Origin (?) of the Universe

2. The Expanding Universe

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The expansion of the universe was established based on observations made in the 1920's, of the Doppler shift of light from galaxies. The proportionality between velocity and distance is the famous Hubble Law. Simplified mathematical models of the universe are based on the idea, which is supported by observations, that there are no preferred locations or directions in space.

Hubble's Law

By the beginning of the present century, astronomers had two important sources of information. Photographic plates more efficient than the human eye supplied images of faint objects while spectrographs analysed the light forming these images into components of different wavelengths. Before proceeding to Hubble's Law let us note how these two sources of information helped early extragalactic astronomy.

The spectra of nebulae were first investigated in 1864 by William Huggins by visual inspection. Only the continuous distribution was clearly visible; the lines, if any, were too faint to be detected. The brightest of the nebulae, M31, was subsequently investigated in detail. (M31 is the catalogue number of the galaxy in the compilation made by Charles Messier). In 1899, J Scheiner established the presence of absorption lines in the spectrum of M31, although he was unable to measure their precise wavelengths.

This six-part series will cover: 1. Historical Background. 2. The Expanding Universe. 3. The Big Bang. 4. The First Three Minutes. 5. Observational Cosmology and 6. Present Challenges in Cosmology.

The breakthrough was made in 1912 by V M Slipher at Lowell Observatory, using a fast camera attached to the observatory's 24-inch refracting telescope. When Slipher measured the wavelengths of the absorption lines in M31, he found a somewhat unexpected result. The spectral lines appeared to be displaced from their natural locations, their observed wavelengths being systematically shorter than the expected (signature) values. The shift was thus towards the violet end of the spectrum. M31 was however the odd one in a steadily growing list of nebulae studied by Slipher, for, by 1925, Slipher's list of such shifts of absorption lines in the spectra of nebulae like M31 had grown to forty one, and it had become clear that the general rule was of a shift in the opposite direction, towards the red end of the spectrum. Such a *redshift* may be defined quantitatively as the fractional increase in the original wavelength.

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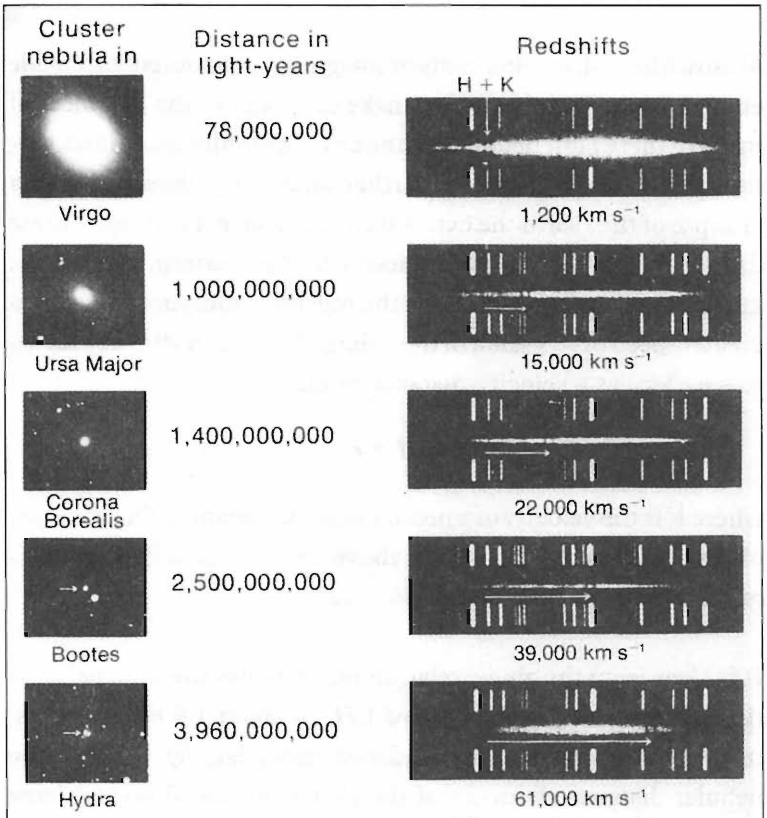


Red-shifts are expressed as velocities, $c\,d\lambda/\lambda$. Arrows indicate shift for calcium lines H and K. One light-year equals about 9.5 trillion kilometers, or 9.5×10^{12} kilometers.
Distances are based on an expansion rate of 50 km/sec per million parsecs.

Figure 1 Redshift-Faintness Relation : Hubble's observations demonstrate how (as we go down the figure) for fainter and fainter galaxies (shown on the left), the shift of absorption lines in the spectra (shown on the right) increases. Hubble converted faintness into distance of the galaxy, and spectral shift into its radial velocity, to arrive at a velocity distance relation.

