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Reasons in favor of a Hubble-Lemaître-Slipher's (HLS) law

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Abstract

Based on historical facts, revisited from a present-day perspective, and on the documented opinions of the scientists involved in the discovery themselves, strong arguments are given in favor of a proposal to include prominent astronomer Vesto Slipher to the suggested addition of Georges Lemaître's name to Hubble's law on the expansion of the Universe, and thus eventually call it Hubble-Lemaître-Slipher's (HLS) law.

1 Introduction

At the XXXth General Assembly of the International Astronomical Union (IAU), celebrated in Vienna (August 20th to 31st, 2018), five Resolutions were proposed for approval [1]. The Fifth of them, Resolution B4, addressed a suggested renaming of the Hubble Law, recommending that from now this law on the expansion of the universe be referred to as the "Hubble-Lemaître law". The basic point in favor of the resolution being

> that the Belgian astronomer Georges Lemaître, in 1927 published (in French) the paper entitled *'Un Univers homogene de masse constante et de rayon croissant rendant compte de la vitesse radiale des nébuleuses extra-galactiques'* [2]. In this, he first rediscovers Friedmann's dynamic solution to Einstein's general relativity equations that describes an expanding universe. He also derives that the expansion of the universe implies the spectra of distant galaxies are redshifted by an amount proportional to their distance. Finally he uses published data on the velocities and photometric distances of galaxies to derive the rate of expansion of the universe (assuming the linear relation he had found on theoretical grounds)".

In the supporting Bibliography, for convenience of the voters, an excerpt from the paper by David L. Block, *"Georges Lemaître and Stigler's Law of Eponymy"*, reporting on an interesting comment on the matter by Lemaître himself, was highlighted: "In a Comment published in Nature [3] Mario Livio has unearthed a letter from Lemaître to W.M. Smart

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(dated 9 March 1931). From that document, it is clear that Lemaître himself translated his 1927 paper into English and who also omitted his determination of the coefficient of expansion of the Universe (H_0) from values of radial velocities available as of 1927. However, in his Comment Livio omits a vital reference, namely thoughts penned by Lemaître himself in 1950 [4]:

> About my contribution of 1927, I do not want to discuss if I was a professional astronomer. I was, in any event, an IAU member (Cambridge, 1925), and I had studied astronomy for two years, a year with Eddington and another year in the U.S. observatories. I visited Slipher and Hubble and heard him in Washington, in 1925, making his memorable communication about the distance [to] the Andromeda nebula. While my Mathematics bibliography was seriously in default since I did not know the work of Friedmann, it is perfectly up to date from the astronomical point of view; I calculate [in my contribution] the coefficient of expansion (575 km per sec per megaparsecs, 625 with a questionable statistical correction). Of course, before the discovery and study of clusters of nebulae, there was no point to establish the Hubble law, but only to calculate its coefficient. The title of my note leaves no doubt on my intentions: A Universe with a constant mass and increasing radius as an explanation of the radial velocity of extra-galactic nebulae.

In 1950, Lemaître clearly did not want the rich fusion of theory and observations contained in his 1927 paper to be buried in the sands of time."

The discussion on the Resolution B4 was very lively but it had to be stopped in order to keep up with the schedule, in particular, the subsequent Closing Ceremony. Some additional questions were sent by email, as this one:

Q. Should other contributors to the data used in the early expansion law (Slipher, Leavitt, Stromgren, ...) be acknowledged as well?

A. No because they did not use their data nor invent new theory to discover the Universal Expansion.

The author is essentially in agreement with all the considerations above, as they were formulated; in particular, with the last one, which refers to Slipher and Leavitt. Sure, one cannot object the sentence, as formulated, that these prominent astronomers "did not use their data" (in particular, Slipher, even if he calculated practically all redshifts used subsequently both by Hubble and Lemaître) or methods (Leavitt's law) profusely used by Hubble as his main tool to obtain all his measures of distances, "in order to invent a new theory to discover the Universal Expansion." However, some crucial historical facts, which have been overseen by almost everybody till now, and which the author has rescued, containing documented opinions of the scientists involved (Hubble, in particular, on several occasion), as well as more recent bibliographical studies (duely mentioned below), have led him to formulate strong arguments in favor of a proposal to include the prominent astronomer Vesto Slipher to the planned addition of Georges Lemaître's name to Hubble's law, to eventually call it Hubble-Lemaître-Slipher's (HLS) law.

