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RESOURCES & ACTIVITIES

Using Remote Telescopes to Chase Supernovae with Undergraduate Students

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Abstract

This paper details a project that utilized a remote network of 0.5-m class telescopes, along with a burst-alert system, to engage undergraduate students in the collection of the early light curves of supernovae. The focus was to create a research experience that could be undertaken at the very earliest point in a student's academic career, as well as contribute to the scientific understanding of the progenitors of supernovae Ia. We discuss the initial motivation and planning stages, highlight both our successes and failures during the execution of the project, and present several light curves taken by the students, as well our observational metadata. In addition, we discuss a subtraction routine we have developed and made available to the wider community that is designed specifically for these kinds of sources and instruments. The information provided should be sufficient for other interested faculty members to bring similar projects to their own institutions.

Keywords: supernovae Ia, undergraduate research, transient, burst-alert network, photometry, IRSA, AAVSO, AstroPy

1 Introduction

The confluence of technology and science has always been at the heart of astronomical research. The information age has brought us to a new stage of this history, as it allows not only for the sharing of expertise, but also the direct access of reasonably cost-effective and technologically advanced instrumentation. Rather than requiring a substantial initial investment to get an observatory up and running, it is now possible for "pay as you go" models of access to allow individuals and institutions to engage in their own projects and develop their own expertise, often in areas of the field under-explored by the larger and most specialized instruments. The impact of these developments on students and educators should not be overlooked. By providing students majoring in astronomy with access to higher quality instruments and data, they can be exposed to more aspects of the field, which can give them a more complete and fully-formed research experience. Rather than a student with a primarily instrumental, observational, or analysis background, we can train students in all three simultaneously by providing them with a full pipeline of astronomical tasks. For an example where the impact of such a research program, folded into a classroom experience, was evaluated, see Hom et al. (2024).

We would like to highlight an additional, and from our perspective under-explored, population of students who can benefit from this increased level of access - everyone else; that is, undergraduate students who are not majoring in astronomy. As we discuss in this paper, engaging in a research experience designed around these new technologies does not require any specific prerequisite skills, and should be viewed very positively by both program directors and future employers when evaluating a student's academic history. The skills developed during this project included those related to computation, data, analysis,

communication, and teamwork, to name a few. A basic introduction to these skills is an essential outcome of this project, but they can be explored on a sliding scale. Students with little experience in data collection can be exposed to it for the first time, while students with previous experience in astronomy can engage in aspects of the project that require a higher level of command over the hardware, software, and data. We note that it has been shown that the use of research experiences in the introductory astronomy classroom have "the potential to increase students' perceived confidence in their science process skills, motivation to learn science, understanding of the scientific process, and attitudes toward doing science." (Wooten et al., 2018). In addition, the use of robotic telescopes in the classroom has specifically been shown to increase student's self-efficacy (Freed et al., 2023).

This paper clearly presents a relatively involved scientific task - the acquisition of early supernovae light curves - which has been undertaken by a group of undergraduate students (majoring in engineering, physics, and biology) under the supervision of a faculty member. Our home institution is moderately sized (about 5,000 students) and focused on undergraduate education, with a limited graduate program, and therefore limited research opportunities. With the increasing accessibility of both instrumentation and software, we did not find any substantial institutional obstruction to this project, aside from moderate financial support (more detail on this point can be found in §3.2). Thus, we see no major challenges to creating similar projects in other academic environments, including smaller liberal arts colleges or high schools.

The rest of this paper is organized as follows: §2 provides the scientific and technological background around which this project was designed. §3 will outline both the initial plan for the project, some of the pitfalls we encountered, and our eventual solutions. The data are presented in §4, which includes a selection of our supernovae data, lights curves, and relevant metadata for our complete source list, which we hope will be helpful for others designing similar projects. The paper concludes in §5 with our final thoughts, as well as the next steps we are planning on taking in our undergraduate astronomy research group.

2 Background

2.1 Astronomical Transients

The primary targets of our research group are astronomical transients, which are identified by the observational characteristic of changing in brightness over a relatively short period of time. Objects in this category include variable stars, novae, asteroids, as well as active galactic nuclei. The reason for the focus on astronomical transients is that various aspects of these objects are not easily studied with larger observatories, that typically have tight scheduling requirements and high barriers to entry. This is in contrast to a network of smaller telescopes in the 0.5-m class, that are more generally available and (as we will detail later) can be used for immediate follow-up of a particular transient source. Of course, larger observatories play an important role in the careful characterization of transient classes, but given there are several dozen of these objects discovered every day, there are far more going unstudied. It is only with a combination of larger telescopes for detailed analysis and smaller telescopes for population studies that we can really build an understanding of the sources in question.

Specifically, we are going to be interested in supernovae Type Ia (SN Ia) (an excellent review, which we cover only very briefly here, can be found in Liu et al. (2023)). They are created in a binary system, when at least one of the components has evolved into a white dwarf. There are generally two proposed formation

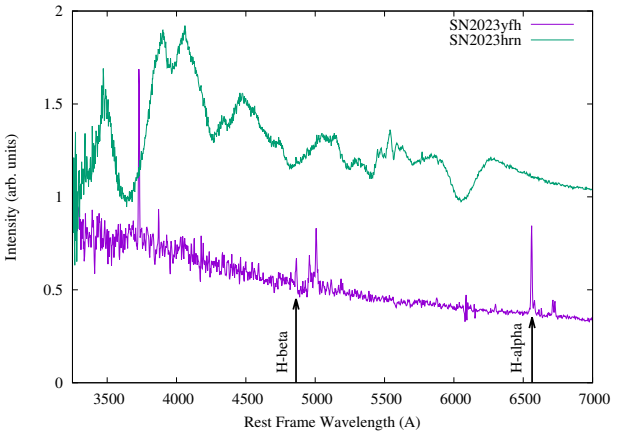


Figure 1. A comparison between the spectra of a supernovae type II (SN2023yfh from Hinkle (2023)) and a supernovae type Ia (SN2023hrn from Rojas-Bravo et al. (2023)). The key difference is the presence of Hydrogen in the Type I spectra, clearly not present in the Type Ia.

mechanisms (Livio, 1999). In the single-degenerate case, as the other star (generally referred to as the secondary, or the mass donor star) evolves into the giant branch, its surface crosses its Roche lobe and starts to transfer mass to the compact companion. Eventually, enough mass is transferred that the white dwarf reaches the Chandrasekhar limit, igniting runaway fusion in its core and triggering the supernovae. In the double-degenerate scenario, both components are white dwarf stars, which merge, bringing the total mass over the limit. Both of these progenitor channels are thought to contribute to the total number of observed SN Ia.

