Hubble or *Hubble-Lemaître Law?*

Krzysztof Bolejko

The University of Sydney

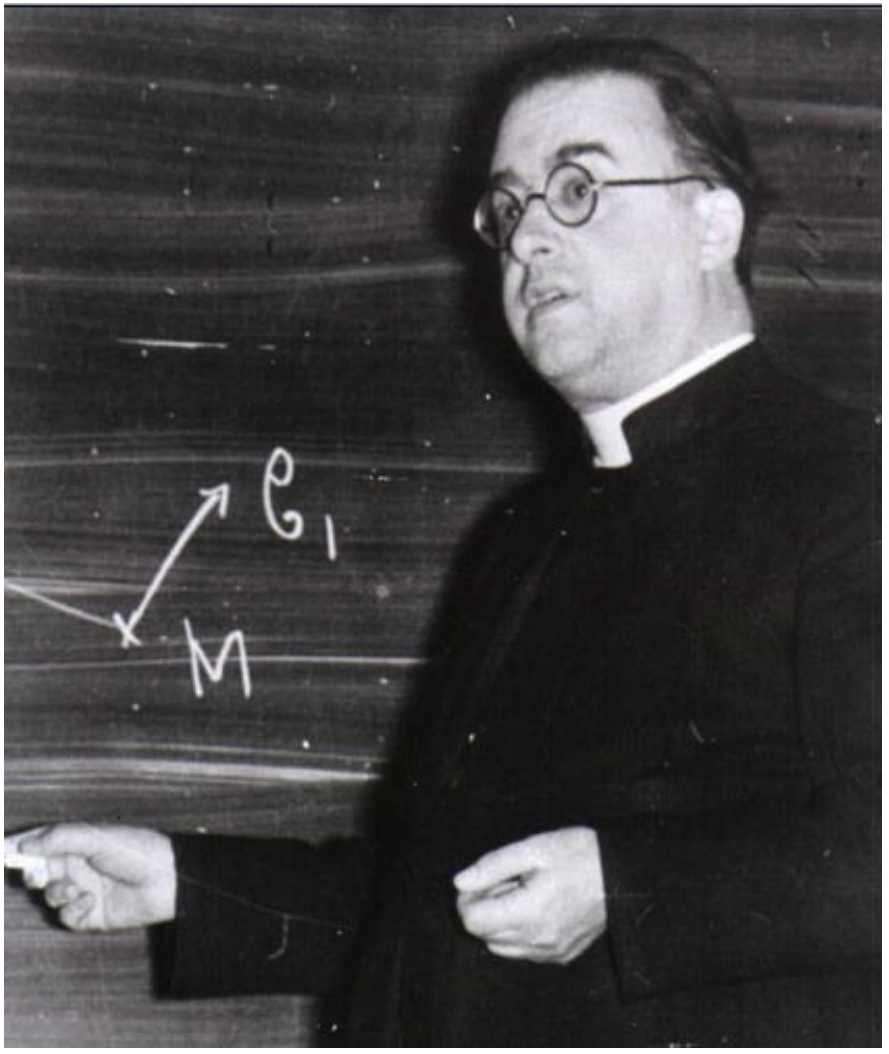
Australian Government

Australian Research Council

26 September 2018, 5th PoToR Meeting

Hubble or *Hubble-Lemaître Law?*

Edwin Hubble



Georges Lemaître

IAU XXX General Assembly

Transactions IAU, Volume XXXB
Proc. XXX IAU General Assembly, August 2018
Teresa Lago, ed.

DOI: 00.0000/X000000000000000X

THIRTHIETH GENERAL ASSEMBLY

RESOLUTIONS PRESENTED TO THE XXXth GENERAL ASSEMBLY

RESOLUTION B4

on a suggested renaming of the Hubble Law

https://www.iau.org/static/archives/announcements/pdf/ann18029e.pdf

IAU XXX General Assembly

Transactions IAU, Volume XXXB
Proc. XXX IAU General Assembly, August 2018
Teresa Lago, ed.

DOI: 00.0000/X000000000000000X

THIRTHIETH GENERAL ASSEMBLY

RESOLUTIONS PRESENTED TO THE XXXth GENERAL ASSEMBLY

RESOLUTION B4

on a suggested renaming of the Hubble Law

https://www.iau.org/static/archives/announcements/pdf/ann18029e.pdf

Über das zulässige Krümmungsmaß des Raumes,
Vierteljahrschrift d. Astronom. Gesellschaft. 35, 337-47 (1900)

“ We are considering the ***possibility of curvature of space****. You already know that besides the usual Euclidean geometry other — non-Euclidean — geometries have been developed during this century (...).*

how small is the curvature of space? and what is a lower bound for its radius of curvature? *(...)*

Karl Schwarzschild

Class. Quantum Grav., 15 2539 (1998)

Über das zulässige Krümmungsmaß des Raumes,
Vierteljahrschrift d. Astronom. Gesellschaft. 35, 337-47 (1900)

"(...)all visible ***stars****, whose number can be estimated to be no greater than* ***40 million****, can be considered to lie within a space of a* ***few hundred AU****, and that* ***outside this is a relative void****. (…)*

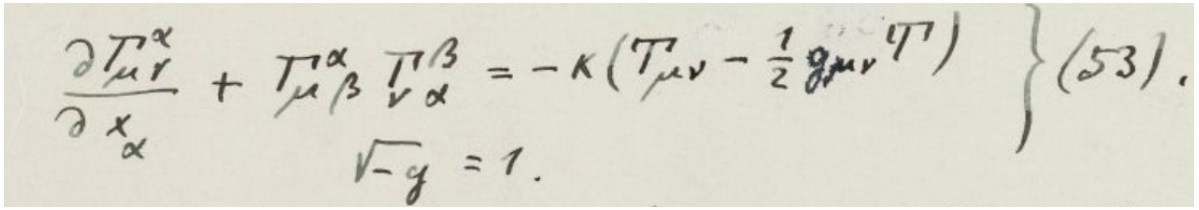
if we could conceive of space as being closed and finite and filled, more or less completely by this stellar system*."*

Karl Schwarzschild

Class. Quantum Grav., 15 2539 (1998)

$$G_{ab} = T_{ab}$$

Annalen der Physik, 354, 769 (1916)



original manuscript available at *http://new.alberteinstein.info*

Albert Einstein

$$G_{ab} - \Lambda\, g_{ab} = T_{ab}$$

Königlich Preußischen Akademie der Wissenschaften, 142 (1917)

$$G_{\mu\nu} = -\varkappa\left(T_{\mu\nu} - \frac{1}{2} g_{\mu\nu} T\right) \qquad (13)$$

$$G_{\mu\nu} - \lambda g_{\mu\nu} = -\varkappa\left(T_{\mu\nu} - \frac{1}{2} g_{\mu\nu} T\right). \qquad (13\,a)$$

Albert Einstein

$$G_{ab} - \Lambda\, g_{ab} = T_{ab}$$

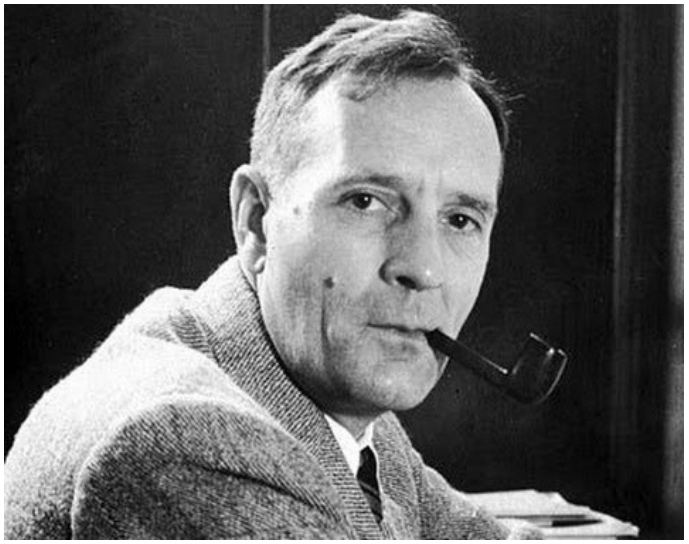
Königlich Preußischen Akademie der Wissenschaften, 142 (1917)

$$G_{\mu\nu} = -\varkappa\left(T_{\mu\nu} - \frac{1}{2} g_{\mu\nu} T\right) \qquad (13)$$

