

Development of a Photometry Pipeline for Las Cumbres Observatory Data in Python

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1. Abstract

Within astronomy, photometry is the process of measuring the flux, or amount of light, coming from an object in space. In this paper, I discuss the development of a photometry pipeline in python, and its application to supernova sn2022wpy, using data taken with the Las Cumbres Observatory network. I compare the resulting light curve generated with the program AstroArt.

Finally, I discuss possible future directions for this pipeline.

2. Introduction and Background

Stars are objects of immense mass. As such, they generate immense gravity. Being an attractive force, this gravity would ordinarily cause the star to continually shrink in size. However, this shrinking eventually generates sufficient densities and temperatures to facilitate nuclear fusion in their center. This nuclear fusion releases energy, which provides outward

pressure, to counteract the force of gravity. These two forces eventually reach a sort of equilibrium, where the star no longer shrinks.

However, as massive as stars are, their mass is still finite. As such, the center of the star eventually runs out of fusion material. Once there is no more outward pressure from nuclear fusion, gravity takes over, once again. What occurs after depends on the star's mass. For stars about the mass of our sun, the outer layers expand, turning the star into a red giant. In this scenario, the outer layers of the star eventually drift away, forming a planetary nebula, and leaving a dense object called a white dwarf, which used to be the core of the star.

Stars that are more massive than our sun, greater than about 7 times the mass of our sun, eventually end in a more violent event, called a supernova. Supernovae are incredibly bright objects, capable of outshining the entire galaxy that the supernova is located in. The core of the star then goes supernova either becomes a neutron star, a more dense version of a white dwarf, or a black hole, where the laws of physics as we know them break down.

There are many types of supernovae, distinguished by the presence, or absence of certain elements' emission or absorption lines in the spectra of the supernova. The main distinction is between supernovae that have hydrogen (type I supernovae), and those that don't (type II supernovae).

Type I supernovae have a sub-classification called type Ia supernova, which is characterized by a singularly ionized silicon line. As it turns out, type Ia supernovae all form in much the same way: they form when a white dwarf accretes too much matter from a companion, and exceeds the Chandrasekhar limit (approximately 1.44 solar masses). This unique property has earned these supernovae the nickname 'standard candle' (7). Due to their uniform nature

of creation, they all have roughly the same peak brightness, and the same drop in brightness over time (4). If we observe a type Ia supernova, we know how bright it should be, so we can compare the theoretical brightness with what we observe to calculate the distance to that supernova. Most famously, type Ia supernovae were used to discover the effect that we call 'Dark Energy' (3).

Photometry means simply to 'measure light'. In the context of astronomy, photometry refers to determining the brightness of an object in space. This is done through the use of detectors mounted behind telescopes. In this section, I will focus on CCD detectors, as that is the type of detector used in this study.

CCD stands for Charge Coupled Device, and is composed of a metal oxide layer that produces electrons when struck by incoming photons (1). These electrons will fall into pixels on the device, and can then be read out. Since more incoming photons will produce more electrons, a notion of brightness (given by the number of electrons in a given pixel), can be obtained. The signal is passed through an analogue to digital converter (ADC) so that it can be presented on a computer screen, and saved to memory, or transferred to other machines for analysis.

Using a CCD device requires a couple of corrections to be applied. The first is a flat field correction (1). Flat field corrections correct for the fact that not all of the pixels on a CCD will produce the same number of electrons from the same number of photons. Because of this, if the number of electrons is read out naively, any notion of brightness is destroyed. To correct for this, the telescope operator shines a bright, uniform light into the instrument. Since the light is uniform, the count of every pixel should be the same, in theory. By taking a measurement of this bright, uniform light, we can assign a correction factor for each pixel, to ensure that this effect is taken care of. For example, consider a CCD detector, consisting of two pixels, pixel

one, and pixel two. If we apply a bright, uniform light to the device, we can then measure the number of electrons in each pixel. Suppose that we find that pixel one has n electrons, whereas pixel two has $1.1*n$ electrons. For future measurements, we then divide the raw number of electrons counted in pixel two by 1.1. Correcting for this effect is called 'flat field' correction.

The other type of correction is related to the so-called 'dark current' of the CCD (1). To understand the dark current, we recall that the energy of electrons is given by a statistical distribution, where some are higher energy, and some are lower energy. To get an electron into a pixel in the CCD, it must cross an energy threshold, set by the metal oxide material. In theory, photons are the only source of necessary energy to cross this boundary. However, as electrons' energy follows a statistical distribution, occasionally, an electron will have enough energy to fall into the pixel by itself, registering a false count. To counteract this, the telescope operator prevents any light from reaching the detector. Then, they take a measurement of the CCD, after letting it expose for some time. From here, we can measure how many electrons were in each pixel, and divide by the length of the exposure, to get the dark current of each pixel, in electrons per second. Then, for future measurements, the scientist would simply subtract off the dark current from their raw electron count. Correcting for the effect is called 'dark subtraction'.

