# Bolometric Corrections

## Definition and Motivation

A bolometric correction is one that is applied to the visual magnitude of an object to convert it to bolometric magnitude. The bolometric magnitude is a magnitude that takes into account the electromagnetic radiation in all wavelengths, which provide us with a more ample and accurate description of our observed source. Various sources of literature provide with different types of models for bolometric light curves which help constrain and calculate physical parameters of the SNe as well as provide information about the progenitor stars of the SN. Bolometric corrections are specific to a band and are mathematically defined as follows

$$BC_\lambda = m_{bol} - m_\lambda \tag{1}$$

Where $BC_\lambda$ is the bolometric correction for the specific band and is often a function of the difference in the apparent magnitudes in the different bands.

$$BC_\lambda = \sum_{k=0}^{n} c_k (m_x - m_y)^k \tag{2}$$

With equation 1 and with the known bolometric correction in the appropriate filters we can find the bolometric magnitude. Once we have this quantity we can compute the bolometric luminosity through the following expression.

$$\frac{L_{bol,*}}{L_{bol,\odot}} = 10^{0.4(M_{bol,\odot} - M_{bol,*})} \tag{3}$$

Where $L_{bol,\odot} = 3.845 \times 10^{33}\,\mathrm{erg\,s^{-1}}$ and $M_{bol_\odot} = 4.74$ where this values are specific to the bolometric luminosity and magnitude of the sun. We see that BC are sensitive to the wavelength, which is why we believe BC should be linked to the color of the SN (a diagnostic of temperature) at that epoch. So BC's in literature are often split into the respective phases of the SNe light curves. Which is why it is important to understand what these phases are and how they are characterized for the case of a type II SNe. Note however that we do not explicitly know the absolute magnitude of ZN-7090 but if we estimate a redshift z $\sim$ 0.1 we can compute the SN luminosity distance and compute the absolute magnitude to the SN as follows.

$$M = m - \log_{10}\left(\frac{D_L}{10\,\mathrm{pc}}\right) \tag{4}$$

# Phases of a SNe Light Curve

### Rise of the light curve

The rise in the LC of a SNe is attributed to either of the following two mechanisms, (1) shock cooling emissions and/or (2) radioactive decay of $^{56}_{28}\mathrm{Ni}$, the combination of these two mechanisms can lead to the following three scenarios that can explain the rise in the LC. The first scenario being solely due to the shock cooling emissions, the second being attributed only to the radioactive decay of $^{56}_{28}$Ni, and the third scenario being a case where both mechanisms contribute to the rise of the LC. In the following subsections we will elucidate on each mechanism and how each one of them can explain the characteristic spike in the SNe LC.

#### Shock Cooling Emission

For CCSNe we know the progenitor star is a red super giant which we know from stellar evolution has an iron core. When this iron core reaches a critical mass, known as the Chandrasekhar mass limit, all the $^{56}_{26}$Fe in core will undergo photo-disintegration, where photons have enough energy to destroy nuclei. At the same time electron capture processes deprive the core from electron degeneracy pressure support, which causes the core to collapse in a runaway process.

As the iron core continues collapsing it will reach a point where it will bounce back due to the repulsive strong nuclear force. This outward moving shock will clash with the collapsing surrounding material which ultimately stalls the shock, however, the stalled shock is able to continue moving outward through some mechanism. It is hypothesised that this driving mechanism is the act of neutrino energy being deposited behind the shock front which allows the shock to continue moving outward. As the envelope's material keeps heating up it will expand and cool causing it to become optically thin allowing photons to diffuse, ultimately causing the LC to have sharp rise.

#### Radioactive Decay of $^{56}_{28}$Ni

In order to properly explain this process we must look at the radioactive decay of the isotopes of Nickle, as this element is the most abundant in type-2 SNe. The decay schemes are presented below,

$$^{56}_{28}\mathrm{Ni} \rightarrow ^{56}_{27}\mathrm{Co} + e^- + \nu_e + \gamma \tag{5}$$
$$^{56}_{27}\mathrm{Co} \rightarrow ^{56}_{26}\mathrm{Fe} + e^- + \nu_e + \gamma \tag{6}$$

When this process dominates in the rise of the light curve of a SNe, the light curve rises slower than in the previous case

# Classification of CCSNe

## Stripped-Envelope SN

Core collapse SNe are categorized into various categories based on their spectra and light curves. SNe with H lines in their spectra are classified as Type II SNe while those lacking H ines are called Type I SNe. Among Type I SNe those having He lines are called Type Ib SNe while those lacking He lines are called Type Ic. Additionally, Type IIb SNe are characterized by hydrogen lines in their early phase and the gradual appearance of He lines in their latter phases Ouchi et al. 2021. SNe Type IIb, Ib and Ic are considered to originate from massive stars that have lost a considereable amount of their envelope during their evolution. Thus these type of SNe are collectively known as Stripped-Enveloped SNe (SESNe).

