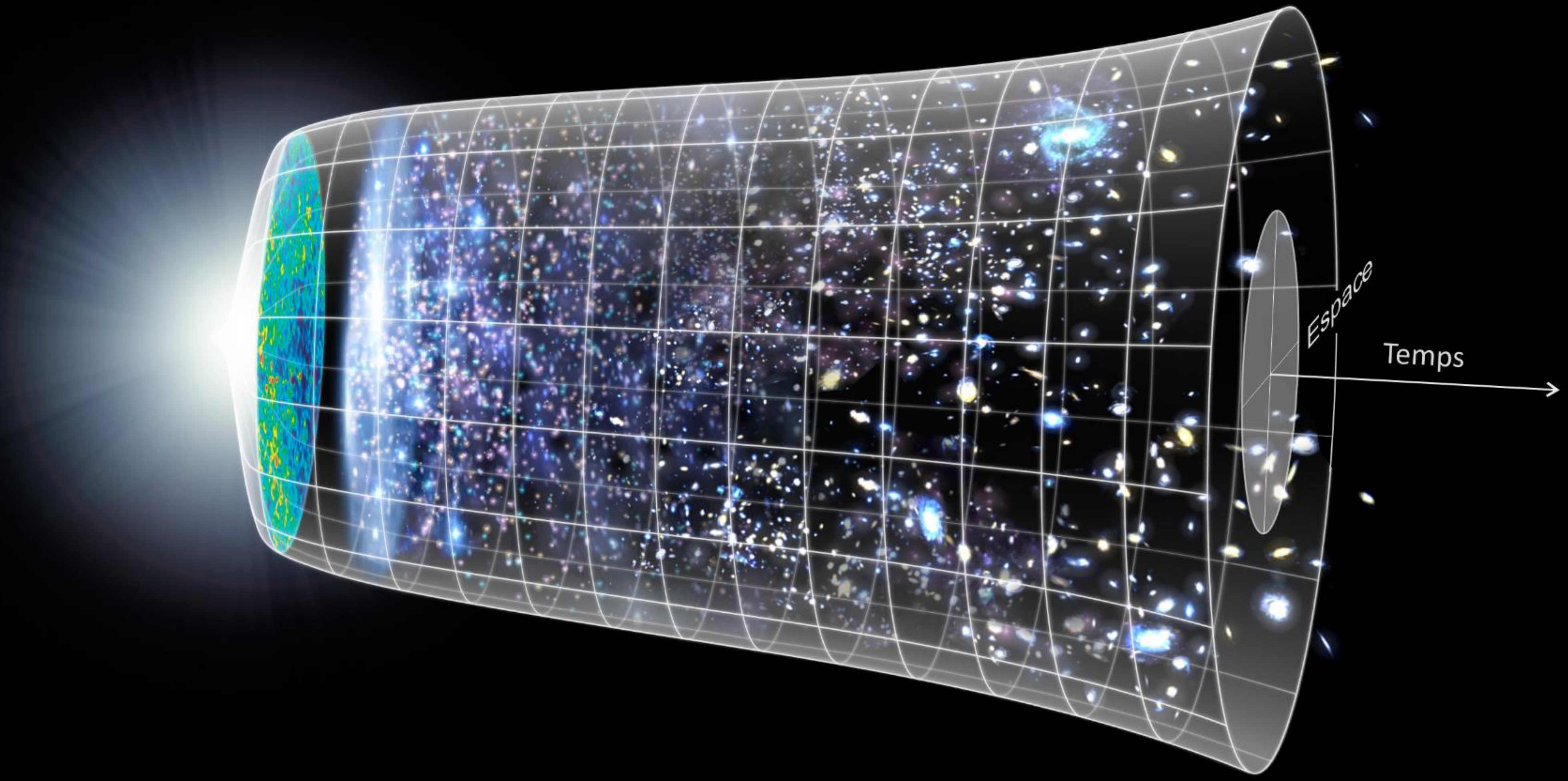
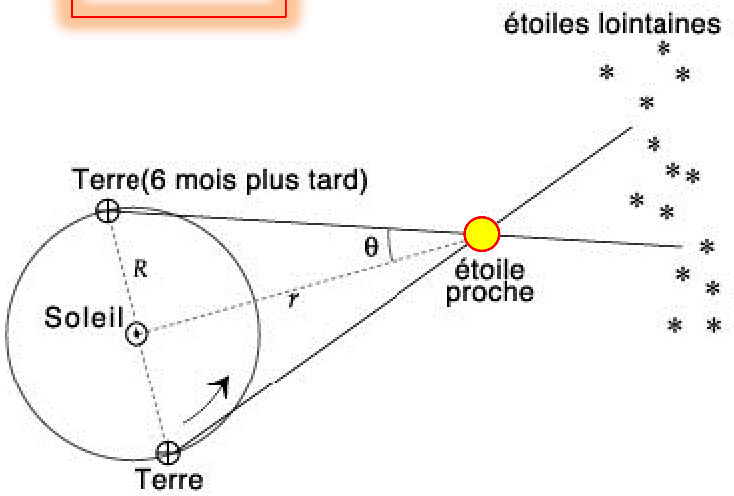
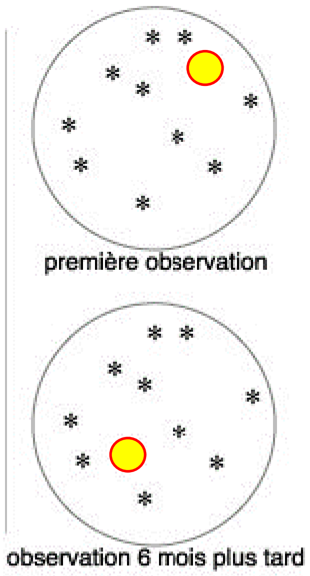
La représentation moderne du monde

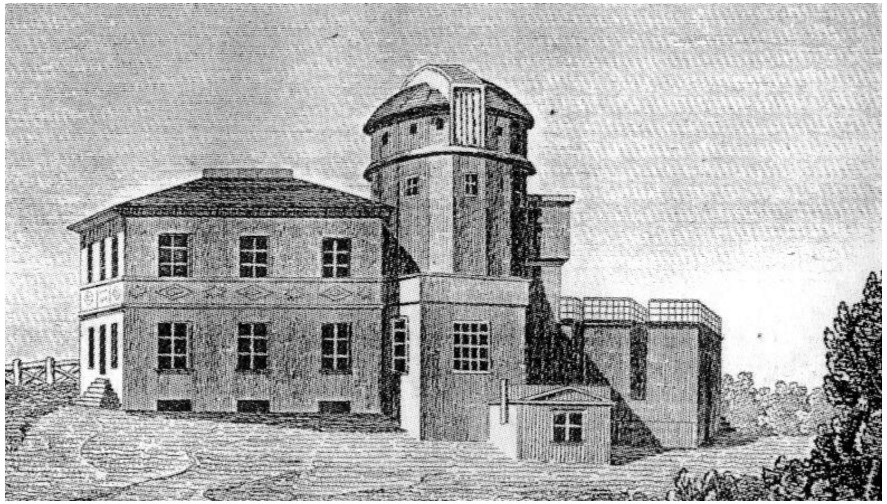


On mesure enfin la distance des étoiles !

1838







L'observatoire de Königsberg vers 1830 avec sa lunette méridienne de 33 cm de diamètre

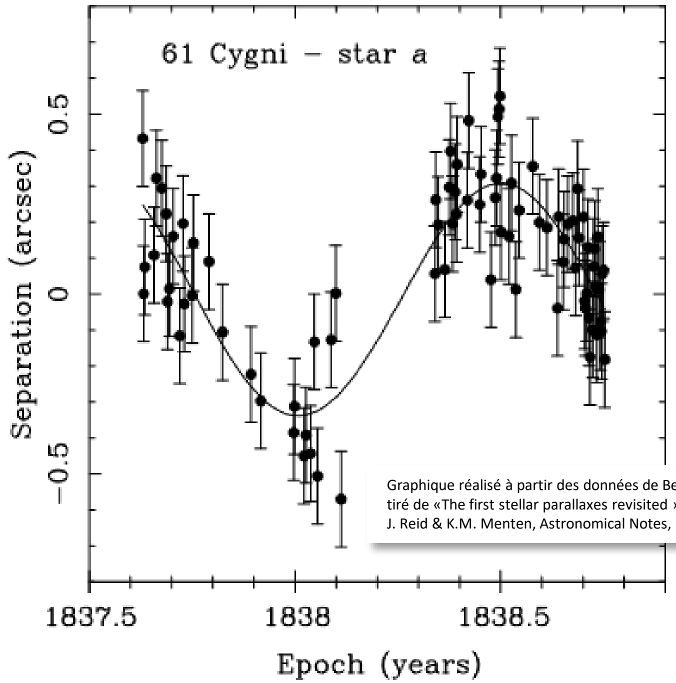
Friedrich Bessel par C. Jensen en 1839, collections de la Ny Carlsberg Glyptotek à Copenhague

$$\tan\theta = 1\text{UA}/r$$

$$\theta \ll 1, r[\text{UA}] = 360 \times 3600 \times 2\pi/\theta[\text{ARCSEC}]$$
$$= 206\,370/\theta[\text{ARCSEC}]$$

1 UA = 15,8 µAL = 4,8 µPc

Découvreur	Année	Etoile	Parallaxe [ARCSEC] / Distance [AL] (valeurs modernes)
Friedrich. Bessel (Königsberg, Prusse)	1838	61 Cygni	0,313 / 10,4 0,287 / 11,4



Graphique réalisé à partir des données de Bessel, tiré de «The first stellar parallaxes revisited », M. J. Reid & K.M. Menten, Astronomical Notes, 2020

On enregistre les premiers spectres !

Philosophical Transactions of the Royal Society of London
Volume 154, Issue 154, P. 413-435, Décembre 1864

1864

XII. *On the Spectra of some of the Fixed Stars. By* WILLIAM HUGGINS, *F.R.A.S., and* W. A. MILLER, *M.D., LL.D., Treas. & V.P.R.S., Professor of Chemistry, King's College, London.*

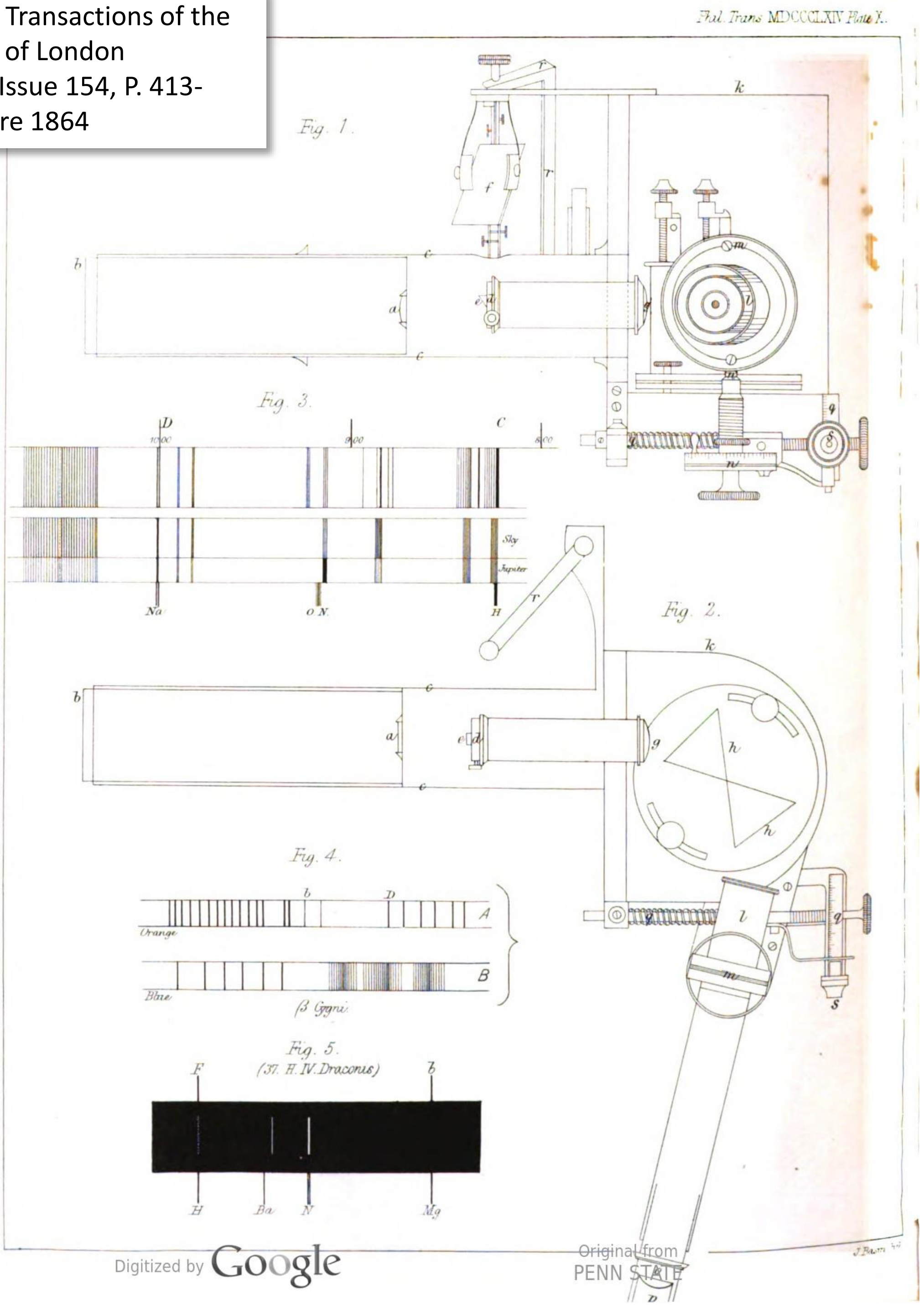
Received April 28,—Read May 26, 1864.

§ I. *Introduction.*

1. THE recent discovery by KIRCHHOFF of the connexion between the dark lines of the solar spectrum and the bright lines of terrestrial flames, so remarkable for the wide range of its application, has placed in the hands of the experimentalist a method of analysis which is not rendered less certain by the distance of the objects the light of which is to be subjected to examination. The great success of this method of analysis as applied by KIRCHHOFF to the determination of the nature of some of the constituents of the sun, rendered it obvious that it would be an investigation of the highest interest, in its relations to our knowledge of the general plan and structure of the visible universe, to endeavour to apply this new method of analysis to the light which reaches the earth from the fixed stars. Hitherto the knowledge possessed by man of these immensely distant bodies has been almost confined to the fact that some of them, which observation shows to be united in systems, are composed of matter subjected to the same laws of gravitation as those which rule the members of the solar system. To this may be added the

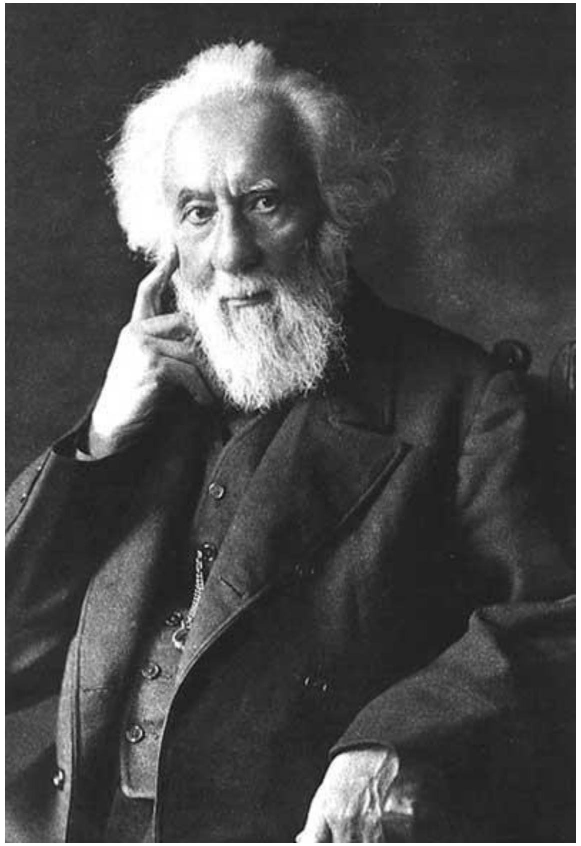
XIII. *On the Spectra of some of the Nebulæ. By* WILLIAM HUGGINS, *F.R.A.S. A Supplement to the Paper "On the Spectra of some of the Fixed Stars. By* WILLIAM HUGGINS, *F.R.A.S., and* W. A. MILLER, *M.D., LL.D., Treas. and V.P.R.S." Communicated by Professor* W. A. MILLER, *M.D., LL.D.*

Received September 8, 1864, and printed in continuation of the paper preceding.



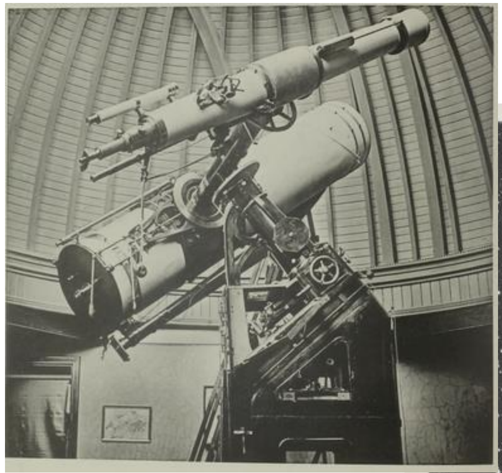
Conclusion des travaux de Huggins (**1864**)

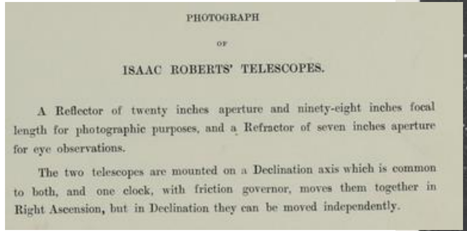
La nébuleuse d'Orion est principalement constituée de gaz alors que la nébuleuse d'Andromède est constituée d'étoiles.



Sir William Huggins, photographié en 1910 à l'âge de 86 ans.

Première photographie astronomique réalisée le 30 septembre **1880** par Henri Drapper qui enregistra la nébuleuse d'Orion en 51 minutes de pose sur une plaque au colloïde humide, avec un instrument de 28 cm de diamètre.





PHOTOGRAPH

OF

ISAAC ROBERTS' TELESCOPES.

A Reflector of twenty inches aperture and ninety-eight inches focal length for photographic purposes, and a Refractor of seven inches aperture for eye observations.

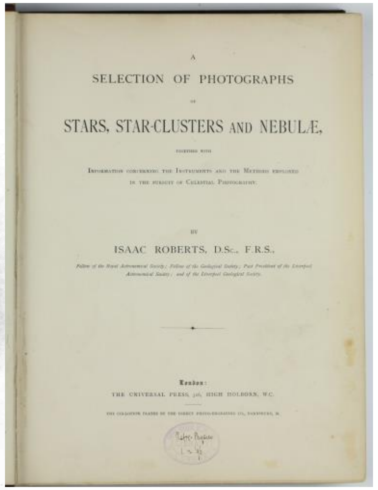
The two telescopes are mounted on a Declination axis which is common to both, and one clock, with friction governor, moves them together in Right Ascension, but in Declination they can be moved independently.

On voit pour la première fois les structures en spirale

GREAT NEBULA IN ANDROMEDA.

Photographed by Dr. I. Roberts, Dec. 29, 1888, *between* 1 *h.* 38 *m. and* 5 *h.* 45 *m.*—4 *hours' exposure. R. A.,* 0 *h.* 37 *m.* 17 *s. Dec. N.* 40° 43.4′. *The three smaller nebulæ were discovered by Miss Herschel in* 1783.

Photographies de Isaac Roberts



A

SELECTION OF PHOTOGRAPHS

OF

STARS, STAR-CLUSTERS AND NEBULÆ,

TOGETHER WITH

INFORMATION CONCERNING THE INSTRUMENTS AND THE METHODS EMPLOYED IN THE PURSUIT OF CELESTIAL PHOTOGRAPHY.

BY

ISAAC ROBERTS, D.Sc., F.R.S.,

Fellow of the Royal Astronomical Society; Fellow of the Geological Society; Past President of the Liverpool Astronomical Society; and of the Liverpool Geological Society.

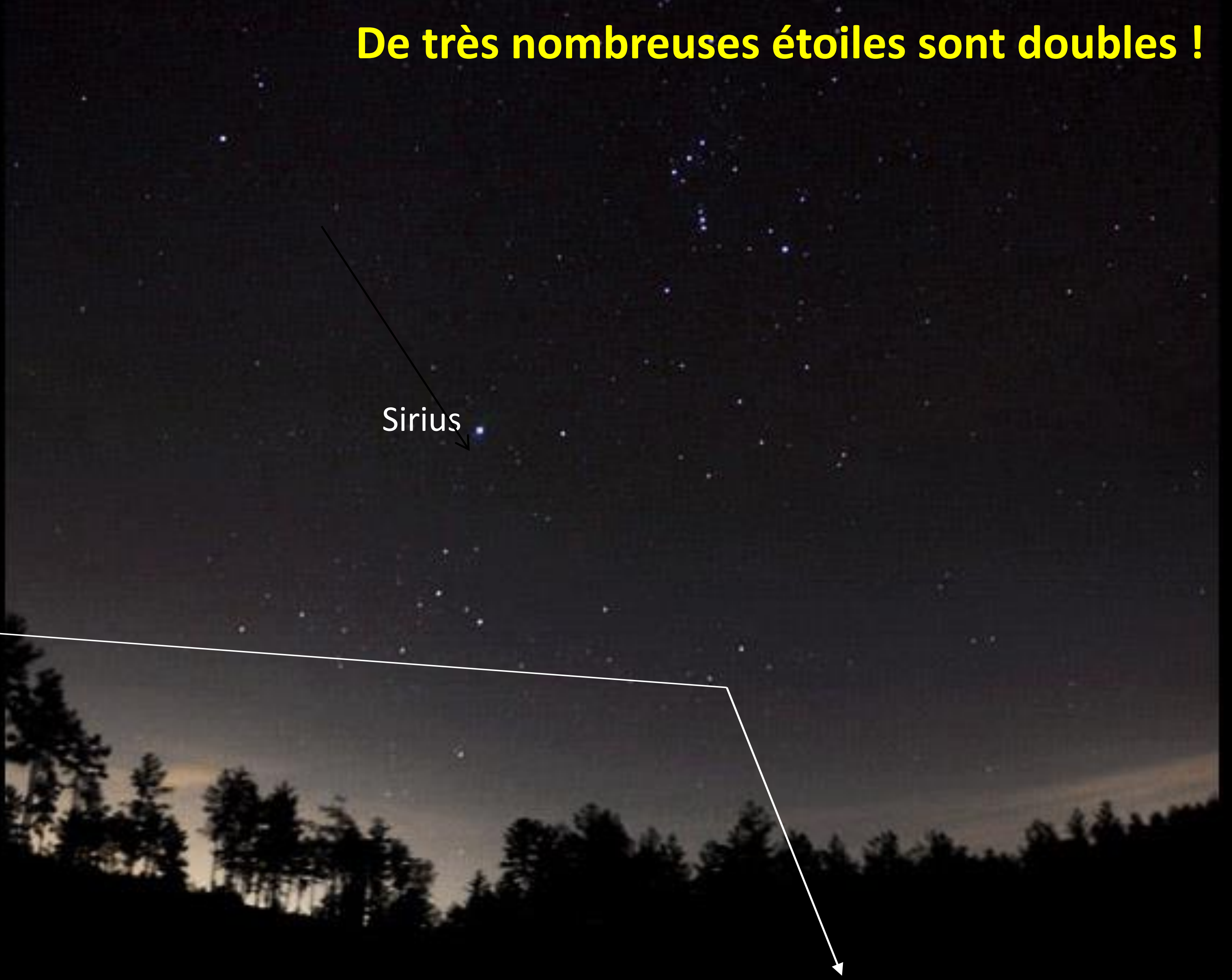
London:

THE UNIVERSAL PRESS, [illegible], HIGH HOLBORN, W.C.

NEBULA M. 33 TRIANGULI.

Extrait de "A Selection of Photographs of Stars, Star-Clusters and Nebulae". Isaac Robert, **1893**

De très nombreuses étoiles sont doubles !



Distance : 8,65 Al

1838 Méthode des parallaxes


Friedrich Bessel

Détection d'une oscillation dans la parallaxe

→ Compagnon Sirius B ?
Période ~ 50 ans

1860-70

Observation de Sirius B
(Lunette de 42 cm de Northwestern Univ. Illinois)

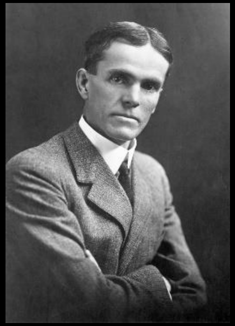

Alvan Graham Clark

$M_A = 2,3\ M_\odot$
$M_B = 1,0\ M_\odot$

$L_A = 23,5\ L_\odot$
$L_B = 0,03\ L_\odot$

1915

Spectre de Sirius B
Téléscope de 2m5 de l'Observatoire du Mt Wilson


Walter Sydney Adams

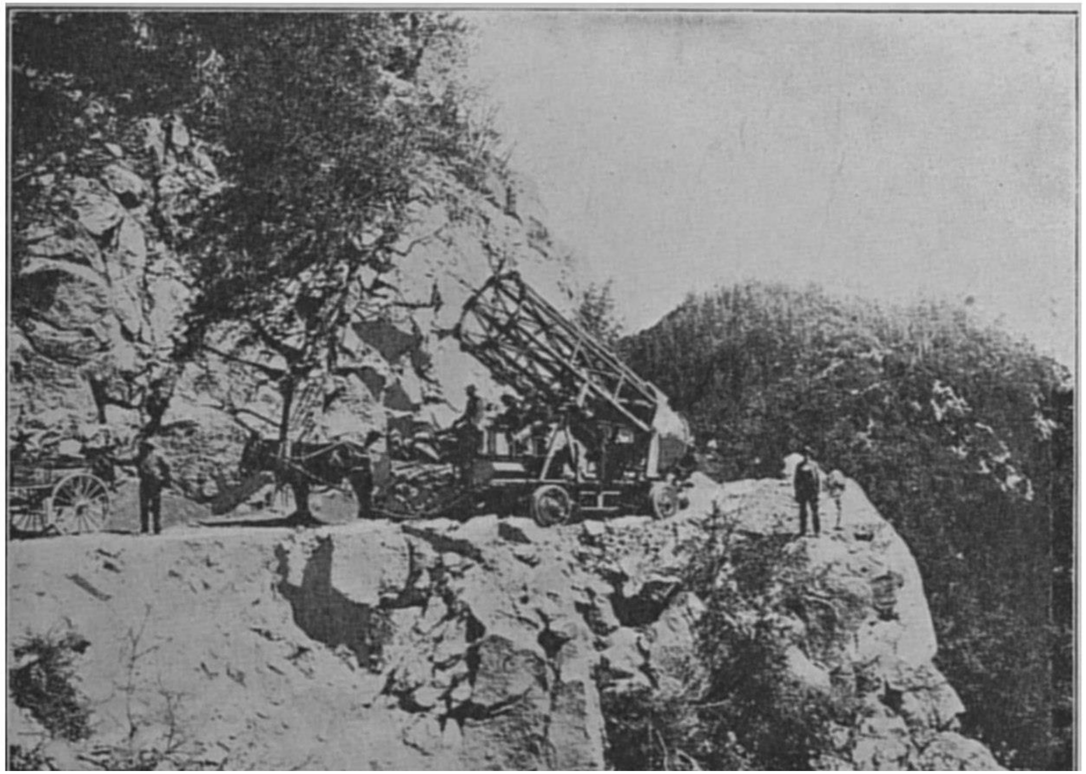
$T_A = 9\ 900\ °K$ $R_A = 1,7\ R_\odot$
$T_B = 27\ 000\ °K$ $R_B = 0,008\ R_\odot$

Densité de Sirius B
4 tonnes / cm^3

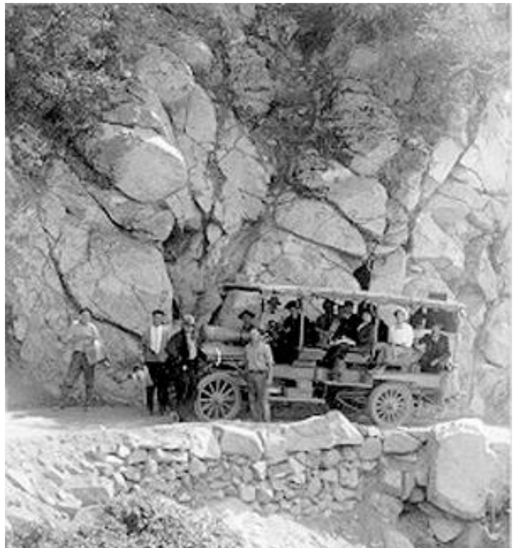
De 1908 à 1917 : construction de l'observatoire du Mont Wilson(1742 m) en Californie (près de Pasadena)

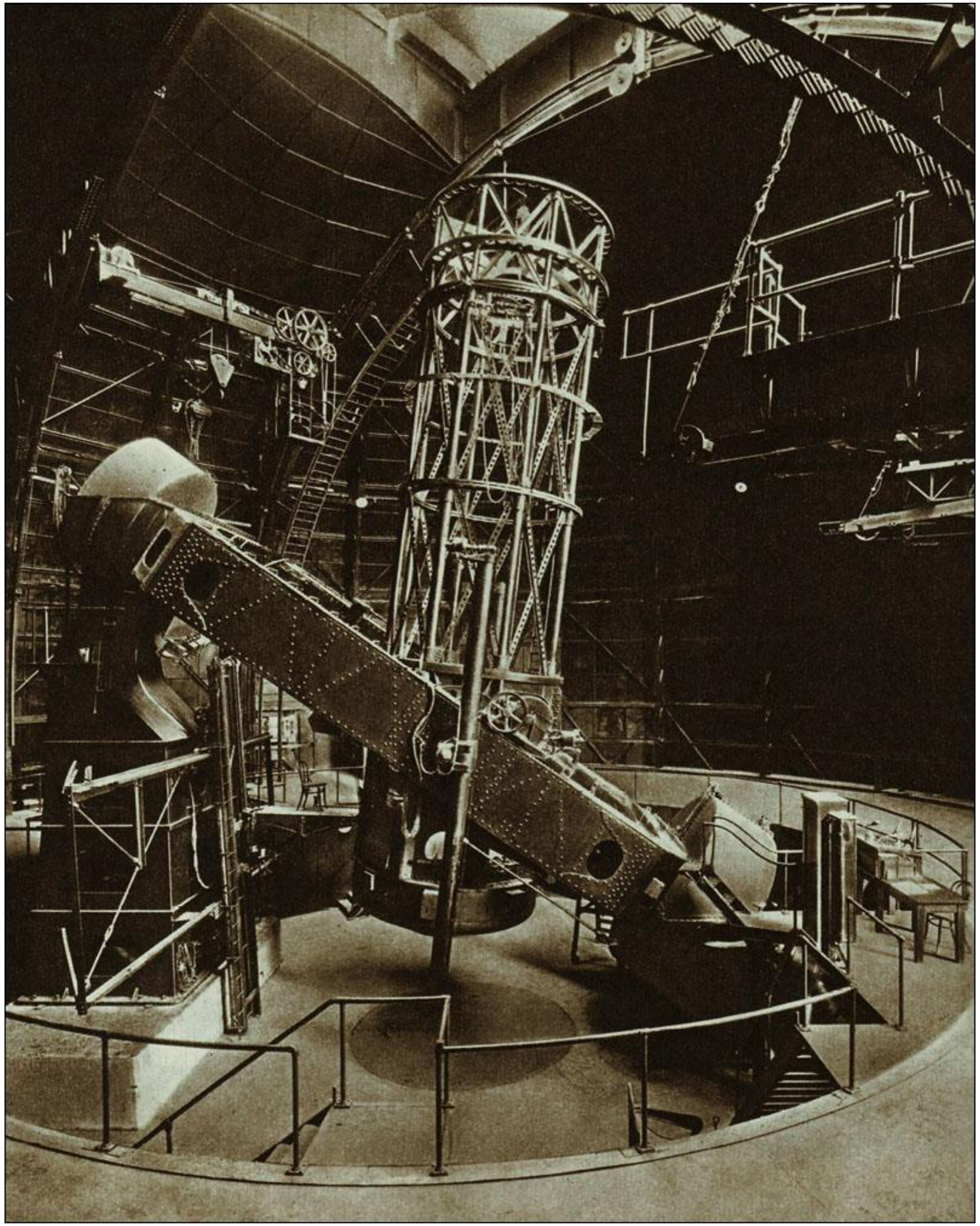
Transport par camion du miroir de 2,5 m de diamètre en 1917 (2 ans de fabrication toujours par St Gobain)

Ce miroir restera celui du plus grand télescope du monde pendant 30 ans

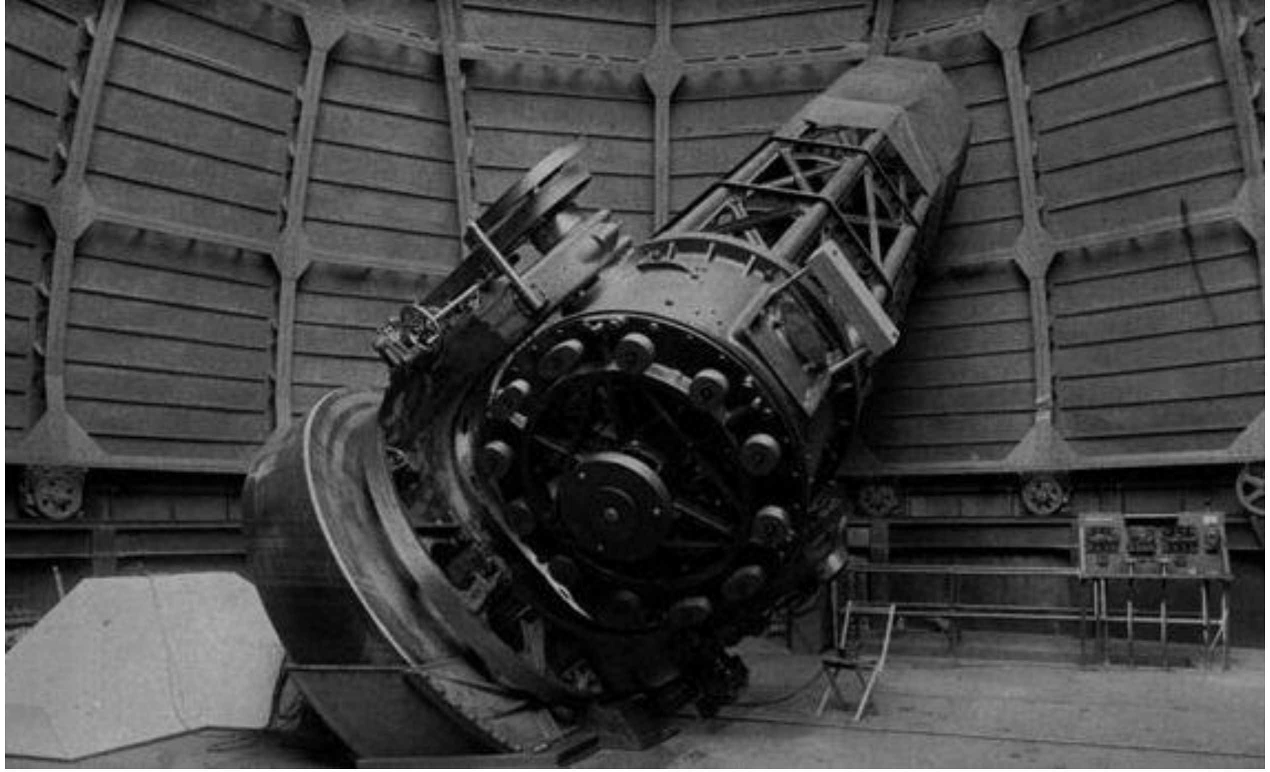


Le miroir du premier télescope de 1,5m de diamètre est hissé en 1908 sur la montagne après avoir été fabriqué en France par St Gobain

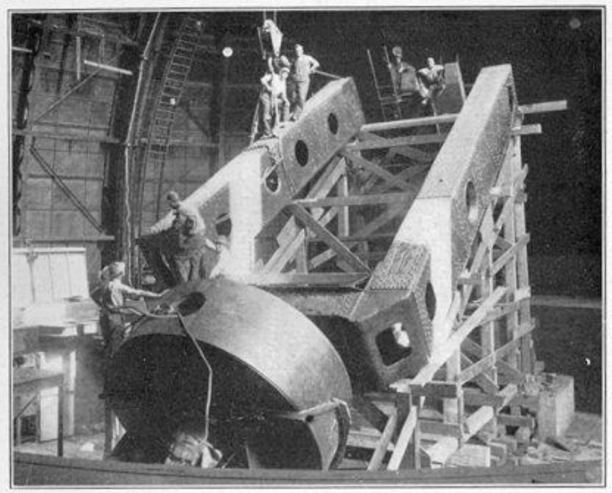




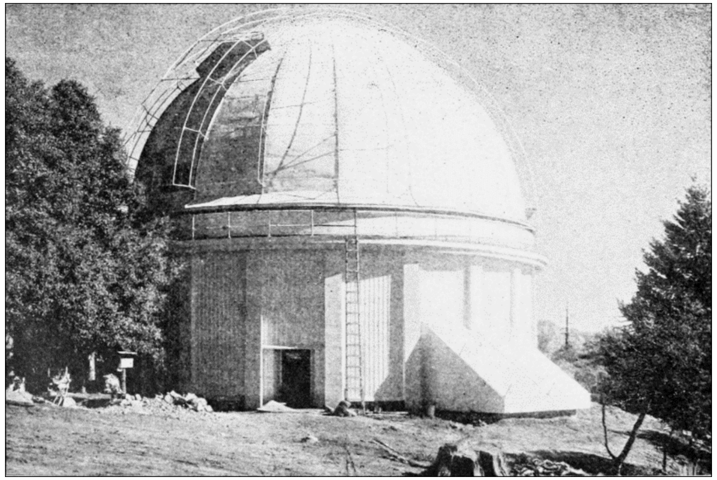
1er nov. 1917 - Le Télescope Hooker : 2m5 de diamètre (100 inches)+ interféromètre



8 décembre 1908 - Le Télescope Hale : 1m5 (60 inches) de diamètre



Ouvriers assemblant l'axe polaire du Hooker



La coupole du Hale

25 Novembre 1915 : Théorie de la relativité générale
13 Janvier 1916 : L'espace-Temps de Schwarzschild

Über das Gravitationsfeld eines Massenpunktes nach der EINSTEINschen Theorie.

