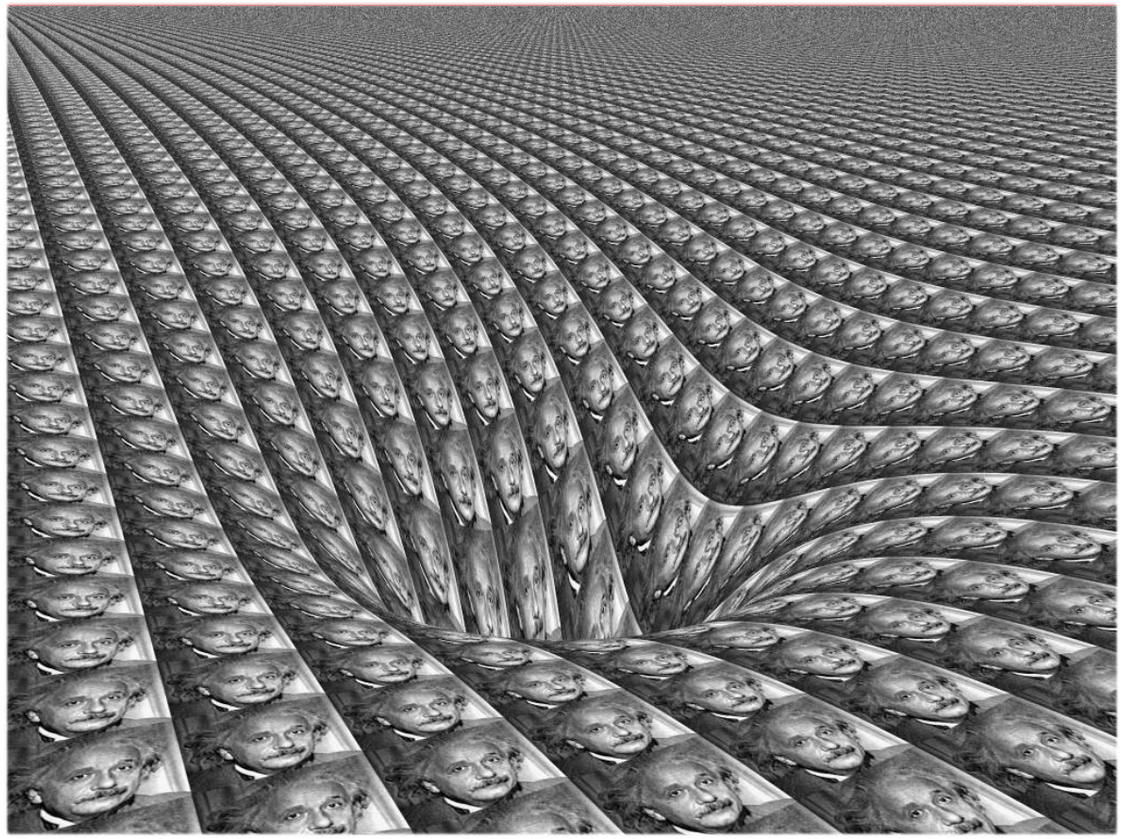
100 JAAR ALGEMENE RELATIVITEIT

UNIVERSITEIT GENT



Albert en het Universum

Gustaaf C. Cornelis

Vrije Universiteit Brussel

CLPS CLWF

Universiteit Antwerpen

Onderwerpen

- bewijzen voor de ART op kosmologische schaal
- implicaties van de ART op kosmologische schaal
- de geciteerde Einstein

Even recapituleren

- $G^{\mu\nu} \sim T^{\mu\nu}$
- $G^{\mu\nu} = \kappa T^{\mu\nu}$
  - $\kappa = 8\pi G/c^4$
    - κ: constante van Einstein (kappa)
    - G: constante van Cavendish: $6{,}6754 \times 10^{-11}\ m^3\ s^{-2}\ kg^{-1}$
  - $G^{\mu\nu}$: Einstein-tensor
    - uitdrukking voor kromming (geometrie)
  - $T^{\mu\nu}$: Energie/impuls-tensor
    - uitdrukking voor massaverdeling, oorzaak van gravitatie

> Space acts on matter, telling it *how to move*.
> In turn, matter reacts back on space, telling it *how to curve*.

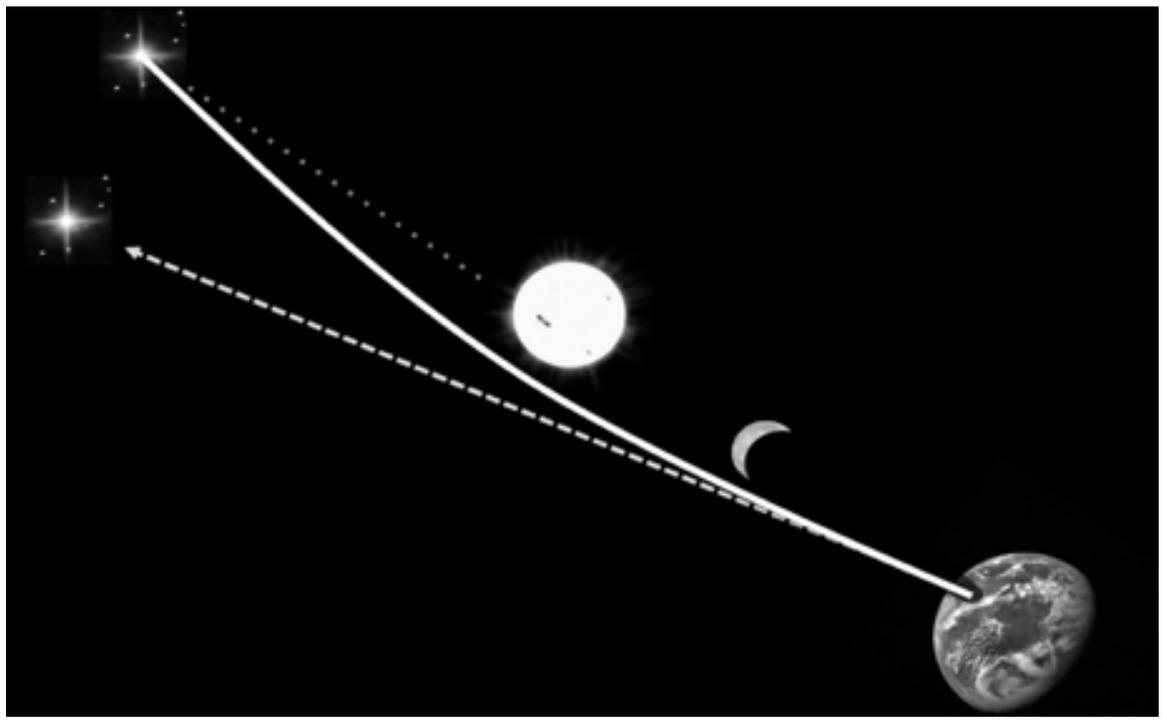
Misner, C.W., Thorne, K.S. & Wheeler, J.A., 1973, *Gravitation*. San Francisco, W.H. Freeman, p.5

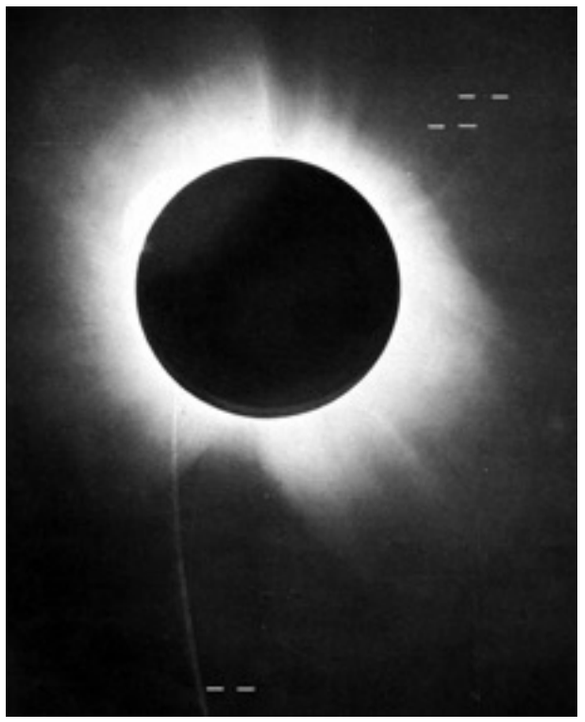
Empirische bewijzen

http://www.elimparcial.es/noticia/23558/sociedad/

Eddingtons vermeende bewijs (1917)

http://link.springer.com





http://astrobob.areavoices.com

Of course, there is no hope of observing this phenomenon directly.

506 SCIENCE Vol. 84, No. 2188

center of the building connecting the main and second floors is being eliminated. New stairways are being constructed on either side, leaving the central space free for exhibits. The main entrance hall will have new cases for changing exhibits and at the back, opposite the front door, a group of herring gulls and common terns on sand dunes at Plymouth harbor. The lecture room floor is being leveled so that the room can be used for children's work also. A new room for study collections is provided in the basement. Exhibits are being rearranged by all the departments with the idea of appealing to the public rather than of adhering to the purely scientific point of view. Herpetological exhibits, for instance, will emphasize life histories and economic value of reptiles and amphibians; birds are grouped by habitat and status as residents. New labels to interest the visitor are being worked out. The museum is closed while alterations are being made. The date for the reopening of the building has not yet been set, but it will probably be early in the coming year.

A COLLECTION of several hundred Californian plants which has all but encircled the earth is now being studied in the herbarium of the California Academy of Sciences in San Francisco. The specimens were collected in 1840 and 1841 by the Russians in the region then known as Russian California ("California boreal. Ross." the labels read) and were sent from California to the herbarium of the Russian Academy in St. Petersburg by way of Vladivostok and across Siberia. These same specimens which have remained unnamed for nearly a hundred years are being determined by J. T. Howell at the California Academy of Sciences after which they will be returned to the herbarium of the Academy of Sciences in Leningrad. The plants, which were collected in different parts of the Russian territory, were obtained by Voznesensky ("Woznessensky"), who was is the first party to climb Mt. St. Helena in the Californian Coast Ranges north of San Francisco. Fort Ross, the chief Russian port and settlement on the Californian coast, is about sixty miles north of San Francisco.

DISCUSSION

LENS-LIKE ACTION OF A STAR BY THE DEVIATION OF LIGHT IN THE GRAVITATIONAL FIELD

Some time ago, R. W. Mandl paid me a visit and asked me to publish the results of a little calculation, which I had made at his request. This note complies with his wish.

The light coming from a star A traverses the gravitational field of another star B, whose radius is R_s. Let there be an observer at a distance D from B and at a distance x, small compared with D, from the extended central line $\overline{AB}$. According to the general theory of relativity, let α_s be the deviation of the light ray passing the star B at a distance R_s from its center.

For the sake of simplicity, let us assume that $\overline{AB}$ is large, compared with the distance D of the observer from the deviating star B. We also neglect the eclipse (geometrical obscuration) by the star B, which indeed is negligible in all practically important cases. To permit this, D has to be very large compared to the radius R_s of the deviating star.

It follows from the law of deviation that an observer situated exactly on the extension of the central line $\overline{AB}$ will perceive, instead of a point-like star A, a luminous circle of the angular radius β around the center of B, where

$$\beta = \sqrt{\alpha_s \frac{R_s}{D}}.$$

It should be noted that this angular diameter β does not decrease like $1/D$, but like $1/\sqrt{D}$, as the distance D increases.

Of course, there is no hope of observing this phenomenon directly. First, we shall scarcely ever approach closely enough to such a central line. Second, the angle β will defy the resolving power of our instruments. For, α_s being of the order of magnitude of one second of arc, the angle R_s/D, under which the deviating star B is seen, is much smaller. Therefore, the light coming from the luminous circle can not be distinguished by an observer as geometrically different from that coming from the star B, but simply will manifest itself as increased apparent brightness of B.

The same will happen, if the observer is situated at a small distance x from the extended central line $\overline{AB}$. But then the observer will see A as two point-like light-sources, which are deviated from the true geometrical position of A by the angle β, approximately.

