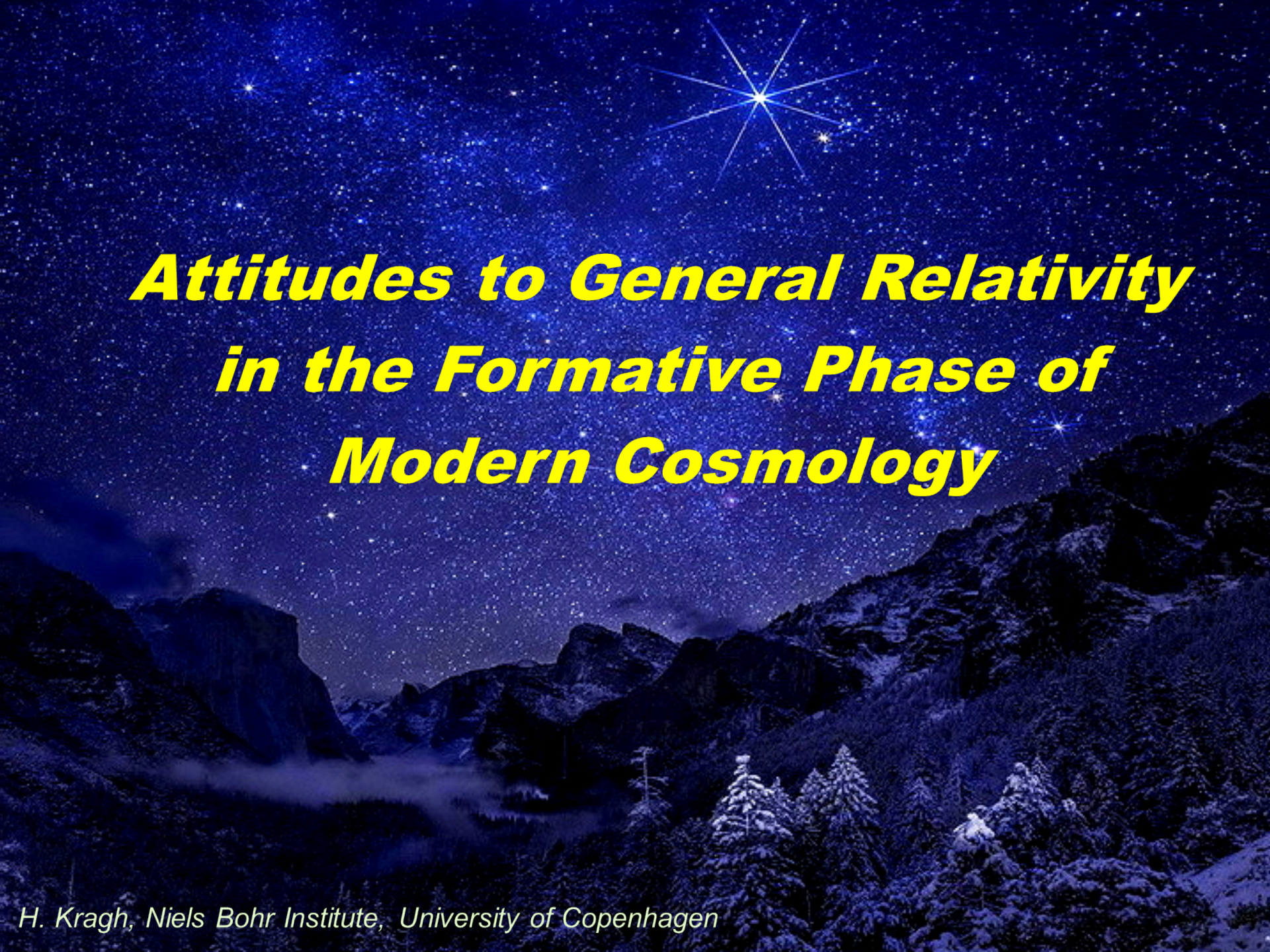


Attitudes to General Relativity in the Formative Phase of Modern Cosmology

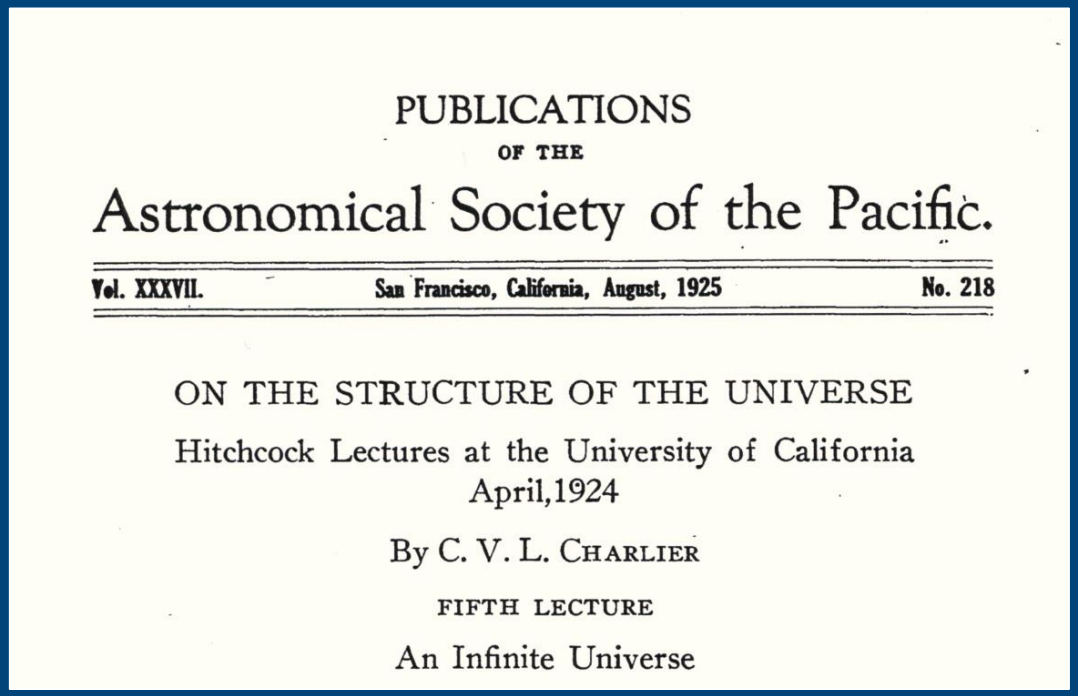
H. Kragh, Niels Bohr Institute, University of Copenhagen

V. Bargmann, “Relativity,”
Rev. Mod. Phys. **29** (1957), 161-174

“Cosmology is the field on which general relativity has had by far the most fruitful and stimulating effect and which is now advancing so rapidly due to the recent extraordinary achievements of astronomy. …

Outside of cosmology, the impact of general relativity on the rest of physics has not been nearly as great as that of special relativity.”

Cosmology without relativity: Charlier's classical universe



PUBLICATIONS
OF THE
Astronomical Society of the Pacific.

Vol. XXXVII. San Francisco, California, August, 1925 No. 218

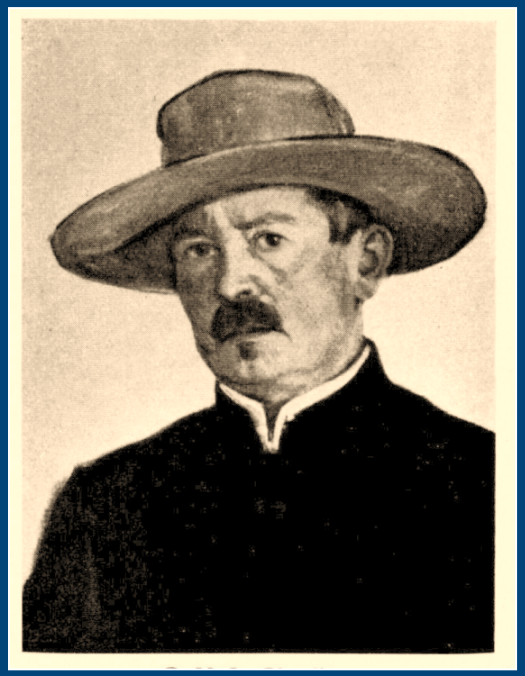
ON THE STRUCTURE OF THE UNIVERSE

Hitchcock Lectures at the University of California
April,1924

By C. V. L. CHARLIER

FIFTH LECTURE

An Infinite Universe



Far from all cosmology in the 1920s (or even 1930s) was influenced by GR. Many astronomers thought of the universe in classical, Newtonian terms. Apart from Eddington and de Sitter, Hubble 1926 was one of the first astronomers to make use of Einstein's universe.

