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SN 1974G and SN 2021J

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The Hubble constant from two sibling Type Ia supernovae in the nearby galaxy NGC 4414: SN 1974G and SN 2021J

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ABSTRACT

Having two “sibling” Type Ia supernovae (SNe Ia) in the same galaxy offers additional advantages in reducing a variety of systematic errors involved in estimating the Hubble constant, \( H_0 \). NGC 4414 is a nearby galaxy included in the Hubble Space Telescope Key Project to measure its distance using Cepheid variables. It hosts two sibling SNe Ia: SN 2021J and SN 1974G. This provides the opportunity to improve the precision of the previous estimate of \( H_0 \), which was based solely on SN 1974G. Here we present new optical BVRI photometry obtained at the Observatorio de Sierra Nevada and complement it with Swift UVOT UBV data, which cover the first 70 days of emission of SN 2021J. A first look at SN 2021J optical spectra obtained with the Gran Telescopio Canarias (GTC) reveals typical SN type Ia features. The main SN luminosity parameters for the two sibling SNe are obtained by using SNooPy, a light curve fitting code based on templates. Using a hierarchical bayesian approach, we build the Hubble diagram with a sample of 96 SNe Ia obtained from the Combined Pantheon Sample in the redshift range \( z = 0.02–0.075 \), and calibrate the zero point with the two sibling type-Ia SNe in NGC 4414. We report a value of the Hubble constant \( H_0 = 72.19 \pm 2.32 \) (stat.) \( \pm 3.42 \) (syst.) \( \text{km s}^{-1} \text{Mpc}^{-1} \). We expect a reduction of the systematic error after a new analysis of the Cepheids period-luminosity relation using the upcoming Gaia DR4 and additional Cepheids from the HST and JWST.


1. Introduction

Type Ia supernovae (SNe Ia) play an essential role as distance indicators for cosmological studies that allow us to explore far out into the Hubble flow. SNe Ia have been standardized by applying various corrections to their absolute luminosity, decline-absolute magnitude and intrinsic color-reddening relationships (Phillips 1993; Hamuy et al. 1993; Riess et al. 1996; Tripp 1998). Hence, SNe Ia have been widely used to determine the Hubble constant \( (H_0) \), which gives an estimate of the expansion rate of the Universe (Hubble 1929). This is a key parameter of the standard \( \Lambda \) CDM cosmological model (Peebles 2012). However, their estimated values at the two extremes of the Universe, in early times from the cosmic microwave background (CMB; Planck Collaboration V1 2020) and in the local Universe from classical methods (e.g. Freedman et al. 2001; Riess et al. 2016), show a discrepancy (see Verde et al. 2019; Riess et al. 2022, for a review). This tension may indicate new physics beyond the standard cosmological model. Therefore, it is mandatory to explore the possible systematics in the local values of \( H_0 \) and obtain more precise measurements.

The nearby galaxy NGC 4414 is an isolated member of the Coma I group (Braine et al. 1997) and is one of the galaxies included in the Hubble Space Telescope (HST) Key Project on the extragalactic distance scale using Cepheid variables stars (Freedman et al. 2001). This galaxy hosts the type-Ia supernova SN 1974G, which has been used in previous studies to measure \( H_0 \) (Schaefer 1998; Gibson et al. 2000), and the type I Ib supernova SN 2013df (Ciabattari et al. 2013; Van Dyk et al. 2014). Type II SNe can also be considered as distance indicators, however, their study would need to be further improved to obtain accurate extragalactic distances (e.g. de Jaeger et al. 2020, 2022). The recently discovered type-Ia supernova SN 2021J, by the Zwicky Transient Factory (ZTF, Bellm et al. 2019), hosted in the same galaxy brings us the opportunity to improve and reduce possible systematic errors in the estimate of the Hubble constant by using two “siblings” supernovae from a single nearby galaxy, such as those related to the host galaxy distance, the peculiar velocity, and other unaccounted properties of the host galaxy (see Burns et al. 2020, for improving the relative precision of SNe Ia as standard candles using siblings SN in nearby galaxies). Moreover, studying siblings offers us a great opportunity to explore many essential aspects related to the cosmological utility of SNe Ia, such as the correlations of SN light curves (LCs), and properties of their host galaxies, including the intrinsic dust extinction, and the validity of the standardization procedure (Scolnic et al. 2020; Biswas et al. 2022).

