Three Methods for the Observation of the Big Bang with our School Telescope

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Abstract

Usually telescope based research on the big bang is performed by the application of huge telescopes like the Hubble-Space-Telescope. However, in our work we propose three methods for the big bang observation, which are applied with an 11 inch telescope in our school observatory. The first method is based on the redshift. We are using the redshift to calculate the velocity of the galaxies in the framework of the Doppler effect and more generally the expansion of space. From the Hubble-diagram, we then can get the age of the universe by doing a regression. The second method we used is based on a comparison of our telescope with the Hubble-Space-Telescope. For the third method we use supernovae. Here we are utilizing the brightness of a supernova. The results show that the observation of the big bang is also possible with a much smaller telescope then e.g. the Hubble-Space-Telescope.

1. Introduction

After the big bang 13.8 billion years ago (Beckmann, 2010), our universe began to expand. Based on the measurements on the redshift of different galaxies done by Slipher (1915), in 1922 Carl Wirtz discovered a relation between the redshift z and the distance d of galaxies (Appenzeller 2009, Wirtz 1922). The theoretical explanation was provided by Alexander Friedmann (1922) and Georges Lemaitre (1927). Later in 1929 Edwin Hubble also found a relation between the distance and the redshift of a galaxy, he formulated Hubble's law (Hubble, 1929). In our work we provide three methods for the observation of the big bang with an 11 inch telescope. In contrast, observations on the big bang are typically based on the usage of large telescopes (see for instance Hubble 1929). The telescope used throughout our research is the Celestron C11 with 2800 mm focal length. We capture our images using the ST-402 camera from SBIG while we take our spectra utilizing the DSS7-spectrograph from SBIG.

2. State of research

There are different methods for determining the age of the universe. In the first method the age is determined by utilizing the radial or escape velocity v of galaxies (see Slipher 1915). If the redshift $z = \Delta\lambda/\lambda$ is *interpreted* by the Doppler effect, we get $v = c \cdot z$ for the radial velocity v of a galaxy. Additionally the distances d of the galaxies are observed (see Hubble 1929). At redshifts smaller than $z \approx 0.2$ the redshift is proportional to the distance: $z \sim d$. This relation is called *Hubble law* and the corresponding factor of proportionality is named *Hubble constant* $H_0 = v \cdot d^{-1}$ (Karttunen et al. 2007). With it one may calculate the *Hubble time* $\tau = H_0^{-1}$. That time is a quite good estimate of the *age of the universe*. However, observations at larger redshifts $z > 0.2$ show deviations from the Hubble law. So the Hubble constant H_0 must be replaced by a time dependent *Hubble parameter* $H(t)$.

3. Method 1

In our first method we observe the redshift z and the flux density S (Karttunen et al. 2007) of the radiation emitted by the galaxies. By utilizing the redshift z we determine the escape velocity v of the galaxies while we determine the distance d of the galaxies by utilizing the flux density S.

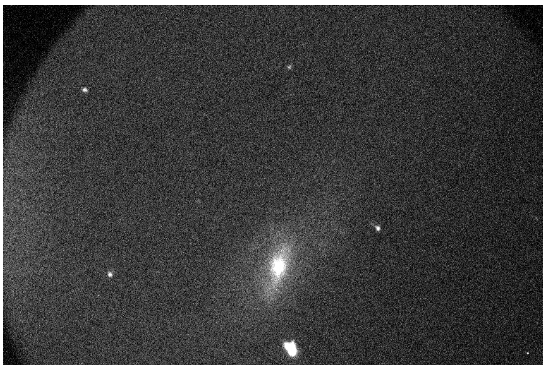

Figure 1: Image of the galaxy M66 using a telescope with the aperture 11 inch. We utilized the telescope Celestron C11 and captured the image through the spectrograph DSS7 by using the camera ST-402.

4. Method 1 - Redshift

The galaxy M66 is an example for this method. First we take an image to focus the telescope on the galaxy (see figure 1).

