Einstein's Universe

General relativity and the big bang

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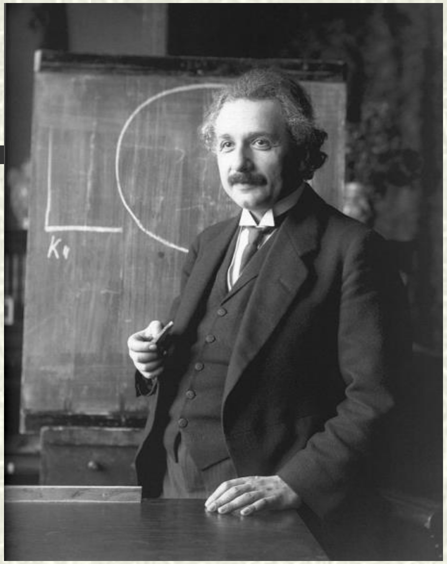
Overview



- **100 years of general relativity**
  - *The special theory of relativity*
  - *The general theory of relativity*
- **General relativity and the universe**
  - *The expanding universe*
  - *The big bang model*
- **Einstein's universe**
  - *Some new findings*

Einstein in California (1931)

100 years of general relativity

First formulation of the equations of GR (1915)

First full formulation of the theory of GR (1916)

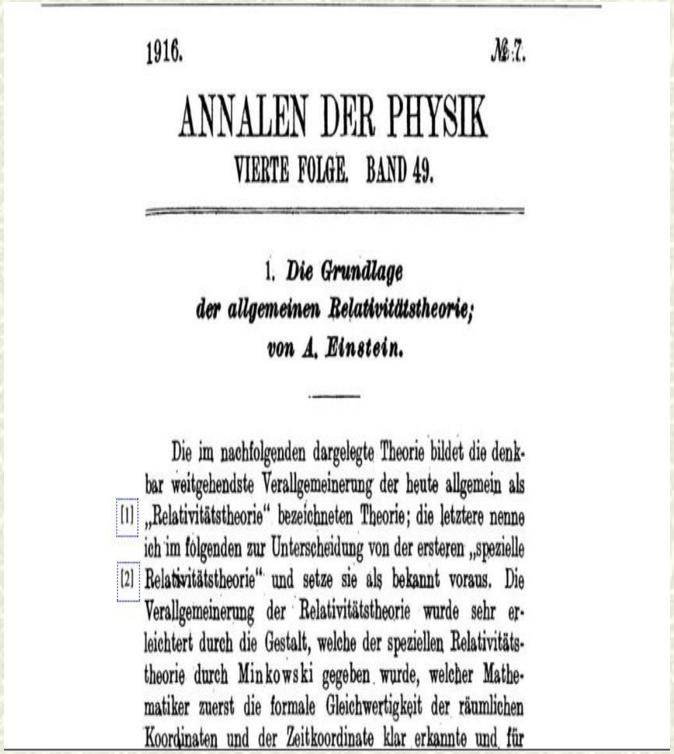
844 Sitzung der physikalisch-mathematischen Klasse vom 25. November 1915

Die Feldgleichungen der Gravitation.

Von A. EINSTEIN.

In zwei vor kurzem erschienenen Mitteilungen[1] habe ich gezeigt, wie man zu Feldgleichungen der Gravitation gelangen kann, die dem Postulat allgemeiner Relativität entsprechen, d. h. die in ihrer allgemeinen Fassung beliebigen Substitutionen der Raumzeitvariabeln gegenüber kovariant sind.

Der Entwicklungsgang war dabei folgender. Zunächst fand ich Gleichungen, welche die NEWTONSCHE Theorie als Näherung enthalten und beliebigen Substitutionen von der Determinante 1 gegenüber kovariant waren. Hierauf fand ich, daß diesen Gleichungen allgemein kovariante entsprechen, falls der Skalar des Energietensors der »Materie« verschwindet. Das Koordinatensystem war dann nach der einfachen Regel zu spezialisieren, daß $\sqrt{-g}$ zu 1 gemacht wird, wodurch die Gleichungen der Theorie eine eminente Vereinfachung erfahren. Dabei mußte aber, wie erwähnt, die Hypothese eingeführt werden,



1916. № 7.

ANNALEN DER PHYSIK

VIERTE FOLGE. BAND 49.

1. *Die Grundlage der allgemeinen Relativitätstheorie;*
von A. Einstein.

Die im nachfolgenden dargelegte Theorie bildet die denkbar weitgehendste Verallgemeinerung der heute allgemein als [1] „Relativitätstheorie" bezeichneten Theorie; die letztere nenne ich im folgenden zur Unterscheidung von der ersteren „spezielle [2] Relativitätstheorie" und setze sie als bekannt voraus. Die Verallgemeinerung der Relativitätstheorie wurde sehr erleichtert durch die Gestalt, welche der speziellen Relativitätstheorie durch Minkowski gegeben wurde, welcher Mathematiker zuerst die formale Gleichwertigkeit der räumlichen Koordinaten und der Zeitkoordinate klar erkannte und für

The special theory of relativity

- **Two new principles (1905)**

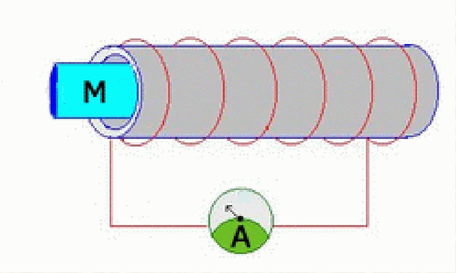
  Laws of physics identical for observers in uniform motion

  Speed of light identical for observers in uniform motion

- **Implications**

  Distance and time not absolute

  Distance and time not identical for bodies in uniform motion



- **Predictions for high-speed bodies**

  Length contraction; time dilation

  Mass increase; mass-energy equivalence $E = mc^2$

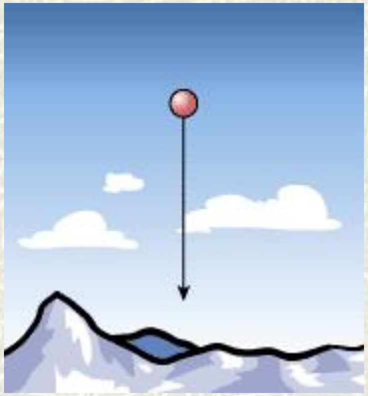
- **Space + time = spacetime**

$$ds^2 = dx^2 + dy^2 + dz^2 - c^2dt^2$$

Evidence for special relativity

- **Invariance of the speed of light**

  Always measured as c



- **Time dilation**

  The long-lived muon

$2\ \mu s \rightarrow 22\ \mu s$

- **Particle experiments at the LHC**

  Maximum velocity = c

  Mass increase

  Particle creation $E = mc^2$

The general theory of relativity (1916)

- **General relativity**

  Relativity and accelerated motion?

  Relativity and gravity?

- **The equivalence principle**

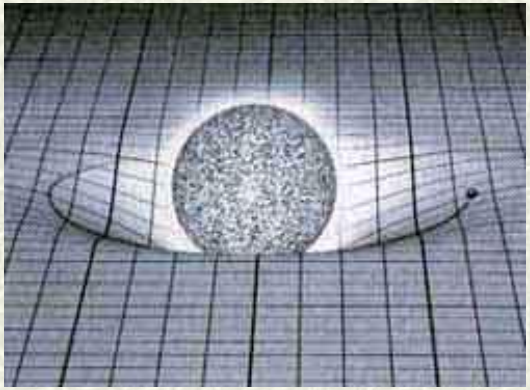
  No distinction between inertial and gravitational mass

- **A new theory (1916)**

  Space-time distorted by mass

  Gravity = curvature of space-time

$$G_{\mu\nu} = -\kappa T_{\mu\nu}$$

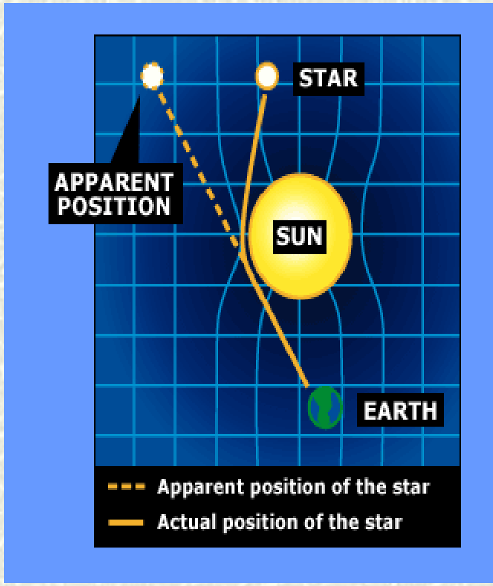


- **Evidence**

  Orbit of Mercury

  Bending of starlight by the sun (Eddington, 1919)

Evidence for general relativity



- **Bending of distant light by stars**

  Gravitational lensing

- **Gravitational time dilation**

  GPS corrections

- **Black holes** $G_{\mu\nu} = -\kappa T_{\mu\nu}$

  Centre of galaxies

- **Gravitational waves**

  Hulse-Taylor (1979): energy loss in binary pulsar

  LIGO (2016); gravitational waves

II Relativity and the universe

- **Apply general relativity to the cosmos (1917)**

  Ultimate test for new theory of gravity

- **Dynamic universe?**

  Expanding or contracting

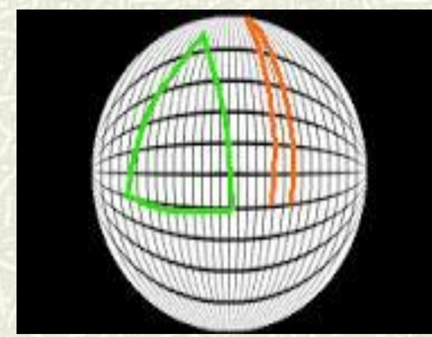
$$G_{\mu\nu} = -\kappa T_{\mu\nu}$$

- **Static universe (observation)**

  Add new term to field equations

  Cosmological constant λ

$$G_{\mu\nu} + \lambda g_{\mu\nu} = -\kappa T_{\mu\nu}$$



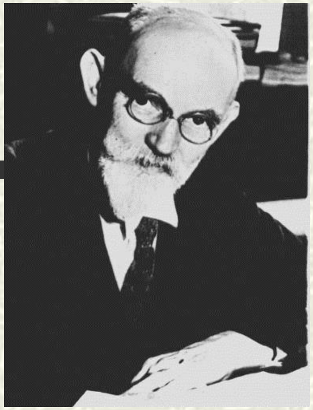
Static, bounded universe

- **Bounded universe**

  Cosmic radius and matter density defined by λ

  No empty space at infinity (Mach's principle)

De Sitter's universe (1917)



- **Alternative static solution**

  'Empty' universe

$$G_{\mu\nu} + \lambda g_{\mu\nu} = 0$$

- **Disliked by Einstein**

  Conflict with Mach's principle

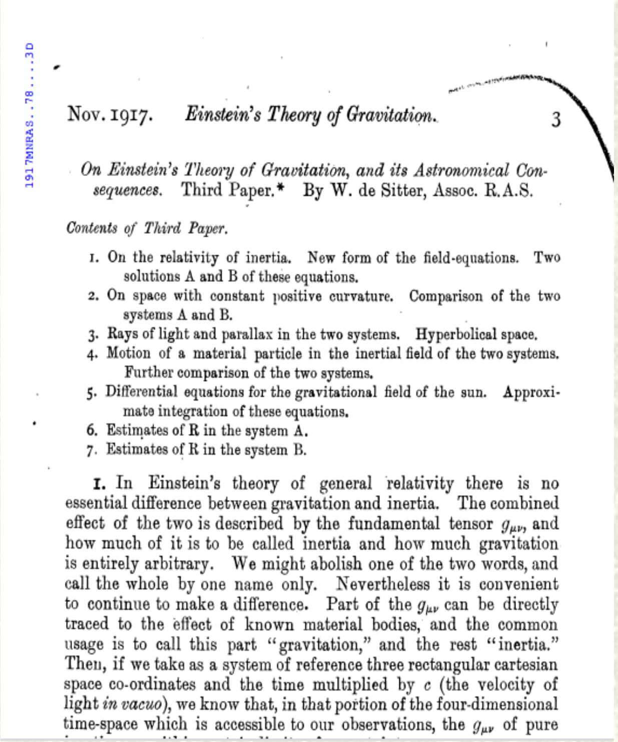
  Beginning of Einstein's dislike for cosmic constant

- **Interest from astronomers**

  Prediction of redshifts – Slipher effect?

