# A new perspective on Einstein's cosmology

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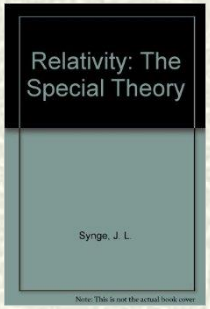
# Dublin Institute for Advanced Studies

- **75 years of DIAS**

  *Founded in 1940 (de Valera)*

  *Modelled on Princeton Research Institute (IAS)*

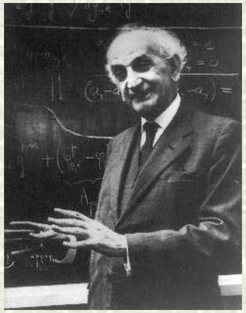


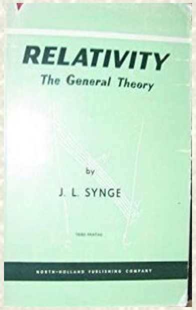

- **Two schools**

  *School of Theoretical Physics*

  *School of Celtic Languages*

  *Only pen and paper required*



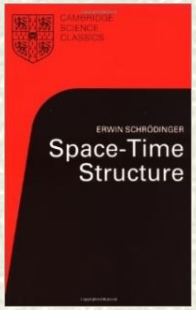



- **Major centre for relativity**

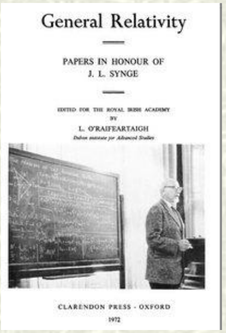
  *Erwin Schrödinger, J.L. Synge,*

  *K. Lanczos, L. O'Raifeartaigh*

  *Pirani, Bertotti,…*







# Overview

- **Introduction**

  *Einstein's cosmological considerations 1915-1930*

1. **Einstein's cosmic model of 1931**

   *Some new observations*

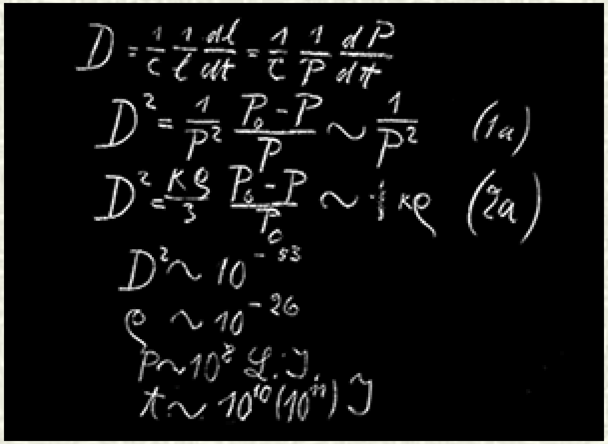
2. **Einstein's steady-state model**

   *Unfinished symphony*

3. **Einstein's cosmology review of 1933**

   *Further development of the Einstein-de Sitter model*

- **Conclusions**



*The Oxford blackboard (1931)*

# Einstein's cosmology (1915-1930)

- **The general theory of relativity (1915, 1916)**

  *A relation between spacetime and matter*

  *Gravity = curvature of spacetime*

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

$$ds^2 = g_{\mu\nu} dx^\mu dx^\nu$$

- **Principles**

  *Principle of equivalence*

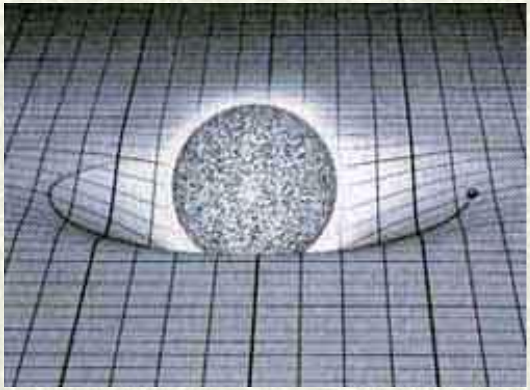
  *Mach's principle: no inertia relative to space*

  *Matter has a primary role, space has a derived one*

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\kappa T_{\mu\nu}$$

- **A burning question: a consistent model of the Cosmos?**

  *"Can relativity be followed through to the finish?"(1918)*



- **Cosmological considerations (1917)**

  *Result of long deliberation s :"A rough and winding road"*

# Einstein's model of the Static Universe

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

  *Ultimate test for new theory of gravitation*

Doc. 43

**Cosmological Considerations in the General Theory of Relativity**

This translation by W. Perrett and G. B. Jeffery is reprinted from H. A. Lorentz et al., *The Principle of Relativity* (Dover, 1952), pp. 175–188.

IT is well known that Poisson's equation

$$\nabla^2\phi = 4\pi K\rho \quad . \quad . \quad . \quad . \quad (1)$$

in combination with the equations of motion of a material point is not as yet a perfect substitute for Newton's theory of action at a distance. There is still to be taken into account the condition that at spatial infinity the potential $\phi$ tends

- **Assumptions**

  *Static universe (small velocities of the stars)*

  *Mach's principle (metric tensor to vanish at infinity)*

  *Isotropy and homogeneity (simplicity)*

- **Boundary problem**

  *A cosmos of closed curvature*

  *No consistent solution*

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\kappa \, T_{\mu\nu}$$

- **Field equations modified!**

  *Additional term in GFE (1916)*

  *Radius and density defined by λ*

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R - \lambda g_{\mu\nu} = -\kappa \, T_{\mu\nu}$$

$$\lambda = \frac{\kappa\rho}{2} = \frac{1}{R^2}$$

# Some key quotes (Einstein 1917)

**"In a consistent theory of relativity, there can be no inertia relative to "space", but only an inertia of masses relative to one another"**

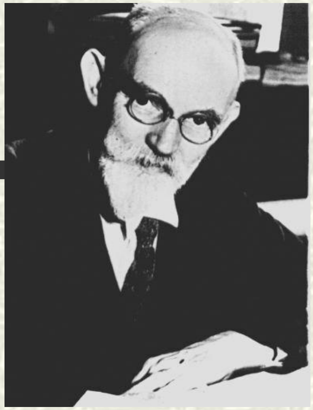
"I have not succeeding in formulating boundary conditions for spatial infinity. Nevertheless, there is still a way out…for if it were possible to regard the universe as a continuum which is finite (closed) with respect to is spatial dimensions, we should have no need at all of any such boundary conditions"

"The most important fact that we draw from experience as to the distribution of matter is that the relative velocities of the stars are very small compared with the velocity of light….. There is a system of reference relative to which matter may be looked upon as being permanently at rest "

**"However, the system of equations ..allows a readily suggested extension which is compatible with the relativity postulate**... For on the left hand side of the field equation…we may add the fundamental tensor $g_{\mu\nu}$ , multiplied by a universal constant , $-\lambda$, at present unknown, without destroying the general covariance "

***Schroedinger's comment (1918): Einstein's response (1918)***

# Einstein vs de Sitter



- **Alternative solution of the GFE**

  *A universe empty of matter (1917)*

- **Solution B**

  *Cosmic constant proportional to curvature of space*

  $$\lambda = 3/R$$

- **Disliked by Einstein**

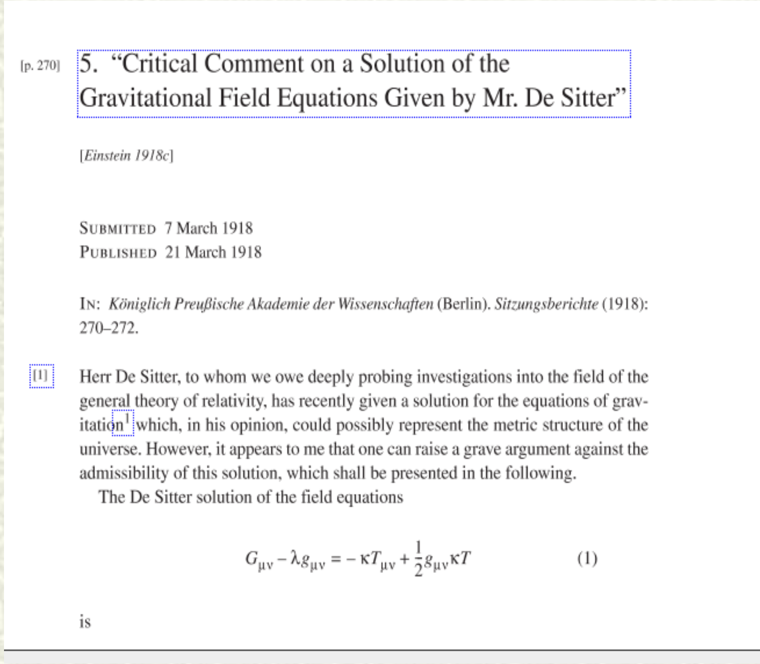
  *Problems with singularities? (1918)*

  *Conflict with Mach's principle*

- **The de Sitter confusion**

  *Static or non-static - a matter of co-ordinates?*

  *Weyl , Lanczos, Lemaître*



[p. 270] 5. "Critical Comment on a Solution of the Gravitational Field Equations Given by Mr. De Sitter"

[*Einstein 1918c*]

SUBMITTED 7 March 1918
PUBLISHED 21 March 1918

IN: *Königlich Preußische Akademie der Wissenschaften* (Berlin). *Sitzungsberichte* (1918): 270–272.

[1] Herr De Sitter, to whom we owe deeply probing investigations into the field of the general theory of relativity, has recently given a solution for the equations of gravitation[1] which, in his opinion, could possibly represent the metric structure of the universe. However, it appears to me that one can raise a grave argument against the admissibility of this solution, which shall be presented in the following.

