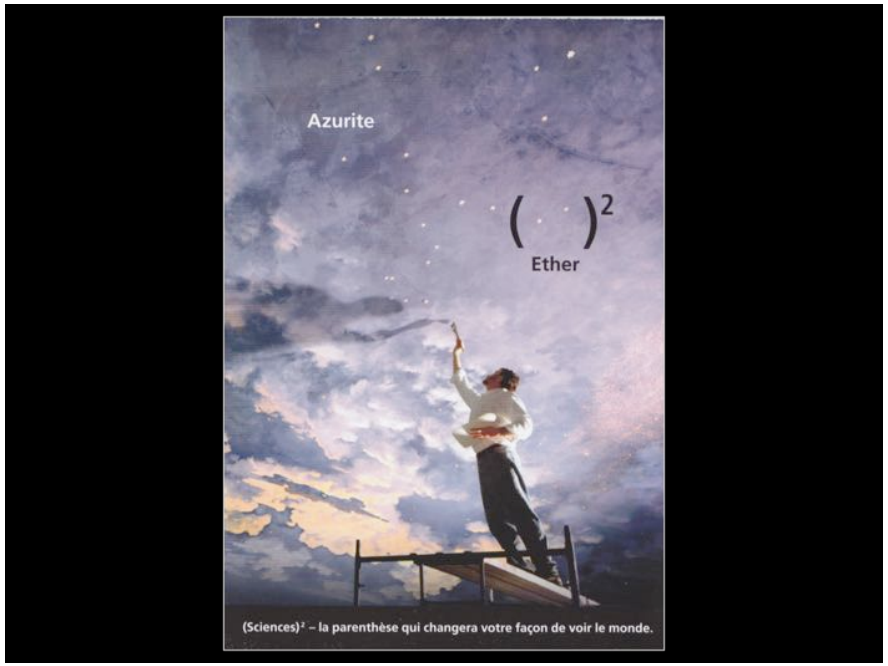

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Histoire de la cosmologie

12 – Expansion de l'Univers

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du laboratoire et du cours : http://lastro.epfl.ch

Histoire de la cosmologie

12 – Expansion de l'Univers

Bibliographie succincte

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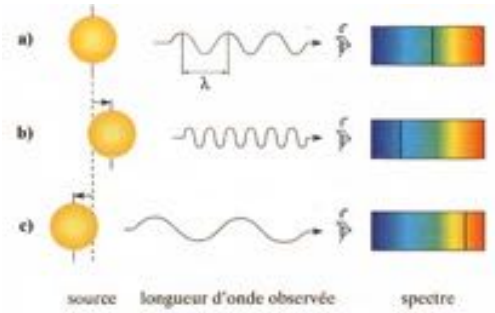
Mesure de mouvements

De nombreuses mesures de mouvements
en astrophysique
(comme dans les autres champs de la physique)
s'effectuent grâce à la spectroscopie
et
aux observations de décalages des raies spectrales

12.1
Les décalages spectraux

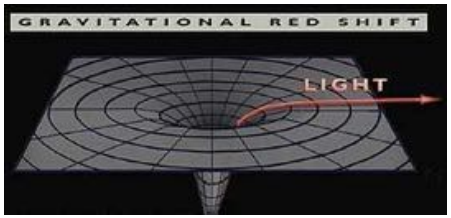
Premier décalage spectral : décalage Doppler

Décalage spectral vers le rouge ou vers le bleu dû au mvt relatif entre la source et l'observateur (effet Doppler)



Deuxième décalage spectral : décalage gravitationnel

Décalage vers le **rouge** gravitationnel dû à un champ gravitationnel local induit par une étoile à neutron, un trou noir stellaire, une galaxie, un trou noir supermassif, …

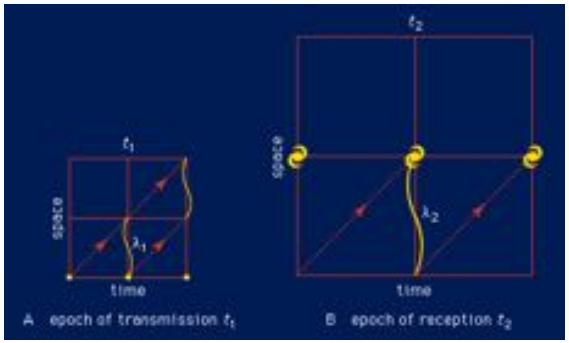


L'effet est local, en ce qu'il est créé dans un volume très petit lorsque comparé à l'univers en entier.

