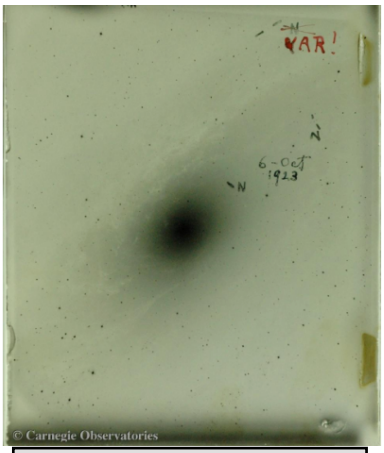
How Far Away is the Andromeda Galaxy?

In the early 20th century, there was an active discussion between astronomers about the nature of “Spiral Nebulae” which had been observed in the night sky. Were they simply gaseous nebulae in our own galaxy, similar to others which can be seen around the sky, or were they isolated stellar systems in their own right, or “island universes”? This culminated in the famous “Curtis-Shapley” debate at the National Academy of Science in 1920, titled “Are Spiral Nebulae Island Universes?”. Curtis thought yes, and Shapley thought now, and the consensus was that Shapley carried the debate, though we now know he was incorrect.

The issue didn’t remain unsettled for long. In 1923, Edwin Hubble (heard of him??) discovered a “Cepheid variable” star in the Andromeda Galaxy, also known as M31. He was able to use observations of this star to show that Andromeda was much further away than any star in our own galaxy (due to errors in his distance calibration, he actually thought the distance was 285 kpc, while we now know that it is closer to 780 kpc).



Hubble’s 1923 photographic plate of M31 from the Mount Wilson Hooker 100” telescope. He found a Cepheid variable, denoted by “VAR!”, in between the two hash marks next to his writing.

How did he do this? He made use of a “recently” discovered correlation between the intrinsic luminosities of Cepheid variable stars, and their period variations. Cepheids are stars which have slightly unstable sizes, causing them to pulsate radially. As they get larger and smaller, their luminosities increase and decrease.

In the late 1800’s, astronomer Edward Pickering was using the Harvard College Observatory’s telescopes to take photographic plates of the night sky. He found that the number of plates far exceeded the help he had, and so he hired women “computers” to help analyze his data. These women had degrees in astronomy or physics, but had few opportunities to advance (Harvard would not even hire women as faculty or allow women to enroll). In one of the greatest stories in astronomy, it was these women, and not their male bosses, who made some of the most fundamental discoveries about stars and stellar evolution. One of these discoveries was made by Henrietta Swan Leavitt, who discovered the correlation between a Cepheid’s period and its luminosity (first called the period-luminosity relation, and now rightly called the Leavitt Law).

Your task today is to re-derive this relation using observational data of Cepheid’s in our Milky Way, obtained from the paper “Cepheid period-luminosity relations in K, H, J and V” by C. D. Laney and R. S. Stobie (1994, MNRAS, 266, 441). The table on the following page lists the information for 22 known Cepheids in our galaxy, including the logarithm of the period (in days), and the absolute magnitudes in four bandpasses. Investigate whether you see a correlation between the log of the period, and the **V-band** absolute magnitude. If so, quantify the correlation, and now you’re in position to put an end to this debate!

Today, we have measured the properties of a large number of Cepheids in M31. Each group will be given a random list of 20 known Cepheids in M31. Use your measured correlation, plus your knowledge of how the apparent and absolute magnitudes relate to the distance, to measure the distance to each M31 Cepheid. Calculate the distance to M31 as the mean of these distances, and calculate an uncertainty. Finally, write your values on the board, and we’ll discuss the accuracy, and possible sources of systematic uncertainty, as a class.

Table 4 from Laney and Stobie 1994

Star	log P	M_J	M_H	M_K	M_V
EV Sct	0.4901	-3.220	-3.519	-3.553	-2.191
QZ Nor	0.7301	-4.210	-4.525	-4.588	-3.128
CV Mon	0.7307	-4.445	-4.814	-4.896	-3.305
V Cen	0.7399	-4.290	-4.641	-4.709	-3.234
CS Vel	0.7712	-4.312	-4.673	-4.753	-3.245
V367 Sct	0.7989	-4.622	-4.943	-4.992	-3.755
U Sgr	0.8290	-4.809	-5.156	-5.214	-3.781
S Nor	0.9892	-5.219	-5.616	-5.697	-3.943
TW Nor	1.0329	-4.922	-5.333	-5.411	-3.797
V340 Nor	1.0526	-5.121	-5.554	-5.640	-3.797
VY Car	1.2766	-6.338	-6.771	-6.864	-4.962
RU Sct	1.2945	-6.322	-6.709	-6.775	-5.186
RZ Vel	1.3097	-6.419	-6.838	-6.934	-5.038
WZ Sgr	1.3394	-6.185	-6.674	-6.789	-4.657
SW Vel	1.3698	-6.459	-6.882	-6.978	-5.129
T Mon	1.4318	-7.059	-7.532	-7.627	-5.550
KQ Sco	1.4578	-7.054	-7.554	-7.653	-5.521
U Car	1.5889	-7.481	-7.901	-7.992	-6.147
RS Pup	1.6169	-7.216	-7.672	-7.764	-5.790
SV Vul	1.6536	-7.493	-7.931	-8.004	-6.028
GY Sge	1.7134	-7.873	-8.306	-8.377	-6.300
S Vul	1.8378	-8.253	-8.717	-8.815	-6.566