In this paper, we present BVRI photometry of SN 2021J in eight epochs obtained with the CCDT150 camera mounted on the 1.5-m telescope at the Observatorio de Sierra Nevada (OSN),...
and UBV photometry from *Swift*-UVOT. Moreover, we report multi-epoch spectra observed with the OSIRIS spectrograph on the Gran Telescopio Canarias (GTC) at La Palma. From the LC analysis of the 2 siblings SN 1974G and SN 2021J in NGC 4414, we determine the Hubble constant by means of a hierarchical bayesian approach using a SNe Ia sample drawn from the Combined Pantheon Sample in the redshift range $z = 0.02 – 0.075$. In Sect. 2 we present our SN 2021J photometric and spectroscopic data, and describe the data used for SN 1974G. In Sect. 3 we focus on the analysis of both SN light-curves, and derive the Hubble constant. Finally, the results are summarised and discussed in Sect. 4.

2. Observations

2.1. Photometry

We used the $B$- and $V$-band photometry of SN 1974G presented in Schaefer (1998), where the author collected existing data from the literature and improved the photometric calibration, building updated $B$- and $V$-band light curves. We note that the existing data contains photographic magnitudes, but if we remove them from our analysis, our results are still consistent within the margins of error. Finally, we decided to consider all the original points despite large uncertainties because the SN peak is better covered (see more details in Appendix D).

SN 2021J was discovered by ZTF in the galaxy NGC 4414 as a new object of magnitude $g(AB) = 17$ mag (Forster et al. 2021), and it was observed as part of the program *SN2: SuperNovae from Sierra Nevada*2. This program aims at building a statistically significant BVRI photometric sample of SNe Ia in nearby Sloan Digital Sky Survey (SDSS) host galaxies to study how their luminosity properties relates with host environment, and thus, how the latter can affect their physical properties. The optical images for SN 2021J were obtained with the CCD150 camera mounted on the 1.5-m telescope at the Observatorio de Sierra Nevada (OSN) located in Granada, Spain (see Fig. 3). We used the Johnson-Cousins $BVRi$ filters to obtain the SN photometry in eight epochs during an observing interval of 60 days from the first observation. Two epochs were observed before the SN peak brightness, which allows to sample the peak luminosity and build a reliable light curve (LC).

The data have been reduced by using a Python-based3 pipeline developed by us to automatically reduce the data obtained for the SN2 observing program. Bias subtraction and flat fielding were implemented using the CDPROC and ASTROPY Python packages (Craig et al. 2017). Subsequently plate-solve calibration was applied to single images using astrometry.net libraries, which were finally stacked into a single calibrated image using SWARP (Bertin et al. 2002). Finally, we performed a differential photometry of the SN by using field stars whose $BVRi$ magnitudes have been measured from observations of the SA98 Landolt field. Magnitudes have been measured with PSF photometry on all the stellar sources in each image having a brightness larger than twice the standard deviation value computed on the image itself, and then using an integrated Gaussian pixel response function as our model for the magnitude measurement. To this aim, we made a wide use of the tools provided within the photutils4 package; in the specific we used the

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Table 1. Information on the OSIRIS/GTC spectroscopy of SN 2021J.

<table>
<thead>
<tr>
<th>Epoch</th>
<th>Date (MJD)</th>
<th>PA (°)</th>
<th>Airmass</th>
<th>Wavelength range (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>59 231.26</td>
<td>90</td>
<td>1.01</td>
<td>3950–10 000</td>
</tr>
<tr>
<td>2</td>
<td>59 233.29</td>
<td>−54</td>
<td>1.03</td>
<td>3950–10 000</td>
</tr>
<tr>
<td>3</td>
<td>59 239.16</td>
<td>−18</td>
<td>1.07</td>
<td>3950–10 000</td>
</tr>
<tr>
<td>4</td>
<td>59 255.26</td>
<td>18</td>
<td>1.09</td>
<td>3950–10 000</td>
</tr>
<tr>
<td>5</td>
<td>59 395.91</td>
<td>−60</td>
<td>1.26</td>
<td>3600–9300</td>
</tr>
</tbody>
</table>

(Gómez-González et al. 2016). The full details of the data reduction and its analysis will be presented in a subsequent publication. Here we present a brief summary. Bias and flat-field corrections were applied to the object and standard images. The 2D spectra were calibrated in wavelength using the HgAr+Ne+Xe lamps from the GTC instrument calibration module. The 1D spectra were extracted using an optimal extraction aperture, and the flux calibration was done using spectro-photometric standard stars, observed the same night and with the same gratings than SN 2021J. The atmospheric extinction was corrected using the ORM extinction curve at the observed airmass. The dust extinction in the host galaxy of SN 2021J has not been corrected. The spectra over the different wavelength ranges were combined into a single spectrum for each epoch, and corrected from foreground Galactic reddening (Schlegel et al. 1998).