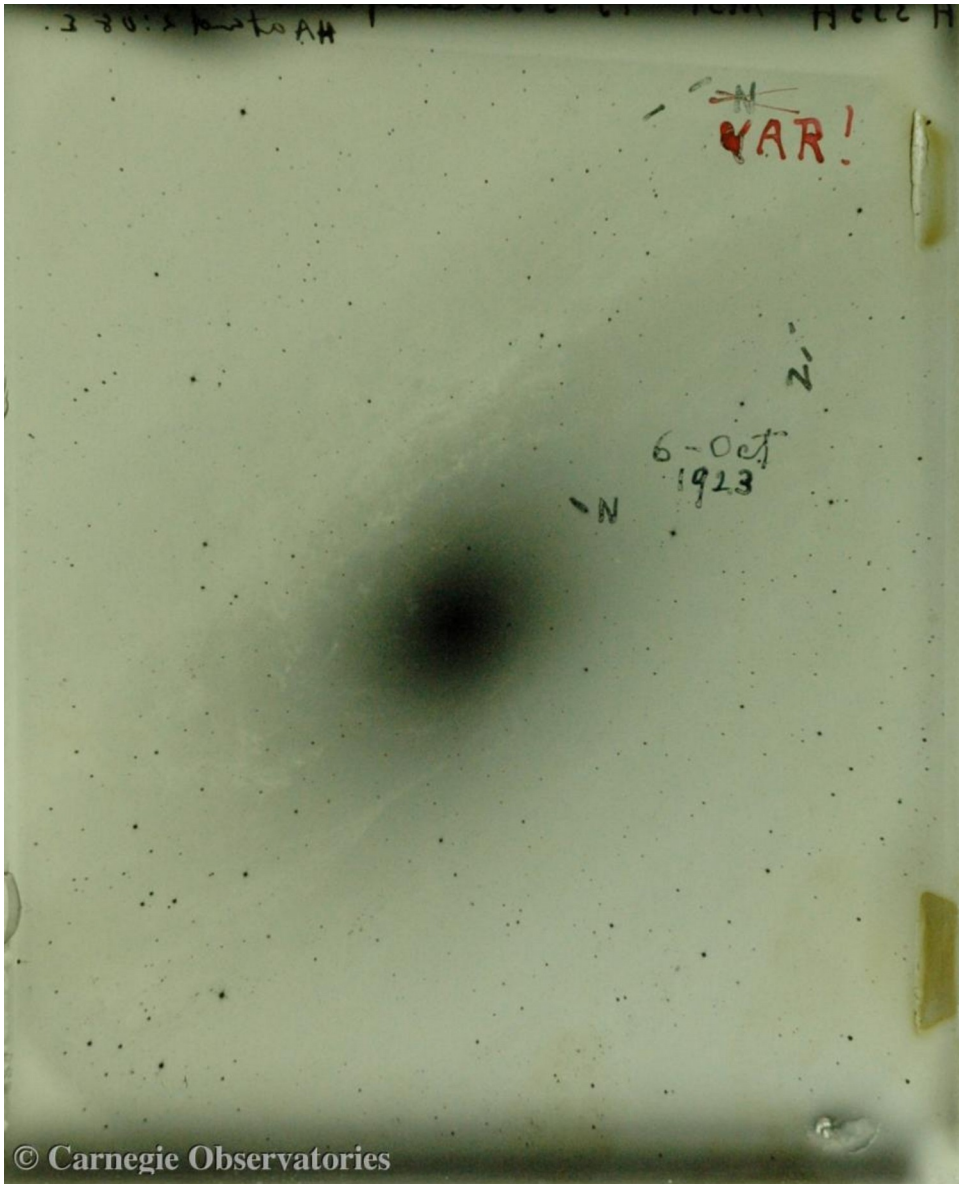
$$G_{\mu\nu} - \lambda g_{\mu\nu} = -\varkappa\left(T_{\mu\nu} - \frac{1}{2} g_{\mu\nu} T\right). \qquad (13\,a)$$