Par exemple, dans l'expérience effectuée pour comparer les temps mesurés par des horloges transportées en avion autour du globe, au temps mesuré par une horloge restée sur Terre, il faut tenir compte du fait que l'horloge sur Terre est dans un champ de gravitation plus intense que l'horloge dans l'avion.

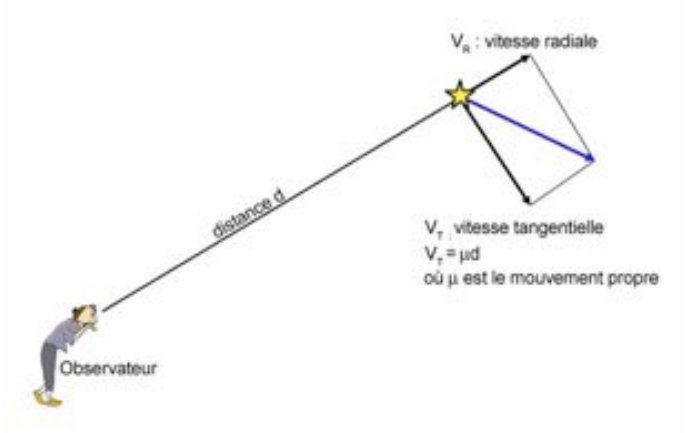
Troisième décalage spectral : décalage cosmologique

Décalage vers le **rouge** dû à l'expansion de l'univers : toutes les galaxies s'éloignent de toutes les galaxies



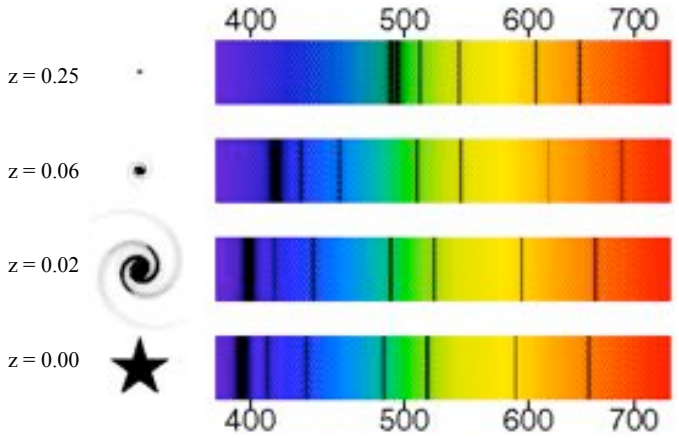
L'effet, décrit par la loi de Hubble, est général, en ce qu'il implique l'univers comme un tout.