  Confusion: static or non-static model?

  Weyl 1923, Lanczos 1923, Lemaître 1925



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. In Einstein's theory of general relativity there is no essential difference between gravitation and inertia. The combined effect of the two is described by the fundamental tensor $g_{\mu\nu}$, and how much of it is to be called inertia and how much gravitation is entirely arbitrary. We might abolish one of the two words, and call the whole by one name only. Nevertheless it is convenient to continue to make a difference. Part of the $g_{\mu\nu}$ can be directly traced to the effect of known material bodies, and the common usage is to call this part "gravitation," and the rest "inertia." Then, if we take as a system of reference three rectangular cartesian space co-ordinates and the time multiplied by c (the velocity of light *in vacuo*), we know that, in that portion of the four-dimensional time-space which is accessible to our observations, the $g_{\mu\nu}$ of pure

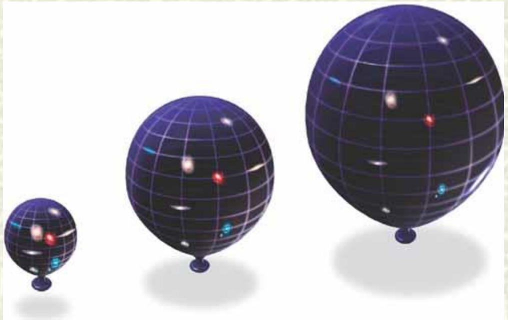
Friedman's universe

Alexander Friedman
(1888 -1925)

- **Allow time-varying solutions (1922)**

  Closed spatial curvature

$$G_{\mu\nu} + \lambda g_{\mu\nu} = -\kappa T_{\mu\nu}$$

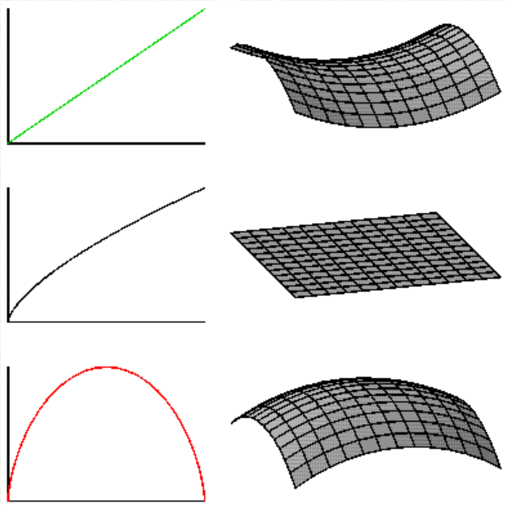


- **Expanding or contracting universe**

- **Badly received**

  Considered "suspicious" by Einstein

  "To this a physical reality can hardly be ascribed"



- **Further Friedman models (1924)**

  Negative spatial curvature

  Cosmic evolution, geometry depends on matter content

Lemaître's universe (1927)

Fr Georges Lemaître

- **Expanding model of the cosmos from GR**

- **Compare with astronomy**

  Redshifts of the spiral nebulae (Slipher)

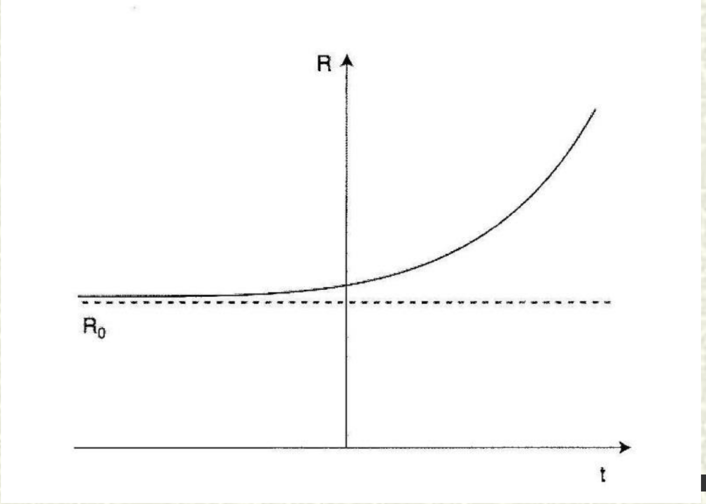
  Distances of the spiral nebulae (Hubble)

  Evidence of cosmic expansion?

- **Ignored by community**

  Belgian journal (in French)

  Einstein: "Votre physique est abominable"



The watershed (1929)

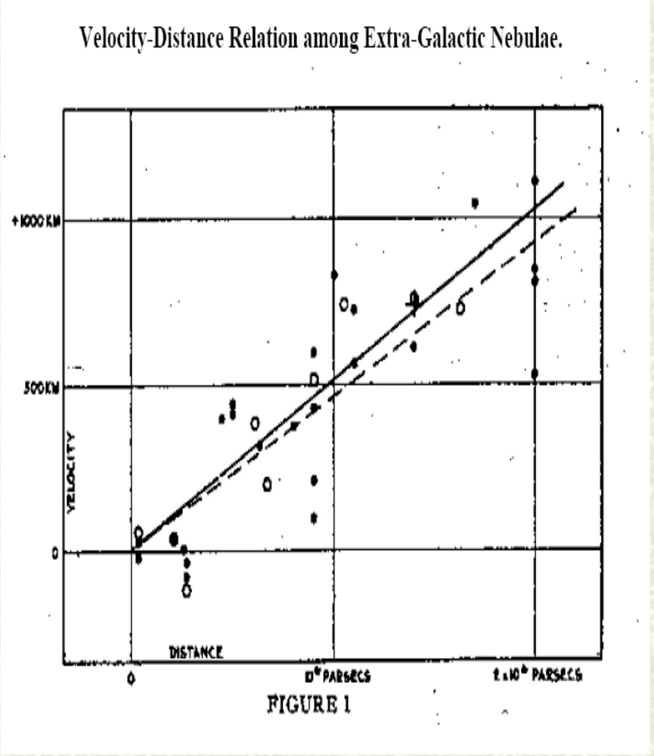
Edwin Hubble (1889-1953)

- Spiral nebulae far beyond Milky Way

  A universe of galaxies (1925)

- A linear relation between redshift and distance : Hubble's law (1929)

  $\boldsymbol{v} = H_o \boldsymbol{d}$ *with* $H = 500\ kms^{-1}Mpc^{-1}$



- Landmark result in astronomy

  Far-away galaxies rushing away

  at a speed proportional to distance

The expanding universe (1930)

- **RAS meeting (1930)**

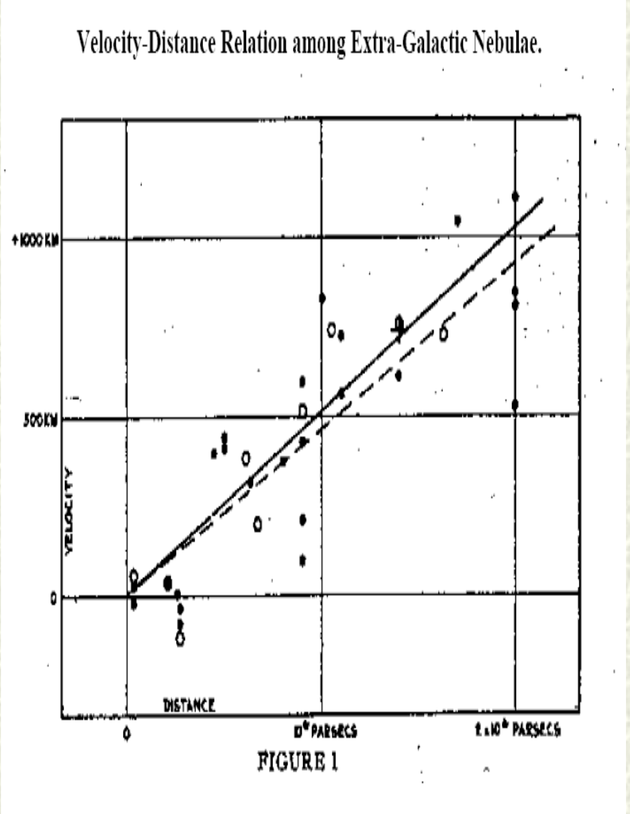
  If redshifts are velocities, and if effect is non-local
  Static cosmic models don't match observations

- **Expanding universe?**

  Hubble's law = expansion of space?
  $H = 500\ kms^{-1}Mpc^{-1}$

- **Friedman-Lemaître model circulated**

  Time-varying radius
  Evolving models
  Time-varying density of matter



Models of the expanding universe

- **Eddington (1930, 31)**

  On the instability of the Einstein universe
  Expansion caused by condensation?

- **Tolman (1930, 31)**

  On the behaviour of non-static models
  Expansion caused by annihilation of matter ?

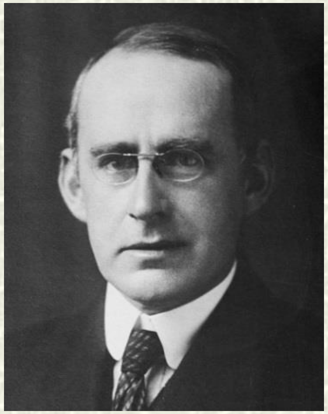
- **de Sitter (1930, 31)**

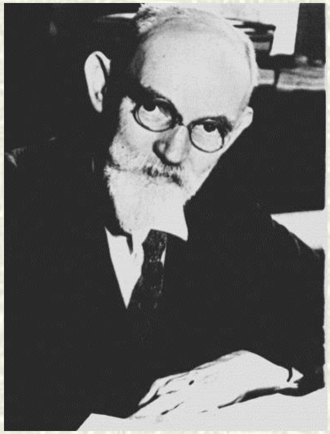
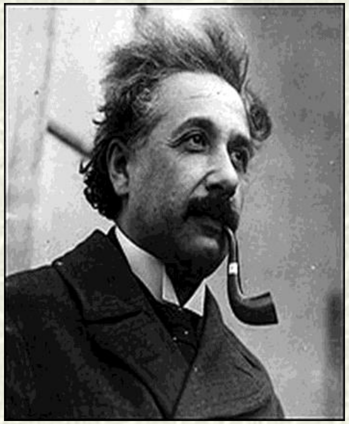
  Further remarks on the expanding universe
  Expanding universes of every flavour

- **Einstein (1931, 32)**

  Friedman-Einstein model $\lambda = 0 , k = 1$
  Einstein-de Sitter model $\lambda = 0, k = 0$

  New: also a steady –state model



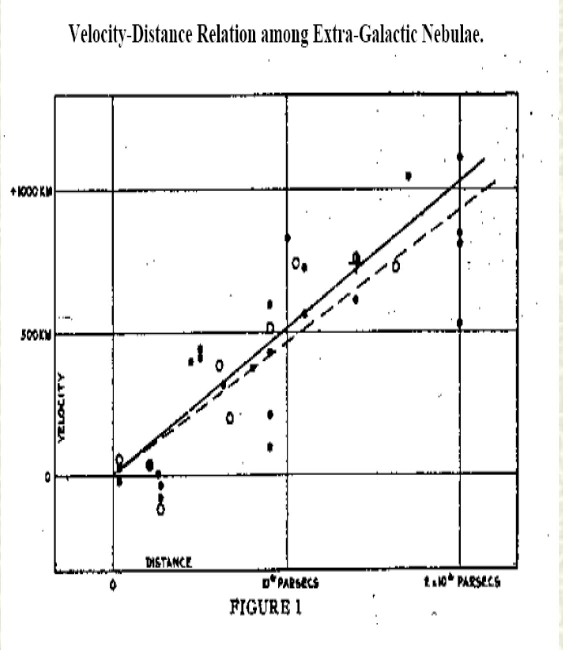



$$G_{\mu\nu} = - \kappa T_{\mu\nu}$$

The big bang model (1931)

- Expanding *U* smaller in the past
- Rewind to early epochs
- Extremely dense, extremely hot
- Explosive beginning at $R = 0$?
- Expanding and cooling ever since

Fr Georges Lemaître



Later called ***<u>'The big bang'</u>***

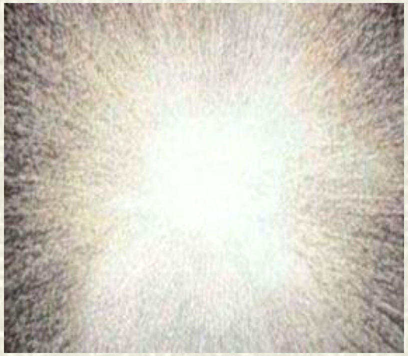
A second line of evidence

- **How were the chemical elements formed?**
  In the stars? Why so much Hydrogen?

