Einstein's Universe

Relativity and the big bang

General Relativity at 100

DIAS
Institiúid Ard-Léinn Bhaile Átha Cliath
Dublin Institute for Advanced Studies
Celebrating 75 Years 1940 - 2015

Cormac O'Raifeartaigh FRAS

Waterford Institute of Technology

Dublin Institute for Advanced Studies

- **75 years of DIAS**

  Founded in 1940 (de Valera)

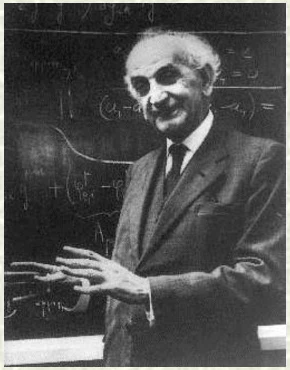
  Modelled on Princeton Research Institute (IAS)

- **Two schools**

  School of Theoretical Physics

  School of Celtic Languages

  Only pen and paper required



- **International expertise in physics**

  Erwin Schrödinger as first Director

  Later followed by Heitler, Lanczos and Synge

- **Major centre for relativity, quantum physics**

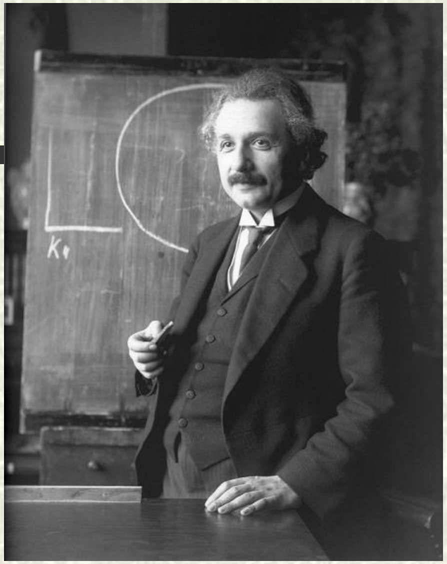
Overview

- **100 years of relativity**
  The special theory of relativity (1905)
  The general theory of relativity (1915)

- **General relativity and the universe**
  The expanding universe

- **Astronomy and the universe**
  The recession of the galaxies
  Models of the expanding universe

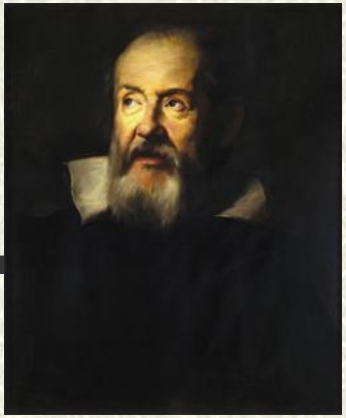
- **The big bang model**
  Rival theories
  Today's big bang model of the universe



Einstein in California (1931)

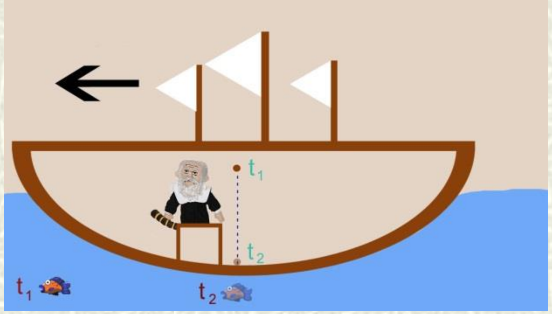
Relativity

- **The principle of relativity**
  Laws of mechanics identical for observers in uniform motion
  Non-accelerated motion



Galileo Galilei (1564-1642)

- **Galileo**
  Motion of ball in cabin of sailing ship
  Impossible to deduce motion of ship



- **Application**
  Elizabeth I and the Irish Chieftains

Elizabeth I (1558-1603)

- **Everyday experience**
  Cup of tea on train
  Life on earth

Relativity in the 19th century

- **Electromagnetism**

  Electricity and magnetism = electromagnetism

  Speed of electromagnetic wave = speed of light

- **Light = an electromagnetic wave**

  Travelling wave

  Changing electric and magnetic fields

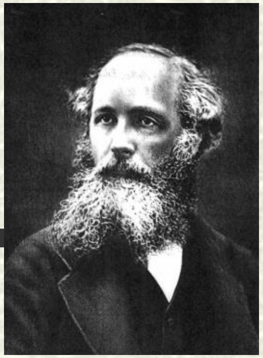
- **The electromagnetic spectrum**

  From radio waves to X-rays

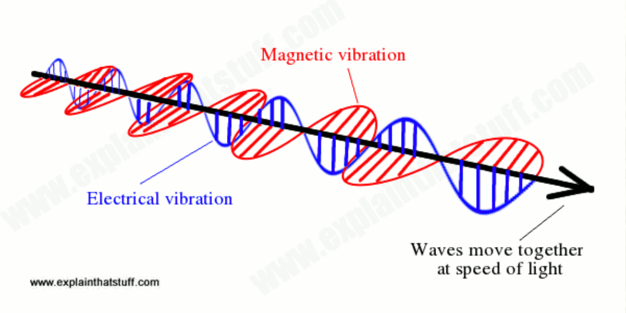
- **Speed of light absolute?**

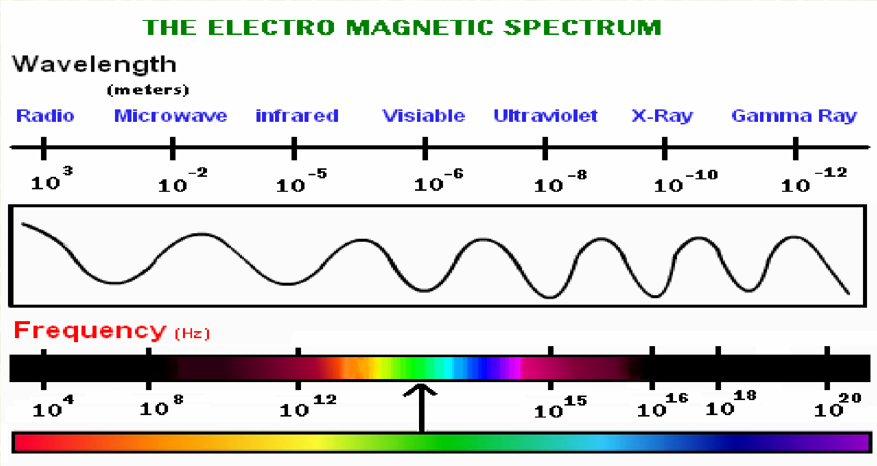
  Fixed for all observers?

  Michelson-Morley experiment

Michael Faraday JC Maxwell



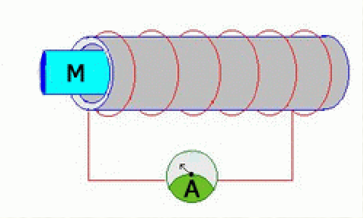


Einstein’s special theory of relativity

- **Two new principles (1905)**

  Laws of physics the same for observers in uniform motion

  Speed of light the same for observers in uniform motion



- **Implications**

  Distance and time not absolute $v = s/t$

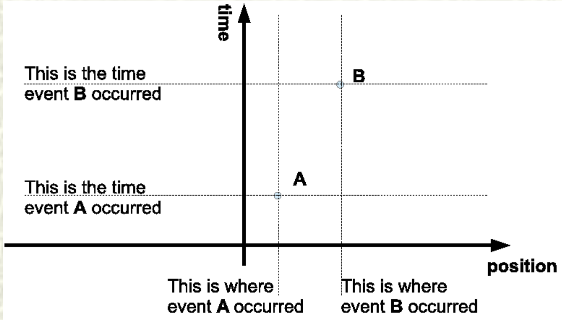
  Experienced differently by bodies in motion

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

- **Predictions for high-speed bodies**

  Length contraction; time dilation

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



- **Space + time = spacetime**

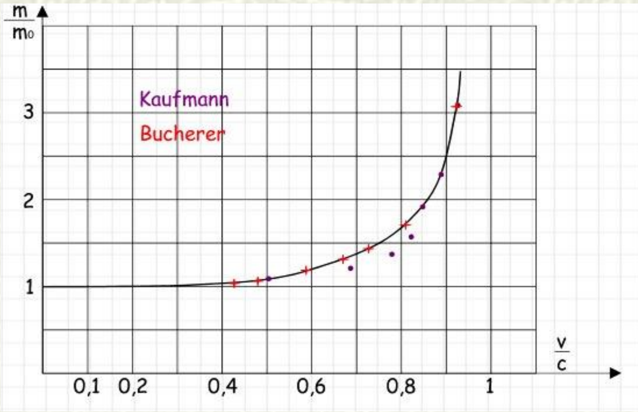
  Space-time invariant (Minkowski)

Evidence for special relativity

- **Mass increase**

  The experiments of Kaufmann and Bucherer

$$m' = \frac{m_0}{\sqrt{1 - v^2/c^2}}$$

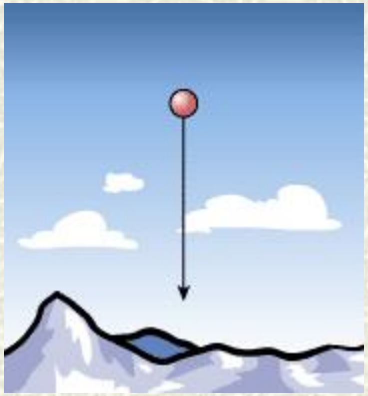


- **Time dilation**

  The long-lived muon

  2 μs → 22 μs

$$t' = \frac{t_0}{\sqrt{1 - v^2/c^2}}$$



- **Invariance of the speed of light**

  Always measured as c

- **Particle experiments at the LHC**

  Maximum velocity = c

  Mass increase

  Particle creation

$$E = mc^2$$

The general theory of relativity (1915)

Albert Einstein
1879-1955

- **General relativity**

  Relativity and accelerated motion?

  Relativity and gravity?

