Important considerations: methods and inconsistencies of stellar distance indicators

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ABSTRACT

Periodic luminous pulses are very important for measurements in Cosmology and Astrophysics, and there are very specific methods and sources which exhibit such properties. Stellar astrophysics provides a number of observational and mathematical sources which give a very important tool in understanding the dynamics of an expanding Universe, and in this document, we will consider some important points that have implications from measurements from such Stellar objects. Further, we will also consider the mathematical relations that are important to measure distances of these “Standard Candles”, and how these are important in clearing some important features that have implications in measurements.

Stellar objects as Standard candles

There are a number of stars and other Stellar objects that provide a simple way of deducing the distance measurements, referred to as “Standard Candles”. Those which have a periodic luminous “flashing” nature have been used for a long time in finding distances. We will consider the *Primary* sources in detail:

Cepheid Variable stars: Those stars that evolve off from the Main sequence strip on a Hertzsprung-Russel diagram into the Cepheid instability strip[2] are called as Cepheid Variable stars. The Type I Cepheid variable stars usually are classified as having a pulsation period from many weeks to many months, while Type II Cepheid variable stars have a greater frequency, up to approximately two months, which provides a quicker and simpler method to measure distances. These stars are usually used to give a precise measurement from the observer to the galactic core, a result of the fact that these are often found near the galactic centre.

Type IA Supernovae: These are highly periodic, and these occur in white-dwarfs, when the energies are sustained from a binary partner so that the heavier companion can reach energies high enough for the (C)N-O process to be

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[2] There is a certain set of stars in the H-R diagram, the RR Lyrae stars that also lie on this strip, see the RR Lyrae section

continued to form radioactive Nickel, specifically ^{56}Ni. Their brightness and their periodicity are used to find the trigonometric parallax, and therefore in the measurements of distances. The variations and possible interferences of the binary companion has been put aside as the exploding star has masses close to the *Chandrasekhar limit*, therefore being simpler to deduce. Also, the thermonuclear explosion is very bright, and this makes them ideal for use as distance indicators, and these are often visible up to 10^{10} parsecs.

Eclipsing Binaries: Many star systems are found in Binary groups, and frequently they "eclipse" each other for a certain period of time. This causes an intensity fluctuation, and the velocity of the system can be constructed from the Spectral-Doppler shift. Further, the time range for which the eclipse occurs can be used to measure the radius, and then by further calculations using the Steffan-Boltzmann law, we can calculate the *Absolute luminosity*.

RR Lyrae stars: These Population II stars have been used as distance indicators for many years, and their primary feature is their periodicity, which is a mere couple of hours. Although they lie around scattered the Cepheid instability strip, their chemical composition and locations are different. Their chemical composition is usually metal poor, and their locations are throughout a galaxy, instead of the nature of usual Cepheid variable stars, which are found close to the galactic core. There are three types of these stars, RRab, RRc and RRd, in the order of decreasing numbers. Although these are quite ideal for use as distance indicators, these are mostly used for closer objects.

These are primarily related deeply to purely observational values, while we will now discuss *secondary* indicators:

Surface Brightness relation: In 1988, Tonry and Schneider constructed a very simple measurement idea. By considering the intensity fluctuations from a certain stellar object, it can be evaluated to measure the distance of that object. By considering the light intensity from different parts of the object, and the fluctuations, we can measure the apparent distance-intensity drop. Also, since the intensity from each part of the galaxy can be different, it is easy to note that these fluctuations can be used to mark the "depth" of each part, thereby making this method easy to use to measure distances.

Tully-fisher relation: In 1977, Tully and Fisher developed a method to approximate the absolute luminosity of ideal spiral galaxies. The usual width of the *absorption* spectra (or the emission line width) is lengthened by the rotation of the galaxy, a result of the Doppler Effect. The increment can be used to find the rotational speed of the galaxy, thereby an indication of the mass, which in turn can be used to find the luminosity.

One very important relation is the relation,

$$l = \frac{L}{4\pi d^2}$$

Here, l denotes the apparent luminosity, while L the absolute luminosity, and d the distance.

Faber-Jackson relation: This is a very simple relation which follows from the *Virial theorem* and relates the luminosity and the stellar luminosity dispersion, and can be used to find distances. Quite similar to the Tully-fisher relation, the only change is in the use of velocity dispersion instead of the rotation of parts, and also follows from the Doppler Effect. Mathematically, we can write the expression,

$$L \propto \sigma^{\gamma}$$

Galactic distance measurement projects

There have been numerous projects that have determined up to a remarkable precision the expansion of the Universe. For instance, the first project that used the Tully-fisher relation gave a present Hubble value of

$$H = 71 \pm 5 \; km \; s^{-1} \; Mpc^{-1}$$

Eventually, the HST Key project gave a much more precise value of

$$H = 71 \pm 3 \pm 7 \; km \; s^{-1} \; Mpc^{-1}$$

Where the first uncertainty is the statistical count, while the second is the *systematic* count. The HST Key project relied on calibration from the Cepheid relation.

