Measuring the Distances to the Stars and Beyond

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INTRODUCTION

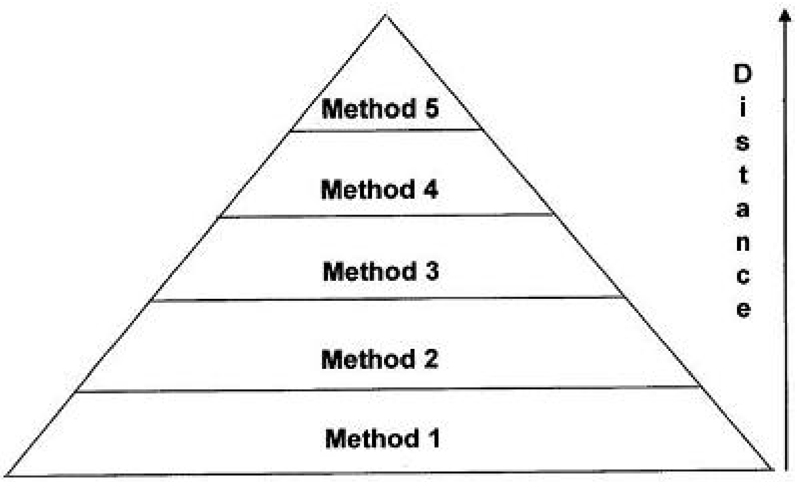
We read on the internet and in books and journals that the nearest star, Alpha Centauri, is 4.3 light years away, that Betelgeuse is 510 light years away and M31 (Andromeda Galaxy) is a staggering 2.5 million light years away.

But how do we know that? Did someone take a surveyor's tape out and measure it?

What we will be looking at in this article is a very brief, very simplified, account of the various techniques astronomers use to arrive at these distances. I have no intention of covering the full range of methods used nor the detailed techniques that each employs, but will look at a few of the main methods.

We will discover that like the construction of a pyramid, one layer of knowledge is built on top of another. We learn what we can from one method. Then, when that method can be taken no further, we build on top of that knowledge with information from another method.

And so on, and so on...



Each of the methods I will touch on is worth a full article on its own. And it becomes immediately obvious from the pyramid, that if there is an error in a lower layer method, this will multiply through the results of all later methods built on top of it.

The Andromeda Galaxy is a good example of this. Back in 1929, Edmond Hubble used a method to calculate the distance to the Andromeda Galaxy (at that time thought to be contained within our galaxy). He calculated it to be 900,000 l.y. thus proving it to be outside our galaxy. On this yardstick, the size of the then known universe was calculated.

Later, the distance of Andromeda was recalculated to 2.5 million l.y. As a consequence, the size of the known universe was more than doubled overnight.

So, where do we start? As Maria Von Trapp sang, let's start at the very beginning.

THE ASTRONOMICAL UNIT

The most basic, fundamental yardstick of astronomy is the Astronomical Unit, the mean distance of the Earth from the Sun. Without a knowledge of its value, we can go no further than to measure other distances in A.U.s. We would not know the distances in km or light years etc.

Ptolemy (the Greek) made a fair stab at it when he estimated 5 million miles) 8 million kilometres.

But the first reliable measurement came from Cassini in 1672. He used parallax to measure the planet Mars' distance from Earth at various times in Mars' orbit.

From Kepler's 3rd Law, $P^2 \alpha D^3$. (That is, the square of P is proportional to the cube of D.)
where P = planet's period of orbit
D = mean distance from Sun.

He already knew that Mars must be 1.52 times further from the Sun than the Earth.

Using measured distances to Mars, he was able to calculate Earth's distance to the Sun as 86 million miles (138 million km). That was pretty good for 1672.

