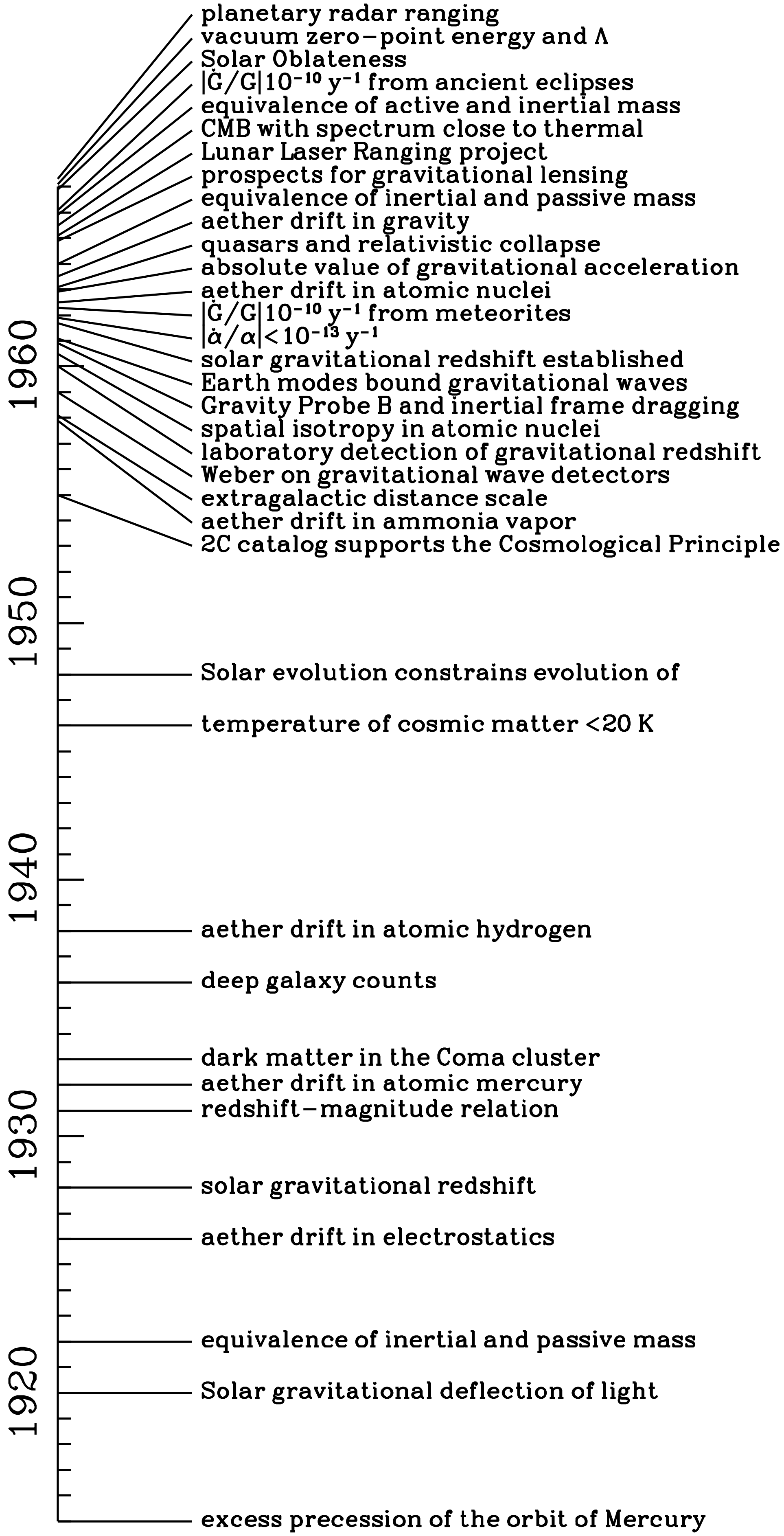
The Revolution of Experimental Gravity Physics, 1957 —1967

PJE Peebles

The MPI for the History of Science
Berlin, December, 2015



planetary radar ranging
vacuum zero−point energy and Λ
Solar Oblateness
$|\dot{G}/G| 10^{-10}\,y^{-1}$ from ancient eclipses
equivalence of active and inertial mass
CMB with spectrum close to thermal
Lunar Laser Ranging project
prospects for gravitational lensing
equivalence of inertial and passive mass
aether drift in gravity
quasars and relativistic collapse
absolute value of gravitational acceleration
aether drift in atomic nuclei
$|\dot{G}/G| 10^{-10}\,y^{-1}$ from meteorites
$|\dot{\alpha}/\alpha| < 10^{-13}\,y^{-1}$
solar gravitational redshift established
Earth modes bound gravitational waves
Gravity Probe B and inertial frame dragging
spatial isotropy in atomic nuclei
laboratory detection of gravitational redshift
Weber on gravitational wave detectors
extragalactic distance scale
aether drift in ammonia vapor
2C catalog supports the Cosmological Principle
Solar evolution constrains evolution of
temperature of cosmic matter <20 K
aether drift in atomic hydrogen
deep galaxy counts
dark matter in the Coma cluster
aether drift in atomic mercury
redshift−magnitude relation
solar gravitational redshift
aether drift in electrostatics
equivalence of inertial and passive mass
Solar gravitational deflection of light
excess precession of the orbit of Mercury

Of the 34 papers in the proceedings of the 1955 Bern Conference, the only significant empirical contact with GR is in Trumpler’s report, on the classical cosmological tests.[1]

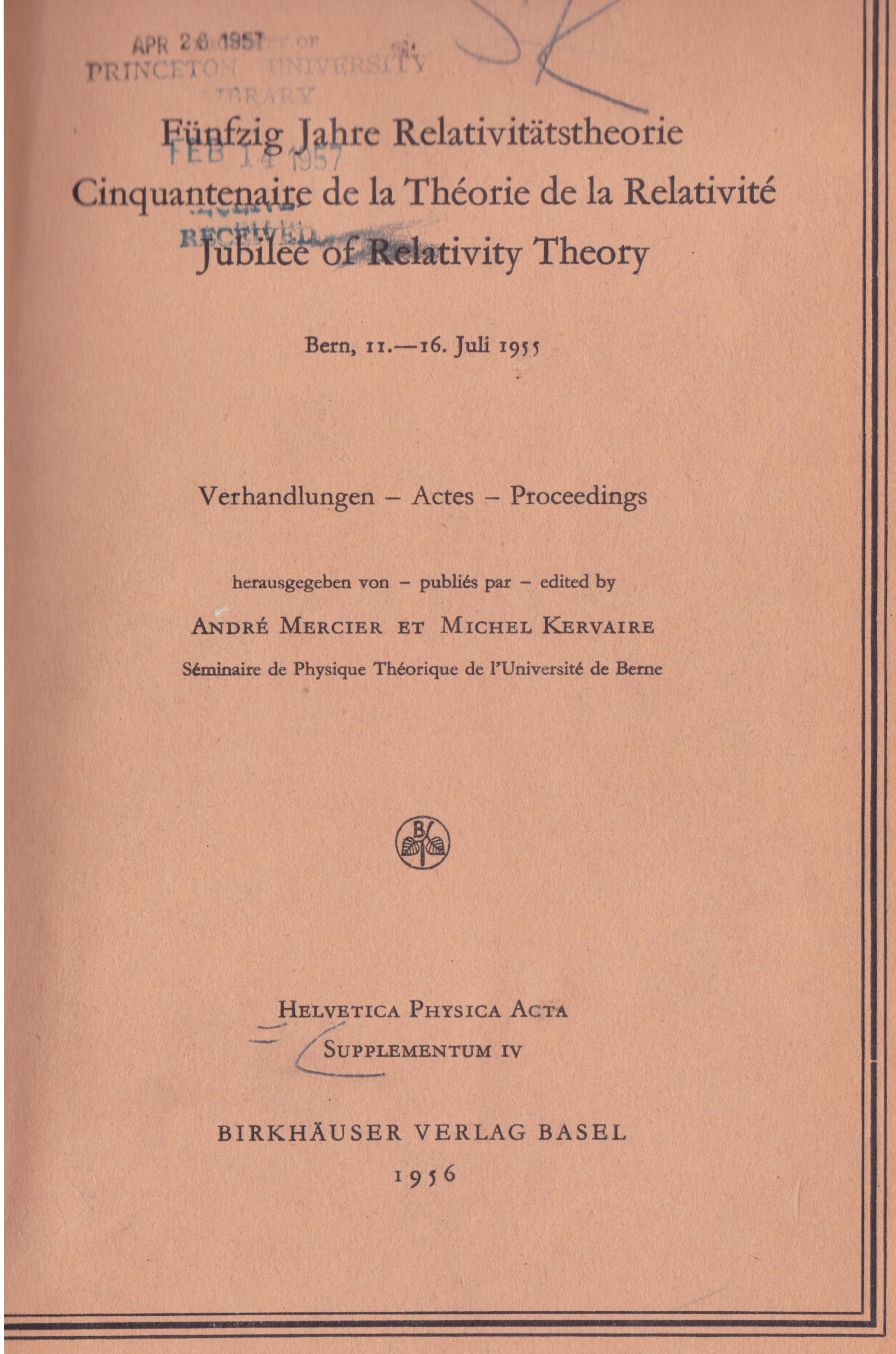
The redshift test Trumpler mentioned, for white dwarfs, proves to be wrong,[2] leaving only the quite uncertain early solar redshift. There were closer to 2.5 classical tests.