Von K. SCHWARZSCHILD.

(Vorgelegt am 13. Januar 1916 [s. oben S. 42].)

§ 1. Hr. EINSTEIN hat in seiner Arbeit über die Perihelbewegung des Merkur (s. Sitzungsberichte vom 18. November 1915) folgendes Problem gestellt:

Ein Punkt bewege sich gemäß der Forderung

$$\delta \int ds = 0, \quad \text{wobei} \quad ds = \sqrt{\sum g_{\mu\nu} dx_\mu dx_\nu} \quad \mu, \nu = 1, 2, 3, 4 \qquad (1)$$

ist, $g_{\mu\nu}$ Funktionen der Variabeln x bedeuten und bei der Variation am Anfang und Ende des Integrationswegs die Variablen x festzuhalten sind. Der Punkt bewege sich also, kurz gesagt, auf einer geodätischen Linie in der durch das Linienelement ds charakterisierten Mannigfaltigkeit.

Die Ausführung der Variation ergibt die Bewegungsgleichungen des Punktes

$$\frac{d^2 x_\alpha}{ds^2} = \sum_{\mu,\nu} \Gamma^\alpha_{\mu\nu} \frac{dx_\mu}{ds} \frac{dx_\nu}{ds}, \quad \alpha, \beta = 1, 2, 3, 4 \qquad (2)$$

wobei

$$\Gamma^\alpha_{\mu\nu} = -\frac{1}{2} \sum_\beta g^{\alpha\beta} \left(\frac{\partial g_{\mu\beta}}{\partial x_\nu} + \frac{\partial g_{\nu\beta}}{\partial x_\mu} - \frac{\partial g_{\mu\nu}}{\partial x_\beta} \right) \qquad (3)$$

ist und $g^{\alpha\beta}$ die zu $g_{\alpha\beta}$ koordinierte und normierte Subdeterminante in der Determinante $|g_{\mu\nu}|$ bedeutet.

Dies ist nun nach der EINSTEINschen Theorie dann die Bewegung eines masselosen Punktes in dem Gravitationsfeld einer im Punkt $x_1 = x_2 = x_3 = 0$ befindlichen Masse, wenn die »Komponenten des Gravitationsfeldes« Γ überall, mit Ausnahme des Punktes $x_1 = x_2 = x_3 = 0$, den »Feldgleichungen«

« Sur le champ gravitationnel d'une masse ponctuelle selon la théorie d'Einstein »

$$\Gamma^1_{11} = -\frac{1}{2}\frac{1}{f_1}\frac{\partial f_1}{\partial x_1}, \quad \Gamma^1_{22} = +\frac{1}{2}\frac{1}{f_1}\frac{\partial f_2}{\partial x_1}\frac{1}{1-x_2^2},$$

$$\Gamma^1_{33} = +\frac{1}{2}\frac{1}{f_1}\frac{\partial f_3}{\partial x_1}(1-x_2^2),$$

$$\Gamma^1_{44} = -\frac{1}{2}\frac{1}{f_1}\frac{\partial f_4}{\partial x_1},$$

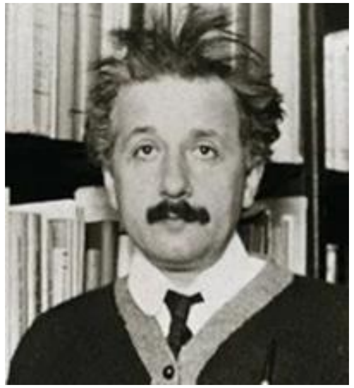
$$\Gamma^2_{21} = -\frac{1}{2}\frac{1}{f_2}\frac{\partial f_2}{\partial x_1}, \quad \Gamma^2_{22} = -\frac{x_2}{1-x_2^2}, \quad \Gamma^2_{33} = -x_2(1-x_2^2),$$

$$\Gamma^3_{31} = -\frac{1}{2}\frac{1}{f_3}\frac{\partial f_3}{\partial x_1}, \quad \Gamma^3_{32} = +\frac{x_2}{1-x_2^2},$$

$$\Gamma^4_{41} = -\frac{1}{2}\frac{1}{f_4}\frac{\partial f_4}{\partial x_1}$$

(die übrigen null).

$$(1-\alpha/R)\left(\frac{dt}{ds}\right)^2 - \frac{1}{1-\alpha/R}\left(\frac{dR}{ds}\right)^2 - R^2\left(\frac{d\phi}{ds}\right)^2 = \text{const.} = h, \qquad (15)$$



Karl Siegmund Schwarzschild

Lettre de K.S. à A.E. le 22 décembre 1915

« *Comme vous le voyez, la guerre m'a traité assez gentiment, en dépit des tirs lourds, pour me permettre de m'éloigner de tout et prendre cette promenade dans le pays de vos idées.* »

Réponse de A.E à K.S. début 1916…

« *J'ai lu votre document avec le plus grand intérêt. Je ne m'attendais pas à ce qu'on puisse formuler la solution exacte du problème d'une manière aussi simple. J'ai beaucoup aimé votre traitement mathématique du sujet. Jeudi prochain, je vais présenter le travail à l'Académie avec quelques mots d'explication.* »

Version détaillée : Jean Eisenstaedt, Einstein et la relativité générale, CNRS Editions, 2013

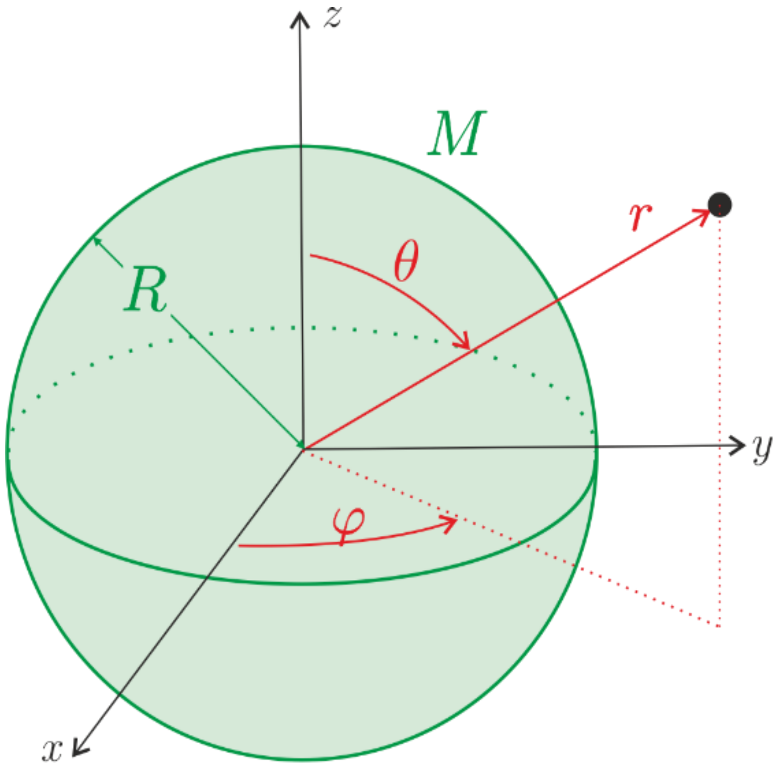
Qu'est ce que l'espace-Temps de Schwarzschild ?

Karl Schwarzschild à son bureau de Potsdam vers 1019 (Emilio Segrè Visual Archives)

Une sphère de matière homogène entourée de vide

2 paramètres : La masse M et le rayon R de la sphère

L'espace-temps correspondant à l'extérieur de la sphère ($r > R$) fait apparaître une distance particulière : le rayon de Schwarzschild : $R_s = \dfrac{2GM}{c^2}$



$$ds^2 = \left(1 - \frac{R_s}{r}\right) dt^2 - \frac{dr^2}{1 - \dfrac{R_s}{r}} - r^2 \left(d\theta^2 + \sin^2\theta d\varphi^2\right)$$

Si le rayon de la sphère est plus petit que son rayon de Schwarzschild $(R < R_s)$: Problèmes

Mathématiques

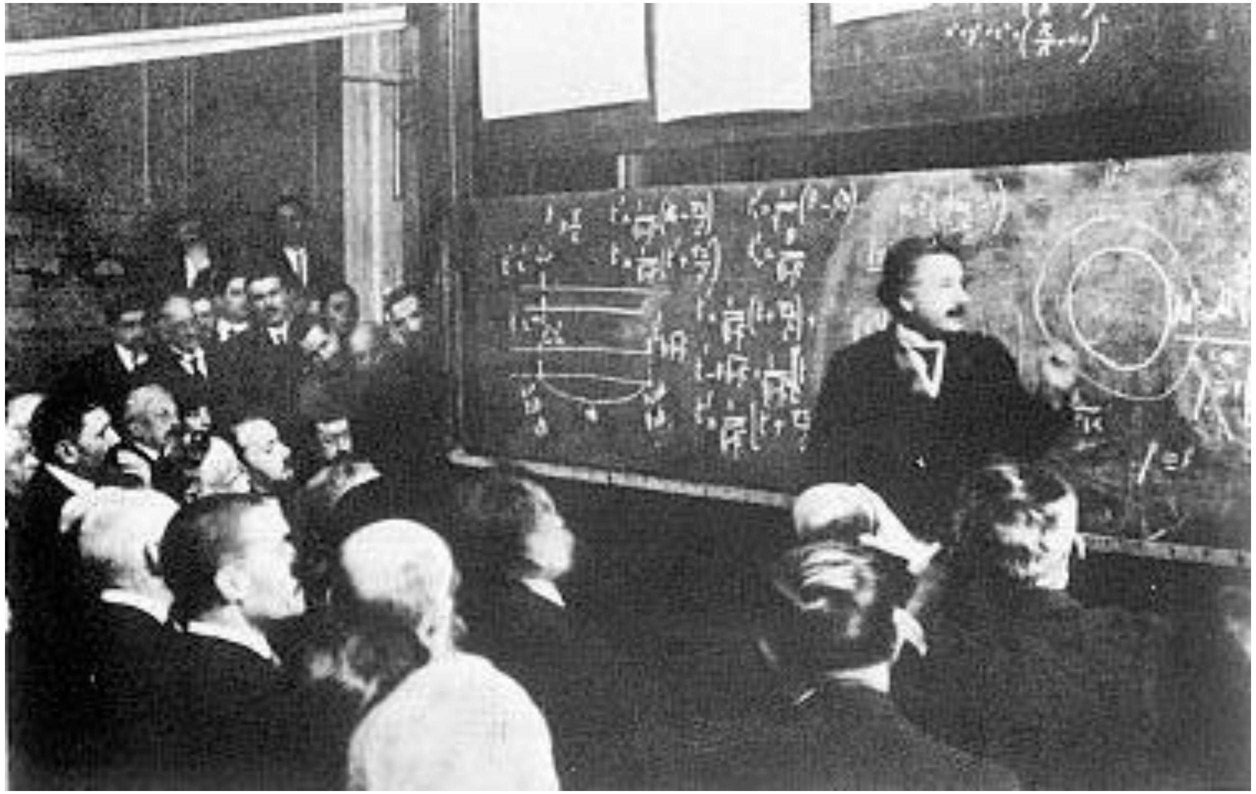
Espace et temps perdent leur identité

Les règles deviennent infinies ....
L'intervalle de temps entre *tic* et *tac* devient nul

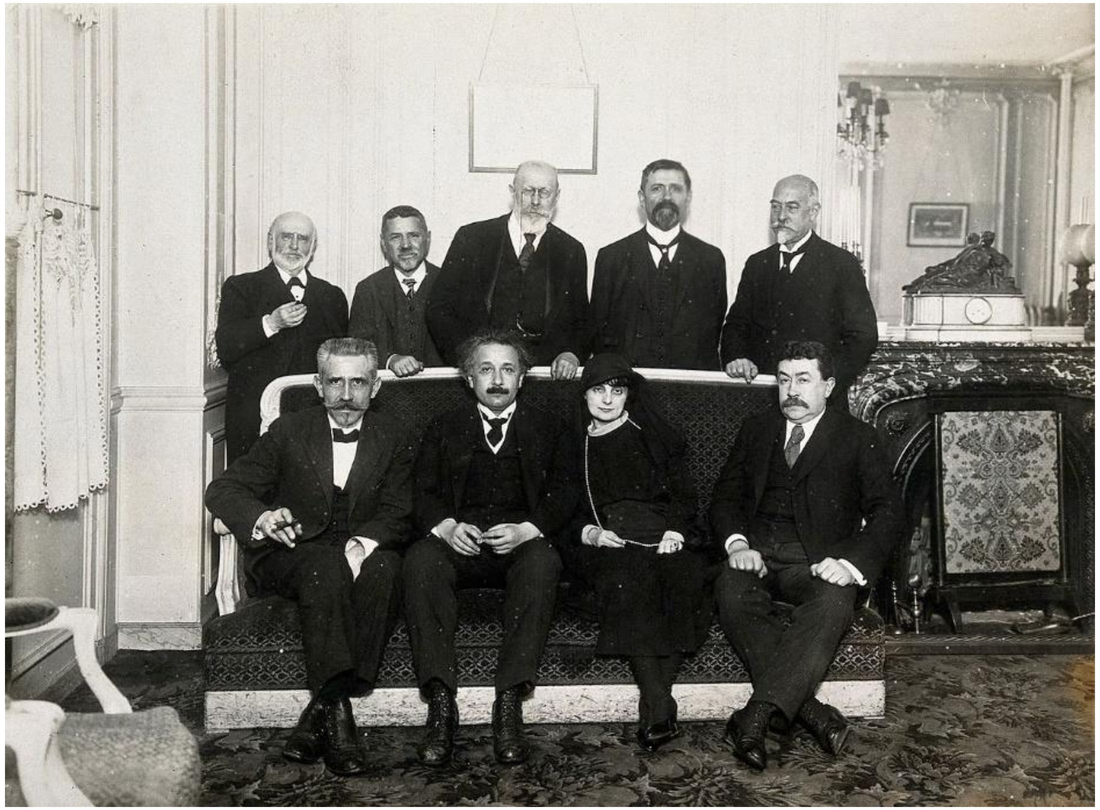
Les problèmes de l'horizon

Sir A. Eddington

« ... il y a un cercle magique à l'intérieur duquel aucune mesure ne peut nous conduire ... »



Colloque de Paris 1922 - Sur la nature de l'horizon



Repas du colloque en hommage à Albert Einstein, avec Paul Langevin, Albert Einstein, Anna de Noailles, Paul Painlevé (assis de gauche à droite) et Émile Borel (derrière Anna de Noailles), Paul Appell (derrière Albert Einstein)

Physique

Pour le Soleil : R_s ~ 3 km

Pour la Terre : R_s ~ 1 cm

Densités correspondantes : 10^{17} g/cm^3

« ... impossible ... »

Y. Hagihara
Jap. J. Astron. Geoph.
1931

Les premiers modèles cosmologiques issus de la relativité générale…

1917

Univers de de Sitter

Univers homogène, isotrope, vide de matière mais rempli d'une constante cosmologique positive et notée ici Λ

Nov. 1917. *Einstein's Theory of Gravitation.* 3

On Einstein's Theory of Gravitation, and its Astronomical Consequences. Third Paper.* By W. de Sitter, Assoc. R.A.S.

Contents of Third Paper.

1. On the relativity of inertia. New form of the field-equations. Two solutions A and B of these equations.
2. On space with constant positive curvature. Comparison of the two systems A and B.
3. Rays of light and parallax in the two systems. Hyperbolical space.
4. Motion of a material particle in the inertial field of the two systems. Further comparison of the two systems.
5. Differential equations for the gravitational field of the sun. Approximate integration of these equations.
6. Estimates of R in the system A.
7. Estimates of R in the system B.

Monthly Notices of the Royal Astronomical Society, Volume 78, Issue 1, November 1917

$$\frac{a(t)}{a_o} = \begin{cases} \cosh(Ht) \text{ si } k = 1 \\ \exp(Ht) \text{ si } k = 0 \\ \sinh(Ht) \text{ si } k = -1 \end{cases}$$

$$H = \sqrt{\Lambda/3}$$

$$ds^2 = c^2dt^2 - a^2(t)\left[\frac{dr^2}{1-kr} + r^2\left(d\theta^2 + \sin^2\theta d\varphi^2\right)\right]$$

Einstein, Ehrenfest & De Sitter - Eddington & Lorentz
Photo prise le 26 Sept. 1923 devant le bureau de De Sitter à Leiden (Hollande)

Univers d'Einstein

Univers **statique** et fermé, de courbure positive (hypersphère), contenant une distribution homogène et isotrope de poussière de densité d'énergie propre ρ_m ainsi qu'une constante cosmologique Λ_E

$$\Lambda_E = \frac{4\pi G\rho_m}{c^2}$$

142 Sitzung der physikalisch-mathematischen Klasse vom 8. Februar 1917

Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie.

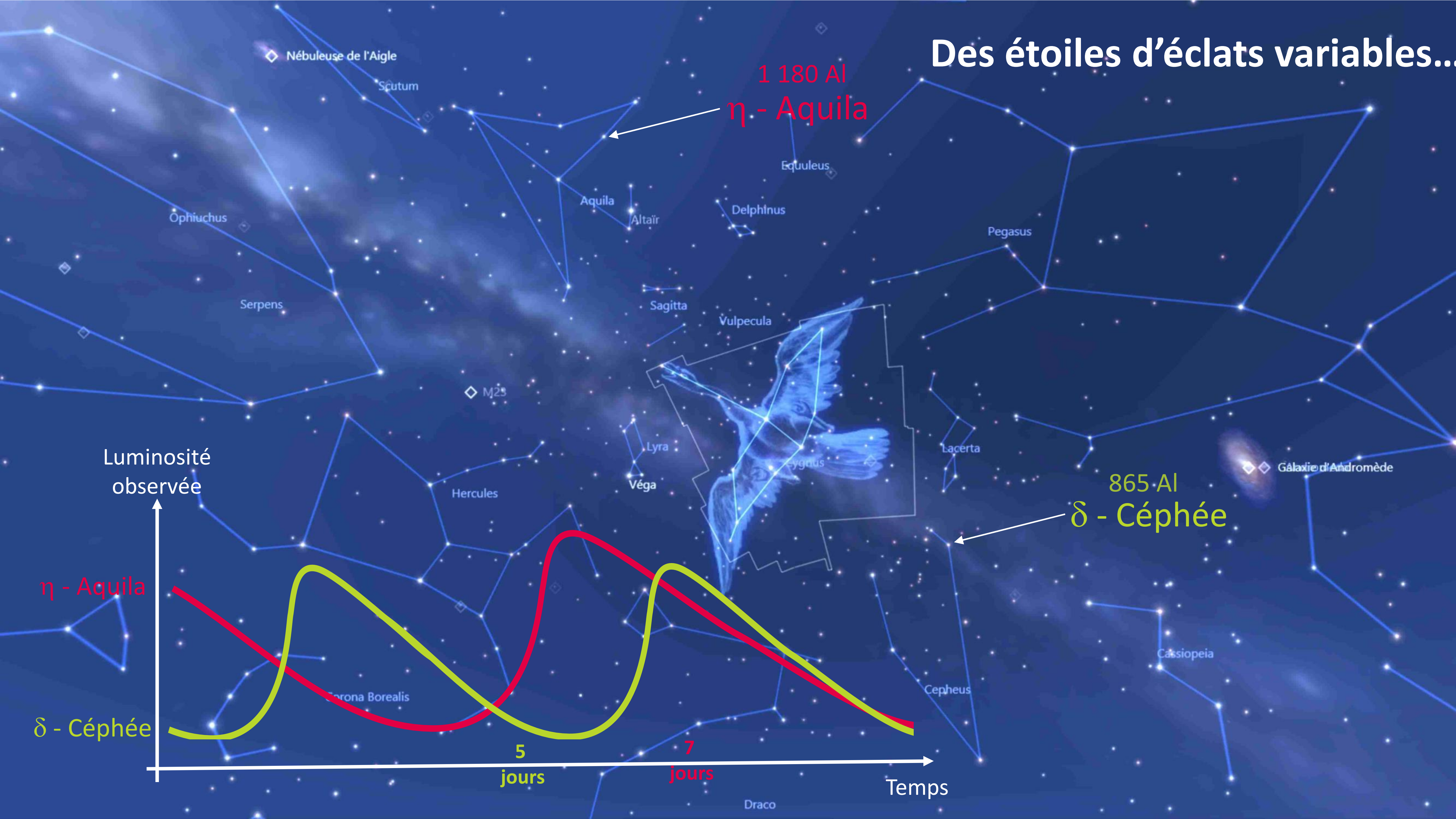
Von A. Einstein.

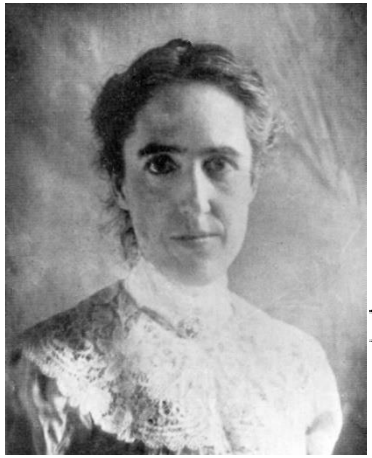
Es ist wohlbekannt, daß die Poissonsche Differentialgleichung

$$\Delta\phi = 4\pi K\rho \qquad (1)$$

in Verbindung mit der Bewegungsgleichung des materiellen Punktes die Newtonsche Fernwirkungstheorie noch nicht vollständig ersetzt. Es muß noch die Bedingung hinzutreten, daß im räumlich Unendlichen das Potential ϕ einem festen Grenzwerte zustrebt. Analog verhält es sich bei der Gravitationstheorie der allgemeinen Relativität; auch hier müssen zu den Differentialgleichungen Grenzbedingungen hinzutreten für das räumlich Unendliche, falls man die Welt wirklich als räumlich unendlich ausgedehnt anzusehen hat.

Sitzungsberichte der Königlich Preußischen Akademie der Wissenschaften (Berlin), Seite 142-152. Fevrier 1917


Des étoiles d'éclats variables…
1 180 Al
η - Aquila
865 Al
δ - Céphée
Nébuleuse de l'Aigle
Scutum
Aquila
Altaïr
Ophiuchus
Serpens
Equuleus
Delphinus
Sagitta
Vulpecula
Pegasus
M25
Lyra
Véga
Hercules
Lacerta
Galaxie d'Andromède
Cepheus
Cassiopeia
Draco
Luminosité observée
η - Aquila
δ - Céphée
5 jours
7 jours
Temps



Henrietta Swan Leavitt

HARVARD COLLEGE OBSERVATORY.

William Henry Pickering

CIRCULAR 173.

PERIODS OF 25 VARIABLE STARS IN THE SMALL MAGELLANIC CLOUD.

The following statement regarding the periods of 25 variable stars in the Small Magellanic Cloud has been prepared by Miss Leavitt.

A Catalogue of 1777 variable stars in the two Magellanic Clouds is given in H.A. 60, No. 4. The measurement and discussion of these objects present problems of unusual difficulty, on account of the large area covered by the two regions, the extremely crowded distribution of the stars contained in them, the faintness of the variables, and the shortness of their periods. As many of them never become brighter than the fifteenth magnitude, while very few exceed the thirteenth magnitude at maximum, long exposures are necessary, and the number of available photographs is small. The determination of absolute magnitudes for widely separated sequences of comparison stars of this degree of faintness may not be satisfactorily completed for some time to come. With the adoption of an absolute scale of magnitudes for stars in the North Polar Sequence, however, the way is open for such a determination.

⋮

EDWARD C. PICKERING.

March 3, 1912.

Période

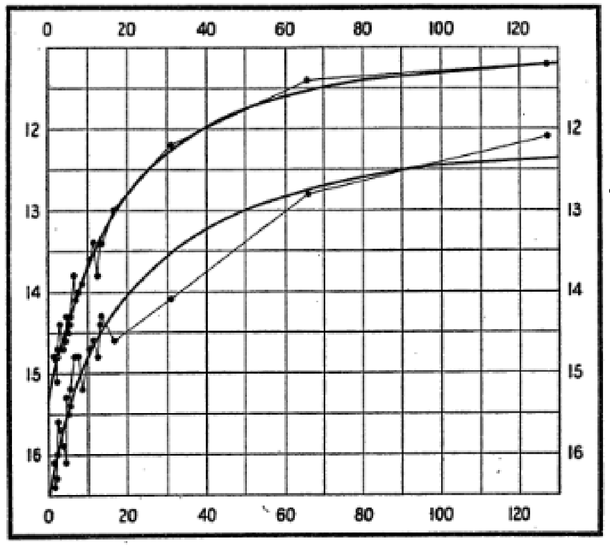


Fig. 1.

Log(Période)

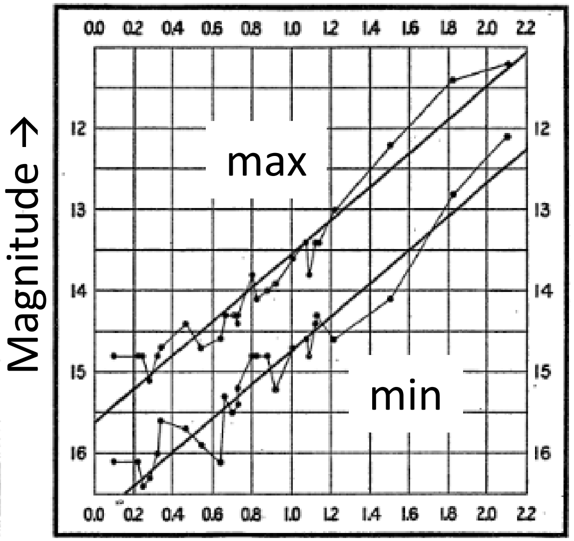


Fig. 2.

Henrietta Leavitt trace la magnitude minimale et maximale en fonction de leurs période d'occurrence…

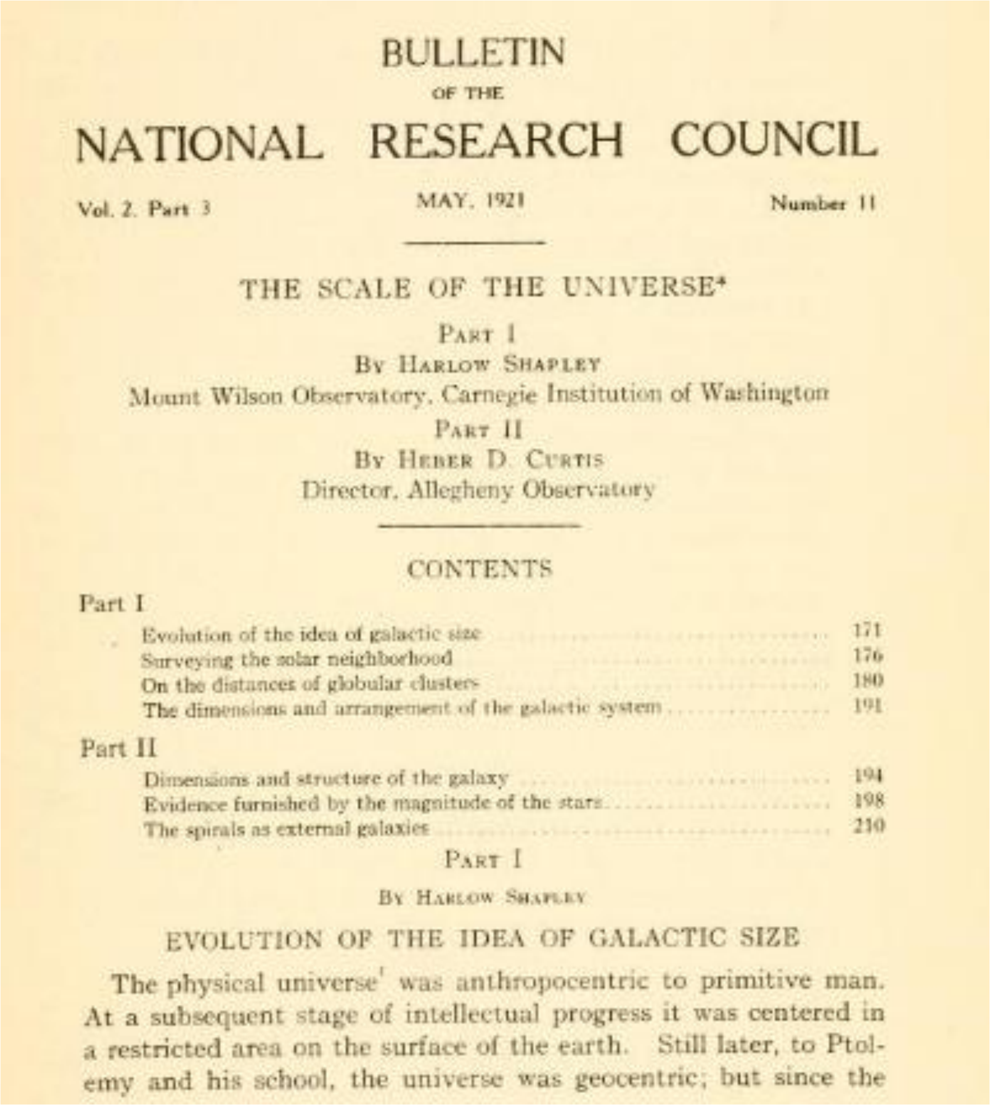
Toutes ces étoiles sont environ à la même distance …
Leur magnitude absolue est affectée du même facteur !

Über die räumliche Verteilung der Veränderlichen vom δ Cephei-Typus. Von E. Hertzsprung.

$$\langle M_V \rangle = -0.6 - 2.1 \log P$$

Le grand débat de 1921

Harlow Shapley



BULLETIN
OF THE
NATIONAL RESEARCH COUNCIL

Vol. 2, Part 3 — MAY, 1921 — Number 11

THE SCALE OF THE UNIVERSE*

PART I
BY HARLOW SHAPLEY
Mount Wilson Observatory, Carnegie Institution of Washington

PART II
BY HEBER D. CURTIS
Director, Allegheny Observatory

CONTENTS

Part I

Evolution of the idea of galactic size	171
Surveying the solar neighborhood	176
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Part II

Dimensions and structure of the galaxy	194
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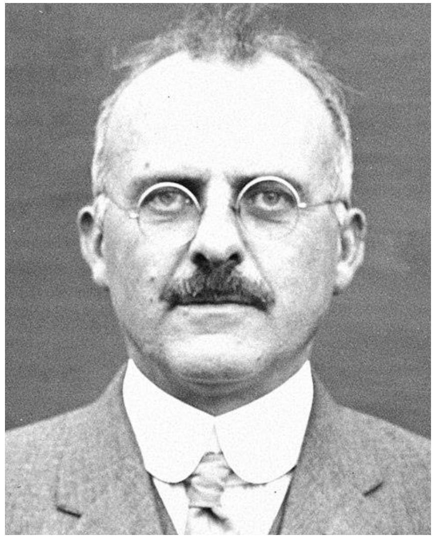
PART I
BY HARLOW SHAPLEY

EVOLUTION OF THE IDEA OF GALACTIC SIZE

The physical universe[1] was anthropocentric to primitive man. At a subsequent stage of intellectual progress it was centered in a restricted area on the surface of the earth. Still later, to Ptolemy and his school, the universe was geocentric; but since the



Heber Doust Curtis

Il calibre la relation de Hertzprung et détermine la distance et la répartition des amas globulaires.

❌ Il pense que la nébuleuse d'Andromède fait partie de la voie lactée.

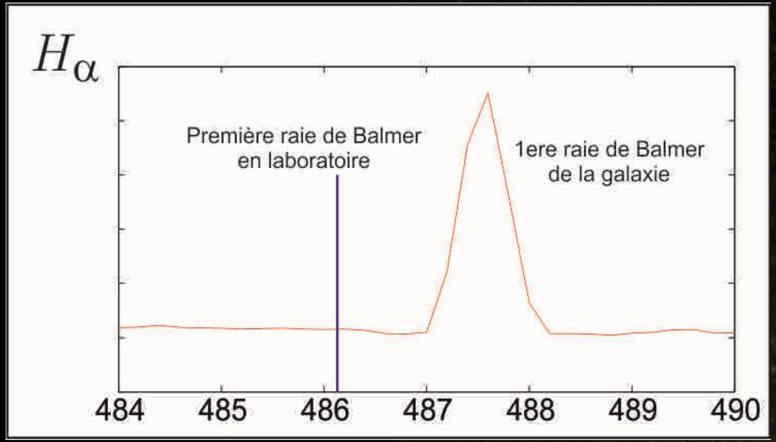
✓ Le soleil n'est pas proche du centre de la voie lactée.

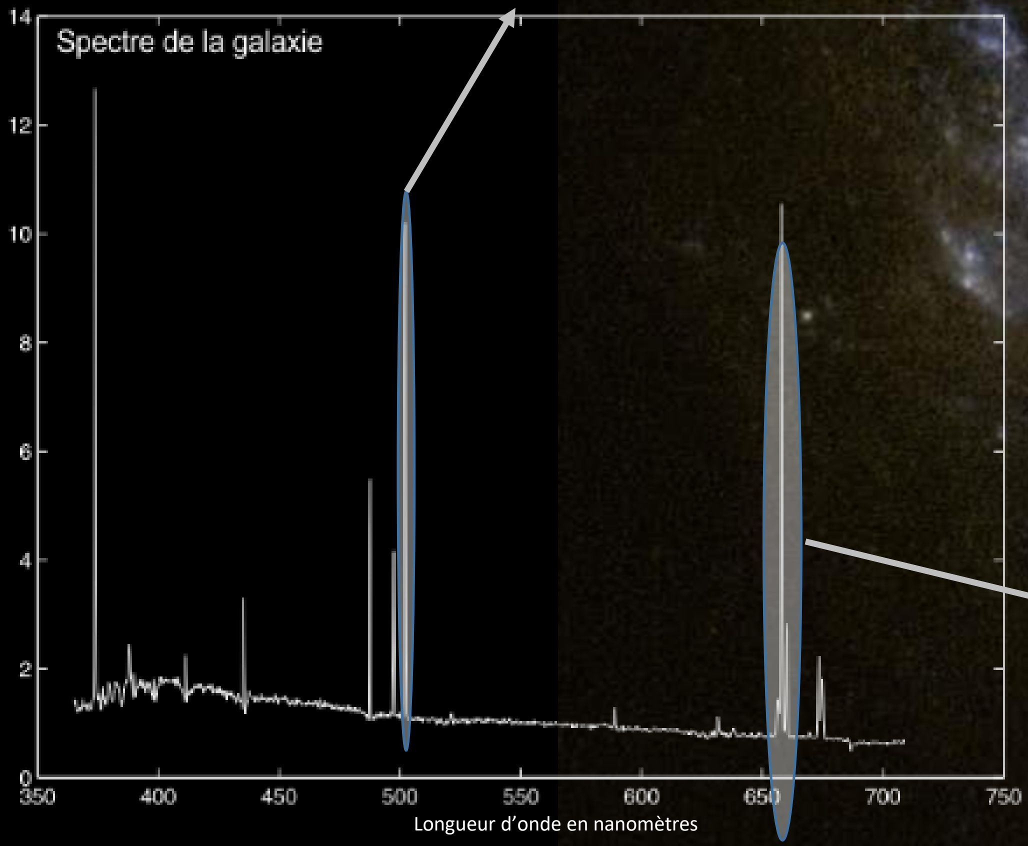
❌ Il pense que la voie lactée représente la totalité de l'Univers qui est centré sur celle-ci : modèle galactocentriste de l'Univers

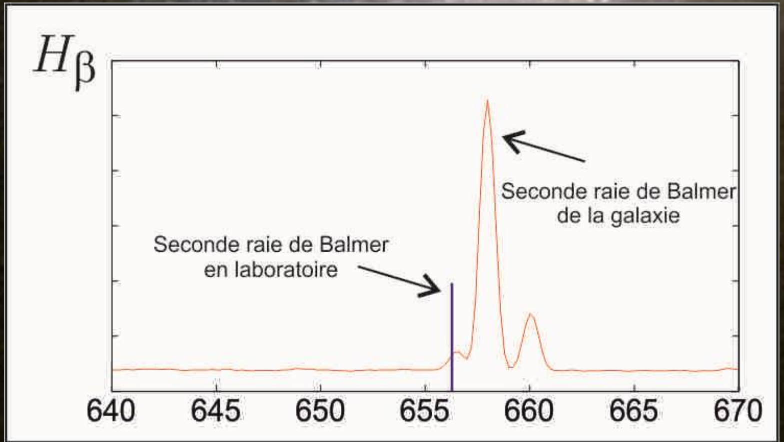
Il se base sur l'observation d'une nova dans la nébuleuse d'Andromède

✓ La nébuleuse d'Andromède est une autre galaxie séparée de la notre par un espace vide.

