The Hubble effect

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Abstract

"Hubble's law" is the linear relation between the logarithms of redshifts of distant cosmic bodies and their apparent magnitudes. There is not yet a satisfactory physical explanation to this law. I propose that the "Hubble effect" — yet to be elucidate — be the physical mechanism responsible for Hubble's law. Accordingly, I put forward a tentative scientific guide for the discovery of such an effect. In this context, it turns out to be very useful a discussion of the heuristic description of the photoelectric effect made by Albert Einstein.

Keywords: Hubble's law, redshifts, tired-light paradigm, cosmology

1 Introduction

The American astronomer Edwin Powell Hubble (1889-1953) systematized and concluded the research about redshifts of distant galaxies, which was realized by himself and several astronomers during the first decades of the 20th century. The empirical relation between galaxy redshifts and their apparent brightness became known as "Hubble's law". Such a relation is applied to a certain class of objects, namely, those that have the same intrinsic luminosity. For example, Hubble's law for the *brightest galaxies of clusters* is very well

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illustrated in Fig. 1. There, one sees photographs of the brightest galaxies of five clusters of galaxies side by side with their spectra.

The observational data available from Fig. 1 are redshifts z — obtained straight from the spectra — and the apparent magnitudes of the galaxies — obtained straight from the photographs.

Assuming that all of the brightest galaxies of clusters have the same intrinsic luminosity, i.e., the same absolute magnitude, their distances can be calculated. The data shown in Fig. 1 are consistent with a direct proportionality between "velocities" and distances r, that is, Hubble's law:

$$v = H_\circ r, \tag{1}$$

where the constant of proportionality $H_\circ$ is called "Hubble's constant". Such an expression, nevertheless, is not the one which relates the observational data. The observational expression of Hubble's law is given by

$$m = 5 \log cz + \text{ constant}, \tag{2}$$

where m is the apparent magnitude (see Hoyle et al. 2000, Figs. 3.1 and 3.2, Eq. 3.1, pp. 20-22).

The linear relation given by Eq. 1 was presented by Hubble for the last time in 1953 (Hubble 1953), the same year that he passed away. In the article, there is data from other clusters, besides those shown in Fig. 1, but the farthest galaxy is still the galaxy in the *Hydra* cluster, with $z = 0.20$.

Hubble adopted the conversion of z into velocity through the formula of the classical Doppler shift, but he considered it as an "apparent" velocity. In other words, he did not really believe that the redshift of a galaxy was caused by its motion of recession from us, which would justify the use of the Doppler shift expression. Contrary to what is presented in textbooks and in popular presentations of cosmology, Hubble did not accepted the idea of an expanding universe. He had many reasons for that — all of them motivated by his observational work. A detailed discussion of such a characteristic of Hubble's thought was made by Assis et al. (2008).

One of the most strong reasons considered by Hubble was the question of the age of the universe. For an expanding universe, its age is approximately given by the inverse of Hubble's constant — note that Hubble's constant has the physical dimension of the inverse of time. Using the value of Hubble's constant known up to the year of his death, 1953, the age of the universe resulted smaller than the geological age of Earth. That was a sign that Hubble,

