APUS Supernova Team Autumn Sky Coverage

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DEDICATION

I dedicate this thesis to my husband and children. Without their patience, understanding, support, and most of all, love, the completion of this work would not have been possible.

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ABSTRACT

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Billions of galaxies in the observable universe are home to supernova explosions that scientists utilize to determine distances and understand stellar and galaxy evolution. To discover these events, there is a need to create galaxy groups for autonomous telescope scripts to provide complete sky coverage for search teams. For this project, an autumn group of galaxies was cataloged for imaging to fill the gap in sky coverage for the APUS Supernova Search Team. Utilizing tools such as Stellarium, Aladin, and Orchestrate, an autonomous telescope script was created. The script includes 18 galaxies that ranged in distance from the Earth between 30 million and 490 million light years. These galaxies range in magnitude from 11.9 to 9.7. The addition of these galaxies brought the APUS Supernova Search team from 177 to 195 galaxies and increased its sky coverage volume by a factor of two. This will allow the team to image galaxies all year long and provide more data and analysis throughout the year for supernova searches.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

"The immense distances to the stars and the galaxies mean that we see everything in space in the past, some as they were before the Earth came to be. Telescopes are time machines."

– Carl Sagan

Chapter Introduction

Billions of galaxies in the observable universe are home to supernova explosions. These explosion events help scientists determine distances to galaxies and understand stellar and galaxy evolution. Supernovae need to be discovered, but due to the sheer number of galaxies, there is a need to create galaxy groups for autonomous telescope scripts to provide complete sky coverage. Creating groups of galaxies to fill holes in observing windows is a way to get coverage of more sky and galaxies. Imaging more galaxies across the sky will fill those gaps and create more opportunities to detect supernova explosions by the APUS Supernova Search Team.

This research project focused on establishing a group of galaxies to provide more sky coverage for the APUS Supernova Search Team. The images obtained and sky coverage mapped will be used in the team's research. The steps outlined were designed to create a repeatable approach for future research students to utilize and build upon moving forward. This paper will provide background information about supernovae and galaxies, the process for determining the time of year for collection, constellations and why those constellations were used as a starting point, the APUS telescope, galaxy candidates, collection strategy for optimal telescope usage, the script used for automated collection, and exposure time selected for the galaxies that made the final cut for this research grouping. This paper will also discuss aims and objectives, limitations, and theoretical framework.

Statement of Problem

There are many important questions that need to be answered about distances to galaxies and stellar and galaxy evolution. Supernova explosions can help scientists better understand these processes. Supernova explosions occur throughout the universe, but there are billions of galaxies in the universe and all of them cannot be studied or imaged at once. This project was done to assist with that. It focused on establishing a group of galaxies to provide more sky coverage for the APUS Supernova Search Team

Aim and Objectives

Aims

There were multiple aims associated with this project. One aim was to get the APUS supernova team closer to full sky coverage of galaxies throughout the year for their research. An additional aim for this project was to increase the number of galaxies collected over time for the team to analyze. The project is also designed to provide students with hands-on training tools and analysis for their future. Finally, the project was designed to provide a repeatable process for other teams and students.

Objectives

The objective of providing full sky coverage for the APUS supernova team is to ensure that the team can view more portions of the sky at all times of the year. The team lacked coverage during the autumn months. To remedy this, a portion of the sky was decided upon that did not have coverage or imaging by the team. Then steps were taken to determine the best galaxies in that part of the sky to image, increasing the sky coverage for the team.

Providing the team with an increased number of galaxies to view was another objective of this project. The probability of detection of a supernova event ties back to the number of galaxies observed and analyzed. The more galaxies the team has for analysis, the more likely they are to discover a supernova event. Increasing these galaxies increases the odds. It also provides the team with images during times of the year they were not receiving images before. This provides an opportunity for analysis all year long. To achieve this outcome, a study of the galaxies in the missing portion of the sky was conducted, and the best candidate galaxies were determined and added for collection and analysis.

This project was also designed to provide online students with hands-on training and experience as part of a research team. Providing more sky coverage and galaxies allows the team to grow bigger while giving students valuable experience and an opportunity to understand what is required to be part of that research team. To accomplish this, the galaxies found and imaged will be added to the team's observing log on the google docs page as images are received, and student volunteers will analyze the new group.

Finally, this project was designed to provide a repeatable process for other teams or students that may want to add to the APUS research or start their own team. This project utilizes multiple free tools and applications so anyone can access the required information to produce a similar project. The project outlines details on how and why each step was accomplished to provide future members with information moving forward. This information can be used to build upon the current APUS Supernova Search Team project or to create future supernova projects in the future.

Significance to the Field

Supernova detection is significant to astronomy as it allows astronomers to better predict distances to the galaxies these explosions happen in. Scientists use interlocking techniques to determine cosmic distances. This is sometimes referred to as the cosmic distance ladder. It starts with measuring nearby objects using radar. Once radar is no longer a feasible option, scientists use parallax and standard candles to measure distance. Supernova events can be used as standard candles in this part of the distance ladder. From there, Cepheid variables, distance standards, and Hubble's law is used to measure distances further away (Bennett et al., 2020). Studying supernovae helped scientists determine that the universe was expanding. It is important to detect supernovae quickly after their explosion to capture the light curve associated with each event. SNe II supernova can provide information about stellar evolution and SNe I provide information about compact objects. (Cendes, 2022). The APUS supernova team images their galaxies anytime weather permits and then analyzes those images. The more galaxies they image, the more likely they are to discover a supernova event. The team could then get this information out to the field for further analysis of the supernova event. The addition of 18 galaxies in the Autumn grouping could allow astronomers to view a supernova event quickly after it happens to glean important information about its characteristics and light curve.

Background

This section will provide background information relevant to the project. It details types of supernovae, including Type I and Type II. It goes on to discuss the use of supernova events in science. Furthermore, it covers supernova rates, classification and types of galaxies, and the types of supernovae likely to be seen in those galaxies. Finally, this section covers the B-V color index.

Supernova Types

Two primary types of supernovae are Type I and Type II. Type Ib, Type Ic, and Type II supernovae are closely related and are called core-collapse supernovae. Scientists determine which type of supernova occurred based on observations such as its light curve and certain elements present or not in its spectrum. Type Ia supernova are characterized by the presence of Si II lines, or Silicon. Type Ib supernova are designated when strong helium lines are present in its spectrum. Type Ic supernova are designated when there is an absence of helium lines in their spectrum. Type II supernova have a strong presence of hydrogen lines in their spectrums (Al Dallal & Azzam, 2021).

Type Ia supernovae are believed to be caused by white dwarf supernova explosions. Scientists believe that these white dwarfs reach the Chandrasekhar limit and then explode (Williams et al., 2011). Chandrasekhar limit is when the mass of the white dwarf reaches 1.4 solar masses (Al Dallal & Azzam, 2021). It is believed that these white dwarfs reach this limit in one of two ways. The first is that the star may have a companion star and accrete matter from that star. Second, if two white dwarfs merge, they could reach the Chandrasekhar limit and die in a supernova explosion (Williams et al., 2011).

Type Ib, Type Ic, and Type II supernovae are also called core-collapse supernova. These explosions start from progenitor stars of $\sim 8\ M_\odot$ or larger. These massive stars are known to live fast and die young. They undergo various stages of fusing heavier and heavier elements to form an iron core before they explode in a brilliant, luminous way. Core-collapse supernovae produce heavy elements that are crucial to life. Scientists have directly observed core-collapse supernovae, including the most famous SN1987A (Couch, 2017).

Supernova Use in Science

Scientists use supernova explosions to assist in determining distances from Earth to the galaxies these supernovae are in. Knowing the distances to galaxies is essential to identify the luminosities of galaxies and stars accurately, better understand star formation, and characterize dark matter. Multiple methods are used to determine the distance to galaxies; all have varying levels of uncertainty. Some methods used include the tip of the red giant branch (TRGB), surface brightness fluctuations (SBF), planetary nebulae luminosity function (PNLF), and Type Ia supernova (SNe Ia) methods (McQuinn et al., 2017).

The SNe Ia method of measuring the distance to galaxies is important as SNe Ia are considered standard candles in the scientific community. These supernovae provide precise measurements of extragalactic distances. They are direct evidence for cosmic acceleration. SNe Ia are collected via multiple collection methods, including optical and near-infrared. Recent studies show that near-infrared is excellent for observations and data collection. Luminosity and light curve of SNe Ia are essential factors when determining distances to SNe Ia events (Avelino et al., 2019).

Discovering a SN Ia and then collecting data with appropriate methods quickly is important for scientists to receive the data required after the SN Ia event. Type SNe Ia have a high luminosity at maximum brightness, and their light curves decline slowly after the maximum, giving their curve a broad appearance. The typical SNe Ia reaches maximum luminosity at around 20 days and slowly decreases after that (Lyutykh et al., 2021). It is crucial to detect these explosions early to collect as much data as possible about the light curve leading up to maximum luminosity and how that light curve declines over time. This allows scientists to help determine the type of supernova explosion and other vital data for future analysis. Multiple supernova research teams are utilizing different methods to detect these events. These teams will be discussed in further detail. Multiple teams must be searching for supernovae because there are so many galaxies that it would not be possible for one team to study and collect data on all of them.

Supernova Rates

The Hubble Space Telescope took an image of a tiny patch of sky over a 23-day period. This image is referred to as the Hubble eXtreme Deep Field. There are thousands of galaxies in that one image. Scientists used this image to estimate the number of galaxies in the sky. They did this by counting the number of galaxies in the image and multiplying it by the number of photos it would take to capture the entire sky. Scientists have determined that there are over 100 billion large galaxies in the observable universe, and more smaller galaxies can be counted using this technique (Bennett et al., 2020).

In a galaxy the size of the Milky Way, scientists expect to see one supernova explosion every 50 years. Estimating that there are 100 to 200 billion galaxies in the observable universe, scientists expect there to be around 10 billion observable supernovae per year or around one per second (Miller et al., 2021). One team of searchers cannot view billions of galaxies at a time. Multiple teams are looking at different galaxies using varying techniques to achieve the goal of detecting supernovae.

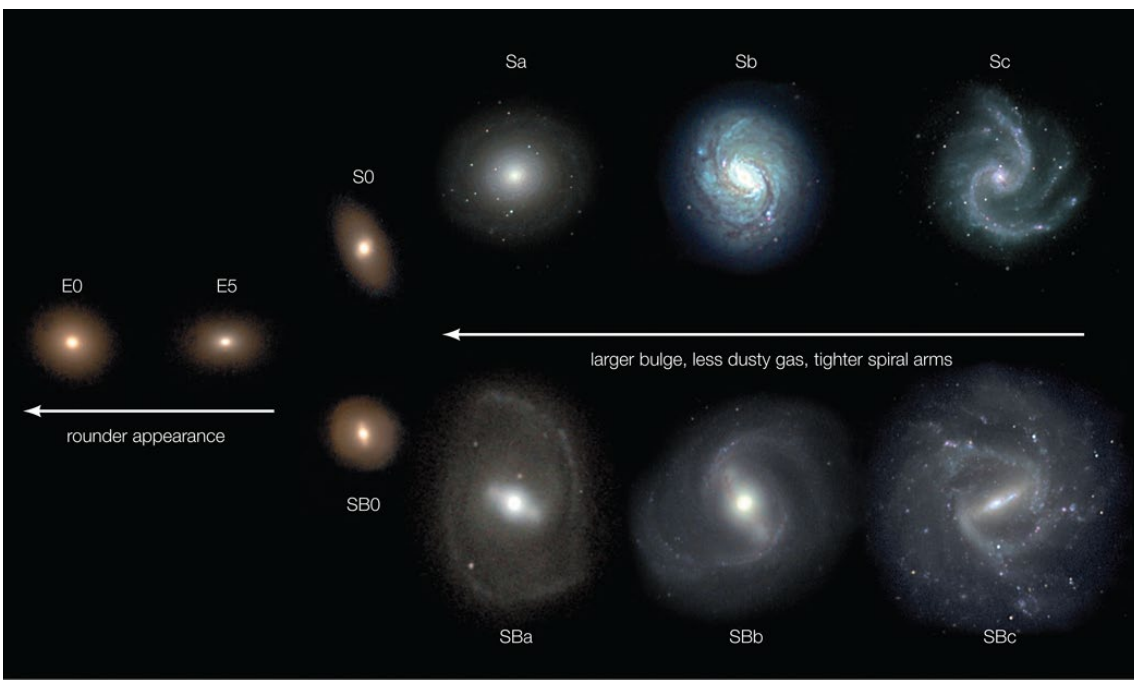
The probability of detecting a supernova event depends on a few different factors. One factor, as discussed, is the probable rate of supernova events in the universe, and an additional factor is the sample size. With the addition of the region of the sky for an autumn grouping, the APUS team will view 195 galaxies. The larger the galaxy sample size, the more likely a team is to detect a supernova. The APUS search team can expect to detect about three supernovae per year. Supernova rates based on a volumetric rate averaged over early, and late-type galaxies are an acceptable way to determine rates for the APUS team. The reported rates for different supernova are as follows; the SNe Ia rate is 0.301, the SNe Ib & Ic rate is 0.258, and the SNe II rate is 0.447. These are measured in units of 10^{-4} SN Mpc^{-3} yr^{-1} (Miller et al., 2021).