- **Elements formed in the hot big bang?**
  Georges Gamow
  Predicts U = 75% Hydrogen, 25% Helium

Georges Gamow

- **Agreement with observation**
  Victory for big bang model
  (Heavier atoms formed in stars)



A third line of evidence

- **Infant universe very hot indeed**

  Dominated by radiation

- **Still observable today?**

  A fossil from the early universe

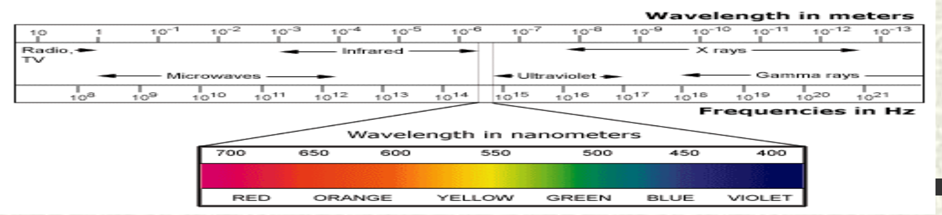
- **The cosmic microwave background**

  Low temp, microwave frequency

  Released when atoms formed (300,000 yr)

Alpher, Gamow and Herman

<u>No-one looked (1940s)</u>



Steady-state universe (1948)

- **Alternative to big bang**

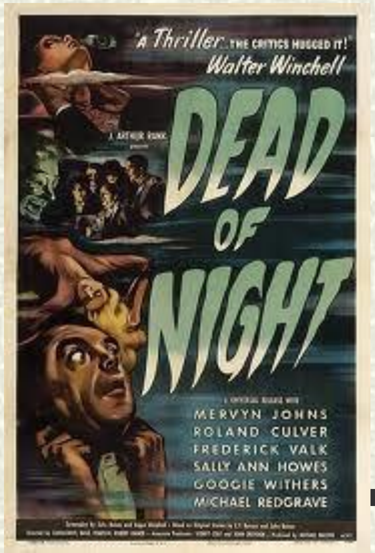
  Hoyle, Bondi and Gold

- **Expanding, unchanging universe?**

- **Continuous creation of matter**

  Very little matter needed

- **No assumptions about early epochs**

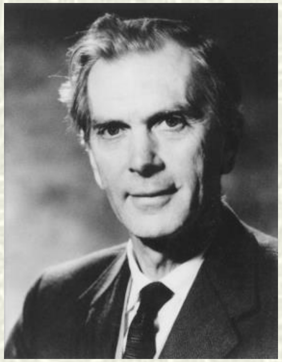


Steady-state vs big bang

- **Radio-astronomy (1950s, 1960s)**

  Galaxy distributions at different epochs

  Evidence of evolution



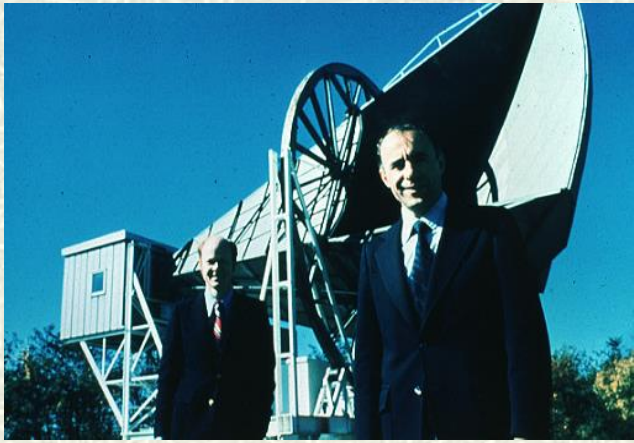
Martin Ryle

- **Quasars, pulsars (1960s)**

- **Cosmic microwave background (1965)**

  Low temperature, low frequency

  Remnant of young, hot universe



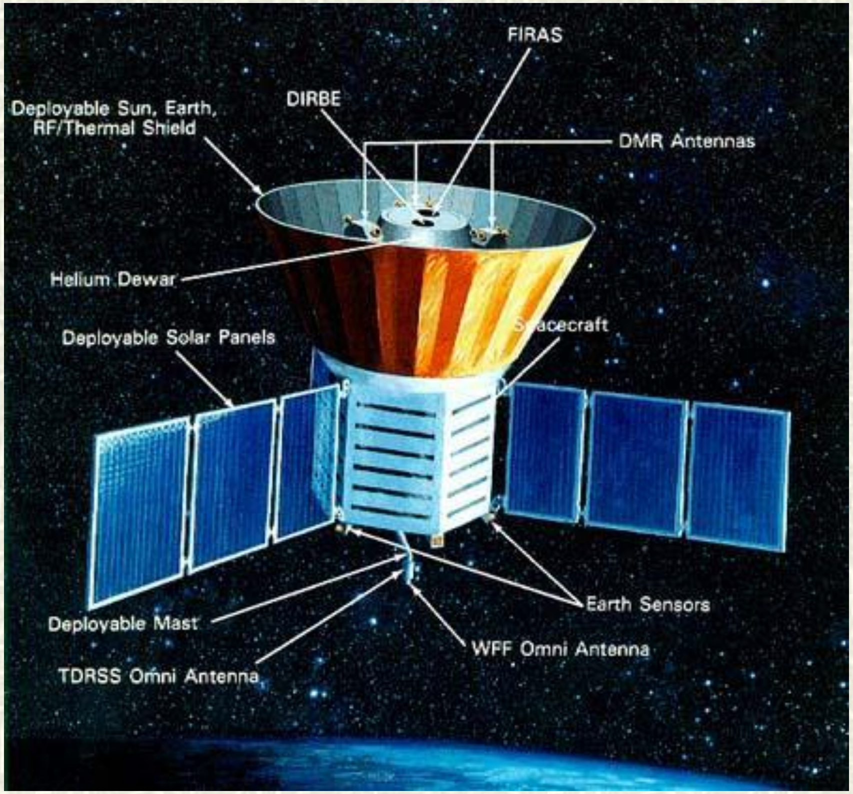
Strong support for big bang model

Penzias and Wilson (1965)

Modern measurements of the CMB

- Details of background radiation
- Full spectrum
- Comparison with theory
- Perturbations?

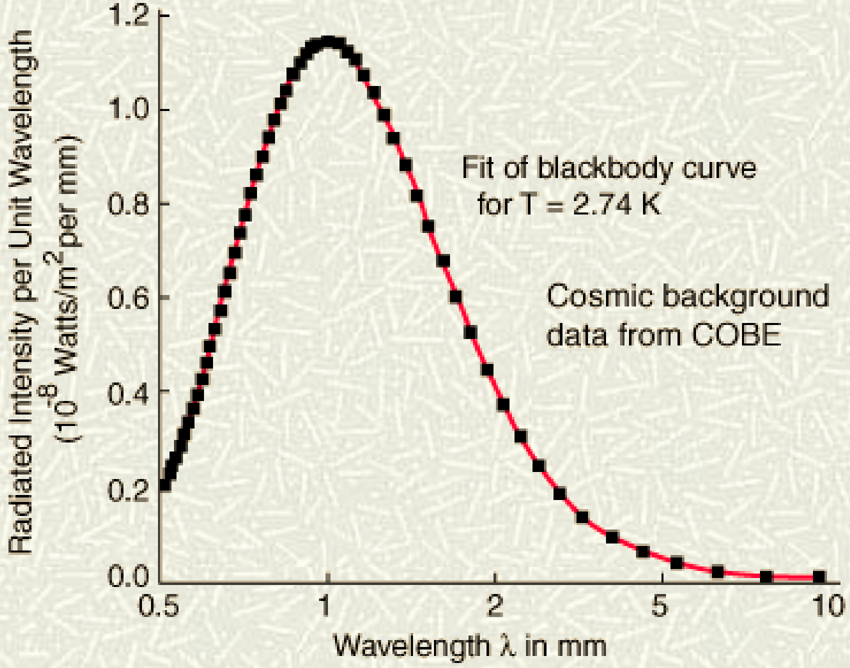
  - ***Ground telescopes***
  - ***Balloon experiments***
  - ***Satellite experiments***



COBE satellite (1992)

COBE measurements of CMB

- Expected temperature
- Expected frequency
- Perfect blackbody spectrum



- *Radiation very uniform*
- *Variation of 1 in* 10^5
- *Seeds of galaxies ?*

COBE (1992)

Nobel Prize

The big bang – evidence

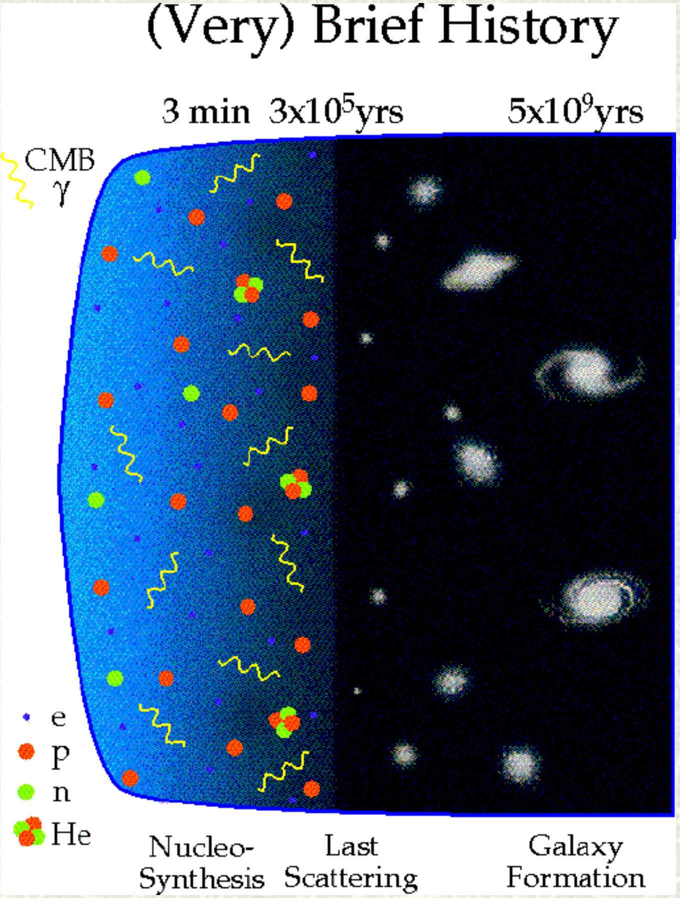
1. The expansion of the *U*

2. The abundance of ***H*** and ***He***

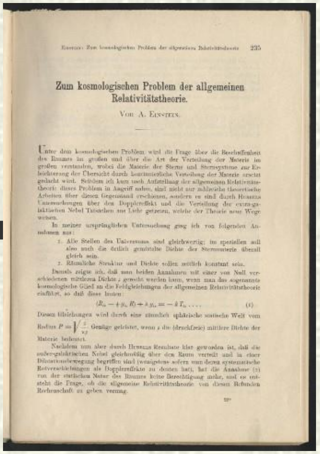
3. The distribution of the galaxies

4. The cosmic microwave background

How did it start?