❌ Le soleil est proche du centre de la voie lactée.







1912-1922 – Vesto Slipher
Découvre le décalage spectral
des galaxies vers le rouge
Il l'interprète comme une vitesse

LOWELL OBSERVATORY

BULLETIN No. 58

VOL. II — No. 8

THE RADIAL VELOCITY OF THE ANDROMEDA NEBULA

Keeler, by his splendid researches on the nebulæ, showed, among other things, that the nebulæ are generally spiral in form, and that such nebulæ exist in far vaster numbers than had been supposed. These facts seem to suggest that the spiral nebula is one of the important products of the forces of nature. The spectra of these objects, it was recognized, should convey valuable information, and they have been studied, photographically, first by Huggins and Scheiner, and recently more extensively by Fath and Wolf; but no attempt has to my knowledge been made to determine their radial velocity, although the value of such observations has doubtless occurred to many investigators.

The one obstacle in the way of the success of this undertaking is the faintness of these nebulæ. The extreme feebleness of their dispersed light is difficult to realize by one not experienced in such observing, and it no doubt appears strange that the magnificent Andromeda Spiral, which under a transparent sky is so evident to the naked eye, should be so faint spectrographically. The contest is with the low intrinsic brightness of the nebular surface. a condition which no choice of telescope can relieve, However, the proper choice of parts in the spectrograph will make the best of this difficulty. The collimator must of course fit the telescope, but the dispersion-piece and the camera may and should be carefully selected for ters. When making this exposure the brightness of the nebula on the slit-plate compared with that of the clusters indicated that one night's exposure should suffice for the single-prism, and suggested that, by extending the exposure through several nights, one could employ the battery of three dense flint prisms whose dispersion would make it possible to observe the velocity of the nebula. The success of the plate bore out this suggestion. Indeed, upon subsequent examination of this plate it was seen that the nebular lines were perceptibly displaced with reference to the comparison lines. The next plate secured showed the same displacement. Still other single-prism plates were obtained during the autumn and early winter, but the observing program with the 24-inch telescope did not allow an opportunity to carry out the original plan to make the longer exposure spectrogram with the prism-train.

These spectrograms were measured with the Hartmann spectrocomparator, using a magnification of fifteen diameters. A similar plate of Saturn was employed as a standard. The observations were as follows:

1912,	September 17,	Velocity,	—284 km.
	November 15–16,	"	296
	December 3–4,	"	308
	December 29–30–31,	"	—301
		Mean velocity,	—300 km.

Radial Velocity Observations of Spiral Nebulæ.

GENTLEMEN,—

In the *Observatory*, No. 511, p. 131, Mr. Reynolds has a letter which I fear might lead the reader to suppose that little confidence should be placed in the velocity-observations of spiral nebulæ such as I initiated in 1912 and have had in progress since at the Lowell Observatory, and I beg space for a few remarks upon this work.

It is indeed true—as Mr. Reynolds points out—that the extreme faintness of the spectra of the spiral nebulæ makes very long exposures necessary, and this seriously retards the securing of plates for their spectrographic investigation. Because these spectra are continuous, their linear dispersion must be made small in order to keep the exposure-times within practicable limits. The scale of the instrument I have used is somewhat greater than that of the Mt. Wilson one referred to.

My observations of the spiral nebulæ are carried out with the same precautions as are star-velocity observations, which includes test-observations of objects whose velocities are known. The method of exposing the comparison-spectrum I employ is very different from the faulty one Mr. Reynolds mentions—namely,

Mr. Reynolds referred to observations of the velocity of the Great Andromeda Nebula as bearing out his criticism. The results of this object known to me are the following:—

—300	km.	Slipher; from several plates.
—304	"	Wright (Lick); from one plate.
—300–400	"	Wolf; one plate, which he believed not "good enough to give any security."
—329	"	Pease (Mt. Wilson); from one plate.

We would, indeed, be fortunate in science if the inaccuracy of observation were never more than a small fraction of the quantity observed.

I am, Gentlemen,
Yours faithfully,
V. M. SLIPHER.

Lowell Observatory,
Flagstaff, Arizona,
1917, June 15.

1912-1922 – Vesto Slipher
Découvre le décalage spectral des galaxies vers le rouge
Il l'interprète comme une vitesse

Les mesures ne sont pas faciles il faut s'y reprendre à plusieurs fois…

L'un des premiers livre de cours de RG

THE MATHEMATICAL THEORY

OF

RELATIVITY

BY

A. S. EDDINGTON, M.A., M.Sc., F.R.S.

PLUMIAN PROFESSOR OF ASTRONOMY AND EXPERIMENTAL PHILOSOPHY IN THE UNIVERSITY OF CAMBRIDGE

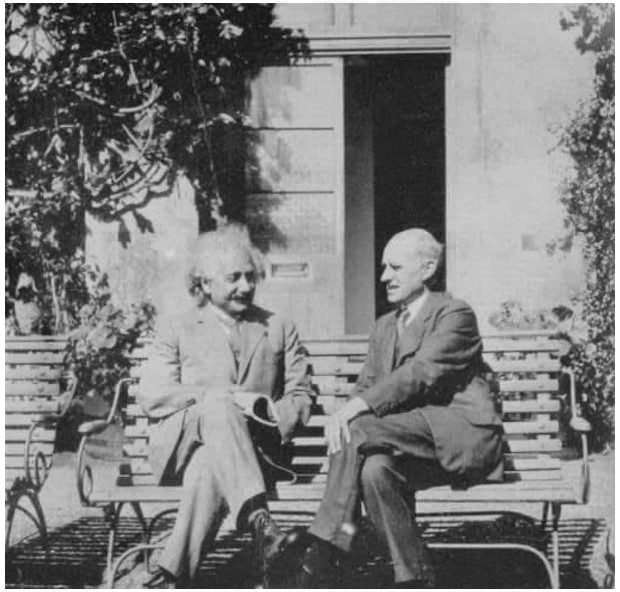
CAMBRIDGE

AT THE UNIVERSITY PRESS

1923

It seems natural to regard de Sitter's and Einstein's forms as two limiting cases, the circumstances of the actual world being intermediate between them. De Sitter's empty world is obviously intended only as a limiting case; and the presence of stars and nebulae must modify it, if only slightly, in the direction of Einstein's solution. Einstein's world containing masses far exceeding anything imagined by astronomers, might be regarded as the other extreme—a world containing as much matter as it can hold. This view denies any fundamental cleavage of the theory in regard to the two forms, regarding it as a mere accident, depending on the amount of matter which happens to have been created, whether de Sitter's or Einstein's form is the nearer approximation to the truth. But this compromise has been strongly challenged, as we shall see.

Ch. 5 - Properties of de Sitter's spherical world, p. 271



Arthur Eddington et Albert Einstein à Cambridge en juin 1930

Eddington est pour le compromis

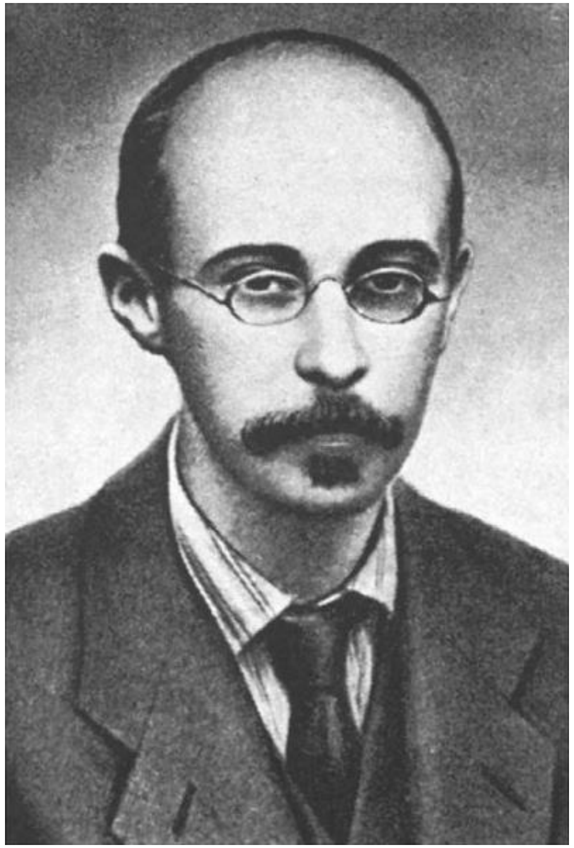
Après la guerre les russes découvrent la RG…

Un jeune professeur de St Petersbourg s'y intéresse et crée un groupe de travail…

L'université de St Petersbourg (1724) vers 1830

Vsevolod Konstantinovich Frederiks

Yuri Aleksandrovitch Krutkoff



Aleksandr Aleksandrovitch Fridman

Et de nombreux étudiants

Über die Krümmung des Raumes.

Von **A. Friedman** in Petersburg.

Mit einer Abbildung. (Eingegangen am 29. Juni 1922.)

§ 1. 1. In ihren bekannten Arbeiten über allgemeine kosmologische Fragen kommen Einstein[1]) und de Sitter[2]) zu zwei möglichen Typen des Weltalls; Einstein erhält die sogenannte Zylinderwelt, in der der Raum[3]) konstante, von der Zeit unabhängige Krümmung besitzt, wobei der Krümmungsradius verbunden ist mit der Gesamtmasse der im Raume vorhandenen Materie; de Sitter erhält eine Kugelwelt, in welcher nicht nur der Raum, sondern auch die Welt in gewissem Sinne als Welt konstanter Krümmung angesprochen werden kann[4]). Dabei werden wie von Einstein so auch von de Sitter gewisse Voraussetzungen über den Materietensor gemacht, die der Inkohärenz der Materie und ihrer relativen Ruhe entsprechen, d. h. die Geschwindigkeit der Materie wird als genügend klein vorausgesetzt im Vergleich zu der Grundgeschwindigkeit[5]) — der Lichtgeschwindigkeit.

Das Ziel dieser Notiz ist, erstens die Ableitung der Zylinder- und Kugelwelt (als spezielle Fälle) aus einigen allgemeinen Annahmen, und zweitens der Beweis der Möglichkeit einer Welt, deren Raumkrümmung konstant ist in bezug auf drei Koordinaten, die als Raumkoordinaten gelten, und abhängig von der Zeit, d. h. von der vierten — der Zeitkoordinate; dieser neue Typus ist, was seine übrigen Eigenschaften anbetrifft, ein Analogon der Einsteinschen Zylinderwelt.

2. Die Annahmen, die wir unseren Betrachtungen zugrunde legen, zerfallen in zwei Klassen. Zu der ersten Klasse gehören Annahmen, welche mit den Annahmen Einsteins und de Sitters zusammen-

« Sur la courbure de l'espace » Zeitschrift für Physik 10 (1), p. 377–386, **1922**

Über die Möglichkeit einer Welt mit konstanter negativer Krümmung des Raumes.

Von **A. Friedmann** in Petersburg.

(Eingegangen am 7. Januar 1924.)

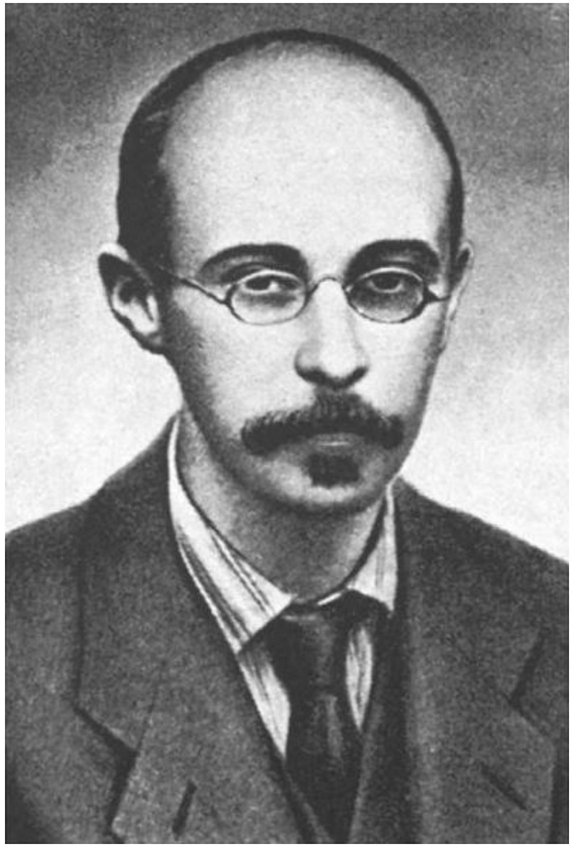
§ 1. 1. In unserer Notiz „Über die Krümmung des Raumes"[1]) haben wir diejenigen Lösungen der Einsteinschen Weltgleichungen betrachtet, welche zu Welttypen führen, denen eine konstante positive Krümmung als gemeinsames Merkmal angehört; dabei haben wir alle möglichen Fälle erörtert. Die Möglichkeit, aus den Weltgleichungen eine Welt konstanter positiver räumlicher Krümmung abzuleiten, steht aber mit der Frage nach der Endlichkeit des Raumes im Zusammenhange. Aus diesem Grunde dürfte es von Interesse sein zu untersuchen, ob man aus denselben Weltgleichungen eine Welt konstanter negativer Krümmung erhalten kann, von deren Endlichkeit (auch unter einigen ergänzenden Annahmen) wohl kaum die Rede sein kann.

In der vorliegenden Notiz wird gezeigt, daß es wirklich möglich ist, aus den Einsteinschen Weltgleichungen eine Welt mit konstanter negativer Krümmung des Raumes abzuleiten. Wie in der zitierten Arbeit, so haben wir auch hier zwei Fälle zu unterscheiden, nämlich 1. den Fall einer stationären Welt, deren Krümmung zeitlich konstant ist, und 2. den Fall einer nichtstationären Welt, deren Krümmung zwar räumlich konstant ist, wohl aber im Laufe der Zeit variiert. Zwischen den stationären Welten konstanter negativer und denjenigen konstanter positiver räumlicher Krümmung besteht ein wesentlicher Unterschied. Die Welten stationärer negativer Krümmung lassen nämlich keine positive Dichte der Materie zu; dieselbe ist entweder Null oder negativ. Die physikalisch möglichen stationären Welten (d. h. diejenigen mit nicht negativer Dichte der Materie) finden demzufolge ihr Analogon in der de Sitterschen, nicht aber in der Einsteinschen Welt[2]).

Zum Schluß dieser Notiz werden wir die Frage berühren, ob man überhaupt auf Grund der Krümmung des Raumes über dessen Endlichkeit oder Unendlichkeit urteilen darf.

2. Wir wenden uns zu unseren allgemeinen Annahmen, die wir in dieselben zwei Klassen wie in der zitierten Notiz gruppiert denken;

« Sur la possibilité d'un monde avec une courbure négative constante de l'espace », Zeitschrift für Physik 21 (1): 326–332, **1924**



Aleksandr Aleksandrowitsch Fridman

Ces deux articles généralisent complètement les univers d'Eisntein et de De Sitter à des univers homogènes et isotropes quelconques

Controverse…

Bemerkung zu der Arbeit von A. Friedmann[1]) „Über die Krümmung des Raumes“.

Von A. Einstein in Berlin.

(Eingegangen am 18. September 1922.)

Die in der zitierten Arbeit enthaltenen Resultate bezüglich einer nichtstationären Welt schienen mir verdächtig. In der Tat zeigt sich, daß jene gegebene Lösung mit den Feldgleichungen (A) nicht verträglich ist. Aus jenen Feldgleichungen folgt nämlich bekanntlich, daß die Divergenz des Tensors T_{ik} der Materie verschwindet. Im Falle des durch (C) und (D_3) charakterisierten Ansatzes führt dies auf die Beziehung

$$\frac{\partial \varrho}{\partial x_4} = 0,$$

welche zusammen mit (8) die zeitliche Konstanz des Weltradius R erfordert. Die Bedeutung der Arbeit besteht also gerade darin, daß sie diese Konstanz beweist.

Berlin, September 1922.

1) ZS. f. Phys. 10, 377—386, 1922.

Les résultats concernant un univers non statique me semblent douteux…

Zeitschrift fur Physik,11, 326, 1922

- 19 juin 1922 : premier papier de Friedmann
- 18 septembre 1922 : réfutation d’Einstein
- 6 décembre 1922: Friedmann apprend l’objection d’Einstein de son ami, Yuri A. Krutkov, qui est en visite à Berlin. Friedmann écrit une lettre détaillée à Einstein. Einstein voyage et ne le lit pas.
- 7 Mai 1923: Einstein rencontre Krutkov à Leiden, tous deux à la conférence d’adieu de Lorentz – Ils reprennent les calculs et Einstein reconnait que Friedmann à raison
- 31 mai 1923 : Rétractation d’Einstein

Déroulé des évènements

En aout et septembre 1923 puis en avril 1924 Friedmann est à Berlin mais il ne parvient pas à rencontrer Einstein…

Einstein ne réagit pas au second article de 1924

En 1925 Friedmann est nommé directeur de l’institut de géophysique de *Léningrad*. Durant l’été, avec l’aviateur Fedosenko il bat le record d’altitude en ballon stratosphérique (7400m).

Le 16 septembre 1925 il meurt subitement de la fièvre typhoïde.

51. “Note to the Paper by A. Friedmann ‘On the Curvature of Space’”[1]

[*Einstein 1923g*]

Received 31 May 1923
Published June–July 1923

In: *Zeitschrift für Physik* 16 (1923): 228.

In an earlier note 1) I exercised criticism on the mentioned paper. 2) My objection, however, was based on a calculation error—as I have become persuaded, at the suggestion of Mr. Krutkoff,[2] guided by a letter by Mr. Friedmann. I consider Mr. Friedmann’s results correct and illuminating.[3] It is demonstrated that the field equations permit, aside from the static solution, dynamic (i.e., variable with the time coordinate), centrally symmetrical solutions for the structure of space.[4]

Tiré de « Einstein’s papers - Princeton University Press »

Un opposant plus pérenne mais non germanophone,
qui publie en français et qui est un abbé !

Georges Lemaître vers 1929

— 49 —

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

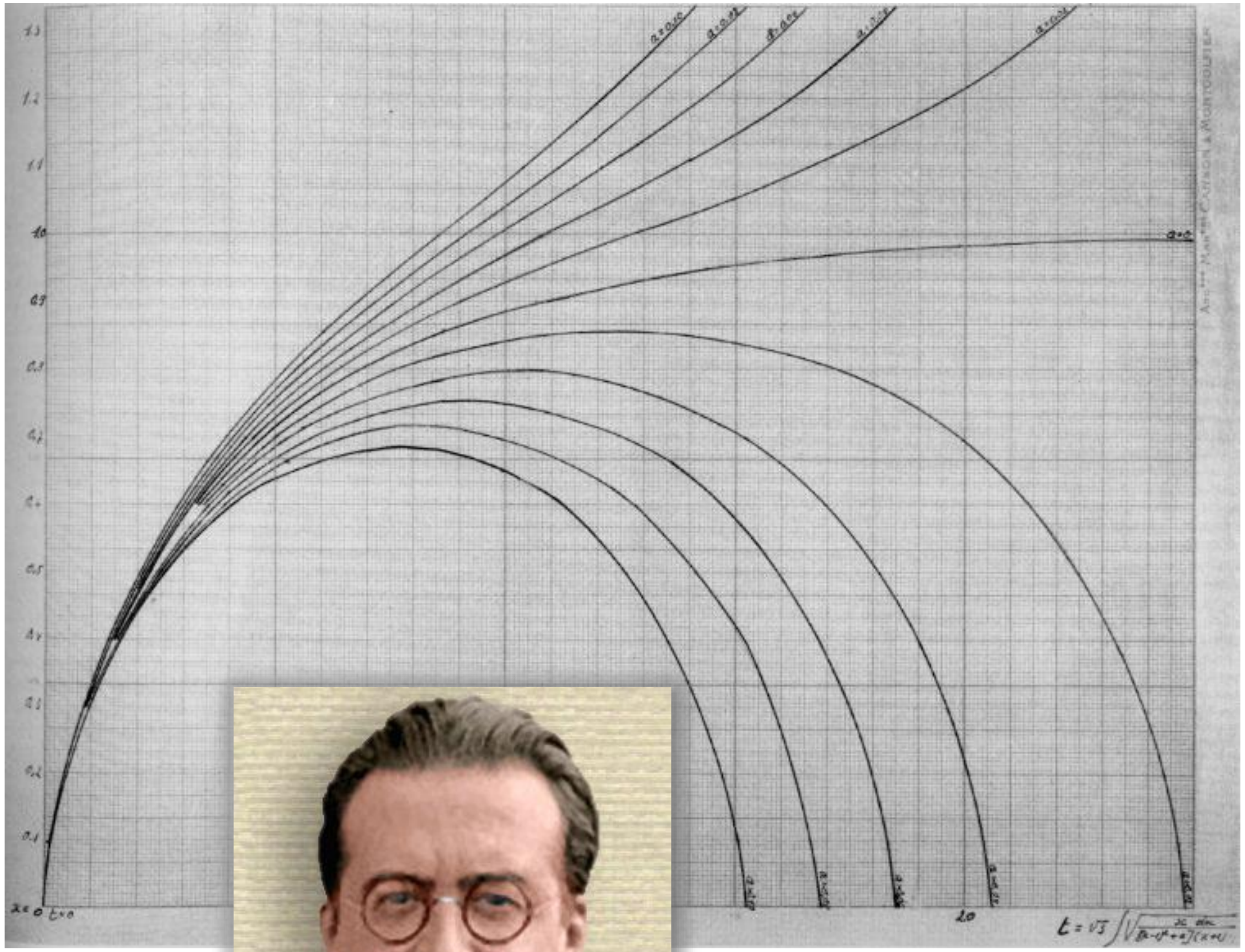
1. Généralités.

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.

L'autre solution est celle d'Einstein. Elle tient compte du fait évident que la densité de la matière n'est pas nulle et elle conduit à une relation entre cette densité et le rayon de l'univers. Cette relation a fait prévoir l'existence de masses énormément supérieures à tout ce qui était connu lorsque la théorie a été pour la première fois comparée avec les faits. Ces masses ont été depuis découvertes lorsque les distances et les dimensions des nébuleuses extra-galactiques ont pu être établies. Le rayon de l'univers calculé par la formule d'Einstein est d'après les données récentes quelques

Annales de la Société scientifique de Bruxelles, vol. 47, avril 1927, p. 49



Manuscrit 1927 - Archives Lemaitre, Louvain

Georges Lemaître vers 1929

- ***Interprétation des décalages spectraux observés;***
- ***Nouvelles solutions;***
- ***Discussion de la singularité;***
- ***Arrive à convaincre Einstein***

Lemaitre parvient à discuter avec Einstein
lors du 5e congrès Solvay en octobre 1927 à Bruxelles

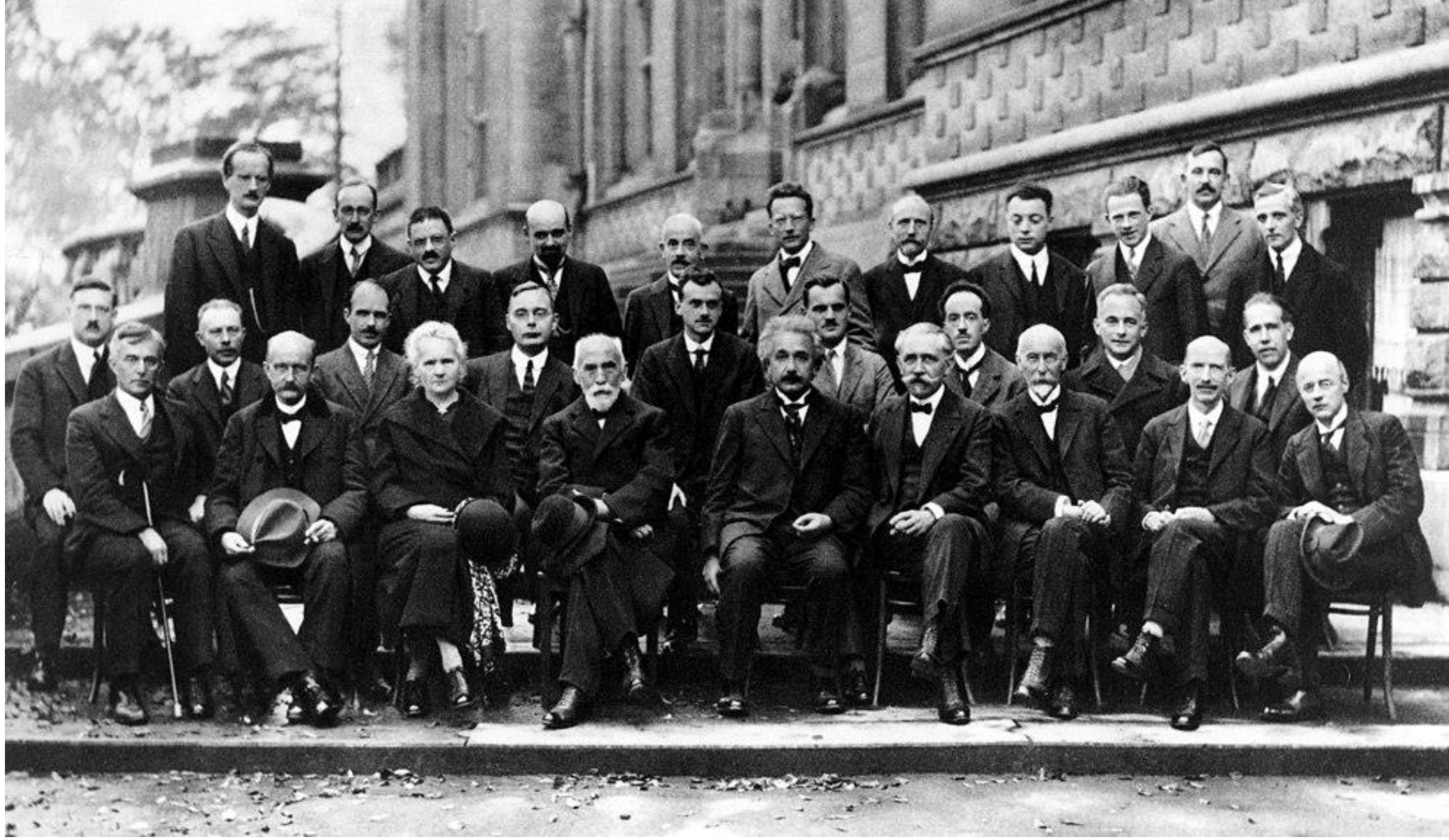
« En se promenant dans les allées du parc Léopold,
Il me parla d'un article, peu remarqué, que j'avais écrit l'année précédente et qu'un ami lui avait fait lire.

Après quelques remarques techniques favorables, il conclut en disant que du point de vue physique cela lui paraissait tout à fait abominable!»

« Comme je cherchais à prolonger la conversation, Auguste Picard qui l'accompagnait m'invita à partager leur taxi pour aller visiter son laboratoire.
Dans le taxi je parlai des vitesses des nébuleuses et j'eu l'impression qu'Einstein n'était guère au courant des faits astronomiques.

Tout le reste de la visite se déroula en allemand… »

Archives Lemaitre @Louvain
Extrait du livre « Essais de cosmologie. Précédé de : Invention du Big Bang »
Jean-Pierre Luminet, Editions du Seuil, 1997



Rangée à l'arrière : Auguste Piccard, Émile Henriot, Paul Ehrenfest, Édouard Herzen, Théophile de Donder, Erwin Schrödinger, Jules-Émile Verschaffelt, Wolfgang Pauli, Werner Heisenberg, Ralph H. Fowler, Léon Brillouin ;

Rangée du milieu : Peter Debye, Martin Knudsen, William Lawrence Bragg, Hendrik Anthony Kramers, Paul Dirac, Arthur Compton, Louis de Broglie, Max Born, Niels Bohr ;

Rangée à l'avant : Irving Langmuir, Max Planck, Marie Curie, Hendrik Lorentz, Albert Einstein, Paul Langevin, Charles-Eugène Guye, Charles Thomson Rees Wilson, Owen Willans Richardson.

« Vos mathématiques sont admirables,
mais votre physique est déplorable ! »

L'âge de l'Univers
& la loi d'Hubble-Lemaitre

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

Annales de la Société Scientifique de Bruxelles, A47, p. 49-59, 1927

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

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

Cette relation nous permet de calculer R_o. Nous avons en effet par (16)

$$\frac{R'}{R} = \frac{1}{R_o\sqrt{3}}\sqrt{1 - 3y^2 + 2y^3} \qquad (25)$$

où nous avons posé

$$y = \frac{R_o}{R} \qquad (26)$$

D'autre part, d'après (18) et (26),

$$R_o^2 = R_E^2\, y^3 \qquad (27)$$

et donc

$$3\left(\frac{R'}{R}\right)^2 R_E^2 = \frac{1 - 3y^2 + 2y^3}{y^3} \qquad (28)$$

Introduisant les valeurs numériques de $\frac{R'}{R}$ (24) et de R_E (19), il vient :

$$y = 0{,}0465.$$

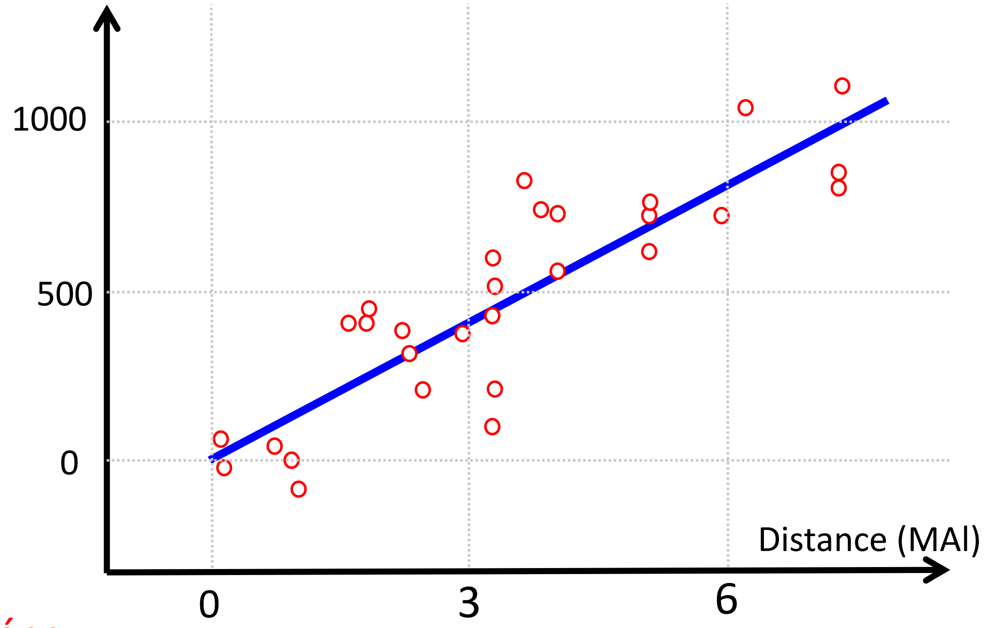
On a alors :

$$R = R_E\sqrt{y} = 0{,}215\ R_E = 1{,}83 \times 10^{28}\ \text{cm.} = 6 \times 10^9\ \text{parsecs}$$

$$R_o = Ry = R_E\, y^{\frac{3}{2}} = 8{,}5 \times 10^{26}\ \text{cm.} = 2{,}7 \times 10^8\ \text{parsecs}$$
$$= 9 \quad \times 10^8\ \text{années de lumière.}$$

Si $R_o = c\,T$ alors T = 0,9 milliard d'années

(pas dans l'article ou $\Lambda \neq 0$ et T=+∞)



Einstein avoue avoir commis la plus grande erreur de sa carrière. Il se détourne de la cosmologie…

A RELATION BETWEEN DISTANCE AND RADIAL VELOCITY AMONG EXTRA-GALACTIC NEBULAE

By Edwin Hubble

Mount Wilson Observatory, Carnegie Institution of Washington

Communicated January 17, 1929

Proc. of the Nat. Ac. of Sciences of the USA, 15, 168-173 (1929)

TABLE 1

NEBULAE WHOSE DISTANCES HAVE BEEN ESTIMATED FROM STARS INVOLVED OR FROM MEAN LUMINOSITIES IN A CLUSTER

OBJECT	m_s	r	v	m_t	M_t
S. Mag.	..	0.032	+ 170	1.5	−16.0
L. Mag.	..	0.034	+ 290	0.5	17.2
N. G. C. 6822	..	0.214	− 130	9.0	12.7
598	..	0.263	− 70	7.0	15.1
221	..	0.275	− 185	8.8	13.4
224	..	0.275	− 220	5.0	17.2
5457	17.0	0.45	+ 200	9.9	13.3
4736	17.3	0.5	+ 290	8.4	15.1
5194	17.3	0.5	+ 270	7.4	16.1
4449	17.8	0.63	+ 200	9.5	14.5
4214	18.3	0.8	+ 300	11.3	13.2
3031	18.5	0.9	− 30	8.3	16.4
3627	18.5	0.9	+ 650	9.1	15.7
4826	18.5	0.9	+ 150	9.0	15.7
5236	18.5	0.9	+ 500	10.4	14.4
1068	18.7	1.0	+ 920	9.1	15.9
5055	19.0	1.1	+ 450	9.6	15.6
7331	19.0	1.1	+ 500	10.4	14.8
4258	19.5	1.4	+ 500	8.7	17.0
4151	20.0	1.7	+ 960	12.0	14.2
4382	..	2.0	+ 500	10.0	16.5
4472	..	2.0	+ 850	8.8	17.7
4486	..	2.0	+ 800	9.7	16.8
4649	..	2.0	+1090	9.5	17.0
Mean					−15.5

m_s = photographic magnitude of brightest stars involved.
r = distance in units of 10^6 parsecs. The first two are Shapley's values.
v = measured velocities in km./sec. N. G. C. 6822, 221, 224 and 5457 are recent determinations by Humason.
m_t = Holetschek's visual magnitude as corrected by Hopmann. The first three objects were not measured by Holetschek, and the values of m_t represent estimates by the author based upon such data as are available.
M_t = total visual absolute magnitude computed from m_t and r.

En 1931 Lemaitre propose sa théorie de l'atome primitif : l'ancêtre du modèle du Big-Bang

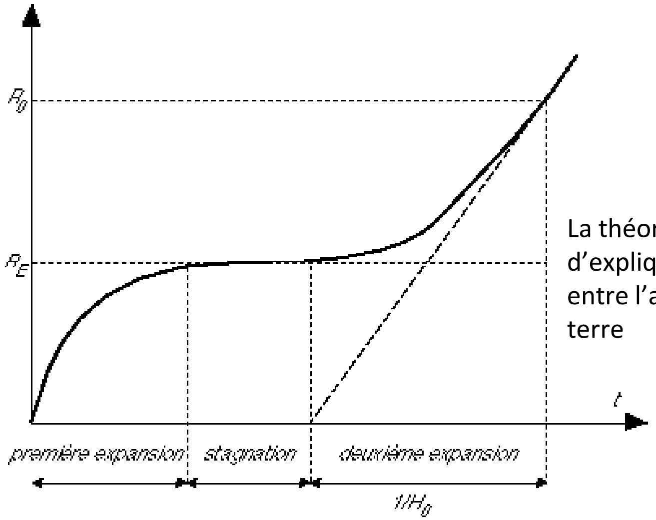
The Expanding Universe. By Abbé G. Lemaître.

(*Communicated by Sir A. S. Eddington.*)

1. *Introduction.*

Eddington has suggested that the expansion of a universe in equilibrium may be started by the formation of condensations. A preliminary investigation by W. H. McCrea and G. C. McVittie seems to point out an effect of opposite sense according to the nature of the condensations.* I find that the formation of condensations and the degree of concentration of these condensations have no effect whatever on the equilibrium of the universe. Nevertheless, the expansion of the universe is due to an effect very closely related to the formation of condensations, which may be named the "stagnation" of the universe. When there is no condensation, the energy, or at least a notable part of it, may be able to wander freely through the universe. When condensations are formed this free kinetic energy has a chance to be captured by the condensations and then to remain bound to them. That is what I mean by a "stagnation" of the world—a diminution of the exchanges of energy between distant parts of it.

