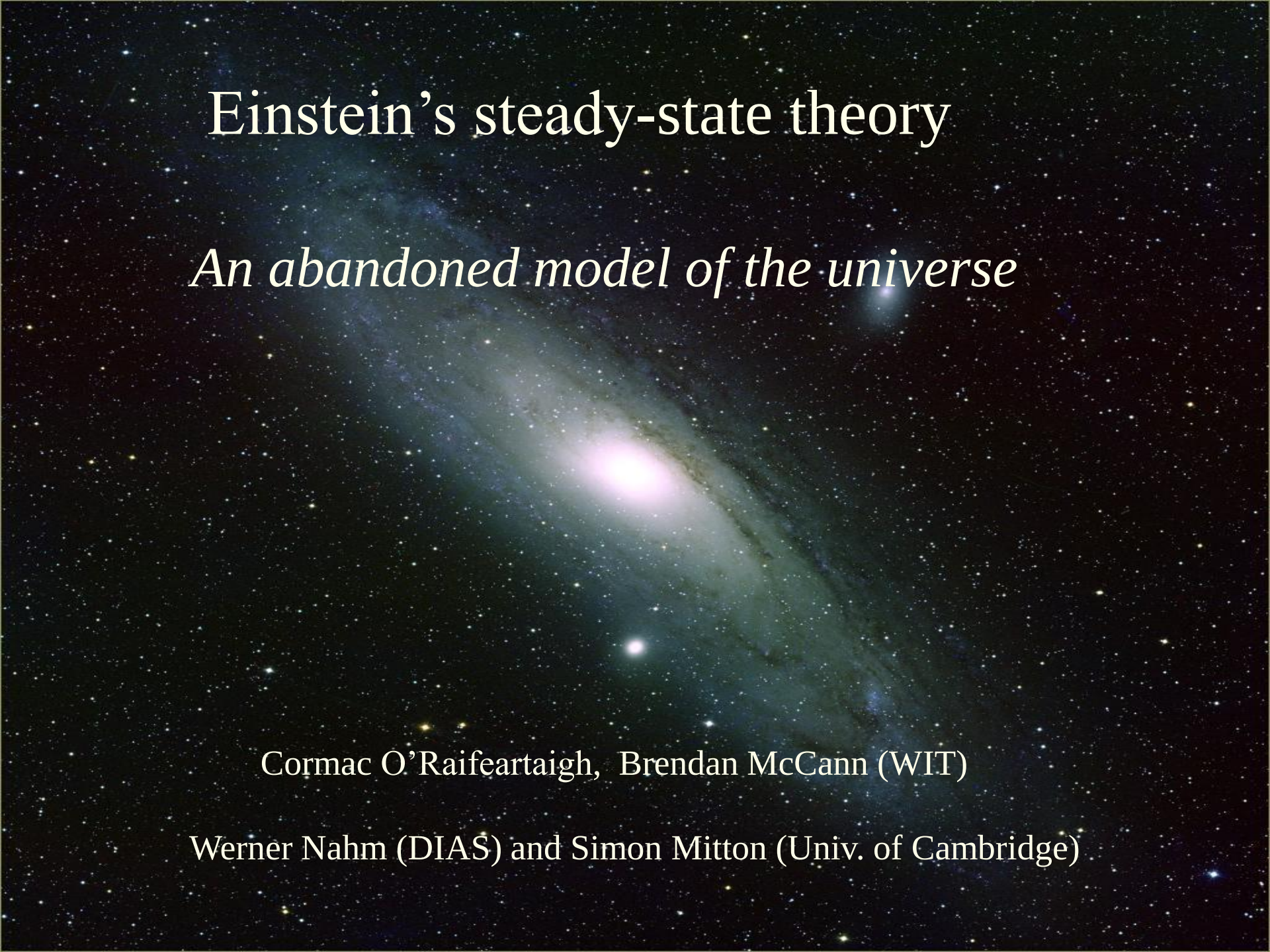
Einstein's steady-state theory

An abandoned model of the universe



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Physics > History and Philosophy of Physics

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

Cormac O'Raifeartaigh, Brendan McCann, Werner Nahm, Simon Mitton

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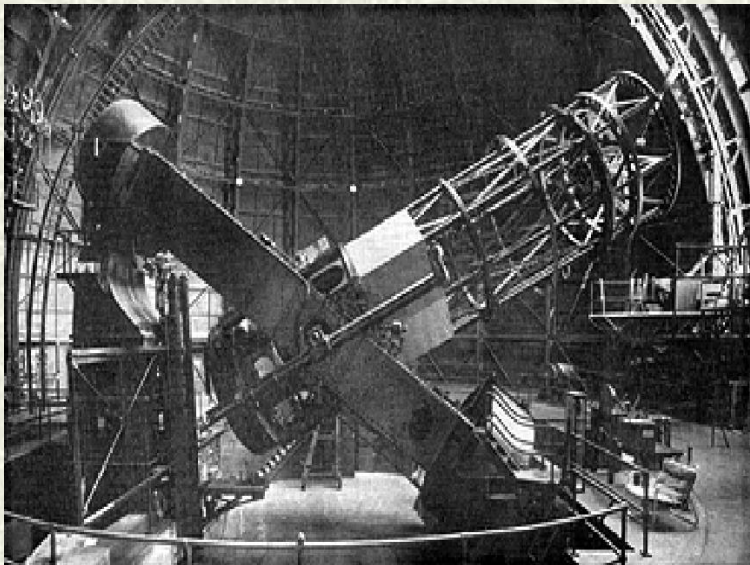
We present a translation and analysis of an unpublished manuscript by Albert Einstein in which he attempted to construct a 'steady-state' model of the universe. The manuscript, which appears to have been written in early 1931, demonstrates that Einstein once explored a cosmic model in which the mean 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 known Einsteinian models of the cosmos (both static and dynamic) but anticipates the later steady-state cosmology of Hoyle, Bondi and Gold in some ways. We find that Einstein's steady-state model contains a fundamental flaw and suggest that it was abandoned for this reason. We also suggest that he declined to explore a more sophisticated version because he found such theories rather contrived. The manuscript is of historical interest because it reveals that Einstein debated between steady-state and evolving models of the cosmos decades before a similar debate took place in the cosmological community.

