The Size of Space

By Colin Johnston, Science Communicator

As visitors to Armagh Planetarium admire the images in our Celestial Cathedral, they often ask variations on the question “How do we know how far away these things in space are?” In recent Astronotes I have tried to answer this by showing how astronomers have, over the past couple of centuries, carefully developed techniques to measure the Universe. As pioneered by Bessel, the distance to relatively nearby stars can be determined through their parallax, their apparent movement in the sky as the Earth’s orbital movement alters our vantage point. For more distant stars we must use other techniques.

Fortunately nature has provided us with a very useful standard candle. Leavitt showed that the yellow variable stars called cepheids pulse at a steady beat proportionate to their brightness. By watching the pulse rate of a cepheid we can tell how bright it is and work out how far away it is. Hence if we see a distant galaxy and can pick out any cepheids lying within it, we can calculate its distance. Later Hubble discovered than the light from distant galaxies was ‘stretched out’ or redshifted by amounts proportional to the galaxies’ distances. This was later called Hubble’s Law. Here then is another method to gauge the size of the Universe and there are yet more.

> “the star is blasted apart, briefly becoming the brightest star in the galaxy”

Novae are enormous nuclear explosions which occur when a white dwarf star in a binary system accumulates a critical mass of hydrogen leeched from its companion star. When there is enough hydrogen crushed into a small enough volume at high enough temperature a nuclear fusion reaction sweeps across the white dwarf’s surface and eventually we will see a spectacularly bright new star (hence nova) in our skies. The white dwarf itself is left more or less intact after this ordeal. As this cataclysm always occurs at a particular threshold, the magnitude of the explosion tends to be always the same. In other words all novae are, more or less, equally bright. Therefore they are another standard candle. Novae have been observed in nearby galaxies and their brightness has been used to compute their distances. The results are good matches to the distances obtained through cepheid variable stars.

This, however, is not the only catastrophe that can befall such a white dwarf star. Some experience a much worse fate. If enough material falls fast enough on to the dwarf, the additional mass can cause the star to collapse in on itself, abruptly compressing the matter in the star. Now white dwarfs are rich in carbon, and in these unusual circumstances, nuclear fusion occurs in this carbon. This releases so much energy so quickly that the star is blasted apart,

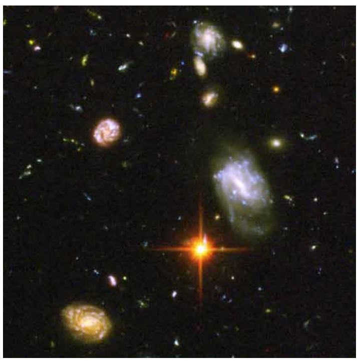

Image Credit: NASA

A section of the Hubble Ultra Deep Field The light from these galaxies was emitted as ultra-violet. They are so far away that the Hubble red shift has transformed ultra-violet to visible.

briefly becoming the brightest star in the galaxy. This dramatic utter destruction of a star is called a Type 1a supernova (the ‘1a’ is to distinguish it from stars which have exploded through other mechanisms). A supernova can remain extraordinarily luminous for a long time: in the early 1600s Kepler’s supernova was visible for 366 days. From observations we know that the bigger and brighter the 1a supernovae, the longer it takes to fade. So we have yet another standard candle, some 1a supernovae have been seen in other very distant galaxies, too far away for us to resolve cepheids, allowing astronomers to determine their distances, and helping verify Hubble’s Law.

Spiral galaxies rotate extremely slowly, taking hundreds of millions of years to make a rotation. It may seem surprising but we can measure their speeds of rotation. Once again, the technique uses the Doppler effect, the phenomenon where light waves from an approaching source are squeezed towards the blue end of the spectrum and light waves from a receding source are stretched into red. In a nutshell, by observing the red shift of the side of the galaxy which is turning away from us and the blue shift of the side turning towards us we determine the galaxy’s rotation speed. Why is this relevant to the size of the Universe? Analysis shows that there is a relationship between the rotational speed of a galaxy and its brightness. This is called the Tully-Fisher relation. So if the rotational velocity of a spiral galaxy can be measured, the luminosity can be determined. Combine this with how bright it looks and we get the galaxy’s distance.

Astronomers have developed a range of methods to measure the size of the Universe to a great deal of confidence. At present, the deepest image of the universe ever taken in visible light is the celebrated Hubble Ultra Deep Field. This astonishing picture from the space telescope includes about ten thousand galaxies like scattered grains of sand. Some of the smaller, reddish galaxies are the most distant galaxies we have ever seen, existing when the universe was just 800 million years old. These are the furthest away things in the observable Universe (not necessarily in the entire Universe) and they are some 13 billion light years away. Bessel, Leavitt and Hubble’s discoveries were the foundations on which our knowledge of the scale of the Universe is built. They would be astonished and awed by what has been revealed.