The De Sitter solution of the field equations

$$G_{\mu\nu} - \lambda g_{\mu\nu} = -\kappa T_{\mu\nu} + \frac{1}{2} g_{\mu\nu} \kappa T \qquad (1)$$

is

***Prediction of redshifts – Slipher effect?***

# Einstein vs Friedman

- **Allow time-varying solutions (1922)**
  *Assume homogeneity, isotropy, positive curvature*
  *Two independent differential equations from GFE*

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

$$\frac{R'^2}{R^2} + \frac{2RR''}{R^2} + \frac{c^2}{R^2} - \lambda = 0.$$

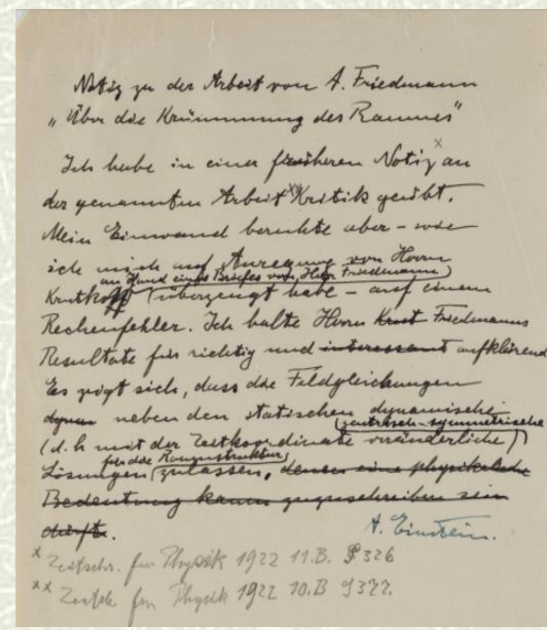
*Alexander Friedman*
*(1888 -1925)*

- **Evolving universes**
  *Density of matter varies over time*

$$\frac{1}{c^2}\left(\frac{\mathrm{d}R}{\mathrm{d}t}\right)^2 = \frac{A - R + \frac{\lambda}{3c^2}R^3}{R}$$

- **Overlooked by community**
  *Considered 'suspicious' by Einstein*
  *Mathematical correction, later retracted*
  *"~~To this a physical reality can hardly be ascribed~~"*

$$t = \frac{1}{c}\int_a^R \sqrt{\frac{x}{A - x + \frac{\lambda}{3c^2}x}}\,\mathrm{d}x + B$$


Notiz zu der Arbeit von A. Friedmann
„Über die Krümmung des Raumes" x
Ich habe in einer früheren Notiz an
der genannten Arbeit xx Kritik geübt.
Mein Einwand beruhte aber – wie
ich mich ~~auf Anregung von Herrn~~ (an Hand eines Briefes von Herrn Friedmann)
~~Krutkoff~~ überzeugt habe – auf einem
Rechenfehler. Ich halte Herrn ~~Krut~~ Friedmanns
Resultate für richtig und ~~interessant~~ aufklärend.
Es zeigt sich, dass die Feldgleichungen
~~dyn~~ neben den statischen dynamische (zentrisch-symmetrische)
(d. h. mit der Zeitkoordinate veränderliche)
Lösungen (für die Raumstruktur) ~~zulassen, denen eine physikalische~~
~~Bedeutung kaum zuzuschreiben sein~~
~~dürfte~~. A. Einstein
x Zeitschr. f. Physik 1922 11. B. S. 326
xx Zeitschr. f. Physik 1922 10. B S. 377

- **Negative spatial curvature (1924)**
  *Cosmic evolution, geometry depends on matter*
  *Overlooked by community*

# Einstein vs Lemaître (1927)

Fr Georges Lemaître

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

  *Similar but not identical to Friedman 1922*

  *Starts from static Einstein Universe*

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

$$2\frac{R''}{R}+\frac{R'^2}{R^2}+\frac{1}{R^2}=\lambda-\kappa p$$

- **Redshifts of galaxies = expansion of metric***?*

  *Redshifts from Slipher, distances from Hubble*

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

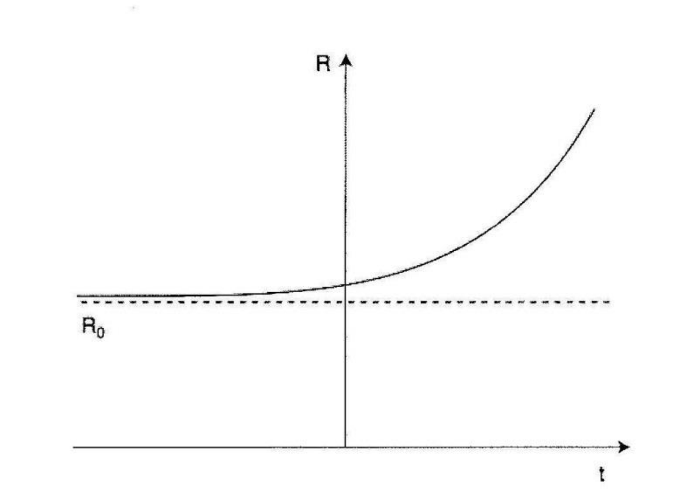
- **Ignored by community**

  *Belgian journal (in French)*

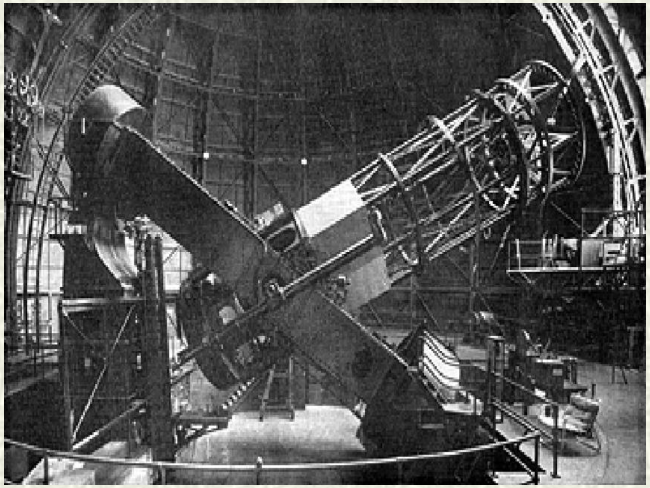
  *Rejected by Einstein: "Votre physique est abominable"*

- **Lemaître's recollection (1958)**

  *"Einstein not up-to-date with astronomy"*



# Hubble's law (1929)



- **A redshift/distance relation for the nebulae?**

  *Motivation: establishing distances of all nebulae*

- **Linear relation (Hubble, 1929)**

  *20 redshifts from Slipher: not acknowledged*

  *Most important data point not shown (8Mpc, 4000 km/s)*

- **Landmark result in astronomy**

  $H = 500\ kms^{-1}\ Mpc^{-1}$

- **Not the expanding universe!**

  *Astronomy, not cosmology*

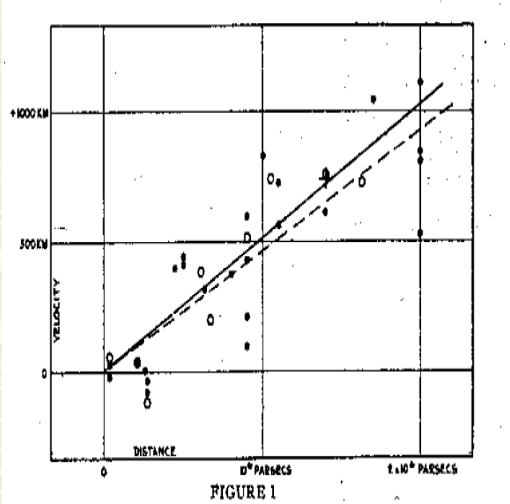


FIGURE 1

# The watershed

- **RAS meeting (1930)**

  *If redshifts are velocities, and if effect is non-local*

  *Hubble's law = expansion of space? (Edd., de Sitter)*

- **Dynamic model required**

  *"Motion in Einstein's model or matter in de Sitter's?"*

- **Lemaître's intervention**

  *1927 expanding model republished in English (1931)*

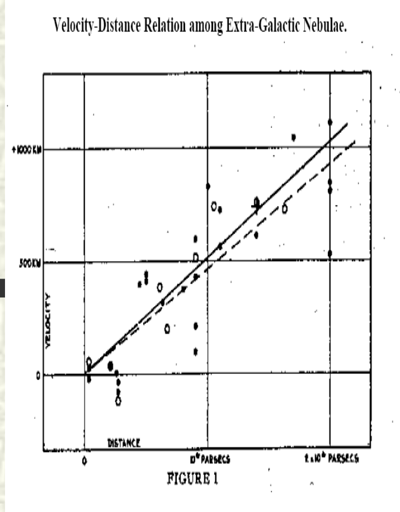
  *Observational section omitted (rightly)*

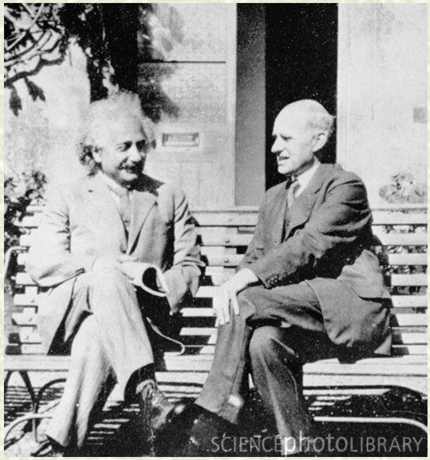
- **Lemaître model circulated**

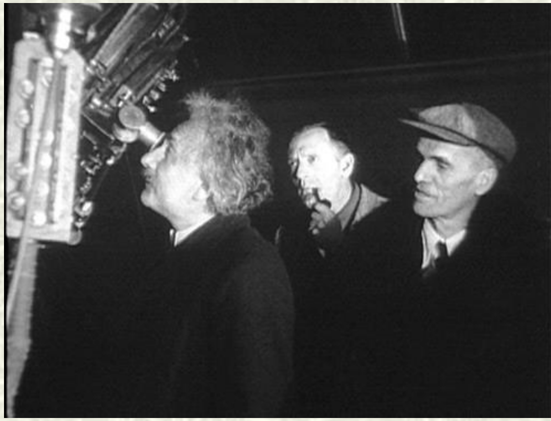
  *Time-varying radius, density of matter*

