Steady-state cosmologies in context

From Arrhenius to Einstein, from Hoyle to Linde

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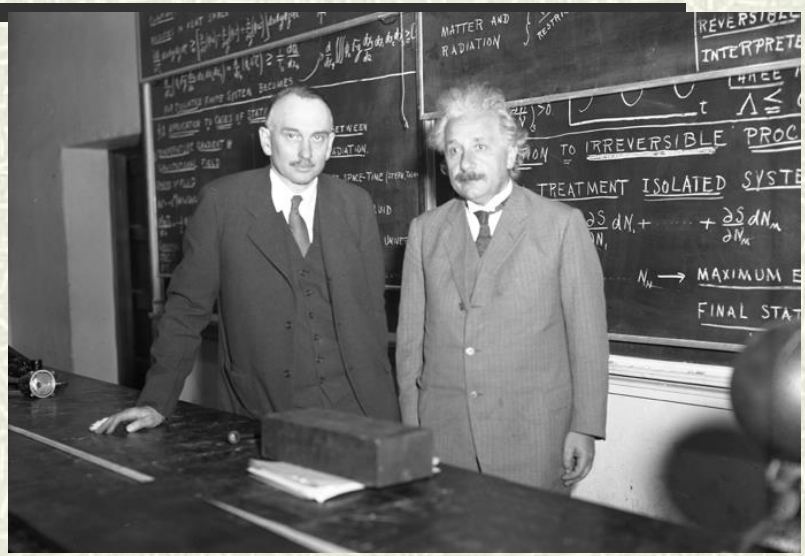
Overview

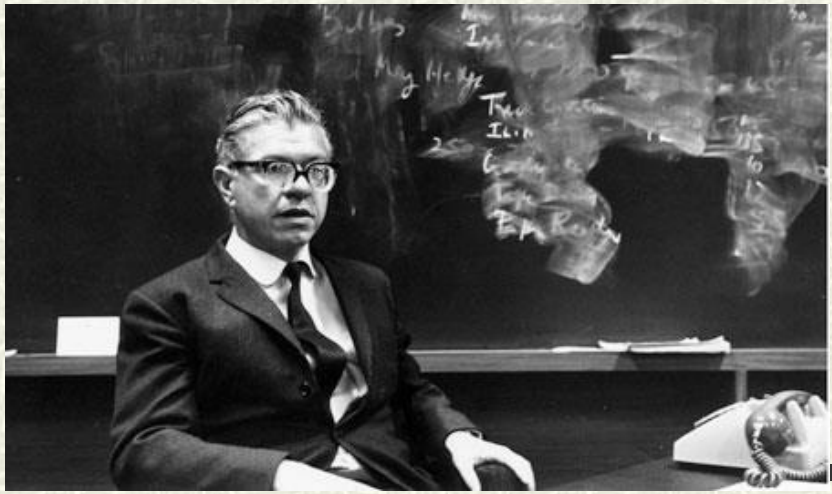
- **Steady-state cosmology (static)**
  The ideas of Arrhenius; Nernst
  MacMillan; Millikan

- **Steady-state cosmology (non-static)**
  Tolman; Einstein; Mimura; Schrödinger
  Einstein's steady-state model

- **The cosmologies of Hoyle, Bondi and Gold**
  Einstein vs Hoyle

- **Steady-state cosmology today**
  Eternal inflation and the steady-state universe





The steady-state universe (static)

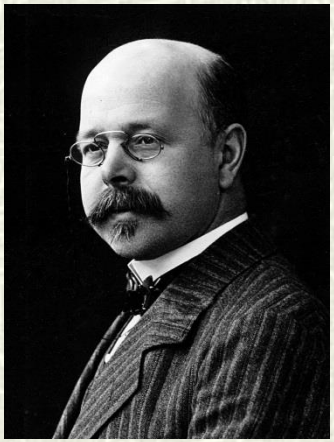
- **2nd law of thermodynamics (1850-)**
  Irreversible degenerating universe? 'Heat death'