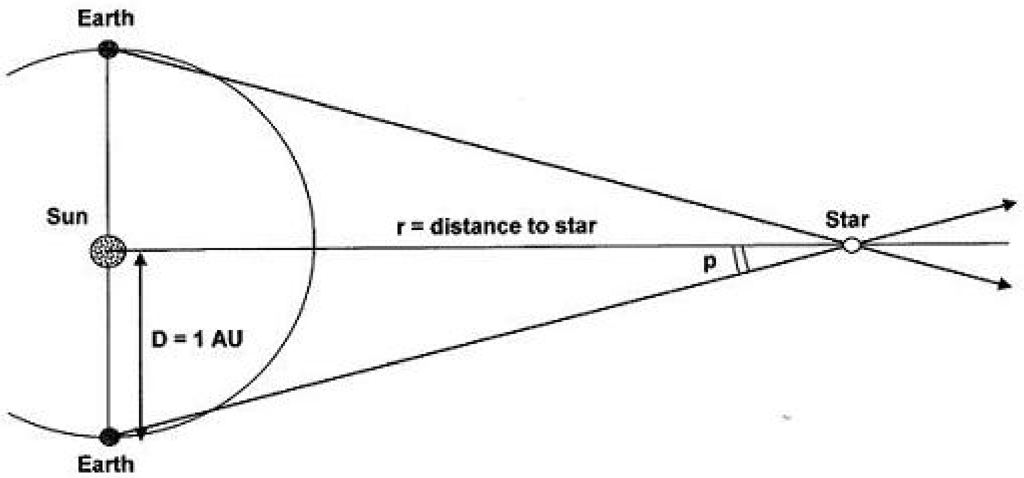
The epic measurement took place in 1769 when Captain Cook travelled to Tahiti to observe the transit of Venus. Believe it or not, the whole purpose of that trip was to gain data to measure the Astronomical Unit, NOT to discover Australia.

This measurement involved using a large baseline on Earth (ie London to Tahiti) and Kepler's 3rd Law. They got it pretty right at 92 million miles.

Current methods involve bouncing radar off Venus and other measurements by planetary satellites. The end result is an accurate A.U. of 92,976,000 miles or 149.49 million km.
With this yardstick, the A.U., the first step to measuring the distances to the stars can be taken.

TRIGONOMETRIC PARALLAX

Note: This is called 'trigonometric' parallax because there is another kind...more of that later.
Let's start by recognising a basic problem. The nearest star to the Sun is a VERY LONG WAY AWAY. We now know it to be 4.37 l.y. That is 276,560 Astronomical Units.
So, what is the parallax method?



The parallax angle of a star is defined as 'the angle subtended at the star by the radius of the Earth's orbit.' (Note: Not its orbit's diameter.) That is, the angle at the star subtended by one A.U.
This is usually done by using photographs to measure the angular displacement of the subject star (earlier astronomers didn't use photographs, of course, they did it the hard way) against the 'fixed' background stars from the opposite ends of Earth's orbit at right angles to the direction of the star to the Sun. The actual angle measured is halved (or averaged) to give the parallax, 'p'.
The measurement of this parallax angle is agonisingly painstaking.

FIRSTLY, because it is so small. The closest star has a parallax of less than one second of arc, and one second of arc equals 1/3600th of a degree.

SECONDLY, because the star is actually moving very slowly across our line of sight. This is called proper motion and needs to be measured and taken into account.

THIRDLY, the background stars can have their own parallax. This needs correction.

FOURTHLY, atmospheric aberrations and other astronomical phenomena need to be allowed for.

FIFTHLY, limits to accuracy of even the best telescopes.

Eventually, the astronomer has a parallax angle ,p, he has confidence in. After that, it's simple. With apologies for the maths:

Distance $r = D/p$
where D = Earth's Orbit's Radius, p = the parallax in radians (a unit of angle = 57.29 deg.)
Now, there are 206,265 seconds of arc in one Radian.
Therefore, $r = 206{,}265 \times D/p$ where p is in arcseconds (")
If $D = 1$ A.U., then $r = 206{,}265 \times 1/p$ A.U.s

It's done this way because p is always small (less than 1 arcsecond). However, it's a cumbersome formula, so let's simplify it.
If we DEFINE the distance to a star with a parallax of 1" as a PARSEC, we get
1 parsec = 206,265 x 1 A.U. /1 = 206,265 A.U.
We know 1 A.U. = 149.49×10^6 km
Therefore 1 parsec (pc) = 3.083×10^{13} km = 3.26 light-years
We now have a smorgasbord of formulae to calculate the distance to the star:
r = 206,265 x 1/p" A.U.s
= 3.26 x 1/p" light-years
= 1/p" parsec (pc)

The history of parallax measurements is fascinating. I suggest you read it up sometime.
The first star to have its parallax measured was 61 Cygni. In 1838, the German astronomer F.W. Bessel calculated a parallax of 0.35" (giving a distance of 2.86 pc or 9.3 l.y.). The currently accepted value is 0.30" (equal to 10.9 l.y.)
The irony is that a Scottish astronomer, Thomas Henderson, working from South Africa's Cape University had earlier (about 1835) calculated the parallax of Alpha Centauri. It was easier because it was much closer than 61 Cygni. But he wasn't in a hurry to publish his results and Bessel went to press first, getting all the kudos. The moral: Publish or be damned!