EXTRA-GALACTIC NEBULAE[1]

By EDWIN HUBBLE

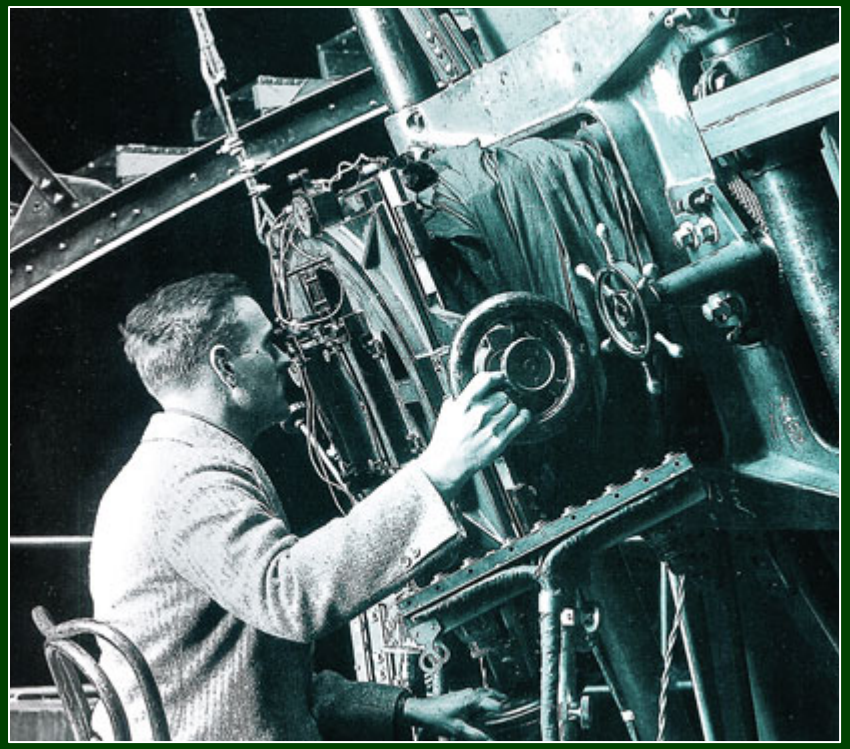
THE FINITE UNIVERSE OF GENERAL RELATIVITY

The mean density of space can be used to determine the dimensions of the finite but boundless universe of general relativity. De Sitter[1] made the calculations some years ago, but used values for the density, 10^{-26} and greater, which are of an entirely different order from that indicated by the present investigations. As a consequence, the various dimensions, both for spherical and for elliptical space, were small as compared with the range of existing instruments.

For the present purpose, the simplified equations which Einstein has derived for a spherically curved space can be used.[2] When

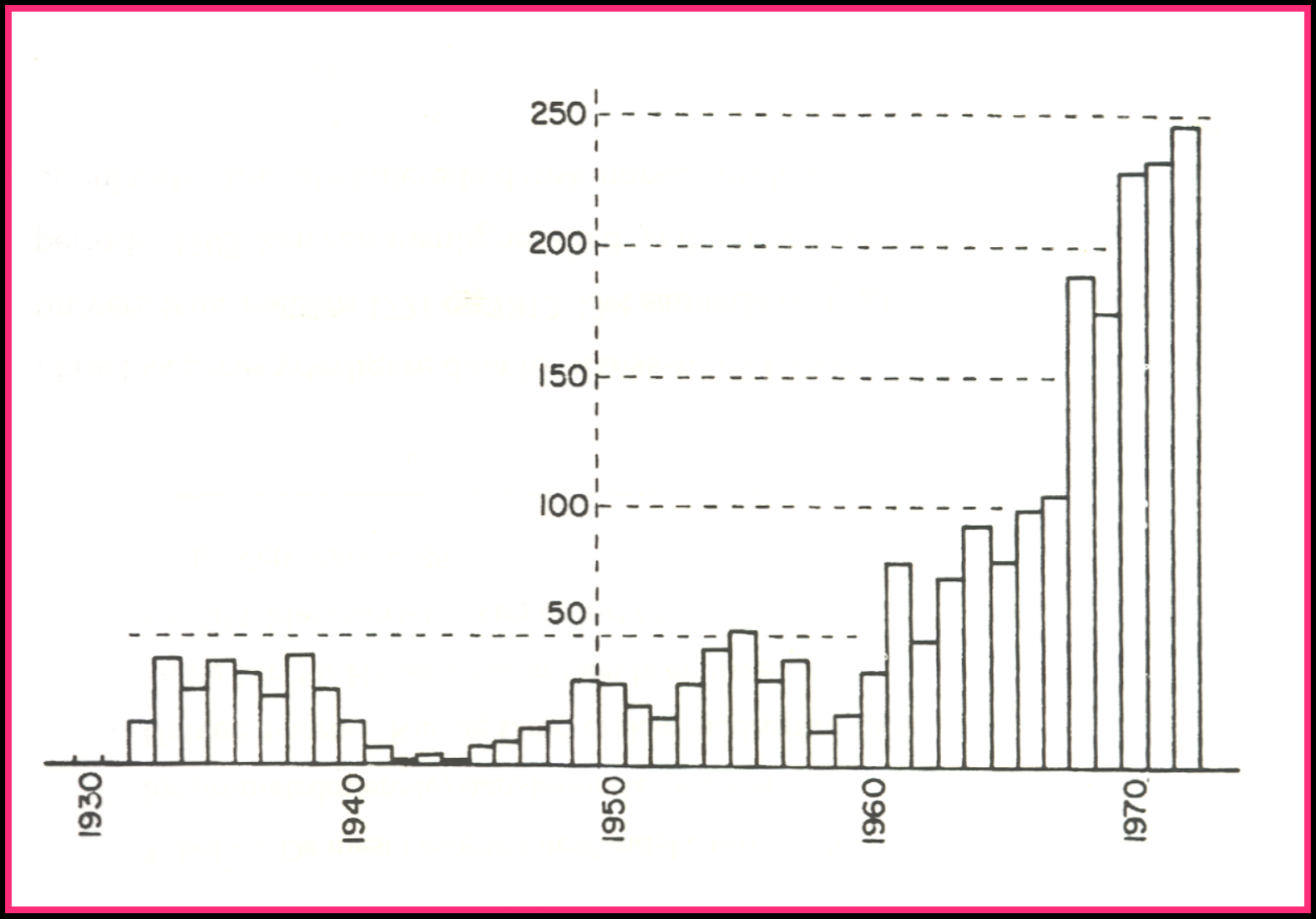
[1] *Monthly Notices*, **78**, 3, 1917.

[2] Haas, *Introduction to Theoretical Physics*, **2**, 373, 1925.

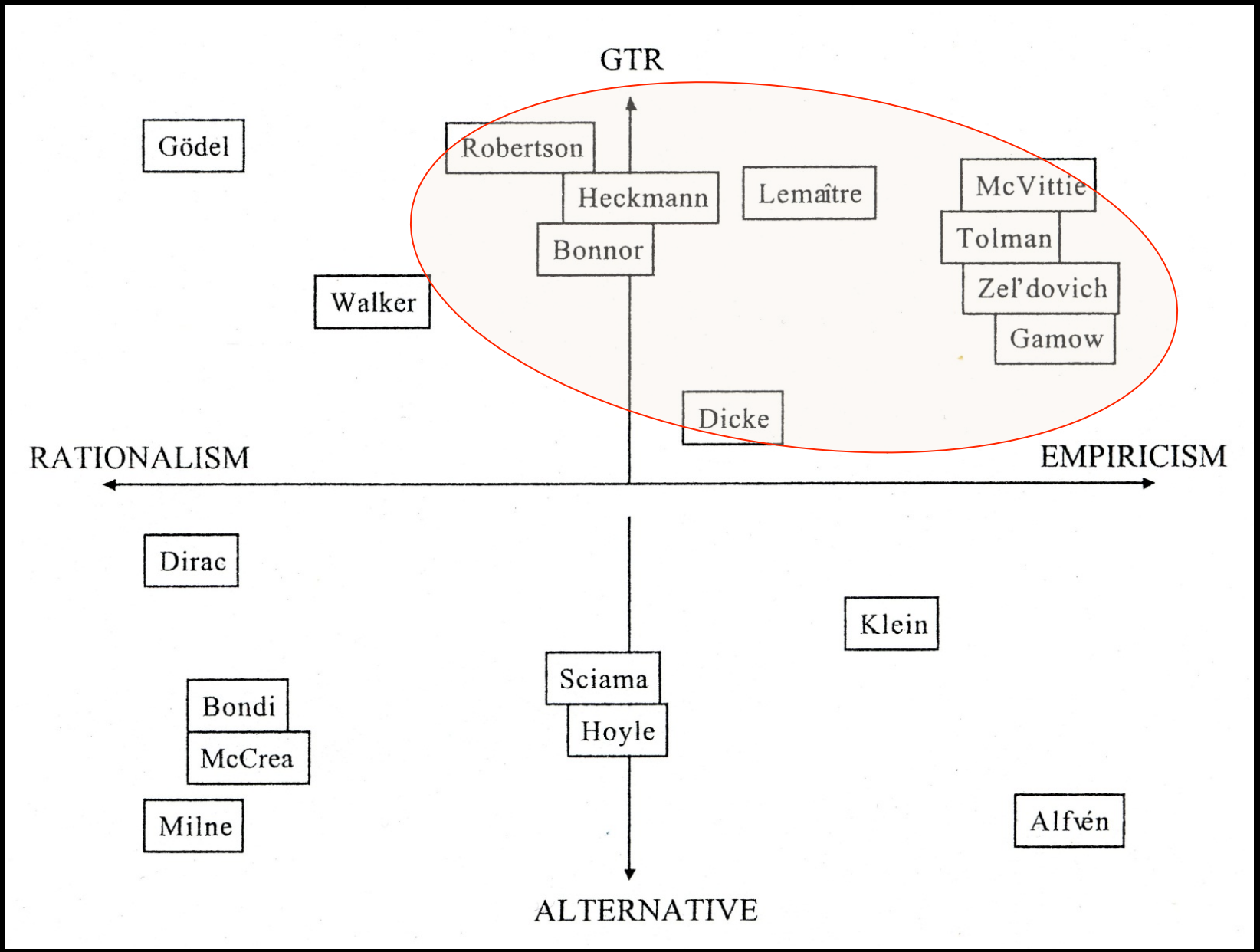


Referring to ”the finite universe of general relativity,” Hubble (1926) estimates the mean density of matter in the universe to 1.5×10^{-31} g/cm^3 and its radius to 27×10^9 pc.

