13 FAR OUT and YONDER TO INFINITY

SYNOPSIS

FAR OUT – Measuring the Universe

Scaling and measuring the cosmos. How far is a star or a galaxy? Distances are so vast they are described in light years – the distance light travels in a year. Nearby stars are measured by trigonometry – the technique of parallax. Farther out, astronomers use so-called "standard candles". The pulsing and luminosity of Cepheid variable stars works up to about 100-million light years. Then, Type Ia supernovae are the standard candle. Beyond that the "redshift" of galaxies reveals their distances.

YONDER TO INFINITY – End of the Universe

Rather than slowing down, the expansion of the cosmos seems to be speeding up. The 50-billion galaxies thought to comprise the Universe are moving farther and farther apart. As energy runs out, the ultimate prospect is cold, dark and lonely. Intriguingly, other universes may exist. But, within our own, we have yet to understand the nature of mysterious dark energy and dark matter – together believed to comprise 96 per cent of the Universe. Astronomy reveals more and more - but we still live in a mystery.

BACKGROUND

Astronomers describe distances in light years – the distance light travels in a year. It makes sense because in one year light travels nine-and-a-half million million kilometres (9.5-million million kilometres). Consider the "nearby" galaxy of Andromeda which lies 2.5-million light years away. Its light takes two-and-a-half million light years to reach us. Without light years, the distance would have too many zeros to make much sense.

Our own Galaxy, the Milky Way, is 100-thousand light years wide. The Sun is 30-thousand light years from the Galactic Centre. But how do astronomers measure these distances? How do they calculate the light years to a neighbouring star or to the farthest reaches of the cosmos? They use known distances close to home and extrapolate deeper into space using so-called standard candles.

Their first key in scaling the cosmos is the diameter of Earth's orbit around the Sun – almost 300-million kilometres. Viewed from Earth, a nearby star appears to shift in relation to background stars much farther away during our planet's annual orbit of the Sun. The shift is quite significant between, say, January and July. By factoring in the shift and the diameter of Earth's orbit, simple trigonometry gives the distance to the star.

The technique is called stellar parallax and works for stars out to several hundred light years. That includes a lot of stars, but is only a small fraction of the size of our Milky Way Galaxy. So how can we extend these measurements for nearby stars out to far more distant objects in our Galaxy, or to stars in other galaxies?

The answer is to use the inverse square law to calculate the distance to an object, given its apparent brightness – which is easy to measure – and its true intrinsic brightness. But how do we know a star's true intrinsic brightness or luminosity?

It turns out that all so-called main sequence stars (like the Sun) have a well established relationship between their colour (which we can measure) and their luminosity. So, we measure the colour of the star through several filters, use the known relationship to turn colour into luminosity, and then use the luminosity and the apparent brightness to get the distance.

Another method uses stars known as Cepheid variables. Cepheids appear to pulse very regularly as they expand and contract. The pulsing speed is directly related to a Cepheid's true intrinsic brightness. By calibrating nearby Cepheids – those close enough to be measured by other methods – astronomers use them as a standard candle to work out the distance of apparently fainter Cepheids deeper and deeper in space.

The Cepheid standard candle works to a distance of about 100-million light years. Beyond that another standard candle lights up – Type Ia supernovae. Such explosions occur when a white dwarf star draws matter from a red giant companion. Matter builds up on the surface of dwarf and when it reaches 1.4 times the mass of the Sun, the resulting detonation has a standard intrinsic brilliance. By calibrating Type Ia supernovae in galaxies whose distance has already been determined using Cepheid variables, astronomers can measure the distance of such flashes a hundred times beyond.

For the most distant objects in the cosmos, for galaxies father than one-billion light year away, measurement is by redshift. In the late 1920s, the American astronomer Edwin Hubble made a profound discovery as he studied the spectra of remote galaxies. He observed that the fainter and more distant the galaxy, the more the lines in its spectrum were shifted towards the red.

Hubble realised it meant the Universe was expanding. But it was space, not the galaxies, that was expanding. As it did so, space was carrying the galaxies with it. Light from those galaxies was stretched towards the red end of the spectrum. Today, the aptly named Hubble Space Telescope detects galaxies in an infant Universe 13-billion years ago. Their distances and antiquity are measured by redshift.