Once all corrections have been taken into account, we can proceed with photometry. The ultimate goal of photometry is to obtain the magnitude of an object. Magnitude is a measure of brightness, and is a function of photons per second, per unit area. One option would be to simply look at the number of counts we get, in our image, that come from the object, and divide by the exposure time, and telescope area. However, there are a number of problems with this. The major problem is that the atmosphere distorts the light coming in from outer space. This can make the object appear dimmer than it actually is.

To overcome this problem, we use a guide star. A guide star is a star that has a well known magnitude, and is also in the field of view of the telescope, along with the object of interest. Since we know the magnitude of the guide star, we can directly compare the number of counts that the guide star has, and the number of counts that the object of interest has. From this, we can calculate the difference in magnitude, from which we can calculate the magnitude of the object of interest.

Data reduction pipelines are pieces of software that take in raw images from instruments, and modify the images in some way, depending on the specific needs of the instrument, or observer. Some examples of typical data reduction pipeline components are flat field correction, or dark subtraction, as mentioned before.

2. Data Collection

Data for this project were gathered entirely with the Las Cumbres Observatory (LCO) global network of telescopes (2). All data were taken with the SBIG 6303 telescopes. The SBIG 6303 telescope is 0.4 meters in diameter, and has a field of view of 29.2×19.5 square arcminutes.

The CCD detectors are 3000 by 2000 pixels in total.

We took data over about a month of observation. We used four different filters for each observation: Bessel B, Bessel V, SDSS r' , and SDSS g' . We had originally requested SDSS i' , but the observation was executed with SDSS r' instead. Each exposure was 80 seconds in length, with two exposures taken for each filter, for each night. The data were initially processed with the LCO's data reduction pipeline, Beautiful Algorithms for Normalizing Zillions of Astronomical Images (BANZAI) (4). BANZAI performs a number of calibrations, and corrections

automatically. These include dark and bias subtraction, astrometric calibration, and bad pixel masking. The BANZAI pipeline also performs source extraction, for photometry, but that feature was not utilized in this study.

3. Data Analysis

First, for every image, 6 header entries to the fits files were added. These header entries corresponded to the x and y coordinates, and the radius of the supernova, and reference star. This was so that the main Photometry pipeline could automatically process all of the files at once (see Section 4. Discussion and Future Directions for more detail on this choice).