Vitesse spatiale = vitesse radiale + vitesse tangentielle

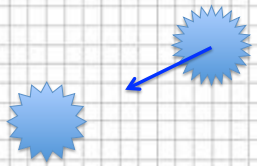


Spectroscopie des étoiles et galaxies

exemples de décalages spectraux vers le rouge, d'origine cosmologique

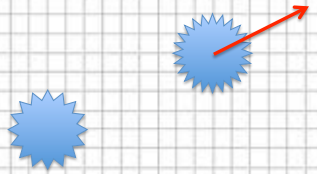


Mouvement entre deux étoiles qui se rapprochent : décalage vers le bleu



effet Doppler

Mouvement entre deux étoiles qui s'éloignent : décalage vers le rouge

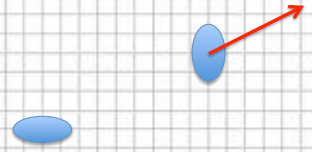


effet Doppler

Mouvement entre deux galaxies qui se rapprochent : décalage vers le bleu

effet Doppler

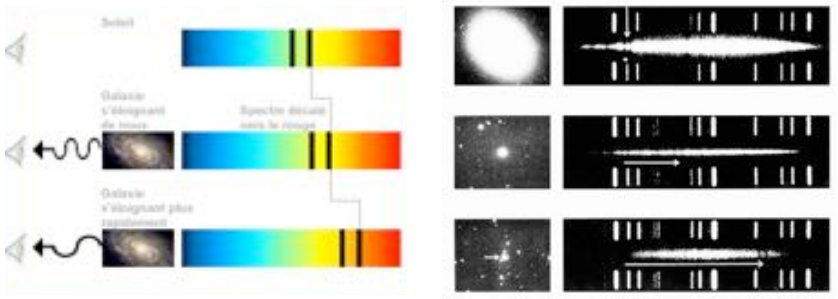
Mouvement entre deux galaxies qui s'éloignent : décalage vers le rouge



effet Doppler

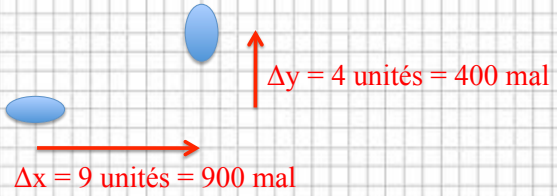
12.2
Le décalage spectral vers le rouge cosmologique

Spectroscopie des galaxies



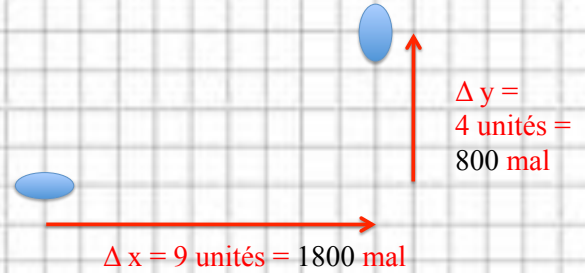
L'expansion de l'Univers

au temps t



L'expansion de l'Univers

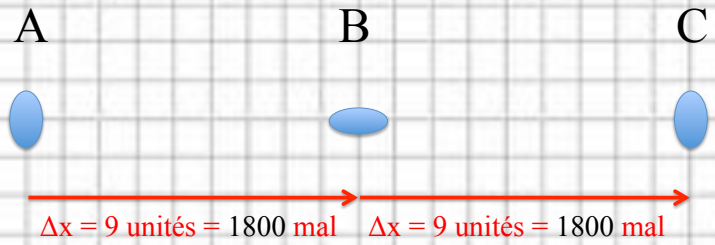
au temps t + Δt



pas l'effet Doppler

L'expansion de l'Univers

au temps $t + \Delta t$

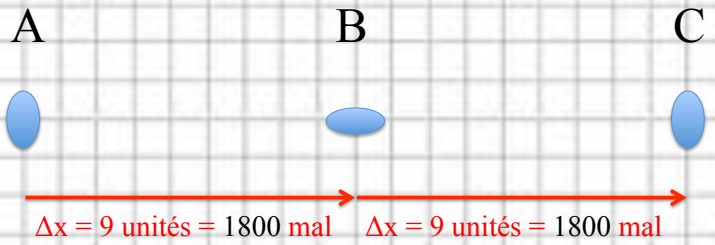


$v_A(B) = 900 \text{ mal} / \Delta t$ mais $v_A(C) = 900 \text{ mal} / \Delta t + 900 \text{ mal} / \Delta t$