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As our understanding of the Universe grows, science faces big questions. Is ours the only universe? Are there parallel universes with time and space like ours but with different forms of matter? Physicists now realise that the four dimensions thought to describe the Universe (three dimensions of space and one of time) were not enough. There are actually eleven dimensions and in such a scenario, the notion of one universe budding from another is not so wild. Eleven dimensions could accommodate a multiverse of endless universes.

Another theory is a multiverse of bubbles – each bubble floating freely and unconnected. Should two bubbles touch, is there a cataclysmic explosion, a big bang?

Does it trigger a new universe – meaning ours may not have been the first? Intriguing – but until these theories are developed, they remain science fiction. Conventional thinking sets our Big Bang as the start of everything. We know nothing of what may have gone before.

Fourteen-billion years ago, time and space began. So did radiation and matter. As the first atoms were created, 76 per cent were hydrogen and 23 per cent helium plus traces of deuterium and lithium. Lithium was the heaviest element of the early Universe. Only when massive stars formed were heavy materials like iron created.

When those stars died and exploded in supernovae, heavy elements blasted through space to forge even heavier elements such as uranium. Thus did supernovae seed the cosmos with 92 naturally-occurring elements - like most of the matter than constitutes Earth and us.

Astonishingly, only four per cent of matter is visible. The rest is hidden and thought to comprise 96 per cent of the Universe. Of that, most is mysterious dark energy – 73 per cent of all there is. The remainder – 23 per cent – is so-called dark matter. Cosmologists believe dark matter was crucial in the early Universe. It probably dominated gravity, dictating the way galaxies formed and clustered.

Dark matter is only detected by its gravity. It causes the outer parts of galaxies to spin faster than visible matter justifies. Dark matter makes stars gently oscillate as they orbit their galactic centre. On a larger scale, galaxies within clusters orbit one another. Were it not for dark matter and its invisible mass, they would not orbit so closely.

Although we see its effect, the nature of dark matter is a mystery. But dark matter is crucial in determining the fate of the Universe – as is the total amount of matter. Scientists call it critical density. Our Universe faces one of three possibilities.

The first is the theory of the Big Crunch. It means we live in a closed universe with sufficient matter of all kinds for gravity to eventually halt and reverse cosmic expansion. The second idea is a flat universe where space has a curvature of zero. In this theory, total matter is exactly the same as critical density implying the Universe has no bounds and will expand for ever.

The third theory is the most likely – an open saddle-shape where total matter is less than critical density. This universe expands for ever – and it accelerates because dark energy is thought to be an anti-gravity force. Whatever the ultimate fate of the cosmos, stars will continue to form and shine for up to 100-trillion years. But inexorable expansion means the Universe will be increasingly cold, dark and lonely.

Weblinks for FAR OUT – Measuring the Universe

http://www.astronomynotes.com/starprop/s2.htm - from Nick Strobel's Astronomy Notes, a detailed discussion of the trigonometrical parallax method of measuring the distances to stars, with formulae and review questions.

http://www.windows.ucar.edu/tour/link=/kids_space/star_dist.html - From the University Corporation for Atmospheric Research's "Windows to the Universe" website, an introduction to how astronomers measure the distances to stars, with information available at beginner, intermediate and advanced levels.

http://curious.astro.cornell.edu/question.php?number=261 – From the "Curious about Astronomy?" pages at Cornell University, a collection of links and previously asked questions about measuring the distances to stars.

http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/970415c.html - From the "Imagine the Universe" site at NASA's Goddard Space Flight Center, an introduction to measuring the distances to stars.

http://www.suite101.com/article.cfm/astronomy/11999
and
http://www.suite101.com/article.cfm/astronomy/13217
and
http://www.suite101.com/article.cfm/astronomy/13754 - From the Suite101 website, three articles about the cosmic distance scale: 1 – parallax; 2 – stars as standard candles; and 3 – measuring the Hubble Constant.