The SN 2021J spectroscopic evolution over the five epochs is shown in Fig. 2. The strongest early-time features, seen prior to and near the peak brightness, are the Mg II, S II, Si II, and Ca II lines, which are typically observed in type-Ia SNe at similar epochs (Gal-Yam 2017). The late nebular spectrum (day 163 after the peak) shows typical forbidden emission lines of [Fe III] and [Co III] that are generally observed at these late epochs of the SN explosion. The spectra are made publicly available on WISEREP5 (Yaron & Gal-Yam 2012). A detailed analysis of the spectral series of SN 2021J will be presented elsewhere.

3. Analysis

3.1. The light curves of SN 1974G and SN 2021J

The SNe light curves were fitted with the SNooPy (SuperNovae in object oriented Python) package (Burns et al. 2010). The software generates uBVgriYJH light-curve templates to perform a LC fitting to determine the main luminosity parameters. We parameterized the SNe LCs using the decay-rate parameter $\Delta m_{15}$ introduced by Phillips (1993), and defined as the difference in magnitude between the peak and 15 days after peak of SN emission in the B band. We selected the max-model implemented in SNooPy for the fits to determine in each filter the maximum magnitude and $\Delta m_{15}$. This model does not assume any intrinsic extinction of the SN, neither in the host galaxy nor in the intergalactic medium. The model only corrects for the Milky Way extinction using the Schlegel maps (Schlegel et al. 1998), and it uses the spectral template of Hsiao et al. (2007) to compute K-corrections6. We considered a value of $cz = 991$ km s$^{-1}$ for the recessional velocity of NGC 4414 with respect to the CMB rest frame7 (Carrick et al. 2015).

Table 2 shows the LC parameters for both SNe. The first four rows correspond to the maximum brightness in the different filters. We note that SN 1974G has photometric data only in B and V bands. The fifth row indicates the MJD day of $B$-maximum, and the last row shows the decay-rate parameter. Figure 3 shows the LCs fits for SN 1974G and SN 2021J, respectively. The solid black lines are SNooPy fits for the different filters. Dashed lines in LC fits indicate the 1-$\sigma$ errors.

3.2. The Hubble constant

In order to measure the Hubble constant using these two sibling SNe in NGC 4414 as calibrators, we followed the procedure described in Khetan et al. (2021, hereafter K21).

First, we modeled the observed B magnitudes at their maximum brightness, and the last row shows the decay-rate parameter. Figure 3 shows the LCs fits for SN 1974G and SN 2021J, respectively. The solid black lines are SNooPy fits for the different filters. Dashed lines in LC fits indicate the 1-$\sigma$ errors.

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details in K21). To calibrate the model, here, we used SN 1974G and SN 2021J in the galaxy NGC 4414 with its distance modulus measured from Cepheid variables. By using $\Delta m_{15}$ to shape the LCs, instead of the color-stretch used in K21, the observed $B$ magnitude at peak is:

$$B_{\text{max}} = P_0 + P_1(\Delta m_{15} - 1.1) + R(B_{\text{max}} - V_{\text{max}}) + \mu_{\text{calib}}$$

where $P_0$ and $P_1$ relate the maximum magnitude to the decalrate parameter $\Delta m_{15}, R$ includes the extinction correction that covers other possible causes of reddening, in addition to the galactic extinction that was already taken into account in the LC fitting. We note that our cosmological analysis does not require distinguishing between the different sources of extinction because our goal is not to study the properties of the dust in the galaxy compact size, its high surface brightness and a strong source crowding made the study of the Cepheids in NGC 4414 one of the most challenging in the HST Key Project. We adopted the distance modulus of the host galaxy.