Galaxy Classification vs Supernova Types

When astronomers first started classifying galaxies, they focused primarily on the galaxy's shape to classify them. Edwin Hubble came up with a diagram to help visualize these galaxy shapes. The diagram looks very similar to a tuning fork. The handle portion of the tuning fork contains the elliptical galaxies starting with E0. These galaxies are spheres and move towards more of an oval or cigar shape closer to the E7 classification. As the fork splits, there are classifications of S0 and SB. These are galaxies that are somewhere between the elliptical galaxy and the spiral galaxy shape. The prongs on the fork represent spiral galaxies and barred spiral galaxies. The tuning fork diagram does not show irregular galaxies (Bennett et al., 2020). The classification of galaxies determines which type of supernova events are expected to be seen.

Figure 1

Hubble's Tuning Fork



Note. This tuning fork diagram shows Hubble's galaxy classes utilized to describe galaxy types. From Bennett, J. O., Donahue, M., Schneider, N., & Voit, M. (2020).

Some classifications of galaxies are more likely than others to produce different types of supernova events. There have been multiple studies conducted regarding the size, age, and classifications of galaxies to determine which type of supernova is most likely to occur in these galaxies. Interestingly, elliptical galaxies only produce SNe Ia explosions. All types of Supernova events can be found in spiral galaxies. SNe II, SNe Ib, and SNe Ic tend to be found in the spiral arms of spiral galaxies. While possible, SNe Ia are rarely found in the spiral arms of these types of galaxies. Additionally, the bluer the spiral galaxy, the higher the star formation rate, and the higher the rate of supernova events. SNe II supernova are the most frequent in spiral galaxies, followed by SNe Ic, SNe Ib, and SNe Ia (Meyers, 2002).

Elliptical galaxies are thought to have stopped star formation billions of years ago. Elliptical galaxies no longer host massive stars and only produce SNe Ia. The other types of supernovae are thought to occur from massive stars of larger than eight solar masses, so we only see SNe Ia in elliptical galaxies. SNe Ia are thought to be produced by white dwarfs accreting matter from a nearby star and exploding when they reach the Chandrasekhar Limit (Meyers, 2002).

Galaxy B-V color index vs Supernova Types

In addition to being categorized by type, galaxies are also categorized by color. The most common color index used is the B-V color index. This index is used for individual stars as well as galaxies. Hotter stars and galaxies appear closer to blue in color, while cooler stars and galaxies are closer to red in color. The B-V color index uses two different filters to quantify the index. The B filter allows a narrow range of wavelengths through and is centered on blue colors. The V filter is a visual filter and allows green-yellow wavelengths through. The closer the galaxy or star is to zero or into the negative, the bluer or hotter that star or galaxy is. The closer it is to

2.0, the cooler or redder the star or galaxy is (Palma, 2022). Bluer galaxies have more massive stars and generally have ongoing star formation, while redder galaxies have stars in the lower main sequence and less or no star formation. The B-V scale can indicate which types of supernovae are likely to be found in that galaxy. Galaxies with ongoing star formation that are closer to zero or negative in the B-V scale are more likely to produce SNe II, SNe Ib, and SNe Ic events. While cooler redder galaxies that are closer to the 2.0 B-V color scale are more likely to have SNe Ia events. Remember that galaxies that do not have large stars or ongoing star formation do not produce SNe II, SNe Ib, or SNe Ic Supernova.

Terms and Definitions

Astronomical Twilight – This occurs when the geometric center of the sun is 18 degrees below the horizon (US Department of Commerce, 2021).

Blink Compare – Blinking or flipping back and forth between a reference image and a new or observed image (Miller et al., 2021).

Charge-coupled device (CCD) – A type of electronic light detector that has largely replaced photographic film in astronomical research (Bennett, 2020).

New General Catalogue (NGC) – Is a reference list of star clusters, nebulas, and galaxies (Gregersen, n.d.).

Planewave CDK 24 – Is a 24-inch diffraction-limited telescope.

Supernova – The explosion of a star (Bennett, 2020).

CHAPTER 2: LITERATURE REVIEW

“The nitrogen in our DNA, the calcium in our teeth, the iron in our blood, the carbon in our apple pies were made in the interiors of collapsing stars. We are made of star stuff.”

– Carl Sagan

Chapter Introduction

Discovering many supernova events as soon as possible after the event occurs is important to astronomy research. To do this, it is important to have multiple teams looking at as much of the sky as possible. Because there are billions of galaxies in the observable universe, it is difficult for one team to view all galaxies all the time. For teams to have good odds of success in discovering supernova, they must determine which galaxies are best for their group and telescope, how many galaxies they will image, and which parts of the night sky they can view. As the team grows or gaps in coverage are identified the team can modify its collection efforts.

This chapter details current supernova search teams around the globe including details about their methods and telescopes team compositions. The chapter discusses their successes as well as their similarities and differences to the APUS Supernova Search Team. It goes on to detail the limitations of this project including telescope limitations, weather limitations, and nighttime observing.

Supernova Search Teams

The APUS Supernova Search Program was created to provide space studies students with an opportunity to have hands-on experience and develop leadership skills. Additionally, the program documents new supernova events throughout the universe. This program is unique in that all students are 100% online learners. The supernova research time is performed by graduate and undergraduate students with faculty members as mentors for the program. The students are volunteers who lead teams, conduct research, and continuously find ways to improve the program (Miller et al., 2021). The program has continued to evolve since its inception. The team utilizes google docs as a collaboration platform, Aladin to compare and blink images for possible detections, Slack to communicate with team members across the globe, and Zoom to host meetings. This is not the only research program looking for supernova events; many others exist.

Multiple teams utilize different methods for searching for supernova. Some supernova research teams include the Supernova Hunters team housed within the Zooniverse community, utilizing citizen scientists to analyze data; the Eagle Hill Supernova Search team, comprised of astronomers in eastern Maine utilizing the "blink compare" method for their analysis; The Backyard Observatory Supernova Search (BOSS) team is an amateur team located in Australia and New Zealand, is comprised of six members, and utilizes visual comparison, blink, and supernova search software in their search for supernova events; The Chilean Automatic Supernova Search (CHASE) utilizes an automatic search criteria for galaxies and can image up to 250 galaxies a night focusing on galaxies in the southern hemisphere; The Lick Observatory Nearby Galaxy Supernova Search (Lick NGSS) started in 1998 confirmed more than one thousand supernova events, and the data was used to get a better understanding of supernova rates; the Puckett Observatory Supernova Search (POSS) started in 1994, is an amateur team, and has discovered more than 376 supernova events; finally the Global SuperNovae Search Team (GSNST) started in 2018 with five members searching for Young Supernovae.

Table 1

Supernova Search Teams

Supernova Search Teams Around the Globe					
Team Name	**Number of Members**	**Team Type**	**Methods**	**Number of Galaxies/Images**	**Supernova Discoveries**
Zooniverse Supernova Hunters	15,493 members	amateur citizens	multiple images with multiple analysts per image	98,000 images	507

Eagle Hill Supernova Search Team	unknown	professional astronomers	unknown	unknown	unknown
Backyard Observatory Supernova Search (Boss)	six members	amateur astronomers	visual comparison, blink, automated	20,000 images over its lifetime	400+
Chilean Automatic Supernova Search (CHASE) *dome decommissioned in 2021	unknown	professional astronomers and students	automated	250 galaxies per night	2.5 per month
Lick Observatory Nearby Galaxy Supernova Search (Lick NGSS)	unknown	professional astronomers	automated	14,882 galaxies	1000+
Puckett Observatory Supernova Search (POSS)	eighteen members	amateur astronomers	blink compare	1200 to 1600 per night	376+
Global SuperNovae Search Team (GSNST)	10 members	professional astronomers	unknown	unknown	unknown

Zooniverse Supernova Hunters

Zooniverse Supernova Hunters is an online research team that utilizes citizens to analyze collected data. The program uses the Pan-STARSS1 telescope to accomplish collection. This telescope has a wide field of view and can scan large sky areas each night, collecting multiple galaxies. The Supernova Hunters team has programs that sift through large amounts of data each night. These programs can sometimes produce detections of a supernova that humans must filter for confirmation. The team utilizes citizens to filter through the data faster than a smaller team could filter it. It is essential to filter the data quickly so that scientists do not miss the peak of the supernova explosion. The team had over 6,000 possible detections identified and was able to confirm 507 as supernovae. They were not the first to discover all 507, but the discoveries still prove that their technique works in the supernova hunt across the universe (Supernova Hunters, n.d.).

The team gathers multiple volunteers via its website and collects several annotations per image. The images are 20x20 pixel grayscale images. They do this to compensate for individual mistakes or biases of these largely untrained citizen scientists. The results are then used to answer scientific questions and to train machine learning to automate processes better in the future. This method allows the team to sift through more data faster and refine processes for future teams to do the same (Wright et al., 2019).

Eagle Hill Supernova Search Team

The Eagle Hill Supernova Search Team is located in Eastern Maine and comprises astronomers from that area. The team started in January of 2013 and utilizes images taken from a 16-inch Schmidt Cassegrain telescope located in Hampden, Maine. When comparing archival and newly taken images for signs of supernova, they utilize the blink method. The team has made multiple supernova discoveries over its tenure (The Eagle Hill Supernova Search Team, n.d.). This team has been successful in its goals of supernova detection using the same processing method as the APUS supernova team as well as utilizing just one telescope. The APUS team also utilizes only one telescope compared to some of the other teams listed that have access to multiple telescopes across their team.

Backyard Observatory Supernova Search Team (BOSS)

The Backyard Observatory Supernova Search (BOSS) is a team of six members that utilize their equipment in their backyards to search for supernova. They collaborate on their findings and research. The team utilizes a 30-second imaging time for their images and uses blink analysis to compare images. When they find a suspected supernova, they conduct background research among each other before presenting their finding to a broader audience. Their goal is to provide researchers with reliable data so they can make the best possible distance analysis from supernova events found by the BOSS search team. This team also utilizes the blink compare method to analyze their data just as the APUS team does. They are successful in their pursuit of their goals with the methods they have utilized.