Oh, yes. Alpha Centauri's parallax is 0.746" = 1.34 pc = 4.37 l.y.

What are the limits of the parallax method? After considering the previously mentioned corrections, by using a large number of photographic plates and the most modern techniques, the error can be reduced to about 0.004". Using CCD technology fitted to large telescopes, this can theoretically be reduced to 0.002" for stars as faint as 20th magnitude.

However, accuracy can improve by putting your telescope up in space, away from the Earth's atmosphere. Between 1989 and 1993, a satellite called HIPPARCOS in Earth orbit and unencumbered by the atmosphere's distortion of light paths, progressively measured the parallaxes of 120,000 stars to an error of +/- 0.001". Its catalogue of star parallaxes was published in 1997. A lower precision Tycho catalogue of more than a million stars was published at the same time, and an enhanced Tycho 2 catalogue of 2.5 million stars was published in 2000.

But all that means is they can measure distances up to 100 pc (=326 l.y.) with a confidence of +/- 10%. And that's about the theoretical (not practical) limit. About 80 times the distance to the nearest star.

So, how do we measure distances beyond 100 parsec?

This is where we start building our pyramid of knowledge. A number of different techniques exist and, to some degree, overlap. I will attempt to describe some of the better known techniques. At this stage, it is difficult to be concise and comprehensive at the same time.

SPECTROSCOPIC PARALLAX

As you are probably aware stars can be categorised by their colour and luminosity. Colour is determined by the star's surface temperature and its luminosity (the total amount of energy radiated by the star) by its subsequent size.

TABLE 1

RELATIONSHIP BETWEEN INSTRINSIC BRIGHTNESS, TEMPERATURE AND DIAMETER OF THREE M-TYPE STARS

	RED STAR		
	DWARF	GIANT	SUPERGIANT
Absolute Luminosity Relative to Sun	0.01	100	10,000
Temperature	3,000°K	3,000°K	3,000°K
Approx. Diameter Relative to Sun	0.4	40	400

Table 1 above shows that a star's colour is not a unique indication of its size. That is, a star may appear red (for example) but it could be a dwarf, a giant or a supergiant. More information is needed about the star to determine its size. That's another issue.

The luminosity of a star is characterised by its Absolute Magnitude, which is defined as the Apparent Magnitude the star would have if it was 10 parsec (32.6 l.y.) from Earth.

If a star was exactly 10 parsec away, its Absolute Magnitude would equal its Apparent Magnitude (by definition). See Table 2 for some examples. If it is more than 10 parsecs away, it will appear less bright than it would at 10 parsec. However, in one of those quirks of terminology, the historic system of measuring a star's magnitude results in a fainter star having a higher numerical magnitude. For example, a star of magnitude 2 is fainter than a star of magnitude 1, while a magnitude 3 star is even fainter. So, if a star is further away than 10 parsecs, its apparent magnitude will be higher (in numerical value) than its absolute magnitude. Of course, the reverse applies so that Alpha Centauri at only 1.34 parsec has an apparent magnitude much lower than its absolute magnitude.

The purpose of this technical explanation is that once astronomers have been able to identify the Spectral Class (colour) and Luminosity (Absolute Magnitude) of a star, it is possible to calculate the distance to that star.

The tool used to do this is the so-called Inverse Square Law of Light. That is, if a source of light is twice as distant as another identical source, its apparent brightness is reduced by a factor of 2 squared = 4. Three times distant, 9 times fainter etc.

Combined with the definition of Absolute Magnitude, and a knowledge of the logarithmic scale of Magnitude (see Table 3), a complex looking but relatively simple formula for calculating the distance to the star can be used. The magnitude scale is logarithmic in that on increment of magnitude corresponds to a ration of brightness of the fifth root of 100, equal to 2.512. So an increase in 5 magnitudes equals 2.512^5 = 100.

