Measuring the Distance to Multiple Type Ia Supernovae using Different Dust Extinction Methods Patrick Rogers, Mentor: Jamie Kern Bridgewater State University



We analyze the B filter light curves of ASAS-SN 16lg, ASAS-SN 18bt, and AT2021 gtp to measure the distance to the event using the distance modulus. For type Ia supernovae there is a widely understood relationship between the decline rate of the B filter and the distance to the supernova. By incorporating the V filter, we work to create a dust extinction calculation to more accurately account for absorption due to stellar and interstellar dust clouds between the object and our location. Many methods to account for dust extinction exist so we study the benefits and precisions of these models.

Introduction



supernovae are an incredible 1a phenomenon that takes place in some binary star systems. A white dwarf, the remnant of a dead low-mass star, can accrete matter off a companion star. The white dwarf will continue to accumulate matter until it reaches the Chandrasekhar limit. At this point the weight of the accreted matter is so strong that the white dwarf begins nuclear fusion of all the remaining hydrogen atoms at the same time. This outshine phenomenon can its host galaxy. Because of the uniform nature of

these explosions, a relationship between distance Before fitting the lightcurve, we account for the time-delay caused by expansion of the universe. As the universe expands, Fig. 1 – Artist's depiction of a and decline in the brightness can be used to light takes longer to reach us, not originating at the times we observe them. The observed times must be corrected for this. type la supernova. (1) calculate the distance to the supernova and give We then create a gaussian fit to our corrected points. To test the accuracy of the fit, we calculate an R² value (a value of 1 important insight into expansion of the universe, the Hubble constant, and help map indicates the fit is a perfect representation of the data). Once we calculate the best fit, we use the distance modulus. *m* is the nearby universe. We seek to improve our measurement of the distance by the maximum apparent magnitude of the supernova, calculated by taking the peak fit magnitude and adding the reference applying an observational correction for interstellar dust extinction. star's magnitude (found using the VizieR database and logarithmically averaging all measurements in that filter). We calculate M using the decline rate relationship for Ia SNe. Δ_{15-Day} is the difference in magnitudes of the gaussian fit at its Methods maximum and 15 days after. Then we correct for dust extinction. This is tricky because most galaxies have not been studied for how much dust exists within them, so a guess may be made based on the type and orientation of the galaxy. However, Using the astronomers telegram and the Rochester astronomy database from 2015this can be very inaccurate. It's common to assume the absorption is minimal in most galaxies and only calculate absorption 2021 to find targets, the B.E.A.R. Team has observed many type Ia supernovae. We in the Milky Way. In hope of better accounting for host extinction we look at the dust extinction term of the distance focused on ASAS-SN 16lg, ASAS-SN 18bt, and AT2021gtp. ASAS-SN 15li, ASAS-SN modulus represented by E(B-V)*R or E(B-V), the difference in transmission in the B and V filters₃. We reviewed various 15ln, PTSS-17ygs, SN2017bgp, and SN J081659.74+511233.7 were all excluded due interpretations of this and compared their results to previous measurements.

 $M = -21.726 + 2.68\Delta_{15-Dav}$

to overall signal-to-noise ratios under 20 or less than 5 nights' worth of usable observations. Data images were dark and flat calibrated to remove electronic and illumination errors within the imaging system. We then removed images with blurry stars, a background gradient, and low signal to noise ratios. Pictures are stacked with others from the same night and filter, decreasing the amount of data points but increasing the signal. Maxim DL is then used to perform photometry, differential for ASAS-SN 18bt and ensemble for ASAS-SN 16lg and AT2021 gtp. This process subtracts a reference star (differential) or stars' (ensemble) magnitude from the targets to remove fluctuations due to sky conditions. It is important to pick stable reference stars because any variability within the star will be subtracted as if it was a fluctuation due to the sky. This data is then exported to Excel where a gaussian fit is created for the decline rate of the supernova's brightness.



Fig. 2 - Choices made for reference stars for AT2021 gtp ensemble photometry. We use the VizeR astronomical database to calculate the reference stars' actual magnitudes by using the logarithmic average for magnitudes. When we work with ensemble photometry, do an average for all the stars then average all those averages.