---

[1] There was empirical contact with cosmology in the 1950s:

Baade on H_o,,
Robertson on the z - m relation,
Hoyle on stellar evolution ages,
Bondi on the Steady State cosmology,
which grew into demanding tests of GR,
but that was a half century later.

[2] Greenstein, Oke, and Shipman 1985



Fünfzig Jahre Relativitätstheorie
Cinquantenaire de la Théorie de la Relativité
Jubilee of Relativity Theory

Bern, 11.—16. Juli 1955

Verhandlungen – Actes – Proceedings

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Helvetica Physica Acta
Supplementum IV

BIRKHÄUSER VERLAG BASEL
1956

WADC TECHNICAL REPORT 57-216

PROCEEDINGS
OF THE
CONFERENCE ON THE ROLE OF GRAVITATION IN PHYSICS

University of North Carolina, Chapel Hill, January 18-23, 1957

UNDER THE SPONSORSHIP
OF THE

International Union of Pure and Applied Physics, with financial support from UNESCO
National Science Foundation
Wright Air Development Center, U. S. Air Force
Office of Ordnance Research, U. S. Army

This conference was an activity of the North Carolina Project of the Institute of Field Physics, established in 1956 in the Department of Physics of the University of North Carolina, Chapel Hill.

Its organization has been carried out through the Institute of Natural Science of the University of North Carolina, Chapel Hill.

STEERING COMMITTEE

Frederick J. Belinfante, Purdue University
Peter G. Bergmann, Syracuse University
Bryce S. DeWitt, University of North Carolina
Cécile M. DeWitt, University of North Carolina
Freeman J. Dyson, Institute for Advanced Study
John A. Wheeler, Princeton University

MARCH 1957

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

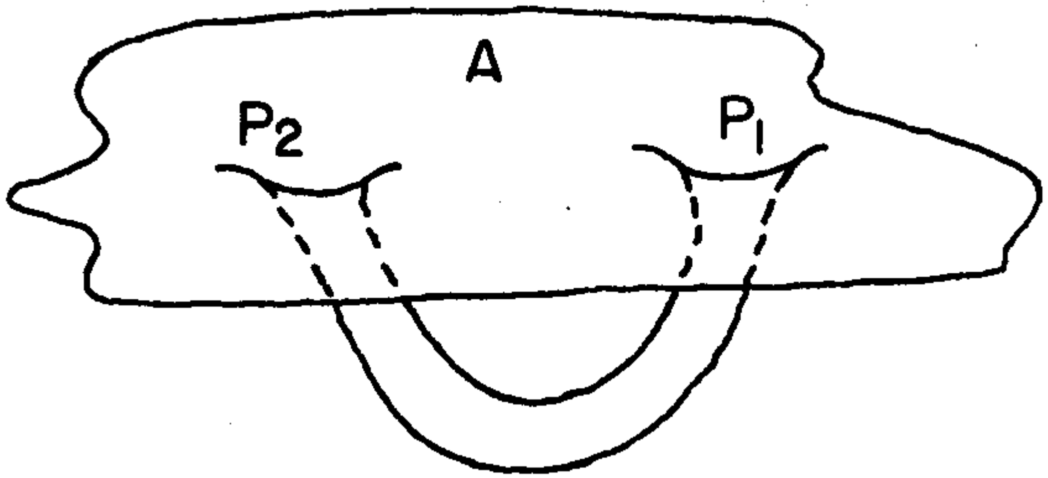
SESSION 1

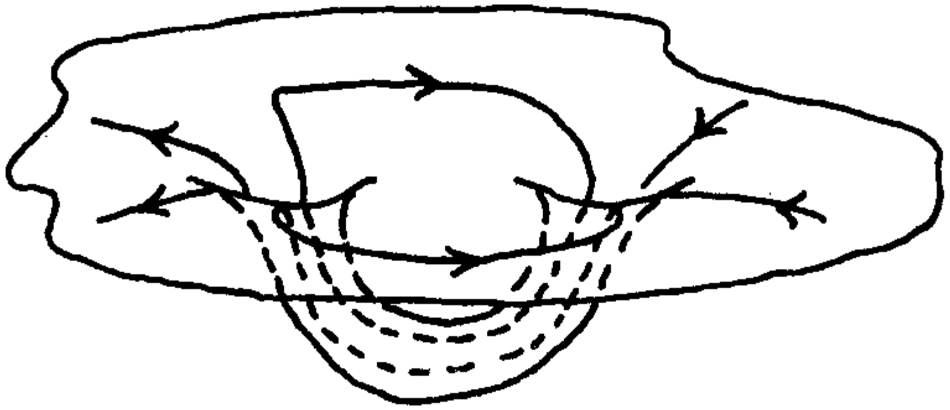
UNQUANTIZED GENERAL RELATIVITY

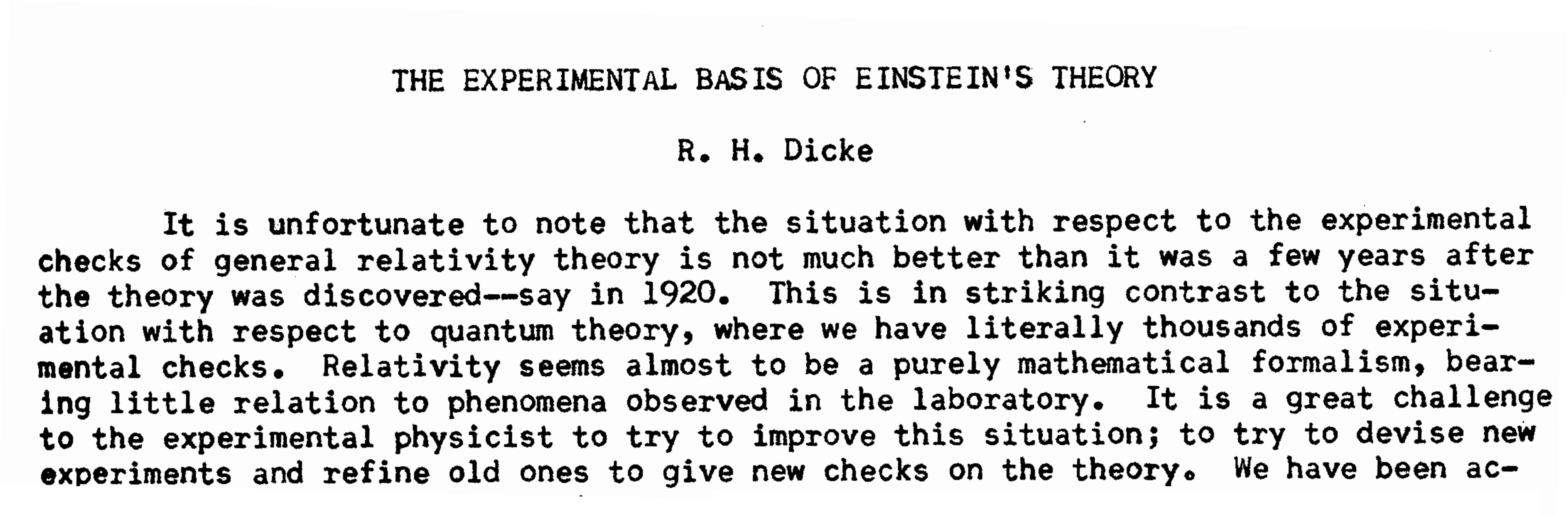
THE PRESENT POSITION OF CLASSICAL RELATIVITY THEORY, AND SOME OF ITS PROBLEMS

John Wheeler

We are here to consider an extraordinary topic, one that ranges from the infinitely large to the infinitely small. We want to find what general relativity and gravitation physics have to do with the description of nature. This task imposes a heavy burden of judgment and courage on us, for never before has theoretical physics had to face such wide subject matter, assisted by so comprehensive a theory but so little tested by experiment.