The apparent brightness of A will be increased by the lens-like action of the gravitational field of B in the ratio η. This η will be considerably larger than unity only if x is so small that the observed positions of A and B coincide, within the resolving power of our instruments. Simple geometric considerations lead to the expression

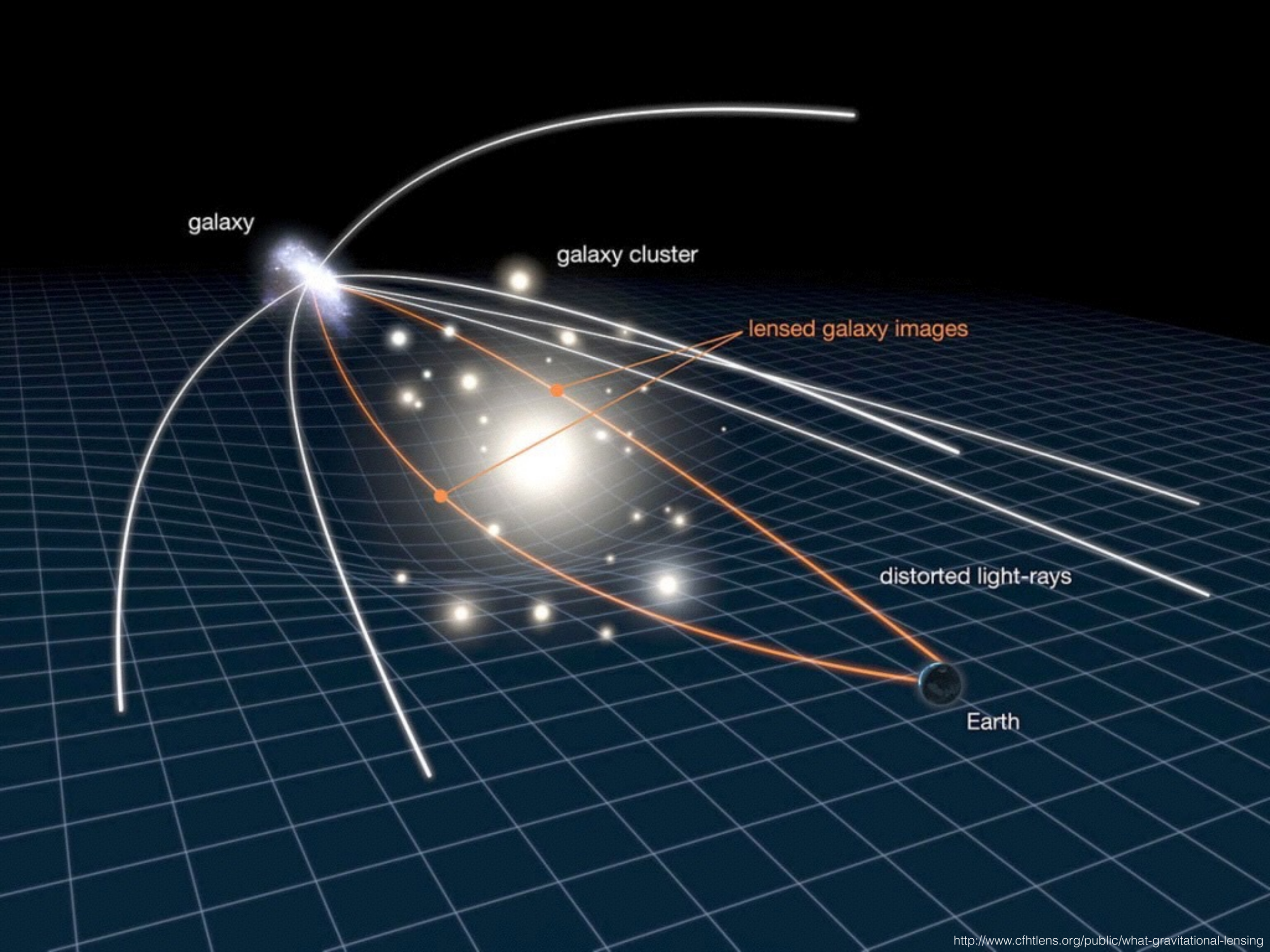
$$\eta = \frac{1}{x} \cdot \frac{2 + \frac{x^2}{2D^2}}{\sqrt{4 + \frac{x^2}{D^2}}},$$

where

$$l = \sqrt{\alpha_s D R_s}.$$

Einstein, A., 1936, “Lens-like action of a star by the deviation of light in the gravitational field”. *Science* 84, pp.506-507.

Tweeling Quasar (1979)



http://www.cfhtlens.org/public/what-gravitational-lensing

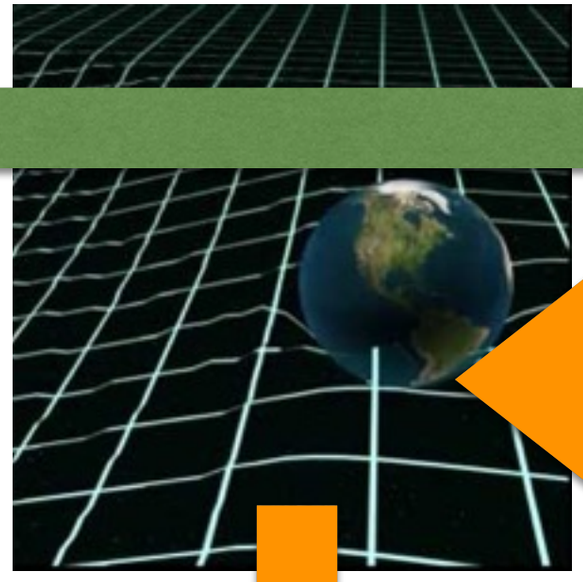
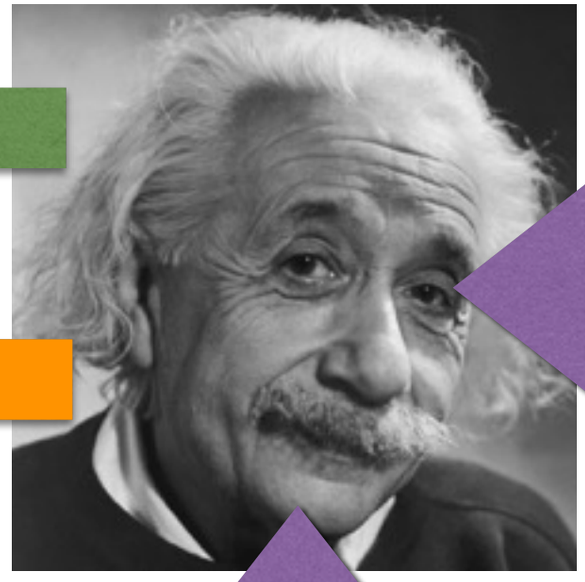
http://www.spacetelescope.org/images/potw1204a/

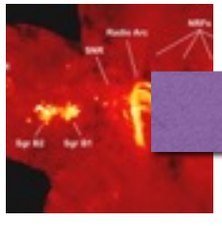
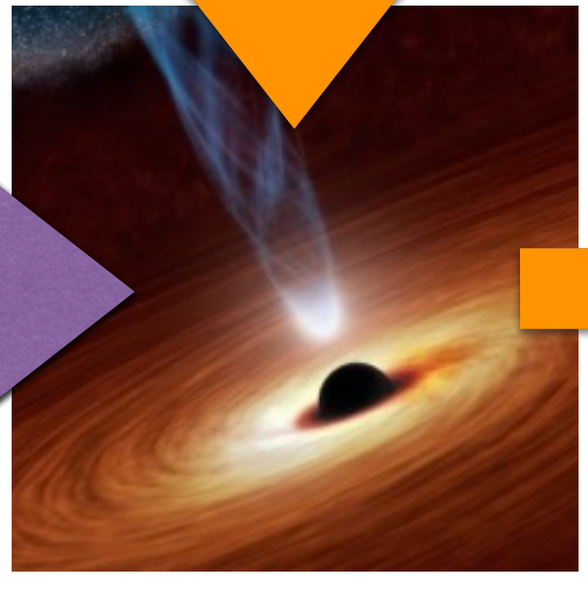
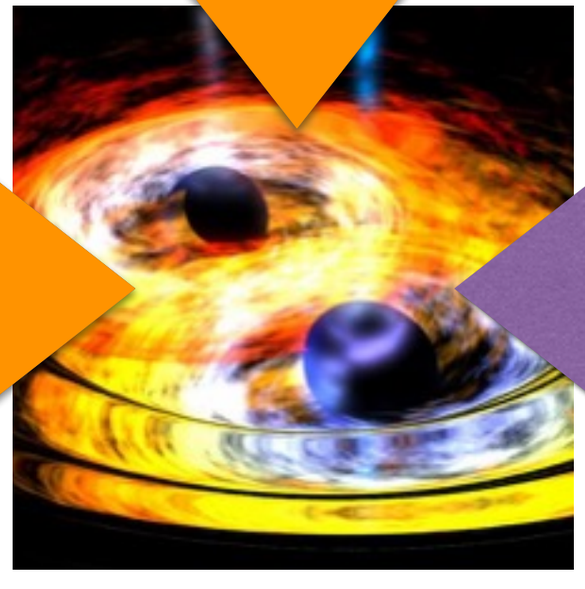
https://www.mpg.de/7127350/supermassive-neutron-star