Important Equations for Type 1a SN Distance Measurements

Redshift Corrected Time = $\frac{Time - Time_0}{1 + 7} + Time_0$

Residuals

Gaussian Mag = $Mag_{Max}^* e^{\frac{(RCT - RCT_0)^2}{2\sigma^2}} + Shift$

Distance Modulus = $m - M + E(B - V) * R = 5 \log \frac{d}{10}$

Logarithmic Average for Magnitudes =

Analysis

For ASAS-SN 18bt, we tried various dust corrections. We plotted the difference in B and V magnitudes for each night vs. corrected time. We tried linear and gaussian fits to that plot. When using the gaussian E(B-V) fit we subtracted fit magnitudes from the B magnitudes and created a new gaussian fit. We attempted this method thinking both B and V emission curves were gaussians and a gaussian subtracted from a gaussian should be a gaussian. We subtracted the gaussian E(B-V) from the B filter gaussian because we thought the dust extinction should be proportional to the amount of light emitted. This new fit was then used to calculate the 15-day decline rate and we removed the dust correction term from our distance modulus. We then tried this method, but without the shift factor in the gaussian E(B-V) fit. A decision was made to not include the shift factor because it does not affect the shape of the fit. There is also going to be a natural difference in location on the Y-axis of different filtered gaussians because the reference stars and targets don't necessarily have the same color ratios. Our next method was to use the 15-day decline rate of the gaussian E(B-V) fit as the dust correction term. As a different method, we tried using the slope of our linear E(B-V) fit as the E(B-V)*R term. The Y-intercept was left off because we only needed the ratio of light in the two filters. The final method of dust extinction was subtracting the maximum value of the B gaussian fit from the V gaussian fit. This value was used as the dust extinction term in the distance modulus.

		ASAS-SN 16lg					ASAS-SN 18bt					AT 2021 gtp		
Column1 💌	Column2 💌	Column3 🗾 🔽	Column4 💌	Column5 💌	Column1 💌	Column2 💌	Column3 🛛 🔽	Column4 💌	Column5 💌	Column1 💌	Column2 💌	Column3 🛛 🔽	Column4 💌	Column5 💌
RCT (JD)	Mag	Time Since Peak	Time 0	2457676	RCT (JD)	Mag	Time Since Peak	Time 0	2458162.61	RCT (JD)	Mag	Time Since Peak	Time 0	2459309.21
2457673.49	14.5869567	-2.51432871	Sigma	7.6	2458163.62	14.324	1.008487435	Sigma	16.300166	2459303.64	15.8783535	-5.56970018	Sigma	6.73309475
2457674.46	14.5565094	-1.537157599	Shift factor	14.9	2458164.6	14.356	1.984037475	Shift Factor	16.6351917	2459304.62	15.8264162	-4.592449886	Shift Factor	17.0251387
2457680.36	14.5948835	4.358103273	Max Mag	-0.35	2458168.54	14.458	5.926650356	Max Mag	-2.286476	2459308.56	15.3616649	-0.656379802	Max Mag	-1.5998043
2457694.02	14.8727883	18.02293703			2458176.46	15.021	13.84347365			2459313.47	15.701305	4.259459142		
2457687.18	14.7782165	11.17548544			2458195.2	16.372	32.58990633			2459315.36	16.0420086	6.149690812		
Average	14.6778709		Residuals	Squares	2458196.25	16.381	33.63356272	Residuals	Squares	2459318.37	16.3705037	9.151621256	Residuals	Square
			0.00033553	0.00826538	2458197.17	16.424	34.55604955	0.0008461	1.01952294	2459324.22	16.8057686	15.01044887	0.00011081	0.12291652
RCT (JD)	Gaussian	Time Since Peak	3.3269E-07	0.01472861	Average	15.3337143		9.1983E-05	0.95592522	2459328.12	16.9674339	18.91074847	0.00476953	0.16203187
2457673	14.5762329	-3	6.6906E-05	0.0068869				0.00136649	0.76687551	2459331.06	17.1070777	21.84742301	0.00507704	0.75218005
2457674	14.5619117	-2	3.8182E-05	0.0379928	RCT (JD)	Gaussian	Time Since Peak	0.0003998	0.09779022	Average	16.228948		0.00020043	0.27840718
2457675	14.5530167	-1	9.3552E-06	0.01006924	2458156	14.5294375	-6.614656751	0.00217577	1.07803722				0.0050498	0.03494634
2457676	14.55	0	Sums		2458157	14.4804142	-5.614656751	0.00031889	1.09680737	RCT (JD)	Gaussian	Time Since Peak	0.0003781	0.02003802
2457677	14.5530167	1	0.00045031	0.07794294	2458158	14.4385327	-4.614656751	0.00092942	1.18872294	2459304	15.8397043	-5.21345017	0.00740747	0.33272202
2457678	14.5619117	2			2458159	14.4042497	-3.614656751	Sums		2459305	15.7098191	-4.21345017	0.00071405	0.54536141
2457679	14.5762329	3	R^2	0.99422256	2458160	14.3779432	-2.614656751	0.00612845	6.20368143	2459306	15.5975429	-3.21345017	0.0081387	0.7711118
2457680	14.5952691	4			2458161	14.3599062	-1.614656751			2459307	15.5094868	-2.21345017	Sums	
2457681	14.618109	5			2458162.61	14.3487158	0	R^2	0.99901213	2459308	15.4511054	-1.21345017	0.03184593	3.01971521
2457682	14.6437128	6			2458162.68	14.3487362	0.068919629			2459309	15.4261382	-0.21345017		
2457683	14.6709903	7			2458163.62	14.3530877	1.008487435			2459310	15.4362132	0.78654983	R^2	0.989454
2457684	14.698877	8			2458164.6	14.3655908	1.984037475			2459311	15.4806715	1.78654983		