- **Replenishment of energy lost by the stars?**
  William Rankine (1852); Arthur Holmes (1914)
  William Crookes (1886); George Toulmin (1789)
  Catastrophism vs uniformitarianism

- **Svante Arrhenius: infinite, perpetual universe**
  Continuous replenishment of celestial bodies via radiation pressure and galactic collisions (1903)

- **Walther Nernst (1912, 1916)**
  Zero point energy of the ether = energy resevoir

Svante Arrhenius (1859-1927)



Walther Nernst (1864-1941)

The static steady-state universe (1920s)

- **William Duncan MacMillan (1918, 1925)**

  Radiant energy from the stars absorbed by the ether

  Energy reconstituted as new matter

- **Robert Millikan (1928)**

  Support for MacMillan

  Cosmic rays from interstellar space (1925)

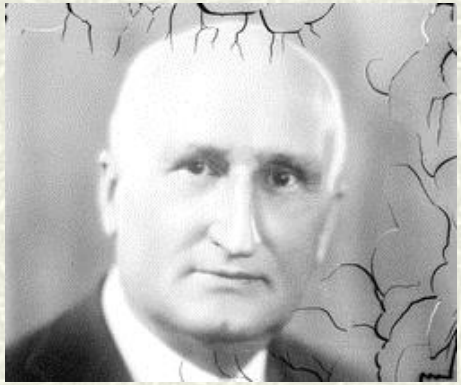
  Birth cry of creation of heavier elements (1928)

  Replenishment of protons from stellar radiation

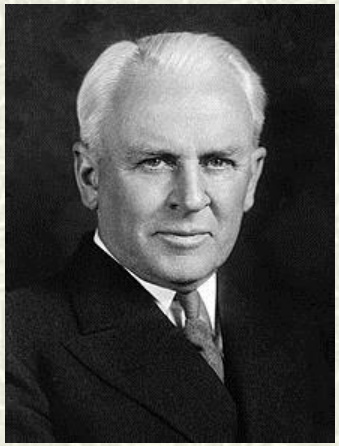
  Atom building in interstellar space: media attention

- **James Jeans (1928)**

  Continuous creation of matter in centre of spiral nebulae



William MacMillan (1871-1948)



Robert Millikan (1868-1953)

The steady-state universe (non-static)

- **Hubble's law (1929)**

  Linear redshift/distance relation for the spirals

- **RAS meeting (1930)**

  A cosmic expansion (relativists)

  Eddington, de Sitter; non-static cosmic model required

  Lemaître (1927, 1931); Friedman 1922

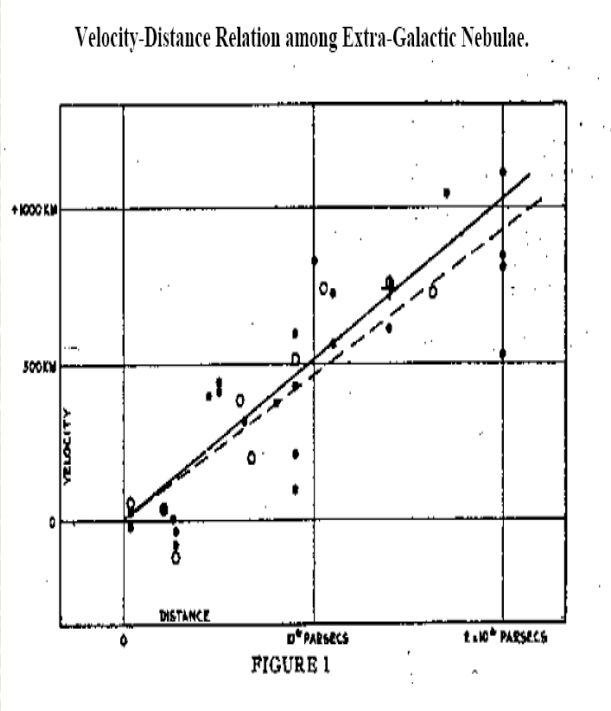
- **Expanding, evolving universe (1929, 1930-)**