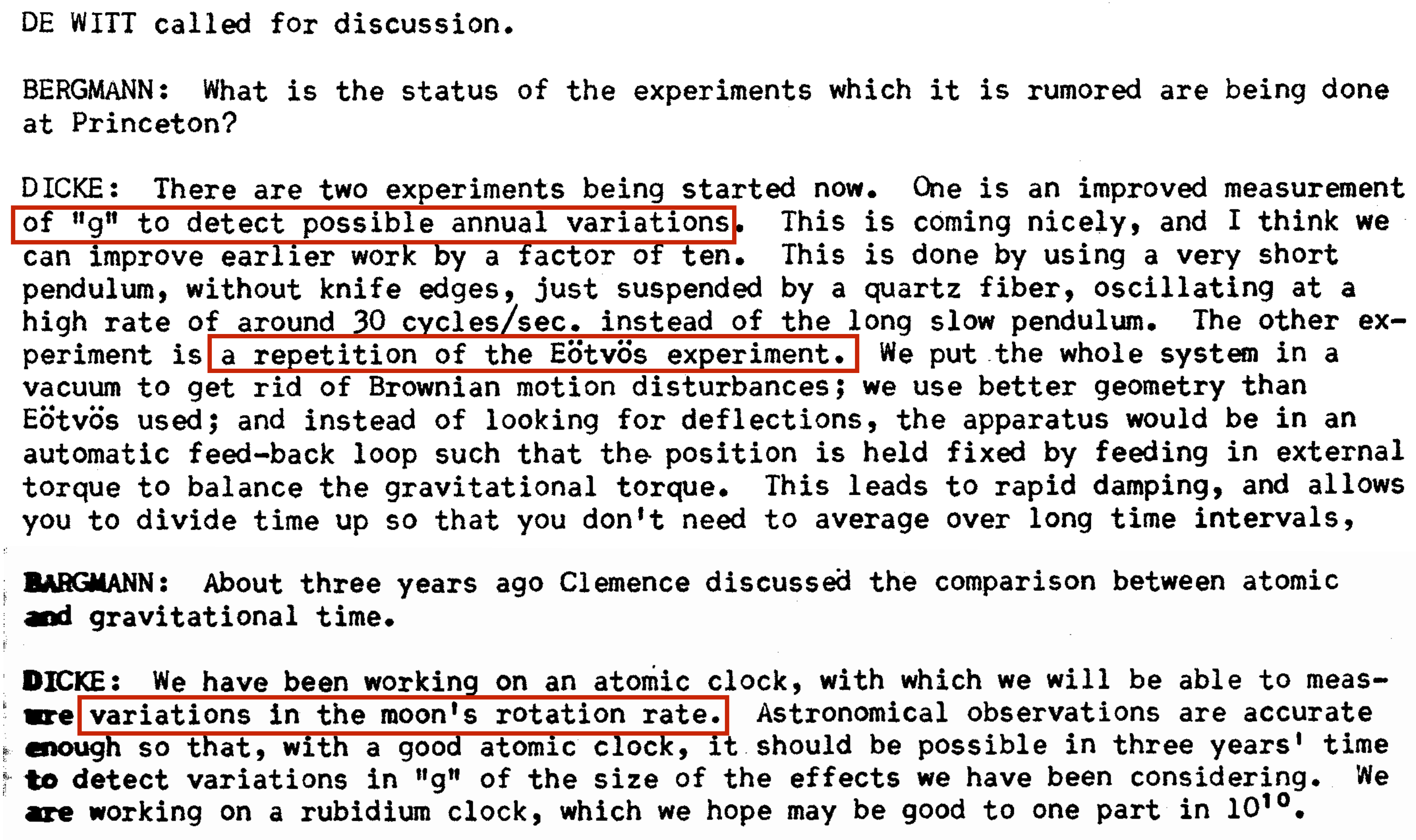
THE EXPERIMENTAL BASIS OF EINSTEIN'S THEORY

R. H. Dicke

It is unfortunate to note that the situation with respect to the experimental checks of general relativity theory is not much better than it was a few years after the theory was discovered--say in 1920. This is in striking contrast to the situation with respect to quantum theory, where we have literally thousands of experimental checks. Relativity seems almost to be a purely mathematical formalism, bearing little relation to phenomena observed in the laboratory. It is a great challenge to the experimental physicist to try to improve this situation; to try to devise new experiments and refine old ones to give new checks on the theory. We have been ac-

Dicke on the three classical cosmological tests (but closer to two):
“This is really flimsy evidence on which to hang a theory”

The 1957 Chapel Hill Conference



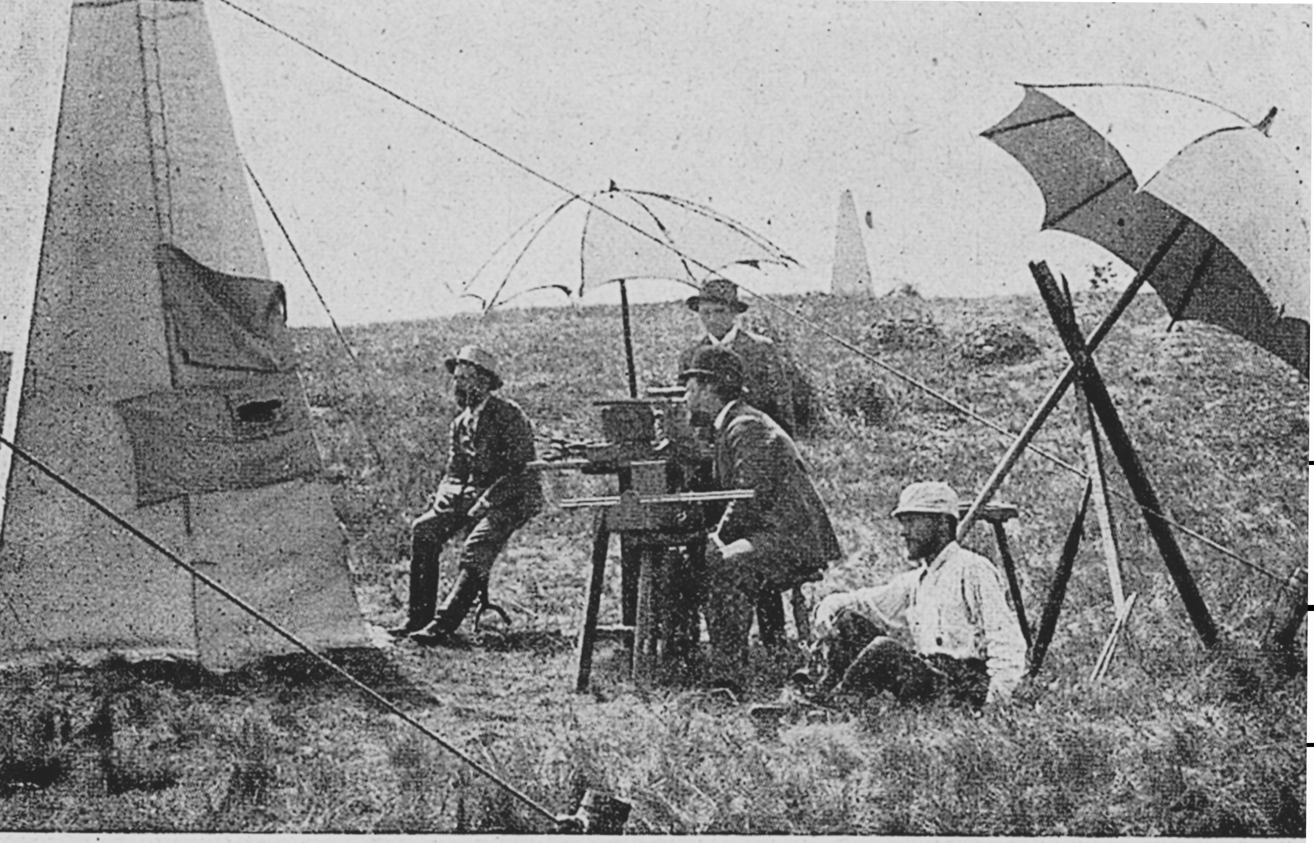
DE WITT called for discussion.

BERGMANN: What is the status of the experiments which it is rumored are being done at Princeton?

