# Preparing for Spectroscopic Observations of Supernovae with the UNG Observatory

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## 1 Project Description

The goal of this project is to develop the capability to use the new UNG observatory to measure the spectrum of light from exploding stars (supernovae). Observing a particular kind of exploding star, called 'Type Ia Supernovae', or SNe, has become one of the top priorities in cosmology, because these type of SN always explode with a standard intrinsic brightness.

It was observations of SNe in the 1990s that led to the discovery that the expansion of the universe was accelerating, which won the Nobel Prize for Physics in 2011 (Riess et al., 1998; Perlmutter et al., 1999). This discovery has motivated the search for thousands more SNe, in order to precisely chart the accelerated expansion of the universe, and help to understand the cause. In the 2020s, the new Vera Rubin Observatory (VRO) is expected to discover hundreds of thousands of SNe. Observations from the VRO will be able to estimate the distance to the SNe by measuring the observed peak brightness. However, observations from the VRO will miss a key measurement that is essential to use SNe for cosmological studies: a measurement of the spectrum of light from the SN.

The SN spectra allows us to classify the precise kind of SN, so that we only include the particular 'Type 1'. Moreover, the spectra allows us to measure the 'redshift' of the SN. Redshift observations are crucial for cosmology; it is only with measurements of both the peak brightness and the redshift that we can fully use SNe to study the expansion of the universe.

This situation presents a unique opportunity for the new UNG observatory to make a significant contribution to cosmology with the VRO by measuring the redshifts of SNe. The focus of this project is to develop the 'spectroscopic reduction pipeline': computer code that will take the observed data, and process it to produce a wavelength-calibrated spectrum that can be used to measure the redshift.

## 2 Significance

Measuring spectroscopic redshifts of SNe will transform the prospects for cosmology research at UNG. One of the most important topics in cosmology at the moment is the precise value of 'Hubble's Constant' ($H_0$); which describes how fast the universe is expanding. By measuring the distances and redshifts to SNe, (Riess et al., 2016), find a value of $H_0$ which is now in significant tension with theoretical expectations, and may hint at the possibility of physics beyond our current standard model. In Macaulay et al. (2019), we analyzed high-redshift SNe to measure $H_0$, and found a value more consistent with the standard model. Additional redshifts and spectroscopic classification of nearby SNe will be essential to determine if the $H_0$ tension is due to un-accounted for systematic effects, or represents new physics.

Measuring the SN redshift also allows us to measure the velocity of the SN-host galaxy. While this velocity is often considered as a source of noise, the velocities of galaxies contain a wealth of information about the large-scale structure of our universe (e.g. Macaulay et al., 2012, 2017). Measuring the redshifts of SNe directly at UNG will be an important step towards mapping the velocities of the galaxies in our local universe, and understanding the physics of the large-scale structure formation.

## 3 Long-term Contributions to Undergraduate Research

The long-term goal of this project is to establish an ongoing, student-led program to measure spectroscopic redshifts of SNe. Each year, there will be many SNe (and other transient objects) that will be observable at UNG. In the era of the VRO, far more SNe will be discovered than can be followed-up spectroscopically. With the spectroscopic analysis code pipeline developed during this FUSE project, we will be able to regularly measure redshifts for supernovae at UNG. The long-term plan for this project is to have student Telescope Operators (TOs) leading the observations, analysis, and publications arising from the spectroscopic observing program. These SN redshifts will be essential for cosmology research at UNG, and will also be significantly beneficial for the wider cosmology and astrophysics communities.

## 4 Methodology

The method is based on developing code which can read in raw, digital image data recorded from a spectrograph, and process the digital data to output a spectrum. The raw data from the spectrograph is a digital image of the spectrum of light from the source. Considerable processing is required in order to transform such a raw image into a processed spectrum (which tells us the intensity of light at a given wavelength). An important part of the method is the processing of several calibration images (called 'flats', 'bias', and 'dark' frames). These technical images allow us to isolate the spectrum from the raw image, and also estimate the noise and uncertainty of the measurement. Perhaps the most important step is the processing of the calibration images. These are images of the spectra of calibration lamps with clear spectral features at very well-known wavelengths. These calibration images are used to map the relation between pixel locations on the raw image, and the corresponding wavelength of light.