Several difficulties such as the galaxy compact size, its high surface brightness and a strong source crowding made the study of the Cepheids in NGC 4414 one of the most challenging in the HST Key Project. We adopted the distance modulus of $\mu_{\text{NGC 4414}} = 31.24 \pm 0.05$ (stat.) mag as provided in the final results work of the Key Project (Freedman et al. 2001). They improved the value obtained by Turner et al. (1998) and Gibson et al. (2000) by including new corrections in the distance modulus to the Large Magellanic Cloud (LMC), new Wide Field and Planetary Camera 2 (WFPC2) photometric calibration, and improved corrections for metallicity and reddening on the observed period-luminosity (PL) relation of the Cepheids. We used $\mu_{\text{LMC}} = 18.477 \pm 0.004$ (stat.) $\pm 0.026$ (syst.) mag recently obtained from an analysis of detached eclipsing binary stars (Pietrzyński et al. 2019) instead of $\mu_{\text{LMC}} = 18.50$ mag adopted by Freedman et al. (2001).

Second, we used the same cosmological sample as K21, composed of 96 SNe extracted from the Combined Pantheon Sample (Scolnic et al. 2018). We did not apply an upper limit to the SN redshifts, but we selected those SNe from the subsample with good quality photometric data that allows us to adequately sample the LC (see more details in K21). The final redshift range of the sample is $0.02 < z < 0.075$. The lower $z$ cut was selected to minimize impact of peculiar velocities uncertainties. We performed a hierarchical Bayesian regression to infer the model parameters from a likelihood function of the cosmological SN sample, and the two siblings SNe, acting as calibrator sample. Following the methodology by K21, the posterior of the model parameters is given by Bayes’ theorem as

$$P(\Theta|D) \propto P(D|\Theta)P(\Theta).$$

In our study, the LC fit parameters $B_{\text{max}}, V_{\text{max}}, \Delta m_{15}$ corresponding to the observable SN properties are included in the vector $D$, and the model parameters $P_0, P_1, R, H_0$ are represented by the vector $\Theta$. Their Eq. (6) gives the likelihood probability distribution $P(D|\Theta)$ after marginalising over all $\Theta_i$ computed for each SN, that incorporated the two calibrators and the cosmological sample. In our case, $N_{\text{calib}} = 2$ and $\mu_{\text{calib}} = \mu_{\text{NGC 4414}}$. We used their Eq. (4) for the SNe cosmological sample to substitute the distance modulus in Eq. (1) as a function of redshift and $H_0$. They considered a cosmological model with a Robertson-Walker metric and a spatially flat Universe (Weinberg 1972; Visser 2005). The values for cosmic deceleration and cosmic jerk are $q_0 = -0.55$ and $j_0 = 1$, respectively (Planck Collaboration VI 2020). In order to derive $H_0$, we consider a hierarchical Bayesian approach consisting of two sub-models, one for the SNe cosmological sample and another for the two sibling SNe in NGC 4414. The variance for each of the two SNe is:

$$\sigma^2_{\text{calib},i} = \sigma^2_{B,i} + \sigma^2_{\text{perturb},i} + (P_1\sigma_{\Delta m_{15}})^2 + 2R(\sigma_{B,i}^2 + \sigma_{V,i}^2) - 2R\sigma_{B,i}^2,$$

We used Eq. (11) in K21 to calculate the variance of each SN in the cosmological sample. This equation includes the term $\sigma_{\text{int,cosmo}}$ which accounts for any unknown scatter in the sample. For the priors, we considered a Half Cauchy distribution for $\sigma_{\text{int,cosmo}}$ and normal distributions for the rest of the parameters. We obtained the best-fit parameters of the model $P_0, P_1, R, H_0,$ and $\sigma_{\text{int,cosmo}}$ by performing a Markov chain Monte Carlo (MCMC) sampling implemented in Python with the PyMC3.
In this study, we revisit the LC analysis of the known type-Ia SN 1974G in the nearby galaxy NGC 4414. This single calibrator yields a value of the Hubble constant $H_0 = 70.19 \pm 3.32$ (stat.) km s$^{-1}$ Mpc$^{-1}$, as presented in Sect. 3.2. We obtain a more accurate and precise value of $H_0$, as compared to the significantly lower estimates reported in the literature (see Table 3), by introducing important improvements in our analysis. First, we improved the methodology by applying the SNooPy LC fitter to determine more accurately the LC parameters for all SNe Ia in the cosmological sample and the two sibling SNe in NGC 4414 (SN 1974G and the recently discovered SN 2021J). Secondly, we constructed the Hubble diagram using our sibling SNe (together and separately) as the zero-point calibrators. We used a distant SNe Ia sample extracted from the Combined Pantheon Sample, in the redshift range $z = 0.02 - 0.075$, instead of using the Calán-Tololo (Hamuy et al. 1996) considered in those SN 1974G previous works. Our cosmological sample is of higher quality and has a larger number of SNe compared with the Calán-Tololo sample (96 vs. 29), which improves the statistical uncertainties in the $H_0$ estimates.