## Type II-P & II-L Supernovae

These type of SNe also arise from a core collapse process, however, main distinction depends on the morphology of their light curves post maximum brightness. Type II-P displays a constant magnitude in the VIR bands within a decay of $\leq 0.5$ mag within an approximate time span of $\sim 100$ day. While Type II-L (Linear) decays in a linear rate where its magnitude decays in the order of $10^{-2}$ per day, until it settles onto the radioactive tail. Gall, E. E. E. et al. 2015. Additionally, light curve models and surveys strongly suggest that Type II SNe have red super-giants as their progenitors with masses in range of $8.5 \leq M/M_{\odot}$ Smartt et al. 2015. In specific Type II-P SN progenitors have a mass of $\sim 8.5\,\mathrm{M}_{\odot}$ to $16.5\,\mathrm{M}_{\odot}$. While the progenitors for Type-L are red super giants with a mass range $17\,\mathrm{M}_{\odot}$ to $25\,\mathrm{M}_{\odot}$ (Smartt et al. 2015, Anderson et al. 2014).

### Plateau Phase

For stars with massive Hydrogen envelopes the plateau phase occurs due to the balance between the cooling and recombination in the ejecta. Recombination starts occurring when the ejecta has effectively cooled to $\sim$ 5-6 kK (recombination temperature for Hydrogen). The recombination wave occurs in a manner such that a constant amount of energy is released through time, which causes the plateau shape in the LC. Gall, E. E. E. et al. 2015

### Linear Phase

Type II-L arise from stars that have lost most of their Hydrogen envelope than the progenitors of Type II-P. Formally defining the linear decline of Type II-L SNe we it must satisfy that in the first 50 days after its peak magnitude in the V-band is reached the magnitude must decrease by $> 0.5$ mag so a hundredth of a magnitude per day, this would indicate the hydrogen recombination in the ejecta is minimal and does not provide significant luminosity to the SNe.

# KSP-ZN7090 Bolometric Light Curve

## Classifying KSP-ZN7090 and its Phases

In order to apply the bolometric correction from Martinez et al. 2022 and Lyman, Bersier, and James 2013 we need to classify KSP-ZN7090 and identify its respective light curve phases. Using the same classification criterions of Gall, E. E. E. et al. 2015 and Anderson et al. 2014 we can classify KSP-ZN7090 as a Type II-L CCSNe, from studying its light curve in the V-band.

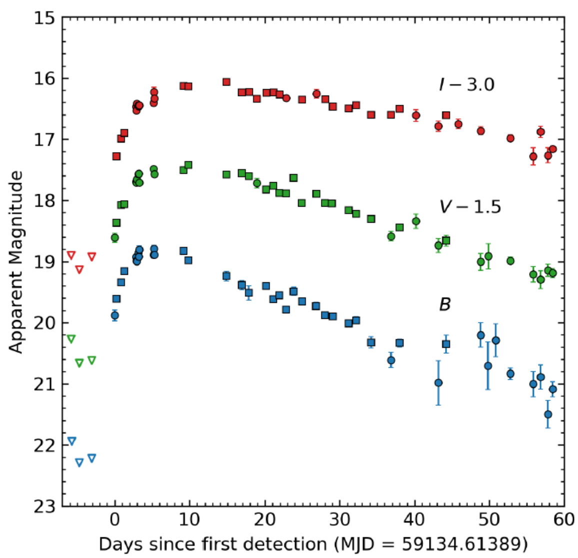


Figure 1: Color and extinction corrected light curves for KSP-ZN7090. Clear linear decay of > 0.5 mag in 50 days, which is how we characterize the lack of plateau phase (Hydrogen recombination) during the cooling after the peak magnitude

Additionally, noticing the rapid incline in the luminosity of the V-band light curve we can infer that the dominating process for this phase is shock cooling emission as opposed to a process dominated by the radioactive decay of $^{56}_{28}$Ni. Additionally we can discard the case where the rise of the light curve is attributed to both processes because we do not see a double peak in our light curve.