Comments: 22 pages, 2 figures. Includes first English translation of unpublished Einstein manuscript. Accepted for publication in Eur.Phys.J.(H)
Subjects: **History and Philosophy of Physics (physics.hist-ph)**
Cite as: **arXiv:1402.0132 [physics.hist-ph]**
(or **arXiv:1402.0132v3 [physics.hist-ph]** for this version)

The discovery of the galaxies (1925)

- **Hooker telescope (Mt Wilson)**
  100-inch reflector (1917)
- **Edwin Hubble (1921)**
  Ambitious and dedicated astronomer
- **Resolved Cepheid stars in nebulae (1925)**
  Leavitt's period-luminosity relation
  Standard candle
- **Spirals beyond Milky Way**
  Beginning of end of 'Great Debate'
  Nebulae = galaxies

Edwin Hubble (1889-1953)



The recession of the galaxies (1929)

- **A redshift/distance relation for galaxies?**

  Motivation: establishing distance to the galaxies

- **Combine 24 nebular distances with redshifts**

  Redshifts from Slipher : not acknowleged

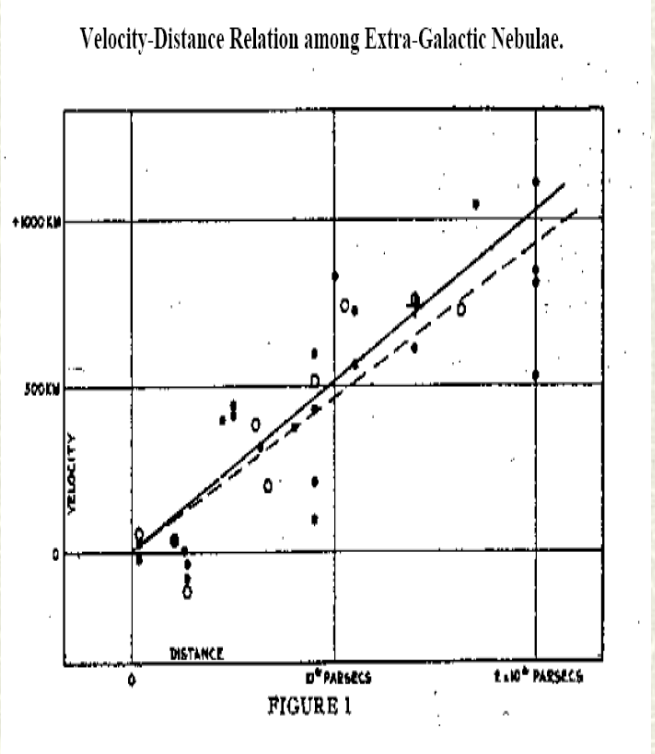
- **Approx linear relation (Hubble, 1929)**

  Some errors (Peacock)

  Most important point not shown

- **What do the redshifts mean?**

  Reference to de Sitter universe



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

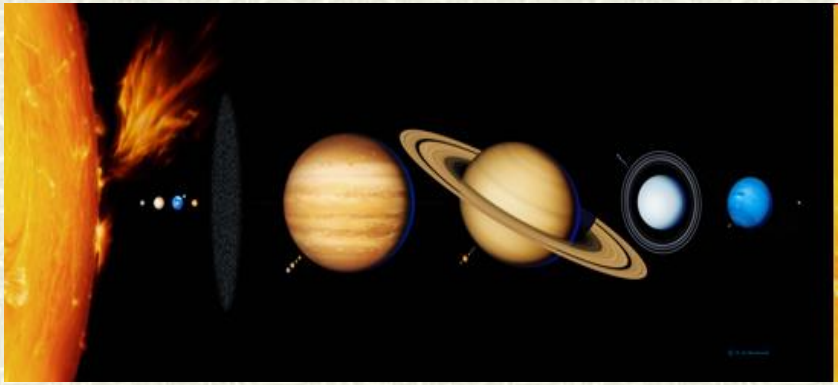
Explanation for runaway galaxies?

Newton

- **Gravity pulls in not out**
- **Universal long range force**
- **Space is fixed**
- **Time has no beginning**

Isaac Newton

How can galaxies be receding?
What is pushing out?



