THE APUS SUPERNOVA SEARCH PROGRAM:

TESTING SUPERNOVA DETECTION METHOD

A Master Thesis

Submitted to the faculty

of

American Public University

by

Cary Dean Hatch

In Partial Fulfillment of the

Requirements for the Degree

of

Masters of Arts

March 2019

American Public University

Charles Town, WV

DEDICATION

I dedicate this to my wife Yvette, for her love and support.

ACKNOWLEDGMENTS

I wish to thank the Dr. Keith Woodman for his patience and feedback during the writing of this thesis.

I also wish to thank Dr. Edward Albin, Dr. Kristen Miller and Dr. Katelyn Milliman for allowing me to pilot the APUS Supernova Search Program.

ABSTRACT OF THE THESIS

We present the results from a pilot study with the American Public University System's (APUS) supernova search program. Using a quantitative descriptive theory methodology, this study evaluated seven blink-comparison software programs: Aladin Sky Atlas, Astrometrica, GrepNova, MaxIm DL Supernova Search Tool, PhAst, SAOImage DS9 and Starblinker with 52 FITS format images (26 reference and 26 subject) to determine which software program is most effective to use with the supernova search program. 11 tests were conducted with the software on Windows, Mac OS and Linux computers. Problems with reference and subject images were resolved by adding World Coordinate System (WCS) data. Aladin Sky Atlas was determined to be the most effective blink-comparison software due to cross platform compatibility, free usage without limitation and ease of use of image loading, panning, zoom, invert and contrast adjustments. The Aladin Sky Atlas will be utilized by student-scientists in conjunction with student-based research opportunities.

THE APUS SUPERNOVA SEARCH PROGRAM:

TESTING SUPERNOVA DETECTION METHOD

by

Cary Dean Hatch

American Public University System, March 18, 2019

Charles Town, West Virginia

Professor Keith Woodman, PhD, Thesis Professor

Table of Contents

CHAPTER I: INTRODUCTION

Current Method of Observing Supernovae

All around the universe, stars are exploding and for the most part, due to the cosmic distances involved, are never observed from here on Earth. Detecting, finding and cataloging supernova as they occur can be a tedious and challenging process. SN1054 was first seen brightly in the night sky in the year 1054 by Chinese astronomers and was observable for almost two years without a telescope, unfortunately, like a vast majority of the supernovae they occur much like SN1054 did, without warning. Due to their distance from the Earth, within a relatively short period, a supernovae peak in intensity and then fade away into the cosmic background. The Pan-STARRS1 (Panoramic Survey Telescope and Rapid Response System) telescope in Hawaii developed a detection method which has been set up to image galaxies during clear evenings to observe for potentially illusive supernovae. Through this process, more data is collected and stored than the research team assigned has time to process. The Pan-STARRS1 team in an attempt to alleviate this bottleneck in data collection and analysis has implemented computer software to aid in the identification of potential supernova candidates. Unfortunately, the computer data output contains too many false detections, and due to the sheer amount of data left to examine, it still cannot be directly utilized by the researchers. While the computer reduces the overall amount of data which needs to be analyzed, there is still a massive amount of data to sift through in which the automated computer software has identified as potential supernovae. To assist in reducing the gross amount of data left to search through, Pan-STARRS1 has partnered with the website Zooniverse.org under a program called "Supernova Hunters." Supernova Hunters are set up to enlist the public in a crowdsourcing event to become citizen scientists and help in the analysis of the data reduced by the Pan-STARRS1 computer to sort through. Anyone can create a profile, log in and with some basic training, begin to compare image data with reference data to confirm or reject images with potential supernova presence in just a few minutes. Through the efforts of crowdsourcing, the overall amount of data for researchers to sort through reduces to a manageable amount of potential positive matches from which the researchers can then comb through and identify if there is a decisive match or not. While this load sharing is a great benefit to the scientific community, public results from this process are available in minimal amounts, such as a few images of positive matches posted to the Supernova Hunter's web page or the findings are instead published in a formal journal article or paper.

A Local Option for Getting Involved

Currently, if APUS's Space Studies courses would like to teach students about supernovae, the university must rely upon information coming from textbooks, lectures prepared by instructors or data to observe provided by other observatories or institutions which can be limited in scope. With the addition APUS's telescope in 2015 and the ability to image galaxies in the night sky, the Space Studies department can provide tailor-made data for students to analyze and derive reports. Utilizing reference images of galaxies observable from the telescope's location, galaxies can be reimaged as often as needed, increasing the amount of available data and the ability to compare data for potential appearance of a supernova. This data, through the Supernova Search Program, can be made available to students in which they can observe and analyze the data with reference images to determine if there is a supernova present or not. If found, back-data can be retrieved and studied to determine potential duration length of the event, and if found soon enough, requests can be made for more data on the event as it is occurring. As participants of this operation, students are doing science, not just reading about it and through this process, students can pour through locally procured data, study cosmological structures in search of supernovae and utilize the original data in their classroom studies, research, and even theses. Having an opportunity to participate in the supernova search program not only increases the number of people analyzing data in this field but also puts students in the driver's seat of research allowing them to have participated and reported on findings which are essential to the overall scientific community.

Pilot Experiment of APUS Supernova Search Program

While in theory and development, a program such as the Supernova Search Program should prove useful and meet the expectation of the developers and programmers. Initial testing allows for a rough version of the program to operate whereby allowing the developers and programmers to work through known bugs and inconsistencies to allow for proper operation and functionality of programs. After completion of this step, pilot testing can begin. It is the purpose of this thesis to propose a pilot test of the Supernova Search Program. The purpose of the pilot test is to run the program through its paces to determine if the workflow from imaging, observation, analysis, and documentation of the images containing potential supernova is ready for operational release and undergraduate students to start utilizing the program. Questions expected to answer from the pilot testing include:

- What problems exist in the software for the comparison of a reference image and a data image?
- Can problems, errors or bugs be re-mediated through adding, editing, adjusting or removing variables?
- Which blink-comparison software is most effective?
- Is this program operationally ready for further studies used to assess if undergraduate students can utilize the Supernova Search Program as part of their curriculum or as an independent study?

Expected Gains

If the piloting of the Supernova Search Program succeeds, it does so on a twofold process. First, by utilizing the university's telescope during the evening hours in between scheduled requests and through a computer scripting function which controls the telescope's mobility, orienting the telescope to previously programmed galaxy locations. From here the scripting program automatically images (and reimages as necessary) the candidate galaxies, potentially several dozens per night. While one might think that mapping all of the galaxies observable by the telescope will not take long, the goal here is not to only to capture an image file of a galaxy. The potential for a supernova to happen and be ready to capture its image is difficult because the when and where it happens is random due to vast distances between them and the earth. It is only through constant reimaging of the galaxies multiple times which increases the odds of capturing a supernova event as it is happening along with adding subsequent images to the APUS database, providing a relative timeline of potential changes to occur. Data collected through this process is available for continued galaxy image comparison and for any other future projects which the APUS Space Studies Program or as its students require of them. The second process if the project succeeds is the incorporation of undergraduate students into the research portion of the activity. Participation in the galaxy image comparison puts students in the driver's seat where through their analysis while comparing images, they are inspecting for any changes between the sample and control images, determining if there is an event in one that is not in the other. Knowledge of celestial objects improves as students learn to identify astronomical components such as galactic structures, stars, gravitational lensing, and potentially comets to name a few which they may observe in their comparisons. As part of their research, students can directly utilize the data they collect as part of their classroom assignments, reports or essays. Students working on exciting and challenging assignments could potentially utilize data collected, analyzed and reported on by fellow students for larger overarching projects. One driving element for some students may be the thrill of the search, to potentially identify an undocumented supernova or other celestial events which happens to be in the data image they are reviewing. Due to the nature of supernovae and their seemingly random appearance, data collection never comes to an end and the potential number of students participating in the search year after year helps put hands-on research, building an excitement to participate in astronomy in a way that has not been available at this level of institution in the past. Ultimately, talking to someone about marvels and wonders of space may only capture their attention for so long, but when they have the opportunity to look and study for themselves, the universe opens up, and their experience becomes personal.

Next Steps

The Supernova Search Program at this point has progressed passed the planning and developing phase. Components of the project have been assembled to include creating a script which automatically controls the telescope in collecting images of galaxies within its optical limits. Next, is the aggregation of data into a database for retrieval and finally, procuring computer software with the ability to compare reference galaxy images with newly collected data images and utilizing a "blink" function to look for changes in the images or potential supernova. The creator of these elements becomes intimately familiar with each of the components as they bring them together and therefore have a biased outlook as to how the entire process should work for a student who has not had any experience with it. It is essential to attempt to pilot the testing portion of the Supernova Search Program as if an undergraduate student who is new to this program. It is also imperative to attempt to follow the instruction sets provided to see if the process from setup, operation, the collection of data, cataloging of data and report of results found conform in the manner expected for undergraduate students. Data returned from the piloting process of the project could be valuable for the project creators as there may be a need to add, edit, adjust or remove variables from the process which would prepare this project for mainstream usage. If unsuccessful, data learned could help reshape the project to perform as intended, however if successful and this program works as intended with there is the potential for other spin-off projects and opportunities for students to perform research studying variable stars or even exoplanets. The potential of a successful project at this level could spark similar projects at other colleges even worldwide, increasing the opportunity and ability to participate in original astronomical research and increasing the network potential for collaboration and data sharing.

Process of Testing

The process of testing utilizes the qualitative methods to observe the meaning of the experience as a pilot tester of the Supernova Search Program. Within the experience of stepping through the process of the project during which observations and documented results, testing provides the necessary opportunity to determine if any portion needs additions, edits, adjustments or removal. The ultimate goal is to end up with a project when in the hands of an undergraduate student, can launch it, utilize it, catalog and document findings while preparing results in a manner which are reportable. It is imperative the system be free from bugs, faults or flaws in which could cause discontinuation of the project's usage due to frustration.

Benefits of Successful Supernova Program Testing

While the testing of the Supernova Search Program is to determine if it is ready for mainstream usage, an operational program is not the only benefit realized. APUS through their telescope managed by the Space Studies Astronomy department can generate galaxy maps data and add to its database to allow usage now and in the future. The APUS Space

Studies program faculty can also tailor the abilities of the project for use in multiple classes available to students such as Planetary and Solar System studies, Astrophysical studies, Lunar Geology, Astronomical Instrumentation, Comets, Asteroids and Meteorites as they progress through their degree programs. Personally, students have an opportunity to participate in collecting and studying locally procured data which they would be able to utilize within their studies and reports. Undergraduate students could potentially utilize the data from their research in writing research papers and thesis. A significant side effect through this project, students can feel a personal connection to their contribution in astronomy and develop and excitement which then fuels their desire to continue in this concentration of study.

While initially starting as a project to search for supernova, the project could potentially be modified to search for exoplanets, variable stars and other stellar phenomena, widening the usage of the program and the potential of discovering new objects through data collected and analyzed. A successful project could also potentially open the door for other colleges or universities to set up similar programs based on a successful model, programs which could potentially be networked in both data and people to widen data available for undergraduate research, but also the shared knowledge base of professors and students across the world.

The first portion of this study begins with a literature review of the Supernova Search Program and its associated components which make up this project in Chapter II: Literature Review. Chapter III: Methodology of the Pilot Program, discusses the steps taken during the pilot as would be expected by a student participating with the final product. Chapter IV: Results explains the findings from the pilot program, what worked and what did not along with what changes were made to refine the process. Chapter V: Summary concludes this study and looks at the development of potential spin-off projects for a broader base of students to become a part of utilizing the data collected from the Supernova Search Program.

CHAPTER II: LITERATURE REVIEW

Supernovae Search Programs – Astronomer's search for more knowledge

The search for supernovae began with a man, a camera and his attempt to collect photographic evidence of the astronomical event. Through trial, error and implementing cutting-edge technology as it was developed, astronomers have gone from finding a small handful of supernovae per year to hundreds and even thousands today. The following literature review illustrates that supernovae search programs have been driving astronomers to advance technology to its limits, not only to discover supernovae but to, more importantly, catch them in their infancy and track them through their relatively short lifespans. The review also demonstrates the tenacity of people by showcasing software created to aid professional and amateur astronomers alike in reducing mundane tasks and allowing more time for discovery.

A Man and His Camera Started it All at Palomar

Zwicky (1964) began the first systematic photographic search for supernova utilizing a 3-inch F/4.5 photographic camera in 1932, unfortunately with no results. Zwicky petitioned to have an 18-inch Schmidt telescope built and oversaw the completion of the project in 1936. The author quickly produced 175 photographic plates, each with 65 degrees of viewing area allowing him to discover seven supernovae, two of which were bright supernovae located in IC 4182 and NGC 1003. The article stated that details Zwicky learned over the next four years included data such as the frequency of supernovae appearance is not dictated on the structural types of the galaxies; however, the analysis showed a majority of the supernovae found appeared in the outskirts of the galaxies with relatively few found near the core. Zwicky further noted that due to the spectra of the supernova, they could now be classified into two distinct types, termed type I and type II.

Palomar – Upgrade to 48-inch Telescope

Sargent et al. (1974) stated that the introduction of the 18-inch Schmidt telescope was the key which unlocked the ability for the observatory to begin to rapidly discover a total of 15 supernovae between 1936 and 1940. The article described that in 1959 another step forward was taken, and the supernovae search moved to the 48-inch Schmidt telescope at the Palomar Observatory. The author noted that three dark nights a month were allocated for the supernovae search which allowed for making galactic exposures of between 6 and 25 minutes in duration on 10-inch square photographic plates. While overexposure of the plates provided greater detail of distant galactic features, it, unfortunately, caused objects nearer to become washed out and blurred, potentially missing any supernova which may have been closer than the focal area. The article stated the comparison of these newly imaged plates to the standard reference plates took place immediately after the exposure. Comparison of the newly acquired images with the references took place through a process called blinking which looks for any differences between the two plates, differences which potentially required a quick follow up telescopic observation to confirm a potential supernova. The authors noted between 1956 and 1962, utilizing mainly the 48-inch Schmidt, the Palomar Observatory discovered another sixty supernovae, and when the study finally discontinued in 1974, the total number of supernovae discovered on the 48-inch Schmidt was 281.

Berkeley Automated Supernova Search (BASS) – CCD Introduction

Kare (1984) stated measuring images on photographic plates aided in finding supernovae; however, in attempts to automate the process, due to the amount of data on the plates and the prohibitive cost of the hardware needed to automate the measuring, the project was canceled. The article further describes the BASS program as one of the first attempts to utilize mini- and microcomputers and a high-quantum efficiency charged-coupled device (CCD) to image the stars built off of a failed attempt at utilizing an electronic image detector. The author noted the CCD had a resolution of 320 x 512 pixels, allowing for 2.4 arc seconds per pixel. A 30-inch f/8 Ritchey-Chrétien telescope at the Leuschner Observatory of the University of California had the CCD and associated computer equipment paired together. The article stated the computer system controlled the telescope movement, aligned with reference stars and managed exposure times whereas due to the data size of the images recorded, it was necessary to utilize Betamax format videotape. According to the author, at the time of the article's writing, the system was initially only being utilized for sky surveys and had not yet begun to search for supernovae. However, the author estimated the telescope would be able to image approximately 1,200 galaxies on a four-night cycle and potentially discover one or two supernovae per month the telescope was in operation. Muller et al. (1992) noted in their article, during its five years of operation (1986-1991) BASS discovered 20 supernovae.

Supernova Cosmology Project – High Redshift Search

Kim (1999) noted in his article that the successful project BASS sparked another project called Supernova Cosmology Project (SCP) at Berkeley labs. This project developed a new search technique in which to find and then reobserve high-redshift supernovae. The author stated while similar to the BASS technique, SCP also relied upon comparing newly acquired images to historical reference images; however, the timing of the observations was different. Reiss et al. (1999) in their article stated supernovae take an average of an approximately two-week to cool down after it has reached maximum light; therefore, reference images are taken just after the new moon on a 2.5-4-meter telescope utilizing a wide-field CCD, easily capturing hundreds of galaxies per image. Approximately two weeks later just before the new moon in what is termed a "dark run," new observation images are taken and then compared to the previous reference images for any newly exploded high-redshift supernovae which show as a new light on the images. Kim stated that new objects are sorted on a list and scheduled for photometric confirmation and spectroscopy the next day. Schmidt et al. (1998) detailed a challenge with the SCP is the observatory does not have the computing power to analyze the data created, requiring after collection transportation of the data to Berkeley to examine the data and be made available for human scanners to investigate. Each image after collection by the telescope due to its size takes the data collection computer six minutes to process for storage and typically results in 2 – 3 Gigabytes of data each night. Kim (1999) noted in his article that SCP was used to find more than 70 type 1a supernovae of a red-shift $0.3 < z < 1.2$.

Robotic Katzman Automatic Imaging Telescope

Filippenko et al. (2001) in their article described the third robotic telescope produced by the University of California, Berkeley, which is the Katzman Automatic Imaging Telescope (KAIT) located at Lick Observatory in Southern California. The authors noted that this telescope is fully robotic and automatic and performs all of its functions with minimal human intervention. The project labeled Lick Observatory Supernova Search (LOSS) utilizes KAIT, a telescope with a 0.76m diameter primary and a Ritchey-Chrétien mirror set with a focal ratio of f/8.2. As described in the article, the CCD is an Apogee AP7 CCD camera with a 512 x 512-pixel chip which provides a field of view of 6.8 deg^2. The article states while LOSS has a humble catalog of 5,000 galaxies for reference samples, this allows the system to find most of the supernovae before they reach maximum brightness. Li et al. (2000) stated that galaxies are observed for 25 seconds before KAIT automatically moves to the next galaxy and due to the efficiency of the system, KAIT can image close to 1,000 galaxies in a single clear winter night and can automatically start reimaging galaxies within 3 – 4 nights. Filippenko et al. went on to state that even automated image processing is possible due to the speed at which computers operate. LOSS entirely takes care of image processing, making templates, image subtraction, candidate detection and verifying its results. Only after all of this will humans become involved and review the potential candidates by looking at the template image, the new image, and the subtraction image and if necessary, schedule any follow-up observations. The authors stated that while there are bigger, faster and deeper-looking telescopes in operation, small automated robotic telescopes like KAIT open new avenues of observations especially for astronomy students and provides compelling exercises for laboratory and classroom curricula. Leaman (2008) detailed in their study that between the years 1997 and 2006, LOSS discovered 844 supernovae through its robotic and automated processes.

Pan-STARRS1 – Data Avalanche

Chomiuk et al. (2011) noted that the Pan-STARRS1 (PS1) telescope, sitting near the top Haleakala on the Island of Maui, utilizes a 1.8 m diameter, f/4.4 primary mirror and a 0.9 m secondary. The PS1's imager utilizes 60 4,800 x 4,800 (1.4 billion) pixel detectors with each pixel covering about 0.258 arc-seconds allowing for a total viewing area of 7.1 deg^2. After the CCD completes an exposure, the Maui High Performance Computer Center receives the unprocessed data where a computer cluster submits the images to a battery of processes which includes flat fielding (improve the quality of the digital image), de-warping (converting to a flat plane), artifact removal, object detection, and even photometry. According to Jedicke et al. (2006), the amount of data flowing through this telescope is incredible, especially on a winter night when the telescope takes 3 GB images every 45 seconds for upwards of 10 hours. Magnier et al. (2016) noted in their article that the University of Hawaii installed a 178-node Cray supercomputer utilizing 20 cores per node with 128 GB of memory each to handle and process the throughput of data coming from the telescope.

Bloom et al. (2012) stated that with projects such as PS1, Large Synoptic Survey Telescope (LSST) and other future projects it is critical to teach machines how to analyze better and deduce images produced from large scans to reduce the number of false positives generated. Wright et al. (2017) went on to state that training machines to make better predictions for future observations require data from past surveys which was manually inspected by human experts. The article explained that the massive amounts of data are required to train machines, so their predictions are more accurate; however, this becomes a problem when dealing with large surveys or with small research groups. The author noted that to deal with this, the PS1 needed to look beyond the scientific community for help and looked to acquire assistance from citizen scientists. PS1 had data uploaded to the websites Galaxy Zoo, Snapshot Supernova and Supernova Hunters where citizen scientists became engaged in classifying images for potential supernovae. Smith et al. (2011) listed volunteer taskings to include examining a reference image, target image, and a difference image; following the observation, citizen scientists were provided a series of questions about the images and depending on their answers the candidate supernova received a score. The article went on to say that after seven different volunteers scored each candidate, the candidate was labeled classified and removed from the project. Once classified, candidate supernovae were ranked, and the most promising were reobserved. Wright et al. continued that within 6 months, 5,845 citizen scientists made 1,082,170 classifications, and the project averaged 21,000 classifications within the first 24 hours of the release of new data with 8,200 more classifications in the second 24 hours, typically resulting in all subjects being found and retired by this point. The author noted there was enough data learned from the citizen scientist's analysis of the images to improve the learning algorithm of the computer now tasked to process incoming data.

Jones et al. (2018) wrote about the success of PS1 of which during the four-years in which it was in operation, PS1 discovered 5,235 supernovae of which, approximately 1,000 were type Ia. The article also stated 90 percent (4,715) of the supernovae could not be spectrally classified due to the sheer volume of astronomical data produced and lack of available time on telescopes to perform a more detailed follow-up survey.

The Future is Here – Zwicky Transient Facility

Bellum et al. (2019) noted that the Zwicky Transit Facility (ZTF) is the next step after the successful Palomar Transient Factory (PTF) and Intermediate Palomar Transient Factory (iPTF). The article listed that this new robotic observing platform is connected to the 48-inch Schmidt telescope and utilizes 16 CCDs each of which have ~$6{,}000^2$ pixels providing a field of view of 47 deg^2 or about 6.5 times larger than its predecessors. Along with upgraded electronics for the telescope and support systems, this reduces the overhead rate between exposure time resulting in an overall faster survey speed. The authors currently estimate data collection to come in at around 1 petabyte over a three-year operation; however, Laher et al. (2017) estimate expansion of the architecture more to the tune of 3 petabytes in the same amount of time is a more accurate statement. Masci et al. (2019) detailed that the ZTF utilizes a data pipeline to analyze the images. The first step is an algorithm which examines the newly acquired image with a historical reference for any differences. Next, if the data is determined a potential candidate, it is vetted against the database for objects which may have similar features, all of which is output on a full report to human operators on average in 13 minutes from initial observation for their review and action if needed. Bellum et al. went on to state that with such a comprehensive view of the night sky and quick speed to react to inputs and produce images, the ZTF is a critical machine in multi-messenger astronomy. The article went on to mention that detections made by IceCube Realtime Program could detect a neutrino and determine approximately where in the sky it came from. Those coordinates then are sent to ZTF where it can quickly and with excellent detail, re-image the region of the sky multiple times over the next few days in an attempt to locate an optical source for the neutrino emission.

Astrometrica

The growth of supernovae searches at universities and other scientific institutions relied more and more on computers to aid in the work which required skilled programmers that understood machine language of FORTRAN, BASIC, C, and SQL to name a few. However, those without resources to leverage the larger computer systems turned to microcomputers which brought other options for those working with Linux or Windows computers which were becoming readily available. Aguirre (1997) noted that Astrometrica was one of the initial computer software programs available developed by Herbert Raab, an amateur astronomer, who developed the software to aid in mapping comets and asteroids, which later also become useful in searching for and discovering novae and supernovae. The author noted that the software works by employing a historical reference image and defining reference stars within that image. When uploaded, a newly acquired image immediately is processed by the software which looks for the same reference stars on the new image for a reference and reorients the images to be perfectly stacked allowing for measurement of any transient objects (comets, asteroids, and meteorites) to within one arcsecond or closer. The article stated that to search for supernovae utilize the same method in comparing two images through a blinking method which alternately flashes two images allowing the human scanner to observe any differences, potentially indicating supernovae. In utilizing Astrometrica, Buchheim (2008) stated that it is a remarkably helpful program when observing closely spaced star pairs or potential transient objects as it automatically calculates the right ascension and declination to allow for checks against other available database records.

Savanyvych et at. (2015) noted that both professional and amateur astronomers had employed the Astrometrica software alike when measuring celestial objects in the solar system and supernovae from greater distances from images produced by their CCD cameras. The authors stated that Astrometrica was valuable and did contribute to the field of astronomy; however, the article listed there was a disadvantage with the automated search capabilities in that it was severely limited when it came to processing large amounts of data. The article listed that for projects dealing with small amount of data, this was not a factor.

GrepNova

GrepNova is a software package written in 2005 by Dominic Ford to aid amateur astronomers in the search for supernovae by automating many time-consuming features. Ford (2015) stated in his article that as newly acquired images import directly from the CCD camera, GrepNova's algorithms search the database for a suitable match and processes it by resizing and realigning the images until they match up in a standard orientation. Once complete the two images are analyzed through the program's image viewer which utilizes blink comparison technology, which allows the astronomer to search for differences between the two images. The article listed a critical feature of this program is the ability to analyze incoming images, automatically find a reference match, standardized and align the two images and present them to the human user for end analysis. These essential steps which use to consume much of the amateur astronomer's valuable time are now available for more time spent on searching the collected data for cosmological gems.

Supernova Search Tool

Diffraction Limited created its commercial product Maxim DL CCD image processing software with the purpose to aid astronomers in processing the images produced by the CCD cameras connected to their telescopes. Mobberly (2009) documented that one amateur astronomer, Ajai Shegal, tasked with helping sort through vast amounts of data produced by the Backyard Observatory Supernova Search, wrote a free-ware add-on, Supernova Search Tool to aid in finding supernovae. In his book, Mobberly stated that the program required historical reference images to be in one folder and the newly acquired images need to be in a second folder and both images needed to have the same name, however they did not have to be in the same format (eg. .png, .jpg, or .FITS). If set up correctly, the program brings up the first two images to compare, and the program automatically starts the blink comparison. According to the author, when the analysis is complete, the observer selects on the "Next" button and the program advances to the succeeding pair of images which require analysis.