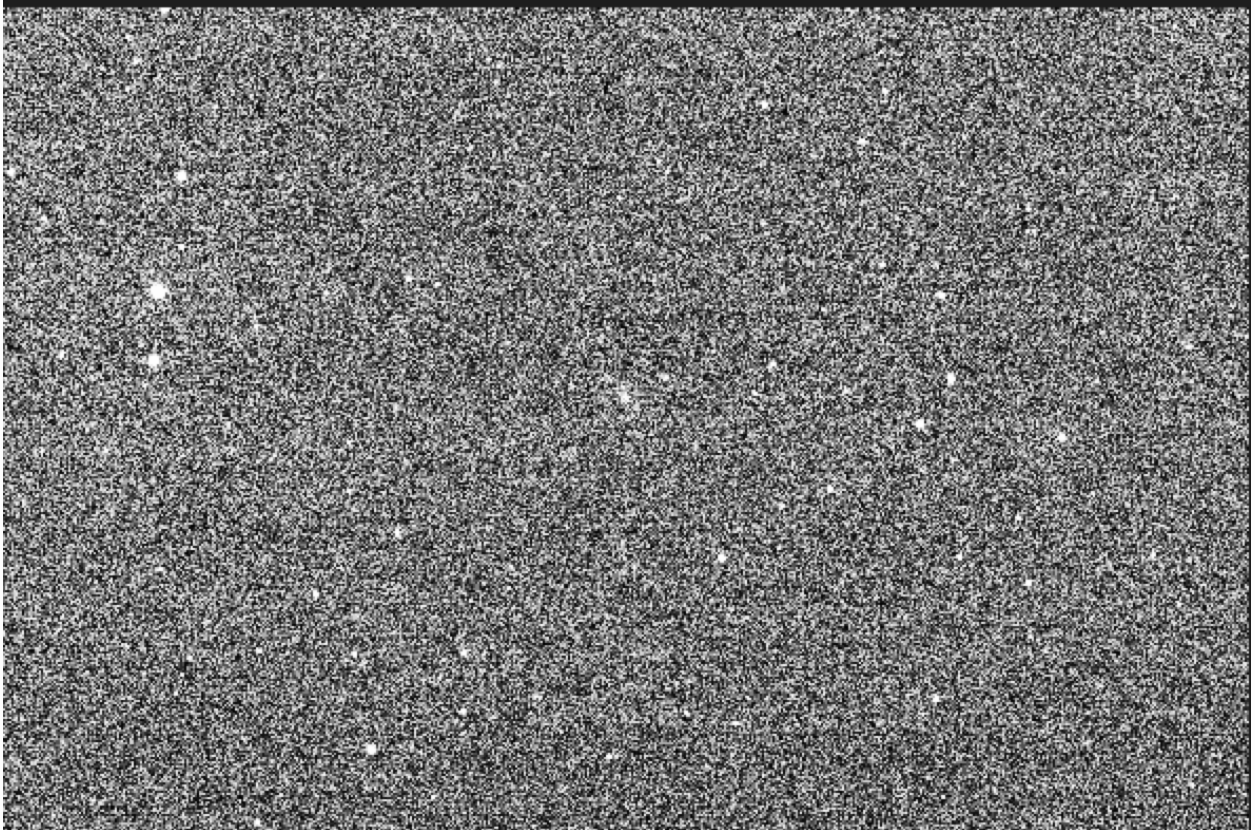


Fig. 1: The full frame of an image. The host galaxy of supernova sn 2022wpy is in the center of the image. Notice the three stars on the left, in an almost vertical line.

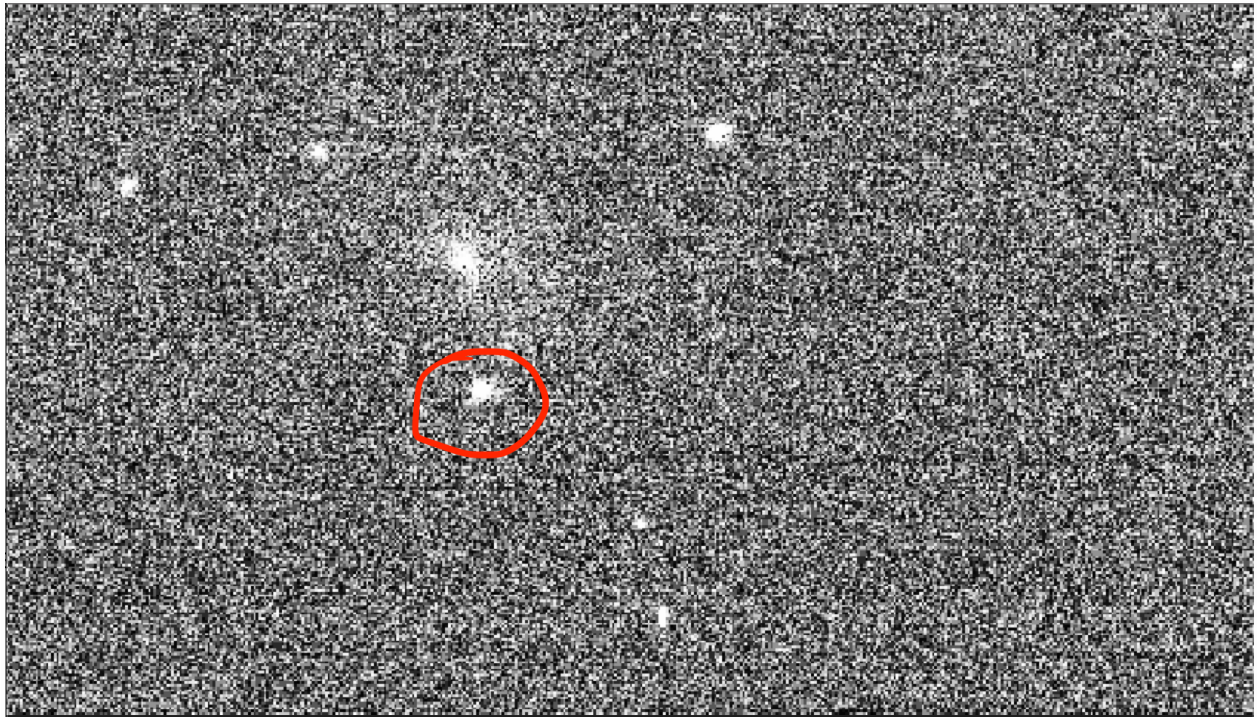


Fig. 2: The center of the previous image, zoomed in. The supernova is circled in red. The core of the host galaxy is visible directly above the supernova.

For this study, I chose the star HIP 22206. Its magnitude was acquired through the SIMBAD (5) database. This star was selected, for a number of reasons. First, it was a star that had information regarding its magnitude for each of the bands that we measured in. Second, it was not noted to be a variable star, by the SIMBAD database, making the magnitude measurements more reliable. And last, the brightness, when compared to the background, was helpful in locating the star in each of the images, as I could easily locate it, even when viewing the entire image.