As supernovae are relatively rare - 1 every 40 years in our galaxy for example (Tammann et al., 1994) - they are most often observed in other galaxies, and the progenitor system is not known before hand. They undergo an increase in brightness of several magnitudes for several days, before taking several weeks to fade back to invisibility. The classification of Type I comes from a lack of hydrogen in the spectra, as opposed to Type II, in which the presence of hydrogen is indicative of a core-collapse progenitor. Figure 1 illustrates this difference using two of the sources we observed. There are several sub-classifications of these objects (Liu et al. (2023) detail 8 distinct classifications, aside from the most common $\sim$ 70%, based mostly on the shape of the light curve), but for our purpose we just note that type Ia are formed from white dwarfs in binary systems, as described above.

2.2 Discovery and Identification of SN Ia

Before the advent of computer-controlled telescopes, the discovery of a new SN Ia was an event that occurred far less than once in a human lifetime. The modern approach is to automatically scan the sky, looking for new candidates, and there are several systems dedicated to this endeavor (relevant examples for us are the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS, Chambers et al. (2019)) and the Asteroid Terrestrial Impact Last Alert System (ATLAS, Smith et al. (2020))). The essential task is to image as much of the sky as possible per night, compare the images to a set taken earlier, and use an automatic detection scheme to search for new sources. These are announced to the community on a regular basis, and might result in $\sim$ 50 candidate sources each day.

Of course, the nature of these sources is essentially unknown

- they could be a supernovae of scientific interest, an asteroid or other true astrophysical transient, or a misidentification (cosmic ray or other technical issue). In the case of supernovae, the basic Type I/II classification requires a spectrometer, an instrument sufficiently sensitive to look for the hydrogen feature (see Figure 1), and the scheduling time available. As the magnitude of these objects are in the 15-20 range, they require relatively specialized instruments - such as the Public ESO Spectroscopic Survey of Transient Objects (ePESSTO+) on the 3.58-m New Technology Telescope (Smartt et al., 2015) and the Spectral Energy Density Machine (SEDM) on the 1.5-m Palomar Telescope (Blagorodnova et al., 2018). As these objects are relatively short-lived, the rapid identification of them is an important task.

2.3 Analysis

Once the classification of a particular source is known, one can design follow-up studies according to the specific scientific goals. For example, the transition from the initial fireball phase to the radioactive decay phase in SN II (along with several other phase changes, see Martinez et al. (2022)). In the SN Ia case, the maximum brightness of these objects are important as standard candles in cosmology (Branch & Miller, 1993). We would like to highlight a relatively recent advance, which this study has the opportunity to directly impact, which is the nature of the progenitor in SN Ia (discussed in §2.1). Recent theoretical work has suggested that for the single-degenerate scenario, a excess rise in the light curve of the SN through particular filters can be seen pre-maximum light, due to the interactions of the explosion with the secondary (Kasen, 2010). This signal is interesting because it is purely photometric, and although requiring access to the pre-maximum light curve, it does not require spectroscopic analysis to observe. As this occurs predominantly in the bluer filters, it is informally referred to as the “blue bump”, and has been confirmed in a small number of cases, where the instrumentation was available for both spectroscopic classification and long-term photometric monitoring (Sand et al., 2018; Hosseinzadeh et al., 2017; Dessart et al., 2014; Hosseinzadeh et al., 2023). However, to answer the fundamental question of the relative fraction of each formation channel, we need to have a large number of sources, with both positive and negative observations of the blue bump. We attempted such a study with archive data from the Open Supernovae Catalog (Guillochon et al., 2017), but were only able to identify a small number of candidates where the signal might have been present (Duston & Santos, 2023). One of the long-term goals of our undergraduate research group is to gather SN Ia light curves that are 1) sufficiently early to see the blue bump, if it exists, and b) sufficiently high-quality (in both cadence time and magnitude) to develop a trigger for the signal.

2.4 The Merrimack College Astronomical Research Group

The Merrimack College Astronomical Research Group (MCARG[1]) was formed in 2019, with the primary goal of engaging undergraduate students in observational astronomy, focusing on the use of our on-campus observatory facilities (a 18” Ritchey-Chrétien telescope, various CCD cameras, and a commercial spectrometer). The initial targets were on variable stars, but we have expanded to a variety of transient objects, such as asteroids, comets, novae, and exoplanets, depending on the interests of the students. The group typically involves 3-4 students at a given time, and have had a total of 19 since its inception including several high school students. Thus far it has been entirely funded internally, and managed by one faculty member with a background in astronomy. We have included SN in our list of targets since the beginning, but the initial design of the project covered by this paper began in 2020, with the primary work presented here being done over the calendar year of 2023. We would also point out that students who join this group typically have no exposure of any kind of astronomical science - although approximately half have taken our introductory astronomy class. A key feature of the group is to provide all the necessary background and training in the field, under the idea that this exposure will help them be prepared for research or internships in their chosen field.