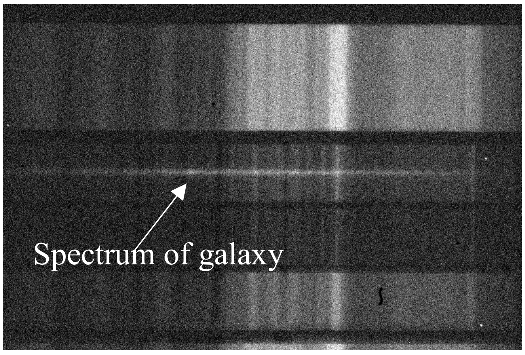

Figure 2: Spectrum of the galaxy M66 measured with the telescope Celestron C11 and with the spectrograph DSS7. Horizontal stripe: spectrum of the galaxy. Surrounding spectrum: light pollution in Stade.

We measure the redshift by taking the spectrum of the galaxy utilizing the spectrograph (see figure 2). Second we capture the spectrum by cutting out the horizontal stripe at which the spectrum of the galaxy is placed within the image from the spectrograph (see figure 2). To get accurate measurements we have to calibrate the spectrograph. Calibration is done in a process consisting of five steps. First we take the spectral image of a neon lamp that contains some mercury in addition. Second we use the software called "spectra" to sum up the image intensities for each column. This gives us a plot of the unscaled calibration spectrum (see figure 3).

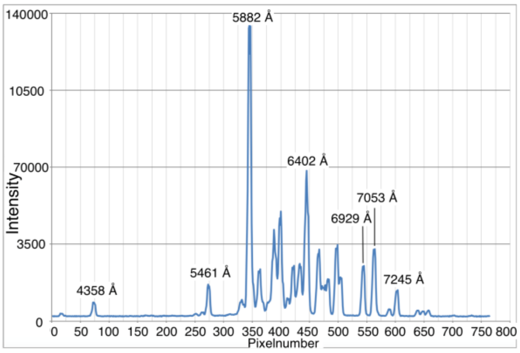

Figure 3: Plot of the unscaled spectrum.

In the third step we find known lines of neon and mercury in the plot of the calibration spectrum. Fourthly we transfer the wavelength and the horizontal position in the unit pixel of the known lines to a calibration graph (see figure 4). Fifthly we do a linear regression on the points in our calibration graph (see figure 4). This gives us the calibration equation $y = 5.4506x + 3971.6$ with x as the pixel coordinate in horizontal direction and y being the corresponding wavelength in Å. After having calibrated the spectrograph, we now can measure the redshift. For doing so, we first have to identify the Hα-line in the captured spectrum. Next we use our calibration equation, from the calibration process, to get the wavelength λ' of the Hα-line in our captured spectrum of the galaxy.

Nr	lambda	Kalibrierlampe
73	4358	Hg
273	5461	Hg
347	5882	Ne
445	6402	Ne
545	6929	Ne
562	7053	Ne
604	7245	Ne

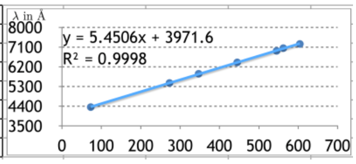

Figure 4: Calibration graph of calibration spectrum.

Because we know the wavelength λ of the Hα-line from literature, we can easily calculate the redshift $z = (\lambda' - \lambda)\lambda^{-1} = \Delta\lambda \cdot \lambda^{-1}$ where λ' is the Hα-wavelength from our captured spectrum of the galaxy and λ the Hα-wavelength from literature.

5. Method 1 - Distance

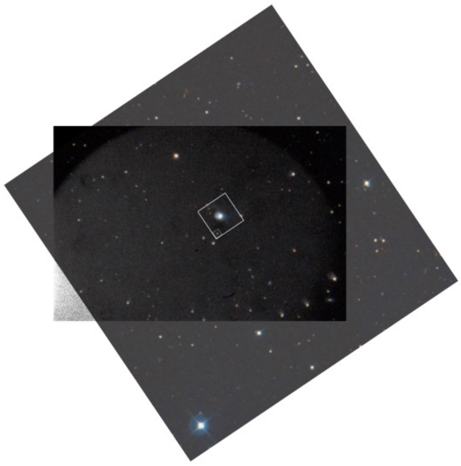

Figure 5: Our photo of the galaxy UGC 8058 (small image) with overlay (large image): Identification of stars that are nearly in the direction of the galaxy UGC8058 using images of public databases (see Wikisky 2007).

Next we measure the distance to each observed galaxy. For calculating that distance, we are utilizing the observed apparent magnitude m of the captured galaxy. With the apparent magnitude m we determine the flux density S (see Karttunen et al. 2007).