donc $v_A(C) = 2\, v_A(B)$

L'expansion de l'Univers

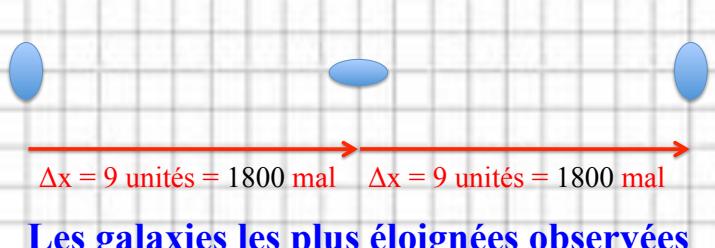
au temps $t + \Delta t$



Plus une galaxie est éloignée,
plus sa vitesse de récession est grande

L'expansion de l'Univers

au temps $t + \Delta t$



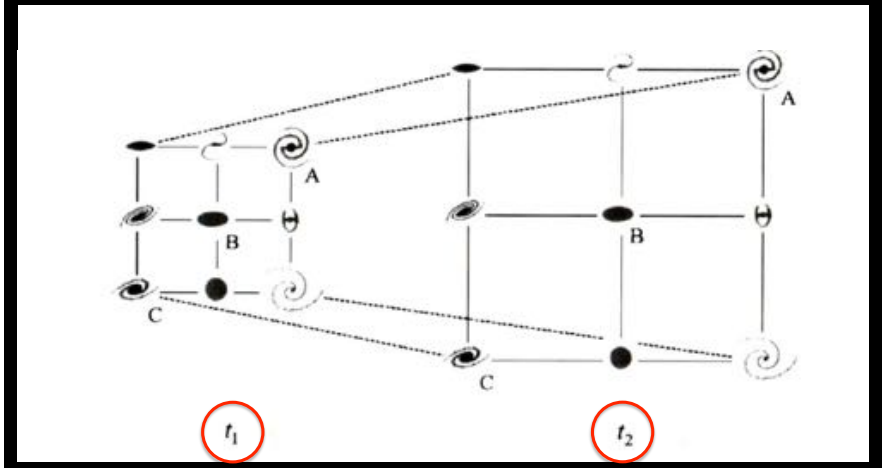
Les galaxies les plus éloignées observées
possèdent des vitesses de récession
proche de celle de la lumière

L'expansion de l'Univers
n'est pas due à l'éloignement
de galaxies
par rapport à d'autres galaxies
mais à l'augmentation de l'espace
entre toutes les galaxies

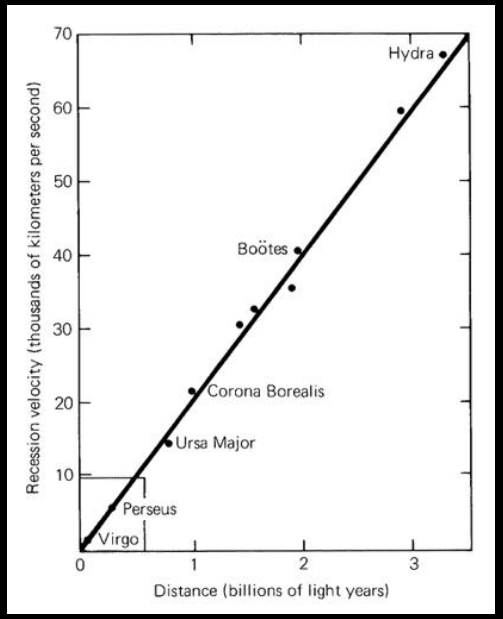
A grandes échelles, dans l'Univers,
tout s'éloigne de tout