Physicists already had an explanation for such spectral shifts. First discovered by the Dutch physicist C Doppler (1803-54) in the case of sound waves, the explanation is equally applicable to light waves. The shifts are expected to occur whenever there is a relative motion between the source and the observer. If the relative motion is one of recession, a redshift is observed: if it is of approach, there will be a violetshift. The magnitude of the redshift can be used to calculate the speed of recession of the source. Edwin Hubble and his young colleague Milton Humason carefully analysed the data on spectral shifts. In particular, before deciding whether a distant nebula was approaching or receding from our galaxy, they corrected for our own motion relative to the galactic centre (recall that the earth moves around the sun, which in turn moves around the galactic centre).

Looking at his distance estimates, Hubble noticed a definite pattern: the greater the distance, the larger the redshift, and hence greater the speed of recession of the nebula. In 1929 Hubble expressed this pattern as a velocity-distance relation.

Meanwhile, using other tools of imaging, astronomers had made enough progress to be able to make estimates of the distances of many of these faint nebulae. Using an (admittedly crude) assumption that a fainter object is farther away, they thus had a first glimpse of the size of the extragalactic universe. Looking at these distance estimates, Hubble noticed a definite pattern, namely, the greater the distance, the larger the redshift, implying therefore a greater speed of recession of the nebula. Hubble in 1929 expressed this pattern as a velocity-distance relation:

$$V = H \times r$$

where V is the velocity of a nebula and r its distance. The constant of proportionality, H, in the above relation is called ***Hubble's constant***, and the relation ***Hubble's law***.

It is clear from the above relation that $1/H$ has the dimension of time. Hubble's own estimate of $1/H$, of about 1.8 billion years, turned out to be a gross underestimate, largely because the nebular distance estimates of the 1920's contained several large systematic errors. The present estimates of $1/H$ are in the range of 10 to 15 billion years.

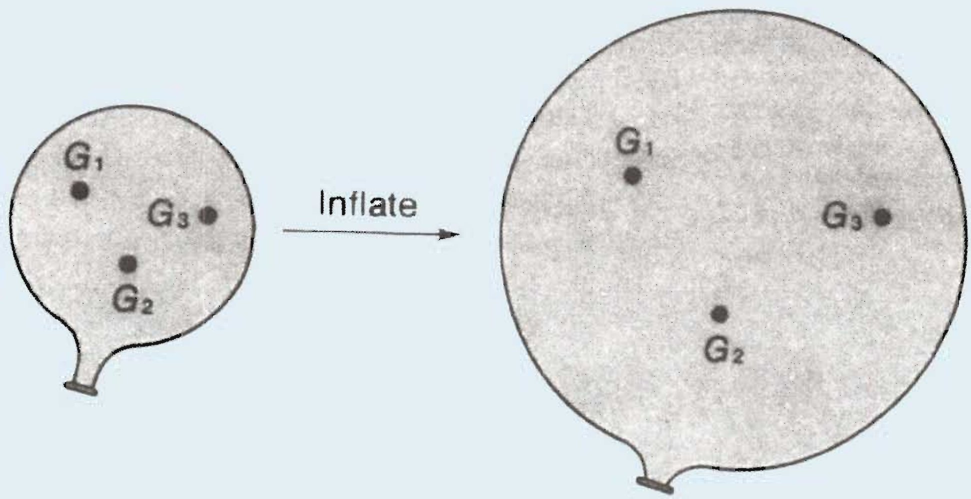
The Expanding Universe

The velocity-distance relation which Hubble obtained originally from observations of eighteen nebulae has since been determined for a much larger number of galaxies out to distances more than several hundred times greater than those in his original sample. The phenomenon of the redshift and its relationship to distance appears to hold. So we have *prima facie* evidence that other galaxies appear to be rushing away from our own. Have we finally arrived, then, at a situation which singles out our location in the universe as a somewhat special one?

No. A little reflection on the velocity-distance relation will assure us that there is nothing special about our location. Observers viewing the galactic population from another galaxy will find the same law as Hubble, with all galaxies rushing away from their own.

The expanding universe exhibits two important properties: there are no privileged positions and no preferred directions.

Figure 2 The Expanding Universe: An anology explaining this phenomenon is that of a balloon with dots G_1, G_2 ... on it. As the balloon is blown up the dots move away from one another. Each dot may 'think' that the others are receding from it.



As we inflate the balloon, the dots G_1, G_2, and G_3 on its surface move away from each other. Yet, no dot can claim a privileged site on the spherical surface.