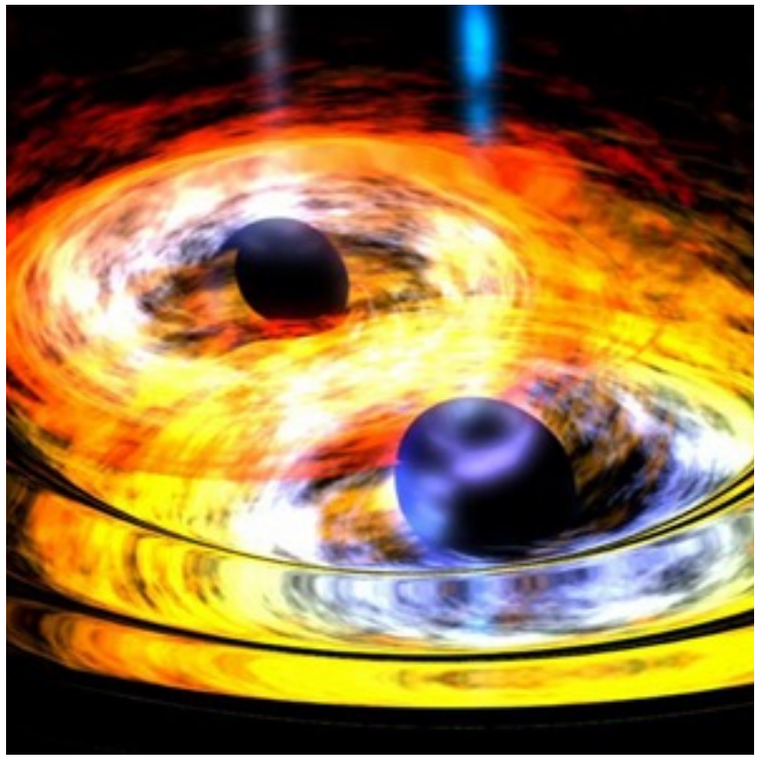
http://www.jb.man.ac.uk/features.html

http://www.jb.man.ac.uk/news/2004/doublepulsar/

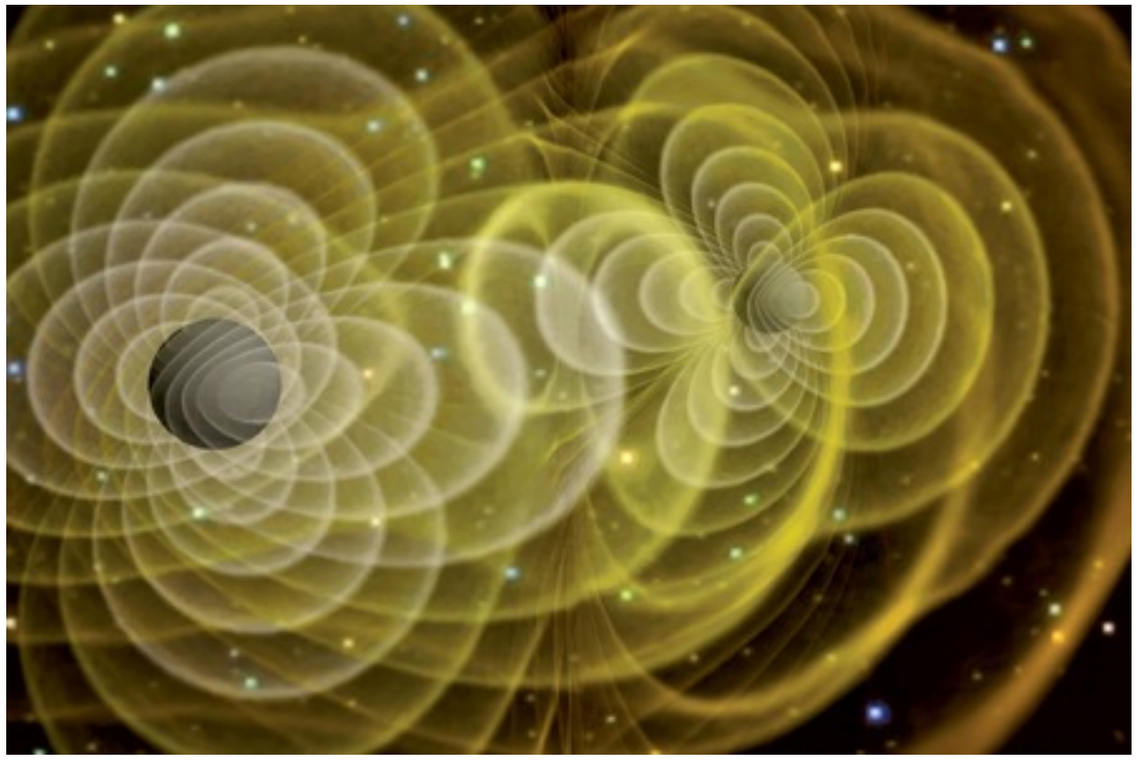
Gravitatiegolven

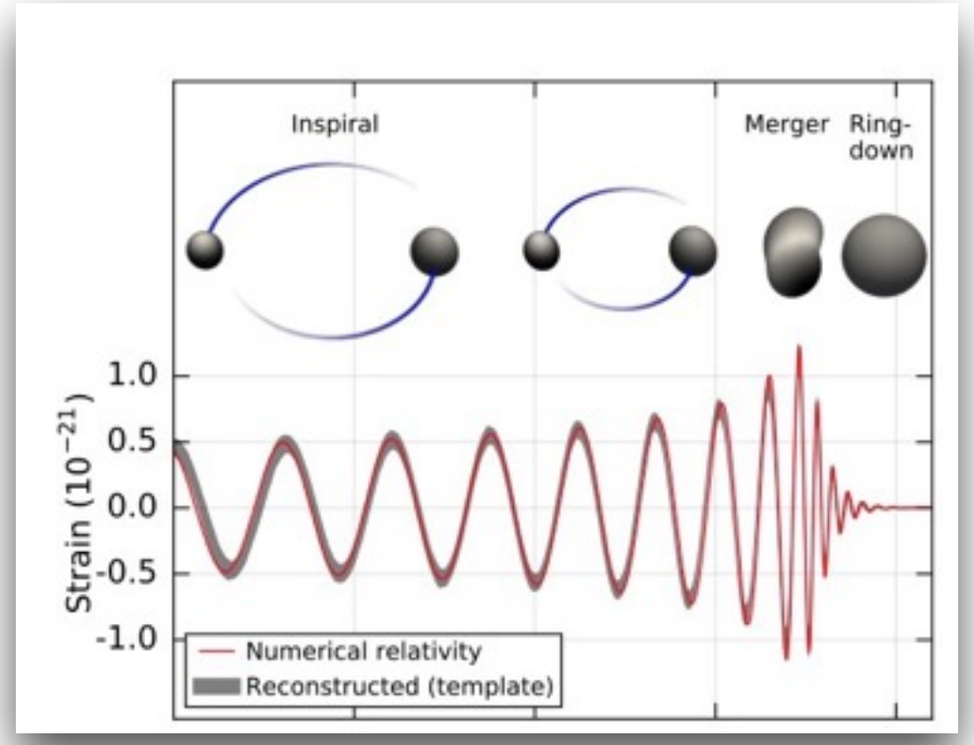




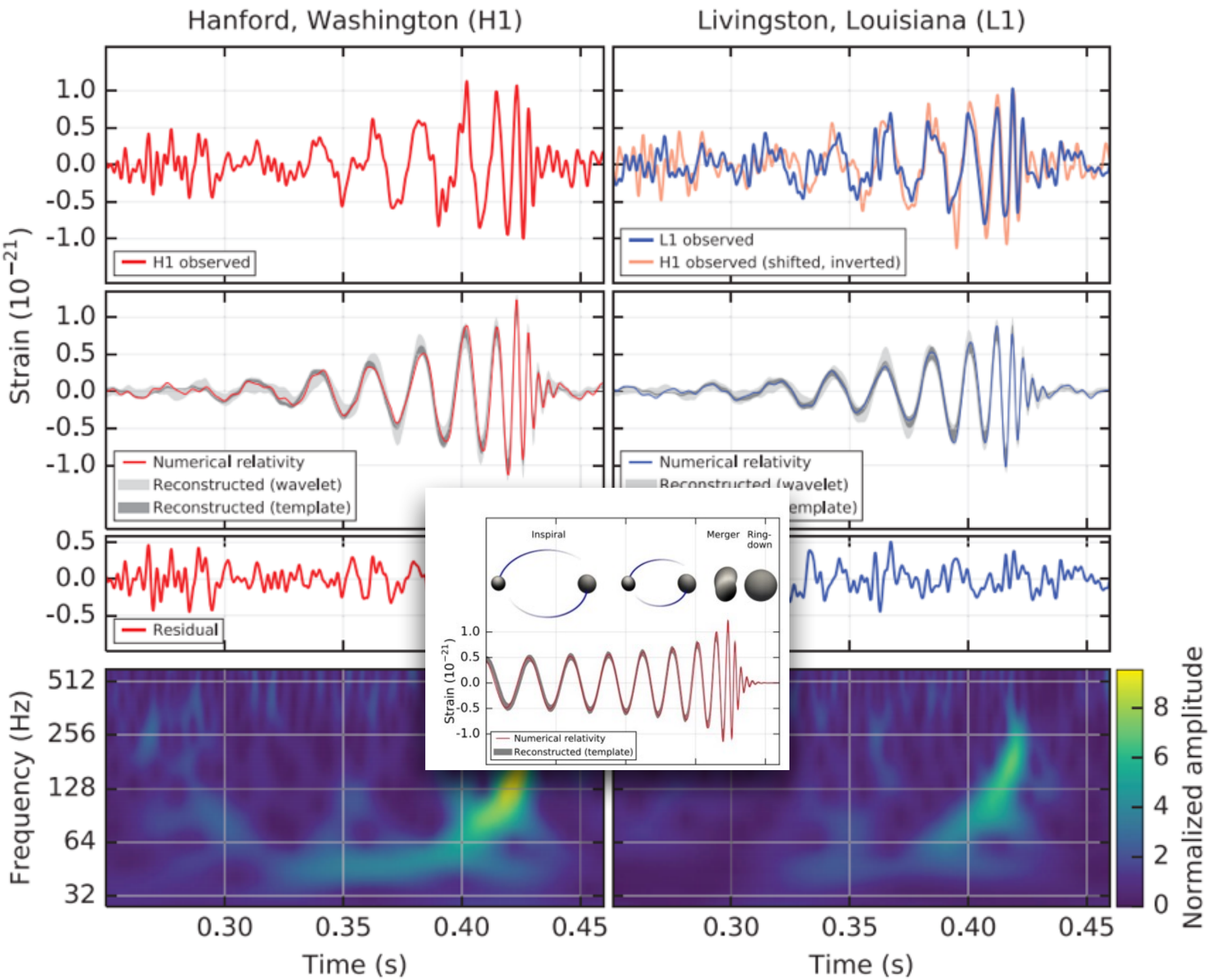
http://physicsworld.com/cws/article/news/2016/feb/11



https://www.newscientist.com/article/2076754



http://journals.aps.org/prl/pdf/10.1103/PhysRevLett.116.061102



Relativistische kosmologie

Artikel uit 1917

Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie.

Von A. Einstein.

Es ist wohlbekannt, daß die Poissonsche Differentialgleichung

$$\Delta\phi = 4\pi k\varrho \qquad (1)$$

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.

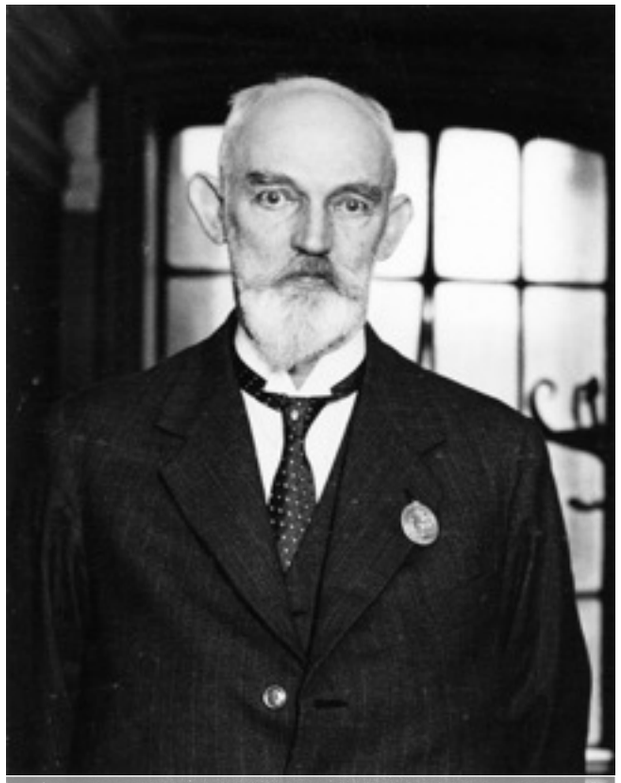
Bei der Behandlung des Planetenproblems habe ich diese Grenzbedingungen in Gestalt folgender Annahme gewählt: Es ist möglich, ein Bezugssystem so zu wählen, daß sämtliche Gravitationspotentiale $g_{\mu\nu}$ im räumlich Unendlichen konstant werden. Es ist aber a priori durchaus nicht evident, daß man dieselben Grenzbedingungen ansetzen darf, wenn man größere Partien der Körperwelt ins Auge fassen will. Im folgenden sollen die Überlegungen angegeben werden, welche ich bisher über diese prinzipiell wichtige Frage angestellt habe.

§ 1. Die Newtonsche Theorie.

Es ist wohlbekannt, daß die Newtonsche Grenzbedingung des konstanten Limes für ϕ im räumlich Unendlichen zu der Auffassung hinführt, daß die Dichte der Materie im Unendlichen zu null wird. Wir denken uns nämlich, es lasse sich ein Ort im Weltraum finden, um den herum das Gravitationsfeld der Materie, im großen betrachtet, Kugelsymmetrie besitzt (Mittelpunkt). Dann folgt aus der Poissonschen Gleichung, daß die mittlere Dichte ϱ rascher als $\frac{1}{r^2}$ mit wachsender Entfernung r vom Mittelpunkt zu null herabsinken muß, damit ϕ im

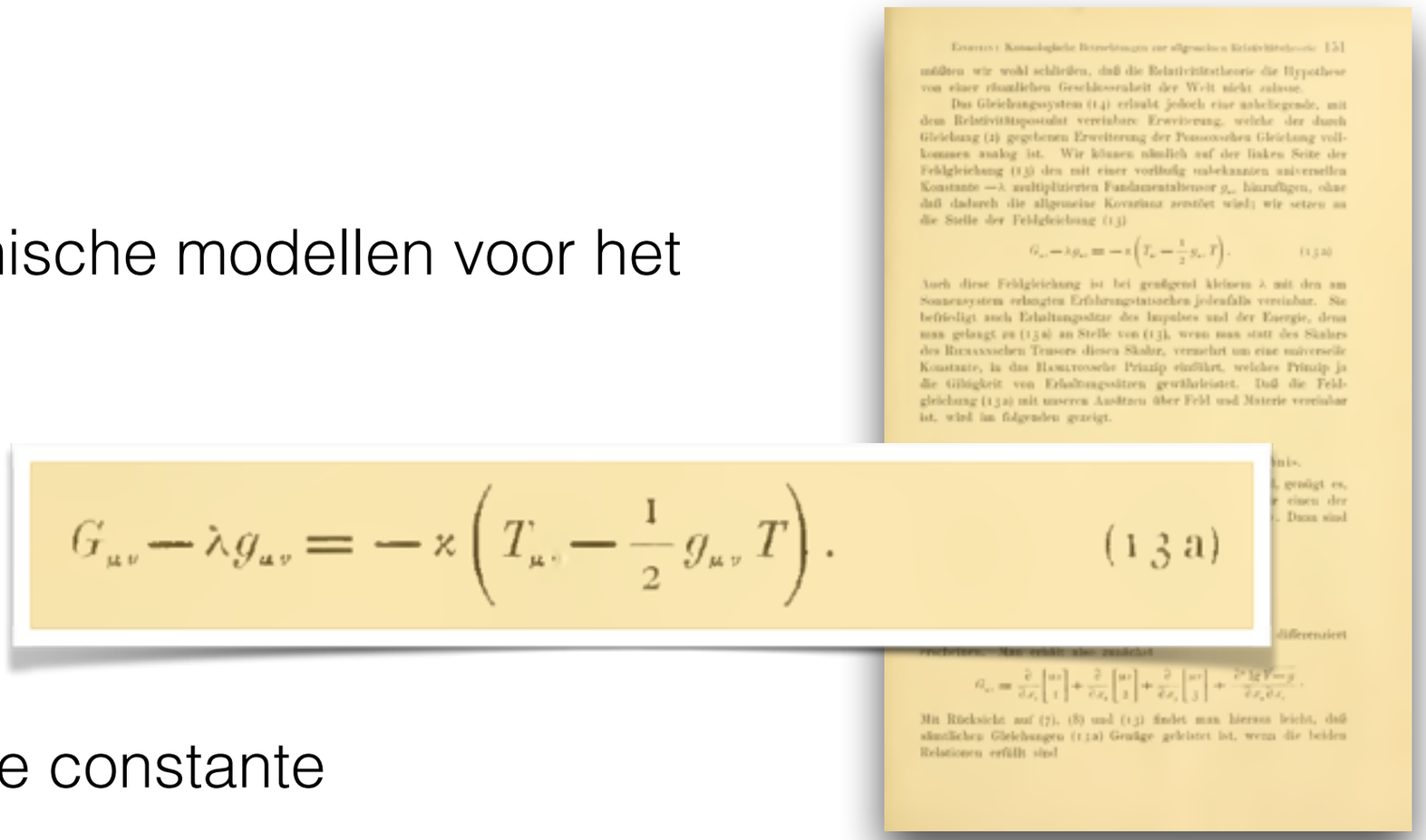
Opdracht door Willem de Sitter

- Wat als we alle massa in het universum in rekening brengen?
- Hoe kromt het universum zichzelf?