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2 Vesto Melvin Slipher

It is quite easy to become convinced of how extremely difficult it is to calculate distances in astronomy. The order of magnitude of the mistakes committed in this respect during past epochs is overwhelming. Let us just recall that, in the first models of the cosmos (Anaximander's one, for instance) the stars were considered to be closer to the Earth than the Sun [5]. This is why the discovery done by Henrietta Swan Leavitt in 1912, after several years of collecting thousands of data, in particular from the Magellanic clouds, was so extraordinarily important. Namely the period-luminosity relationship of Cepheid variable stars: a linear dependence of the luminosity vs. the logarithm of the period of variability of the star's luminosity [6]. It would be interesting to describe the favorite physical mechanisms available to explain such relationship (as the Eddington valve [7], for a very beautiful one), but regretfully, there is no place here for that. Henrietta was a distinguished member of the so-called Edward Pickering's Harvard harem, better known as Harvard computers, a group of young ladies that did a tremendous job in astronomy at that time (interested readers can find more details in, e.g., [8]). Leavitt's result was an extremely powerful tool to calculate distances, in fact the main one employed by Hubble in the years to follow. And by several generations of astronomers, later, with enormous success, until other improved techniques appeared [9], most recently, the SNIa standardizable candles [10], which led to the discovery of the acceleration of the Universe expansion (Physics NP 2011).

Because of this extraordinary difficulty to calculate distances, until 1923 the most extended belief was that the Milky Way contained the entire universe, which, on the other hand, had always existed and was static, which is the natural final state of any physical system under very general conditions and enough time to evolve. The discovery of a Cepheid in Andromeda [11] allowed Hubble to determine, by using Leavitt's law, that this nebula was clearly outside of the Milky Way, and thus confirm the so-called Island Universe hypothesis. The hypothesis of the possible existence of Island Universes had by then a long history already, going back at least to the 18th Century (see, e.g., M.J. Way [12]), with contributions by, among others, Swedenborg (1734), Wright (1750), Kant (1755), and Lambert (1761) [13]. William Herschel (1785) [14] was also convinced for a time that spiral nebulae were outside the Milky Way, but changed his mind later [15].

In the very same year of 1912 that Leavitt had published her results, Vesto Slipher started a project aimed at obtaining the radial velocities of spiral nebulae from their spectral blue- or red-shifts, by using the 24-inch telescope of the Lowell Observatory, in Arizona. Actually, his very first calculation, which he produced on 17 September 1912, was for the Andromeda nebula, a blueshift [16]. In 1914, in a meeting of the American Astronomical Society, he presented results for a total of 15 nebulae. He was so convincing that his results were received by the audience (chronicles say) with a very long, standing ovation [17]. This was really unusual, in a scientific conference, then as now, and that day went into the History of Astronomy [18, 19, 20].

Slipher was the first to photographically detect galaxy spectra with sufficient signal to noise ratio to reliably measure their Doppler shifts. As Hubble himself later recognized, he was the first astronomer to note that something highly remarkable, very strange, was going on in the cosmos: how could the Universe be static with those distant nebulae receding at such enormous speeds? Of course peculiar velocities were at play also, the dipole effect had to be taken into account, and later the translation speed of our own galaxy could be measured. But, already in these very first results, the general scattering trend of the far distant objects was apparent. It is thus clear why the potential importance of Slipher's

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discovery was immediately appreciated by the attendees [18, 19, 20, 21].

In a previous paper of 2013 Slipher had measured the blueshift of Andromeda to be 300 km s^{-1}. In another, in 1914, he presented what seems to be the first demonstration that spiral galaxies rotate. An in his most famous one, of 2015, corresponding to the just mentioned AMS meeting of 1914, he reported on 15 nebulae, 11 were clearly redshifted, and the other four (the closest ones) blueshifted. By 1917 Slipher had 25 results, four of them blueshifts, and he provided an interpretation on the enormous receding mean velocity, of nearly 500 km s^{-1}, of these objects. He said namely that

> "This might suggest that the spiral nebulae are scattering but their distribution on the sky is not in accord with this since they are inclined to cluster."