To provide this reliable data, the BOSS team researches a suspected supernova to rule out other events. The team will rule out events such as cosmic rays, variable stars, hot pixels, asteroids, previously discovered supernova, and CCD artifacts. Many objects in space can appear at first glance like a supernova and turn out to be something else entirely. Once the team has ruled out these other cosmic events, they can pass on the information. They estimate that for every 10-20 suspected supernova they see, only one turns out to be the real deal. The team has taken nearly 20,000 images and has discovered more than 400 supernovae during their search. During their search, they utilized automated software, visual comparison, and blink imaging techniques (Pearl, n.d.). The BOSS team utilizes six telescopes and reports nine to 15 supernova events on average in a year (Miller et al., 2021).

The Chilean Automatic Supernova Search (CHASE)

The Chilean Automatic Supernova Search (CHASE) was formed in 2007. This search focuses on supernova in the southern hemisphere because more supernovae have been found historically in the northern hemisphere skies. Additionally, this automated search aims to find supernova events as young as possible. The earlier the information is obtained once a supernova event has occurred, the more that can be determined about its progenitor and the explosion (Pignata et al., 2009).

CHASE has fully automated its target selection, data acquisition, download, and reduction to find supernova events in near real-time. This search uses a 40-second exposure time and has determined that the limiting magnitude for their supernova search is 18. Once all the information for each target is collected and automatically processed, the visual inspection of candidate events is completed by members of the CHASE team and undergraduate students. If the visual inspection confirms further data is needed, the team will task the telescope to collect that location again at a high priority. The telescopes they utilize can observe about 250 galaxies a night. As of the CHASE article's publication, the search averaged 2.5 supernova discovered per month (Pignata et al., 2009).

Lick Observatory Nearby Galaxy Supernova Search (Lick NGSS)

Lick Observatory Nearby Galaxy Supernova Search (Lick NGSS) is a nearby supernova search that started in March 1998. This team has had great success in discovering supernova events. They aim to provide data on the statistics of supernova rates in galaxies of different types and colors. This program observed 14,882 galaxies and confirmed more than a thousand supernova events for data analysis (Li et al., 2011).

Puckett Observatory Supernova Search (POSS)

The Puckett Observatory Supernova Search (POSS) has observatories in Georgia, Arizona, and Osoyoos, British Columbia. The team images galaxies each night using remote telescopes and has 18 active team members that help with the search from across the globe. The team started searching for supernova events in 1994 and has made 376 discoveries since then (Puckett, 2018). This team utilizes two telescopes, which also helps increase their possibility of detection. They currently report 15 to 20 supernova events a year (Miller et al., 2021).

Global SuperNovae Search Team (GSNST)

The Global SuperNovae Search Team (GSNST) started in 2018 with five members and search for young supernovae. The search team currently consists of ten members and observes from multiple locations across the globe. The telescope locations are in The Canary Islands, La Dehesa, Chile; South-West France; Northern British Columbia, Benson Arizona; Buenos Aires Argentina; Quebec Canada; Osoyoos Canada; Frontenac Quebec, and Arizona's sky village. The search is hoping to add more telescopes in the future for its studies (GSNST, n.d.). Similar to the APUS supernova team, this team utilizes members from different locations across the globe to analyze data. This team, however, has multiple telescopes, unlike the APUS Supernova Team that only has one telescope.

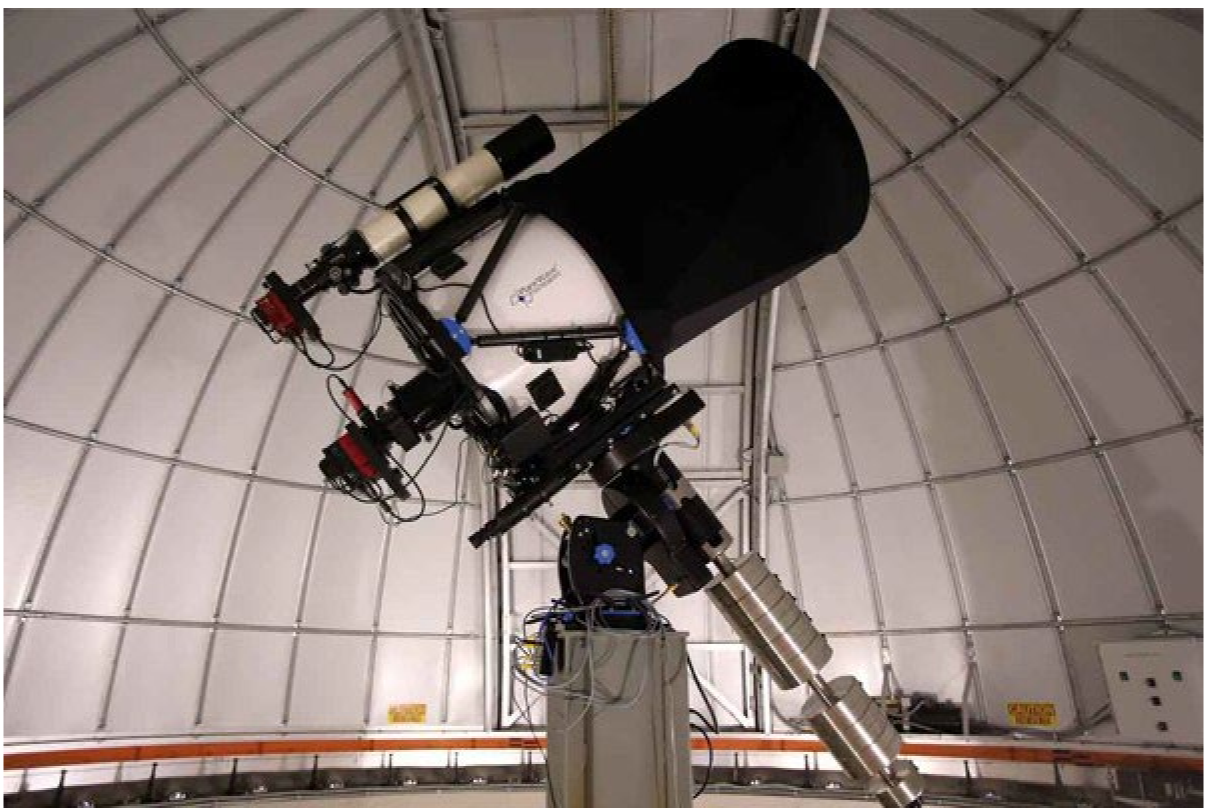
Limitations

This project was conducted with thorough research and an understanding of the limitations of all aspects of the study. There are limitations with the telescope and dome such as the location and time it takes for the dome to move. Also, there are limitations due to the location of the telescope and the weather in that location. Additionally, hours of darkness play a factor in limitations for imaging time and duration. Furthermore, the number of volunteers and their availability to analyze images is a limitation in the amount of time it takes for images that are collected to be viewed. Finally, the New General Catalogue of Nebulae and Clusters of Stars (NGC) was the only one used to identify candidate galaxies, leaving a potential gap in galaxies if they were not in the NGC.

The APUS Telescope has limitations for the magnitude of galaxies it can image and the locations of the sky that the telescope can view. The limitation is approximately a magnitude of 16. The APUS team images galaxies of a 12 magnitude or better for their search team. The telescope is in Charles Town, West Virginia. The telescope is housed in a dome on top of the Information Technology building at the campus. This dome is fully automatic so that the telescope and dome can be operated remotely. The telescope is a Planewave CDK24. The focal length is 155.98 inches with an aperture of 24 inches. It has a focal ratio of f/6.5. To capture images, the telescope has a 16.8-megapixel SBIG STC-16803 CCD camera (Miller et al., 2021).

Figure 2

APUS Planewave CDK24 Telescope in Dome (Wallace E. Boston Observatory)



Note: This is the APUS Planewave CDK24 Telescope inside the dome located in the Wallace E. Boston Observatory. This image was taken during the trial run for the Autumn script. Pate, Angela M. (2023). Desktop Trial Run of Script. [Screen Capture]

The location of the telescope and the fact that it is in the Northern Hemisphere limits the parts of the sky that the telescope can image. The telescope is limited to targets specifically viewable from the northern hemisphere above 30 degrees. Additionally, the telescope is limited to parts of the sky visible from its location throughout the year. The telescope can view targets in different areas as the year goes on. It cannot always view the same galaxy throughout the entire year. There will be months of the year when some galaxies do not get imaged due to this limitation.

This telescope has been tested and can image galaxies with a magnitude as low as 15 for a 60-second exposure time. These galaxies can be seen, but the detail is not great, and the images can be difficult to exploit. To stay within the parameters of the telescope for 60 seconds of exposure, it was determined that the best results for the telescope imaging is looking for galaxies that are 12 magnitude or brighter. This limited the number of galaxies in the grouping for the fall collection of images. While the grouping is limited to galaxies with a magnitude 12 of or brighter, there were still 19 galaxies identified to add into a group for collection. This increased the supernova team's sky coverage and chances to view a supernova event meeting the objective of this project.

The telescope is fully automated and has a large dome. The time it takes the telescope to slew and the dome itself to move is also a limiting factor for image collection. The dome is large and heavy. The dome takes time to move as the telescope slews. For most collection opportunities, the dome takes approximately 60 seconds to move to a location and catch up with the telescope. The telescope can move quickly to its next position for imaging, but the images cannot be taken until the dome catches up. The telescope must move, the dome must move, the 60-second image must be taken, and then the collection of the next galaxy can begin. Combine these with limited hours of darkness and it is clear that there is not unlimited time and opportunities to collect data. This constraint has been mitigated by providing a collection strategy that maximizes data collection. The strategy focuses on moving from East to West, allowing for less back and forth for the dome and proving more time for imaging of the galaxies in the autumn group.

The weather in West Virginia can be a limiting factor sometimes as well. Charles Town is cloudy 52% of the year. The clearest months of the year are between June and November, with the clearest month of the year on average being September (WeatherSpark, n.d.). This group of galaxies should have clearer days to image than previous groups based on the average weather statistics for the telescope's area. The weather still contributes to limitations and imaging throughout the year. The mitigation strategy here is to make sure collection happens on any clear nights available. Collection can also take place on nights that may be partly cloudy. During these times, images may be able to be taken for part of the night or part of the group. Even if all galaxies cannot be collected, there is still value in imaging as many galaxies as possible for analysts to view.

Hours of darkness can be a limiting factor when considering the number of galaxies collected each night. During the summer months, there are more hours of light and fewer hours of darkness. As fall and winter approach, there are more hours of darkness and fewer hours of light. At the beginning of September, there are about 13 hours of light and 11 hours of darkness. As the end of September approaches, the hours of daylight drop below 12 hours, and night increases to more than 12 hours. During the fall months, there will be more time for imaging the galaxies. The months of October and November will have fewer limitations in imaging than September. In October, the hours of daylight drop below 11, while in November, the hours of darkness increase (TimeandDate, n.d.). To mitigate the hours of darkness factor it is important to start imaging as soon as possible. The collection strategy was also designed to be time effective to maximize the imaging and collection opportunities during the hours available.