Albert Einstein

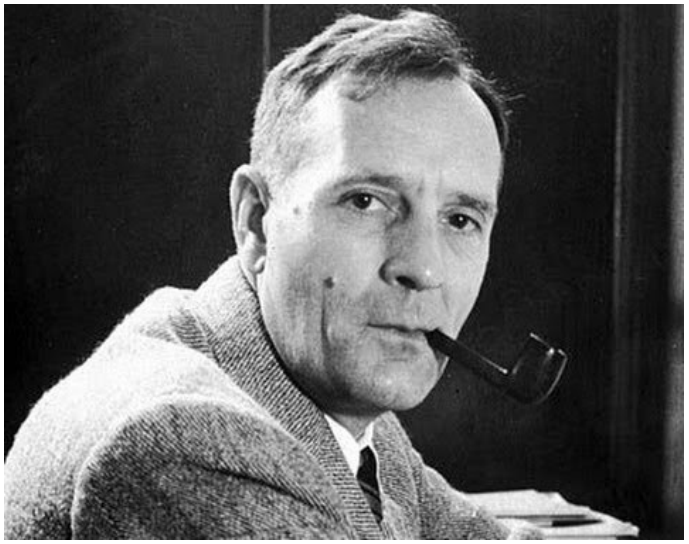
$$R_E \sim Mpc \gg 100\ AU$$



Edwin Hubble

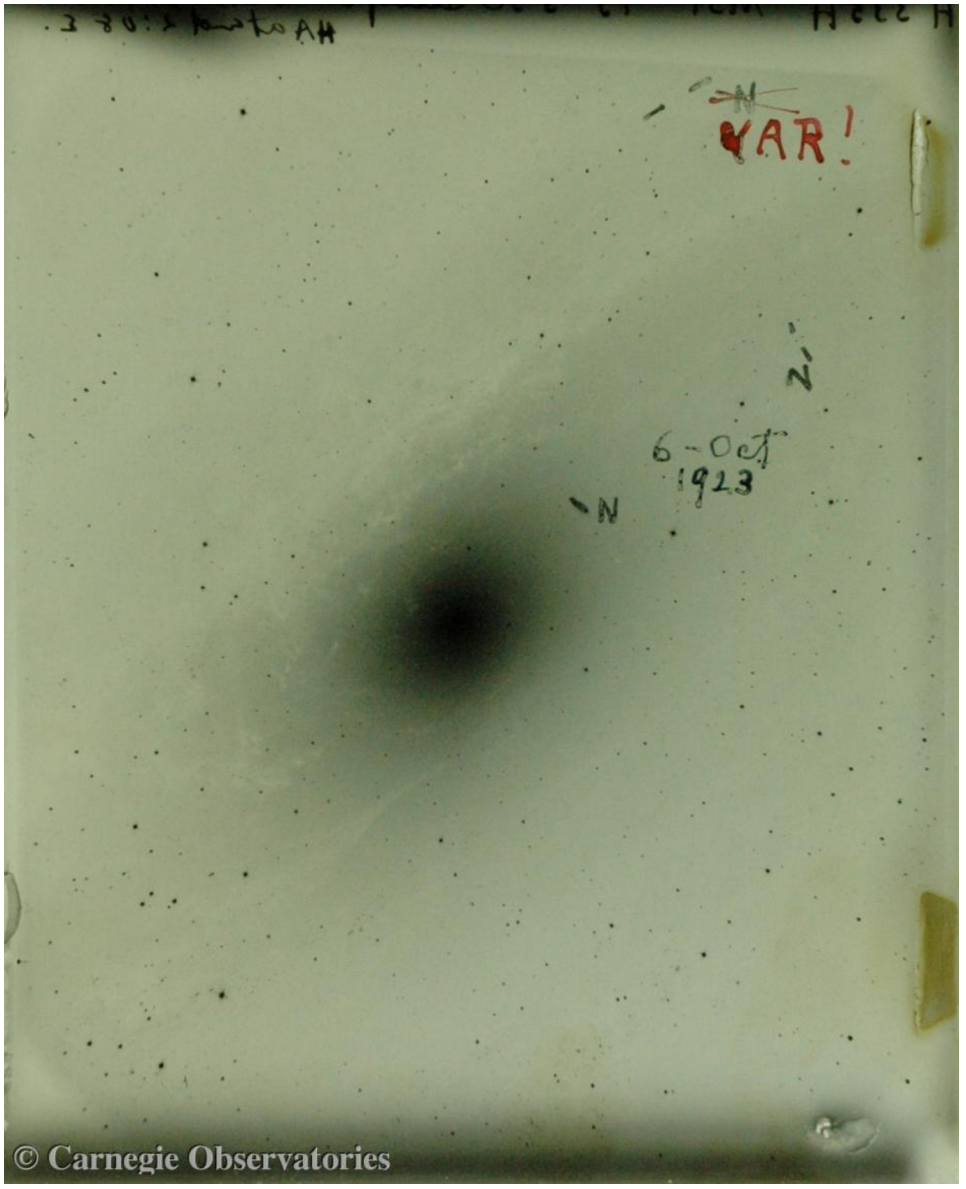


6 October 1923

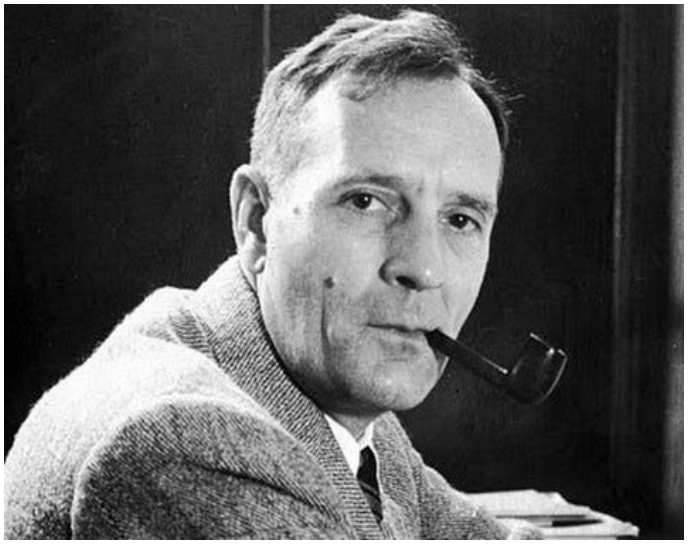


Edwin Hubble

$$100\,AU \ll 285\,Kpc < R_E$$



6 October 1923



Edwin Hubble

Georges Lemaître

1924 AAS Meeting in Washington

WASHINGTON MEETING OF THE AMERICAN ASTRONOMICAL SOCIETY, AT U. S. NAVAL OBSERVATORY

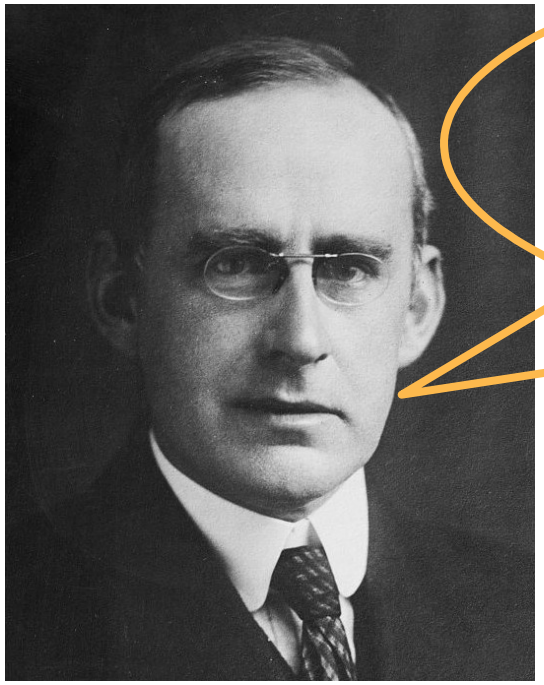
Vesto Slipher

Radial Velocities of Spiral Nebulae

\+ indicates receding, − approaching

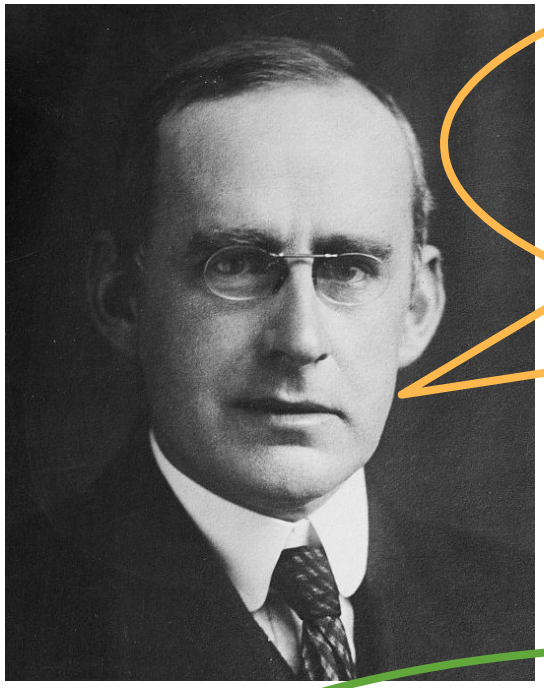
N. G. C.	R. A. h m	Dec. ° ′	Rad. Vel. km. per sec.	N. G. C.	R. A. h m	Dec. ° ′	Rad. Vel. km. per sec
221	0 38	+40 26	− 300	4151*	12 6	+39 51	+ 980
224*	0 38	+40 50	− 300	4214	12 12	+36 46	+ 300
278†	0 47	+47 7	+ 650	4258	12 15	+47 45	+ 500
404	1 5	+35 17	− 25	4382†	12 21	+18 38	+ 500
584†	1 27	− 7 17	+1800	4449	12 24	+44 32	+ 200
598*	1 29	+30 15	− 260	4472	12 25	+ 8 27	+ 850
936	2 24	− 1 31	+1300	4486†	12 27	+12 50	+ 800
1023	2 35	+38 43	+ 300	4526	12 30	+ 8 9	+ 580
1068*	2 39	− 0 21	+1120	4565†	12 32	+26 26	+1100
2683	8 48	+33 43	+ 400	4594*	12 36	−11 11	+1100
2841†	9 16	+51 19	+ 600	4649	12 40	+12 0	+1090
3031	9 49	+69 27	− 30	4736	12 47	+41 33	+ 290
3034	9 49	+70 5	+ 290	4826	12 53	+22 7	+ 150
3115†	10 1	− 7 20	+ 600	5005	13 7	+37 29	+ 900
3368	10 42	+12 14	+ 940	5055	13 12	+42 37	+ 450
3379*	10 43	+13 0	+ 780	5194	13 26	+47 36	+ 270
3489†	10 56	+14 20	+ 600	5195†	13 27	+47 41	+ 240
3521	11 2	+ 0 24	+ 730	5236†	13 32	−29 27	+ 500
3623	11 15	+13 32	+ 800	5866	15 4	+56 4	+ 650
3627	11 16	+13 26	+ 650	7331	22 33	+33 23	+ 500
4111†	12 3	+43 31	+ 800				

Eddington, *The mathematical theory of relativity* (1923)



“Shall we put a little motion into Einstein’s world of inert matter, or shall we put a little matter into De Sitter’s Primum Mobile?”

Eddington, *The observatory* 53, 39 (1930)



“Shall we put a little motion into Einstein’s world of inert matter, or shall we put a little matter into De Sitter’s Primum Mobile?”

Eddington, *The observatory* 53, 39 (1930)

“Dear Professor Eddington,
I have just read the February n◦ of the Observatory and your suggestion of investigating non statical intermediary solutions between those of Einstein and De Sitter. I made these investigations two years ago.”

Archives Lemaître of Louvain-la-Neuve

UN UNIVERS HOMOGÈNE DE MASSE CONSTANTE ET DE RAYON CROISSANT, RENDANT COMPTE DE LA VITESSE RADIALE DES NÉBULEUSES EXTRA-GALACTIQUES

Note de M. l'Abbé G. LEMAÎTRE

1. GÉNÉRALITÉS.

La théorie de la relativité fait prévoir l'existence d'un univers homogène où non seulement la répartition de la matière est uniforme, mais où toutes les positions de l'espace sont équivalentes, il n'y a pas de centre de gravité. Le rayon R de l'espace est constant, l'espace est elliptique de courbure positive uniforme $1/R^2$, les droites issues d'un même point repassent à leur point de départ après un parcours égal à πR, le volume total de l'espace est fini et égal à $\pi^2 R^3$, les droites sont des lignes fermées parcourant tout l'espace sans rencontrer de frontière (1).

Deux solutions ont été proposées. Celle de DE SITTER ignore la présence de la matière et suppose sa densité nulle. Elle conduit à certaines difficultés d'interprétation sur lesquelles nous aurons l'occasion de revenir, mais son grand intérêt est d'expliquer le fait que les nébuleuses extra-galactiques semblent nous fuir avec une énorme vitesse, comme une simple conséquence des propriétés du champ de gravitation, sans supposer que nous nous trouvons en un point de l'univers doué de propriétés spéciales.

Georges Lemaître

Annals of the Scientific Society of Brussels, 47A, 41 (1927)

Deux solutions ont été proposées. Celle de DE SITTER ignore la présence de la matière et suppose sa densité nulle. Elle conduit à certaines difficultés d'interprétation sur lesquelles nous aurons l'occasion de revenir, mais son grand intérêt est d'expliquer le fait que les nébuleuses extra-galactiques semblent nous fuir avec une énorme vitesse, comme une simple conséquence des propriétés du champ de gravitation, sans supposer que nous nous trouvons en un point de l'univers doué de propriétés spéciales.

Annals of the Scientific Society of Brussels, 47A, 41 (1927)

Georges Lemaître

Two solutions have been proposed. That of DE SITTER ignores the existence of matter and supposes its density equal to zero. It leads to special difficulties of interpretation which we will be referred to later, but it is of great interest as explaining the fact that extragalactic nebulæ seem to recede from us with a huge velocity, as a simple consequence of the properties of the gravitational field, without having to suppose that we are at a point of the universe distinguished by special properties.

General Relativity and Gravitation., 45:1635-1646 (2013)

$$ds^2 = -\mathrm{R}^2\, d\sigma^2 + dt^2 \qquad (1)$$

$d\sigma$ est l'élément de longueur d'un espace de rayon égal à un ; le rayon R de l'espace est une fonction du temps. Les équations du champ de gravitation s'écrivent

$$3\frac{\mathrm{R}'^2}{\mathrm{R}^2} + \frac{3}{\mathrm{R}^2} = \lambda + \kappa\rho \qquad (2)$$

et

$$2\frac{\mathrm{R}''}{\mathrm{R}} + \frac{\mathrm{R}'^2}{\mathrm{R}^2} + \frac{1}{\mathrm{R}^2} = \lambda - \kappa p \qquad (3)$$

Annals of the Scientific Society of Brussels, 47A, 41 (1927)

Georges Lemaître

$$ds^2 = -R^2 d\sigma^2 + dt^2 \qquad (1)$$

where $d\sigma$ is the elementary distance in a space of radius unity, and the radius of space R is a function of time, we find that the field equations can be written