DICKE: There are two experiments being started now. One is an improved measurement of "g" to detect possible annual variations. This is coming nicely, and I think we can improve earlier work by a factor of ten. This is done by using a very short pendulum, without knife edges, just suspended by a quartz fiber, oscillating at a high rate of around 30 cycles/sec. instead of the long slow pendulum. The other experiment is a repetition of the Eötvös experiment. We put the whole system in a vacuum to get rid of Brownian motion disturbances; we use better geometry than Eötvös used; and instead of looking for deflections, the apparatus would be in an automatic feed-back loop such that the position is held fixed by feeding in external torque to balance the gravitational torque. This leads to rapid damping, and allows you to divide time up so that you don't need to average over long time intervals,

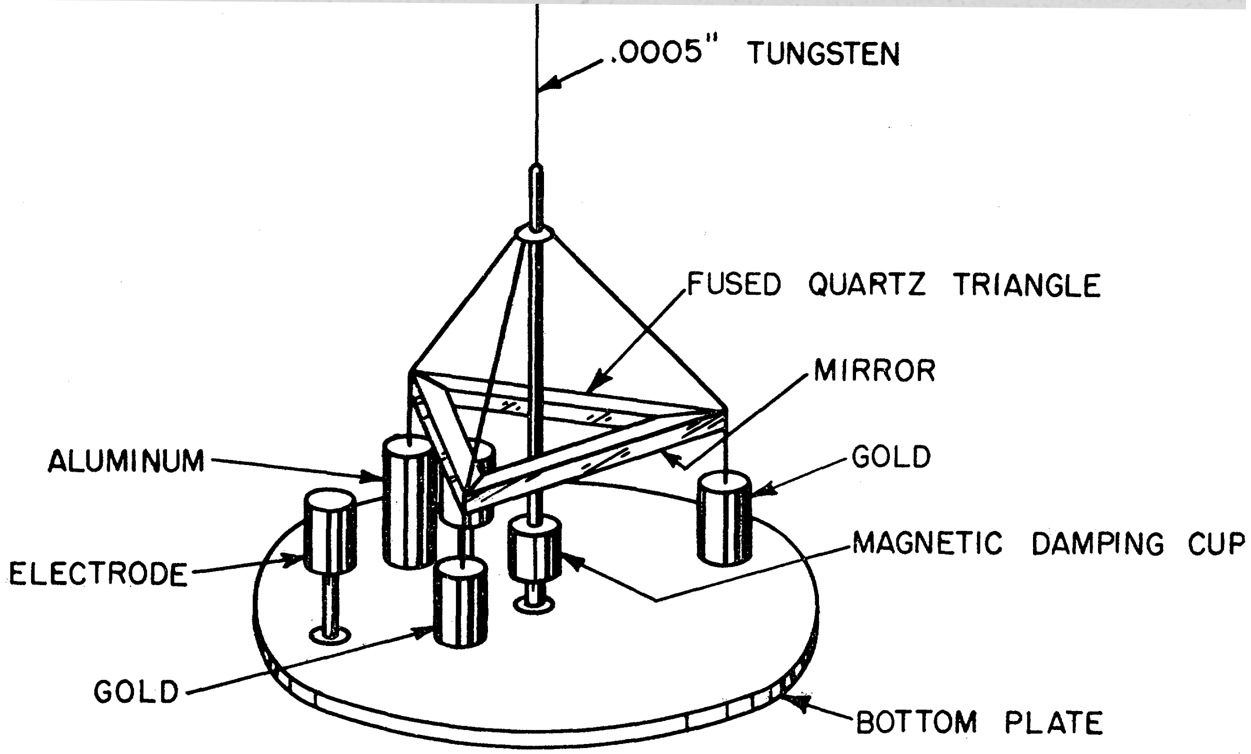
BARGMANN: About three years ago Clemence discussed the comparison between atomic and gravitational time.

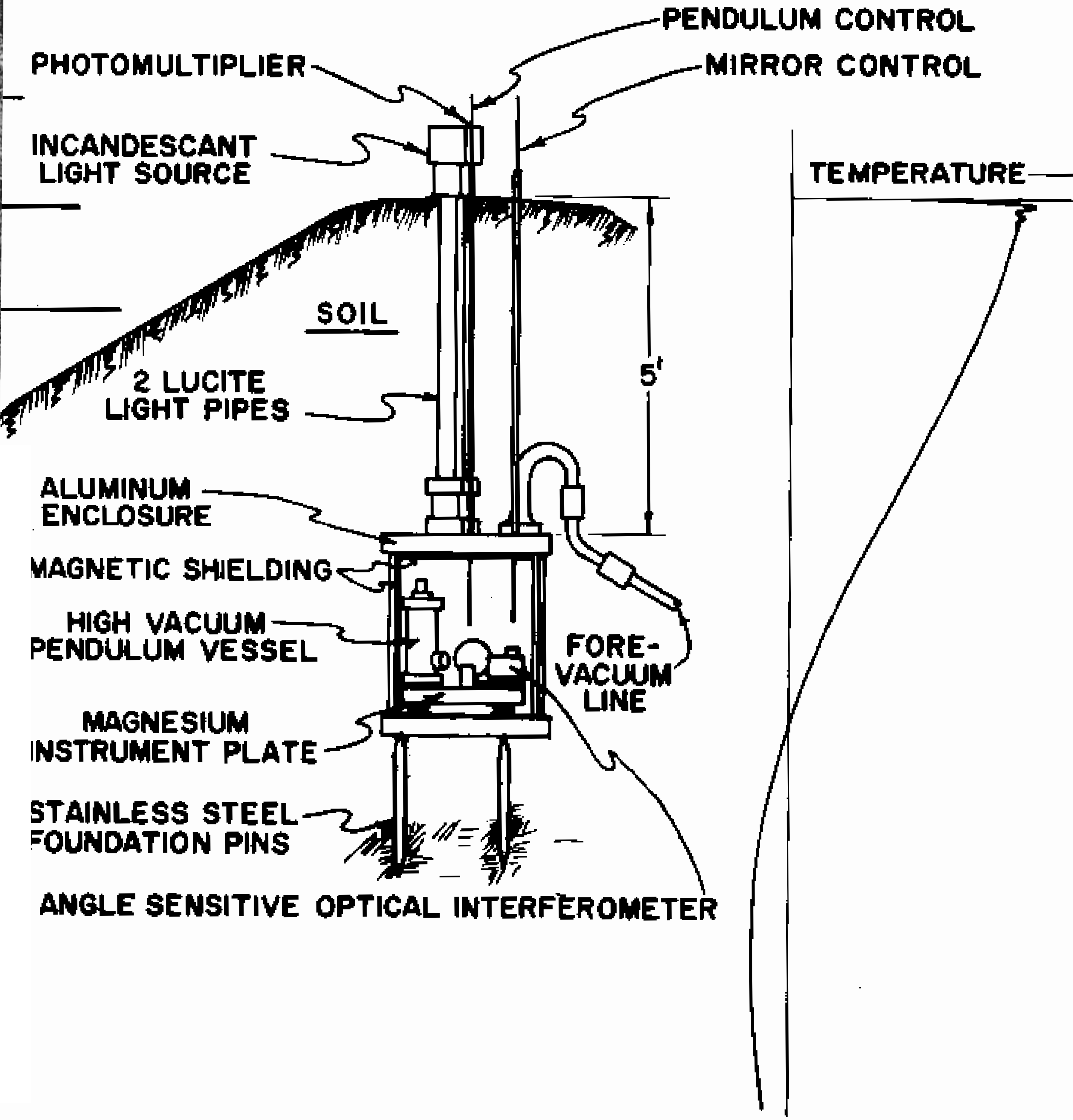
DICKE: We have been working on an atomic clock, with which we will be able to measure variations in the moon's rotation rate. Astronomical observations are accurate enough so that, with a good atomic clock, it should be possible in three years' time to detect variations in "g" of the size of the effects we have been considering. We are working on a rubidium clock, which we hope may be good to one part in 10^{10}.



L. Bodola K. Tangl R. Kövesligethy R. Eötvös

Eötvös's erste Gravitationsmessungen im Freien, auf dem Sághberg im Jahre 1891.