Characteristically, his source was a general textbook on theoretical physics (a translation of a German book by A. E. Haas) .



This depiction of the no. of publications on ”cosmology” in *Physics Abstracts* (1930-75) shows a field which only began it ”normal” growth in the 1960s. Yet, throughout the period the share of cosmology papers was only ~ 0.4% of the physics papers.


GTR
Gödel
Robertson
Heckmann
Lemaître
McVittie
Tolman
Bonnor
Walker
Zel'dovich
Gamow
Dicke
RATIONALISM
EMPIRICISM
Dirac
Klein
Sciama
Bondi
Hoyle
McCrea
Milne
Alfvén
ALTERNATIVE

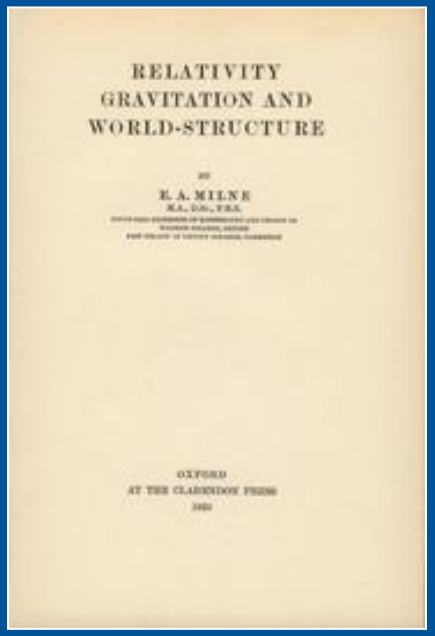
The 1950s: is cosmology a respectable science?

- The choice between cosmological models remains "a matter for aesthetic judgment" (Ernst Öpik, 1954).

- Cosmology is a field where "personal taste will greatly influence the choice of basic hypotheses" (Oskar Klein, 1953).

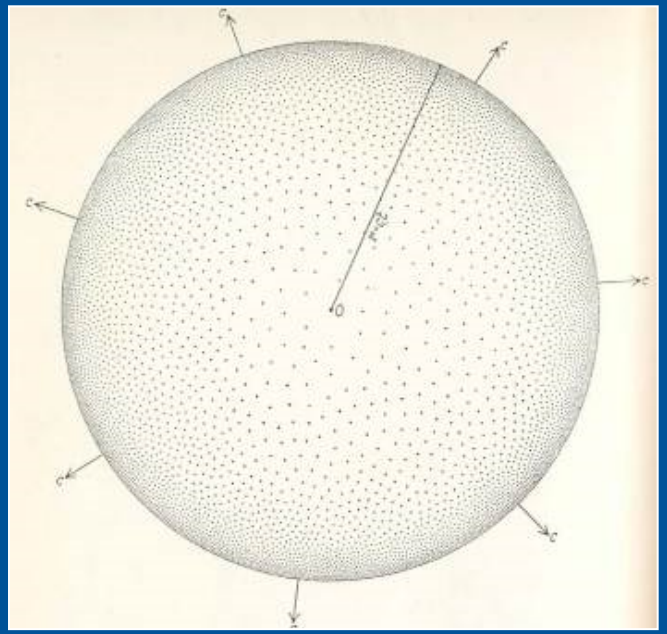
- "Cosmologists have always lived in a happy state of being able to postulate theories which had no chance of being disproved" (Martin Ryle, 1953).

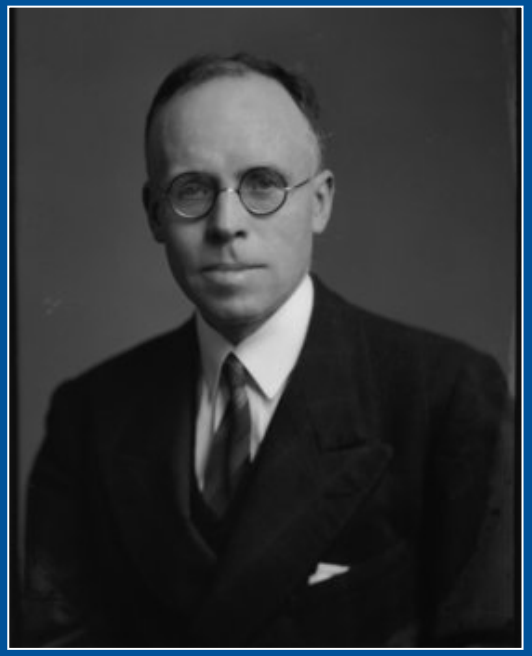
- "Cosmologists are often in error, but never in doubt" (Lev Landau?)