In addition to SN 1974G, we used a recent supernova SN 2021J in the same galaxy as a calibrator. These “siblings” offer additional advantages by sharing several sources of systematics that in general have a non-negligible weight in the estimation of the distance, and then in the calibration of the luminosity relations of the SN. Among these, we have not only the same host distance, but also the peculiar velocity, and host galaxy properties that can have an influence on the luminosity, such as the extinction. However, while Scolnic et al. (2021) find correlations in some SN properties for SNe hosted in the same galaxy, such as the stretch parameter, they do not find greater correlation in the distance modulus values computed by siblings than in any other SN pairs.

Therefore, we have significantly reduced the statistical uncertainties, down to 3.2%, in the determination of $H_0$ from the two sibling SNe in NGC 4414. However, our estimate of $H_0 = 72.19 \pm 2.32$ (stat.) $\pm 3.42$ (syst.) km s$^{-1}$ Mpc$^{-1}$ still has large systematic errors in determining the distance modulus to NGC 4414, as explained in Sect. 3.2. We believe that a new Milky Way Cepheid PL calibration using the upcoming Gaia DR4, together with additional Cepheids from new HST observations, will significantly improve the systematic error of the NGC 4414 distance modulus, and hence provide an accurate determination of $H_0$ at the level of the statistical error.

We have also explored the possibility of measuring the distance modulus to NGC 4414 using the Tip of the Red Giant Branch (TRGB) method. Considering that there are no deep images sampling the stellar halo of the galaxy in the HST archive, it does not seem possible to estimate a distance with this method (Barry Madore, Wendy Freedman, private communications). NGC 4414 may be a good target for the upcoming James Webb space telescope (JWST).

Our estimate of the Hubble constant from the two sibling SNe in NGC 4414 is consistent, within $\sim 1\sigma$, with that obtained from early-universe CMB measurements (Planck Collaboration VI 2020) and local estimates from Cepheid variables (Riess et al. 2022; Brout et al. 2022), TRGBs (Freedman 2021), and SBF (K1). Before requiring additional new physics beyond the standard cosmological model, it is imperative to further study possible systematic errors and provide more reliable measurements of $H_0$ using different methodologies in the local Universe. The possibility of finding at least three more pairs of sibling SNe Ia in galaxies with Cepheid distances would not be negligible in the next decade. The ZTF survey (Bellm et al. 2019) discoveries reinforce the previous premise, reporting 1–2 SNe Ia every year in the 20 Mpc volume (Dhawan et al. 2022), where HST observations can provide robust distance estimates by means of Cepheids or TRGB. As a back-of-the-envelope calculation, this means reducing the statistical error of $H_0$ down to 1.7%, similar to what is expected from the entire sample of SNe Ia, and more importantly, it would strongly reduce the systematic error, given that it mainly depends on the uncertainty on the distance
modulus of a small number of host galaxies. We finally recall that the systematic error of $H_0$ using these sibling SNe also represents an upper limit since it will be greatly reduced using the incoming Gaia calibrations.

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Table 3. Posterior probability of the modeling parameters.

<table>
<thead>
<tr>
<th>Supernova</th>
<th>$P_0$ (mag)</th>
<th>$P_1$ (mag)</th>
<th>$R$</th>
<th>$\sigma_{\cosmo}$</th>
<th>$H_0$ (km s$^{-1}$ Mpc$^{-1}$)</th>
<th>$H_0$ (pub) (km s$^{-1}$ Mpc$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SN 1974G</td>
<td>$-19.17 \pm 0.10$</td>
<td>$0.57 \pm 0.08$</td>
<td>$1.81 \pm 0.20$</td>
<td>$0.18 \pm 0.02$</td>
<td>$70.19 \pm 3.32$</td>
<td>$55 \pm 8^{(2)}$</td>
</tr>
<tr>
<td>SN 2021J</td>
<td>$-19.06 \pm 0.10$</td>
<td>$0.57 \pm 0.08$</td>
<td>$1.81 \pm 0.21$</td>
<td>$0.18 \pm 0.02$</td>
<td>$74.02 \pm 3.13$</td>
<td>$-32 - 32 \pm 3 \pm 1$</td>
</tr>
<tr>
<td>Both SNe</td>
<td>$-19.11 \pm 0.07$</td>
<td>$0.56 \pm 0.08$</td>
<td>$1.83 \pm 0.20$</td>
<td>$0.18 \pm 0.02$</td>
<td>$72.19 \pm 2.32$</td>
<td>$-32 - 32 \pm 3 \pm 1$</td>
</tr>
</tbody>
</table>