A new theory of gravity : general relativity

- **Space+time = space-time**

  Spacetime dynamic (1905)

- **Spacetime distorted by mass**

  Distortion causes other mass to move *(1915)*

Albert Einstein

Gravity = curvature of space-time

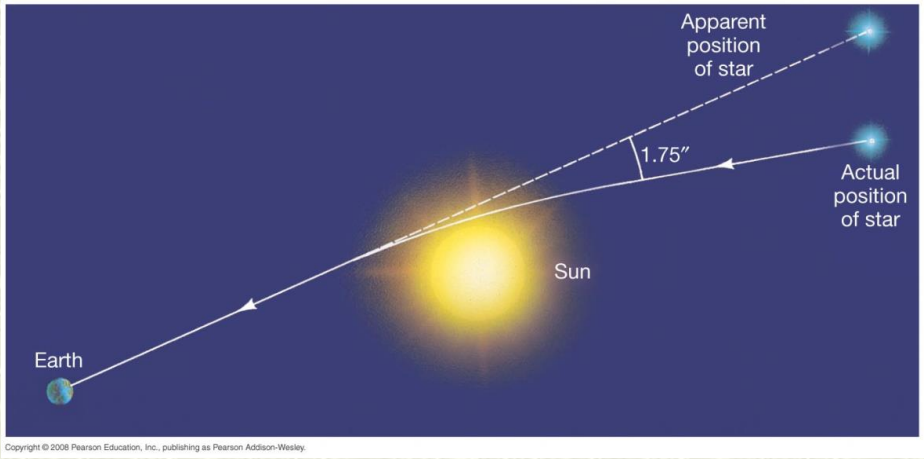
$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

- **Dyson/Eddington expeditions (1919)**

  Measure bending of light?

  Successful result

  General relativity well-known



Relativity and the universe

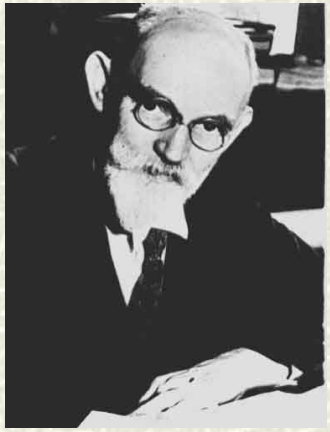
Einstein model (1917)

- Homogenous fluid of uniform density
- Equations predict non-static universe
- No evidence for such a universe
- Add cosmic constant – ‘static’
- Closed curvature, finite radius

$$G_{\mu\nu} + \lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

De Sitter (1917)

- Empty universe
- Apparently static (co-ordinate system)
- Cosmic constant determined by curvature of space
- Redshifts due to time dilation/matter



Disliked by Einstein: Mach’s principle

Friedman models of the cosmos

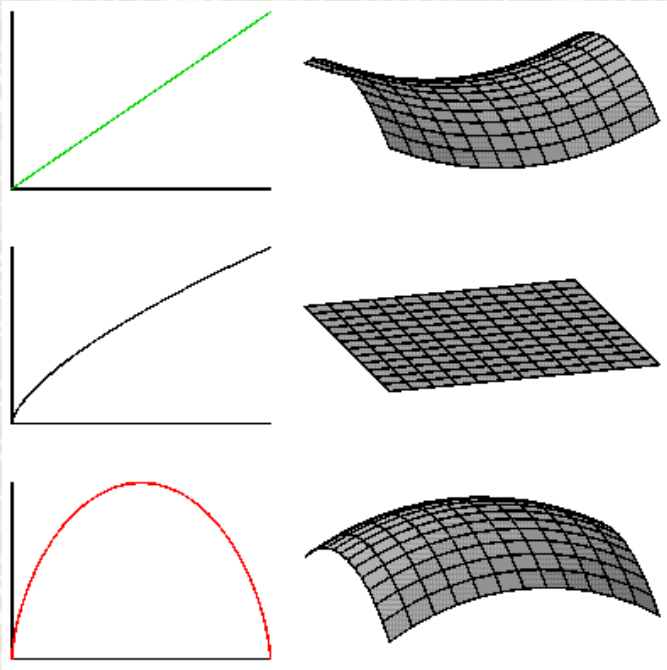
Alexander Friedman 1888 -1925

- **Allow time-varying solutions to the field equations**
  Expanding, contracting universes
  Include cosmic constant

- **Geometry, evolution depends on matter**
  Positive curvature (1922)
  Hyperbolic curvature (1924)

- **Hypothetical models (Zf. Ph.)**
  To be decided by astronomy

- **Disliked by Einstein**
  Correction and retraction



Ignored by community

Lemaître's universe (1927)

Fr Georges Lemaître

- **De Sitter model not static (1925)**

  New evolving solution : Einstein → de Sitter

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

  Rate of expansion from mean distances and redshifts

  H = 585 km/s/Mpc

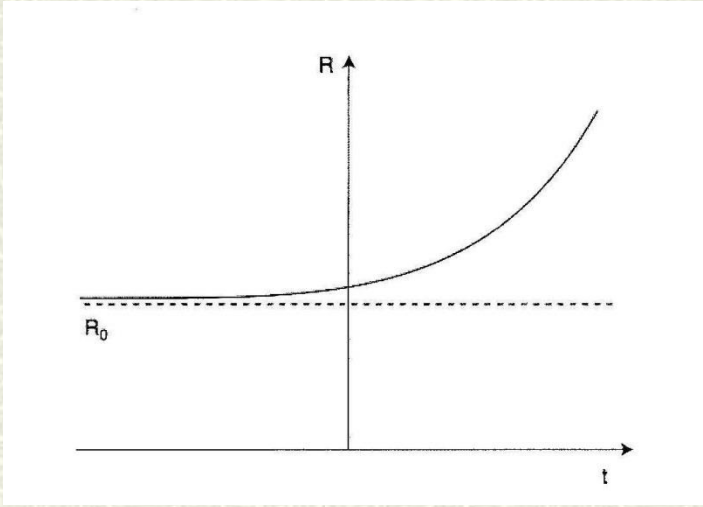
Not an empirical law
Edited in 1931 translation