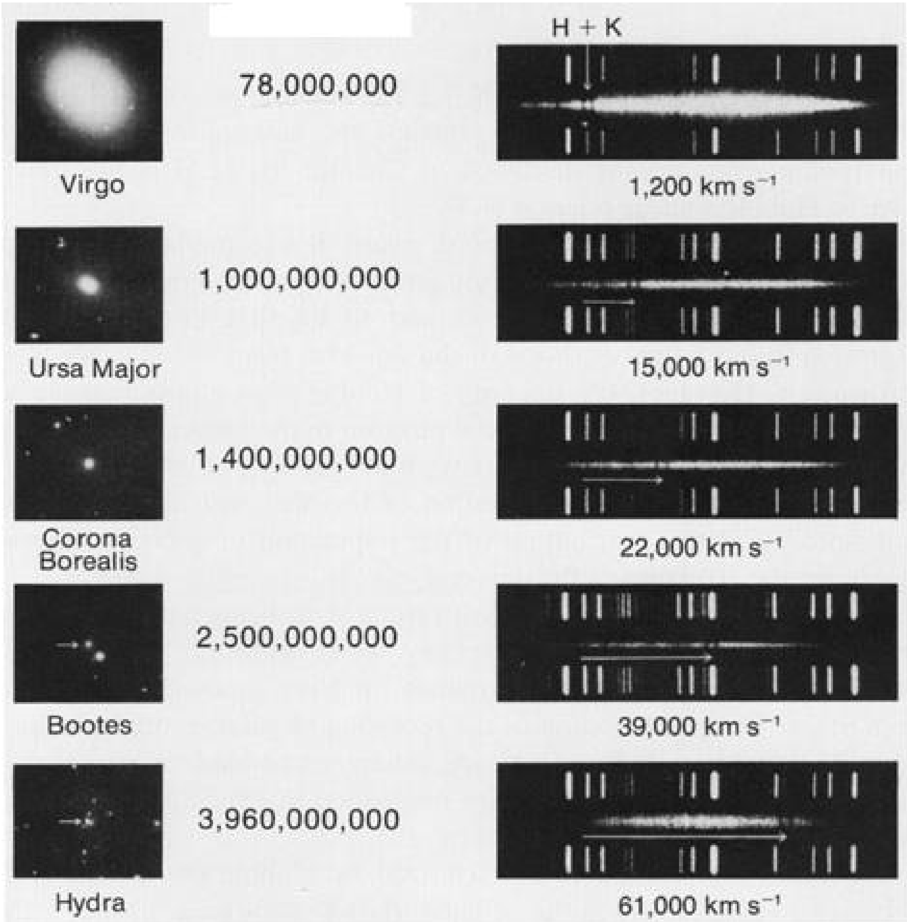

Figure 1: Photographs, distances and redshifts for the brightest galaxies of clusters of galaxies. Galaxies are identified by the names of the clusters where they sit in. Distances, in the middle column, are given in light-years. Arrows, in the central section of each spectrum, indicate the shifts of lines H (λ =3968 Å) and K (λ =3934 Å) of the chemical element calcium — in its first ionization state, or CaII ("calcium two", in the astronomical jargon). The shifts are measured with respect to the same spectral lines observed from a stationary source in the laboratory. Redshifts $z = \Delta\lambda/\lambda$ are indicated below each spectrum as velocities, calculated with the expression of the non-relativistic Doppler shift $v = cz$, where c is the speed of light in vacuum (Figure: Palomar Observatory, California Institute of Technology, United States).

a scientist extremely aware of the value of observational and experimental data, could not ignore.

2 Redshift and velocity

The Standard Model of Cosmology (SMC) — also known as the Big-Bang model — gives the function $v(z)$, which can be inserted in Eq. 2.

In what follows, I show how the SMC transforms Eq. 2 into the popular equation $v = H_\circ r$ (Eq. 1).

As an example of the expected result from the SMC, I shall use the critical Friedmann model (flat spatial geometry; see de Souza 2004, chaps. 2 and 3, and Harrison 2000, chaps. 14 and 15). Redshift is caused by the expansion of space. The space-time in relativistic theories, i.e., derived from the Theory of General Relativity, is characterized by a metric that can vary with time. Thus, in Friedmann's models the space expands. Such an expansion is an intrinsic property of the space itself, not related to anything external. The value of z depends on the expansion velocity, as illustrated in Fig. 2. It is worthwhile mentioning that the expansion velocity can be larger than the speed of light in vacuum.

For the Friedmann model, there are two possible functions: the observed value of z can be associated to the expansion velocity of the universe at the instant of time in which the light was emitted, or to the expansion velocity at the instant in which the light was detected. Fig. 2 shows the last one, identified as *Friedmann "now"* (see this same curve in Fig. 1 of Bedran 2002, where a comparison between the relativistic Doppler and cosmological redshifts is made).

Fig. 2 shows also, for comparison, the expected functions $v(z)$ from the Doppler effect — classical and relativistic. In the Doppler effect, the redshift is caused by the motion of recession of the light source.