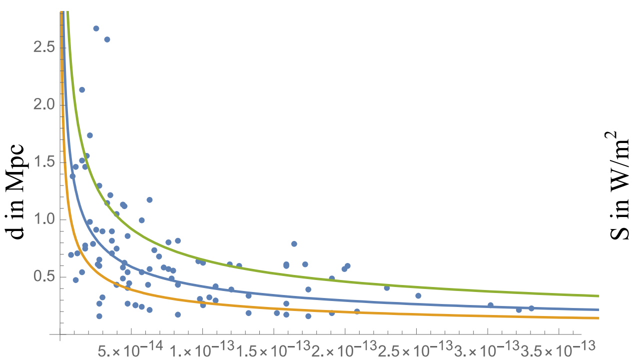

Figure 6: Data of starburst galaxies with a regression function and the corresponding standard deviation (see NASA/IPAC 2018).

We estimate an averaged luminosity P for the galaxy as follows. We observe galaxies with relatively intensive Hα – lines only. Next we measure the distance to each observed galaxy. For calculating that distance, we are utilizing the observed apparent magnitude m of the captured galaxy. With the apparent magnitude m we determine the flux density S (see Karttunen et al. 2007). We estimate an averaged luminosity P for the galaxy as follows. We observe galaxies with relatively intensive Hα – lines only. Based on the observed flux density S and on the luminosity P of similar galaxies we determine the distance d of the observed galaxy utilizing the following equation:

$$d = (P \cdot (4\pi S)^{-1})^{0.5} \qquad \{1\}$$

Before using this equation, we read out the counts for each pixel in the image. After the background was subtracted, we sum up all counts of all pixels in the star or galaxy. By doing so, we get a ratio of the number of counts and the flux density S of the stars for one image. Based on this ratio, we can now calculate the flux density S of the galaxy, by summing up all counts of all pixels of the galaxy and then multiply the sum with the ratio of the flux density and the counts. Here the used luminosity P is the average over approximately 100 starburst galaxies (see figure 6). This was done by collecting a list of distances and flux densities from literature (see NASA/IPAC 2018).

OBJECT	z	v in Ly/y	d in 10^9 Ly
EARTH	0	0	0
M66	0.00234 [14]	0.00234[14]	0.295[2]
NGC 3516	0.008816[133]	0.008816[133]	0.127[5]
NGC 1275	0.01756[12]	0.01756[4]	0.203.9[3]
NGC 2276	0.008062[10]	0.008062[10]	0.120[39]
NGC 4151	0.003262[67]	0.003262[67]	0.0127[23]
UGC 8058	0.04147[8]	0.04147[8]	0.593[7]

Table 1: Data for the Hubble diagram (see NASA/IPAC 2018).

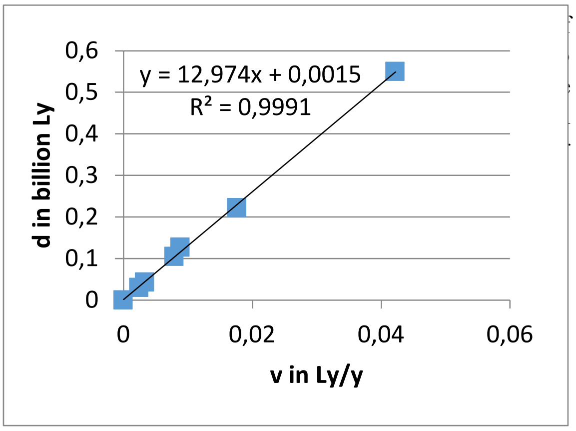

Figure 7: Data for the Hubble diagram (see NASA/IPAC 2018).