Il n'existe pas de point privilégié,
l'Univers ne possède pas de centre

univers en expansion:
toutes les galaxies s'éloignent de toutes les galaxies



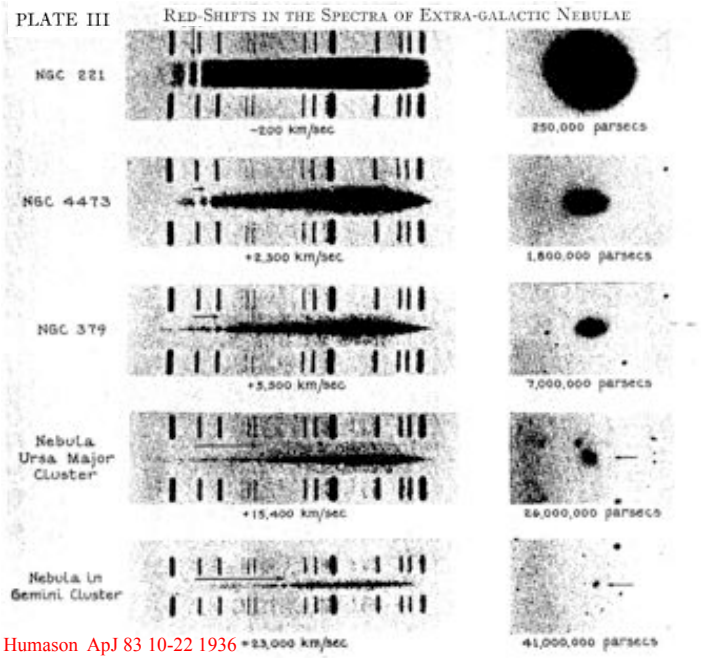
12.3
La loi de Hubble :
des vitesses de récession proportionnelles aux distances



Loi de Hubble 1929

$v = H_0 d$

Hubble retrouve la loi de proportionnalité entre la vitesse de récession et la distance publiée par Lemaître en 1927



Humason ApJ 83 10-22 1936

L'expansion de l'Univers mesurée via les vitesses radiales des galaxies (1929) :

première preuve observationnelle du Big Bang

The Velocity-Distance Relation among Extra-Galactic Nebulae

Hubble and Humason

Astrophysical Journal, vol. 74, p.43, July 1931

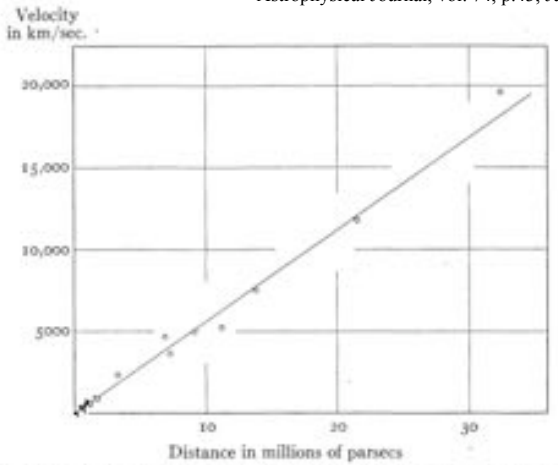
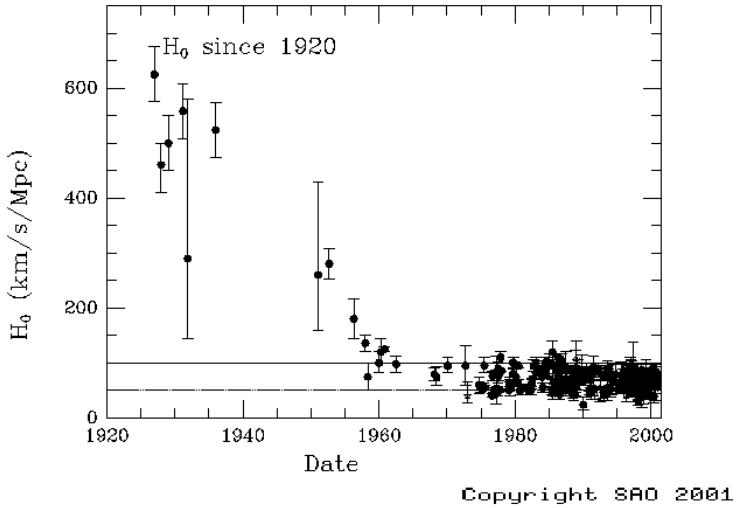


FIG. 5.—The velocity-distance relation. The circles represent mean values for clusters or groups of nebulae. The dots near the origin represent individual nebulae, which, together with the groups indicated by the lowest two circles, were used in the first formulation of the velocity-distance relation.

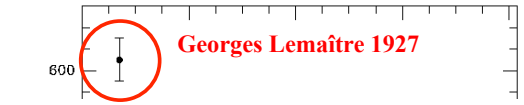
12.4
La loi et la constante de Hubble ou de Lemaître ???