III Einstein’s 1931 model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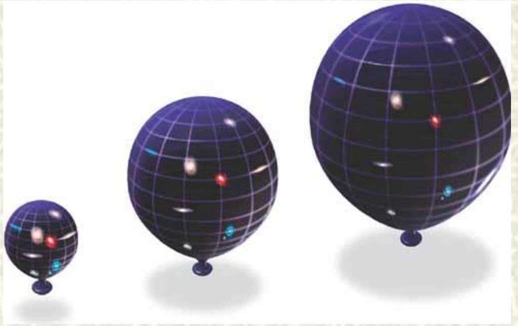
Zum kosmologischen Problem der allgemeinen Relativitätstheorie.

Von A. Einstein.

- **Einstein’s first dynamic model of the cosmos**

  Rarely cited (German)



- **Adopts Friedman 1922 model**

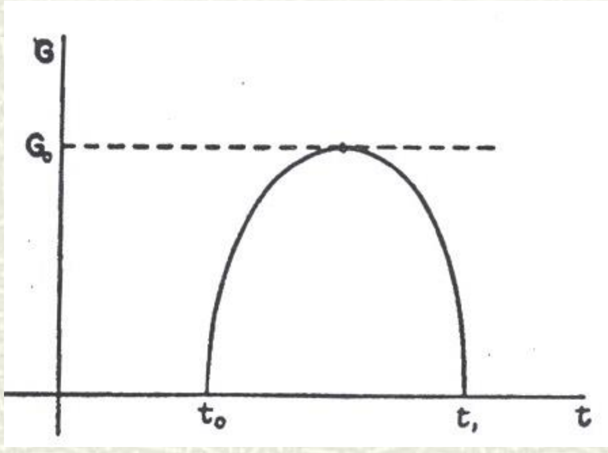
  Time-varying, closed universe: $k = 1$

  Cosmic constant redundant: set $\lambda = 0$

- **Use Hubble to extract empirical parameters**

  Radius $R \sim 10^8$ lyr , *timespan 10^{10}* yr

  Density of matter $\rho \sim 10^{-26}$ g/cm^3



- **<u>Not a cyclic model</u>**

Einstein’s 1931 model (research)

- **First translation into English**

  O’Raifeartaigh and McCann 2014

- **Anomalies in calculations**

  $R \sim 10^{8}$ lyr : *should be 10^{9} lyr*

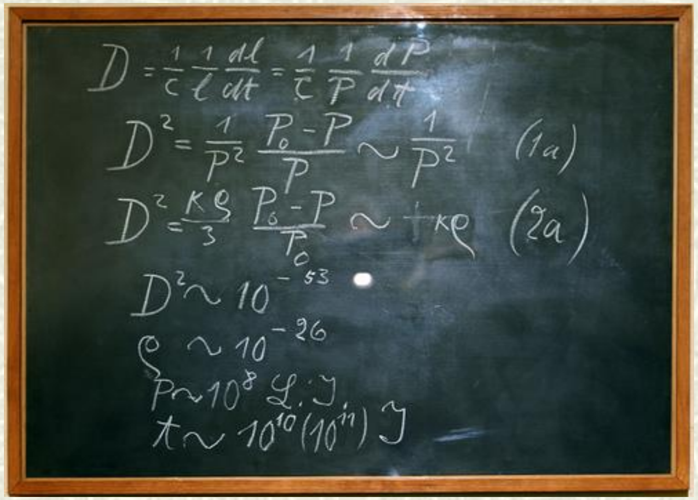
  $\rho \sim 10^{-26}$ g/cm^{3} : *should be 10^{-28} g/cm^{3}*

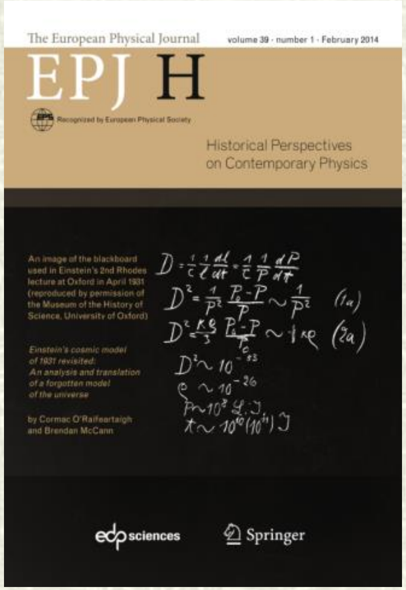
  $t \sim 10^{10}$ yr : *should be 10^{9} yr*

- **Error in Hubble constant**

  Oxford blackboard: $D^{2} \sim 10^{-53}$ cm^{-2}

- **Implications for timespan problem**





Finding 2: Einstein's steady-state model

- **Unpublished manuscript**

  Archived as draft of Einstein's 1931 model

- **Steady-state model**

  Expanding model of constant density

  "The density is constant and determines the expansion"

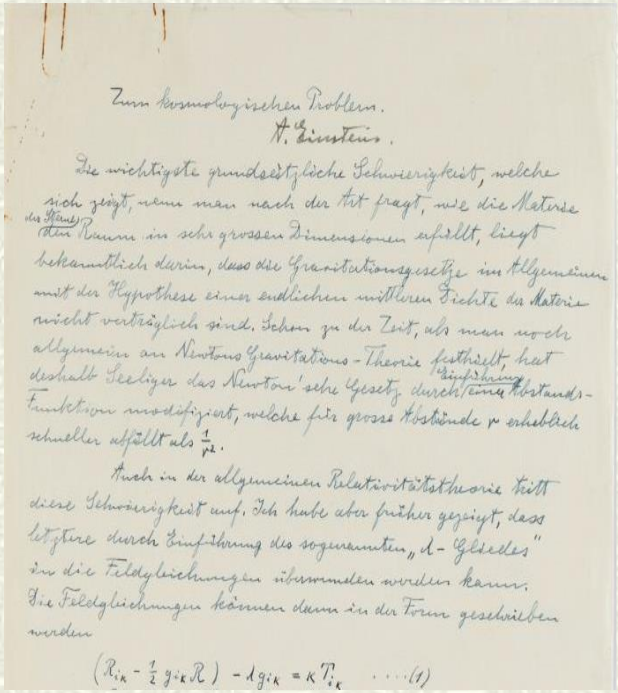
- **Continuous creation**

  Continuous formation of matter from vacuum

  Associated with cosmic constant

- **Fatal flaw: abandoned**

  Evolving models adopted instead

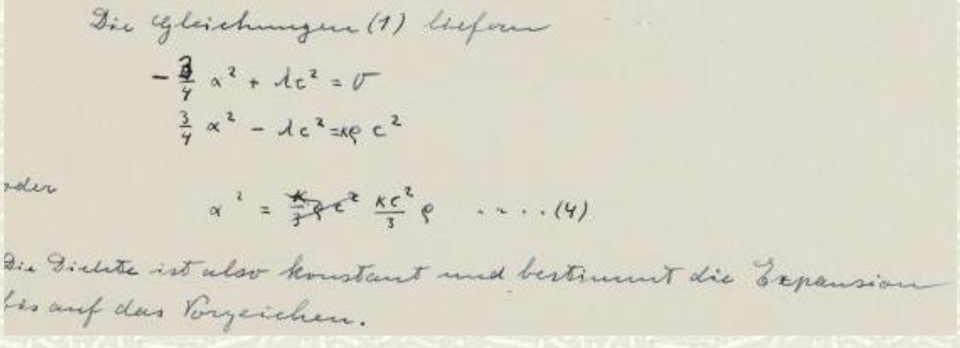


Zum kosmologischen Problem.
A. Einstein.

Die wichtigste grundsätzliche Schwierigkeit, welche sich zeigt, wenn man nach der Art fragt, wie die Materie den Raum in sehr grossen Dimensionen erfüllt, liegt bekanntlich darin, dass die Gravitationsgesetze im Allgemeinen mit der Hypothese einer endlichen mittleren Dichte der Materie nicht verträglich sind. Schon zu der Zeit, als man noch allgemein an Newtons Gravitations-Theorie festhielt, hat deshalb Seeliger das Newton'sche Gesetz durch Einführung einer Abstands-Funktion modifiziert, welche für grosse Abstände r erheblich schneller abfällt als $\frac{1}{r^2}$.

Auch in der allgemeinen Relativitätstheorie tritt diese Schwierigkeit auf. Ich habe aber früher gezeigt, dass letztere durch Einführung des sogenannten „λ-Gliedes" in die Feldgleichungen überwunden werden kann. Die Feldgleichungen können dann in der Form geschrieben werden

$$\left(R_{ik} - \frac{1}{2} g_{ik} R\right) - \lambda g_{ik} = \kappa T_{ik} \quad \ldots (1)$$



Die Gleichungen (1) liefern

$$-\frac{3}{4}\alpha^2 + \lambda c^2 = 0$$

$$\frac{3}{4}\alpha^2 - \lambda c^2 = \kappa \rho c^2$$

oder

$$\alpha^2 = \frac{\kappa c^2}{3} \rho \quad \ldots (4)$$

Die Dichte ist also konstant und bestimmt die Expansion bis auf das Vorzeichen.

Abandoned model

- **Correct geometry**

  de Sitter line element

- **Simultaneous equations**

  Error in derivation

  Null solution

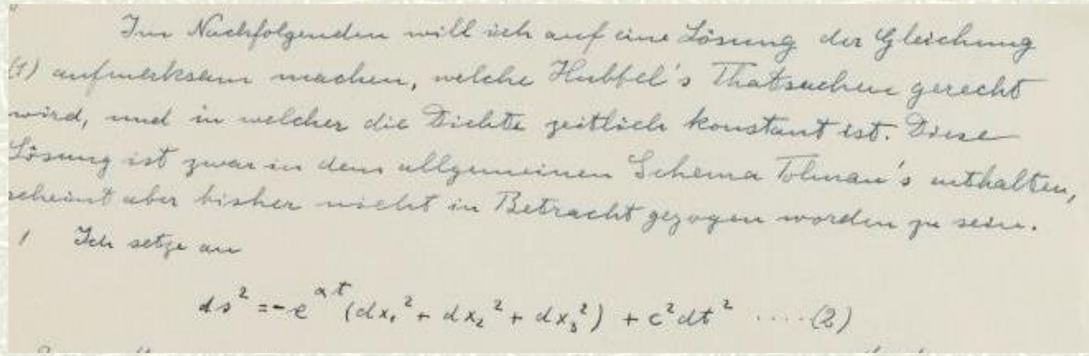
- **Einstein's crossroads**

  Realised problem on revision

  Declined to amend model

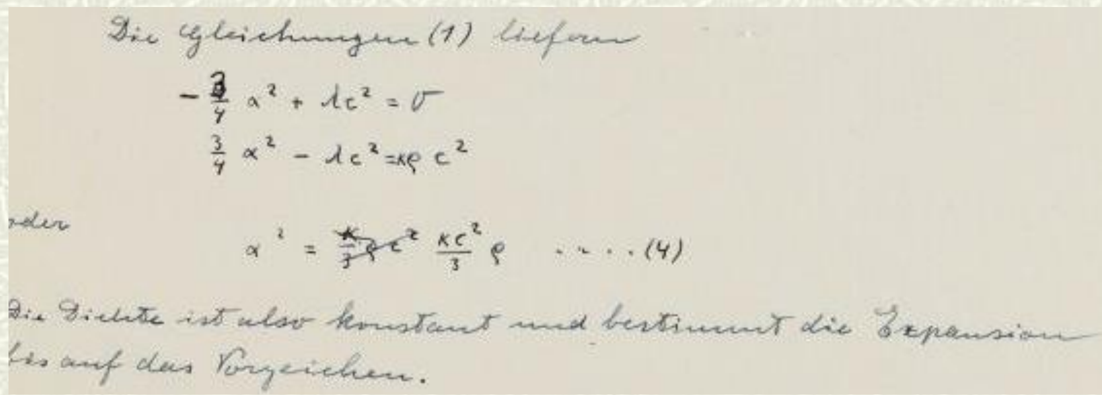
- **Evolving models**

  Less contrived and set $\lambda = 0$


Im Nachfolgenden will ich auf eine Lösung der Gleichung (1) aufmerksam machen, welche Hubbel's Thatsachen gerecht wird, und in welcher die Dichte zeitlich konstant ist. Diese Lösung ist zwar in dem allgemeinen Schema Tolman's enthalten, scheint aber bisher nicht in Betracht gezogen worden zu sein.