Monthly Notices of the Royal Astronomical Society, Volume 91, Issue 5, March 1931, Pages 490–501,



La théorie de l'univers hésitant permet d'expliquer l'apparente contradiction entre l'age de l'univers et celui de la terre

La reconnaissance Internationale !

N° 81.

L'expansion de l'espace

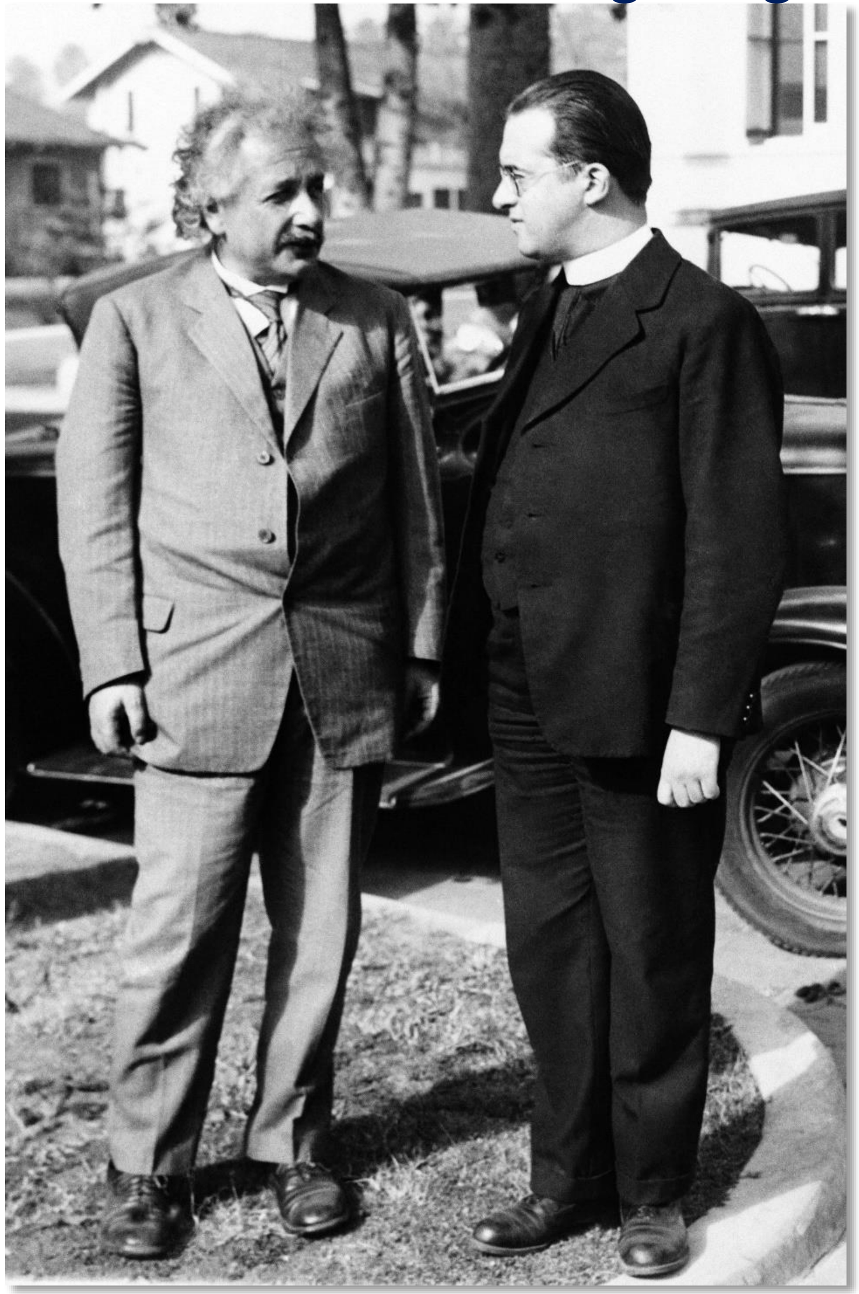
par M. G. Lemaître (1)

A la suite des cosmogonies de Laplace et de Kant, nous avons pris l'habitude de concevoir, comme point de départ de l'évolution du monde, une nébuleuse diffuse remplissant l'espace et se condensant progressivement en nébuleuses partielles, puis en étoiles.

Cette idée très ancienne a été adaptée aux progrès de nos connaissances astronomiques. Elle a récemment été exposée à nouveau dans le beau livre que Sir James Jeans a consacré à l'étude de l'univers. Il est possible maintenant de se rendre compte de la densité de la nébuleuse primitive, en estimant les masses et les distances des grandes condensations d'étoiles, appelées nébuleuses extra-galactiques, qui composent ce que nous connaissons de l'univers. En supposant que la masse des étoiles a été jadis uniformément répartie dans l'espace occupé par les nébuleuses, on trouve que la nébuleuse primitive a dû être plus raréfiée que le vide le plus extrême que nos physiciens peuvent rêver de réaliser dans leurs laboratoires. La densité de l'univers s'exprime par 10^{-31} gramme par centimètre cube, chiffre généralement considéré comme connu à un facteur cent près.

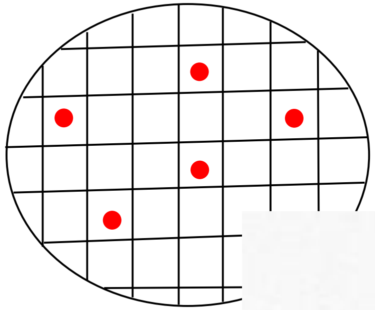
La conception de la nébuleuse primitive se heurte dès l'abord à une difficulté très sérieuse, qui n'a pu être écartée d'une manière satisfaisante qu'avec l'aide de la théorie de la relativité et des géométries non-euclidiennes : les diverses parties de la nébuleuse s'attirent les unes les autres et semblent devoir tomber vers leur centre de

(1) Revue des Questions scientifiques, 4ᵉ série, t. 20 (1931, 3), p. 391.



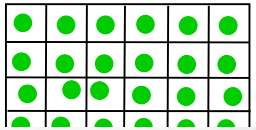
Discussion entre Lemaître et Einstein à Passadena en 1932 où Lemaitre donnait un séminaire

Introduction de la mécanique quantique : Etat dégénéré de la matière ….

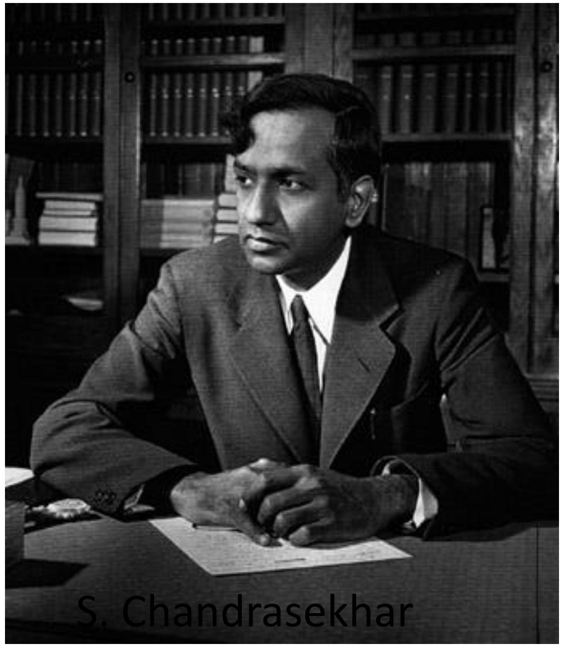


Taille des boîtes

Nombre de particules par boîte



Etat faiblement d



1931

1983

THE MAXIMUM MASS OF IDEAL WHITE DWARFS

By S. CHANDRASEKHAR

ABSTRACT

The theory of the *polytropic gas spheres* in conjunction with the equation of state of a *relativistically degenerate electron-gas* leads to a *unique value for the mass of a star* built on this model. This mass (=0.91☉) is interpreted as representing the upper limit to the mass of an ideal white dwarf.

In a paper appearing in the *Philosophical Magazine*,[1] the author

$M < 1{,}4\ M_{\odot}$

~~IMPOSSIBLE~~

~~(Eddington)~~

La théorie de l'évolution stellaire se construit !

1933-1938 : F. Zwicky et W. Baade,
Scénario des Supernovæ
lien avec les « étoiles à neutrons »
et les rayons cosmiques

1935-38
H. Bethe
Les étoiles sont
des machines thermonucléaires

1967

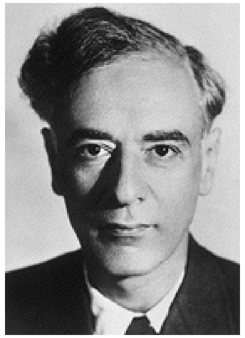
1935

Découverte des neutrons par Chadwick, **1932**

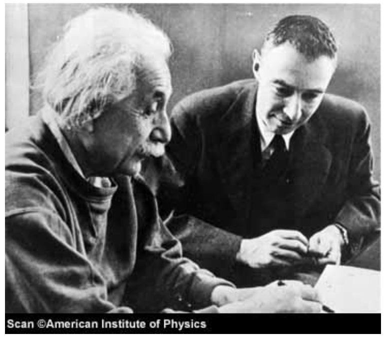
Si la masse d'une étoile $> M_c$
➔ Etoile à neutron 🡐

1938 L.D. Landau :
Hypothèse sur le cœur de neutron pour l'énergie des étoiles

(appel à l'aide)



1962



Immédiatement infirmé par Oppenheimer et Serber

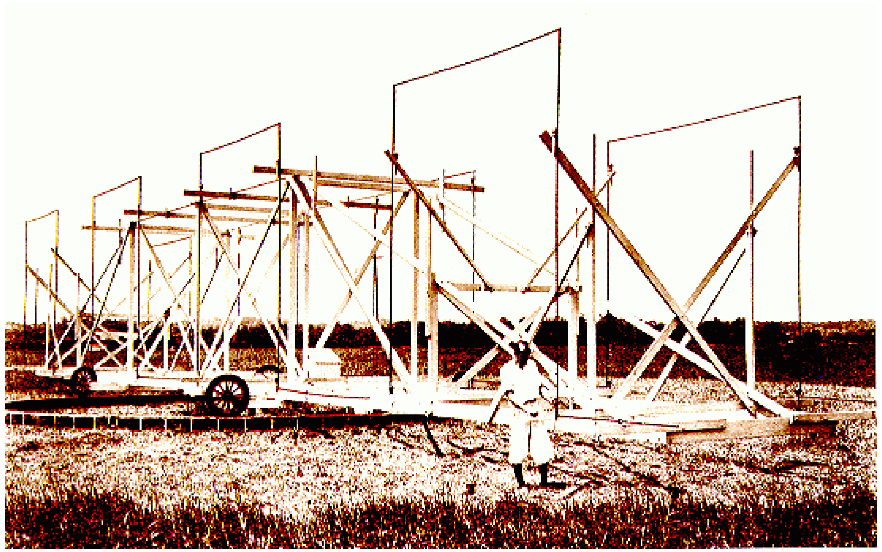
1939 Oppenheimer et Volkoff, les étoiles à neutrons ont une masse maximale (quelques $M_\odot$)

La gravité finit par l'emporter

Oppenheimer et Snyder : Effondrement ➔ Singularité

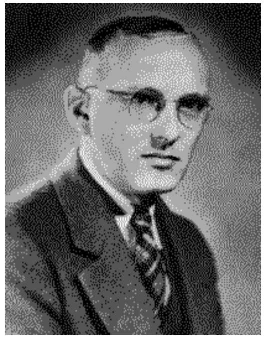
La singularité est inévitable : Hypothèse des trous noirs

Le début de la radioastronomie

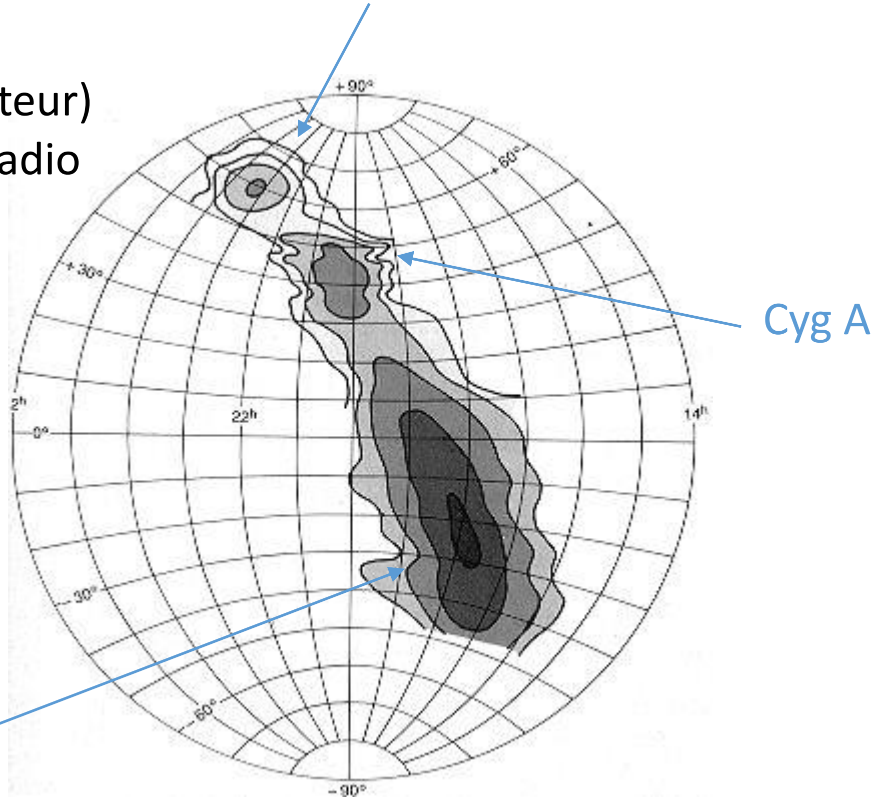


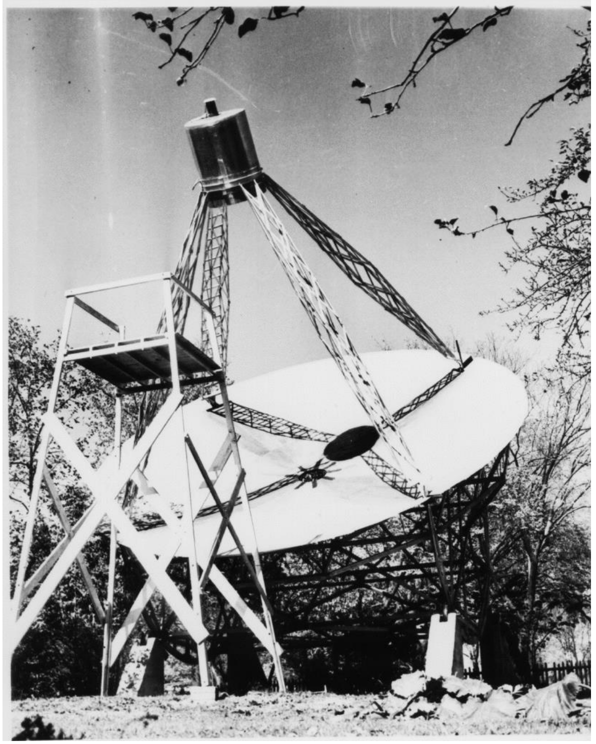
1932 : Karl Jansky (Bell Telephon)

« *le centre de la galaxie émet des ondes radio* »



1944 : Grote Reber (Radio amateur)
découverte de 3 sources radio



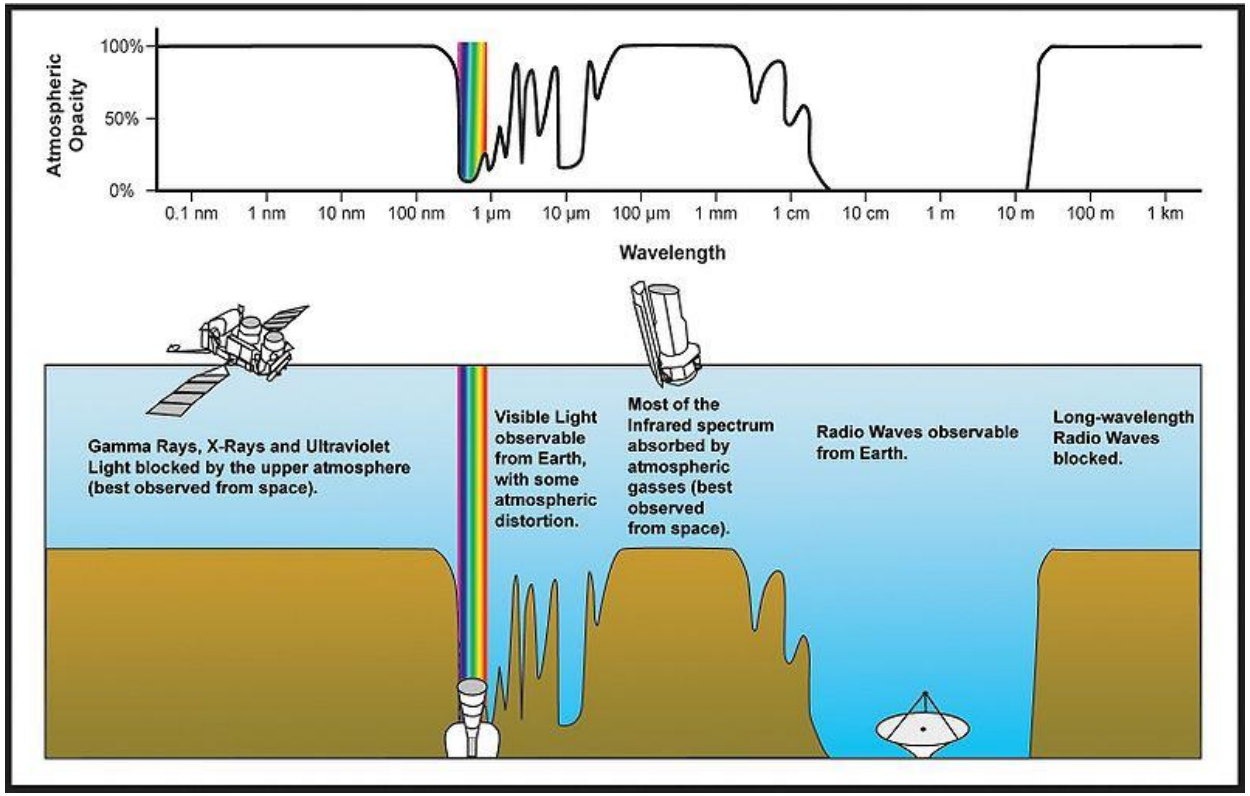


La raie à 21 cm

La raie à $\lambda = 21$ cm
est découverte par Oort et Van de Hulst en 1940, dans le spectre de l'hydrogène neutre
(transition hyperfine spin up->down à 1420,4 MHz)

2. In discussion with H.C. van de Hulst, at the reception on the occasion of Oort's quadrennial jubilee as a staff member of Leiden Observatory, 1964.

Le «trou» radio est découvert par Janski dans les années 30



Les nuages interstellaires et les galaxies sont essentiellement constitués d'hydrogène neutre…

❶ αβγ paper, publié un 1er avril

1948

3 actes majeurs en cosmologie !

PHYSICAL REVIEW VOLUME 73, NUMBER 7 APRIL 1, 1948

Letters to the Editor

PUBLICATION of brief reports of important discoveries in physics may be secured by addressing them to this department. The closing date for this department is five weeks prior to the date of issue. No proof will be sent to the authors. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents. Communications should not exceed 600 words in length.

The Origin of Chemical Elements

R. A. Alpher*
Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland
AND
H. Bethe
Cornell University, Ithaca, New York
AND
G. Gamow
The George Washington University, Washington, D. C.
February 18, 1948

As pointed out by one of us,[1] various nuclear species must have originated not as the result of an equilibrium corresponding to a certain temperature and density, but rather as a consequence of a continuous building-up process arrested by a rapid expansion and cooling of the primordial matter. According to this picture, we must imagine the early stage of matter as a highly compressed neutron gas (overheated neutral nuclear fluid) which started decaying into protons and electrons when the gas pressure fell down as the result of universal expansion. The radiative capture of the still remaining neutrons by the newly formed protons must have led first to the formation of deuterium nuclei, and the subsequent neutron captures resulted in the building up of heavier and heavier nuclei. It must be remembered that, due to the comparatively short time allowed for this process,[1] the building up of heavier nuclei must have proceeded just above the upper fringe of the stable elements (short-lived Fermi elements), and the present frequency distribution of various atomic species was attained only somewhat later as the result of adjustment of their electric charges by β-decay.

Thus the observed slope of the abundance curve must not be related to the temperature of the original neutron gas, but rather to the time period permitted by the expansion process. Also, the individual abundances of various nuclear species must depend not so much on their intrinsic stabilities (mass defects) as on the values of their neutron capture cross sections. The equations governing such a building-up process apparently can be written in the form:

$$\frac{dn_i}{dt}=f(t)(\sigma_{i-1}n_{i-1}-\sigma_i n_i) \quad i=1,2,\cdots 238, \qquad (1)$$

where n_i and σ_i are the relative numbers and capture cross sections for the nuclei of atomic weight i, and where $f(t)$ is a factor characterizing the decrease of the density with time.

We may remark at first that the building-up process was apparently completed when the temperature of the neutron gas was still rather high, since otherwise the observed abundances would have been strongly affected by the resonances in the region of the slow neutrons. According to Hughes,[2] the neutron capture cross sections of various elements (for neutron energies of about 1 Mev) increase exponentially with atomic number halfway up the periodic system, remaining approximately constant for heavier elements.

Using these cross sections, one finds by integrating Eqs. (1) as shown in Fig. 1 that the relative abundances of various nuclear species decrease rapidly for the lighter elements and remain approximately constant for the elements heavier than silver. In order to fit the calculated curve with the observed abundances[3] it is necessary to assume the integral of $\rho_n dt$ during the building-up period is equal to 5×10^4 g sec./cm^3.

On the other hand, according to the relativistic theory of the expanding universe[4] the density dependence on time is given by $\rho \cong 10^6/t^2$. Since the integral of this expression diverges at $t=0$, it is necessary to assume that the building-up process began at a certain time t_0, satisfying the relation:

$$\int_{t_0}^{\infty}(10^6/t^2)dt \cong 5\times10^4, \qquad (2)$$

which gives us $t_0 \cong 20$ sec. and $\rho_0 \cong 2.5\times10^5$ g sec./cm^3. This result may have two meanings: (a) for the higher densities existing prior to that time the temperature of the neutron gas was so high that no aggregation was taking place, (b) the density of the universe never exceeded the value 2.5×10^5 g sec./cm^3 which can possibly be understood if we

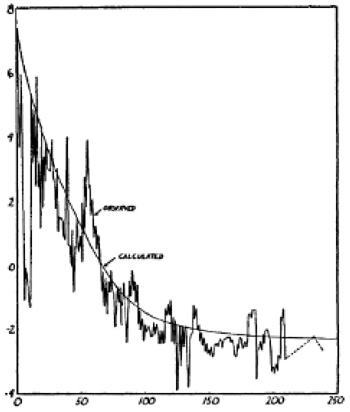
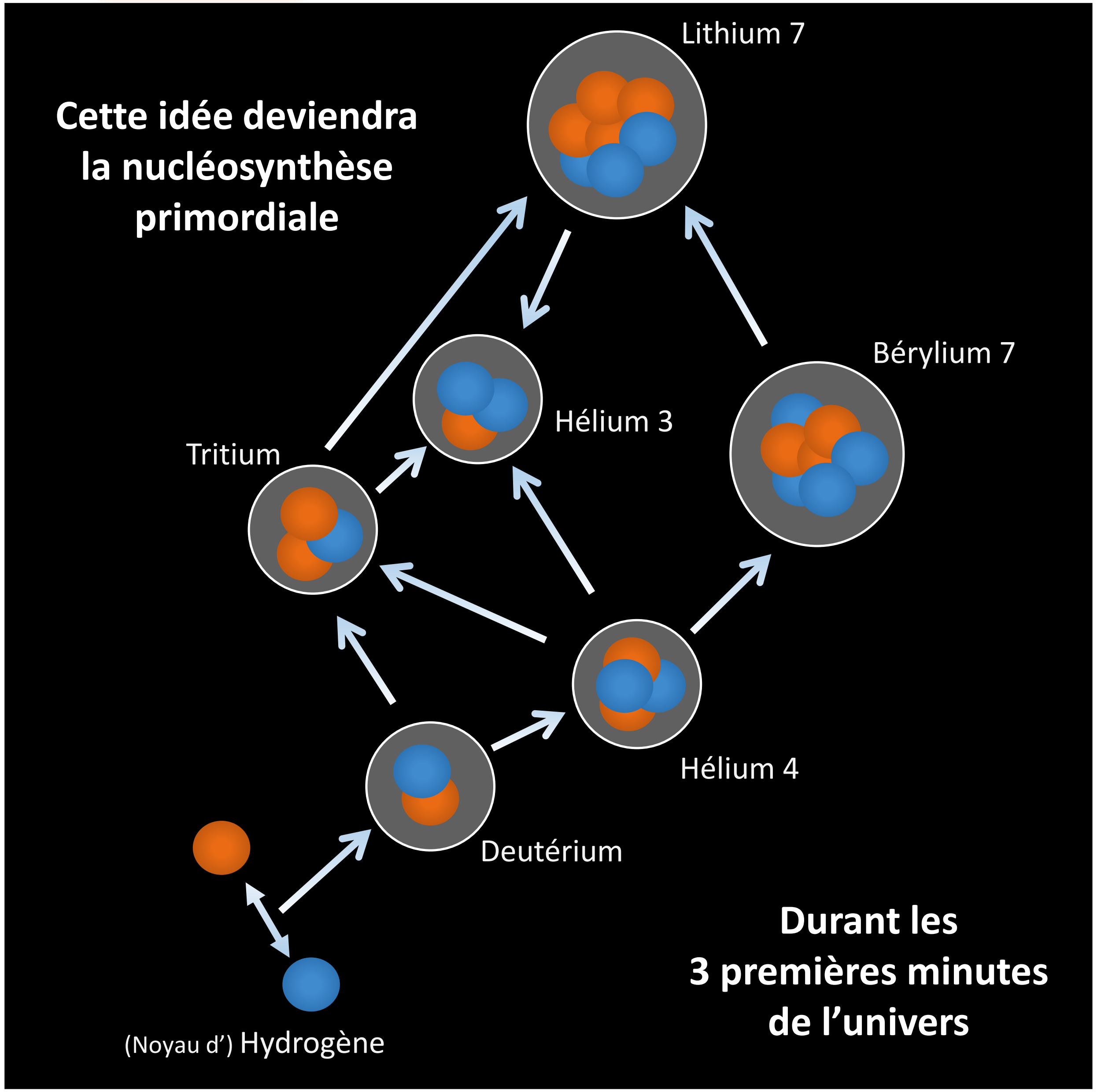


Fig. 1.
Log of relative abundance
Atomic weight



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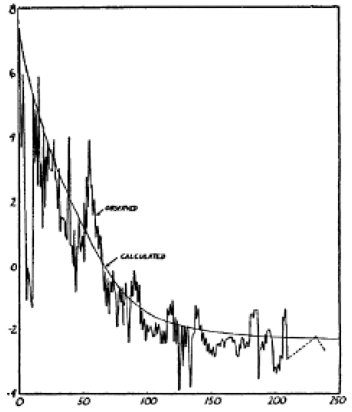

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Atomic weight

THE STEADY-STATE THEORY OF THE EXPANDING UNIVERSE

❷

H. Bondi and T. Gold

(Received 1948 July 14)

Summary

The applicability of the laws of terrestrial physics to cosmology is examined critically. It is found that terrestrial physics can be used unambiguously only in a stationary homogeneous universe. Therefore a strict logical basis for cosmology exists only in such a universe. The implications of assuming these properties are investigated.

Considerations of local thermodynamics show as clearly as astronomical observations that the universe must be expanding. Hence, there must be continuous creation of matter in space at a rate which is, however, far too low for direct observation. The observable properties of such an expanding stationary homogeneous universe are obtained, and all the observational tests are found to give good agreement.

The physical properties of the creation process are considered in some detail, and the possible formulation of a field theory is critically discussed.

1. *The perfect cosmological principle*

1.1. The unrestricted repeatability of all experiments is the fundamental axiom of physical science. This implies that the outcome of an experiment is not affected by the position and the time at which it is carried out. A system of cosmology must be principally concerned with this fundamental assumption and, in turn, a suitable cosmology is required for its justification. In laboratory physics we have become accustomed to distinguish between conditions which can be varied at will and the inherent laws which are immutable.

Such a distinction between the "accidental" conditions and the "inherent" laws and constants of nature is justifiable so long as we have control over the "accidental", and can test the validity of the distinction by a further experiment. In astronomical observations we do not have this control, and we can hence never prove which is "accidental" and which "inherent". This difficulty, though logically a very real one, need not concern us in an interpretation of the dynamics of the solar system. We may be satisfied when we discover that the solar system with all its numerous orbits is accurately one of the many systems permitted by our "inherent" laws.

But when we wish to consider the behaviour of the entire universe, then the logical basis for a distinction between "inherent" laws and "accidental" conditions disappears. Any observation of the structure of the universe will give as unique a result as, for instance, a determination of the velocity of light or the constant of gravitation. And yet, if we were to contemplate a changing universe we should have to assume some such observations to represent "accidental" conditions and others "inherent" laws.

Such assumptions were in fact implied in all theories of evolution of the universe; they were necessary to specify the problem. Without them, there would be no rules and hence unlimited freedom in any extrapolation into the future or into the past. Some such sets of assumptions may be intellectually much more

Hoyle, Bondi & Gold

l'Univers pourrait être éternel et immuable, il suffit pour cela de supposer l'existence d'un phénomène de création continue de matière

Ces auteurs ne croient pas à l'autre scenario émergent qu'ils parodient en l'appelant Théorie du Big Bang…

❶ αβγ paper, publié un 1er avril

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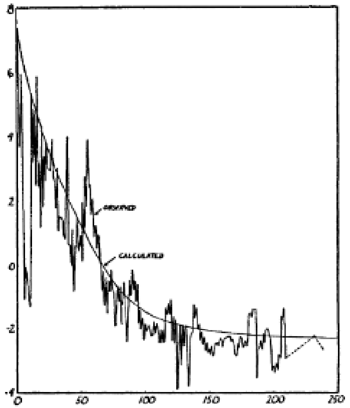

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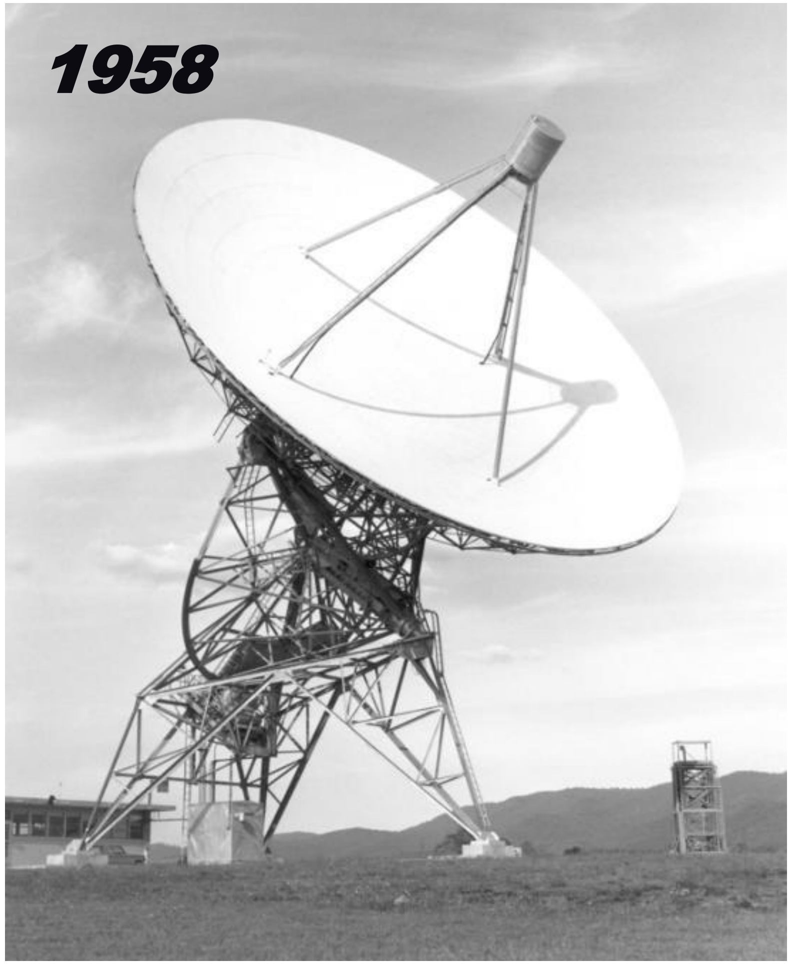
❸

George Gamow prévoit l'existence d'un rayonnement fossile à une température de 7K

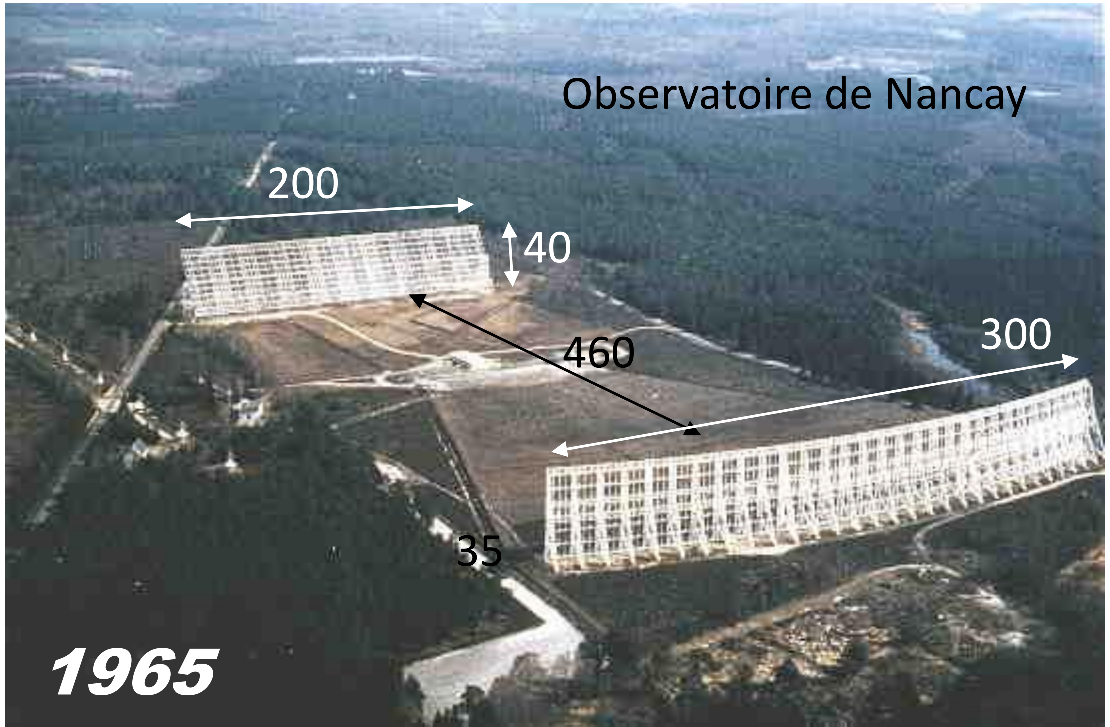
Après avoir imaginé la nucléosynthèse en 1945

Construction des grands observatoires radio



Radio-Observatoire de GreenBank
Virginie Occidentale (26m)

Radio-Observatoire d'Owens Valley Caltech



1965

Découverte des quasars

Sources
très petites,
très lumineuses,
…
et très lointaines !

$$z = 1 + \frac{\lambda - \lambda_0}{\lambda}$$

z = 1,1307
L'univers est agé d'au moins plusieurs milliards d'années

THE EXISTENCE OF A MAJOR NEW CONSTITUENT OF THE UNIVERSE: THE QUASI-STELLAR GALAXIES

ALLAN SANDAGE
Mount Wilson and Palomar Observatories
Carnegie Institution of Washington, California Institute of Technology

Received May 15, 1965

ABSTRACT

Photometric, number count, and spectrographic evidence is presented to show that most of the blue, starlike objects fainter than $m_{pg} = 16^m$ found in color surveys of high-latitude fields are extragalactic and represent an entirely new class of objects Members of the class called here quasi-stellar galaxies (QSG) resemble the quasi-stellar radio sources (QSS) in many optical properties, but they are radio-quiet. The QSG brighter than $m_{pg} = 19^m$ are 10^3 times more numerous per square degree than the QSS that are brighter than 9 flux units. The surface density of QSG is about 4 objects per square degree to $m_{pg} = 19^m$.

