Constructing Light Curves for Type Ia Supernovae

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Abstract

Type Ia supernovae (SNe Ia) are crucial to probing the expansion history of the universe and, by extension, gaining insights into the properties of dark energy. This is due to their nature as "standard candles," which allows us to estimate their distance from us very precisely if we know their apparent magnitude. In this project, I focused on two SNe Ia to confirm whether they are, in fact, SNe Ia: SN 2019bkh and AT2019bqe. Using remotely operated telescopes in Auberry, California, and Mayhill, New Mexico, as well as the larger of the two telescopes at the Leitner Observatory in New Haven, Connecticut, I imaged both of these supernovae in the Johnson-Cousins V, R, and I bands. I then reduced the image data, which allowed me to compare the instrumental magnitudes of the supernovae with the standard magnitudes listed in the APASS catalogue. Next, I constructed a rough approximation of a light curve for each supernova. Both light curves showed rapid declines in brightness a few weeks after the creation of the supernova, which is characteristic of SNe Ia. The end goal of this work was two-fold: I hoped to confirm that these supernovae are SNe Ia through constructing their light curves, and this work is intended to serve as a proof of concept for a project that high school students in the Yale Summer Program in Astrophysics will complete this summer.

Introduction

Type Ia supernovae (SNe Ia) occur when a white dwarf in a binary system with a larger star accretes enough matter from its partner to reach a mass of 1.4 $M_{\odot}$. Gravity then overpowers electron degeneracy pressure, and the white dwarf collapses inward before exploding outward in a supernova. Because all of these white dwarves reach nearly identical conditions before they explode, the resulting supernovae reach similar brightnesses, making them "standard candles."

- Identifying a Type Ia supernova (SN Ia) and measuring its brightness therefore provides a reasonable estimate of how far away it is, and we can then calculate when it went off, simply by dividing the distance by the speed of light.
- We can also calculate the cosmological redshift of the light from any supernova, which tells us, after a quick calculation, the size of the universe when the supernova went off.

Therefore, each SN Ia provides one point on a size vs. time graph of the universe (Figure 1), allowing us to track the expansion history of the universe and predict future expansion or contraction. This begins with constructing light curves for these supernovae, which was the focus of my project.

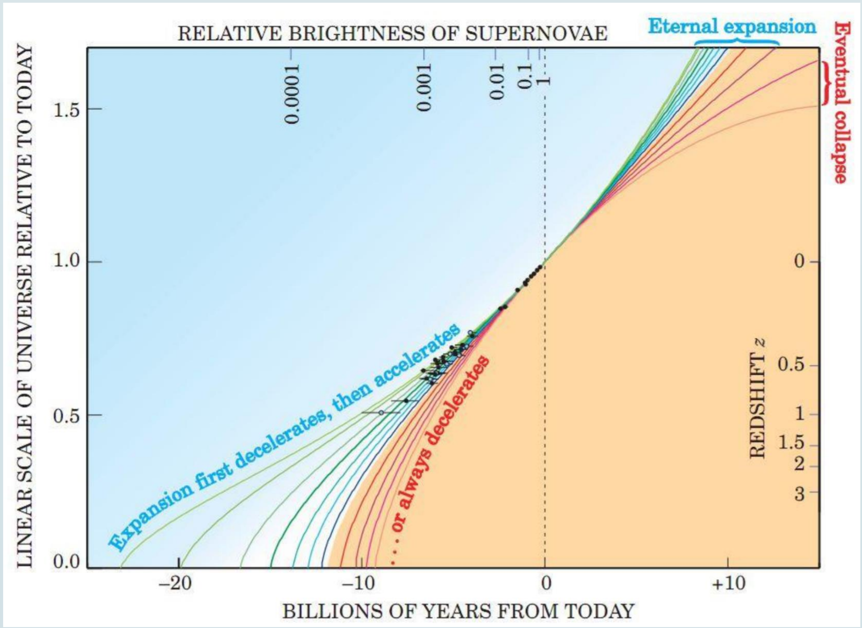

Figure 1: The expansion history of the universe, where each point represents one Type Ia supernova (Saul Perlmutter, *Physics Today*, 2003)

Methodology

Telescopes Used:

- 0.43-meter telescope at the New Mexico Skies Remote Observatory; remotely controlled through iTelescope.net (designated as "T21" on iTelescope.net)
- 0.61-meter telescope at the Sierra Remote Observatory; also remotely controlled through iTelescope.net (designated as "T24" on iTelescope.net)
- 0.4-meter telescope at the Leitner Observatory

Filters Used (Johnson-Cousins):

- T21: V, R
- T24: V, I
- Leitner: V, R

I imaged each supernova on eight separate nights spread out across March and early April, always taking care to observe as close to each supernova's transit time as possible.