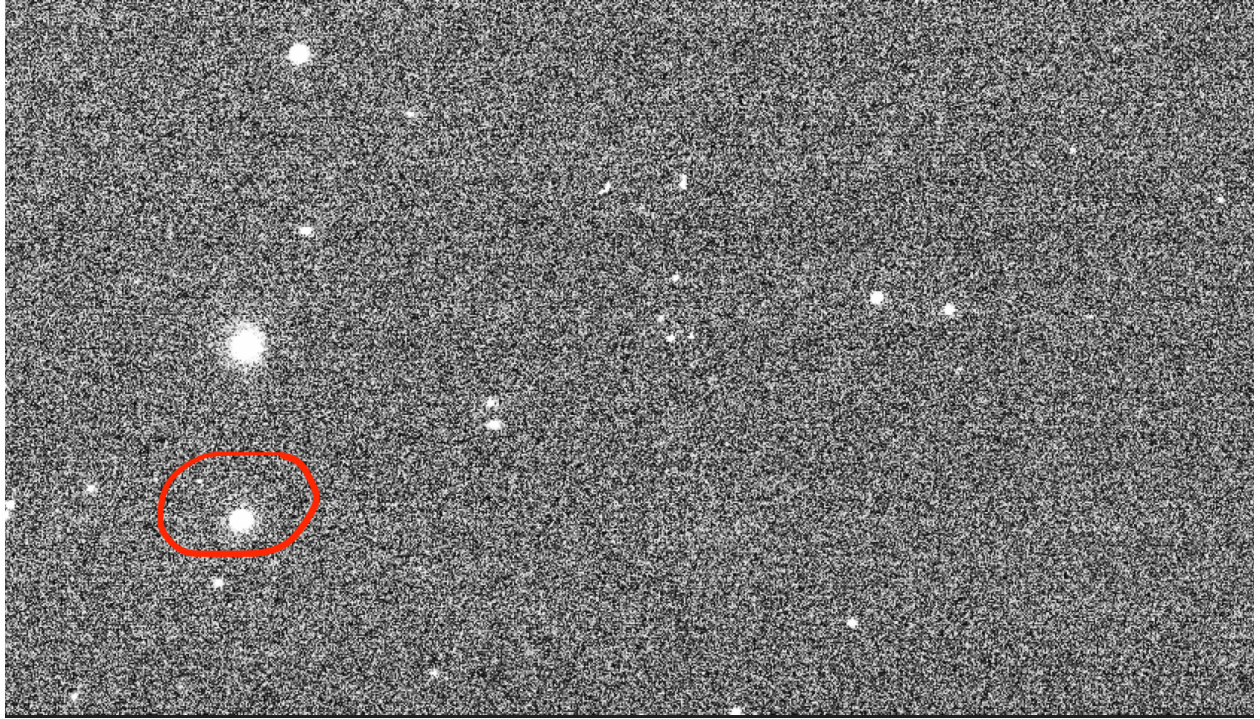


Fig 3: A zoomed in view of the three bright stars, from figure 1. The star circled in red is HIP 22206, the star selected to be the guide star for this study.

First, before processing the images, our photometry pipeline subtracted the median pixel value, from each pixel in the image. This is essentially to remove the light that the sky introduces. Then, using the median subtracted data, the pipeline computes the magnitude of the supernova. From the fits header, I can extract the date that the image was taken. I then do the same for all files, and store the results.

I can plot magnitude versus time for each of the bands to obtain a lightcurve:

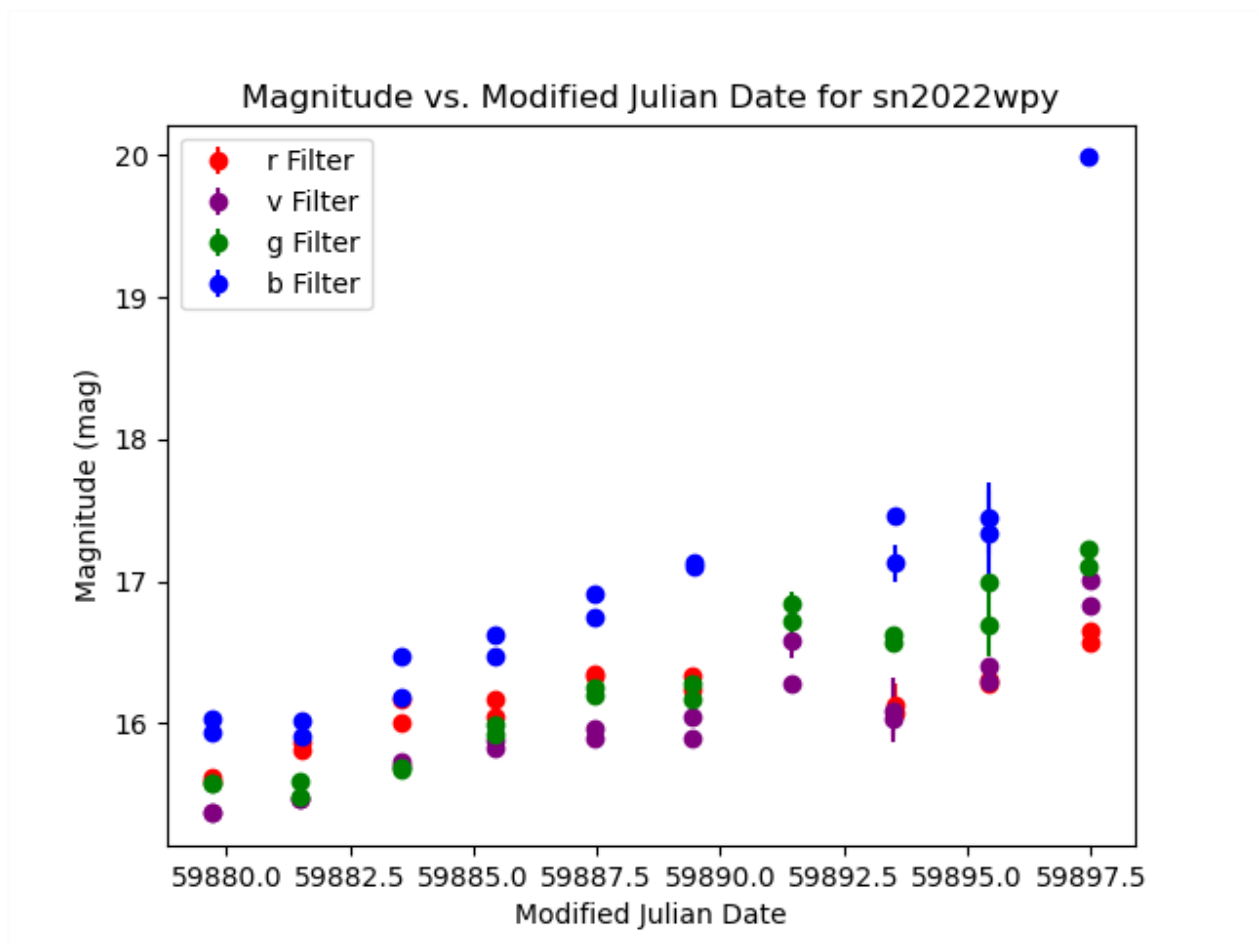


Fig 4: Light curve obtained from the data. Recall that a higher magnitude value reflects a lower brightness. Error bars are simply statistical variation between the two exposures for each night.

Note that it is standard to have the y-axis inverted from what is presented here, so that higher brightness is located higher on the y-axis. This is not the case here, so we can see that as time progresses, the supernova gets dimmer, as we expect. A collaborator on the project, used a third party program, called AstroArt, to do a similar analysis of sn2022wpy, using the same data set(6).

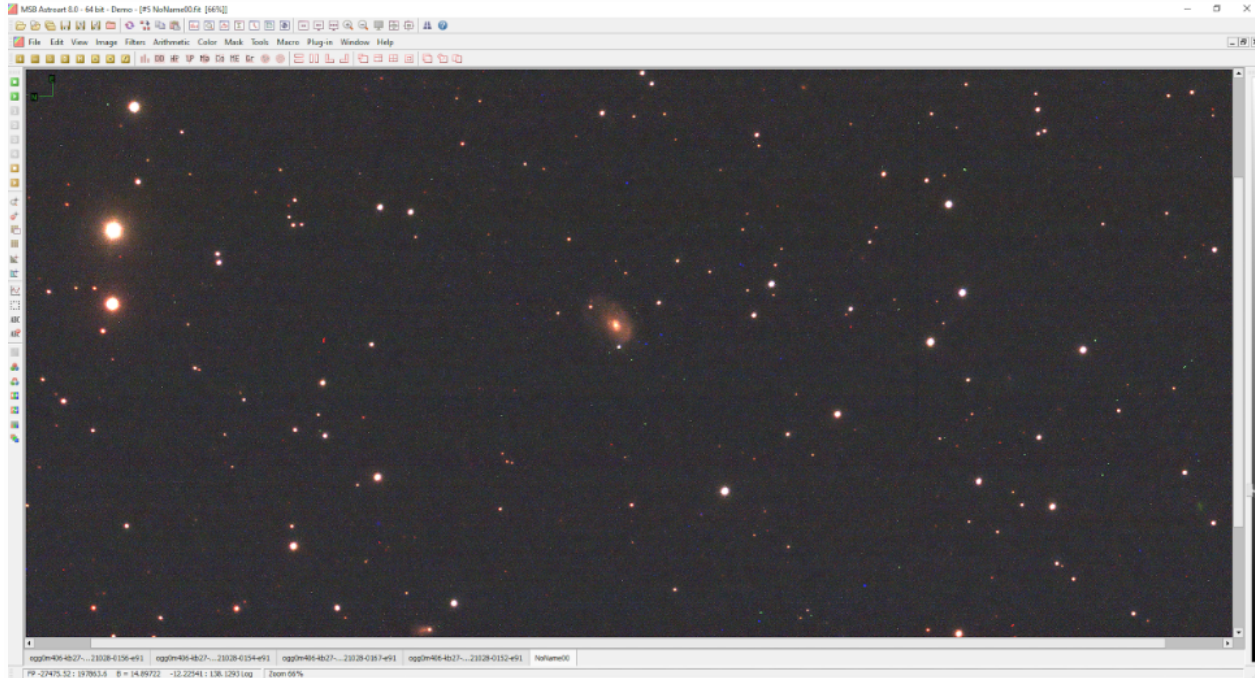


Fig 5: Color composite image of data, generated with AstroArt. Note the three bright stars on the left, and the much more visible host galaxy in the center of the image, when compared to the raw data alone (see Fig 1). sn2022wpy is visible as a bright dot, under the host galaxy(6).