- **The principle of equivalence**

  Cannot distinguish between gravity and acceleration

- **A new theory (1915)** $G_{\mu\nu} = -\kappa T_{\mu\nu}$

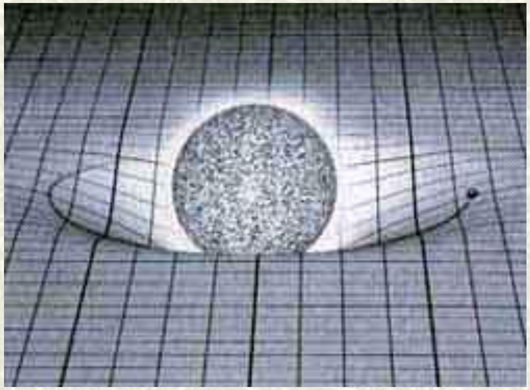
  Space-time distorted by mass

  Gravity = curvature of space-time

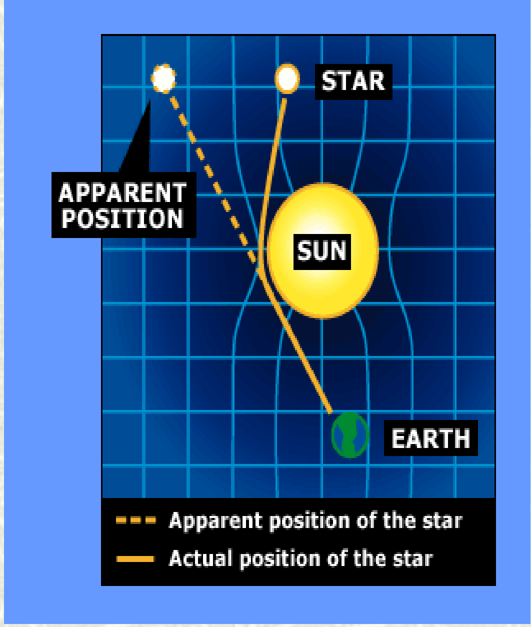
- **Empirical evidence**

  Orbit of Mercury

  Bending of starlight by the sun (Eddington, 1919)



Evidence for general relativity

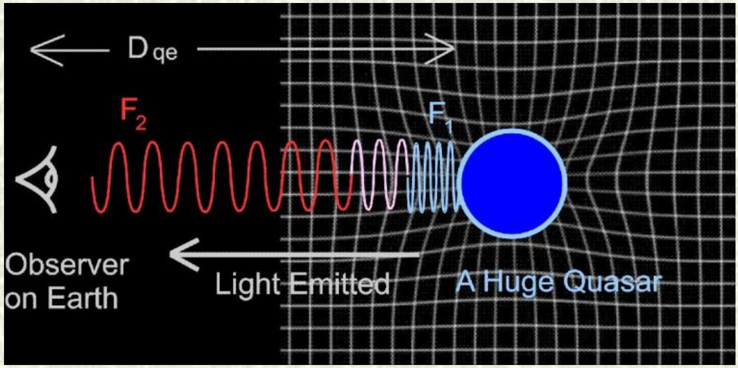


- **Bending of distant light by stars**

  Gravitational lensing

- **Gravitational redshift**

  Shift in wavelength of light due to gravity



- **Gravitational time dilation**

  GPS corrections

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

  Centre of galaxies

- **Gravitational waves**

  Hulse –Taylor binary system

II Relativity and the universe

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

  Ultimate test for new theory of gravity

- **Dynamic universe?**

  Expanding or contracting

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

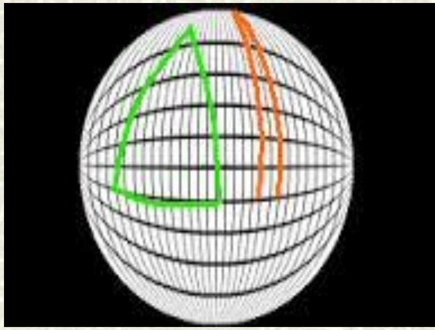
Einstein's universe

- **Observation: static universe**

  Add new term to field equations

  The cosmological constant λ

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

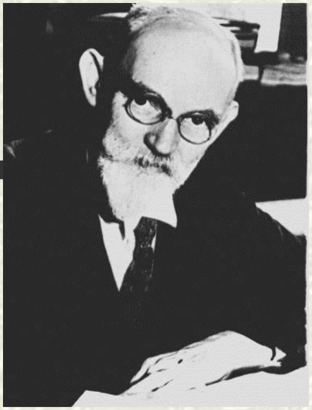


- **A static spherical universe**

  Closed universe with no boundaries

  Cosmic radius and matter density defined by λ

De Sitter's universe (1917)



- **Apply general relativity to the cosmos**

  Alternative solution

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

- **'Empty' universe**

  Reasonable approximation

- **Disliked by Einstein**

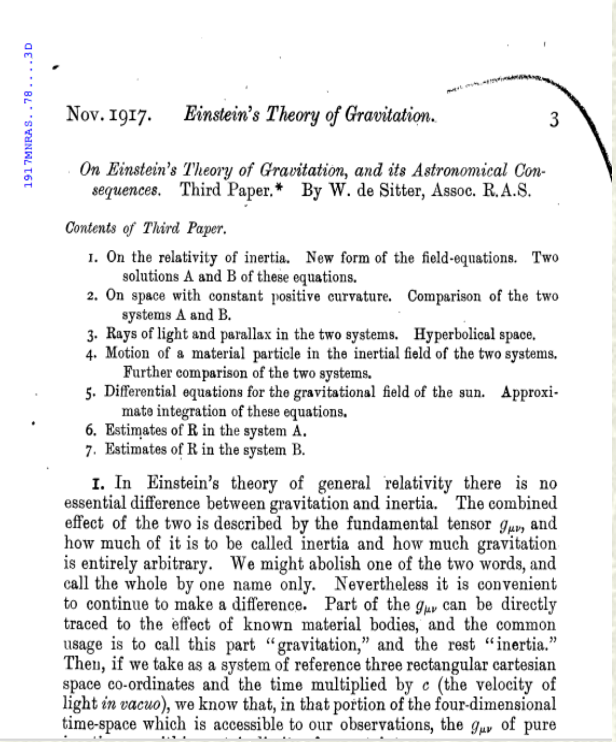
  Conflict with Mach's principle

  Beginning of Einstein's dislike for cosmic constant

- **Interest from astronomers**

  Redshift prediction – Slipher effect?

  Static or non-static model? (Weyl 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

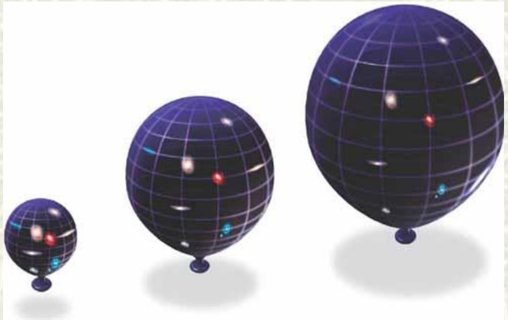
Friedman's universe

Alexander Friedman
(1888 -1925)

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

  Assume positive spatial curvature

  Universe of time-varying radius $$G_{\mu\nu} + \lambda g_{\mu\nu} = - \kappa T_{\mu\nu}$$



- **Expanding or contracting universe**

  A universe evolves over time

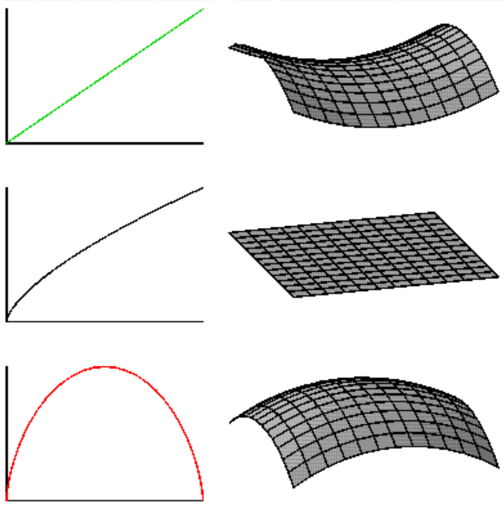
- **Badly received**

  Considered "suspicious" by Einstein

  "To this a physical reality can hardly be ascribed"

- **Negative spatial curvature (1924)**

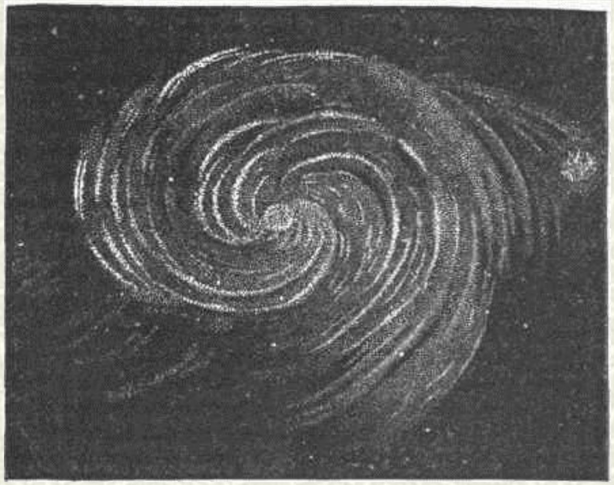
  Cosmic evolution, geometry depends on matter content



III Astronomy and the Universe

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

  Spiral nebulae = galaxies beyond Milky Way?



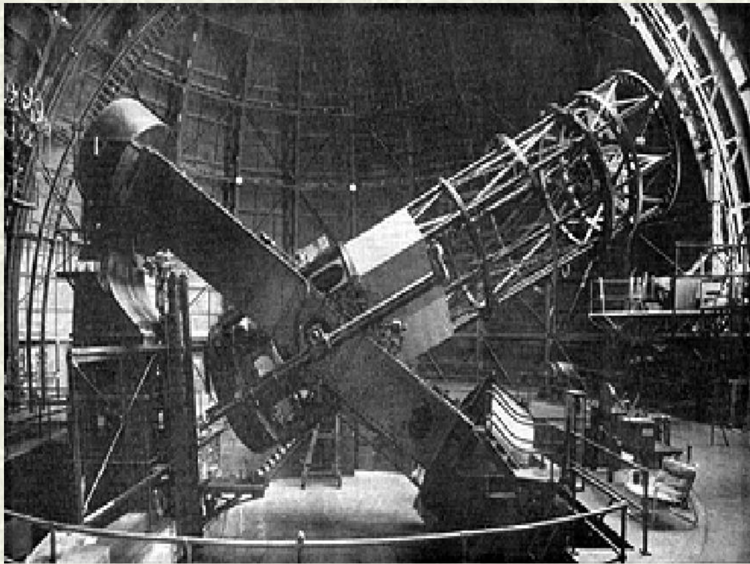
- **The Hooker telescope (1917)**

  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

- **The redshift of the nebulae**

  V.M Slipher (Lowell Observatory)

  Light from most nebulae redshifted (1915, 1917)

- **Doppler effect**

  Frequency of light depends on

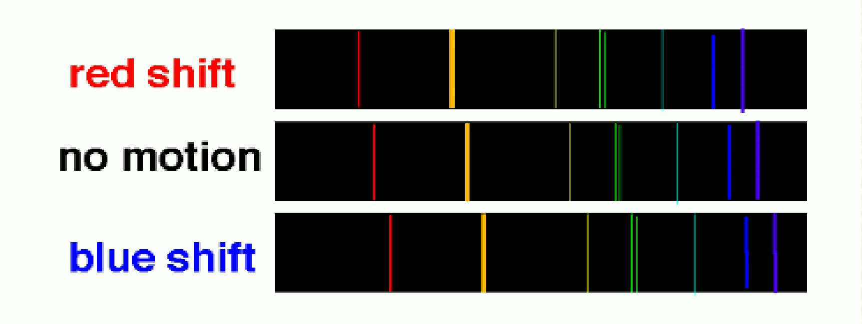
  motion of source relative to observer

- **Nebulae moving outward?**

  Galaxies moving outward?