- **No beginning: indefinite age**

  Starts from Einstein universe at t = - ∞

- **Rejected by Einstein (1927)**

  "Votre physique est abominable"



An expanding universe? (1930-)

- **RAS meeting (1930)**

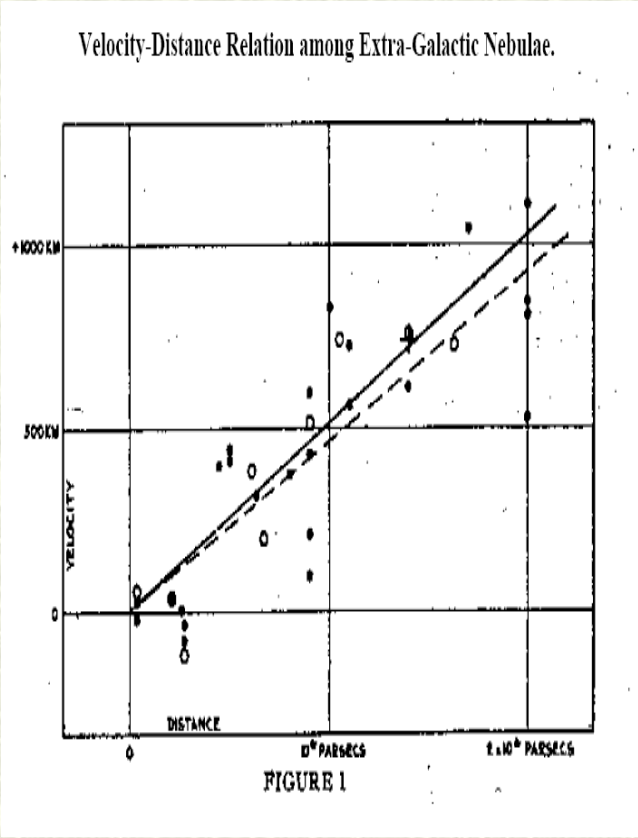
  Eddington, de Sitter
  Redshift/distance relation of the nebulae
  Einstein/de Sitter models don't fit
  New model required

- **Expansion of space-time metric?**

  Considered by many theoreticians
  If redshifts are velocities (Zwicky)
  If effect is non-local

- **Letter from Lemaître**

  Reminds Eddington of his 1927 model
  Eddington, de Sitter impressed



Cosmic expansion?

The expanding universe (1930 -)

- **Eddington (1930, 31)**

  On the instability of the Einstein universe
  The Eddington-Lemaître model
  Expansion caused by condensation?

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

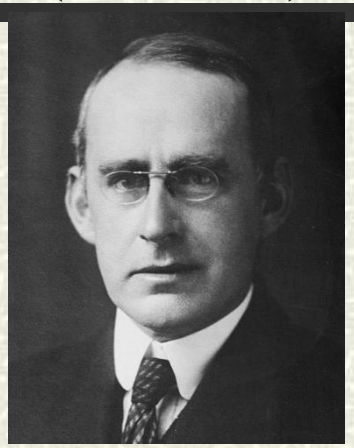
  Further remarks on the expanding universe
  Expanding universes of every flavour

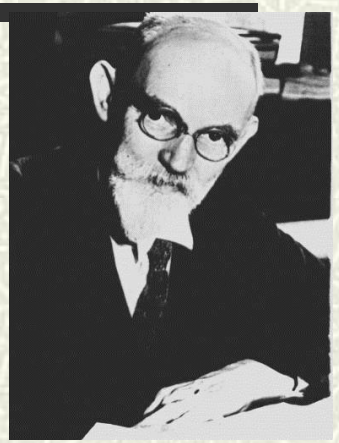
- **Tolman (1930, 31)**

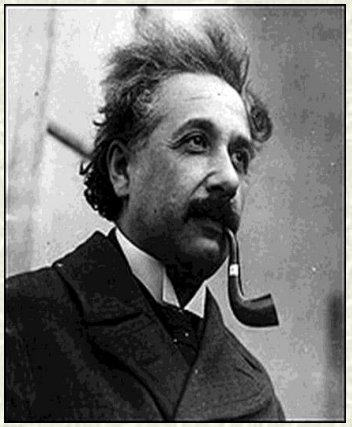
  On the behaviour of non-static models
  Expansion caused by annihilation of matter ?

- **Einstein (1931, 32)**

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

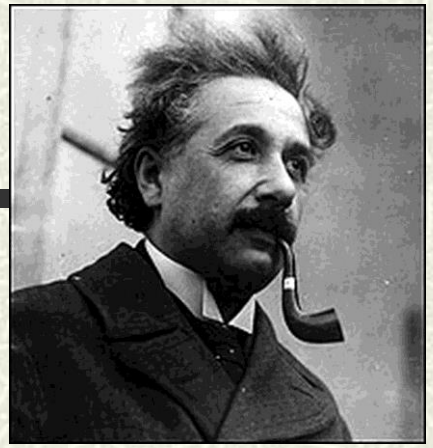






<u>If</u> redshifts represent expansion…
Evolving models

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



- **Instability of static universe**

  Eddington's paper

- **Hubble's observations**

  Expanding cosmos

  Remove cosmic constant?