http://www.astro.ucla.edu/~wright/distance.htm - From the University of California Los Angeles, an extremely detailed discussion of a large number of different methods used by astronomers for measuring the distances of objects in space.

http://en.wikipedia.org/wiki/Standard_candle - From Wikipedia, the free encyclopedia, an introduction to the use of "standard candles" for distance measurement in astronomy.

http://universe-review.ca/R02-07-candle.htm - A more detailed overview of the use of standard candles in astronomy.

http://imagine.gsfc.nasa.gov/docs/science/mysteries_l1/cepheid.html - From the "Imagine the Universe" site at NASA's Goddard Space Flight Center, an introduction to using Cepheid variables as cosmic yardsticks.

http://map.gsfc.nasa.gov/m_uni/uni_101expand.html - From the WMAP site at NASA's Goddard Space Flight Center, an overview of how astronomers use Cepheid variable stars to measure how fast the Universe is expanding.

http://en.wikipedia.org/wiki/Supernova - From Wikipedia, the free encyclopedia, a comprehensive introduction to supernovae, including a discussion of the Type Ia supernovae used as standard candles in distance measurement.

http://en.wikipedia.org/wiki/Hubble's_Law - From Wikipedia, the free encyclopedia, a discussion of Hubble's Law.

http://starchild.gsfc.nasa.gov/docs/StarChild/questions/redshift.html - From the StarChild website at NASA's Goddard Space Flight Center, an introduction to redshift and Hubble's Law.

Weblinks for YONDER TO INFINITY – End of the Universe

http://map.gsfc.nasa.gov/m_uni/uni_101bb2.html - From the WMAP site at NASA's Goddard Space Flight Center, an excellent introduction to the foundations of Big Bang cosmology.

http://en.wikipedia.org/wiki/Age_of_the_universe
and
http://en.wikipedia.org/wiki/Shape_of_the_Universe - From Wikipedia, the free encyclopedia, two useful articles on the age and shape of the Universe.

http://chandra.harvard.edu/xray_astro/dark_matter.html - From the Chandra X-ray Observatory website, a discussion of the dark matter mystery.

http://map.gsfc.nasa.gov/m_uni/uni_101matter.html - From the WMAP site at NASA's Goddard Space Flight Center, an introduction to what the Universe is made of and the dark matter mystery.

http://astro.berkeley.edu/~mwhite/darkmatter/dm.html - The Berkeley Cosmology Group's dark matter page.

http://www.astro.princeton.edu/~dns/MAP/Bahcall/final.html - David Spergel's comprehensive discussion of dark matter.

http://en.wikipedia.org/wiki/Dark_energy - From Wikipedia, the free encyclopedia, an introduction to dark energy.

http://physicsweb.org/articles/world/17/5/7 - From PhysicsWeb, an excellent introduction to the accelerating universe and dark energy.

http://imagine.gsfc.nasa.gov/docs/science/mysteries_l1/dark_energy.html - From the "Imagine the Universe" site at NASA's Goddard Space Flight Center, an introduction to dark energy.

http://map.gsfc.nasa.gov/m_uni/uni_101shape.html
and
http://map.gsfc.nasa.gov/m_uni/uni_101accel.html
and
http://map.gsfc.nasa.gov/m_uni/uni_101fate.html - From the WMAP site at NASA's Goddard Space Flight Center, three excellent overviews on the shape and geometry of the Universe, the cosmological constant, and the ultimate fate of the Universe.

http://en.wikipedia.org/wiki/Ultimate_fate_of_the_universe
and
http://en.wikipedia.org/wiki/Big_Crunch

and
http://en.wikipedia.org/wiki/Heat-death_of_the_Universe - From Wikipedia, the free encyclopedia, three overviews of various scenarios for the ultimate fate of the Universe, including the Big Crunch and the Heat Death.

http://www.space.com/scienceastronomy/big_rip_030306.html - Popular article about the Big Rip – a new theory that ends the Universe by shredding everything.

http://en.wikipedia.org/wiki/Multiverse_%28science%29 – From Wikipedia, the free encyclopedia, a detailed introduction to multiverse theories.