3 Project Details

As we would like our work to be easily reproducible with minimal time investment on the part of interested faculty and students, this section will be focusing on the process we used to design and execute the project. As a brief overview, the essential tasks that needed to be planned and completed were

- Identification of candidate sources.
- Planning of observations.
- Updating and monitoring of observations.
- Ending observations.
- Data finalization and analysis.
- Follow-up observations.

Details about how we initially envisioned each of these tasks, as well as how they were actually executed during the study, constitute the remainder of this section.

3.1 Identification of Candidate Sources from Burst-Alert Networks

There are currently several available burst-alert networks that search for new transients. Our early design actually focused on curated lists of supernovae, such as the Rochester Latest Supernovae List[2], rather than actual alert services. However, as our sights focused more on the early light curves as a science goal, we found these lists lag too far behind the initial discoveries. The next idea was to use the broker service Lasair (Smith et al., 2019), that provides custom searches over a variety of criteria for both The Zwicky Transit Facility (ZTF, Bellm (2014)) and the Rubin Observatory (formerly the Large Synaptic Survey Telescope (LSST, Ivezić et al. (2019)). This certainly provided us with more immediate alerts, but we found it difficult to develop the right search parameters to filter out things that were very unlikely to be supernovae. For example, Lasair uses an algorithm called Sherlock (Young, 2023), which mines historical transient data, in an attempt to classify new sources, differentiating between SN, variable stars, active galactic nuclei, etc. However, our initial testing found that Sherlock often classified objects as SN when they were either a) obviously unlikely to be, or b) were outside of our detection threshold. To illustrate this, Table 1 shows 8 sources we were tracking during 2019-2020, all of which were initially classified by Sherlock as SN.

Based on the analysis of this sample (as well as several others done around this time), it was determined that initial Sherlock classification was not sufficiently accurate for our purpose. For sure, it detected some supernovae (and Ia at that), but the classification of obvious variable stars and isolated sources (“ORPHAN”) as initially SN, despite not SN by visual inspection, led us to develop an approach with more human involvement in the

1 https://sites.google.com/merrimack.edu/mcarg/

2 https://www.rochesterastronomy.org/supernova.html

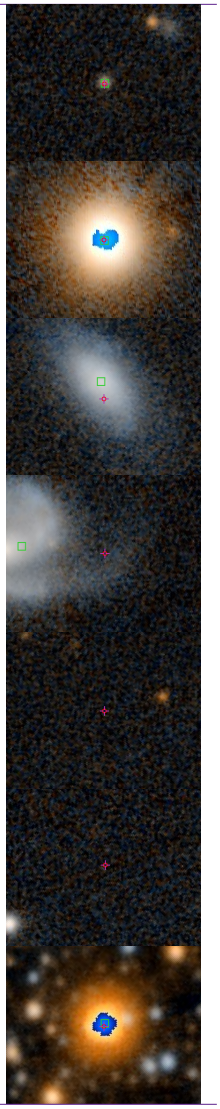
ZTF Name	Other Name	Initial Classification	Current Classification	Preview Image
ZTF19aavkbfk	AT2019aamc	SN	SN	
ZTF18aanzrfr	–	SN	Variable	
ZTF19acyjviz	SN2019wnc	SN	SN IIn	
ZTF19acyfakk	SN2019wmx	SN	SN Ia	
ZTF20aahtqmm	–	SN	ORPHAN	
ZTF20aakebfp	–	SN	ORPHAN	
ZTF19abcplrr	–	SN	Variable Star	

Table 1. A selection of identified transients from Lasair, initially classified as SN by Sherlock.

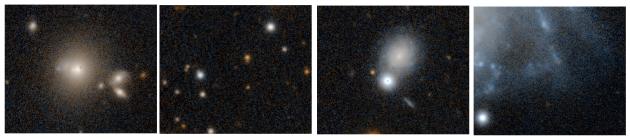


Figure 2. A snapshot selection from the TNS daily alert (from 20240207). After just a brief visual inspection, it is easy to see that of the four sources with available preview images, 3 are likely to be SN candidates (showing a relatively large and nearby galaxy), whereas one is not. These sources are, left to right, AT2024bus, AT2024bud, SN2024bto, and SN2024btj, and the images are from the Aladin Sky Atlas (Baumann et al., 2022)

decision making process[3].

We have found that the daily email alert system from the Transient Alert Network (TNS[4]) is easy enough to use, and gives sufficient information in its alert system to design reliable observation plans. It collects information from several reporting sources (at least Pan-STARRS, ATLAS, and ZTF), and provides one-line summaries for quick magnitude assessment, as well as links out to preview images. This preview image can be used for basic sanity checking, in a way we found more helpful than Lasair. For example, on a recent day we checked the daily alerts for sources with magnitudes between 17 and 19 (a total of 10), found 6 with no preview images, with the four remaining included as Figure 2. From this we can see that three are viable candidates, whereas one is not. This analysis took under 10 minutes, and represents a relatively small drain on a faculty member's time. We should note that a disadvantage of TNS is there is an access rate limit that interferes with the ability to make this process any faster - although their website provides information about avoiding the rate limits using a Python API.

Finally, we would also like to mention that this first task, as well as the last (template subtraction), are the only tasks that fell under the primary responsibility of the faculty mentor on this project - everything else was done entirely by the undergraduate students, under supervision by the faculty member.

3.2 Project Design and Planning

The observational planning stage is relatively simple - for each of the candidate sources, determine which ones are optimally placed for our remote telescope network to observe them over a time period that is likely to include the maximum of the light curve (we typically used 20 days).