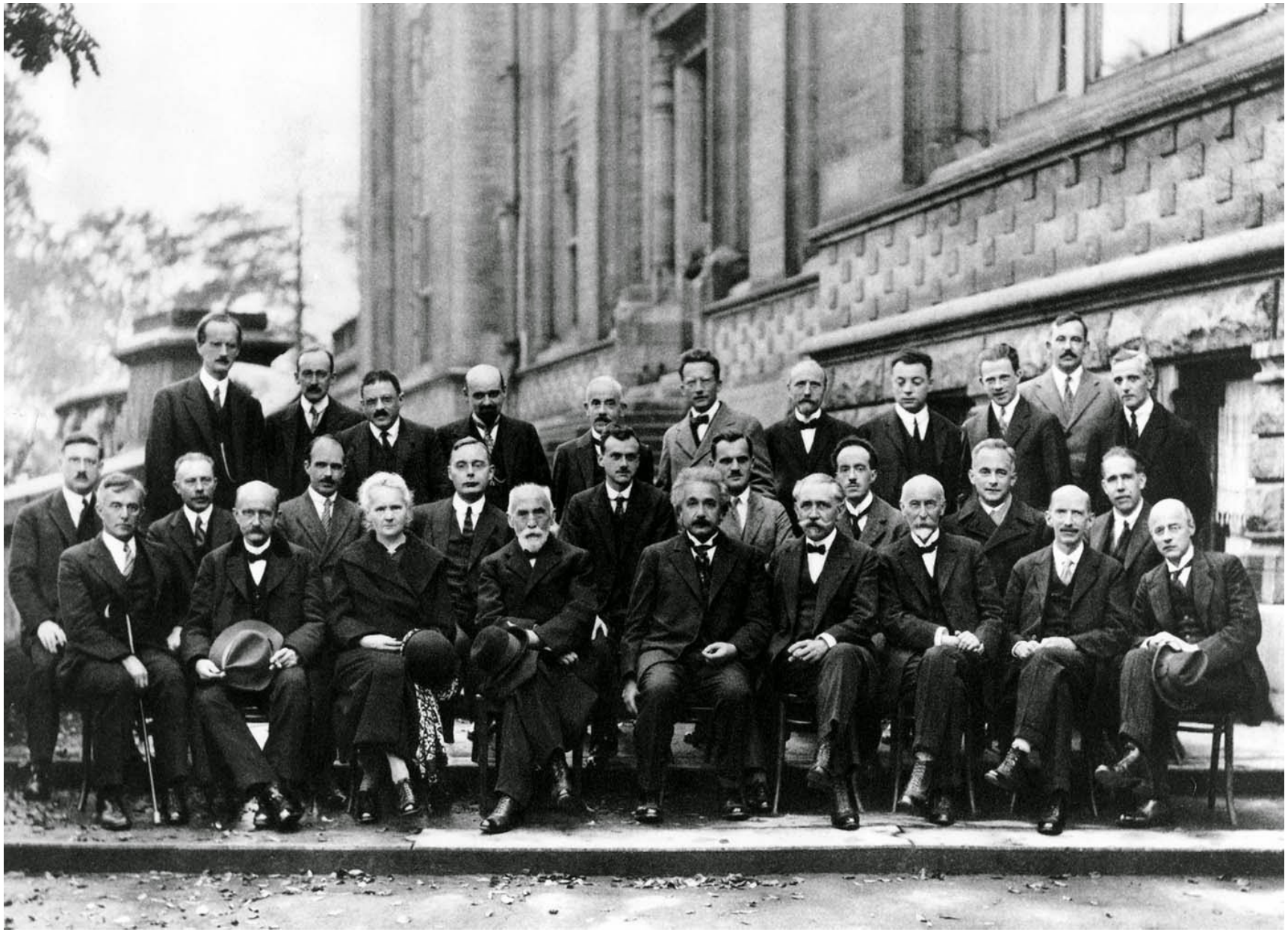
$$3\frac{R'^2}{R^2} + \frac{3}{R^2} = \lambda + \kappa\rho \qquad (2)$$

and

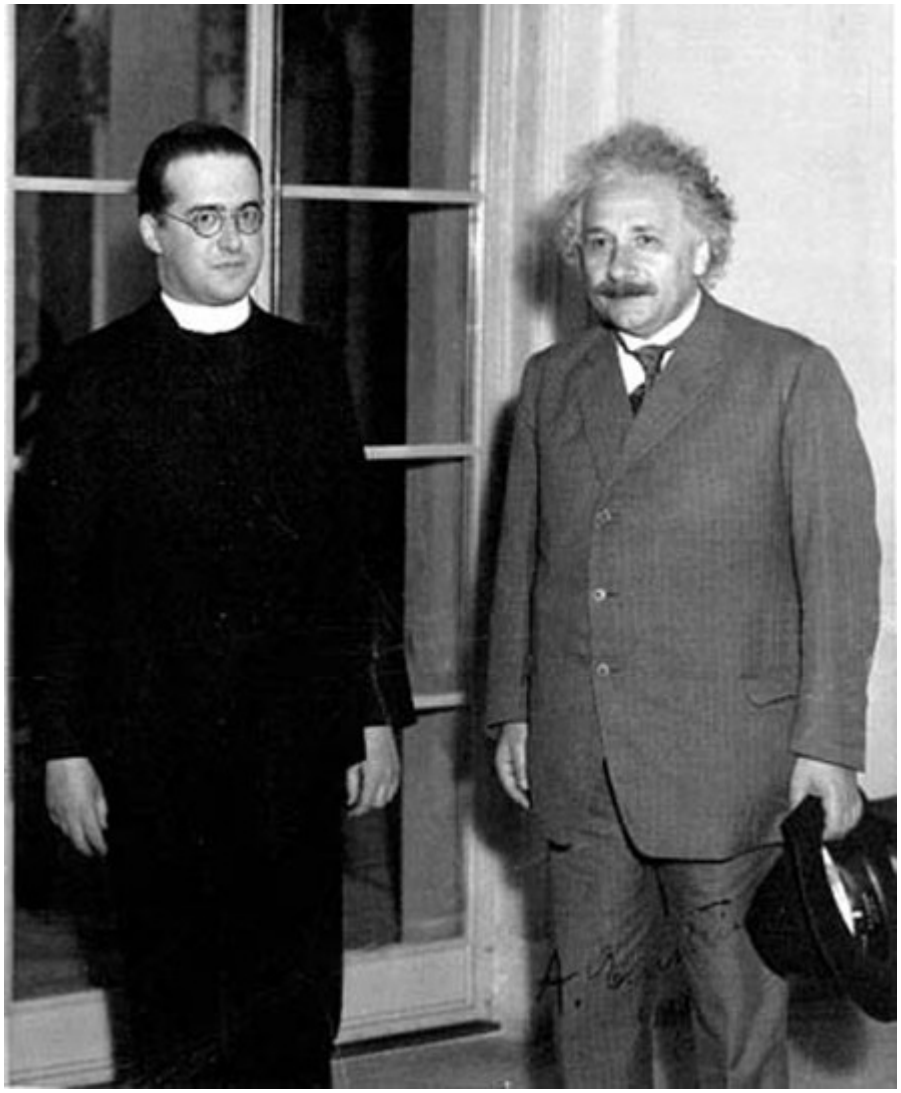
$$2\frac{R''}{R} + \frac{R'^2}{R^2} + \frac{1}{R^2} = \lambda - \kappa\rho \qquad (3)$$

General Relativity and Gravitation., 45:1635-1646 (2013)

The Solvay Conference, 1927



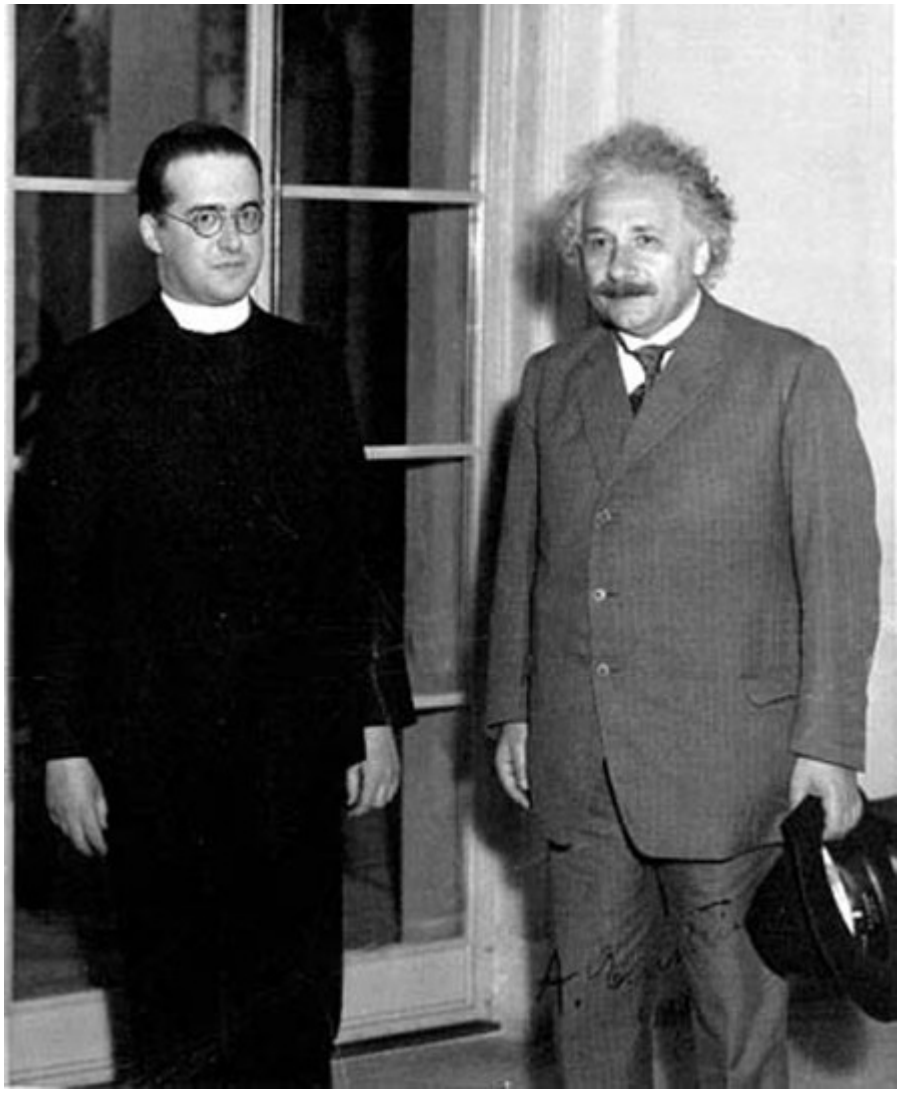
The Solvay Conference, 1927



"*While walking in the alleys of the Parc Léopold, [Einstein] spoke to me about an article (...)* ***After some favorable technical remarks, he concluded by saying that from the physical point of view that appeared completely abominable to him.*** *(...)* "

G. Lemaître, "Rencontres avec Einstein".
Revue des Questions Scientifiques, 79, 129–132 (1958)

The Solvay Conference, 1927



"***I spoke about the speeds of nebulae and I had the impression that Einstein was hardly aware of the astronomical facts.***"

G. Lemaître, "Rencontres avec Einstein".
Revue des Questions Scientifiques, 79, 129–132 (1958)

où r est la distance de la source. Nous avons donc

$$\frac{R'}{R} = \frac{v}{cr} \qquad (23)$$

Les vitesses radiales de 43 nébuleuses extra-galactiques sont données par Strömberg (1).

