of alternative computationally driven methods for calculating K-correction at low redshifts, namely:

- [Fielder et al. \(2022\)](#) — *Empirically-Driven Multiwavelength K-corrections At Low Redshift* provides a more empirical framework based on linear regression fits, assuming a model of the form

$$K(z) = a_1 z + a_2 z^2 \quad (3)$$

with a two-step fitting process and strips off the outliers. I utilized their publicly available code from the GitHub repository (<https://github.com/cfielder/K-corrections/>).

- [Chilingarian et al. \(2010\)](#) — *Analytical Approximations of K-corrections in Optical and Near-Infrared Bands* presented a similar but more direct approach that assumes K-corrections as functions of redshift and color ( $C$ ) i.e., a 2D polynomial fit of the form

$$K(z, C) = \sum_{i=0}^{N_z} \sum_{j=0}^{N_c} a_{ij} z^i C^j \quad (4)$$

Their online tool (<http://kcor.sai.msu.ru>) remains widely used, and I tried to replicate parts of their method using datasets downloaded from Sloan Digital Sky Survey (SDSS) [SkyServer](#).

## Intermediate Phase: Narrowing the Learning Gap

During the next stage (weeks 6–8) I was focused on learning the statistical and computational tools that were required to navigate through the papers. My main reference in that time became [Fielder et al. \(2022\)](#) which presented an empirical regression-based approach to K-corrections. To follow it properly, I had to learn several statistical tools such as bootstrap sampling, dealing with outliers, Huber regression, and Normalized Median Absolute Deviation (NMAD) etc.

I used *Practical Statistics for Astronomers* by [Wall & Jenkins \(2012\)](#) as a reference text and began coding small exercises in Python to understand the mathematics behind regression and fitting. This was my first hands-on experience with libraries like NumPy, pandas, matplotlib, and scikit-learn. I also explored astronomical data libraries such as astroquery and astropy, which later proved essential for data acquisition and handling. It is also to be noted that my university final exams were going on around this time and my progress was comparatively slow compared to the initial phases. By the end of this phase, I had a basic understanding of how statistical analysis, programming, and astrophysics connect in real research.

## Final Phase: Data Acquisition and Analysis

In the final month (weeks 10 and beyond), my focus shifted to actual implementation of K-correction models. The two main papers shaped this part of the work.

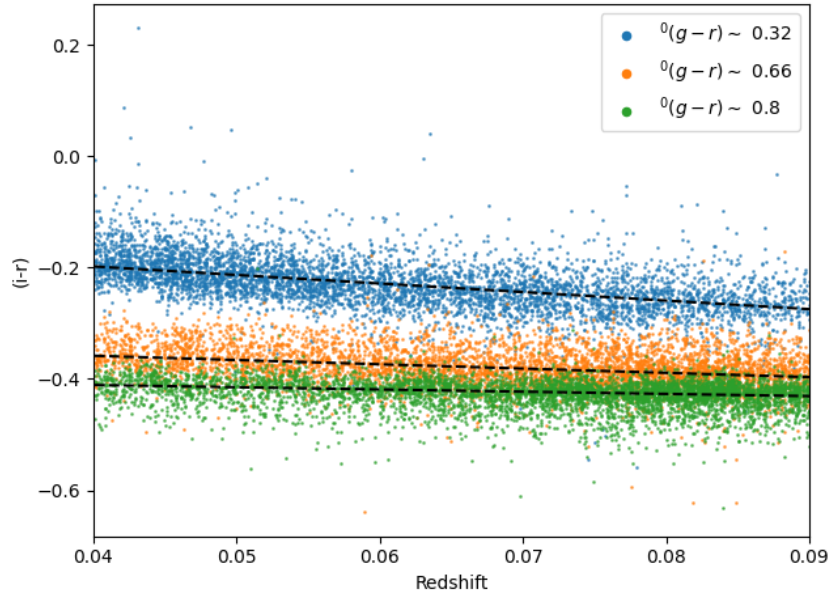


Figure 1: Observed color vs redshift for a few representative bins (e.g. bins 1, 10, 20). Sample from GSWLC optical data provided in GitHub repository.

In order to test both methods, I needed real data. For Chilingarian et al. (2010), I worked with data from the SDSS SkyServer, while for the Fielder et al. (2022) implementation I used the data from the GALEX–SDSS–WISE Legacy Catalog (GSWLC), provided in their public GitHub repository. They provided data in two bands, optical data from GSWLC and infrared data from the Wide-field Infrared Survey Explorer (WISE).

I also had to make a few adjustments to the Fielder code (`kcorrection_function_v2.py`) for compatibility with newer Python versions and running checks using synthetic data arrays generated with NumPy. As I was facing difficulty with handling the data files provided by the authors on GitHub, I needed a couple of long meetings with my supervisor to help me through the process and debugging. It taught me how to retrieve, read, and handle survey data. This was a completely new territory for me and made me less nervous about approaching and handling real data. I learned to work with FITS tables, manage missing values, and merge datasets for analysis.