CCDSoft

Sherrod (2018) described in his book that in the past people have carefully examined an image of a galaxy and compared it to a master reference image to observe for any differences between the two, however, this can become cumbersome especially if the analyzed photos contain a significant number of stars to search through. The author mentions that computer programs have sped up the process of starfield analysis through “blinking programs,” which allow for quicker identification of potential transients. The in his article, the author, noted that Software Bisque’s commercial product CCDsoft quickly and easily performs this task. The text states that utilizing two FITS format images, which are both opened in the program, the user then selects a distinct star in each of the images to allow the program to align the images correctly. Once complete, the images alternately appear on the screen, “blinking” and any new objects or differences between images begin to flash (due to one image having it and the other not). CCDSoft is not just limited to blinking reference and newly acquired images as according to Boles (2006), CCDSoft can also trigger the camera shutter and automatically deposit the image into a destination folder. Boles's article also stated that with another computer program automating the telescope's movements and alignment to target galaxies, CCDSoft triggers the camera shutter, stores the image and waits for the telescope to move to the next galaxy and repeats the process. The author noted that with this setup, an astronomer could easily collect between 135 and 210 new images per hour, depending on the length of exposure and telescope slew time.

Finding the needles in the haystack

The scientific mind and its ability to integrate technology continue to produce bigger cameras with smaller pixels but higher resolution and faster computers with reliable analytics all in the search for the elusive supernova. Technology has brought the community to the point where computers are performing all the work, leaving humans only to provide maintenance and final transient detection verification. Reflecting on the scientist's ingenuity, the literature review in this report defines essential advancements made in supernova search programs and the software employed to assist astronomers in their discovery. However, as stated by Filippenko et al. (2001), there need to be current advances in observation which provide compelling applications for laboratory and classroom curriculum, particularly for astronomy students.

CHAPTER III: METHODOLOGY

This chapter intends to present the research methodology for this quantitative descriptive theory pilot-study of which software with supernova blink-comparison components will work best for APUS's Supernova Search Program. Utilizing this approach permitted for an in-depth understanding of the components of the supernova blink-comparison programs and provides a way to develop theory from data to determine which software program will be the most applicable for the undergraduate researcher in the APUS Supernova Search Program. The relevance of descriptive theory along with a positivist approach within this work is covered in-depth inside this chapter.

Research Questions

- What problems exist in the software for the comparison of a reference image and a data image?
- Can problems, errors or bugs be re-mediated through adding, editing, adjusting or removing variables?
- Which blink-comparison software is most effective?
- Is this program operationally ready for further studies used to assess if undergraduate students can utilize the Supernova Search Program as part of their curriculum or as an independent study?

Methodology Selected

Utilizing a quantitative methodology is suitable when emphasizing objective measurements or determining the relationship between one variable and another within a population (Babbie

2012). Leedy and Ormrod (2001) supposed that quantitative research builds upon present theories through specific observation and scientific research. The outcome of quantitative research is that data collected through reality is objectively measured (Williams, 2007). As stated by Hopkins (2008), a quantitative approach works best when quantifying relationships between variables, which include performance, compatibility or efficiency. Variables are measured on a sample of subjects, in this case, blink-comparison software. The central tenant of this study was to compare software programs with supernova blink-comparison options and determine which will be most applicable for the APUS Supernova Search Program and a quantitative approach was selected as the most suitable option.

Descriptive Theory Methodology

This quantitative study was conducted utilizing the descriptive theory methodology. Descriptive research, according to Williams (2007), is an elementary method of research which considers the situation at hand as it is. Descriptive theory answers the fundamental question, "what is," in turn looking for a correlation of characteristics or traits between two or more variables (Fawcett and Downs, 1986). Stjelja (2013) stated that what can be articulated about a pre-identified phenomenon or variable is a descriptive theory.

Creswell (2014) stated that components of the descriptive theory include the postpositivist world view also known as the scientific method. While positivism seeks a stance in which maintains independence between the researcher and the object which is being researched (Bergman, 2016), Creswell claimed that researchers could not remain independent, and their existing beliefs, values, knowledge, and general background can ultimately influence the observation and to account for this, a postpositivist view considers any effects these biases may have. For postpositivists, the undisputed approach to scientific inquiry entails beginning with a theory, collecting data which can either support or disprove the said theory and with that data, make any required alterations or updates from what was learned and administer additional tests.

This work was conducted employing descriptive theory with a postpositive approach. The aim of descriptive theory of which postpositive context plays a part is: “aimed at casting light on current issues or problems through a process of data collection that enables them to describe the situation more completely than was possible without employing this method” (Fox & Bayat, 2007, p. 45). It was the goal of this research work to cast light on different computer software programs utilizing supernova search components to determine through testing with dedicated reference and subject images which programs will be most suitable for usage by student scientists in the APUS Supernova Search Program.

During this study utilizing postpositive descriptive theory, importance was placed on following the steps of scientific research, through asserting claims, then through testing and rechecking, adjustments made, or all together claims were scrapped for other stronger claims (Phillips& Burbules, 2000). Reevaluating results and anomalies within the data helped in the attempt to ascertain, describe or identify “what is” (Ethridge, 2004). It was necessary for the researcher to be perceptive during the testing to ensure the ability to answer the question “What is” and to observe for details in the data which entail those similarities and differences which could rank the usefulness of the different software being tested. The subsequent theory is the interpretation of the data by the researcher, maintaining consistency with postpositive descriptive theory.

The Researcher

The researcher has worked in multiple fields to include, electronics maintenance, computer network security and physical security over the last 19 years and holds a Bachelor of Science in Information Systems Security. There were no other participants in this pilot study which eliminated any conflict of interests or any unintentional external bias to propagate into the research study.

The researcher is qualified with the necessary skills and abilities to administer the designed pilot study. The researcher has worked with Linux, Mac OS and Windows operating systems and various computer image processing programs. The researcher's skills useful for this study include troubleshooting computer software problems and writing how-to guides to aid others in getting started quickly with unfamiliar computer programs. Since 2009, the researcher has been responsible for training users in the operation of a nationwide networked access control system.

Study Sample

The sample was chosen from computer programs which could blink-compare two or more images. Programs chosen could operate on computers utilizing Windows, Mac OS and Linux operating system. All computer programs had to be free, shareware or have a trial license with enough time to allow for evaluation of the software before expiring. The software needed to access any of the following image formats: FITS, .bmp, .jpeg, .jpg, .tif and .tiff. Access to the programs had to be available via download through the internet directly from the official websites which offered them. The final number of programs selected to participate was 7, as ascertained by quota (Martínez-Mesa, 2016).

Data Collection

This study utilized an observation method where the researcher and two desktop computers and a laptop computer all with internet access were the instrumentation used. LibreOffice Calc spreadsheets saved in Microsoft Excel 2007-2013 XML (.xlsx) format was utilized to collect any research notes and thoughts both during and after the observation. Fifty-two NGC images (26 reference images taken on 7 November 2018 and 26 re-image subject images taken on 18 December 2018 were utilized) produced by the APUS telescope and pre-processed which is the subtraction of bias and flatfielding of the image. Observations began by starting one of the computer programs with a blink-capable function. Both reference and subject image of the same NGC (e.g., reference NGC 7332 and subject NGC 7332) were loaded, and the software attempted to match both images spatially. When the spatial matching completed, the blink-comparison function was enabled allowing the two images to alternately blink, with the reference image blinking on, while the subject image is blinking off, then alternating vice-versa. The observation continued with the researcher investigating the alternating images for any differences between the images potentially identifying a supernova. Data gathered and annotated on the electronic spreadsheet included the image number, galaxy name, computer analysis software, template image quality, subject image quality, software problems, potential supernovae, other observed phenomena, and other information to include usable/unusable images, cloud interference, heavy pixilation or spatial rotational issues. Evaluation took place with all 26 pairs of images before testing the next software. Each of the seven blink-comparison software was tested and data recorded in the same format. Limitations encountered with the data collection resulted due to several imperfect subject images which entailed either thin cloud cover or a light bloom of unknown source which washed out all but the brightest stars resulting in unusable images with several of the software suites. Subsequent re-imaging of the NGC may produce a set of images with a more promising outcome.

Procedures Followed

The researcher downloaded seven computer programs from internet websites which featured blink-comparison functions as part of their software and one Interactive Data Language (IDL) virtual machine (VM) software. Four of the programs were free to use, while a fifth even though was free to use, the IDL VM software which operated as the program's backbone, required a free two-week trial license. Program number six was shareware and was free to use for 60 days, beyond that payment was required to continue use. The seventh program had a 30-day trial period after which a paid license was necessary to continue utilization.

The programs were initially investigated to determine if they contained blink-comparison functions as part of the software, when determined they did, the programs were downloaded and installed. The initial installations were completed on a Windows 10 Pro computer and later on an iMac OS X El Capitan version 10.11.6 and a laptop operating Linux Mint 19.1. Observations and notes were made as each of the 26 image pairs (reference and subject) were loaded into the program and tested with the blink comparison software. Notes were made electronically on LibreOffice Calc spreadsheets saved in Microsoft Excel 2007-2013 XML (.xlsx) format.

Descriptive theory intends to find out "what is" and utilize observational methods to collect descriptive data (Borg et al., 2003). Because observations may bring to light information which may refute a claim or change a parameter, adjustments can be made, and tests can be accomplished again. Testing of two of the software programs determined that they could not spatially match the reference image to the subject image without WCS information embedded in the images. After adding the additional information through the nova.astrometry.net website, the images were spatially matched (very precisely) while there was no noticeable change when these modified images were retested on the other programs.

A postpositivist approach was taken with this study which acknowledges that the researcher may be influenced by biases based on their existing knowledge, values or beliefs; however, this does give free license to knowingly allow biases into the study (Phillips & Burbules, 2000). On the contrary, the researcher does what they can in an attempt to minimize the bias introduced (Winchester & Salji, 2016). One way to reduce the introduction of bias is through good note taking. Note-taking during an observation will annotate experiences and events as they happen, objectively, while they are still fresh. Later, notes will serve to remind the researcher of their thoughts at the time of writing and help to avoid relying solely on memory which could potentially inject researcher bias into the data (Chong & Yeo, 2015). Notes typically include parameters checked, observed anomalies, errors to be corrected, new questions yet answered, and thoughts on events and potential changes to claims due to observations.

Data Analysis

The Supernova Observation Worksheets were completed during the analysis of the reference and subject images with each software package. Filling out the observation sheets at the time of examination allowed for the immediate notation of problems, an interesting phenomenon, and potential new criteria to expand the data collection form as important information was revealed.

The observation worksheets were utilized to capturing data as it was observed by the researcher and a systematic capture of the data provided a consistent format between all software packages when comparing the results of the data (Driscoll, 2011).

Collecting data through observation worksheets allowed the observed information to be amassed in organized and manageable amounts, which was an integral part of the analysis of the data. Data collection utilizing the descriptive theory focused on collecting data which answered the fundamental question "what is" regarding critical aspects of the different blink-comparison software programs. The observation worksheets helped the researcher maintain focus on critical areas of interest along with consistent data collection between the seven blink-comparison software programs (van Teijlingen & Hundley, 2001). The data was collected in a consistent format to ensure ease of reading and analysis.

After completion of the supernova search observation worksheets, a data table was created to compare data between the software programs themselves and the data collected from their observation worksheets. The compilation of data was an effort to provide an overall view of how the blink-comparison software ranked and to potentially determine which programs would be most useful for inclusion with the APUS supernova search program. The researcher aimed to utilize the data gathered from utilizing these computer programs and attempt to make sense of the data and bring meaning to it collectively (Denzin & Lincoln,1994).

Trustworthiness

To provide a credible argument that their work is academically sound, qualitative researchers rely on trustworthiness for support. Trustworthiness and validity need to be based on reliability, dependability, confirmability, and objectivity (Winter, 2000). One of the ways to ensure dependability and confirmability is by way of an audit trail which indicates the exact method of data collection, raw data used and other records, which is utilized by another researcher, could independently follow and verify the study (Adcock & Collier, 2001). Confirmability ensures the absence of researcher bias along with objectivity when the data is measured, collected and analyzed, as the data it is, answering the descriptive theory question of "what is" (Fawcett and Downs, 1986).

The use of the same 52 NGC images (26 references and 26 subjects) ensured the seven blink-comparative software's capabilities were tested equally. Another aspect, utilizing the Supernova Observation Worksheets were critical to capturing data from testing as it happened and allowed for consistency of data captured between all seven programs and capturing the raw data necessary to uphold objectivity and confirmability. Reliability was limited in this research study as time available allowed for spot checks and not full retests to verify stability (Heale & Twycross, 2015).

Potential limitations in this research which could detract from trustworthiness are the limited access of the NGC data images (Coughlan, 2007). The NGC data images are the property of APUS and are only accessible through the APUS university website, and then specific permissions are required to access the data storage. Another potential limitation is computer utilized for the testing of the blink-comparison software. With the potentially endless configurations between Window's, Mac and Linux based machines, similar results cannot be guaranteed, even as an independent study by another researcher utilizing a different computer.

Creswell (2014) noted that the postpositivist approach differs from the positivist approach in that it recognizes that researcher bias may influence the study and cannot be 100% avoided, however, there were several ways in which the researcher strove to minimize the ability for bias to enter the study. Utilizing the Supernova Observation Worksheet provided a set number of parameters of data to record which kept the data recordings consistent and prevented any external data from entering the study. Utilizing the same NGC data images between software programs prevented any anomalous results which may have skewed the resultant data. Notes and data made only at the time of observation aided to prevent bias from creeping into the study.

Summary

The objective of this section was to investigate the research method utilized to answer the research questions. Analysis of the methodology, study participants and data collection provided details regarding the conduct of the study and the software being evaluated. A postpositive descriptive theory methodology was utilized to evaluate blink-comparative software to determine which would be most effectively used in the APUS Supernova Search Program. Through the evaluation process, data collected served to describe the situation more thoroughly, shedding light onto the similarities and differences between the software programs. To ensure and exhibit the methodology detailed here in Chapter III was followed, Chapter IV will provide the results of the study.

CHAPTER IV: RESULTS

This chapter incorporates the findings of the descriptive theory methodology study conducted to answer the proposed research questions:

- What problems exist in the software for the comparison of a reference image and a data image?
- Can problems, errors or bugs be re-mediated through adding, editing, adjusting or removing variables?
- Which blink-comparison software is most effective?
- Is this program operationally ready for further studies used to assess if undergraduate students can utilize the Supernova Search Program as part of their curriculum or as an independent study?

Also included within this chapter is a dialogue which maintains that the analysis conducted was sound and valid in conjunction with descriptive theory methodology and how the resultant data forms direct links to the aforementioned research questions.

Sample

Seven blink-comparable software programs evaluated this pilot study were Aladin Sky Atlas, Astrometrica, GrepNova, MaxIm DL Supernova Search Tool, PhAst, SAOImage DS9 and Starblinker (Appendix A). Appendix B details the software program demographics which outline the minimum necessary elements to be included in the study as outlined in Chapter III. All seven (100%) of the blink-comparable software programs run on a Windows operating system, while three (43%) also ran on Mac OS and four (57%) also functioned on Linux operating systems.

Utilizing the Windows version of the software via cross-platform, multi-boot solutions, or emulators such as WINE, Parallels or Boot Camp was not attempted as part of this study. All software packages were available via download from the official websites which offered the software.

Four of the software programs or 57% of the sample group were free to download and use without cost or limitation. Of the remaining three (43%) software programs available, one (14%) was considered shareware and was available to use without cost or restriction for 60 days, another program (14%) was available to use without charge or limitation for 30 days, both when the trial time ended, required paid licensing fee to continue usage of any part of the software. The final software program (14%) while free to use without cost or limitation was dependent on an IDL VM provided by Harris Geospatial Solutions to operate which in of itself was usable without cost or limitation for a 14-day period, afterward paid licensing was required. There were two free to use IDL VM systems available, GNU Data Language 0.9.8 (GDL) and Fawlty Language 0.79.46; however, due to time constraints and lack of IDL knowledge, these systems were not utilized nor tested.

Six of the seven blink-comparison programs were able to process the FITS data files, leaving one (14%) program to require the use of the GNU Image Manipulation Program (GIMP) to convert the FITS format files to either .jpg, .jpeg, .tif, .tiff or .bmp image files. Three (43%) of the seven programs required the addition of WCS data to the FITS data files, enabling the applications to spatially align the reference and subject images, while the other four (57%) spatially aligned the images through other methods. Of the seven blink-comparison programs, only two

(29%) allowed for queuing of multiple images to test, while the remaining five (71%) required manually loading a new image pair after each analysis.

In regards to correctly processing (loading, spatially matching, and blink-comparison) of the reference and subject images, none of the blink-comparison programs were able to process all 26 image pairs (100%) correctly, however six of the seven programs were able to correctly handle 25/26 image pairs (96%), leaving one program which successfully prepared 21/26 image pairs (80%). Failed processing included incorrect spatial matching or poor imagery unable to resolve WCS data.

Supernova search how-to setup guides were created by the researcher to detail the process utilized in launching each of the programs, loading both the reference and subject images, blink comparison of the images and loading the next set of images to be analyzed. The individual supernova search how-to setup guides are located in: Aladin Sky Atlas (Appendix D), Astrometrica (Appendix E), GrepNova (Appendix F), MaxIm DL Supernova Search Tool (Appendix G), PhAst (Appendix H), SAOImage DS9 (Appendix I) and Starblinker (Appendix J).

Data Collection

The seven blink-comparison software tested with 52 NGC images (26 reference and 26 subject) functioned as the primary source of data from the study. Blink-comparison software manuals where available provided supporting research data for the study. During the testing of the blink-comparison software, data was transcribed to Supernova Search Worksheets to ensure in accordance with descriptive theory methodology, data was noted as observed, answering the fundamental question “what is.” The original data transcribed to the Supernova Search Worksheets are provided in Appendix K through U.

Data and Analysis

All data acquisition took place during the testing of the blink-comparison software as each software package was evaluated with the same 52 NGC FITS format images produced by the APUS telescope. Data was transcribed during the testing directly to LibreOffice Calc spreadsheets as the observations happened. When portions of the testing process failed to work, adjustments were made to allow for a retest and continuation of the experiment, whereas other minor errors beyond the scope of this study which did not hinder the work were noted for later correction before any future testing or the project going operational.

NGC Image Files

Evaluation of the seven blink-comparison software programs on a level field required each program to be tested with the same control reference and subject NGC images listed in Appendix C. These FITS format images were produced by the APUS telescope and went through pre-processing, which included subtracting the bias and flatfielding of the image. The resultant reference and subject images were tested with each of the blink-comparison software programs to determine if they would a) load properly in the program, b) spatially align properly and c) properly blink (alternate) when the blink function was activated.

Non-FITS Format Compliant Images

Starblinker is a simple program which has one purpose, and that is to blink-compare two images; however, this program can only utilize one of the following image format types: .bmp, .jpg, .jpeg, .tif, and .tiff. To manage creating usable format images, the FITS format images were converted to one of the accepted formats through the GNU Image Manipulation Program (GIMP) which converted and exported the FITS format images into .tif files accepted by Starblinker. As necessary, before export, image contrast and shade levels were adjusted on some images as necessary for better readability as Starblinker does not have contrast adjustment within its program. Figures 1 details NGC 7331 as it appeared in FITS format viewed from SAOImage DS9 in comparison to the same image (Figure 2) converted to the .tif format and viewed from Starblinker. Virtually no imagery data is lost during the format conversion. Once all 52 images were converted to the .tif format, Starblinker was tested.

World Coordinate System (WCS) Data

During the evaluation of the programs, SAOImage DS9 and Aladin Sky Atlas failed to align the FITS format images properly spatially and did not provide any options within the program to designate reference points to align the images manually. It was determined that the programs Astrometrica, GrepNova, MaxIm DL Supernova Search Tool, PhAst, and Starblinker picked reference points from the reference and subject images and utilizing a process of algorithms, systematically aligned each image pair accurately. SAOImage DS9 and Aladin Sky Atlas on the other hand spatially align images through a different process called WCS or a virtual coordinate map of the stars within the image.

Figure 1 *NGC 7331 in FITS format as viewed from SAOImage DS9.*

Figure 2 *NGC 7331, same as above, converted to .tif format by GIMP and as viewed from Starblinker.*

Native pre-processed FITS format images do not have WCS data embedded on them unless it has been added as part of the pre-processing step (when the bias is subtracted) or afterward. WCS data was added to all 52 images by uploading each image to nova.astrometry.net one-by-one. The website takes several minutes to examine the star details of the image (much like Astrometrica, GrepNova and the other programs) and when enough data is developed, the website returns the image with astrometric calibration meta-data or astrometry world coordinate system. Not only does the website provide the sky coordinates for all of the stars and objects in the image it will also give a list of the known objects within the data (Figure 3). Once APUS reference and subject images had the WCS data embedded into the images, SAOImage DS9 and Aladin Sky Atlas were able to spatially align the images almost exactly.

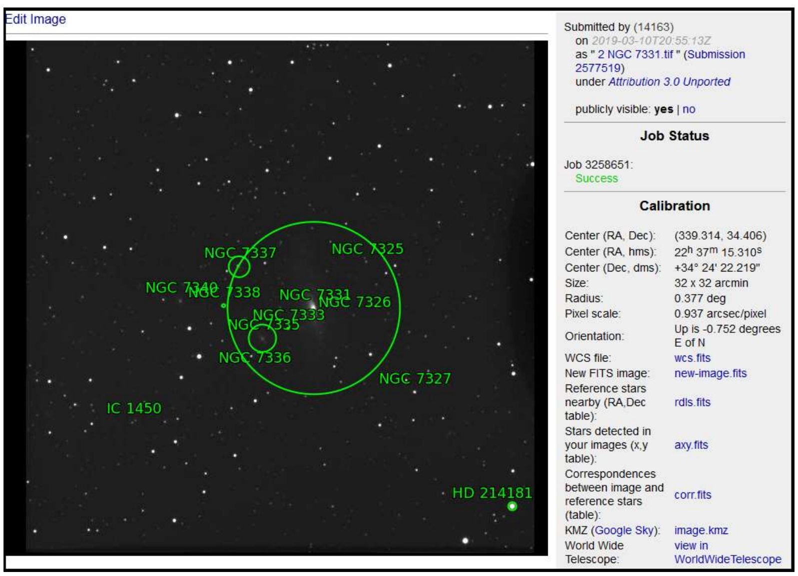


Figure 3 *nova.astrometry.net identifies objects along with providing their coordinates embedded in the FITS format file for NGC 7331.*

While PhAst could load and blink images without WCS, it also had the option available to align images which did contain WCS data spatially. Images which included the new WCS data were reapplied to Astrometrica, GrepNova, MaxIm DL Supernova Search Tool, and PhAst.

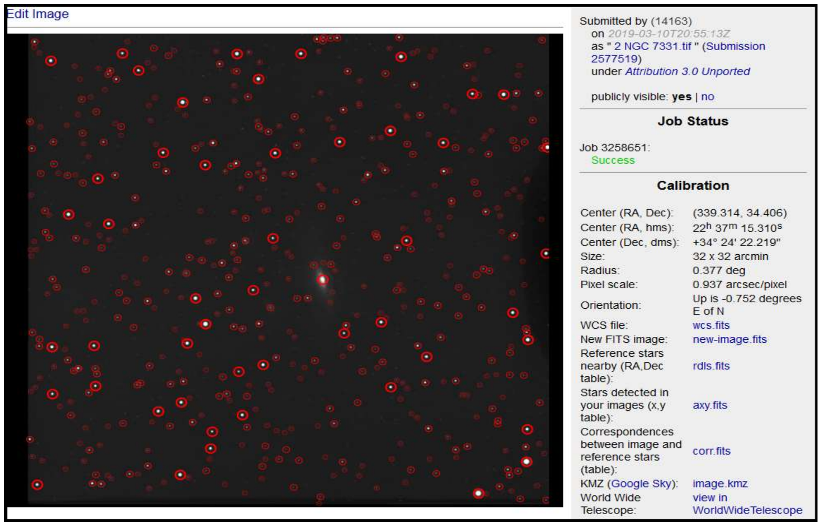


Figure 4 *indicates how many points nova.astrometry.net examines and attempts to correlate for an image of NGC 7331.*

Image Calibration Problems

One problem encountered during this study was regarding subject image 19, NGC 578, which imaged incorrectly from the telescope, leaving no discernible data available (even after adjusting contrast) to which the blink-comparison software was able to lock onto nor was nova.astrometry.net able to correlate and add WCS data. For this reason, none of the blink-comparison programs achieved 100% successful images processed.

Out of all seven programs, only GrepNova failed to open more than 21 of the 26 image pairs or opened them incorrectly, with another four images noticeably misaligned. Due to imaging problems which incurred concerning light blooms or clouds obscuring enough stars on the subject images, GrepNova's pattern recognition algorithm was unable to match or re-orientate images as necessary for analysis spatially. Notes reflected on the Supernova Search Worksheet which of the image pairs did not process correctly for comparison to the other blink-comparison software packages.

Subject images which contained problems or mistakes during imaging provided for a good test of the abilities of the blink-comparison software. As noted, GrepNova failed to resolve four image pairs due to a lack of reference stars for its algorithm software to process and a fifth subject image which contained no data, which also caused the other six blink-comparison programs a processing failure with the same image. Even though Aladin Sky Atlas, Astrometrica, MaxIm DL Supernova Search Tool, PhAst, SAOImage DS9, and Starblinker were able to align and match the four images, GrepNova failed to spatially, those images had very little usable data due to light blooms and clouds obscuring all but the brightest stars in the picture.