  Eddington; de Sitter; Tolman; Robertson; Heckmann; Einstein

- **<u>Expanding, non-evolving universe? (1929-30)</u>**

  Considered by Tolman; Einstein;

  Mimura; Schrödinger (1939)



Tolman and the steady-state universe

- **On the astronomical implications of the de Sitter line element** (1929)

17. *Hypothesis of continuous formation : "Process of formation of the nebulae is a continuing one which will maintain an approximately uniform concentration of nebulae"*

"Little inherent probability"

"Nevertheless, we should not completely disregard the possibility that such a process – perhaps associated with a condensation of radiation into matter – might be taking place"

- **The effect of the annihilation of matter on the wavelength of light** (1930)

Conclusions: "The explanation would certainly fall to the ground, if in reality the universe should prove to be in a steady state, the mass of the stars being continually replenished by some cyclical process whose steps are unknown. There is indeed little evidence in favour of such a cycle and astrophysicists are not inclined to this view: nevertheless I myself and many others would be glad to give it credence if we could."

- **May have inspired Einstein at Caltech** (Nussbaumer 2014)

Einstein's steady-state model

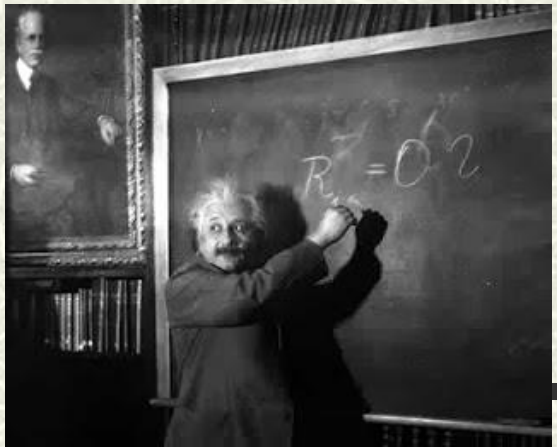
- **Unpublished manuscript**
  O'Raifeartaigh et al. 2014; Nussbaumer 2014
  Almost certainly written in early 1931

- **Contains 'steady-state' model of the cosmos**
  Expanding universe of constant matter density?
  Continuous formation of matter associated with λ

- **Mathematical flaw**
  Abandoned, not amended

- **Evolving models embraced: λ set to zero**
  Friedman-Einstein 1931, Einstein-de Sitter 1932

Einstein in California (1931)



Einstein's steady-state model

- **Misfiled as draft of *F-E* model**

  Similar title, opening

- **Introduction**

  Hubble's law

  Instability of static model

  Evolving models cited (Tolman)