Vesto Slipher

Lowell Observatory



The runaway galaxies (1929)

Edwin Hubble (1889-1953)

- **A relation between redshift and distance for the galaxies?**

- **Combine 24 distances with redshifts**

  Redshifts from Slipher: not acknowledged

- **Linear relation: 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

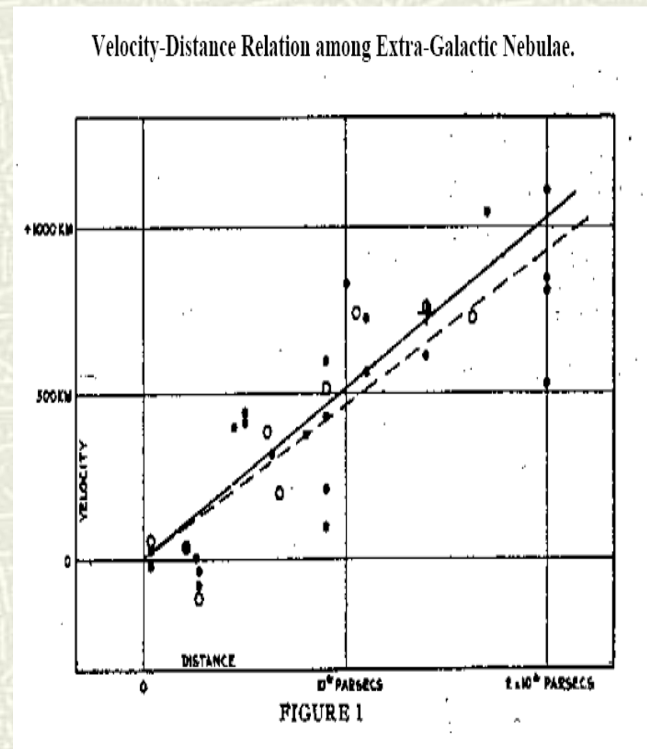


FIGURE 1

<u>Why ?</u>

Lemaître's universe (1927)

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

  Similar to Friedman 1922 model

  Starts from static Einstein universe

Fr Georges Lemaître

- **Recession of nebulae = expansion of space***?*

  Redshifts from Slipher, distances from Hubble

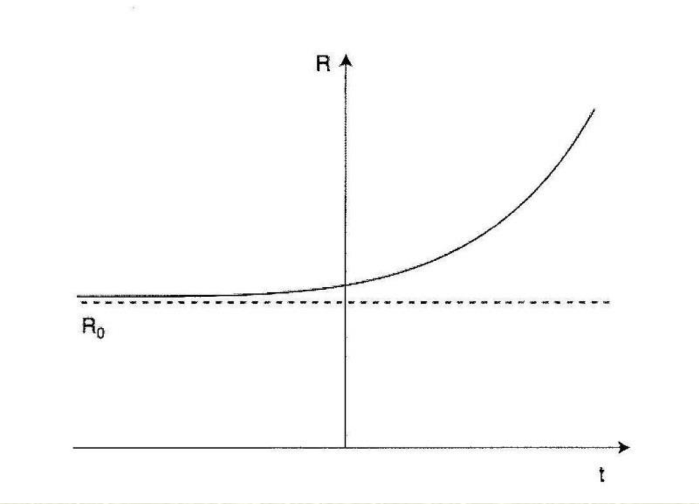
  $H = 585\ kms^{-1}Mpc^{-1}$

- **Ignored by community**

  Belgian journal (in French)

  Rejected by Einstein: "Votre physique est abominable"

  Einstein not up-to-date with astronomy?



The expanding universe (1930)

- **RAS meeting (1930)**

  Eddington, de Sitter
  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
  Time-varying density of matter
  <u>Evolving universe</u>

Velocity-Distance Relation among Extra-Galactic Nebulae.

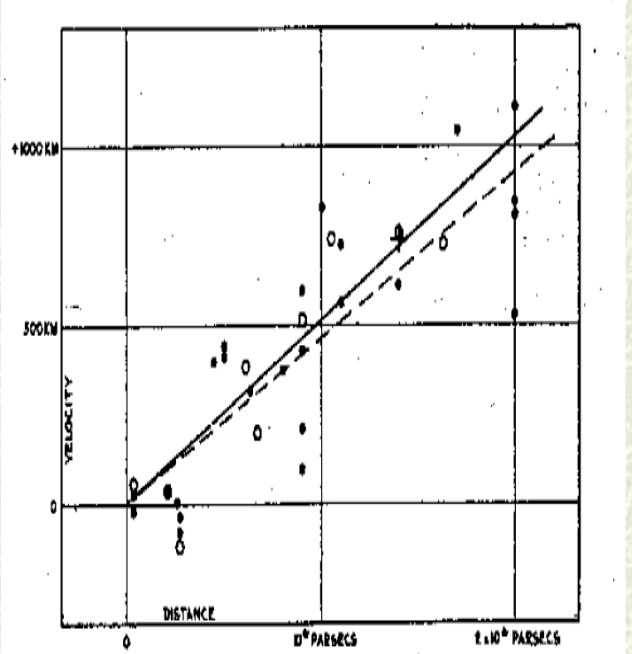


FIGURE 1

Models of the expanding universe (1930 -)

- **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

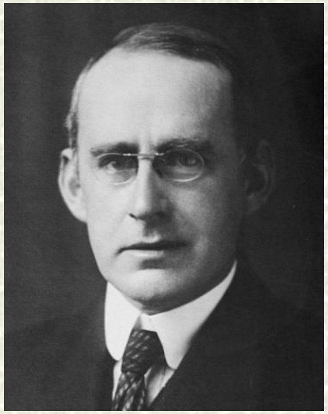
  Expanding universes of every flavour

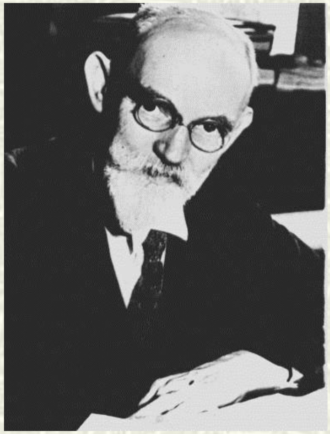
- **Einstein (1931, 32)**

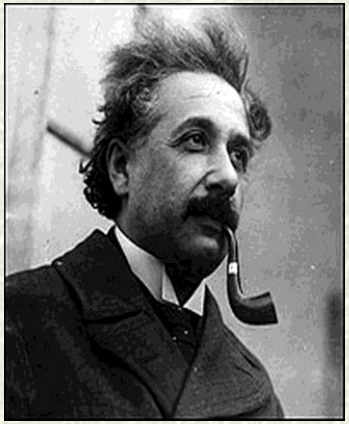
  Friedman-Einstein model $\lambda = 0$, $k = 1$

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

Occam's razor?







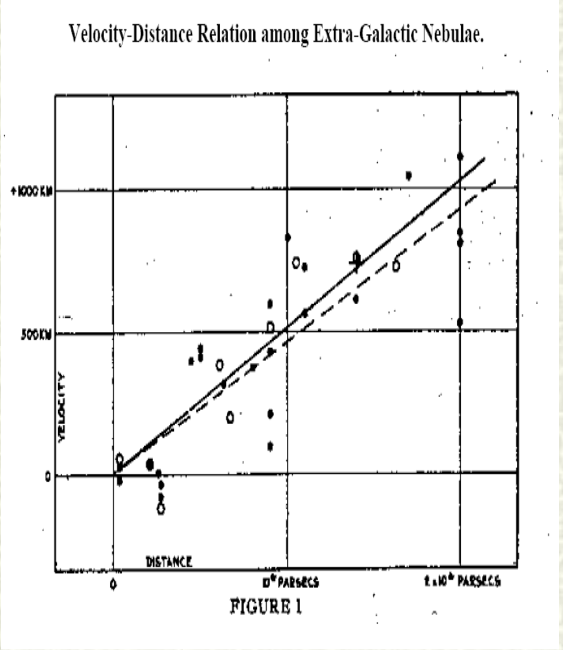
Evolving models

No mention of origins

The big bang model (1931)

Fr Georges Lemaître

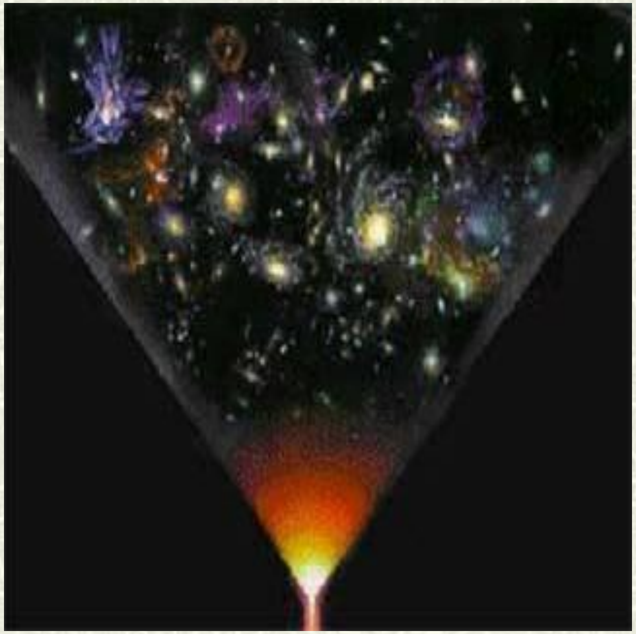
- Expanding *U* smaller in the past
- Rewind expanding model to early epochs
- Extremely dense, extremely hot
- Expanding and cooling ever since
- Explosive beginning at *R* = 0?



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

IV The 'big bang' model (1931)

- Infant *U* concentrated in tiny volume
- Extremely dense, hot
- Expanding and cooling ever since



Where do the laws of physics come from?

Wrong age (Hubble constant)

Singularity problem

∞ density, ∞ temp at $t = 0$?