Aladin Sky Atlas

Initially, Aladin Sky Atlas was unusable until it was determined that the FITS format images required WCS data to align the image pair properly spatially. After adding WCS data to the images, Aladin Sky Atlas spatially aligned the images very accurately (Linux data see Appendix K, Mac OS data see Appendix T, Windows data see Appendix M). During the blink-comparison stage, Aladin Sky Atlas provided the ability to pan around the image; however, the zoom function was inactive. To reactivate the zoom function of the blink-comparison, the blinking process had to be stopped, the current blink layer deleted, then each of the two layers (reference and subject) had to be sized separately to the desired zoom depth. Once at the desired zoom depth, the blink layer could be recreated, and the blink analysis could resume. Contrast adjustment of the two images could be adjusted when an image was selected, and the right mouse button was depressed and held while dragging the mouse right to left and toward and away the user until the desired contrast was achieved. Only a single pair of images could at a time.

Astrometrica

Astrometrica properly aligned 25 out of the 26 image pairs as already noted (Windows data – see Appendix N) and automatically rotated two templates 180° for proper alignment. Due to clouds partially obscuring several of the images, it became necessary to invert the image colors (black hot) through the hot bar tool to better make out some of the fainter stars in the images. Contrast adjustment could be made to the individual images before blinking through the background and range tool icon. Zoom functions also were located in the hot bar while panning through the image required the utilization of the image's slider bars to the right side and bottom of the blinking frame. The pan and zoom functions were operational while the blinking utility was active. Only a single pair of images could be loaded at a time.

GrepNova

Even with the least impressive track record during this testing of five images not resolved and another four with alignment problems, GrepNova did adequately align all of the image pairs which did not have any of the poorer qualities, including automatically rotating two template images 180° for proper alignment (Windows data – see Appendix P). GrepNova does not have a zoom function capability at all; however, the images were pannable during active blinking using the mouse scroll wheel for up and down or through the scroll bars located on the right side and bottom of the image. GrepNova was only one of two programs which offered the feature to queue an entire batch of reference and subject images, allowing one button click to progress through each of the image pairs until completion of analysis.

MaxIm DL Supernova Search Tool

MaxIm DL is a suite of astronomy tools which range from image acquisition from the telescope, processing, and even analysis through various mechanisms. Supernova Search Tool was created to mesh with MaxIm DL scripting interface to allow both programs to work together to utilize technology and reduce repetitive tasks performed by astronomers. The Supernova Search Tool is the second of two programs which target both a reference image directory and a subject image directory; however, oddly enough for this add-on to work, it requires both the reference and subject image pairs to have the exact same name. While the image names must be the same, the image format types can be different such as mixing .fit, .bmp, .jpg, or .tif. When the blink process is started, the images will open up in MaxIm DL and begin to blink. Image pairs now blink, allowing the operator to zoom in and out utilizing the mouse scroll wheel, pan up and down by holding Shift + mouse scroll wheel or Ctrl + mouse scroll wheel to pan the image right or left. If the image may have a potential supernova, clicking the "Re-Shoot" button saves the image to a separate directory where retakes of the images can be made and compared to. Once the analysis is complete with the image pair, selecting the Next button will advance the images to the next image pair in the directory (Windows data – see Appendix Q).

PhAst

PhAst or **Ph**otometry **Ast**rometry is the only program of the seven which required an interactive data language (IDL) virtual machine for it to operate. PhAst displays and analyzes FITS format images; however, it is not dependent on WCS to properly spatially orient the reference and subject images. While not reliant on WCS, PhAst did have the option to utilize WCS if it was already embedded on the images. PhAst was another program in which only one image pair could be loaded at a time, and the mouse scroll wheel-controlled zoom functions while panning was accomplished by clicking and holding the green square in the image overview in the upper left-hand corner of the program. Windows data collected from PhAst are located in Appendix R.

SAOImage DS9

SAOImage DS9 was the second of two programs which failed to spatially orient any of the images without WCS data present on the FITS format images (Linux data – see Appendix L, Mac OS data – see Appendix U, Windows data – see Appendix O). With WCS data present on the images, loading them into SAOImage DS9 was a matter of clicking through either the drop-down menus or the hot bar buttons. New frames must be loaded before opening each image. Selecting the Scale drop-down menu or hot bar button allowed for the changing of the upper and lower limits of the image which were typically set to log, from here the contract on the active image was adjusted by holding down the right mouse button and dragging the mouse to the left until the desired contrast was reached. Once both images had comparable in contrast levels, they also needed to be equally sized; afterward, they were frame matched via the WCS data and locked together through the frame menu. Locking the images together allowed them to be panned and zoomed in unison during the analysis process. To enable the panning option required opening the Edit drop-down or accessing the Edit hot bar button and then selecting Pan. During the blinking process, zooming in and out of the image was accomplished by scrolling on the mouse scroll wheel. While panning did not work the way, it does in most programs by holding the mouse button and sliding the mouse around, instead here it required the user to double click towards the edge of the view screen in the direction the image needed to move. For example, clicking at the bottom of the viewable screen caused the image to shift down in halting movements.

Starblinker

The testing of Starblinker was straightforward as it had only a couple of options to choose besides the blink-comparison function. The initial spatial alignment of the reference and subject image was close, but noticeably off, however, in the image's menu was the option refinement which reanalyzed the image in an attempt to align the images more accurately spatially. Starblinker also had the options to zoom in and out utilizing hot bar buttons and had the opportunity to pan the image by holding down the left mouse button and moving the mouse around to. Starblinker also featured the option to draw a mark (red circle) around objects in question and even the option under the Blink drop-down menu to check the differences between the images as a quick way to see if there was a potential supernova in one of the images. The one problem with this was if the image is slightly warped or stretched through the imaging or alignment process, the skewed areas will show more false differences than the regions which are not skewed. Unfortunately, Starblinker cannot work with FITS format images; however, utilizing GIMP's export process, images were converted to a compatible format such as .bmp, .jpg or .tif (Windows data – see Appendix S).

Figures one and two compare a FITS format image in relation to a .tif format of the same image exported from GIMP, with only slight modifications to the contrast and shader levels.

Conclusion

The result of this chapter captured the outcome of the study by limiting researcher bias and lay bare the reliability of the analysis with the descriptive theory methodology. Seven blink-comparison software programs were evaluated for this descriptive theory examination. Direct observation and immediate recording of data allowed for accurate record keeping while limiting researcher bias which according to the postpositivist world view, is inevitable, but in recognizing that, all is done to reduce bias creep into the results. All seven blink-comparison software programs were successful in the ability to blink-compare reference and subject image pairs, however not all to the same degree of success.

Unswerving with descriptive theory methodology and the fundamental purpose to answer the question, “what is,” results which appeared during the observations were immediately noted in a consistent format between all programs tested. During testing challenges arose which threatened failure, however descriptive theory methodology allows for reevaluation, adjusting variables and retesting of the process to determine if another way is possible to reach the expected conclusion. Almost half of the programs tested required remediation through adding, editing, adjusting or removing variables which led to successful outcomes. Further data detailing parallels or divergences between the blink-comparison were also illustrated in this chapter. Even with the efforts made for these programs to perform the primary function of blink-comparison between a reference and subject images in the search for illusive supernovae, there is enough variability which makes some of the programs more efficient to use with student scientists and their academic research. Chapter V is comprised of the review for the principal evaluation and analysis of the seven blink-comparison software programs.

CHAPTER V: SUMMARY

This quantitative descriptive theory study intended to evaluate seven blink-comparison software programs, the purpose of the testing was to determine if problems encountered during analysis could be overcome and ultimately decide which of the programs were most effective. Detailed in this chapter is a discussion of the major findings regarding the evaluation of the seven blink-comparative software programs Aladin Sky Atlas, Astrometrica, GrepNova, MaxIm DL Supernova Search Tool, PhAst, SAOImage DS9, and Starblinker. The conclusion of this chapter entails a conversation relating to the limitations of the study, potential research opportunities stemming from this work, along with a summary.

The contents of this chapter include discussion along with prospective research possibilities to facilitate answering the proposed research questions:

- What problems exist in the software for the comparison of a reference image and a data image?
- Can problems, errors or bugs be re-mediated through adding, editing, adjusting or removing variables?
- Which blink-comparison software is most effective?
- Is this program operationally ready for further studies used to assess if undergraduate students can utilize the Supernova Search Program as part of their curriculum or as an independent study?

Assessment of the blink-comparison software sought to explore and determine if there were any problems presented during the comparison of the reference images and subject images. As part of the postpositive world view of the descriptive theory, when roadblocks appeared, attempts to add, edit, adjust or remove variables are encouraged to allow for a retest to complete the first exercise. When remediation of errors completed, then comparison testing of the seven blink-comparison software commenced determining which software package was most effective at what it did, and which would be the best fit for undergraduate students to utilize as a part of their curriculum in the search for a supernova.

Interpretation of the Findings

During the evaluation of the seven blink-comparison computer programs, three prominent problems emerged when attempting to utilize them for analysis during the study. Resolution from two of the three issues allowed for the continuation of the assessment of the blink-comparison software. The following sections describe each evaluation.

WCS Data

This study's findings suggest that the addition of WCS data to a FITS format image increases the value of the image not only for required usage in Aladin Sky Atlas and SAOImage DS9 blink-comparison programs, but also as additional data stored in the FITS format annotating world coordinates attached to each pixel of a FITS image (Greisen et al., 2006). Mapping image points translate to each pixel tagged with its location concerning right ascension and declination which in turn, allows for very accurate spatial alignment between reference and subject images.

Non-FITS Format Compliant Images

One of the blink-comparison programs evaluated, Starblinker, could not read the FITS format images and required the use of an external application for conversion of the images to a compatible format including .bmp, .jpg and .tif. It was determined that this process was undesirable as, during the conversion or exportation process, stripping all of the archival FITS data from the image.

Image Calibration Problems

Several of the subject images utilized for blink-comparison testing had varying degrees of faults or errors which affected the ability for the programs to either properly resolve the images or allow for proper analysis of the images. While not ideal, they did serve to identify certain limits to which the programs could resolve or produce data to analyze. It was determined that these faulty images did not negatively impact the study and were utilized; however, the study limitations and recommendations for future research section of this paper outlines potential retest possibilities in which to allow comparison of those outcomes to the results of this study.

Aladin Sky Atlas

This study concludes that Aladin Sky Atlas is the most effective blink-comparison software of those tested to utilize with the APUS Supernova Search Program. Aladin Sky Atlas is a cross-platform program which is free to use without limitation which would provide freedom for students to utilize this program on a computer with one of the three major operating systems. This program requires the FITS format images to have WCS data embedded to spatially align and has been in continued development and operation since 1993 (Bonnarel et al., 2000). Useful built-in functions during the blinking process include image panning, zoom, invert and contrast adjust.

Astrometrica

Astrometrica is not recommended for usage with the APUS Supernova Search Program due to being limited for use only on Windows-based computers and because of the licensing fee associated with it.

GrepNova

Testing of GrepNova revealed this blink-comparison program has difficulty processing images with faults or errors due to improper imaging or preprocessing, failing to properly align or resolve more images than the other programs tested and is not recommended for use with the APUS Supernova Search Program.

MaxIm DL Supernova Search Tool

MaxIm DL Supernova Search Tool was determined not to be a useful blink comparison tool due to the need to utilize the same name for both the reference image and the subject image, leaving the potential for mixing up images or accidentally overwriting images when moved to a different folder. Licensing fees per user also make this product less desirable. This product is more intended for addition to a pipeline setup where the Maxim DL software automatically preprocesses the images from the telescope through scripting and then deposits the images into an evaluation folder linked to the Supernova Search Tool, ready for the astronomer to evaluate.

PhAst

Evaluation of PhAst determined it not to be a useful blink-comparison tool for the APUS Supernova Search Program. Due to programming complications, PhAst was not tested on Mac OS, and Linux computers and the IDL VM required a paid license for allowed regular usage. PhAst operated as intended on a Windows-based computer and has the potential for usage under advanced research for providing astrometric solutions, aperture photometry and discovery of near-earth objects (Mighell et al., 2012).

SAOImage DS9

SAOImage DS9 was determined to be a close runner up behind Aladin Sky Atlas as an effective blink-comparison tool for the APUS Supernova Search Program. SAOImage DS9, also a cross-platform tool, can perform all of the same blink-comparison functions as Aladin Sky Atlas in visualizing astronomical images; however, it requires several more steps when loading comparison images and the panning tool is imprecise requiring the operator to double click on the image to make it pan instead of the typical click and drag operation.

Starblinker

Utilization of Starblinker as a blink-comparison tool for the APUS Supernova Search Program is not recommended due to the program's inability to analyze FITS format images; instead, requiring conversion to .bmp, .jpg or .tif images (Dickinson 2015). Conversion from FITS format strips all of the FITS and WCS data located on the file and requires reloading the image to nova.astrometry.net to read the data; however, the output file is then converted back to FITS format. There is potential value in utilizing Starblinker with High School or Undergraduate students as a simple instrument to operate as an introductory tool in the blink-comparison process of two images.

Study Limitations and Recommendations for Future Research

Quantitative research was determined to be the best fit for this study, as it was intended to gather hard facts by answering the question "what is" concerning evaluating blink-comparison software. The credibility of this study could be enhanced in two potential ways, first by reconducting the blink-comparison evaluation with multiple persons and then secondly, followed up with qualitative research. Additional persons testing this process could add validation or repudiation to the process while a quantitative interview could pose questions in which to gain insights into problems with the process or help develop potential ideas to streamline it.

The multi-person evaluation would help eliminate any unintentional bias creep introduced through this study. Utilization of such an assessment would also serve to compare the results from several viewpoints, increasing validity and confidence of the study. Follow-up interviews designed for qualitative research could illuminate potential arguments for and against the blink-comparison software attributed through their usage and not just hard quantitative facts of what they are. Results from these exercises could potentially tailor a product which would not only capture the interest of student scientists but possibly excite them in the field of research, motivating them to ask their own questions and searching out solutions.

Another potential study which would add to the results of this study's findings would be an identical study which utilized 26 image pairs (reference and subject images) which are clean or in other words, free from imaging errors and pre-processing faults. A clean set of images could provide a more accurate baseline between programs with the results being produced under more ideal circumstances. An alternately similar study could compile a series of problematic images including flat-fielding errors, pre-processing faults, warped images, light-bloom exposures, and thin cloud cover to name a few. Comparative processing of questionable images is aimed at pushing the limits of the blink-comparison programs to determine which ones could compensate the best under those circumstances. Alternately such a study may establish all programs having difficulty processing those images and could lead to looking at refining the image capture process and pre-processing procedures to reduce the number of problematic images making it to the analyst's table.

Conclusion

To turn astronomy program students into student scientists, the Space Studies Astronomy department at APUS has created a Supernova Search Program which will allow the students to become involved in the potential discovery of supernovae imaged from APUS's campus telescope. Such a program takes much work to build and implement and at any point along the way; a simple problem can cause delays, frustrations or even project cancellations. The purpose of this paper was to document the pilot testing of the APUS Supernova Search Program and evaluate seven potential blink-comparison software programs potentially utilized by the student scientists in their coursework or special projects. The pilot program was developed to run the blink-comparison programs through their paces to determine if any of the critical processes leading from imaging, observation, analysis, and documentation were working as intended and ready for operational release and undergraduate student usage. Expected questions to be answered included was there problems with the software in comparing the reference and subject images, if so, could these problems be remediated, and which blink-comparison software was most effective and ready for student use?

Testing took place with seven blink-comparison software programs: Aladin Sky Atlas, Astrometrica, GrepNova, MaxIm DL Supernova Search Tool, PhAst, SAOImage DS9, and Starblinker. During the testing of these programs, it was determined that WCS data was a vital data component to be added to FITS format images, not only allowing proper spatial alignment for applications such as Aladin Sky Atlas and SAOImage DS9, but also for archiving relational data of each pixel in comparison to the sky map. It was also determined that converting images to .bmp, .jpg and .tif was undesirable due to the loss of any FITS data during the conversion process.

While several subject images contained varying degrees of faults or errors, it was accepted for use to determine how the various programs would handle them.

Of the seven blink-comparison software programs, Aladin Sky Atlas stood above the rest. Other programs while able to do the same work, had detractors who made them undesirable for usage with the APUS Supernova Search Program. Some of these detractors include licensing fees, limited computer platform availability, excessive failures to properly resolve images or complicated set-up procedures. Aladin Sky Atlas had the benefits of being free to use, installable on Windows, Mac OS or Linux computers, utilizes FITS format images with WCS data and easily loads comparison images and quickly begins the blinking process. The data adn information accumulated from this study will provide the necessary information to the project leaders to allow them to determine if a more extensive study is warranted or if the project is ready for mainstream usage. If a more extensive study is justified, data gathered from that exercise would provide a more extensive data sample across several individuals providing the opportunity to reduce bias creep and allow for comparison of data between projects.

Pilot testing of the APUS Supernova Search Program set out to test and determine through analysis which blink-comparison software was most effective and ready for mainstream usage among student-scientists. Further testing of images and image formats allowed for limits of the programs to be pushed, negative results learned and alternate methods of measurement to complete the software evaluation. The result of this study suggested that Aladin Sky Atlas is the best fit blink-comparison software program for the APUS Supernova Search Program. Hopefully, the university students will soon be able to start comparing reference and subject images as part of their assignments and projects. Hopefully, excitement felt through opportunities to do actual hands-on research will help them develop their own questions and create solutions to find the answers. Ultimately the end goal is to get students to sit in the same chair as Fritz Zwicky and develop a love and fascination for hunting supernovae.

Appendix A: New General Catalog Galaxy Chart

Blink Comparison Software Programs	Website
Aladin Star Atlas	**https://aladin.u-strasbg.fr/**
Astrometrica	**http://www.astrometrica.at/**
GrepNova	**https://in-the-sky.org/software.php**
MaxIm DL Supernova Search Tool	**http://diffractionlimited.com/product/maxim-dl/**
PhAst	**https://www.noao.edu/staff/mighell/phast/**
SAOImage DS9	**http://ds9.si.edu/site/Home.html**
Starblinker	**http://starblinker.com/**

Appendix B: Evaluation of Blink Comparison Software

	Aladin	Astrometrica	DS9	GrepNova	MaxIm DL	Starblinker	PhAst
Free	x	*Shareware (60 day trial)*	x	x	*30 day trial*	x	*2 week trial license*
Cost		x			x		x
Windows	x	x	x	x	x	x	x
Mac	x		x				x*
Linux	x		x	x*			x*
FITS Compatible	x	x	x	x	x		x
WCS Required	x		x				x
Accurate Spatial Matching	x	x	x	x	x	x	x
Zoom Function	x	x	x		x	x	x
Pan Function	x	x	x	x	x	x	x
Adjust Contrast		x	x	x	x	x**	x
Invert		x	x			x**	x
Image Queuing				x	x		
Extended Controls	x		x	x	x		
Additional Functionality	x		x		x		x
Special Requirements						x	x
Images Successfully Processed	25/26	25/26	25/26	21/26	25/26	25/26	25/26

*Images were not tested with these versions of the operating system due to lack of program compiling knowledge.

** Images being converted from FITS format to .tif can adjust the levels or contrast during the conversion process in GIMP.

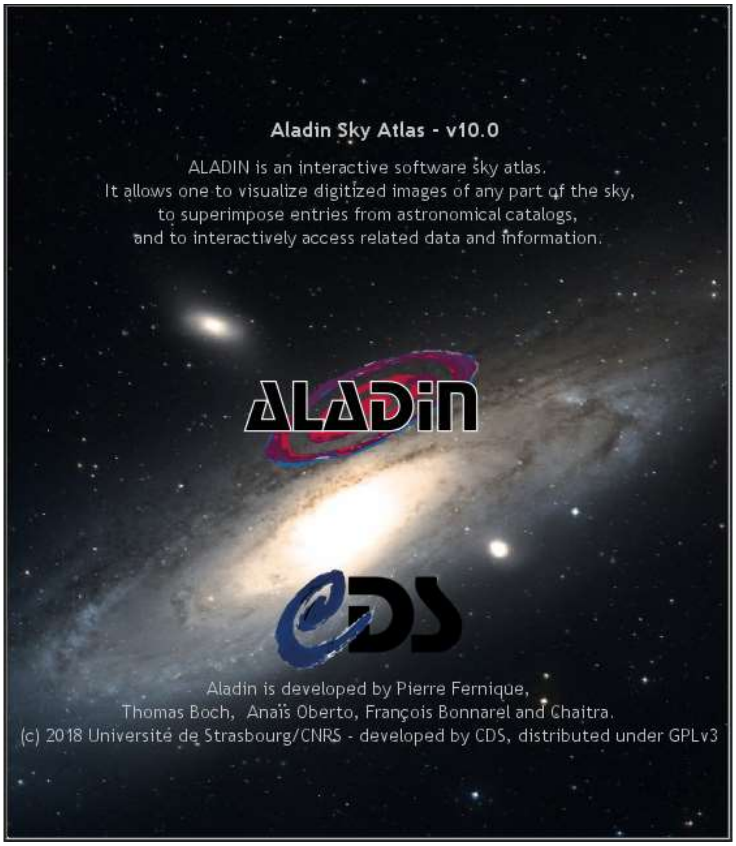
Appendix C: New General Catalog Galaxy Chart

Group I Survey	Right Ascension	Declination
NGC 7217	$22^h\ 07^m\ 52.4^s$	+31° 21′ 33″
NGC 7332	$22^h\ 37^m\ 24.5^s$	+23° 47′ 54″
NGC 7479	$23^h\ 04^m\ 56.6^s$	+12° 19′ 22″
NGC 7640	$23^h\ 22^m\ 06.58^s$	+40° 50′ 43.5″
NGC 224	$00^h\ 42^m\ 44^s$	+41° 16′ 9″
NGC 448	$01^h\ 15^m\ 16.5^s$	−01° 37′ 34″
NGC 598	$01^h\ 33^m\ 50^s$	+30° 39′ 37″
NGC 628	$01^h\ 36^m\ 42^s$	+15° 47′ 1″
NGC 672	$01^h\ 47^m\ 54.523^s$	+27° 25′ 58.00″
NGC 772	$01^h\ 59^m\ 19.6^s$	+19° 00′ 27″
NGC 891	$02^h\ 22^m\ 33.4^s$	+42° 20′ 57″
NGC 925	$02^h\ 27^m\ 16.913^s$	+33° 34′ 43.97″
NGC 7606	$23^h\ 19^m\ 04.8^s$	−08° 29′ 06″
NGC 7727	$22^h\ 26^m\ 10.90^s$	−12° 17′ 34″
NGC 45	$00^h\ 14^m\ 3.99^s$	−23° 10′ 55.5″
NGC 157	$00^h\ 34^m\ 46.8^s$	−08° 23′ 47.4″
NGC 247	$00^h\ 47^m\ 08.5^s$	−20° 45′ 37″
NGC 253	$00^h\ 47^m\ 06^s$	−25° 17′ 00″
NGC 578	$01^h\ 30^m\ 00^s$	−22° 40′ 00″
NGC 720	$01^h\ 53^m\ 00.5^s$	−13° 44′ 19″
NGC 908	$02^h\ 23^m\ 04.6^s$	−21° 14′ 02″
NGC 936	$02^h\ 27^m\ 37.4^s$	−01° 09′ 22″
NGC 1055	$02^h\ 41^m\ 45.2^s$	+00° 26′ 35″
NGC 1068	$02^h\ 42^m\ 40.771^s$	−00° 00′ 47.84″
NGC 1073	$02^h\ 43^m\ 40.5^s$	+01° 22′ 34″
NGC 1087	$02^h\ 46^m\ 25.2^s$	−00° 29′ 55″

Appendix D: Aladin Sky Atlas – Supernova Search How-to Setup Guide

Aladin Sky Atlas

Supernova Search How-to Setup Guide



https://aladin.u-strasbg.fr/

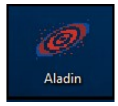
Windows Operating System Instructions

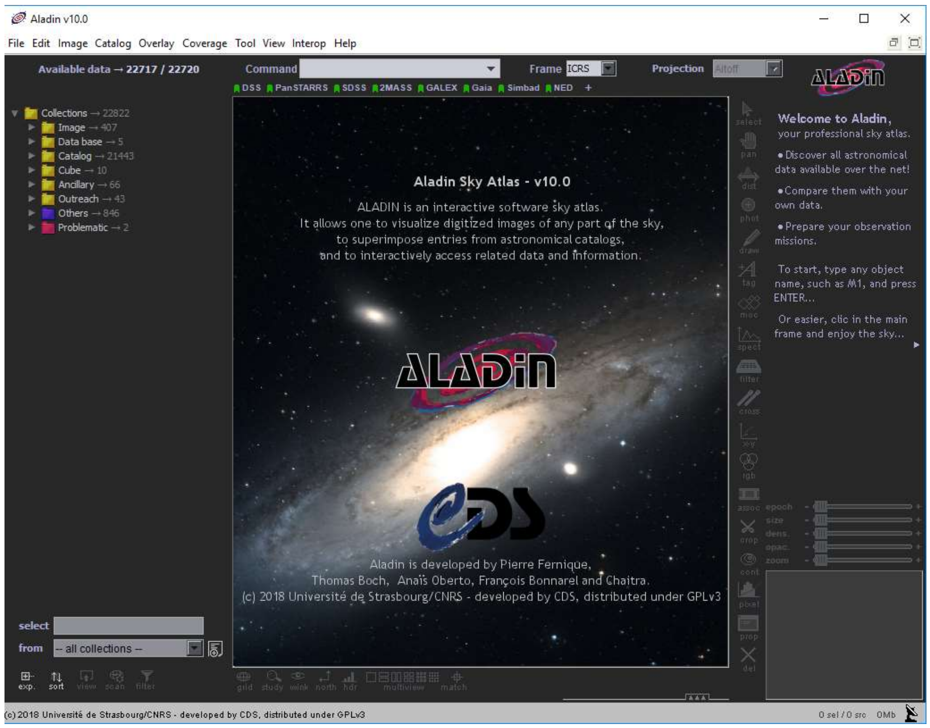
Note: All images utilized in Aladin must contain World Coordinate System (WCS) data. To add WCS data to an image, upload it to http://nova.astrometry.net/. After the website finishes adding the WCS data, the new image will be available for download – remember to rename the image prior to downloading others which were

Cary D. Hatch

02 March 2019

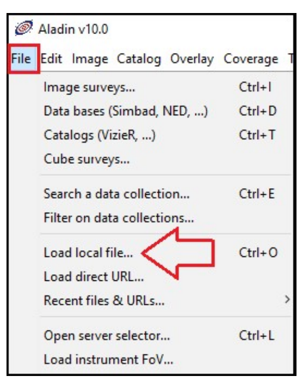
1. <u>Double click on **Aladin** icon to open the program.</u>





<u>Figure 1:</u> *The main screen of Aladin. Frequently used options will be on the horizontal toolbar at the upper left and the vertical tool bar on the right.*

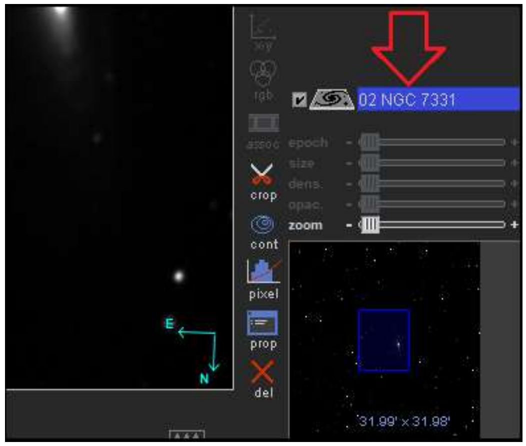
2. To add a reference image, select **File** drop down menu and then select **Load local file** or utilize keyboard shortcut **CTRL-O**.