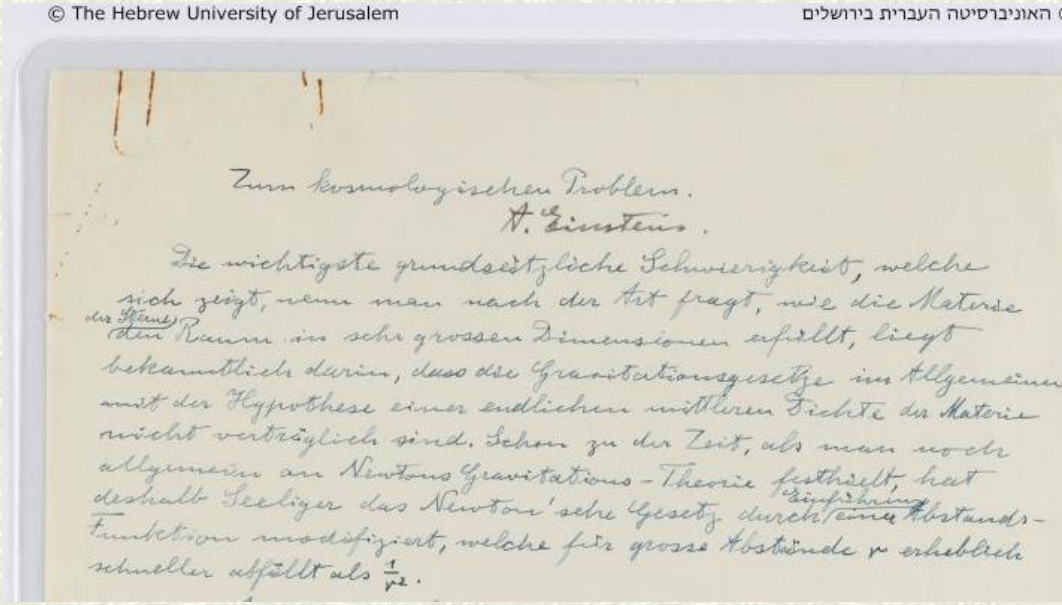
  Age problem noted

  Origins puzzle <u>not</u> mentioned (Jan 31)

- **<u>Alternate solution</u>**

  Expanding, unchanging cosmos?

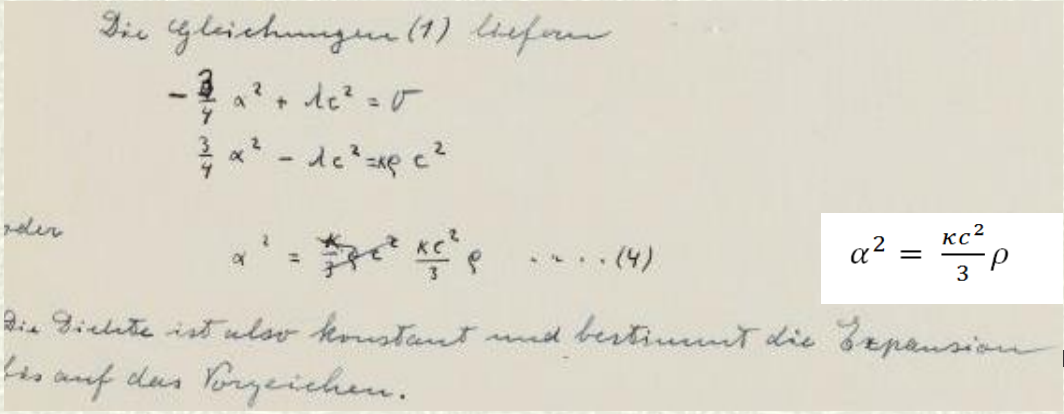
  Expansion set by matter creation



Zum kosmologischen Problem.

A. Einstein.

Die wichtigste grundsätzliche Schwierigkeit, welche sich zeigt, wenn man nach der Art fragt, wie die Materie der Sterne 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 $\frac{1}{r^2}$.



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.

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

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 "