La grandeur apparente m de ces nébuleuses se trouve dans le travail de Hubble. Il est possible d'en déduire leur distance, car Hubble a montré que les nébuleuses extra-galactiques sont de grandeurs absolues sensiblement égales (grandeur $-15{,}2$ à 10 parsecs, les écarts individuels pouvant atteindre deux grandeurs en plus ou en moins), la distance r exprimée en parsecs est alors donnée par la formule $\log r = 0{,}2m + 4{,}04$.

Annals of the Scientific Society of Brussels, 47A, 41 (1927)

Georges Lemaître

where r is the distance of the source. We have therefore

$$\frac{R'}{R} = \frac{v}{cr} \qquad (23)$$

Radial velocities of 43 extragalactic nebulæ are given by Strömberg (6).

The apparent magnitude m of these nebulæ can be found in the work of Hubble. It is possible to deduce their distance from it, because Hubble has shown that extragalactic nebulæ have approximately equal absolute magnitudes (magnitude $= -15.2$ at 10 parsecs, with individual variations ± 2), the distance r expressed in parsecs is then given by the formula $\log r = 0, 2m + 4, 04$.

General Relativity and Gravitation., 45:1635-1646 (2013)

Utilisant les 42 nébuleuses figurant dans les listes de Hubble et de Strömberg (1), et tenant compte de la vitesse propre du soleil (300 Km. dans la direction $\alpha = 315°$, $\delta = 62°$), on trouve une distance moyenne de 0,95 millions de parsecs et une vitesse radiale de 600 Km./sec, soit 625 Km./sec à 10^6 parsecs (2).

Nous adopterons donc

$$\frac{R'}{R} = \frac{v}{rc} = \frac{625 \times 10^5}{10^6 \times 3{,}08 \times 10^{18} \times 3 \times 10^{10}} = 0{,}68 \times 10^{-27}\,\mathrm{cm}^{-1} \qquad (24)$$

Annals of the Scientific Society of Brussels, 47A, 41 (1927)

Georges Lemaître

Using the 42 nebulæ appearing in the lists of Hubble and Strömberg ([7]), and taking account of the proper velocity of the Sun (300 Km/s in the direction $\alpha = 315°$, $\delta = 62°$), one finds a mean distance of 0,95 megaparsecs and a radial velocity of 600 Km/sec, i.e. 625 Km/sec at 10^6 parsecs ([8]).

We will thus adopt

$$\frac{R'}{R} = \frac{v}{rc} = \frac{625 \times 10^5}{10^6 \times 3{,}08 \times 10^{18} \times 3 \times 10^{10}} = 0{,}68 \times 10^{-27}\mathrm{cm}^{-1} \qquad (24)$$

General Relativity and Gravitation., 45:1635-1646 (2013)

3rd IAU General Assembly in Leiden in July 1928

PLATE XVII

DELEGATES AND VISITORS AT THE THIRD SESSION OF THE INTERNATIONAL ASTRONOMICAL UNION, LEIDEN, HOLLAND, JULY 5-13, 1928. (PART 1.)

POPULAR ASTRONOMY, No. 359.

3rd IAU General Assembly in Leiden in July 1928

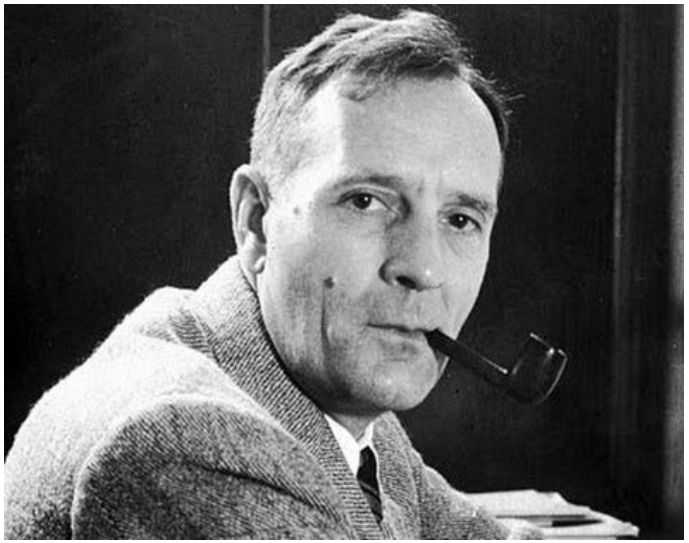
Milton L. Humason

"Dr. Hubble came home rather excited about the fact that two or three scientists over there, astronomers, had suggested that the fainter the nebulae were the ***more distant they were*** *and* ***the larger the red shifts would be****."*

Interview of Milton Humason by Bert Shapiro in circa 1965

www.aip.org/history-programs/niels-bohr-library/oral-histories/4686

Hubble and the expansion of the Universe



Edwin Hubble

secs. Mr. Strömberg has very kindly checked the general order of these values by independent solutions for different groupings of the data.

A constant term, introduced into the equations, was found to be small and negative. This seems to dispose of the necessity for the old constant K term. Solutions of this sort have been published by Lundmark,[3] who replaced the old K by $k + lr + mr^2$. His favored solution gave $k = 513$, as against the former value of the order of 700, and hence offered little advantage.

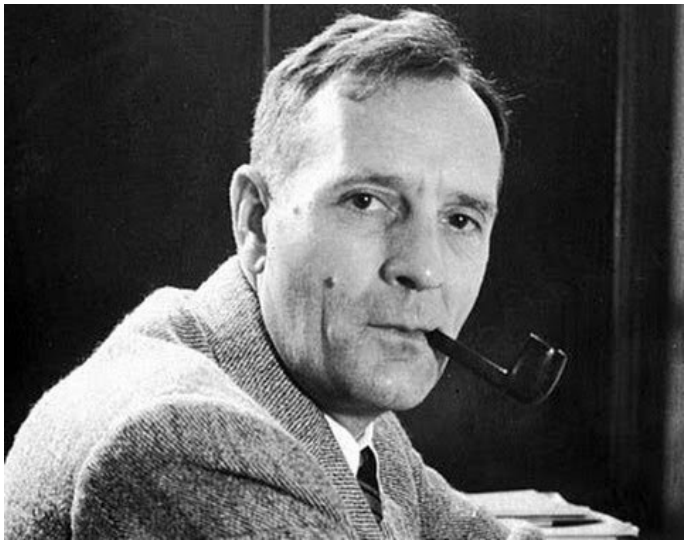
TABLE 2

NEBULAE WHOSE DISTANCES ARE ESTIMATED FROM RADIAL VELOCITIES

	OBJECT	v	v_s	r	m_t	M_t
N. G. C.	278	+ 650	−110	1.52	12.0	−13.9
	404	− 25	− 65	..	11.1	..
	584	+1800	+ 75	3.45	10.9	16.8
	936	+1300	+115	2.37	11.1	15.7
	1023	+ 300	− 10	0.62	10.2	13.8
	1700	+ 800	+220	1.16	12.5	12.8
	2681	+ 700	− 10	1.42	10.7	15.0
	2683	+ 400	+ 65	0.67	9.9	14.3
	2841	+ 600	− 20	1.24	9.4	16.1
	3034	+ 290	−105	0.79	9.0	15.5
	3115	+ 600	+105	1.00	9.5	15.5
	3368	+ 940	+ 70	1.74	10.0	16.2
	3379	+ 810	+ 65	1.49	9.4	16.4
	3489	+ 600	+ 50	1.10	11.2	14.0
	3521	+ 730	+ 95	1.27	10.1	15.4
	3623	+ 800	+ 35	1.53	9.9	16.0
	4111	+ 800	− 95	1.79	10.1	16.1
	4526	+ 580	− 20	1.20	11.1	14.3
	4565	+1100	− 75	2.35	11.0	15.9
	4594	+1140	+ 25	2.23	9.1	17.6
	5005	+ 900	−130	2.06	11.1	15.5
	5866	+ 650	−215	1.73	11.7	−14.5
Mean					10.5	−15.3

Hubble, *PNAS*, 15, 168 (1929)