RELATIVITY
GRAVITATION AND
WORLD-STRUCTURE

E. A. MILNE

OXFORD
AT THE CLARENDON PRESS

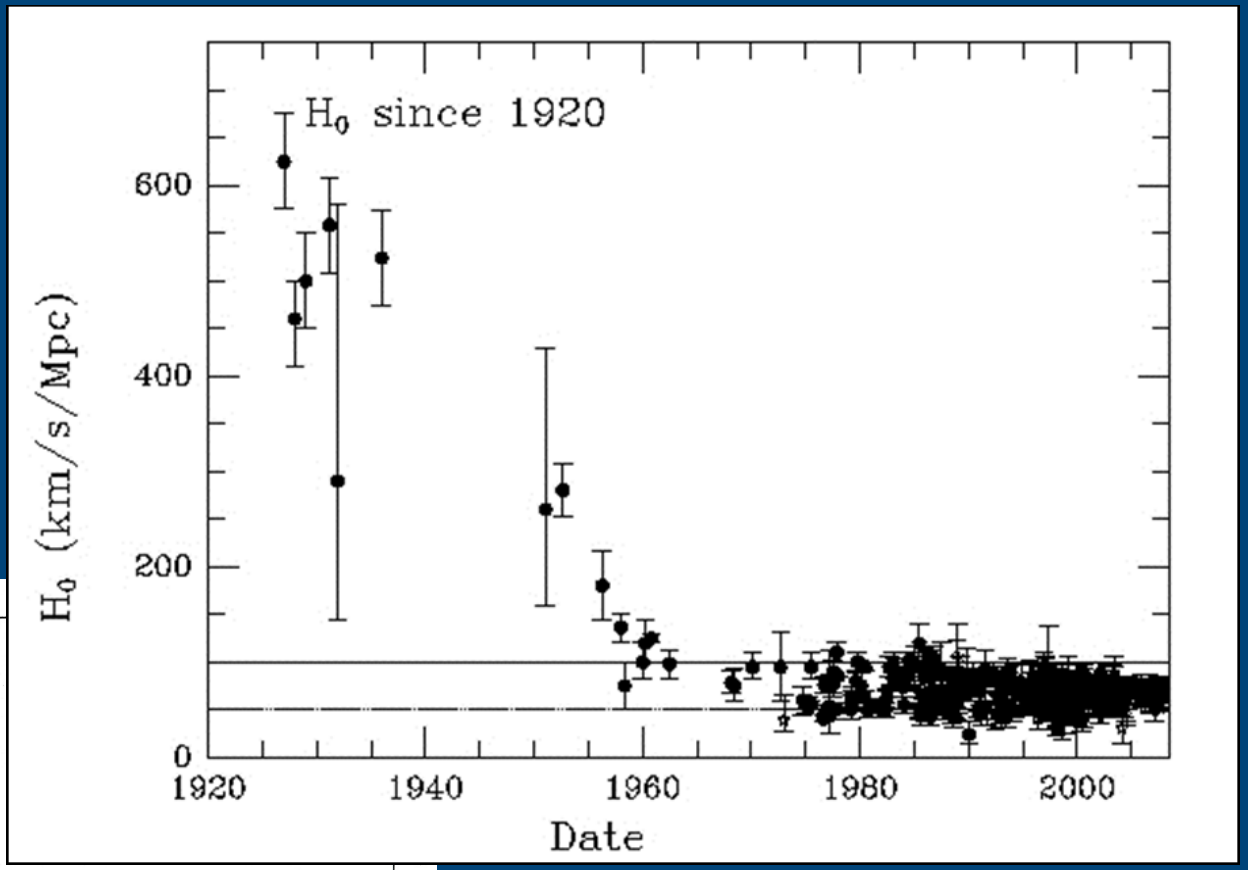


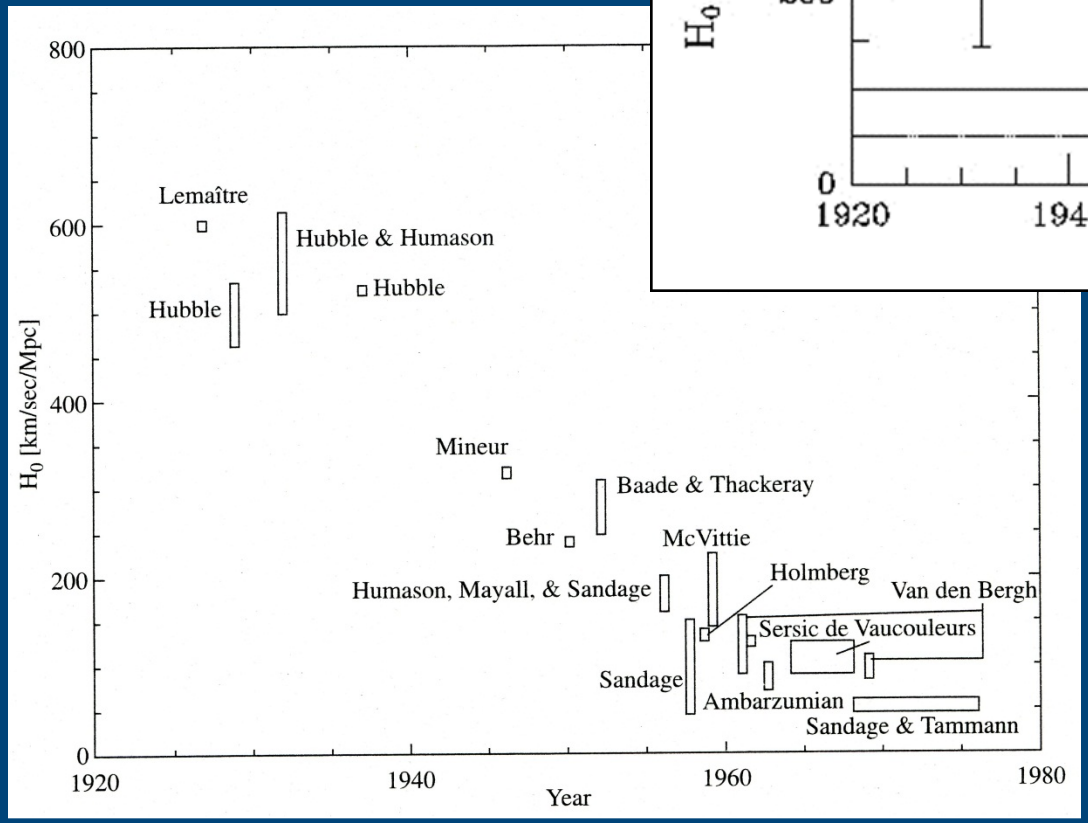


Milne's non-GR cosmological system attracted much interest in UK, and initially also abroad: *"Your paper is very widely discussed and we are holding seminars on the subject."* (Hubble to Milne, 1933). But although it inspired many people, few accepted it, and by 1950 it was essentially abandoned.

The claim by G. Gale that Milne's theory set the agenda and dominated the cosmological scene for a decade is hardly correct (cp. T. Lepeltier, 2006).

The incredible shrinking constant



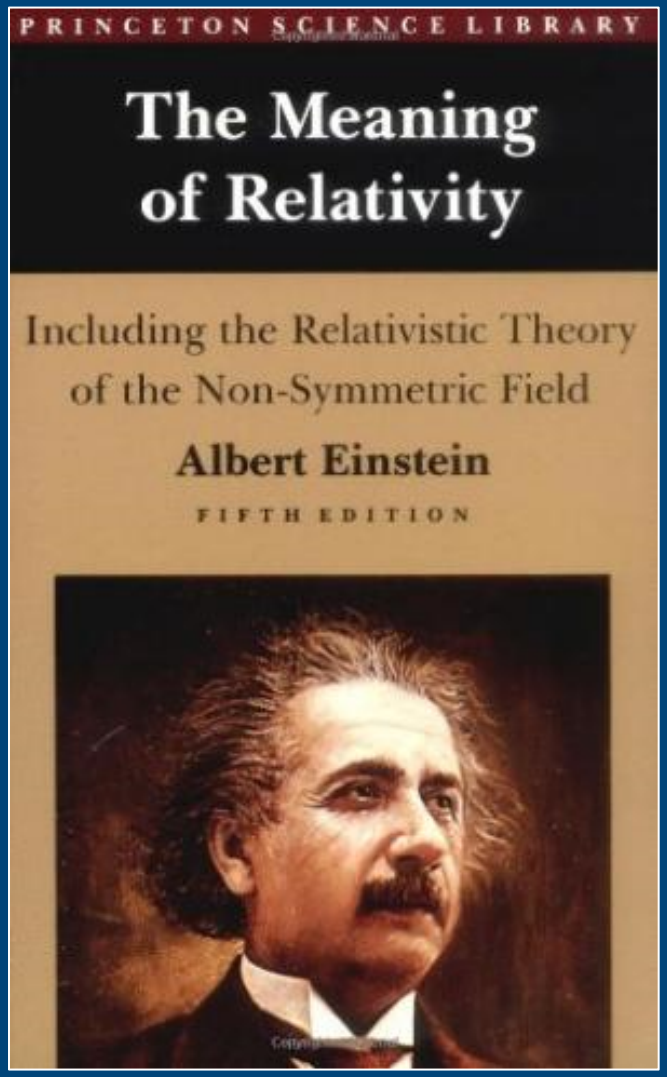


Lemaître 1927	$H_0 \cong 625$ km/s/Mpc
Hubble 1931	$H_0 \cong 558$ km/s/Mpc
Planck 2013	$H_0 = 67.8$ km/s/Mpc

Einstein and the cosmological time-scale problem

"The age of the Earth must certainly exceed that of the firm crust of the Earth as found from the radioactive minerals… . Since determination of age by these minerals is reliable in every respect, the cosmologic theory here would be disproved if it were found to contradict any such results. In this case I see no reasonable solution."

(1945; p. 132)



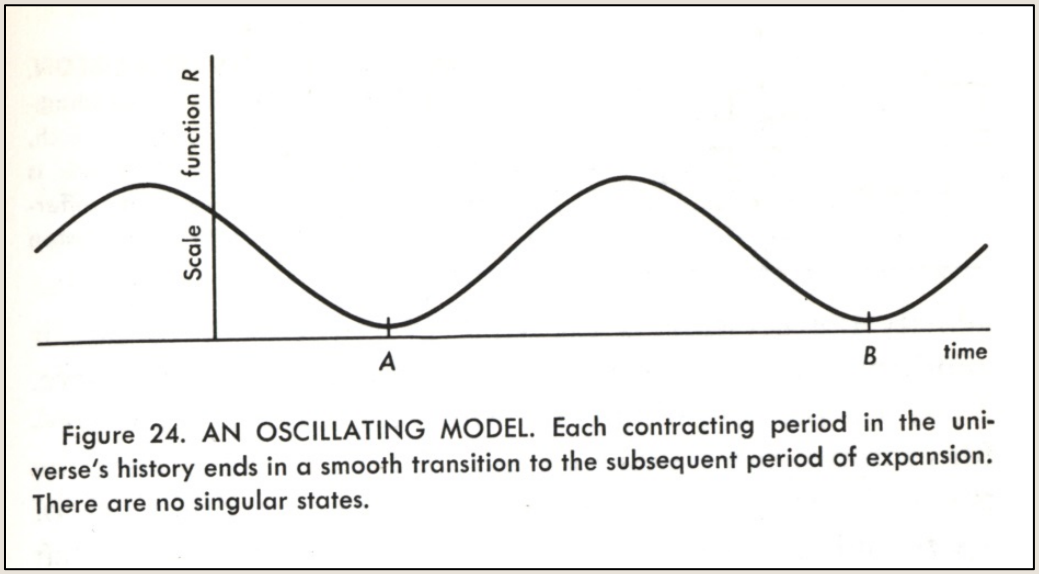
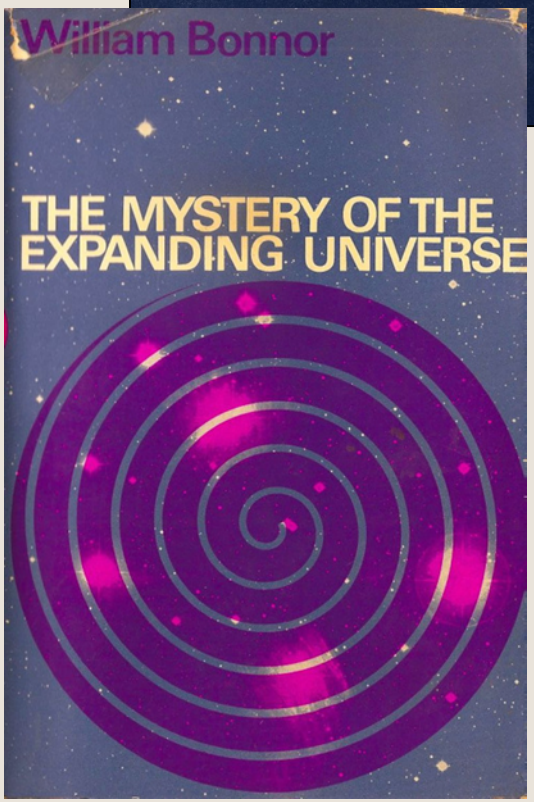


