Classifying and Applying Bolometric Corrections to KSP-ZN7090

Patrick Sandoval[1] and Dae-Sik Moon[1,2]

[1] *University of Toronto*
[2] *Department of Astronomy*

1. INTRODUCTION

In this short report we discuss the progress made on our study for KSP-ZN790 a supernovae with remarkable early data taken by the KMTNet less than one day after the explosion. The observation taken by the Korean Microlensing Telescope Network (KMTNet) are in the B, V, and I bands are particularly rare and of high value. In this report we present the criterion's used to classify our supernovae solely based on the V-band light curve morphology in accordance with the parameters set by Anderson et al. 2014 and Gall, E. E. E. et al. 2015. Having classified ZN7090 we proceed to apply various bolometric correction from Martinez et al. 2022 and Lyman, Bersier, and James 2013 in order to construct the bolometric light curve of our supernovae. It is important to note that we are not generating our bolometric light curve through the direct integration of the SED method as we only have data in three bands which will render insufficient for an integration in all the wavelengths.

1.1. *Classification of Supernovae Based on Light Curve Morphology*

Historically SNe have been broken down into two groups based on their spectral information, Type I lack hydrogen emission line in their spectrum while Type II SNe have strong hydrogen emission lines. Withing the Type II classification there exists two subdivisions based solely on the morphology of the V-band light curve, Type II-L and Type II-P. The former has linear decline post peak magnitude while the latter has plateau phase post peak hence the L and P in their classifications. In Anderson et al. 2014 and Gall, E. E. E. et al. 2015 they study a large samples of Type II-L and Type II-P in order to quantify the defining characteristics of each light curve. The key take-away from these studies is that if the V-band light curve post peak has a decline rate greater than a hundredth of a magnitude per day then the SNe is classified as a Type II-L otherwise it's classified as a Type II-P.

