

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

AD 718264

1. ORIGINATING ACTIVITY (Corporate author) Physics Department Princeton University Princeton, New Jersey 08540	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
	2b. GROUP

3. REPORT TITLE
FINAL REPORT OF O.N.R. GRANT Nonr-1858(30)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report - July 1, 1958 - June 30, 1968

5. AUTHOR(S) (First name, middle initial, last name)
Robert H. Dicke

6. REPORT DATE February 1971	7a. TOTAL NO. OF PAGES 9	7b. NO. OF REFS 85
---------------------------------	-----------------------------	-----------------------

8a. CONTRACT OR GRANT NO. Nonr-1858(30)	9a. ORIGINATOR'S REPORT NUMBER(S) None
b. PROJECT NO. NR 013-101	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
c.	
d.	

10. DISTRIBUTION STATEMENT
This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Office of Naval Research Arlington, Virginia 22217
-------------------------	---

13. ABSTRACT
→ The contract was concerned with gravitation and its relation with astrophysics, geophysics and other parts of physics. Highly precise null-experiments were performed, one for the first time, one representing a thousand-fold improvement over previous experiments. The known tests of gravitational theory were reexamined and one has been challenged by the solar oblateness observed by the group. Many of the astrophysical and geophysical implications of gravitational theory have been examined.

DDC
RECEIVED
FEB 18 1971
REGULATED
B

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
Springfield, Va. 22151

DD FORM 1473
NOV 65

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Gravitation Gravitation, weakness Gravitation, universal General Relativity Relativistic Astrophysics Scalar-Tensor Theory Sun Earth Sun's Core Solar Oblateness Sun's Rotation Eötvös Primeval Fire-Ball Fire-Ball Fire-Ball Radiation						

FINAL REPORT OF O.N.R. GRANT Nonr-1858(30)

Gravitation dominates the behavior of the sun and the solar system. A substantial number of able physicists and astronomers, experimentalists, observers, and theorists have investigated the scalar-tensor theory, vis-a-vis general relativity and still the validity of one or the other theory is unsettled. But it is generally recognized that these gravitational theories contain important implications for a wide range of practical problems, particularly for those involving the sun and earth. Consider two examples: The presence or absence of a rapidly rotating core in the sun is intimately tied to the validity or invalidity of the scalar-tensor theory of gravitation. But the presence or absence of such a core is important to the question of angular momentum transport, internal magnetic fields, and the sunspot cycle. Pulsars appear to be the strongest and most dense objects and containing the strongest magnetic fields observed anywhere. Owing to their high masses and densities, these bodies are sensitive to differences in gravitational theory. But their understanding may be important for the understanding of a wide range of physical problems.

The contract covered a period during which were tried many different approaches to an understanding of gravitation. The diversity is reflected in the publications list. They range from purely theoretical papers, one of which (the 6th) has had a very substantial impact, having led to many dozens of articles by others. One of the articles (the 20th) describes a null experiment on gravitation of great precision, representing a 3-fold increase in precision over the previous similar experiment, that of Eötvös. One of the papers reporting that the sun was oblate received a lot of publicity because of its significance for general relativity. Many of the papers deal with the relationship between astrophysics and gravitational physics. The group played an important role in connection with the discovery, confirmation, and analysis of the so-called primeval fire-ball radiation. This has been called the most important result for cosmology in almost a half century and cosmology provides one our best ways of studying gravitation. Theoretical analyses were made of the evolution of the fire-ball, and the role of gravitation in this evolution. In the past 8 years the relationship between gravitation and astrophysics has developed into a new recognized field of physics with programs at the meeting of the

American Physical Society, international conferences, and its own classification in physics literature.

We learned a great deal about gravitation in the decade 1958-68, but much remains to be done. The fundamental question of which of the two gravitational theories is invalid, general relativity or the scalar-tensor theory, is still unsettled.

Publications Under O.N.R. Grant Nonr-1858(30)