Ich setze an

$$ds^2 = -e^{\alpha t}(dx_1^2 + dx_2^2 + dx_3^2) + c^2dt^2 \quad \ldots (2)$$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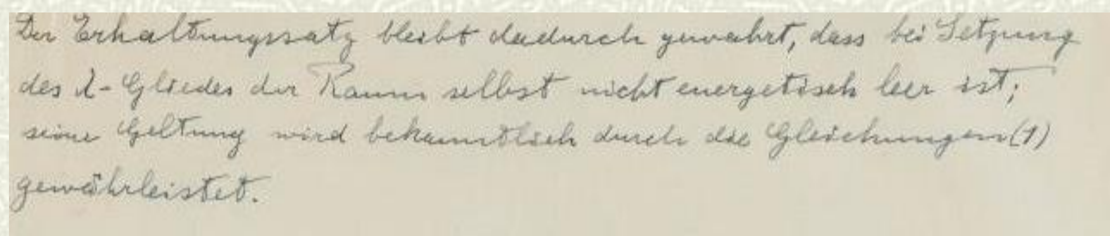
Der Erhaltungssatz bleibt dadurch gewahrt, dass bei Setzung des λ-Gliedes der Raum selbst nicht energetisch leer ist; seine Geltung wird bekanntlich durch die Gleichungen (1) gewährleistet.

nature International weekly journal of science

NATURE | NEWS

Einstein's lost theory uncovered

Physicist explored the idea of a steady-state Universe in 1931.

Davide Castelvecchi

24 February 2014

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SCIENTIFIC AMERICAN™

Einstein's Lost Theory Uncovered

The famous physicist explored the idea of a steady-state universe in 1931

nature

Feb 25, 2014 | By Davide Castelvecchi and Nature magazine

A manuscript that lay unnoticed by scientists for decades has revealed that Albert Einstein once dabbled with an

New Discovery Reveals Einstein Tried To Devise A Steady State Model Of The Universe

2 comments, 2 called-out + Comment Now + Follow Comments

Almost 20 years before the late Fred Hoyle and his colleagues devised the Steady State Theory, Albert Einstein toyed with a similar idea: that the universe was eternal, expanding outward with a consistent input of spontaneously generating matter.

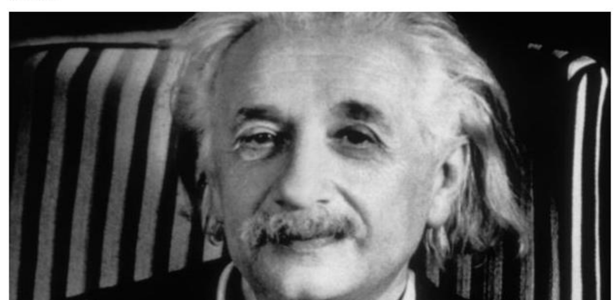
An Irish physicist came across the paper last year and could hardly believe According to this week's article in Nature,

model of the universe very different to today's Big Bang Theory.

The manuscript, which hadn't been referred to by scientists for decades,

WIT researchers discover 'lost' Einstein model of universe

Scientists uncovered misfiled papers while searching Jerusalem university's online archive



100 years of general relativity

- **Published May 1916**

  From Swiss patent office to Berlin

- **A new theory of gravity**

  Gravity = curvature of spacetime

- **Predictions supported by experiment**

  Bending of light by a star

  Expanding universe

  Gravitational time dilation (GPS)

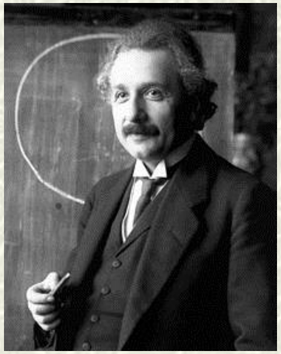
- **One more test**

  Gravitational waves - LIGO 2016!

Einstein in Berlin (1918)

Einstein's universe: conclusions

- **Cosmology = test for general relativity**
  Introduces cosmic constant

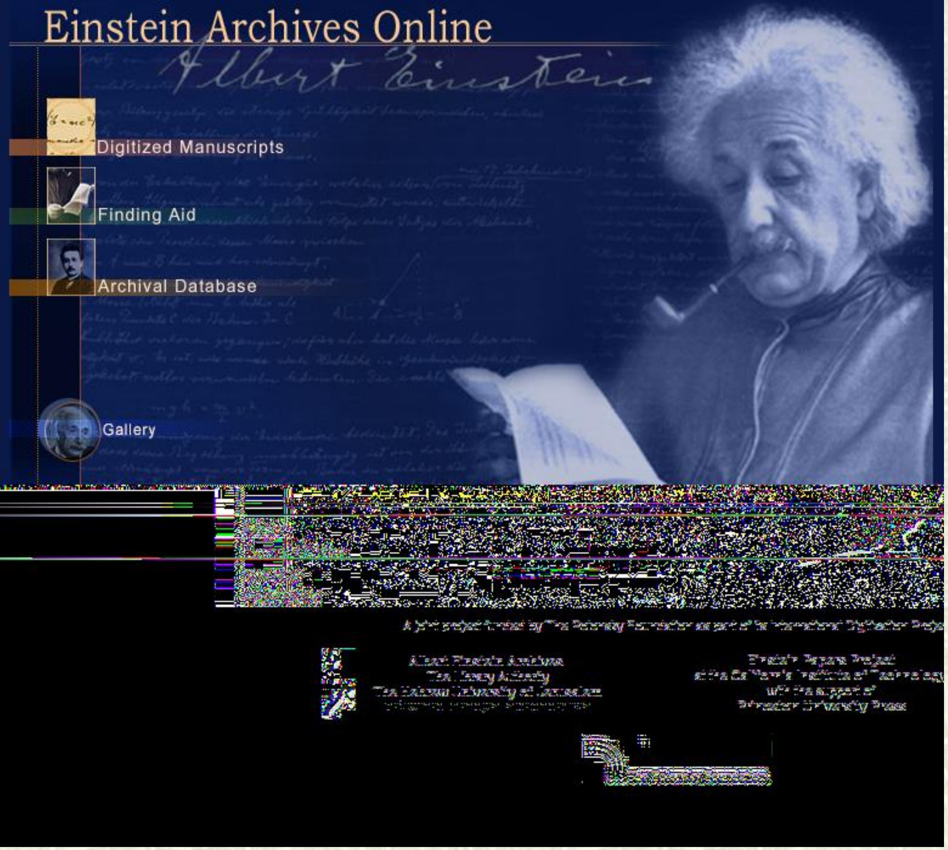


- **Embraces dynamic cosmology**
  New evidence – new models
  Steady-state model
  Evolving models simpler: remove cosmic constant

- **The evolving universe**
  Extract observational parameters
  Timespan problem attributed to simplifying assumptions

Hubble constant revised

- **No discussion of origins**
  Wary of extrapolations to early epochs



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JPG
Über das sogenannte kosmologische Problem.
by Einstein, Albert (Author)
Date: 1932-09-01
Archival Call Number: 1-115
Document Type: Autograph Draft of Document (ADDft)

DB Info
Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie.
by Einstein, Albert (Author)
Date: 1917-02-08
Archival Call Number: 90-9
Document Type: Printed Document (PD)

DB Info
Die Beantwortung Ihrer Frage, überhaupt kosmologischer Fragen
by Einstein, Albert (Author)
Date: 1929-09-20
Archival Call Number: 25-231
Document Type: Carbon/File Copy of Typed Letter (TLC)

DB Info
Das kosmologische Glied soll überholt sein.
by Hopf, Ludwig (Author)
Date: 1932-06-14
Archival Call Number: 13-306
Document Type: Autograph Letter Signed (ALS)

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Über das sogenannte kosmologische Problem.

Archival Call Number:	1-115
Begin Date:	1932-09-01
End Date:	1932-09-30
Main Author:	Einstein, Albert (Author)
Other Persons:	Mayer, Walther (Author)
Language:	German
Archival Location:	Albert Einstein Archives, The Hebrew University of Jerusalem, Israel
Number of Pages:	11.

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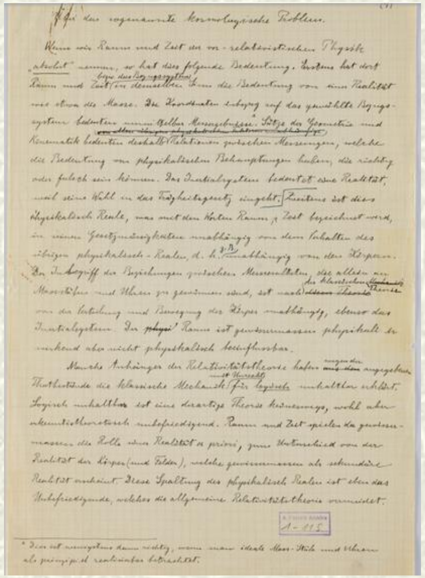
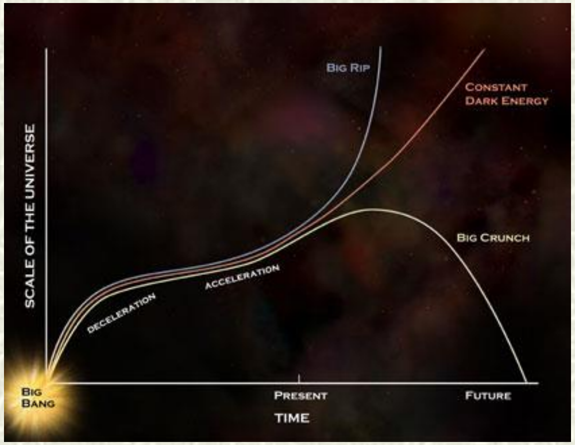


Einstein's steady-state model and cosmology today



- **Dark energy (1998)**

  Accelerated expansion (observation)

  Positive cosmological constant

- **Einstein's dark energy**

  "The conservation law is preserved in that, by setting the λ-term, space itself is not empty of energy; its validity is well known to be guaranteed by equations (1)."

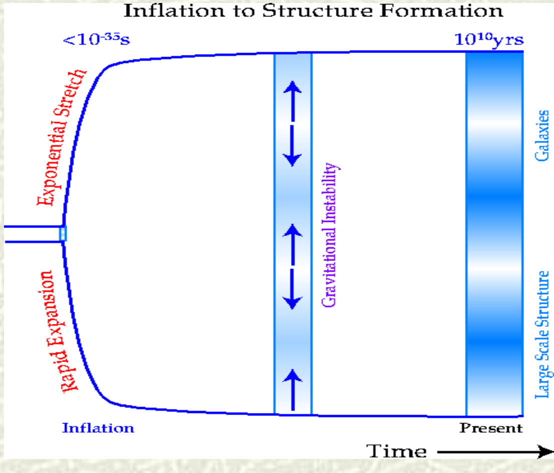
- **Cosmic inflation**

  Inflationary models use de Sitter metric

  Used in all steady-state models

  Flat curvature, constant rate of matter creation

  Different time-frame!