Notes. The first two rows show the mean values obtained for each of the SNe separately in our analysis, and the third row considering both SNe. The last column shows the values of $H_0$ for SN 1974 derived from the literature. Value of the Hubble constant for SN 1974G from the literature.
Appendix A: Systematic uncertainties on the Hubble constant

We adopted the systematic uncertainties in $H_0$ described in Freedman et al. (2001) and Freedman et al. (2012), who provided the Cepheid distance to NGC 4414 used in this study. The former detected Cepheid variables and derived accurate distances to nearby SN Ia hosts, including NGC 4414. The latter focused mainly on the zero point of the Cepheid extragalactic distance scale and a re-evaluation of the systematic error budget, and hence improving the systematic errors.

We show in Table A.1 the systematic error budget on $H_0$ (see more details in Freedman et al. 2012). The systematics of the SNooPy fits were obtained in this work. The total error in $H_0$ was then calculated by combining all the individual errors in quadrature. The choice of the uncertainty in the metallicity parameter is controversial due to the value adopted for the Cepheid metallicity coefficient (see Fig. 14 in Gerke et al. 2011). Although there are works with smaller values (e.g. Riess et al. 2021), we conservatively considered the 4% error adopted in Freedman et al. (2001), since we used the distance to the galaxy from this work. We adopted a 1% uncertainty due to crowding, as reported in Freedman et al. (2012). They present a quantitative analysis of the crowding bias in Cepheid photometry using artificial stars. The blue main sequence stars are the main contributors to the crowding, which make Cepheid photometry brighter and bluer.

The systematic bias closely tracks the line of the Wesenhelt reddening free index (W) in the optical CMD, resulting in a minimal change in the final Cepheid distance (see more details in their Section 3.3 and their Appendix). Freedman et al. (2012) conclude that the crowding effects are less than 0.02 mag (1% in distance), in agreement with the results of Ferrarese et al. (2000). Our estimated value of $H_0$ and its uncertainties from the two sibling SNe in NGC 4414 is $72.19 \pm 2.32$ (stat.) $\pm 3.42$ (syst.) $\text{km s}^{-1} \text{Mpc}^{-1}$.

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Error %</th>
<th>Magnitude (mag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMC zero-point</td>
<td>1.2</td>
<td>0.026</td>
</tr>
<tr>
<td>WFPC2 zero-point</td>
<td>1</td>
<td>0.022</td>
</tr>
<tr>
<td>Reddening</td>
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<td>0.022</td>
</tr>
<tr>
<td>Metallicity</td>
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</tr>
<tr>
<td>Bias in Cepheid PL</td>
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</tr>
<tr>
<td>Crowding</td>
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<td>0.022</td>
</tr>
<tr>
<td>B-band fit SNooPy</td>
<td>0.55</td>
<td>0.012</td>
</tr>
<tr>
<td>V-band fit SNooPy</td>
<td>0.87</td>
<td>0.019</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4.74</td>
<td>0.103</td>
</tr>
</tbody>
</table>
Appendix B: Photometry of SN 2021J

In this section, we report the photometry of SN 2021J. On the one hand, Table B.1 shows BVRI photometry of SN 2021J in eight epochs obtained with the CCDT150 camera mounted on the 1.5m telescope at the Observatorio de Sierra Nevada (OSN). On the other hand, Table B.2 presents UBV photometry observed by Swift-UVOT.

Table B.1. Photometry of SN 2021J obtained with the CCDT150 camera mounted on the 1.5 meter telescope at the OSN.

