Type Ia Supernova Light Curve properties and Rates compared to local Galaxy Colors.
In the following paper, I will attempt to investigate relationships that may exist between type Ia supernovae and their host galaxies. This study will be extended to properties of the light curves of these corresponding supernovae in terms of Dm15 and of Av. We will find, as this paper will show, that there exists a relationship between the color of the supernova and its host galaxies.

"...one of the well known epidemics of our own time is that which occurred when the spectacular star appeared in Gemini in the year 446 H..," Ibn Butlan referring to the Crab Supernova.
The constant war between the components of a star and gravity keeps its life always at the border of disaster. In the cold of interstellar space floats a slim and rarely opaque cloud of gas and dust, most of which is believed to be remnants of older stars or failed ones, made predominantly of Hydrogen (89%) and Helium (9%)\(^1\). The matter in these gaseous clouds feels attraction to other particles of the gas and the outer part of the cloud starts to weigh down, shrinking the cloud and pressing the particles closer to each other. This contraction would continue unchallenged until the particles of the cloud become condensed enough and their temperature warm enough to oppose the contraction of the outer part. The cloud begins to "glow" and a critical balance between internal energy and outside pressure gets in play. Eventually the core of the gaseous cloud warms enough (10 million Kelvin) to combine nuclei of particles in the core. It's the start of the Hydrogen burning phase, and the gaseous cloud is now a proto-star\(^2\). The excess mass that is lost when Hydrogen is burnt into Helium is radiated into the star in the form of energy that halts further collapse of the new baby-star, which is now ready to take its place as a main sequence star.

Stars continue to shine as long as they possess fuel to burn. More massive ones burn longer but eventually all stars must exhaust their energy sources. Main sequence stars are no exception. Once the nuclear reactions in the star stops, collapse takes over again and compresses the material surrounding the helium core that was created after all the hydrogen in the core was burnt. Eventually temperature will rise again to ignite further nuclear burning in a shell surrounding the core. The star once again shines. It's a magnificent process of rejuvenation. The new found temperature will expand the outer layers of the star which then take reddish less hot color (Red Super giants). The new burning shell around the Helium core contracts the latter until its temperature rises to around 100 million Kelvin. At such high temperature, the Helium in the core starts fusing into Carbon. This new burning process releases more energy which the star uses to burn Carbon into Oxygen as Helium burning moves to a shell surrounding the newly formed Carbon core. The structure of the star at the time is described as an onion, as fusion reaction in the core produces heavier elements such as Neon, Magnesium or Silicon and Iron, Helium continues to burn into Carbon in a shell surrounding the core, and a shell of burning Hydrogen surrounds everything else.

It is critical to note that this process of rejuvenation that stars go through as they "age" is not unbounded. Ultimately lighter stars will run out of energy long before they can ignite Carbon and will become massive balls of carbon floating in space. Heavier stars will go through the above mentioned process of burning until elements get transformed into Iron-56 which can only drain energy from the surrounding rather than contributing to the energy of the star. These massive stars that reach that phase of their life become massive iron cores wrapped in several lighter layers of elements.

---

2 I.S. Shklovsky.Supernovae.(London.Clowes and Sons.1968),1
3 Prialnik(1999),69
Even though a star's energy source is exhausted, gravity continues to compress the giant ball of Iron and lighter elements until the electrons are super-packed around their nuclei (electron degeneracy). The star is now very condensed, with all its particles pushed together\(^6\). To an observer on earth, these stars will only appear as faint light balls (Sirius B is a prime example) referred to as White Dwarfs. These White Dwarfs will eventually exhaust the small amount of energy that they had stored from their younger days and become dark dense objects floating in space. Chandrasekhar showed how a Carbon White Dwarf would not support its weight if it were greater than a fixed critical mass (1.4 times the mass of our sun). SO while our predictions for the fate of a White Dwarf applies beautifully to ones exceeding the Chandrasekhar limit, those who fall short continue to collapse into an explosion of unimaginable scale.