  *Friedman 1922 models become known*

  *Positive curvature*



# Models of the evolving universe (1930 -)

- **Tolman (1930, 31)**
  *Expansion caused by annihilation of matter ?*

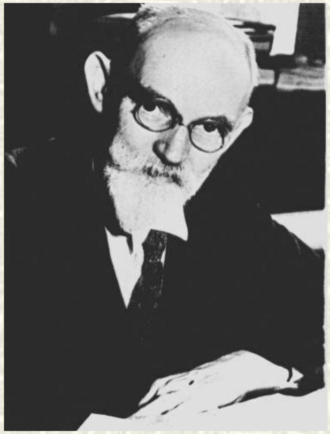
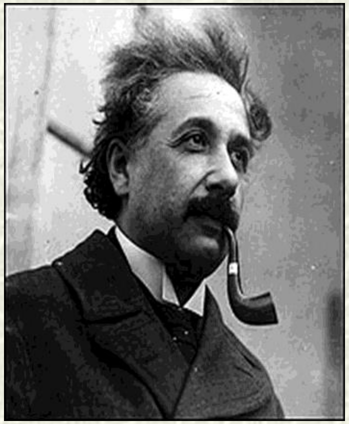
- **Eddington (1930, 31)**
  *On the instability of the Einstein universe*
  *Expansion caused by condensation?*

- **de Sitter (1930, 31)**
  *Variety of expanding models*

- **Heckmann (1931,32)**
  *Spatial curvature (not translated)*

- **Einstein (1931, 32) JMK**
  *Friedman-Einstein model* $\lambda = 0, k = 1$
  *Einstein-de Sitter model* $\lambda = 0, k = 0$



***If** redshifts represent expansion…*
***If** effect is global…*

# Einstein's 1931 model (*F-E*)

- **Einstein's 'first' model of the Expanding Universe**

  *Occasionally cited, rarely read (not translated)*

- **Adopts Friedman 1922 model**

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

- **Set cosmic constant to zero**

  *Instability of static solution*

  *Hubble's observations*

- **Extraction of cosmic parameters!**

  $P \sim 10^8$ lyr : $\rho \sim 10^{-26}$ g/cm$^3$

  $t \sim 10^{10}$ yr : *conflict with astrophysics*

  *Attributed to simplifying assumptions (homogeneity)*

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

$$\frac{P'^2}{P^2} + \frac{2P''}{P} + \frac{c^2}{P^2} - \lambda = 0$$

$$\frac{1}{c^2}\left(\frac{\mathrm{d}R}{\mathrm{d}t}\right)^2 = \frac{A - R + \frac{\lambda}{3c^2}R^3}{R}$$

$$\left(\frac{dP}{dt}\right)^2 = c^2 \frac{P_0 - P}{P}$$

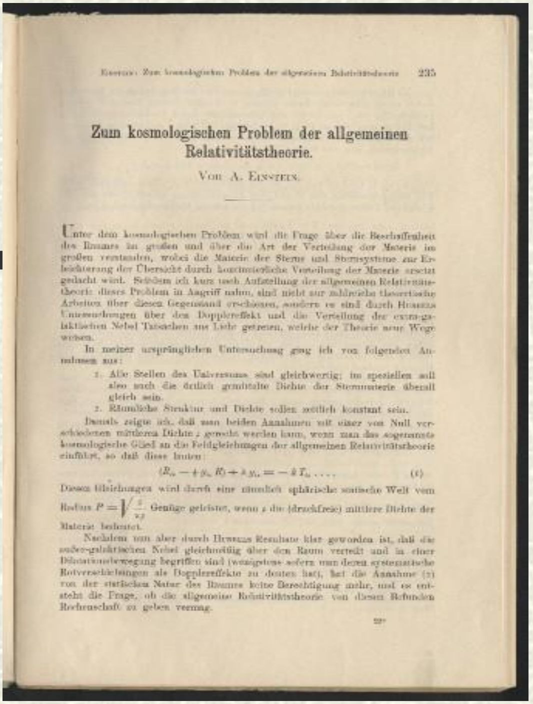
$$D = \frac{1}{P}\frac{dP}{dt}\cdot\frac{1}{c}$$

$$D^2 = \frac{1}{P^2}\frac{P_0 - P}{P}$$

$$P \sim \frac{1}{D}$$

$$D^2 = \frac{1}{3}\kappa\rho\frac{P_0 - P}{P}$$

$$D^2 \sim \kappa\rho$$



Einstein: Zum kosmologischen Problem der allgemeinen Relativitätstheorie 235

**Zum kosmologischen Problem der allgemeinen Relativitätstheorie.**

Von A. Einstein.

Unter dem kosmologischen Problem wird die Frage über die Beschaffenheit des Raumes im großen und über die Art der Verteilung der Materie im großen verstanden, wobei die Materie der Sterne und Sternsysteme zur Erleichterung der Übersicht durch kontinuierliche Verteilung der Materie ersetzt gedacht wird. Seitdem ich kurz nach Aufstellung der allgemeinen Relativitätstheorie dieses Problem in Angriff nahm, sind nicht nur zahlreiche theoretische Arbeiten über diesen Gegenstand erschienen, sondern es sind durch Hubbles Untersuchungen über den Dopplereffekt und die Verteilung der extra-galaktischen Nebel Tatsachen ans Licht getreten, welche der Theorie neue Wege weisen.

In meiner ursprünglichen Untersuchung ging ich von folgenden Annahmen aus:

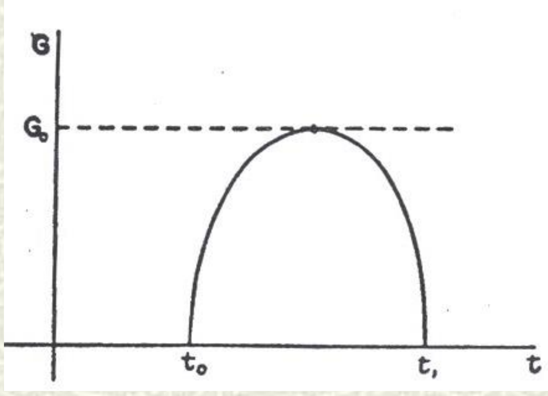
1. Alle Stellen des Universums sind gleichwertig; im speziellen soll also auch die örtlich gemittelte Dichte der Sternmaterie überall gleich sein.
2. Räumliche Struktur und Dichte sollen zeitlich konstant sein.

Damals zeigte ich, daß man beiden Annahmen mit einer von Null verschiedenen mittleren Dichte ρ gerecht werden kann, wenn man das sogenannte kosmologische Glied an die Feldgleichungen der allgemeinen Relativitätstheorie einführt, so daß diese lauten:

$$(R_{ik} - \tfrac{1}{2} g_{ik} R) + \lambda g_{ik} = -\kappa T_{ik} \ldots \quad (1)$$

Diesen Gleichungen wird durch eine räumlich sphärische statische Welt vom Radius $P = \sqrt{\frac{2}{\kappa\rho}}$ Genüge geleistet, wenn ρ die (druckfreie) mittlere Dichte der Materie bedeutet.

Nachdem nun aber durch Hubbles Resultate klar geworden ist, daß die außer-galaktischen Nebel gleichmäßig über den Raum verteilt und in einer Dilatationsbewegung begriffen sind (wenigstens sofern man deren systematische Rotverschiebungen als Dopplereffekte zu deuten hat), hat die Annahme (2) von der statischen Natur des Raumes keine Berechtigung mehr, und es entsteht die Frage, ob die allgemeine Relativitätstheorie von diesen Befunden Rechenschaft zu geben vermag.



# Einstein’s 1931 model revisited

- **First translation into English**

  *O’Raifeartaigh and McCann 2014*

$$D = \frac{1}{P}\frac{dP}{dt}\cdot\frac{1}{c}$$

$$D^2 = \frac{1}{P^2}\frac{P_0 - P}{P}$$

$$P \sim \frac{1}{D}$$

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

  *Einstein:* $P \sim 10^8$ lyr, $\rho \sim 10^{-26}$ g/cm$^3$ , $t \sim 10^{10}$ yr

  *We get:* $P \sim 10^9$ lyr, $\rho \sim 10^{-28}$ g/cm$^3$ , $t \sim 10^9$ yr

$$D^2 = \frac{1}{3}\kappa\rho\frac{P_0 - P}{P}$$

$$D^2 \sim \kappa\rho$$

- **Source of error?**

  *Oxford blackboard:* $D^2 \sim 10^{-53}$ cm$^{-2}$ *should be* $10^{-55}$ cm$^{-2}$

  *Time miscalculation* $t \sim 10^{10}$ yr (*should be* $10^9$ yr)

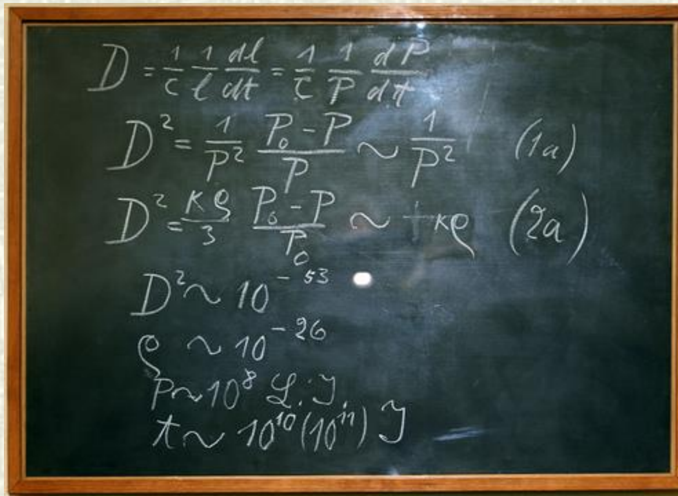
  *Non-trivial error: misses conflict with radioactivity*