<table>
<thead>
<tr>
<th>MJD (days)</th>
<th>B (mag)</th>
<th>V (mag)</th>
<th>R (mag)</th>
<th>I (mag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>59227.17</td>
<td>12.839 ± 0.051</td>
<td>12.653 ± 0.041</td>
<td>12.465 ± 0.041</td>
<td>12.516 ± 0.068</td>
</tr>
<tr>
<td>59230.13</td>
<td>12.488 ± 0.056</td>
<td>12.278 ± 0.079</td>
<td>12.247 ± 0.071</td>
<td>12.247 ± 0.071</td>
</tr>
<tr>
<td>59234.06</td>
<td>12.406 ± 0.092</td>
<td>12.426 ± 0.060</td>
<td>12.149 ± 0.067</td>
<td>12.280 ± 0.083</td>
</tr>
<tr>
<td>59242.18</td>
<td>13.142 ± 0.023</td>
<td>12.367 ± 0.033</td>
<td>12.607 ± 0.049</td>
<td>12.733 ± 0.081</td>
</tr>
<tr>
<td>59246.13</td>
<td>13.502 ± 0.056</td>
<td>12.702 ± 0.050</td>
<td>12.624 ± 0.071</td>
<td>12.527 ± 0.081</td>
</tr>
<tr>
<td>59260.11</td>
<td>14.813 ± 0.064</td>
<td>13.627 ± 0.042</td>
<td>13.154 ± 0.047</td>
<td>12.696 ± 0.079</td>
</tr>
<tr>
<td>59264.02</td>
<td>14.638 ± 0.064</td>
<td>13.650 ± 0.042</td>
<td>13.271 ± 0.047</td>
<td>12.804 ± 0.079</td>
</tr>
<tr>
<td>59287.21</td>
<td>15.532 ± 0.257</td>
<td>14.612 ± 0.128</td>
<td>14.206 ± 0.162</td>
<td>13.809 ± 0.197</td>
</tr>
</tbody>
</table>

Table B.2. Photometry of SN 2021J obtained by Swift Ultraviolet/Optical Telescope.

<table>
<thead>
<tr>
<th>MJD (days)</th>
<th>U_UVOT (mag)</th>
<th>B_UVOT (mag)</th>
<th>V_UVOT (mag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>59219.17</td>
<td>15.35 ± 0.08</td>
<td>14.99 ± 0.03</td>
<td>-</td>
</tr>
<tr>
<td>59220.61</td>
<td>14.74 ± 0.06</td>
<td>14.30 ± 0.04</td>
<td>13.61 ± 0.05</td>
</tr>
<tr>
<td>59221.80</td>
<td>14.17 ± 0.06</td>
<td>13.45 ± 0.03</td>
<td>13.13 ± 0.04</td>
</tr>
<tr>
<td>59222.60</td>
<td>13.95 ± 0.06</td>
<td>13.60 ± 0.03</td>
<td>12.94 ± 0.03</td>
</tr>
<tr>
<td>59223.66</td>
<td>13.41 ± 0.05</td>
<td>13.13 ± 0.02</td>
<td>12.71 ± 0.03</td>
</tr>
<tr>
<td>59225.20</td>
<td>13.02 ± 0.03</td>
<td>13.04 ± 0.06</td>
<td>-</td>
</tr>
<tr>
<td>59230.16</td>
<td>12.49 ± 0.03</td>
<td>12.55 ± 0.03</td>
<td>12.22 ± 0.03</td>
</tr>
<tr>
<td>59230.56</td>
<td>12.50 ± 0.03</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>59232.42</td>
<td>12.62 ± 0.03</td>
<td>12.58 ± 0.02</td>
<td>12.24 ± 0.03</td>
</tr>
<tr>
<td>59234.61</td>
<td>12.78 ± 0.03</td>
<td>12.62 ± 0.02</td>
<td>12.29 ± 0.03</td>
</tr>
<tr>
<td>59241.14</td>
<td>13.51 ± 0.06</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>59245.25</td>
<td>14.02 ± 0.06</td>
<td>-</td>
<td>12.81 ± 0.04</td>
</tr>
<tr>
<td>59249.03</td>
<td>14.41 ± 0.06</td>
<td>-</td>
<td>13.16 ± 0.03</td>
</tr>
<tr>
<td>59253.22</td>
<td>14.88 ± 0.11</td>
<td>13.95 ± 0.04</td>
<td>-</td>
</tr>
</tbody>
</table>
Appendix C: EBV_model2 LC fitting for SN 2021J