Weyl's postulate assumes that the large scale motion of typical units, the galaxies, is highly streamlined. This serves as a reasonable first approximation.

To appreciate this remark, imagine the universe as a lattice structure, with galaxies occupying the lattice points. Suppose now that the entire lattice expands. All points of the lattice will therefore move away from one another, with no particular point occupying a preferred position. This analogy helps us to visualize the oft-repeated statement that the universe is expanding.

The expanding universe exhibits two important properties: there is no privileged position, as we just mentioned, and no preferred direction. Observers brought blindfolded to any location cannot, on removing their blindfolds, tell where they are or in what direction they are looking! Perfect democracy prevails in this universe. This is the kind of symmetry that Aristotle would have liked! But how does his modern counterpart in theoretical cosmology deal with the question of modelling the universe?

Mathematical Models: Basic Assumptions

The concept of an expanding universe can be quantified by using two simplifying assumptions. The first is the so called *Weyl postulate* which assumes that the large scale motion of typical units, the galaxies, is highly streamlined. Thus, there is no randomness, no collisions in the way galaxies are supposed to

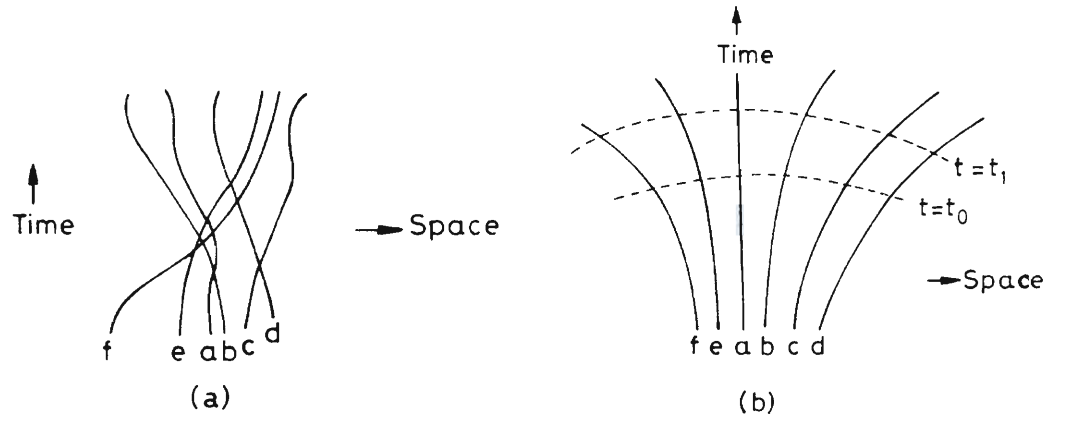


***Figure 3** The Weyl Postulate : A streamlined motion of galaxies shown in (b) may be contrasted with chaotic motion in (a). The former permits us to identify a cosmic time coordinate t. In (b) the streamlines of motion cut orthogonally across surfaces of constant cosmic time.*

move. As we will see later, this idealized situation does not faithfully represent the real universe but servcs as a reasonable first approximation.

The Weyl postulate enables us to identify a unique time coordinate for the *entire* universe. Just as in a wide column of soldiers marching in strict order, we can identify soldiers in the same row, so we can identify galaxies at the same cosmic epoch. This time '*t*' is called the cosmic time.

The second assumption, known as the *cosmological principle*, states the symmetry referred to earlier. In scientific jargon we say that at any given cosmic time the universe is *homogeneous* and *isotropic*, which means that all locations in the universe have physically identical properties, and the universe looks the same in all directions, when viewed from any location.

In the next part of this series we will investigate the models that are based on these simplifying assumptions.

Suggested reading

H Bondi. Cosmology. Cambridge University. 1960.
J V Narlikar. The Lighter Side of Gravity. W H Freeman and Co. 1982.
F Hoyle. Astronomy and Cosmology - A Modern Course. W H Freeman and Co. 1975.

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Pablo Picasso said ... "So how do you go about teaching something new? By mixing what they know with what they do not know. Then, when they see in their fog something they recognise, they think 'Ah, I know that!'. And then it is just one more step to 'Ah, I know the whole thing!' And their mind thrusts forward into the unknown and they begin to recognise what they did not know before and they increase their powers of understanding".

S E Luria observes ... (in *A Slot Machine, A Broken Test Tube, An Autobiography*): "The image of the impartial scientist uncommittedly weighing the various alternatives is a gross simplification. Scientists, like everyone else, have opinions and preferences in their work as in their lives. These preferences must not influence the interpretation of data, but they are definitely an influence on their choice of approaches.