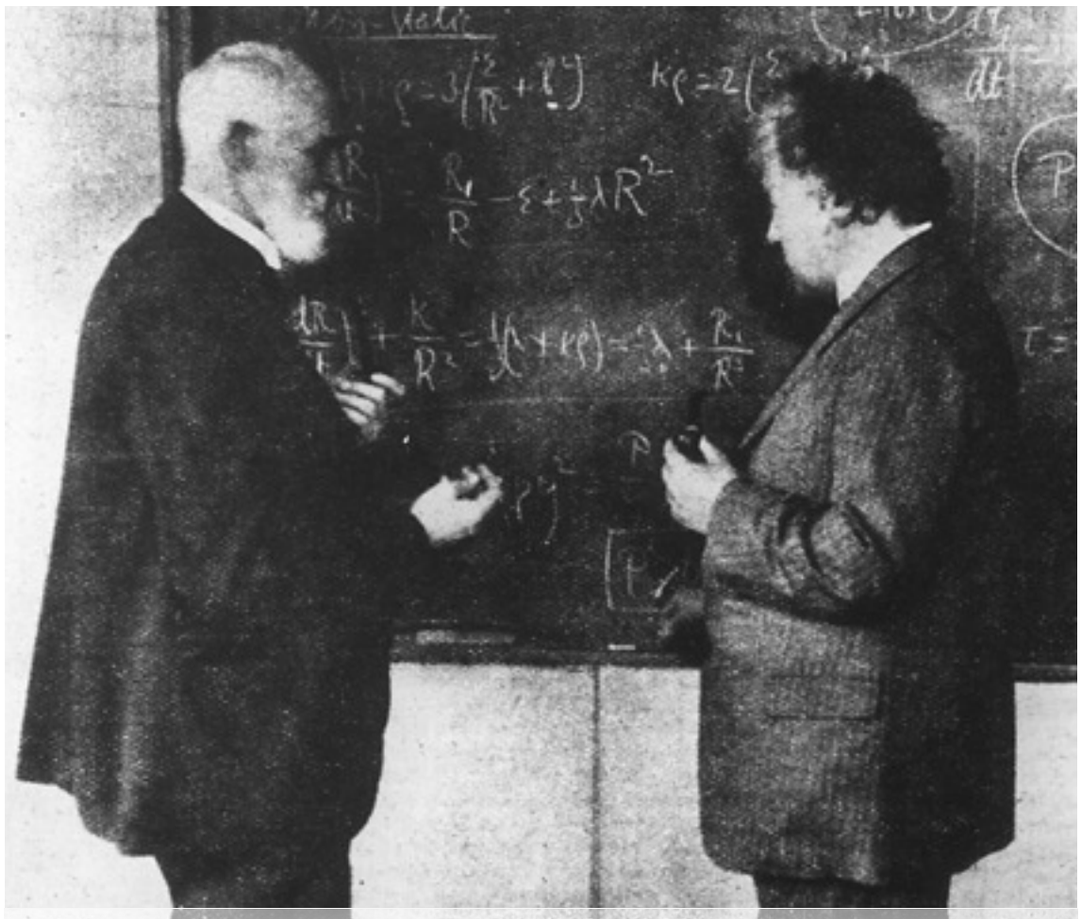


http://alchetron.com/Willem-de-Sitter-1231398-W

- $G_{\mu\nu}=\kappa T_{\mu\nu}$
  - laat enkel dynamische modellen voor het universum toe
- $G_{\mu\nu}+\mathbf{\lambda g_{\mu\nu}}=\kappa T_{\mu\nu}$
  - invoering λ
    - kosmologische constante
    - met geschikte waarde een statisch model
- kosmologisch principe
  - universum is isotroop en homogeen



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



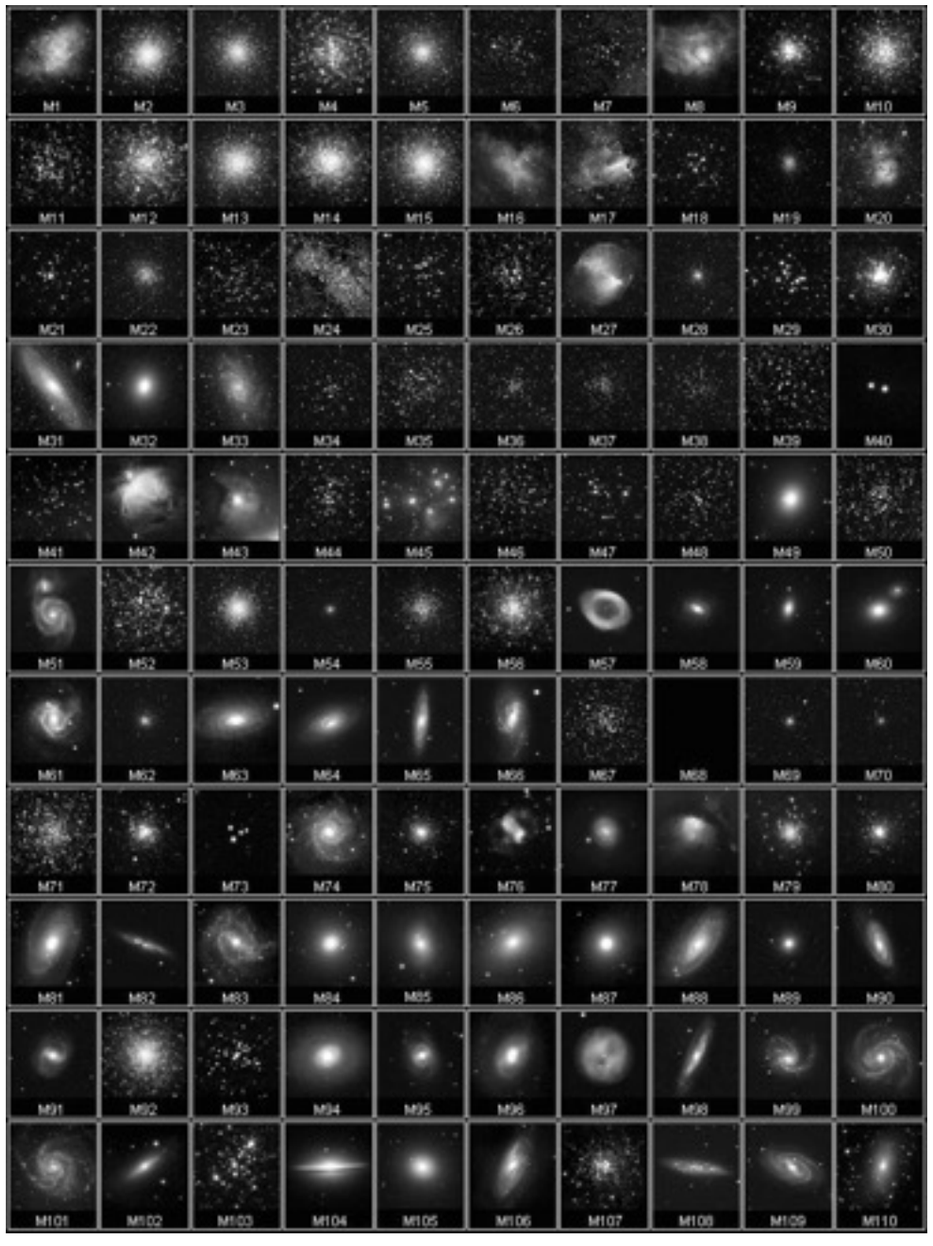
http://forum.lametayel.co.il/forum_getfile_large/id-77745/

Ik wil benadrukken dat uit mijn resultaat een positieve kromming van het universum [implosie] volgt, zelfs als ik de extra term [met lambda] niet toevoeg. Die term is alleen maar nodig om een statisch model mogelijk te maken zoals de lage snelheden van de sterren vereisen.

Ster van Kapteyn:
245 km/s

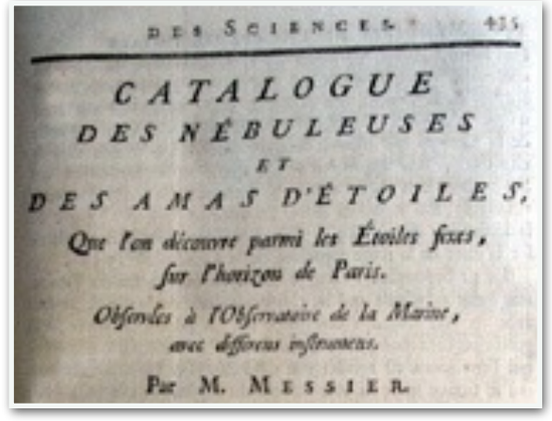
Die theoretische Auffassung der tatsächlichen Welt wäre also, falls dieselbe unserer Betrachtung entspricht, die folgende. Der Krümmungscharakter des Raumes ist nach Maßgabe der Verteilung der Materie zeitlich und örtlich variabel, läßt sich aber im großen durch einen sphärischen Raum approximieren. Jedenfalls ist diese Auffassung logisch widerspruchsfrei und vom Standpunkte der allgemeinen Relativitätstheorie die naheliegendste: ob sie, vom Standpunkt des heutigen astronomischen Wissens aus betrachtet, haltbar ist, soll hier nicht untersucht werden. Um zu dieser widerspruchsfreien Auffassung zu gelangen, mußten wir allerdings eine neue, durch unser tatsächliches Wissen von der Gravitation nicht gerechtfertigte Erweiterung der Feldgleichungen der Gravitation einführen. Es ist jedoch hervorzuheben, daß eine positive Krümmung des Raumes durch die in demselben befindliche Materie auch dann resultiert, wenn jenes Zusatzglied nicht eingeführt wird: das letztere haben wir nur nötig, um eine quasistatische Verteilung der Materie zu ermöglichen, wie es der Tatsache der kleinen Sterngeschwindigkeiten entspricht.

Nebulae



http://messier.seds.org/

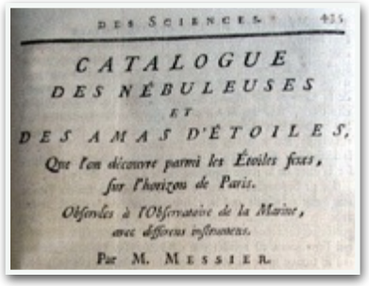
http://www.nasa.gov/



DES SCIENCES. 435

CATALOGUE
DES NÉBULEUSES
ET
DES AMAS D'ÉTOILES,
Que l'on découvre parmi les Étoiles fixes,
sur l'horizon de Paris.
Observés à l'Observatoire de la Marine,
avec différens instrumens.
Par M. MESSIER.