Better technology enabled better tests of GR

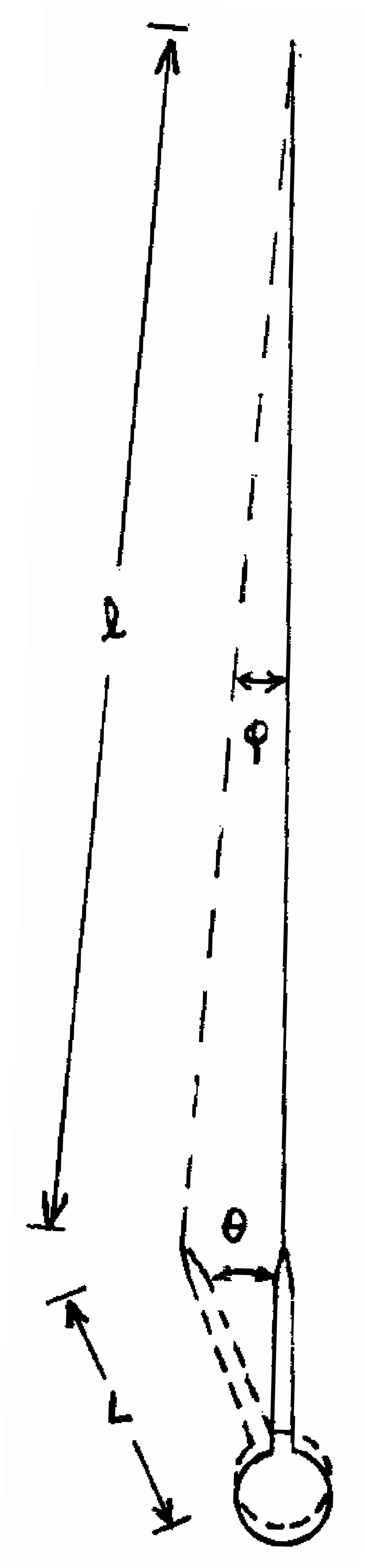
1955: Townes et al. announce a working ammonia beam maser
1957: Møller and Townes consider its possible use to test relativity
1958: Townes et al. report a KT-type aether drift experiment

1958: Mössbauer announces and explains his effect
1960: Pound and Rebka use it for a laboratory detection of gravitational redshift

1960: Ramsey and colleagues have an atomic hydrogen maser
1980: Gravity Probe A: use it to test GR timing, to a part in10^4

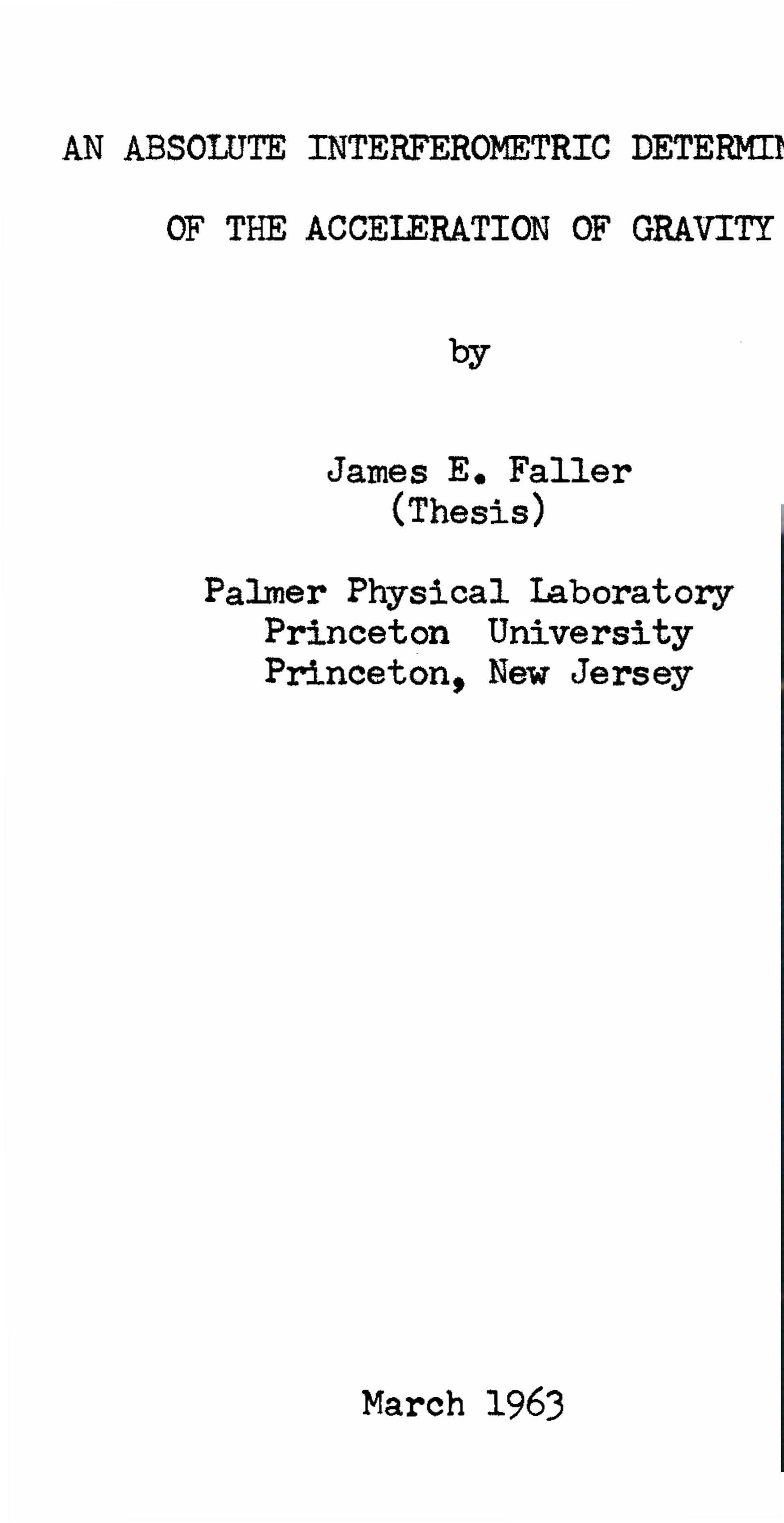
1965: planetary radar detection Mercury's rotation-orbit resonance
1968: Shapiro et al. planetary radar test of relativistic time delay

1957–1967: Dicke followed this mode, as Lunar Laser Ranging, and led searching decade-long explorations of gravity physics



Bill Hoffmann – “g” Variation with 22 Hz Pendulum

This variant of the Kennedy-Thorndike experiment tested for annual variation of the acceleration of gravity. Bill assures me it would have been much more poorly done in the late 1930s; new technology was key.