The term 'scattering' already denotes a tendency to recede in all directions, which might lead your mind to the notion of an expanding universe [21] (see also [22]). He added that:

> "... our whole stellar system moves and carries us with it. It has for a long time been suggested that the spiral nebulae are stellar systems seen at great distances ... This theory, it seems to me, gains favor in the present observations."

In other words, Slipher correctly inferred that our galaxy was in motion at a very high speed, and that, most probably, the receding nebulae could be analogues of the Milky Way. And this was written eighth years before Hubble's detection of the famous Cepheid in Andromeda [11], which finally confirmed the 'island universe' hypothesis.

Actually, Slipher did not repeat the same analysis with the new table of redshifts, which were made public in 1923 on page 162, Chapter 5, of Arthur Eddington's book *The Mathematical Theory of Relativity* [23], which was to become very popular. In fact, Eddington had made a special effort to include a complete list of Slipher's redshifts in his book. He obtained them from Slipher through direct correspondence and consisted of 41 velocities, with only 5 blueshifts. Other astronomers had confirmed a number of Slipher's measurements, by then, but it seems that the importance and physical meaning of a distance-redshift relation was not clear in the early 1920s. In 1924, Eddington discussed the distribution of velocities and tried to make sense of them in the context of general relativity, but he was unable to do what Lemaître achieved just three years later [2]. On the contrary, Eddington thought that some kinematic effect was at work there, even if the most usual interpretation at the time involved the de Sitter model and was that the redshifts probed the curvature of spacetime. Nobody was thinking about an expanding universe when looking for a linear relation between redshift and distance. The aim was to search for the 'de Sitter effect' and thus 'measure the radius of curvature of spacetime' (see e.g., the 1924 references [24]). Truly, in 1923 Hermann Weyl did conclude that "space objects have a natural tendency to scatter" [25], but the reason for that 'natural tendency' remained unknown to him. Even in 1929 Hubble also mentioned "the de Sitter effect" as well as Eddington's argument for a kinematical contribution, without ever saying that expansion could dominate [26].

Vesto Slipher was one of the pioneers who pushed cosmology forward, and his contribution needs to be recognized as such. Also Edwin Hubble was a pioneer, but of a different kind, since in his case his obssession was to make sure that his legacy would prevail. He was very selective in referencing, failing to mention in his publications those of his colleagues (as is known, the famous astronomer Harlow Shapley, one of the contenders of the 'Great Debate' on Apr. 26, 1920 [27], had a long complaint against Hubble on these matters). But this is also precisely why the few but very positive comments Hubble actually made

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on the importance of Slipher's work (see below) are even much more valuable. It should be added that the enormous importance of the redshift measurements and their significance in contradicting the static Universe model were understood, by 1917, by other astronomers working at different observatories, and not only by Slipher (at Lowell), but also by James E. Keeler (at Lick and Allegheny), and William W. Campbell (at Lick). It was not an exclusive Mount Wilson result, as argued by Hubble for many years.

Slipher's table of redshifts in Eddington's book was one of the two ingredients involved in the formulation of the distance-radial velocity relation. The other one, the table of distances, was the result of the work by Edwin Hubble, with a subsequent contribution of Humason, who obtained some additional redshifts, used by Hubble to improve his first results. Although Milton Humason extended the galaxy redshift work to fainter galaxies on behalf of Edwin Hubble, the astronomers at Mount Wilson would not have made rapid progress without Slipher's pioneering results. Hubble was fully aware of the significance and priority of Slipher's early spectroscopy [20], but consistent with his style of claiming sole credit for most topics he worked on, he did not like to emphasize this point, only recognized later in his life.

William Hoyt [28], in his biographical memoir of V.M. Slipher (p. 411) claims that he

> "probably made more fundamental discoveries than any other observational astronomer of the twentieth century."

and John Peackok adds to that [21]

> "Slipher was indeed a great pioneer; not simply through his instrumental virtuosity in achieving reliable velocities where others had failed, but through the clarity of reasoning he applied. Slipher in 1917 lacked the theoretical prior of a predicted linear distance-redshift relation, which de Sitter only published the same year. Slipher was simply looking for a message that emerged directly from the data, and it is therefore all the more impressive that he was able to reach in 1917 his beautiful conclusions concerning the motion of the Milky Way and the nature of spiral nebulae as similar stellar systems. Slipher's other main legacy to modern cosmology remains as relevant as ever. The peculiar velocity field that he discovered has become one of the centerpieces of modern efforts to measure the nature of gravity on cosmological scales."