<u>Figure 1:</u> *Adding reference image*

3. Navigate to the location where the reference images are located in the computer.

4. Select a reference image file, select **OK**.



<u>Figure 2:</u> *After selection, the image will display in the view window and will appear as a slide in the stack. (Note the checked box next to a slide designates which slide is active)*

5. To add a subject image, similar to step 2, select **File** drop down menu and then select **Load local file** or utilize keyboard shortcut **CTRL-O**.

6. Navigate to the location where the subject images are located.

7. Select a subject image, companion to the chosen reference image.

Figure 3: *(Red Arrow) Subject image is now added to the stack and is the active file. (Yellow Arrow) the Assoc function is now available - see next step.*

8. On right side vertical icon menu, select filmstrip icon **Assoc** (*See yellow arrow in Illustration 4*).

9. A pop-up window will appear, here select the two images (reference and subject images) to compare from the drop-down menus (#1 – red arrow and #2 orange arrow).

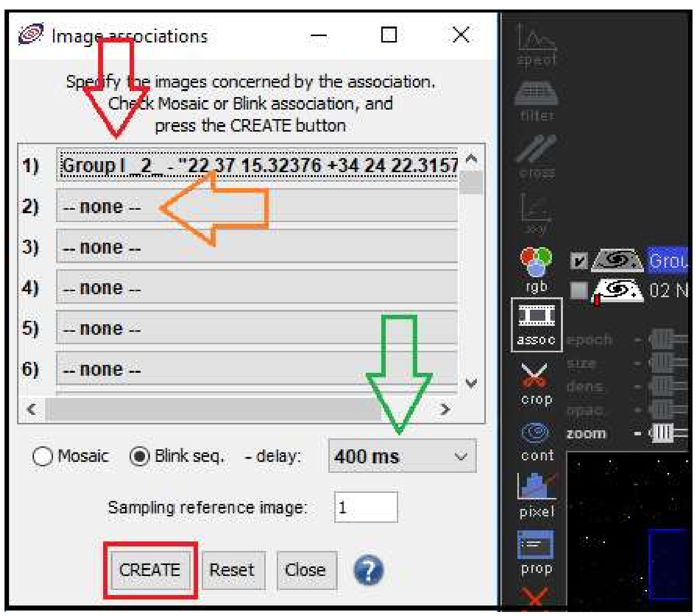


Figure 4: *Red arrow = subject group, orange arrow = reference group, green arrow = blink comparison time rate drop-down menu*

10. A third drop-down menu on the pop-up window provides the option to change the delay rate for the blink-comparison (See green arrow in Illustration 5).

11. When satisfied with the options, select the **Create** button, a new layer, *Blk.img* is created in the stack. The creation of the layer can be observed by a loading bar as the images are spatially matched. This can be a slow process depending on the computer's processing power.

Figure 5: *Red arrow indicates new blink image (combination of reference and subject which alternately blink).*

12. The images will begin to alternately blink on and off.

Figure 6: *Red arrow indicates current image being viewed. Yellow arrow also indicates image being viewed (if more than two images are stacked, it will indicate which image out of the total number stacked).*

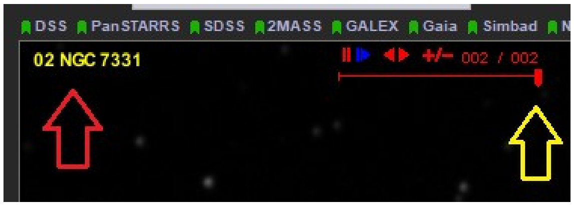


Figure 7: *Note during the blinking process, as the images alternate, so does the name of the image (red arrow) along with its position (yellow arrow)*

13. When analysis of the images has completed, activate the red pause button at the top center of the screen to pause the blinking process.

Figure 8: *Yellow arrow indicates pause button. Also found is the play button to resume the blink comparison or the image-forward and image-back button to manually change image being viewed.*

14. Right click on one of the layers and choose **Delete all planes** to remove the blink layer and both the reference and subject images in preparation for the next image pair.

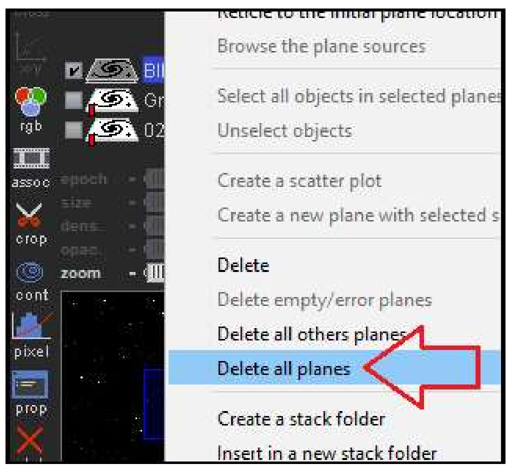


Figure 9: *Right clicking on one of the images in the stack will produce a pop-up menu with the option to* ***Delete all planes****.*

15. When all of the current images in the stack have been deleted, return to step two and start process again to analyze the next image pair. Continue until all of the images have been analyzed.

Appendix E: Astrometrica – Supernova Search How-to Setup Guide

Astrometrica

Supernova Search How-to Setup Guide

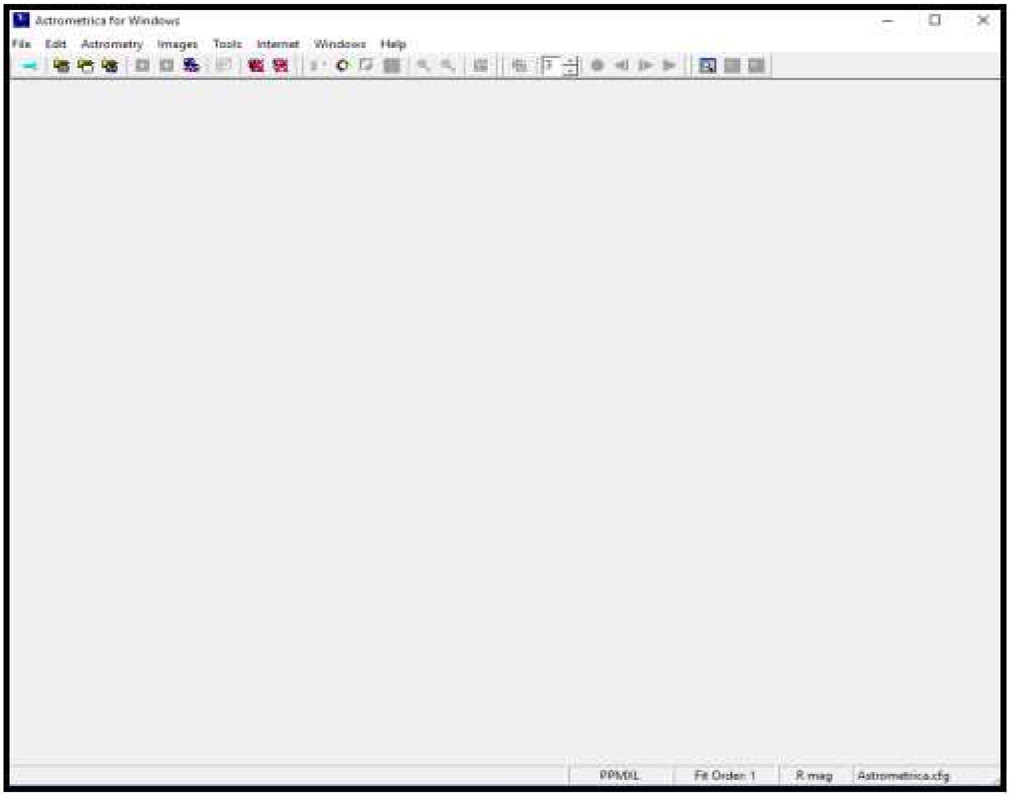
http://www.astrometrica.at/

Windows Operating System Instructions

Cary D. Hatch

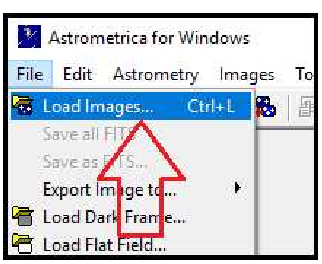
02 March 2019

1. Double click on **Astrometrica** icon to open the program.

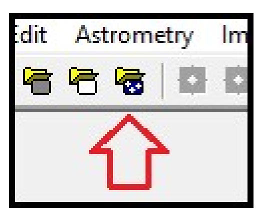


<u>Figure 10:</u> *The main screen of Astrometrica. Frequently used options will be on the horizontal toolbar at the upper portion of the screen or from the drop-down menus*

2. To add a reference image, select **File** drop-down menu and then select **Load Images…**, utilize keyboard shortcut **CTRL-L** or click on tool bar shortcut.



<u>Figure 2:</u> *To add a reference image, select* ***Load Images...*** *from the* ***File*** *drop-down menu.*



<u>Figure 3:</u> *Alternate method to add a reference image, click on folder icon indicated by red arrow.*

3. Navigate to the location where the reference images are located in the computer.

4. Select a reference image file, select **OK**.

5. The image will load along with a pop-up box indicating the date and time the exposure was taken (data provided by the FITS image). Select **OK** to close the pop-up window.

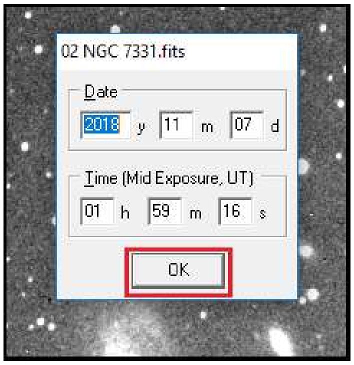


Figure 4: *Pop-up box of the date and time the image was taken.*

6. To add a subject image, similar to step 2, select **File** drop down menu and then select **Load local file** or utilize keyboard shortcut **CTRL-L** or click on tool bar icon.

7. Navigate to the location where the subject images are located.

8. Select a subject image, companion to the chosen reference image. Select OK to close out the time/date pop-up box.

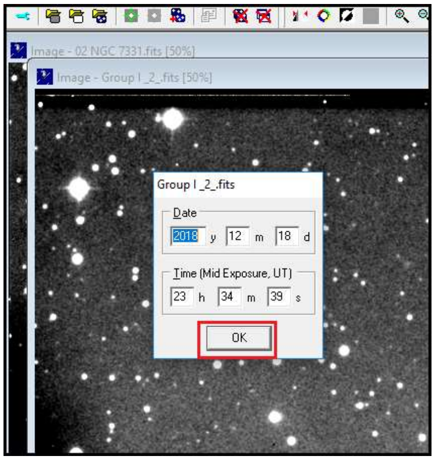


Figure 5: *Notice now the second image (subject) is also opened along with its pop-up window annotating date and time it was imaged.*

9. To start the blink-comparison, select **Tools** drop-down menu and then select **Blink Images**, utilize keyboard shortcut **Ctrl+B** or click on the tool bar icon.

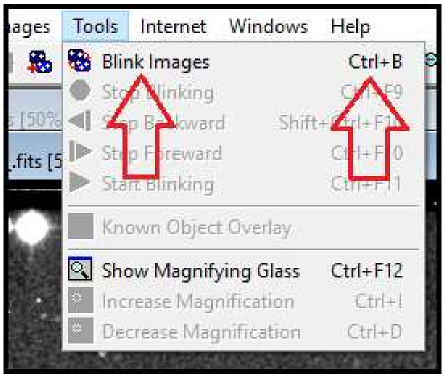


Figure 6: *Select **Tools** drop-down menu and then select option **Blink Images** or utilize keyboard shortcut **Ctrl+B** to start the blinking process.*

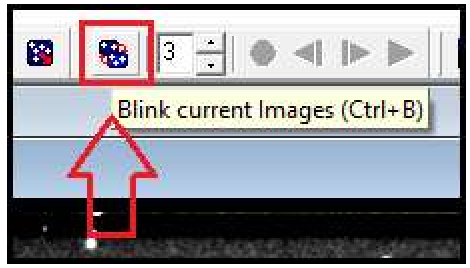


Figure 7: *Red arrow indicates alternate option of clicking tool bar icon to blink the current images.*

10. A third window will open up which will begin the blink-comparison of the two images.

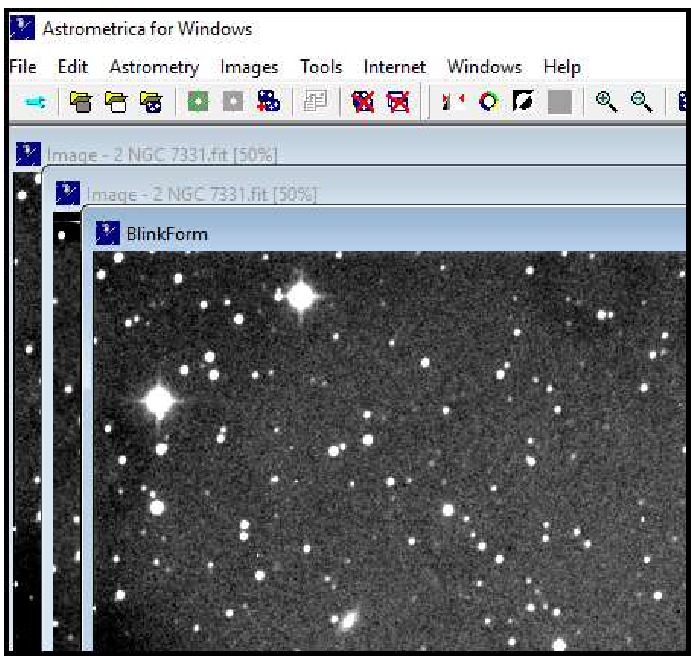
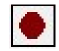
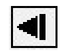
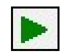


Figure 8: *A third window will load, when complete, it will start blinking between the two images.*

11. Common toolbar icons to be used during blinking include the following:

• Invert	
• Zoom In	
• Zoom Out	
• Stop Blinking (Ctrl+F9)	
• Single Step forward (Shift+Ctrl+F10)	
• Single Step backward (Ctrl+F10)	
• Start Blinking (Ctrl+F11)	

12. When analysis of the images has completed, activate the red button in the tool bar to pause the blinking process.

13. To close all the images, select the tool bar icon **Close all images**.

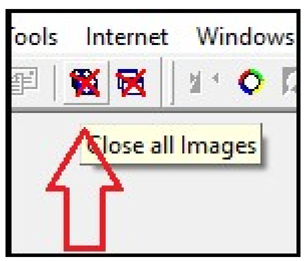


Figure 9: *Red arrow indicates icon utilized to close all open windows.*

14. A pop-up window will appear, select **Yes** to close out all open images.

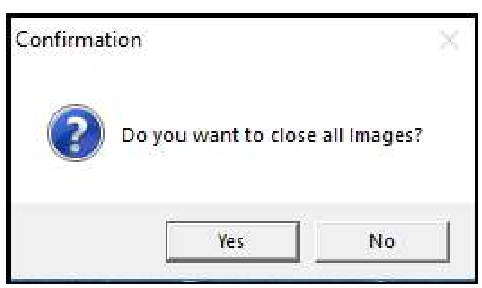


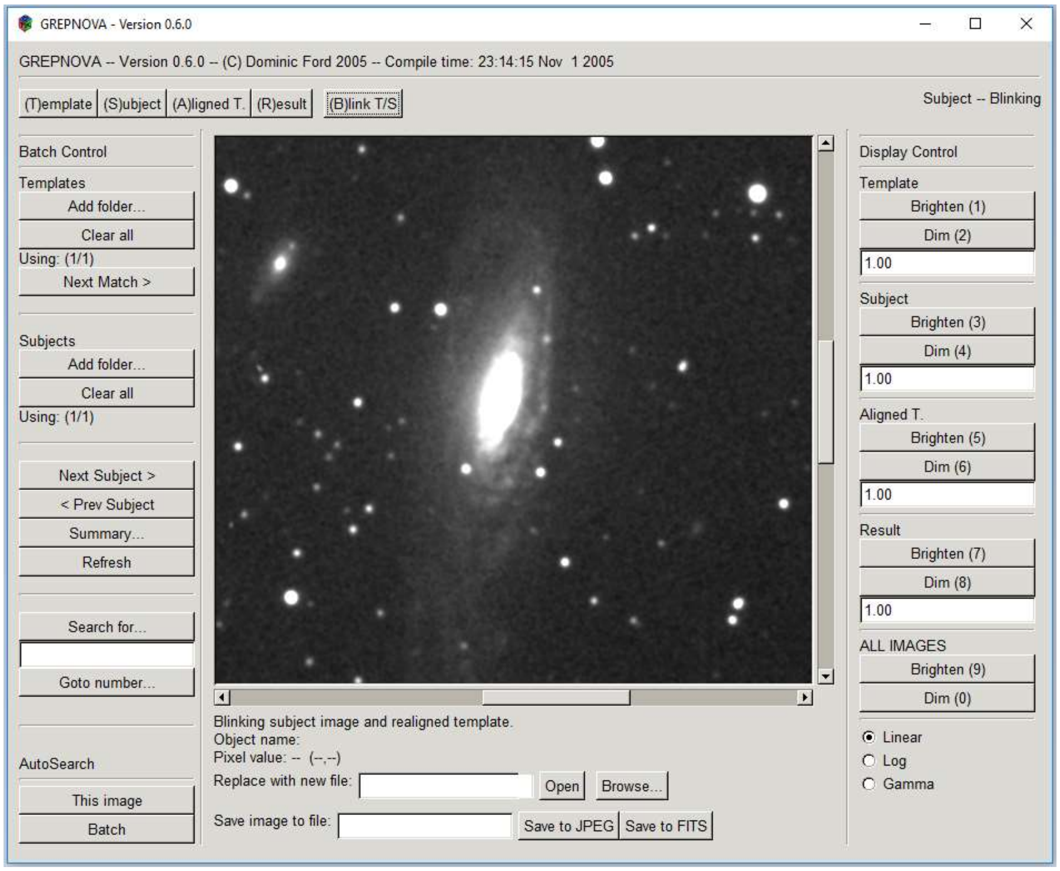
Figure 10: *When closing the images, a dialog box will appear requesting confirmation of request*

15. To view more images, return to step two.

Appendix F: GrepNova – Supernova Search How-to Setup Guide

GrepNova

Supernova Search How-to Setup Guide



https://in-the-sky.org/software.php

Windows Operating System Instructions

Cary D. Hatch

02 March 2019

1. GrepNova does not install like a typical program, instead it runs in the computer's random-access memory. This program does not create a desktop icon, but one can be made for ease of access to start the program.

- After downloading GrepNova's zip file (https://in-the-sky.org/work/grepnova_0.6.0.zip), create a folder in a location of your choosing and unzip GrepNova.
- Open the folders and select: **Sne** => **bin** => **win32**. Look for a file called **grepnova-gui**, this is an application file which starts the program.

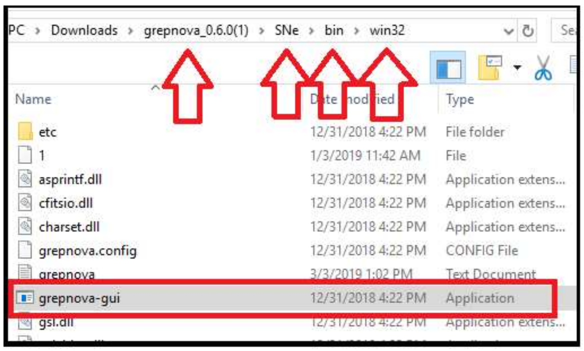


Figure 1: *Red arrows indicate the folder trail to get to the grepnova-gui executable file.*

- Right click on **grepnova-gui** and a pop-up menu will appear, navigate to **Send to** and select **Desktop (create shortcut)**.

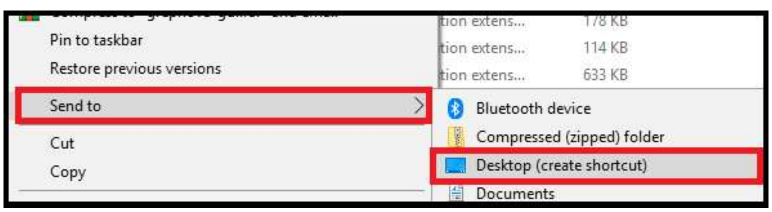


Figure 2: *Red boxes indicate how to get to the create shortcut function.*

- A shortcut icon will now appear on the computer's desktop, if desired; the shortcut can be renamed to **GrepNova** or left as is.

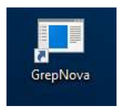
Figure 3: *GrepNova icon with default name after creating shortcut.*

Figure 4: *GrepNova icon renamed.*

- Create two folders (any location on the computer will work), name one folder **Templates** and the other folder **Subjects**. Transfer the reference files to the **Template** folder and the newly acquired images to the **Subject** folder.

- GrepNova is now ready for use.

2. Open GrepNova utilizing the desktop shortcut icon. Two windows will open up, one is the command line information box and the other is the GrepNova graphical user interface. The command line box cannot be closed out during the operation of GrepNova, but can be minimized; however, it may be helpful to indicate any potential errors GrepNova may be having with any of the images.



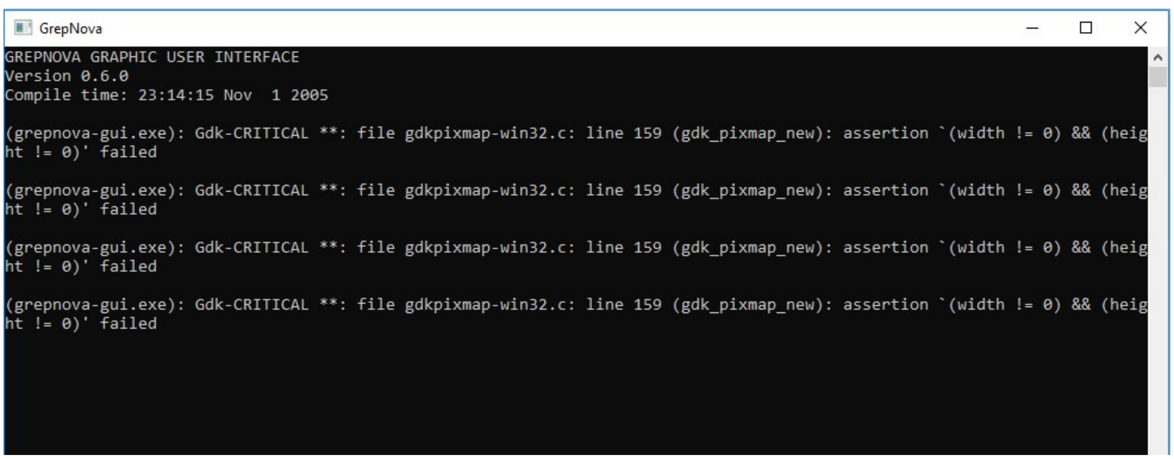


Figure 5: *While the command line box is not necessary for the user, it is critical for GrepNova. This window can be minimized; however, it may display helpful information during times when GrepNova may be experiencing problems.*

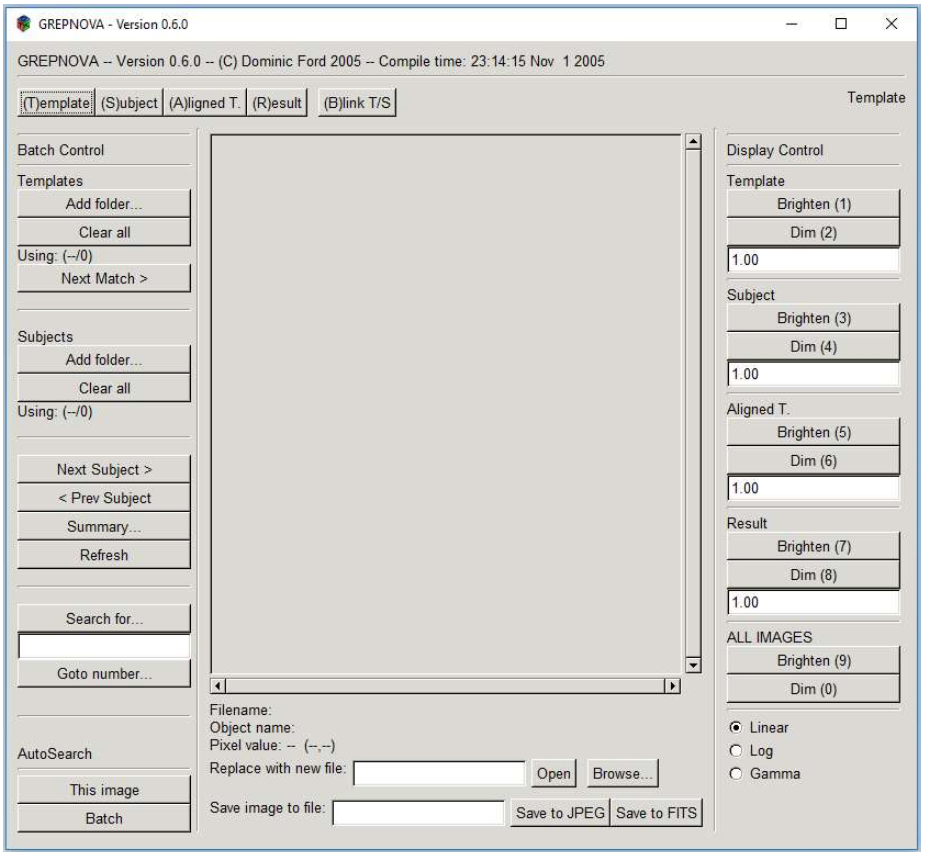


Figure 6: *GrepNova graphical user interface. Most used areas include the top and left side buttons which deal with the template and subject images. The buttons on the right-side control contrast and brightness of images.*

3. To add a template (reference) images, under the **Batch Control** section, **Templates** section on the left, select **Add folder…**.