Table 1 -Shows the calculated magnitudes and redshift corrected time as well as the constants used in the gaussians and the R² values that show the goodness of fit for the gaussians.

References: 1) NASA/CXC/M.Weiss 2) Whittet, D C B, "Dust in the Galactic Environment", 2003, IoP Publishing 3) W. Li et al 2019 ApJ 870 12 4) Rogers, Patrick, 2021,"USING LIGHT CURVES TO MEASURE THE DISTANCE TO SUPERNOVAE ASAS-SN 18BT AND AT2021GTP" [POWERPOINT PRESENTATION]

$$= (Mag_{obs} - Mag_{Gaus})^2$$

Squares =
$$(Mag_{obs} - Mag_{Ave})^2$$

$$= (1 - \frac{\sum Residuals}{\sum Squares})^{2}$$
$$-2.5 * \log(\frac{1}{2}\sum_{i=1}^{n} 10^{\frac{-Mag}{2.5}})$$



Fig. 3 - This graph shows the measured magnitudes and lightcurves of the three supernovae we studied. In this graph, we can see that different supernova have different gaussian shapes although all can be defined by a gaussian curve.

Conclusions

When we used the gaussian E(B-V) fit, the calculations disagreed with our previous calculations 59.2±.7 Megaparsecs (Mps) and that made by W. Li et al. (52.7±1.2 Megaparsecs) by orders of 10 Mpcs. Because of this we decided to stop attempting to use the gaussian E(B-V) fit for dust corrections. When we took the slope of the linear fit and used it in the distance modulus, we got a similar result to our previous one using dust maps. The calculation using dust maps yielded a distance of 59.2±0.7 Mpc, while the linear E(B-V) calculation proposed a distance of 59.5 Mpc. This method was then applied to AT2021 gtp. The yielded result was 38.6 Mpcs for AT2021 gtp. We also did a dust map correction to ASAS-SN 16lg because we did not have any data in the V filter to apply the new method. Our result was a distance of 108.7 Mpcs. When we calculated ASAS-SN 18bt's distance using the difference in peak magnitudes of the B and V-filters, our result was a distance of 56.7 Mpcs, much closer to the measurement done by W. Li et al. Because we only have one supernova to try these corrections on, we cannot draw a firm conclusion. More investigation into these dust corrections will have to be done.

Distance Measurements for ASAS-SN 18bt

	Distance M=m-M+E(B-V)*R=5log(d/10)	
Slope		59539472.2
Peak		56671124.37
Gaussian Fit		35104880.99
Add E(B-V) 15day		68019945.44
E(B-V) No shift		40988875.04

Table 2 - the distances of ASAS-SN 18bt using the five methods. Using the slope of the linear fit and the difference in peak brightness of the B and V filter provided the most precise measurements.

Future Work

The process of fitting the gaussian and calculating the distance modulus is time-consuming. Since we now have access to MATLAB, future work will be to create a MATLAB program capable of fitting a gaussian and exporting the distance calculations. A lot of time was spent testing methods on ASAS-SN 18bt, so we must apply corrections to AT2021 gtp and other supernovae that were observed by the BEAR Team. Additionally, more type Ia supernovae will have to be observed. With more observed supernovae we can also begin to construct our own calculated Hubble constant, better incorporating the expansion of the universe.

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