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

  *“Model fails at P = 0 ”*

  *Contrary to what is usually stated*

*Oxford lecture (May 1931)*



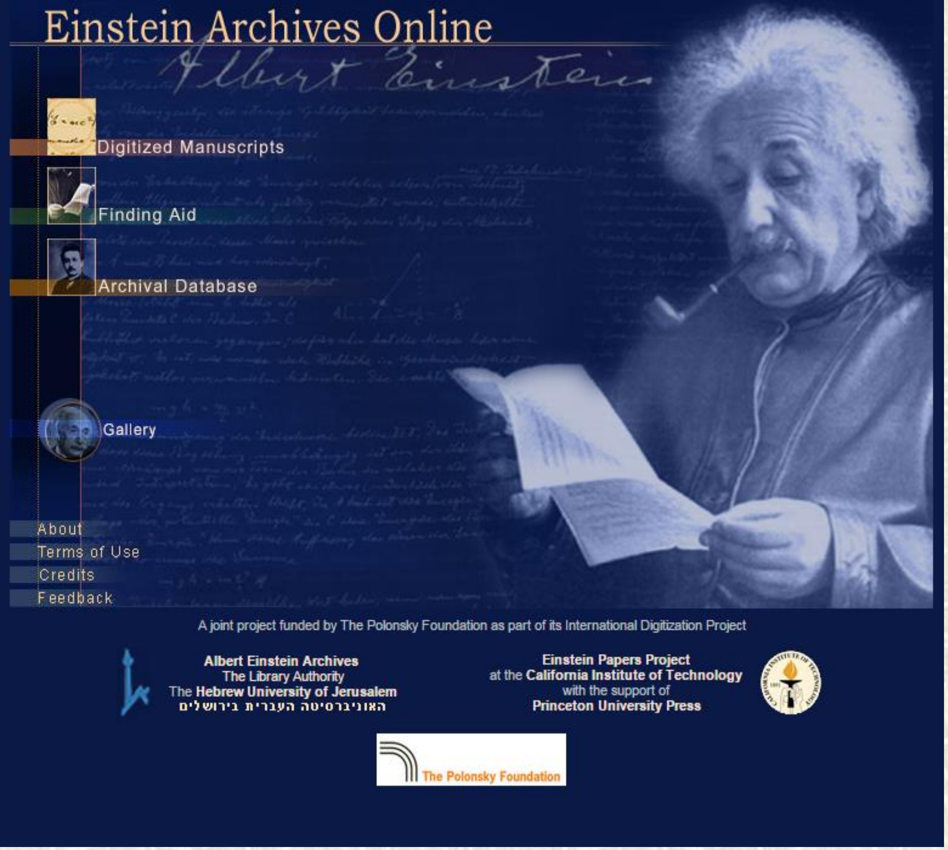
# Some key quotes (Einstein 1931)

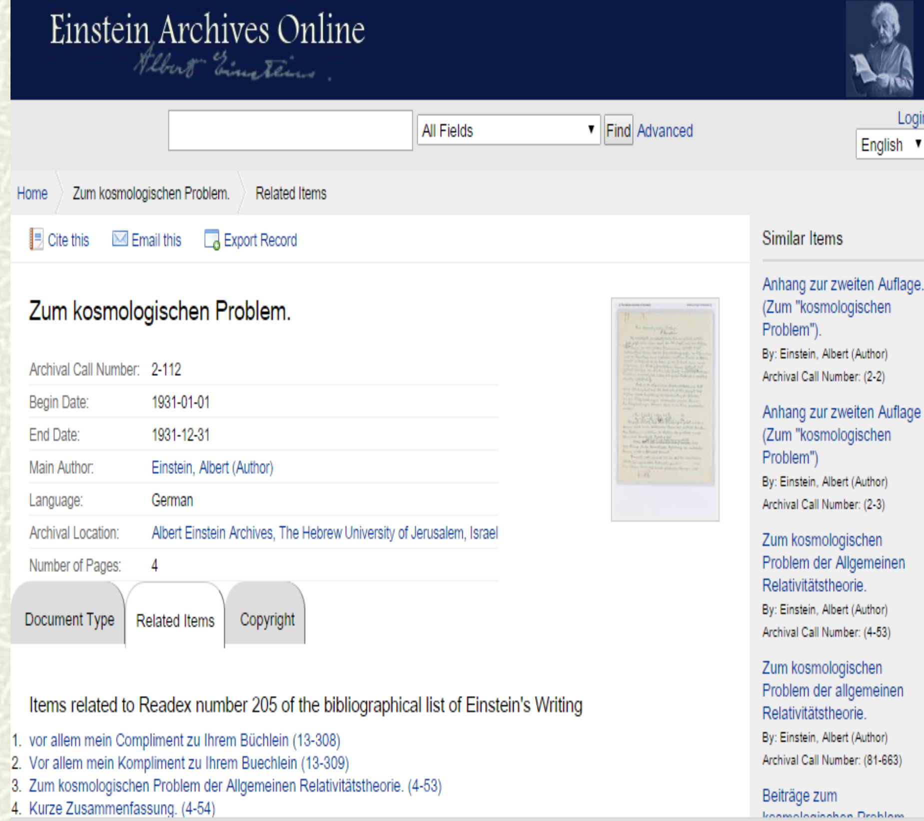
"The cosmological problem is understood to concern the question of the nature of space and the manner of the distribution of matter on a large scale, where the material of the stars and stellar systems is assumed for simplicity to be replaced by a continuous distribution of matter."

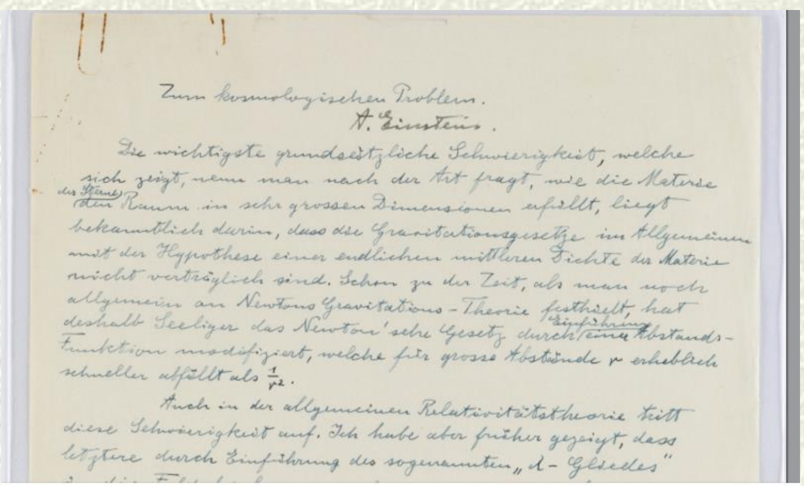
"Now that it has become clear from Hubbel's results that the extra-galactic nebulae are uniformly distributed throughout space and are in dilatory motion (at least if their systematic redshifts are to be interpreted as Doppler effects), assumption (2) concerning the static nature of space has no longer any justification…."

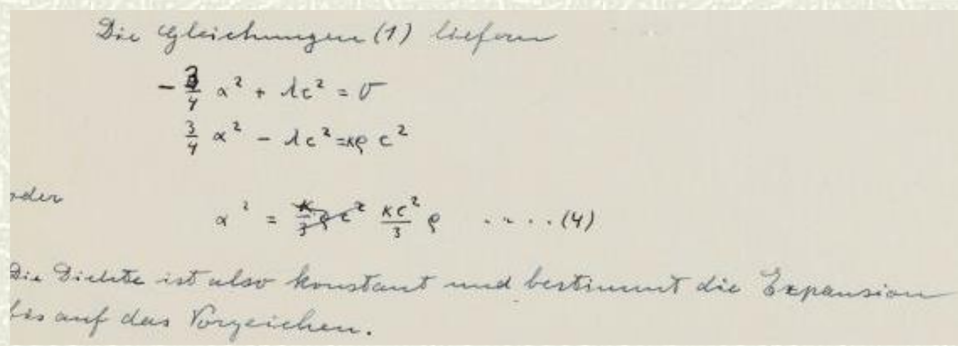
**"Several investigators have attempted to account for the new facts by means of a spherical space whose radius *P* is variable over time. The first to try this approach, uninfluenced by observations, was A. Friedman,[1] on whose calculations I base the following remarks. "**

"However, the greatest difficulty with the whole approach… is that according to (2 a), the elapsed time since P = 0 comes out at only about $10^{10}$ years. One can seek to escape this difficulty by noting that the inhomogeneity of the distribution of stellar material makes our approximate treatment illusory."