Einstein's steady-state model: key quotes

New solution

"In what follows, I wish to draw attention to a solution to equation (1) that can account for Hubbel's facts, and in which the density is constant over time"

Matter creation

"If one considers a physically bounded volume, particles of matter will be continually leaving it. For the density to remain constant, new particles of matter must be continually formed within that volume from space "

Dark energy

"The conservation law is preserved in that, by setting the λ-term, space itself is not empty of energy; its validity is well known to be guaranteed by equations (1)."

Einstein-de Sitter model (1932)

- **Curvature not a given in dynamic models**

  Not observed empirically

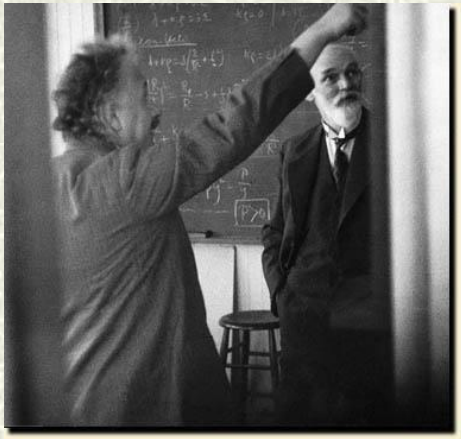
  Remove spatial curvature (Occam's razor)

$$ds^2 = -R^2(dx^2 + dy^2 + dz^2) + c^2dt^2$$

$$\frac{3R'^2}{R^2} + \frac{3c^2}{R^2} - \lambda = \kappa c^2 \rho,$$

$$\frac{1}{R^2}\left(\frac{dR}{cdt}\right)^2 = \frac{1}{3}\kappa\rho.$$

$$h^2 = \frac{1}{3}\kappa\rho$$



- **Simplest Friedman model**

  Time-varying universe with $\lambda = 0$, $k = 0$

  Important hypothetical case: critical universe

  Critical density : $\rho = 10^{-28}$ g/cm^3

- **<u>Becomes standard model</u>**

  Despite high density of matter

  Despite age problem

<u>Time evolution not considered in paper – see title</u>

PROCEEDINGS
OF THE
NATIONAL ACADEMY OF SCIENCES
Volume 18 March 15, 1932 Number 3

ON THE RELATION BETWEEN THE EXPANSION AND THE MEAN DENSITY OF THE UNIVERSE

BY A. EINSTEIN AND W. DE SITTER

Communicated by the Mount Wilson Observatory, January 25, 1932

In a recent note in the *Göttinger Nachrichten*, Dr. O. Heckmann has pointed out that the non-static solutions of the field equations of the general theory of relativity with constant density do not necessarily imply a positive curvature of three-dimensional space, but that this curvature may also be negative or zero.

Einstein-de Sitter model revisited

- **Einstein's cosmology review of 1933**

  Review of dynamic models from first principles

  Culminates in Einstein-de Sitter model

  Cosmic constant banished

  Possibility of flat geometry

- **Parameters extracted**

  Critical density of 10^{-28} g/cm^3 : reasonable

  Timespan of 10^{10} years: conflict with astrophysics

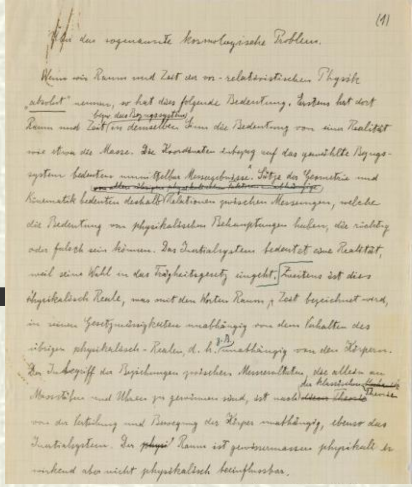
  Attributed to simplifications (incorrect estimate)

- **Published in 1933!**

  French book; small print run

  Intended for scientific journal; not submitted

  Significant paper


(1)
... das sogenannte kosmologische Problem.
Wenn wir Raum und Zeit der vor-relativistischen Physik „absolut" nennen, so hat dies folgende Bedeutung. Erstens hat dort Raum und Zeit (bezw. das Bezugssystem) in demselben Sinne die Bedeutung von einer Realität wie etwa die Masse. Die Koordinaten in Bezug auf das gewählte Bezugssystem bedeuten unmittelbar Messergebnisse. Sätze der Geometrie und Kinematik bedeuten deshalb Relationen zwischen Messungen, welche die Bedeutung von physikalischen Behauptungen haben, die richtig oder falsch sein können. Das Inertialsystem bedeutet eine Realität, weil seine Wahl in das Trägheitsgesetz eingeht. Zweitens ist dies physikalisch Reale, was mit den Worten Raum + Zeit bezeichnet wird, in seinen Gesetzmässigkeiten unabhängig von dem Verhalten des übrigen physikalisch-Realen, d. h. z.B. unabhängig von den Körpern. Der Inbegriff der Beziehungen zwischen Messresultaten, die allein an Massstäben und Uhren zu gewinnen sind, ist nach der klassischen Theorie von der Verteilung und Bewegung der Körper unabhängig, ebenso das Inertialsystem. Der Raum ist gewissermassen physikalisch wirkend aber nicht physikalisch beeinflussbar.

$$2A\frac{d^2A}{dt^2} + \left(\frac{dA}{dt}\right)^2 = 0$$

$$3\left(\frac{\frac{dA}{dt}}{A}\right)^2 = \varkappa\rho c^2.$$

$$3h^2 = \varkappa\rho c^2 \;(= 8\pi K\rho)$$

$$A = c\,(t - t_0)^{\frac{2}{3}}.$$

$$t - t_0 = \frac{2}{3h}.$$

SUR LA STRUCTURE COSMOLOGIQUE DE L'ESPACE [1]

Si nous appelons l'espace et le temps de la physique prérelativiste « absolus », il faut y voir la signification suivante. Tout d'abord l'espace et le temps et, par suite, le système de référence, y figurent dans le même sens comme réalité que, par exemple, la masse. Les coordonnées du système de référence choisi y correspondent immédiatement à des résultats de mesure [2]. Les propositions de géométrie et de cinématique signifient pour cette raison des relations entre des mesures ayant la valeur d'affirmations physiques, qui peuvent être vraies ou fausses. Le système d'inertie possède une réalité physique, parce que son choix entre dans la loi d'inertie. En second lieu, cette réalité physique, qui est désignée par les termes espace + temps, est, quant à ses lois, indépendante du comportement des autres réalités physiques, par exemple, des corps.

Einstein’s steady-state theory: a significant find?

- **New perspective on steady-state theory (1950s)**

  Logical possibility: not a crank theory

- **Insight into scientific progress**

  Evolution of successful theories

  No Kuhnian paradigm shift to ‘big bang’ model

  Slow dawning

- **Insight into Einstein’s philosophy**

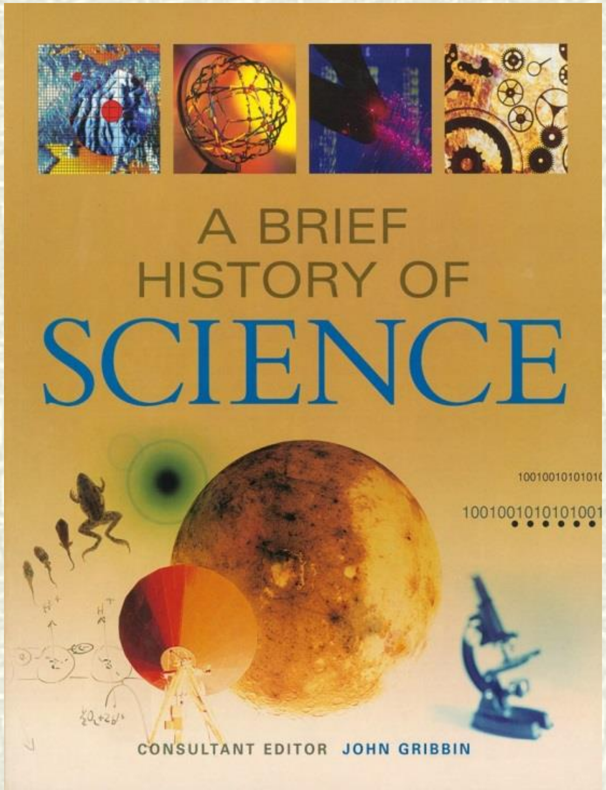
  Simple solution?

  Discards model rather than introduce new term to GFE

  Occam’s razor approach

- **Links with modern cosmology**

  Dark energy, cosmic inflation



Paradigm shift or slow dawning ?

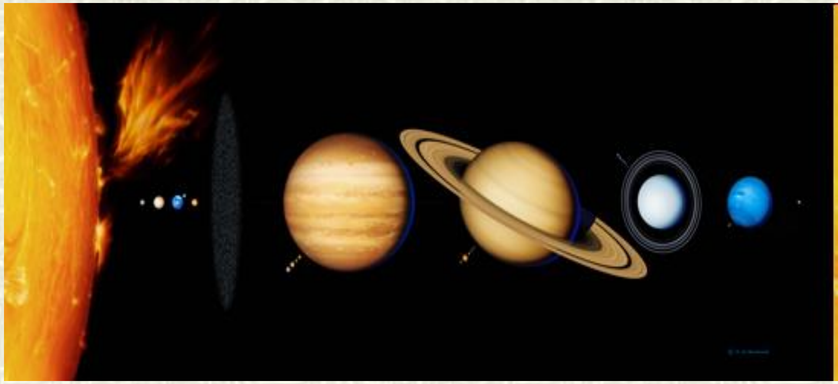
Explanation for runaway galaxies?

Newton

- Gravity pulls in not out
- Space is fixed
- Time has no beginning

Isaac Newton

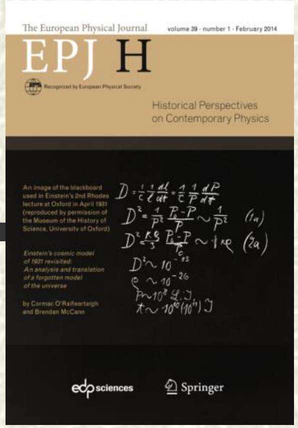
How can galaxies be receding?
What is pushing out?