## Applying Bolometric Corrections on KSP-ZN7090

In order to convert the apparent magnitudes from figure 1 to bolometric magnitudes we will be using the bolometric correction from Martinez et al. 2022 and Lyman, Bersier, and James 2013 to construct the bolometric light curve for KSP-ZN7090. Because we have identified

ZN-7090 to be lacking a plateau phase then we will not be able to use all of the coefficients of Martinez et al. 2022 since all their corrections past the cooling phase are for plateau and radioactive black body tail, ZN-7090 hasn't entered.

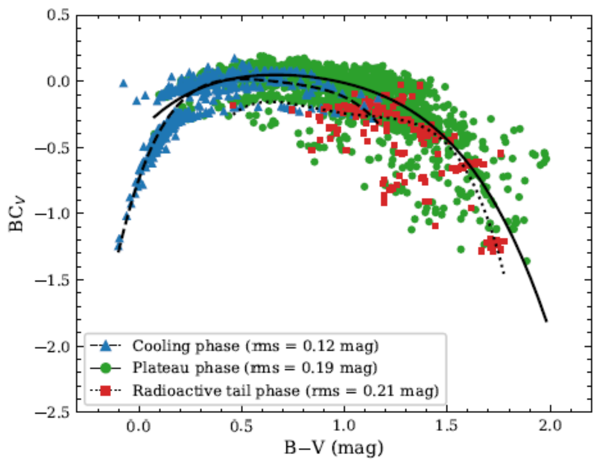


Figure 2: Bolometric correction to the V band as a function of B-V color taken from Martinez et al. 2022

A more attractive option is to use Lyman, Bersier, and James 2013 bolometric corrections as they apply to Type II SNe and are specific for measurements of magnitudes in the Johnson-Cousins filters, which are the same as the ones used by the KMTNet main telescope. Additionally, Lyman, Bersier, and James 2013 provides pseudo-bolometric correction which are representative only of optical and NIR of the SED.

Lastly Lyman, Bersier, and James 2013 also provides a general bolometric correction that was obtained from a large sample of Type II SNe regardless if they are are SE or Type II-L/P. The correction is provided as a form of a polynomial with rms scatter of 0.053 mag.

$$BC_B = 0.004 - 0.297 \times (B - I) - 0.149 \times (B - I)^2 \tag{7}$$

Lastly Lyman, Bersier, and James 2013 provides a more general BC for their entire sample of SNe in the Johnson-Cousins filters the rms scatter for this correction is 0.1 mag.

$$BC_B = -0.057 - 0.219 \times (B - I) - 0.169 \times (B - I)^2 \tag{8}$$

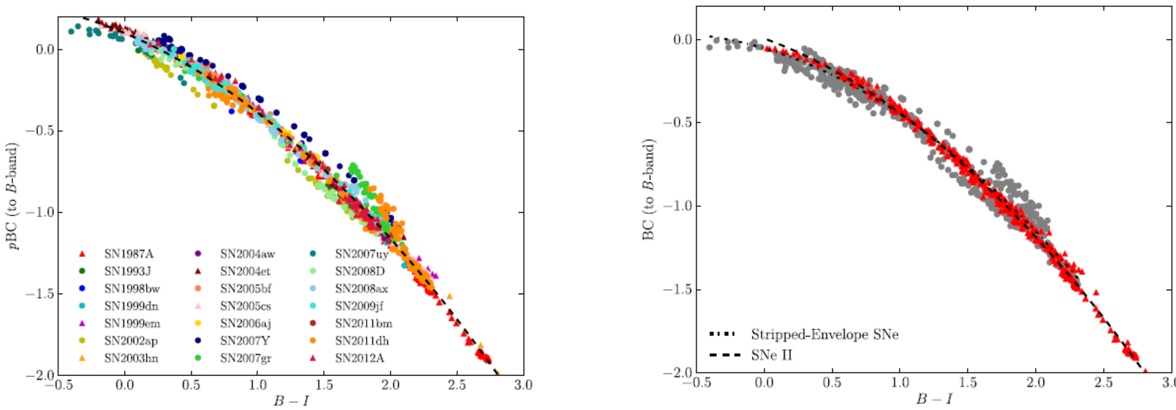


Figure 3: (Left Panel) Pseudo-bolometric correction for Type II SNe in the Johnson-Cousins filter. (Right Panel) Bolometric corrections for Type II SNe in the Johnson-Cousins filter taken from Lyman, Bersier, and James 2013

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