Now we want to show the process of measuring the distance for the galaxy UGC8058 as an example. For it we determine the counts C_u , the minimum flux density S_{min} and the maximum flux density S_{max} of UGC8058. First we select several stars in our image, in our example we select six stars. Second we get the apparent magnitude of those stars from literature. By applying the equation $S_{star} = S_{\odot} \cdot 10^{-0.4(m-m_{\odot})}$ with $m_{\odot}$ as the apparent magnitude of the sun and $S_{\odot}$ as the solar constant, we can calculate the flux density of the stars by substituting m with the apparent magnitude of the star. Next we calculate the sum of counts for the selected stars. This is done by calculating the average count $\bar{c}_S$ of a star in a square of size c_s and the average count $\bar{c}_b$ of the background near the star. The sum of counts for the star can be approximated as $c_S = (\bar{c}_S - \bar{c}_b) \cdot c_s$. Now we get the flux density per count $S_c = S_{star}/c_S$. Before the final step, we calculate the mean $\bar{S}_c$ and the standard deviation σ_c of the flux density per count over all of our selected neighbour stars. Then we calculate the minimal flux density $\bar{S}_{min} = C_u \cdot (\bar{S}_c - \sigma_c)$ and the maximal flux density $\bar{S}_{max} = C_u \cdot (\bar{S}_c + \sigma_c)$. Finally we use the function (see figure 6) $d_{min} = 8.74653 \cdot 10^{-6}/\bar{S}_{min}{}^{0.5}$ to calculate the minimal distance and $d_{max} = 0.0000206188/\bar{S}_{min}{}^{0.5}$ to calculate the maximal distance, both in Mpc. These functions for the distances are derived by utilizing a regression of literature values (see figure 6). Since we are restricted to a telescope with an aperture of 11'', we tend to select galaxies with an especially high luminosity at distances above 150 MLy. So we tend to underestimate the distance of galaxies with distances larger than 150 MLy. Accordingly we utilize the literature value of the distance for the galaxy UGC 8058 (see figure 9).

6. Method 1 – Hubble diagram

The age of the universe can be determined by using the *Hubble diagram* (Beckmann, 2010). At the y-axis of the Hubble diagram we mark the distance d in 10^9 light-years (Ly) and at the x-axis we mark the velocity in Ly$\cdot\, y^{-1}$. First we present the data found in the literature (see table 1 and figure 7) in order to obtain a basis for comparisons.

7. Method 1 - Results

The table (see table 2) lists the values for the redshift, which we measured, and our measured velocities of the galaxies. Additionally the table includes the distances that we calculated as well as the time at which we made the measurements.

Object	z	v in Ly/y	d in 10^9 Ly	Date
Earth	0	0	0	-
M66	0.0026	0.0026	0.02	4/26/11
NGC 3516	0.0104	0.0104	0.075	7/18/15
NGC 1275	0.01664	0.01664	0.114	1/27/17
NGC 2276	0.007467	0.007467	0.079	1/28/17
NGC 4151	0.0006	0.0006	0.068	1/28/17
NGC 6946	0.000133[10]	0.000133[10]	0.01141	2/6/17
UGC 8058	0.0427	0.0427	0.593[7]	3/24/17

Table 2: Our measurements for the Hubble diagram.

By performing a linear regression, we get an equation $y = 12.61x + 0.0063$. Here the gradient of the regression function gives us the age of the universe in the unit one billion years. Therefore we get 12.61 billion years as the age of the universe based on our measurements. State of the art measurements estimate the age of the universe at 13.77 billion years (Planck Collaboration 2016). The Hubble diagrams based on our measurements with our 11 inch telescope are shown in figures (8) and (9).

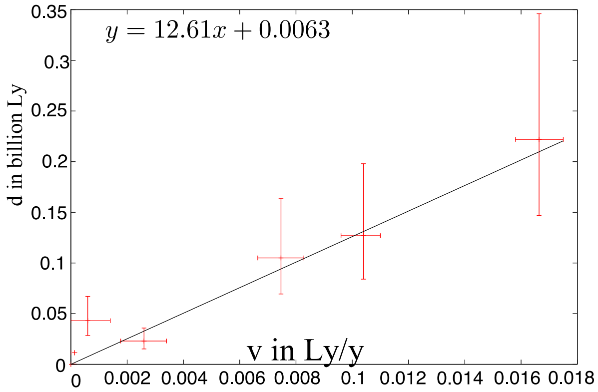

Figure 8: Hubble diagram with error bars for v and d based on our measurements. Because the data point for NGC 6946 is calculated from a literature value for the redshift, no error bars are shown.