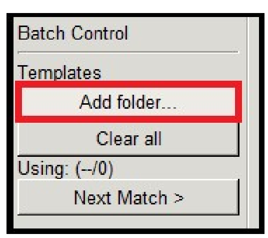


Figure 7: *Select Add folder... to select the folder where the template (reference) images are located.*

4. Navigating folders in GrepNova's interface is a little different than other programs. To navigate to where the template images are located, click the main drop-down bar and select the folder over where the images are located (up red arrow) and then click through the folder window to get to the folder where the images are at. Remember, you are not after a specific image; you are going to select the Template folder where all of the reference images were put.

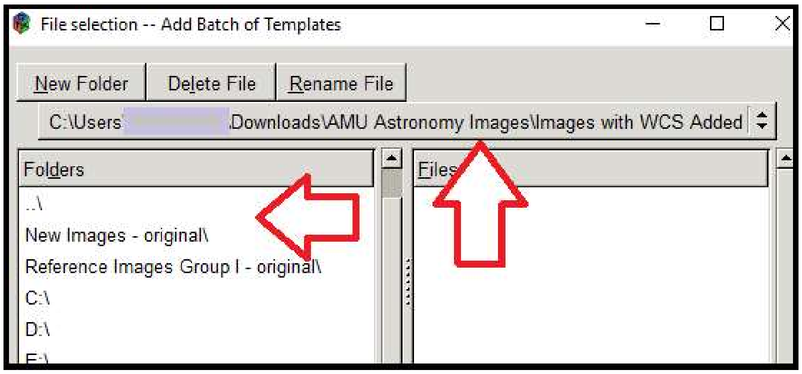


Figure 8: *First utilize the top drop-down bar to locate where the folder is at with the template files here it is located in **Downloads** => **AMU Astronomy Images** => **Images with WCS Added**. Next in the folders window (red left facing arrow), select or click through the folders to select where the template images were put.*

5. With the template folder selected, the image names should show up in the Files window. Select **OK** to add folder.

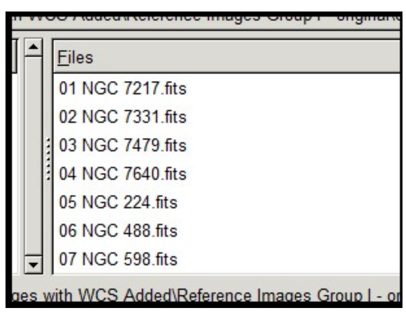
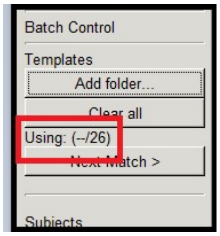


Figure 9: *With the folder selected, the image files will automatically populate in the files window.*

6. The GrepNova should now reflect the number of images in the template folder which was just added.

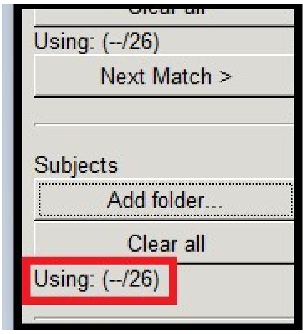


<u>Figure 10:</u> *Image count now populates.*

7. To add a subject (newly acquired) images, under the **Batch Control** section, **Subjects** section on the left, select **Add folder…**.

<u>Figure 11:</u> *Select **Add folder...** under the **Subjects** section.*

8. Go through the same process as steps 4, 5 and 6 for the subject images. When completed, GrepNova should indicate the addition of images.



<u>Figure 12:</u> *Subject image count now populates.*

9. To load the first set of images for analysis, select the button **Next Subject >** on the left side. It may take several seconds for the program to process the request, as it is analyzing the two images and creating reference points from the stars to spatially match.

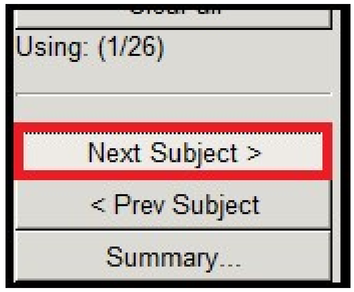
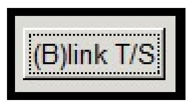


Figure 13: *Select Next Subject > button to load the first pair of images (template and subject).*

10. To start the blinking process, select the **(B)link T/S** button. It may take several seconds for the images to start blinking.



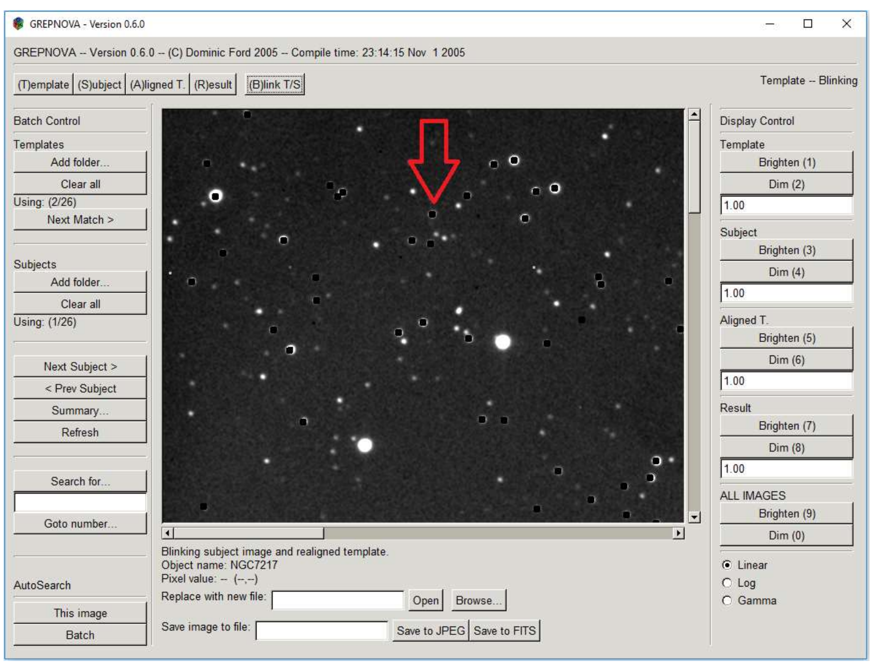
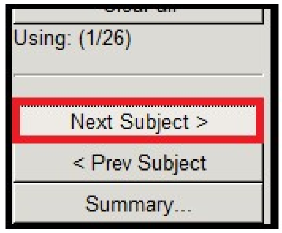


Figure 14: *The template and subject images will alternately blink. It is possible some of the star may be masked by black dots, these are just markers the program utilizes to spatially align the two images.*

11. When analysis is completed with the current image pair, select **Next Subject >** to advance to the next image pair.



12. When analysis of all image pairs has been completed, select the Clear all buttons under both the Template and Subjects sections to clear the folders just used. If more images are to be analyzed, go back and start at step 3.

Appendix G: MaxIm DL Supernova Search Tool – Supernova Search How-to Setup Guide

MaxIm DL

Supernova Search Tool Add-on

Supernova Search How-to Setup Guide

http://diffractionlimited.com/product/maxim-dl/

Windows Operating System Instructions

Note: All reference and subject image pairs utilized in MaxIm DL's Supernova Search Tool Add-on must have the same name, but can be different file formats (eg. reference image = NGC_1735.fit and subject image = NGC_1735.fit or reference image = NGC_1735.fit and subject image = NGC_1735.jpg --- This final example will not work = reference image = NGC_1735.fit and Stargroup_1.fit)

Cary D. Hatch

02 March 2019

1. Double click on the **MaxIm DL** icon to open the program. When open, minimize the program.

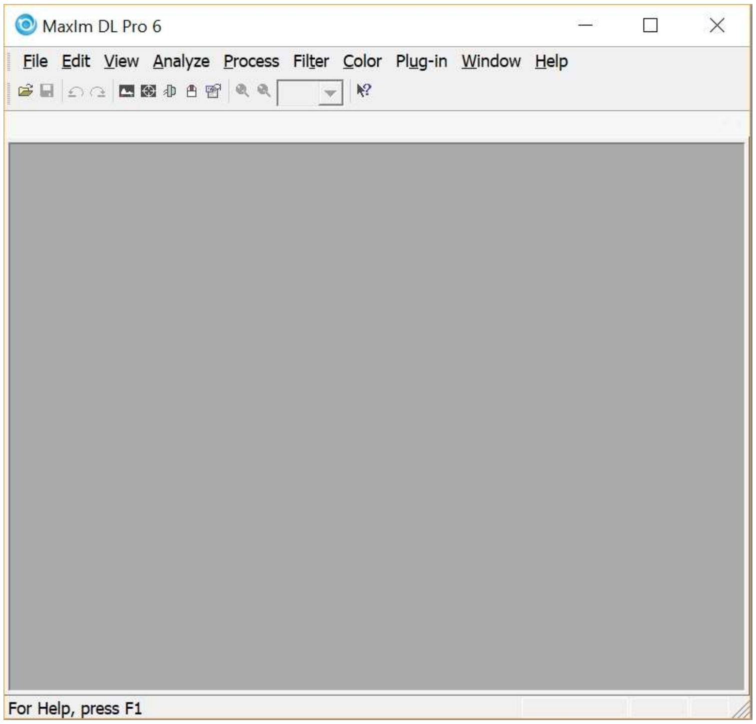


Figure 1: *A view of the MaxIm DL main window.*

2. Navigate to the Windows **Start** button, then select **All Programs** and search for **MaxIm DL 6 folder**. Expand the folder and look for **SN Search** option. Right click on **SN Search** and select **Send to** => **Desktop** (create shortcut) to create a desktop short cut icon to this add-on.

Figure 2: *Navigate to Windows Start => All Programs => MaxIm DL 6 => SN Search.*

3. Double click on the **SN Search** icon to open the program.

4. After the SN Search tool opens, select the locations of your reference (old) images, subject (new) images and a folder for reshoots (while necessary for the program to be pointed to a reshoot folder, this folder will not be utilized for the analysis of the images for this exercise).

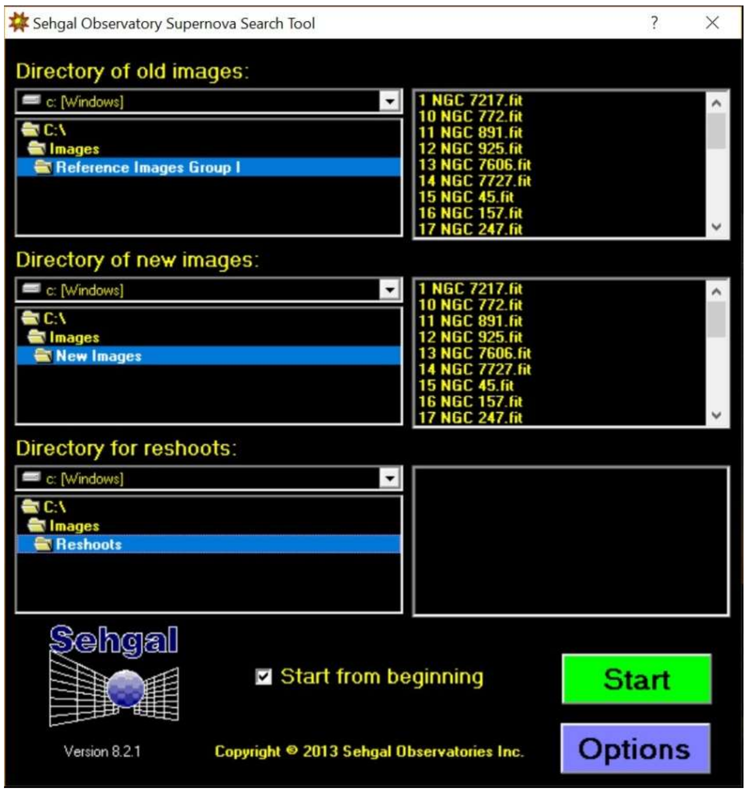


Figure 3: *The Supernova Search Tool main screen.*

5. Images from the folders should appear in the windows to the right of the directories. When ready, select the green button **Start**.

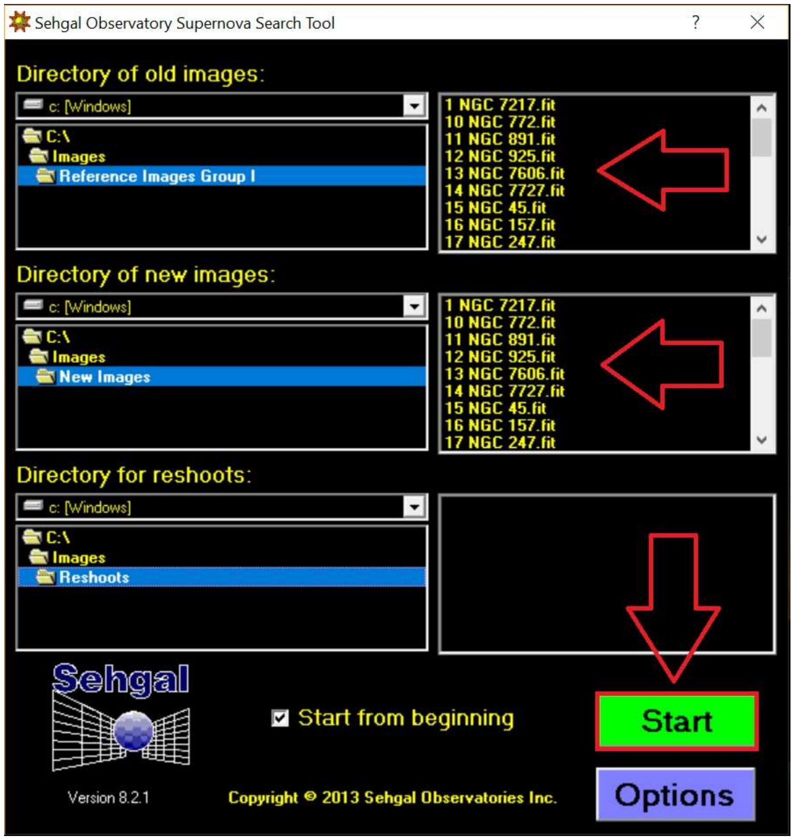


Figure 4: *Red arrows indicate images loaded in both the selected old and new directories along with an arrow indicating the start button.*

6. Maximize the MaxIm DL window and move the SN Tool Control box out of the way of the images.

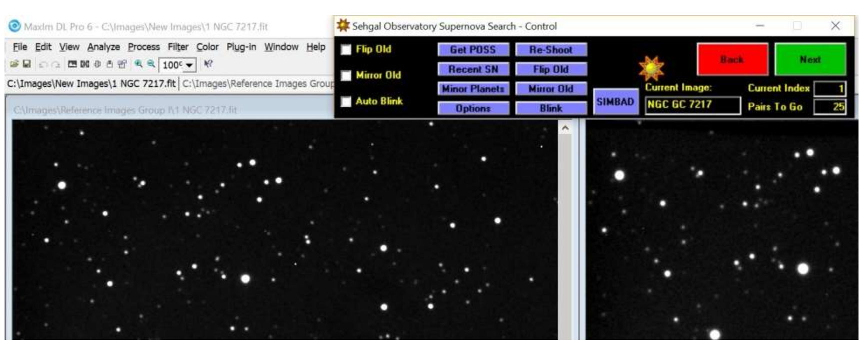


Figure 5: *The SN Search Control box is a floating box which can be moved around.*

7. On the SN Search Control box, select the **Blink** button. MaxIm DL will overlay the two images and begin the blink process. A smaller pop-up box will appear with a few options to control the blinking process.

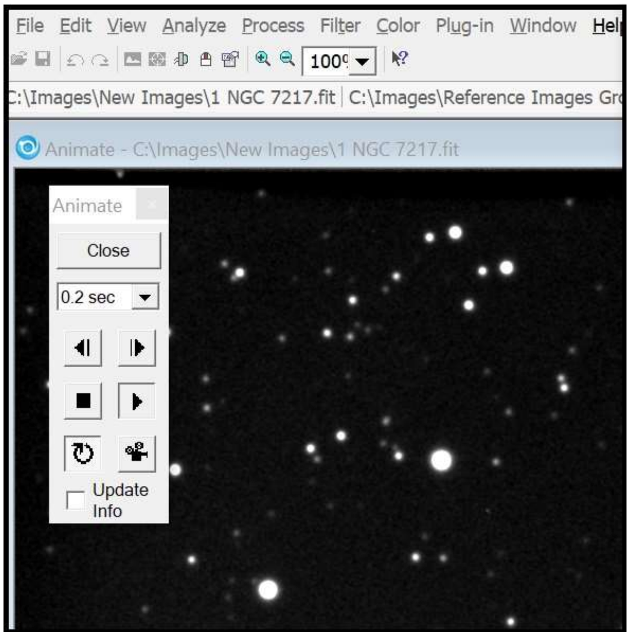


Figure 6: *After the Blink button is selected, MaxIm DL overlays the two images and automatically begins the blink process. Controls such as stop, start, forward frame and reverse frame.*

8. When analysis is complete, select the green **Next** button on the SN Search Control box to advance to the next image pair.

Figure 7: *Select the green Next arrow to advance to the next image pair.*

9. Continue until you have completed your analysis.

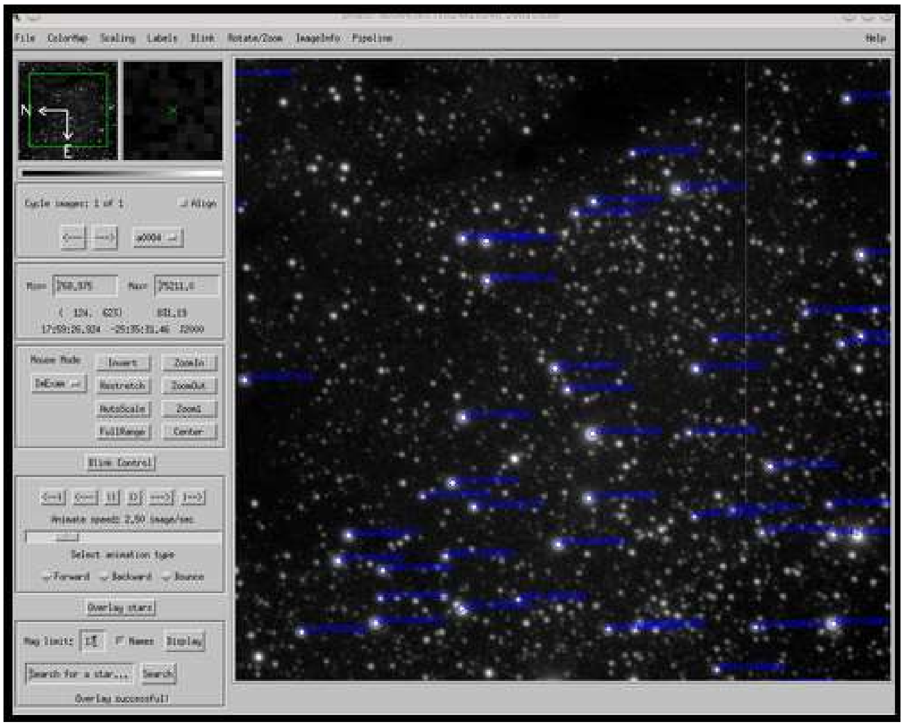
10. If there are more images to analyze, remove the images from the old and new directories and replace them with the next sets of reference and subject images to be analyzed.

Appendix H: PhAst – Supernova Search How-to Setup Guide

PhAst

<u>**Ph**</u>otometry-<u>**Ast**</u>rometry: A Flexible IDL Image Tool

Supernova Search How-to Setup Guide



https://www.noao.edu/staff/mighell/phast/

Windows Operating System Instructions

Note: All images utilized in PhAst must contain World Coordinate System (WCS) data. To add WCS data to an image, upload it to http://nova.astrometry.net/. After the website finishes adding the WCS data, the new image will be available for download – remember to rename the image prior to downloading others which were uploaded.

Cary D. Hatch
02 March 2019

1. Download and install an Interactive Data Language (IDL) 8.0 virtual machine* or higher (requires license to activate either for trial or full use) and install. Also needed is the phast141.zip file (https://www.noao.edu/noao/staff/mighell/phast/index.html), NASA IDL Astronomy User's Library (https://idlastro.gsfc.nasa.gov/) and Coyote Library (https://idlastro.gsfc.nasa.gov/ftp/coyote_astron.tar.gz).

2. Unzip phast141.zip into a folder along with NASA IDL Astronomy User's Library and Coyote Library.

3. To start PhAst, open the folder where PhAst was unzipped, find the file **phast.sav**. Drag **phast.sav** on top of the IDL program icon on the desktop (this will automatically open PhAst in IDL).

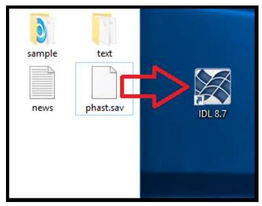


Figure 1: *Drag the **phast.sav** file onto the IDL icon on the desktop to launch PhAst.*

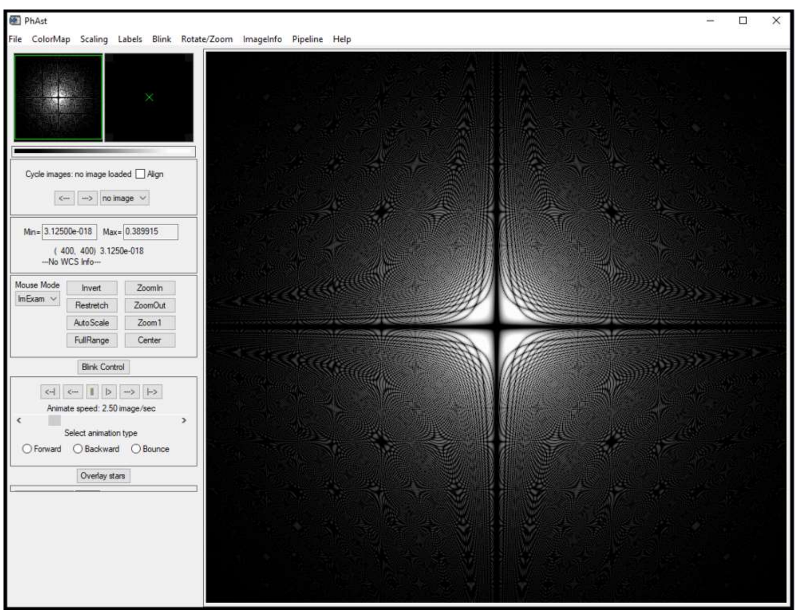
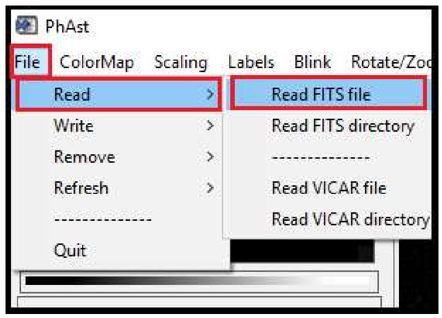


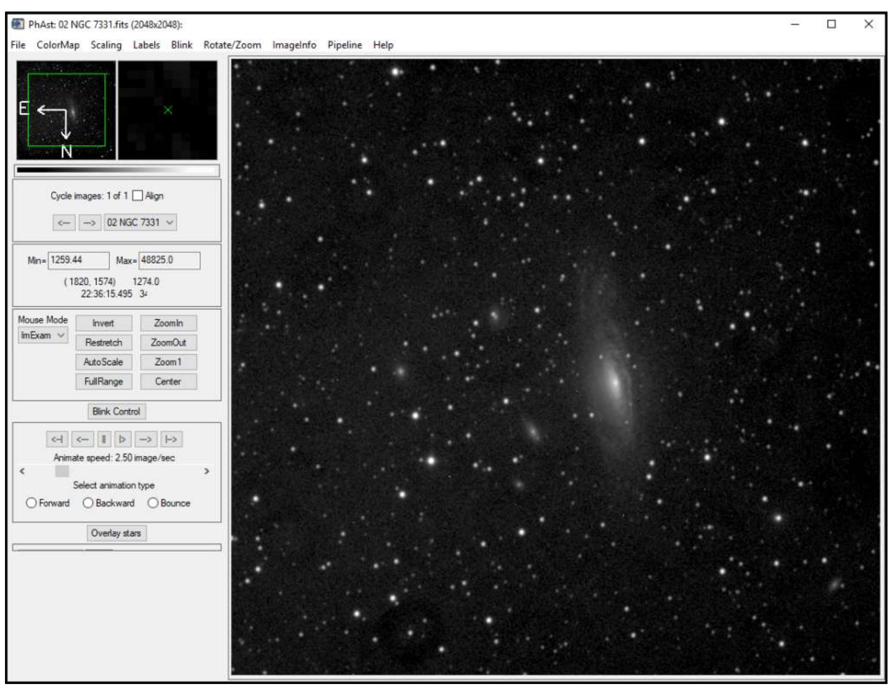
Figure 2: *PhAst's default view.*

* *The Harris Geospatial Solutions IDL Virtual Machine was utilized for this trial with a free two-week evaluation license. There are two other available free IDL virtual machines, GNU Data Language (GDL) 0.9.8 and Fawlty Language 0.79.46 which were not evaluated.*

4. Load one image pair (reference and subject) at a time with **File** => **Read** => **Read FITS file**. Only utilize the function **Read FITS directory** if you have multiple images of the same NGC (e.g. reference image, subject image 1, subject image 2...etc…) and want to blink-compare these images together. After selecting Read FITS file, navigate to the location where the reference image is stored and select it.