A new line of evidence

- **Expert in nuclear physics (1940s)**

  Student of Friedman

- **How were the chemical elements formed?**

  In the stars? Problems

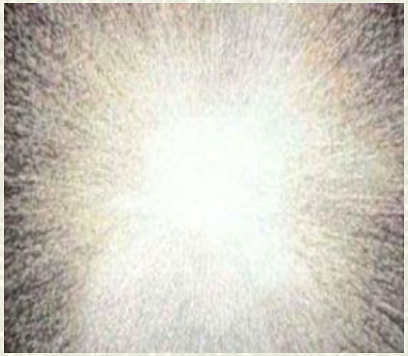
- **Elements formed in the big bang?**

  Predicts U = 75% Hydrogen, 25% Helium

- **Agreement with observation**

  Victory for big bang model

Georges Gamow



Heavier atoms formed in stars

A strange prediction

- Infant universe very hot indeed

- Dominated by radiation

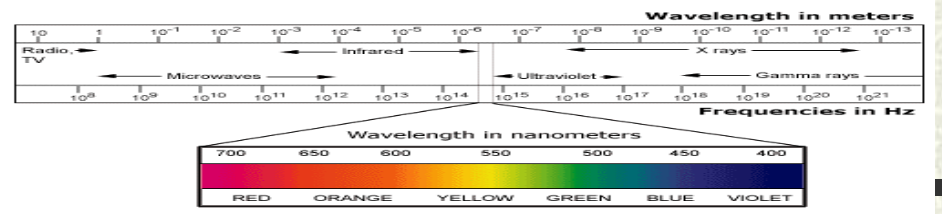
- Still observable today?

  Low temp, microwave frequency

- A fossil from the early universe

  Released when atoms formed (300,000 yr)

Alpher, Gamow and Herman



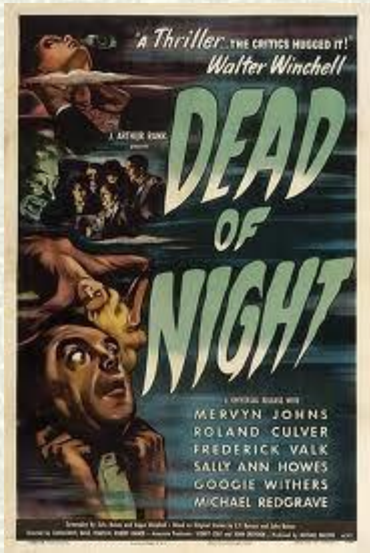
<u>No-one looked (1940s)</u>

Steady-state universe (1948)

- Alternative to big bang *(Fred Hoyle)*
- Expanding universe

BUT

- Continuous creation of matter?
- Unchanging universe
- No beginning, no age problem
- No assumptions about early epochs



<u>Very little matter needed</u>

Steady-state vs big bang

- **Optical astronomy (1950s)**

  Amended timescale of expansion (Baade, Sandage)

  Age problem removed

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

  Galaxy distributions at different epochs

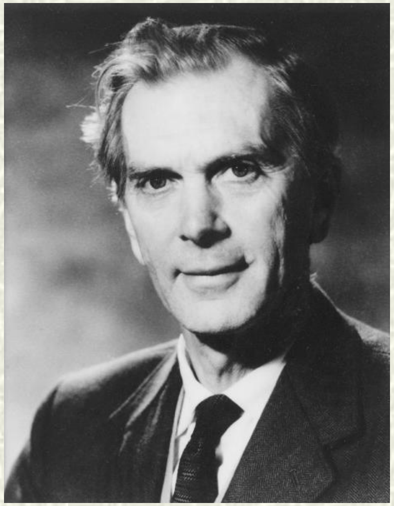
  Cambridge 3C Survey (Ryle)

- **Cosmic microwave background (1965)**

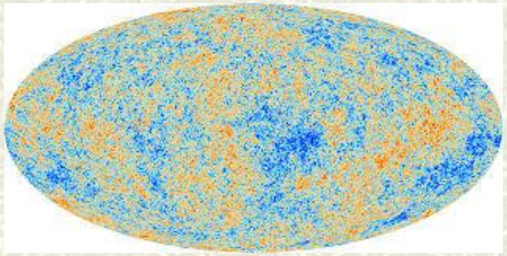
  Low temperature, low frequency

  Remnant of young, hot universe

- **End of steady-state theory**



Martin Ryle



Cosmic microwave background

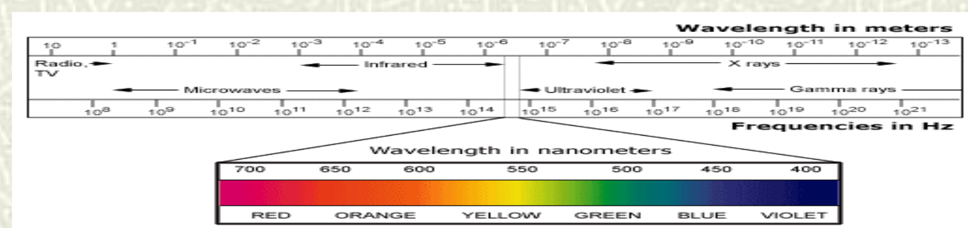
Cosmic background radiation

<u>CMB discovered accidentally</u>

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

Penzias and Wilson (1965)

Echo of Big Bang!



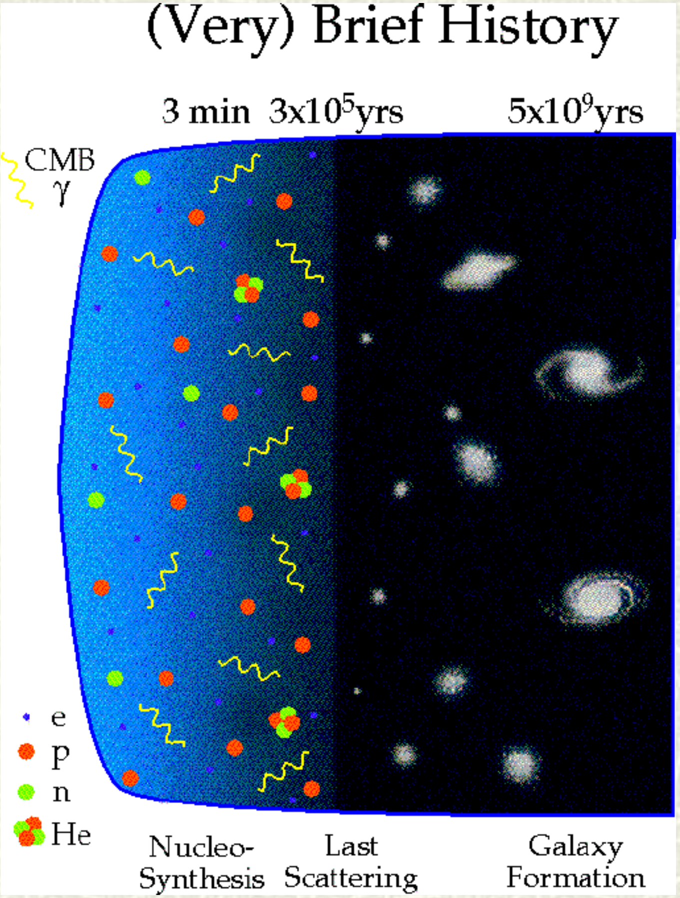
The big bang – evidence

1. The expansion of the *U*

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

3. The distribution of the galaxies

4. The cosmic microwave background

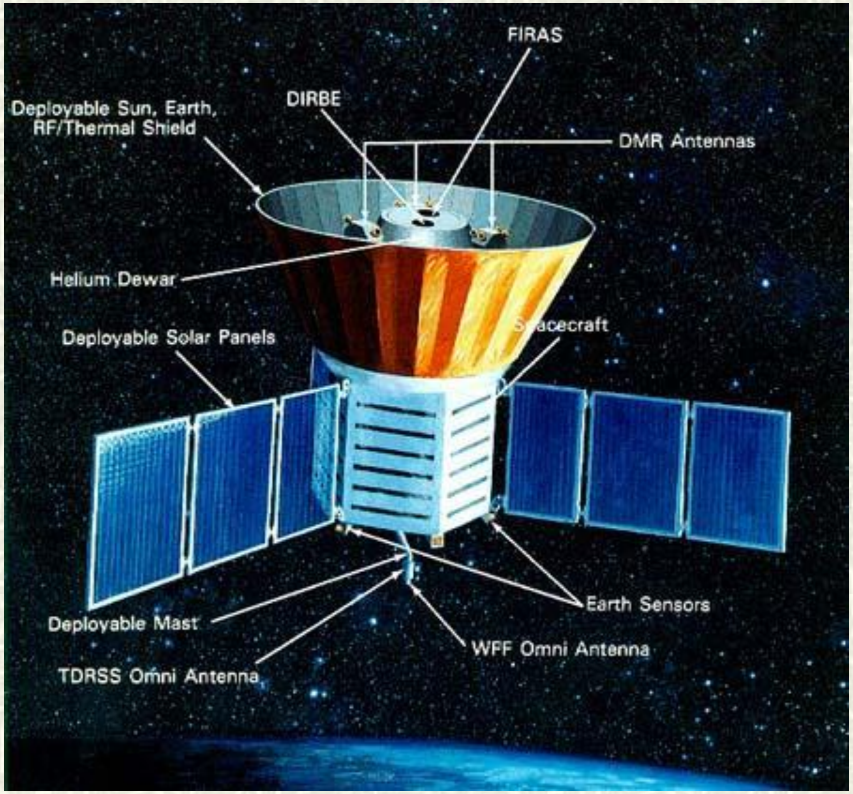


How did it start?

