Ia Supernovae and Their Use in Galactic Distancing

Mihir Bhaskar

COSMOS 2009

July 28, 2009

Abstract

Type Ia supernovae have constant light curves, which can be used to calculate the distance to them. Astronomers can calculate the apparent magnitude, and compare it to the constant peak absolute magnitude to solve for the distance. We imaged the supernova 2009 hl near the galaxy PGC 60431 using 600 second exposures in deep space. From this image, we calculated the apparent magnitude of the supernova to be 17.539, and therefore found the distance to the supernova to be 594 million light years. The information gained from this productive experiment proved valuable to the entire field of Astrophysics – possibly leading the way to a new standard candle in our universe.

Ia Supernovae and Their Use in Galactic Distancing

To most people, the night sky is a uniform sphere decorated with diamonds. Yet how do we really tell how far away a stellar object is? This seemingly simple idea is actually quite a complex process. In fact, astronomers cannot simply measure distances to stars by looking through a telescope either – making galactic distancing more complex than it seems. The lack of a truly reliable method for measuring distances between galaxies has elicited the search for a more ideal standard candle.

A standard candle is an object in the sky that can be used to verify intra-galactic distances by comparing of the object's absolute magnitude to its apparent magnitude on earth (Nave, 2008). With both an object's absolute magnitude and apparent magnitude, the formula $M = m + 5 - 5 \log d$ (M = absolute magnitude, m = apparent magnitude, d = distance) can be used to calculate the distance. Cepheid stars, or variable stars, have a standard light curve, meaning they pulsate in a manner that allows us to verify their absolute magnitude. Astronomers can compare this value with the value they see in images they take from the earth – the apparent magnitude.

Due to their constant light curves, Cepheid stars appear to be ideal standard candles – however in a recent study, Gordon (2007) found that the range of Cepheid stars were limited due to a lack of visibility on the intra-galactic scale, where the farthest visible Cepheid was only about 57 million light years away. This meant that on the intra-galactic scale, Cepheid stars were too faint, and were not practical standard candles. Gordon's study of standard candles further revealed that another celestial object, the type Ia supernova, had a range of visibility 5000 times greater than that of the average Cepheid star, with the farthest observed supernova 11.3 billion light years away (Foust, 2001). Further investigation done by Wood-Vasey et al. (2008) proved that type Ia supernovae retained a standard light curve, making them competitors in the race for the ideal standard candle.