A new role for the cosmic constant

"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

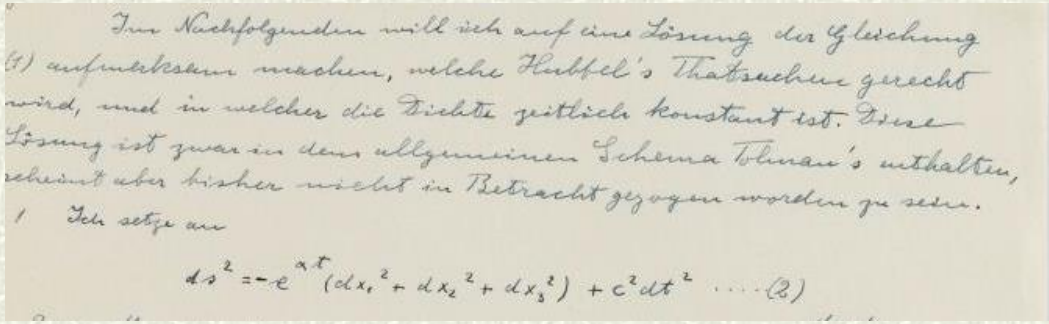
- **A fatal flaw**

  de Sitter metric

  Null result: $\rho = 0$

  Matter creation associated with λ

  Initially masked by derivation error



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

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

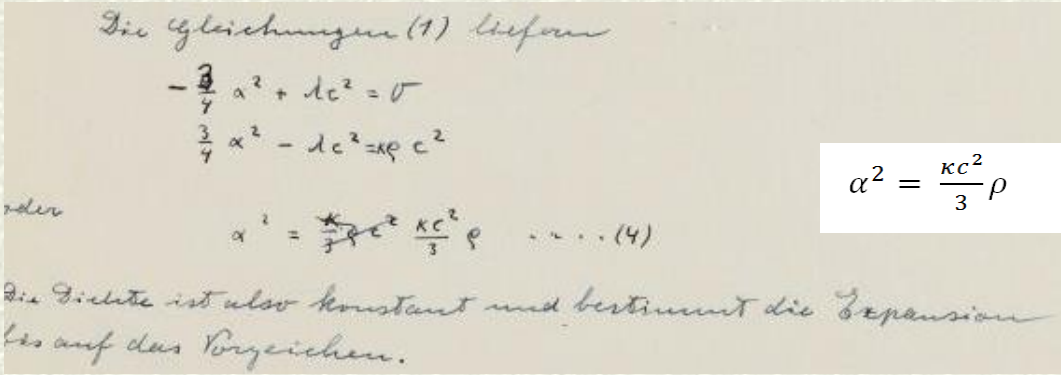
- **Einstein's crossroads**

  Problem identified on revision

  Model abandoned rather than try again

  Creation term in GFE?

  Effects of pressure?



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- **Turns to evolving models**

  Less contrived and set $\lambda = 0$ *(Einstein 1931, Einstein and de Sitter 1932)*

nature International weekly journal of science

NATURE | NEWS

Einstein's lost theory uncovered

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

Davide Castelvecchi

24 February 2014

SCIENTIFIC AMERICAN™

Einstein's Lost Theory Uncovered

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

nature

Feb 25, 2014 | By Davide Castelvecchi and Nature magazine

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

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

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,

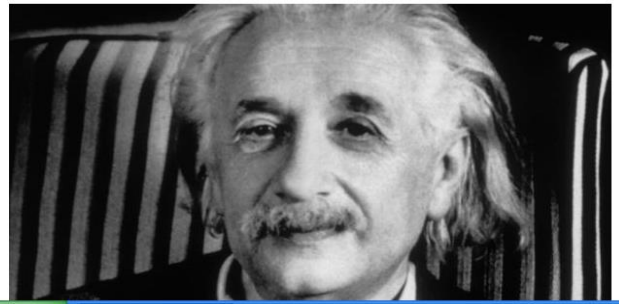
model of the universe very different to today's Big Bang Theory.

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

THE IRISH TIMES Science Monday, March 10, 2014

WIT researchers discover 'lost' Einstein model of universe

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



Latest Ireland »

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

The steady-state universe of Hoyle, Bondi and Gold

- **Expanding but unchanging universe (1948)**

  No origins puzzle, no age puzzle

  No assumptions about physics of early epochs

- **Continuous creation of matter**

  Very little matter required ; below detection limits

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

$$G_{\mu\nu} + C_{\mu\nu} = k\, T_{\mu\nu} \qquad (1948)$$

$$G_{\mu\nu} + \lambda g_{\mu\nu} = k\, T\, (C_{\mu} + C_{\nu}) \qquad (1962)$$

- **Creation term not strictly necessary**

  Negative pressure $p = -\rho$ (McCrea 1951)