111 Messier Objecten


DES SCIENCES. 425

CATALOGUE
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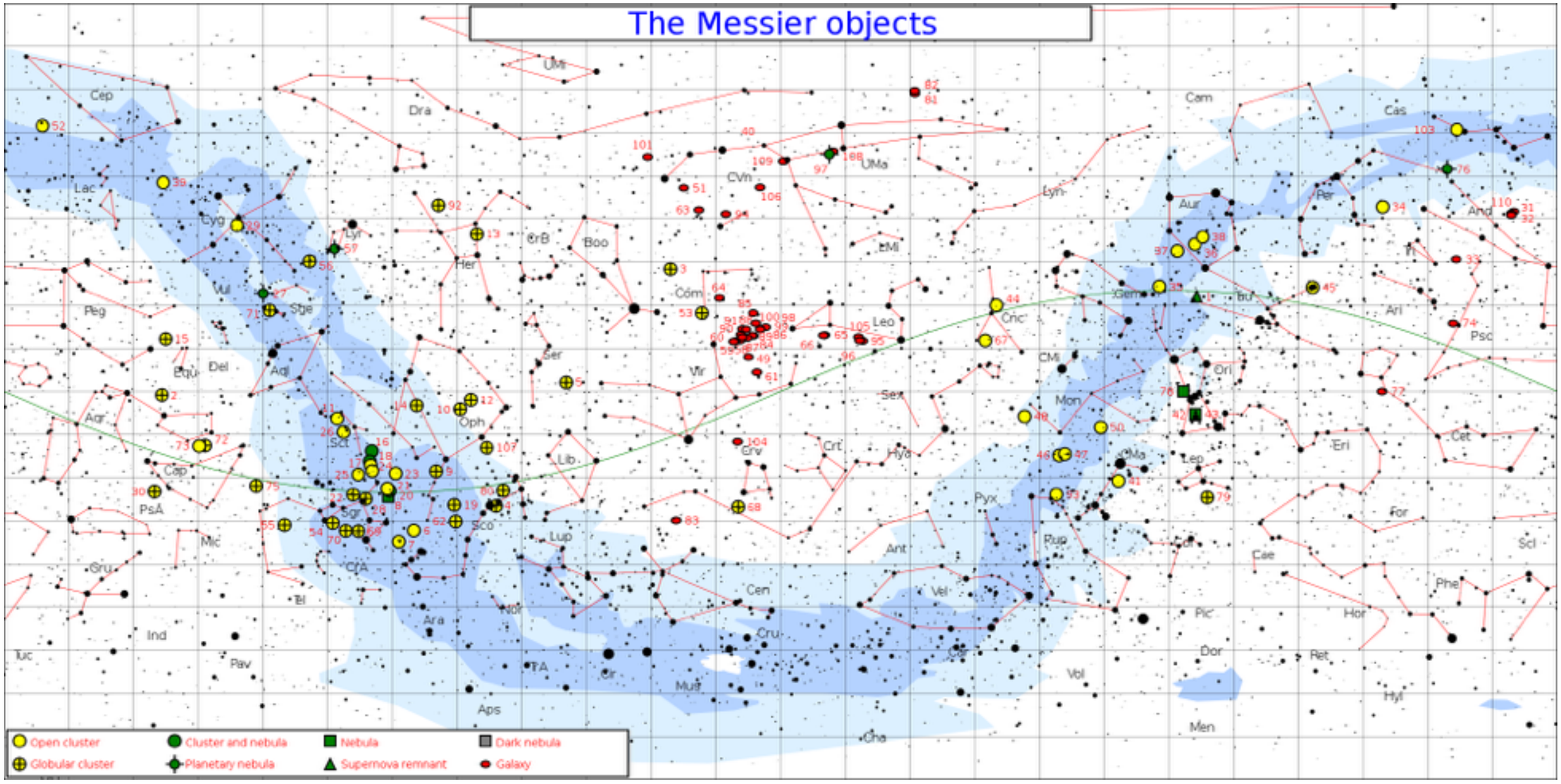
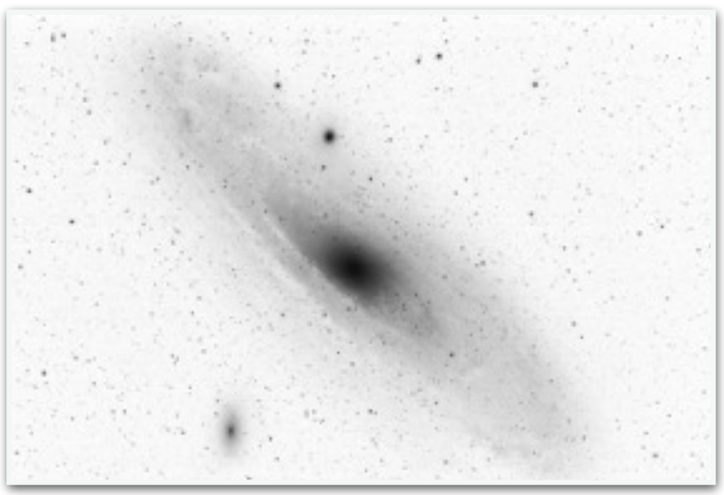


http://www.constellation-guide.com/messier-objects/

http://alchetron.com/Vesto-Slipher-1239034-W

- Vesto Melvin Slipher
- 1912-1914
- nebulae roteren
- nebulae bewegen zich tegen hoge snelheid van ons weg
  - met één uitzondering (M31)



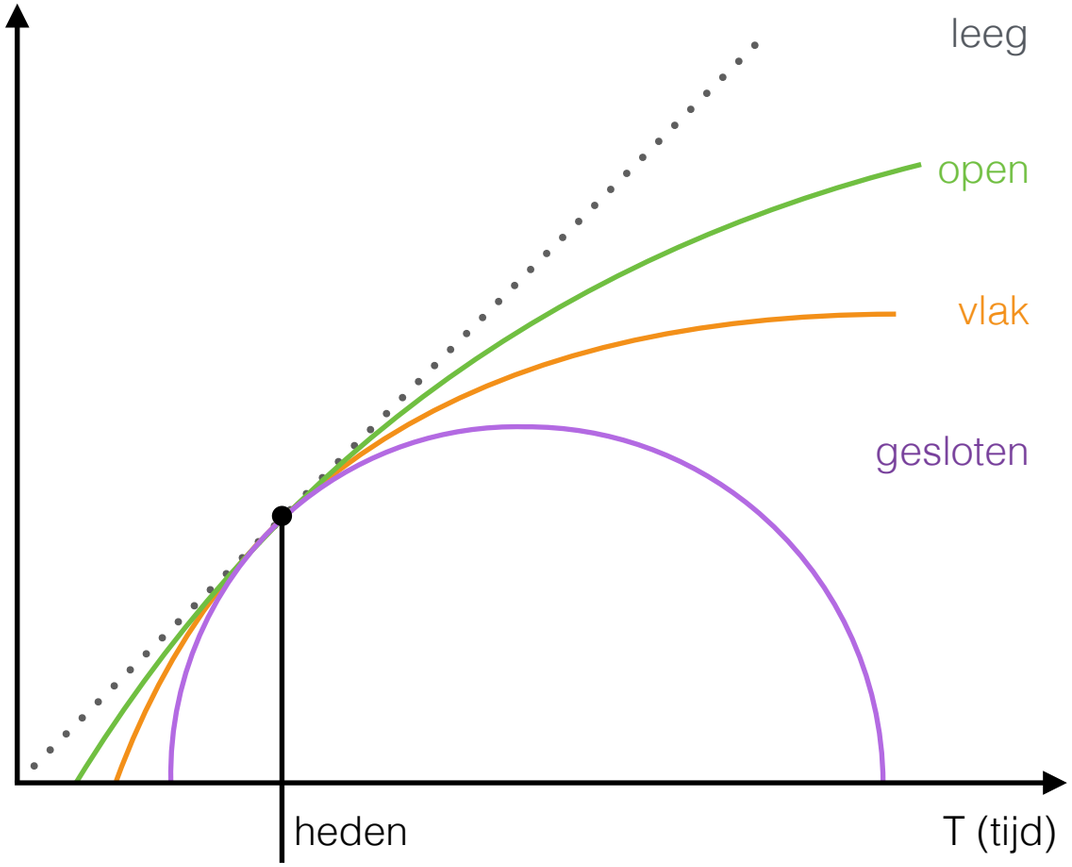
http://www.toledoastronomy.org/

Toestand 1917

- Geen idee van de afstanden tot nebulae
- Het universum is lokaal quasi-statisch
- Een heelalmodel betreft het ganse universum

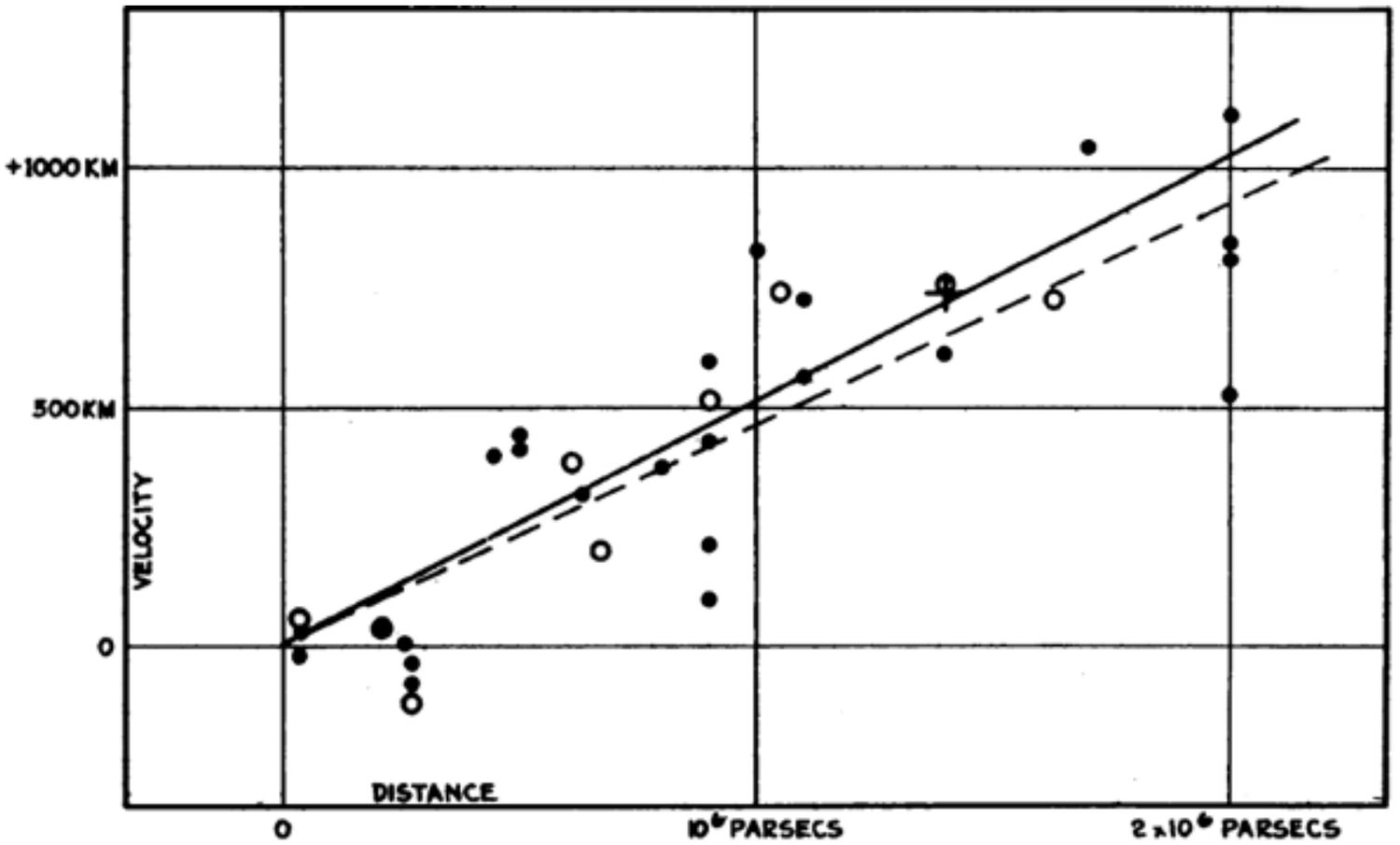
Friedmann modellen (1922-1924)

http://www.frodo.at/Alexander-Friedmann.html



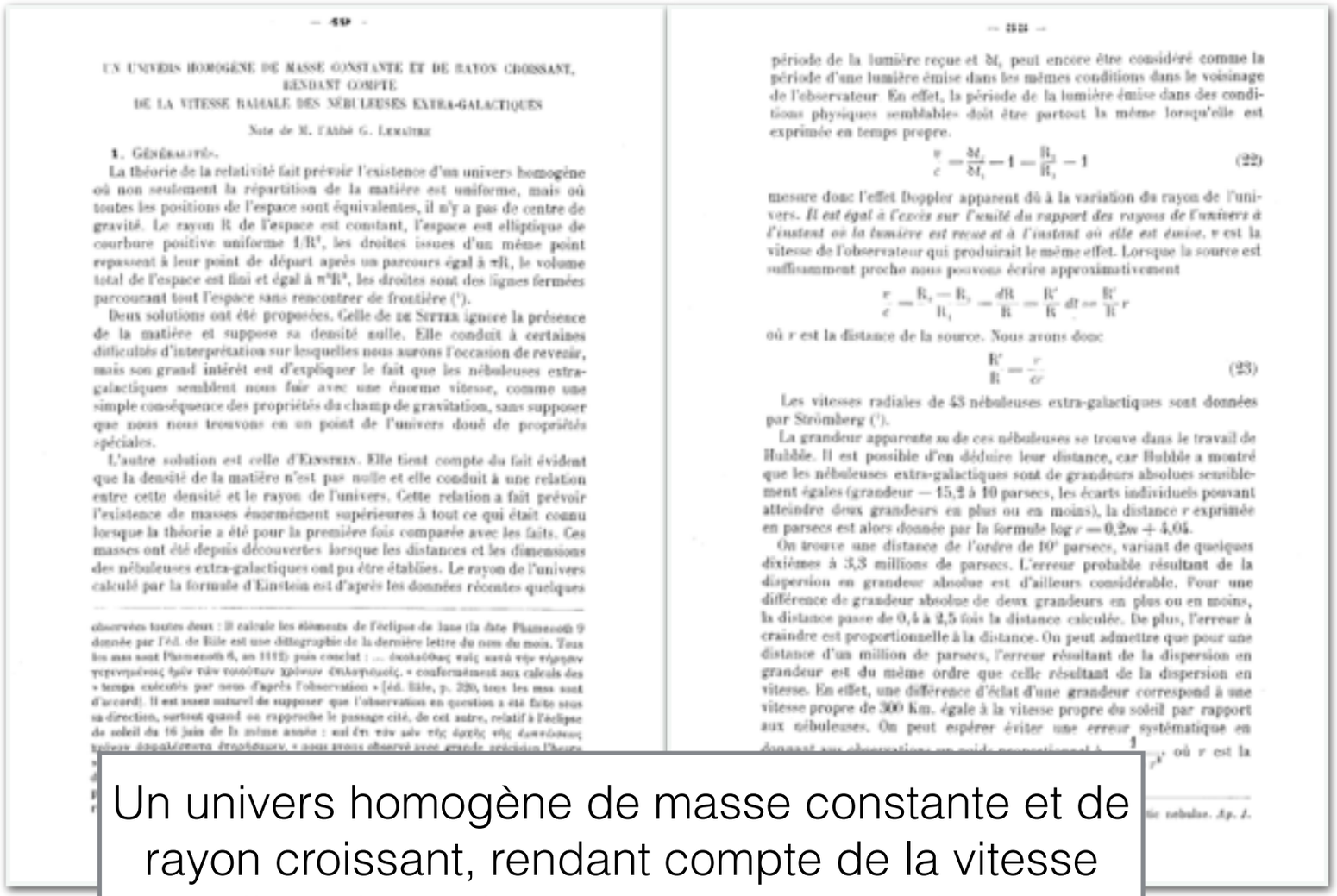
Hubbles ontdekkingen (1923-1929)

https://www.museumofflight.org/iya-hubble



Lemaîtres wet (1927)