As seen previously, we used the max-model in SNooPy to fit the LCs for the SNe, which allowed us to compute the maximum magnitude in each filter and $\Delta m_{15}$ needed for the Bayesian analysis. In this section, we calculate the LC parameters for SN 2021J by using another fitting model: the EBV_model2. This model allows us to compute the distance and the dust extinction of the host galaxy following the work of Prieto et al. (2006). We parameterized the SNe LCs using the color-stretch parameter $s_{BV}$ introduced by Burns et al. (2014) and defined as the time between $B_{\text{max}}$ and $(B_{\text{max}} - V_{\text{max}})$ divided by 30. We obtained a value of the reddening due to the host galaxy of $E(B - V)_{\text{host}} = 0.349 \pm 0.018$ mag, $s_{BV} = 0.988 \pm 0.024$, and $\mu_{\text{NGC 4414}} = 30.927 \pm 0.053$ mag. Figure C.1 shows the LCs fits obtained. Fitting this model to just two filters for SN 1974G is not accurate to correctly disentangle the intrinsic extinction. Therefore, we decided to use the max-model that meets the requirements of our work.

**Fig. C.1.** SN 2021J LCs fits using the EVB_model in SNooPy. The legend indicates the color and shape of the symbols adopted for the different bands. The black lines indicate the SNooPy best-fits. Dashed lines are 1-$\sigma$ errors.
Appendix D: Uncertainty analysis of SN 1974G

In this section, we study the uncertainties corresponding to SN 1974G. As we seen in previous sections, we used the $B$- and $V$-band photometry of SN 1974G presented in Schaefer (1998). Due to the existing data contains both visual and photographic magnitudes, we studied our results in different cases, depending on what points are included in our analysis. Figure D.1 shows the LCs fits for SN 1974G for the different analysis. The solid black lines are SNooPy fits for the different filters. Dashed lines in LC fits indicate the 1-$\sigma$ errors. In a) we have considered all the points that Schaefer (1998) adopted. In b) we have removed the visual, photographic, and points with large uncertainty (Burgat’s points, see Table 3 in Schaefer (1998)). In c) we have removed only the visual, and photographic points. Table D.1 shows the LC parameters for SN 1974G. The results are still consistent within the margins of error. Finally, we decided to consider all the original points because the SN peak is better covered. Furthermore, the large uncertainties of SN 1974G are within our luminosity calibration code and reflected in the different weights of the two SNe.

![SN 1974G LCs fits using SNooPy. The black lines indicate the SNooPy best-fits. Dashed lines are 1-$\sigma$ errors.](image)

Fig. D.1. SN 1974G LCs fits using SNooPy. The black lines indicate the SNooPy best-fits. Dashed lines are 1-$\sigma$ errors. (a) Considering all the point used by Schaefer (1998). (b) Eliminating the visual, photographic, and Burgat’s points. (c) Eliminating the visual, and photographic points.

Table D.1. SNooPy best-fit parameters for the LCs of SN 1974G. (a) Considering all the point used by Schaefer (1998). (b) Eliminating the visual, photographic, and Burgat’s points. (c) Eliminating the visual, and photographic points.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SN1974G (a)</th>
<th>SN1974G (b)</th>
<th>SN1974G (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_{\text{max}}$ (mag)</td>
<td>12.417 ± 0.043 ± 0.012 (syst.)</td>
<td>12.409 ± 0.032 ± 0.012 (syst.)</td>
<td>12.408 ± 0.032 ± 0.012 (syst.)</td>
</tr>
<tr>
<td>$V_{\text{max}}$ (mag)</td>
<td>12.252 ± 0.035 ± 0.019 (syst.)</td>
<td>12.074 ± 0.049 ± 0.019 (syst.)</td>
<td>12.103 ± 0.047 ± 0.019 (syst.)</td>
</tr>
<tr>
<td>$T_{\text{max}}$ (MJD)</td>
<td>42168.645 ± 0.500 ± 0.340 (syst.)</td>
<td>42168.682 ± 0.378 ± 0.340 (syst.)</td>
<td>42168.599 ± 0.357 ± 0.340 (syst.)</td>
</tr>
<tr>
<td>$\triangle m_{15}$ (mag)</td>
<td>1.236 ± 0.074</td>
<td>1.200 ± 0.064</td>
<td>1.195 ± 0.061</td>
</tr>
</tbody>
</table>