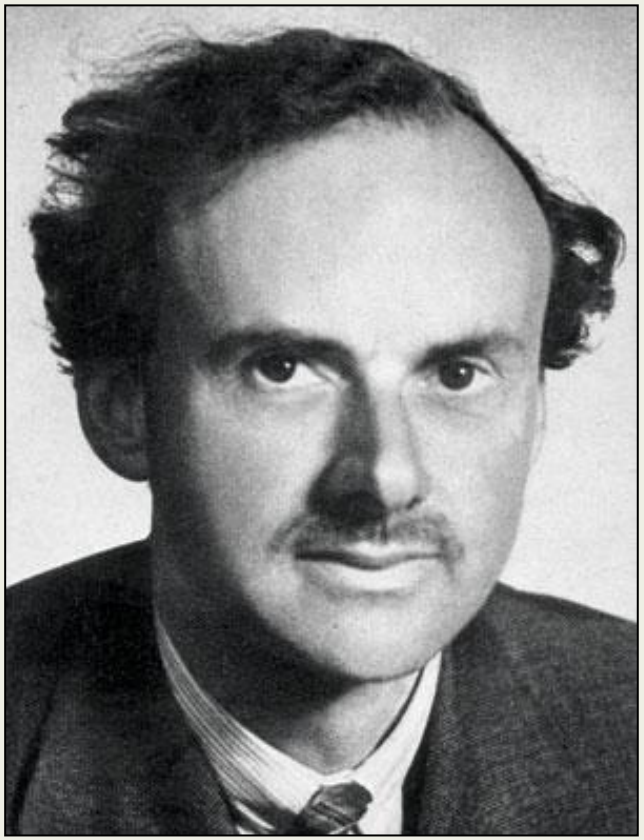
Figure 24. AN OSCILLATING MODEL. Each contracting period in the universe's history ends in a smooth transition to the subsequent period of expansion. There are no singular states.



Wm. Bonnor, orthodox relativist, adversary of steady-state theory but also of GR-based big-bang "creation" theory.

Matter creation is contrary to GR and "violates the basic rules of scientific reasoning."

His preferred model: an eternally cyclic universe with smooth ($R > 0$) transitions and in agreement with GR.



P. A. M. Dirac, 1937-38

"Large Numbers Hypothesis"

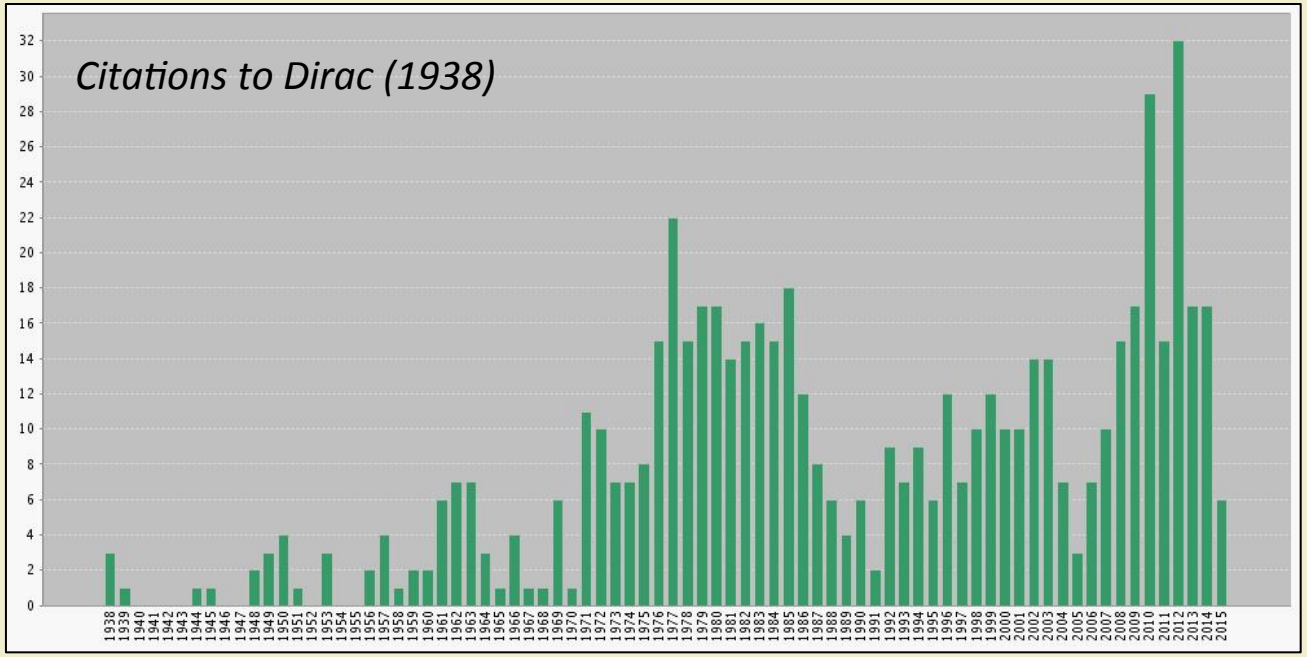
Varying gravitational constant

$$T_0 / e^2 / mc^3 \cong 2\times 10^{39} \; ; \quad e^2 / GmM \cong 7\times 10^{38}$$

$$G(t) \sim 1/t$$

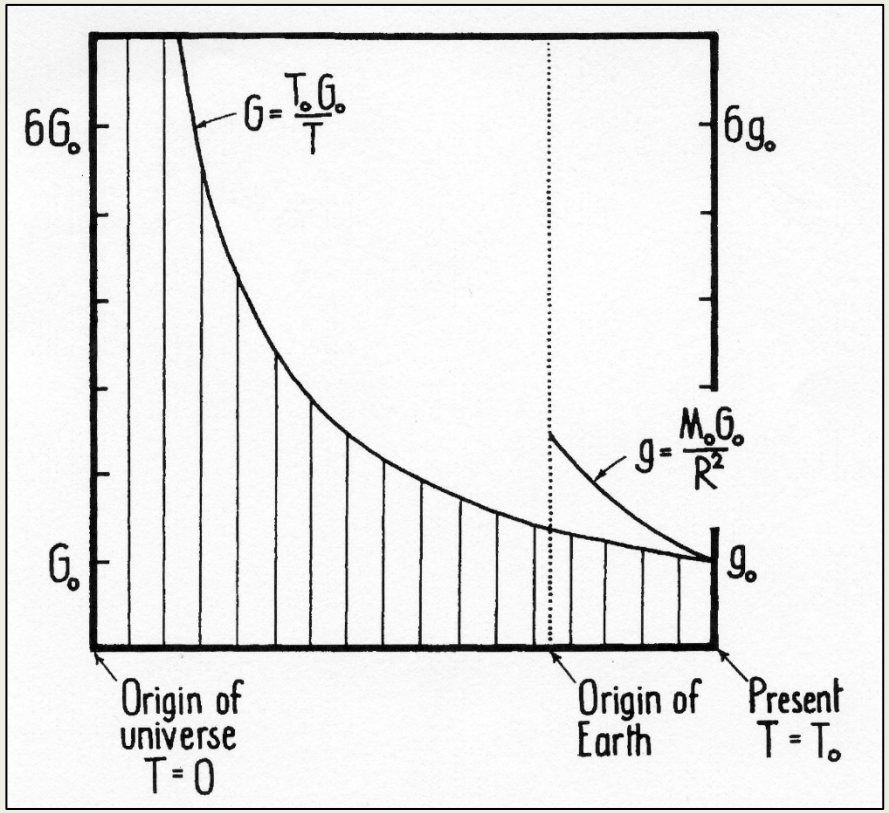
$$t_0 = 1/3 \; 1/H_0 \cong 6\times 10^8 \text{ yr} \quad (< t_{earth})$$

$$1/G \; dG/dt \cong -H_0 \sim -10^{-11} \text{ yr}^{-1}$$



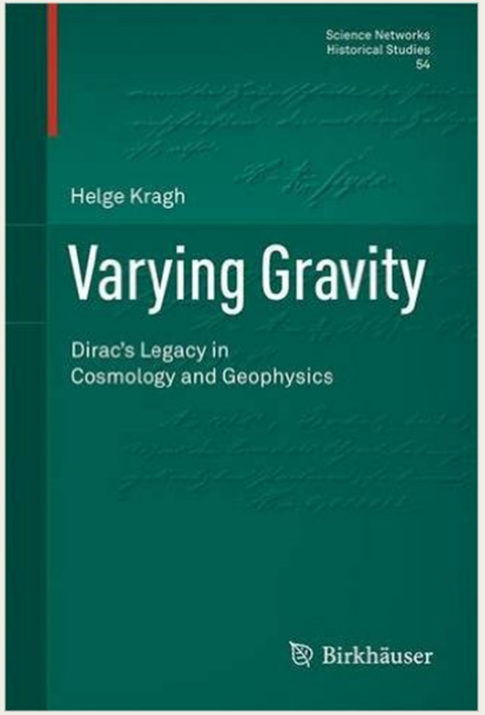
Dirac abandoned his $G(t)$ cosmology after 1938, only to return to it in 1971. A major reason was the disagreement between his theory and GR. He eventually thought to have found a way to make $G(t)$ agree with an extended form of GR.