AstroArt has its own catalog of reference stars that can be used for photometry, rendering the manual search for guide stars unnecessary. Performing photometry on each image, and saving the data externally, a light curve was generated.

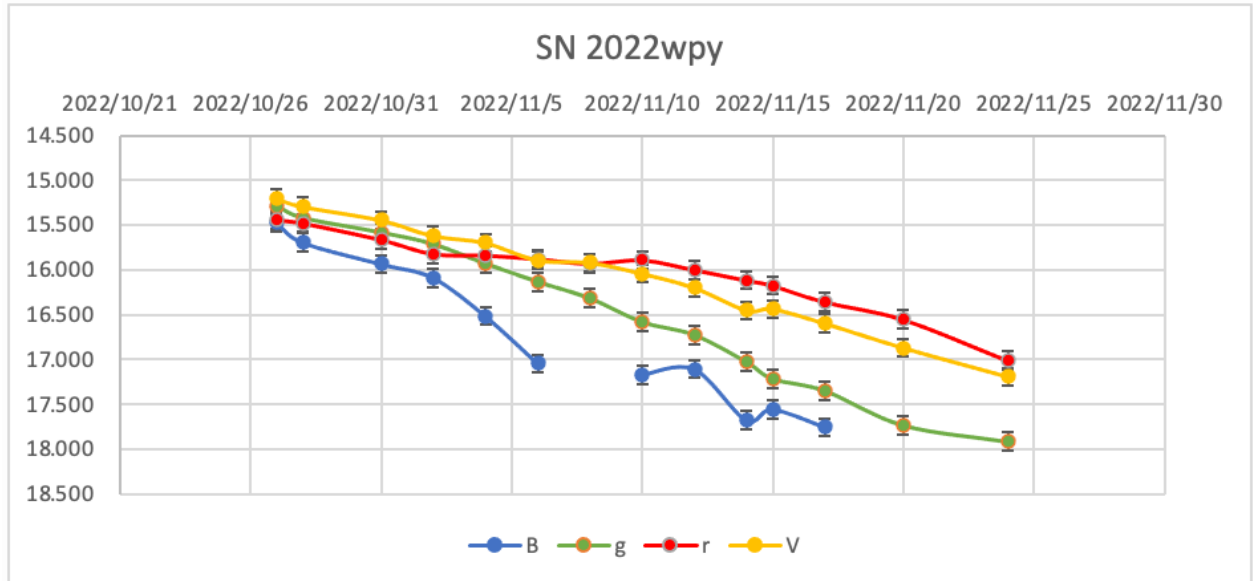


Fig 6: Collaborator's plot, generated using analysis from AstroArt. Graph was generated using Microsoft Excel. Note that magnitude decreases as you move up the y-axis, as is standard, and as is opposite to the graph presented in this paper (6).

We can see that overall trends remain the same between the two different methods of analysis. Namely, that the supernova decreases in brightness over time, and trends regarding the relative brightness of the different bands remains roughly the same. For example, the blue band is the brightest of all bands in both cases, the r and V bands are the lowest, with the g band resting in the middle.

4. Discussion and Future Directions

In summary, I was able to produce a lightcurve, using the data obtained from LCO. We found that the lightcurve produced by the pipeline was comparable to that produced by the AstroArt analysis. The magnitude measurements produced by the pipeline were about the same as those produced by the AstroArt analysis, to within one magnitude, or so, and followed the same general trends, of the supernova getting dimmer over time, as well as the relative brightnesses of the different wavelength bands.

As such, I believe that the photometry pipeline has some potential, although it certainly needs some work. The major next step would be to develop some automatic object finding for the photometry pipeline. This would eliminate error, with regards to the inconsistencies of human selection, regarding the specification of the center, and radius of each source. In addition to this, non circular shapes could be supported, in theory. Beyond that, the pipeline needs a rigorous way to accept or reject images. Within the study, some of the images did not have a clearly visible supernova, especially in the B band. I suspect that this was due to a full moon around that night. To overcome this, I simply disregarded data from where I couldn't see the supernova clearly.