First, a quick note about the remote telescope network we used (which are alternatively known as "internet telescopes"). There are a number of commercially available, relatively affordable, options. Although we did a brief survey of these, once we found one that satisfied our essential needs, we did not continue to develop a complete comparison set. Our choice was the iTelescope network[5], for several reasons:

- There are many ($\sim$ 20) telescopes available, ensuring flexibility in scheduling.
- The 0.5-m class instruments available were located in several different regions of the globe (N America, S America, Europe, and Australia).
- They were equipped with commercial cameras, *i.e.* those we had experience with from our own equipment.
- They were equipped with photometric UBVRI filters.
- The web interface was relatively simple, and they had a complete set of tutorial videos, important for student training.

Absent from this list is the cost of this network, which we did not directly use in our decision making. Our assessment was that a careful estimate of the amount of time required for the project would be uncertain enough to be not worth the process, so we starting proposing small grants, of the order $2000-$4000 per year, to our local institution, with that idea that a post-hoc analysis could be done after we had collected some data to get a real estimate of the cost for the program.

To that end, we found that during the full run of the project in 2023, each student used about $70 of telescope time per week, for a total of around $3500 per year. Another way of measuring this would be around $800 per source, although that metric depends strongly on the decisions made when evaluating potential sources. Balancing that investment against the educational and institutional goals is a local matter, of course, but we would point out a few things:

- There is no set-up fee associated with this cost, it was entirely on an as-needed basis.
- This is roughly equivalent to what it costs to rent remote observatory space in a dark sky location.
- This cost could be minimized by utilizing less expensive telescopes, or using less popular observing windows.

In the end, we found the price of this project to be well worth it, given the student engagement it created and the potential scientific output, as well as the convenience surrounding the pay-as-you-go system. The details around the rest of the initial observation planning are very dependent on the choice of telescope network, the specifics of which we will not go into here. We do want to touch on two points - candidate selection and basic observational procedures.

The original idea was to utilize a planetarium program, such as Stellarium (Zotti et al., 2021) or Kstars (Harris & Mutlaq, 2023) to check if a particular source was visible with a particular telescope, since the students were already familiar with those tools. However, we found that the simple web-based tool STARALT[6] did a better job at this for several reasons. One is that all of the geographic locations of our network were included in it already, so the students could simply select those from a drop-down menu. It was also possible to cut and paste multiple sets of coordinates into the search box, to check the observability of several sources at once. Finally, the data presented was easy to fit into our workflow - a student could easily read off the meridian transit time, the moon rise/set times, and the angular separation of the source from the Moon. Our normal procedure was to send 3-4 sources to each student on a particular day when our observing window was opening, have them check them for our three primary observatories (in Utah/New Mexico, Spain, and Australia), and select one source that was positioned optimally for one observatory.

Finally, we had a default set of observational parameters, which was arrived at by our prior experience with this network. Each observation was started with some variation of 3x300 s exposures in a red (I or R) and a blue (B rather then U, see §3.5) filter, for about 5 days.

3.3 Monitoring of Observations

The first task after setting the observations is to ensure that the source is actually being observed as expected by the telescope network. The second is to monitor the observations until the

3 It should be noted here that it's likely Sherlock's classification system, being based on historical data, has improved since our initial assessment.

4 https://www.wis-tns.org/. The daily email alerts are available to registered users, and registration is free.

5 https://www.itelescope.net/

6 http://catserver.ing.iac.es/staralt/index.php

source has faded sufficiently for them to be terminated. Both of these require a basic understanding of photometry - measuring the amount of light from an astronomical source. We will not go into the details of this topic generally (for good introductions see Gallaway (2016); Warner (2016)), but will just highlight some of the specific techniques and software packages we used in this project.

A key software tool for our students is AstroImageJ (Collins et al., 2017). This is a free and open-source package, written in Java and based on the popular ImageJ[7], which was specifically created for time-series differential photometry, but also has the full calibration pipeline and astrometry tools we required. Generally, the criteria we used when designing the project was that if it can be done in AstroImageJ, it can be taught to an undergraduate student with minimal time investment.

After each night of observation (the first, in particular), our students would download the data from the network, stack the images across the filters, and determine the SNR of the source. These are all relatively simple tasks in AstroImageJ, and they will have received training on this ahead of time using an established set of training data. After this, we determine if the observation needs to be changed (longer exposure time, or perhaps even just halted if the burst alert network identified a false positive). Care was taken not to give up on the source too quickly, since the initial discovery and alert might have occurred before our network was actually able to observe it. On several occasions we decided to move forward with 5 days of observations before making a final decision about chasing after a seemingly invisible target.

Once the observation parameters have been set and verified, it was the student's responsibility to continue this "light" analysis for the time period that the source was observable. Although not strictly necessary (one could wait until the end to download the entire data set), we found it was helpful to keep the students engaged during this time period, and had the practical benefit of making the final analysis somewhat simpler, since each day of observation was ready for final time-series photometry. One could also go further, and ask the students to find the magnitude of the source separately for each day, but the benefits of seeing all of the source images over the ~weeks the observations were underway we felt outweighed that additional step.

3.4 Ending Observations

Deciding when to stop the observations tended to be somewhat unclear. If we started the observations with the new moon, the timing of the next Moon tended to match the expected length of observations from first light to max to dimming (10-20 days). We often found ourselves stopping the observations until the Moon was sufficiently far from the source (as reported by STARALT), and once the observations were taken up again, the source had faded below observability anyway. So while the decision tree around this step was unclear, it's not likely to impact the final light curve for any particular source.

3.5 Differential Photometry and Initial Analysis Plan

After the observations were complete, the next analysis task was differential photometry - that is, measuring both the flux of the target, and several comparison stars in the same image, to determine the magnitude of the target in a particular wavelength band. At this point we need to say that the creation of the final light curve by the students was actually not part of the original design of the project - the original goal was just to collect the data, monitor the observations, and stack the images. However, during the course of the SN project the group undertook a separate project observing cataclysmic variable (CV) stars, and during this the students easily learned, and became quite adept at, time-series differential photometry. We now acknowledge that there is no reason the students could not have been responsible for this task from the beginning; indeed, the sense of finality it would have brought them would have made the experience much more satisfying, we are sure. On the other hand, as we will detail, the final analysis required for our choice of telescopes and targets turned out to be beyond the student's ability to manage. In this section we will outline the strategy we used to try and use differential photometry on these sources, and in the next we will discuss the routine developed to actually produce the light curves in the final section of this paper.