The final reproduced plots from the Fielder et al. (2022) and Chilingarian et al. (2010) methods are illustrated in Figures 1 and 2, respectively.

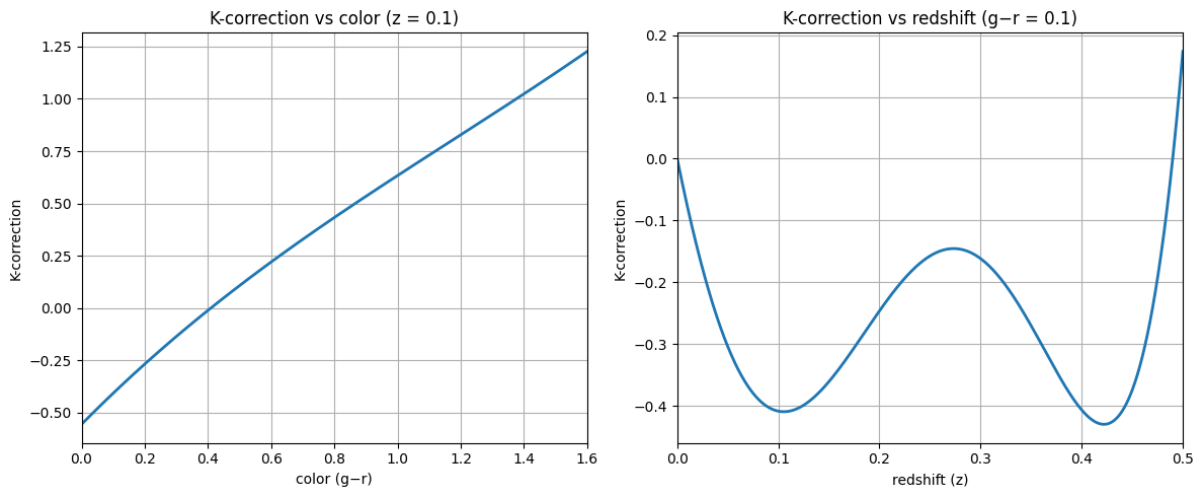


Figure 2:  $K$ -correction in the SDSS  $g$  band following Chilingarian et al. (2010). *Left*: Variation of  $K$  with observed color ( $g - r$ ). *Right*: Variation of  $K$  with redshift  $z$  for a fixed color.

## Learning Takeaways

These are some of my key takeaways from the internship:

- Accessing, reading, and analyzing scientific literature through sources like **arXiv**, **Harvard ADS** etc.
- Acquiring and handling astronomical data from catalogs such as **SDSS Skyserver**, **GSWLC**, **CASJOBS** etc.
- Implementing computational tools (e.g., Python libraries) in the context of astronomical problems and working through actual observational datasets.
- Learning useful statistical tools and witnessed hands-on applications in research works (notably [Fielder et al. \(2022\)](#)).
- Picking up essential cosmological concepts in the early exploration and side quests ranging from Newtonian cosmology to the  $\Lambda$ CDM framework, physics of galaxies, etc.

## Reflections and Future Directions

As an undergraduate primarily trained in theoretical physics, this internship was my first real exposure to data-intensive astrophysics. It taught me not just technical methods but also the practical method of research from reading literature and building intuition to reproducing published results computationally.

During the final few weeks, while still working on K-corrections, I began exploring new interests in particle physics and quantum field theory after reaching out to **Dr. Talal Ahmed Chowdhury** for a project in **quantum field theory and particle physics**, which I plan to pursue as my final-year research project. With my supervisor's full encouragement, I shifted my focus towards the theoretical aspects required for the readings related to QFT for said project.

## Conclusion

This internship has been one of the most rewarding academic experiences I've had so far. Perhaps the biggest takeaway for me would be working with real survey data and using computational tools to reproduce empirical results. Through the papers I reviewed, I learned how theory, statistics, and computation come together in modern astrophysical research.

Going forward, I intend to keep using the skills and habits I picked up during the internship like literature review, critical reading and tackling real-world problems etc. continuously in my academic life and keep growing. I am deeply grateful to Dr. Ahad for her patient mentorship and for creating a learning environment that encouraged both independence and curiosity.

**Khalid Hasan Nahid**

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All weekly reports for the internship can be found here in the [Google Drive link](#).

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# Approval

The internship report titled “*Final Report: ICTP PWF Physics for Bangladesh Online Internship Program (July 15 – October 15, 2025)*” submitted by **Khalid Hasan Nahid**, a participant of the ICTP PWF: Physics for Bangladesh Online Summer Internship, has been found satisfactory in partial fulfillment of the requirements of the internship program. The internship was conducted under the supervision of **Syeda Lammim Ahad** during the period **15 July 2025 to 15 October 2025**.

**Supervisor**

*Lammim Ahad*

*25 October, 2025*

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