Friedman-Einstein universe

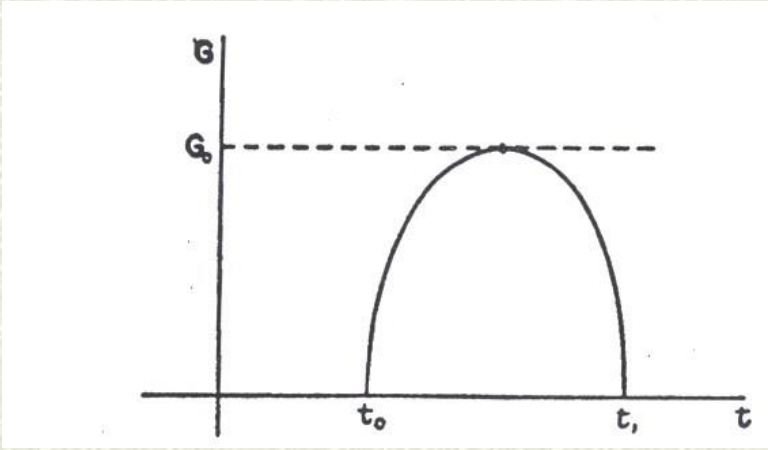
$$\left(\frac{dP}{dt}\right)^2 = c^2 \frac{P_0 - P}{P}$$

- **Adopt Friedman 1922 analysis**

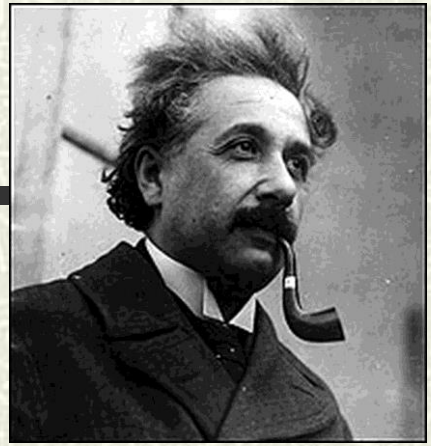
  Time-varying universe, k =1, λ = 0

- **Age and singularity problems**

  Attributes to limitations of theory



Einstein's 1931 model (F-E)



- **Numerical estimates of radius and density**

  Use Hubble parameter

  $P \sim 10^8$ light-years, $\rho \sim 10^{-26}$ g/cm^3

Oxford lecture (May 1931)

- **Calculations problematic**

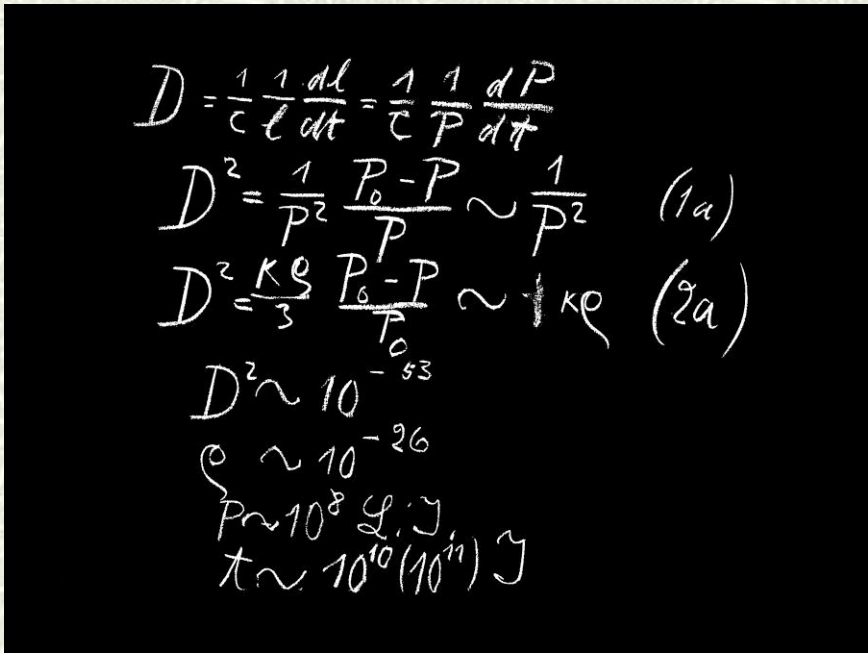
  $H_0 \sim 500$ kms^{-1}Mpc^{-1} : $D^2 \sim 10^{-55}$ cm^{-2}

- **Age estimate problematic**

  Age from Friedman

- **<u>Not a periodic solution</u>**

  "Model fails at P = 0 "



An origin for the universe?

- **Rewind Hubble graph (1931)**

  U smaller in the past

- **Extremely dense, extremely hot**

  Primeval atom

  Expanding and cooling since

The big bang

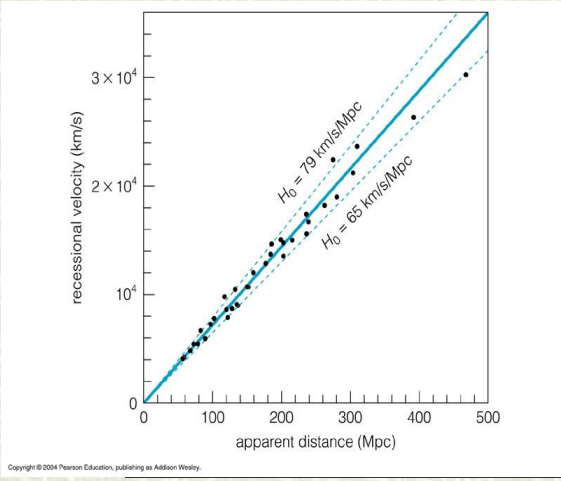
- **Singularity problem**

  ∞ density, ∞ temp at t = 0 ?

  Quantum theory

- **Age problem**

  U younger than stars?



