Lemaître and Hubble: What was discovered – if any – in 1927-29?

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The Big Bang predicted theoretically by Friedmann could not be discovered in the 1920th, since global cosmological distances (more than 300-1000 Mpc) were not available for observations at that time. In 1927-29, Lemaître and Hubble studied receding motions of galaxies at local distances of less than 20-30 Mpc and found that the motions followed the (nearly) linear velocity-distance relation, known now as Hubble's law. For decades, the real nature of this phenomenon has remained a mystery, in Sandage's words. After the discovery of dark energy, it was suggested that the dynamics of local expansion flows is dominated by omnipresent dark energy, and it is the dark energy antigravity that is able to introduce the linear velocity-distance relation to the flows. It implies that Hubble's law observed at local distances was in fact the first observational manifestation of dark energy. If this is the case, the commonly accepted criteria of scientific discovery lead to the conclusion: In 1927, Lemaître discovered dark energy and Hubble confirmed this in 1929.

1 Introduction

It has seemingly been taken for granted that in 1929 Hubble discovered exactly what Friedmann predicted several years before, in 1922 (see, for example, "The brief history of time"by Stephen Hawking [1], a book issued in a number of copies which is much larger than the total number of copies of all other books on cosmology ever published). A book by Alexander Sharov and Igor Novikov declares in its title: "Edwin Hubble, the Discoverer of the Big Bang Universe"[2]. Einstein was among the first physicists and astronomers who adopted or shared this view (but not Friedmann who died in 1925).

A non-traditional point was however made by Steven Weinberg in "The First Three Minutes"[3]: "Actually, a look at Hubble's data leaves me perplexed how he could reach such a conclusion – galactic velocities seem almost uncorrelated. In fact, we would not expect any neat relation of proportionality between velocity

and distance for these 18 galaxies – they are all much too close, none been further than the Virgo Cluster. It is difficult to avoid the conclusion that... Hubble knew the answer he wanted to get."

In [1-3], Lemaître is not given any credit for the linear velocity-distance relation (the very his name cannot be found in [1]), though the discovery of the relation is explicitly reported in his 1927 paper long known to many cosmologists. The observational data he used (especially as presented in a velocity-distance diagram [4]) look somewhat more scattered than that in Hubble's diagram of 1929. So Weinberg's challenge extends equally to Lemaître's result as well.

Contrary to Weinberg, Alan Sandage, who was Hubble's successor in observational cosmology on Mount Wilson and Mount Palomar, accepted Hubble's law for local galaxies as an important well-established empirical fact. He had however doubts about its cosmological interpretation [5-7].

The recent debate on the history of Hubble's law [4,8-11] revives interest to earlier controversial views [1-3,5-7] and rises again a question on the essence of the matter: What was actually discovered – if any – in 1927-29?

2 Paradox

Sandage's argument [5-7] of 1972-99, was, in brief, as follows. Friedmann's cosmology describes a Universe which has the uniform (homogeneous) matter distribution and expands in accordance with the linear velocity-distance relation. The linearity and the uniformity are linked: the matter distribution may be uniform and preserve its uniformity, if and only if the expansion velocity is directly proportional to the distance at any moment of time. The observed Universe is indeed uniform on average over spatial scales of more than 300-1000 Mpc which is the size of the cosmic cell of uniformity. Friedmann's cosmology is applicable to such large distances only, and it says nothing about local spatial scales of less than 2-3 Mpc (or 20-30 Mpc, as it became clear after the distance revision made by Sandage in the late 1950th).

Does it mean that Hubble's law has nothing in common with global cosmological expansion?

Note that not only in cosmology, but also in dynamics of gravitating medium in general, the linear velocity-distance relation assumes uniformity of matter distribution and vice verse. Therefore one should expect matter uniformity in the area where the velocity-distance linearity is observed. But the real matter distribution is highly non-uniform on local scales of a few dozen Mpc.