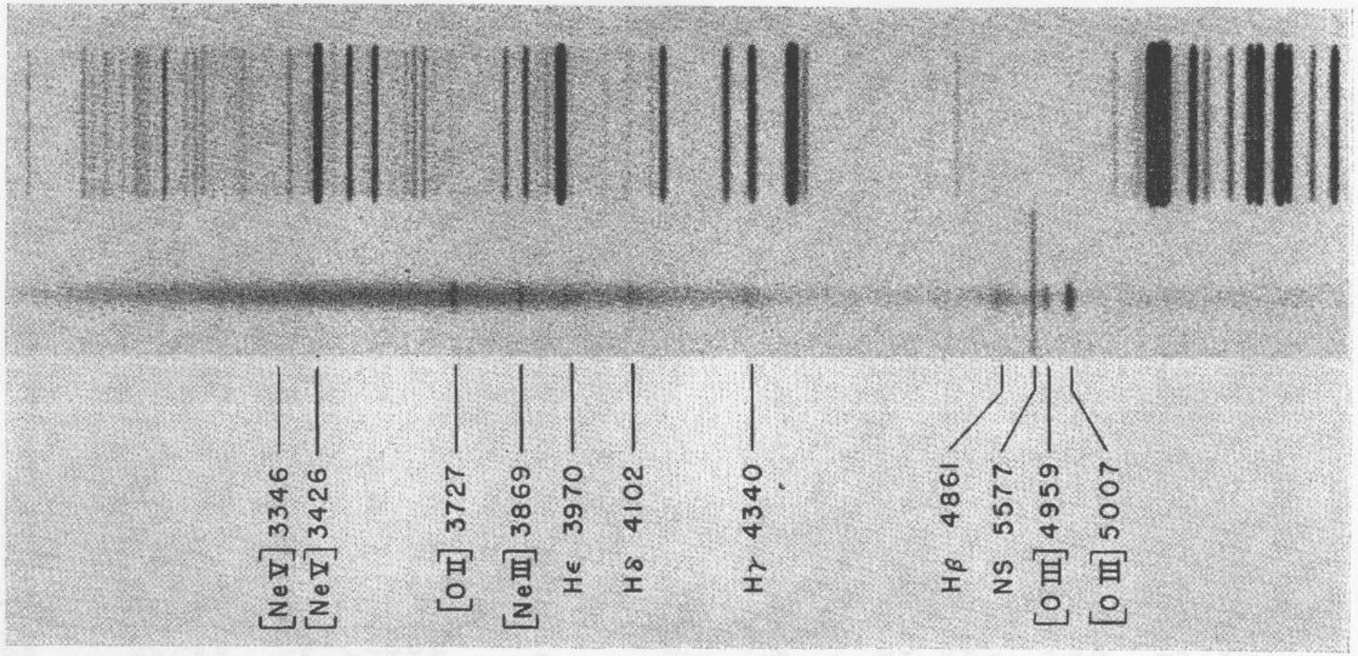
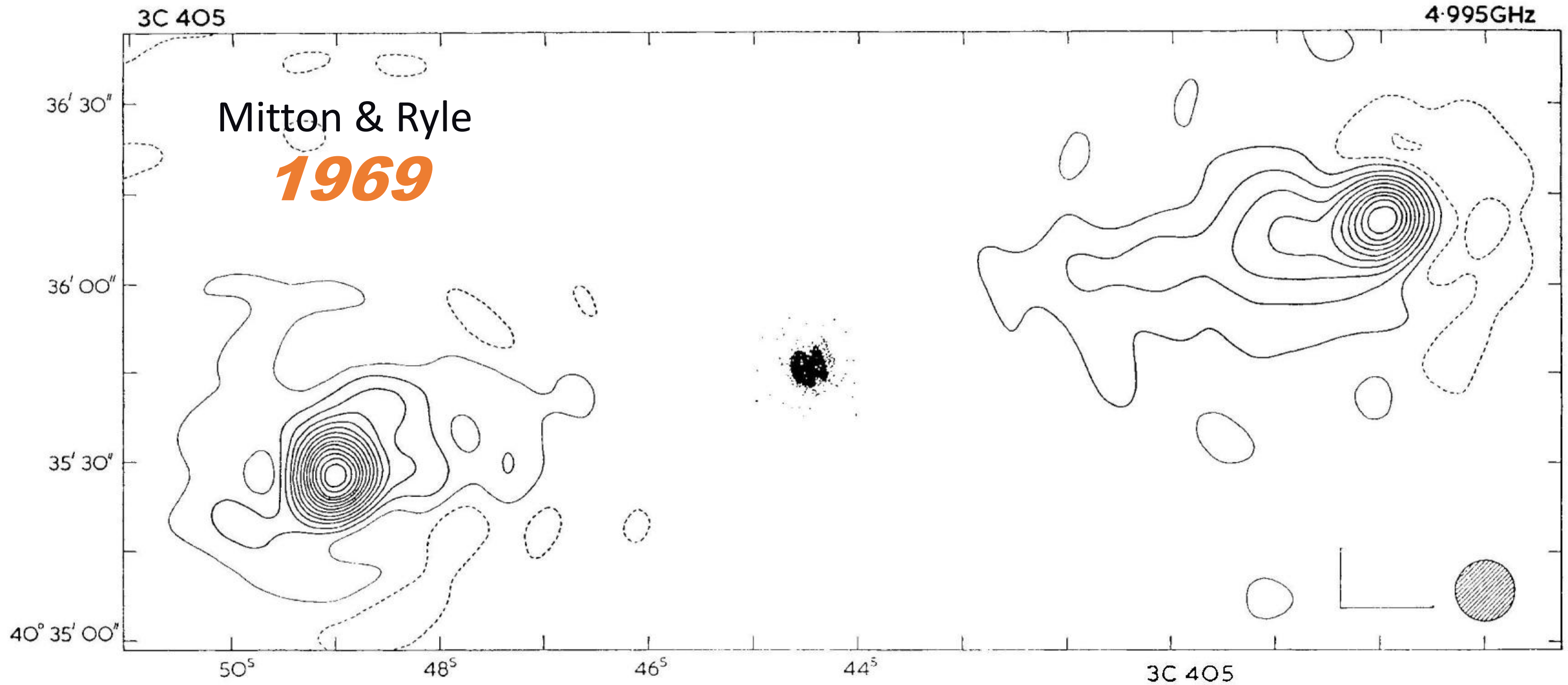
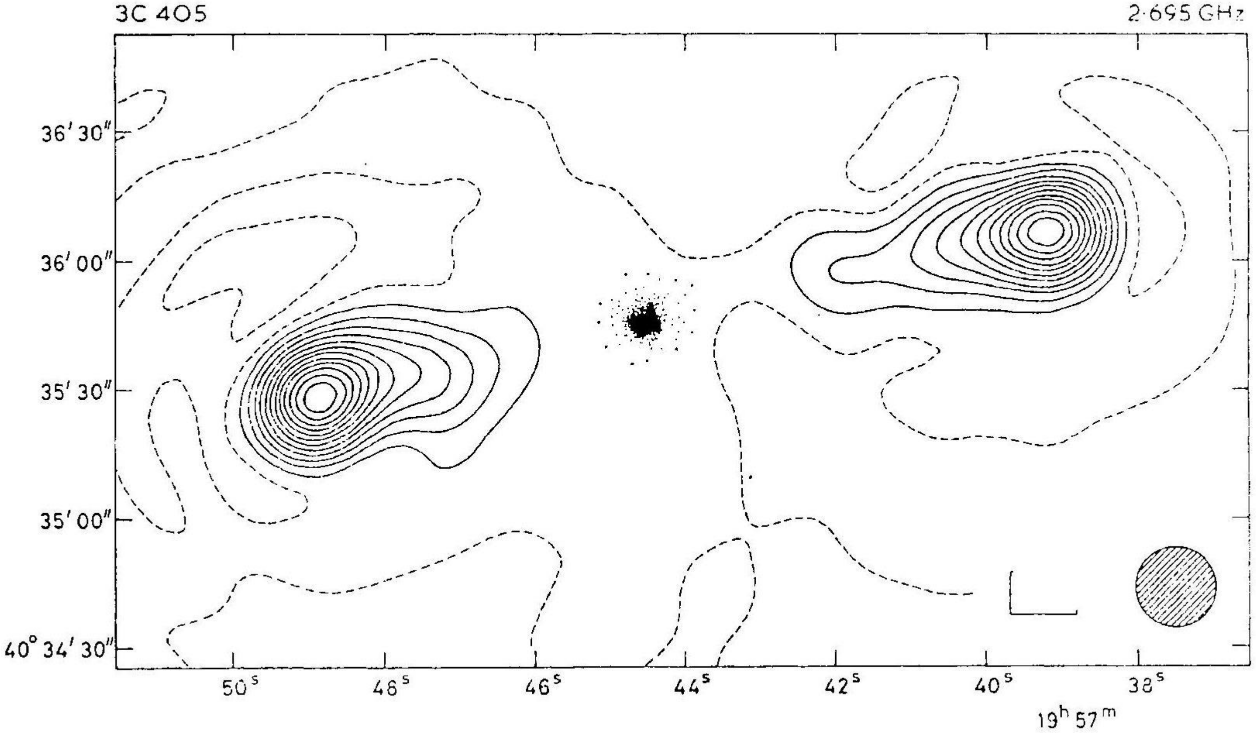


FIG. 6.—Spectrum of Ton 256 showing the narrow forbidden lines of [O III], [O II], and [Ne III], and the broad Balmer series and [Ne V] lines, redshifted from their normal position by a factor of 1.1307.



Le centre des galaxies est l'antre d'un monstre très puissant !



Les 3 piliers du Big-Bang

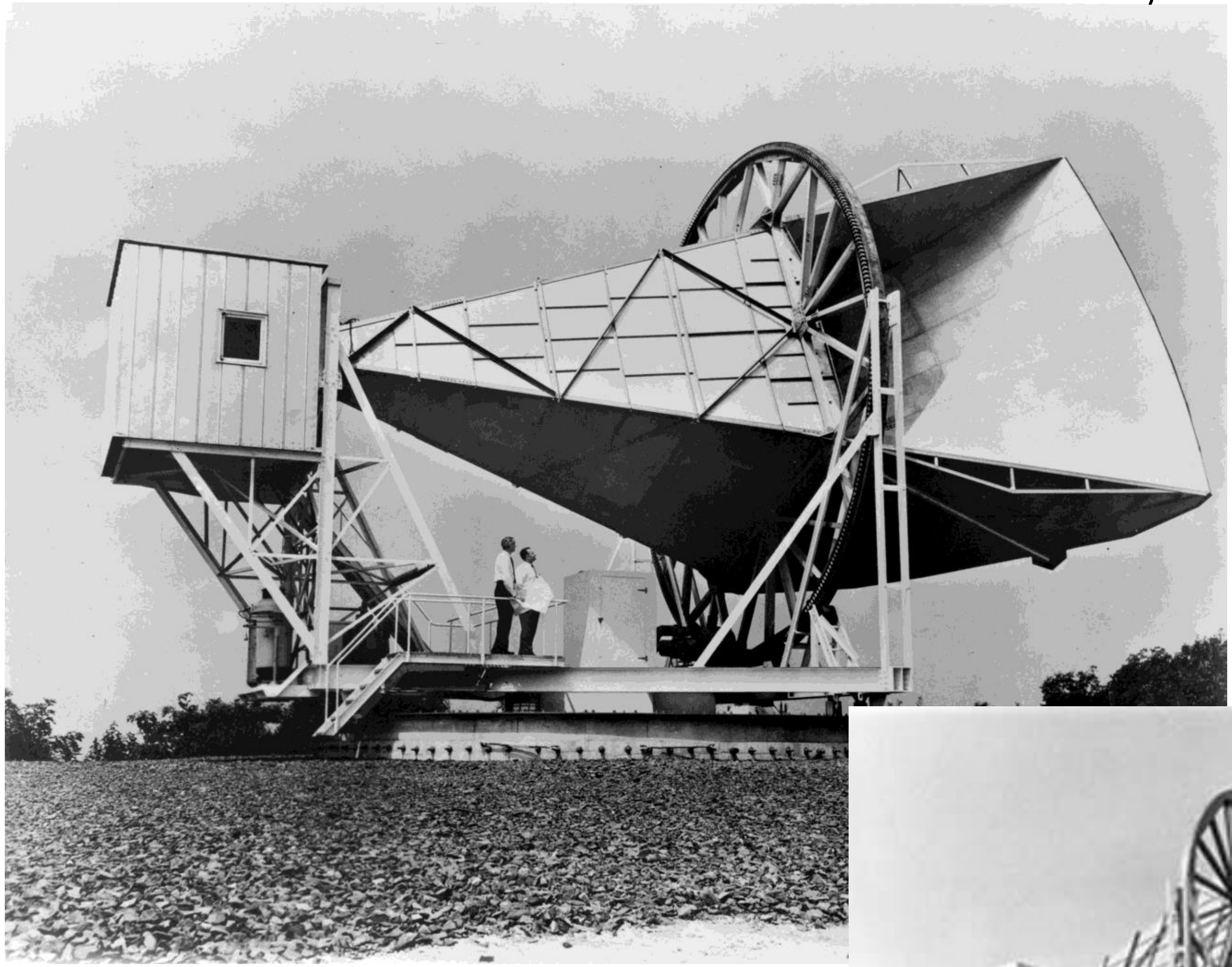
✓ ***Premier Pilier : L'expansion de l'Univers***

Premier intermédiaire : Le fond diffus cosmologique

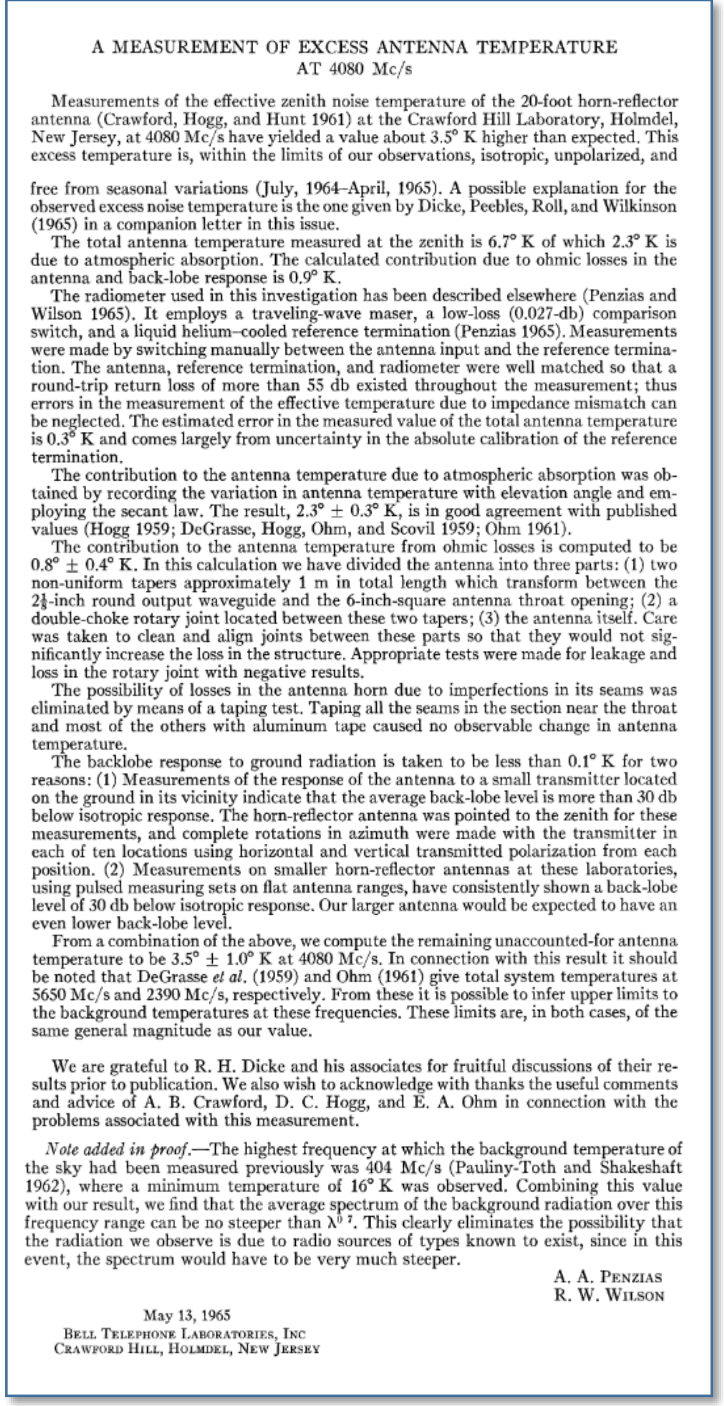
Dernier Pilier L'abondance des éléments légers

Avant les années 60

Antenne d'Holmdel des Laboratoires Bell à Crawford Hill dans le New Jersey.



1965



A MEASUREMENT OF EXCESS ANTENNA TEMPERATURE AT 4080 Mc/s

Measurements of the effective zenith noise temperature of the 20-foot horn-reflector antenna (Crawford, Hogg, and Hunt 1961) at the Crawford Hill Laboratory, Holmdel, New Jersey, at 4080 Mc/s have yielded a value about 3.5° K higher than expected. This excess temperature is, within the limits of our observations, isotropic, unpolarized, and free from seasonal variations (July, 1964–April, 1965). A possible explanation for the observed excess noise temperature is the one given by Dicke, Peebles, Roll, and Wilkinson (1965) in a companion letter in this issue.

The total antenna temperature measured at the zenith is 6.7° K of which 2.3° K is due to atmospheric absorption. The calculated contribution due to ohmic losses in the antenna and back-lobe response is 0.9° K.

The radiometer used in this investigation has been described elsewhere (Penzias and Wilson 1965). It employs a traveling-wave maser, a low-loss (0.027-db) comparison switch, and a liquid helium–cooled reference termination (Penzias 1965). Measurements were made by switching manually between the antenna input and the reference termination. The antenna, reference termination, and radiometer were well matched so that a round-trip return loss of more than 55 db existed throughout the measurement; thus errors in the measurement of the effective temperature due to impedance mismatch can be neglected. The estimated error in the measured value of the total antenna temperature is 0.3° K and comes largely from uncertainty in the absolute calibration of the reference termination.

The contribution to the antenna temperature due to atmospheric absorption was obtained by recording the variation in antenna temperature with elevation angle and employing the secant law. The result, 2.3° ± 0.3° K, is in good agreement with published values (Hogg 1959; DeGrasse, Hogg, Ohm, and Scovil 1959; Ohm 1961).

The contribution to the antenna temperature from ohmic losses is computed to be 0.8° ± 0.4° K. In this calculation we have divided the antenna into three parts: (1) two non-uniform tapers approximately 1 m in total length which transform between the $2\frac{1}{8}$-inch round output waveguide and the 6-inch-square antenna throat opening; (2) a double-choke rotary joint located between these two tapers; (3) the antenna itself. Care was taken to clean and align joints between these parts so that they would not significantly increase the loss in the structure. Appropriate tests were made for leakage and loss in the rotary joint with negative results.

The possibility of losses in the antenna horn due to imperfections in its seams was eliminated by means of a taping test. Taping all the seams in the section near the throat and most of the others with aluminum tape caused no observable change in antenna temperature.

The backlobe response to ground radiation is taken to be less than 0.1° K for two reasons: (1) Measurements of the response of the antenna to a small transmitter located on the ground in its vicinity indicate that the average back-lobe level is more than 30 db below isotropic response. The horn-reflector antenna was pointed to the zenith for these measurements, and complete rotations in azimuth were made with the transmitter in each of ten locations using horizontal and vertical transmitted polarization from each position. (2) Measurements on smaller horn-reflector antennas at these laboratories, using pulsed measuring sets on flat antenna ranges, have consistently shown a back-lobe level of 30 db below isotropic response. Our larger antenna would be expected to have an even lower back-lobe level.

From a combination of the above, we compute the remaining unaccounted-for antenna temperature to be 3.5° ± 1.0° K at 4080 Mc/s. In connection with this result it should be noted that DeGrasse *et al.* (1959) and Ohm (1961) give total system temperatures at 5650 Mc/s and 2390 Mc/s, respectively. From these it is possible to infer upper limits to the background temperatures at these frequencies. These limits are, in both cases, of the same general magnitude as our value.

We are grateful to R. H. Dicke and his associates for fruitful discussions of their results prior to publication. We also wish to acknowledge with thanks the useful comments and advice of A. B. Crawford, D. C. Hogg, and E. A. Ohm in connection with the problems associated with this measurement.

Note added in proof.—The highest frequency at which the background temperature of the sky had been measured previously was 404 Mc/s (Pauliny-Toth and Shakeshaft 1962), where a minimum temperature of 16° K was observed. Combining this value with our result, we find that the average spectrum of the background radiation over this frequency range can be no steeper than $\lambda^{0.7}$. This clearly eliminates the possibility that the radiation we observe is due to radio sources of types known to exist, since in this event, the spectrum would have to be very much steeper.

A. A. Penzias
R. W. Wilson

May 13, 1965
Bell Telephone Laboratories, Inc
Crawford Hill, Holmdel, New Jersey

Astrophysical Journal, vol. 142, p.419-421, Juillet 1965

Arno Penzias et Robert Wilson, physiciens au Bell Labs découvrent un rayonnement radio de fond à 2,7 K.

1978

Arno Penzias et Robert Wilson devant leur antenne

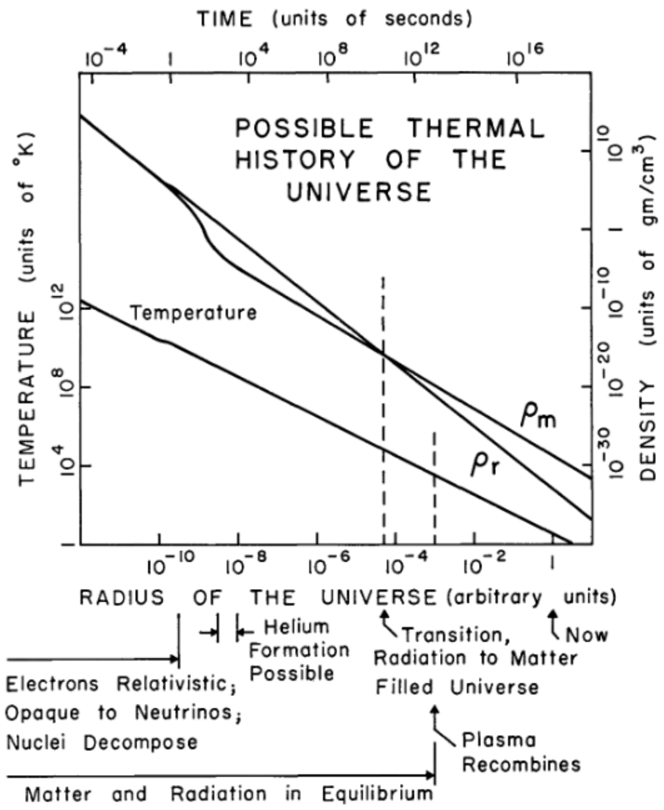
L'article précédent…

1965

COSMIC BLACK-BODY RADIATION*

One of the basic problems of cosmology is the singularity characteristic of the familiar cosmological solutions of Einstein's field equations. Also puzzling is the presence of matter in excess over antimatter in the universe, for baryons and leptons are thought to be conserved. Thus, in the framework of conventional theory we cannot understand the origin of matter or of the universe. We can distinguish three main attempts to deal with these problems.

1. The assumption of continuous creation (Bondi and Gold 1948; Hoyle 1948), which avoids the singularity by postulating a universe expanding for all time and a continuous but slow creation of new matter in the universe.
2. The assumption (Wheeler 1964) that the creation of new matter is intimately related to the existence of the singularity, and that the resolution of both paradoxes may be found in a proper quantum mechanical treatment of Einstein's field equations.
3. The assumption that the singularity results from a mathematical over-idealization,



CONCLUSIONS

While all the data are not yet in hand we propose to present here the possible conclusions to be drawn if we tentatively assume that the measurements of Penzias and Wilson (1965) do indicate black-body radiation at 3.5° K. We also assume that the universe can be considered to be isotropic and uniform, and that the present energy density in gravitational radiation is a small part of the whole. Wheeler (1958) has remarked that gravitational radiation could be important.

For the purpose of obtaining definite numerical results we take the present Hubble redshift age to be 10^{10} years.

Assuming the validity of Einstein's field equations, the above discussion and numerical values impose severe restrictions on the cosmological problem. The possible conclusions are conveniently discussed under two headings, the assumption of a universe with either an open or a closed space.

We deeply appreciate the helpfulness of Drs. Penzias and Wilson of the Bell Telephone Laboratories, Crawford Hill, Holmdel, New Jersey, in discussing with us the result of their measurements and in showing us their receiving system. We are also grateful for several helpful suggestions of Professor J. A. Wheeler.

R. H. Dicke
P. J. E. Peebles
P. G. Roll
D. T. Wilkinson

May 7, 1965
Palmer Physical Laboratory
Princeton, New Jersey


Jim Peebles


Robert Dicke

Astrophysical Journal, vol. 142, p.414-419 , juillet 1965

A MEASUREMENT OF EXCESS ANTENNA TEMPERATURE AT 4080 Mc/s

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A. A. Penzias
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May 13, 1965
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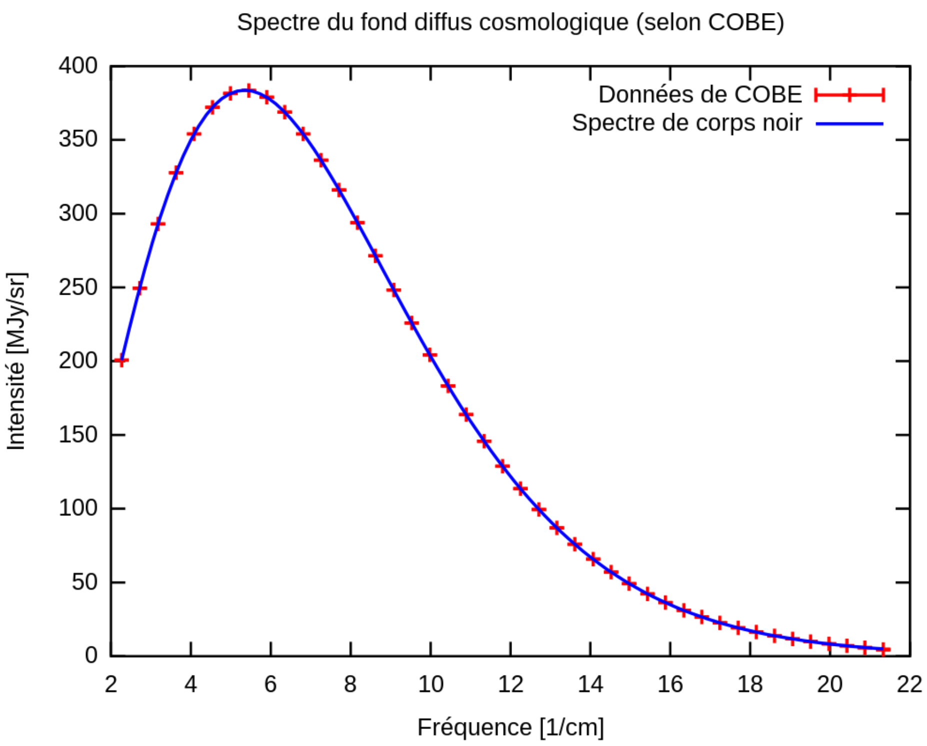
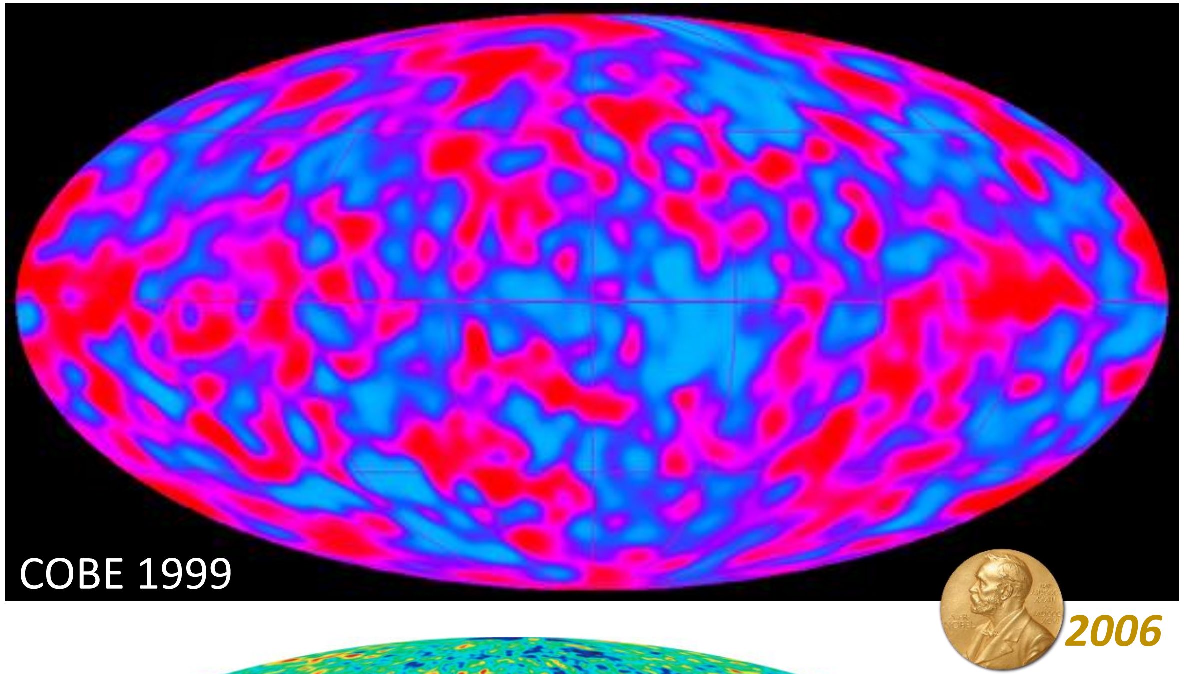
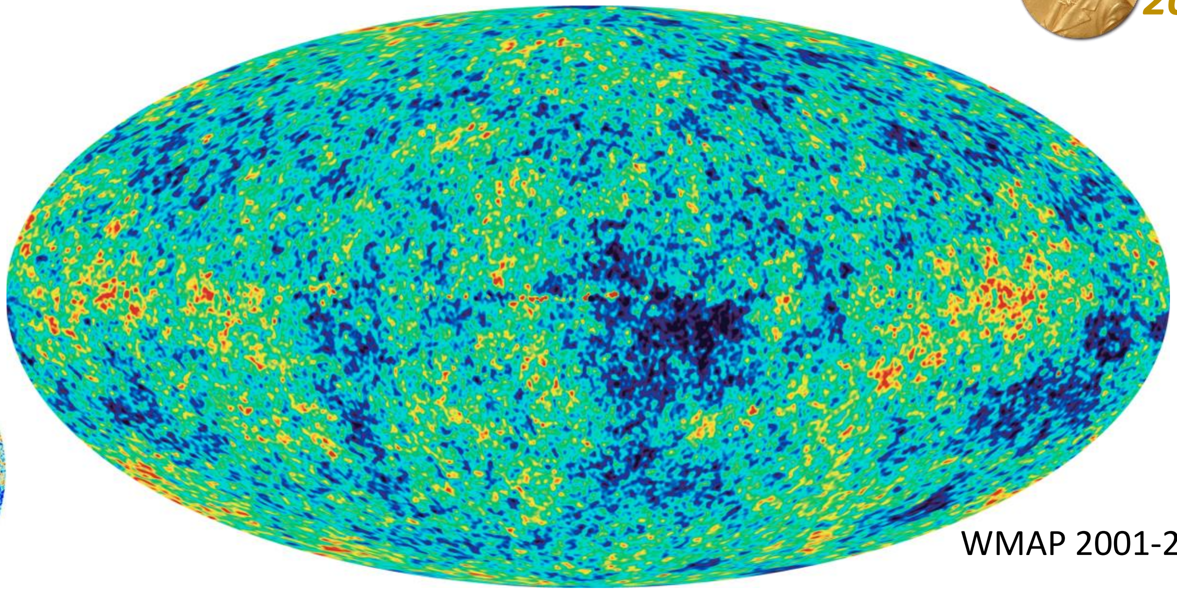
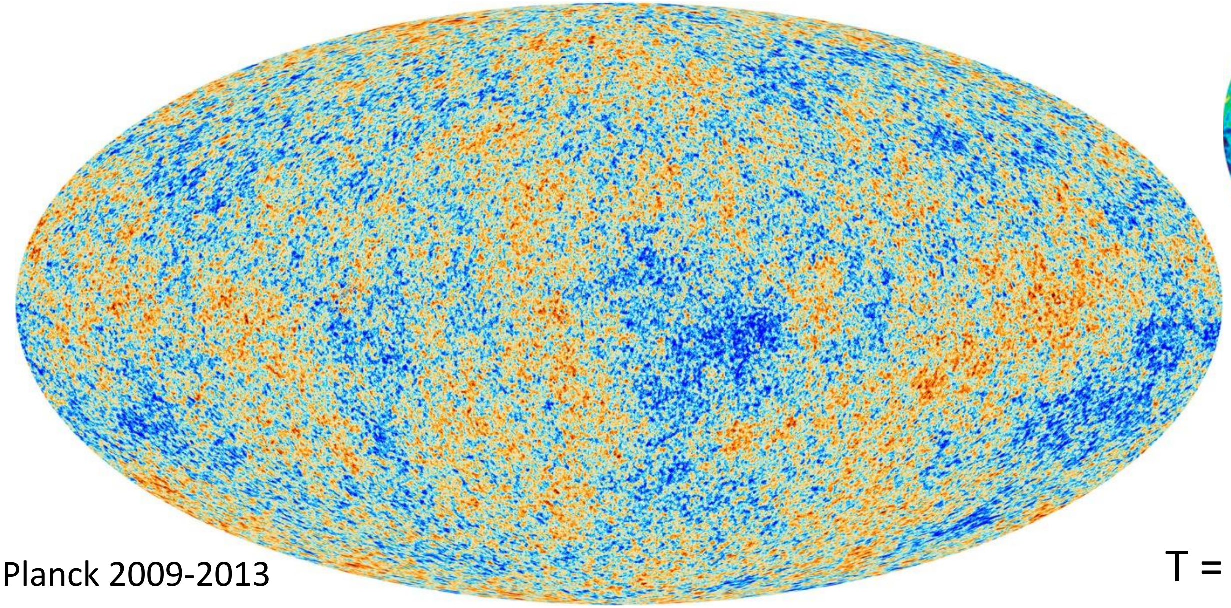






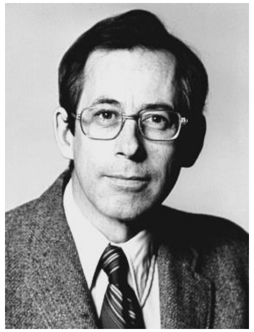
WMAP 2001-2010



Planck 2009-2013

T = 2,7K fluctuations / Répartition angulaire

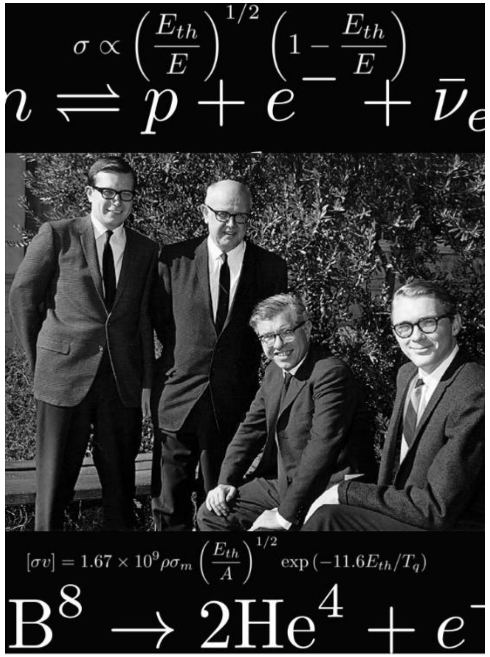
Un scenario de type Big Bang est compatible avec l'abondance en éléments légers de l'Univers



Helium : Peebles 1966

2019

D, He^3, He^4, Li^7 : Pasadena Team



L'équipe de Pasadena en 1966

PRIMEVAL HELIUM ABUNDANCE AND THE PRIMEVAL FIREBALL*

P. J. E. Peebles

Palmer Physical Laboratory, Princeton University, Princeton, New Jersey

(Received 7 February 1966)

We have now a second point[1] on the spectrum of the microwave background,[2] and it is consistent with the idea[3] that this is black-body radiation, the primordial fireball left over from the "big bang." If this is confirmed by further observations at shorter wavelengths we will have learned the present temperature of the universe, and we will be able to trace back from this temperature to find something about the history of the universe. At an early stage in the expansion of the universe, thermal reactions would have produced deuterium and helium: This is the old big bang theory of the formation of the elements. The purpose of this note is to present the results of a recent calculation of the primeval element abundances issuing from the big bang. These depend on two observable quantities, the temperature of the fireball radiation and the mean mass density in the universe. The abundances are high enough that an observational test appears quite possible. The details of the calculation will be described elsewhere.