Bondi, Gold and Hoyle

Hoyle and Narlikar (1962)

Evolving vs steady-state universe

- **Optical astronomy (1950-60)**

  Resolution of timescale puzzle

  (Baade, Sandage)

- **Radio-astronomy (1950-65)**

  Cambridge Surveys (Ryle)

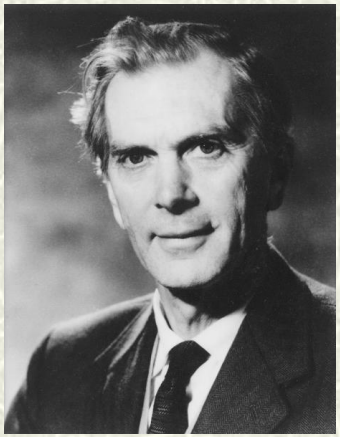
  An evolving universe

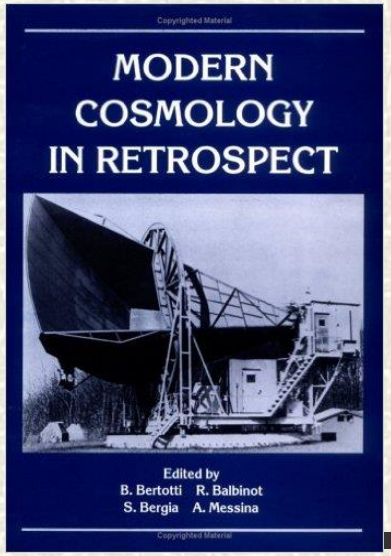
  Discovery of quasars (Schmidt)

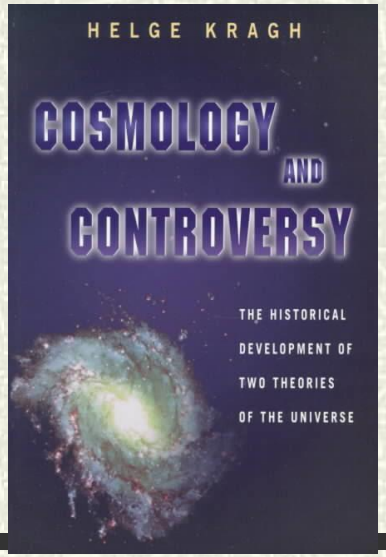
- **Cosmic microwave background (1965)**

  Low temperature, low frequency

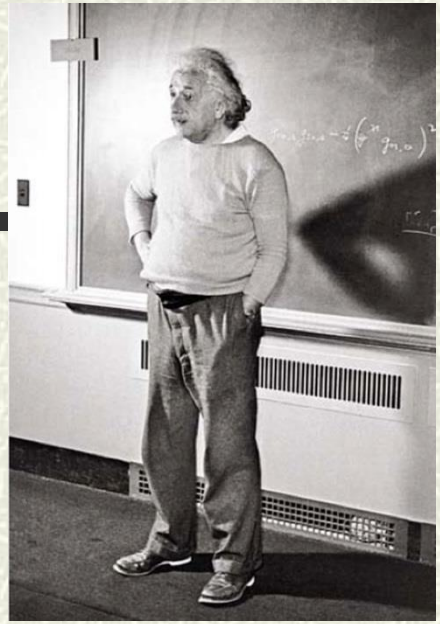
  Remnant of young, hot universe







Einstein vs Hoyle

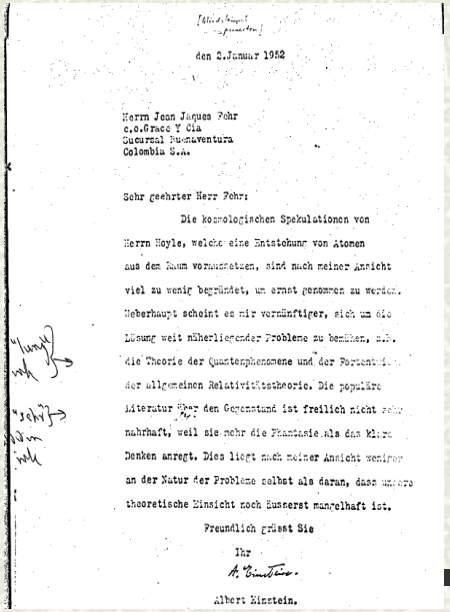


- **Hoyle in Princeton (1952, 53)**

  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.