AN ABSOLUTE INTERFEROMETRIC DETERMINATION
OF THE ACCELERATION OF GRAVITY

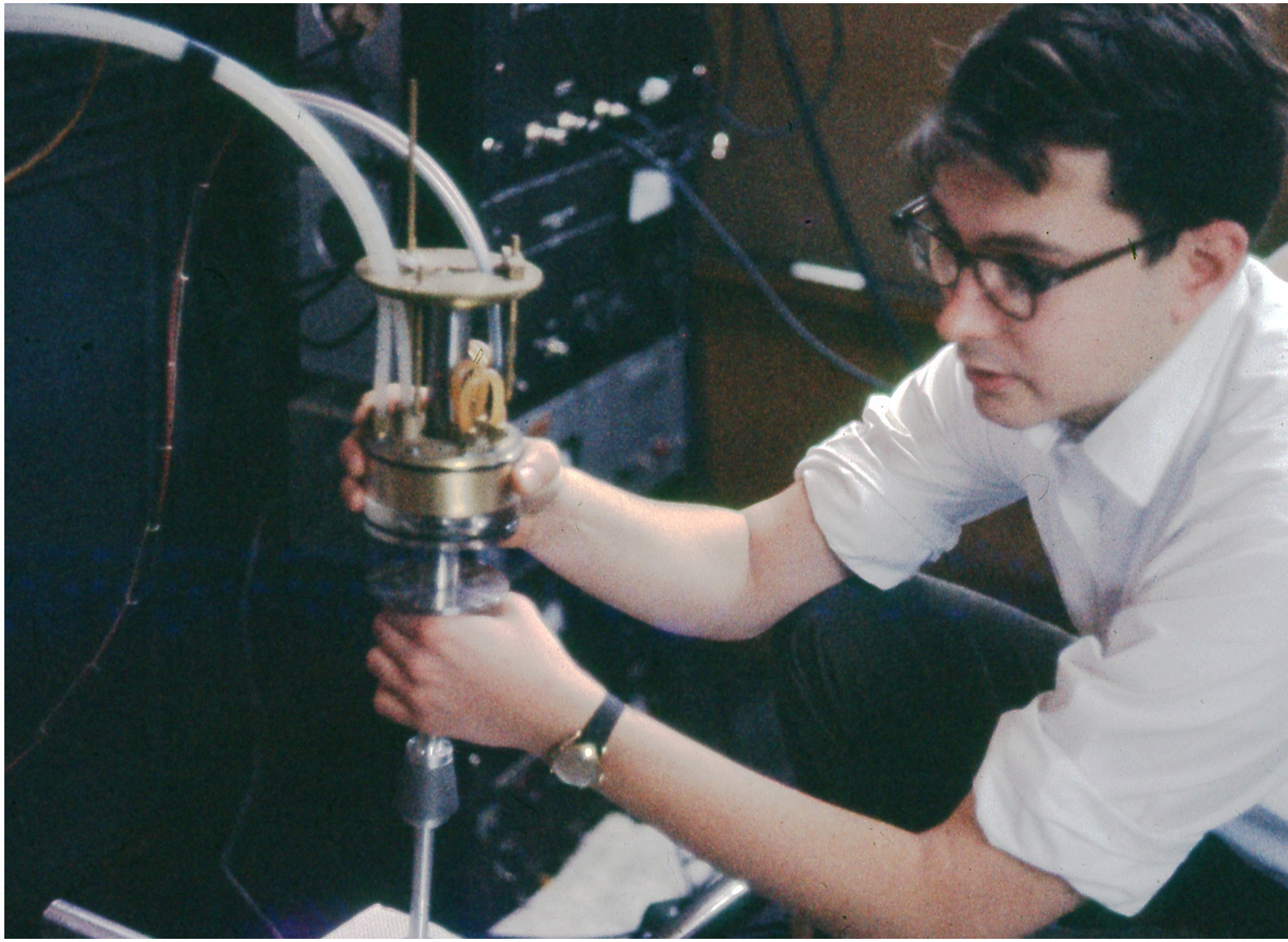
by

James E. Faller
(Thesis)

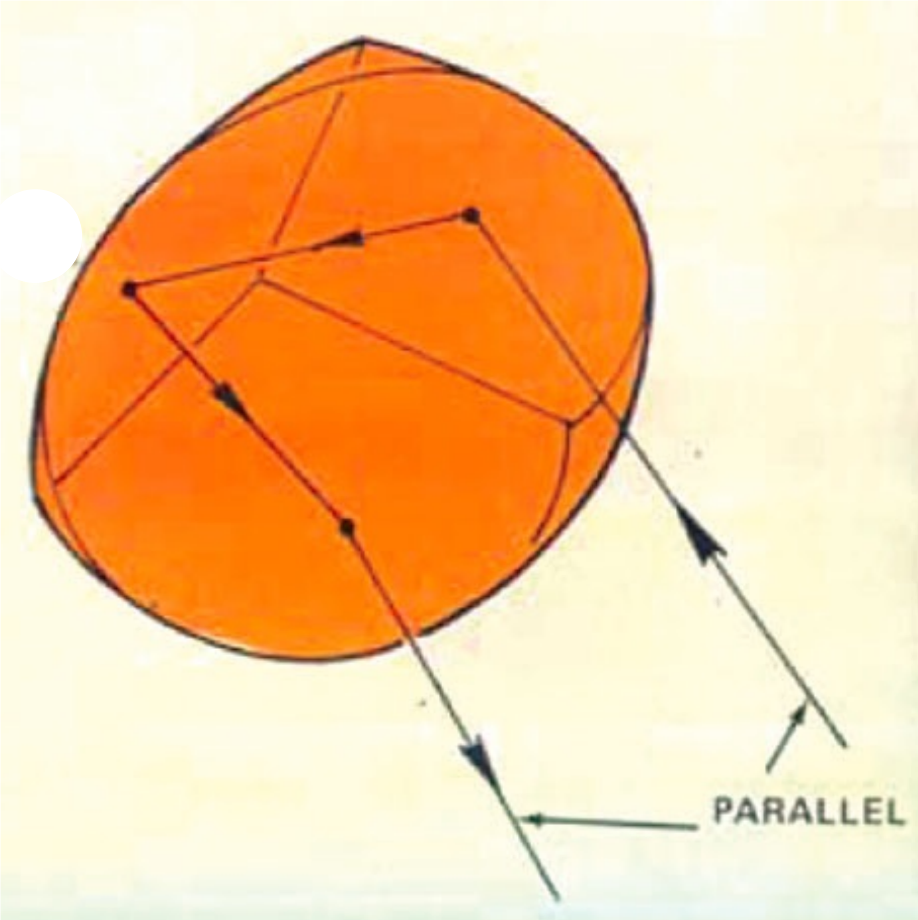
Palmer Physical Laboratory
Princeton University
Princeton, New Jersey