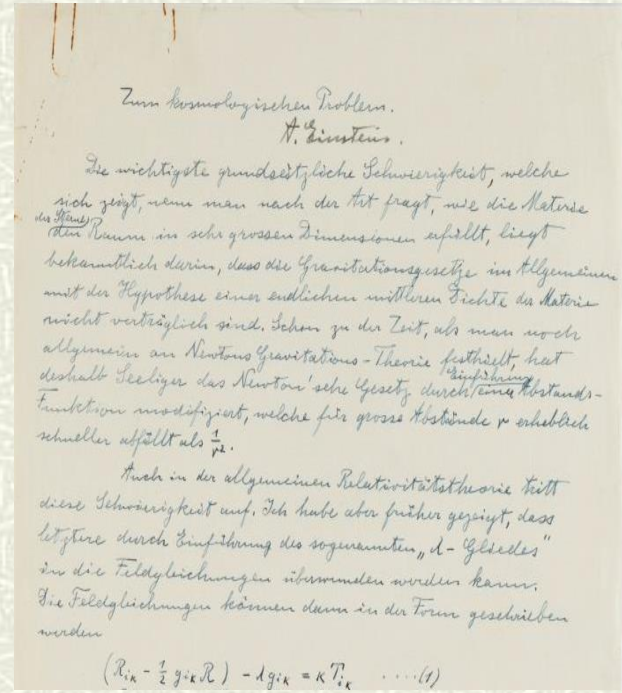




*"The density is thus constant and determines the expansion"*

# 2. Einstein's steady-state model

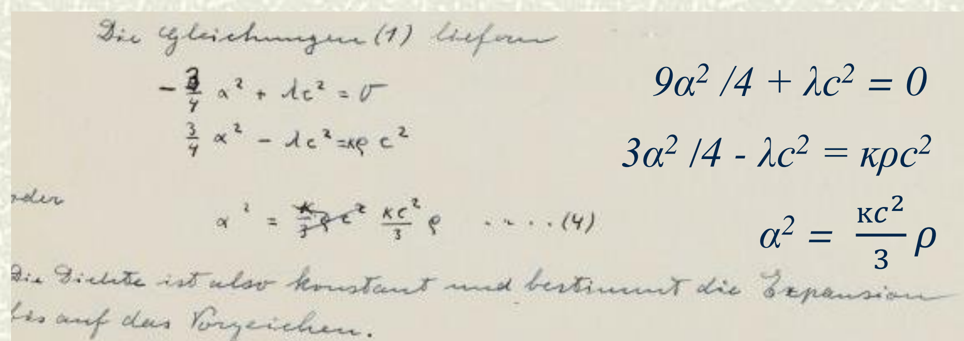
- **Unpublished manuscript**
  - *Archived as draft of F-E model (1931)*
  - *Similar title, opening to F-E model*
- **Something different**
  - *Cosmological constant*
  - *"The density is thus constant and determines the expansion"*
- **Steady-state model of the Expanding Universe**
  - *Anticipates Hoyle solution*
  - *Written in early 1931*
  - *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.

$$9\alpha^2/4 + \lambda c^2 = 0$$

$$3\alpha^2/4 - \lambda c^2 = \kappa\rho c^2$$

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

# Einstein's steady-state model (Jan 31)

**Problem with evolving models**

*"De Sitter and Tolman have already shown that there are solutions to equations (1) that can account for these [Hubbel's] observations. However the difficulty arose that the theory unvaryingly led to a beginning in time about $10^{10}$ – $10^{11}$ years ago, which for various reasons seemed unacceptable."*

**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..*

*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 "*

**Mechanism**

*"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)."*

# An abandoned model

- **Correct geometry**

  *de Sitter metric*

- **Simultaneous equations**

  *Eliminate* $\lambda$

  *Relation between* $\alpha^2$ *and* $\rho$

- **Einstein's crossroads**

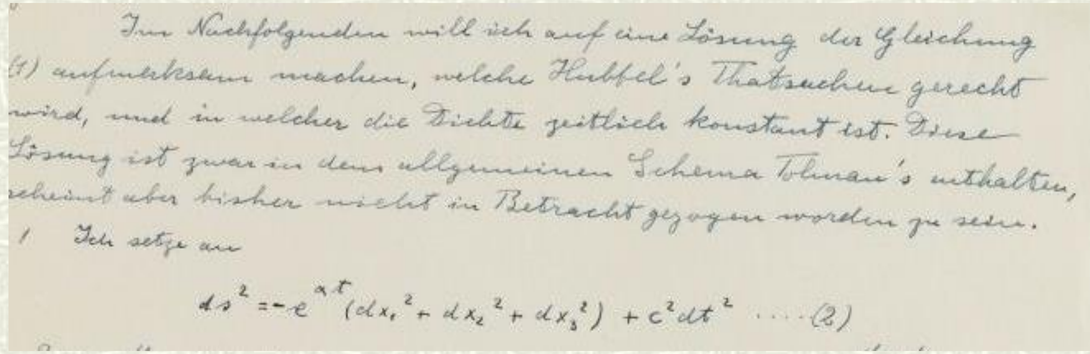
  *Null solution on revision*

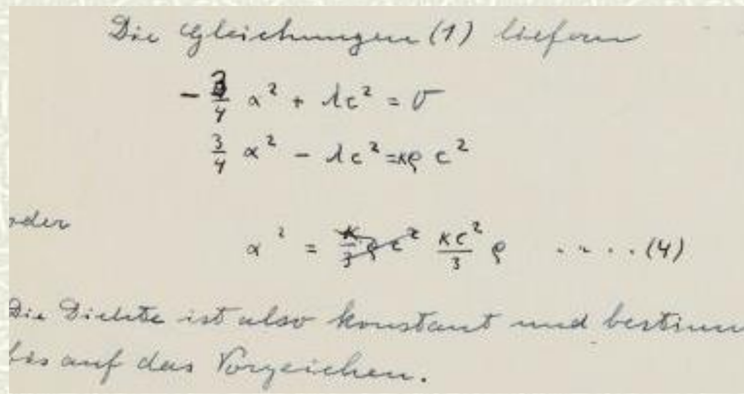
  *Tolman? (Nussbaumer 2014)*

  *Declined to amend GFE*

- **Evolving models**

  *Less contrived: set* $\lambda = 0$

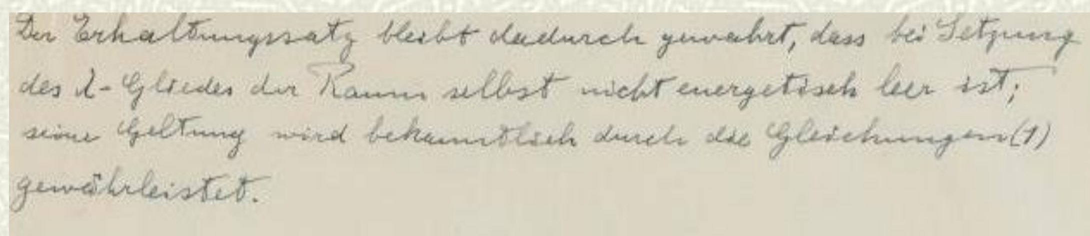



$9\alpha^2/4 + \lambda c^2 = 0$

$3\alpha^2/4 - \lambda c^2 = \kappa\rho c^2$

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



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# 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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# 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

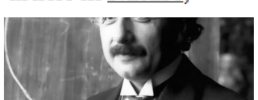
2 comments, 2 called-out | + Comment Now | + Follow Comments

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,



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www.irishtimes.com/news/science/wit-researchers-discover-lost-einstein-model-of-universe-1.1713487

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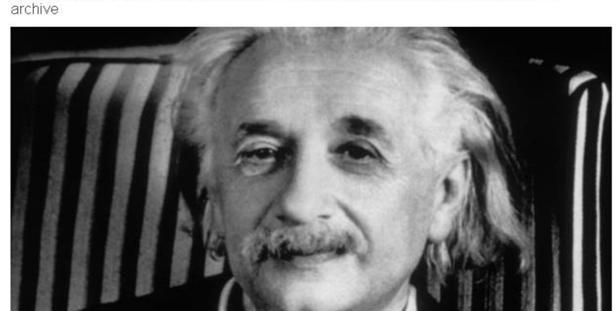
# WIT researchers discover 'lost' Einstein model of universe

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



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- 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