The computed helium and deuterium abundances are shown in Fig. 1. The best estimate for the mean mass density in the universe would be in the range 7×10^{-31} g/cm^3 (the estimated mass in galaxies[4]) to 2×10^{-29} g/cm^3 (the mass density required to close the universe). For this density range, if the present temperature of the fireball is 3°K,[1,2] the computed primeval helium abundance is 27 to 30% by mass. If the average mass density in the universe were a factor of 30 below the accepted estimate of the mass in galaxies, it would lead to a much lower primeval helium abundance.

It would be very interesting to compare the helium abundances in Fig. 1 with the composition of the oldest stars in our galaxy, but at present very little is known about the helium abundance in these stars. From the composition of solar cosmic rays and spectroscopic heavy-element abundances, and from solar models, the helium abundance in the sun is thought to be about 25% by mass,[5] and an abundance as high as 30% would not be excluded.

Physical Review Letters, vol. 16, Issue 10, pp. 410-413

The Astrophysical Journal, Vol. 148, April 1967

ON THE SYNTHESIS OF ELEME *1983* HIGH TEMPERATURES*

Robert V. Wagoner, William A. Fowler, and F. Hoyle

California Institute of Technology, Pasadena, California, and Cambridge University

Received September 1, 1966

ABSTRACT

A detailed calculation of element production in the early stages of a homogeneous and isotropic expanding universe as well as within imploding-exploding supermassive stars has been made. If the recently measured microwave background radiation is due to primeval photons, then significant quantities of only D, He^3, He^4, and Li^7 can be produced in the universal fireball. Reasonable agreement with solar-system abundances for these nuclei is obtained if the present temperature is 3° K and if the present density is $\sim 2 \times 10^{-31}$ gm cm^3, corresponding to a deceleration parameter $q_0 \approx 5 \times 10^{-3}$. However, massive stars "bouncing" at temperatures $\sim 10^9$ ° K can convert the universal D and He^3 into C, N, O, Ne, Mg, and some heavier elements in amounts observed in the oldest stars. The mass gaps at $A = 5$ and 8 are bridged by the reactions $He^3(He^4,\gamma)Be^7(He^4,\gamma)C^{11}$. Bounces at higher temperatures bridge the mass gaps through 3 $He^4 \rightarrow C^{12}$ and mainly produce metals of the iron group, plus a small amount of heavier elements synthesized by a new kind of *r*-process (rapid neutron capture). It is found that very low abundances of He^4, as recently observed in some stars, can be produced in a universe in which the electron neutrinos are degenerate.

Les 3 piliers du Big-Bang

- ✓ ***Premier Pilier : L'expansion de l'Univers***
- ✓ ***Premier intermédiaire : Le fond diffus cosmologique***
- ✓ ***Dernier Pilier : L'abondance des éléments légers***

A partir des années 70

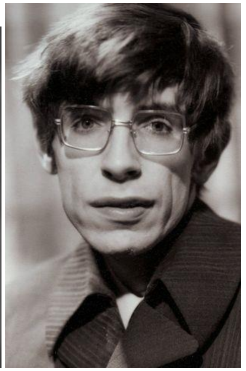
La singularité de genre temps du début de l’Univers

En relativité générale, il y a au moins une géodésique qui n’est pas de genre espace et qui n’est pas infiniment extensible dans le passé : on parle d’une singularité de genre temps.
Dans de nombreux cas tous les chemins spatiaux dirigés vers le passé se terminent vers ce genre de singularité.

- (en) Roger Penrose, « Gravitational collapse ans space-time singularities », *Physical Review Letters*, vol. 14, nº 3, 18 janvier 1965, p. 57-59 (DOI 10.1103/PhysRevLett.14.57, Bibcode 1965PhRvL..14...57P)
- (en) Stephen W. Hawking, « The occurrence of singularities in cosmology. I. », *Proceedings of the Royal Society*, a, vol. 294, nº 1439, 18 octobre 1966, p. 511-521 (DOI 10.1098/rspa.1966.0221, résumé [archive])
- (en) Stephen W. Hawking, « The occurrence of singularities in cosmology. II. », *Proceedings of the Royal Society*, a, vol. 295, nº 1443, 20 décembre 1966, p. 490-493 (DOI 10.1098/rspa.1966.0255, résumé [archive])
- (en) Stephen W. Hawking, « The occurrence of singularities in cosmology. III. Causality and singularities », *Proceedings of the Royal Society*, a, vol. 300, nº 1461, 30 août 1967, p. 187-201 (DOI 10.1098/rspa.1967.0164, résumé [archive])

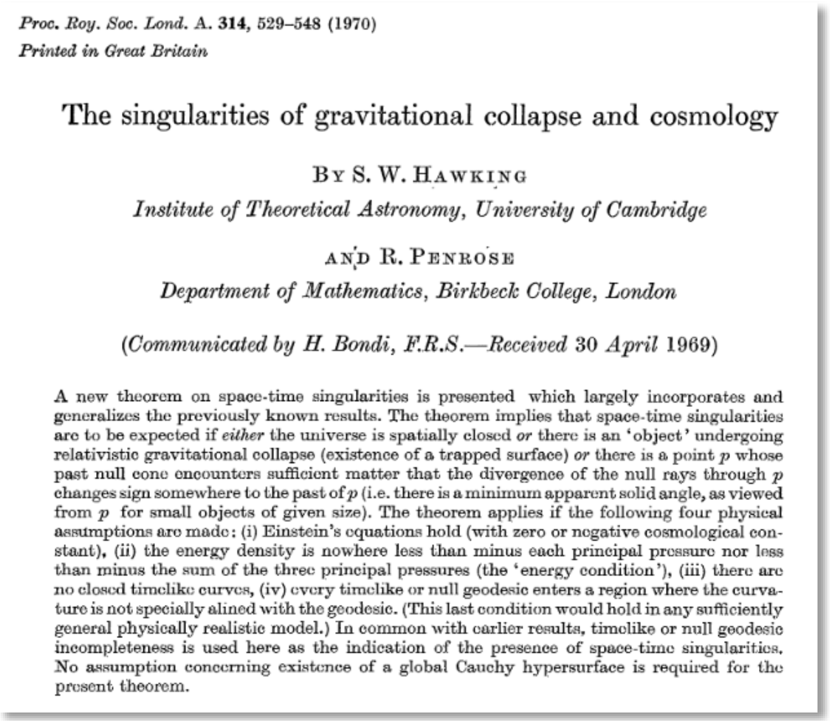
2020

Roger Penrose vers 1970



Stephen Hawking en 1963

1965-1969



Proc. Roy. Soc. Lond. A. **314**, 529–548 (1970)
Printed in Great Britain

The singularities of gravitational collapse and cosmology

By S. W. Hawking
Institute of Theoretical Astronomy, University of Cambridge

and R. Penrose
Department of Mathematics, Birkbeck College, London

(*Communicated by H. Bondi, F.R.S.—Received 30 April 1969*)

A new theorem on space-time singularities is presented which largely incorporates and generalizes the previously known results. The theorem implies that space-time singularities are to be expected if *either* the universe is spatially closed *or* there is an ‘object’ undergoing relativistic gravitational collapse (existence of a trapped surface) *or* there is a point p whose past null cone encounters sufficient matter that the divergence of the null rays through p changes sign somewhere to the past of p (i.e. there is a minimum apparent solid angle, as viewed from p for small objects of given size). The theorem applies if the following four physical assumptions are made: (i) Einstein’s equations hold (with zero or negative cosmological constant), (ii) the energy density is nowhere less than minus each principal pressure nor less than minus the sum of the three principal pressures (the ‘energy condition’), (iii) there are no closed timelike curves, (iv) every timelike or null geodesic enters a region where the curvature is not specially alined with the geodesic. (This last condition would hold in any sufficiently general physically realistic model.) In common with earlier results, timelike or null geodesic incompleteness is used here as the indication of the presence of space-time singularities. No assumption concerning existence of a global Cauchy hypersurface is required for the present theorem.

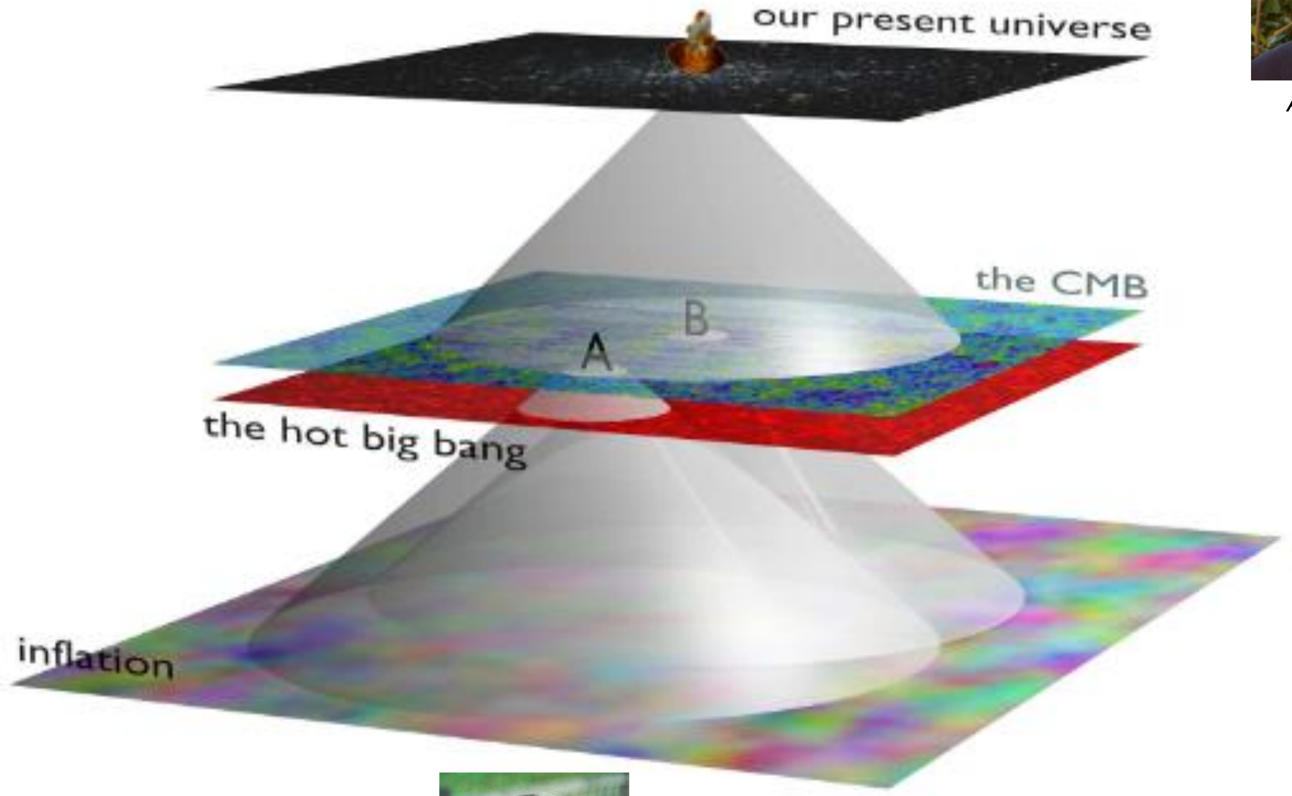
Prozorova, Aleksei Abrikosov, Khalatnikov, Lev Davidovich Landau, Evgeni Mikhailovich Lifchitz

1969 Dans un univers anisotrope cette singularité est chaotique

Singularité de type Belinski-Khalatnikov-Lifchitz (BKL)

Le début de l'histoire de l'univers est associé à des périodes inflationnaires

Un remède pour les pathologies du Big Bang !



PHYSICAL REVIEW D VOLUME 23, NUMBER 2 15 JANUARY 1981


Alan Guth

Inflationary universe: A possible solution to the horizon and flatness problems

Alan H. Guth*
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305
(Received 11 August 1980)

DYNAMICS OF PHASE TRANSITION IN THE NEW INFLATIONARY UNIVERSE SCENARIO AND GENERATION OF PERTURBATIONS

A.A. STAROBINSKY
The Landau Institute for Theoretical Physics, The Academy of Sciences, Moscow, 117334, USSR

Received 13 July 1982


Alexei Starobinskii

Dynamics of non-equilibrium phase transition in the early universe is investigated. The transition is triggered by vacuum fluctuations of a Higgs scalar field which determine the duration of an intermediate inflationary stage and the amplitude of adiabatic perturbations. This amplitude ranges from g^2 to one and more depending on scale that presents a serious problem for the inflationary scenario.

Quantum fluctuations and a nonsingular universe

V. F. Mukhanov and G. V. Chibisov
P. N. Lebedev Physics Institute, Academy of Sciences of the USSR, Moscow

(Submitted 26 February 1981; resubmitted 15 April 1981)
Pis'ma Zh. Eksp. Teor. Fiz. **33**, No. 10, 549–553 (20 May 1981)


Viatcheslav Mukhanov

Over a finite time, quantum fluctuations of the curvature disrupt the nonsingular cosmological solution corresponding to a universe with a polarized vacuum. If this solution held as an intermediate stage in the evolution of the universe, then the spectrum of produced fluctuations could have led to the formation of galaxies and galactic clusters.


Andrei Linde

ETERNALLY EXISTING SELF-REPRODUCING CHAOTIC INFLATIONARY UNIVERSE

A.D. LINDE
International Centre for Theoretical Physics, I-34000 Trieste, Italy and Lebedev Physical Institute, Moscow 117924, USSR [1]

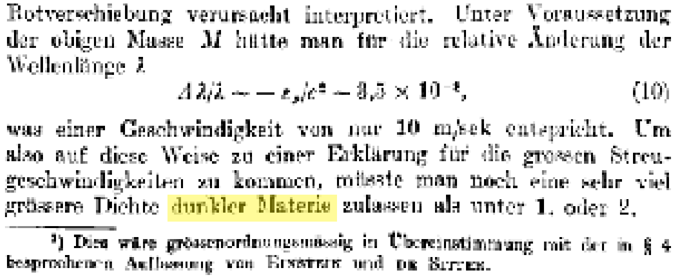
Received 15 May 1986

It is shown that the large-scale quantum fluctuations of the scalar field φ generated in the chaotic-inflation scenario lead to an infinite process of self-reproduction of inflationary mini-universes. A model of an eternally existing chaotic inflationary universe is suggested.

Il doit certainement y avoir beaucoup de matière noire dans l'univers !

Le visionnaire…

Fritz Zwicky



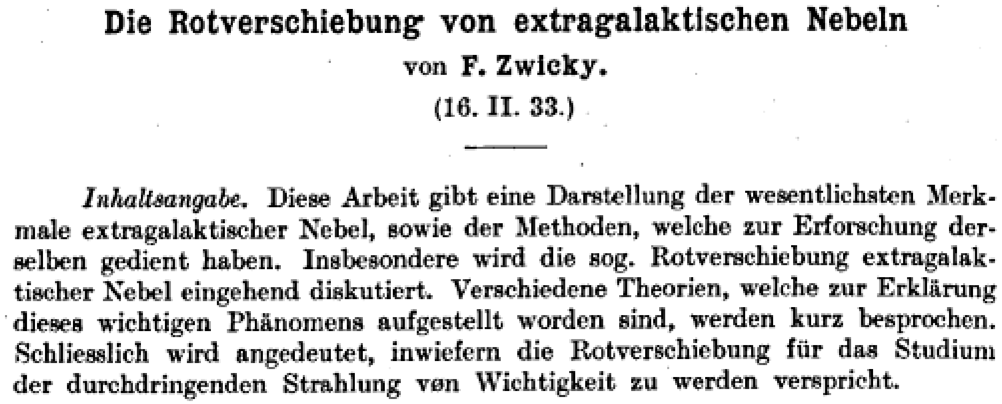
Rotverschiebung verursacht interpretiert. Unter Voraussetzung der obigen Masse M hätte man für die relative Änderung der Wellenlänge λ

$$\Delta\lambda/\lambda = -\varepsilon_p/c^2 = 3{,}5 \times 10^{-8}, \qquad (10)$$

was einer Geschwindigkeit von nur 10 m/sek entspricht. Um also auf diese Weise zu einer Erklärung für die grossen Streugeschwindigkeiten zu kommen, müsste man noch eine sehr viel grössere Dichte dunkler Materie zulassen als unter 1. oder 2.

[1]) Dies wäre grössenordnungsmässig in Übereinstimmung mit der in § 4 besprochenen Auffassung von Einstein und de Sitter.

Le décalage vers le rouge des nébuleuses galactiques



Die Rotverschiebung von extragalaktischen Nebeln

von **F. Zwicky.**

(16. II. 33.)

Inhaltsangabe. Diese Arbeit gibt eine Darstellung der wesentlichsten Merkmale extragalaktischer Nebel, sowie der Methoden, welche zur Erforschung derselben gedient haben. Insbesondere wird die sog. Rotverschiebung extragalaktischer Nebel eingehend diskutiert. Verschiedene Theorien, welche zur Erklärung dieses wichtigen Phänomens aufgestellt worden sind, werden kurz besprochen. Schliesslich wird angedeutet, inwiefern die Rotverschiebung für das Studium der durchdringenden Strahlung von Wichtigkeit zu werden verspricht.

Act. Helv. Phys., 6, 110-127, **1933**

Loi de Hubble ➔ Distance ➔ Taille de l'amas Coma : R ≈ 1Mpc

Vitesse connue pour 8 galaxies (sur 1000) : v ≈ 1000 km/s

Théorème du viriel : $2E_c+E_p = 0$

➔ $M = Rv^2/G$

AN: $M \approx (10^6 \times 3.10^{16}).(10^6)^2 / 6{,}7.10^{-11}$

$\approx 5.10^{44}$ kg $\approx 10^{14} M_\odot$

On dénombre 1000 galaxies contenant chacune environ 1 milliard d'étoiles…

« dunkler materie » , $M/L = 400\ M_\odot/L_\odot$

Amas de la chevelure de Bérénice (Coma) - HST

3 ans plus tard…

ApJ., 83, 23-30, **1936**

THE MASS OF THE VIRGO CLUSTER*

SINCLAIR SMITH

ABSTRACT

The lists of radial velocities now include results for thirty-two members of the Virgo Cluster, thus giving for the first time sufficient data to determine some of the physical characteristics of a cluster of nebulae.

A comparison of the velocities of fainter members of the cluster with those of brighter members shows that the line-of-sight velocity of a nebula has no dependence on its magnitude; hence, equipartition apparently does not hold in the cluster. The distribution of the velocities in right ascension and declination shows that the cluster is not in rotation and that there is no central concentration of high velocities. This result is taken to mean that the cluster is neither condensing nor breaking up, but is a fairly stable assemblage, more or less held together by its gravitational field.

From the observed distribution function for radial velocity is derived the distribution function for space velocity. For an assumed distance of 2×10^6 parsecs this function leads to 2×10^{47} g or $10^{14}\odot$ as a value of the mass of the cluster. On the basis of 500 nebulae in the cluster, the mass per nebula is $2\times10^{11}\odot$.

Although far larger than Hubble's value of $10^9\odot$ for the mass of an average nebula, other evidence lends support to the high value obtained from the Virgo Cluster. It is possible that both figures are correct and that the difference represents a great mass of internebular material within the cluster.

…

move in circular orbits with a speed of 1500 km/sec. Hence we can write either

$$m=\frac{v^2r}{2G} \quad \text{or} \quad \frac{v^2r}{G},$$

the difference being of small importance.

Taking the circular orbit form, and assuming for radius of the cluster 2×10^5 parsecs (i.e., 0.1 times its distance), we find for the mass

$$2\times10^{47}\,\text{grams} \quad \text{or} \quad 10^{14}\odot .$$

Assuming 500 nebulae in the cluster and no internebular material, we find for the mean mass of a single nebula

$$4\times10^{44}\,\text{grams} \quad \text{or} \quad 2\times10^{11}\odot .$$

➡ This value is some two hundred times Hubble's[3] estimate of $10^9\odot$ for the mass of an average nebula. The cause of the discrepancy is not clear. In the determination of the mass of the cluster, the only

…

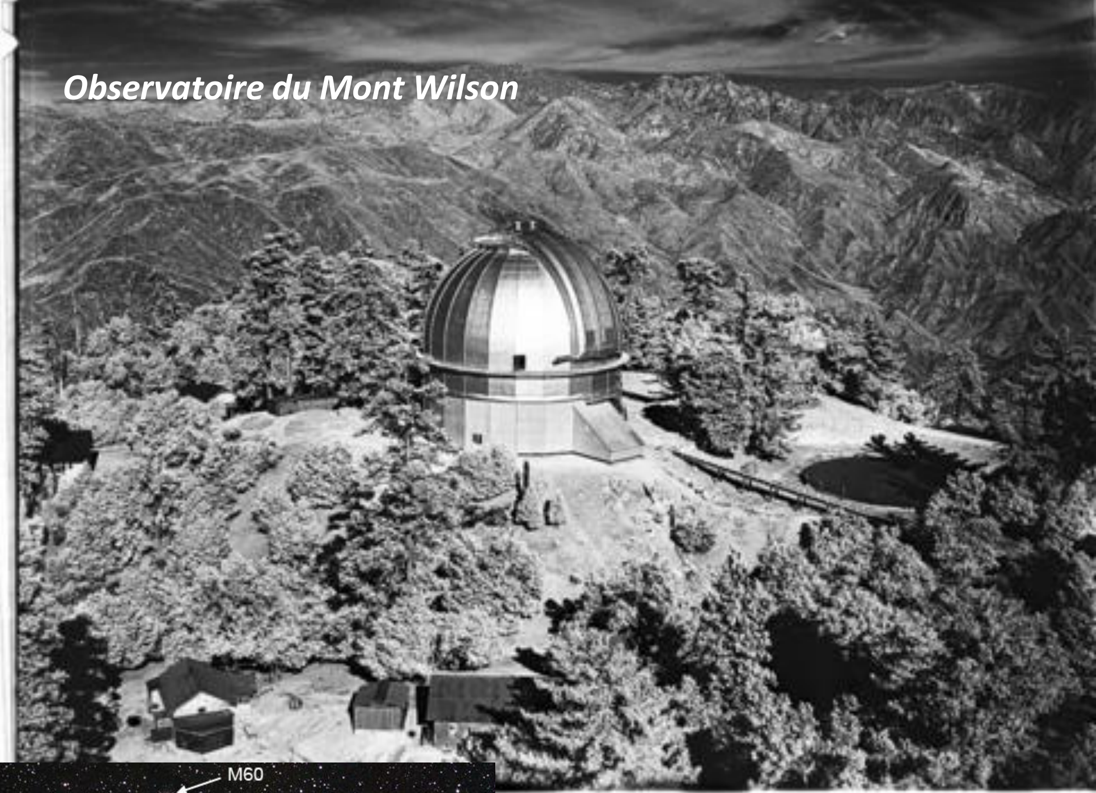
CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
September 1935

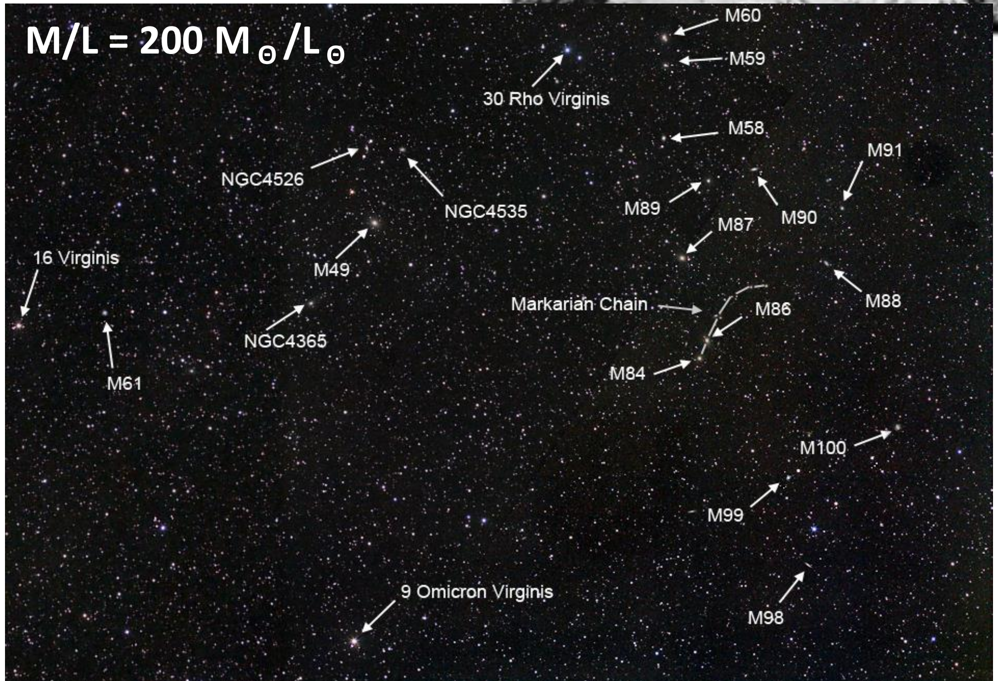
[4] *Mt. W. Comm.*, No. 105; *Proc. Nat. Acad.*, **15**, 168, 1929.

[5] I am indebted to Dr. Hubble for suggesting this point.

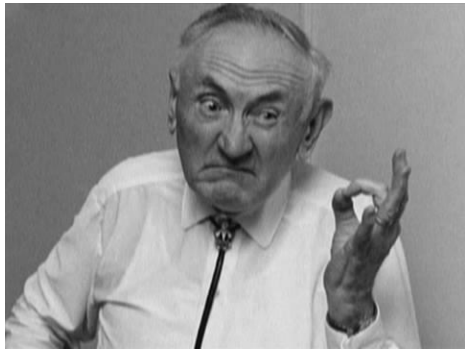
➡ [6] F. Zwicky has pointed out (*Helv. Phys. Acta*, **6**, No. 2, p. 110, 1933) that the velocity range in the Coma Cluster indicates non-luminous matter which is some four hundred times the amount of the observed luminous material.

[7] Stebbins, *Mt. W. Comm.*, No. 113; *Nat. Acad. Proc.*, **20**, 93, 1934.





Conclusion provisoire



THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME 86 | OCTOBER 1937 | NUMBER 3

ON THE MASSES OF NEBULAE AND OF CLUSTERS OF NEBULAE

F. ZWICKY

- Soit, chaque galaxie est bien plus massive que ce que l'on croit : la matière noire est concentrée dans les galaxies ;
- Soit, il y a de la masse invisible entre les galaxies ;
- Soit, la force de gravitation n'est peut-être pas en $1/r^2$ …

… en tous cas $M/L \approx$ de 200 à 500 M/L_{soleil} dans les Amas de galaxie

Faute de conclusion précise on attend de meilleures données observationnelles

Du coté des spirales la courbe de vitesse est plate !

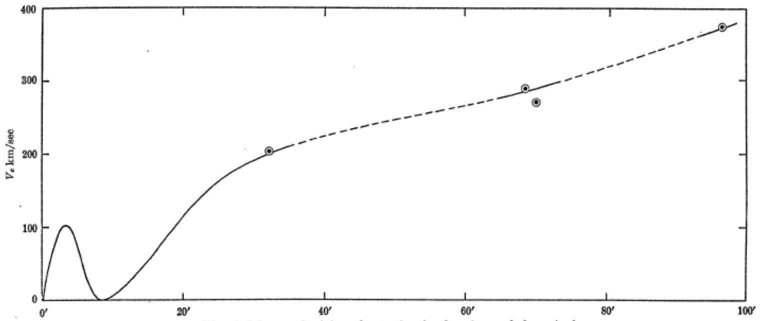


Fig. 4. Mean velocities of rotation in the plane of the spiral.

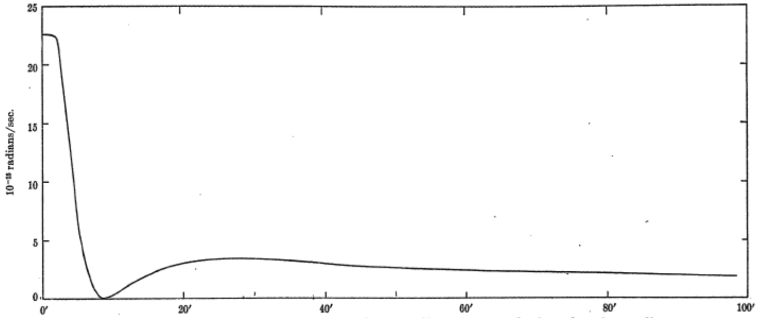


Fig. 5. Angular velocity, ω, in units of 10^{-15} radians per second, plotted against radius.

UNIVERSITY OF CALIFORNIA PUBLICATIONS
ASTRONOMY

LICK OBSERVATORY BULLETIN

NUMBER 498

THE ROTATION OF THE ANDROMEDA NEBULA*

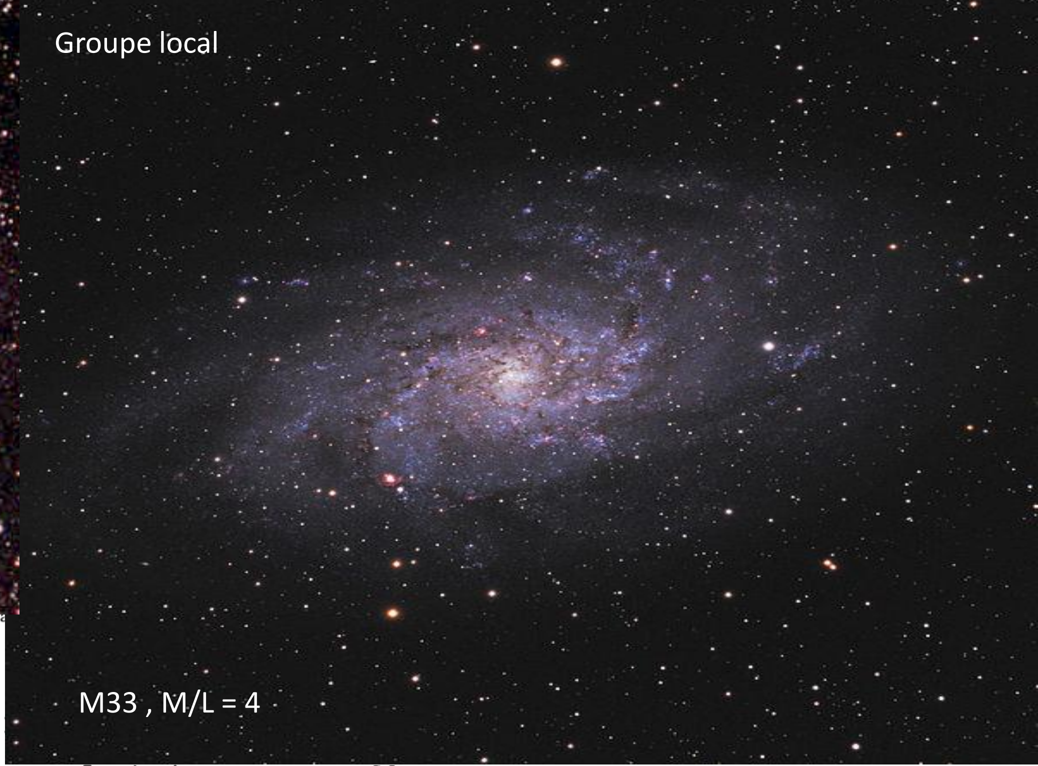
BY

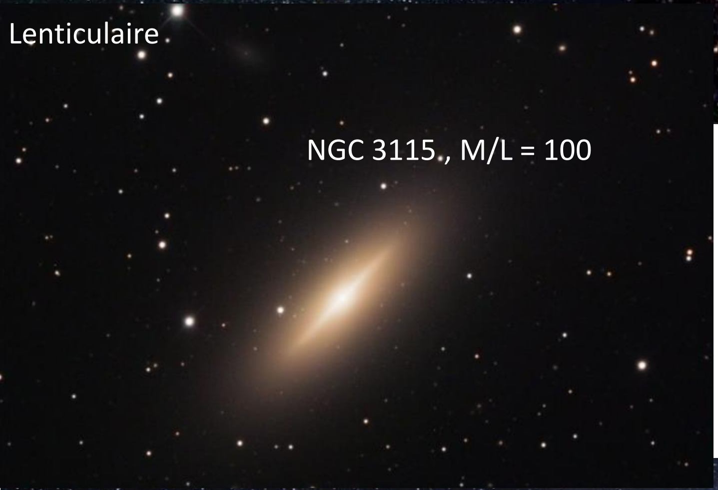
Horace W. Babcock

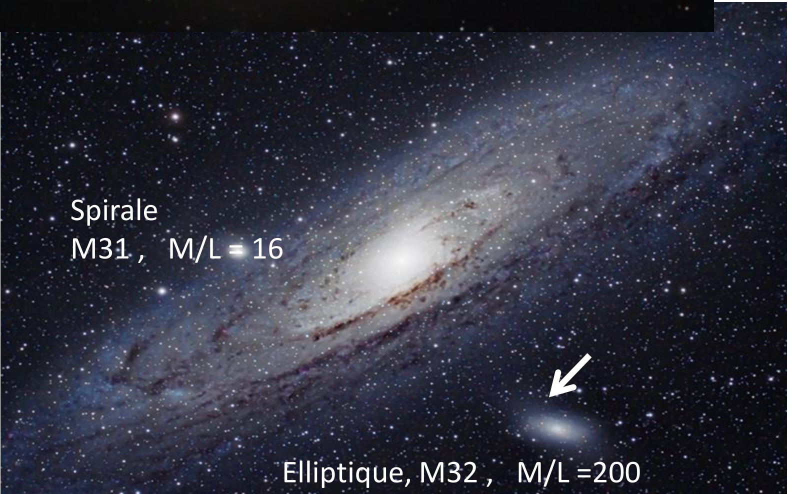
The Andromeda Nebula and the Galaxy have many well-known features in common, but one outstanding discrepancy between the two systems has hitherto been in their diameters. The spiral arms of M31 can hardly be traced to a radius of more than 1°6 or 6 kiloparsecs. Beyond this radius, no stars, comparable to the brighter stars in the vicinity of the sun, have been reported, although Hubble has discovered some outlying globular clusters[10] which lead him to suggest that the radius of the nebula, as outlined by these objects, may possibly be as great as 3½°. This large figure is supported by the photo-electric measurements of Stebbins and Whitford,[19] and by the micro-photometric measures of Shapley,[20] both of which indicate the existence of a widespread, faint, diffuse luminosity.

A new discrepancy is now directly apparent when the rotations of the two systems are compared, for the nearly constant angular velocity of the outer parts of M31 is the opposite of the "planetary" type of rotation believed to obtain in the outer parts of the Galaxy.

Mount Hamilton, California,
March 31, 1939.
Issued October 30, 1939.







intermediate mass-luminosity ratio, suggesting tha
population II and old population I stars.

TABLE VII. SUMMARY OF

Objects	Distance (in kpc)	Luminosity (in sol. lum.)	Mass (in sol. mass)	Mass/Lum. f
Solar Neighborhood	—	—	—	4
Triangulum Nebula, M33	480	1.4×10^9	5×10^9	4
Large Magellanic Cloud	44	1.2×10^9	2×10^9	2
Andromeda Nebula	460	9×10^9	1.4×10^{11}	16
Globular Cluster, M92	11	1.7×10^5	$<8 \times 10^5$	<5
Elliptical Galaxy, NGC 3115	2100	9×10^8	9×10^{10}	100
Elliptical Galaxy, M32	460	1.1×10^8	2.5×10^{10}	200
Average S in Double Gal.	—	1.3×10^9	7×10^{10}	50
Average E in Double Gal.	—	8×10^8	2.6×10^{11}	300
Average in Coma Cluster	25000	5×10^8	4×10^{11}	800

ϒ=M/L dépend des objets considérés

Familles d’objets ⇔ Valeurs de ϒ

BULLETIN OF THE ASTRONOMICAL INSTITUTES OF THE NETHERLANDS

1957 NOVEMBER 9 VOLUME XIV NUMBER 480

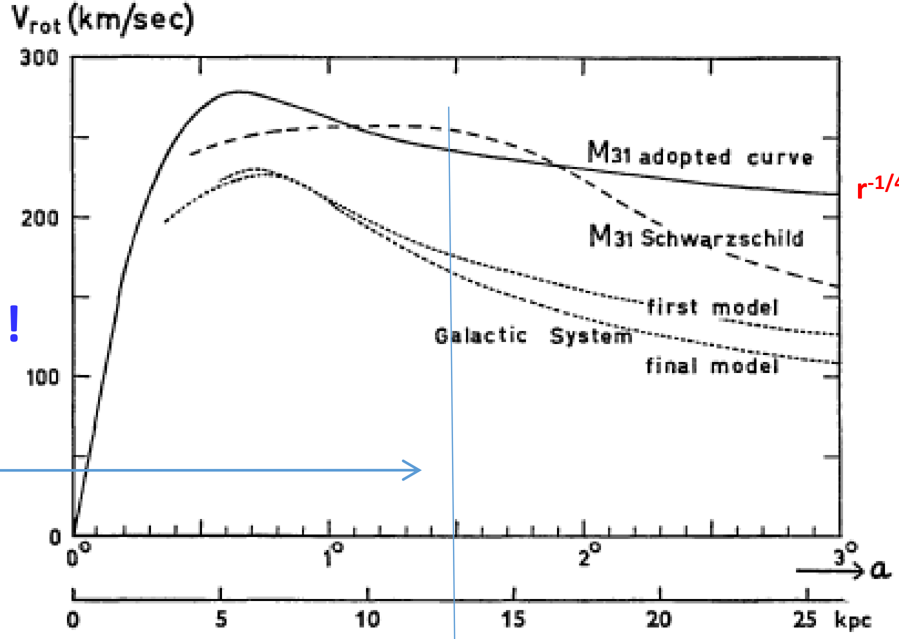
COMMUNICATIONS FROM THE NETHERLANDS FOUNDATION FOR RADIO ASTRONOMY AND THE OBSERVATORY AT LEIDEN

ROTATION AND DENSITY DISTRIBUTION OF THE ANDROMEDA NEBULA DERIVED FROM OBSERVATIONS OF THE 21-cm LINE

BY H. C. VAN DE HULST, E. RAIMOND AND H. VAN WOERDEN

Bull. Astron. Inst. Neth. , 14, 1-16, **1957**

FIGURE 11



Rotation laws of M31 and the Galactic System.