- R. Krotkov and R. H. Dicke Comparison Between Theory and Observations for the Outer Planets, Astronomical Journal 64, 157 (1959)
- R. H. Dicke Cosmology and the Dating of Meteorites, Nature 183, 170 (1959)
- W. F. Hoffmann, R. Krotkov, and R. H. Dicke Precision Optical Tracking of Artificial Satellites, I.R.E. Trans. Mil. 4, 28 (1960)
- R. H. Dicke The Eötvös Experiment and the Gravitational Red Shift, Amer. J. of Physics 28, 344 (1960)
- W. J. Morgan, J. O. Stoner, and R. H. Dicke Periodicity of Earthquakes and the Invariance of the Gravitational Constant, J. of Geophys. Research 66, 3831 (1961)
- C. Brans and R. H. Dicke Mach's Principle and a Relativistic Theory of Gravitation, Phys. Rev. 124, 925 (1961)
- R. H. Dicke Experimental Tests of Mach's Principle, Phys. Rev. Letters 7, 359 (1961)
- R. H. Dicke Implications for Cosmology of Stellar and Galactic Evolution Rates, Rev. of Mod. Phys. 34, 110 (1962)
- R. H. Dicke Mach's Principle and Invariance under Transformation of Units, Phys. Rev. 125, 2163 (1962)
- R. H. Dicke The Lee-Yang Field and Isotropy of the Universe, Phys. Rev. 126, 1580 (1962)
- R. H. Dicke Dating the Galaxy by Uranium Decay, Nature 194, 329 (1962)
- P. J. E. Peebles and R. H. Dicke The Temperature of Meteorites and Dirac's Cosmology and Mach's Principle, J. Geophys. Res. 67, No. 10, 4062 (1962)
- R. H. Dicke Long Range Scalar Interaction, Phys. Rev. 126, 1875 (1962)
- P. J. E. Peebles and R. H. Dicke The Significance of Spatial Isotropy, Phys. Rev. 127, No. 2, 629 (1962)
- P. J. E. Peebles The Eötvös Experiment, Spatial Isotropy, and Generally Covariant Field Theories of Gravity, Ann. of Phys. 20, No. 2, 240 (1962)

Continued: Publications Under O.N.R. Grant Nonr-1858(30)

- R. H. Dicke The Long Range Scalar Field, Phys. Rev. 126, No. 5, 1875 (1962)
- R. H. Dicke and P. J. E. Peebles Cosmology and the Radioactive Decay Ages of Terrestrial Rocks and Meteorites, Phys. Rev. 128, No. 5, 2006 (1962)
- R. H. Dicke Cosmology, Mach's Principle and Relativity, I.C.S.U. Review 5, 40 (1963)
- R. H. Dicke Cosmology, Mach's Principle and Relativity, Amer. J. of Phys. 31, No. 7, 500 (1963)
- P. G. Roll, R. Krotkov, and R. H. Dicke The Equivalence of Inertial and Passive Gravitational Mass, Ann. of Phys. 26, No. 3, 442 (1964)
- K. C. Turner and H. A. Hill New Experimental Limit on Velocity-Dependent Interactions of Clocks and Distant Matter, Phys. Rev. 134, No. 1B, B252 (1964)
- R. H. Dicke and P. J. E. Peebles Evolution of the Solar System and the Expansion of the Universe, Phys. Rev. Ltrs. 12, No. 15, 435 (1964)
- R. H. Dicke The Sun's Rotation and Relativity, Nature 202, No. 4931, 432 (1964)
- C. T. Murphy and R. H. Dicke The Effects of a Decreasing Gravitational Constant in the Interior of the Earth, Proceedings of the American Philosophical Society 108, No. 3, 224 (1964)
- C. Callan, R. H. Dicke and P. J. E. Peebles Cosmology and Newtonian Mechanics, Amer. J. of Phys. 33, No. 2, 105 (1965)
- R. H. Dicke Icarus and Relativity, Astronomical J. 70, No. 6, 395, No. 1331 (1965)
- R. H. Dicke, P. J. E. Peebles, P. G. Roll, and D. T. Wilkinson Cosmic Black-Body Radiation, Astrophysical J. 142, No. 1, 414 (1965)
- R. H. Dicke and P. J. E. Peebles Gravitation and Space Science, Space Science Reviews 4, 419 (1965), D. Reidel Publishing Co., Dordrecht, Holland
- Ranier Weiss and Barry Block A Gravimeter to Monitor the $\alpha\epsilon_0$ Dilational Mode of the Earth, J. of Geophys. Res. 70, No. 22, 5615 (1965)
- P. J. E. Peebles Primeval Helium Abundance and the Primeval Fireball, Phys. Rev. Ltrs. 16, No. 10, 410 (1966)
- P. G. Roll and D. T. Wilkinson Cosmic Background Radiation at 3.2 cm - Support for Cosmic Black-Body Radiation, Phys. Rev. Ltrs. 16, No. 10, 405 (1966)
- P. J. E. Peebles The Black-Body Radiation Content of the Universe and the Formation of Galaxies, Astrophys. J. 142, No. 4, 1317 (1965)

Continued: Publications Under O.N.R. Grant Nonr-1858(30)