Modern measurements of the CMB

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

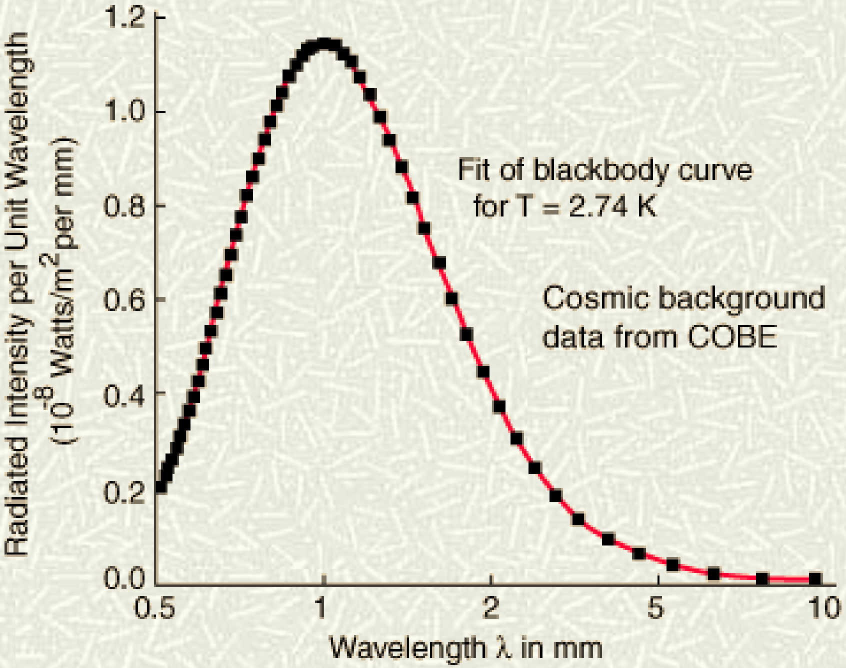
  - ***Ground telescopes***
  - ***Balloon experiments***
  - ***Satellite experiments***



COBE satellite (1992)

COBE measurements of CMB

- Expected temperature
- Expected frequency
- Perfect blackbody spectrum

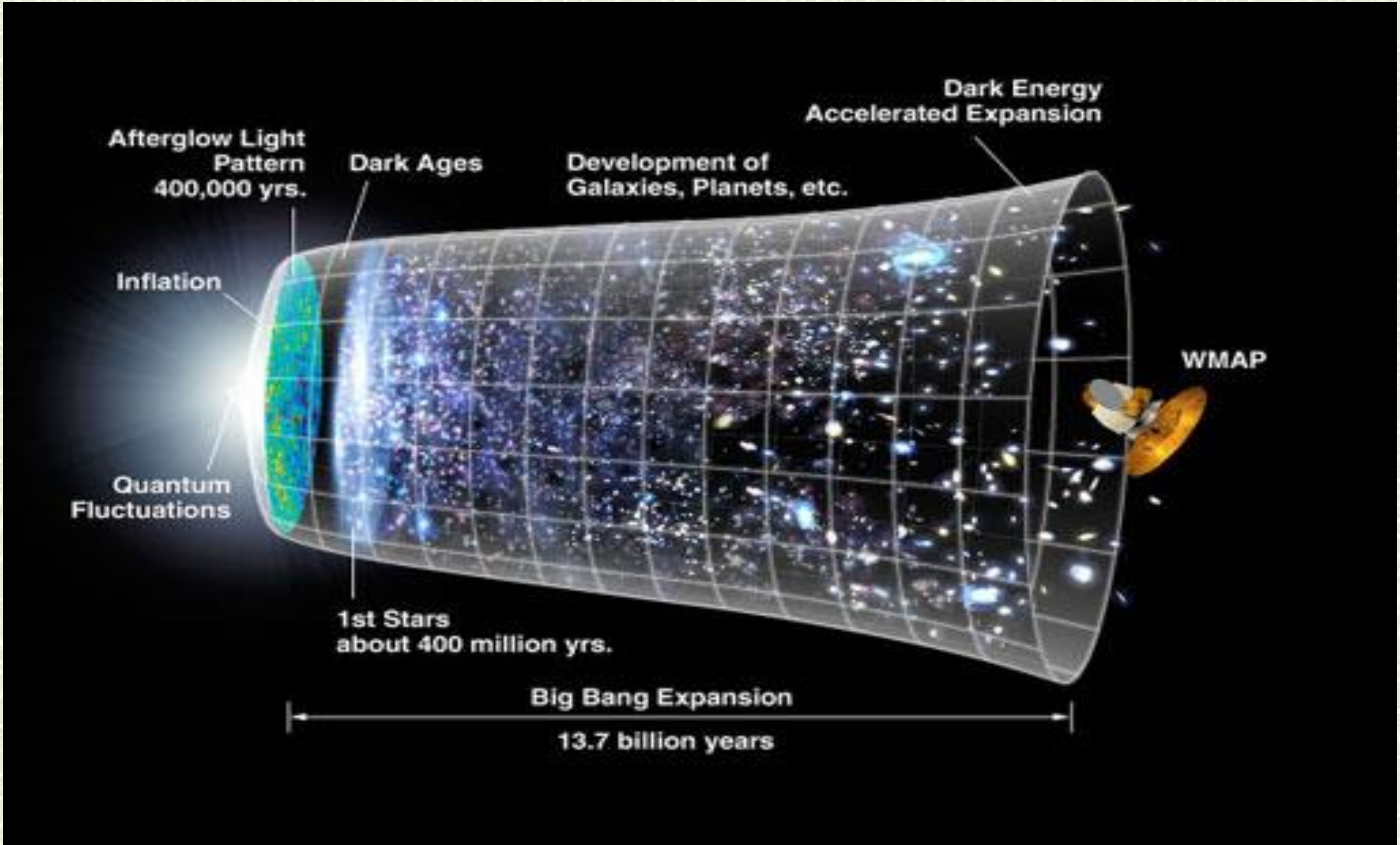


- *Radiation very uniform*
- *Variation of 1 in* 10^5
- *Seeds of galaxies ?*

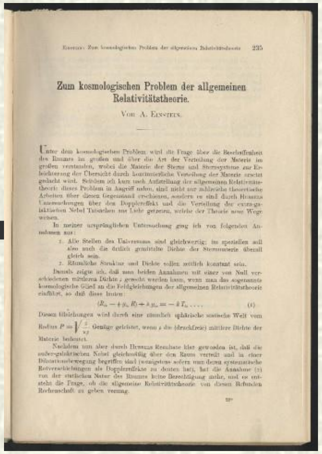
COBE (1992)

<u>Nobel Prize</u>

The big bang model



Coda: Einstein's 1931 model



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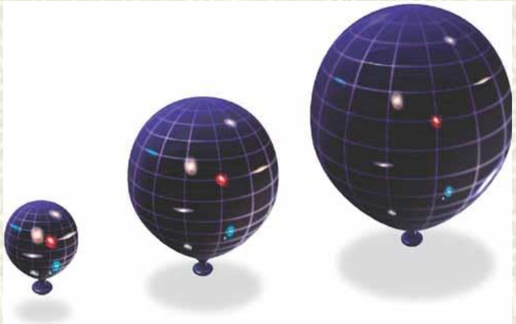
Zum kosmologischen Problem der allgemeinen Relativitätstheorie.

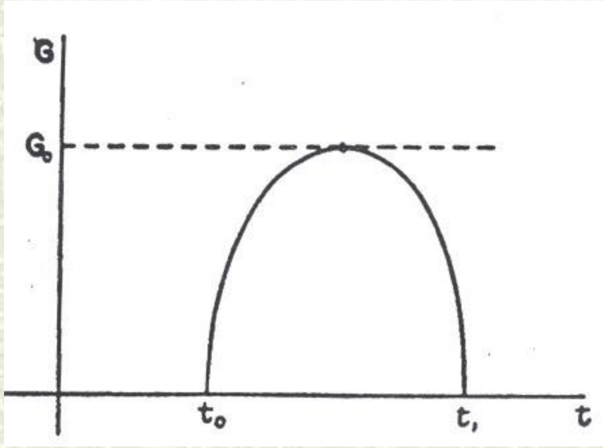
Von A. Einstein.

- **Einstein's first dynamic model of the cosmos**
  Often cited, rarely read (not translated)



- **Adopts Friedman 1922 model**
  Time-varying, closed universe: k =1
  <u>*Cosmic constant redundant:*</u> *set $\lambda = 0$*

- **Use Hubble to extract parameters**
  Radius R ~ 10^8 lyr
  Density of matter $\rho \sim 10^{-26}$ g/cm^3



- **Timespan problem**
  10^{10} yr*: conflict with astrophysics*
  Attributed to simplifying assumptions (homogeneity)

Einstein’s 1931 model revisited

- **First translation into English**

  O’Raifeartaigh and McCann 2014

- **Anomalies in calculations of radius and density**

  $R \sim 10^8$ 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*

- **Source of error?**

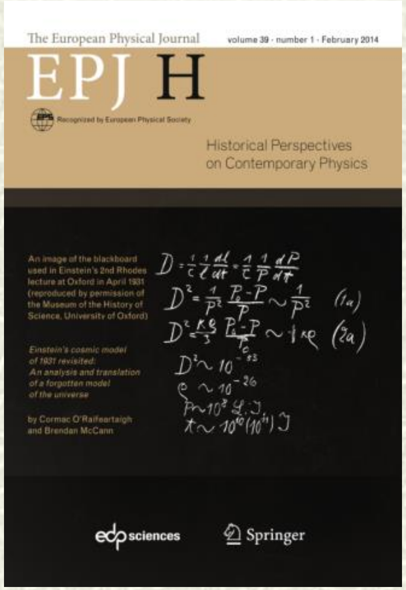
  Error in Hubble constant (Oxford blackboard)

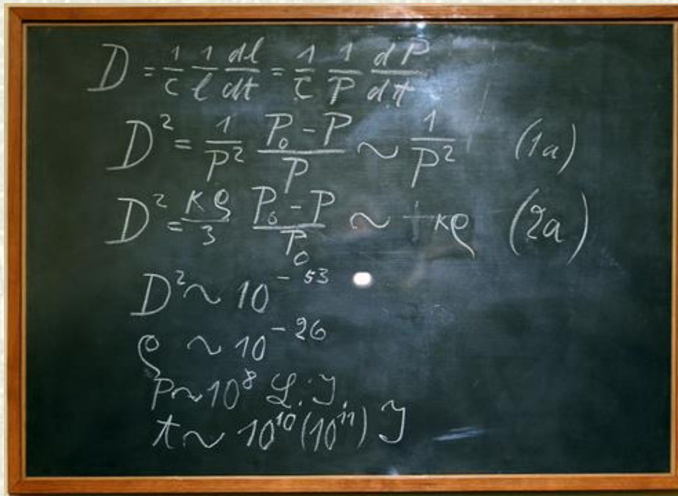
  $D^2 \sim 10^{-53}$ *instead of* 10^{-55} cm^{-2}

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

  “Model fails at P = 0 ”