Slow acceptance: 1935-65

- **Little interest from community**
  - *General relativity difficult, abstruse*
  - *Mathematics departments only*
  - *Cosmic parameters unknown*
  - *No search for the cosmic radiation*

Gamow, Alpher and Hermann

- **Hot big bang** (1940s)
  - *Nucleosynthesis in the hot infant universe?*
  - *Background radiation from early universe?*

Hoyle, Bondi and Gold

- **Steady-state universe** (1948)
  - *Expanding but unchanging*
  - *No age or singularity problems*

The steady-state universe

- **Expanding but unchanging universe**

  No beginning, no age paradox

- **Avoids extrapolation problem**

  No assumptions about physics of early epochs

- **Continuous creation of matter**

  Very little matter required (1948)

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

Violates conservation of energy

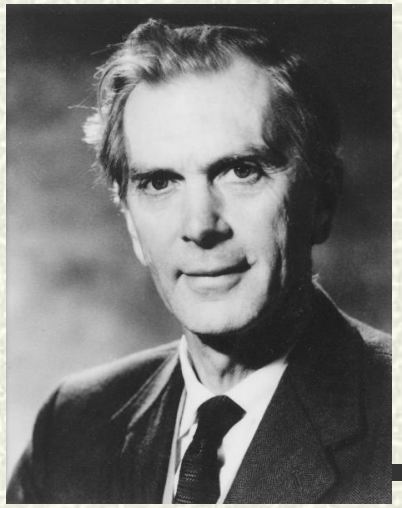
- **Improved version (1962): energy conservation**

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

Hoyle and Narlikar (1962)

A bitter debate

- **Steady-State or Big Bang universe?**
  Unchanging or evolving universe?
- **Study most distant galaxies**
  Compare with local galaxies
- **Galaxy distribution constant over time? (SS)**
  Distribution changing over time ? (BB)
- **Radio-astronomy (Ryle)**
  Cambridge Surveys

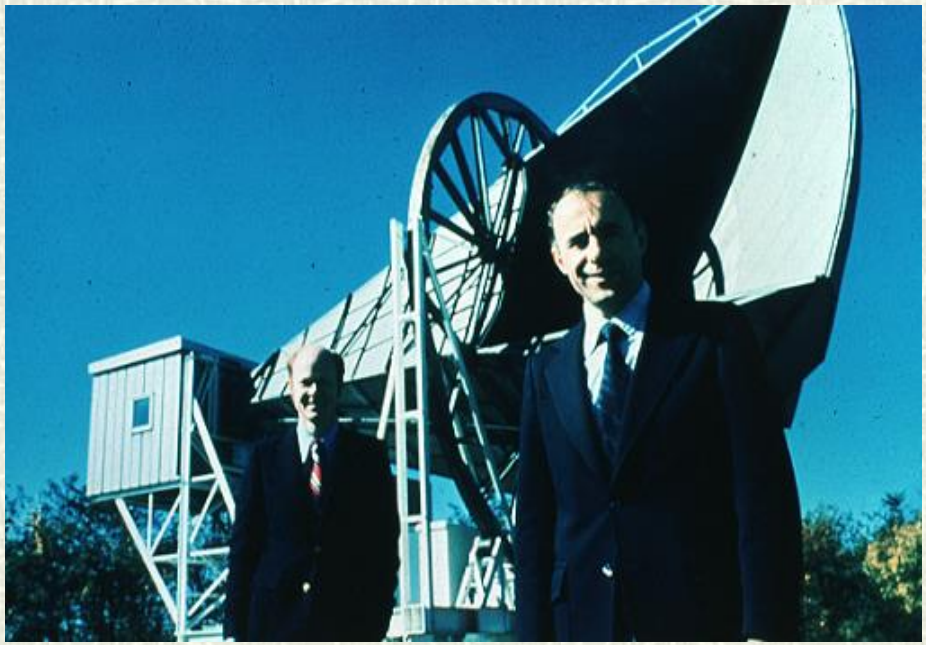


Answer: evolving universe

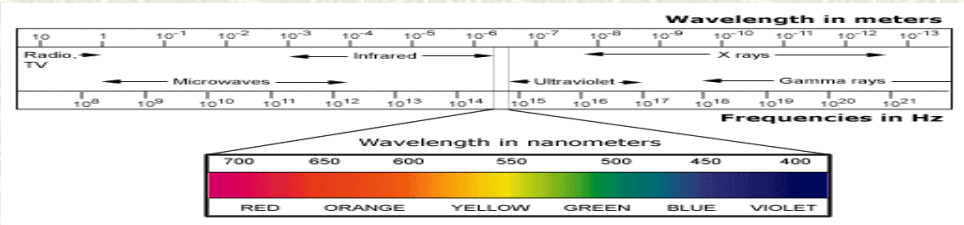
Cosmic microwave background

- **Search for radio signals**
  Large, sensitive receiver
- **Ubiquitous signal (1965)**
  From every direction
- **Low frequency (microwave)**
  Low temperature (3K)
- **Echo of big bang**
  Radiation from early universe