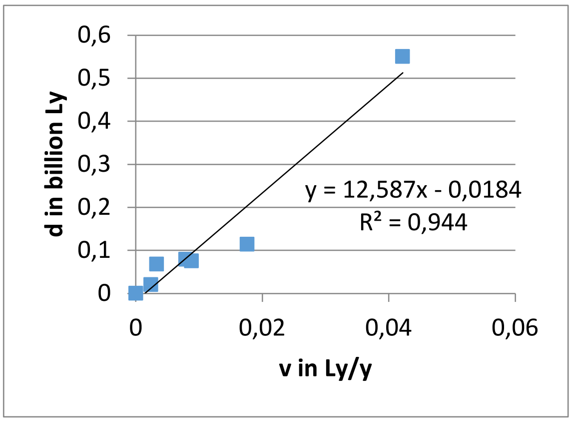

Figure 9: Hubble diagram based on our measurements including the Galaxy UGC 8058, with distance from literature of $0.593 \cdot 10^9$ Ly.

8. Method 2

The second method is based on the comparison of our telescope with the Hubble Space Telescope (HST). The idea is to investigate what the HST should observe when the time were not limited by the big bang. In particular we determine, in which distance the HST should still be able to observe objects. Our telescope in Stade has the aperture diameter $D_{C11} = 11\ inch \approx 0.28m$ and the HST has the aperture diameter $D_H = 2.4m \approx 8 \cdot D_{C11}$.

The galaxy with the largest distance $e = 12 \cdot 10^9 Ly$, that we have already observed with our 11 inch telescope, was APM08279+ 5255 (see figure 10) Thereby the light travelled this distance while the space expanded already to an even larger distance. In this section by distance we mean the distance travelled by the light.

9. Method 2 – constant space

First we test the hypothesis of a universe without a big bang and without an expansion of space. Accordingly we use the hypothesis that the flux density *S=P/A* decreases with the distance proportional to d^{-2}. From it we derive the distance d_H at which the HST should still observe quasars.

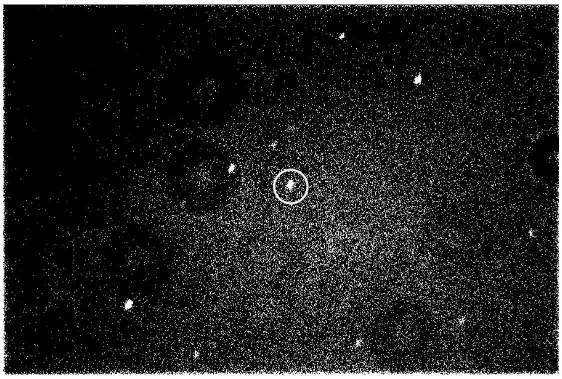

Figure 10: Quasar APM08279+5255 observed with 11'' telescope. Distance: light travelled 12.05 billion Ly.

Since the diameters are related described by $D_H = 8 \cdot D_{C11}$ the aperture areas are related as follows: $A_H = 8^2 \cdot A_{C11}$. So the flux densities required for an observation are related as follows: $S_H = 64^{-1} \cdot S_{C11}$. According to our hypothesis we derived $S \sim d^{-2}$ and we derive further that the HST should be able to observe quasars that are 8 times as far away as those that we can observe using our telescope C11. Based on the distance of the galaxy APM08279+5255 (see figure 10), which is 12.05 billion Ly, the HST should be able to observe quasars at the distance $d_H = d_S \cdot 8 = 12.05 \cdot 10^9 Ly \cdot 8 = 96.4 \cdot 10^9 Ly$. However, the HST never observed a quasar at a distance larger than $14 \cdot 10^9 Ly$. So we reject the above hypothesis.

10. Method 2 – expanding space

In our first hypothesis we considered a constant space. Now we want to include the expansion of space. Accordingly we test the hypothesis of a universe without a big bang and with an expansion of space. Again we derive the distance d_H at which the HST should still observe quasars.

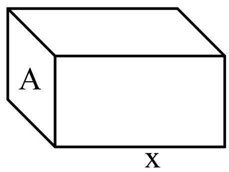

Figure 11: Visualization of the flux propagating through an area *A* at a distance *x*.