Results: publications

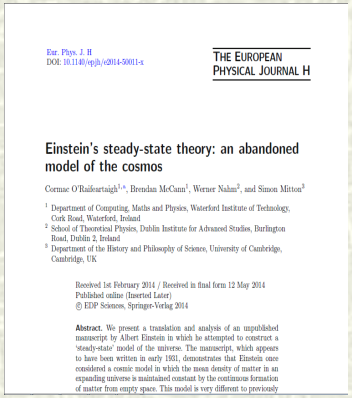
- **Einstein's 1931 model**

Einstein's cosmic model of 1931 revisited; an analysis and translation of a forgotten model of the universe. O'Raifeartaigh, C. and B. McCann. 2014 ***Eur. Phys. J (H)*** **39(1):63-85**



- **Einstein's steady-state manuscript**

Einstein's steady-state theory: an abandoned model of the cosmos. O'Raifeartaigh, C., B. McCann, W. Nahm and S. Mitton. 2014 ***Eur. Phys. J (H)*** **39(3):353-367**



Eur. Phys. J. H
DOI: 10.1140/epjh/e2014-50011-x

THE EUROPEAN PHYSICAL JOURNAL H

Einstein's steady-state theory: an abandoned model of the cosmos

Cormac O'Raifeartaigh[1,a], Brendan McCann[1], Werner Nahm[2], and Simon Mitton[3]

[1] Department of Computing, Maths and Physics, Waterford Institute of Technology, Cork Road, Waterford, Ireland
[2] School of Theoretical Physics, Dublin Institute for Advanced Studies, Burlington Road, Dublin 2, Ireland
[3] Department of the History and Philosophy of Science, University of Cambridge, Cambridge, UK

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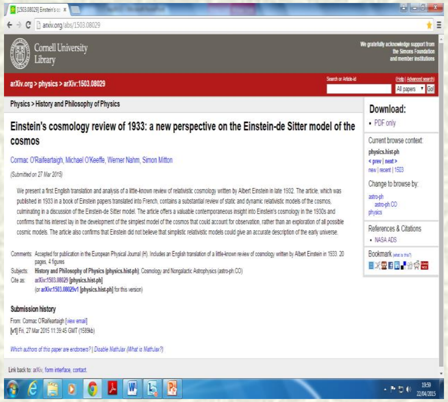
Abstract. We present a translation and analysis of an unpublished manuscript by Albert Einstein in which he attempted to construct a 'steady-state' model of the universe. The manuscript, which appears to have been written in early 1931, demonstrates that Einstein once considered a cosmic model in which the mean density of matter in an expanding universe is maintained constant by the continuous formation of matter from empty space. This model is very different to previously

- **Einstein-de Sitter model**

Einstein's cosmology review of 1933: a new perspective on the Einstein-de Sitter model of the cosmos. O'Raifeartaigh, C., M.O'Keeffe, W. Nahm and S. Mitton. 2015. To be published in ***Eur. Phys. J (H)***



- **Review paper: conclusions**

ASTRONOMICAL SOCIETY OF THE PACIFIC
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VOLUME 471

ORIGINS OF THE EXPANDING UNIVERSE: 1912–1932

Edited by
Michael J. Way and Deidre Hunter

Eur. Phys. J. H
DOI: 10.1140/epjh/e2013-40038-x

THE EUROPEAN PHYSICAL JOURNAL H

Einstein's cosmic model of 1931 revisited: an analysis and translation of a forgotten model of the universe

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Department of Computing, Maths and Physics, Waterford Institute of Technology, Cork Road, Waterford, Ireland

Received 21 September 2013 / Received in final form 20 December 2013
Published online 4 February 2014

Abstract. We present an analysis and translation of Einstein's 1931 paper "*Zum kosmologischen Problem der allgemeinen Relativitätstheorie*" or "*On the cosmological problem of the general theory of relativity*". In this little-known paper, Einstein proposes a cosmic model in which the universe undergoes an expansion followed by a contraction, quite different to the monotonically expanding Einstein-de Sitter model of 1932. The paper offers many insights into Einstein's cosmology in the light of the first evidence for an expanding universe and we consider his views of issues such as the curvature of space, the cosmological constant, the singularity and the timespan of the expansion. A number of original

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The European Physical Journal volume 39 · number 1 · February 2014

EPJ H

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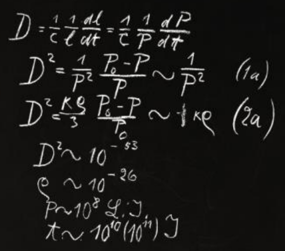
Historical Perspectives on Contemporary Physics

An image of the blackboard used in Einstein's 2nd Rhodes lecture at Oxford in April 1931 (reproduced by permission of the Museum of the History of Science, University of Oxford)



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edp sciences Springer

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THE EUROPEAN PHYSICAL JOURNAL H

Einstein's steady-state theory: an abandoned model of the cosmos

Cormac O'Raifeartaigh[1,a], Brendan McCann[1], Werner Nahm[2], and Simon Mitton[3]

[1] Department of Computing, Maths and Physics, Waterford Institute of Technology, Cork Road, Waterford, Ireland
[2] School of Theoretical Physics, Dublin Institute for Advanced Studies, Burlington Road, Dublin 2, Ireland
[3] Department of the History and Philosophy of Science, University of Cambridge, Cambridge, UK

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Abstract. We present a translation and analysis of an unpublished manuscript by Albert Einstein in which he attempted to construct a 'steady-state' model of the universe. The manuscript, which appears to have been written in early 1931, demonstrates that Einstein once considered a cosmic model in which the mean density of matter in an expanding universe is maintained constant by the continuous formation of matter from empty space. This model is very different to previously

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arxiv.org/abs/1503.08029

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Physics > History and Philosophy of Physics

Einstein's cosmology review of 1933: a new perspective on the Einstein-de Sitter model of the cosmos

Cormac O'Raifeartaigh, Michael O'Keeffe, Werner Nahm, Simon Mitton

(Submitted on 27 Mar 2015)

We present a first English translation and analysis of a little-known review of relativistic cosmology written by Albert Einstein in late 1932. The article, which was published in 1933 in a book of Einstein papers translated into French, contains a substantial review of static and dynamic relativistic models of the cosmos, culminating in a discussion of the Einstein-de Sitter model. The article offers a valuable contemporaneous insight into Einstein's cosmology in the 1930s and confirms that his interest lay in the development of the simplest model of the cosmos that could account for observation, rather than an exploration of all possible cosmic models. The article also confirms that Einstein did not believe that simplistic relativistic models could give an accurate description of the early universe.

Comments: Accepted for publication in the European Physical Journal (H). Includes an English translation of a little-known review of cosmology written by Albert Einstein in 1933. 20 pages, 4 figures
Subjects: History and Philosophy of Physics (physics.hist-ph); Cosmology and Nongalactic Astrophysics (astro-ph.CO)
Cite as: arXiv:1503.08029 [physics.hist-ph]
(or arXiv:1503.08029v1 [physics.hist-ph] for this version)

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[v1] Fri, 27 Mar 2015 11:39:45 GMT (1589kb)

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Physics > History and Philosophy of Physics

A new perspective on Einstein's philosophy of cosmology

Cormac O'Raifeartaigh

(Submitted on 11 Apr 2015)

It has recently been discovered that Einstein once attempted - and subsequently abandoned - a 'steady-state' model of the universe, i.e., a cosmic model in which the expanding universe remains essentially unchanged due to a continuous creation of matter from empty space. The discovery offers several new insights into Einstein's cosmology, from his view of the role of the cosmological constant to his attitude to the question of cosmic origins. More generally, Einstein's exploration of steady-state cosmology casts new light on his philosophical journey from a static, bounded cosmology to the dynamic, evolving universe, and is indicative of a pragmatic, empiricist approach to cosmology.

Comments: 20 pages, 2 figures. To be published in the book 'The Philosophy of Cosmology: Foundations and Perspectives' (Cambridge University Press)
Subjects: History and Philosophy of Physics (physics.hist-ph); Cosmology and Nongalactic Astrophysics (astro-ph.CO)
Cite as: arXiv:1504.02873 [physics.hist-ph]
(or arXiv:1504.02873v1 [physics.hist-ph] for this version)

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From: Cormac O'Raifeartaigh [view email]
[v1] Sat, 11 Apr 2015 13:38:49 GMT (663kb)

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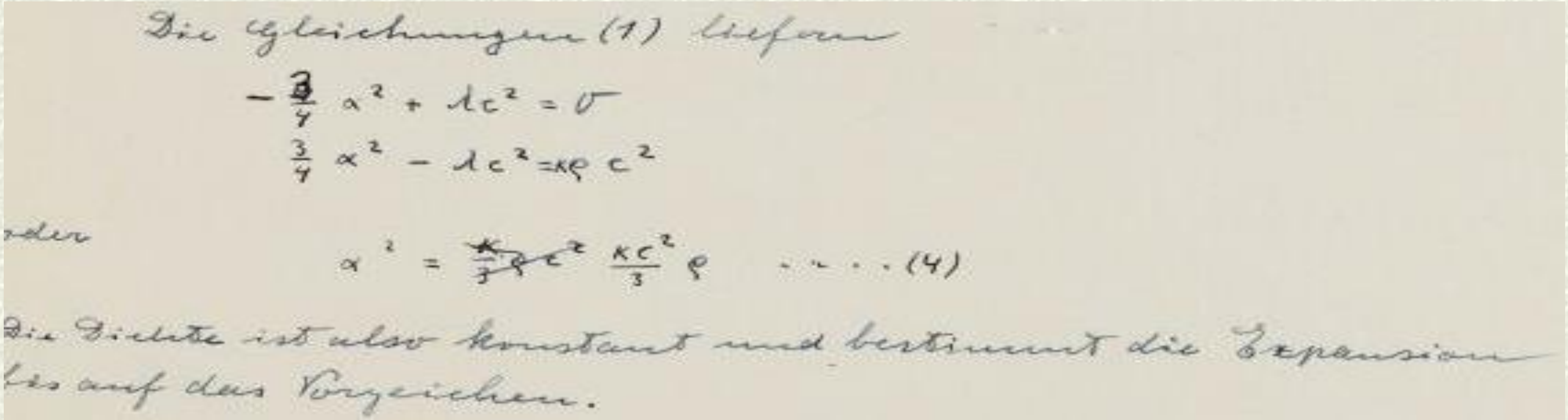

Die Gleichungen (1) liefern

$-\frac{3}{4}\alpha^2 + \lambda c^2 = 0$

$\frac{3}{4}\alpha^2 - \lambda c^2 = \kappa\rho c^2$

oder

$\alpha^2 = \frac{\kappa c^2}{3}\rho \quad \ldots\ldots (4)$

Die Dichte ist also konstant und bestimmt die Expansion bis auf das Vorzeichen.

Taking $T_{44} = \rho c^2$ (all other components zero) in the *time* component of equation (1) we obtain $\left(R_{44} - \frac{1}{2}g_{44}R\right) - \lambda g_{44} = \kappa\rho c^2$.

This gives on analysis $-3\alpha^2/4 + 3\alpha^2/2 - \lambda c^2 = \kappa\rho c^2$

the second of Einstein's simultaneous equations.

From the *spatial* component of equation (1), we obtain $\left(R_{ii} - \frac{1}{2}g_{ii}R\right) - \lambda g_{ii} = 0$.

This gives on analysis $3\alpha^2/4 - 3\alpha^2/2 + \lambda c^2 = 0$

for the first of the simultaneous equations.

It is plausible that Einstein made a sign error here, initially getting $3\alpha^2/4 + 3\alpha^2/2 + \lambda c^2 = 0$ for this equation. (W. Nahm)

Einstein's steady-state model and cosmology today

- **Accelerated expansion (1998)**

  Supernova measurements

  Dark energy – positive cosmological constant

- **Einstein's dark energy**

  "The conservation law is preserved in that, by setting the λ-term, space itself is not empty of energy; its validity is well known to be guaranteed by equations (1)."

  Anticipates positive cosmological constant

- **De Sitter line element**

  $ds^2 = -e^{\alpha t}(dx_1^2 + dx_2^2 + dx_3^2) + c^2dt^2 \ldots$

  Necessary for all steady-state models

  Identical to inflationary models (different time-frame)

The steady-state universe (1948)

- **Expanding but unchanging universe**
  Hoyle, Bondi and Gold (1948)
  Disliked speculation about physics of early epochs
  Perfect cosmological principle?

Bondi, Gold and Hoyle

- **Continuous creation of matter**
  Very little matter required
  No beginning, no age paradox

- **Replace λ with creation term** (Hoyle)

$$G_{\mu\nu} + C_{\mu\nu} = -k\,T_{\mu\nu}$$

- **Improved version (1962)**

$$G_{\mu\nu} + \lambda g_{\mu\nu} = k\,T\,(C_{\mu} + C_{\nu})$$

Hoyle and Narlikar (1962)

Conclusions

- **Cosmology – a testing ground for general relativity?**

  Assumptions; space-time = space + time

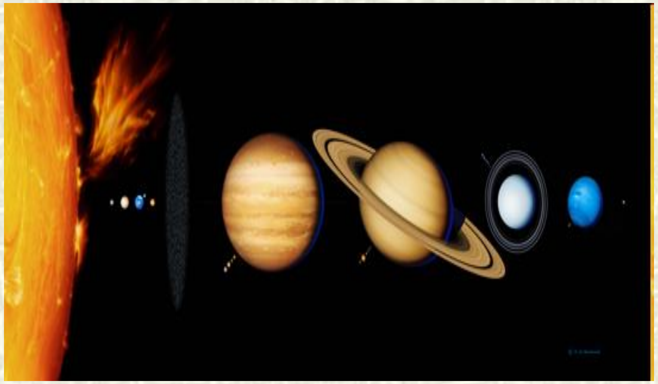
  Homogeneity and isotropy

  Static universe

- **Dynamic cosmology**

  Steady-state universe?