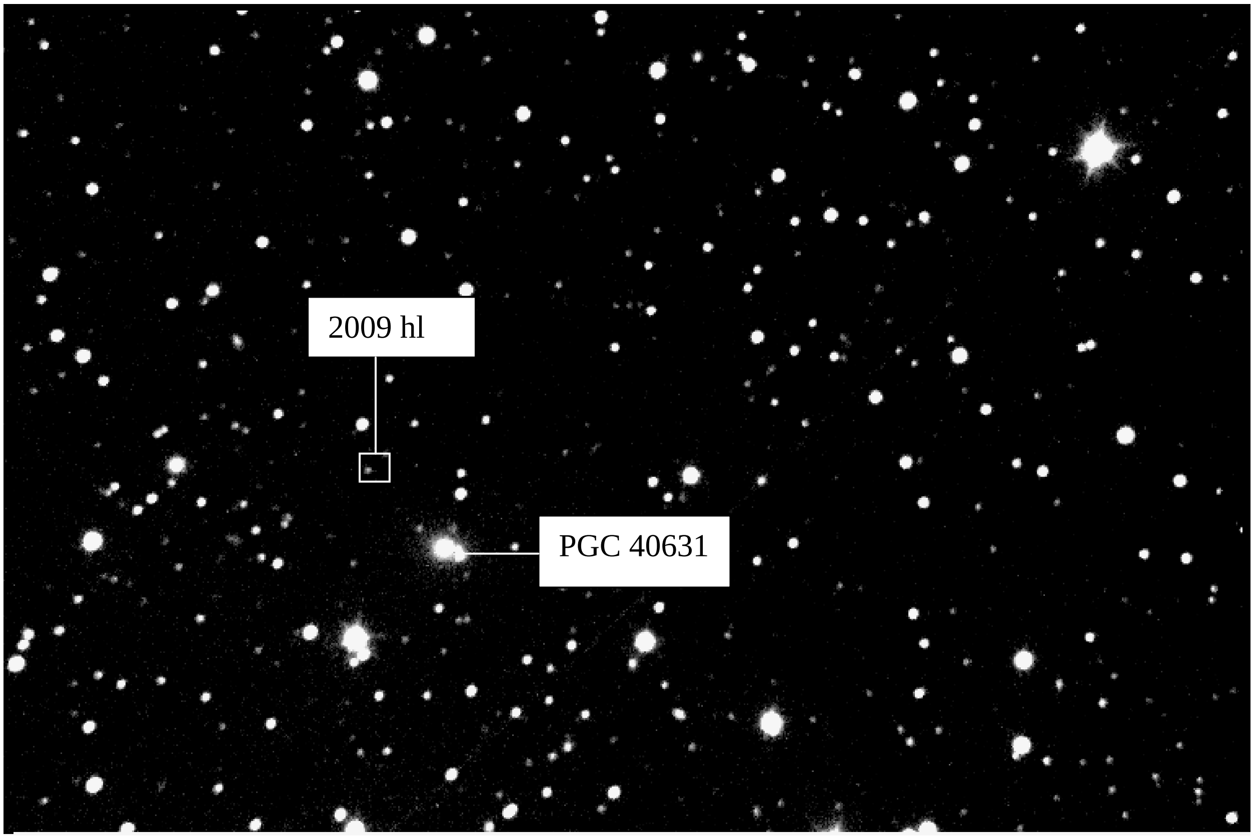
Type Ia supernovae result from the explosion of white dwarf stars. Elcea (2001) found that white dwarfs no longer undergo fusion as most stars do, and simply accumulate mass. Elcea also found that white dwarfs were the final stage for most medium or smaller sized stars. According to Leibundgut (2005), white dwarf stars are limited to masses below the Chandrasekhar limit, or about 1.38 solar masses. This means that white dwarf stars that accumulate a mass greater than that by even the smallest amount collapse in a supernova. Yet every white dwarf that does collapse into a supernova does so at the same exact mass because of this limit. Thus, all type Ia supernovae have the same light curve – or a curve with few inconsistencies (Preuss, 2009). Preuss also recorded that type Ia supernovae are also incredibly bright, having a consistent peak absolute magnitude of -19.3, making them as bright as entire galaxies themselves. Because of the extended range of luminosity of the type Ia supernova, we can calculate distances to galaxies and other celestial objects which are further away than ever before.

According to Chaisson and McMillan (2005), the field of astrophysics is becoming more and more specialized – making distance determination a science on its own. This makes the discovery of a reliable standard candle a necessity within the next decade. Thus, differentiating between the current standard candles is a clear motivation for studying the usefulness of light curves of type Ia supernovae. Research and further experiments in galactic distancing are necessary to expand our view of the universe.

In order to fulfill the motivation, our study was to measure the particular distance to the supernova 2009 hl in deep space to test the use of the Ia supernova as a standard candle.

Data

Data for this experiment were collected on July 22, 2009 by astronomers Paul Feldstein and Chris Fassnacht using an SBIG ST-8 Dual CCD Camera and Telescope apparatus with a 600 second exposure. We are grateful for their help in taking all of our data, and processed the images to obtain the value for magnitude that we needed. After obtaining the images, we used CCD software to reduce and process the data. First, the dark images taken were compiled and subtracted from the flat images, leaving a reduced set of flats. The flats and the darks were then reduced from the image, producing three clean pictures of our object. After aligning the images, they were combined to create a final image. The pictures were taken from the roof of the physics building at UC Davis. The apparent magnitude at that location on the given date for that supernova was 17.539 magnitudes. The object the telescope focused on was the nearby galaxy PGC 60431, and the supernova was supernova Ia 2009 hl.