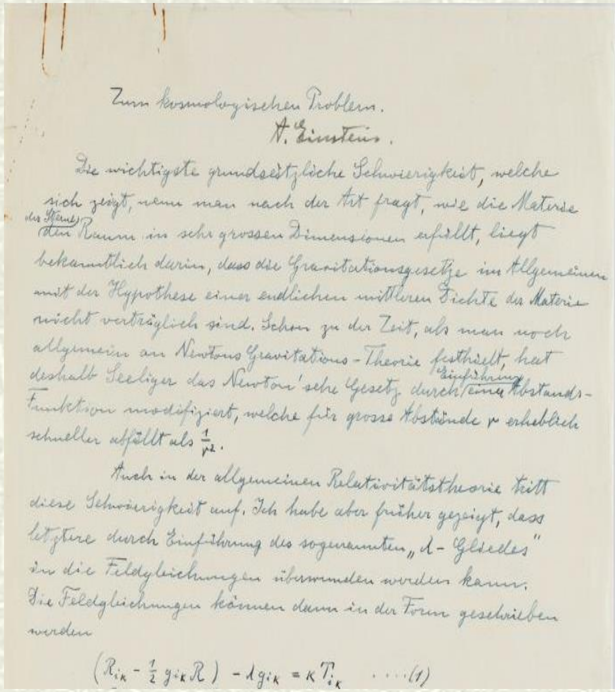
  Contrary to what is often stated





Bonus: Einstein's steady-state model

- **Unpublished manuscript**
  - *Archived as draft of Einstein's 1931 model*
  - *Similar title, opening*
- **Something different**
  - *Cosmological constant* ***λ***
  - *"Constant matter density determines expansion"*
- **Steady-state model**
  - *Continuous formation of matter from vacuum*
  - *Fatal flaw; abandoned*



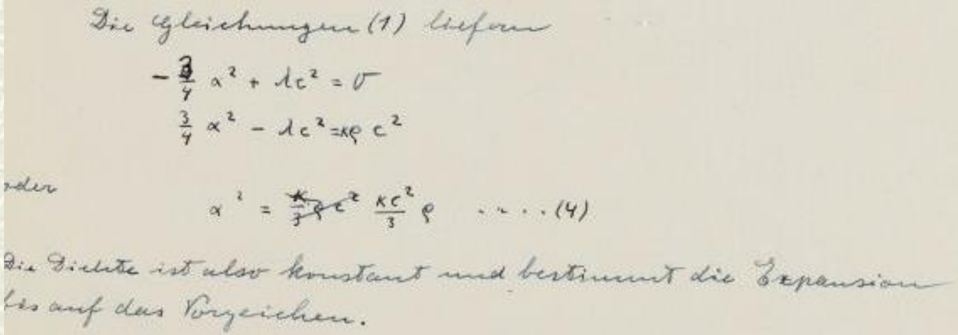
Zum kosmologischen Problem.

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.

Anticipates Hoyle's theory

Abandoned model

- **de Sitter line element**

  Correct geometry

- **Simultaneous equations**

  Error in derivation

  Null solution

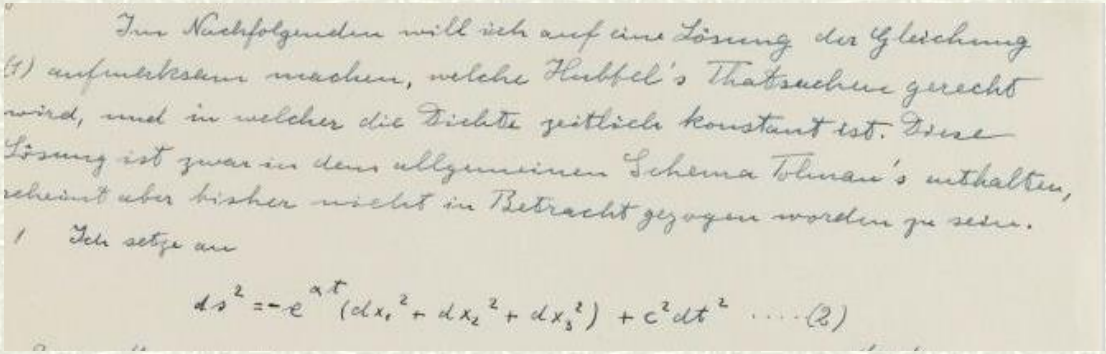
- **Einstein's crossroads**

  Realised problem on revision

  Declined to amend model

- **Evolving models**

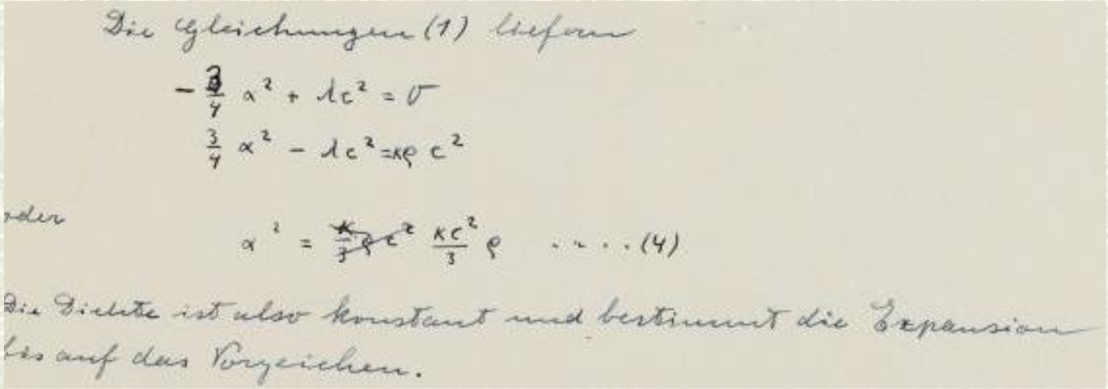
  Less contrived and set λ = 0



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

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



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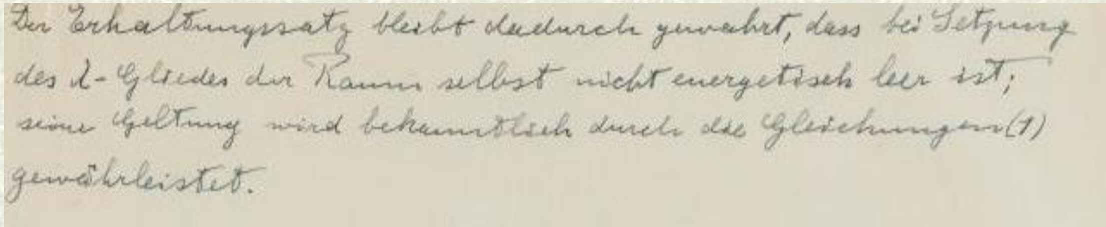


Der Erhaltungssatz bleibt dadurch gewahrt, dass bei Setzung des λ-Gliedes der Raum selbst nicht energetisch leer ist; seine Geltung wird bekanntlich durch die Gleichungen (1) gewährleistet.

NATURE | NEWS

Top

Einstein's lost theory uncovered

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

Davide Castelvecchi

24 February 2014

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

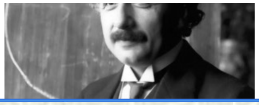
2 comments, 2 called-out + Comment Now + Follow Comments

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,

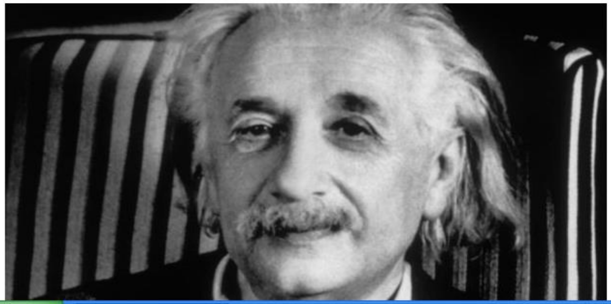
model of the universe very different to today's Big Bang Theory.

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



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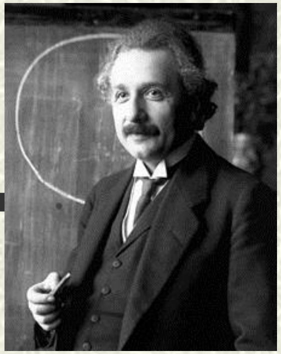
- 12:26 Quinn confirms Flannery approached hm with Rehab concerns
- 09:07 Man in his twenties stabbed in north Dublin
- 09:05 Family hope public appeal will help daughter beat cancer
- 08:42 Gardaí investigate death of woman in Dublin
- 08:25 Flannery faces call from all parties to attend PAC

Einstein's universe: conclusions



- **Cosmology = test for general relativity**

  *Introduces **λ**-term to the field equations*

- **Embraces dynamic cosmology**

  New evidence – new models

  Steady-state vs evolving universe

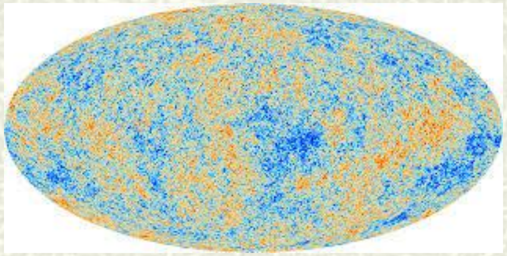
  *Evolving models simpler: remove **λ**-term*

Hubble constant revised

- **The evolving universe**

  Extract observational parameters

  Timespan problem attributed to simplifying assumptions



- **No discussion of origins**

  Wary of extrapolations

Cosmic microwave background
Homogeneous, flat universe

100 years of general relativity

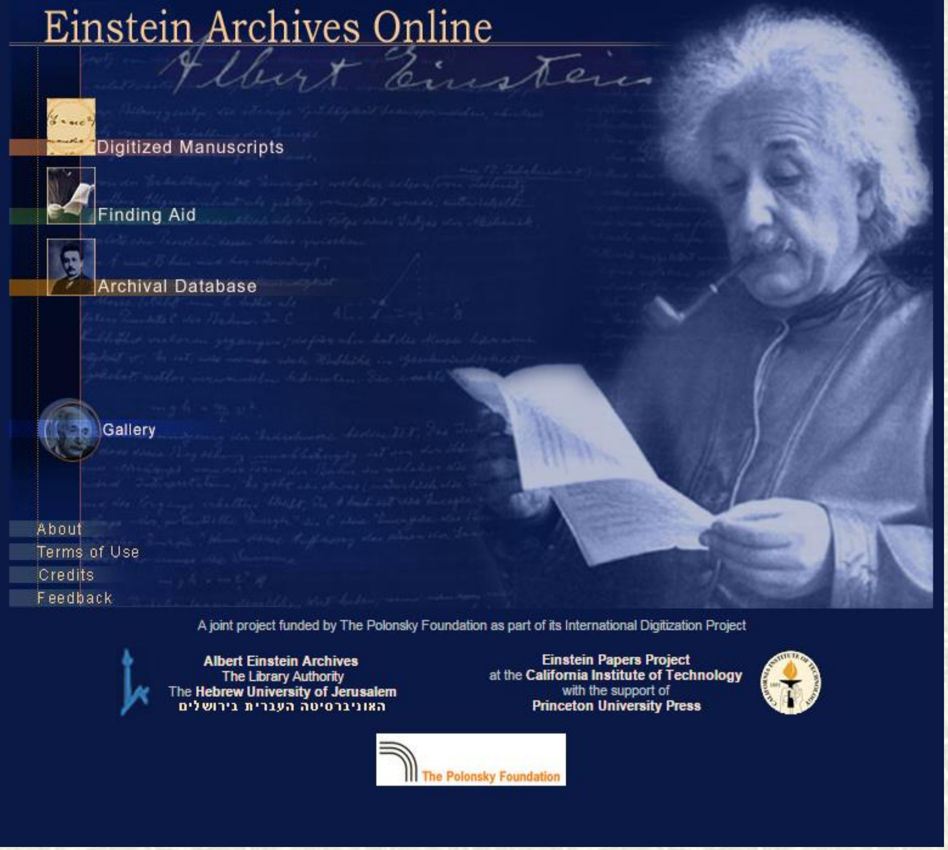
- **Published Nov. 25th 1915**
  From Swiss patent office to Berlin