3 Hubble on Slipher

In his 1929 paper [26], Hubble used a sample of red and blue-shifts of 24 nebulae, measured by Slipher; 20 of those were redshifts, with a maximum of 1100 km s^{-1}. This was precisely the sample made available by Slipher in 1917. By adding to Slipher's velocities his measured distances, Hubble concluded that the mean velocity of the sample was positive (e.g., a recession, a redshift) and that a linear correlation between redshifts and distances was apparent. As Peackok explains in much detail [21], actually "Hubble was fortunate in a number of ways to have been able to make such a claim with the material to hand. Hubble admitted that he was following up previous searches for a distance-redshift correlation, and that these studies were explicitly motivated by the theoretical prior of the de Sitter effect."

Two years later, in 1931, Hubble and Humason pushed the maximum velocity by almost twenty, up to 20,000 km s^{-1} [29]. However, their distance measurements were again based on Lundmark's (unjustified) assumption of 1924, namely, that galaxies could be treated as standard objects for calculating their distances —in the absence of other well-justified distance estimates. Again following Peacock, "one could imagine that the 1931 paper should have received a good deal of critical skepticism, but by this time a linear D(z) relation was already regarded as having been proved. The farther away a galaxy is, the faster it is moving. These results flew in the face of both Isaac Newton and Albert Einstein's notions of the universe, which argued for a static Universe. If Hubble was right, the visible objects of the universe were actually in expansion."

This was certainly a very remarkable achievement, even if it was just a first step towards the modern conception: it did say nothing about the expansion of the Universe itself, of the fabric of spacetime. All what was said was just, that distant nebulae were receding from us with a velocity proportional to their radial distance, an empirical conclusion; so that the visible Universe was not static, it was expanding at rather large speed. The very 'subtle' difference between two possible interpretations, namely (i) the celestial objects are moving away (cf. a child running away from us), or (ii) the objects have small peculiar motions but are in a fast moving reference frame (the child being now on a departing high-speed train and just maybe walking the corridor, to stretch his legs), what actually corresponds to an expanding solution of the universe model (Friedmann's solution of Einstein's General Relativity, in our case) was, and still is nowadays, for the non-specialist, a most crucial point. For one, it took Einstein several years to understand this concept in its final version, namely that the second interpretation was the right one, the one that is universally accepted nowadays.

Just to repeat, Hubble only contributed with his own work, half of his famous plot, i.e. the distance measurements, and it so happens that his values turned out to be off by a whole order of magnitude, because of the incorrect identification of the stars used as standard candles. By contrast, the recession velocities on the y-axis of the plot, obtained by Vesto Slipher at the Lowell Observatory in Flagstaff, Arizona, had much smaller errors. Hubble used them with permission from Slipher (they were already public, actually, as explained above), but gave no credit to him in the references of his 1929 work [26]. It is true that in the 1931 paper by Hubble and Humason [29] a generous acknowledgment to Slipher's contribution appears. However, in these two years that elapsed between the two papers, Hubble's name had been already associated with the distance-redshift correlation, and the fact without possible discussion is that Slipher's contribution was largely forgotten subsequently. And it is still being forgotten today, since Edwin Hubble continues very often to be incorrectly credited (in many reference books, articles, talks and conferences, even by Nobel Prize awardees) with having obtained *both* the redshifts and the distances of the galaxies in his famous plot [30].

Later, however, having already acquired all his fame and by looking in retrospect, Hubble himself did recognize the extremely important role of Vesto Slipher, talking of

> *"your velocities and my distances"*,

in a Letter of E.P. Hubble to V.M. Slipher, Mar 6, 1953 [Biographical Memoirs, Vol 52, National Academy of Sciences (U.S.)]. This actually ocurred, as Marcia Bartusiak explains [31, 27], as follows: "In 1953, as Hubble was preparing a talk, he wrote Slipher asking for some slides of his first 1912 spectrum of the Andromeda Nebula, and in this letter he, at last, gave the Lowell Observatory astronomer due credit for his initial breakthrough, writing:

> *'I regard such first steps as by far the most important of all. Once the field is opened, others can follow.'*

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Also during the lecture, Hubble recognized that his discovery

> *'emerged from a combination of radial velocities measured by Slipher at Flagstaff with distances derived at Mount Wilson.'*

Further, in his famous book [32], he repeated almost the same sentence, while referring to Slipher, saying once more that

> *"... the first steps in a new field are the most difficult and the most significant. Once the barrier is forced further development is relatively simple."*

All those quotes are explicit recognition by Hubble of the seminal role of Vesto Slipher in the derivation of the expansion law. Regretfully, this just happened too late, as we can witness nowadays (please re-read the sentence two paragraphs above).