Hubble constant estimates from 1927 on



http://cfa-www.harvard.edu/~huchra

Hubble constant estimates from 1927 on



« Un univers homogène de masse constante et de rayon croissant, rendant compte de la vitesse radiale des nébuleuses extra-galactiques »

in Georges Lemaître, 1927,
Annales de la Société scientifique de Bruxelles,
Série A, t. XLVII, avril 1927, pp. 29-39

H_0 = 625 km s^{-1} Mpc^{-1} data from Strömberg (1925)

Date

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http://cfa-www.harvard.edu/~huchra

Hubble constant estimates from 1927 on

« A Homogeneous Universe of Constant Mass and Increasing Radius accounting for the Radial Velocity of Extra-Galactic Nebulae »

in Georges Lemaître,1931,
MNRAS, 91, pp. 483-490

H_0 = 625 km s^{-1} Mpc^{-1} data from Strömberg (1925)

Date

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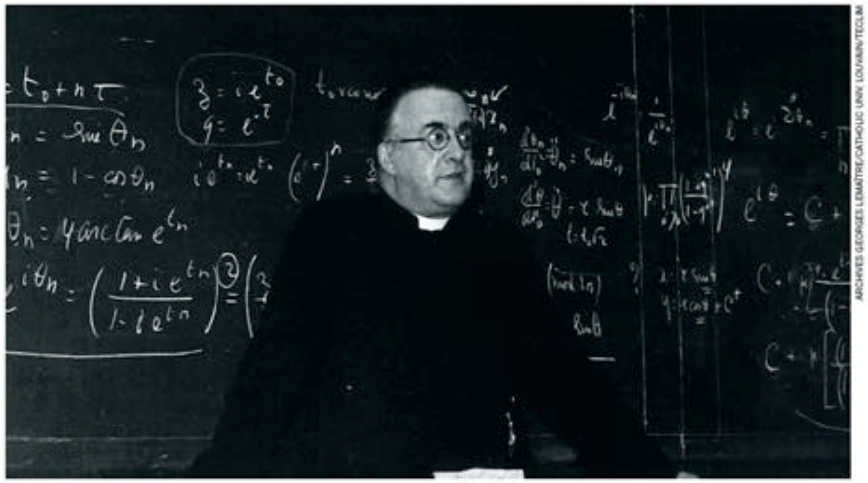
Georges Lemaître (1894 - 1966)



Georges Lemaître giving a lecture at the Catholic University of Louvain in Belgium.

Ph.D. thesis : MIT Department of Physics, 1927, entitled «The gravitational field in a fluid sphere of uniform invariant density according to the theory of relativity; Note on de Sitter Universe; Note on the theory of pulsating stars. »

Hubble cleared

A painstaking study absolves US astronomer Edwin Hubble of censoring a Belgian rival.

Edwin Hubble is that relatively rare thing among dead astronomers — a global household name. He owes his status mainly to the NASA space telescope named in his honour. So when researchers suggested this year that Hubble might have censored the work of a rival to secure credit for the groundbreaking discovery that the Universe is expanding, they triggered a fuss that was far removed from the usual arcane wrangling over historical research priority.

In an admirably thorough Comment on page 171, Mario Livio, an astronomer at the Space Telescope Science Institute in Baltimore, Maryland, clears Hubble of wrongdoing. As a result, NASA and a generation of researchers whose careers are closely tied to the Hubble brand can look skywards with some relief.

The charges against Hubble certainly warranted examination. In 1927, the Belgian astronomer Georges Lemaître published a French-language paper in the *Annales de la Société Scientifique de Bruxelles* that laid out the essentials of a picture of galaxies expanding away from one another, and derived an expansion parameter on the basis of then-recent observations. In 1929, Hubble independently put forward and confirmed the same idea, and the parameter later became known as the Hubble constant. In 1931, Lemaître's paper was translated into English and published in the *Monthly Notices of the Royal Astronomical Society*, but most English speakers probably learned of Hubble's contribution before they learned of Lemaître's.