The differential photometry task was greatly aided by AstroImageJ, but it was a challenge to select high-quality comparison stars, *in the correct filter*, to be convinced that our measurements were accurate. Although one could approach this problem using all-sky photometric methods (so-called transition coefficients are indeed available for many of the telescopes in the network), it is our view that the direct method of comparison with other stars in the image was simpler and more understandable for the students.

Our first plan in this regard was to use the variable star sequences produced by the American Association of Variable Star Observers (AAVSO (Kloppenborg, 2023)). Along with being an excellent reference for variable star observers, they will also produce custom sequences for community-requested targets. We should also mention that the photometry tool VPhot (Klingenberg & Henden, 2021), available from the AAVSO to members, is also an easy-to-use alternative to AstroImageJ, although we have found AstroImageJ to be a little more powerful and flexible, and deals with imperfect images a little bit better than VPhot (as well as being free and open source).

However, after going through the additional steps of contacting AAVSO for custom sequences a few times (for some of the more uncommon filters, outside of B and V), we came across an approach, developed to study asteroid light curves, to convert J and K magnitudes from the 2 Micron All Sky Survey (2MASS (Skrutskie et al., 2006)) into the BV(RI)c photometric system (Warner, 2007)[8]. This approach selected 128 stars for which high-quality magnitudes were available in both J and K and BV(RI)c, and fit an order 3 polynomial to the J-K color differences to determine the conversion between the systems. In particular color ranges, this provides 0.01 magnitude accuracy, and allows one to create their own sequences in the BV(RI)c system[9].

Specifically, we used the NASA Infrared Science Archive (IRSA[10]) to find and download comparison star magnitudes, according to the conditions outlined in the above works. By utilizing simple spreadsheet tasks and the ability to import apertures into AstroImageJ, we were essentially able to construct sequences of any size we desired (typically 5-10 stars). This was also an opportunity for the students to develop general analysis skills, such as looking for outliers in the data, identifying saturated sources, and verifying the constancy of the comparisons.

As mentioned previously, the primary goal of this study was to engage undergraduate students in as much of the project as possible, relying on them for the majority of planning, data collection, and analysis. However, it was at this stage that it

7 https://imagej.net/ij/

8 We initially learned about this approach through the information-dense *Photometry for Dummies* web page, http://brucegary.net/dummies/x.htm

9 Incidentally, this is why we chose to avoid the U filter; those sequences are uncommon on AAVSO/VPhot, and the U filter was not part of the photometry system conversion from J and K filters.

10 https://irsa.ipac.caltech.edu/applications/Gator/

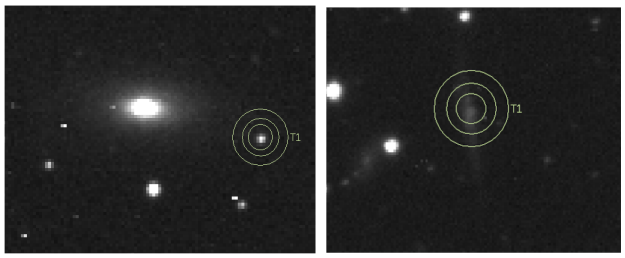


Figure 3. This figure illustrates the typical nature of the targets in this study, along with automatically determined photometric apertures from AstroImageJ. On the left is SN2023hrn, and demonstrates a case when the SN is sufficiently separated from the host galaxy for background determination (inside the annulus) to be relatively consistent through the annulus. On the right is shown SN2023ctn, demonstrating a case when the background is highly variable and cannot be separated from the host in any meaningful way.

became clear that the analysis task we needed was going to require another level of training for the students, which we did not anticipate needing. The source of this complication was the contamination of the source from the background light of the galaxy.

In a little more detail, the best practice in photometry is to identify a local background around the source extraction region which can be subtracted from the source counts. However, in the case of a point source near a galaxy, the background is heavily contaminated by the galaxy itself. It's easy to imagine this situation looking at Figure 2, but we illustrate our case more specifically in Figure 3.

In a single case (SN2023hrn), background determination was possible, and we were confident that the light curve extraction via differential photometry worked. However, we found that this was not the most common situation, and for the most part the contamination from the host galaxy was too extensive to allow for the construction of light curves. It was a disappointment that we were not able to minimize this problem, as we had hoped, but there are a variety of established techniques to deal with it. We discuss the implementation of one such technique in the next subsection.

3.6 Follow-up Observations and Template Subtraction

Although we initiated this project being aware of the problem surrounding the determination of the photometric background for SN Ia, we thought with the number of sources available (recall the TNS service includes dozens of new sources each day) we could select only those which appeared well-separated from the host galaxies (*e.g.* like SN2023hrn, shown in the left of Figure 3). There were several factors that lead us to mostly collecting sources that looked more like the right hand side of Figure 3:

- Many of the sources found by the various transit searches do not have preview images available on TNS. This means they were not inside the Sloan Digital Sky Survey (SDSS (Taghizadeh-Popp et al., 2020)) or Pan-STARRS footprint. This greatly reduced the number of potential sources we actually had available to us.
- Many more of the sources were obviously not SN Ia, being not clearly associated with a bright host galaxy.
- The resolution of the 0.5-m class telescopes used meant that the point spread functions were large enough that the background from the galaxy varied significantly across the background region. This effect can be seen clearly in Figure 3.