Hubble was quite right in finally acknowledging the importance of Slipher's contribution. Although Slipher did not calculate the distances to the far away objects, his results on the redshifts, which he started to obtain in 1912, where very remarkable, as sufficiently emphasized above, pointing in some cases to very high recession speeds. He was undoubtedly the first astronomer to recognize that something weird, incredibly unusual was happening in the Universe: how could it be static at all? When he presented his results corresponding to 15 nebulae in the 1914 meeting of the American Astronomical Society he received a long, standing ovation. The community of astronomers realized immediately that an important discovery was on the making. So did Hubble, too, and this was an inspiration for his subsequent work that led to his famous law, using Slipher's redshifts. A very detailed account of Slipher's contribution can be found in [33].

4 The expanding universe

However, as already remarked, to say that the Universe is expanding because the far distant nebulae are receding at incredible speeds (this last sentence may be acceptable to everybody) is conceptually very far from the actual comprehension of the universe expansion as we understand it today: the stretching of the fabric of space and time itself, of the coordinate system of the cosmos. To obtain a fundamental, physical explanation one needs a theoretical model to match the observational results, and it turned out that the de Sitter model, considered at first, was not the right one. That was not an easy challenge. To the best minds of the time (as Eddington or Einstein), even when confronted with the astronomic observations and the theoretical model (see, e.g. [30], for a detailed account), it took several years to understand that Friedmann's expanding solution was the correct one. This may sound nowadays almost incredible, because Einstein was the father of the theory (GR) from which all the solutions emanated, and he had spent so much time and penetrated so deeply into the nature of the physical laws, and gravity in particular, to construct his magnificent theory of space and time.

Actually it was no other than George Lemaître the first to understand what could be going on, in his now famous but for many years neglected paper of 1927 [2] (read, please, again the Introduction section here). He found a value for the slope of the linear relation between distance and velocity, and this *in the context of an expanding universe* (his rediscovered Friedmann's solution). And that happened two full years before Hubble published his famous law. Lemaître's role in this story—as the first who actually obtained Hubble's

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expansion rate and who did interpret this expansion as a true stretching of space—has been already explained in the Introduction (for more details, see also [30]).

We now here give a more general and wider perspective. Some other scientists, as Carl Wirtz, Ludwik Silberstein, Knut Lundmark, or Willem de Sitter himself, were actually looking for a redshift-distance relation of the same kind, which could fit into the context of de Sitter's model [24] (see also [12]). As reported in [34], the first theoretical explanation capable of accounting for the Doppler Effect, as conjectured by Slipher, was suggested by Alexander Friedmann in 1922 [35]

> *"the Universe may expand since General Relativity (GR) equations admit dynamical solutions."*

Having been told of this conclusion by P. Ehrenfest, it is a fact that Einstein missed its implications completely. First, he believed for a while that he had discovered a mistake in Friedmann's calculations, what he had to retract later, at the instance of the last, when he replied to Einstein that his calculations were perfectly right, and that it was Einstein who was in error. Had the creator of General Relativity, or maybe also W. de Sitter (who had himself already discovered an expanding solution, as early as 1917, although for a massless universe) realized these implications, they could have predicted the expansion of the universe from purely theoretical grounds (as Pauli did later, in predicting the existence of the neutrino, or Dirac with the positron prediction), before astronomical evidence was there. Belenkiy sustains the opinion that, had this been the case, Einstein himself together with Friedmann and Slipher could had been solid candidates for a Nobel Prize in Physics [34].

Lemaître could have qualified for the Nobel Prize on his own since he played the role Einstein missed, namelyto connect Friedmann's theory, Slipher's red-shifts and Hubble distances. No wonder, Lemaître had visited Hubble at Mount Wilson and Slipher at the Lowell Observatory, and graciously obtained the corresponding tables from each of them. Actually Lemaître (Hubble too) was indeed nominated for the Nobel Prize in Physics in 1954 for "his 1927 theoretical prediction of the expanding universe which was subsequently confirmed by the work of Hubble and Humason in the U.S.A." [37]. And for the expansion rate of the Universe, now called Hubble's constant, he had obtained a value very closed to that of Hubble in the 1929 paper [26] (no wonder. since they used paractically the same datasets).