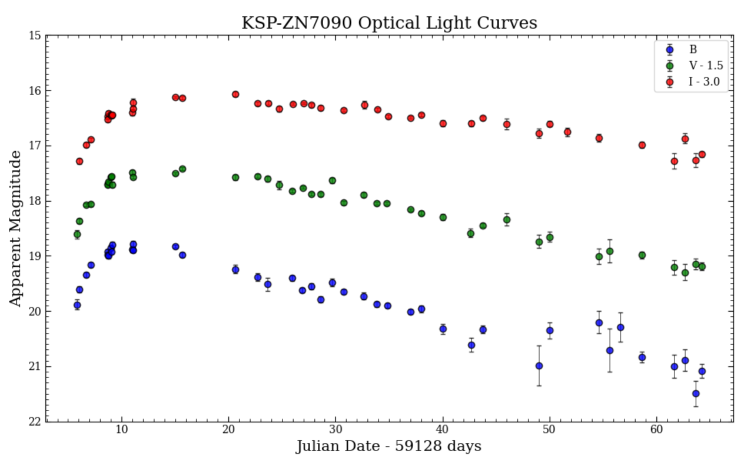


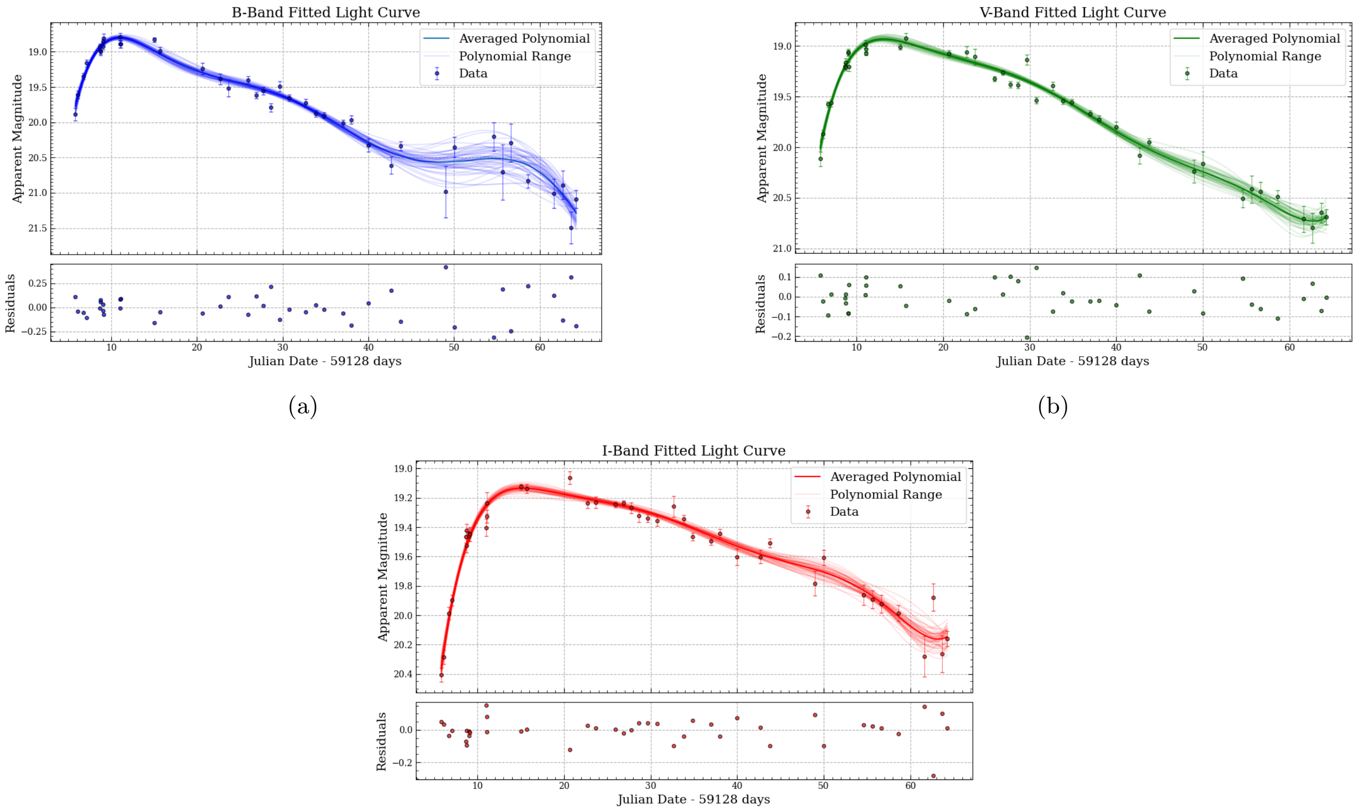
Figure 1: KSP-ZN7090 B, V, and I light curves, after applying color corrections, extinction corrections and binning. V and I light curves have been vertically displaced by equal amounts for easier comparison

From Figure 1 we see a strong linear trend post peak for the V-band light curve, however, it is not entirely clear where V-band peaks and therefore the epoch of m_{max} is not easily constrained. In the following section we address this problem and constrain the peak magnitude epoch and compute the magnitude decline post peak.

2. DATA REDUCTION & METHODS

2.1. *High Order Polynomial Fitting on Light Curves*

High order polynomial fits have been used in literature before to estimate the peak epoch Shappee et al. 2018, in this case the most common polynomial used for light curve fitting is a polynomial of degree seven. With this model fit we will clearly be able to see the peak epoch and will be able to compute the decline rate of the V-band light curve. This fit was also performed on the other two light curves as the peak epoch is a very important parameter which we will discuss on later on this paper. With the peak epoch properly constrained we can fit a polynomial of degree one past this epoch and compute the decline rate of the V-band light curve to be 3.91 ± 0.01 mags/100 days. We clearly see that the decline of the V-band light curve satisfies the condition specified in 1.1. This provides strong evidence that ZN-7090 is a Type II-L SNe instead of a Type II-P.



(a) (b) (c)

Figure 2: High order polynomial fitting on optical light curves of KSP-ZN7090, done through Monte Carlo Gaussian sampling of individual data points. (Solid dark lines) are the polynomials with the averaged coefficients from all the Monte Carlo simulation, and the (solid transparent lines) are the individual computed polynomials from each sampling. The peak epochs are 10.9 ± 0.3, 13.1 ± 0.3 and 15.2 ± 0.3 for the B, V and I light curves respectively.

2.2. *Interpolation Methods for Light Curves*

In order to apply the bolometric corrections from Martinez et al. 2022 and Lyman, Bersier, and James 2013 we need our magnitudes in the B,V and I bands to be in the same epoch, if we carefully study Figure 1 we see that some points in certain magnitudes do not have corresponding data in the other magnitudes. In order to address this issue we tried several different interpolation methods and opted to perform spline linear interpolation on the light curves as this method preserved the shape of the light curve.