# A useful find

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

  *Logical idea: not a crank theory*

  *Tolman, Schroedinger, Mimura : considered steady-state universe*

- **Insight into scientific progress**

  *Unuccessful theories important in the development of science*

- **Links with modern cosmology**

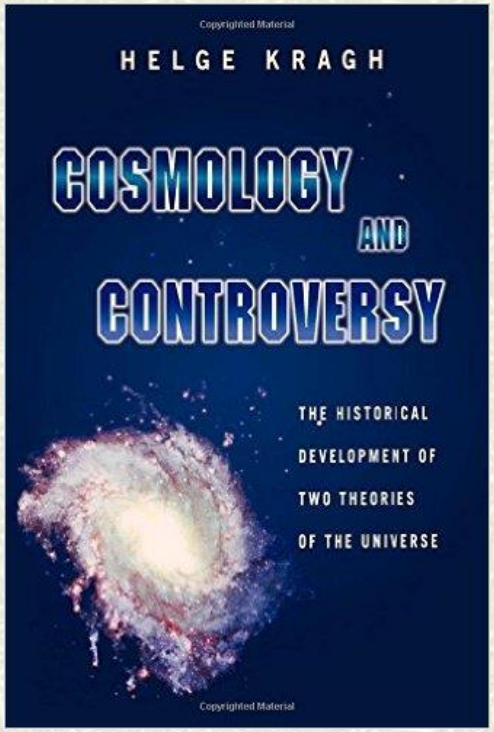
  *Creation energy and λ: dark energy*

  *de Sitter metric: cosmic inflation*

- **Insight into Einstein's cosmology**

  *Turns to evolving models rather than introduce new term to GFE*

  *Pragmatic approach: F-E model*



# 3. Einstein-de Sitter model (1932)

- **Curvature not a given in dynamic models (Heckmann)**

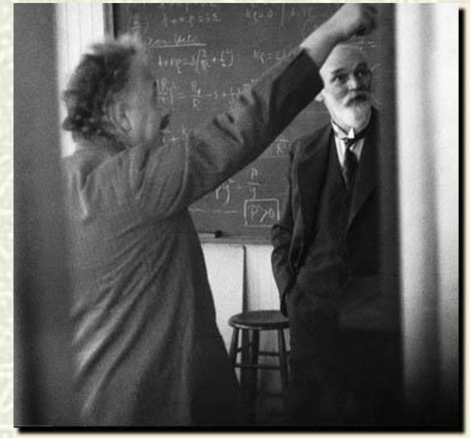
  *Not observed empirically*

  *Remove spatial curvature (Occam's razor)*

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

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

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



- **Simplest Friedman model**

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

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

  *Important hypothetical cosmos: critical case*

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

  *Despite high density of matter, age problem*

  *Time evolution not considered*

  *Eddington's anecdote*

PROCEEDINGS
OF THE
NATIONAL ACADEMY OF SCIENCES

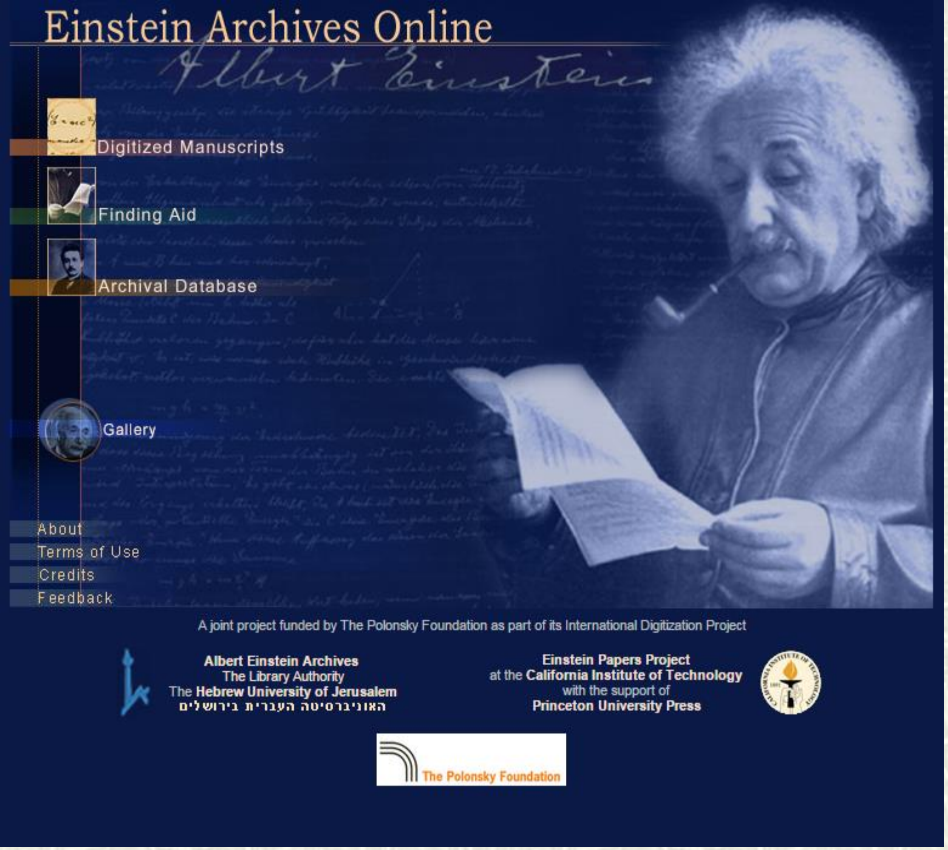
Volume 18 March 15, 1932 Number 3

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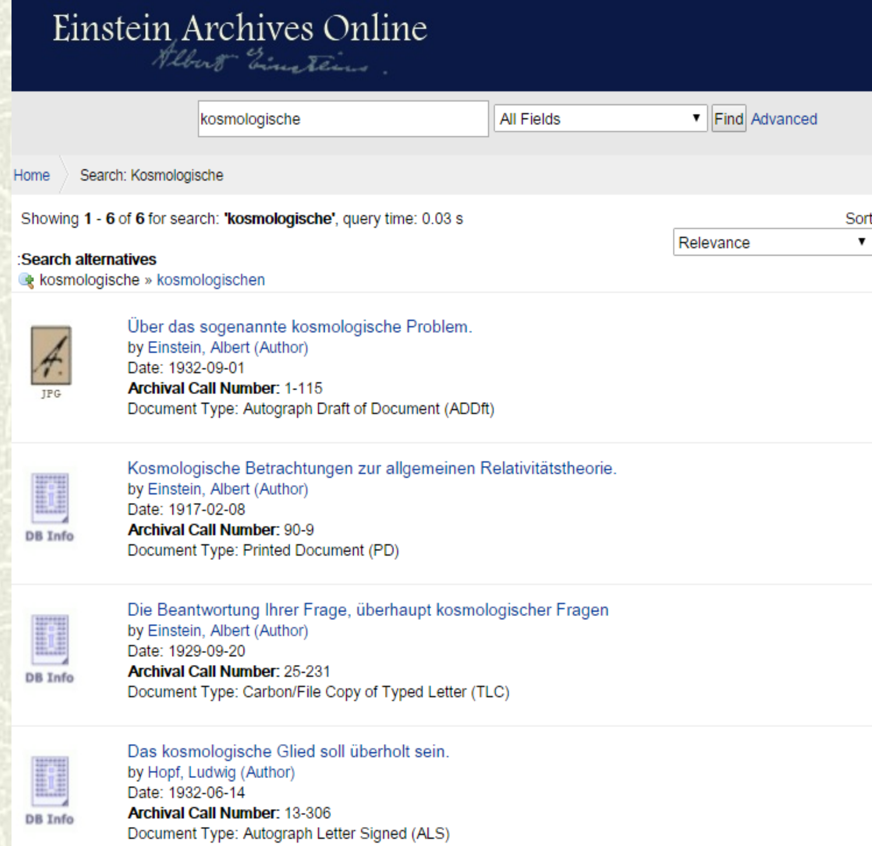
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Über das sogenannte kosmologische Problem.
by Einstein, Albert (Author)
Date: 1932-09-01
Archival Call Number: 1-115
Document Type: Autograph Draft of Document (ADDft)
JPG
Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie.
by Einstein,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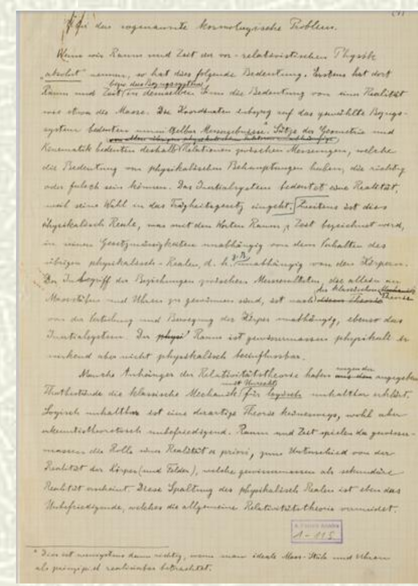
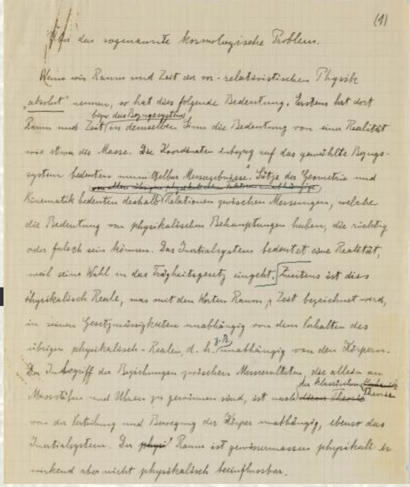


# Einstein-de Sitter model revisited




- **Einstein's cosmology review of 1933**
  - *Overview of dynamic models from first principles*
  - *Significant exposition*
  - *Culminates in Einstein-de Sitter model*
  - *Including time evolution*

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

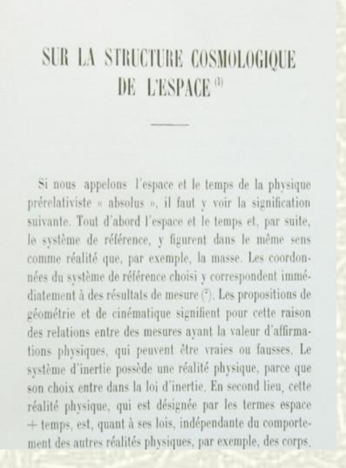
$$3\left(\frac{\frac{dA}{dt}}{A}\right)^2 = \varkappa\rho c^2.$$

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

- **Published in 1933**
  - *French book (transl. Solovine); small print run*
  - *Intended for scientific journal; not submitted*

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


- **Parameters extracted**
  - *Critical density of $10^{-28}$ g/cm$^3$ : reasonable*
  - *Timespan of $10^{10}$ years: <u>incorrect estimate</u>*
  - *Conflict with astrophysics: attributed to simplifications*



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.

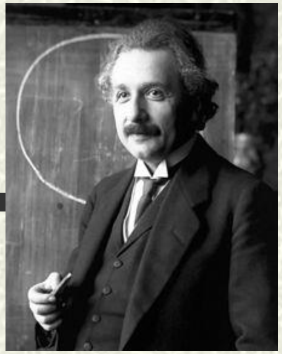
# Some key quotes (Einstein 1933)

"Since, according to the general theory of relativity, the metric properties of space are not given in themselves but are instead determined by material objects that force a non-Euclidean character on the continuum, a problem arises….since we may assume that the stars are distributed with a finite density everywhere in the world, that is, a non-zero average density of matter in general, there arises the question of the influence of this mean density on the (metric) structure of space on a large scale; this is the so-called cosmological problem "

"Thus the theory can now, without the introduction of a $\lambda$-term, accommodate a finite (mean) density of matter $\rho$ on the basis of equations (1), using relation 3(a) with $P$ (and $\rho$) variable over time"

**"It follows from these considerations that in the light of our present knowledge, the fact of a non-zero density of matter need not be reconciled with a curvature of space, but instead with an expansion of space. Of course, this does not mean that such a curvature (positive or negative) does not exist. However, there is at present no indication of its existence. In any case, it may well be substantially smaller than might have been suggested by the original theory (see equation 5)."**