$r^{-1/4}$ au lieu de $r^{-1/2}$

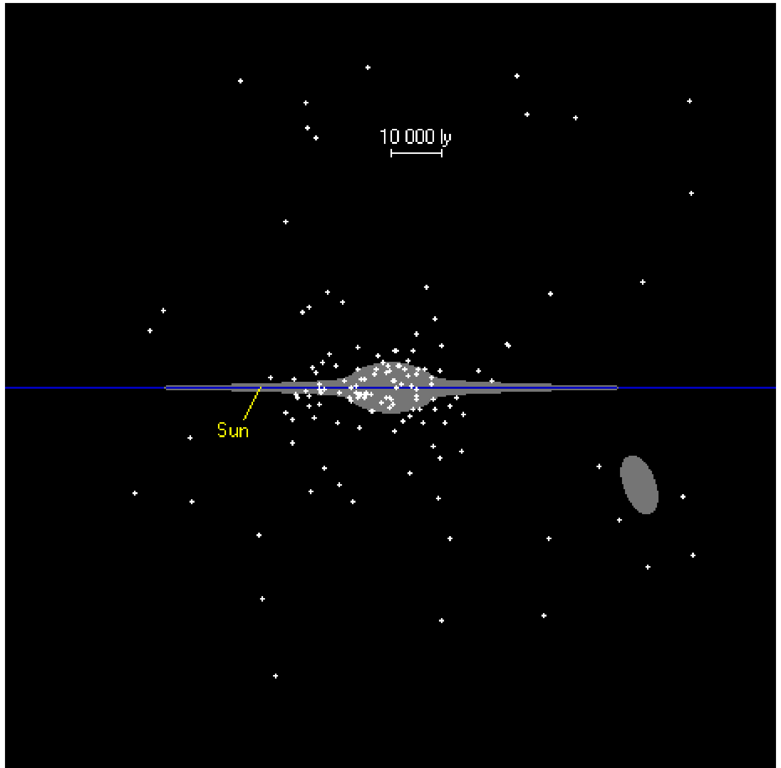
Les spirales sont bien plus grandes que ce que l'on croyait !

Galaxie d'Andromède
- Rayon apparent : 1,5 °
- Rayon « effectif » : 3,18°

Visible optique | Visible 21 cm

Et la courbe de rotation est toujours assez plate…

Quand on commence à se poser des questions…



MNRAS , 127, 21-30, **1963**

ON THE VALIDITY OF NEWTON'S LAW AT A LONG DISTANCE

Arrigo Finzi

(Communicated by F. A. E. Pirani)

(Received 1963 June 6)*

Summary

An attempt is made to solve the longstanding problem of the stability of clusters of galaxies by assuming a law of gravitation that implies a much stronger attraction at a long distance than that predicted by the law of Newton. It is further shown that the same hypothesis could provide a solution to a number of other problems in different fields of astrophysics.

… en se basant sur le mouvement des amas globulaires autour de notre galaxie, il calcule pour sa masse une valeur 3 fois plus grande que celle provenant des mesures de rotation de la partie centrale. Il propose une modification de la loi de Newton à grande distance ($r^{-2} \rightarrow r^{-1,5}$)

Les premières simulation numériques

THE ASTROPHYSICAL JOURNAL, 168:343–359, 1971 September 15

NUMERICAL EXPERIMENTS WITH A DISK OF STARS

FRANK HOHL
NASA, Langley Research Center, Hampton, Virginia
Received 1971 March 10; revised 1971 April 28

ABSTRACT

The evolution of an initially balanced rotating disk of stars with an initial velocity dispersion given by Toomre's local criterion is investigated by means of a computer model for isolated disks of stars. It is found that the disk is unstable against very large-scale modes. After about two rotations the central portion of the disk tends to assume a bar-shaped structure. A stable axisymmetric disk with a velocity dispersion much larger than that given by Toomre's criterion is generated. The final mass distribution for the disk gives a high-density central core and a disk population of stars that is closely approximated by an exponential variation.

100 000 particules dans un disque en rotation et en équilibre (gravité/centrifuge)

… une spirale se forme mais elle disparait rapidement !

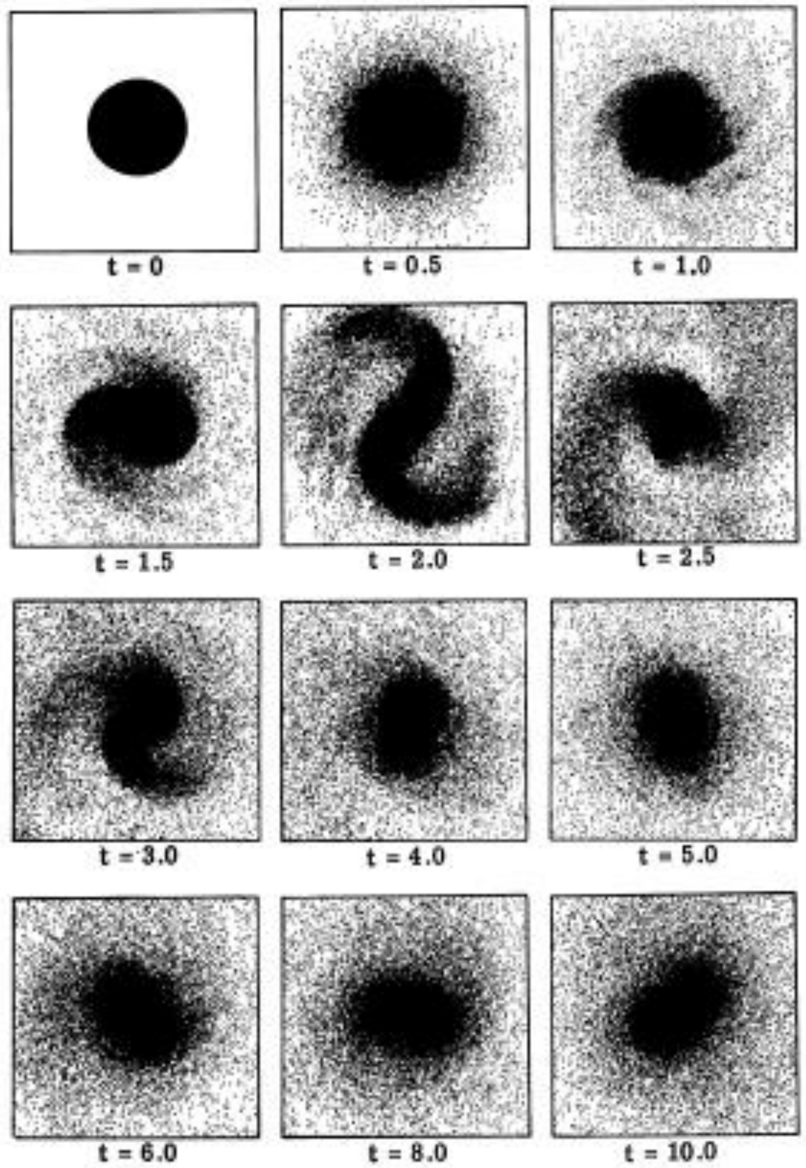
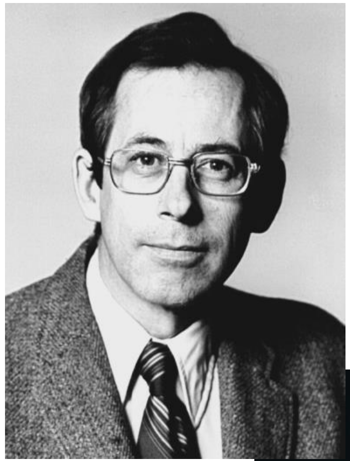


FIG. 4.—Unconstrained evolution of the initially balanced uniformly rotating disk of 100000 stars. The stars have an initial velocity dispersion given by Toomre's criterion.

THE ASTROPHYSICAL JOURNAL, 186:467–480, 1973 December 1



A NUMERICAL STUDY OF THE STABILITY OF FLATTENED GALAXIES: OR, CAN COLD GALAXIES SURVIVE?*

J. P. OSTRIKER
Princeton University Observatory
AND
P. J. E. PEEBLES

Matière Noire
à l’échelle galactique

THE ROTATION CURVES OF GALAXIES

IAU Symposium 1975

M. S. ROBERTS

National Radio Astronomy Observatory, Green Bank, W. Va., U.S.A.*

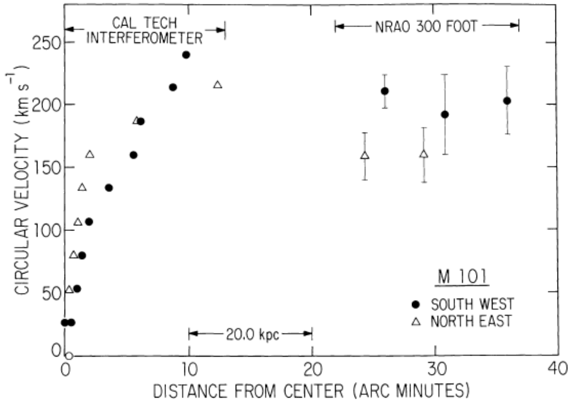


Fig. 3. The rotation curve for M101. All data points are based on 21-cm observations. The inner 12′ are from interferometer measurements by Rogstad and Shostak (1971) and are for major axis values in their Figure 4. The outer points are from recent measurements made with the 300-ft telescope.

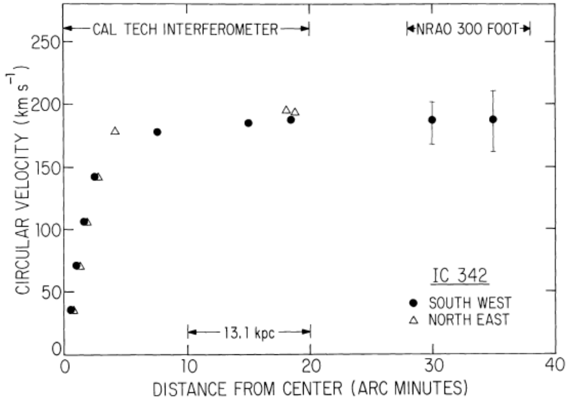
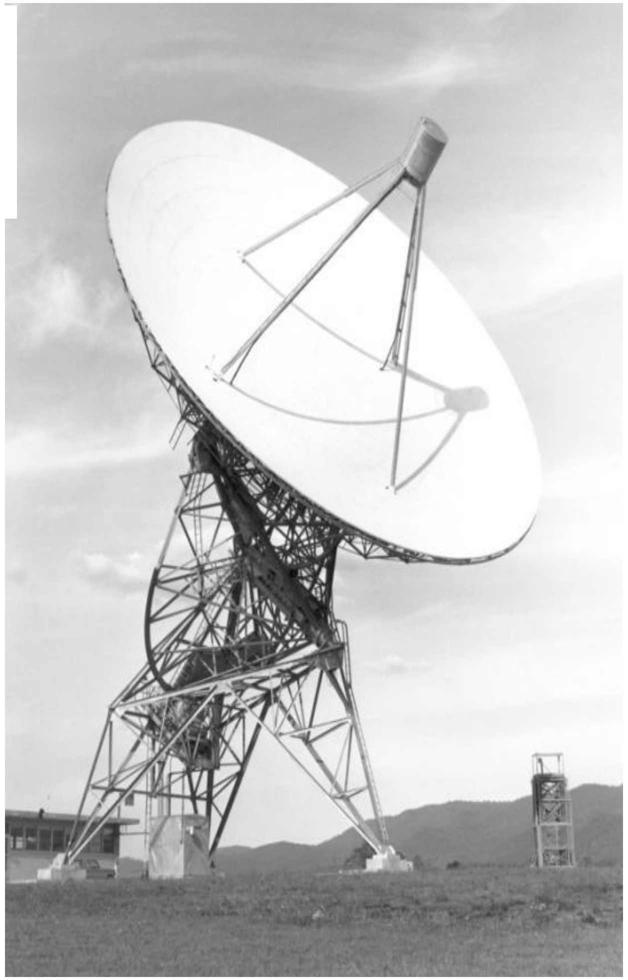


Fig. 4. The rotation curve for IC 342. All data points are based on 21-cm observations. The inner 19′ are from interferometer measurements by Rogstad *et al.* (1973) and are for major axis values in their Figure 5. The outer points are from recent measurements made with the 300-ft telescope.



Radio-Observatoire de Green Bank
Virginie Occidentale (26m)
(GBI : x 3)
Effondrement en 1988

Astron. Astrophys. 223, 47–60 (1989)

ASTRONOMY AND ASTROPHYSICS

H I rotation curves of spiral galaxies
I. NGC 3198

K. G. Begeman

Kapteyn Astronomical Institute, Groningen University, Postbus 800, NL-9700 AV Groningen, The Netherlands

Received December 14, 1988; accepted April 3, 1989

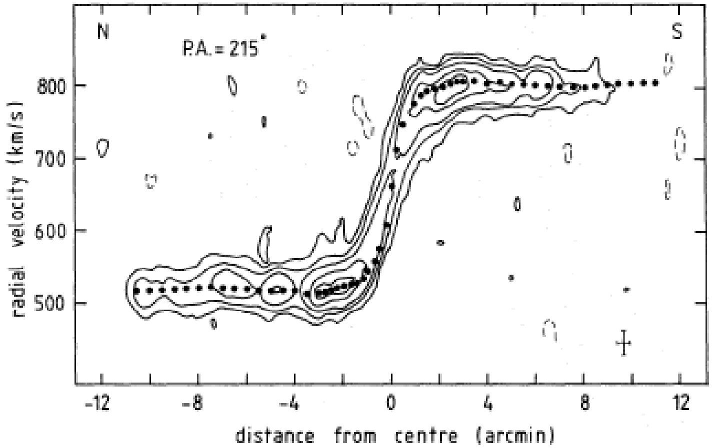


Fig. 9. The mean rotation curve for northern and southern half projected on a position-velocity map at a position angle of 215°. Contour levels are −1, 1, 3, 6, 13, 19 K. This map has not been corrected for primary beam attenuation

Le « double horn »

Il y en a de partout !

1983 -1987 Les premières simulations cosmologiques

THE ASTROPHYSICAL JOURNAL, 292:371–394, 1985 May 15

THE EVOLUTION OF LARGE-SCALE STRUCTURE IN A UNIVERSE DOMINATED BY COLD DARK MATTER

MARC DAVIS,[1,2] GEORGE EFSTATHIOU,[1,3] CARLOS S. FRENK,[1,4] AND SIMON D. M. WHITE[1,5]
Received 1984 August 20; accepted 1984 November 30

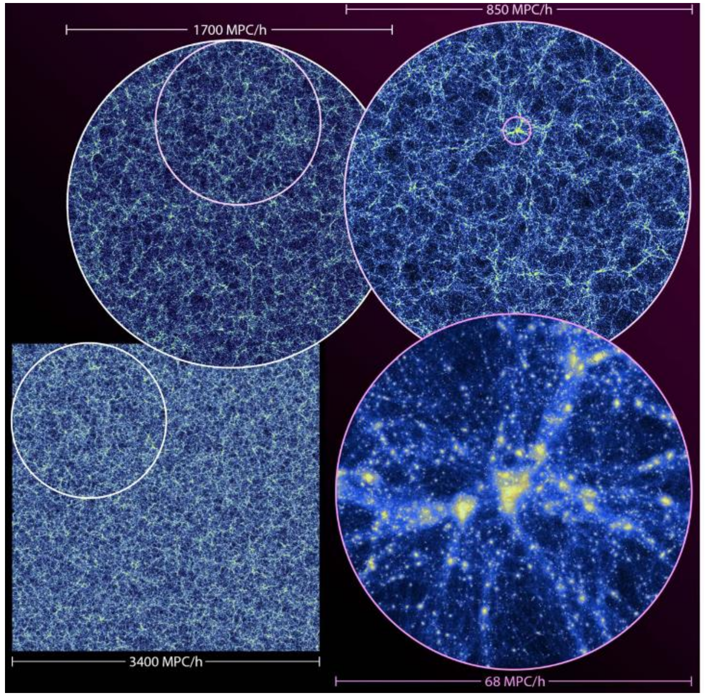
ABSTRACT

We present the results of numerical simulations of nonlinear gravitational clustering in universes dominated by weakly interacting, "cold" dark matter (e.g., axions or photinos). These studies employ a high resolution *N*-body code with periodic boundary conditions and 32,768 particles; they can accurately represent the theoretical initial conditions over a factor of 16 in length scale. We have followed the evolution of ensembles of

1985

32^3 particules

C'est devenu un business !



THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 252:19 (14pp), 2021 February https://doi.org/10.3847/1538-4365/abcc67

CrossMark

The Last Journey. I. An Extreme-scale Simulation on the Mira Supercomputer

Katrin Heitmann[1], Nicholas Frontiere[1,2], Esteban Rangel[1,3], Patricia Larsen[1], Adrian Pope[2], Imran Sultan[1], Thomas Uram[3], Salman Habib[1,2], Hal Finkel[3], Danila Korytov[1,4], Eve Kovacs[1], Silvio Rizzi[3], Joe Insley[3], and Janet Y. K. Knowles[3]
[1] High Energy Physics Division, Argonne National Laboratory, Lemont, IL 60439, USA
[2] Computational Science Division, Argonne National Laboratory, Lemont, IL 60439, USA
[3] Argonne Leadership Computing Facility, Argonne National Laboratory, Lemont, IL 60439, USA
[4] Department of Physics, University of Chicago, Chicago, IL 60637, USA
Received 2020 June 2; revised 2020 November 13; accepted 2020 November 18; published 2021 January 27

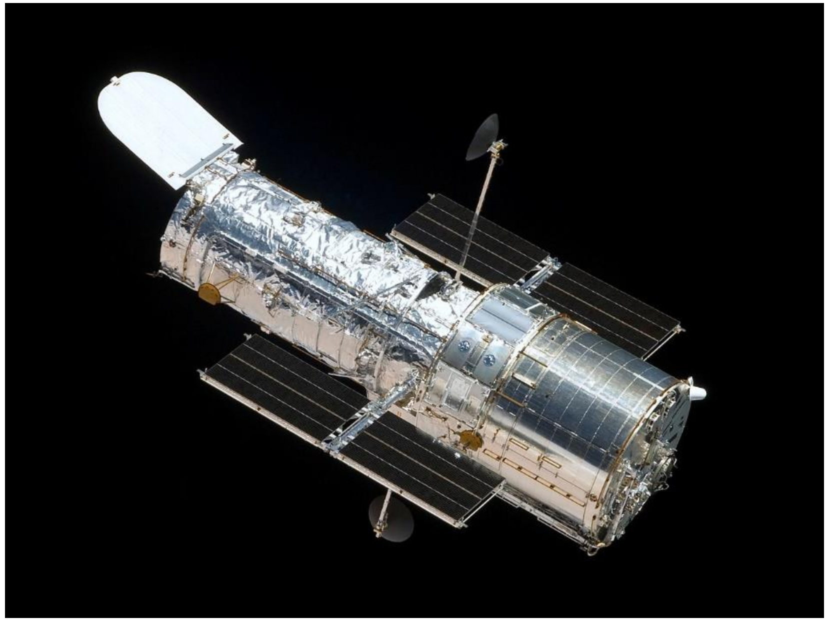
12600^3 particules

2020

Abstract

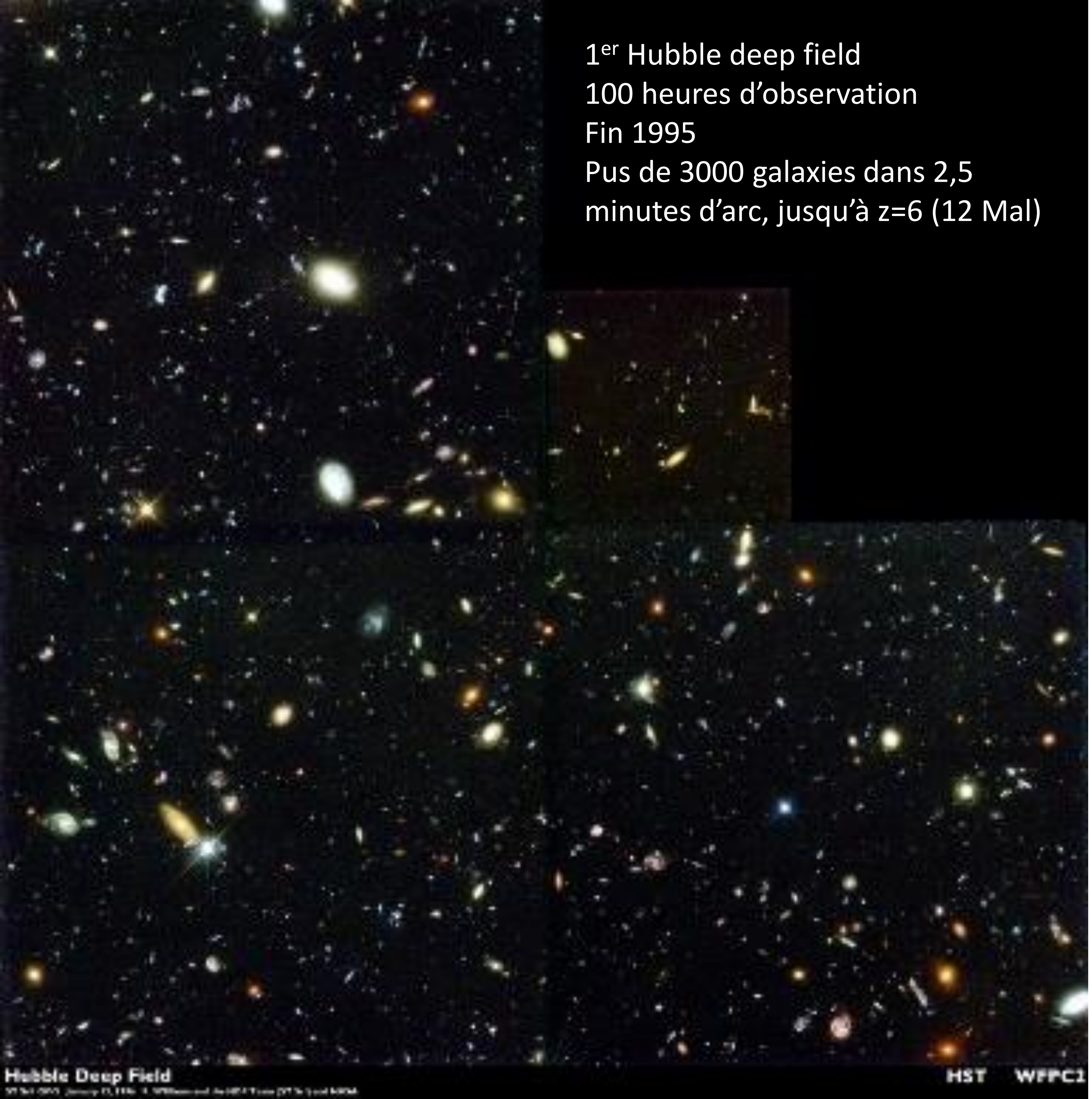
The Last Journey is a large-volume, gravity-only, cosmological *N*-body simulation evolving more than 1.24 trillion particles in a periodic box with a side length of 5.025 Gpc. It was implemented using the HACC simulation and analysis framework on the BG/Q system Mira. The cosmological parameters are chosen to be consistent with the results from the Planck satellite. A range of analysis tools have been run in situ to enable a diverse set of science projects and, at the same time, keep the resulting data amount manageable. Analysis outputs have been generated starting at redshift $z \sim 10$ to allow for construction of synthetic galaxy catalogs using a semianalytic modeling approach in postprocessing. As part of our in situ analysis pipeline, we employ a new method for tracking halo substructures, introducing the concept of subhalo cores. The production of multiwavelength synthetic sky maps is facilitated by generating particle light cones in situ, also beginning at $z \sim 10$. We provide an overview of the simulation setup and generated data products; a first set of analysis results is presented. A subset of the data is publicly available.

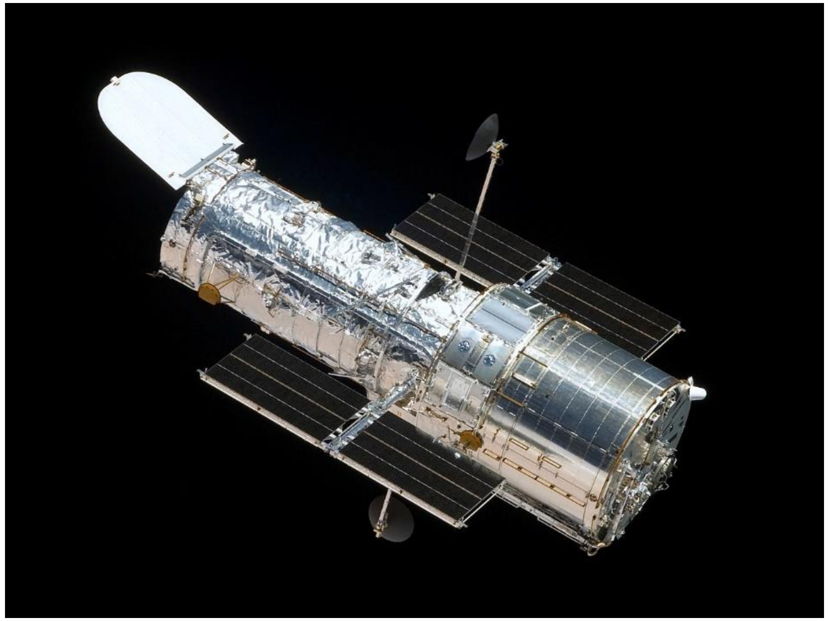
Les piliers de la création
1er avril 1995
Région de formation d'étoiles dans
La nébuleuse de l'aigle



HST - Lancement : 24 avril 1990 (opérationnel 3 ans plus tard)

1er Hubble deep field
100 heures d’observation
Fin 1995
Pus de 3000 galaxies dans 2,5 minutes d’arc, jusqu’à z=6 (12 Mal)





HST - Lancement : 24 avril 1990 (opérationnel 3 ans plus tard)

Découverte de la première exo planète
51 pegasi B (50,9 Al)

Le 6 octobre 1995

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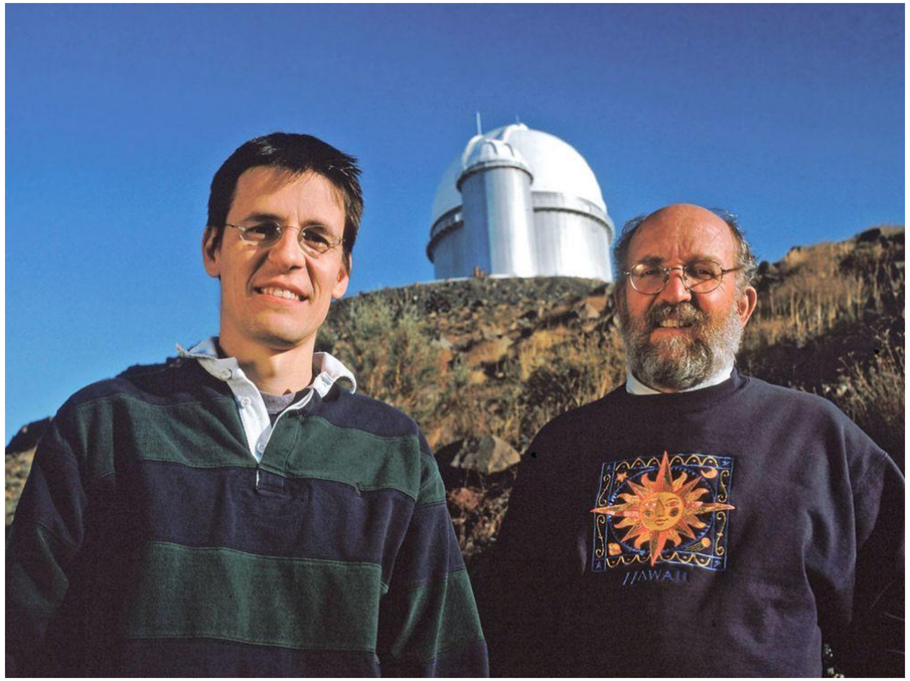
Phone 617-495-7244/7440/7444 (for emergency use only)


51 PEGASI
     M. Mayor and D. Queloz, Geneva Observatory, have reported
the discovery of a Jupiter-mass object in orbit around the solar-type
star 51 Peg.  The announcement was made in Florence on Oct. 6 at the
Ninth "Cambridge" Workshop on "Cool Stars, Stellar Systems, and the Sun".
The claim is based on 18 months of precise Doppler measurements made with
the ELODIE spectrograph of the Observatoire de Haute-Provence.  The
parameters of the orbital motion are as follows: P = 4.2293 +/- 0.0011
days, e = 0 (assumed), K = 0.059 +/- 0.003 km/s, T0 = 2449797.773 +/- 0.036.
The minimum mass of the companion is 0.47 +/- 0.02 Jupiter mass.
Alternative explanations for the radial-velocity variation (pulsation
or spot rotation) seem to be ruled out by the absence of any
significant corresponding photometric variation.

     Following the Oct. 6 announcement, confirmation of the 4.2-day
radial-velocity variation was obtained in mid-October by G. Marcy
and P. Butler (San Francisco State University, University of California
atBerkeley) at the Lick Observatory, as well as by a joint team from
the Harvard-Smithsonian Center for Astrophysics (R. Noyes, S. Korzennik,
M. Krockenberger and P. Nisenson), the High Altitude Observatory (T. Brown,
T. Kennelly and C. Rowland) and Pennsylvania State University (S. Horner).