March 1963

new technology was key here, too

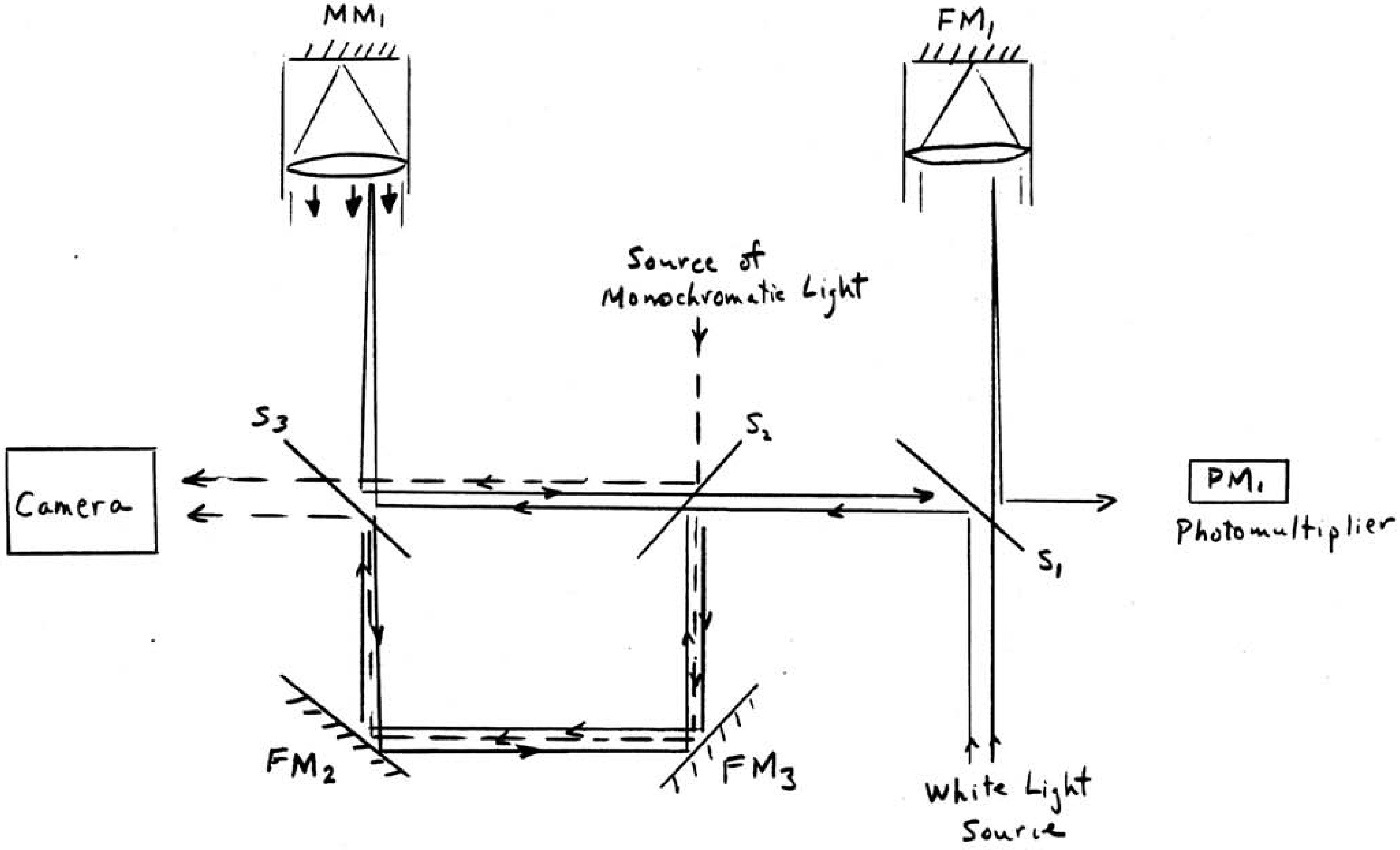


Jim Faller – “g” Measurement with Falling Body



From the Princeton Graduate Alumni Newsletter, Jim Wittke, 1962

- 4 -



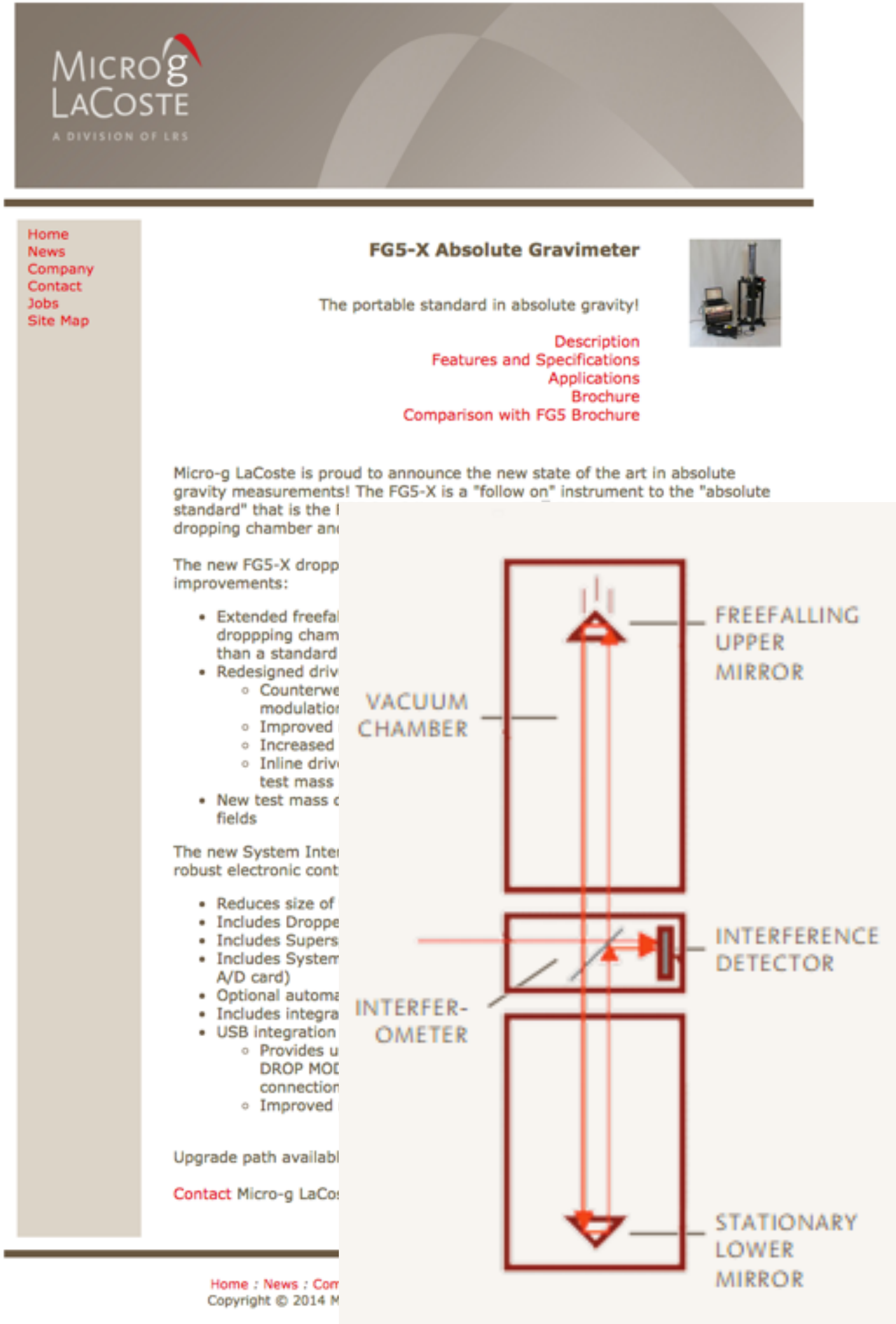
The device is basically a Michelson interferometer. A beam of white light is split by the half-silvered mirror S_1 , one beam going to the fixed mirror FM, and returning, via S_1 , to the photomultiplier PM_1 . The second beam from S_1 can traverse any of three paths before returning to S_1 and the photomultiplier: 1) thru beam splitter S_2 , off beam splitter S_3 to mirror MM_1 and back by the same path; 2) thru S_2 and off S_3 to the mirror MM_1 , but back by traversing S_3 to the fixed mirrors FM_2 and FM_3, and then off S_2 to S_1 and the photomultiplier 3) from S_1 to S_2 and then to the mirror MM_1 via the fixed mirrors FM_3 and FM_2 , and back by the same path. Since a white light source is used, fringes are detected by the photomultiplier only when one of these paths is equal in length to that including reflection off mirror FM_1 . Mirror MM_1 and its lens dropped, in the experiment, and as the mirror and lens combination falls, three sets of white light fringes are detected at PM_1 . Clock circuits permit accurate timing of the occurrences of the white light fringes. The exact differences in path lengths between the three possibilities are determined by using various monochromatic light sources in a secondary set of interferometric paths, with an auxilliary camera, as shown in the sketch. A lens and mirror combination is used for the freely falling element, to eliminate path differences and optical misalignments due to rotation of the mirror MM_1 as it falls. Thus far the equipment has produced results somewhat better than obtainable previously.

In the 1950s pendulum and free fall experiments measured g to about a part in 10^6.

Faller's (1963) thesis measurement had similar accuracy.

Faller & Hammond (1967) used the new stabilized lasers to get a few parts in 10^8.

This commercial version of Faller's experiment advertises precision of 1 part in 10^{10} "at a quiet site …in 6.25 hours," allowing monitoring of long-term variation of a water table level, rebound from the last ice age …



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The portable standard in absolute gravity!

Micro-g LaCoste is proud to announce the new state of the art in absolute gravity measurements! The FG5-X is a "follow on" instrument to the "absolute standard" that is the
dropping chamber an

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improvements:

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- Redesigned driv
  - Counterwe modulatio
  - Improved
  - Increased
  - Inline driv test mass
- New test mass fields

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- Reduces size of
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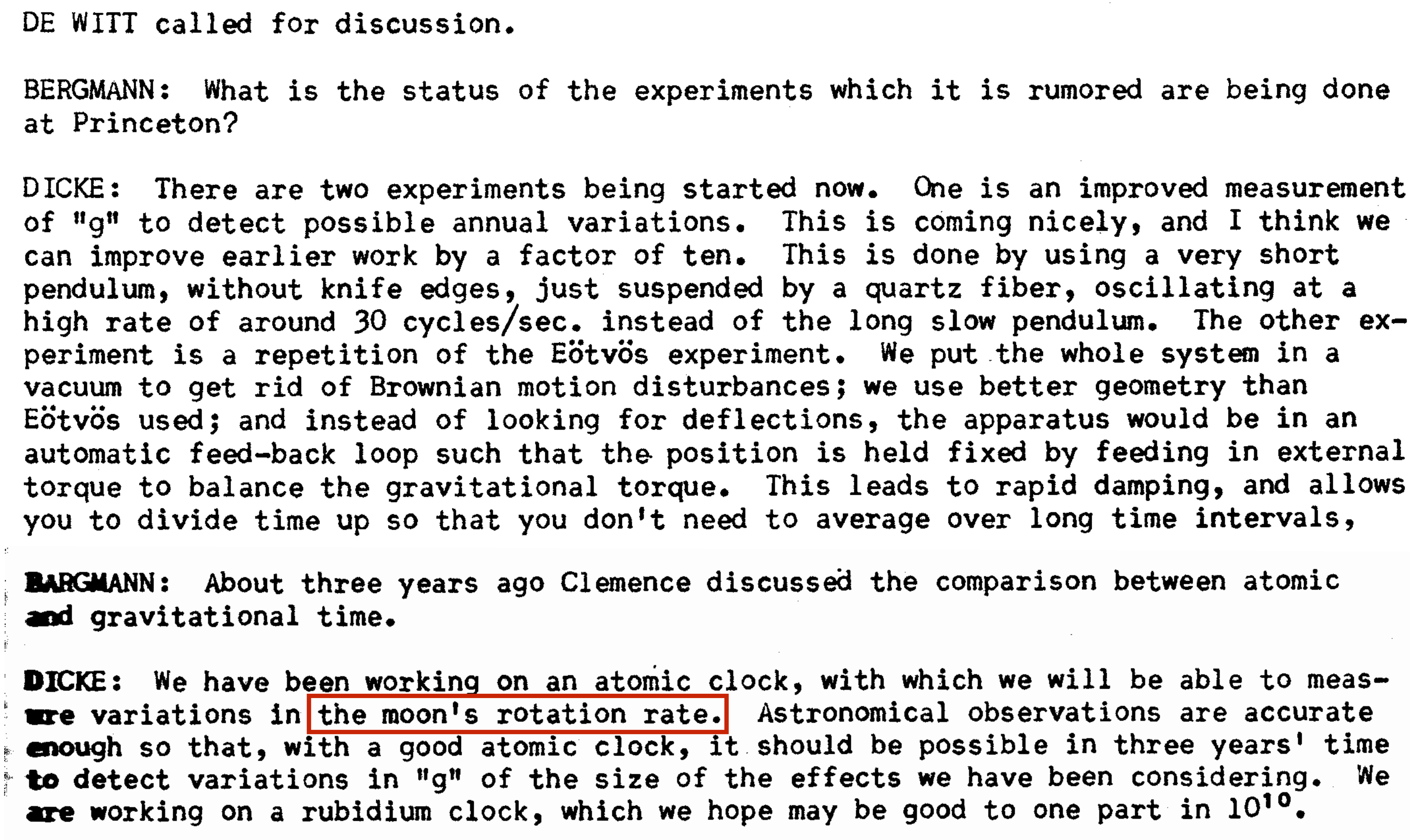
The 1957 Chapel Hill Conference