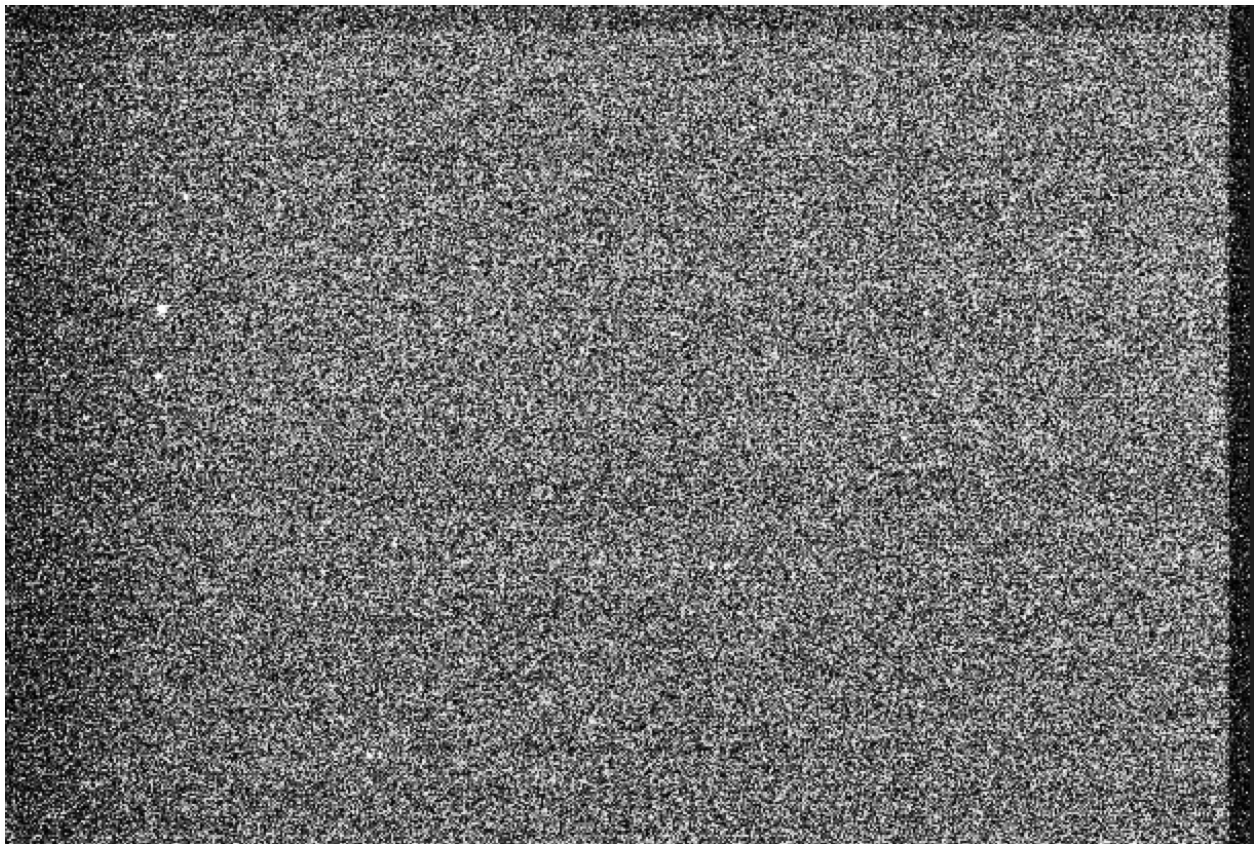


Fig 7: An image of a file not included in the final analysis. Note that the galaxy, and supernova, are not visible. Also note that the selected guide star is just barely visible, on the left.