After taking the images, I median-combined all the images of the same supernova taken by the same telescope on the same night with the same filter and performed flat-field corrections. All of this data reduction was performed in MaxIm DL. I then uploaded the flat-fielded images to nova.astrometry.net to plate-solve them, and once that was done, I used SAOImage DS9 to retrieve standard magnitudes from the APASS catalog for nine reference stars around each supernova. After then measuring the instrumental v and r magnitudes in MaxIm, I calculated the appropriate transformation coefficients using the equations $V - R = T_{vr}(v - r) + C_{vr}$ and $V - v = T_v(V - R) + C_v$ and constructed the simple light curves in Figure 4.

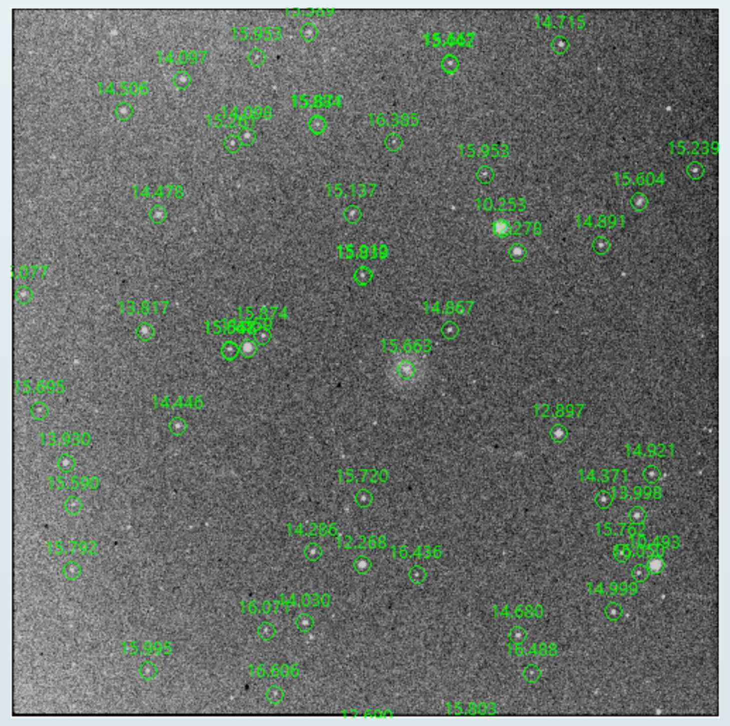

Figure 2: An image of AT2019bqe in the galaxy NGC 3074 (at the center of the image) modified in DS9 to include standard V magnitudes of many visible stars; unfortunately, the supernova is obscured by the green ring over the center of the galaxy