<u>Figure 3:</u> *Select **File** => **Read** => **Read FITS file** to add first a reference image and repeat to add the subject image.*



<u>Figure 4:</u> *After selecting a reference image, it will then appear in the view window and as an option in the drop-down box in the cycle images section towards the upper left.*

5. To load the subject image, follow the same procedure as in step 4, File => **File** => **Read** => **Read FITS file** and then navigate to the location where the subject images are located in the computer.

6. Select a subject image, select **OK**.

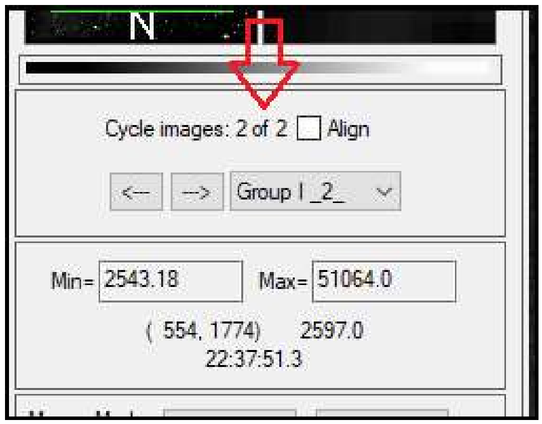


Figure 5: *When the subject image has been added, the cycle images counter will now show the total number of images loaded.*

7. Select the check box to align the images (if the images contain WCS data).

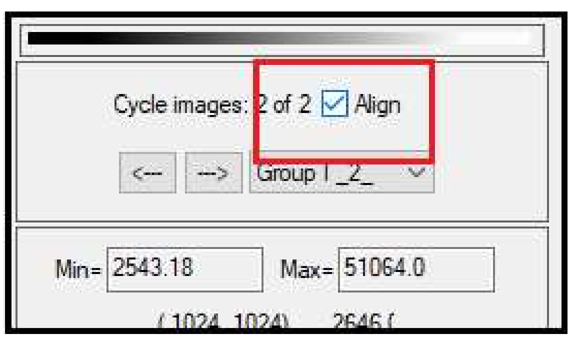


Figure 6: *Select the check box to align the two images via embedded WCS data.*

8. Next step is to begin the blink-comparison process. Navigate to the **Blink Control** section (expand it if it is collapsed) and click on the **Start Animation** (|>) button.

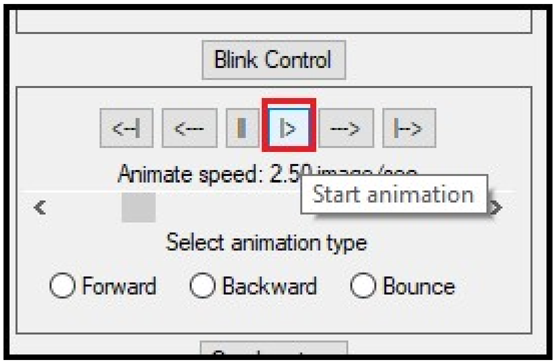


Figure 7: *Blink control buttons from left to right:* ***First Frame****,* ***Previous Image****,* ***Pause Animation****,* ***Start Animation****,* ***Next Image*** *and* ***Last Image****. Animate (blink) speed can be adjusted via slider bar.*

9. The ability to pan around the image is enabled in the over-view image (upper left corner with green box). Utilizing the right or left mouse buttons, hold down the mouse button and drag the green box to the location of the image you wish to view.

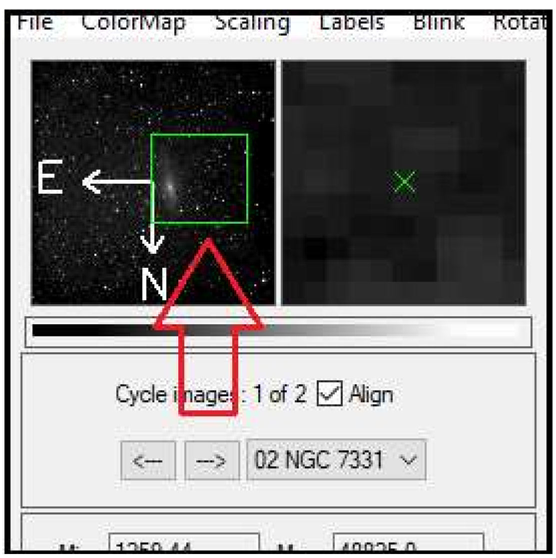


Figure 8: *By utilizing the right or left mouse button, move the green box to display a different area of the image.*

10. Other controls such as **ZoomIn**, **ZoomOut** and **Center** are located on the left side of the user interface.

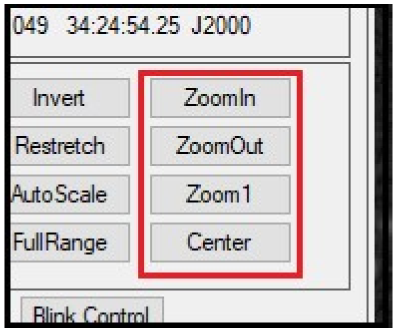


Figure 9: *User controls such as **ZoomIn**, **ZoomOut** and **Center** are also available.*

11. When analysis is completed of the current image pair, select **File** => **Remove** => **Remove all images** to close out currently open images.

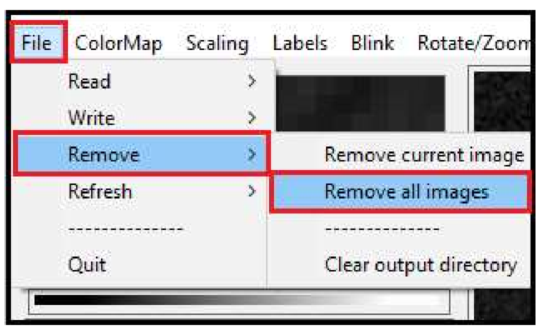


Figure 10: *To remove current images, select **File** => **Remove** => **Remove all images**.*

12. To load another image pair, return to step 4.

<u>**Appendix I: SAOImage DS9 – Supernova Search How-to Setup Guide**</u>

SAOImageDS9

Supernova Search How-to Setup Guide

Note: All images utilized in SAOImageDS9 must contain World Coordinate System (WCS) data. To add WCS data to an image, upload it to http://nova.astrometry.net/. After the website finishes adding the WCS data, the new image will be available for download – remember to rename the image prior to downloading others which were uploaded.

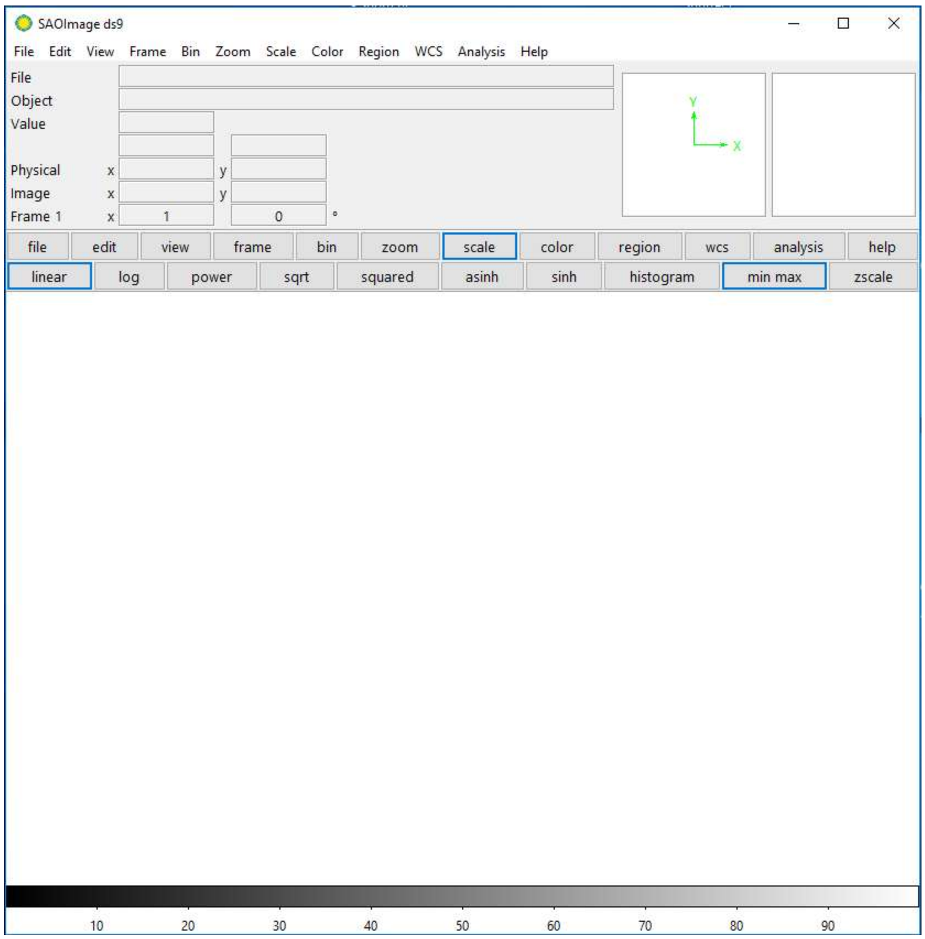
http://ds9.si.edu/site/Home.html

Windows Operating System Instructions

Cary D. Hatch

02 March 2019

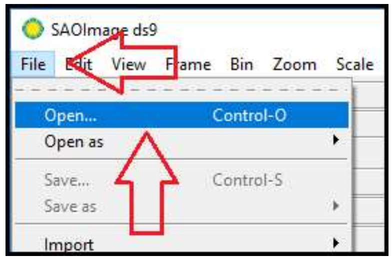
1. Double click on **SAOImageDS9** icon to open the program.



<u>Figure 1:</u> *The main screen of SAOImageDS9. Frequently used options are found in the upper drop-down menus or in the middle toolbar section.*

2. There are two ways to add reference and subject images, drop-down menus and toolbar options.

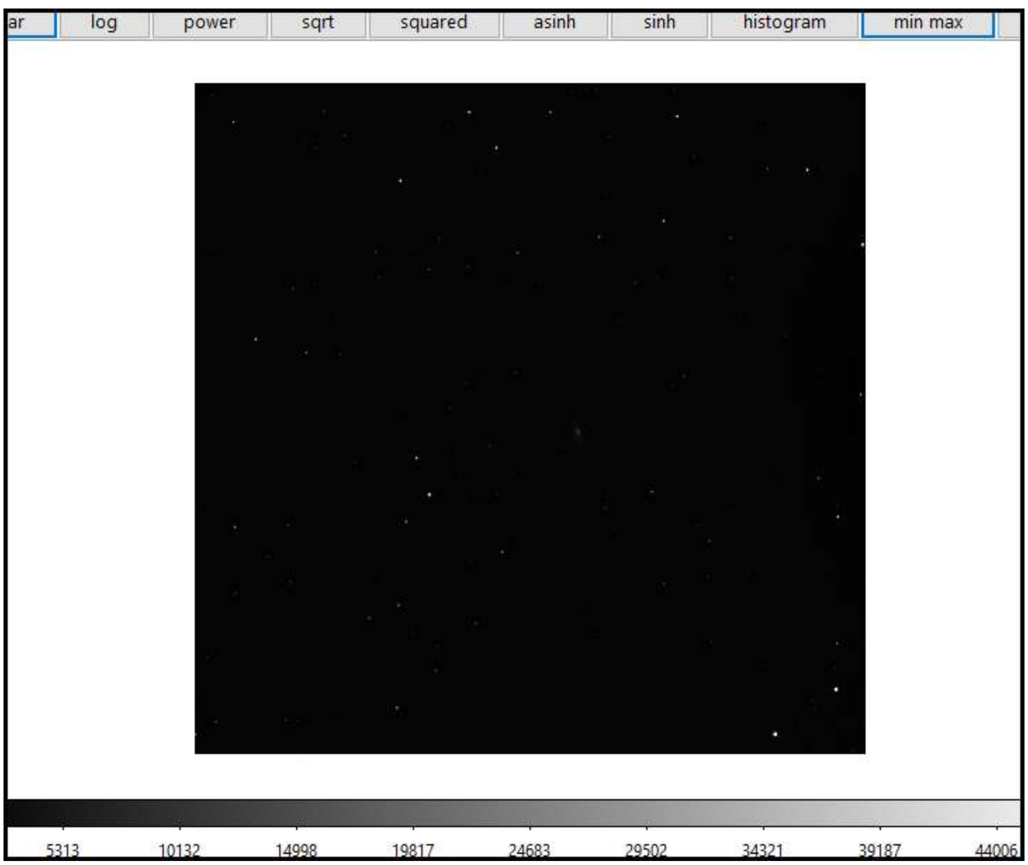
3. **<u>Option 1</u>** – <u>Drop-down menu</u>: Select **File** in the drop-down menu, then select **Open**.



<u>Figure 2:</u> *To open a reference image, select **File** from the drop-down and then **Open.***

4. Navigate to where the image files are stored and select a reference image, then select **OK**.

5. Use the scroll-wheel on the mouse to adjust the size of the image so the entire image fits within the viewing area.



<u>Figure 3:</u> *Adjust the size of the image so it fits within the view window of the program.*

6. The next step creates a second frame for the subject image to load to. Select the **Frame** drop-down menu and then select **Tile Frames**, followed by selecting **New Frame**. The purpose of tile frames allows both reference and subject image to be side by side (easier to size match).

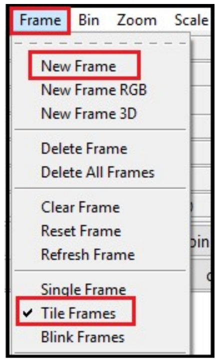


Figure 4: *Red boxes highlight the* ***Tile Frames*** *and* ***New Frame*** *options in the* ***Frame*** *drop-down menu.*

7. Repeat steps 3, 4 and 5 to select and load the subject image. Ensure the new image is the same size as the reference image. To move back and forth between images, select **Frame** drop-down menu and the select either **Previous Frame** or **Next Frame** depending on which image you need to see. (*Proceed to step 12*).

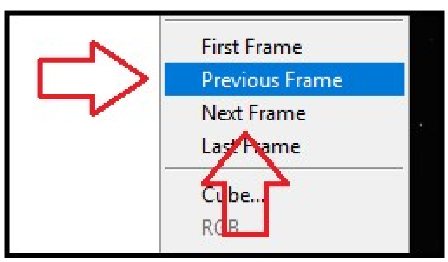


Figure 5: *The red arrows show the two options which can be used to cycle back and forth between images to ensure they are the same size.*

8. **Option 2** – Toolbar: On the toolbar, select the **File** button, then select **Open** button.

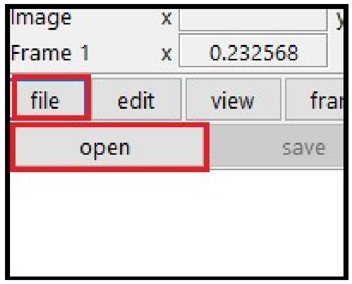


Figure 6: *The red boxes indicate the **File** button and the **Open** button needed to access the reference image.*

9. Navigate to where the subject image is located, select an image and then select **OK**.

10. The next step creates a second frame for the subject image to load to. Select the **Frame** button and then select the **Tile** button and then the **New** button. The view area will go white as the new frame does not have an image loaded against it yet.

Figure 7: *Red boxes indicate the **Frame** button, **Tile** button and the **New** button needed to add the subject image.*

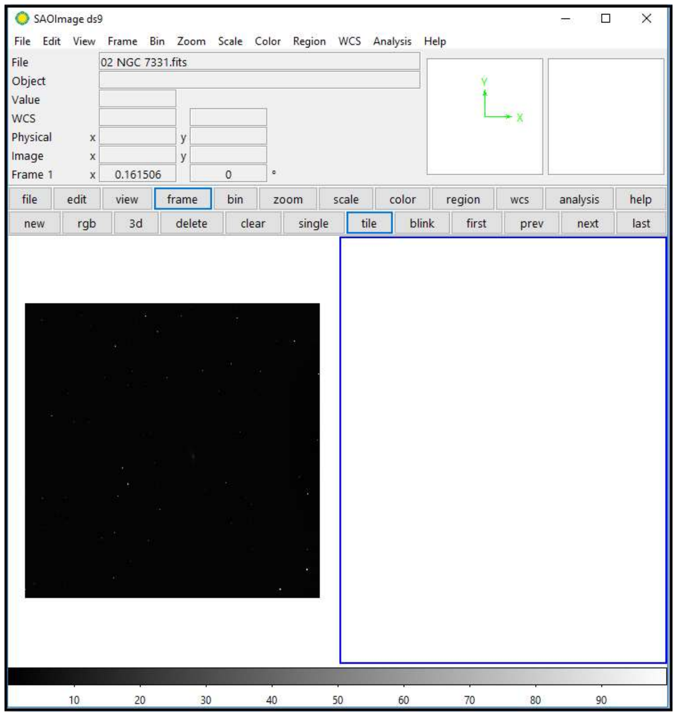


Figure 8: *This image displays the current opened reference image with a new blank frame for the subject image next to it.*

11. Follow steps 8 and 9 to load the subject image. Ensure the subject image is the same size as the reference image after loading.

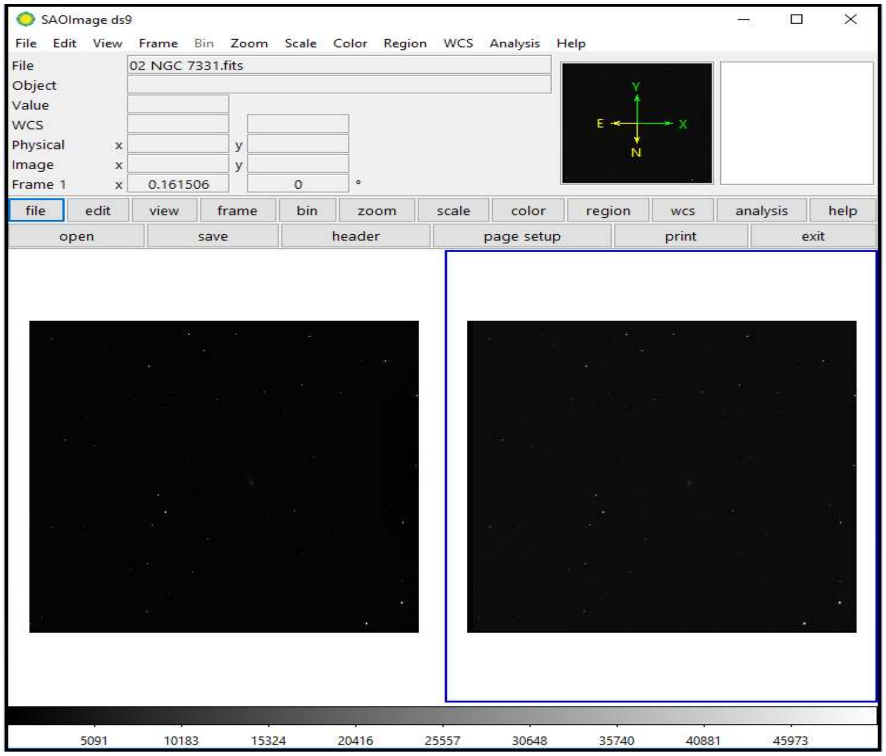


Figure 9: *This image shows both the reference and subject images tiled, side by side to ensure they are the same size.*

12. Next step will align the two images (note: images will not align in DS9 unless they have WCS data loaded on them). This can only be accomplished through the drop-down menu. Select Frame drop-down menu and then select **Match** => **Frame** => **WCS**. It is possible the images will shift or rotate to ensure they are spatially matched correctly.

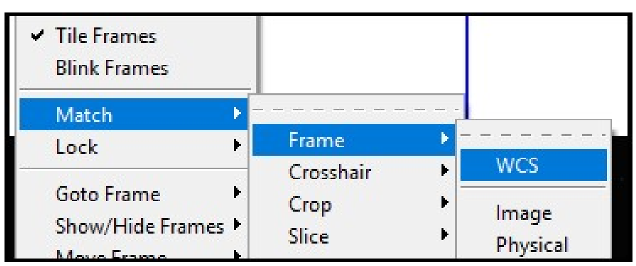


Figure 10: *As each of the menu items are selected, the option tree will continue to expand.*

13. In this step, the images will be locked together so that both will zoom in/out and pan in unison. Select Frame drop-down menu, then select **Lock** => **Frame** => **WCS** to lock the two frames together.

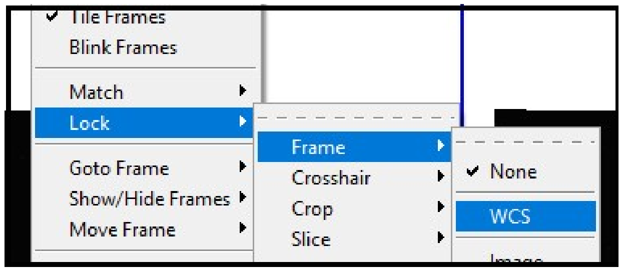


Figure 11: *Select from the **Frame** menu, **Lock, Frame** and **WCS** to lock the two frames together.*

14. To initiate blink-comparison, select Frame drop-down and then select Blink Frames.

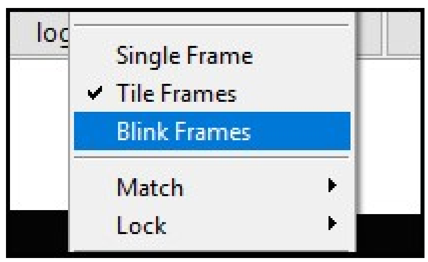


Figure 12: *Selecting **Blink Frames** from the **Frame** drop-down will start the blinking process.*

15. The blink option can also be initiated through the toolbar.

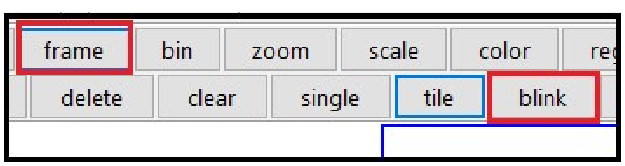


Figure 13: *In the tool bar, select **Frame** and then **Blink** to start the blinking process.*

16. To stop the blinking process, click on the **Single** button in the tool bar. To remove the images, select the **Delete** button twice to delete both images. To load the next images, select the **New** button (or **Frame** => **New Frame**) and then proceed to either step 3 or 8 depending on which method you choose.

- Sometimes images initially show up dark when loaded into SAOImageDS9. To adjust the contrast of an image, hold down the right mouse-button and drag the mouse to the left. The image should begin to appear lighter, stop when there is a level which works for the images which shows enough detail, but does not wash out.