  Evolving models less contrived



- **Evolving models**

  Timespan problem: attributed to assumptions

  Origins puzzle: ignored

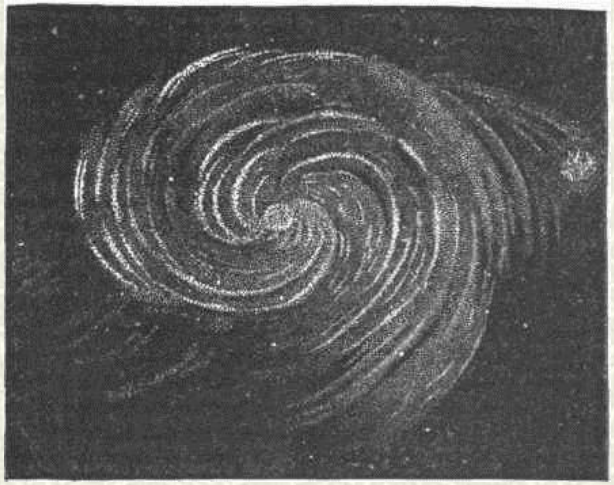
- **Verdict**

  More data needed

III Astronomy and the Universe

- **The Great Debate (1900-1925)**

  Spiral nebulae = galaxies beyond Milky Way?



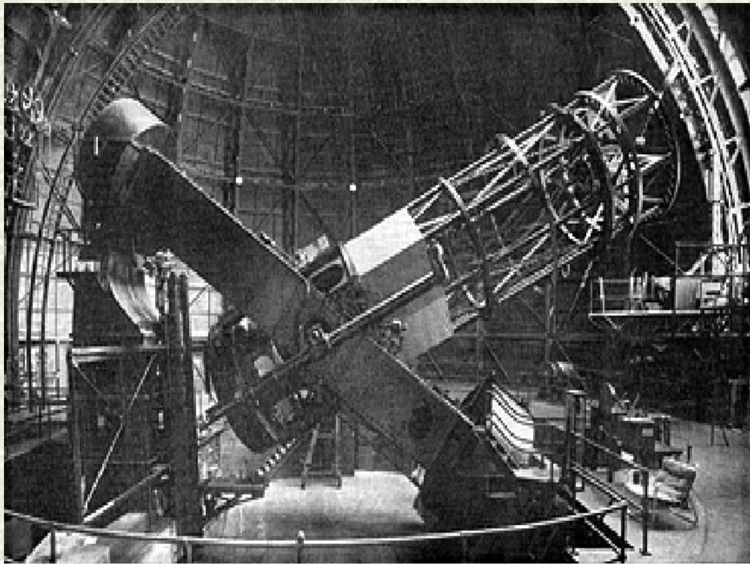
- **The Hooker telescope (1917)**

  Edwin Hubble (1921)

- **The distances of the nebulae (1925)**

  Cepheid variables resolved in two nebulae

  Leavitt's period-luminosity relation



- **Spirals far beyond Milky Way**

  A universe of galaxies

The motion of the nebulae

Vesto Slipher

- **The redshift of the nebulae**

  V.M Slipher (Lowell Observatory)

  Light from most nebulae redshifted (1915, 1917)

- **Doppler effect**

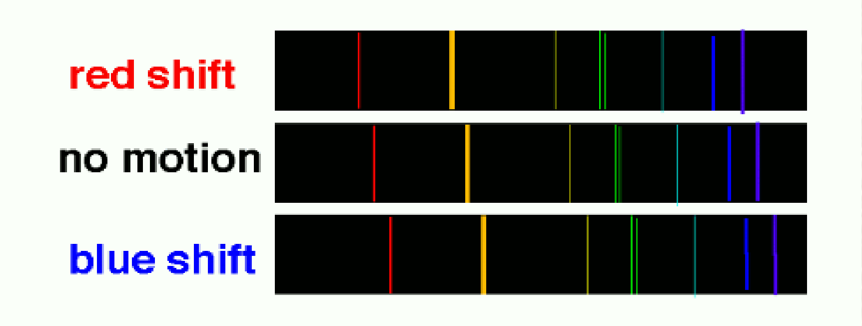
  Frequency of light depends on

  motion of source relative to observer

- **Nebulae moving outward?**

  Galaxies moving outward?

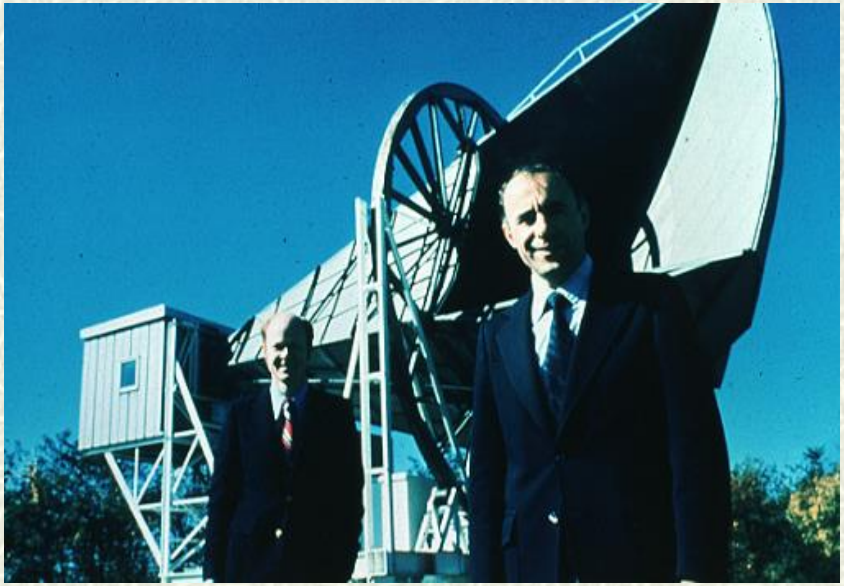
Lowell Observatory



Cosmic background radiation

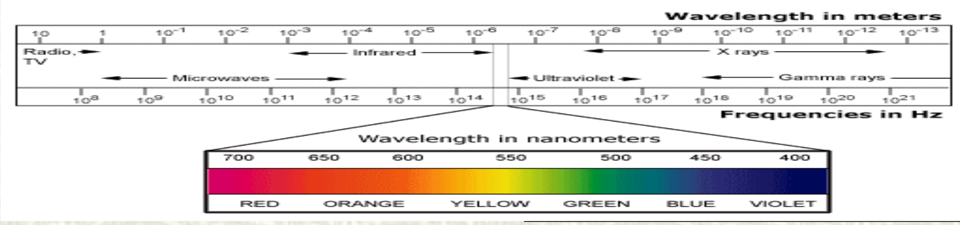
<u>CMB discovered accidentally</u>

- Universal signal (1965)
- Low frequency (microwave)
- Low temperature (3K)

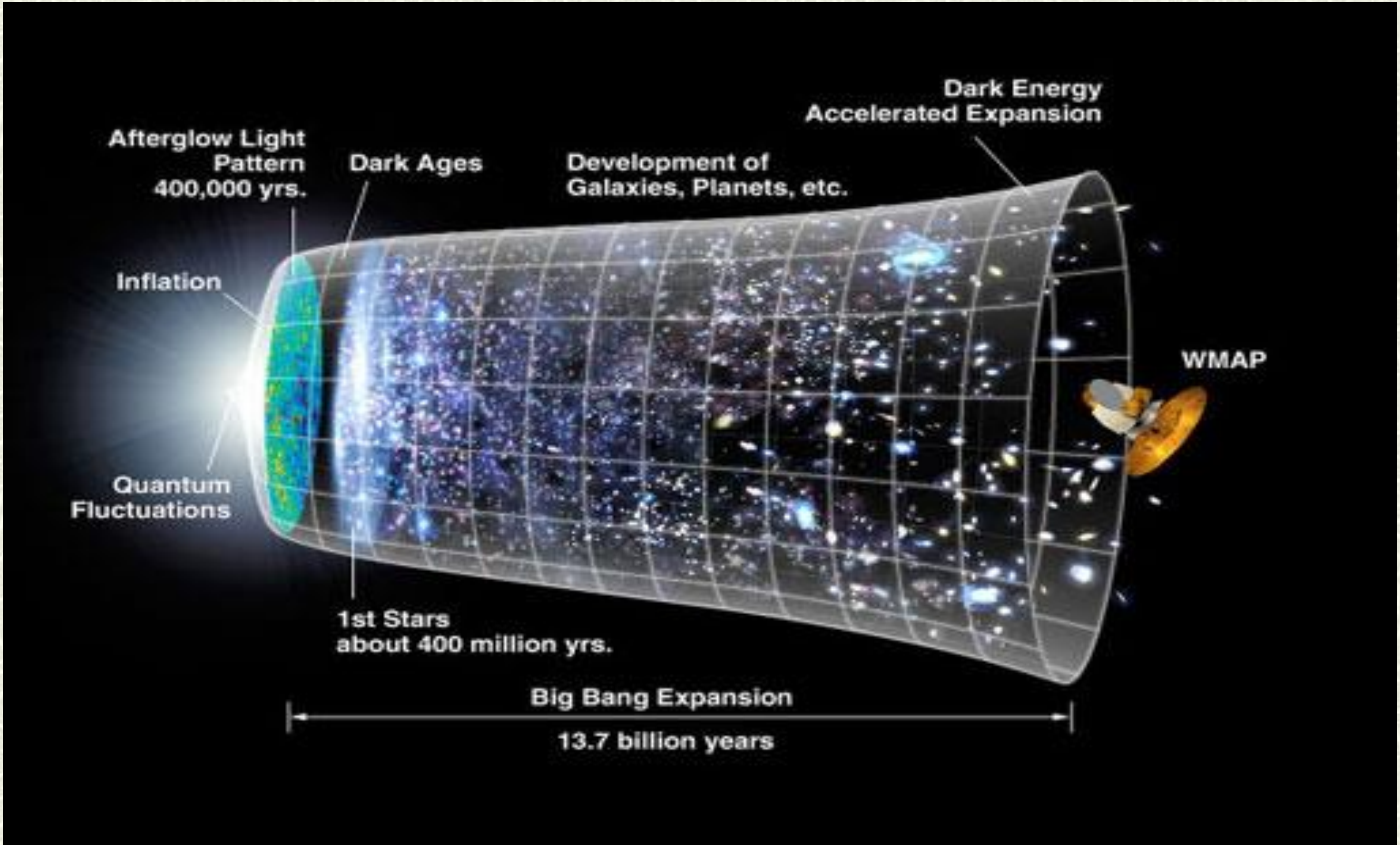


Penzias and Wilson (1965)

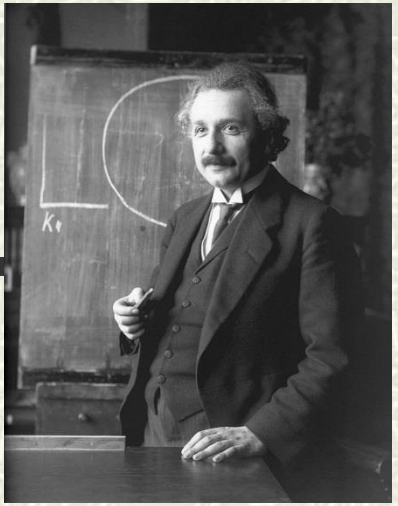
Echo of Big Bang!



The big bang model



Overview



- **100 years of relativity**
  - *The special theory of relativity (1905)*
  - *The general theory of relativity (1916)*

- **General relativity and the universe**
  - *The expanding universe (astronomy)*
  - *The big bang model*

- **Einstein's universe**
  - *Some new discoveries*