There have been many other projects, whose values are slightly less precise as compared to the now agreed HST Key project value. For instance, the *Supernova Cosmology project* identified the Hubble value as

$$H = 67 \; km \; s^{-1} \; Mpc^{-1}$$

Which relied on many Type IA Supernovae to yield this result, although many other values have also been measured, such as one of the most recent ones, which gave a Hubble value of

$$H = 62 \; km \; s^{-1} \; Mpc^{-1}$$

This is among the many results of using Type IA Supernovae. Also, the Faber-Jackson relation has been further extended to the *Fundamental plane* relation, which yields a result of

$$H = 78 \; km \; s^{-1} \; Mpc^{-1}$$

Some points that have been considered key are:

1. The Cepheid Periodicity-Luminosity relation, which labelled Cepheid variable stars as “Standard Candles”, and are ideal to map the distance to galaxies, and this is somewhat based on the Cepheid stars in the LMC.
2. Some galaxies used in the HST Key were those which housed Cepheid variable stars, because of their ideal nature as Standard Candles. The following have been considered:

NGC 224, NGC 300, NGC 598, NGC 925, NGC 1326A, NGC 1365, NGC 1425, NGC 2090, NGC 2403, NGC 2541, NGC 3031, NGC 3198, NGC 3319, NGC 3351, NGC 3368, NGC 3621, NGC 3627, NGC 4258, NGC 4321, NGC 4414, NGC 4496A, NGC 4535, NGC 4536,NGC 4548, NGC 4639, NGC 4725, NGC 5253, NGC 5457, NGC 7331, IC 1613, IC 4182

3. There had been considered a total of 31 different galaxies for the HST Key project, and many were considered along secondary source parameters, for instance, most considered the Tully-fisher relation, while some considered Type IA Supernovae measurements.

4. Some considered additional calibration, like the consideration of the fundamental plane, and this was for FP-Leo, FP-Virgo and FP-Fornax.
5. Systematic sources of uncertainty have lied in despite the consideration of many considerations, both from ground based telescopes and from the HST, and although these have been attempted at to be calibrated, there are still significant sources of uncertainty in the calculation of H.

In some considerations, each of these sources have some advantage over the other. For instance, the problem of Luminosity evolution proves that the Type IA Supernova distance measurement methodology is better than that of smaller Standard Candles. Also, the Tully-fisher relation is one of the easiest ways to efficiently[3] measure distances, and has been used as a secondary measurements uncertainty counting parameter in the HST Key project.

Metallicity and gravitational lensing also are important in considerations to prevent any additions of errors. Further, observational inconsistencies such as Photometric corrections, Redshift errors, Light curve shape and selection effects are also differences that pose potential problems to the observation-measurement inequalities. So, there is still a lot to consider before the statistical and systematic errors and uncertainties can all be removed from a given observation, and we are making progress on doing so.

Further: measurements and the acceleration of the Universe

The Supernovae Cosmology project considered 42 Type IA Supernovae, and data shows the following values:

$$\Omega_M = 0.28^{+0.09}_{-0.08}(stat.)^{+0.05}_{-0.04}(syst.)$$

When considering data, we usually measure the age after setting the Redshift $z = 0$. We read the following relation:

$$t = \int_0^1 \frac{ds}{x\sqrt{\Pi}}$$

And here, Π is defined as:

$$\Pi = \Omega_\Lambda + \Omega_K x^{-2} + \Omega_M x^{-3} + \Omega_R x^{-4}$$

As we are considering the Cosmology to be "*flat*", we set $\Omega_K = \Omega_R = 0$, and by considering the above relation for look-back time and age relation, we get the age of the Universe (under quoted statistical and systematic uncertainties) as:

$$t = 13.4^{+1.3}_{-1.0} \times \left(\frac{70 \times 10^9}{H}\right) yrs.$$

The units of the terms in the bracket have the dimensions $km\ s^{-1}\ Mpc^{-1}$.

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[3] Here by efficiently we mean quickly and comparatively accurate. Measurements of Type IA Supernovae in distance measurements stands out as one of the most prominent distance measurement sources because of their periodicity and intensity parameters being ideal even to be viewed from a large distance away, and this classifies them "efficient". The Tully-fisher still is somewhat comparatively secondary than Type IA Supernovae, but still is considered widely.

Now, we can calculate the deceleration parameter from the equation,

$$\Omega_\Lambda + \Omega_M = 1$$

And by setting $\Omega_M \approx 0.28$, we can find out the value of the deceleration parameter (depicted as q) to be ≈ -0.5, meaning that the Universe is accelerating. These observations are based on the Supernovae-Cosmology project, and through these measurements, we can safely say that distance indicators and Cosmological parameter measurement relations are two very close results, and that we have been able to answer the following major questions in Cosmology:

1. Is the Universe expanding?
2. With what acceleration is the Universe expanding with?
3. How can we measure distances in Cosmology so as to be able to measure expansion?
4. What are the problems we may face using a stellar source of distance measurement?
5. How can we get around these problems?
6. How can we measure collective stellar objects to find the expansion of the Universe?

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