BB model goes mainstream

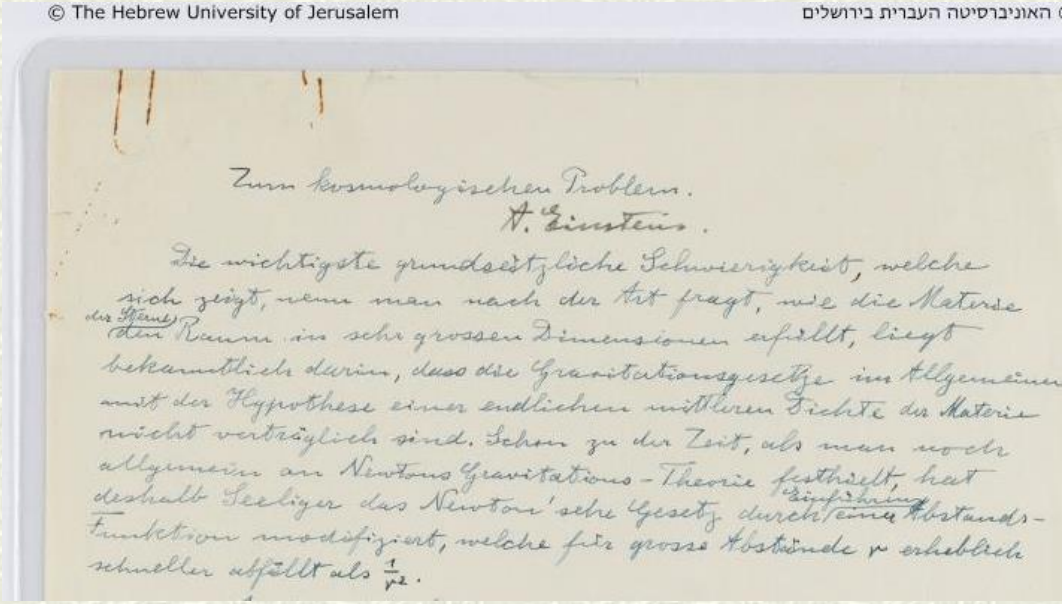


Penzias and Wilson



New: Einstein's steady-state model (1931?)

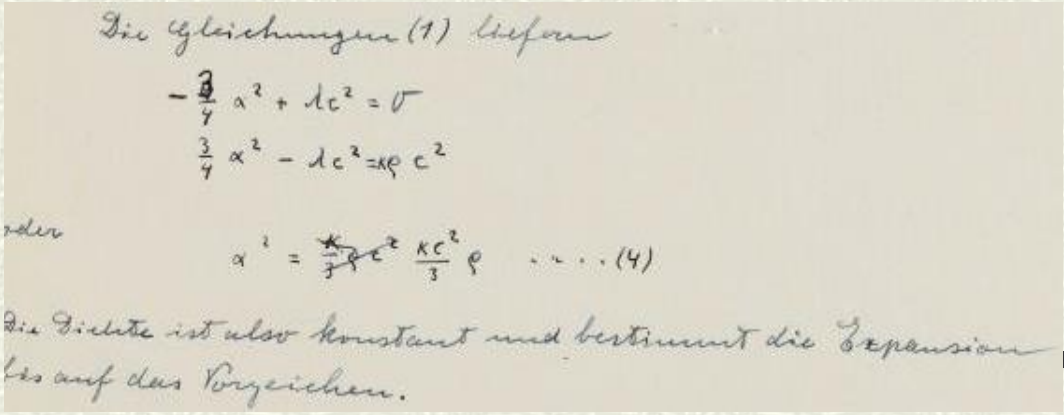
- **Filed as draft of 1931 model**
  Similar title, opening
- **Instability of static universe**
  Cites Hubble's law
- **Cites evolving models (Tolman)**
  Conflict with stellar ages
- **<u>Proposes alternative solution</u>**
  Expanding, unchanging cosmos?
  Continuous creation of matter
  Associated with λ - energy of space



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 eine Abstands-Funktion modifiziert, welche für grosse Abstände r erheblich schneller abfällt als $\frac{1}{r^2}$.



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.

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

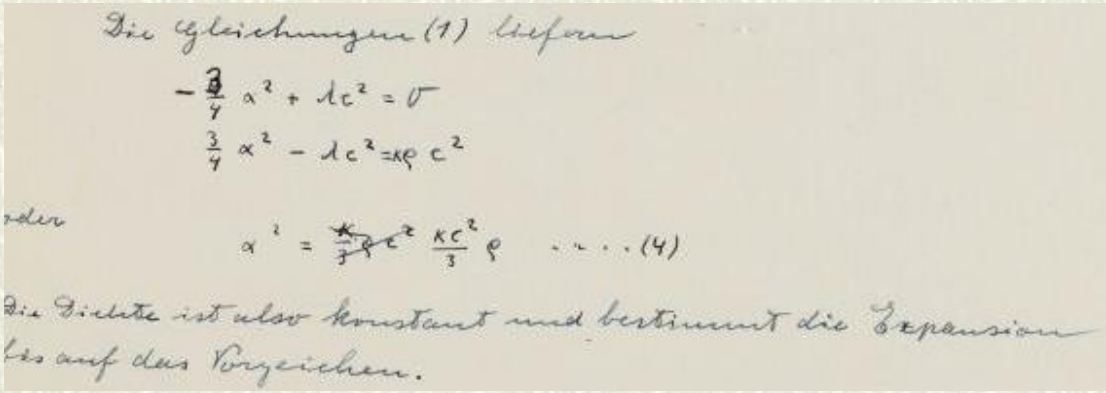
"If one considers a physically bounded volume, particles of matter will be continually leaving it. For the density to remain constant, new particles of matter must be continually formed within that volume from space "

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's steady-state model

- **Model fails**
  - *De Sitter metric*
  - *No creation term in GFE*
  - *λ not sufficient*
- **Null solution masked by error**
  - *Error in Christoffel coefficient*
- **Einstein's crossroads**
  - *Realised problem on revision*
  - *Declined to alter GFE*
- **Evolving models**
  - *Less contrived and set λ = 0*