First we derive the *energy density u* corresponding to the flux density *S* as follows: The flux density is the energy *E* per area *A* and time *t*: $S = E/(A \cdot t)$ (see figure 11). Next we expand this fraction by the length *x* that the light travelled during the time *t*: $S = E \cdot x/(A \cdot x \cdot t)$. Here the product $A \cdot x$ is the volume *V* filled by the radiation that crossed the area A perpendicularly: $V = A \cdot x$. Moreover the fraction x/t presents the velocity of light $c = x/t$. We insert these terms and obtain the relation between the flux density and the energy density u as follows:

$$S = u \cdot c \qquad \{2\}$$

Second we analyse how an energy density u_0 comes from a source to a telescope at a distance q. In general radiation achieves the distance q by a superposition of the velocity of propagation and by the expansion. Thereby the expansion can be much more effective than the propagation, see for instance figure 10. In order to achieve a lower bound for the density u at the distance q we omit the propagation. Correspondingly the change of the wavelength of a photon is $\lambda' = \lambda/q$. So the energy per photon ε changes as follows: $\varepsilon' = \varepsilon/q$. Additionally the volume of a portion of energy increases by the factor of q^3, $V' = V \cdot q^3$. So the energy density corresponding to N photons changes as follows:

$$u' = N \cdot \varepsilon'/V' = N \cdot \varepsilon/q^4 \qquad \{3\}$$

We realize that the energy density changes by the factor q^{-4}. According to equation {2} the flux density changes by the same factor:

$$S' = S/q^4 \qquad \{4\}$$

The HST and our telescope in Stade receive the same power of the light for their cameras when the following condition holds (see equation {4}):

$$S'_{C11} \cdot A_{C11} = S'_{HST} \cdot A_{HST} = S_{C11}/q_{C11}^4 \cdot A_{C11} \qquad \{5\}$$

$$\text{Or } S_{C11}/q_{C11}^4 \cdot A_{C11} = S_{HST}/q_{HST}^4 \cdot A_{HST} \qquad \{5\}$$

After solving the equation for q_{HST} we get $q_{HST} = \sqrt{8} \cdot q_{C11} \approx 2.8 \cdot q_{C11}$. Now we can calculate the distance at which the HST should be able to observe quasars: $d_{HST} = d_{C11} \cdot \sqrt{8} = 12 \cdot 10^9 Ly \cdot \sqrt{8} \approx 34 \cdot 10^9 Ly$. However, the HST never observed a quasar at a distance larger than $14 \cdot 10^9 Ly$. So we reject the above hypothesis.

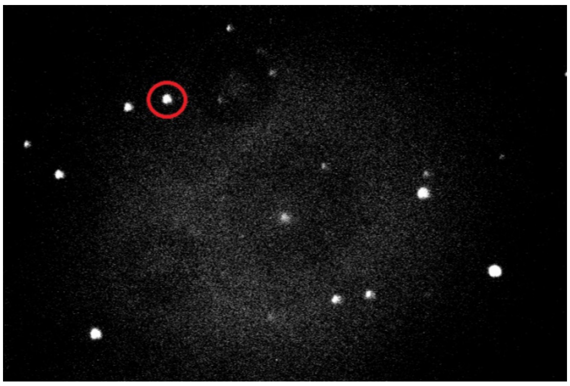

Figure 12: Using our telescope C11 we took an image of the supernova SN 2017eaw (red circle) in the fireworks galaxy NGC 6946 (center).

Summarizing the comparison of the C11 and the HST based on figure (10) indicates that there has been a big bang.

11. Method 3

The third method is similar to the first method. However here we utilize supernovae to determine the distance (see figure 12). To calculate the distance, we measure the observed apparent magnitude m of a supernova. From it we calculate the flux density F of the supernova. Since the luminosity of a supernova is well known (see Karttunen et al. 2007), we also know the power emitted from the supernova. From it we calculate the distance of the supernova. So we obtain the distance of the corresponding galaxy. By utilizing this method we eliminate the missing precise knowledge of power emitted by the galaxy (see figure 6). So our measurement of the distance of the galaxy becomes more accurate than in our first method.

12. Summary

Finding out more about the universe was always a driving factor in human curiosity, knowledge and science. Observations of the big bang are an important step for understanding our universe. In our research we show three methods for observing the big bang, whereby these methods are accessible even to pupils. In addition, our methods only require a telescope with a diameter of 11 inch. However, while the measurement of the wavelength works also for large distances, the determination of the distance with our first method works accurately only up to 150 MLy while we can measure also large distances accurately by utilizing supernovae.

13. Acknowledgement

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