TABLE 2

MAGNITUDES OF SAMPLE OBJECTS

OBJECT	APPARENT MAGNITUDE	ABSOLUTE MAGNITUDE
Sun	-26.8	+4.8
Full Moon	-12.5	
Venus (when brightest)	-4.4	
Sirius	-1.47	+1.4
Alpha Centauri	-0.3	+4.7
Vega	0.03	+0.5
Antares	+1.0	-4.0
Andromeda Galaxy	+3.5	-21.2

TABLE 3

BRIGHTNESS - MAGNITUDE VALUES

INTENSITY RATIO	MAGNITUDE DIFFERENCE
1:1	0.0
1.6:1	0.5
2.5:1	1.0
4:1	1.5
6.4:1	2.0
10:1	2.5
16:1	3.0
40:1	4.0
100:1	5.0
400:1	6.5
1,000:1	7.5
10,000:1	10.0
1,000,000:1	15.0
100,000,000:1	20.0

The formula used is:

$$M = m + 5 - 5 \cdot \log r$$

where M = absolute magnitude

m = apparent magnitude
r = distance in parsecs
(m - M) = Distance Modulus

If we know the value of m and M, we can calculate the distance r as:

$\text{Log } r = [(m - M) + 5]/5$

or $r = 10^{[(m - M) + 5]/5}$

A simple example helps to explain it.
We have identified a star as a particular spectral and luminosity class which should have an Absolute Magnitude of M= +5. (eg a Class G2 V like the Sun).
The observed Apparent Magnitude m = +10.
What is the star's distance?

Method 1: Distance Modulus (m-M) = (10-5) =5
Therefore, the star is 5 magnitudes fainter.
Therefore, 100 times less intense (refer to Table RB.3) than it is at the standard distance of 10 parsec. By the Inverse Square Law of Light, the star must be Sq. Root (100) = 10 times more distant than the Standard Distance = 10 x 10 = 100 parsec.