- **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

Einstein in Berlin (1918)



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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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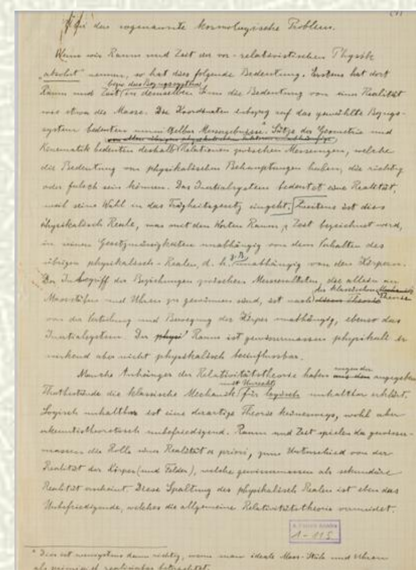
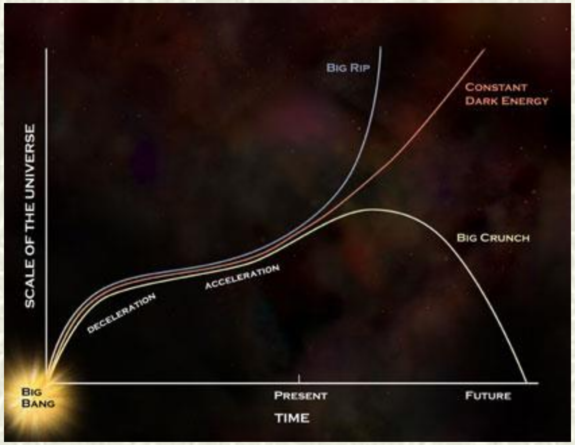

Über das sogenannte kosmologische Problem.

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).”

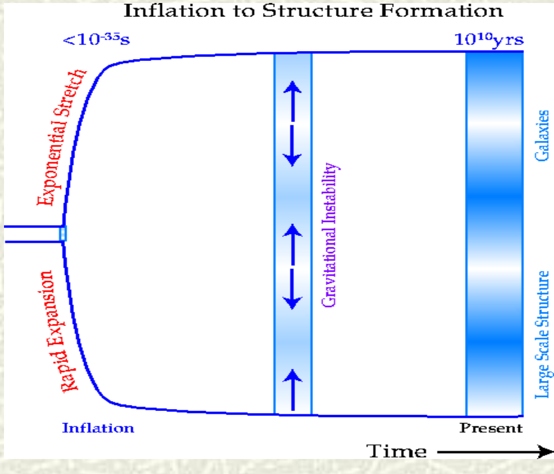
- **Cosmic inflation**

  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

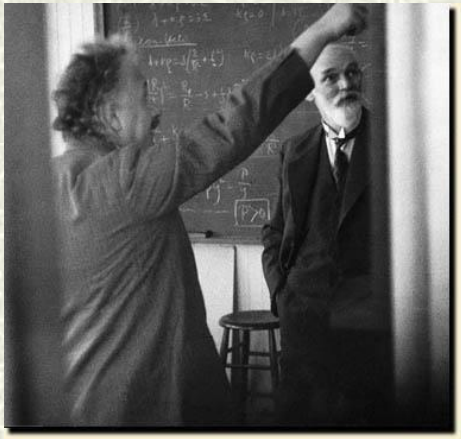
  Remove spatial curvature (Occam's razor)

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

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

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

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



- **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

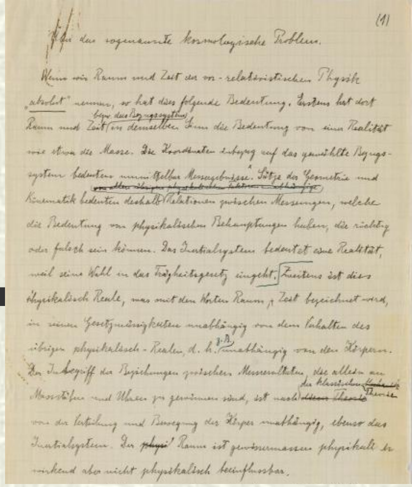
ON THE RELATION BETWEEN THE EXPANSION AND THE MEAN DENSITY OF THE UNIVERSE

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

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

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

- **Parameters extracted**

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

  <u>Timespan of 10^{10} years</u>: conflict with astrophysics

  Attributed to simplifications (incorrect estimate)

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

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

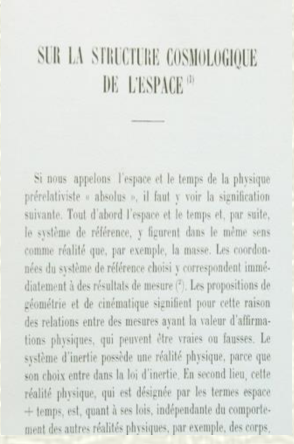
- **Published in 1933!**

  French book; small print run

  Intended for scientific journal; not submitted

  Significant paper

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



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**

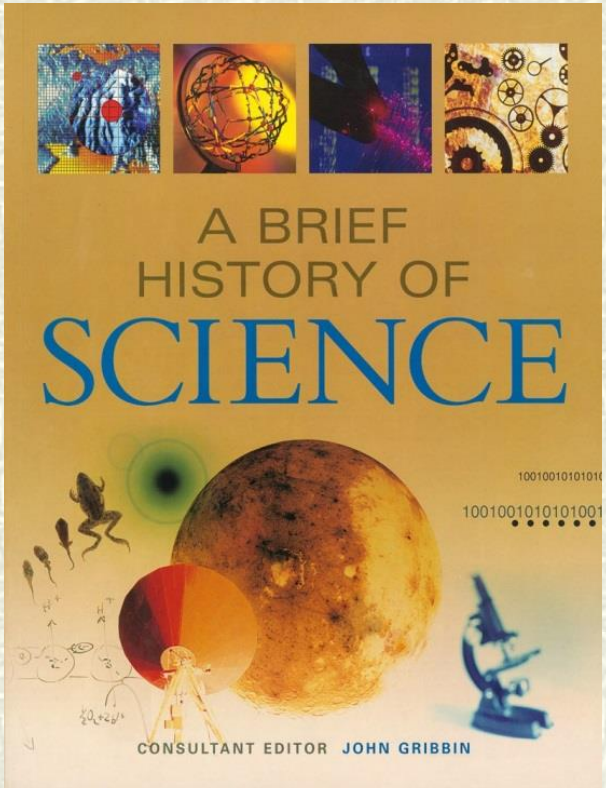
  Simple solution?

  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 ?

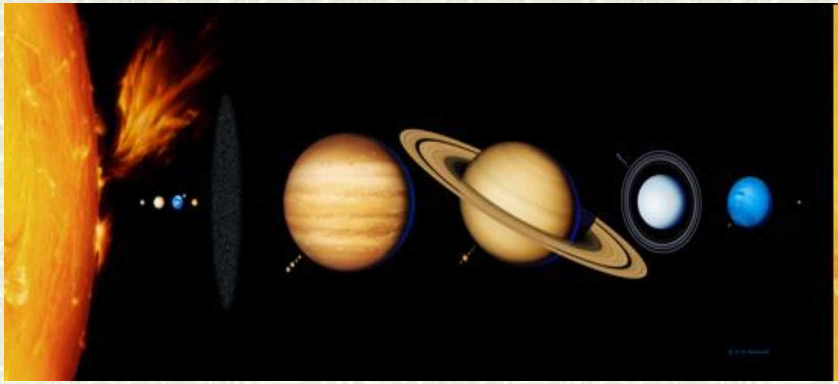
Explanation for runaway galaxies?

Newton

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

Isaac Newton

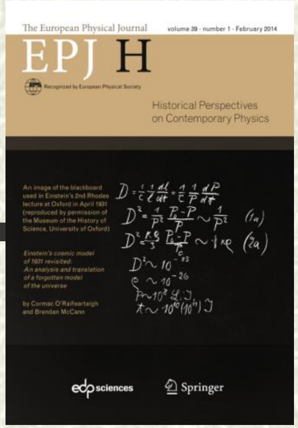
How can galaxies be receding?
What is pushing out?



Results: publications

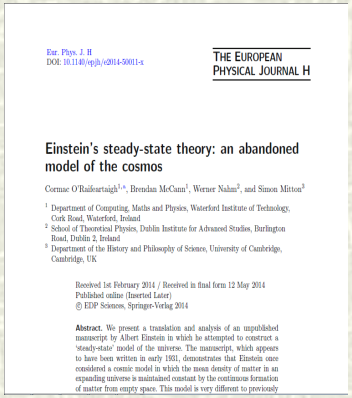
- **Einstein's 1931 model**

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

Received 1st February 2014 / Received in final form 12 May 2014
Published online (Inserted Later)
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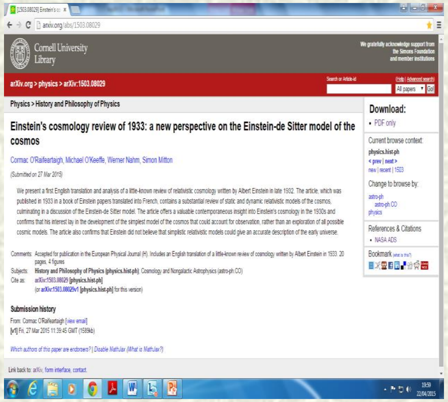
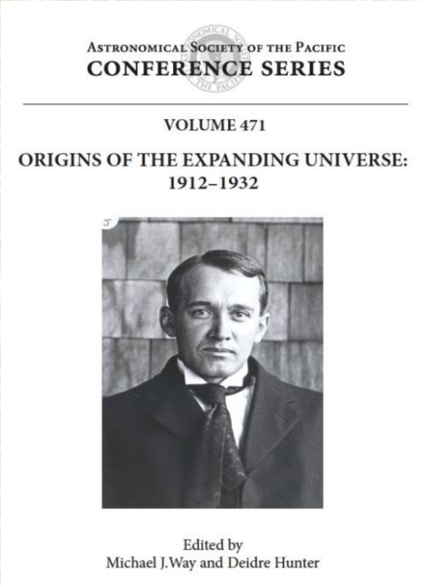
Abstract. We present a translation and analysis of an unpublished manuscript by Albert Einstein in which he attempted to construct a 'steady-state' model of the universe. The manuscript, which appears to have been written in early 1931, demonstrates that Einstein once considered a cosmic model in which 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**