De radiale snelheid van de nebulae neemt toe met de afstand



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

(1) observées toutes deux : Il calcule les éléments de l'éclipse de lune (la date Phamenoth 9 donnée par l'éd. de Bâle est une dittographie de la dernière lettre du nom du mois. Tous les mss sont Phamenoth 6, an 1112) puis conclut : « ἀκολούθως ταῖς κατὰ τὴν τήρησιν γεγενημέναις ἡμῖν τὸν τοσοῦτον χρόνον ἐπιπορεύσεις. » conformément aux calculs des « temps calculés par nous d'après l'observation » [éd. Bâle, p. 220, tous les mss sont d'accord]. Il est assez naturel de supposer que l'observation en question a été faite sous sa direction, surtout quand on rapproche le passage cité, de cet autre, relatif à l'éclipse de soleil du 16 juin de la même année : καὶ ἐπὶ τῶν ἀπὸ τῆς ἀρχῆς τῆς ἀνατολῆς τηρήσεων ἀκριβέστατα ἐπορεύσαμεν. » nous avons observé avec grande précision l'heure

période de la lumière reçue et δt, peut encore être considéré comme la période d'une lumière émise dans les mêmes conditions dans le voisinage de l'observateur. En effet, la période de la lumière émise dans des conditions physiques semblables doit être partout la même lorsqu'elle est exprimée en temps propre.

$$\frac{v}{c} = \frac{\delta t}{\delta t_1} - 1 = \frac{R_2}{R_1} - 1 \qquad (22)$$

mesure donc l'effet Doppler apparent dû à la variation du rayon de l'univers. *Il est égal à l'excès sur l'unité du rapport des rayons de l'univers à l'instant où la lumière est reçue et à l'instant où elle est émise.* v est la vitesse de l'observateur qui produirait le même effet. Lorsque la source est suffisamment proche nous pouvons écrire approximativement

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

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

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

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

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

On trouve une distance de l'ordre de 10^7 parsecs, variant de quelques dixièmes à 3,3 millions de parsecs. L'erreur probable résultant de la dispersion en grandeur absolue est d'ailleurs considérable. Pour une différence de grandeur absolue de deux grandeurs en plus ou en moins, la distance passe de 0,4 à 2,5 fois la distance calculée. De plus, l'erreur à craindre est proportionnelle à la distance. On peut admettre que pour une distance d'un million de parsecs, l'erreur résultant de la dispersion en grandeur est du même ordre que celle résultant de la dispersion en vitesse. En effet, une différence d'éclat d'une grandeur correspond à une vitesse propre de 300 Km. égale à la vitesse propre du soleil par rapport aux nébuleuses. On peut espérer éviter une erreur systématique en donnant aux observations un poids proportionnel à $\frac{1}{r^2}$, où r est la

(1) ...ic nebulae. *Ap. J.*

Un univers homogène de masse constante et de rayon croissant, rendant compte de la vitesse radiale des nébuleuses extra-galactiques.
Annales de la Société scientifique de Bruxelles

Your calculations are correct, but your grasp of physics is abominable. *Einstein, 1927.*

http://www.astrosurf.com/luxorion/Illustrations/einstein-lemaitre-pasadena-1932.jpg

Hubbles publicatie (1929)

appearance the spectrum is very much like spectra of the Milky Way clouds in Sagittarius and Cygnus, and is also similar to spectra of binary stars of the W Ursae Majoris type, where the widening and depth of the lines are affected by the rapid rotation of the stars involved.

The wide shallow absorption lines observed in the spectrum of N. G. C. 7619 have been noticed in the spectra of other extra-galactic nebulae, and may be due to a dispersion in velocity and a blending of the spectral types of the many stars which presumably exist in the central parts of these nebulae. The lack of depth in the absorption lines seems to be more pronounced among the smaller and fainter nebulae, and in N. G. C. 7619 the absorption is very weak.

It is hoped that velocities of more of these interesting objects will soon be available.

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

Determinations of the motion of the sun with respect to the extra-galactic nebulae have involved a K term of several hundred kilometers which appears to be variable. Explanations of this paradox have been sought in a correlation between apparent radial velocities and distances, but so far the results have not been convincing. The present paper is a re-examination of the question, based on only those nebular distances which are believed to be fairly reliable.

Distances of extra-galactic nebulae depend ultimately upon the application of absolute-luminosity criteria to involved stars whose types can be recognized. These include, among others, Cepheid variables, novae, and blue stars involved in emission nebulosity. Numerical values depend upon the zero point of the period-luminosity relation among Cepheids, the other criteria merely check the order of the distances. This method is restricted to the few nebulae which are well resolved by existing instruments. A study of these nebulae, together with those in which any stars at all can be recognized, indicates the probability of an approximately uniform upper limit to the absolute luminosity of stars, in the late-type spirals and irregular nebulae at least, of the order of M (photographic) = -6.3.[1] The apparent luminosities of the brightest stars in such nebulae are thus criteria which, although rough and to be applied with caution,

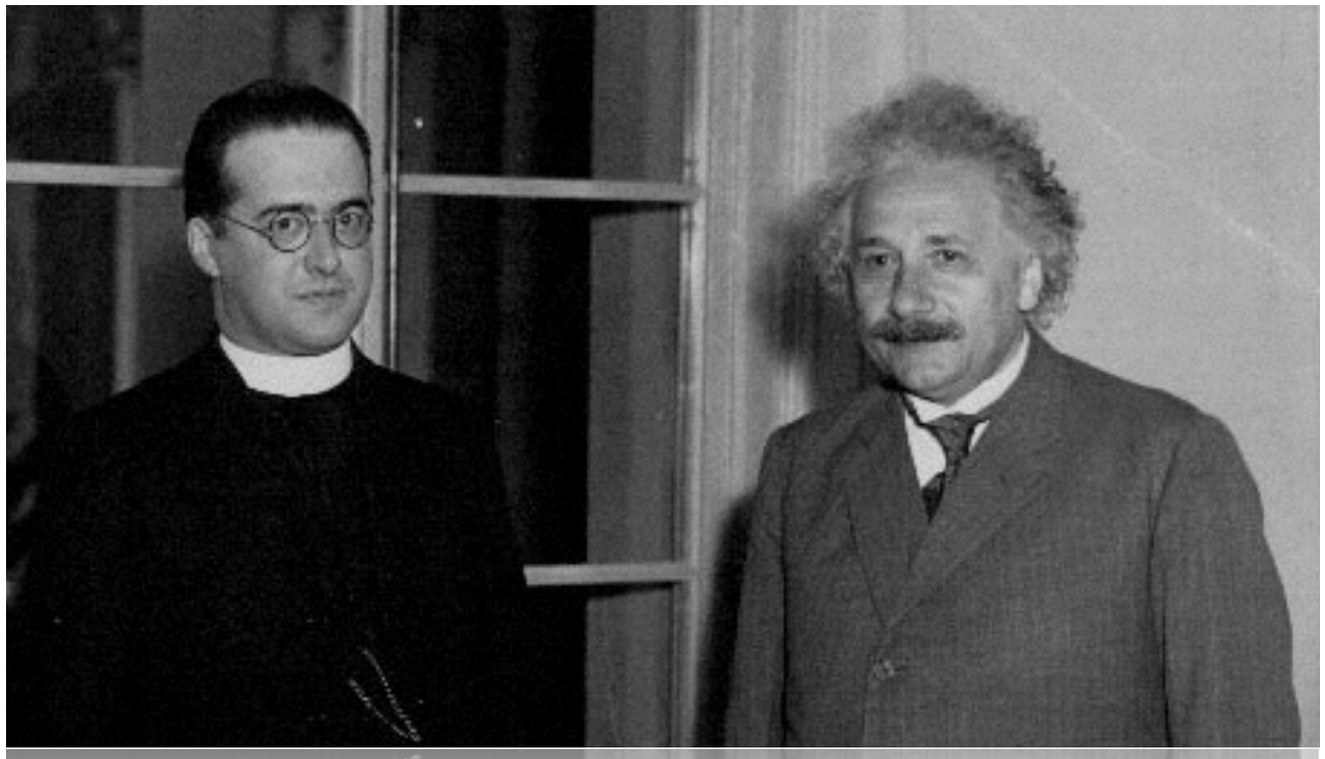
http://www.interactions.org/quantumuniverse/qu2006/discovering/einstein.html

The beginning of the world from the point of view of quantum theory
Lemaîtres oerknalmodel

If the world has begun with a single quantum, the notions of space and time would altogether fail to have a meaning at the beginning. […] *If this suggestion is correct, the beginning of the world happened a little before the beginning of space and time.* I think that such a beginning of the world is far enough from the present order of Nature to be not at all repugnant.

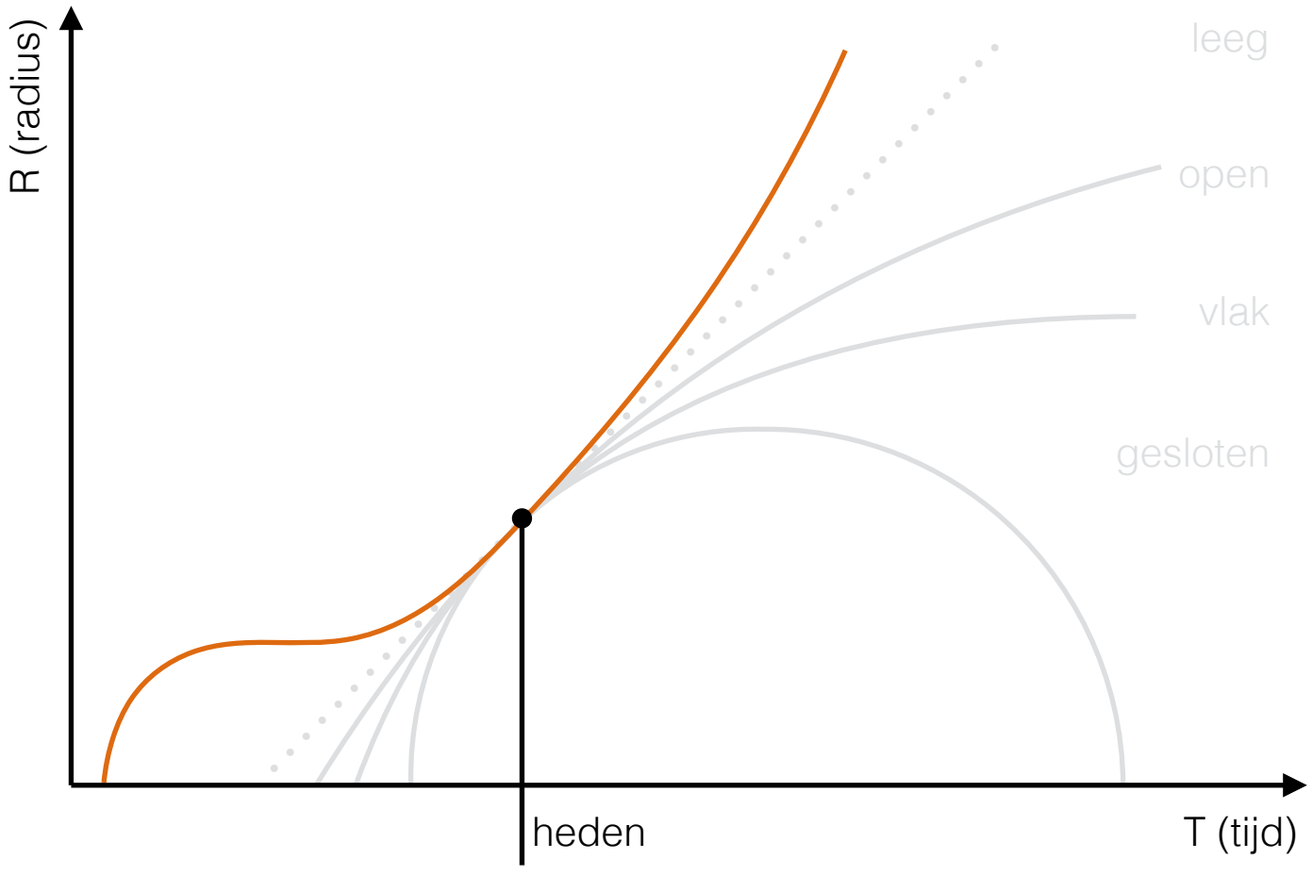
Nature 127, 706 (9 May 1931)