Method 2: $\log r = [(m-M) + 5]/5 = [5 + 5]/5 = 2$

Therefore, $r = 10^2 = 100$ parsec

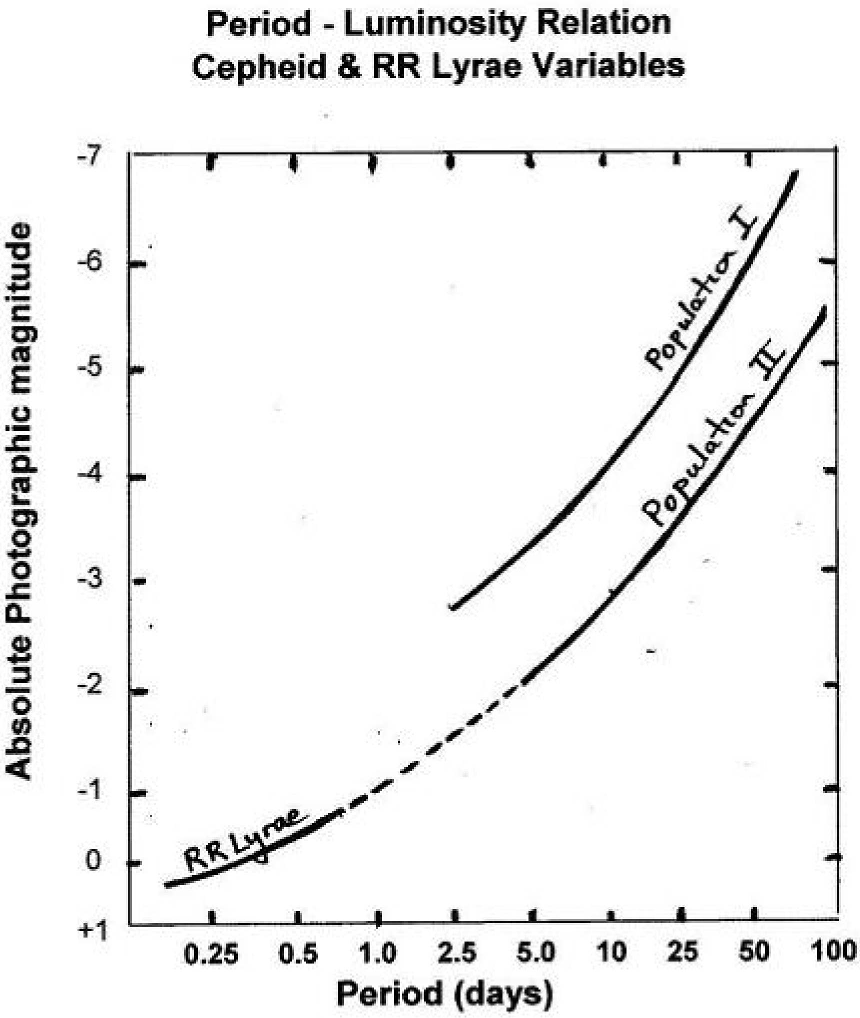
CEPHEID VARIABLES

The darling of astronomers is the Cepheid Variable. No other star type has been more instrumental in allowing astronomers to make the leap to calculate distances outside our galaxy.
The science and use of Cepheids is quite complex but, in the end, the concept is relatively simple (if you don't think about it too much).
But first some history. In 1783, a young astronomer, John Goodricke, who was both deaf and mute and died before he was 23 (what a waste), was observing variable stars. This included the orbiting binary type (called Algols after Algol or β Persei, the first observed). He also observed the star Delta Cephei which was, in fact, a true variable. That is, it varied in brightness in its own right.
He noted that Delta Cephei varied in magnitude from 3.5 to 4.4 with a strictly regular period of 5 days, 8 hours, 37.5 minutes.
Later, other stars were discovered to have similar strict periods of variation. These were described as Cepheid Variables, in honour of the first discovered by John Goodricke.
Cepheids can have periods of variation from 1 to 50 days.

Over the years, the following features about Cepheids have been discovered:
* They are yellow supergiants of great brilliance. Up to 10,000 times the brilliance of the Sun.
* The more luminous the Cepheid, the longer its period of variation.
* Their spectra exhibit Doppler shifts in synchronisation with the period change of their brightness. In fact, it is now known that these stars are actually pulsating backwards and forwards like an inflating and deflating balloon.

Now, why is this important?
In 1912, an American, Henrietta Leavitt was studying Cepheids in the Magellanic Clouds. She discovered many Cepheids in the Clouds, just as there are scattered around the Milky Way and in globular clusters.
After the collection of a huge amount of data, she plotted the apparent magnitudes of the Cepheids against their observed periods of variance.
She obtained a graph similar to this shown in Figure 4 below.

Figure 4



Leavitt was able to show that the longer the period of variation, the brighter the Cepheid appeared.

As it was reasonable to say that all the Cepheids in each Magellanic Cloud were the same distance from us, it followed that the longer period stars were in fact the more luminous.

With this knowledge, she was able to provide a direct method of identifying a Cepheid's brightness by measuring its period of variation. (This was able to be done at great distances, when determining the star's spectral/luminosity class was impossible).

It turns out that Cepheid variables come in a number of classes. Population I Cepheids or 'Classical Cepheids' , scattered within the disc portion of the Milky Way, are younger and brighter than the older Population II stars, found in the halo of the Milky Way.

The other type, also a Population II star, is the RR Lyrae (named after the first of its type discovered). These are old blue-white giant stars frequently found in the central region of the galaxy and globular clusters. RR Lyraes vary in magnitude by about 0.5 to 1.0 in less than a day.

Now, none of the Cepheids or RR Lyrae variables are close enough to measure their distance by either Trigonometric or Spectroscopic parallax methods.

A large array of indirect methods is used to calculate distances to the nearest variable stars, mostly RR Lyrae types in nearby globular clusters. (It is interesting to note that Delta Cephei is calculated to be 1031 l.y. away).

The main problem with using the Cepheids was that at first they couldn't calibrate the Period-Luminosity chart. That is, they could plot Period against apparent magnitude for groups of Variables in a common cluster, but they couldn't convert the apparent magnitudes to absolute magnitudes. This is where the RR Lyraes proved their value.

Astronomers were able to use statistical methods (amongst others) utilising proper motions and radial velocities of RR Lyrae stars in common clusters to obtain mean distances to the RR Lyrae stars. This allowed them to calibrate the RR Lyrae part of the Period-Luminosity chart and by combining the RR Lyrae and Cepheids on the chart, they had a calibrated chart for the Cepheids.

So how can they use them? Let's take an example using hypothetical numbers.

An astronomer may observe a Cepheid in the Andromeda Galaxy and make the following measurements:

Period of Variation = 5 days

Apparent Magnitude = +21.5

From the Period and the P-L chart, we 'know' that the absolute mag. of the Cepheid is -2.7.

Using the Inverse Square Law equation

Log r = [(m-M) + 5]/5
we get Log r = [(21.5 -(-2.7)) + 5]/5 = 29.2/5 = 5.84
Therefore, r = 7 x 10^5 parsec = 2.2 million light years.

From this, we deduce that the Andromeda Galaxy is 2.2 million l.y. away. (We now know that the Andromeda Galaxy is more like 2.5 million light years away. The numbers used above were approximations only.)

In Hubble's first calculations, he incurred errors in the distances to Cepheids and the calibration of the P-L chart. When this was later corrected the distance to Andromeda Galaxy was corrected from 900,000 to 2.2 million l.y.