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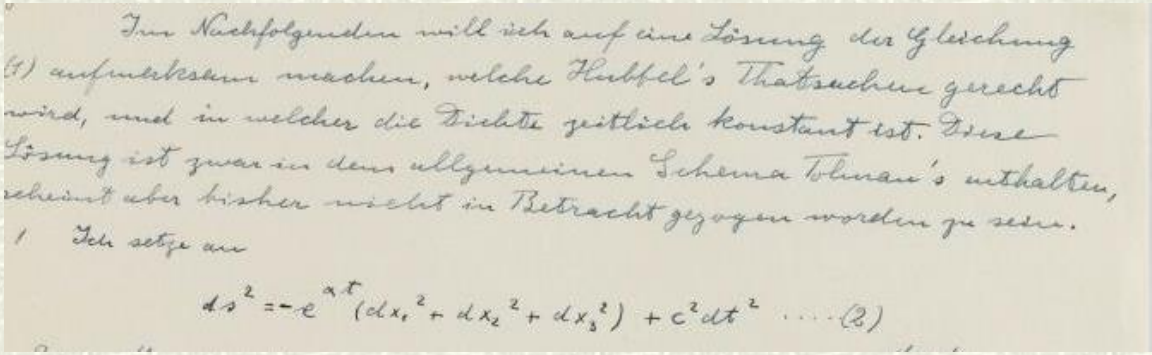
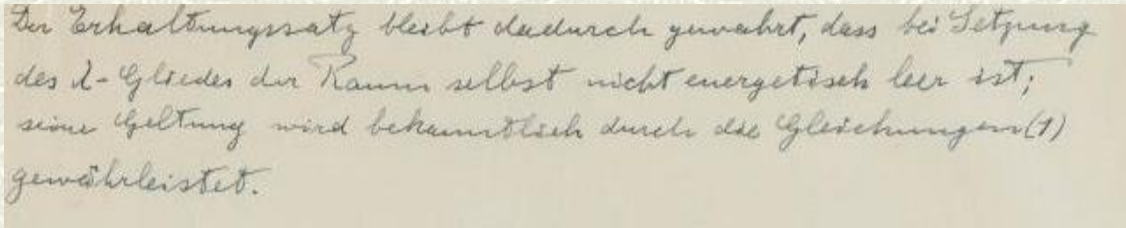


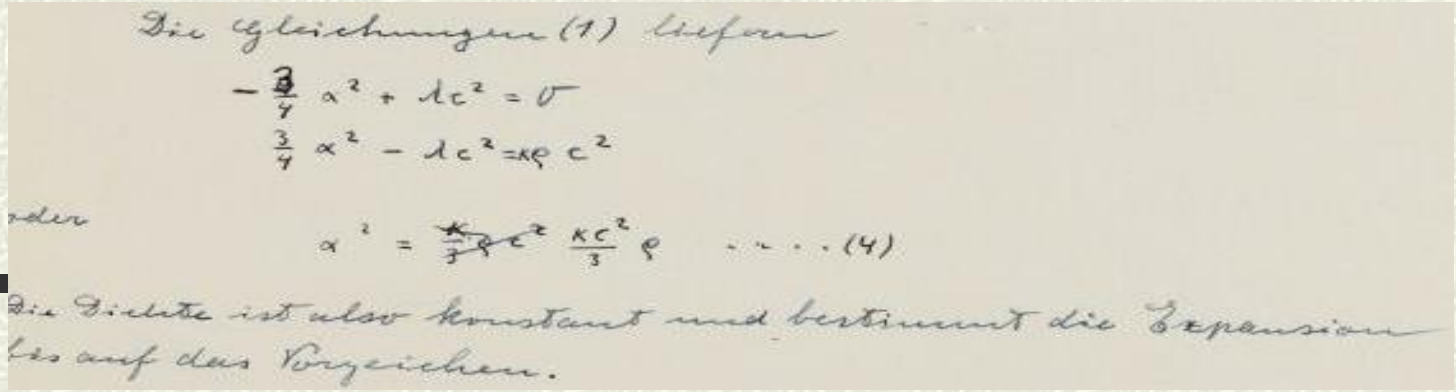
Im Nachfolgenden will ich auf eine Lösung der Gleichung (1) aufmerksam machen, welche Hubbel's Thatsachen gerecht wird, und in welcher die Dichte zeitlich konstant ist. Diese Lösung ist zwar in dem allgemeinen Schema Tolman's enthalten, scheint aber bisher nicht in Betracht gezogen worden zu sein.

Ich setze an

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



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.



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.

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**

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

  Necessary for all steady-state models

  Identical to inflationary models (different time-frame)

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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

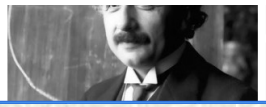
2 comments, 2 called-out + Comment Now + Follow Comments

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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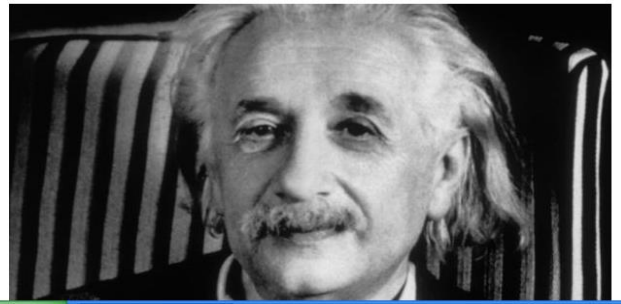
WIT researchers discover 'lost' Einstein model of universe

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

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