This is the most beautiful and satisfactory explanation of creation to which I have ever listened. *Einstein, 1933*



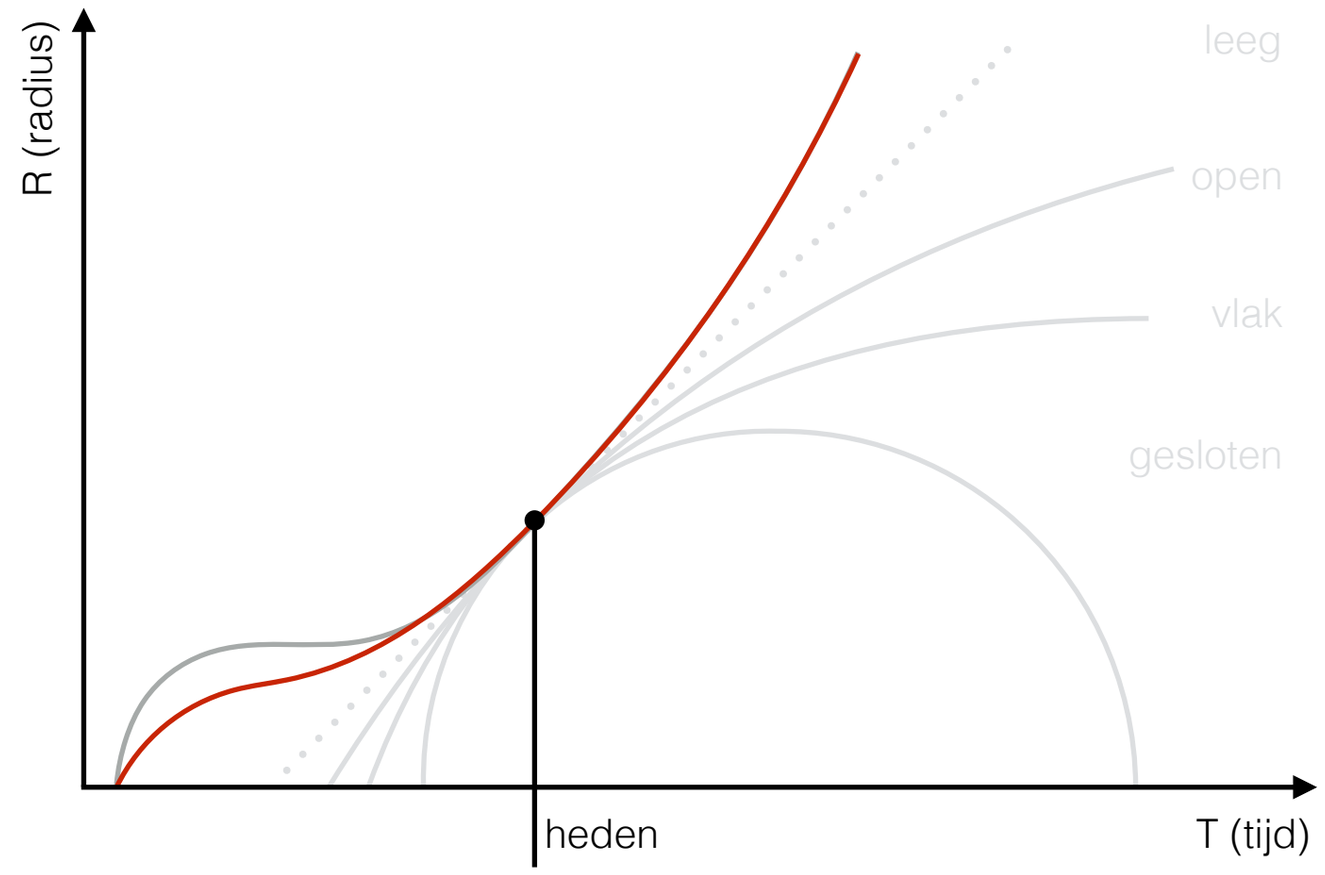
http://www.astr.ucl.ac.be/images/abouttheinstitute/Lemaitre_Einstein.jpg