3. DATA ANALYSIS & MODELING

With the light curves interpolated and with all the data points having matching dates we can begin to apply the bolometric corrections from external literature in order to construct the bolometric light curves. It is important to note that the KMTNet's filters are calibrated with respect to Johnson Cousin filters therefore the correction we must apply must be compatible with these filters.

3.1. *Martinez Cooling Bolometric Correction*

The bolometric corrections provided by this paper are split into 3 different sections corresponding to the different phases of a Type II-P SNe, shock cooling, plateau and radioactive tail phase. As discussed in 2.1 we do not believe ZN-7090 to be a Type II-P SNe therefore we will not use the corrections for that phase. Additionally, we will not use the radioactive tail correction because we have do not observe such behaviour in early epoch of the light curve Anderson et al. 2014 usually such behaviour is seen at a epoch $>$ 100 days from the explosion. Therefore, the only correction that we will be using from this paper is for the shock cooling phase.

3.1.1. *Monte-Carlo Gaussian Sampling*

In order to apply the correction specified by this paper we need to first compute the colors for this correction, colors are often referred to as the difference between two magnitudes, in the case of this paper we are only provided a single color (B - V). So for the uncertainty propagation for this correction we implemented a Monte Carlo Gaussian sampling method where we sample data points from our light curves and compute the color, bolometric correction terms and the bolometric magnitude.

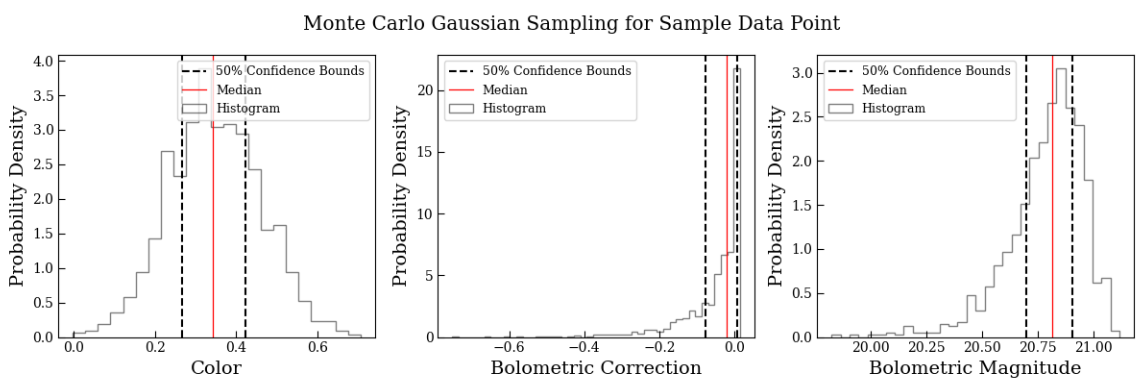


Figure 3: Probability density distributions for Gaussian sampling method on bolometric corrections.(Dashed lines) indicates the boundaries of the 50% confidence interval, (Solid red line) indicates the median of the distribution.

The most important aspect to take away from Figure 3 is that the bolometric magnitude distribution is asymmetric, which means a good measure of the spread of the distribution is the interquartile range instead of the standard deviation, as this quantity provides us information regarding the asymmetry of the distribution. Additionally, because our distribution is asymmetric we are using the median instead of the mean because the median is as better statistical representation about the populations true distribution.

3.1.2. *Bolometric Correction & Color Sensitivity*

After applying the Gaussian sampling method outlined in section 3.1.1 we can now take a look the the bolometric light curve and also look at several other plots which provide us with insightful information about the nature of the correction itself.

From Figure 4 we can see that much of the early data that we have on ZN-7090 is not within the range of colors specified by the correction, however, this is to be expected because early data on SNe is very rare therefore these negative colors are rather uncommon to see in literature. We see this play a noticeable role in our bolometric light curve as we can see on the top left panel there are two data points with error bars of around 3 magnitude which rises concern about the origin of those two points. We can then note the bottom right figure and locate these same two