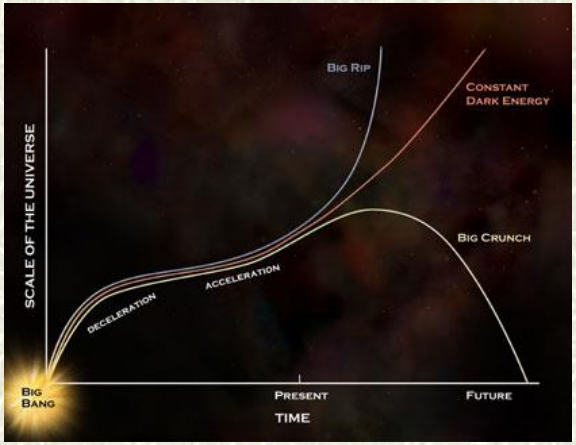
Freundlich grüsst Sie

Ihr

A. Einstein.

Albert Einstein.

Steady-state cosmology today



- **Observable universe not in a steady state**

  Evolution of galaxies

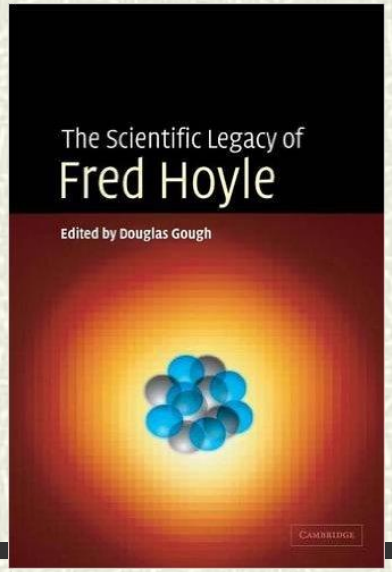
  Cosmic microwave background

- **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**

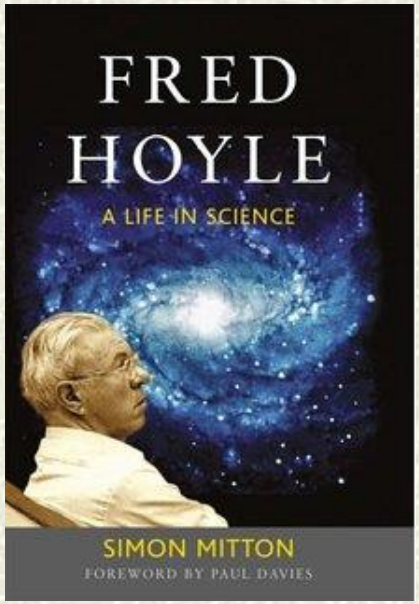
  Different regions undergo different inflation?

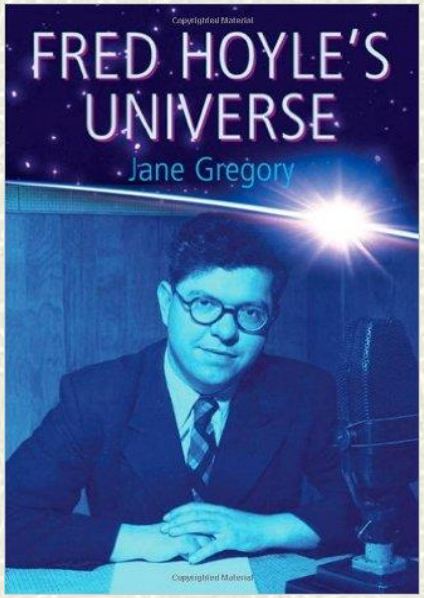
  Inflation begets further inflation (Vilenkin 1983; Linde 1986)