Sandage introduced the notion of "expansion flows"for systems of receding galaxies with nearly linear velocity-distance relation to describe the observational situation in most obvious way. When deviations from linearity (velocity dispersion) are small, the flow is considered "quiet". The quietness of expansion flows has repeatedly been confirmed in increasingly precise observations both inside and

outside the cosmic cell of uniformity. In 1999 [7] and again in 2006 [12], Sandage (together with his collaborators) reported that expansion flows were quiet in the distance interval from a few Mpc to the global cosmological scales. It is especially puzzling that the rate of expansion (the velocity-to-distance ratio known as Hubble's factor in cosmology) is the same within 10-15% accuracy for all these distances and for the global expansion as well.

How may this be possible, if local flows have nothing in common with cosmology?

Thus, Sandage pointed out a paradox: 1) Linear flows are observed inside the cosmic cell of uniformity where the matter distribution is highly non-uniform and such flows cannot exist. 2) The expansion rates of the local flows are practically the same as in the Universe as a whole.

In 1999, 70 years after Hubble, Sandage concluded: "We are still left with the mystery"[7]. A year later, in 2000, a solution to the paradox was suggested [13]: 1) Local flows of expansion are nearly linear due to dark energy. 2) Omnipresent dark energy dominates the dynamics of both local and global flows and makes their expansion rates be (almost) identical.

Sandage and his colleagues commented this suggestion in 2006: "No viable alternative to vacuum [dark] energy is known at present. The quietness of the Hubble flow lends support for the existence of vacuum energy"[12].

3 Dark energy in quiet flows

Dark energy was discovered in 1998-99 at largest horizon-scale cosmological distances [14,15]. It contributes about 3/4 to the total mass/energy balance of the observed Universe as a whole. Its microscopic structure is completely unknown – this is considered as the most severe problem of fundamental physics and astronomy of the 21st century.

In macroscopic description, dark energy may adequately be treated as a vacuum-like perfectly uniform fluid which produces antigravity. The observed effective (anti)gravitating density of dark energy is 6 times the gravitating mean cosmic matter (dark matter and baryons) density for the Universe as a whole at the present epoch. Because of this dark energy controls (mainly) the observed global cosmological expansion and makes the Universe expand with acceleration. These are the key features of the currently standard ΛCDM cosmological model in which dark energy is represented by Einstein's cosmological constant Λ.

In [13] (see also [16-22]), it was demonstrated that dark energy could act and even dominate not only globally, but also locally, inside the cosmic cell of uniformity. Since dark energy exists everywhere and has a perfectly the same density in any point of space, it makes the whole world more uniform on local scales. The effect is strong in low-density areas outside large matter overdensities such as groups and clusters of galaxies. Local expansion flows are observed just

in such low-density areas. In these areas, flow galaxies move (almost) as "test particles"on the dynamical background dominated by dark energy.

In terms of hydrodynamics, if dark energy dominates dynamics of expansion flows, it brakes the hard link between the kinematics of the flows and the matter distribution in them and around. Because of this, a highly non-uniform matter distribution becomes compatible with the quietness of an expansion flow. In this way, the first aspect of the paradox above is eliminated. The second aspect is also resolved since dark energy dominates both local and global flows. The local and global flows do not "know"about each other, but the both are (mainly) controlled by the same physical agent which is omnipresent perfectly uniform dark energy.

Quantitatively, when dark energy dominates, the expansion rate (both local and global) is determined (mainly) by dark energy only; as a result, the rate should be close to the universal value $H_\Lambda = (\frac{8\pi}{3}\rho_\Lambda)^{1/2} \simeq 60$ km/sec/Mpc, where ρ_Λ is the density of dark energy measured in global observations [14,15]. According to the ΛCDM model, the observed global expansion rate is $H_0 = 70 - 72$ km/s/Mpc. The local rate found recently by Sandage and collaborators [12] is $H = 63$ km/s/Mpc for the distance interval from 4 to 200 Mpc. Both rates (measured with the accuracy of about 10%) are indeed close to the universal value H_Λ, and because of this they prove to be close to each other.