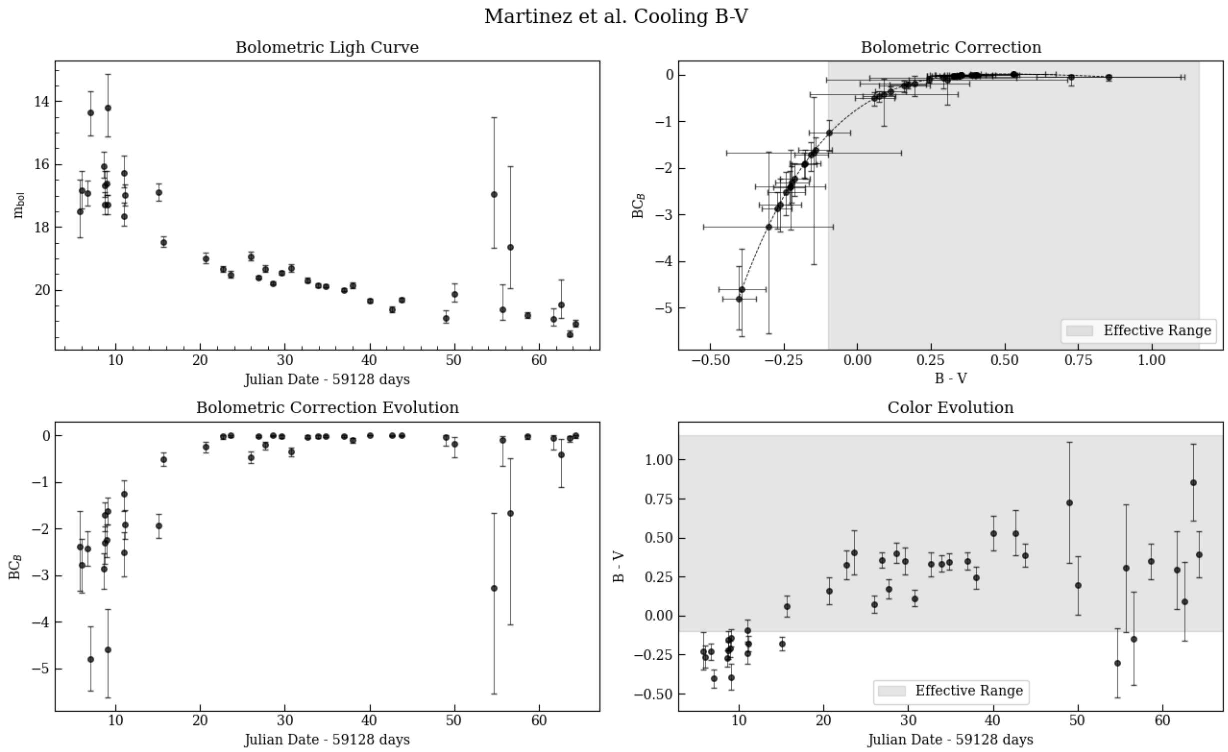


Figure 4: (Top left panel) Bolometric light curve where data points are the median of the Monte Carlo Gaussian sampling distribution and error-bars are the IQR of the sampling.(Top right panel) Bolometric correction as a function of color, shaded region is the color range from the SNe sample used in Martinez et al. 2022. (Bottom left) Bolometric correction term evolution through time, (Bottom right) Color evolution through time.

points outside the effective range, from this observation we can notice that all color data points outside the effective range have their bolometric correction term uncertainty increase. We can probe the sensitivity of the correction to color by slightly changing/perturbing the color and measuring the respective change in bolometric correction. Then the ratio between the change in bolometric correction to the change in color will tell us how sensitive the correction is to color.

From Figure 5 we see that higher perturbations in the color lead to even higher changes in the bolometric correction when we are outside the range provided by the paper. This tells us that the bolometric correction is highly sensitive to colors specially the ones located outside the effective range.

3.2. *Layman Cooling Bolometric Corrections*

As opposed to the correction presented in section 3.1 Lyman, Bersier, and James 2013 offers a wider variety of bolometric corrections for a wider range of color (B - V), (B - I), and (V - I) for the Johnson cousin filters. Additionally, the corrections are split up into two phases, cooling and radiatively-/recombination-powered phases. Therefore, in order to apply these correction we need be able to determine the powering mechanism that is driving the light curve. The observable difference between these two powering mechanism is the light curve's rise time from first light to peak magnitude González-Gaitán et al. 2015. As previously shown in section 2.1 we have been able to constrain the peak epoch for all three light curves, now we need to find the epoch of first light. For this we need to perform a power law fit to data points prior to the first detection and up to the peak epoch González-Gaitán et al. 2015

$$f = \begin{cases} a(t - t_0)^n & t \geq t_0 \\ 0 & t < t_0 \end{cases} \tag{1}$$