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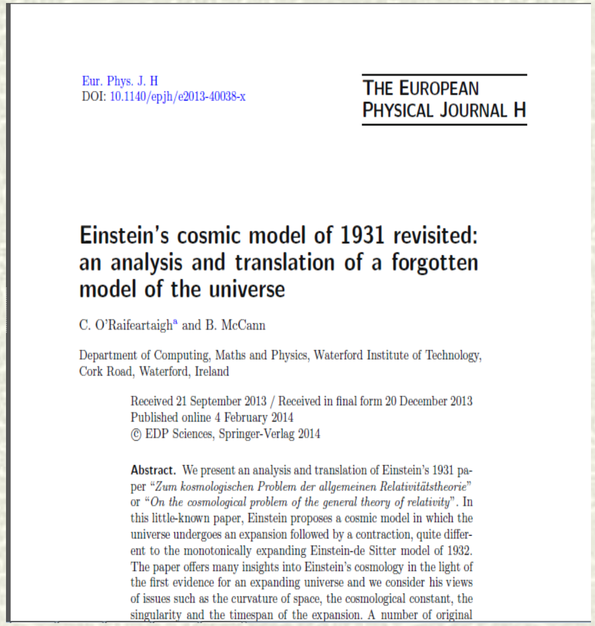
VOLUME 471

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

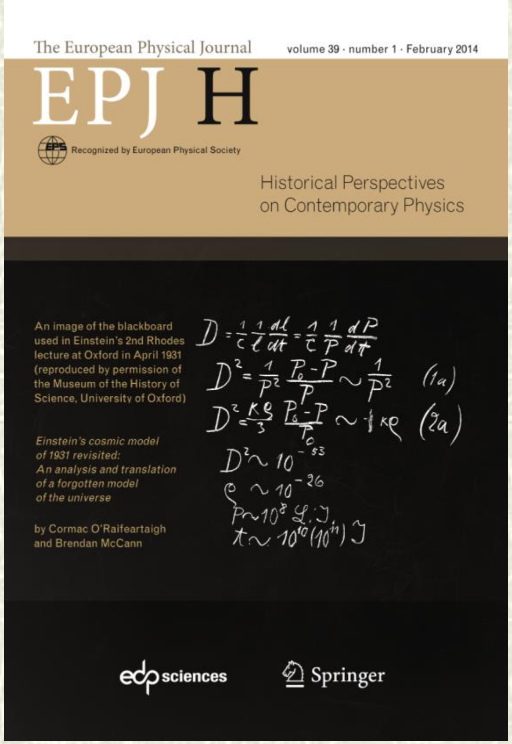
Einstein's cosmic model of 1931 revisited: an analysis and translation of a forgotten model of the universe

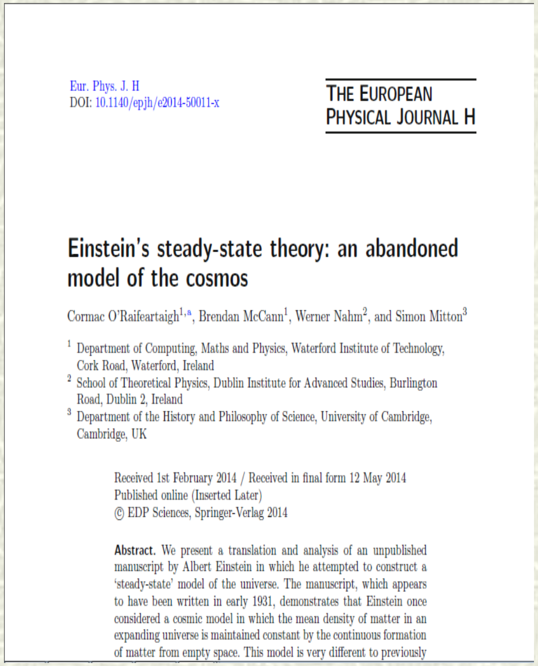
C. O'Raifeartaigh[a] and B. McCann

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





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
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[3] Department of the History and Philosophy of Science, University of Cambridge, Cambridge, UK

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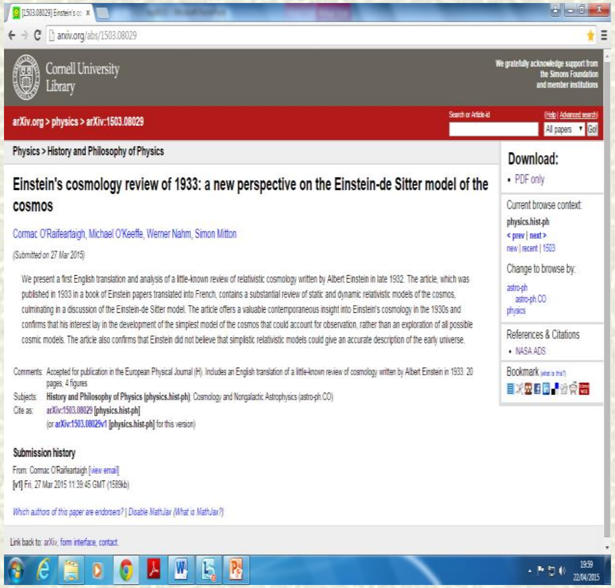

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Physics > History and Philosophy of Physics

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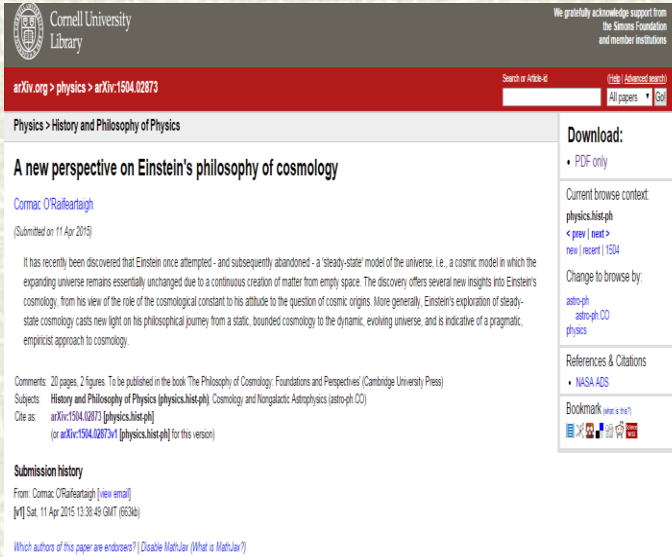
[v1] Fri, 27 Mar 2015 11:39:45 GMT (1589kb)



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A new perspective on Einstein's philosophy of cosmology

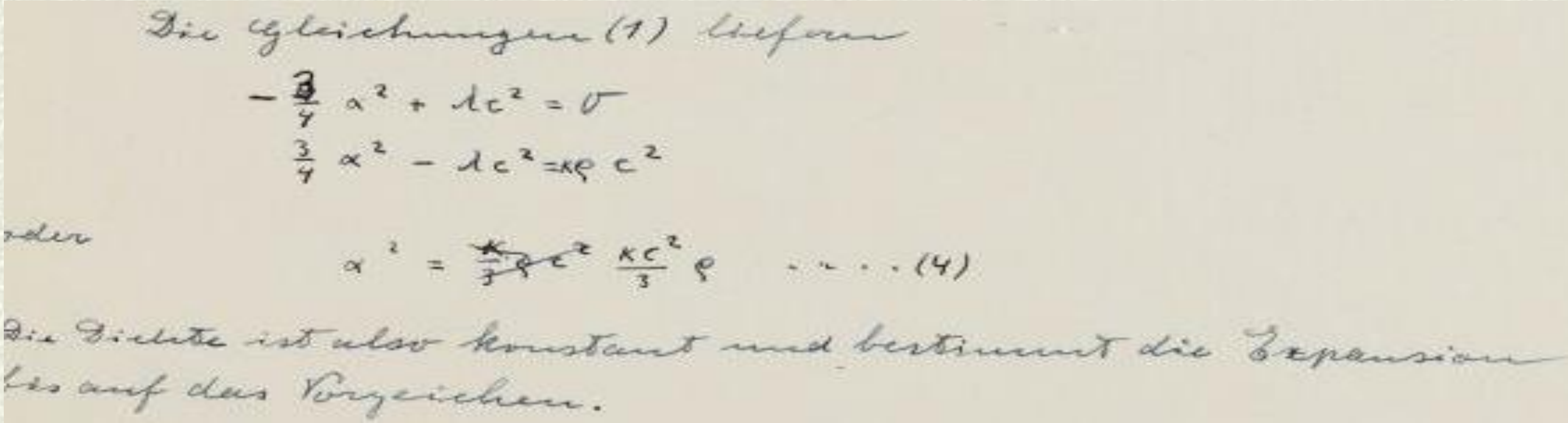
Cormac O'Raifeartaigh

(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)

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


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

Hoyle and Narlikar (1962)

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

$$\boldsymbol{G}_{\mu\nu} + \boldsymbol{C}_{\mu\nu} = -k\,\boldsymbol{T}_{\mu\nu}$$

- **Improved version (1962)**

$$\boldsymbol{G}_{\mu\nu} + \lambda g_{\mu\nu} = k\,\boldsymbol{T}\,(\boldsymbol{C}_{\mu} + \boldsymbol{C}_{\nu})$$

Conclusions

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

  Assumptions; space-time = space + time

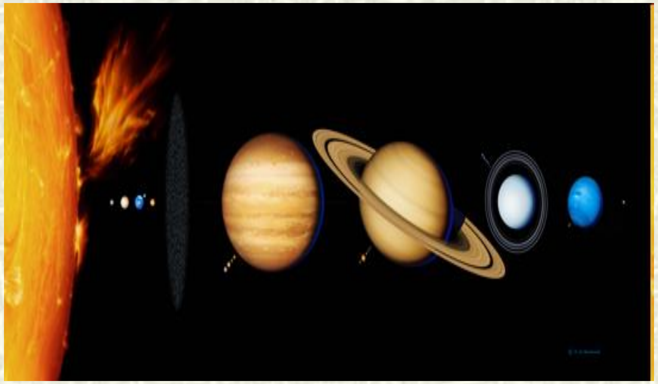
  Homogeneity and isotropy

  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