"It would be desirable to have our theory conforming to Einstein's general relativity. Now Einstein's theory demands mass conservation. … I believe [multiplicative creation] is to be preferred, because it clashes less violently with Einstein's theory." (Dirac, 1972).



”It was believed that a theory with a varying *G* falls outside the scope of general relativity. However, it has been shown by C. Gilbert that *G* ~ 1/*t* may be deduced by using the principles of general relativity theory. I therefore …”

Nature 186 (1960).



#3

THE THEORY OF A VARIABLE "CONSTANT" OF GRAVITATION

There exists, then, one Theory of Gravitation originating out of Einstein's own Theory which we shall now describe. This latter, which I have called the "Generalized Theory" (in German, "Erweiterte Gravitationstheorie") does not declare Einstein's theory to be false and inapplicable as to gravitation. But it does declare that a certain degree of generalization of his theory is necessary to explain all phenomena which are related to gravitation. If our Hypothesis is accepted, Einstein's Theory is too restricted - it must be "generalized".

The fundamental idea behind this new theory is the definition of f, the Newtonian Constant of Gravitation, in the Theory of Relativity, by the expression

(1) $G = \frac{8\pi f}{c^2}$

(where c is the velocity of light (3×10^{10} cm/sec^2)
(and G, the universal "constant" of gravitation (6.67×10^{-8} dyne/cm^2/gm^2)

In agreement with Newton, Einstein admits that G is a true constant, unchanging in value, throughout space, and over all time.

Instead of this, we assert the Hypothesis

G is a variable.

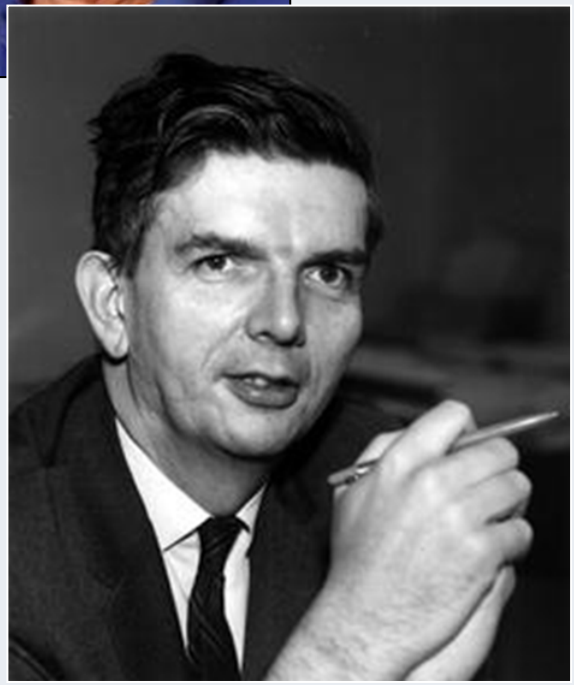
G does vary, with time, and G may also vary from place to place.

1954 essay to GRF competiition

P. Jordan's extended (scalar-tensor) theory of gravitation and cosmology, ca. 1948-1980.

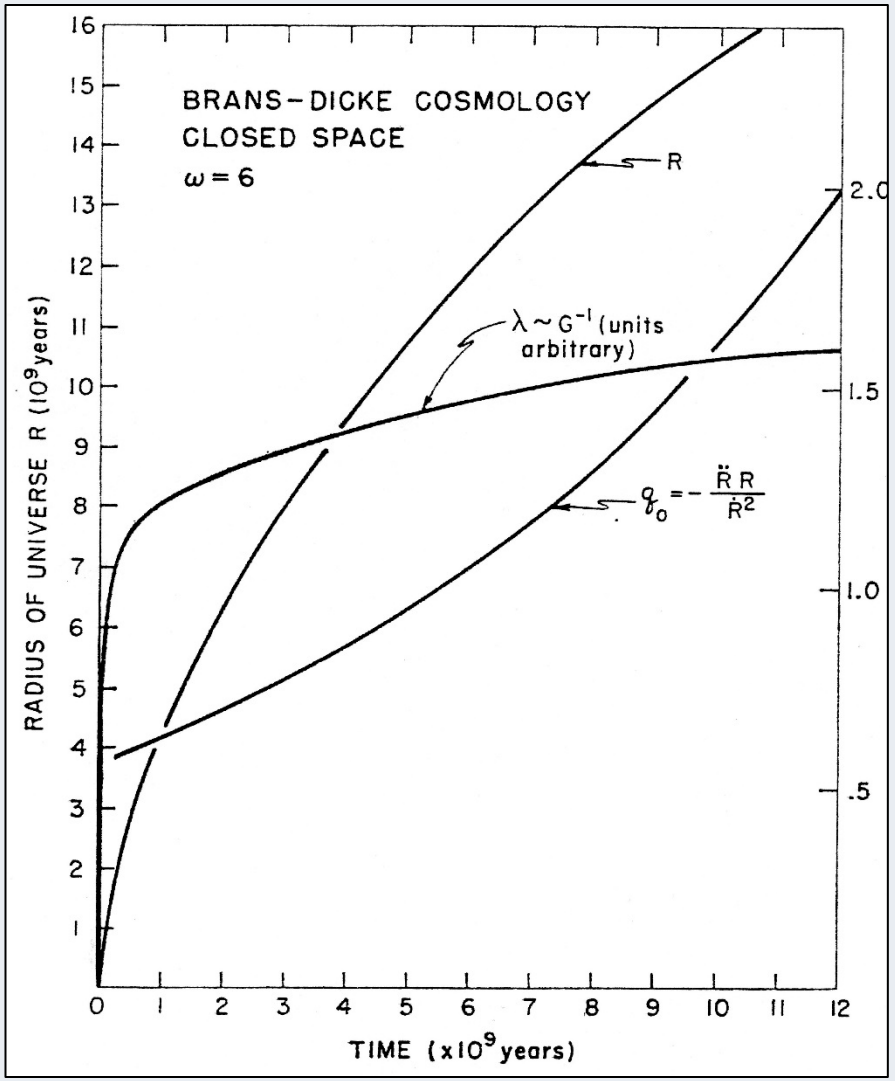
Brans-Dicke (scalar-tensor) gravitation theory