Dubbed Supernovae, these explosions are rare in our observable neighborhood\(^7\). Of the very few that were seen from earth, they were not all type Ia as (SN1987A) which was on type II but was able to teach a lot about supernovae in general since it happened in our own backyard. However the existence of Supernovae and a lot of their characteristics were understood and studied for a long time. The analysis of the luminous objects that appeared in various regions of the stars led astronomers to analyze their light spectra and study their distance. Rapidly after Hartwig discovered a new star near the core of the Andromeda nebula\(^8\) that was more luminous than the surrounding several other novae were observed. Telescopes were improved after WWII and scientists were observing supernovae left and right. nowadays astronomers and cosmologists are convinced there exists at least two types of supernovae the classification of which is largely due to the efforts of Fritz Zwicky and Walter Baade who

\(^6\) Marschall (1988),177
\(^7\) Shklovsksy(1968),7
\(^8\) Marschall (1988),178
measured and studied the light curves of these supernovae\textsuperscript{9} while Rudolph Minkowski and Milton Humason studied their light spectra. Minkowski was the first to notice the absence of Hydrogen lines in the spectra of most observed supernovae and called those type I supernovae. This interesting type of supernovae has a distinct and now famous light curve. Minkowski and astronomers after him noticed a typical fade-off period that occurs at the same rate in all type I supernovae. The study of light spectra of Type I supernovae never stopped since their discovery. One simple fact that all scientists agree upon is the unpredictability of supernovae. How to predict an event that may go unnoticed hundreds of years after it took place?\textsuperscript{10}

2-The Sloan Digital Sky Survey

Starting in the year 2000, The Sloan Digital Sky Survey has in recent years made the most daring and ambitious attempt at challenging some of our preset ideas about supernovae. The SDSS' mission goes beyond mapping over a quarter of the sky and cataloging the various luminous object observable from our corner in the cosmos\textsuperscript{11}. The dedicated 2.5 meter telescope and the 120-megapixel camera used by SDSS obtain deep images of the sky.

\textsuperscript{10} Due to the unimaginable size of the ever expanding universe, supernovae may be great cosmological “candles”.
Using dedicated optical filters, the powerful mega-pixel camera took deep images of the sky. Those above mentioned filters are critical to this paper as we will be using the photometry data obtained through these filters to analyze colors of type Ia supernovae and their host galaxies. The Sloan Supernovae Survey obtained in the first few years of its operation over 500 confirmed Type I Supernovae. Huge photometry data files collected through the Sloan’s camera were released to the scientific community. Presented below is a sample of data distribution inside of the files:

3-Technique of retrieving relevant data from the SDSS files.

Using a computer script, the immense number of photometry data was siphoned and values of the camera filters for both the “spot” of the supernovae events and their host galaxies. These Filters [u g r I z] each representing a spectrum (corresponding to ultra violet, green, red,

---

infra-red, and further infra-red) were needed to plot the relationship between consecutive colors for both the spot and the host.

The computer script would open each data file, read in only the relevant lines and retrieve the values for each filter. On its second pass though the file, the program would check the retrieved values for errors then output the outcome into a single data file which would be later used as a new source for data.\(^\text{13}\)

The newly formed data file would contain not only the specific SN Ia \{u g r i z\} imaging fluxes but also their corresponding uncertainties. The next step in the data collecting process involved looking at a different (smaller) set of SN files which are confirmed SN Ia. Another computer script ran through the list of confirmed type Ias and compared it to the old file eliminating those not corresponding to confirmed instances of Ia supernovae\(^\text{14}\). Finally we are left with a file corresponding only to confirmed Ias containing the following data:

- The SN identification number, and photometric values corresponding to each high-band filter [u g r i z].

The same process was repeated to retrieve photometric values for the host galaxies, its peak (referred to as Av) and the parameter dm15 specifying the amount of extinction of the light curve. At this point plots could be produced. The interest was in examining the rate of SN Ia as a function of galactic age or to investigate any possible correlation between that rate and the two parameters Av and Dm15.

**4-Plotting the color of the spot versus Av and Dm15:**

---

\(^{13}\) This computer program was created with the generous help of Mathew Taylor.

\(^{14}\) The script used was written in C++
In this section, I shall describe the plots created from the above mentioned data files to investigate relations between the color of the SN Ia and Av or Dm15. I will refer to the area in the galaxy where the Sn event took place as the “Spot” and to the galaxy itself as the “Host”. By “color” we mean the difference between neighboring filter values as in ‘u-g’ or ‘g-r’.