Unfortunately, Cepheids cannot be detected further out than the nearer galaxies in our Local Group. However they are immensely useful for distance measures for stars and clusters in our own galaxy and the closer Local Group galaxies. This is another layer of the pyramid of distances.

DISTANCE INDICATORS

Deriving an accurate yardstick for galactic distances is vital to all cosmological data. Without such distances, crucial questions about our universe cannot begin to be answered. Such issues as:

* Linear dimensions of the universe
* Spatial distribution
* Intrinsic luminosities and masses of galaxies
* The physical and evolutionary differences between galaxies
* The mean density of the universe
* The universe's rate of expansion
* The type of Cosmological model.

All these depend on a correct scale of distance.

Once we know the distances to the nearest galaxies in our Local Group, how do we determine the distances to the more remote galaxies when parallax and Cepheids fall short?

To start with, the determination of distances rests on the assumption that similar objects in our galaxy and other galaxies have the same physical characteristics. Thankfully, astronomers so far have no reason to doubt this assumption.

Suitably chosen objects can serve as "standard candles" of known luminosity from investigations made of them in our galaxy.

The observed apparent luminosity of a recognised "standard candle" in a distant galaxy, combined with the knowledge of its intrinsic (true) luminosity, allows the calculation of the distance to the other galaxy.

e.g. Using the now familiar formula log r = [(m-M) + 5]/5

Different types of standard candles yield different maximum distances to which they can meaningfully be used to determine distances. See Table 5.

For dependability, Cepheid Variables remain the most effective. However, they are restricted in use due to the difficulty in singling them out in distant galaxies. Perhaps with the increased resolution available from the improved Hubble Space Telescope, the Keck twin telescopes and other Very Large Telescopes (in interferometric mode), with absolutely staggering powers of resolution, it will allow Cepheids to be detected in even further galaxies, allowing the 'yardstick' to be re-calibrated and even greater distances re-evaluated for other distance indicators.

Table 5

DISTANCE INDICATORS

Brightest of its Type (Standard Candles)	Absolute Magnitude (M)	Approx. Maximum Distance (light years)
RR Lyrae variables	0	1,400,000
Population II red giants	-3	5,000,000
Cepheids	-6	20,000,000
Blue Supergiants	-9	80,000,000
Novae	-9	80,000,000
Globular Clusters	-10	132,000,000
H II emission nebulae	-12	320,000,000
Supernovae	-19	8,000,000,000

Another example using a Blue Supergiant indicator:

The 'corrected' apparent magnitude of an extremely bright blue supergiant star in a remote galaxy is m= +21. From Table 5 above, astronomers 'know' that this type of supergiant has a true luminosity of M = -9.

Thus, we can calculate the distance r by:

$\log r = ([+21 - (-9)] + 5)/5 = (21 + 9 + 5)/5 = 35/5 = 7$

Therefore, $r = 10^7$ = 10,000,000 parsecs = 32.6 million light years.

It gets to the point when individual objects cannot be resolved or identified in a very distant galaxy. We then have to compare the luminosities of the galaxies themselves.

Judgements can be made on the basis of the galaxy's total luminosity, its surface brightness, and its apparent size, or its light-to-mass ratio.

Precautions need to be taken when using galaxies as standard candles. One has to recognise the particular class of the galaxy involved (and there are many classes of galaxies) or major errors of scale will occur.

A more reliable technique involves examining a large cluster of galaxies and selecting, say, the ten brightest galaxies and determining the average apparent magnitude. This is then compared to the luminosity of the average brightness of a closer galaxy cluster for which we have a 'known' distance. At worst, we can obtain a fair idea of the relative distances to the galaxies.

For greater and greater distances, measurements of luminosities and such become inadequate, if not totally useless.

We then arrive at what might be considered the greatest yardstick of all, as well as one of the most significant discoveries in recent astronomical history.

HUBBLE'S LAW OF RECESSION

One would have to present a completely separate article to do this subject any justice. This paper gives just the briefest coverage.