A representation of the relative numbers in each of these categories can be seen in the snapshot analysis we presented in §3.1 - of the 10 sources from that day, 6 were in the first category, and 1 in the second. We acknowledge that there is probably much room for improvement for the problem presented in the first category - it's highly unlikely that there is not at least one survey that covers any particular region of the sky. As a practical demonstration of this, we choose one of those sources (AT 2024bti[11]) and were able to find this location in the Digitized Sky Survey (DSS[12]) images available in Aladin's option menu. Thus, reducing the number of candidates in the first category above would amount to a minor change in the human-review process of each source. Dealing with the second bullet point is essentially the reason we moved away from Lasair to TNS, since we can easily skip those sources by visual inspection.

In any case, we clearly needed an analysis pipeline that can handle background confusion from the galaxy. Such routines are well-known in the community (for an example utilizing hypothesis testing to subtract out galaxies to detect transients, see Zackay et al. (2016)), but are outside the abilities of most undergraduate students. The essence of the idea is to subtract a *template* of the galaxy, without the source in it, to remove the galaxy from the background completely. This must be done either before the SN exists (impossible in our context), or many months later, when the source has faded beyond observability. After waiting sufficiently long for this to occur for one of our sources, we took such template images and worked on developing an appropriate routine to subtract it from the source images.

Our initial attempt was to implement this subtraction routine in AstroImageJ, since we believe that anything done in that software package could be managed by our students. After significant testing, this proved impossible. The primary issue is one of normalization - the sky brightness varies substantially night-to-night, due to weather, altitude, Moon glow, and other uncontrollable factors. AstroImageJ does not have a sufficiently robust way to normalize the galaxy brightness across the entire image set to make the subtraction routine workable. There are other things impossible in the software as well, such as rotating images to deal with small camera offsets, but the normalization is the primary one.

Having decided that the GUI-based AstroImageJ was insufficient for our needs, we set about exploring alternatives, focusing on the Python-based AstroPy library (Astropy Collaboration et al., 2022). This software package includes many of the necessary routines needed for this task (including arbitrary rotation and alignment, PSF matching, image math, and so forth), and there are online resources available, for example the Global Relay of Observatories Watching Transients Happen (GROWTH) Astronomy Summer School program[13] has several modules dealing with this analysis task. This task fell outside of the skill set of our undergraduates, but the faculty member leader developed such a routine, adapted to our telescopes and source characteristics, utilizing AstroPy tools as well as Swarp (Bertin et al., 2002) for astrometric projection. This routine is publicly available via Github[14], and we will present the results of this subtraction routine on a subset of our sources in the next section. Some effort was made for this routine to be understandable enough for our undergraduate students to use it in the future.

11 https://www.wis-tns.org/object/2024bti
12 https://archive.eso.org/dss/dss
13 https://www.growth.caltech.edu/growth-school-2020.html
14 https://github.com/cduston44

Name[1]	N Obs	Redshift[2]	Type	Separation (“)	Discovery Mag
2023ctn	8	0.051	Ia	2	18.5
2023cyx	11	0.033	Ia	2	17.4
2023dpj	3	0.014	II	13	17
2023eoc	3	0.036	Ia	5	17.4
2023hrn	22	0.020	Ia	70	18.4
2023hrk	6	0.060	Ia	12	18.8
2023hst	3	0.070	Ia	11	18.5
2023mcj	18	0.050	–[3]	8	19.2
2023koy	18	0.068	Ia	7	19
2023pnt	32	0.033	II	16	19.5
2023sse	7	–[4]	–[3]	5	19.4
2023umf	13	0.062	–[3]	3	20.4
2023yfh	4	0.035	II	3	17.9

Table 2. Metadata for our complete set of observations.

[1] TNS convention is to name new objects with the prefix AT until they are confirmed to be supernovae, at which point the prefix is changed to SN.
[2] As reported in TNS.
[3] This object is still unknown.
[4] The red shift of the host was not able to be determined.

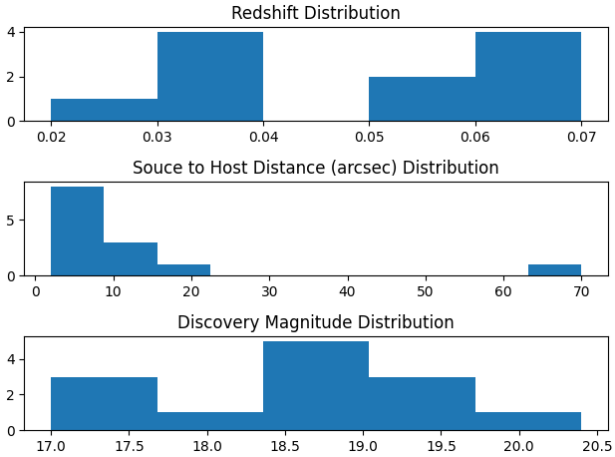


Figure 4. The distributions of the red shift, SN to host galaxy separation, and discovery magnitude.

4 Data

In this section we discuss the complete data set and present the relevant metadata and light curves we have been able to successfully extract with the previously-discussed analysis pipeline. We emphasize again that this data was collected by a group of undergraduate students, with majors both inside and outside of the physical sciences. The information presented is intended to serve as an example for someone else looking to undertake a project like this one, to give a sense of the amount and character of data that can be collected. Table 2 presents our overall observations, and relevant metadata such as red shift, separation, type (if currently known), and magnitude of discovery. Figure 4 gives the distributions of these parameters.

We can make some essential observations about the fidelity of the data collection process. For example, although we are mostly interested in SN Ia, and we started observing these objects before the classifications were actually known, 77% ended up being “real” supernovae, and 53% were typed Ia. The remaining SN II might not be specifically interesting to us, but the resulting light curves would still be relevant for future studies of these objects. We view these numbers positively, and note that there is at least the potential for an increase of the scale for this project several fold. In other words, although each day we started observations we generally selected a single source to track, once we had started tracking that source, we did not look for any others for over ~20 days. Thus, even with our simple, fairly naive selection criteria, there is possibly 5-10 times as many sources that could be investigated further using this same criteria.