Hubble presented, for the first time, the relation given by Eq. 1 in 1929 (Hubble 1929), and later increased the range of redshifts (Hubble 1936). The article of 1929 is generally considered as the discovery article of Hubble's law, although recently there has been much dispute over this (e.g., Livio 2011 and references therein).

Fig. 3 shows the same curves of Fig. 2 but now for the interval $0 \leq z \leq 0.1$. In this range of z, all functions $v(z)$ can be written as:

$$v(z) \simeq cz. \tag{3}$$

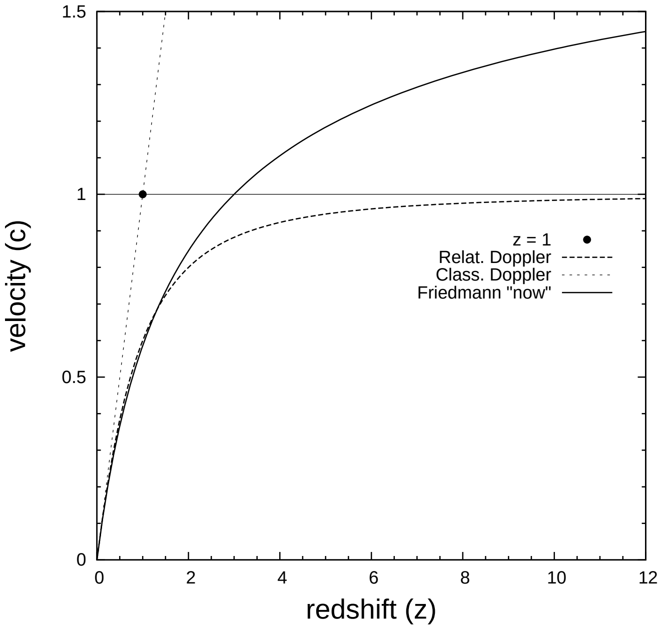

Figure 2: Functions $v(z)$ for the Friedmann model and for the Doppler shift. The curve identified as *Friedmann "now"* represents $v(z)$ corresponding to the expansion velocity of the universe prevalent at the instant of light detection. Note that the expansion velocity can be larger than the speed of light c.

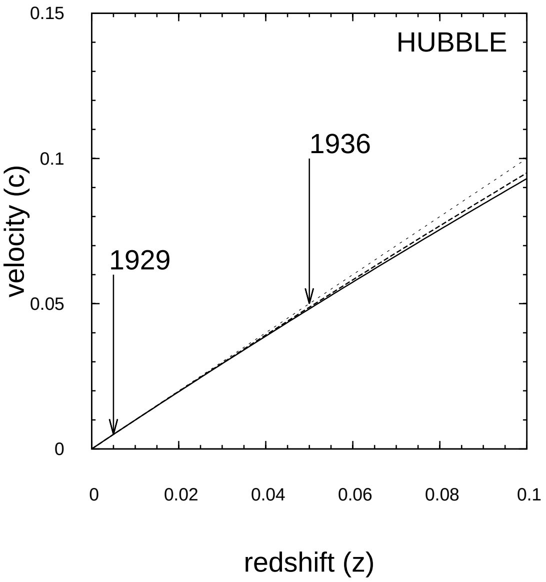

Figure 3: Functions $v(z)$ of Fig. 2 are shown in a restrict range of redshifts, $0 \leq z \leq 0.1$. Arrows indicate the maximum values of z presented by Hubble in his articles of 1929 and 1936. Note that the three functions do not substantially differ in that range of redshifts.

In the case of the classical Doppler shift we have $v(z) = cz$ exactly.

Hubble's law is only valid for redshifts much smaller than unity ($z \ll 1$), i.e., those considered in Fig. 3. In this range of z, the Friedmann model may, therefore, be approximated by $v(z) = cz$.