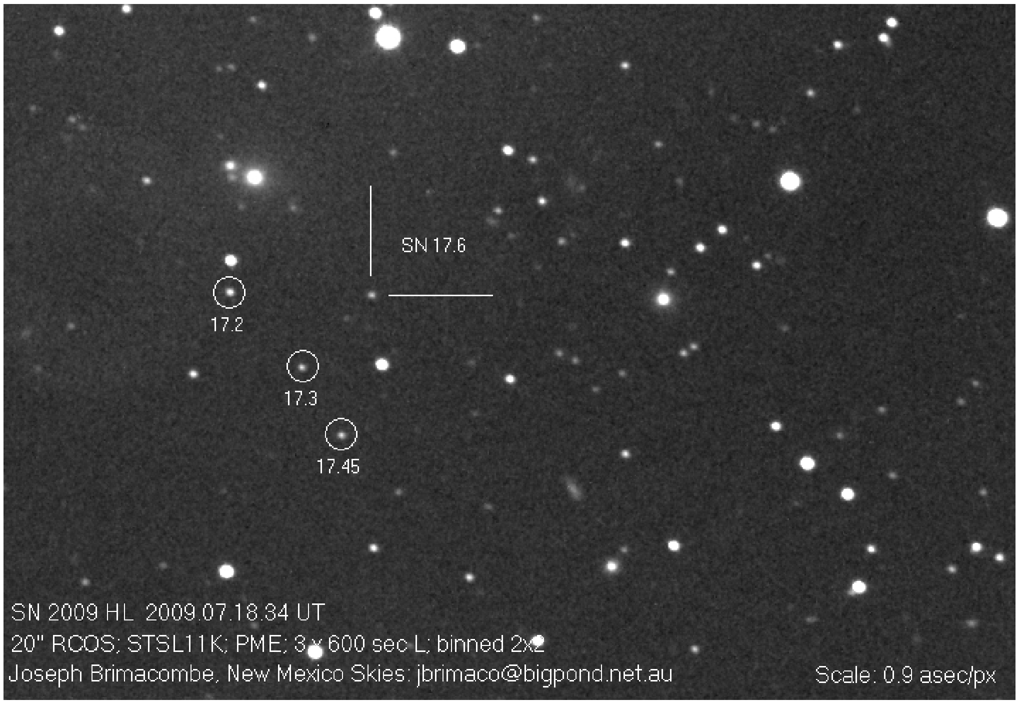


Processed image taken by P. Freidman and C. Fassnacht

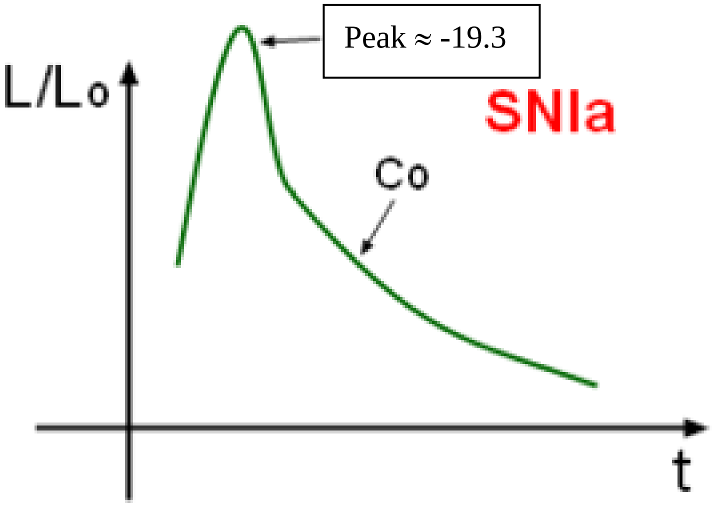
The data were collected in the form of three CCD images. Two of the images displayed an array of stars and galaxies un-interfered, while the third image had a streak on it (most likely a satellite), but was still useful for our data. All three images brightly displayed the galaxy PGC 60431, along with its accompanying supernova.

Analysis

After obtaining the final image, its contrast was adjusted until both the galaxy and supernova could be identified. After obtaining a final, clear image of the supernova, we used the software to obtain an apparent magnitude of the supernova. This was a rather complex process; to obtain the apparent magnitude, we observed a nearby star with a confirmed apparent magnitude of 17.3 magnitudes and compared the pixel count with that of the supernova. The ratio of the pixel counts was 0.6, from which we divided the difference per magnitude, or 2.512 to get the difference in magnitude between the star and the dimmer supernova. The difference was calculated to 0.239, meaning the apparent magnitude was 17.3 + 0.239 which was 17.539 magnitudes. However, even with the apparent magnitude, we still had to account for the varying light curve of the Ia supernova. This was because the value known for Ia supernovae, or -19.3 magnitudes, was at the peak of the curve (Nave, 2008). The value of 17.539 magnitudes was not at the peak of the curve, due to a previously observed magnitude of 17.039 (Brimacombe, 2009). In order to make up for the difference in values, we plotted a light curve mirroring Wood-Vasey (2008) with 17.039 at the peak, and found the difference between the peak and observed value was 0.561. We then accommodated for the difference by adding it to the absolute magnitude of -19.3 to get an absolute magnitude of -18.739.