Table 2

Astronomical Twilight Table for Autumn in Charleston, WV

Astonomical Twilight Table for Autumn Months														
September 2023					October 2023					November 2023				
	Sunrise/Sunset		Astronomical Twilight			Sunrise/Sunset		Astronomical Twilight			Sunrise/Sunset		Astronomical Twilight	
Sep	Sunrise	Sunset	Start	End	Oct	Sunrise	Sunset	Start	End	Nov	Sunrise	Sunset	Start	End
1	6:55 am ↑	7:56 pm ↑	5:23 AM	9:29 PM	1	7:22 am ↑	7:09 pm ↑	5:54 AM	8:37 PM	1	7:52 am ↑	6:27 pm ↑	6:23 AM	7:56 PM
2	6:56 am ↑	7:55 pm ↑	5:24 AM	9:27 PM	2	7:23 am ↑	7:08 pm ↑	5:55 AM	8:35 PM	2	7:53 am ↑	6:25 pm ↑	6:24 AM	7:55 PM
3	6:57 am ↑	7:53 pm ↑	5:25 AM	9:25 PM	3	7:23 am ↑	7:06 pm ↑	5:56 AM	8:34 PM	3	7:54 am ↑	6:24 pm ↑	6:25 AM	7:54 PM
4	6:58 am ↑	7:52 pm ↑	5:26 AM	9:23 PM	4	7:24 am ↑	7:05 pm ↑	5:56 AM	8:32 PM	4	7:55 am ↑	6:23 pm ↑	6:25 AM	7:53 PM
5	6:59 am ↑	7:50 pm ↑	5:27 AM	9:21 PM	5	7:25 am ↑	7:03 pm ↑	5:57 AM	8:31 PM	Note: hours shift because clocks change				
6	7:00 am ↑	7:48 pm ↑	5:28 AM	9:20 PM	6	7:26 am ↑	7:01 pm ↑	5:58 AM	8:29 PM	5	6:56 am ↑	5:22 pm ↑	5:26 AM	6:52 PM
7	7:01 am ↑	7:47 pm ↑	5:29 AM	9:18 PM	7	7:27 am ↑	7:00 pm ↑	5:59 AM	8:28 PM	6	6:57 am ↑	5:21 pm ↑	5:27 AM	6:51 PM
8	7:01 am ↑	7:45 pm ↑	5:30 AM	9:16 PM	8	7:28 am ↑	6:58 pm ↑	6:00 AM	8:26 PM	7	6:59 am ↑	5:20 pm ↑	5:28 AM	6:51 PM
9	7:02 am ↑	7:44 pm ↑	5:31 AM	9:14 PM	9	7:29 am ↑	6:57 pm ↑	6:01 AM	8:25 PM	8	7:00 am ↑	5:19 pm ↑	5:29 AM	6:50 PM
10	7:03 am ↑	7:42 pm ↑	5:32 AM	9:13 PM	10	7:30 am ↑	6:56 pm ↑	6:02 AM	8:23 PM	9	7:01 am ↑	5:18 pm ↑	5:30 AM	6:49 PM
11	7:04 am ↑	7:41 pm ↑	5:34 AM	9:11 PM	11	7:31 am ↑	6:54 pm ↑	6:03 AM	8:22 PM	10	7:02 am ↑	5:18 pm ↑	5:31 AM	6:48 PM
12	7:05 am ↑	7:39 pm ↑	5:35 AM	9:09 PM	12	7:32 am ↑	6:53 pm ↑	6:04 AM	8:20 PM	11	7:03 am ↑	5:17 pm ↑	5:32 AM	6:48 PM
13	7:06 am ↑	7:38 pm ↑	5:36 AM	9:07 PM	13	7:33 am ↑	6:51 pm ↑	6:05 AM	8:19 PM	12	7:04 am ↑	5:16 pm ↑	5:33 AM	6:47 PM
14	7:07 am ↑	7:36 pm ↑	5:37 AM	9:06 PM	14	7:34 am ↑	6:50 pm ↑	6:06 AM	8:18 PM	13	7:05 am ↑	5:15 pm ↑	5:34 AM	6:46 PM
15	7:08 am ↑	7:34 pm ↑	5:38 AM	9:04 PM	15	7:35 am ↑	6:48 pm ↑	6:07 AM	8:16 PM	14	7:06 am ↑	5:14 pm ↑	5:35 AM	6:46 PM
16	7:08 am ↑	7:33 pm ↑	5:39 AM	9:02 PM	16	7:36 am ↑	6:47 pm ↑	6:08 AM	8:15 PM	15	7:07 am ↑	5:14 pm ↑	5:36 AM	6:45 PM
17	7:09 am ↑	7:31 pm ↑	5:40 AM	9:00 PM	17	7:37 am ↑	6:45 pm ↑	6:09 AM	8:13 PM	16	7:08 am ↑	5:13 pm ↑	5:37 AM	6:44 PM
18	7:10 am ↑	7:30 pm ↑	5:41 AM	8:59 PM	18	7:38 am ↑	6:44 pm ↑	6:10 AM	8:12 PM	17	7:09 am ↑	5:12 pm ↑	5:38 AM	6:44 PM
19	7:11 am ↑	7:28 pm ↑	5:42 AM	8:57 PM	19	7:39 am ↑	6:43 pm ↑	6:11 AM	8:11 PM	18	7:11 am ↑	5:11 pm ↑	5:39 AM	6:43 PM
20	7:12 am ↑	7:26 pm ↑	5:43 AM	8:55 PM	20	7:40 am ↑	6:41 pm ↑	6:11 AM	8:10 PM	19	7:12 am ↑	5:11 pm ↑	5:39 AM	6:43 PM
21	7:13 am ↑	7:25 pm ↑	5:44 AM	8:53 PM	21	7:41 am ↑	6:40 pm ↑	6:12 AM	8:08 PM	20	7:13 am ↑	5:10 pm ↑	5:40 AM	6:42 PM
22	7:14 am ↑	7:23 pm ↑	5:45 AM	8:52 PM	22	7:42 am ↑	6:39 pm ↑	6:13 AM	8:07 PM	21	7:14 am ↑	5:10 pm ↑	5:41 AM	6:42 PM
23	7:14 am ↑	7:22 pm ↑	5:46 AM	8:50 PM	23	7:43 am ↑	6:37 pm ↑	6:14 AM	8:06 PM	22	7:15 am ↑	5:09 pm ↑	5:42 AM	6:42 PM
24	7:15 am ↑	7:20 pm ↑	5:47 AM	8:48 PM	24	7:44 am ↑	6:36 pm ↑	6:15 AM	8:05 PM	23	7:16 am ↑	5:09 pm ↑	5:43 AM	6:41 PM
25	7:16 am ↑	7:19 pm ↑	5:48 AM	8:47 PM	25	7:45 am ↑	6:35 pm ↑	6:16 AM	8:04 PM	24	7:17 am ↑	5:08 pm ↑	5:44 AM	6:41 PM
26	7:17 am ↑	7:17 pm ↑	5:49 AM	8:45 PM	26	7:46 am ↑	6:34 pm ↑	6:17 AM	8:02 PM	25	7:18 am ↑	5:08 pm ↑	5:45 AM	6:41 PM
27	7:18 am ↑	7:15 pm ↑	5:50 AM	8:43 PM	27	7:47 am ↑	6:32 pm ↑	6:18 AM	8:01 PM	26	7:19 am ↑	5:07 pm ↑	5:46 AM	6:40 PM
28	7:19 am ↑	7:14 pm ↑	5:51 AM	8:42 PM	28	7:48 am ↑	6:31 pm ↑	6:19 AM	8:00 PM	27	7:20 am ↑	5:07 pm ↑	5:47 AM	6:40 PM
29	7:20 am ↑	7:12 pm ↑	5:52 AM	8:40 PM	29	7:49 am ↑	6:30 pm ↑	6:20 AM	7:59 PM	28	7:21 am ↑	5:07 pm ↑	5:48 AM	6:40 PM
30	7:21 am ↑	7:11 pm ↑	5:53 AM	8:39 PM	30	7:50 am ↑	6:29 pm ↑	6:21 AM	7:58 PM	29	7:22 am ↑	5:06 pm ↑	5:48 AM	6:40 PM
					31	7:51 am ↑	6:28 pm ↑	6:22 AM	7:57 PM	30	7:23 am ↑	5:06 pm ↑	5:49 AM	6:40 PM

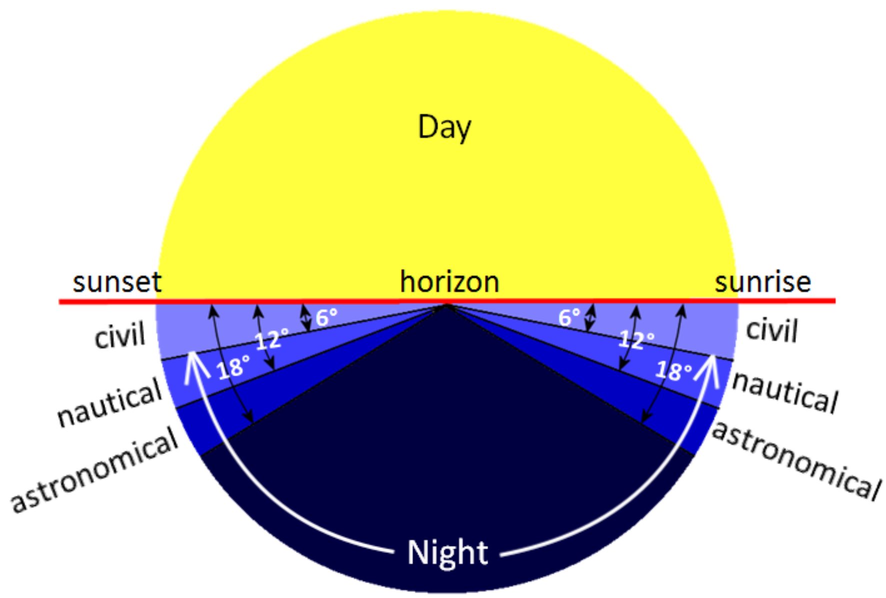
Note: hours shift because clocks change backward 1 hour. All times are local time for Charleston. Time is adjusted for DST when applicable. They consider atmospheric refraction. Dates are based on the Gregorian calendar (TimeandDate, n.d.).

Galaxies, nebula, and globular clusters must be observed after astronomical twilight when the geometric center of the sun is more than 18 degrees below the horizon (US Department of

Commerce, 2021). This further limits the hours of darkness available for imaging galaxies with the APUS telescope. The image below shows a visual representation of the types of twilight including astronomical twilight. For example, on 1 September 2023 astronomical twilight begins 1 hour and 34 minutes before sunrise and after sunset (US Department of Commerce, 2021).

Figure 3

Civil, Nautical, and Astronomical Twilight



Note. The figure above shows civil, nautical, and astronomical twilight. The angles are not to scale in order to show the three twilight categories with more clarity. From US Department of Commerce, 2021, (https://www.weather.gov/lmk/twilight-types#:~:text=Astronomical%20Twilight%3A,urban%20or%20suburban%20light%20pollution.)

The APUS Supernova Search Team is comprised of graduate and undergraduate space studies program volunteers. The current volunteer team consists of 33 members. The number of members limits the number of images that can be viewed. These volunteers all have lives outside of school with careers and families that can also limit their availability to analyze images as they arrive from the telescope. When images are taken and ready to be analyzed, a message will go out in the Slack channel for the volunteers. Members that have time will start analyzing images and filling out tracking documents. Sometimes images cannot get analyzed right away due to the availability of volunteers. At other times the images are analyzed within a few hours of posting. The speed at which images are analyzed and any suspected supernova candidates are identified is solely based on volunteers having the time to work on the images provided.

Finally, the galaxies identified for the autumn group for the APUS supernova search were limited to NGC galaxies. This could limit the sample by not including galaxies from other catalogs. The NGC was explicitly used to find galaxies that fit the imaging parameters. During the initial Stellarium search, galaxies from other catalogs were not identified. However, other catalogs were not utilized to identify any additional galaxy candidates once viewing the NGC.

Chapter Summary

This chapter detailed the literature review detailing some current and previous supernova search teams along with their techniques and successes. Additionally, this chapter discussed limitations such as telescope limitations, weather considerations, and nighttime observing considerations. This information is a great framework for future teams to expand upon to make their teams a success.

CHAPTER 3: METHODOLOGY

"Astronomy compels the soul to look upwards and leads us from this world to another"

– Plato

Chapter Introduction

This chapter will discuss the methodology used to research candidate galaxies and come to a final conclusion of which galaxies to use for an autumn grouping for the APUS supernova search team. As stated previously, this project is designed to provide the APUS supernova search team with more sky coverage during the year, specifically focused on providing coverage during the autumn months. This will allow the team to observe more galaxies throughout the year, take more images, make more observations, and provide them with a higher chance of discovering a supernova event.