In order to get Eq. 1 from Eq. 2, we have to use the approximation $v(z) = cz$ and the definition of apparent magnitude m. In terms of the absolute magnitude M and of the distance r, the apparent magnitude is given by:

$$m - M = 5\log r - 5, \text{ or}$$

$$m = 5\log r + \text{ constant.} \tag{4}$$

By inserting Eq. 4 and $v(z) = cz$ in Eq. 2, we get $v = H_\circ r$. Consequently it becomes evident that Hubble's law is *consistent* with a model of expanding space.

The trouble is that the model of the expanding universe, described by the SMC, *is not proved by the observations*. In order that such a model be valid it is necessary to admit the existence of substantial quantities of *dark matter* — that is, undetected matter — and of a *dark* component of non electromagnetic energy. Only 0.5% of the total content of mass and energy of the universe are directly observed; a summary of the amounts of matter and energy in the universe, according to the SMC, is described in Soares (2002). *Dark energy* has non trivial properties and would be responsible for the accelerated expansion of the universe, prevailing at the current cosmic epoch. The reality of the accelerated expansion is also questionable. A discussion of this issue is presented in Soares (2009).

In conclusion, the SMC is not completely satisfactory for the explanation of Hubble's law, as seen above. It turns out to be perfectly reasonable, then, the search for a physical mechanism that offers an alternative to that explanation.

3 A physical mechanism for Hubble's law

Hubble's observations are consistent with the idea of an expanding universe, but they are not necessarily a proof of it. Hubble himself was aware of that and searched during all his life the correct answer for the question raised by his discovery: what does cause redshifts? (Assis et al. 2008).

A possibility considered by him was the so-called *tired-light paradigm*. This was originally conceived by one of the greatest friends of Hubble's, Fritz Zwicky (Zwicky 1929). We shall seek, therefore, a physical mechanism — the *Hubble effect* — valid for the tired-light paradigm. Generally speaking, the tired-light paradigm states that light looses energy — its wavelength increases —, when it "travels" from the source to the observer.

What physical mechanism could be this one?

At this point, it is worthwhile remembering what happened in the past, in a similar situation, when Einstein put forward a heuristic interpretation of the *photoelectric effect*. One can make here a very useful counterpoint to the path for the discovery of the mechanism responsible for the Hubble effect.

Einstein's heuristic model was based on the following experimental evidences (see discussion in Stachel 1998, p. 36):

(a) the effect does not depend on the intensity of the source of radiation;

(b) the blackbody radiation, for short wavelengths, is described by Wien's limit;

(c) the blackbody radiation, for large wavelengths, is described by the Rayleigh-Jeans distribution.

The items (b) and (c) were incorporated in Planck's explanation of the blackbody radiation, which also introduced the *quanta* of energy in physics. Such a conception led Einstein to the idea that light consists of quanta of energy, and from there to the explanation of the photoelectric effect (Stachel 1998, p. 217). However, in 1905, Einstein did not use the complete distribution law of radiation for the blackbody, obtained by Planck in 1900, to the formulation of his model for the photoelectric effect (cf. Stachel 1998, p. 37).

A heuristic program for the Hubble effect might, in a similar manner, contemplate the following observational evidences:

(a) the effect depends on the flux of the source of radiation according to Hubble's law, given by Eq. 2;

(b) the redshift does not depend — or, has a very weak dependence — on the wavelength of the radiation;

(c) the effect is quantized (Tifft 2003, Arp 1998 and references therein);

(d) the effect does not cause light scattering which is, in general, selective, i.e., wavelength-dependent. Otherwise, images of distant extended sources would be "blurred", as if they were out of focus, which is not observed (cf. Harrison 2000, p. 312).

In general, it is not observed large discrepancies in the redshift of a distant source, with respect to the measured wavelength (e.g., Sandage 1978 and Rood 1982, where redshifts in the optical and radio wavelengths are studied). The fact that z be independent of λ is a characteristic both of the SMC — z is a consequence of the expansion of the space — and of the hypothesis of the Doppler effect — $z = v/c$. One should not discard, nevertheless, the possibility that there is a small dependence of z with λ, which would be an interesting feature of the putative Hubble effect.

We have, therefore, a program that would certainly open up the way to a satisfactory physical theory for the tired-light paradigm, in other words, to the discovery of the Hubble effect.

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