Suspicions of foul play emerged earlier this year, when amateur historians noticed that the derivation of the expansion constant is missing from the English translation of Lemaître's work. Knowing that Hubble was concerned that he, and the Mount Wilson Observatory in Pasadena, California, at which he made his observations, should get ample credit for confirming the expansion of the Universe, it was tempting to speculate that he had a hand in the editing of the Belgian's paper. But motive alone doesn't build a case, and professional historians, who had known of the irregularity for years, remained sceptical.

Livio's research suggests that they were right to hesitate. After reviewing hundreds of documents in the archives of the Royal Astronomical Society in London, Livio found a copy of a 1931 letter by Lemaître in which he said that in translating his paper, he had deleted discussion of the velocities of galaxies because it was "of no actual interest". Why exactly Lemaître thought this is unclear, but it seems that he was not very concerned about getting the credit for his work in the way that modern followers have assumed; instead, he may have worried more about seeming out of date, given that the data on which the expansion constant was based had been improved since 1927.

The idea that the accuracy of papers and their relevance to colleagues ought to be more important than ensuring priority at every step may seem fantastic in today's cut-throat world of science. And perhaps it was then, too. Perhaps Lemaître was simply so flattered to be invited to translate his paper that, aware of Hubble's importance among English-speakers and fearful of repercussions, or eager to join the Royal Astronomical Society, he self-censored. The case against Hubble is closed, but there may still be a story for motivated historians to look into.

Space agencies should also take note. Whether or not Hubble deliberately censored Lemaître, the fact is that in the English-speaking world, Lemaître has lost — to Hubble — priority for his contributions. The Belgian's name is a worthy candidate for the title of a future space mission. ■

NATURE.COM
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News, 2011, Nature 479 171

Lemaître studied at the University of Cambridge UK, at MIT for his PhD thesis, visited regularly Harvard, Caltech and many other places in the USA.

Since the paper in English is a slightly trimmed version of the paper in French, some asked who translated his 1927 paper into the 1931 English version ?

Mystery of the missing text solved

A discovered letter explains the loss of key paragraphs during the translation of one of Georges Lemaître's papers about the expanding Universe, shows **Mario Livio**.

not surprinsingly
the translater was Lemaître himself
(as already mentioned in various historical studies)

suspicion that someone censored a key paper by the Belgian priest and cosmologist Georges Lemaître to ensure Hubble's priority[2,3].

There is little doubt that Lemaître deserves the credit for proposing an expanding Universe. But the censorship charges tarnish Hubble's genuine achievement of confirming and extending the idea. As someone intimately involved with Hubble's namesake — the Hubble Space Telescope — I became intrigued by this 'whodunnit' mystery, and decided to investigate. As a result, I unearthed

NATURE.COM
Edwin Hubble in translation trouble:
go.nature.com/lca654

noted that: "The great preponderance of positive [receding] velocities is very striking." But he added that a lack of observations of southern nebulae prevented him from drawing further conclusions.

In 1927, Lemaître published, in French, a remarkable paper in the relatively obscure *Annals of the Scientific Society of Brussels*[4]. It was entitled (in its English translation): 'A homogeneous Universe of constant mass and increasing radius accounting for the radial velocity of extra-galactic nebulae'. In it, Lemaître reported his discovery of dynamic solutions to Einstein's general relativity equations, from which he derived what ▶

Livio, 2011, Nature 479 171

" It is difficult to believe
that the velocities are real,
that all matter is actually scattering away
from our region of space "

E. P. Hubble, Los Angeles Times, 1929

In 1927 (and 1931) Lemaître mentions
Hubble, Strömberg, and Slipher,
while in 1929, using the same data,
Hubble does not cite any of them

Dans son fameux livre *The Realm of the Nebulae.*
New Haven : Yale University Press YUP, 1936,
Hubble ne mentionne pas une fois le nom de Lemaître…

It does not decrease the glory of Hubble
to acknowledge that Lemaître deserves
credit and recognition
for his pioneering studies
and for having written the "Hubble law"
before its "author" did …