One of the reference images taken by J. Brimacombe used for reference in the light curve.



A sample light curve, courtesy of Optcorop.

We then used the simple formula relating the variables of absolute magnitude, apparent magnitude, and distance to the object of $M = m + 5 – 5 \log d$ (M = Absolute magnitude, m = Apparent magnitude, d = distance). The equation, when substituted and rearranged, looked like this: $d = 10^{-(-18.739 - 17.539 - 5)/5}$. The final result for the distance to the supernova was $d = 1.801 \times$

10^8 parsecs, or 180 mpc which was equivalent to 5.943×10^8 light years or about 594 million light years.

We were able to calculate the distance to the Ia supernova 2009 hl by using the fact that type Ia supernovae have identical light curves, and retain a peak absolute magnitude of -19.3. This is clear evidence that the use of Ia supernovae is a feasible method for calculating distance on the intra-galactic scale. The object we calculated the distance was over 500 million light years farther away than the brightest Cepheid star, proving the extended range of the Ia supernova, and increasing its usefulness to astronomy. We utilized the Ia supernova's ideal qualities as an exceedingly bright standard candle to create a formula which could, in a very simple and practical manner, calculate the distance to the supernova on an intra-galactic scale.

Conclusion

We used the ideal light curve of the type Ia supernova to calculate its distance from the Earth. From the data obtained, we could reference other stars to come up with a value for the apparent magnitude of the supernova, which was compared with the absolute magnitude of all Ia supernovae. After adjusting to make up for the light curve of the supernova, the simple equation of $M = m + 5 - 5 \log d$ (M = Absolute magnitude, m = apparent magnitude, d= distance) to solve for distance, which was 594 million light years. The distance obtained is on the intra-galactic scale, showing the significance of this calculation. Astronomers can use the Ia supernova as a practical tool to calculate distances and map out the galaxy with more knowledge. The extended range of the supernova makes it the brightest object in the sky we can use for galactic referencing, showing the significance of its value to astronomy. Through experimentation, the type Ia supernova has become a more reliable standard candle in our universe, a tool that we can use to calculate distances on an intra-galactic scale more efficiently. The Ia supernova and its ideal properties prove as a useful tool astronomers can utilize to broaden their view of the universe.

References

Brimacombe, J (2009, July 18). 2009 hl supernova. Retrieved from <http:// www.rochesterastronomy.org/sn2009/c198m46s1.jpg>.

Chaisson, E., & McMillan, S (2005). *Astronomy Today* (5th ed) New Jersey: Prentice Hall

Elcea, R (2001). White dwarfs and their use in the field of Astrophysics [Electronic version]. The Astrophysical Journal 419, 221.

Foust, G (2001, July 12). New Supernova is groundbreaking in field of Astronomy – Berkely Lab News Center. Retrieved from: http://spaceflightnow.com/news/n0104/03supernova/.

Gordon, J (2007). Standard candles – Cepheid stars or supernovae? [Electronic version]. Astrophysics and Space Science 301, 31-45.

Leibundgut, B (2004). Are type Ia supernovae standard candles? [Electronic version]. Astrophysics and Space Science 290, 29-41.

Nave, R (2008). Standard candle approach to distance measurement. Retrieved July 17, 2009, from: Georgia State University, Dept. of Physics and Astronomy, Hyper Physics Website <http://hyperphysics.phy-astr.gsu.edu/hbase/astro/stdcand.html>.

Optcorp (2008) Type Ia supernova. Retrieved July 21 from: <http://www.optcorp.com/pdf/opt/edu/280px-sniacurva.png>.

Preuss, P (2009, May 9). Cosmology's best standard candles get even better – Berkely Lab News Center. Retrieved July 15 from: <http://newscenter.lbl.gov/press-releases/2009/05/18/best-standard-candles/>.

Wood-Vasey et al. (2008, December 10). Type Ia supernovae are good standard candles in the near infrared: evidence from PAIRITEL [Electronic version]. The Astrophysical Journal 689, 3.