With this method we are able to estimate the rise time of each light curve to be 5.1 ± 0.3, 7.25 ± 0.3, and 9.3 ± 0.3 for the B, V, and I light curves respectively. Rise times vary depending on the wavelength observed, in table 3 from

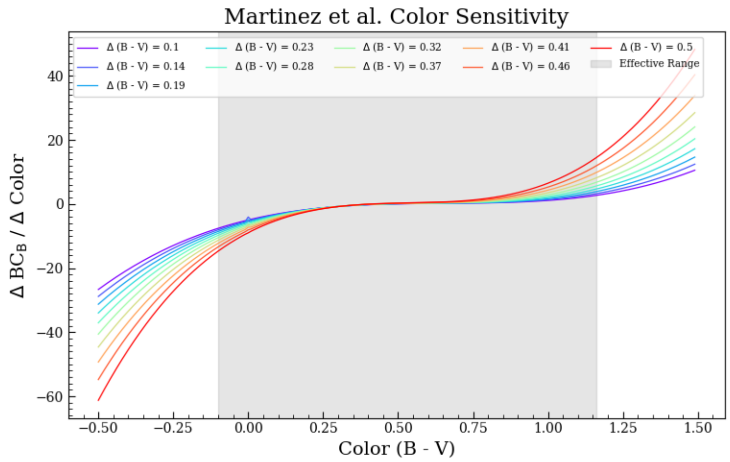


Figure 5: Color sensitivity plot for Martinez et al. 2022 bolometric correction where y-axis measures the change in the correction compared to the change in color. Different colored lines have different color perturbations in percentages as indicated in the legend.

González-Gaitán et al. 2015 we can see the rise time of shock cooling SNe. From this table we can see that B-band shock cooling light curves have median rise time of $6.1^{+2.5}_{-2.3}$, $7.9^{+3.6}_{-2.9}$ for V-band and $10.1^{+3.6}_{-2.3}$ for I band. While in Lyman, Bersier, James, et al. 2016 their study in SE SNe which are believed to be powered by radioactive decay of ^{56}Ni and ^{56}Co have an average V-band rise time of 17.6 days. This is a strong suggestion that ZN-7090's light curve is primarily powered by shock cooling emission.