This chapter discusses the current galaxy groupings and gaps. It also discusses some of the programs and techniques used to determine where the gap was and how to fill the gap in coverage. Additionally, this chapter lists the candidate galaxies as well as the final galaxies selected for imaging with the APUS telescope. Furthermore, this chapter provides a detailed description of each galaxy that was chosen and discusses the method used to script the telescope. Finally, this chapter discusses the construct validity and reliability of the methods used and chosen for this project.

Methodology Used

The APUS supernova research team has six galaxy groupings collected at various times of the year to be analyzed. These groups do not provide full sky coverage during all months of the year. The team needs to have more galaxies and sky coverage to have better odds at detecting supernova events. To communicate and document analysis and collection, the team utilizes multiple tools and methods. They use Google Drive as a space to store images, track progress, and track possible detections. Google Drive is accessible to all team members from anywhere in the world. They use Slack as a means of communication with other team members, team leads, and their professor. Slack allows student researchers to ask questions and share information. The supernova research team also utilizes Zoom to conduct video meetings once a month where new findings are shared, training is shared, or guest speakers provide development to team members.

Galaxy Coverage Gap & Methodology Considerations

The APUS Supernova research team currently has six galaxy groupings collected during various times of the year. There are some gaps in galaxy coverage throughout the year. One gap was that the team did not have a fall grouping of galaxies to observe for analysis. This was the starting point for determining a new group of galaxies for collection. This new group will allow for more sky coverage for the team and increase their odds of finding a supernova event.

The APUS telescope is in West Virginia; this location is important to choosing candidate galaxies, as those galaxies will need to be able to be collected by the telescope students use for observations. Once the telescope was selected and coordinates for the telescope determined, it was time to determine which galaxies could be viewed from that telescope during the fall months.

Data Collection Technique

The planetarium program, Stellarium, was used to determine which galaxies are viewable during the autumn months for this part of the process. The program is free and downloadable for anyone, making it an excellent choice for students to use. The free program helps this part of the process stay repeatable for students or amateur astronomers if they choose to do a similar project. The program also allows students to add specific coordinates for their telescopes. The coordinates of 39.2890N and 77.8597W were added for the APUS telescope and saved for future use. The next step was to ensure that the program was set to the time of night for collection and the month of collection for this group of galaxies. Utilizing Stellarium's date and time window feature, the time was set to 2000 and the date set to 1 September 2023. The sky was too bright for collection during this time, so the time switched to 2100. The Stellarium program was now set up for the next steps and is an excellent visualization of what can be seen from the input spot during the time of night and date.

The next step was to utilize the constellation labels feature to overlay the names and outlines of the constellations onto the night sky. This allows for a visualization of the different constellations and a starting point for the search of galaxies that could be candidates for collection. This also helps orient a researcher to the sky during that time of year.

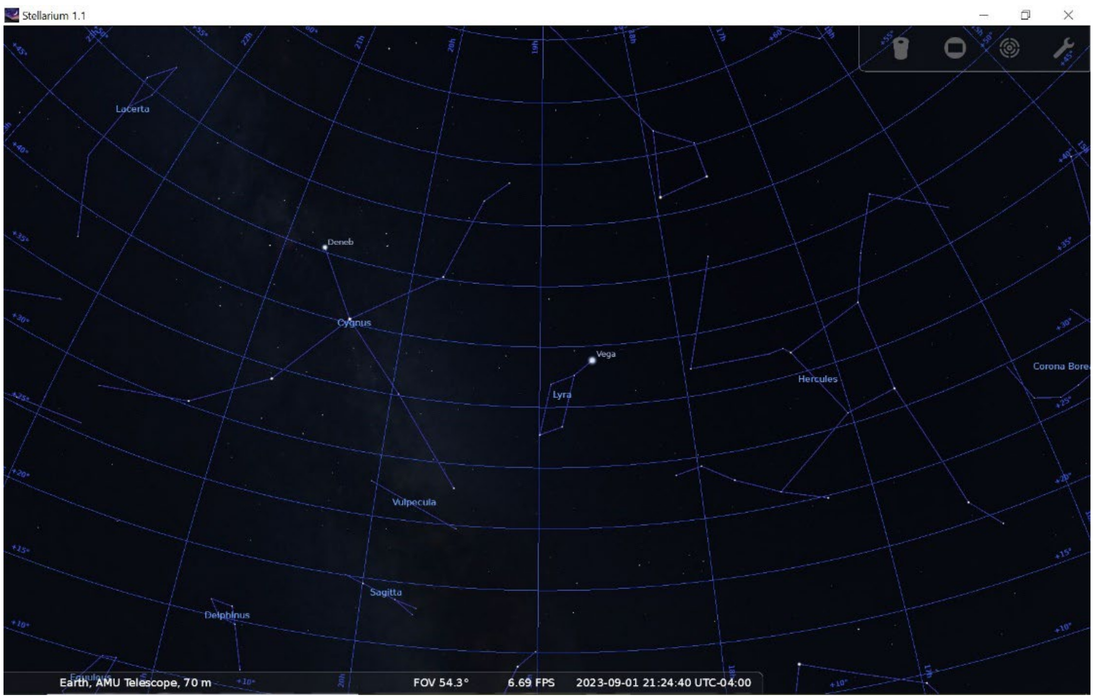
The equatorial grid feature was the next overlay that needed to be added. This shows the Right Ascension (RA) and Declination (Dec) across the sky. This also provides starting points and data for the next steps in the search. Viewing the RA and Dec, the determination was made to start with an RA between 16 and 20 hours and a Dec between 49 and -10 degrees. This was a large area of the sky that would be easily visible to the APUS telescope during the night. The telescope and dome need time to move during collection, and the night sky is also moving. The RA and Dec were a great boundary to consider, ensuring collection would be possible throughout the night.

The Stellarium program also has a feature to view deep-sky objects. This overlay was selected and filtered to include only galaxies and active galaxies. Keeping all deep sky objects overlayed on the night sky cluttered the view and made it more challenging to find the galaxies needed for this project. Now the sky had grid lines, constellation outlines and labels, and galaxies that were in a visible, easily digestible format.

The galaxies in view in the Stellarium program had multiple types and magnitudes. Some of the galaxies were elliptical or spiral. Magnitudes for galaxies showed a wide range, and they were associated with many constellations. The next step had to consider the limitations of the telescope being used. The below image is a snip of the Stellarium program to show how it looked at this point in setup for this project.

Figure 4

Stellarium Snip



Note. This is a snip made from the Stellarium program showing the constellations visible between the RA 17h to 20h and Dec -10 to 30, included to show a visual of the Stellarium setup.

The limitations and other aspects of this method have been discussed in the limitations section. Due to the limitations of the APUS telescope, with an imaging time of 60 seconds for each galaxy, galaxies with a magnitude of 11 or brighter were determined to be the ideal candidates for potential collection. With the constraints for magnitude, RA, and Dec, it was quickly determined that this method and constraints provided a group of only five galaxies for collection. The goal was to have a group between 10 and 20 galaxies for the fall grouping.

At this time, the decision was made to expand the parameters for Dec. The new Dec was set to -10 and 75 degrees; this was still well within the capabilities of the APUS telescope. The determination was also made based on data viewed during the first search to change the magnitude limitation for galaxies to 12; this magnitude decrease was still within the capabilities of the APUS telescope.

The original method used for finding galaxies in Stellarium was to scroll through the night sky hour by hour, degree by degree of RA and Dec. This method was extremely time-consuming and left room for error. The program did not show all the galaxies of all magnitudes. The researcher would have to zoom in further and further to see them. It was determined that an alternative method needed to be utilized. Scrolling through Stellarium by hand was time-consuming and left much room for error in finding galaxies. The decision was made to change the method at this step so there would be less chance of error, and the data would be more complete.

Next the constellations fell within the field of view of the APUS telescope was determined. Searching the sky on Stellarium for constellation names was more manageable than searching for individual galaxies and left less room for error. The constellations selected were Ophiuchus, Lyra, Hercules, Ursa Maj, Cygnus, and Draco. The constellation names were searched for in the New General Catalogue (NGC) web page. This page produces all galaxy names and data for those that fall within the constellation. This technique enabled the candidate galaxy list to grow to 56. These galaxies were located within the newly established magnitude, RA, and Dec. The 25 candidates had a range of magnitude from 11.9 to 9.7.

Table 3

Candidate Galaxies

Constellation	Galaxy Name	Right Accession	Declination	Magnitude
Ophiuchus	NGC 6384	17 h 32 m	+07°03'	10.6
Lyra	NGC 6703	18 h 47 m	+45°33'	11.4
Hercules	NGC 6482	17 h 51m	+23°04'	11.4
Hercules	NGC 6207	16 h 43 m	+36°49'	11.6
Hercules	NGC 6166	16 h 28 m	+39°34'	11.9
Hercules	NGC 6181	16 h 32 m	+19°49'	11.8
Ursa Maj*	NGC 5474	14 h 05 m	+ 53°39'	11.3
Ursa Maj*	NGC 5585	14 h 19 m	56°43'	11.2
Cygnus*	NGC 6946	20 h 34 m	+60°09'	9.7
Cygnus	NGC 6824	19 h 43 m	+56°06'	11.8
Draco*	NGC 4236	12 h 16 m	+69°27'	9.7
Draco	NGC 4125	12 h 08 m	+65°10'	9.7
Draco*	NGC 5866	15 h 12 m	+55°47'	9.9
Draco*	NGC 6503	17 h 49 m	+70°08'	10.3
Draco*	NGC 5907	15 h 15 m	+56°19'	10.4
Draco	NGC 3147	10 h 16 m	+73°24'	11.9
Draco	NGC 6340	17 h 10 m	+72°18'	11.1
Draco	NGC 5982	15 h 38 m	+59°21'	11.1
Draco	NGC 6643	18h 19 m	+74°34'	11.1
Draco	NGC 6015	15 h 51 m	+62°18'	11.2
Draco	NGC 5879	15h 9 m	+57°00'	11.5
Draco	NGC 6654	18 h 39 m	+73°34'	11.8
Draco	NGC 6412	17 h 29 m	+75°42'	11.7
Draco	NGC 4750	12 h 50 m	+72°52'	11.8

Note: The table shows galaxies that fit within the RA 10hrs to 21hrs and Dec between +7° and 76°. The asterisks show galaxies that were being collected in other groups and were removed from the final Autumn group.

The process for determining candidates was still not complete. The next step was to determine if any galaxies were already being collected in one of the other six groups of galaxies being imaged for the APUS Supernova Research team. The list of galaxies already being imaged was downloaded and then compared to the 25 candidates. Through this process, it was determined that seven galaxies from the candidate list were already being collected. Galaxies NGC 6946, NGC 5866, NGC 6503, NGC 5907, NGC 4236, NGC 5474, and NGC 5585 were being collected in various other collection groups by the APUS telescope, and these galaxies were removed from the list and are denoted in the table above with an asterisk following their constellation name. The final grouping of galaxies for collection became 18 galaxies located within the constellations of Cygnus, Draco, Hercules, Lyra, and Ophiuchus.

The list of final galaxies was established, and galaxy descriptions and research were conducted. Each galaxy is unique, part of different constellations, and at various distances from Earth. The galaxy descriptions include the type of galaxy & Hubble Type, distance away from the Earth in light-years, B-V color-magnitude, and diameter of the galaxy.

Galaxy Descriptions

NGC 6384 is a spiral galaxy located in the constellation of Ophiuchus. The galaxy Hubble type is an Sbc. This galaxy lies approximately 87 million light-years from Earth and is 150 thousand light-years across. It has a B-V color-magnitude of 0.99. This galaxy has a magnitude of 10.6 with a RA of 17h 32m and a Dec of +07°03'. The galaxy will be visible to the APUS telescope during the fall months for imaging and data collection. A Type Ia supernova explosion was seen in this galaxy in 1971. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches. It being a spiral galaxy, it could produce any type of supernova event.