In this project, we will be developing code to automate the processing of all of the steps involved in analyzing a spectrum. We will use the Python programming language, which already has a great deal of support and libraries of code for handling the 'FITS' image format from the spectrographs.

## 5 Plan for Undergraduate Involvement

I will start the project by working closely with the student to understand the process of analyzing spectroscopic data, and also the scientific motivation and context for the observations. We will also start developing and learning the necessary Python coding skills, depending on the prior experience of the student. The first weeks of the project will start with closer student supervision, and regular, daily meetings, focussing on the coding priorities for each day. As the project develops, the focus will shift to obtaining calibration data from the spectrograph, and connecting individual code modules to automate the analysis. I hope to provide the opportunity to allow the student to take ownership of the project, and always provide support and supervision in person, over email, and regularly scheduled meetings. Towards the end of the project, the focus will be on testing and using the code for genuine spectroscopic observations. A priority will be to ensure that the end-product codes are all fully documented, and available via code repositories. This will enable this project to be the strongest possible start to a long-term plan for undergraduate-led spectroscopic observations.

## 6 Goals & Products

The ultimate, long-term goal of the spectroscopic observations is to obtain spectroscopic redshifts and classifications of SNe. The spectroscopic redshifts of SNe will make a significant contribution to several of the most important topics in cosmology, including the value of Hubble's constant, and the nature of Dark Energy.

The specific goal of this proposal is to develop the analysis code required to process the spectroscopic observations. We will make the code publicly available via web-based code repositories. This code will be used extensively at the UNG observatory for any astronomical measurements of the spectra of stars, galaxies, and transient objects (including SNe). We will provide complete documentation for the code along with the code repository, and present the work at GRAM 2020 and the ARC conference at UNG.

## 7 Budget

The priority for this project is to capitalize on the existing investment in the new observatory; this project will not need additional budget for equipment. The software packages that we will use – including `PyCharm`, `MARZ`, `AstroPy`, and `PyFits` are either open-source, or available for academic use at no cost (Hinton, 2016; Price-Whelan et al., 2018). As such, the budget request for this proposal is only to cover stipends for students and staff. The cost breakdown is: Faculty Stipend $4,000, Student Stipend, 40 hours per week, 8 weeks, at $10 per hour = $3,200, Total: $7,200.

## 8 Timeline

Construction of the UNG Observatory is scheduled to be completed by the 1st of June 2020. If the UNG observatory opens as scheduled, we may have the opportunity to test the analysis code on spectroscopic observations from UNG. It is important to emphasize that in the event of a delay to the opening of the UNG observatory, we will still be able to deliver on the goals and products of this proposal. Completing the analysis code is independent of the construction status of the observatory. The main goals and tasks for each week of the FUSE project will be:

| Week | Main Tasks |
|---|---|
| 1 | Introduction to Python coding, reading and writing FITS image files. Creating a code repository for project. |
| 2 | Taking preliminary calibration data from spectrograph ('bias', 'dark', 'flat', and 'arc' images). Coding preliminary image combinations. |
| 3 | Writing code to produce 'master' combined versions of 'bias', 'dark', and 'flat' images, necessary for further data reduction |
| 4 | Code wavelength calibration module; code to map pixel numbers to wavelength values |
| 5 | Testing wavelength calibration with lab-based lamps. Refining individual analysis modules. |
| 6 | Progressing to obtaining 'science' frames; spectra from astronomical sources (initially stars). Developing code to combine and automate individual analysis modules. |
| 7 | Advanced observations for 'science' frames; potentially extra-galactic spectra. Testing analysis code for automation and error-handling. |
| 8 | Finalizing code versions on repository, writing documentation. Inspecting astronomical spectra observed during project. |

## References


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