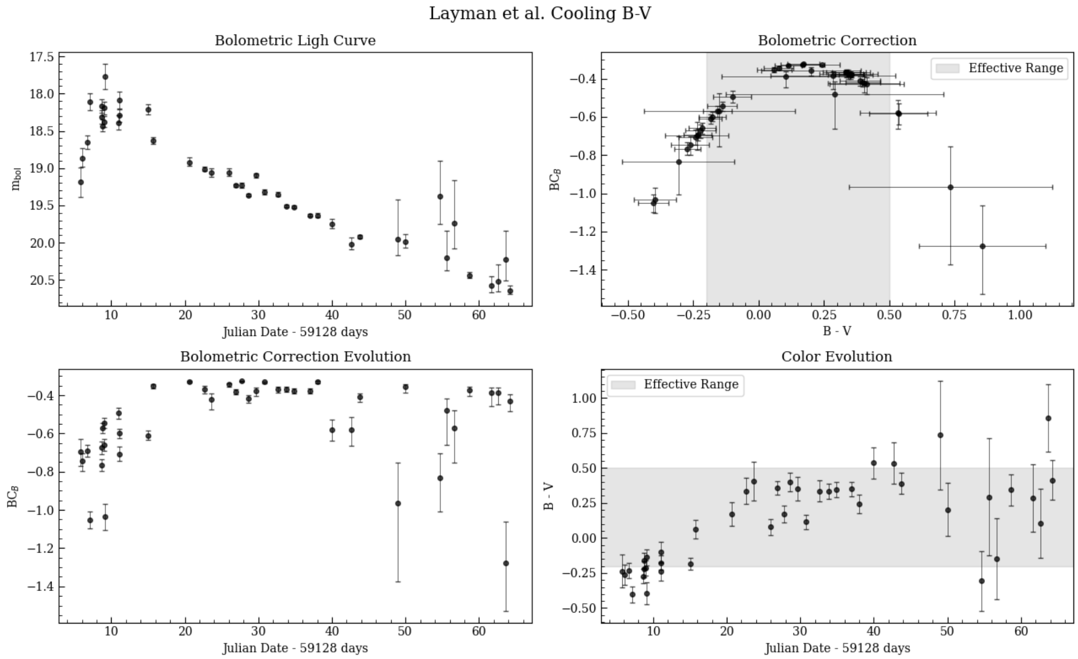
3.2.1. *Bolometric Corrections*

Now that we have been able to constrain the powering mechanism for the light curve we can starts applying the bolometric corrections from Lyman, Bersier, and James 2013. It is important to note that we really have only two colors that we can apply, because the third color is a superposition of the previous two. So in our case we have decided to look at the (B - V) correction and the (B - I) correction and exclude the (V - I) correction as this one has a very narrow color range which causes most of our colors to be outside the effective range which altogether affects the quality of the bolometric light curve. We can see from Figure 6a and Figure 6b that the bolometric light curve exhibits better structure and clear decline post peak than the one in Figure 4

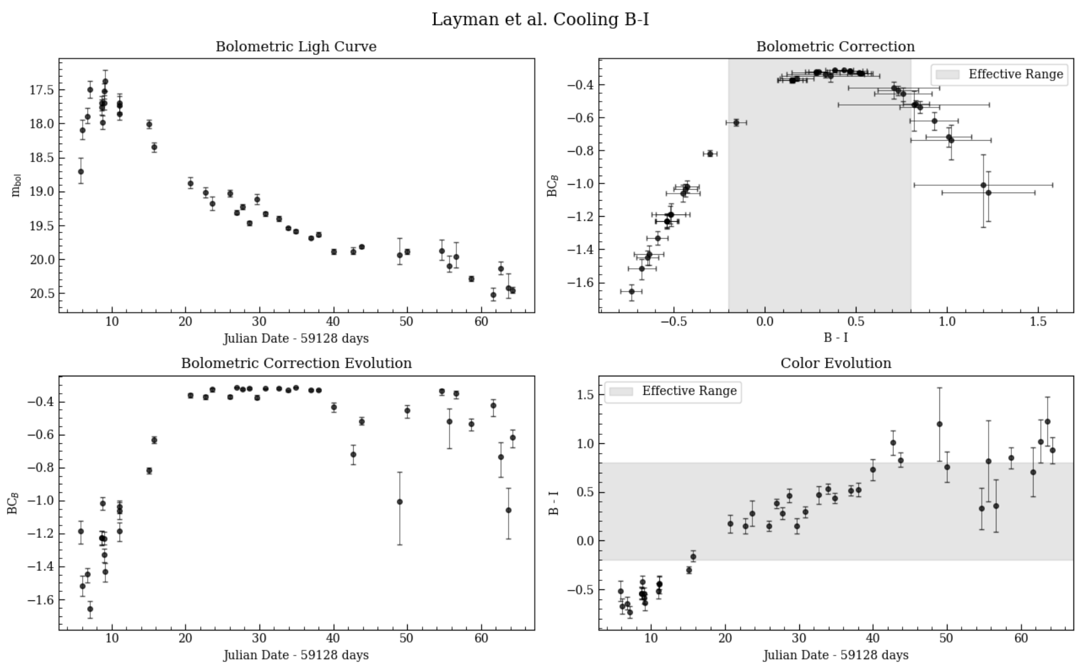
3.3. *Final Remarks & Discussion*

After finalizing the the Layman's bolometric corrections we notice that even though this corrections had a lesser color range than the ones presented in Martinez' paper the structure of the bolometric light curves is better. We believe this is the case due to the difference in the order of polynomial each correction applies and its corresponding behaviour to color. We see that even though multiple color points in the (B - I) spectrum are outside the specified range we do not observe uncertainty magnification as in the Martinez correction. This indicates that the nature of the Layman correction does not vary the bolometric term uncertainty by a substantial amount when the color is not within the effective range.

Additionally, from this work we would like to perform spectral analysis on KSP-ZN7090 as this will shed light on the further spectral classification of the SNe. Which will help us determine if we can use additional bolometric corrections from Lyman, Bersier, and James 2013.



(a)



(b)

Figure 6: Applied bolometric corrections from Lyman, Bersier, and James 2013 for colors (B - V) and (B - I). Corrections where only taken from the shock cooling powered phase. Additionally, all error propagation methods where done through a Gaussian sampling methods where each data point represent the median of the distribution and the the error-bars represent the IQR of the same distribution.

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