Hubble and the expansion of the Universe



Edwin Hubble

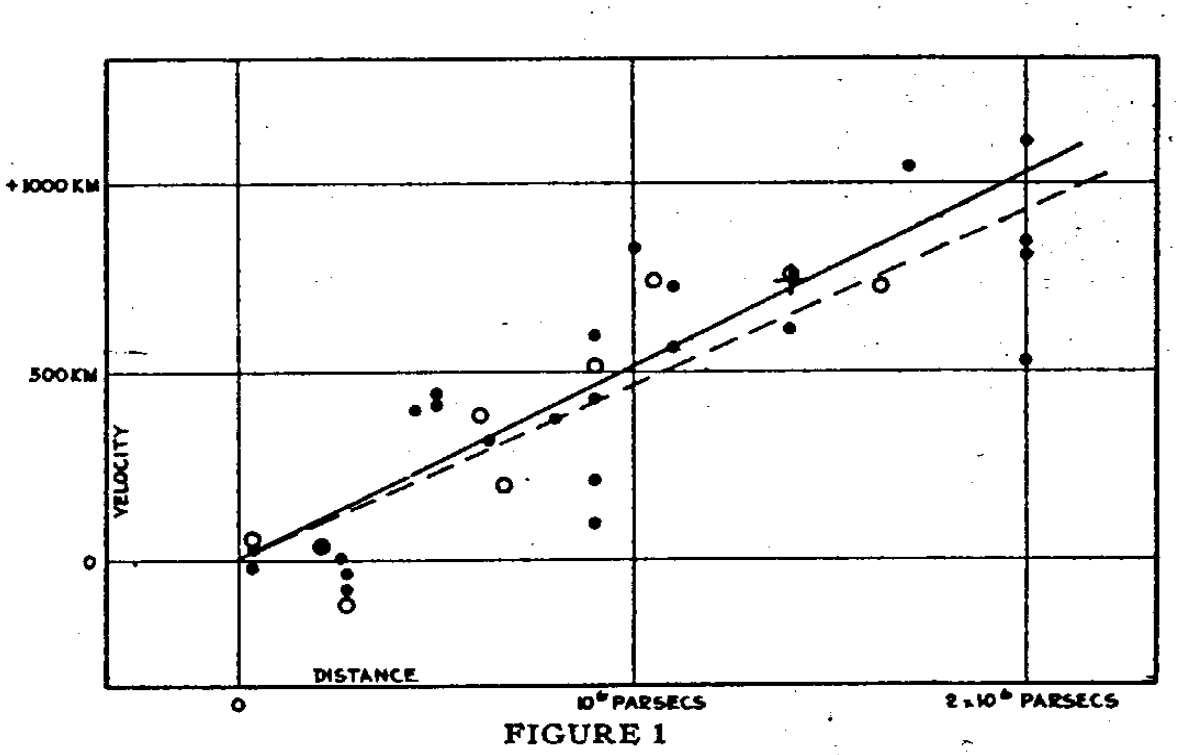
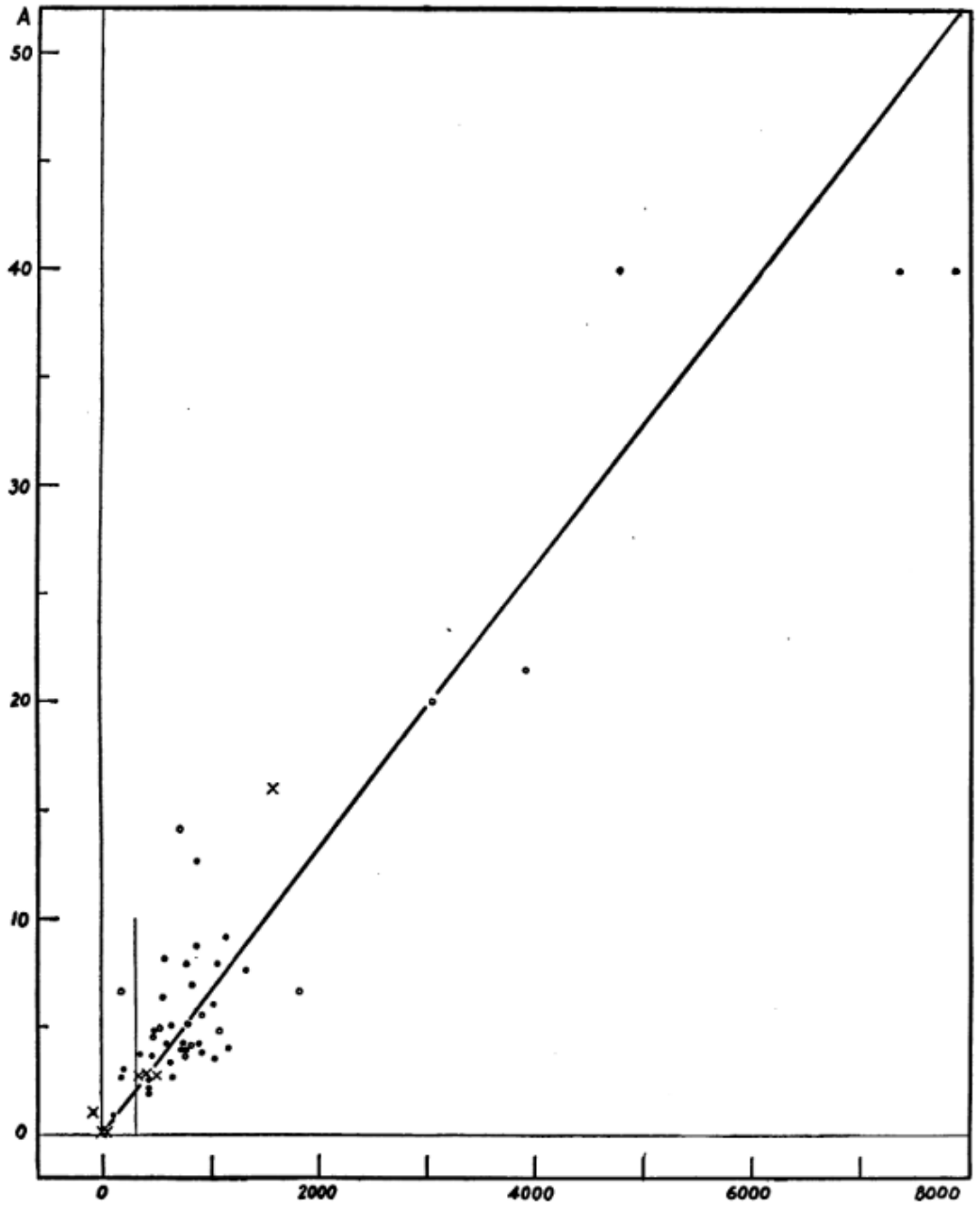
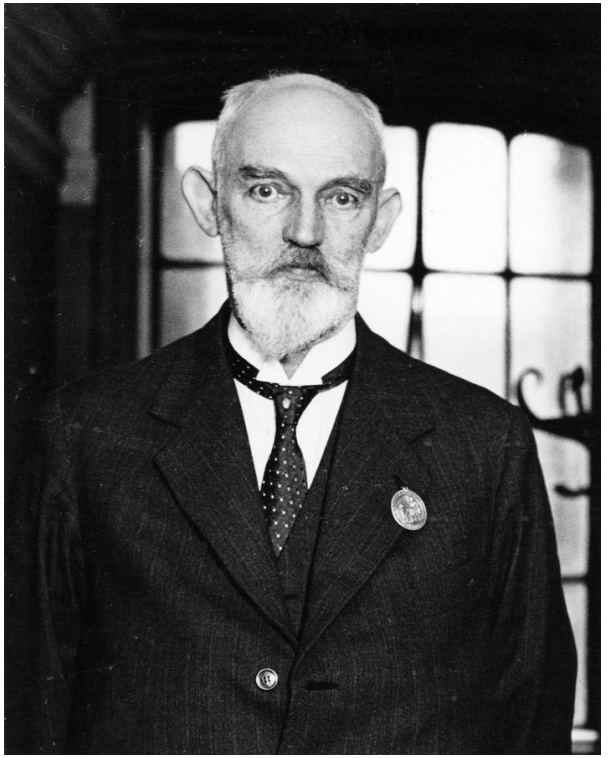


FIGURE 1

corrected for solar motion. The result, 745 km./sec. for a distance of 1.4×10^6 parsecs, falls between the two previous solutions and indicates a value for K of 530 as against the proposed value, 500 km./sec.

Hubble, *PNAS*, 15, 168 (1929)

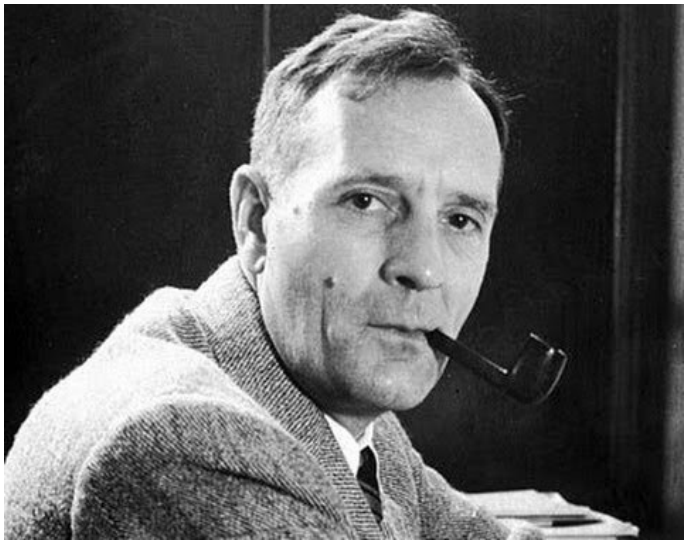




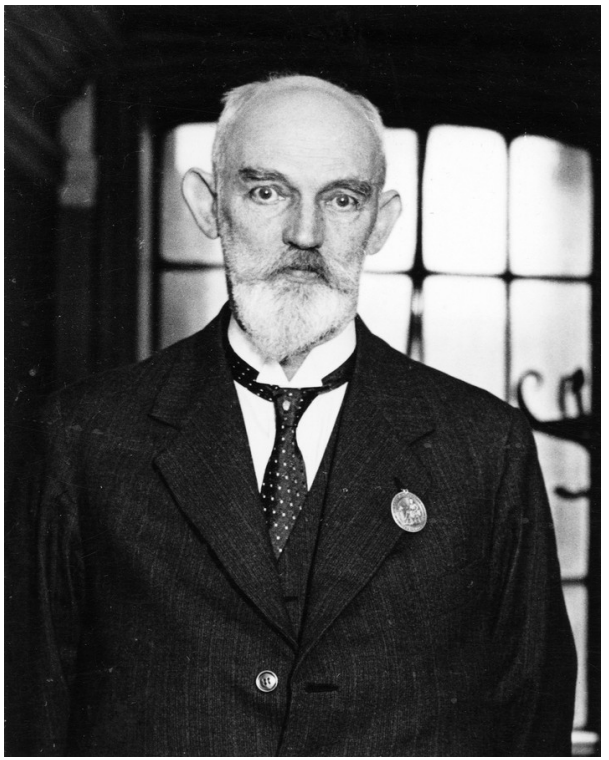
Willem de Sitter

$H_0 = 461$ km s^{-1} Mpc^{-1}

de Sitter, *PNAS* 16, 474 (1930)