After producing these, no discernible correlation between color of the spot and Av or Dm15 could be detected. Here’s an example of ‘u-g’ color versus Av. The presence of the shapeless condensation of SN events strongly suggests no relation between color and the parameter.

and the same could be said about the plot of the same color versus Dm15.
Another un-interesting pattern of SN events goes against any relation. The remainder of the plots can be found at the end of this paragraph and none of them exhibited any interesting pattern.
5-plots for the color of the spot versus that of the host.

The next step was to create plots for the spot as a function of the color of the host galaxy. For each color, a graph showing the rate of event versus host was plotted. The host color values are shown on the y axis as in the sample plot below corresponding to ‘u-g’ color. A discernible pattern can be easily identified here. It would seem that the predominant majority of SN event happen in host values within the interval [-5,+5] (with few exceptions).
This is a significant result of course that merits further investigation. The other three plots corresponding to 'g-r', 'r-I', 'i-z' were equally as important.
This is the plot of 'G-R' (Green – red) color. With the exception of the lone point at (-9,1.2) the massive lump of points seem to be concentrated near the upper right corner of the plot.
As noticed, these plots were crude due to two main reasons:

a- The vast amount of SN points plotted.

b- The uncertainties that involve measuring these photometric values.

6- **Technique to remove unwanted data points.**

As evident from the plots above, the data originally used to study the relationship between the color of the spot and the various other properties of the host galaxies needed “cleaning”. Due to uncertainties in measurements of the filter band values, some unwanted points may have made their way into our plots. To eliminate doubt about the events being plotted and to get a better graphical representation of the relationship that was apparent in the previous plots between the spot and the host, we used the original flux values for each filter to weed out point with poor fit. The only points accepted were those that showed
a mean dispersion flux value/error >2. This cut did not remove SN event that are too red as the negative dispersion points were kept. Histograms of the errors were made to show the dispersion of the points. A sample histogram the following representing the “u” filter values.

The signal strength versus noise is weak for the “u” filter as it is evident from this histogram. There seems to be less accurate results for the “u” filter values coming through the SDSS’s camera as most of the points seem to be gathered between 0 and 2. The actual points used in our final plots are located right of the point x=2. As it can be easily noticed, there were few.

Here are now the remaining histograms corresponding to the consecutive spot colors.
New plots were then generated using the improved data values for filters and host galaxies. Here’s the plot for the “u-g” color with better point. The clumping of values between [-2,2] is still evident further confirming our previous finding of the correlation between older galaxies and the rate of supernovae. The remaining three plots corresponding to ‘g-r’, ‘r-I’, ‘i-z’ are shown below.
In the above plot corresponding to G-R versus color of the host, notice how well placed the points are in accordance with our view of relationship between the color of the spot and the host.
Cleaned Values of R-I color Vs Host Galaxy
7—How do these plots fit our predictions?

To better understand what these plots mean in terms of data, Histograms were made to showing the areas were data points seem to be concentrated. These histograms show without doubt that there seem to an inclination for type Ia supernovae to happen in bluer parts of the galaxy contrary to common belief. Here’s the histogram for the U-G color data.
There is a noticeable shift of the data points away from the zero point. With the exception of the I-Z data points, the rest of histograms show that same trend. It is worth mentioning here that the Z filter is the most unreliable since it is strongly dependent on atmospheric conditions and light pollution. Here are the rest of the histograms.
Another way to confirm the results laid out by these histograms is to compute the mean of all the data displayed in the histograms.

Here are the results for the specified colors:

- \( u-g = 0.250 \)
- \( g-r = 0.097 \)
- \( r-i = 0.029 \)
- \( i-z = -0.147 \)

As expected, these results reflect our conjecture about the relationship between the frequencies of type Ia supernovae and bluer parts of the host galaxies. Note the negative value generated in our computation of the mean value of the \( i-z \) color values. The "z" filter is the most delicate and hence unreliable filter used at SDSS. It is easily affected by atmospheric conditions and data generated
though that filter may not be as accurate as it should be, hence the fact that the galaxy color-spot color histograms gives a negative value should not be taken seriously as it is apparent that the data is unreliable.

8-Conclusions

The common accepted belief about Type Ia Supernovae is that they must occur more frequently in redder galaxies since stars in those galaxies would have already completed their life cycle, however as the above plots and numbers indicate, there appear to be an inclination for supernovae to occur in bluer parts of galaxies. This very interesting result goes of course against the expected and should of course be investigated further as our study only focused on data retrieved in 2005.
References