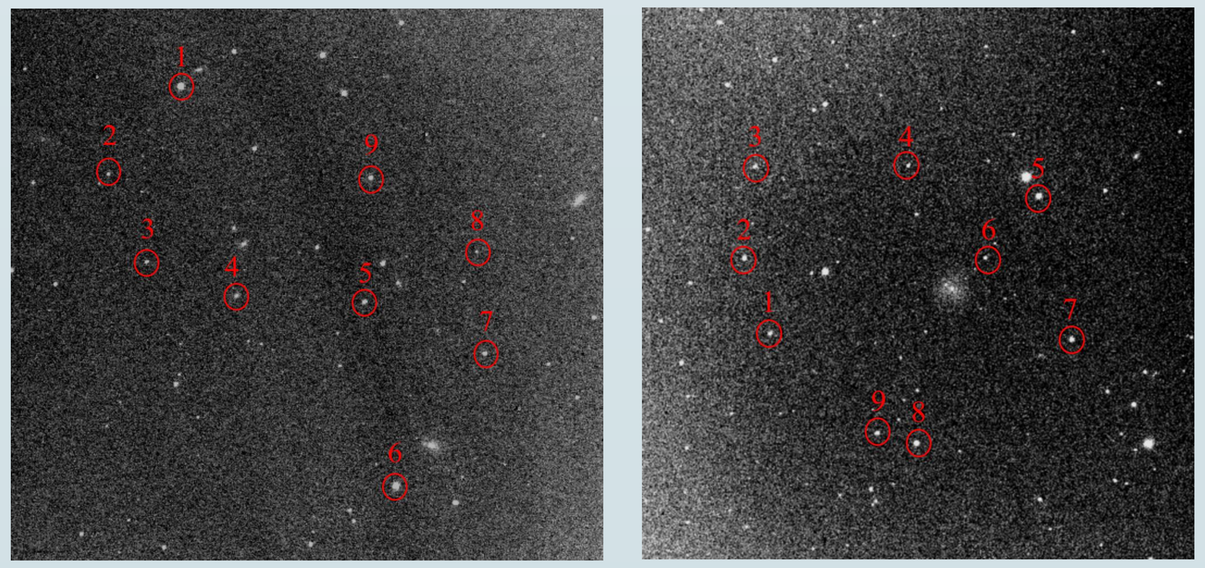

Figure 3: Reference stars for SN 2019bkh (left) and AT2019bqe (right)

Results

SN 2019bkh:

- Its V magnitude light curve has the characteristic shape for a Type Ia supernova.
- Peak V magnitude was likely around 15.4 and likely occurred within two days of March 25th.
- The V-R color curve shows noteworthy variations, though likely with large uncertainties.

AT2019bqe:

- Its V magnitude light curve has most of the characteristic shape, but it lacks the distinct peak that is clearly visible in the V magnitude light curve for SN 2019bkh.
- Peak V magnitude almost surely did not occur between my first and last observations (March 12th – April 10th); I would estimate it to be close to 14.
- Its V-R color variations displayed a similar pattern to those of SN 2019bkh, though likely also with large uncertainties.