Interestingly enough, the relation above together with the observed local expansion rate H might be used to estimate (approximately) the dark energy density: $\rho_\Lambda \sim \frac{3}{8\pi}H^2$. With the local figure for H from [12], the dark energy density estimated in this way is very close (if not exactly equal) to the value measured at the horizon-scale distances. Note that such an approximate evaluation of the dark energy density might be made even in 1927-29 with the use of the observed expansion rates (though overestimated at that time).

4   The very local flow

Karachentsev and his collaborators [23] have recently found (with the use of the HST) a nearly linear velocity-distance relation in the "very local"flow of dwarf galaxies at distances less than 3 Mpc from us. Well studied both observationally and theoretically (see [24] and references therein), the flow presents a good (and most close to us) example of the general picture sketched briefly above. Recall that our Galaxy, the Milky Way, together with the giant Andromeda Nebula and dozens less massive galaxies form the Local Group of galaxies. This is a gravitationally bound quasi-stationary system of 2 Mpc across embedded – as all bodies of nature – in the uniform dark energy background. Around the group, at distances 1-3 Mpc from the group barycenter, two dozen dwarf galaxies move away from the group forming the very local expansion flow. The flow is quiet: it follows closely to the linear velocity-distance relation [23].

The force field in the flow area is a sum of the gravity produced by the matter

(dark matter and baryons) of the group and the antigravity produced by the dark energy background. The selfgravity of the flow dwarfs contributes little to the force field, and they may reasonably be considered as test particles. Estimates indicate that the dark energy antigravity is stronger than the gravity of the Local Group at distances larger than $\simeq 1$ Mpc from the group barycenter. Since antigravity dominates in the flow area, the flow is accelerated by dark energy. Our models show also that the accelerated flow might be rather chaotic initially, but it is getting more and more regular and quiet with time under the action of the dark energy antigravity. Asymptotically, the flow becomes exactly linear, and its expansion rate approaches the universal value $H_\Lambda \simeq 60$ km/sec/Mpc which is determined by the dark energy density only (see Sec.2). A similar asymptotic behavior is prescribed by the ΛCDM model to the global cosmological expansion: its expansion rate (the Hubble factor) tends to the same universal value H_Λ. Since the observed values of H and H_0 are close to H_Λ, the present-day states of both local and global flows are not far from their common asymptotic state – as it should be indeed where and when dark energy dominates.

Quiet local flows of expansion have also been observed recently around two other nearby groups of galaxies and around the Virgo Cluster of galaxies. The nearly linear velocity-distance relation and similar expansion rates are characteristic for each of them. Dark energy domination is recognized to control the major trend of the flow evolution and determines the asymptotic value of the expansion rate, while small individual deviations from this are due to specific local conditions in the flows and around them. The structure, dynamics and the very origin of the local flows are due to the local gravity-antigravity interplay and little affected by the global Big Bang (not saying about "initial inflation").

5   Conclusions

To summarize, neither Lemaître, nor Hubble discovered the Big Bang in 1927-29. This has been done decades after that by Sandage and other astronomers (including the authors of the works [14,15]) who have extended extragalactic observations to the truly cosmological distances of 300-1000 Mpc and more. At local distances of less than 20-30 Mpc, Lemaître in 1927 and then Hubble in 1929 dealt with accidental sets of galaxy-members of local expansion flows. These galaxies preserve in their quiet collective kinematics a dynamical signature of dark energy. The signature is the (nearly) linear velocity-distance relation. Recognized empirically at local distances, this relation has occurred to be the first observational manifestation of omnipresent dark energy.

Thus, the present-day understanding of the essence of the matter and commonly accepted criteria of scientific discovery lead to the conclusion: In 1927, Lemaître discovered dark energy and Hubble confirmed this in 1929.

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