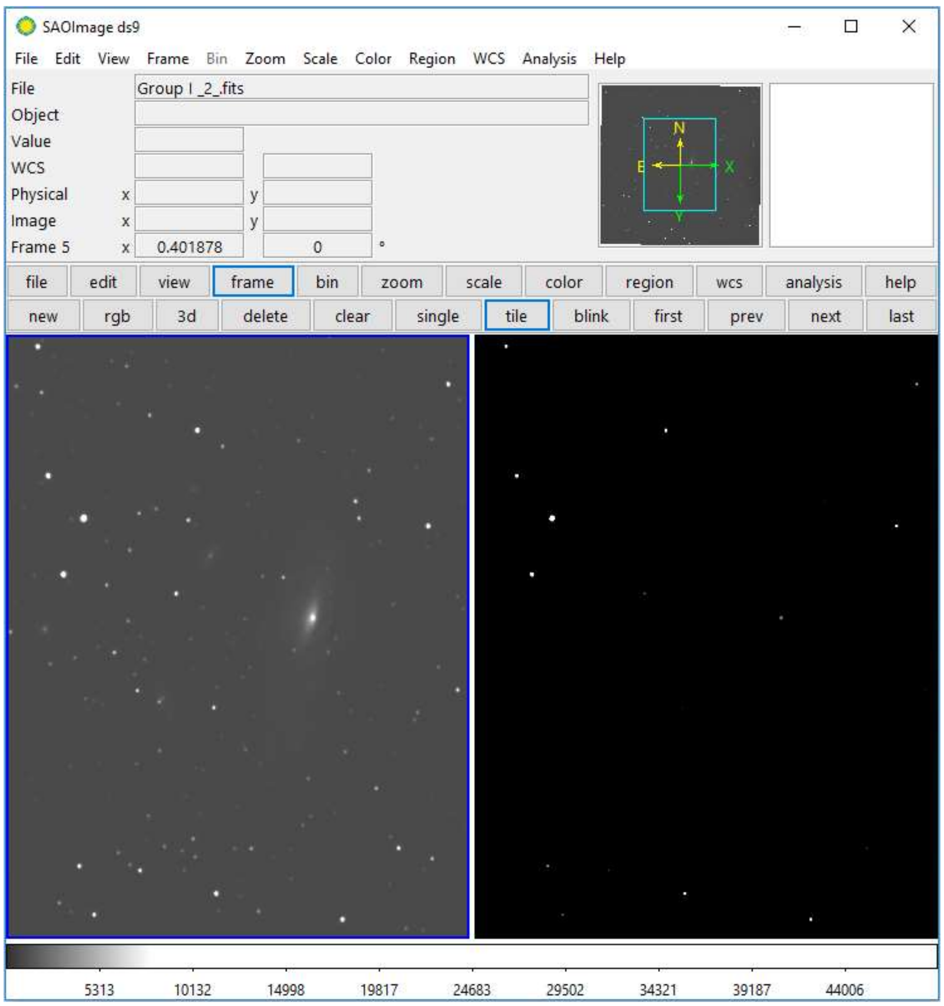


Figure 14: *This image shows right frame after adjusting the contrast while the left frame appears as it loaded. Adjust both images to an appropriate contrast to make it easier during analysis of images during the blink-comparison.*

Appendix J: Starblinker – Supernova Search How-to Setup Guide

Starblinker

Supernova Search How-to Setup Guide

http://starblinker.com/

Windows Operating System Instructions

Note: All images utilized in Starblinker must be converted to any of the following formats to work: .bmp, .jpg, .jpeg, .tif, or .tiff.

Cary D. Hatch

02 March 2019

1. Double click on the **Starblinker** icon to open the program.

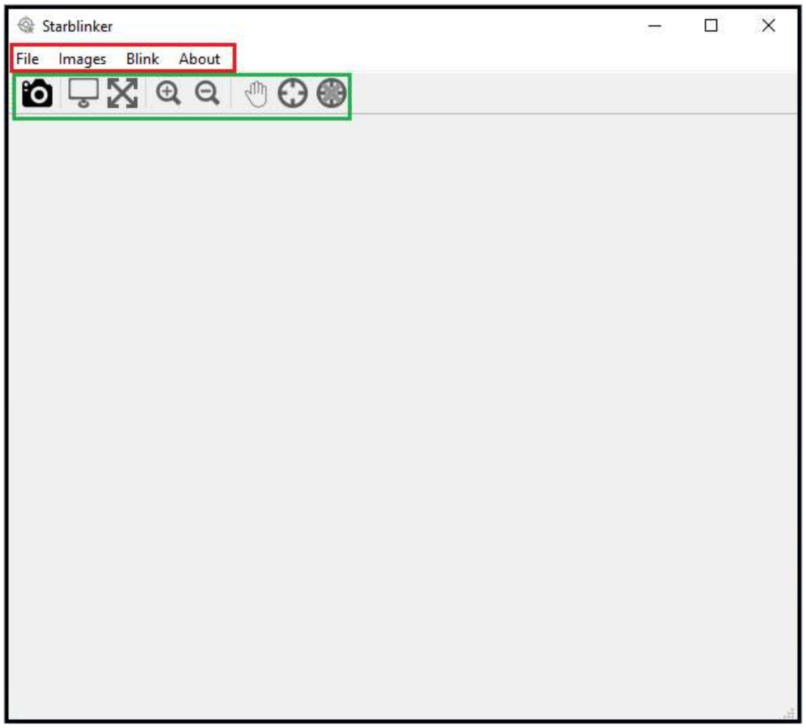


Figure 1: *Main view of the Starblinker program. The red box indicates drop-down menu options while the green box highlights the same options in a hot bar format.*

2. When initially opening the program, a selection box will automatically appear. Navigate to where the reference images are stored and select an image and then select **Open**.

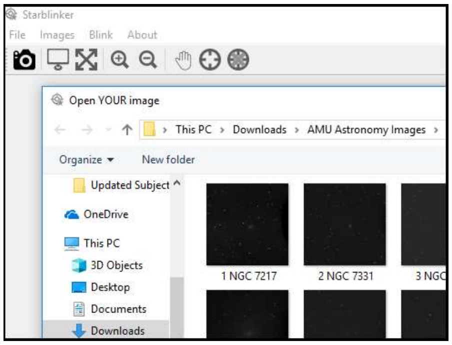


Figure 2: *Initial pop-up window allows for selection of reference image.*

3. After selecting the reference image, another pop-up box will appear allowing for selection of comparison image. Navigate to the comparison image, select an image and select **Open**.

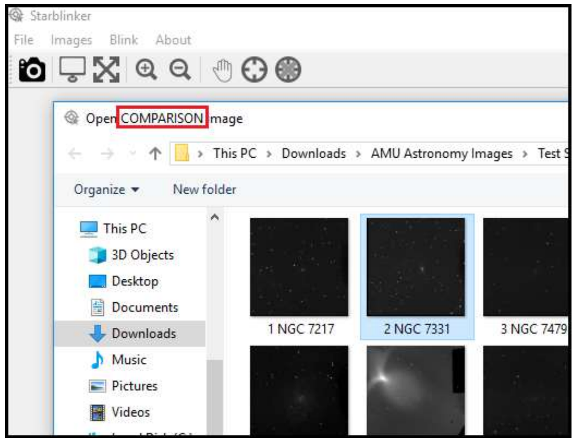


Figure 3: *A second pop-up box opens and allows selection of comparison image.*

4. After selection of comparison image, Starblinker attempts to spatially align the two images which may take time depending on the processing power of the computer.

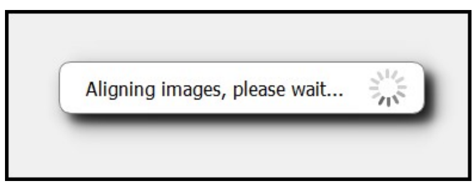


Figure 4: *Aligning the two images wait time depends on the processing power of the computer.*

5. If successful, the two images will appear and begin to alternate (blink).

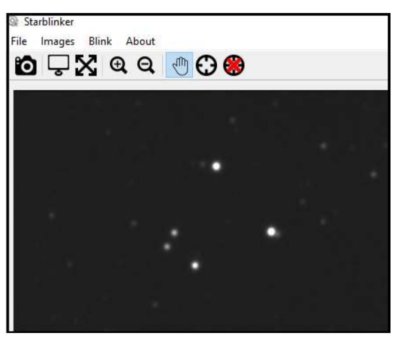


Figure 5: *The reference and comparison image will alternately blink allowing for analysis of differences in the images.*

6. It is possible to receive an error message if either the reference and comparison images do not match or if there is not enough information on the image for the program to correlate the two spatially.

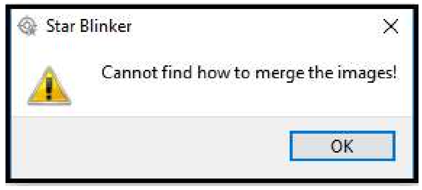


Figure 6: *Error message could indicate a mismatch in the selected images or not enough information in one of the images to*

7. One feature of this program is to mark areas of interest on the image. To do so, select **Draw a mark** from the hot bar.

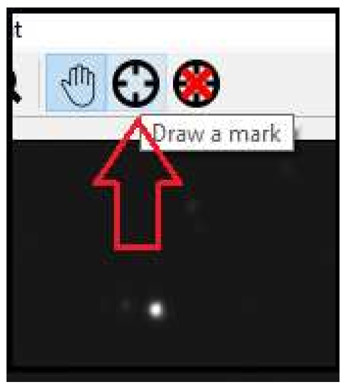


Figure 7: *Red arrow indicates the Draw a mark function.*

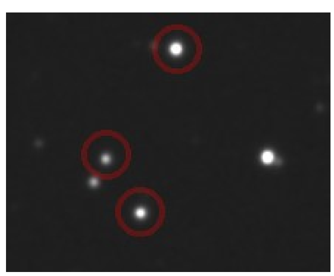


Figure 8: *Celestial objects with a mark placed around them.*

8. When analysis is complete, select either through the drop-down menu **File** => **Open Images** or select the **camera icon** (Open Images) from the hot bar.

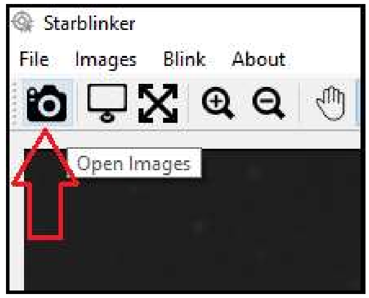


Figure 9: *Either utilize the File drop-down menu or the camera icon to select the next images.*

9. Return to step 2 and start the process over for the next set of images.

Appendix K: Supernova Observation Sheet – Aladin – Linux

	Analysis Date:	22-Feb-19				
	Image Group	I				
	Observatory	APUS Telescope				
	Analyzed by:	C. Hatch	Linux			
Image #	Galaxy	Analysis Software	Template Quality	Subject Quality	Other Information	Software Problems
1	NGC 7217	Aladin	Good	Good	Good alignment	None
2	NGC 7331	Aladin	Good	Good	Good alignment, slightly warped	None
3	NGC 7479	Aladin	Good	Good	Good alignment	None
4	NGC 7640	Aladin	Good	Good	Good alignment, slightly warped at bottom of im	None
5	NGC 224	Aladin	Blurry (clouds)	Blurry (clouds)	Good alignment	None
6	NGC 448	Aladin	Sharp	Blurry (image shift)	Good alignment	None
7	NGC 598	Aladin	Sharp	Blurry (image shift)	Good alignment – subject blurry	None
8	NGC 628	Aladin	Sharp	Light Bloom	Alignment slightly off – most stars blown out	None
9	NGC 672	Aladin	Sharp	Good	Good alignment	None
10	NGC 772	Aladin	Sharp	Light Bloom	Good alignment – most stars blown out	None
11	NGC 891	Aladin	Sharp	Sharp	Good alignment	None
12	NGC 925	Aladin	Sharp	Blurry (clouds)	Good alignment	None
13	NGC 7606	Aladin	Good	Pixelated?	Good alignment – pixelated, most stars blown	None
14	NGC 7727	Aladin	Good	Good	Good alignment	None
15	NGC 45	Aladin	Good	Pixelated?	Alignement is significantly off,due to warping?	None
16	NGC 157	Aladin	Good	Good	Good alignment	None
17	NGC 247	Aladin	Good	Good	Good alignment	None
18	NGC 253	Aladin	Good	Good/Dark	Good alignment	None
19	NGC 578	Aladin	Good	Unreadable	Subject image could not accept WCS data.	Could not resolve
20	NGC 720	Aladin	Good	Blurry (clouds)	Good alignment	None
21	NGC 908	Aladin	Good	Good	Good alignment	None
22	NGC 936	Aladin	Good	Good	Good alignment	None
23	NGC 1055	Aladin	Good	Blurry (clouds)	Good alignment – clouds obstructing part	None
24	NGC 1068	Aladin	Good	Blurry (clouds)	Good alignment – clouds obstructing part	None
25	NGC 1073	Aladin	Sharp	Blurry (clouds)	Good alignment – clouds obstructing part	None
26	NGC 1087	Aladin	Sharp	Blurry (clouds)	Good alignment	None

Appendix L: Supernova Observation Sheet – SAOImage DS9 – Linux

	Analysis Date:	22-Feb-19				
	Image Group	I				
	Observatory	APUS Telescope				
	Analyzed by:	C. Hatch	Linux			
Image #	Galaxy	Analysis Software	Template Quality	Subject Quality	Other Information	Software Problems
1	NGC 7217	SAOImageDS9	Good	Good	Very good spatial alignment	None
2	NGC 7331	SAOImageDS9	Good	Good	Very good spatial alignment	None
3	NGC 7479	SAOImageDS9	Good	Good	Very good spatial alignment	None
4	NGC 7640	SAOImageDS9	Good	Good	Very good spatial alignment	None
5	NGC 224	SAOImageDS9	Blurry (clouds)	Blurry (clouds)	Very good spatial alignment - slightly hazy	None
6	NGC 448	SAOImageDS9	Sharp	Blurry (image shift)	Very good spatial alignment - slightly hazy	None
7	NGC 598	SAOImageDS9	Sharp	Blurry (image shift)	Good alignment – subject appears warped	None
8	NGC 628	SAOImageDS9	Sharp	Light Bloom	Very good spatial alignment - washout	None
9	NGC 672	SAOImageDS9	Sharp	Good	Very good spatial alignment	None
10	NGC 772	SAOImageDS9	Sharp	Light Bloom	Very good spatial alignment - washout	None
11	NGC 891	SAOImageDS9	Sharp	Sharp	Very good spatial alignment	None
12	NGC 925	SAOImageDS9	Sharp	Blurry (clouds)	Very good spatial alignment	None
13	NGC 7606	SAOImageDS9	Good	Pixelated?	Very good spatial alignment - pixelated	None
14	NGC 7727	SAOImageDS9	Good	Good	Very good spatial alignment	None
15	NGC 45	SAOImageDS9	Good	Good	Very good spatial alignment	None
16	NGC 157	SAOImageDS9	Good	Good	Very good spatial alignment	None
17	NGC 247	SAOImageDS9	Good	Good	Very good spatial alignment - auto rotated	None
18	NGC 253	SAOImageDS9	Good	Good/Dark	Very good spatial alignment - auto rotated	None
19	NGC 578	SAOImageDS9	Good	Unreadable	WCS data not accepted	Could not resolve
20	NGC 720	SAOImageDS9	Good	Blurry (clouds)	Very good spatial alignment	None
21	NGC 908	SAOImageDS9	Good	Good	Very good spatial alignment	None
22	NGC 936	SAOImageDS9	Good	Good	Very good spatial alignment	None
23	NGC 1055	SAOImageDS9	Good	Blurry (clouds)	Very good spatial alignment - slightly hazy	None
24	NGC 1068	SAOImageDS9	Good	Blurry (clouds)	Very good spatial alignment - slightly hazy	None
25	NGC 1073	SAOImageDS9	Sharp	Blurry (clouds)	Very good spatial alignment - slightly hazy	None
26	NGC 1087	SAOImageDS9	Sharp	Blurry (clouds)	Very good spatial alignment - slightly hazy	None

Appendix M: Supernova Observation Sheet – Aladin – Windows

	Analysis Date:	14-Feb-19				
	Image Group	I				
	Observatory	APUS Telescope				
	Analyzed by:	C. Hatch	Windows			
Image #	Galaxy	Analysis Software	Template Quality	Subject Quality	Other Information	Software Problems
1	NGC 7217	Aladin	Good	Good		None
2	NGC 7331	Aladin	Good	Good		None
3	NGC 7479	Aladin	Good	Good		None
4	NGC 7640	Aladin	Good	Good		None
5	NGC 224	Aladin	Blurry (clouds)	Blurry (clouds)	Subject fuzzy due to clouds	None
6	NGC 448	Aladin	Sharp	Blurry (image shift)	Subject fuzzy due to clouds	None
7	NGC 598	Aladin	Sharp	Blurry (image shift)	Subject fuzzy due to clouds	None
8	NGC 628	Aladin	Sharp	Light Bloom	Subject image contract adjusted for light bloom	None
9	NGC 672	Aladin	Sharp	Good	Adjusted contrast on both images	None
10	NGC 772	Aladin	Sharp	Light Bloom	Most stars blown out due to light bloom.	None
11	NGC 891	Aladin	Sharp	Sharp	Very good spatial alignment	None
12	NGC 925	Aladin	Sharp	Blurry (clouds)	Usable	None
13	NGC 7606	Aladin	Good	Pixelated?	Heavily pixelated	None
14	NGC 7727	Aladin	Good	Good		None
15	NGC 45	Aladin	Good	Pixelated?	Heavily pixelated	None
16	NGC 157	Aladin	Good	Good	Good alignment	None
17	NGC 247	Aladin	Good	Good	Properly auto rotated template 180°	None
18	NGC 253	Aladin	Good	Good/Dark	Properly auto rotated template 180°	None
19	NGC 578	Aladin	Good	Unreadable	WCS data not accepted	Could not resolve
20	NGC 720	Aladin	Good	Blurry (clouds)	Dark image	None
21	NGC 908	Aladin	Good	Good	Aligned very well	None
22	NGC 936	Aladin	Good	Good	Slightly blurry	None
23	NGC 1055	Aladin	Good	Blurry (clouds)	Clouds obscure all but brighter stars	None
24	NGC 1068	Aladin	Good	Blurry (clouds)	Clouds obscure all but brighter stars	None
25	NGC 1073	Aladin	Sharp	Blurry (clouds)	Clouds obscure all but brighter stars	None
26	NGC 1087	Aladin	Sharp	Blurry (clouds)	Slightly blurry, difficult to use	None

Appendix N: Supernova Observation Sheet – Astrometrica - Windows

	Analysis Date:	14-Feb-19				
	Image Group	I				
	Observatory	APUS Telescope				
	Analyzed by:	C. Hatch	Windows			
Image #	Galaxy	Analysis Software	Template Quality	Subject Quality	Other Information	Software Problems
1	NGC 7217	Astrometrica	Good	Good		None
2	NGC 7331	Astrometrica	Good	Good		None
3	NGC 7479	Astrometrica	Good	Good		None
4	NGC 7640	Astrometrica	Good	Good		None
5	NGC 224	Astrometrica	Blurry (clouds)	Blurry (clouds)	Invert image (black hot)	None
6	NGC 448	Astrometrica	Sharp	Blurry (image shift)	Invert image (black hot)	None
7	NGC 598	Astrometrica	Sharp	Blurry (image shift)	Invert image (black hot)	None
8	NGC 628	Astrometrica	Sharp	Light Bloom	Subject image contract adjusted for light bloom	None
9	NGC 672	Astrometrica	Sharp	Good		None
10	NGC 772	Astrometrica	Sharp	Light Bloom	Most stars blown out due to light bloom.	None
11	NGC 891	Astrometrica	Sharp	Sharp		None
12	NGC 925	Astrometrica	Sharp	Blurry (clouds)		None
13	NGC 7606	Astrometrica	Good	Pixelated?	Heavily pixelated	None
14	NGC 7727	Astrometrica	Good	Good		None
15	NGC 45	Astrometrica	Good	Good	Heavily pixelated	None
16	NGC 157	Astrometrica	Good	Good	Good alignment	None
17	NGC 247	Astrometrica	Good	Good	Properly auto rotated template 180°	None
18	NGC 253	Astrometrica	Good	Good/Dark	Properly auto rotated template 180°	None
19	NGC 578	Astrometrica	Good	Unreadable	Heavily pixelated, not enough reference points	Could not resolve
20	NGC 720	Astrometrica	Good	Blurry (clouds)	Slightly blurry, brighter stars due to clouds	None
21	NGC 908	Astrometrica	Good	Good		None
22	NGC 936	Astrometrica	Good	Good	Slightly blurry - usable	None
23	NGC 1055	Astrometrica	Good	Blurry (clouds)	Clouds obscure all but brighter stars - poor	None
24	NGC 1068	Astrometrica	Good	Blurry (clouds)	Clouds obscure all but brighter stars - poor	None
25	NGC 1073	Astrometrica	Sharp	Blurry (clouds)	Clouds obscure all but brighter stars - poor	None
26	NGC 1087	Astrometrica	Sharp	Blurry (clouds)	Slightly blurry, not very usable	None

Appendix O: Supernova Observation Sheet – SAOImage DS9 - Windows

	Analysis Date:	14-Feb-19				
	Image Group	I				
	Observatory	APUS Telescope				
	Analyzed by:	C. Hatch	Windows			

Image #	Galaxy	Analysis Software	Template Quality	Subject Quality	Other Information	Software Problems
1	NGC 7217	SAOImageDS9	Good	Good	Very good spatial alignment	None
2	NGC 7331	SAOImageDS9	Good	Good	Very good spatial alignment	None
3	NGC 7479	SAOImageDS9	Good	Good	Very good spatial alignment	None
4	NGC 7640	SAOImageDS9	Good	Good	Very good spatial alignment	None
5	NGC 224	SAOImageDS9	Blurry (clouds)	Blurry (clouds)	Very good spatial alignment	None
6	NGC 448	SAOImageDS9	Sharp	Blurry (image shift)	Very good spatial alignment - slight haze	None
7	NGC 598	SAOImageDS9	Sharp	Blurry (image shift)	Very good spatial alignment - slight haze	None
8	NGC 628	SAOImageDS9	Sharp	Light Bloom	Very good spatial alignment - some washout	None
9	NGC 672	SAOImageDS9	Sharp	Good	Very good spatial alignment - slight haze	None
10	NGC 772	SAOImageDS9	Sharp	Light Bloom	Very good spatial alignment - adj contrast	None
11	NGC 891	SAOImageDS9	Sharp	Sharp	Very good spatial alignment	None
12	NGC 925	SAOImageDS9	Sharp	Blurry (clouds)	Very good spatial alignment	None
13	NGC 7606	SAOImageDS9	Good	Pixelated?	Very good spatial alignment - faint - adj contrast	None
14	NGC 7727	SAOImageDS9	Good	Good	Very good spatial alignment	None
15	NGC 45	SAOImageDS9	Good	Good	Very good spatial alignment	None
16	NGC 157	SAOImageDS9	Good	Good	Very good spatial alignment	None
17	NGC 247	SAOImageDS9	Good	Good	Very good spatial alignment - auto rotated	None
18	NGC 253	SAOImageDS9	Good	Good/Dark	Slightly off spatial alignment - auto rotated	None
19	NGC 578	SAOImageDS9	Good	Unreadable	Subject could not accept WCS data	Could not resolve
20	NGC 720	SAOImageDS9	Good	Blurry (clouds)	Very good spatial alignment	None
21	NGC 908	SAOImageDS9	Good	Good	Very good spatial alignment	None
22	NGC 936	SAOImageDS9	Good	Good	Very good spatial alignment	None
23	NGC 1055	SAOImageDS9	Good	Blurry (clouds)	Very good spatial alignment	None
24	NGC 1068	SAOImageDS9	Good	Blurry (clouds)	Very good spatial alignment - slight haze	None
25	NGC 1073	SAOImageDS9	Sharp	Blurry (clouds)	Very good spatial alignment - blurry	None
26	NGC 1087	SAOImageDS9	Sharp	Blurry (clouds)	Very good spatial alignment - blurry	None

Appendix P: Supernova Observation Sheet – GrepNova – Windows

	Analysis Date:	13-Feb-19				
	Image Group	I				
	Observatory	APUS Telescope				
	Analyzed by:	C. Hatch	Windows			
Image #	Galaxy	Analysis Software	Template Quality	Subject Quality	Other Information	Software Problems
1	NGC 7217	GrepNova	Good	Good		None
2	NGC 7331	GrepNova	Good	Good		None
3	NGC 7479	GrepNova	Good	Good		None
4	NGC 7640	GrepNova	Good	Good		None
5	NGC 224	GrepNova	Blurry (clouds)	Blurry (clouds)		None
6	NGC 448	GrepNova	Sharp	Blurry (image shift)		Mis-aligned
7	NGC 598	GrepNova	Sharp	Blurry (image shift)		None
8	NGC 628	GrepNova	Sharp	Light Bloom	Slightly usable	Failed match
9	NGC 672	GrepNova	Sharp	Good		None
10	NGC 772	GrepNova	Sharp	Light Bloom	Very good spatial alignment - adj contrast	Failed match
11	NGC 891	GrepNova	Sharp	Sharp		None
12	NGC 925	GrepNova	Sharp	Blurry (clouds)		None
13	NGC 7606	GrepNova	Good	Pixelated?	Heavy pixilation	None
14	NGC 7727	GrepNova	Good	Good		None
15	NGC 45	GrepNova	Good	Good	Possible slight coud interference	Mis-aligned
16	NGC 157	GrepNova	Good	Good	Possible slight coud interference	None
17	NGC 247	GrepNova	Good	Good	Properly auto-rotated	None
18	NGC 253	GrepNova	Good	Good	Properly auto-rotated	None
19	NGC 578	GrepNova	Good	Unreadable	Subject could not accept WCS data	Failed match
20	NGC 720	GrepNova	Good	Blurry (clouds)	Slightly blurry, not enough stars to align	Failed match
21	NGC 908	GrepNova	Good	Good		None
22	NGC 936	GrepNova	Good	Good	Slightly blurry, usable	None
23	NGC 1055	GrepNova	Good	Blurry (clouds)	Cloud obscure most stars, barely usable	Aligned 90%
24	NGC 1068	GrepNova	Good	Blurry (clouds)	Cloud obscure most stars, barely usable	Failed match
25	NGC 1073	GrepNova	Sharp	Blurry (clouds)	Cloud obscure most stars, barely usable	Aligned 75%
26	NGC 1087	GrepNova	Sharp	Blurry (clouds)	Slightly blurry, usable	None