The distribution of source-host separations in Figure 4 is somewhat expected, as the distribution of stars in these galaxies are typically far denser in the inner regions, but the number of targets with sub-5 arcsecond separations we ended up observing was unexpected. We typically chose larger resolutions (camera binning), in the 2-3 arcsecond range, to increase the sensitivity of the cameras, but that was not well-matched with the resulting sources. It also clearly highlights the need for the template subtraction routine described in §3.6, as most of the sources fall within the visible boundary of the galaxy.

The redshift and magnitude distributions are less obviously helpful. For sure, the fact that we only found sources with redshift under 0.07 is tied to the sensitivity of the burst alert network, but the relatively flat redshift distribution is likely just due to a combination of redshift dependent galactic density and transient brightness. The discovery magnitude distribution could be helpful in our search procedures (we had already noticed that sources brighter then magnitude 17 typically turned out to be lacking a host galaxy, and likely variable stars or classical novae), but the specific shape is likely due to the increasing number of sources at dimmer magnitudes competing with the dimming of the host galaxies and a decreased likelihood to be observable with the available instrumentation.

Finally, we present images and light curves for the set of our sources for which we had a sufficient number of observations to potentially determine their astronomical properties, shown in Figure 5. In these examples, the subtraction routine functioned adequately (in the sense that it can be seen that the background galaxy was indeed removed), but there were residual stellar images present. The source of these residual images was saturation - if stars in either the science or reference images were saturated, they would not be appropriately normalized. This does not impact our photometry routine, since the background subtracted images were amenable to instrumental magnitudes, rather then differential ones.

This also raises another issue that we encountered - one of student training. Although the faculty involved created training documents and videos, the students ended up taking data in a variety of non-optimal ways that they were not immediately sensitive too. The saturation issue mentioned in the last para-

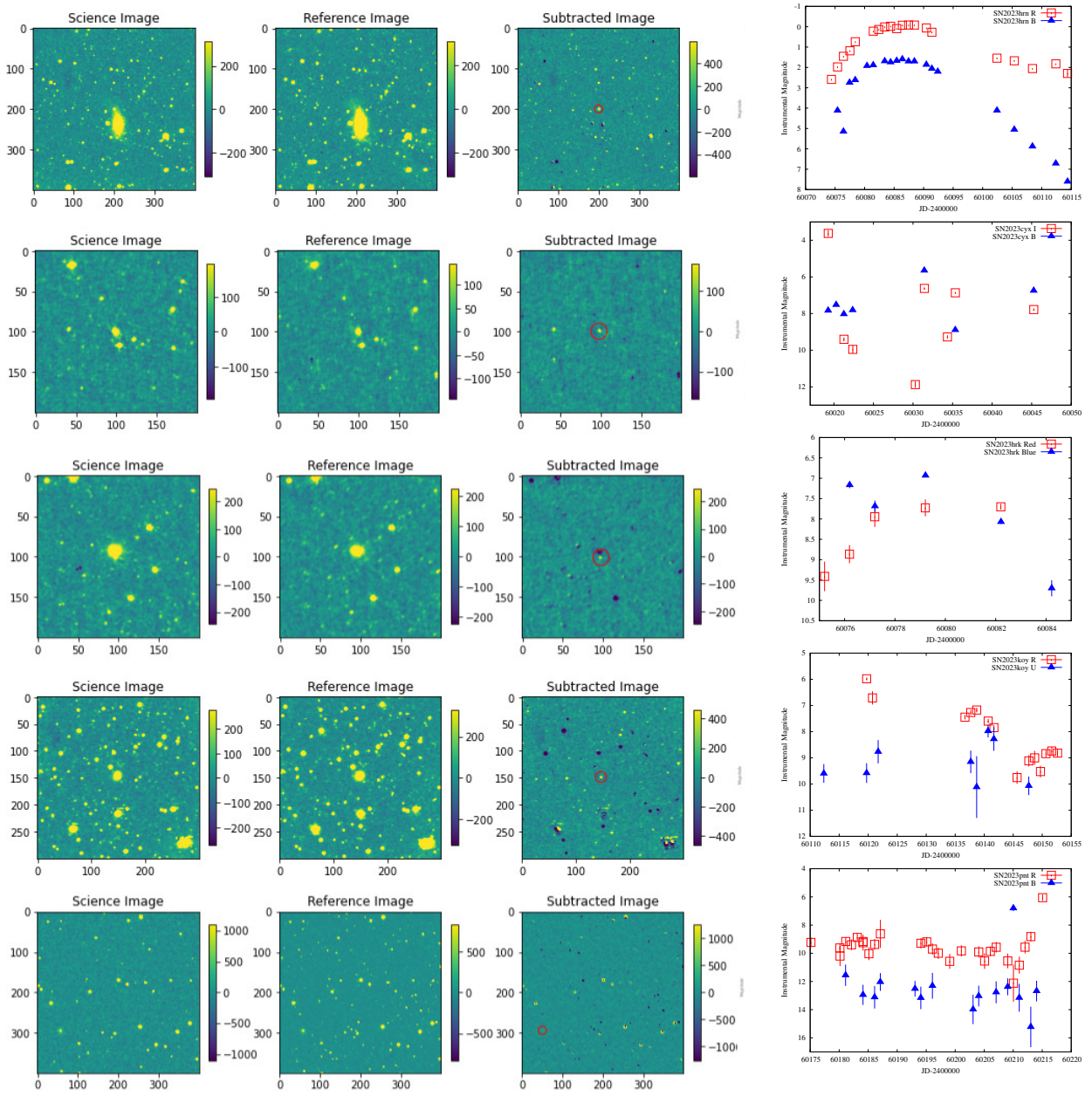


Figure 5. Images and light curves for the set of sources which had sufficient coverage to potentially identify a SN-like light curve. In this figure, the "Science Image" is the first night of observation of a particular source, the "Reference Image" is the image taken several months later, after the SN has dimmed, and the "Subtracted Image" is the scaled science minus the reference. On the far right is the resulting light curve for each source (circled in red), showing how the instrumental magnitude changes over time in the two filters used. We point out the photometric errors vary from under 0.1 to over 1, depending on the source and filter.