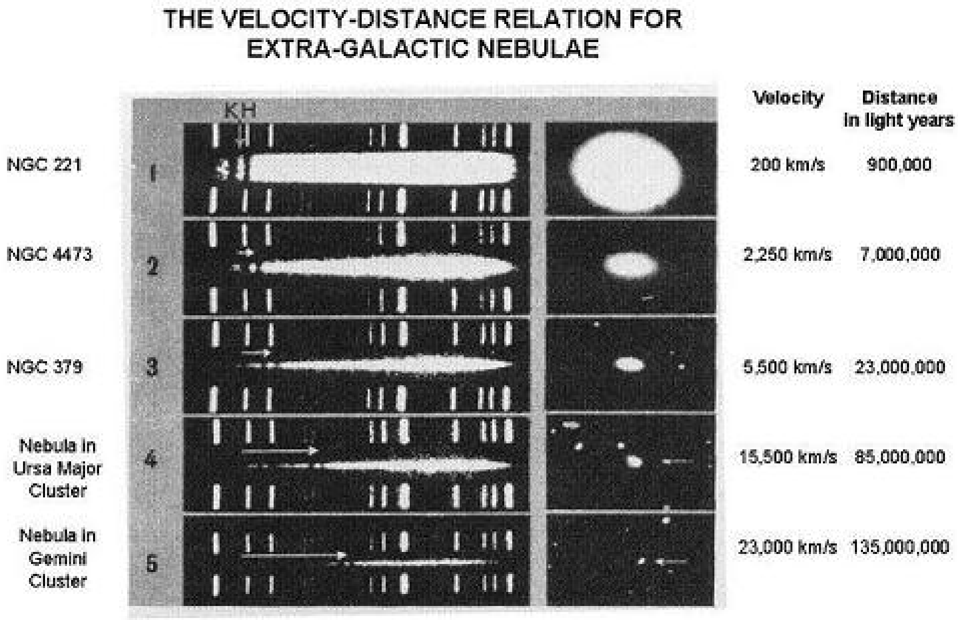
Vesto Melvin Slipher
1875-1969

Around 1912, Vesto Slipher studied the absorption spectrums of a large number (about 41) of 'spiral nebulae' (which up to that time astronomers believed to all be part of our galaxy which comprised the whole Universe) and discovered unusually large 'red shifts' of up to 1100 miles/sec (1700km/sec). Even larger red shifts (or velocities away from us) were found for fainter (and further, it transpired) galaxies by other astronomers.

Eventually, Edwin Hubble, working at the Mount Wilson Observatory using its 100" telescope was able to use other methods (as previously discussed) to estimate the distances to some galaxies for whom red shifts had been observed. Without diminishing Hubble's achievement, it is not so well known that Hubble used the results of a number of other astronomers' prior work to develop his own, a perfectly legitimate process of scientific research.

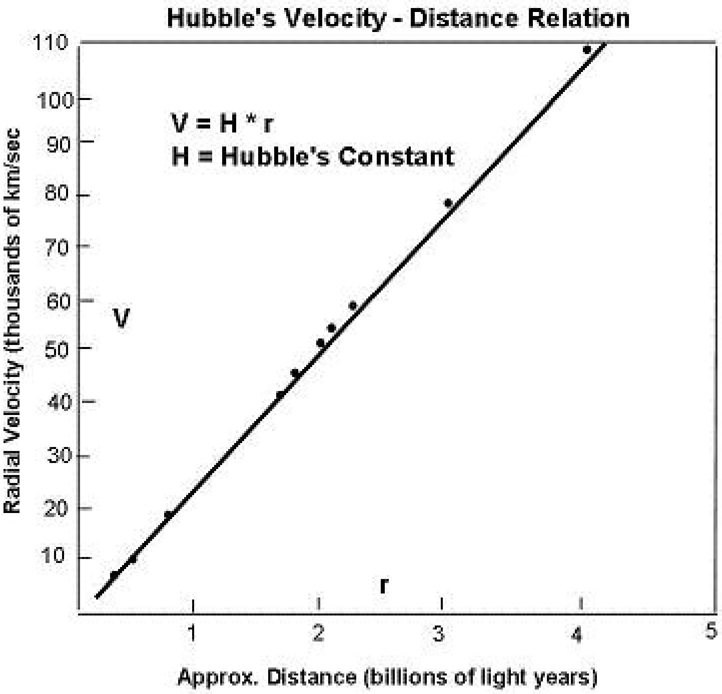
Edwin Hubble

A sample of these red shifts with their determined velocities and estimated distances is shown in the table below.



This was the first evidence that those ‘spiral nebulae’ were not in fact smallish nebulae within our galaxy but were individual galaxies such as our own at immense distances away. The Universe ‘overnight’ became a very large place.