     G. Burki, M. Burnet and M. Kuenzli, Geneva Observatory and
Lausanne University, communicate: "Intensive photometric monitoring of
51 Peg has been carried out at the European Southern Observatory.  There
is no evidence for eclipses in the system.  The rms of the V magnitude
(on 17 nights) is 0.037, two comparison stars being used.  A 4.2-day
photometric variability larger than 0.002 mag can be ruled out."
```

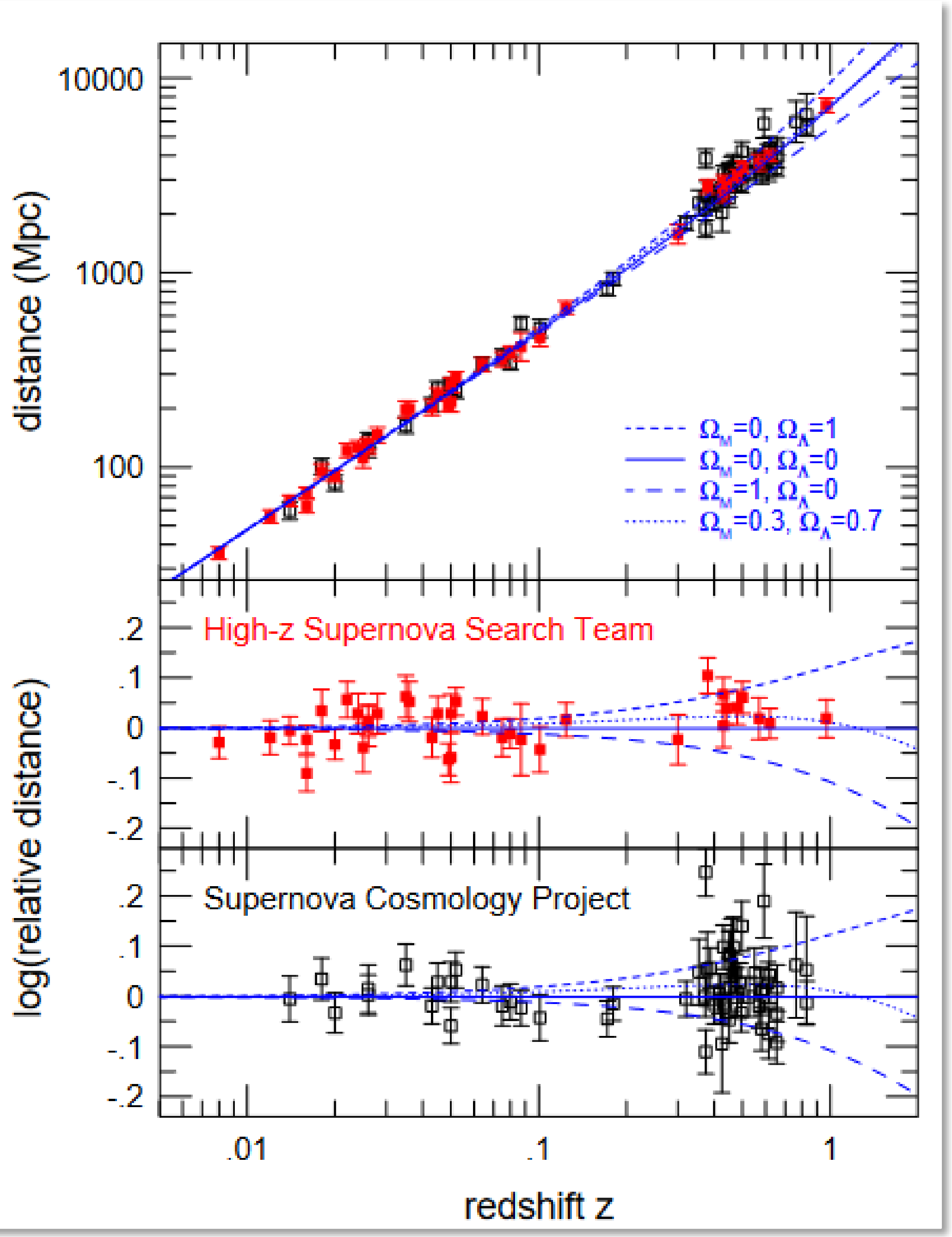
Circulaire de l'Union Astronomique Internationale annonçant la découverte



Didier Queloz et Michel Mayor (Prix Nobel 2019)

2019

En 2022 nous en sommes à 5285 exoplanètes confirmées !



Données de combinées : *The High-z Supernova Search Team* (Riess et al. 1998) et *Supernova Cosmology Project* (Perlmutter et al. 1999).

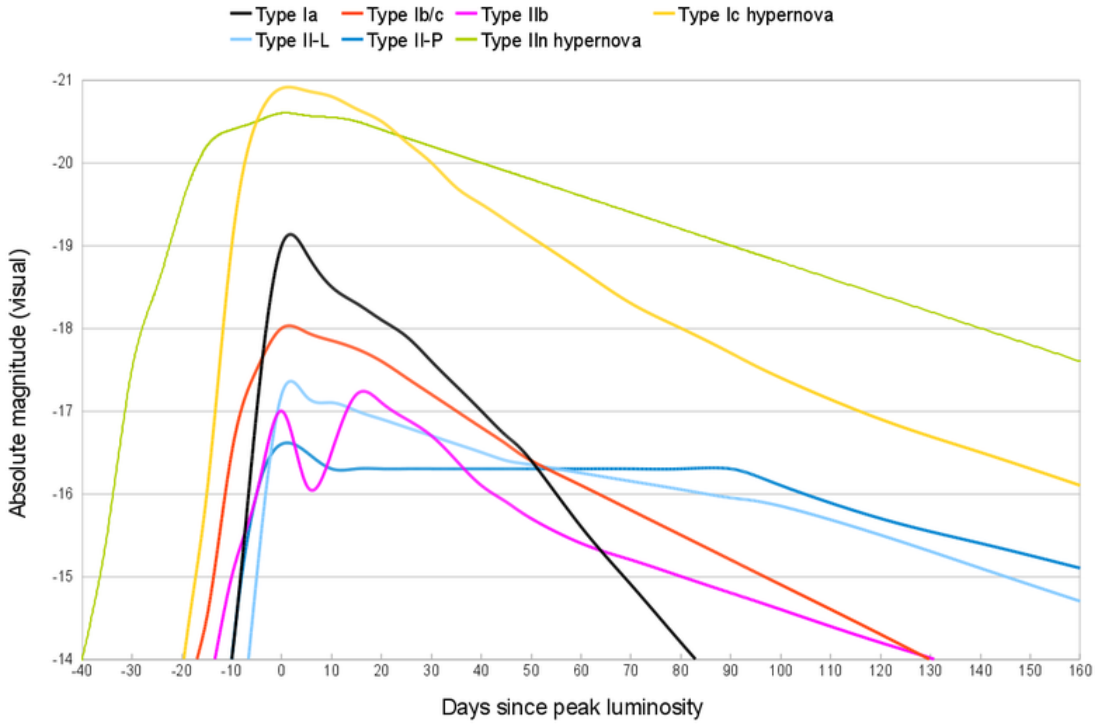
High-Z Supernova Search Team

Supernova Cosmology Project

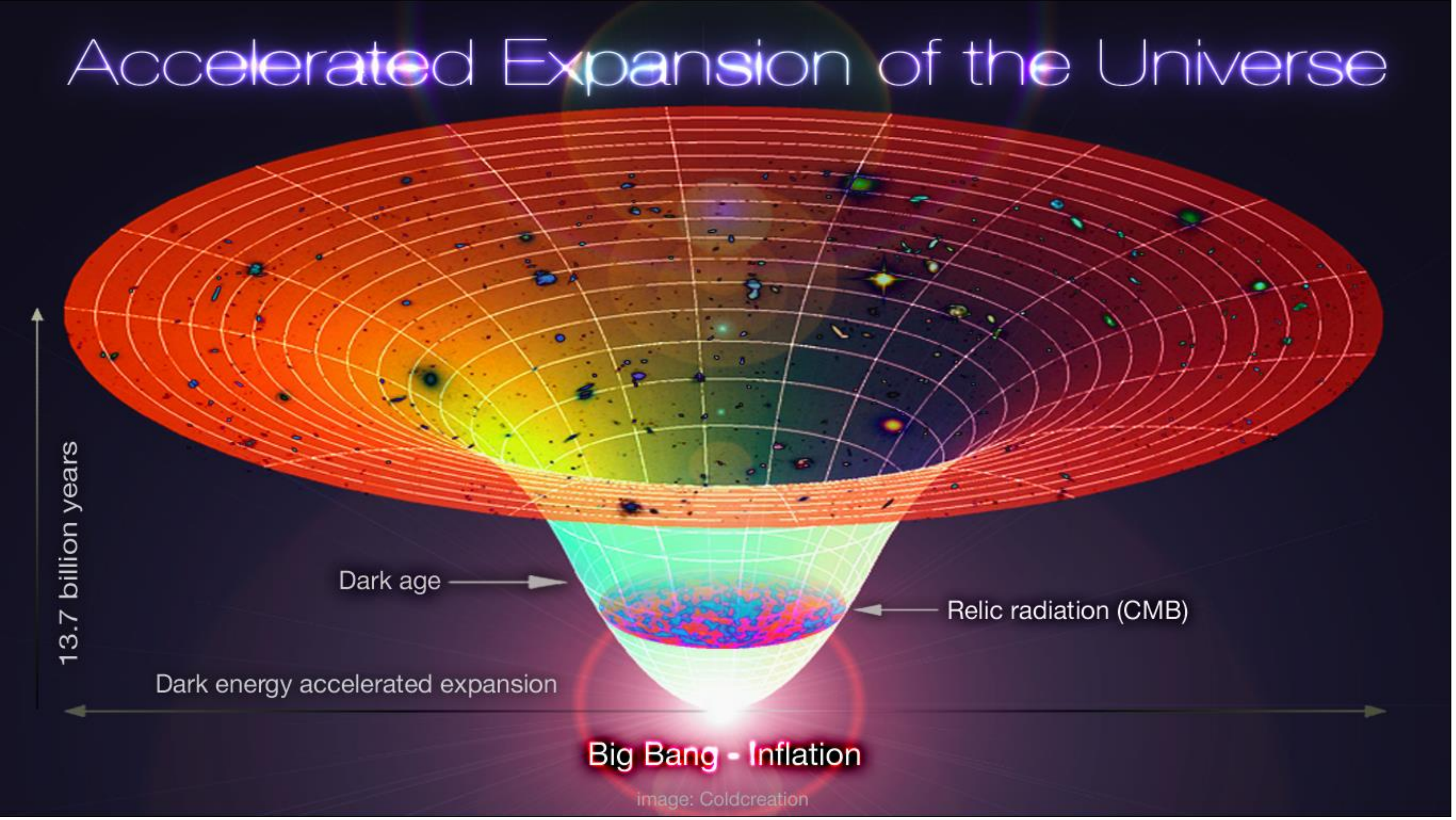
1998 *(prix Nobel physique 2011)*

Le retour de Λ

SN 1994D in NGC 4526 - High-Z Supernova Search Team/HST/NASA

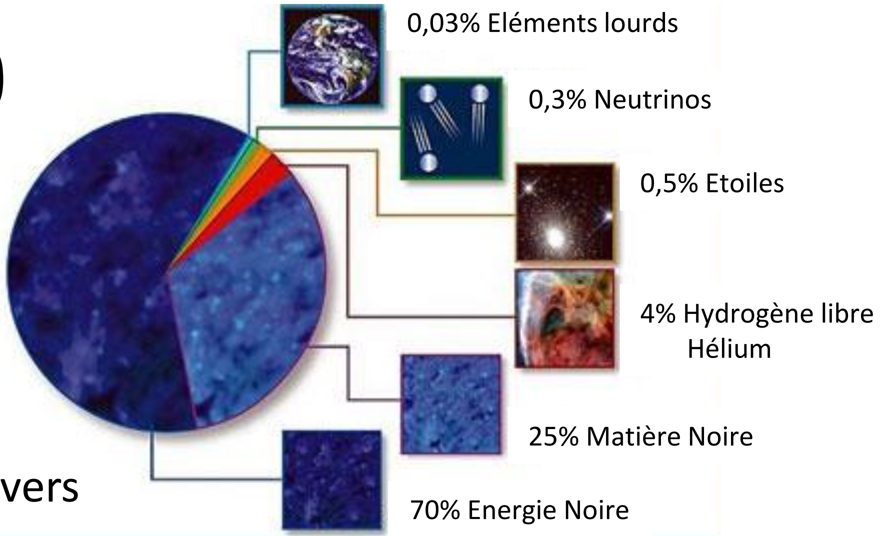


Courbes de lumière des différents types de supernovae



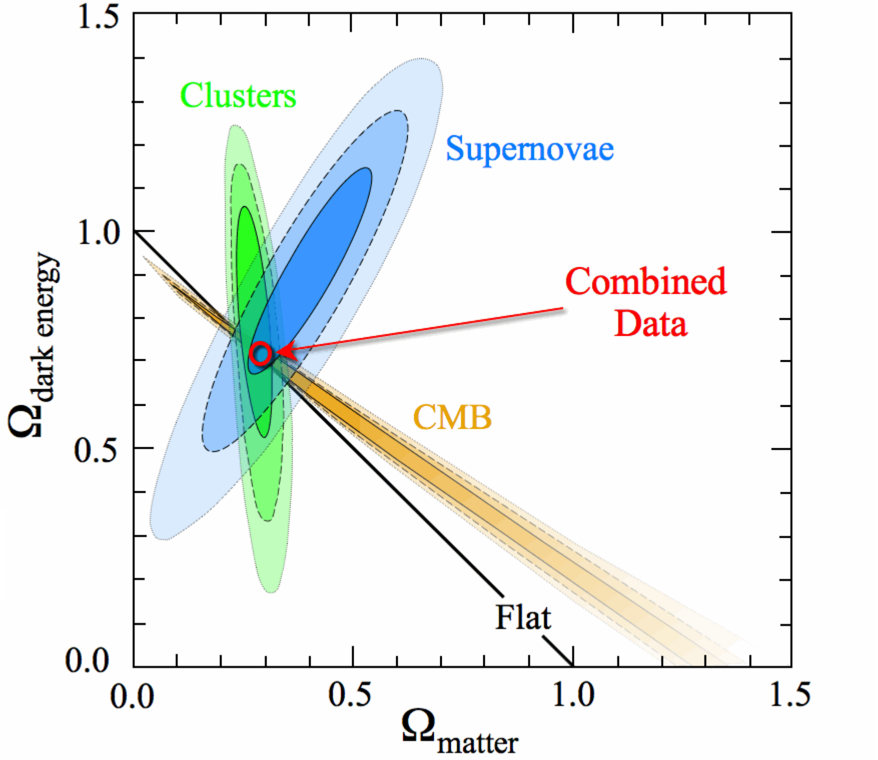
Modèle Λ-CDM

Depuis l'an 2000

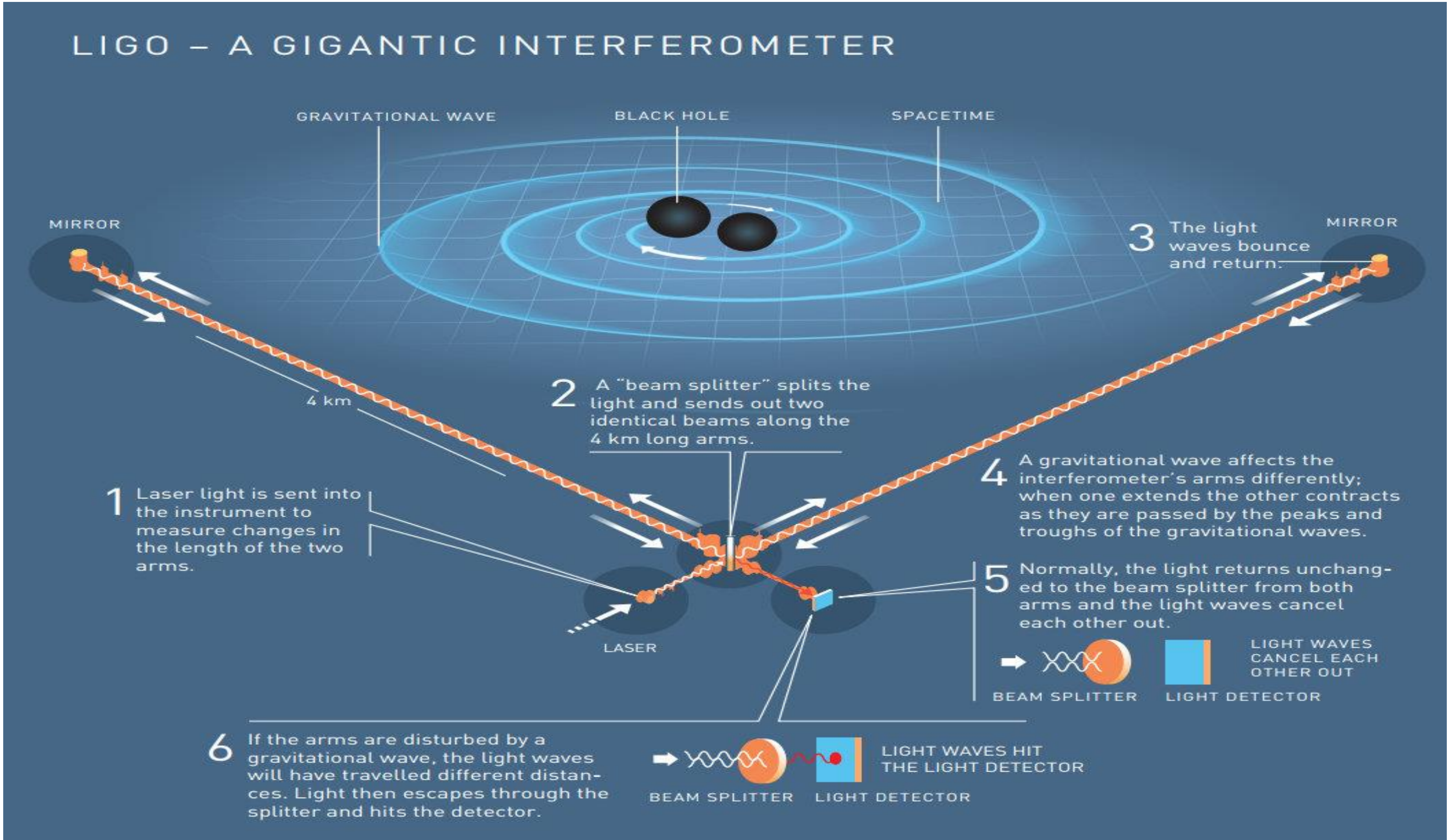


Composition de l'univers

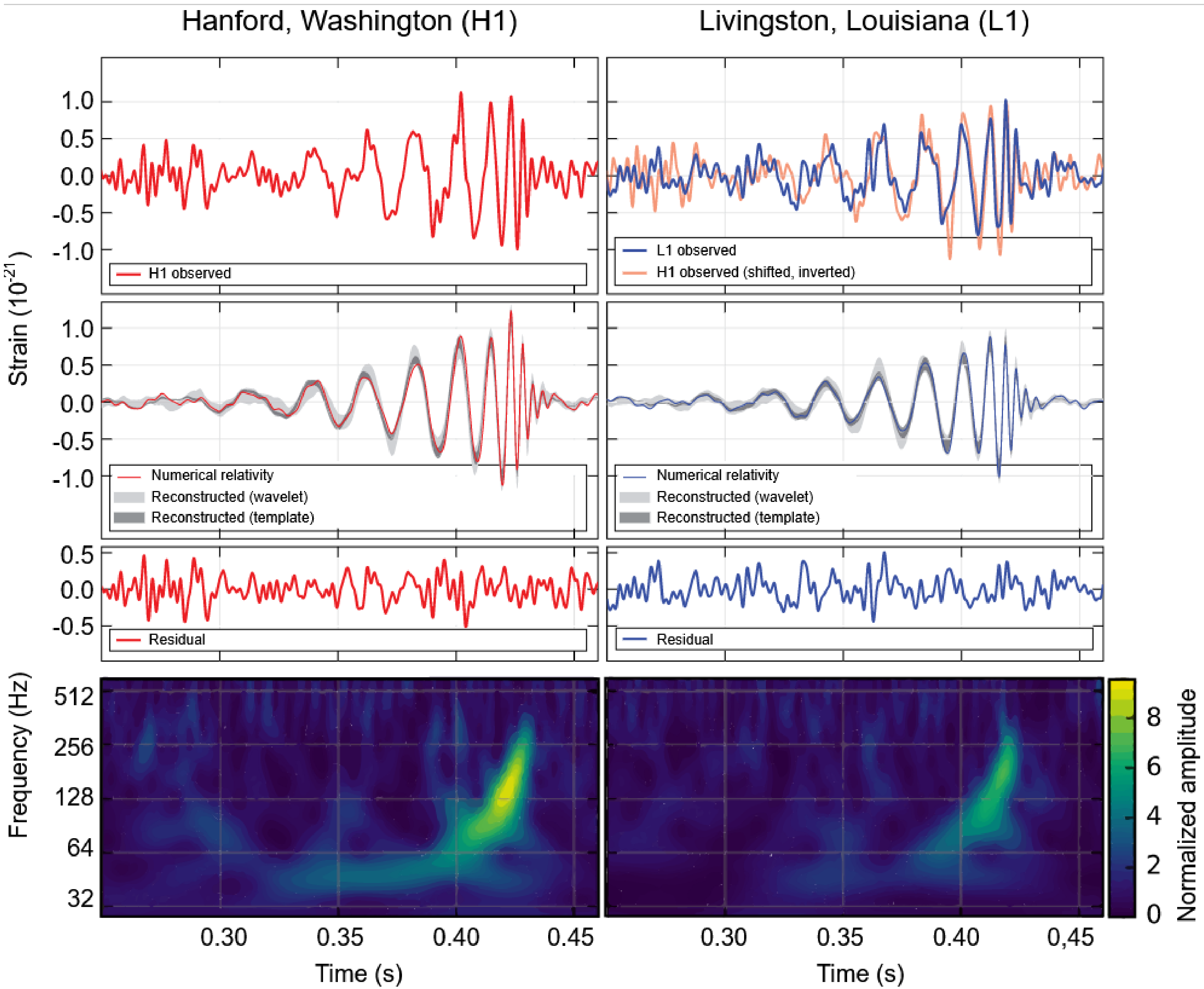
Tiré de Jaan Einasto, Dark matter (arXiv:0901.0632) 2009



Detection d’ondes gravitationnelles



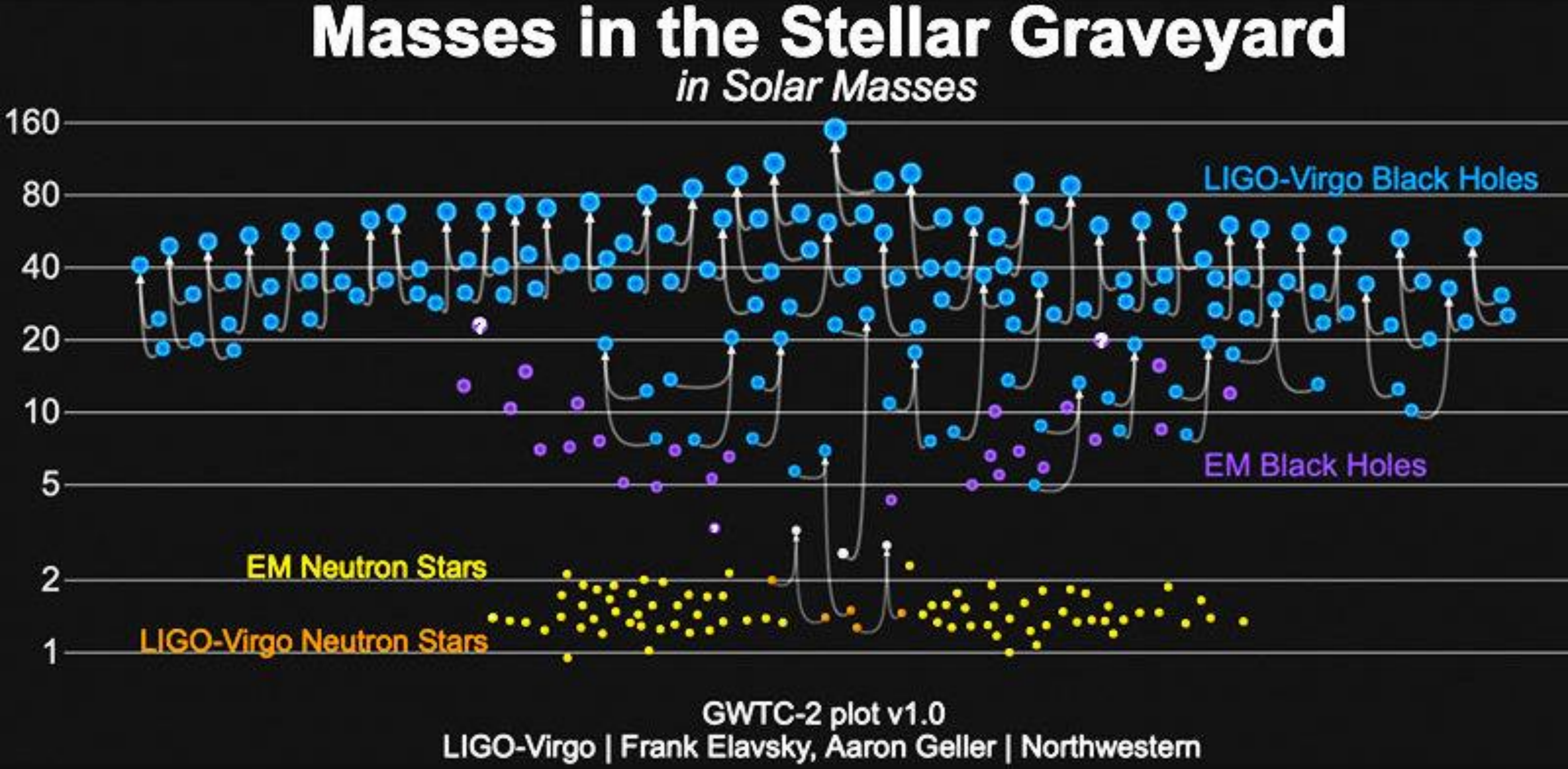
Première détection : le 11 février 2016 à 9 h 50 min 45 s UTC



GW150914

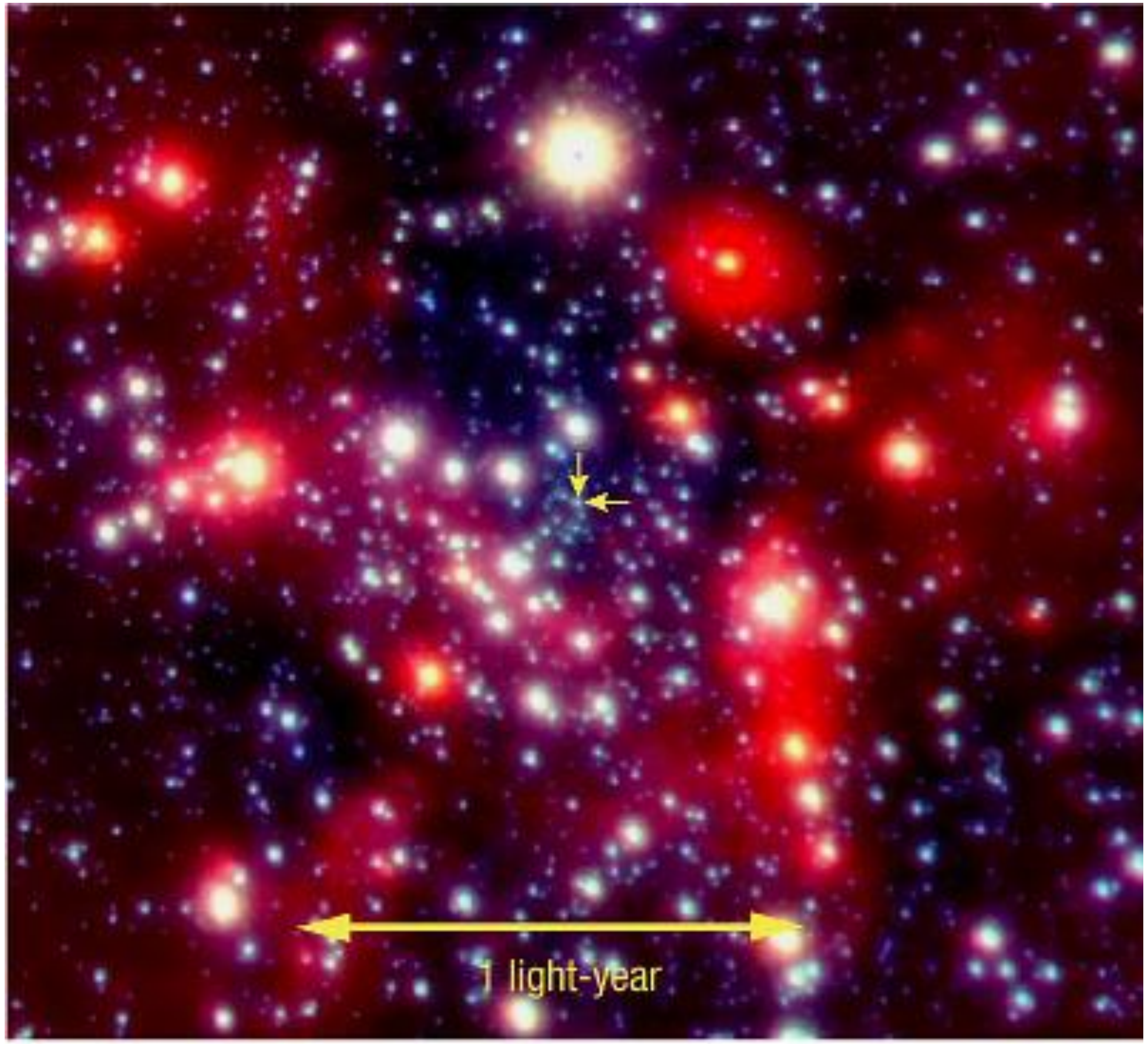
fusion d'un trou noir binaire

2017



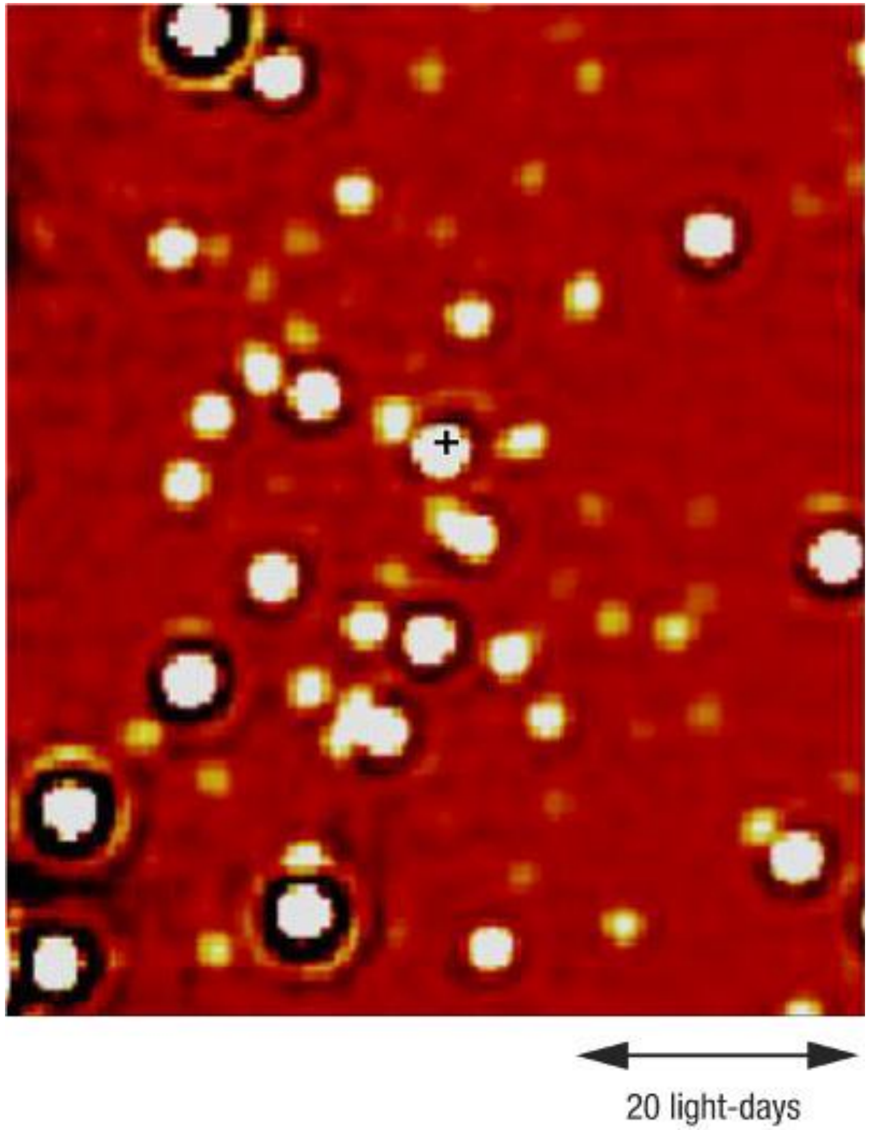
Depuis le 16 février 2016, les trous noirs sont devenus une réalité !

Entre 1992 et 2006 les astronomes pistent le centre galactique…



The Centre of the Milky Way
(VLT YEPUN + NACO)

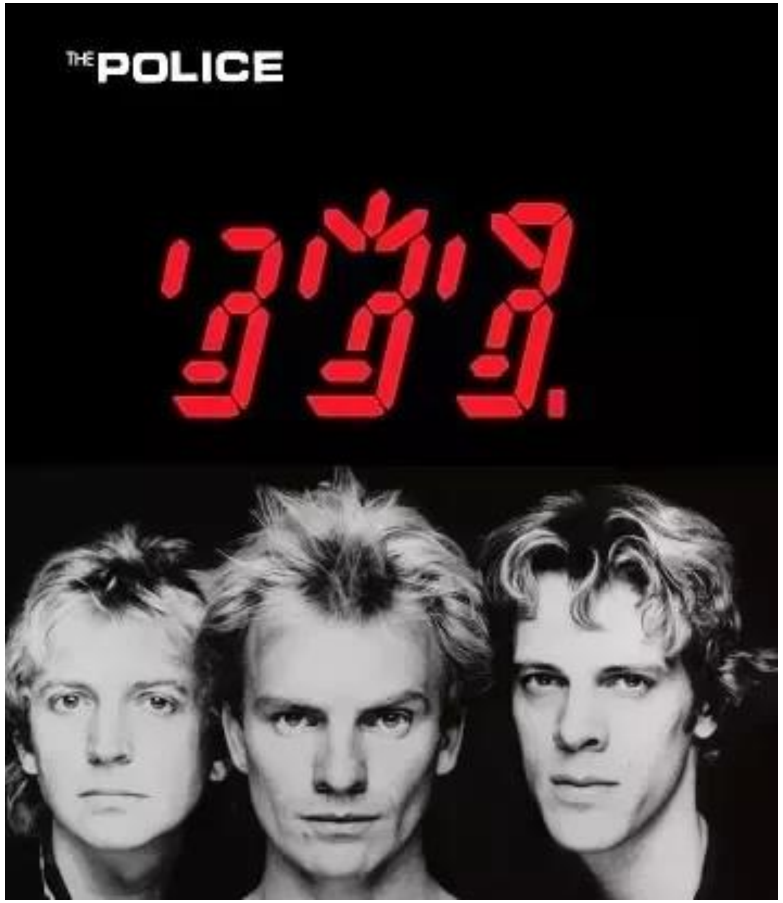
ESO PR Photo 23a/02 (9 October 2002)



The Centre of the Milky Way (detail)
(VLT YEPUN + NACO)

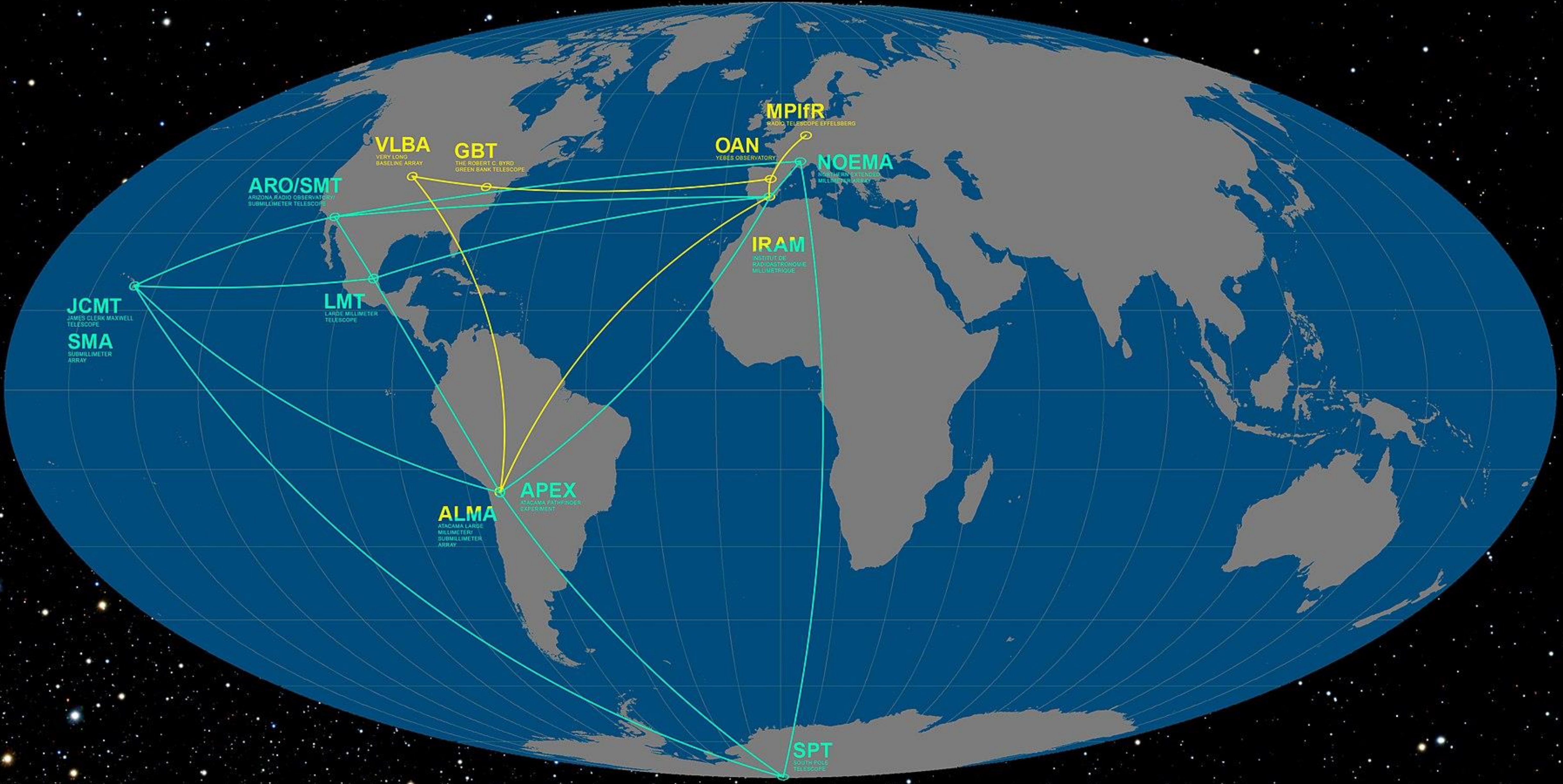
15 années d'observations à l'observatoire austral européen…

Montage JP – Bande son : The Police - Invisible Sun (album Ghost in the Machine/1981)

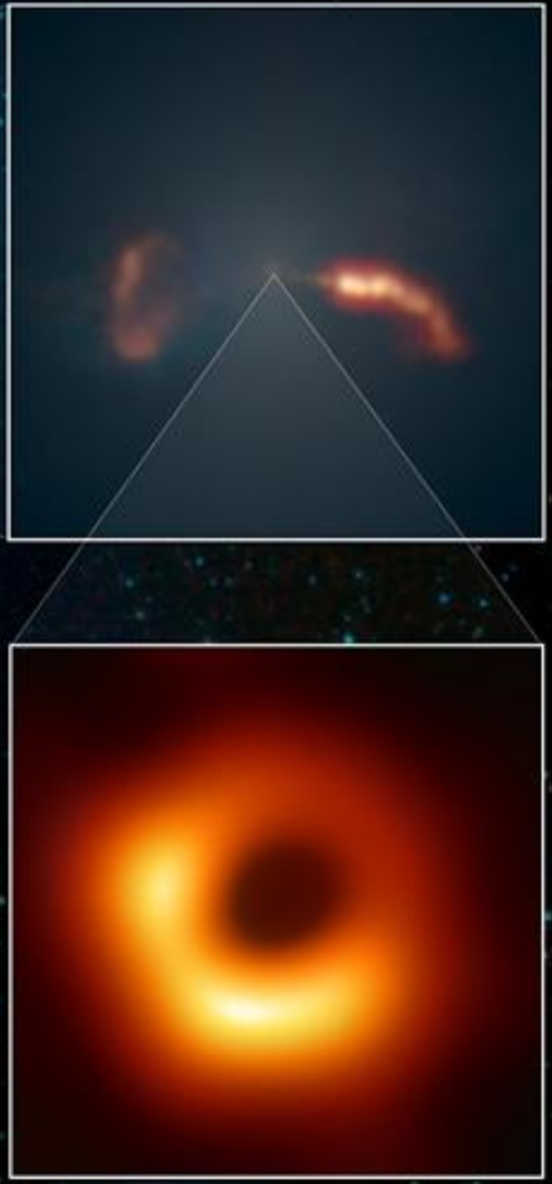


2020

Event Horizon Telescope Mise en service de 2006 à 2017



M87
Distance : 53 Mal
Masse : 2 400 Gmo
Diametre : 120 kAl

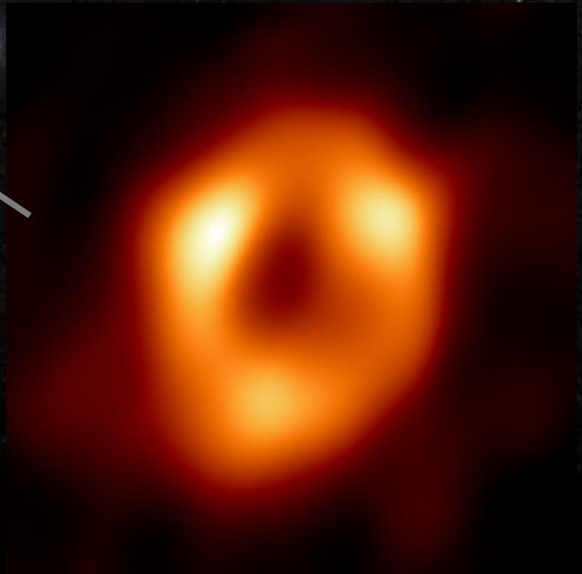


Première image : 10 avril 2019

M87*
Masse estimée : 6,5 ± 0,7 milliards de masses solaires
Diamètre de son horizon : 38 milliards de kilomètres
ou 254 ua ou 1,5 jour-lumière
,
ou 3 diamètre de l'orbite moyenne de Pluton…

Seconde image : 22 mai 2022

Voie Lactée
Distance Soleil/centre : 26 kal (1000x mois que M87*)
Masse : 1 2500 Gmo (= M87 /2)
Diametre : 105 kAl (= 0,8 M87)



Sagitarus A*
Masse estimée : 4,15 millions de masses solaires (1000x mois que M87*)
Diamètre de son horizon : 12 millions de kilomètres (1000x mois que M87*)
ou 10 fois le diamètre du soleil

CL211
FAREWELL CLIP