Varying gravity, but slower and less determinate than in Dirac theory

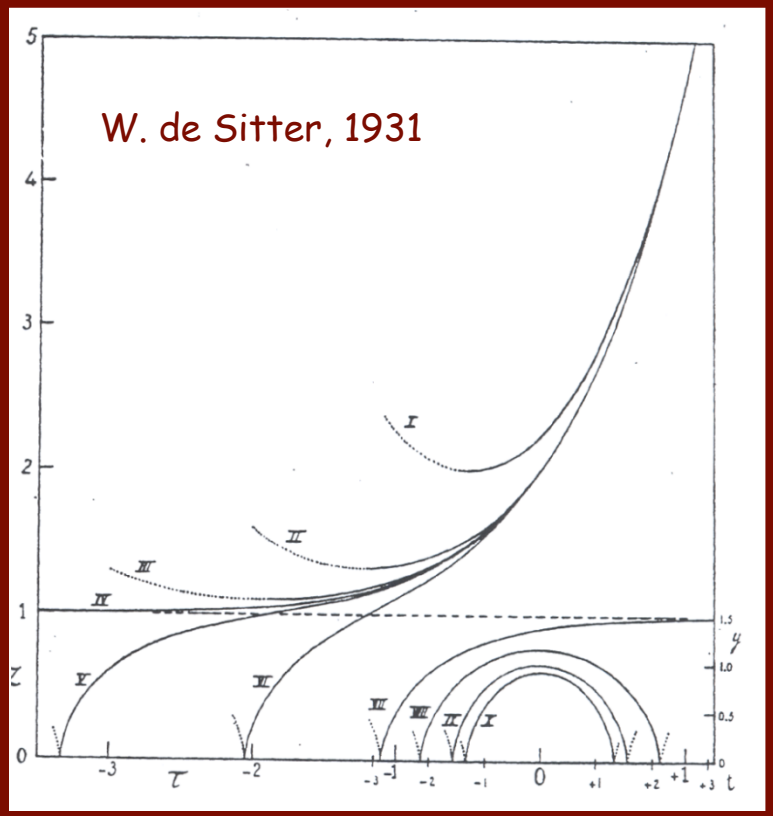


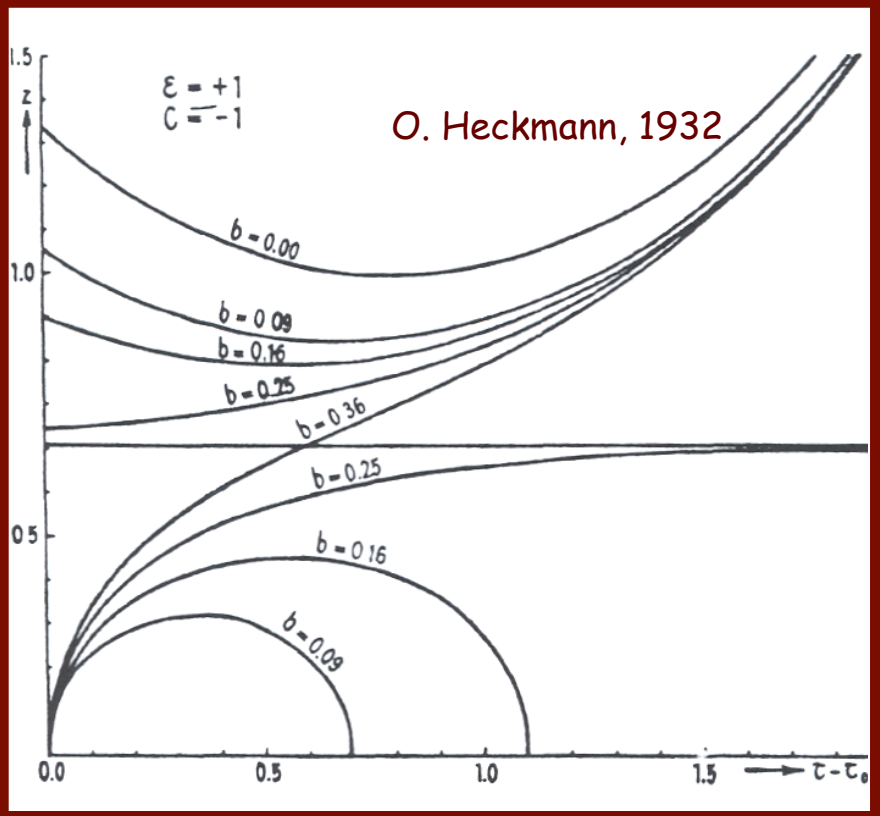
Carl Brans; Robert Dicke

$$G \cong G_0 \, (t/T_0)^{-0.1}$$



"In general relativity a very wide range of models is available … The number of free parameters is so much larger than the number of observational points that a fit certainly exists." (Bondi & Gold 1948)





"The plethora of world-models is something of an embarrassment to the relativistic theory." (Bonnor 1961)

Bondi on Cosmology and/vs. General Relativity

”I do not regard cosmology as a minor branch of general relativity … but unfortunately this view persists to this day. … In any conflict between general relativity and the cosmological principle it seems that it is general relativity that must be abandoned.”

H. Bondi, *Cosmology* (1952).

”In our view general relativity cannot be adapted to our theory, in spite of its great attraction. … We feel that [Hoyle’s field-theoretical] formulation is unsatisfactory and unacceptable.”

Bondi & Gold, 1948

GR-like steady-state theory

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R + C_{\mu\nu} = -\kappa T_{\mu\nu}$$

”We shall obtain, within the framework of general relativity theory, … a universe satisfying the wide [‘perfect’] cosmological principle.” (Hoyle, 1948)

”It seems preferable that the question of continuous matter creation should be discussed by a modification of the existing [GR] theory.” (Hoyle, 1949)

Relativistic steady-state theories

"… a satisfactory description of the creation hypothesis may be obtained without any modifications of Einstein's equations." (McCrea, 1951)

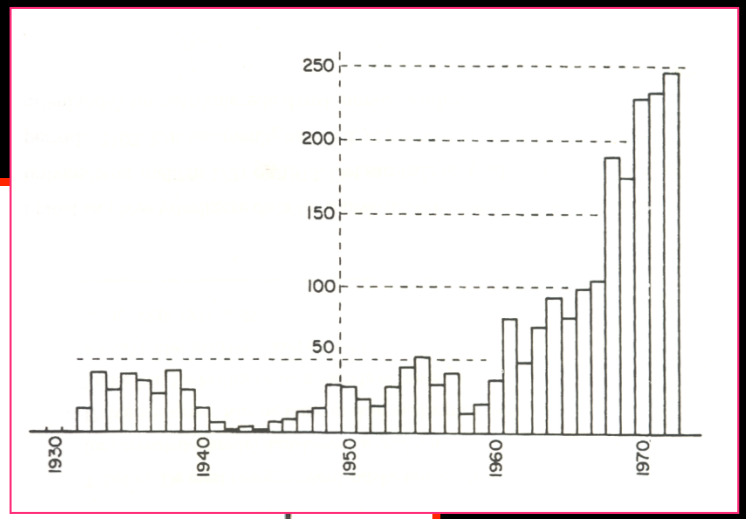
"… a continuous creation process can exist in a suitably chosen general relativity model of the universe." (McVittie, 1952)

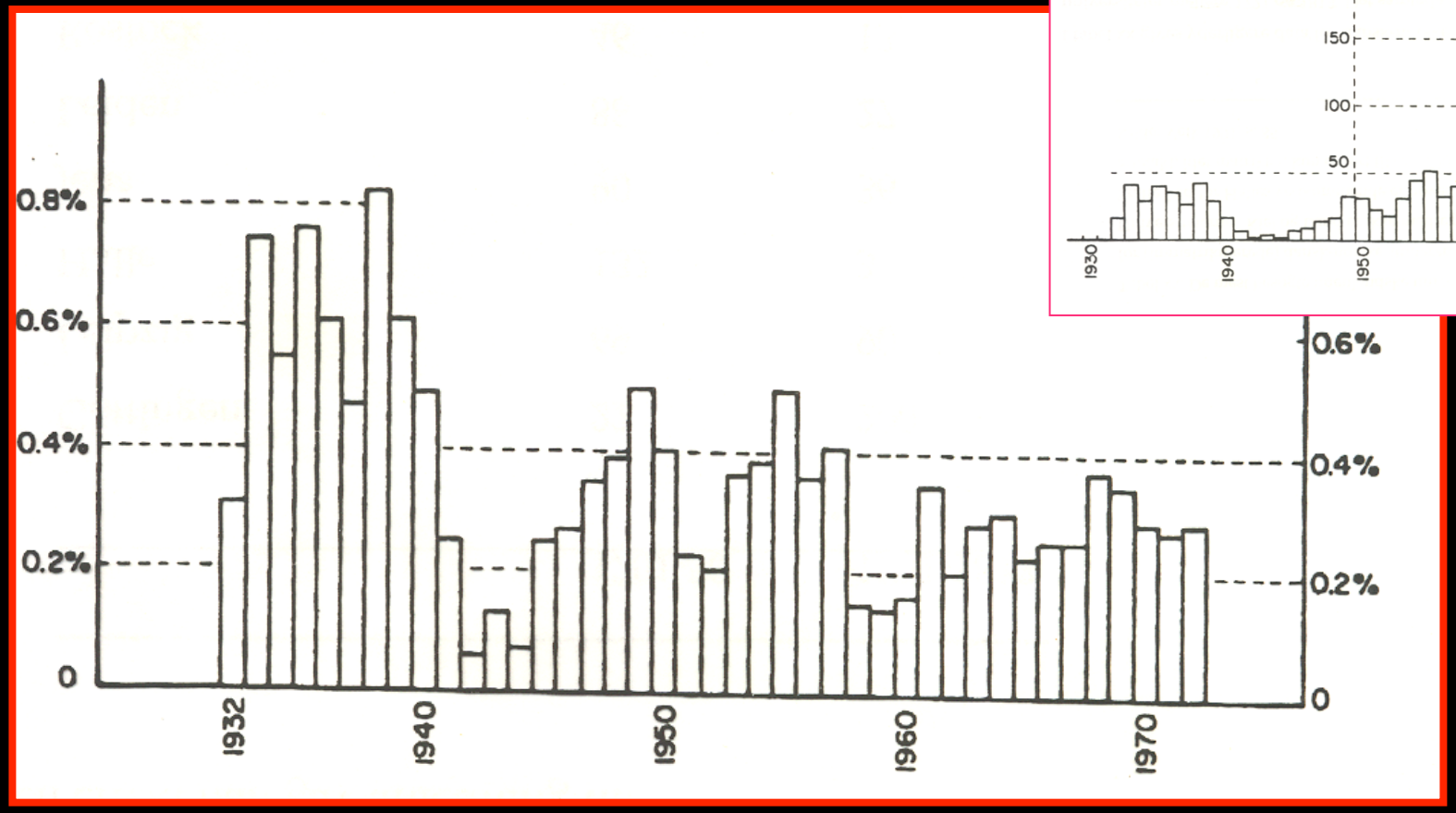
"Granted the existence of McCrea's negative pressure, then "indeed, the steady-state model does satisfy Einstein's field equations." (Bonnor, 1955)