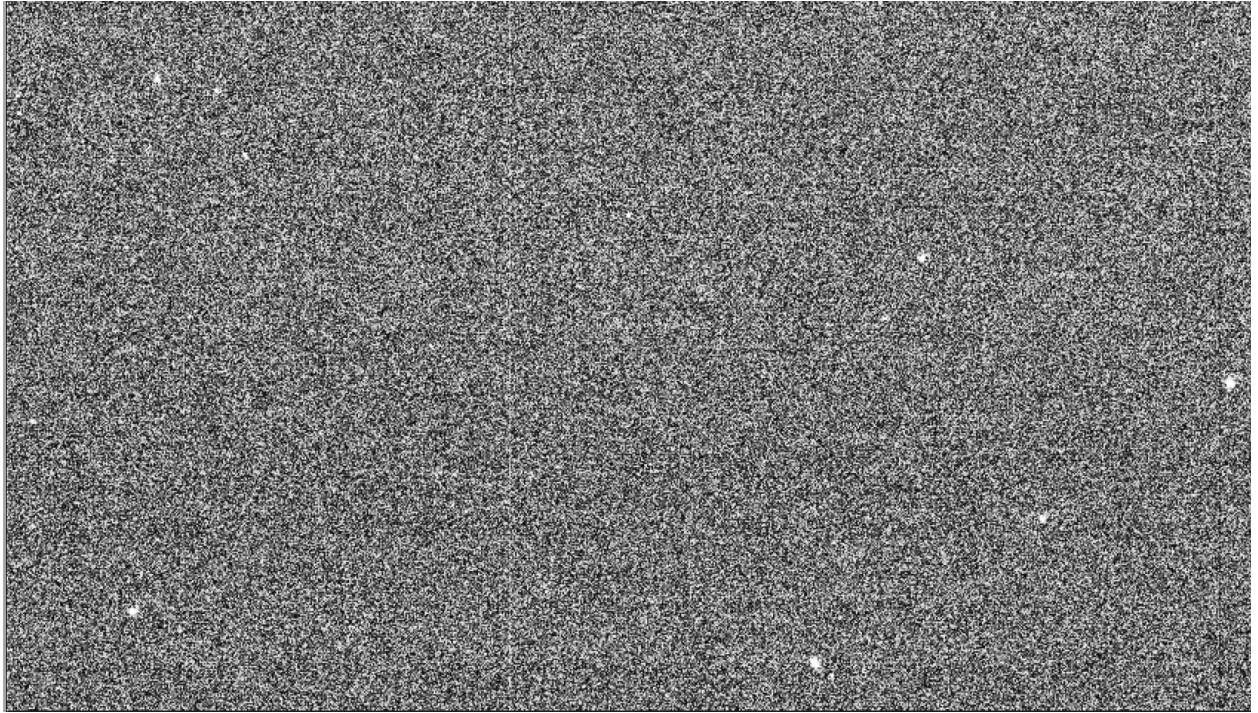


Fig 8: Image of Fig 7, zoomed into the center. Note that this is where the galaxy, and supernova are, yet they are not visible.

Another next step would be to account for transients in our consideration of background subtraction, as we picked up a number of (unintended) transients in our measurements, which I suspect are simply satellites. However, this transient behavior could affect the median of the image, thus skewing the background subtraction.

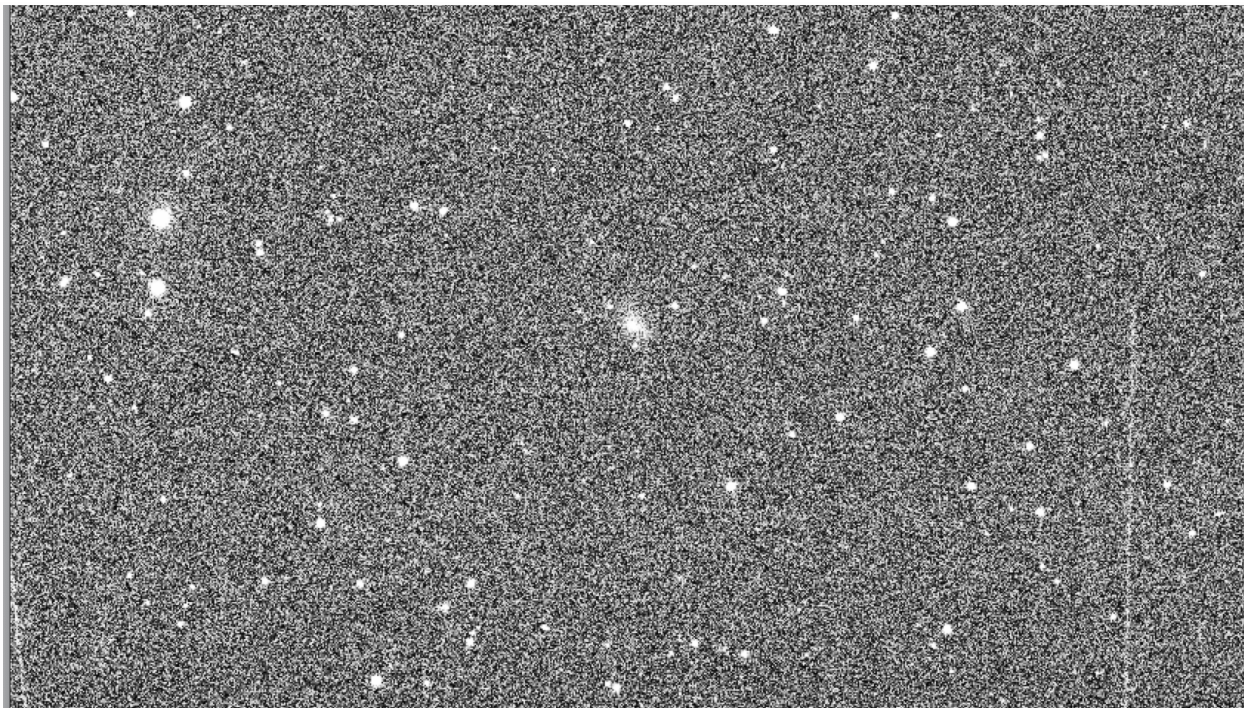


Fig 9: Satellites appear in some of our images, such as this one. Note the vertical lines on the right and left sides of the image.

In addition, options for inverting the y-axis to match the standard orientation, and toggling between modified julian date, and human readable date are next steps, along with more robust error calculation.

5. Acknowledgements

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6. Bibliography

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