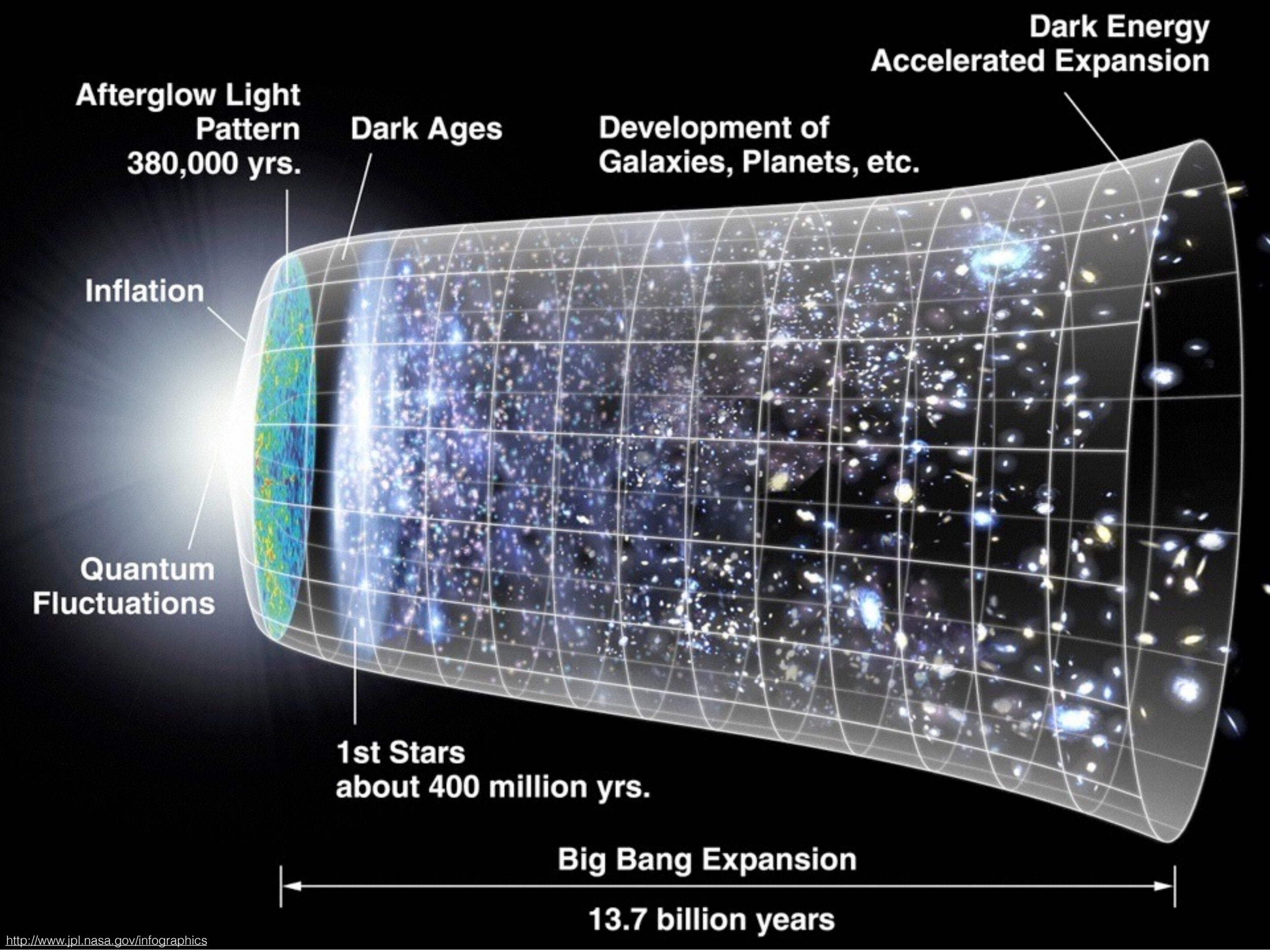
Model van Lemaître



http://www.zaujimavysvet.sk

Concordantiemodel

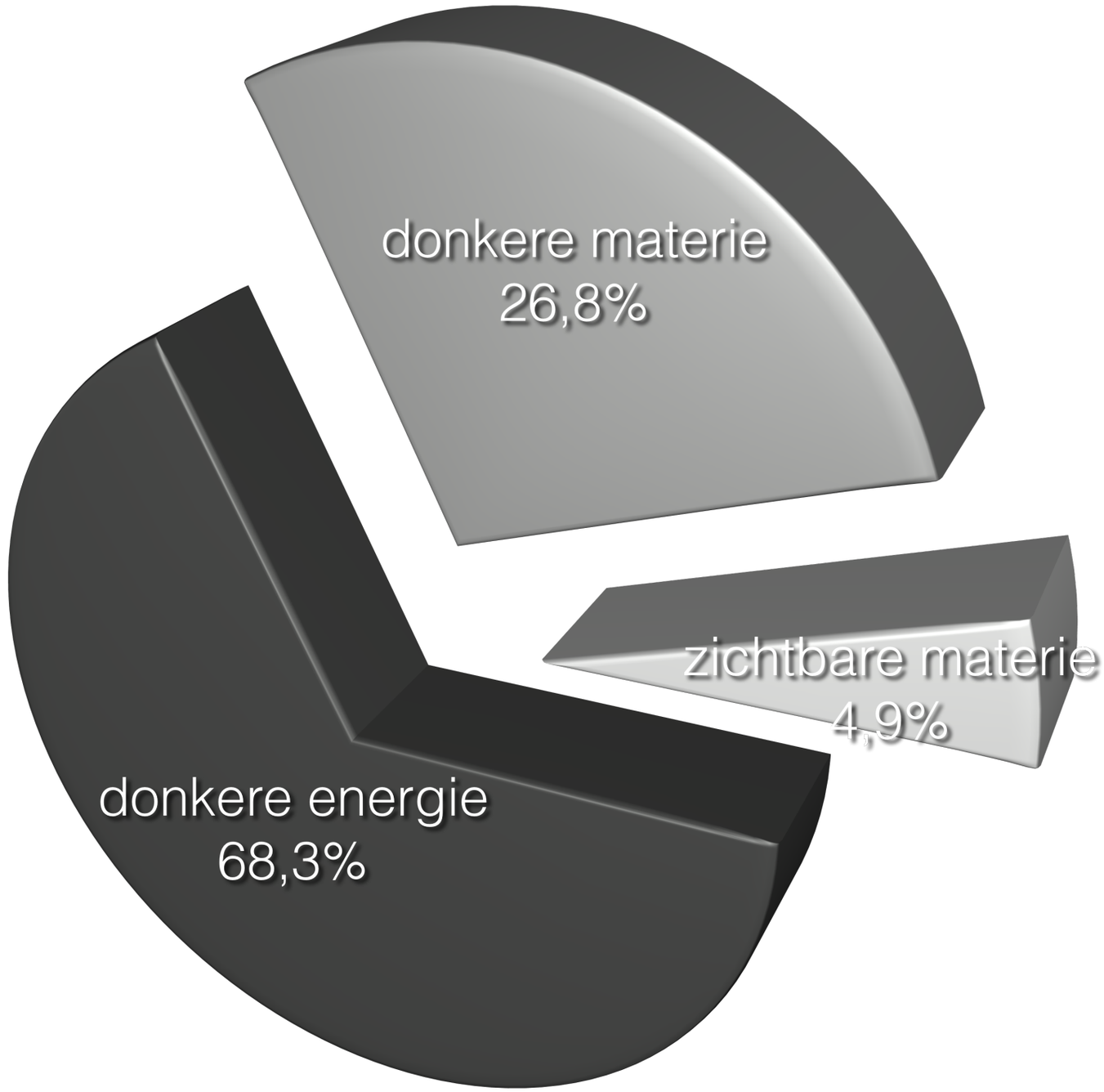




http://www.jpl.nasa.gov/infographics

ΛCDM
Lambda Koude Donkere Materie

Lambda speelt een rol: vertegenwoordigt de invloed van donkere energie



ΛCDM

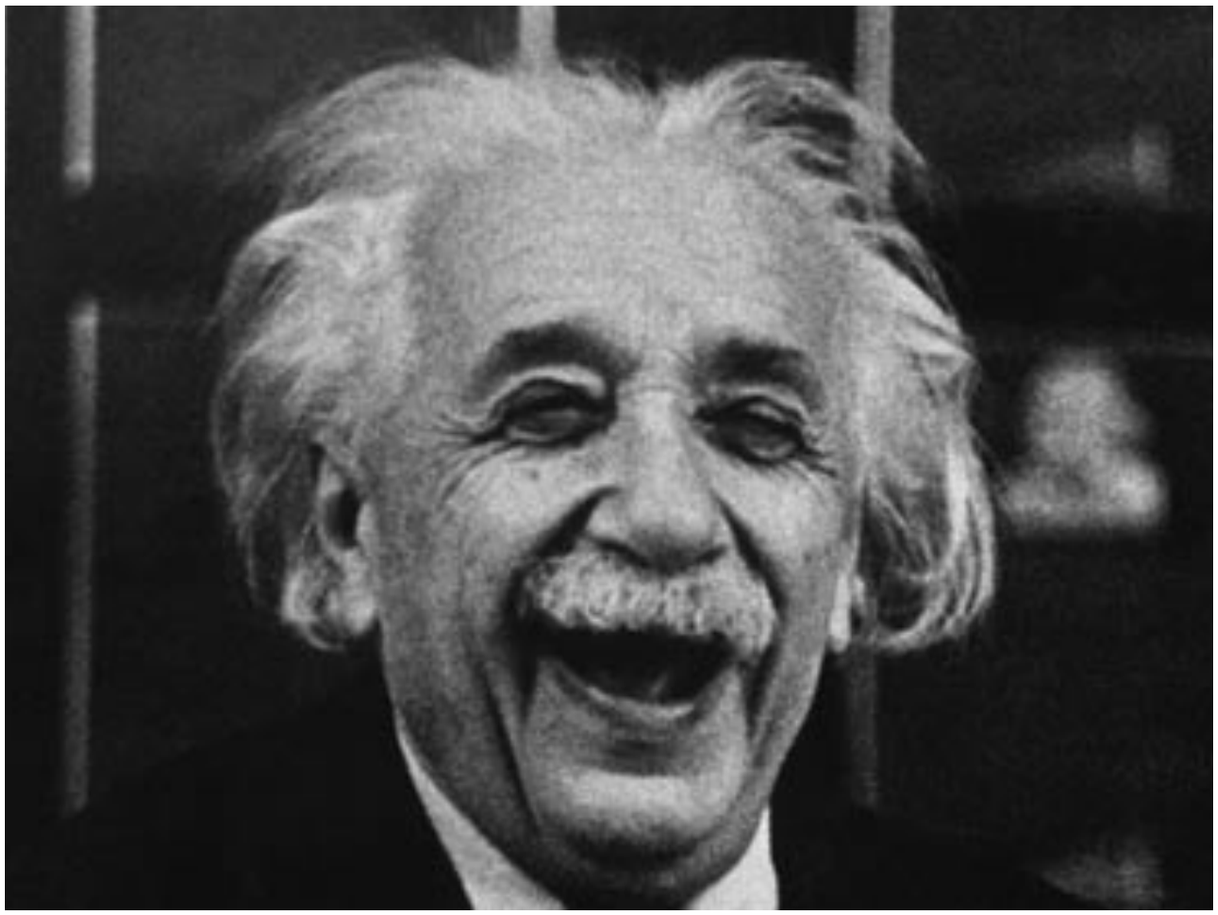
- terugkijktijd ~13,750×10^{9} jaar
- samenstelling
  - ~5% baryonische materie (atomen)
  - ~27% donkere materie
  - ~68% donkere energie (aanvankelijk)
- kosmologische parameters drukken de karakteristieken van het heelal uit:
  - $\boldsymbol{\Omega_{\Lambda}}$ = 0,7 – kan positief of negatief zijn (antigravitatie of extra gravitatie)
  - Ω_{M} = 0,3 – bijdrage van de massa (baryonische en donkere materie)
  - H_{0} = ~70 km/s/Mpc (constante van Hubble)
  - q < 0 (vertraging of versnelling)

Einsteins blunder?

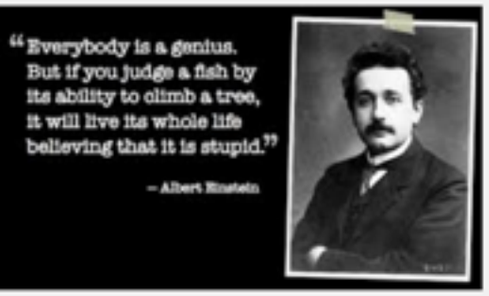
Einstein zou volgens George Gamow (1956) de invoering van lambda de grootste blunder van zijn leven genoemd hebben. Er is geen andere bron. (Mario Livio)

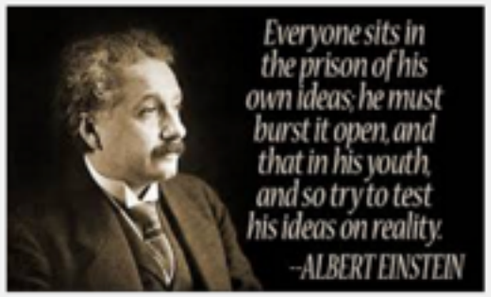
Einstein quickly recognized the importance of this discovery. In the last edition of his book *The Meaning of Relativity* he wrote: "The mathematician Friedman found a way out of this dilemma. He showed that it is possible, according to the field equations, to have a finite density in the whole (three-dimensional) space, without enlarging these field equations ad hoc." Einstein remarked to me many years ago that the cosmic repulsion idea was the biggest blunder he had made in his entire life.

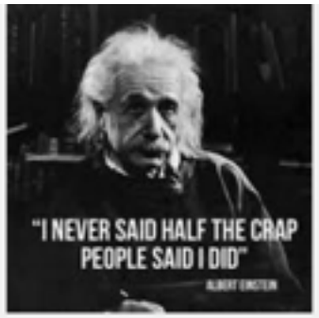
http://www.theatlantic.com/technology/archive/2013/08/einstein-likely-never-said-one-of-his-most-oft-quoted-phrases/278508/

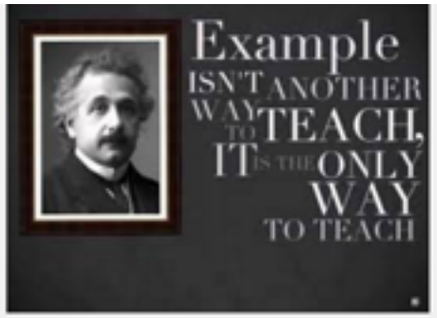


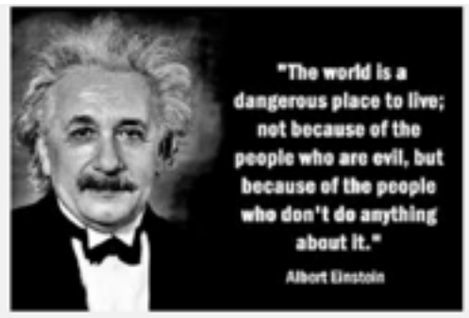
De geciteerde Einstein

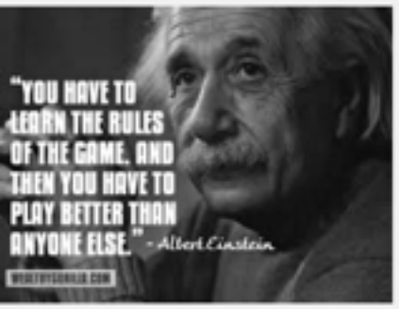


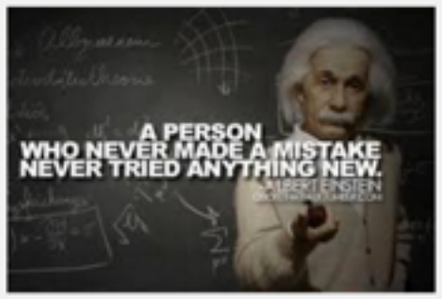


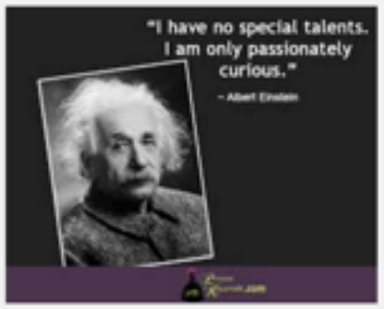


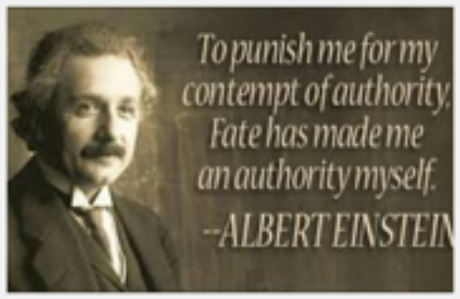


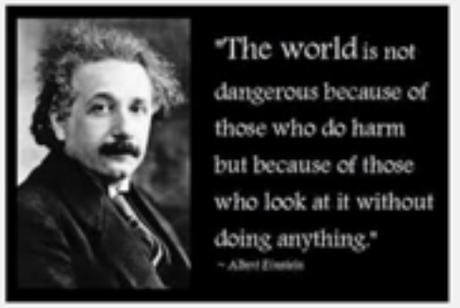


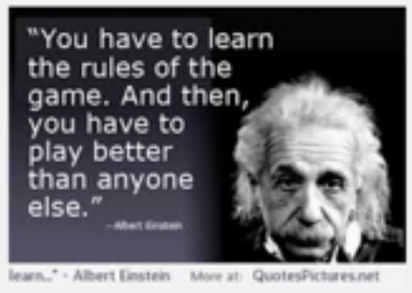




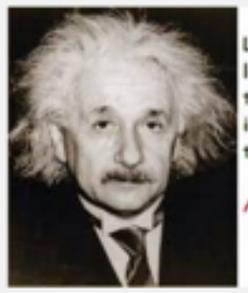






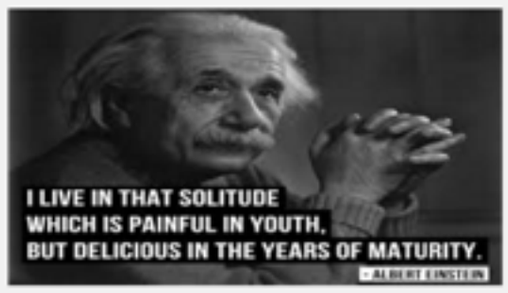


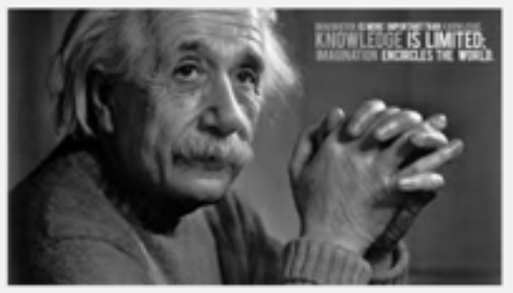
learn..." - Albert Einstein More at: QuotesPictures.net

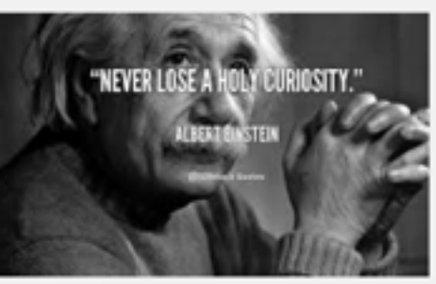


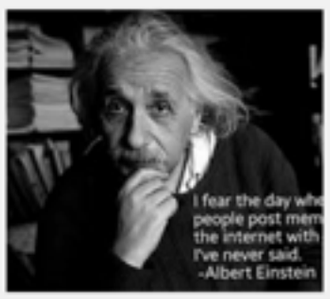
Learn from yesterday, live for today, hope for tomorrow. The important thing is not to stop questioning.

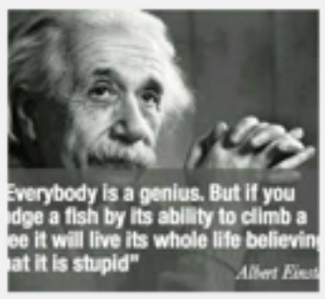
Albert Einstein

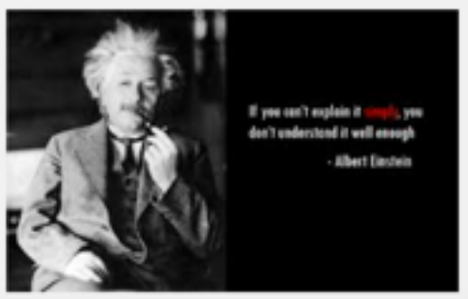


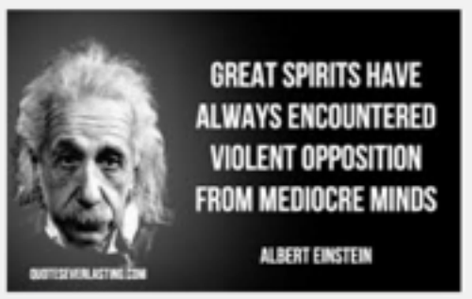












... da könnt’ mir halt der liebe Gott leid tun, die Theorie stimmt doch.

–Einstein, controversieel citaat, via Ilse Rosenthal-Schneider

I want to know how God created this world. I'm not interested in this or that phenomenon, in the spectrum of this or that element. I want to know His thoughts; the rest are details.

–Einstein, controversieel citaat, via Esther Salaman

> While it is true that scientific results are entirely independent from religious or moral considerations, those individuals to whom we owe the great creative achievements of science were all of them imbued with the truly religious conviction that this universe of ours is something perfect and susceptible to the rational striving for knowledge.

Einstein, A., 1941, “Science, Philosophy and Religion, A Symposium”, *Conference on Science, Philosophy and Religion in Their Relation to the Democratic Way of Life*, New York.

Nog eens alles lezen?