Appendix Q: Supernova Observation Sheet – MaxIm DL SNT – Windows

	Analysis Date:	15-Feb-19				
	Image Group	I				
	Observatory	APUS Telescope				
	Analyzed by:	C. Hatch	Windows			
Image #	Galaxy	Analysis Software	Template Quality	Subject Quality	Other Information	Software Problems
1	NGC 7217	MaximDL SNT	Good	Good		None
2	NGC 7331	MaximDL SNT	Good	Good		None
3	NGC 7479	MaximDL SNT	Good	Good		None
4	NGC 7640	MaximDL SNT	Good	Good		None
5	NGC 224	MaximDL SNT	Blurry (clouds)	Blurry (clouds)	Inverted image (black hot)	None
6	NGC 448	MaximDL SNT	Sharp	Blurry (image shift)	Inverted image (black hot)	None
7	NGC 598	MaximDL SNT	Sharp	Blurry (image shift)	Inverted image (black hot)	None
8	NGC 628	MaximDL SNT	Sharp	Light Bloom	Slightly usable	None
9	NGC 672	MaximDL SNT	Sharp	Good		None
10	NGC 772	MaximDL SNT	Sharp	Light Bloom	Slightly usable	None
11	NGC 891	MaximDL SNT	Sharp	Sharp		None
12	NGC 925	MaximDL SNT	Sharp	Blurry (clouds)		None
13	NGC 7606	MaximDL SNT	Good	Pixelated?	Can see a few stars, mostly the brighter ones	None
14	NGC 7727	MaximDL SNT	Good	Good		None
15	NGC 45	MaximDL SNT	Good	Good	Possible slight coud interference	None
16	NGC 157	MaximDL SNT	Good	Good	Possible slight coud interference	None
17	NGC 247	MaximDL SNT	Good	Good	Properly auto-rotated and aligned	None
18	NGC 253	MaximDL SNT	Good	Good	Properly auto-rotated and aligned	None
19	NGC 578	MaximDL SNT	Good	Unreadable	Heavily Pixelated	Failed match
20	NGC 720	MaximDL SNT	Good	Blurry (clouds)	Slightly blurry, not enough stars to align	Failed match
21	NGC 908	MaximDL SNT	Good	Good		None
22	NGC 936	MaximDL SNT	Good	Good	Slightly blurry, usable	None
23	NGC 1055	MaximDL SNT	Good	Blurry (clouds)	Cloud obscure most stars, barely usable	Pixel issue
24	NGC 1068	MaximDL SNT	Good	Blurry (clouds)	Cloud obscure most stars, barely usable	Failed match
25	NGC 1073	MaximDL SNT	Sharp	Blurry (clouds)	Cloud obscure most stars, barely usable	Aligned 75%
26	NGC 1087	MaximDL SNT	Sharp	Blurry (clouds)	Slightly blurry, usable	None

Appendix R: Supernova Observation Sheet – PhAst – Windows

	Analysis Date:	15-Feb-19				
	Image Group	I				
	Observatory	APUS Telescope				
	Analyzed by:	C. Hatch	Windows			
Image #	Galaxy	Analysis Software	Template Quality	Subject Quality	Other Information	Software Problems
1	NGC 7217	PhAst	Good	Good	Selected Full Range Option	None
2	NGC 7331	PhAst	Good	Good	Selected Full Range Option	None
3	NGC 7479	PhAst	Good	Good	Selected Full Range Option	None
4	NGC 7640	PhAst	Good	Good	Selected Full Range Option	None
5	NGC 224	PhAst	Blurry (clouds)	Blurry (clouds)	Selected Full Range Option	None
6	NGC 448	PhAst	Sharp	Blurry (image shift)	Selected Full Range Option	None
7	NGC 598	PhAst	Sharp	Blurry (image shift)	Inverted	None
8	NGC 628	PhAst	Sharp	Light Bloom	Inverted	None
9	NGC 672	PhAst	Sharp	Good	Inverted	None
10	NGC 772	PhAst	Sharp	Light Bloom	Selected Full Range Option	None
11	NGC 891	PhAst	Sharp	Sharp	Inverted	None
12	NGC 925	PhAst	Sharp	Blurry (clouds)	Selected Full Range Option	None
13	NGC 7606	PhAst	Good	Pixelated?	Selected Full Range Option and Invert	None
14	NGC 7727	PhAst	Good	Good	Selected Full Range Option and Invert	None
15	NGC 45	PhAst	Good	Pixelated?	Selected Full Range Option and Invert	None
16	NGC 157	PhAst	Good	Good	Selected Full Range Option and Invert	None
17	NGC 247	PhAst	Good	Good	Did not auto rotate/align	None
18	NGC 253	PhAst	Good	Good/Dark	Did not auto rotate/align	None
19	NGC 578	PhAst	Good	Unreadable	WCS layer unsuccessful	Could not resolve
20	NGC 720	PhAst	Good	Blurry (clouds)	Selected Full Range Option and Invert	None
21	NGC 908	PhAst	Good	Good	Selected Full Range Option	None
22	NGC 936	PhAst	Good	Good	Selected Full Range Option and Invert	None
23	NGC 1055	PhAst	Good	Blurry (clouds)	Selected Full Range Option and Invert	None
24	NGC 1068	PhAst	Good	Blurry (clouds)	Selected Full Range Option and Invert	None
25	NGC 1073	PhAst	Sharp	Blurry (clouds)	Selected Full Range Option and Invert	None
26	NGC 1087	PhAst	Sharp	Blurry (clouds)	Selected Full Range Option and Invert	None

Appendix S: Supernova Observation Sheet – Starblinker – Windows

	Analysis Date:	22-Feb-19				
	Image Group	I				
	Observatory	APUS Telescope				
	Analyzed by:	C. Hatch	Windows			
Image #	Galaxy	Analysis Software	Template Quality	Subject Quality	Other Information	Software Problems
1	NGC 7217	Starblinker	Good	Good	Slight spatial matching offset	None
2	NGC 7331	Starblinker	Good	Good	Very good alignment	None
3	NGC 7479	Starblinker	Good	Good	Very good alignment	None
4	NGC 7640	Starblinker	Good	Good	Good alignment - subject slightly blurry	None
5	NGC 224	Starblinker	Blurry (clouds)	Blurry (clouds)	Slight spatial matching offset	None
6	NGC 448	Starblinker	Sharp	Blurry (image shift)	Slight spatial matching offset	None
7	NGC 598	Starblinker	Sharp	Blurry (image shift)	Slight spatial matching offset	None
8	NGC 628	Starblinker	Sharp	Light Bloom	Slight spatial matching offset - some washout	None
9	NGC 672	Starblinker	Sharp	Good	Slight spatial matching offset	None
10	NGC 772	Starblinker	Sharp	Light Bloom	Slight spatial matching offset - some washout	None
11	NGC 891	Starblinker	Sharp	Sharp	Slight spatial matching offset	None
12	NGC 925	Starblinker	Sharp	Blurry (clouds)	Slight spatial matching offset	None
13	NGC 7606	Starblinker	Good	Pixelated?	Good spatial matching - pixelated	None
14	NGC 7727	Starblinker	Good	Good	Good alignment - subject slightly blurry	None
15	NGC 45	Starblinker	Good	Good	Very good alignment	None
16	NGC 157	Starblinker	Good	Good	Very good alignment	None
17	NGC 247	Starblinker	Good	Good	Very good alignment - Auto rotated	None
18	NGC 253	Starblinker	Good	Good	Very good alignment - Auto rotated	None
19	NGC 578	Starblinker	Good	Unreadable	Could not adjust levels/contrast enough	Unreadable
20	NGC 720	Starblinker	Good	Blurry (clouds)	Slight spatial matching offset	None
21	NGC 908	Starblinker	Good	Good	Slight spatial matching offset	None
22	NGC 936	Starblinker	Good	Good	Slight spatial matching offset	None
23	NGC 1055	Starblinker	Good	Blurry (clouds)	Very good alignment - Cloud obscuring	None
24	NGC 1068	Starblinker	Good	Blurry (clouds)	Very good alignment - Cloud obscuring	None
25	NGC 1073	Starblinker	Sharp	Blurry (clouds)	Slight spatial matching offset	None
26	NGC 1087	Starblinker	Sharp	Blurry (clouds)	Slight spatial matching offset	None

Appendix T: Supernova Observation Sheet – Aladin – Mac OS

	Analysis Date:	23-Feb-19				
	Image Group	I				
	Observatory	APUS Telescope				
	Analyzed by:	C. Hatch	Mac OS			
Image #	Galaxy	Analysis Software	Template Quality	Subject Quality	Other Information	Software Problems
1	NGC 7217	Aladin	Good	Good	Very well spatially aligned	None
2	NGC 7331	Aladin	Good	Good	Well aligned, slight warping	None
3	NGC 7479	Aladin	Good	Good	Very well spatially aligned	None
4	NGC 7640	Aladin	Good	Good	Well aligned, slight warping	None
5	NGC 224	Aladin	Blurry (clouds)	Blurry (clouds)	Well aligned, slight warping	None
6	NGC 448	Aladin	Sharp	Blurry (image shift)	Well aligned, slight warping - Slightly hazy	None
7	NGC 598	Aladin	Sharp	Blurry (image shift)	Well aligned - Slightly hazy	None
8	NGC 628	Aladin	Sharp	Light Bloom	Well aligned, slight warping - severe light bloom	None
9	NGC 672	Aladin	Sharp	Good	Very well spatially aligned	None
10	NGC 772	Aladin	Sharp	Light Bloom	Well aligned, slight warping - severe light bloom	None
11	NGC 891	Aladin	Sharp	Sharp	Very well spatially aligned	None
12	NGC 925	Aladin	Sharp	Blurry (clouds)	Well aligned, clouds obscure fainter stars	None
13	NGC 7606	Aladin	Good	Pixelated?	Well alignde, clouds/pixelation obscure stars	None
14	NGC 7727	Aladin	Good	Good	Very well spatially aligned	None
15	NGC 45	Aladin	Good	Pixelated?	Aligned, image warping, decent amount of stars	None
16	NGC 157	Aladin	Good	Good	Very well spatially aligned	None
17	NGC 247	Aladin	Good	Good	Good image alignment, some warping, properly	None
18	NGC 253	Aladin	Good	Good/Dark	Very well spatially aligned - properly rotated.	None
19	NGC 578	Aladin	Good	Unreadable	No WCS available, unreadable	Could not resolve
20	NGC 720	Aladin	Good	Blurry (clouds)	Very well spatially aligned - fainter stars hard to	None
21	NGC 908	Aladin	Good	Good	Very well spatially aligned - can see some dust s	None
22	NGC 936	Aladin	Good	Good	Very well spatially aligned	None
23	NGC 1055	Aladin	Good	Blurry (clouds)	Very well spatially aligned - fainter stars hard to	None
24	NGC 1068	Aladin	Good	Blurry (clouds)	Well aligned, fainter stars are very hard to see d	None
25	NGC 1073	Aladin	Sharp	Blurry (clouds)	Well aligned, fainter stars are hard to see due to	None
26	NGC 1087	Aladin	Sharp	Blurry (clouds)	Well aligned, fainter stars difficult to see due to	None

Appendix U: Supernova Observation Sheet – SAOImage DS9 – Mac OS

	Analysis Date:	23-Feb-19				
	Image Group	I				
	Observatory	APUS Telescope				
	Analyzed by:	C. Hatch	Mac OS			
Image #	Galaxy	Analysis Software	Template Quality	Subject Quality	Other Information	Software Problems
1	NGC 7217	SAOImageDS9	Good	Good	Very well spatially aligned	None
2	NGC 7331	SAOImageDS9	Good	Good	Well aligned, slight warping	None
3	NGC 7479	SAOImageDS9	Good	Good	Very well spatially aligned	None
4	NGC 7640	SAOImageDS9	Good	Good	Well aligned, slight warping	None
5	NGC 224	SAOImageDS9	Blurry (clouds)	Blurry (clouds)	Well aligned, slight warping	None
6	NGC 448	SAOImageDS9	Sharp	Blurry (image shift)	Well aligned, slight warping - Slightly hazy	None
7	NGC 598	SAOImageDS9	Sharp	Blurry (image shift)	Well aligned - Slightly hazy	None
8	NGC 628	SAOImageDS9	Sharp	Light Bloom	Well aligned, slight warping - severe light bloom	None
9	NGC 672	SAOImageDS9	Sharp	Good	Very well spatially aligned	None
10	NGC 772	SAOImageDS9	Sharp	Light Bloom	Well aligned, slight warping - severe light bloom	None
11	NGC 891	SAOImageDS9	Sharp	Sharp	Very well spatially aligned	None
12	NGC 925	SAOImageDS9	Sharp	Blurry (clouds)	Well aligned, clouds obscure fainter stars	None
13	NGC 7606	SAOImageDS9	Good	Pixelated?	Well alignde, clouds/pixelation obscure fainter s	None
14	NGC 7727	SAOImageDS9	Good	Good	Very well spatially aligned	None
15	NGC 45	SAOImageDS9	Good	Pixelated?	Ok aligned, image warping, decent amount of st	None
16	NGC 157	SAOImageDS9	Good	Good	Very well spatially aligned	None
17	NGC 247	SAOImageDS9	Good	Good	Good image alignment, some warping, properly	None
18	NGC 253	SAOImageDS9	Good	Good/Dark	Very well spatially aligned - properly rotated.	None
19	NGC 578	SAOImageDS9	Good	Unreadable	No WCS available, unreadable	Could not resolve
20	NGC 720	SAOImageDS9	Good	Blurry (clouds)	Very well spatially aligned - fainter stars hard to	None
21	NGC 908	SAOImageDS9	Good	Good	Very well spatially aligned - can see some dust s	None
22	NGC 936	SAOImageDS9	Good	Good	Very well spatially aligned	None
23	NGC 1055	SAOImageDS9	Good	Blurry (clouds)	Very well spatially aligned - fainter stars hard to	None
24	NGC 1068	SAOImageDS9	Good	Blurry (clouds)	Well aligned, fainter stars are very hard to see du	None
25	NGC 1073	SAOImageDS9	Sharp	Blurry (clouds)	Well aligned, fainter stars are hard to see due to	None
26	NGC 1087	SAOImageDS9	Sharp	Blurry (clouds)	Well aligned, fainter stars difficult to see due to	None

List of References

Aguirre, Edwin L. (1997, August). Comets, Asteroids, and Astrometrica. *Sky and Telescope*, *94*(2), 72–74.

Adcock, R., & Collier, D. (2001). Measurement Validity: A Shared Standard for Qualitative and Quantitative Research. *The American Political Science Review*, *95*(3), 17.

Babbie, E. R. (2012). *The Practice of Social Research* (13th ed.). Belmont, CA: Wadsworth Cengage.

Bellm, E. C., Kulkarni, S. R., Graham, M. J., Dekany, R., Smith, R. M., Riddle, R., Zolkower, J. (2019). The Zwicky Transient Facility: System Overview, Performance, and First Results. *Publications of the Astronomical Society of the Pacific*, *131*(995), 018002. https://doi.org/10.1088/1538-3873/aaecbe

Bergman, M. (2016). *International Encyclopedias of Communication*. (Wiley, John, Ed.) (Vol. 1). John Wiley & Sons, Inc.

Bhattacherjee, A. (2012). *Social Science Research: Principles, Methods and Practices*. Global Text Project. Retrieved from https://scholarcommons.usf.edu/oa_textbooks/3/

Boles, T. (2006). Tools for supernovae: Discovery and follow up. *Journal of the British Astronimical Association*, *116*(5), 229–238.

Bonnarel, F., Fernique, P., Bienayme, O., Egret, D., Genova, F., Louys, M., … Bartlett, J. G. (2000). The ALADIN Interactive Sky Atlas. *ArXiv:Astro-Ph/0002109*. Retrieved from http://arxiv.org/abs/astro-ph/0002109

Buchheim, R. K. (2008). CCD Double-Star Measurements at Altimira Observatory in 2007. *Journal of Double Star Observations*, *4*(1), 27–31.

Chomiuk, L., Chornock, R., Soderberg, A. M., Berger, E., Chevalier, R. A., Foley, R. J., Wainscoat, R. J. (2011). Pan-STARRS1 Discovery of Two Ultraluminous Supernovae at $z \approx 0.9$. *The Astrophysical Journal*, *743*(2), 114. https://doi.org/10.1088/0004-637X/743/2/114

Chong, C.-H., & Yeo, K.-J. (2015). An Overview of Grounded Theory Design in Educational Research. *Asian Social Science*, *11*(12). https://doi.org/10.5539/ass.v11n12p258

Coughlan, M., Cronin, P., & Ryan, F. (2007). Step-by-step guide to critiquing research. Part 1: quantitative research. *British Journal of Nursing*, *16*(11), 658–663. https://doi.org/10.12968/bjon.2007.16.11.23681

Creswell, J. W. (2014). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (4th ed.). Thousand Oaks, California: SAGE.

Driscoll, D. L. (2011). Introduction to Primary Research: Observations, Surveys, and Interviews. In C. Lowe & P. Zemliansky (Eds.), *Writing Spaces: Readings on Writing* (Vol. 2). Parlor Press. Retrieved from https://wac.colostate.edu/books/writingspaces2/driscoll--introduction-to-primary-research.pdf

Ethridge, D. E. (2004). *Research Methodology in Applied Economics* (2nd ed.). Iowa: Wiley-Blackwell.

Fawcett, J., & Downs, F. (1986). *The Relationship Between Theory and Research*. Norwalk, Ct.:

Appelton Centry Crofts. Retrieved from http://www.indiana.edu/~educy520/readings/fawcett86.pdf

Filippenko, A. V., Li, W. D., Treffers, R. R., & Modjaz, M. (2001). *The Lick Observatory Supernova Search with the Katzman Automatic Imaging Telescope*. International Astronomical Union Colloquium, 183, 121–130. https://doi.org/10.1017/S0252921100078738

Ford, D. (2011). GrepNova: A tool for amateur supernova hunting. *Journal of the British Astronomical Association*, *121*(6), 5.

Fox, W., & Bayat, M. S. (2007). *A Guide to Managing Research*. Juta Academic Publications.

Gall, M. D., Borg, W. R., & Gall, J. P. (2003). *Educational Research: An Introduction* (7th ed.). Pearson.

Greisen, E. W., Calabretta, M. R., Valdes, F. G., & Allen, S. L. (2006). Representations of spectral coordinates in FITS. *Astronomy & Astrophysics*, *446*(2), 747–771. https://doi.org/10.1051/0004-6361:20053818

Heale, R., & Twycross, A. (2015). Validity and reliability in quantitative studies. *Evidence Based*

Nursing, *18*(3), 66–67. https://doi.org/10.1136/eb-2015-102129

Hopkins, W. G. (2008). Research Designs: Choosing and Fine-tuning a Design for Your Study. sportsci.org. Retrieved from https://www.sportsci.org/2008/wghdesign.htm

Jedicke, R., Magnier, E. A., Kaiser, N., & Chambers, K. C. (2006). The next decade of Solar System discovery with Pan-STARRS. *International Astronomical Union. Proceedings of the International Astronomical Union; Cambridge*, *2*(S236), 341–352. http://dx.doi.org.ezproxy1.apus.edu/10.1017/S1743921307003419

Jones, D. O., Scolnic, D. M., Riess, A. G., Kessler, R., Rest, A., Kirshner, R. P., Waters, C. (2017). Measuring the Properties of Dark Energy with Photometrically Classified Pan-STARRS Supernovae. I. Systematic Uncertainty from Core-Collapse Supernova Contamination. *The Astrophysical Journal*, *843*(1), 6. https://doi.org/10.3847/1538-4357/aa767b

Kare, J. T. (1984). *An Automated Search for Supernovae (telescope, Ccd)* (Ph.D.). University of California, Berkeley, United States -- California. Retrieved from http://search.proquest.com/docview/303335959/abstract/57EFADC48B4D4BA5PQ/5

Kim, M. Y. (1999). *The search for high-redshift supernovae and the image reduction* (Ph.D.).

University of California, Berkeley, United States -- California. Retrieved from http://search.proquest.com/docview/304495997/abstract/57EFADC48B4D4BA5PQ/6

Laher, R. R., Masci, F. J., Groom, S., Rusholme, B., Shupe, D. L., Jackson, E., … Kulkarni, S. R. (2017). Processing Images from the Zwicky Transient Facility. *ArXiv:1708.01584 [Astro-Ph]*. Retrieved from http://arxiv.org/abs/1708.01584

Leaman, J. F. (2008). *The supernova rate in the local universe* (Ph.D.). University of California, Berkeley, United States -- California. Retrieved from http://search.proquest.com/docview/304696977/abstract/AB1DF2AC71F94F82PQ/4

Leedy, P. D., & Ormrod, J. E. (2001). *Practical Research: Planning and Design* (7th ed.). Upper Saddle River, NJ and Thousand Oaks, CA: Merrill Prentice Hall and SAGE Publications.

Li, W. D., Filippenko, A. V., Treffers, R. R., Friedman, A., Halderson, E., Johnson, R. A.,

Magnier, E. A., Chambers, K. C., Flewelling, H. A., Hoblitt, J. C., Huber, M. E., Price, P. A., Wainscoast, R. J. (2016). The Pan-STARRS Data Processing System. *ArXiv:1612.05240 [Astro-Ph]*. Retrieved from http://arxiv.org/abs/1612.05240

Martínez-Mesa, J., González-Chica, D. A., Duquia, R. P., Bonamigo, R. R., & Bastos, J. L. (2016). Sampling: how to select participants in my research study? *Anais Brasileiros De Dermatologia*, *91*(3). https://doi.org/10.1590/abd1806-4841.20165254

Masci, F. J., Laher, R. R., Rusholme, B., Shupe, D. L., Groom, S., Surace, J., Kulkarni, S. R. (2019). The Zwicky Transient Facility: Data Processing, Products, and Archive. *Publications of the Astronomical Society of the Pacific*, *131*(995), 018003. https://doi.org/10.1088/1538-3873/aae8ac

Mighell, K. J., Rehnberg, M., Crawford, R., Trueblood, M., & Lebofsky, L. A. (2012). PhAst: An IDL Astronomical Image Viewer Optimized for Astrometry of Near Earth Objects. *Publications of the Astronomical Society of the Pacific*, *124*(922), 1360–1368. https://doi.org/10.1086/669032

Modjaz, M. (2000). The Lick Observatory Supernova Search, 5. https://pdfs.semanticscholar.org/fba2/ff4e58cde74724ebf89ebed2e4a5fe35999f.pdf

Muller, R. A., Newberg, H. J. M., Pennypacker, C. R., Perlmutter, S., Sasseen, T. P., & Smith, C. K. (1992). High rate for Type IC supernovae. *The Astrophysical Journal*, *384*, L9. https://doi.org/10.1086/186251

Phillips, D. C., & Burbules, N. C. (2000). *Postpositivism and Educational Research*. Lanham, Maryland: Rowman & Littlefield Publishers, Inc.

Riess, A. G., Filippenko, A. V., Challis, P., Clocchiattia, A., Diercks, A., Garnavich, P. M., Tonry,

J. (1998). Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant. *The Astronomical Journal*, *116*(3), 1009–1038. https://doi.org/10.1086/300499

Savanevych, V., B. Briukhovetskyi, A., N. Ivashchenko, Y., Vavilova, I., M. Bezkrovniy, M., N. Dikov, E., … Khlamov, S. (2015). Comparative analysis of the positional accuracy of CCD measurements of small bodies in the solar system software CoLiTec and Astrometrica. *Kinematics and Physics of Celestial Bodies*, *31*, 302–313. https://doi.org/10.3103/S0884591315060045

Schmidt, B. P., Suntzeff, N. B., Phillips, M. M., Schommer, R. A., Clocchiatti, A., Kirshner, R. P., … Ciardullo, R. (1998). The High-Z Supernova Search: Measuring Cosmic Deceleration and Global Cur vature of the Universe Using Type Ia Supernovae. *The Astrophysical Journal*, *507*(1), 46–63. https://doi.org/10.1086/306308

Sherrod, C. (2018). *Supernova Search Atlas and Guide* (Illustrated). Lulu.com. Retrieved from https://books.google.com/books?id=8c9aDwAAQBAJ&pg=PA16&lpg=PA16&dq=how+to+use+ccdsoft+to+search+for+supernova&source=bl&ots=JpL5FdENYG&sig=yoz_JBWqUbwTrSiaR09qgAWiWK4&hl=en&sa=X&ved=2ahUKEwjMztSC7c_fAhUFyFkKHbfGC7IQ6AEwBXoECAQQAQ#v=onepage&q=how%20to%20use%20ccdsoft%20to%20search%20for%20supernova&f=false

Smith, A. M., Lynn, S., Sullivan, M., Lintott, C. J., Nugent, P. E., Botyanszki, J., Walters, R. (2011). Galaxy Zoo Supernovae. *Monthly Notices of the Royal Astronomical Society*, 13. https://doi.org/10.1111/j.1365-2966.2010.17994.x

Stjelja, M. (2013). The Case Study Approach: Some Theoretical, Methodological and Applied Considerations, 41.

van Teijlingen, E. R., & Hundley, V. (2001). The Importance of Pilot Studies. *Social Research Update*, (35), 4.

Williams, C. (2007). Research Methods. *Journal of Business & Economic Research*, *5*(3), 8.

Winchester, C. L., & SaljiFox, W., & Bayat, M. S. (2007). *A Guide to Managing Research*. Juta Academic Publications., M. (2016). Writing a Literature Review. *Journal of Clinical Urology*, *9*(5), 308–312. https://doi.org/10.1177/2051415816650133

Winter, G. (2000). A Comparative Discussion of the Notion of "Validity" in Qualitative and Quantitative Research. *The Qualitative Report*, *4*(3&4), 16.

Wright, D. E., Lintott, C. J., Smartt, S. J., Smith, K. W., Fortson, L., Trouille, L., Young, D. R.

(2017). A transient search using combined human and machine classifications. *Monthly Notices of the Royal Astronomical Society*, *472*(2), 1315–1323. https://doi.org/10.1093/mnras/stx1812

Zwicky, F. (1964). Basic Results of the International Search for Supernovae. *Annales D'Astrophysique*, 300–312. https://doi.org/1964ANAP...27..300Z