**The Distance to the Galaxy M100 using Cepheid Variables[[1]](#footnote-1)**

From repeated observations of the galaxy Messier 100 using the Hubble Space Telescope, astronomers were able to identify more than a dozen Cepheid variables, and measure their brightness as a function of time. Cepheid variables are pulsating stars with regular periods of a few weeks. Henrietta Leavitt, working at the Harvard College Observatory early in the 20th century, discovered that the period of a Cepheid variable is related to its brightness. Brighter Cepheids pulsate with longer periods. From the Hubble measurements of Cepheid variables in M100, the periods of the variables, and hence the absolute magnitudes of the variables, could be determined. Once both the absolute magnitudes and the apparent magnitudes are known, the distance to M100 can be calculated.

The relation between a Cepheid's period and its absolute magnitude is given by the “Leavitt Law:”

Mv = -2.8 log(P) -1.4, where Mv is the absolute magnitude and P is he period in days.

For convenience, this expression is shown in graphical form in the plot below.



Use the light curves on the next two pages to determine the periods of each of the Cepheids, as well as the average apparent magnitude of each one. Record these values in the table below.

* The period is the time between successive maxima of the Cepheid variable.
* The average apparent magnitude is half way between the maximum and minimum brightness in the light curve.



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* Use the Leavitt Law relating period to absolute magnitude to determine the absolute magnitude of each Cepheid. The measurements for Cepheid No. 1 have already been entered.

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| --- | --- | --- | --- | --- | --- |
| *Cepheid Number* | *Period (days)* | *Absolute Magnitude (M)* | *Average App. Mag. (mave)* | *Distance Modulus (mave-M)* | *Distance (Mpc)**(see chart)* |
| *1* | *53.4* | *-6.2* | *24.9* | *24.9-(-6.2)=31.1* | *16.6* |
| *2* |  |  |  |  |  |
| *3* |  |  |  |  |  |
| *4* |  |  |  |  |  |
| *7* |  |  |  |  |  |
| *8* |  |  |  |  |  |
| *11* |  |  |  |  |  |
| *12* |  |  |  |  |  |
| ***Distance to M100 in Megaparsecs:*** |  |

* Compute the distance modulus (the difference *apparent magnitude – absolute magnitude)*.
* Convert the distance modulus to the distance in megaparsecs using either the formula below or the chart on the next page.
* From these data, estimate the distance in megaparsecs to the galaxy M100.

The **distance modulus** is related to the distance (recall that the "absolute magnitude" of a star is the apparent magnitude that star would have if it were at a distance of 10 parsecs or 3.26 light years). The relation can be written mathematically as:

Distance (in parsecs) = 10(mave -M+5)/5)

where mave is the average apparent magnitude and M is the absolute magnitude, and mave-M is the distance modulus. The chart below graphs the above relation to convert distance modulus to distance in megaparsecs for your convenience.

The Cepheid variables in M100 give a wide range of distances. What are some possible reasons why the distances might vary so much from star to star?

Compare the size of M100 to its distance (M100 is similar in size to our own Milky Way, with a diameter of about 30 kiloparsecs). Could the variation in the distance to M100 from the different Cepheid period measurements result from the difference in location of the Cepheid variables within M100? Why or why not?

In the original scientific paper reporting on the distance to M100 using the Hubble observations, the distance was calculated to be 17.1 ± 1.8 Mpc (about 56 million light years). The presence of interstellar dust within M100 causes the apparent magnitudes of the Cepheids to be dimmer than they should be, so that they appear to be more distant than they really are.

1. *This exercise is based on an ESA/ESO Astronomy Exercise, Series 2, and has been adapted for use in our class. The original data on which the exercise is based were taken from Freedman et al. 1994, Nature, 371, 757* [↑](#footnote-ref-1)