In January 1930, Eddington and de Sitter publicly rejected the very inspiration for Hubble's investigation 'de Sitter's theory' as inadequate to explain the linear law! [38] This, together with the fact that Lemaître sent Eddington again his 1927 paper, led soon the latter to re-consider this time Lemaître's finding as a great discovery. Moreover, as explained in [34], both Hubble's and Lemaître's findings were made in spite of mistaken assumptions, and it happened that neither Lemaître immediately nor Hubble ever renounced their mistaken beliefs. In his 1930 letter to Eddington, Lemaître writes (still he does not realize the mistake in putting the spurious logarithmic term in his model): "I consider a Universe of constant curvature in space but increasing with time and I emphasize the existence of a solution in which the motion of the nebulae is always a receding one from time minus infinity to plus infinity." [39] Lemaître finally dropped this term when Eddington pointed out that "such logarithmic singularities have no physical significance", and then started to consider the model with initial singularity, a prototype of the Big Bang model (the 'monotone world of the first kind', in Friedmann's terminology). [40, 34]

As is now well known, Hubble never accepted the interpretation of his discovery as 'expansion of the universe.' He tried to provide alternative explanations:

> *"it is difficult to believe that the velocities are real; that all matter is actually scattering away from our region of space. It is easier to suppose that the light waves are lengthened and the lines of the spectra are shifted to the red, as though the objects were receding, by some property of space or by forces acting on the light during its journey to the Earth."* [41, 39]

It is quite understandable that Hubble, together with the largest part of the astronomical community, were skeptical towards the idea of an expanding universe. This concept, which we nowadays consider almost trivial, was extremely difficult to accept at that time, by astronomers and also by theoreticians, even if Friedmann's and Lemaître's solutions were at hand. Indeed, in Hubble's case, though he recognized that the 'expanding universe' could be a possibility, on which feasibility theoreticians, as de Sitter for one, had to decide (this is what he wrote in a letter to W. de Sitter), he considered that

> *"the 200-inch telescope will definitely answer the question of the interpretation of red-shifts, whether or not they represent actual motions, and if they do represent motions 'if the universe is expanding' the 200-inch may indicate the particular type of expansion."* [32]

5 Conclusion

The discovery of expanding solutions to Einstein's GR equations was first made by W. de Sitter in 1917 (for the vacuum case, with cosmological constant) [42], and by A. Friedmann in 1922 [35], and later by G. Lemaître in 1925 [36], for a more general expanding universe. Observational support for all these solutions was provided by the accurate redshift measurements of V.M. Slipher, starting in 1912, and also by the much less precise (because of the inherent difficulties) distance measurements of E. Hubble in the 1920s. In 1927, Lemaître was the first to connect velocity and distance of spiral nebulae (the two tables, of Slipher and Hubble, respectively), and obtain what is now known as the Hubble constant, relating it with the expansion rate of his non-static solution of Einstein's equations—which he ignored had been previously found by Friedmann. The linear relationship between velocity and distance was confirmed by Hubble first in early 1929 [26] and later, in association with M. Humason, in 1931 [29]. Hubble's confirmation was not associated with non-static solutions for the universe until early in 1930 when A. Eddington and W. de Sitter became aware of Lemaître's 1927 paper. As rightfully pointed out by Belenkiy [34]: "Errors can still lead to progress. The errors made on the way to the discovery of the expanding universe by the pioneers of modern cosmology did not prevent the cosmological community from getting finally the right physical interpretation."

Furthermore, the first, key observation that led to conclude that the Universe is expanding was the fact that most of the spectra obtained by Slipher, over the years subsequent to his first measurement of the spectrum of the Andromeda Nebula (M31), showed a redshift, indicating velocity away from the observer. Even without distance measurements this could have led to an interpretation in terms of cosmic expansion. Slipher was too an extremely cautious and serious scientist, dedicated to scientific accuracy, to adventure possible interpretations without more definite proofs, and without excluding other possibilities. One of those was, e.g., that as all redshifts were obtained, at first, for objects visible from the northern hemisphere, it could well be that the results just indicated a movement of our solar system or the galaxy itself in the opposite direction. In the 1930s the importance of Slipher's results (and those of other astronomers, as well) were obscured by Hubble, who definitely liked to promote himself and the Mount Wilson Observatory, where he worked, as the first and only reference, when talking about the expansion law (he even dared to seriously advert W. de Sitter on that, in a letter written in 1930).