NGC 6703 is a lenticular galaxy located in the constellation of Lyra. The galaxy Hubble type is E-S0. This galaxy lies approximately 87.9 million light-years from Earth and is 37 thousand light-years across. It has a B-V color-magnitude of 1.00. The magnitude of galaxy

NGC 6703 is 11.4 with a RA of 18h 47m and a Dec of +45°33'. The galaxy will be visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches.

NGC 6482 is an elliptical galaxy located in the constellation of Hercules. The Hubble type is E. This galaxy is approximately 180 million light-years from Earth and is 148 thousand light-years across. It has a B-V color-magnitude of 0.90. The magnitude of galaxy NGC 6482 is 11.3 with a RA of 17h51m and a Dec of +23°04'. The galaxy will be visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches. Since NGC 6482 is an elliptical galaxy, current research shows that it will only produce SNe Ia events from white dwarfs accreting from a companion star.

NGC 6207 is a spiral galaxy located in the constellation of Hercules. The Hubble type is Sc. The galaxy is approximately 30 million light-years from Earth and is 39 thousand light-years across. It has a B-V color-magnitude of 0.22. The magnitude of galaxy NGC 6702 is 11.6 with a RA of 16h 43 minutes and a Dec of +36°49'. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches. Since this galaxy is a spiral, researchers can expect to see any type of supernova event, with an SNe II being the most likely.

NGC 6166 is an elliptical galaxy located in the constellation of Hercules. The Hubble type is E. The galaxy is approximately 490 million light-years from Earth and is 225 thousand light-years across. It has a B-V color-magnitude of 1.00. The magnitude of galaxy NGC 6166 is 11.9 with a RA of 16h 28m and a Dec of +39°34'. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen due to its location in the sky, magnitude, and type as a candidate for supernova searches. Considering NGC 6166 is an elliptical galaxy, current research shows that it will only produce SNe Ia events from white dwarfs accreting from a companion star.

NGC 6181 is a spiral galaxy located in the constellation of Hercules. The Hubble type is SABc. The galaxy is approximately 102 million light-years away from Earth and is 45 thousand light-years across. It has a B-V color-magnitude of 0.41. The magnitude of galaxy NGC 6181 is 11.8 with a RA of 16h 32m and a Dec of +19°49'. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen due to its location in the sky, magnitude, and type as a candidate for supernova searches. This galaxy is a spiral and most likely to produce SNe II, but it can produce any supernova explosion.

NGC 6824 is a spiral galaxy located in the constellation of Cygnus. The Hubble type is Sab. The galaxy is approximately 220 million light-years away from Earth and is 100 thousand light-years across. It has a B-V color-magnitude of 1.19. The magnitude of galaxy NGC 6824 is 11.8 with a RA of 19h 43 and a Dec of +56°06'. Supernova SN2017glx was discovered in this galaxy in 2017. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches. With NGC 6824 being a spiral galaxy, it can be expected to produce any type of supernova explosion, with SNe II being the most likely to be seen.

NGC 4125 is an elliptical galaxy located in the constellation of Draco. The Hubble type is E. The galaxy is approximately 80 million light-years away from Earth and is 120 thousand light-years across. It has a B-V color-magnitude of 0.93. The magnitude of galaxy NGC 4125 is 9.7 with a RA of 12h 8m and a Dec of +65°10'. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches. Since this is an elliptical galaxy, current research shows that it will only produce SNe Ia events from white dwarfs accreting from a companion star.

NGC 3147 is a spiral galaxy located in the constellation of Draco. The Hubble type is Sbc. The galaxy is approximately 130 million light-years away from Earth and is 75 thousand light-years across. It has a B-V color-magnitude of -0.68. The magnitude of galaxy NGC 3147 is 11.9 with a RA of 10h 16m and a Dec of +73°24'. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches. With this being a spiral galaxy, researchers can expect it to produce any of the types of SNe, but the most likely to be seen would be an SNe II.

NGC 6340 is a lenticular galaxy located in the constellation of Draco. The Hubble type is S0-a. The galaxy is approximately 61 million light-years away from Earth and is 48 thousand light-years across. It has a B-V color-magnitude of 0.86. The magnitude of galaxy NGC 6340 is 11.1 with a RA of 17h 10 min and a Dec of +72°18'. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches.

NGC 5982 is an elliptical galaxy located in the constellation of Draco. The Hubble type is E. The galaxy is approximately 130 million light-years away from Earth and is 59 thousand light-years across. It has a B-V color-magnitude of 0.91. The magnitude of galaxy NGC 5982 is 11.1 with a RA of 15h 38m and a Dec of +59°21'. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches. NGC 5892 is an elliptical galaxy, and current research shows that it will only produce SNe Ia events from white dwarfs accreting from a companion star.

NGC 6643 is a spiral galaxy located in the constellation of Draco. The Hubble type is Sc. The galaxy is approximately 64 million light-years from Earth and is 86 thousand light-years across. It has a B-V color-magnitude of 0.65. The magnitude of galaxy NGC 6643 is 11.1 with a RA of 18h 19m and a Dec of +74°34'. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches. With this being a spiral galaxy, researchers can expect it to produce any of the types of SNe, but the most likely to be seen would be an SNe II.

NGC 6015 is a spiral galaxy located in the constellation of Draco. The Hubble type is Sc. The galaxy is approximately 44 million light-years from Earth and is 71 thousand light-years across. It has a B-V color-magnitude of 0.44. The magnitude of galaxy NGC 6015 is 11.2 with a RA of 15h 51m and a Dec of +62°18'. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches. Since NGC 6015 is a spiral galaxy, researchers can expect it to produce any SNe type, but the most likely to be seen would be an SNe II.

NGC 5879 is a spiral galaxy located in the constellation of Draco. The Hubble type is Sbc. The galaxy is approximately 39 million light-years from Earth and is 25 thousand light-years across. It has a B-V color-magnitude of 0.65. The magnitude of galaxy NGC 5879 is 11.5 with a RA of 15h 09m and a Dec of +57°00'. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches. Considering this is a spiral galaxy, researchers can expect it to produce any of the types of SNe, but the most likely to be seen would be a SNe II.

NGC 6654 is a spiral galaxy located in the constellation of Draco. The Hubble type is SBcd. The galaxy is approximately 96 million light-years from Earth and is 43 thousand light-years across. It has a B-V color-magnitude of 0.97. The magnitude of galaxy NGC 6654 is 11.8 with a RA of 18h 39m and a Dec of +73°34'. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches. As a spiral galaxy, researchers can expect it to produce any SNe type, but the most likely to be seen would be an SNe II.

NGC 6412 is a spiral galaxy located in the constellation of Draco. The Hubble type is SABc. The galaxy is approximately 49 million light-years from Earth and is 16 thousand light-years across. It has a B-V color-magnitude of 0.55. The magnitude of galaxy NGC 6412 is 11.7 with a RA of 17h 29m and a Dec of +75°42'. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches. With this being a spiral galaxy, researchers can expect it to produce any of the types of SNe, but the most likely to be seen would be an SNe II.

NGC 4750 is a spiral galaxy located in the constellation of Draco. The Hubble type is Sab. The galaxy is approximately 85 million light-years from Earth and is 37 thousand light-years across. It has a B-V color-magnitude of -0.31. The magnitude of NGC 4750 is 11.8 with a RA of 12h 50m and a Dec of +72°52'. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches. As a spiral galaxy, researchers can expect it to produce any SNe type, but the most likely to be seen would be an SNe II.

NGC 5908 is a spiral galaxy located in the constellation of Draco. The Hubble type is SBb. The galaxy is approximately 158 million light-years from Earth and is 89 thousand light-years across. It has a B-V color-magnitude of 0.91. The magnitude of NGC 5908 is 11.9 with a RA of 15h 16m and a Dec of +55°24'. The galaxy is visible to the APUS telescope during the fall months for imaging and data collection. This galaxy was chosen for its location in the sky, magnitude, and type as a candidate for supernova searches. Spiral galaxies are most likely to produce SNe II but can produce all types of supernova explosions.

Data Imaging Order and Technique

With the final list of galaxies determined, the imaging order needs to be determined. When deciding the imaging order, critical factors to consider are the galaxy's location in the sky, the time it takes the telescope to move, and the time it takes the telescope's dome to move. Starting with imaging in the west and moving east is an excellent option, as it allows for galaxies close to the limit of the field of view to be imaged first before they are no longer visible for the night. Using Stellarium to visualize the location of each galaxy in the sky, galaxies to image were listed from west to east. The final order for the galaxy list is given in the table below. This strategy optimizes imaging galaxies and optimizes telescope usage.

Table 4

Galaxy Imaging Order

Constellation	Galaxy Name	Right Accession	Declination	Magnitude
Draco	NGC 3147	10 h 16 m	+73°24'	11.9
Draco	NGC 4125	12 h 08 m	+65°10'	9.7
Draco	NGC 4750	12 h 50 m	+72°52'	11.8
Draco	NGC 5879	15h 9 m	+57°00'	11.5

Draco	NGC 5908	15 h 16 m	+55°24'	11.9
Draco	NGC 5982	15 h 38 m	+59°21'	11.1
Draco	NGC 6015	15 h 51 m	+62°18'	11.2
Hercules	NGC 6166	16 h 28 m	+39°34'	11.9
Hercules	NGC 6181	16 h 32 m	+19°49'	11.8
Hercules	NGC 6207	16 h 43 m	+36°49'	11.6
Draco	NGC 6340	17 h 10 m	+72°18'	11.1
Draco	NGC 6412	17 h 29 m	+75°42'	11.7
Ophiuchus	NGC 6384	17 h 32 m	+07°03'	10.6
Hercules	NGC 6482	17 h 51m	+23°04'	11.4
Draco	NGC 6643	18h 19 m	+74°34'	11.1
Draco	NGC 6654	18 h 39 m	+73°34'	11.8
Lyra	NGC 6703	18 h 47 m	+45°33'	11.4
Cygnus	NGC 6824	19 h 43 m	+56°06'	11.8

Note: The table shows the imaging order of the galaxies chosen for this project. This imaging order optimizes telescope time during the collection process.

Scripting the Telescope

The first step for coding the telescope with the final selection of galaxies is to get access to the telescope desktop. The APUS information technology team must build a profile and grant access to the telescope desktop to any individual that is requesting access. Once this step is complete, the individual will have access to the required applications on the desktop for the next steps.

Orchestrate is the software program utilized for the APUS telescope scripting process. Orchestrate is software that allows a user to control multiple astronomical devices by creating scripts. This is an easy-to-use graphical user interface that will allow the individual to control the dome, the telescope, and the CCD camera for imaging. In this instance, it is what will be used to script the chosen galaxies for the autumn group.

Script steps

To script using the Orchestrate program, there are eight columns to choose from that data can be input into for scripting purposes. For this project, four columns were utilized to create the script. The columns used were Command, Arguments, Comment, Compiled Arg1, and Compiled Arg2. The rest of the columns available were not required to run this script and image these galaxies effectively.

Each column serves a purpose for scripting the telescope to get the required data for the project. The Command column is where commands for the telescope are input. The commands used for this project were SlewToObject, WaitFor, and TakeImage. The SlewToObject command tells the telescope which object in the sky will be imaged. The WaitFor command is for timing of the telescope and dome to slew and move to the object, and the TakeImage command tells the telescope to image the object. The Arguments column lists the NGC galaxies that were selected for this project as well as the times to wait for the telescope and dome to move and the imaging time for taking images. In the Comment column, the number of the galaxy in order as well as the constellation are listed. This allows for easy tracking after the images are taken. The Compiled Arg1 column lists the RA for each galaxy listed. For this project, hours, minutes, and seconds were used. The Compiled Arg2 column lists the RA for each galaxy that needs to be imaged.