- D. R. Currott Earth Deceleration from Ancient Solar Eclipses, Astronomical J. 71, No. 4, 264 (1966)
- P. J. E. Peebles and R. H. Dicke Origin of the Microwave Background, Nature 211, No. 5049, 574 (1966)
- P. J. E. Peebles Primordial Helium Abundance and the Primordial Fireball II, Astrophys. J. 146, No. 2, 542 (1966)
- R. H. Dicke Gravitational Theory and Observation, Physics Today 21, No. 1, (1967); also in Bulletin of the Institute of Physics and Phys. Soc., 199 (1967)
- R. H. Dicke and H. Mark Goldenberg Solar Oblateness and General Relativity, Phys. Rev. Ltrs. 18, No. 9, 313 (1967)
- R. B. Partridge and P. J. E. Peebles Are Young Galaxies Visible? II. The Integrated Background, Astrophys. J. 148, 377 (1967)
- R. B. Partridge and D. T. Wilkinson Isotropy and Homogeneity of the Universe from Measurements of the Cosmic Microwave Background, Phys. Rev. Ltrs. 18, No. 14, 577 (1967)
- P. J. E. Peebles The Gravitational Instability of the Universe, Astrophys. J. 147, 859 (1967)
- R. B. Partridge and P. J. E. Peebles Are Young Galaxies Visible?, Astrophys. J. 147, 868 (1967)
- P. J. E. Peebles and R. B. Partridge Upper Limit on the Mean Mass Density Due to Galaxies, Astrophys. J. 148, 713 (1967)
- R. H. Dicke and H. Mark Goldenberg Differential Rotation and the Solar Oblateness, Nature 214, No. 5095, 1294 (1967)
- P. J. E. Peebles Microwave Radiation from the Big Bang, Lect. in Ap. Math. 8, 274 (1967)
- R. B. Partridge Possible Population II Binary Stars, Astronomical J. 72, No. 6, 713 (1967)
- P. G. Roll and D. T. Wilkinson Measurement of Cosmic Background Radiation at 3.2-cm Wavelength, Ann. of Phys. 44, No. 2, 289 (1967)
- R. H. Dicke The Solar Spin-Down Problem, Astrophys. J. 149, L121 (1967)
- D. T. Wilkinson and R. B. Partridge Large Scale Density Inhomogeneities in the Universe, Nature 215, No. 5102, 719 (1967)
- R. A. Stokes, R. B. Partridge and D. T. Wilkinson New Measurements of the Cosmic Microwave Background at $\lambda = 3.2$ cm and $\lambda = 1.58$ cm - Evidence in Support of A Blackbody Spectrum, Phys. Rev. Ltrs. 19, 1199 (1967)

Continued: Publications Under O.N.R. Grant Nonr-1858(30)

- D. T. Wilkinson Measurement of the Cosmic Microwave Background at 8.56 mm Wavelength, Phys. Rev. Ltrs. 19, 1195 (1967)
- B. E. McDonald and R. H. Dicke Solar Oblateness and Fluid Spin-Down, Science 158, 1562 (1967)
- R. H. Dicke Scalar-Tensor Gravitation and the Cosmic Fireball, Astrophys. J. 152, 1 (1968)
- P. J. E. Peebles Primeval Element Abundances, reprinted from Origin and Distribution of the Elements, edited by L. H. Ahrens, Pergamon Press, Oxford and New York, 31 (1968)
- L. B. Kreuzer Experimental Measurement of the Equivalence of Active and Passive Gravitational Mass, Phys. Rev. 169, No. 5, 1007 (1968)

Also submitted to O.N.R. during this time period were the following:

- Proposal for a Contract for Research on, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated June 2, 1958.
- Status Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated July 1 - December 1, 1958.
- Status Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated December 1, 1958 - March 1, 1959.
- Annual Summary Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated 1 January 1959 - 31 December 1959.
- Status Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated March 1, 1959 - June 1, 1959.
- Proposal for Renewal of Contract on, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated July 1, 1959 - June 30, 1960.
- Annual Summary Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated 1 December 1959 - 15 November 1960.
- Status Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated December 1, 1959 - March 1, 1960.
- Status Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated March 1, 1960 - June 1, 1960.
- Proposal for Renewal of Contract on, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated July 1, 1960 - June 30, 1961.
- Status Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated June 1, 1961.
- Annual Summary Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated 1 January 1961 - 31 December 1961.
- Proposal for Renewal of Contract on, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated July 1, 1961 - June 30, 1962.
- Annual Summary Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated 1 January 1962 - 31 December 1962.
- Status Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated June 1, 1962.
- Proposal for Renewal of Contract on, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated July 1, 1962 - June 30, 1963.
- Annual Summary Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated 1 October 1962 - 30 September 1963.
- Proposal for Renewal of Contract on, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated January 1963.

Status Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated June 15, 1963.

Annual Summary Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated 1 October 1963 - 30 September 1964.

Proposal for Renewal of Contract on, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated February 1964.

Status Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated 1 July 1964.

Proposal for Renewal of Contract on, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated March 1965.

Status Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated June 10, 1965.

Annual Summary Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated December 31, 1965.

Proposal for Renewal of Contract on, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated February 1966.

Status Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated June 30, 1966.

Annual Summary Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated December 31, 1966.

Proposal for Renewal of Contract on, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated March 1967.

Annual Summary Report, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated December 31, 1967.

Proposal for Renewal of Contract on, "Experimental and Theoretical Investigation of Gravitation" by R. H. Dicke, dated January 1968.