Now, having examined the most relevant literature, old and new, on the universe expansion issue, we conclude that a large share of the credit for the discovery of the expanding universe is due to Slipher, and yet, I fully coincide with Peacock that "he tends to take very much second place to Hubble in most accounts." [21] Slipher's other achievements in astronomy are also important, as his discovery of the atmospheric conditions of Mars, and his participation in the discovery of Pluto. [19] The cosmology community can debate whether reference to Lemaître should now be added to that to Hubble for the velocity-distance relation, but it seems fair to prominently acknowledge Slipher's pioneering contribution, as well.

To conclude, going back to the very beginning of this paper and trying to summarize as much as possible, my main points in vindicating Hubble, in the context of the IAU Resolution, are the following.

1. In all the discussion, the IAU text of the resolution, and follow ups (as [43], for one) a very important issue has been systematically neglected: the very crucial role of the astronomer Vesto Slipher in the derivation of Hubble's law. To obtain the law, you need to compare two tables: one of radial velocities and one of distances to the extragalactic objects.

2. While there is no doubt that Hubble produced the table of distances (he was a master in this respect, systematically using Henrietta Levitt's law), the table of velocities was due to Vesto Slipher.

3. Hubble himself was the first to recognize (albeit too late) the extremely important role of Slipher, talking of *"your velocities and my distances"*, in a Letter of E.P. Hubble to V.M. Slipher, Mar 6, 1953 [Biographical Memoirs, Vol 52, National Academy of Sciences (U.S.)], and writing in his famous book E.P. Hubble, *"The realm of the nebulae"* [32], while referring to Slipher that *"... the first steps in a new field are the most difficult and the most significant. Once the barrier is forced further development is relatively simple."* This is an explicit recognition of the seminal role of Slipher in the conception of the expansion law.

4. Why did Hubble eventually say that? Although Slipher did not calculate the distances to the objects, his results on the redshifts, which he started to obtain in 1912, where so astonishing, pointing in some cases to such enormously high recession speeds, that he was undoubtedly the first astronomer to recognize that something weird, incredibly unusual was happening in the Universe: how could it be static at all if those objects were around, receding at such speeds? When he presented his results in the 1914 meeting of the American Astronomical Society chronicles say that he received a long, standing ovation! The community of astronomers (Hubble included) realized immediately that an important discovery was on the making.

5. It may seem contradictory that in Lemaître's 1927 paper (now being vindicated) there is no mention to the table of redshifts by Vesto Slipher (what, by the way, adds reasons to his having been neglected!). This may seem very strange, since Lemaître perfectly

knew about Slipher's results, from his visit to the Lowell observatory in Arizona during the period of his MIT Thesis. Instead, in deriving Hubble's law Lemaître takes his radial velocities from a table due to G. Strömberg [44]. But, alas, you need only read the first page, even just the two first lines of Strömberg's paper to realize that all of it is, again, an extraordinary homage to Slipher: *"the great majority of the determinations being by Slipher."* Obtained *"through the perseverance of Professor M. Slipher."* And so on.

Summing up,

1. I consider the role of Slipher in the derivation of Hubble's law to be of paramount importance, as recognized (implicitly and explicitly), to begin with, by the two other actors of this drama, and subsequently by an increasing number of reputed specialists. His role was invaluable, both in inspiring the whole development (Hubble's dixit) and in providing one of the two tables that are absolutely necessary for the formulation of the law, both by Hubble and Lemaître (what nobody can oppose).

2. I therefore propose to re-name the Hubble law as Hubble-Lemaître-Slipher (HLS) law. I do consider the IAU could improve the original idea and give due credit to the three main actors of this play.

3. I am absolutely sure that both Edwin Hubble and Georges Lemaître would had been extremely happy with this decision.

4. Further, I am also sure that, if the three brilliant cosmologists were alive *now*, under the standard criteria of the Nobel Academy, they would be the most perfect candidates for a shared Nobel Prize for their work that led to the discovery of the Universe expansion law.

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