The commands can be changed depending on what is required for the user when writing the script. Each column is customizable to better utilize the telescope and get the needed results. For this project the WaitFor time was set to 60 seconds for each galaxy. This allows the telescope to slew and then the dome to catch up. If the dome takes more or less time than the amount of time listed in the Arguments column, then the WaitFor command can be adjusted as needed. The APUS team utilizes a 60-second imaging time for its galaxies. This time was determined sufficient to image galaxies with the APUS telescope and CCD at magnitudes of 12 or brighter. The imaging time can also be changed if a longer or shorter time is required. This would be changed in the Arguments column in the row next to the TakeImage command for each object in the script.

Once the script is completed, a test run of the script is performed. This test run is completed during daylight hours to ensure that the telescope test run does not interfere with actual data collection during night hours. The test run is used to confirm that the telescope and dome will operate appropriately during imaging and check for any errors in the script. During this time, the user can adjust the WaitFor time if needed for the dome; this time can be adjusted shorter or longer depending on what is needed for that portion of the script. The script reported two errors during the test run. These errors were due to the galaxies being below the horizon. The rest of the script ran well, and no adjustments were required as the galaxies in question will be above the horizon during the actual collection times. The final script for this project's Autumn listing of galaxies is in the table below. Additionally, the image below shows the actual test run of the telescope as the script is running.

Final Script.

Table 5

The Final Script. For the Autumn Group

Orchestrate Script Autumn Group							
Command	Arguments	Comment	Status	Error Msg	Compiled Cmd	Compiled Arg1	Compiled Arg2
SlewToObject	NGC3147	1 Draco				10h 16m 54s	+73°24'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC4125	2 Draco				12h 08m 06s	+65°10'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC4750	3 Draco				12h 50m 7s	+72°52'

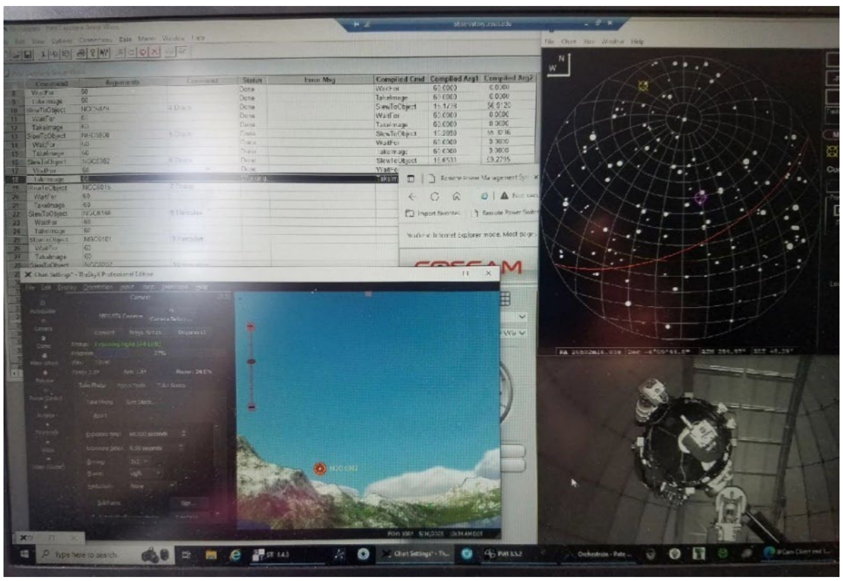
WaitFor	60						
TakeImage	60						
SlewToObject	NGC5879	4 Draco				15h 9 m 46s	+57°00'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC5908	5 Draco				15h 16m 4s	+55°24'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC5982	6 Draco				15h 38m 40s	+59°21'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC6015	7 Draco				15h 51m 25s	+62°18'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC6166	8 Hercules				16h 28m 38s	+39°34'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC6181	9 Hercules				16h 32m 20s	+19°49'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC6207	10 Hercules				16h 43m 03s	+36°49'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC6340	11 Draco				17h 10m 24s	+72°18'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC6412	12 Draco				17h 29m 36s	+75°42'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC6384	13 Ophiuchus				17h 32m 24s	+07°03'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC6482	14 Hercules				17h 51m 48s	+23°04'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC6643	15 Draco				18h 19 m 47s	+74°34'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC6654	16 Draco				18h 39m	+73°34'
WaitFor	60						
TakeImage	60						
SlewToObject	NGC6703	17 Lyra				18h 47m 18s	+45°33'
WaitFor	60						

TakeImage	60						
SlewToObject	NGC6824	18 Cygnus				19h 43m 41s	+56°06'
WaitFor	60						
TakeImage	60						

Note. The table above shows the final script for the Autumn group.

Figure 5

Script Trial Run



Pate, Angela M. (2023). Desktop Trial Run of Script. [Screen Capture]

Theoretical Framework, Construct Validity, & Reliability

The APUS Supernova team utilizes Slack to communicate daily. This is a free downloadable application. This application can be used on Android phones as well as iPhones. Additionally, students can access Slack from their computers through the Slack website. Slack can be accessed from anywhere worldwide if the researcher has internet or phone service. This application is very reliable. Many organizations utilize it as a collaborative workspace; researchers can respond in real-time. The team members can also upload pictures and documents to Slack from their phones or computers, making it a versatile tool. A critical aspect of supernova research is finding a supernova as early as possible. Utilizing a real-time messaging application to inform the team that there are images to review allows the ability to analyze the images quickly.

Furthermore, researchers who find a possible detection can message team leads in Slack, and those team leads can start the verification process quickly. Utilizing this tool has been proven effective for this team and many other teams in differing fields of work. Due to the proven effectiveness of Slack, it was utilized to communicate with one of the lead researchers for approval and questions about galaxy research and candidates during the process. It was also used to communicate progress to one of the lead researchers.

Google docs is another tool that has proven effective for the supernova search team to document the results of their research. The members would document which images from different groups they were analyzing and annotate any information about possible detections onto a spreadsheet in google docs. This allowed other researchers to see which images were being analyzed in real-time so as not to duplicate efforts. Due to this being such an effective way to pass information and prevent duplication of effort for the research team, google docs was chosen as the tool for the new grouping of fall galaxies. A google docs page was created with spreadsheets that indicated which galaxies were candidates, which galaxies were chosen for final selection, and the order in which the galaxies would be imaged. This was done so that the lead researchers could view the progress of the new grouping, and any student researchers could also see the process. Google docs is a reliable and proven program for collaboration across the globe and a great way to store information for future use. While google docs is a great way to store information and collaborate, it is not a great visualization tool.

A visualization tool and virtual observatory that is often used by researchers in the space studies and astronomy fields is called Aladin. This tool allows researchers to view, compare, and import their own images. This tool has been proven to be an asset in multiple types of research. The tool is free to download and use, making it great for student researchers. This tool has proven reliable and compatible with many computer setups that students and other researchers might have. For example, one team used this tool to look for new common proper-motion pairs in three young stellar kinematic groups and was quite successful. The team identified nine unknown systems and verified their technique by identifying 14 previously known systems (Alonso-Floriano et al., 2012). This tool is excellent for imagery visualization and utilizing the blink method for analysis.

The method used by the APUS research team to analyze galaxy images is the blink method. With this method, a researcher will load an older comparison image into the Aladin program, align the two images using the stars and create a blink image. Once the blink image is created, the researcher will carefully study the entire image to determine if there are any supernova candidates on the image. This method is reliable for determining changes between the two images. The changes could be a new supernova, a previously reported supernova, an asteroid, a variable star, or an anomaly from the sensor. This method makes it easy to compare images as it blinks between them. The construct validity for this method has been proven through other supernova search teams and teams in other fields, such as military imagery change detection.

Eagle Hill Supernova Search team and BOSS both use the blink method for their programs to determine supernova candidates for further study. These teams have discovered multiple supernova events as active search groups. The BOSS team also utilizes AI and side-by-side comparison for their search. These options have their limitations. AI can identify something on images that needs further investigation; then, the researcher will utilize side-by-side or blink to confirm that AI has found something of interest. The APUS research team could also compare the image side by side. This technique is more difficult to visualize and find change and leaves more room for error than the blink method, where the images are aligned on top of each other.

Imagery analysts in the military also use the blink method, sometimes called the flicker method, for change detection. It has proven to be a reliable method for their analysts. This method allows analysts to see tiny changes in an environment that may not be easily detectable with a side-by-side view. Using the blink method can prevent analysts from missing something due to change blindness, rapid eye movements, or other disturbances in an image (Nystrom, 2003).

Another great tool to utilize for visualization of the night sky is the Stellarium tool. Stellarium has proven to be a reliable, valid, and effective tool for students and amateur astronomers to develop their research competence and abilities. Research competence lies in a few factors, including knowledge, skills, and abilities, and experience in research activities. Students in online universities do not always have access to the same types of labs and tools as those at a brick-and-mortar university. In an online university such as APUS, students can access online tools. Stellarium, as a virtual planetarium and research tool, is free for these students and allows them to develop skills they would otherwise not be able to (Mokhun et al., 2022).

Countries around the world are already using Stellarium for students to visualize the path of the Sun, determine the distance to the Sun, determine the planets' position, and build HR diagrams. A recent study has proposed the use of Stellarium to study exoplanets. The study shows how Stellarium can be used in this study and showcases Stellarium as a tool that allows students to form the qualities needed of researchers, the ability of students to work with large amounts of data and information, the ability to systematize, analyze, summarize, and formulate conclusions (Mokhun et al., 2022). This study shows there can be multiple uses for Stellarium for astronomy students. It is also a great tool to analyze galaxies, the placement of galaxies in the sky, and to determine galaxy candidates for supernova research.

Many supernova search teams discussed utilizing amateur astronomers to identify supernova candidates. This method has been used because of the massive amounts of galaxies and images. The more eyes on the targets, the more likely a team is to identify a supernova candidate. Utilizing students and amateur astronomers frees up astronomers and research leads to focus on other aspects of the research and allows students and amateurs to get hands-on training and real-life experiences as part of the research team. As seen in many of the supernova search teams, this method of utilizing amateurs has proven valid and reliable. The teams that utilize amateurs are finding supernova candidates and events all over the night sky. The Eagle Hill Supernova search team utilizes amateur astronomers and the blink method to identify supernova candidates. This team has discovered multiple supernovae since its first supernova was discovered in 2013. The Supernova Hunters also utilizes amateur astronomers as part of its construct. The program has discovered 757 potential supernova events utilizing its methods. The use of amateur astronomers leaves room for some mistakes in identification, but coupling them on teams with astronomers and lead researchers proves to be a valid and reliable method of detecting supernova candidates for further research and study. It allows for more images to be analyzed, increasing the likelihood of discovery.

The APUS Supernova Search Team uses a 60-second exposure and images galaxies that are a 12 magnitude or brighter. The limiting magnitude of a CCD camera depends on the quality of the camera as well as seeing conditions. For different telescopes, a limiting magnitude equation below could be used to assist with what magnitude can be viewed with different CCD cameras and exposure times. The average "M" value is about 16 (CrossoverManiac, 2019).