# Einstein's cosmology: conclusions



- **Major test for general relativity**

  *Conscious of assumptions of homogeneity, isotropy*

Hubble constant revised

- **Embraces dynamic cosmology**

  *New evidence – new models (JMK)*

  *Timespan of expanding models puzzling*

  *Steady-state universe?*

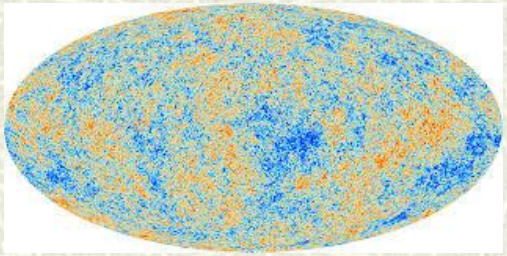
- **Evolving models (less contrived)**

  *Cosmic constant not necessary*

  *Extraction of parameters compatible with observation*

  *Closed and open models*

  *Timespan problem attributed to simplifying assumptions*



Cosmic microwave background
Homogeneous, flat universe

***Verdict (1933, 1945): more observational data needed***

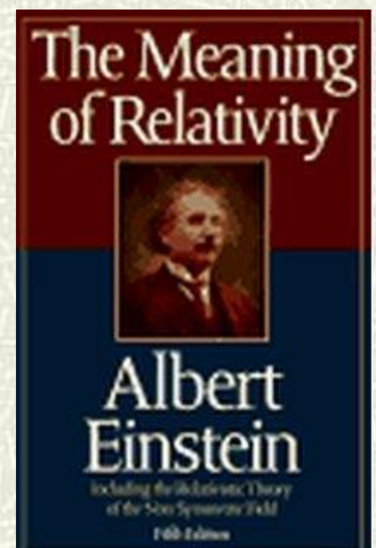
***No mention of origins***

# Einstein’s greatest hits (cosmology)


- **Einstein’s model of the Static Universe (1917)**
  *First relativistic model of the cosmos*


- **Einstein’s steady-state model (Jan 31)**
  *Natural successor to static model: abandoned*

- **Friedman-Einstein model of the Universe (1931)**
  *Use of Hubble constant to extract observational parameters*

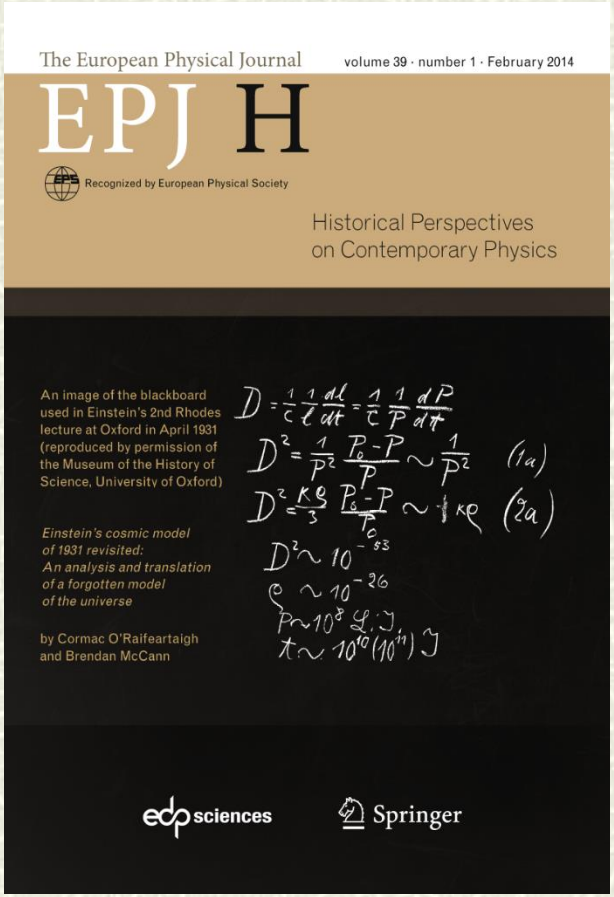


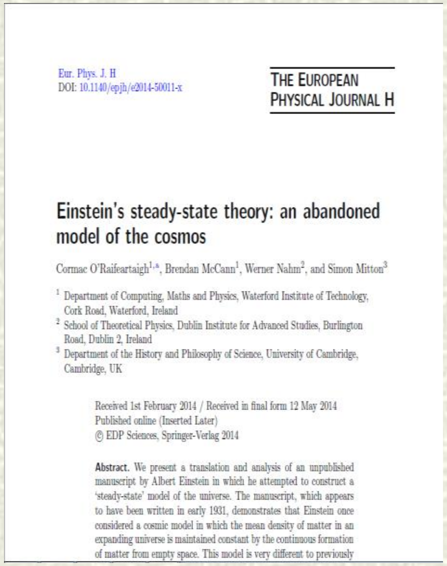

- **Einstein-de Sitter model of the Universe (1932)**

- **1933 review: 1945 review (Appendix)**
  *Conversations with Gamow, Godel, Straus*

***No mention of origins***

# Further reading




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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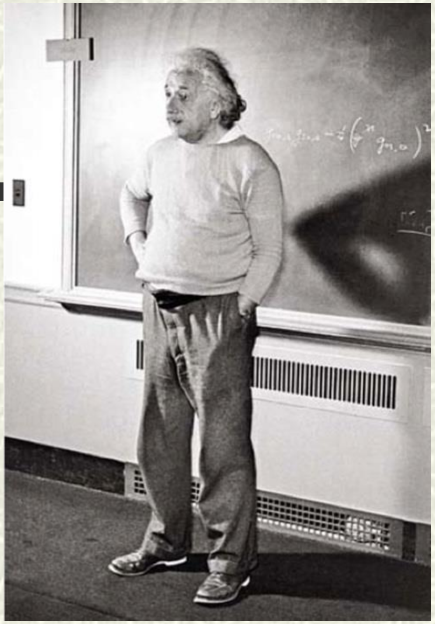
Published online (Inserted Later)




**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



# Coda: Einstein vs Hoyle

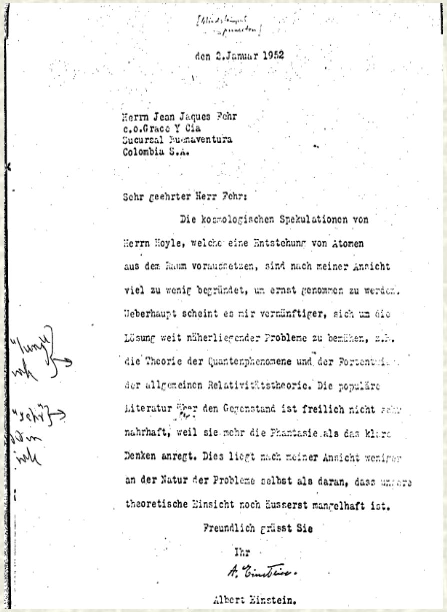


- **Fred Hoyle in Princeton (1952, 53)**

  *Einstein remark to Manfred Clynes*

  *"Romantic speculation" (Michelmore 1962)*

- **Letter to Jean Jacques Fehr (1952)**
- *"The cosmological speculations of Mr Hoyle, which presume a formation of atoms from space, are in my view much too poorly grounded to be taken seriously. On the whole, it seems to me more reasonable to seek a solution to problems far closer to hand, e.g., the theory of quantum phenomena or the further development of the general theory of relativity. The popular literature on the subject is not very fruitful, as it encourages flights of fancy rather than clear thinking. In my opinion, this is less because of the nature of the problem itself than because our theoretical insight is still extremely deficient."*



den 2.Januar 1952

Herrn Jean Jaques Fehr
c.o.Grace Y Cia
Sucursal Buenaventura
Colombia S.A.

Sehr geehrter Herr Fehr:

Die kosmologischen Spekulationen von Herrn Hoyle, welche eine Entstehung von Atomen aus dem Raum voraussetzen, sind nach meiner Ansicht viel zu wenig begründet, um ernst genommen zu werden. Ueberhaupt scheint es mir vernünftiger, sich um die Lösung weit näherliegender Probleme zu bemühen, z.B. die Theorie der Quantenphenomene und der Fortentwicklung der allgemeinen Relativitätstheorie. Die populäre Literatur über den Gegenstand ist freilich nicht sehr nahrhaft, weil sie mehr die Phantasie als das klare Denken anregt. Dies liegt nach meiner Ansicht weniger an der Natur der Probleme selbst als daran, dass unsere theoretische Einsicht noch äusserst mangelhaft ist.

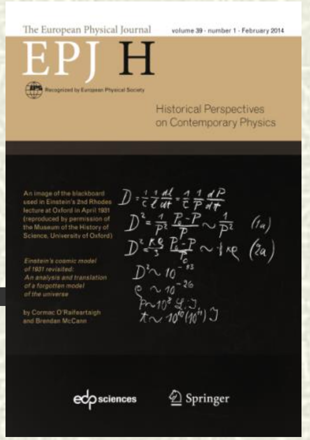
Freundlich grüsst Sie

Ihr

A. Einstein.

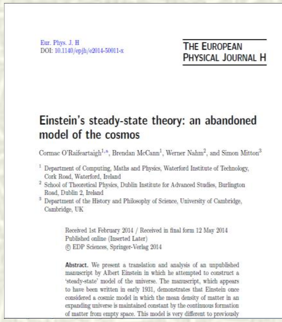
Albert Einstein.