graph is a prime example - we did not provide enough detail to the students about avoiding saturation problems, because our original plan (differential photometry) was relatively insensitive to it. Another example can be seen for SN2023hrk in Figure 5; RGB filters were utilized rather then UVBRI. This was not part of any of the documentation provided to the students, but once the student "made the mistake" of starting with RGB, the only choice was to either abandon the source altogether or continue with those filters for the entire observation run. From the practical training side of things, we do not view that as a error - it provided a good demonstration for the students of how critical observation planning is for these transient sources. On the other hand, the scientific value of that data is questionable. The issue at hand is essentially one of expectation matching - giving lots of agency to undergraduate students can result in somewhat lower quality scientific production, combined with a potentially large amount of experiential and learning gain on the part of the students.

With the quality of the light curves at hand, our long-term scientific goal of a statistical analysis of the blue bump is not possible, but it is worthwhile to compare and contrast these curves as we have them. First, it is clear that SN2023hrn is the only one with a distinctly SN-like shape (rise and fade times). Specifically, the change in B magnitude 15 days after peak brightness being around 2.0 is roughly consistent with the Phillips relation (although we do not have access to the absolute magnitude due to our subtraction routine) (Liu et al., 2023). The quality of SN2023hrn can be explained using the table of metadata - it has a small redshift and is the furthest from the center of its host galaxy (by about an order of magnitude). So, the background is both constant and relatively insignificant (this can be clearly seen in the source image, Figure 3). Some of the other sources in Figure 5 also show some evidence of the SN-light structure - rise but not fade, or vise versa, for example. Given that our subtrac-

tion routine did in fact work well for a bright, well-placed source, it's likely just a signal to noise issue for dimmer sources, and our exposure times (typically 10-15 min per filter) were insufficient for these kinds of targets. In any case, it is worth mentioning that to our knowledge, these are the only light curves available for those 5 sources.

5 Summary

It is our contention that commercially available networks of 0.5-m class telescopes are underutilized in academic environments, in particular for the introduction of undergraduates to research in astronomical sciences. For example, a recent work discussing astronomial data use in the classroom focused primarily on archive data (Rebull, 2024). A few remote options were discussed, but a commercial network such as the one utilized here was not.

Although the remote observatories do require some financial investment, the commitment pales in comparison to what would be required to construct an equivalent observatory from scratch, and the ability to "pay as needed" makes the commercial networks convenient for institutions whose focus may not be research. In addition, the barriers for students are quite low in this type of work (prerequisite knowledge is relatively minor, compared to fields with extensive laboratory training or theoretical background requirements), so they can engage deeply in the research process fairly quickly. We would actually advocate for the use of these observatories even aside from the scientific goals that one could achieve. Training a student to verify existing facts about various astronomical phenomena, being a fundamental part of the process of science, should be motivation enough.

In this paper, we have presented an approach to go one step further - that is, design a project that utilizes such a remote network of telescopes, engages undergraduate students at a level they are ready for, and also tries to answer a question of scientific import about the progenitor population of SN Ia. As demonstrated, the project utilized a wide variety of publicly available resources: a burst alert network, free software packages, and archive data, to name a few. The vast majority of the tasks were wholly under the control of the students, the exceptions being at the very beginning and end of the observation pipeline. In the course of this project, these students learned a variety of skills specifically applicable to observational astronomy, such as observation planning and design, data collection, data storage, and photometric analysis. Although delivering these skills to students who are studying astronomy gives them an experience clearly in line with their interests and future careers, we also pointed out that since the barrier to entry is so low, any undergraduate student can engage in and benefit from a project such as this one.

We also identified a key failure point in our original analysis pipeline - that many of the sources suffered from background confusion with the host galaxy. This problem was expected, but we anticipated its impact could be minimized due to the number of sources being found each day by the burst alert networks. The subtraction routine has, in large part, solved that issue, but the data collection process is now not as well optimized for the analysis routine. Specifically, we should have used higher resolutions and shorter individual exposure times to minimize saturation issues. An improved filter could also be developed through Lasair or TNS, so that we are not sorting through dozens of sources each day by hand. To this end, we are planning another iteration of this project with the same population of students which includes improved training procedures that better match the required analysis routines. After the next stage of this project is complete, we may be able to make some progress on the scientific goal of identifying and classifying the "blue bump" in the early light curve of SN Ia, while continuing to give the students an engaging and satisfying research experience.

5.1 List of abbreviations

2MASS: 2 Micron All Sky Survey
ATLAS: Asteroid Terrestrial impact Last Alert System
CV: Cataclysmic Variable
DSS: Digitized Sky Survey
GROWTH: Global Relay of Observatories Watching Transients Happen
Pan-STARRS: Panoramic Survey Telescope and Rapid Response System
SDSS: Sloan Digital Sky Survey
SN: Supernovae
ZTF: Zwickey Transit Facility

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5.3 Author's Contributions

C Duston: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, writing - initial draft, writing - reviewing and editing. L Bell: data curation, investigation, methodology, and writing - review and editing. J Pelletier: data curation, investigation, methodology, and writing - review and editing. F Quintana: data curation, investigation, methodology, and writing - review and editing. E Torkildsen: data curation, investigation, methodology, and writing - review and editing. L Venturotti: data curation, investigation, methodology, and writing - review and editing.

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