LM = M + 2.5 * log10 (d * d * sqrt(t))

Time frame

Table 6

Thesis Time Frame

Supernova Additional Sky Coverage Thesis Proposal Timeline			
Stage	**Activity**	**Estimated duration**	**Deliverable**
Background information	Supernova types	3 days	Detailed information on different types of supernovae for background knowledge
	Galaxy types	3 days	Detailed information on galaxy types as they play a role in different types of supernovae events and likelihood
	Rates and likelihood	3 days	Information on rates and likely hood of different types in galaxies selected for collection
Literature review	Supernova teams	1 week	Detailed information on other teams that search for supernovae events
	Teams methods	1 week in conjunction with supernova team research	The methods and processes of different supernova teams
Methodology	Stellarium	3 days	Download the program to use as a virtual planetarium to plan sky location and galaxy candidates
	Constellation determinatio n	1 day	Determine which constellations are in the part of the sky that the APUS supernova team needs coverage for

	Determine galaxy candidates	1 week	Determine galaxy candidates and deconflict with galaxies already being collected
	Galaxy collection order	2 days	Determine galaxy collection order for scripting purposes
	Telescope script	1 week	Write script for galaxy collection
Limitations	Telescope limitations	2 days	Understand the limitations of the telescope
	Weather limitations	2 days	Understand weather in telescope location and how it affects the project
	Hours of darkness	1 day	Know the hours of darkness for galaxy collection purposes
	Volunteers	1 day	Understand that the number of volunteers determines the number of images that can be analyzed
Construct Validity	Reliability of techniques	1 week	Understand how reliable the techniques being utilized are
	Validation of techniques	1 week	Understand if the techniques used are valid

Chapter Summary

This chapter detailed the methodology used to research candidate galaxies and the 18 autumn galaxies established for this project. Additionally, this chapter covered the current galaxy groupings and gaps. It also discussed some of the programs and techniques used to determine where the gaps were and how to fill the gap in coverage for the APUS Supernova Search Team. Furthermore, this chapter listed the final galaxies selected for imaging. Moreover, this chapter provided a detailed description of each galaxy that was chosen and discussed the method used to script the telescope. Finally, this chapter detailed the construct validity and reliability of the methods used for this project.

CHAPTER 4: DATA/RESULTS

"Astronomy is the science in which you are not able to touch anything you study."

– Allan Sandage

Chapter Introduction

This chapter will discuss the data and results of the autumn galaxy group that was added for the APUS Supernova Search Team. In this chapter, information will be given with regards to the new group location. Additionally, statistics will be provided related to the number of galaxies that are located in that area vs. the number of galaxies selected for this project. Furthermore, this chapter details the additional galaxies regarding the statistical probability of detecting a supernova for the supernova search team. Finally, this chapter details the added coverage and amount of sky the team is now viewing regarding groups throughout the year.

Results

New Group Location

The new group location was determined by viewing an electronic planetarium set to the time and date for the grouping as well as the location of the telescope. It was determined that the RA for this group would be between 16 and 20 hours. The best declination was determined to be between -10 and 75 degrees. The original constellations identified between these parameters were Draco, Hercules, Ophiuchus, Lyra, Cygnus, Sagitta, Scutum, Vulpecula, Aquila, and Serpens. Each constellation was reviewed for galaxy candidates.

Galaxies available vs Galaxies Selected

Within the location viewable to the telescope, galaxies in each constellation were reviewed to see which would be good candidates for this project. The Draco constellation has

266 galaxies listed, of which 11 met the parameters required for this project. The Hercules constellation has 184 galaxies listed, of which four met the required parameters. The Ophiuchus constellation listed 10 galaxies, of which one of those met the required parameters. The Lyra constellation listed 22 galaxies, of which one met the required parameters. The Cygnus constellation listed nine galaxies, of which one met the required parameters. Sagitta and Scutum do not list any galaxies within the constellation. The Vulpecula constellation lists three galaxies, of which none met the required parameters. Aquilla lists 11 galaxies, none of which met the required parameters. Finally, the Serpens constellation lists 68 galaxies, of which none met the required parameters. In total, there were 575 galaxies reviewed with 18 selected equaling a 3.13% selection rate. The table below shows a visual depiction of the data.

Table 7

Constellation and Galaxy Data

Constellation and Galaxy Data			
Constellation	**Total Galaxies**	**Galaxies in Parameters**	**Percentage Selected**
Draco	266	11	4.13%
Hercules	184	4	2.17%
Ophiuchus	10	1	10%
Lyra	22	1	4.54%
Cygnus	9	1	11.11%
Sagitta	0	0	0%
Scutum	0	0	0%
Vulpecula	3	0	0%
Aquila	11	0	0%
Serpens	68	0	0%
Total	575	18	3.13%

Probability of Supernova Detection

As stated earlier, the probability of detecting a supernova event is based on several factors. One of those factors is the number of galaxies observed. The APUS supernova team was previously imaging 177 galaxies throughout the year. With the addition of the autumn group, they can now image 195 galaxies throughout the year. This is an increase of 10.2% from the previous list. There are established and calculated supernova rates based off supernova type that were completed by the Lick Observatory NGSS program. These rates were calculated as a function of galaxy mass and supernova type for nearby galaxies. They used units of 10^{-4} SN Mpc^{-3} yr^{-1}. With these units being used they concluded the following rates SNIa 0.301, SNIbc, 0.258 and SNII 0.447. The previous APUS Supernova team sample had a radius of approximately 19.8 with the team assuming a spherical distribution the volume was about 32.5 x 10^4 Mpc^3. Given this volume the rates the team would expect to see would be SNIa 0.83 yr^{-1}, SNIbc, 0.83 yr^{-1}, and SNII 1.45 yr^{-1}. This equates to around 3 supernovae a year (Miller, 2021).

The furthest galaxy from Earth in the new group is galaxy NGC 6166 at approximately 490 million light years or 1.5 x 10^2 Mpc from Earth and the next furthest is galaxy NGC 6824 at approximately 220 million light years or 6.7 x 10^1 Mpc from Earth. This increases the volume by a factor of 2.

Chapter Summary

This chapter discussed the data and results of the autumn galaxy group that was added for the APUS Supernova Search Team. The autumn group location was found between the RA of 16 and 20 hours with Dec between -10 and 75 degrees. Additionally, there were 575 galaxies within the constellations identified for analyses with 18 being selected for this project. Finally, this project identified galaxies as far away from Earth as 490 million light years adding to the volume for the Supernova Search team and increasing it by a factor of two and providing more opportunities for the search team to image and analyze data in hopes of discovering a supernova event.

CHAPTER 5: DISCUSSION

Chapter Introduction

This chapter will summarize this project to create an autumn group for the supernova search team, discuss the problem statement about supernovae discoveries and full sky coverage, address how the problem was tackled utilizing tools and software accessible from anywhere in the world, and provide an interpretation of the data collected during the project. This chapter also covers the limitations of the project and will provide suggestions for practical applications along with recommendations for future scientific investigations.

Sky Coverage Discussion & Data Interpretation

The project to provide an autumn group of galaxies for the APUS Supernova Search Team established sky coverage for a portion of sky with an RA between 10 hours and 20 hours and a Dec between +5° and 75°. This portion of sky was previously not being imaged by the team. They were limited in galaxies that they could observe during the autumn months. In the end, the project utilized software and tools that are easily accessible to students and other supernova search teams to create the galaxy grouping making the process easily repeatable. It established 18 new galaxies to image for the team increasing the sky coverage throughout the year with an autonomous telescope script.

The APUS Supernova Search team previously did not have coverage during Autumn. This coverage was needed to provide more complete sky coverage and higher chances of supernova detection. There are billions of galaxies in the sky that could produce a supernova explosion at any time. It is important for scientists to detect and image these explosions quickly after the event in order to collect data and light curve information to inform scientific research. The APUS Supernova Search team is now equipped to image more galaxies throughout the year than had been previously and increased its galaxy sample radius.

The data shows that adding a new group of galaxies to the APUS Supernova Search Team has increased their volume of sky coverage by a factor of 2. It has also increased their galaxies for imaging by 10.2%. The Autumn project was able to successfully add sky coverage utilizing easily accessible tools for students. Additionally, the project was able to utilize an autonomous telescope script to establish the grouping to collect the 18 new galaxies during the autumn months when they are visible to the APUS telescope being utilized.

The Limitations

As stated in the limitations chapter there are limitations to this project. Some of the major limitations include the following. The telescope is located in West Virginia and is limited to viewing objects in the Northern Hemisphere above 30 degrees. Additionally, the telescope is limited to imaging galaxies at a magnitude of 16. The APUS supernova team has limited their magnitude to 12 for galaxies to allow for better images and collection. The telescope is in a large dome; this dome takes time to move through the night. Couple that with the time it takes the telescope to slew and add 60 seconds for the exposure of the image, and there is also a limitation on how many images could be collected during the night. Furthermore, the weather where the telescope is plays a factor in limitations. Cloud cover can be significant and would not allow for proper conditions for telescope imaging. Moreover, hours of darkness and astronomical twilight during the autumn months can limit telescope use and collection opportunities. Furthermore, the APUS Supernova Search team utilizes volunteers to view images, and the availability of volunteers and quickness of analysis by those volunteers is a limiting factor. Finally, the NGC was utilized to find and provide galaxies for this project. If there was a galaxy in the area of sky being studied that was not listed in the NGC catalog this could be an area of improvement for future projects.

Practical Applications

This project has many practical applications. Research teams can utilize the methods and tools described in this project to create more teams, observe more sky coverage, or add galaxies to already existing works. Students in Space Studies or Astronomy can utilize this project as the groundwork for future projects with the supernova search teams or utilize the same tools and methods to create completely different search and research teams or projects. The Autumn group has already been added to the APUS Supernova Search Team's work and will start being imaged and analyzed as soon as the galaxies within it are visible during the Autumn months. The application will allow current and future students the ability to analyze the galaxies that were selected and give them hands-on training as part of a research team.

Recommendations for Future Studies

Future studies are needed for supernova research as scientists still have many gaps in their knowledge of how supernova work and the different types of supernovae observed. Imaging and collecting data on supernovae as soon as they are detected is instrumental in increasing understanding of these amazing events. Additionally, adding more galaxies and sky coverage to teams or creating new teams is another recommendation for future studies. Furthermore, the community could benefit from collaboration between the teams that are already searching in order to share ideas, best practices, and future projects. This could allow for better processes and opportunities among all teams to propel their projects and science forward.

Chapter Summary

This chapter summarized the project to create an autumn group for the supernova search team. It addressed the problem of providing full sky coverage and an autonomous telescope script for the APUS Supernova Search team. The project was tackled utilizing tools and software accessible from anywhere in the world. The data collected allowed for more sky coverage, an increased volume area, and brought the team's total galaxies for analysis up to 195. This chapter also covered the limitations of the project including telescope limitations, weather limitations, and volunteer researcher limitations. Finally, this chapter provided suggestions for practical applications along with recommendations for future scientific investigations.

CHAPTER 6: SUMMARY/CONCLUSION

"Remember to look up at the stars and not down at your feet. Try to make sense of what you see and wonder about what makes the universe exist."

- Stephen Hawking

Summary

The supernova full sky coverage autumn project focuses on establishing a new target group of galaxies that will provide full sky coverage for the APUS Supernova Search team. The images fill a gap in the sky during the autumn months that was not previously able to be imaged. The methods and tools utilized were selected to provide a repeatable approach for future projects that will continue to provide sky coverage for the research team. The number of galaxies observed directly relates to the probability of finding a supernova event. The more galaxies and sky area covered, the more likely the team is to discover an event and provide that data to the scientific community. The paper provided background information about supernovae and galaxies, the process for determining the time of year for collection, constellations and why those constellations were chosen, the APUS telescope, galaxy candidates, collection strategy for optimal telescope usage, the script used for automated collection, and exposure time selected for the galaxies that made the final cut for this group of sky coverage.

This project provided the APUS Supernova Search Team with 18 more galaxies to analyze during the year and increased the volume of sky coverage by a factor of 2. The galaxies established for this project included spiral, elliptical, and lenticular galaxies. They ranged in distance from the Earth between 30 million light years and 490 million light years. The autonomous telescope script created was added to the team's collection deck at the observatory and will start being imaged as soon as the galaxies are high enough in the sky to do so. This project was detailed and is a repeatable process for future students or other teams to utilize and adapt to fit their goals and research needs. Billions of galaxies in the observable universe are home to supernova explosions. The APUS Supernova Search team is now able to image 195 of those for analysis.

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