Edwin Hubble

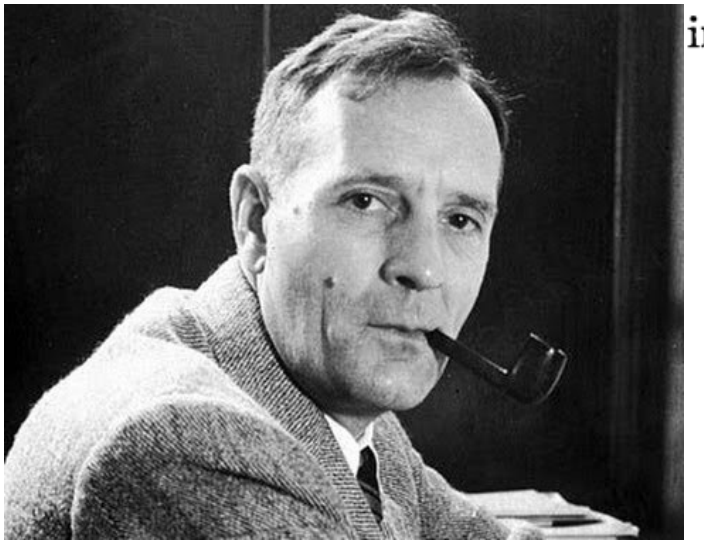


Willem de Sitter

letter to De Sitter, 21 August 1930:

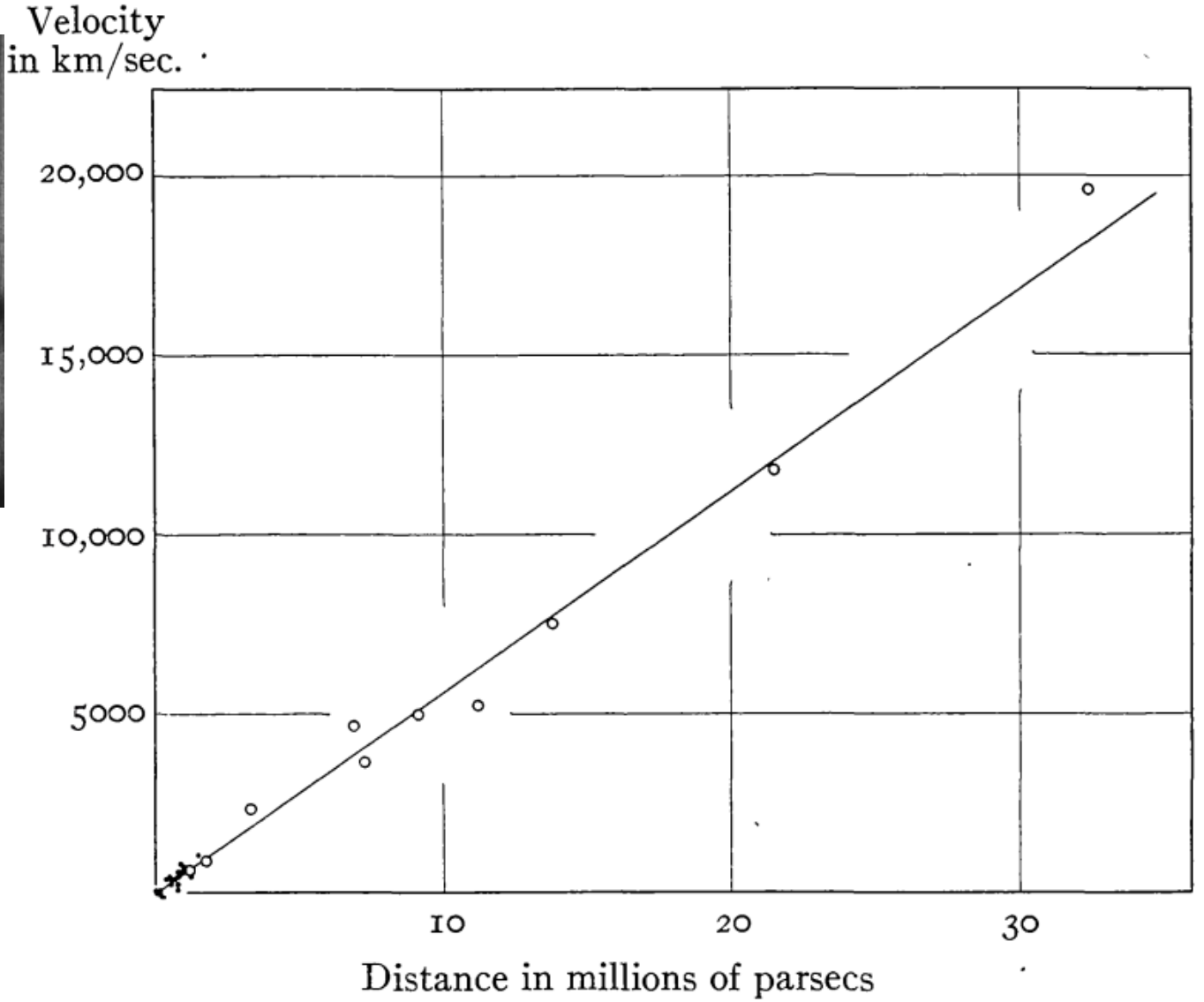
*"I consider the **velocity-distance relation**, its formulation, testing and confirmation, as **a Mount Wilson contribution** and **I am deeply concerned in its recognition as such**"*

quoted in Block, D.: A Hubble Eclipse: Lemaître and Censorship (2011)



Edwin Hubble

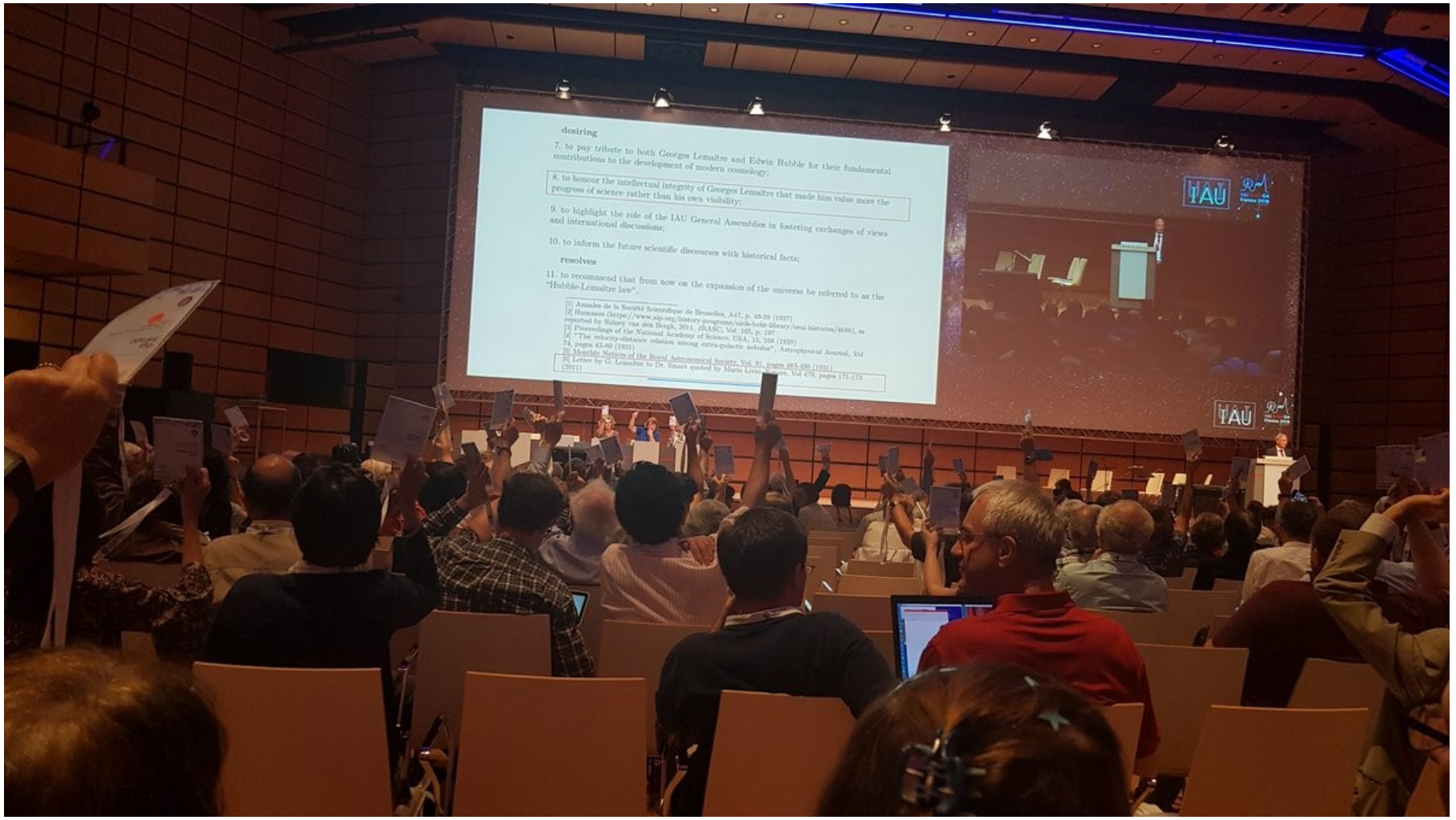
Milton L. Humason



Hubble & Humason, *Astrophys. J.* 74, 43 (1931)