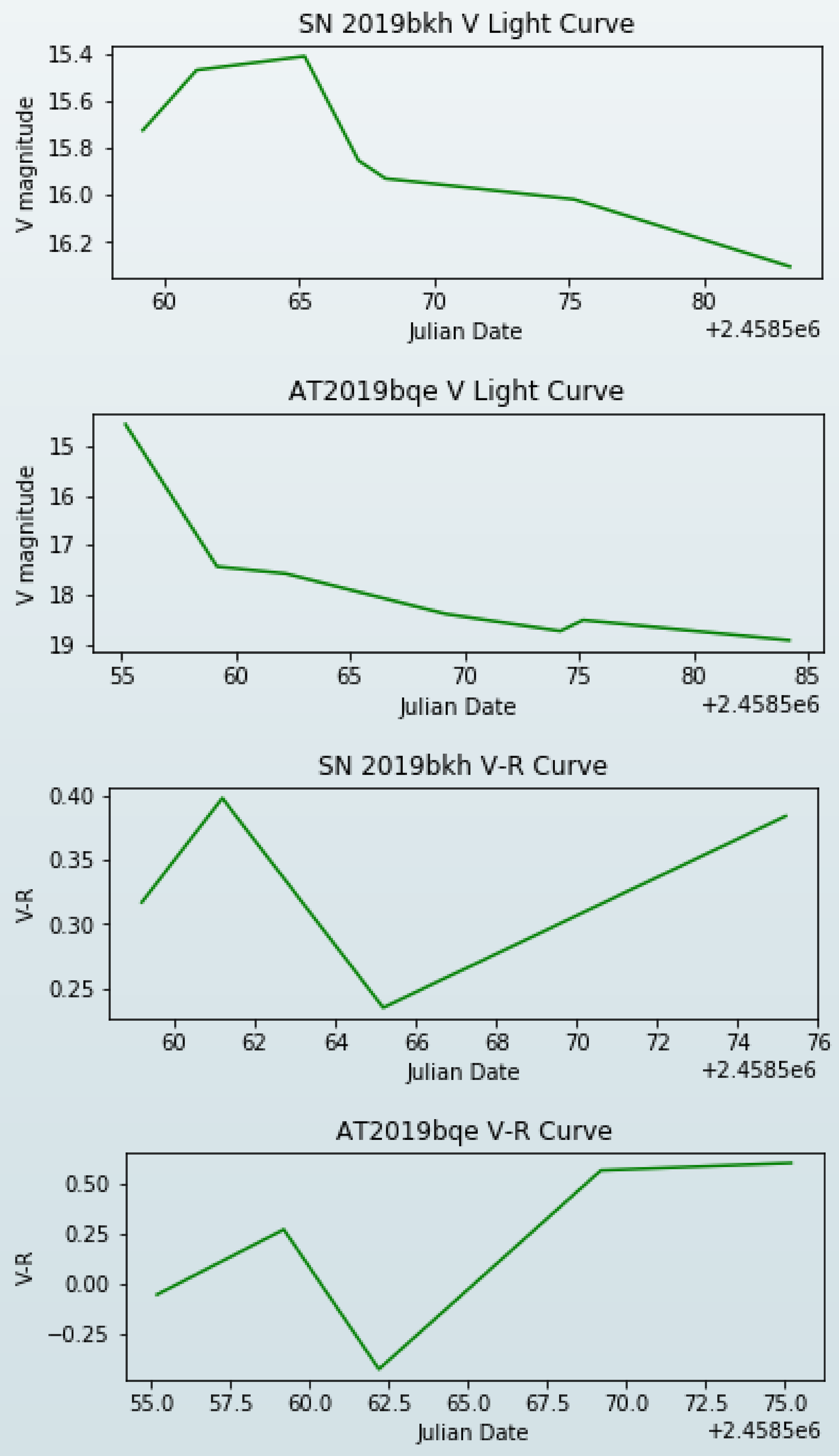

Figure 4: V magnitude light curves and V-R color curves for SN 2019bkh and AT2019bqe

Conclusion

The V magnitude light curve for SN 2019bkh displayed the characteristic shape expected for a Type Ia supernova, with a distinct peak followed by a rapid decline. I expect that had I begun observing AT2019bqe a week earlier, I would have seen a seen a similar shape in its light curve, since the steep drop in magnitude from March 12th to March 16th suggests that the supernova was at peak brightness not long before March 12th.

It's worth noting that SN 2019bkh was located so close to the center of the galaxy in which it appeared that when I was recording its instrumental magnitude using MaxIm, it was impossible to find an aperture size small enough to measure the light from the supernova without including the light from the galaxy's center. This likely did not have a significant effect on the overall shape of SN 2019bkh's light curve, though, since it would have shone brighter than nearly everything else in the galaxy for most of the time I spent observing it.

It's also worth noting that some of the data points in the V magnitude light curves were obtained without using the V-R transformation coefficients I described in the Methods section. Because T24 doesn't have a Johnson-Cousins R filter, using that method would have been impossible. Instead, to recover a standard V magnitude for the two supernovae, I found a line of best fit between the instrumental v magnitudes and the standard V magnitudes of the reference stars around both supernovae and used the slopes and intercepts of those lines (which displayed nearly perfect linear correlation) to approximate the standard V magnitudes of the supernovae.

The V-R color curves for the two supernovae displayed similar patterns, which makes sense given that these are both the same type of supernova. Each supernova was the most green around its peak, after which it became more red as its V magnitude declined, only to become more green again as its brightness declined more slowly to level out at the average brightness of its surrounding stars.

Based on the shapes of their light curves, one can safely conclude that SN 2019bkh and AT2019bqe are Type Ia supernovae. The similarity of their color curves supports that conclusion. Furthermore, based on my own experience working on this project for the past month, this seems like a very reasonable project for talented high schoolers to finish in a similar amount of time during the summer. There are many ways I would have liked to expand upon the work I did, the least of which would be to automate the data reduction process using Python, and I imagine that if I were to have had an uninterrupted month over the summer to work on this, that and much more would have been possible.

Acknowledgements

This project would not have been possible without the gracious support of Dr. Michael Faison, of the Astronomy department at Yale University. The same goes for my professor in ASTR 255, Professor Marla Geha, also of the Yale Astronomy department.

Figure 5: The Leitner Family Observatory and Planetarium, on the campus of Yale University, in New Haven, Connecticut; the telescope I used is the closer of the two (Photograph from leitnerobservatory.yale.edu)