# Further reading




- ## **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**


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]

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- ## **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**

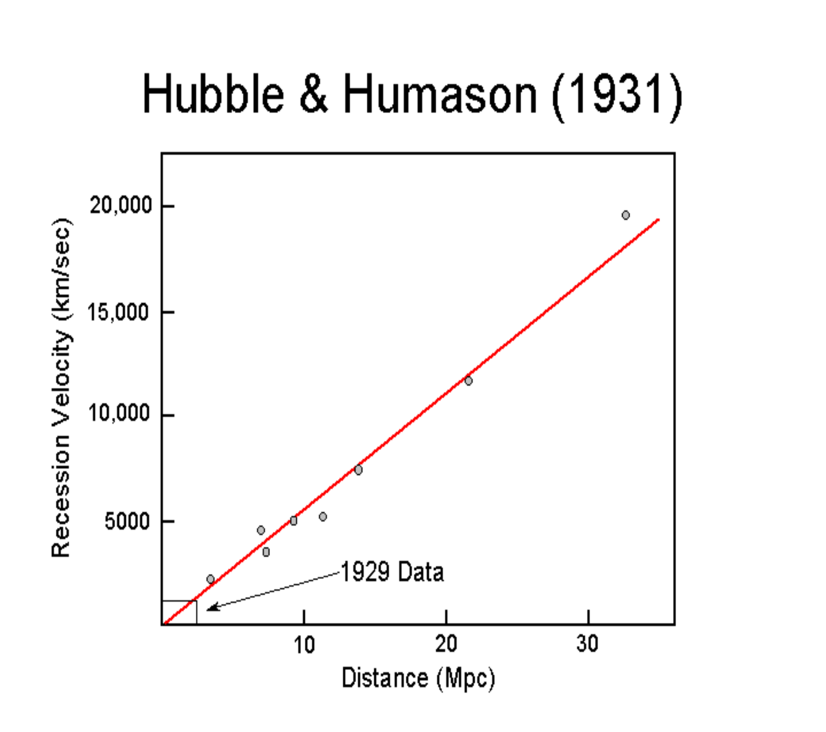

- ## **Einstein-de Sitter model**

*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. ***Eur. Phys. J (H) 40 (3) 301-335***

- ## **Review paper**

# Observational parameters needed (1930s)

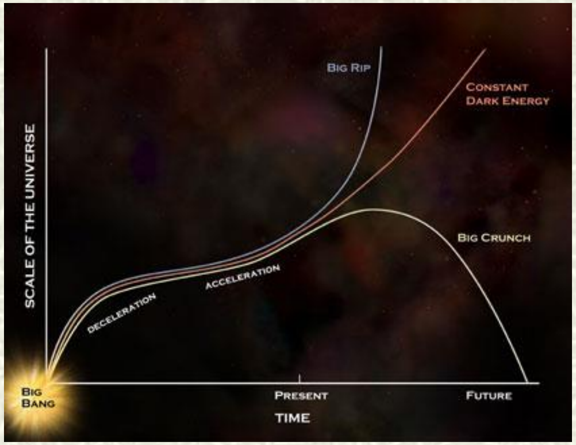
- **Spatial curvature** $k = -1, 0, 1?$
- **Cosmic constant** $\lambda = 0?$
- **Deacceleration** $q_0 = -\ddot{R}/\dot{R}^2$
- **Density of matter** $\rho < \rho_{crit}$ ?
- **Timespan** $\tau = 10^{10}$ yr?
- **Hubble constant** $\dot{R}/R = 500\ kms^{-1}Mpc^{-1}$?




***What do redshifts represent?***
***Is expansion a local effect?***

*Hubble and Tolman 1935*

# 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).”*

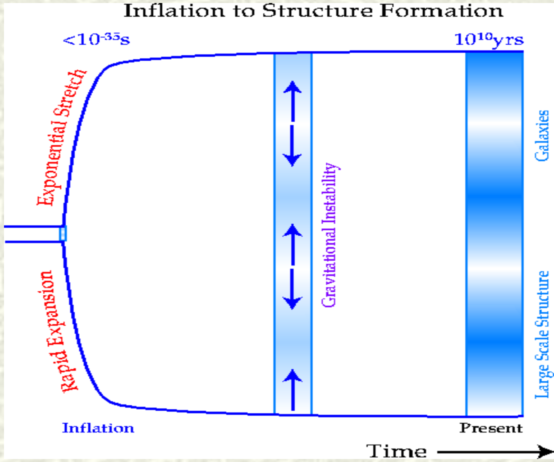
- **Cosmic inflation**

  *Inflationary models use de Sitter metric*

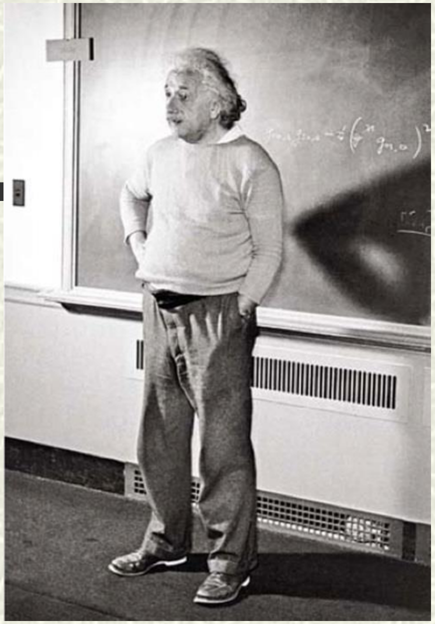
  *Used in all steady-state models*

  *Flat curvature, constant rate of matter creation*

  *Different time-frame!*



# Einstein vs Hoyle



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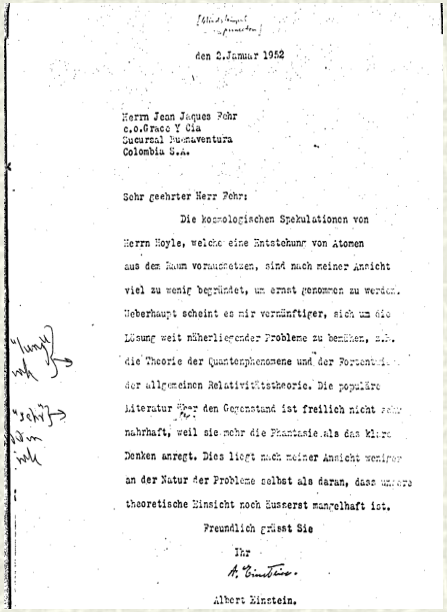

den 2.Januar 1952

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c.o.Grace Y Cia
Sucursal Buenaventura
Colombia S.A.

Sehr geehrter Herr Fehr:

Die kosmologischen Spekulationen von Herrn Hoyle, welche eine Entstehung von Atomen aus dem Raum voraussetzen, sind nach meiner Ansicht viel zu wenig begründet, um ernst genommen zu werden. Ueberhaupt scheint es mir vernünftiger, sich um die Lösung weit näherliegender Probleme zu bemühen, z.B. die Theorie der Quantenphenomene und der Fortentwicklung der allgemeinen Relativitätstheorie. Die populäre Literatur über den Gegenstand ist freilich nicht sehr nahrhaft, weil sie mehr die Phantasie als das klare Denken anregt. Dies liegt nach meiner Ansicht weniger an der Natur der Probleme selbst als daran, dass unsere theoretische Einsicht noch äusserst mangelhaft ist.

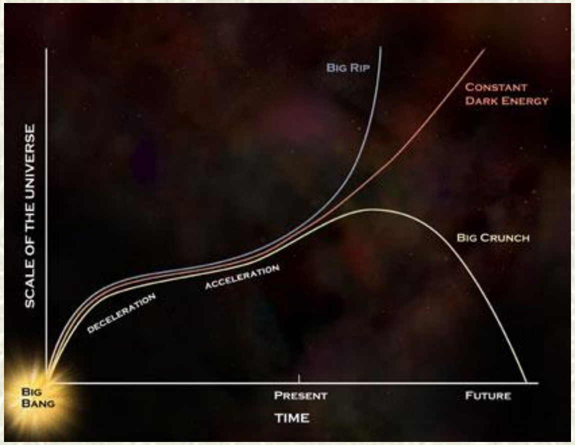
Freundlich grüsst Sie

Ihr

A. Einstein.

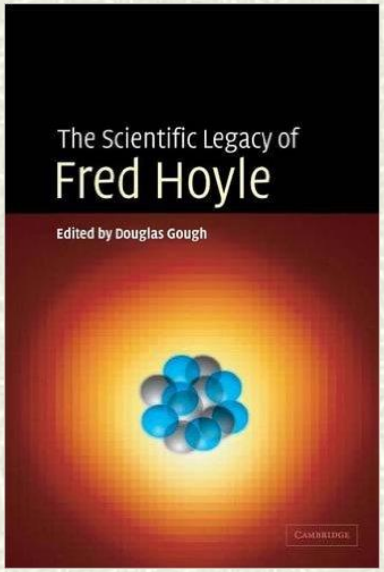
Albert Einstein.

# Steady-state cosmology today




- **Observable universe not in a steady state**
  *Evolution of galaxies*
  *Cosmic microwave background*

- **Inflationary cosmology = steady-state model**
  *de Sitter metric*
  *Steady-state model with different time-frame! (Hoyle 1990)*
  *Matter creation term not mandatory in Hoyle models (McCrea 1951)*




- **Eternal inflation**
  *Different regions undergo different inflation?*
  *Inflation begets further inflation (Vilenkin 1983; Linde 1986)*
  *Observable universe embedded in global steady-state cosmos?*

***Hoyle's revenge!*** (Hoyle and Narlikar 1966; Barrow 2005)

# 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)*

# Einstein's cosmology (traditional view)

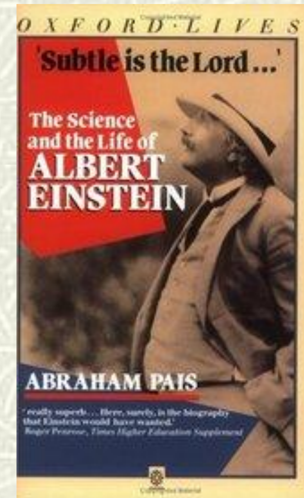
- **Static, bounded model of the cosmos (1917)**
  *Resistance to empty de Sitter 'static' solution*

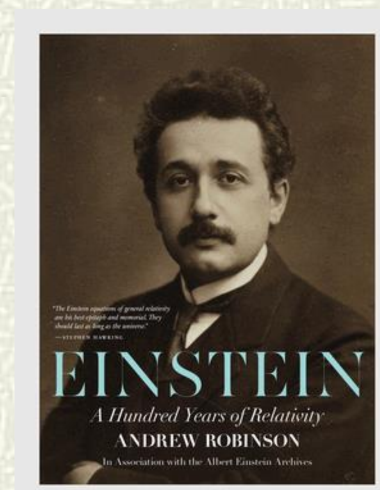
- **Resistance to time-varying models**
  *Friedman, Lemaitre*

- **Einstein the conservative**
  *Hidebound by philosophical prejudice*
  *Disinterested in evolving cosmologies*

- **Dynamic model 1932 (1931)**
  *Minimalist, cursory models*

***A new perspective?** Guided by physical intuition*



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.