In 1929, Hubble plotted the estimated distances against the radial velocities and discovered something marvellous. A ‘straight line’ relationship between receding velocity and distance. That is, the further a galaxy is from us, the faster it is travelling.



This became known as the **Hubble Law of Recession** and led to the proposal that the universe is expanding. Another topic of its own, opening up the whole new concept of cosmology and our Universe.

The Hubble Law of Recession can be stated mathematically as

$$V = H \cdot r$$

where H is the Hubble Constant, the "Holy Grail" of cosmologists.

If you know the value of H, and you can measure V (using red shift), then you can estimate the distance to the galaxy (or whatever object being studied). This has been the basis for many decades now of calculating the distances to extremely remote (and early) galaxies, going back almost to near the beginning of the formation of galaxies, billions of years ago.

TYPE 1a SUPERNOVAE

However, a 'new' standard candle has entered the field, allowing more direct and precise calculation of distances to vastly remote galaxies. It involves the convenient uniformity of the brightness of the light from a particular type of supernova, the Type 1a. This is when a white dwarf star, collecting material from the surface of a bloated giant companion star, eventually reaches a mass of the 1.4 solar masses (called the Chandrasekhar Limit, after its computation by Subrahmanyan Chandrasekhar) and totally obliterates itself in a cataclysmic explosion. These explosions are, to all practical effect, uniform in nature and absolute brightness. As they can be observed in nearby galaxies and their distances computed with some confidence using earlier methods, if they can be identified in galaxies at much greater distances (and they can because of their characteristic profile of luminosity over time) then by measuring their observed apparent luminosity and using the inverse-square law (as covered previously), then their distance can be established with some confidence. Think of them as the new 'Cepheid variables'. An object with a characteristic signature that can be observed at great distance, its magnitude measured and translated to distance.

The measurement of Type 1a supernovae has helped measure the distances to some of the most remote galaxies in our universe and led to the paradigm-shattering discovery in 1998 that the Universe's expansion is in fact accelerating, introducing the concept of Dark Energy and re-introducing Einstein's long discarded Cosmological Constant (another article for another time).

A SUMMARY OF THE DISTANCE PYRAMID

To summarise what has been covered, typical steps for measuring distances from the Sun to the End of the Universe are:

1. Determine the Astronomical Unit.
2. Measure distances to nearest stars using Trigonometric Parallax
3. Use Spectroscopic Parallax to determine distances to further stars.
4. Determine distances to Clusters containing Cepheids.
   Determine absolute magnitudes of Cepheids.
5. Determine distances to nearby Spiral Galaxies in Local Group containing Cepheids.
6. From distances of these spiral galaxies, determine Galaxy 'standard candles'.
7. Using scaling method, determine distances to farther similar spiral galaxies.
8. Determine average absolute magnitude of spiral galaxies of given shapes.
9. Obtain spectra and red shifts of remote spiral galaxies. Obtain distances by measuring apparent magnitudes and comparing with 'known' absolute magnitudes (from step 8).
10. From red shifts and distances, determine the Hubble Constant.
11. From the Hubble Constant and measured (red shift) velocities, determine other galaxy and object distances.
12. Identify Type 1a supernovae, measure their apparent magnitudes (in concert with other necessary characteristics) and calculate distances from inverse-square law.

CONCLUSION:

Let me end this article by saying that the Hubble Constant's value (H) is still a bone of contention. It was initially estimated at about 55 km/sec/megapc. That is, a recessional velocity of 55 km/sec for every million parsecs the galaxy is away from us.

For example, if a galaxy had a velocity of 55,000 km/sec, it would be estimated to be 1,000 million parsecs away, or about 3.3 billion light years.

However, ongoing measurements have led to hotly disputed controversies about the value of H. It was thought to be anywhere between 40 to 80 km/sec/megapc.

This is vitally important (to cosmologists, anyway) because it helps determine the age of the universe. The smaller the value of H, the older the universe and vice versa. Think about it. For a smaller speed of recession, and a given distance, the longer it took the galaxy to get out that far. Therefore, the older the universe.

Thus the ongoing debate and frantic measurement projects. Was the universe 10 billion or 20 billion years old? Or somewhere in between?

The most recent proposed value of H is 72 km/sec/megapc. This, when combined with other cosmological values, including the so-called Cosmological Constant which 'causes' the acceleration of the Universe's expansion, provides the presently accepted age of the Universe as 13.7 billion years, +/1 100 million years.

Time, and bigger telescopes and perhaps new paradigm-shattering discoveries sometime in the future, may require these values to be revised again.

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