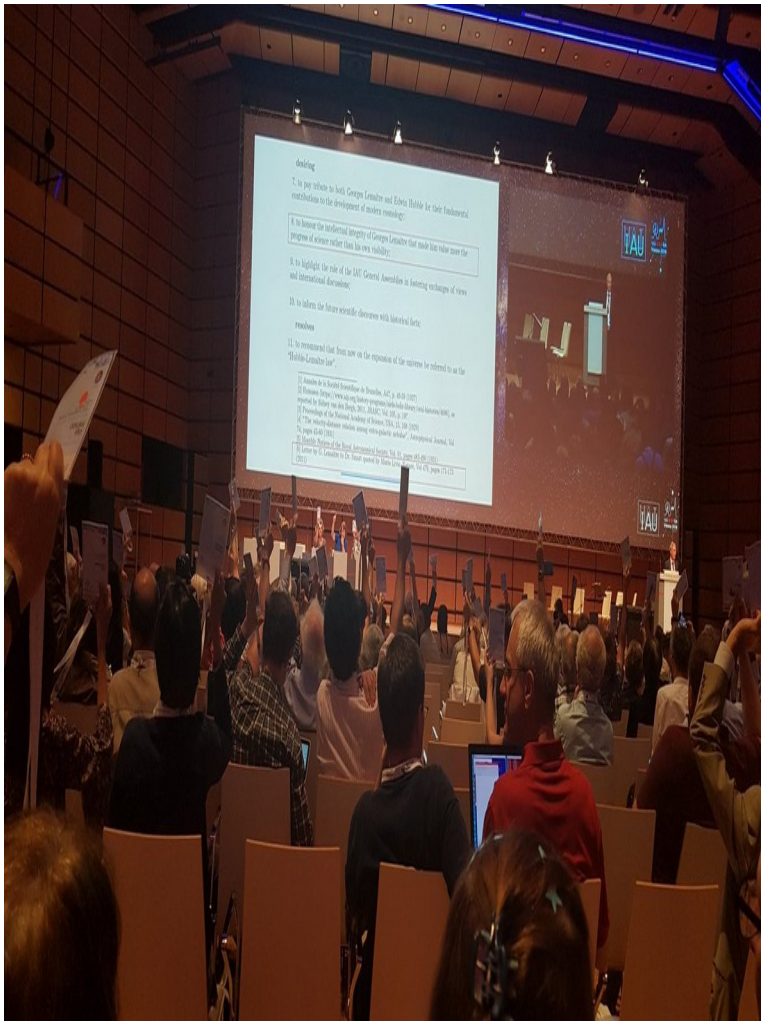
$H_0 = 558$ km s^{-1} Mpc^{-1}

Renaming the Hubble Law



credit: Itziar Aretxaga (@ItziMex)

Renaming the Hubble Law: implications



credit: Itziar Aretxaga (@ItziMex)

- Should the IAU be involved in this?
  - time and resources
  - adverse effects on the IAU actions
- International Science Council (former ICSU)?
- Chance to promote Polish discoveries?

où r est la distance de la source. Nous avons donc

$$\frac{R'}{R} = \frac{v}{cr} \qquad (23)$$

Les vitesses radiales de 43 nébuleuses extra-galactiques sont données par Strömberg (1).

La grandeur apparente m de ces nébuleuses se trouve dans le travail de Hubble. Il est possible d'en déduire leur distance, car Hubble a montré que les nébuleuses extra-galactiques sont de grandeurs absolues sensiblement égales (grandeur $-15{,}2$ à 10 parsecs, les écarts individuels pouvant atteindre deux grandeurs en plus ou en moins), la distance r exprimée en parsecs est alors donnée par la formule $\log r = 0{,}2m + 4{,}04$.

Annals of the Scientific Society of Brussels, 47A, 41 (1927)

Georges Lemaître

where r is the distance of the source. We have therefore

$$\frac{R'}{R} = \frac{v}{cr} \qquad (23)$$

Radial velocities of 43 extragalactic nebulæ are given by Strömberg (6).

The apparent magnitude m of these nebulæ can be found in the work of Hubble. It is possible to deduce their distance from it, because Hubble has shown that extragalactic nebulæ have approximately equal absolute magnitudes (magnitude $= -15.2$ at 10 parsecs, with individual variations ± 2), the distance r expressed in parsecs is then given by the formula $\log r = 0, 2m + 4, 04$.

General Relativity and Gravitation., 45:1635-1646 (2013)

Utilisant les 42 nébuleuses figurant dans les listes de Hubble et de Strömberg (1), et tenant compte de la vitesse propre du soleil (300 Km. dans la direction $\alpha = 315°$, $\delta = 62°$), on trouve une distance moyenne de 0,95 millions de parsecs et une vitesse radiale de 600 Km./sec, soit 625 Km./sec à 10^6 parsecs (2).

Nous adopterons donc

$$\frac{R'}{R} = \frac{v}{rc} = \frac{625 \times 10^5}{10^6 \times 3{,}08 \times 10^{18} \times 3 \times 10^{10}} = 0{,}68 \times 10^{-27}\,\mathrm{cm}^{-1} \qquad (24)$$

Annals of the Scientific Society of Brussels, 47A, 41 (1927)

Georges Lemaître

Using the 42 nebulæ appearing in the lists of Hubble and Strömberg ([7]), and taking account of the proper velocity of the Sun (300 Km/s in the direction $\alpha = 315°$, $\delta = 62°$), one finds a mean distance of 0,95 megaparsecs and a radial velocity of 600 Km/sec, i.e. 625 Km/sec at 10^6 parsecs ([8]).

We will thus adopt

$$\frac{R'}{R} = \frac{v}{rc} = \frac{625 \times 10^5}{10^6 \times 3,08 \times 10^{18} \times 3 \times 10^{10}} = 0,68 \times 10^{-27}\mathrm{cm}^{-1} \qquad (24)$$

General Relativity and Gravitation., 45:1635-1646 (2013)

Utilisant les 42 nébuleuses figurant dans les listes de Hubble et de Strömberg (1), et tenant compte de la vitesse propre du soleil (300 Km. dans la direction $\alpha = 315°$, $\delta = 62°$), on trouve une distance moyenne de 0,95 millions de parsecs et une vitesse radiale de 600 Km./sec, soit 625 Km./sec à 10^6 parsecs (2).

Nous adopterons donc

$$\frac{R'}{R} = \frac{v}{rc} = \frac{625 \times 10^5}{10^6 \times 3{,}08 \times 10^{18} \times 3 \times 10^{10}} = 0{,}68 \times 10^{-27}\ \text{cm}^{-1} \qquad (24)$$

Annals of the Scientific Society of Brussels, 47A, 41 (1927)

Georges Lemaître

$$\frac{v}{c} = \frac{R_2 - R_1}{R_1} = \frac{dR}{R} = \frac{R'}{R}dt = \frac{R'}{R}r$$

where r is the distance of the source. We have therefore

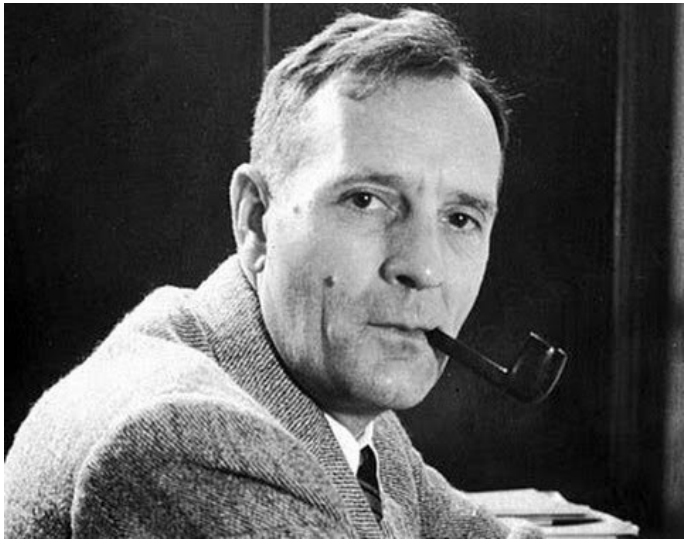
$$\frac{R'}{R} = \frac{v}{cr} \qquad . \quad . \quad . \quad . \quad . \quad (23)$$

From a discussion of available data, we adopt

$$\frac{R'}{R} = 0{\cdot}68 \times 10^{-27}\ \text{cm.}^{-1} \qquad . \quad . \quad . \quad (24)$$

Monthly Notices of the Royal Astronomical Society, 91, 483 (1931)

The Hubble Law



Edwin Hubble

$$d = \frac{c\,z}{H_0}$$

THE LAW OF RED-SHIFTS

George Darwin Lecture, delivered by Dr Edwin Hubble on* 1953 *May* 8

* *Editorial Note.*—This paper comprises the text of the George Darwin Lecture, which the late author had intended to revise before publication. His notes, together with the manuscript from which he spoke, made it clear what form he wished the published material to take. A reorganization of the original manuscript according to his marginal notes, with the addition of a few connecting sentences, was the extent of the editing required.—A. R. Sandage.

The term " apparent velocity " will be discarded, and replaced by " velocity " signifying $c \,.\, d\lambda/\lambda$, or red-shifts expressed on a scale of velocities. The procedure is not formally correct but it is convenient.

Hubble, *MNRAS* 113, 658 (1953)