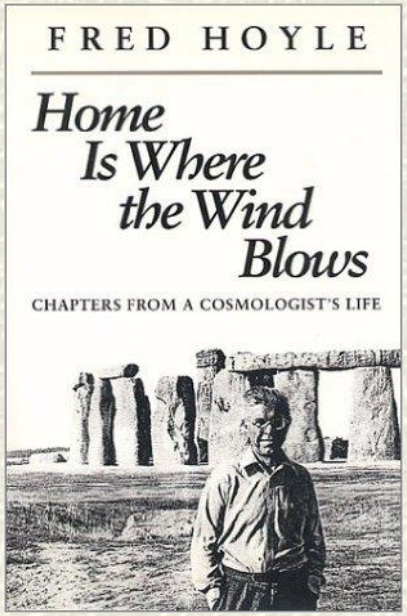
  Observable universe embedded in global steady-state cosmos?

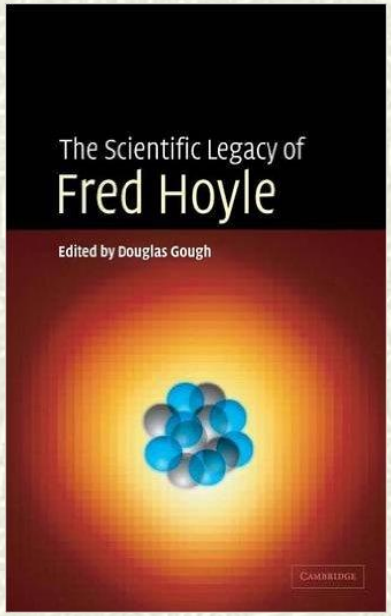
Hoyle's revenge! (Hoyle and Narlikar 1966; Barrow 2005)

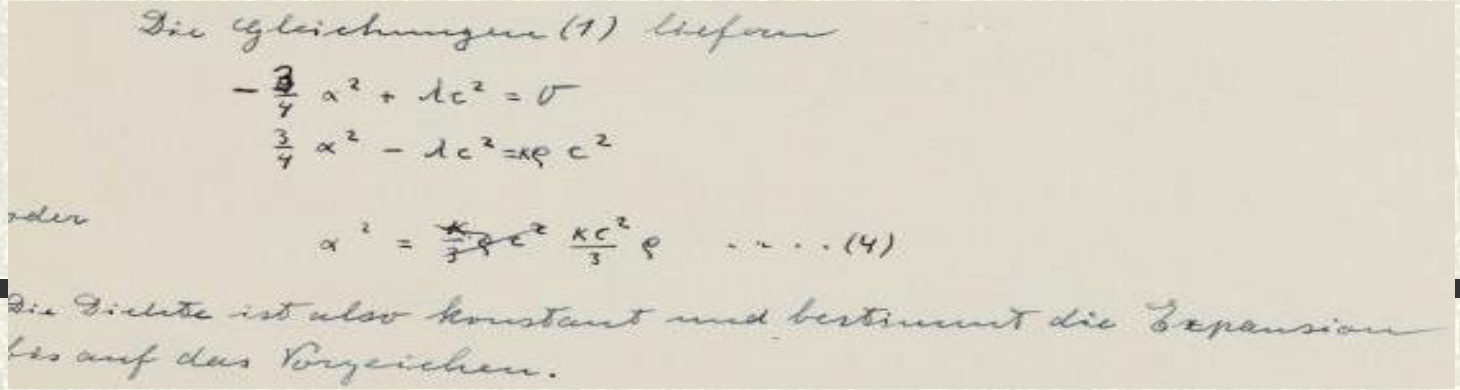
Sources and further reading











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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.