11th Solvay Congress 1958: Structure and evolution of the universe

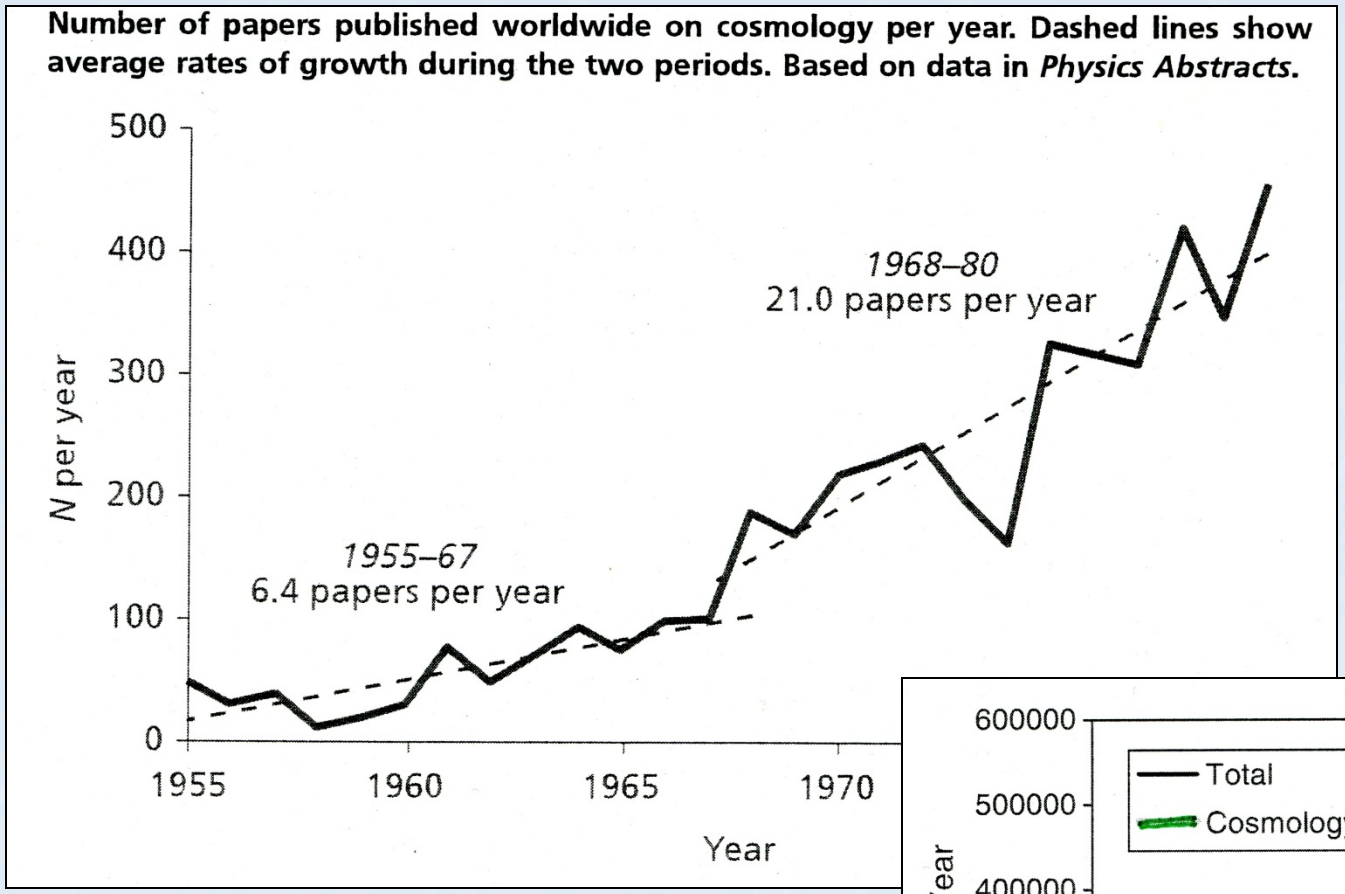
Although the Solvay congress meant an acknowledgment of cosmology as part of physics, it included no speakers supporting physical (big bang) GR-cosmology in the style of Gamow. Of the 12 addresses, 7 were astronomical/astrophysical and 3 were given by steady-state advocates.

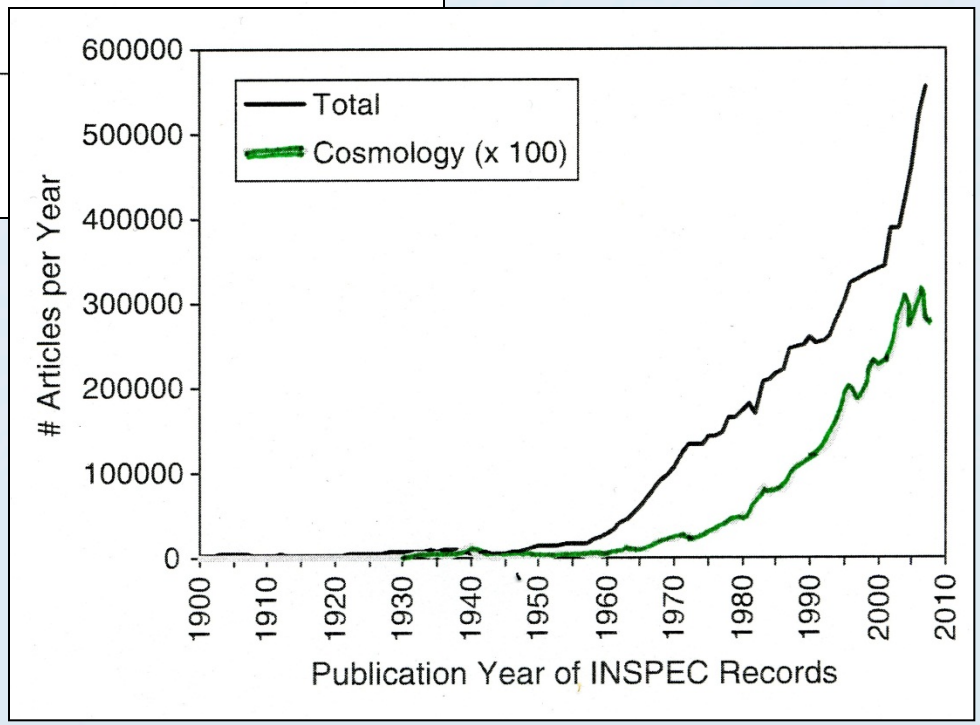

That's all Folks!





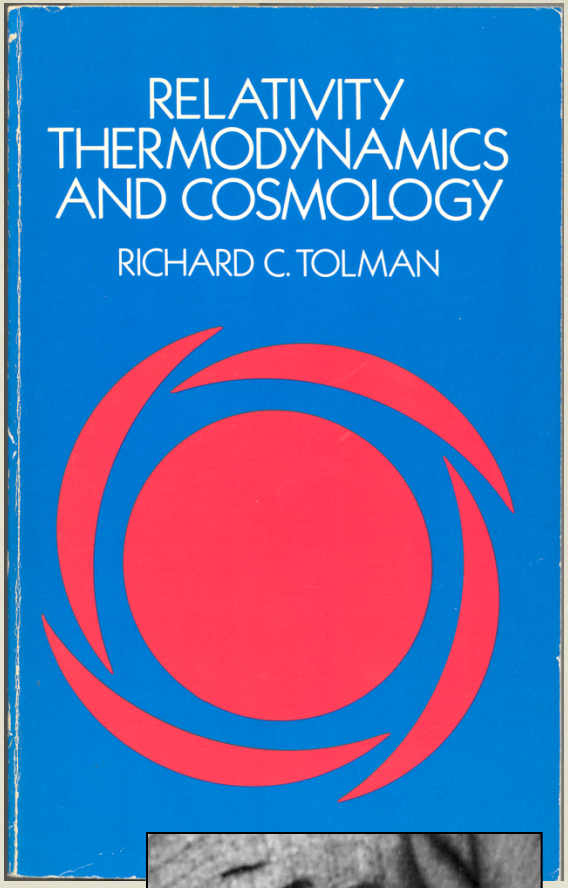
BUT, if the data are taken relative to all articles in *Physics Abstracts*, we get a very different picture: now, the 1930's look like a fine decade, while the progress in the 1960s has entirely vanished!



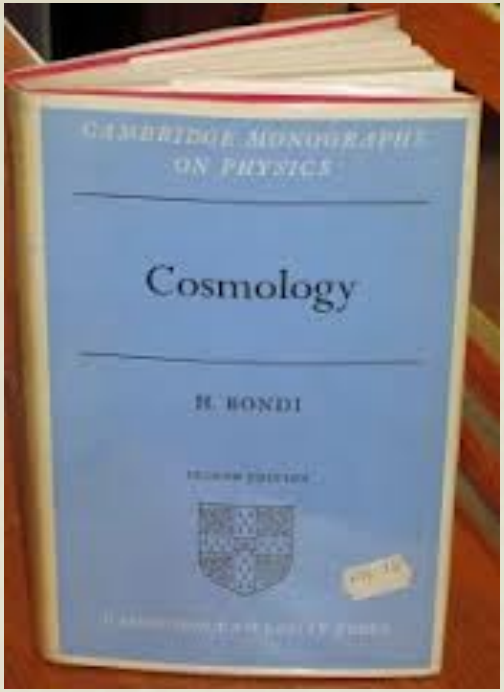


The growth of cosmology as a science:

Bibliometric measure.


RELATIVITY
THERMODYNAMICS
AND COSMOLOGY
RICHARD C. TOLMAN


FORTSCHRITTE DER ASTRONOMIE
HERAUSGEGEBEN VON DER ASTRONOMISCHEN GESELLSCHAFT
DURCH P. TEN BRUGGENCATE
2
THEORIEN DER
KOSMOLOGIE
VON
OTTO HECKMANN
VERLAG / BERLIN
1942


Cosmology
H. BONDI