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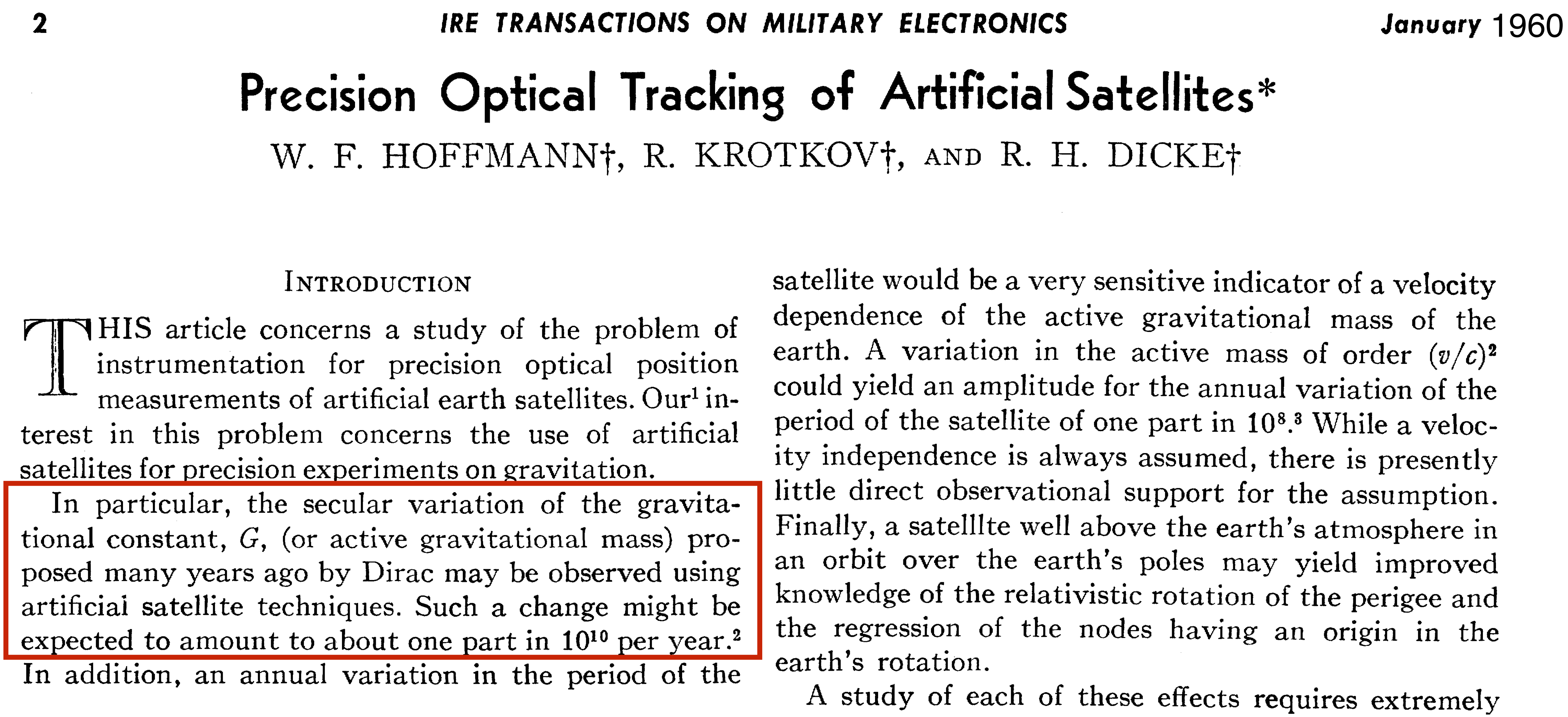


2 IRE TRANSACTIONS ON MILITARY ELECTRONICS January 1960

Precision Optical Tracking of Artificial Satellites*

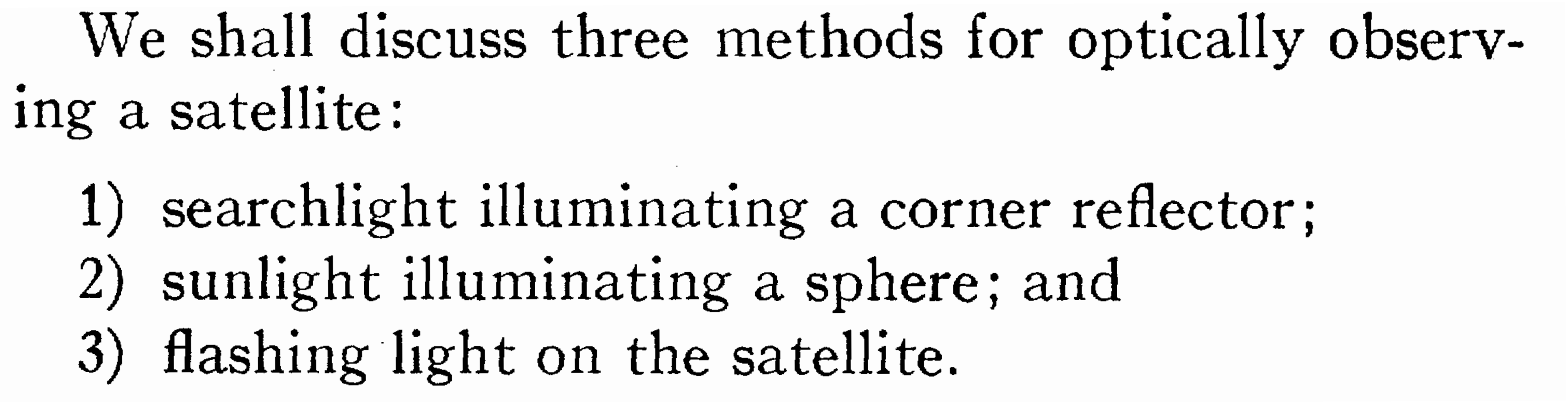
W. F. HOFFMANN†, R. KROTKOV†, AND R. H. DICKE†

INTRODUCTION

THIS article concerns a study of the problem of instrumentation for precision optical position measurements of artificial earth satellites. Our[1] interest in this problem concerns the use of artificial satellites for precision experiments on gravitation.

In particular, the secular variation of the gravitational constant, G, (or active gravitational mass) proposed many years ago by Dirac may be observed using artificial satellite techniques. Such a change might be expected to amount to about one part in 10^{10} per year.[2] In addition, an annual variation in the period of the satellite would be a very sensitive indicator of a velocity dependence of the active gravitational mass of the earth. A variation in the active mass of order $(v/c)^2$ could yield an amplitude for the annual variation of the period of the satellite of one part in 10^8.[3] While a velocity independence is always assumed, there is presently little direct observational support for the assumption. Finally, a satellite well above the earth's atmosphere in an orbit over the earth's poles may yield improved knowledge of the relativistic rotation of the perigee and the regression of the nodes having an origin in the earth's rotation.

A study of each of these effects requires extremely



We shall discuss three methods for optically observing a satellite:

1) searchlight illuminating a corner reflector;
2) sunlight illuminating a sphere; and
3) flashing light on the satellite.

Why was Dicke doing this? Consider:

Mach (1893): inertial motion may be relative.

Einstein (1921): a Machian universe ought to be homogeneous and isotropic. (But Einstein lost interest in Mach before it was found that the universe actually is very close to homogeneous).

Dirac (1917): maybe the strength of gravity is so small relative to electromagnetism, and comparable to the size of a proton relative to the size of the observable universe, because both ratios are evolving at about the same rate.

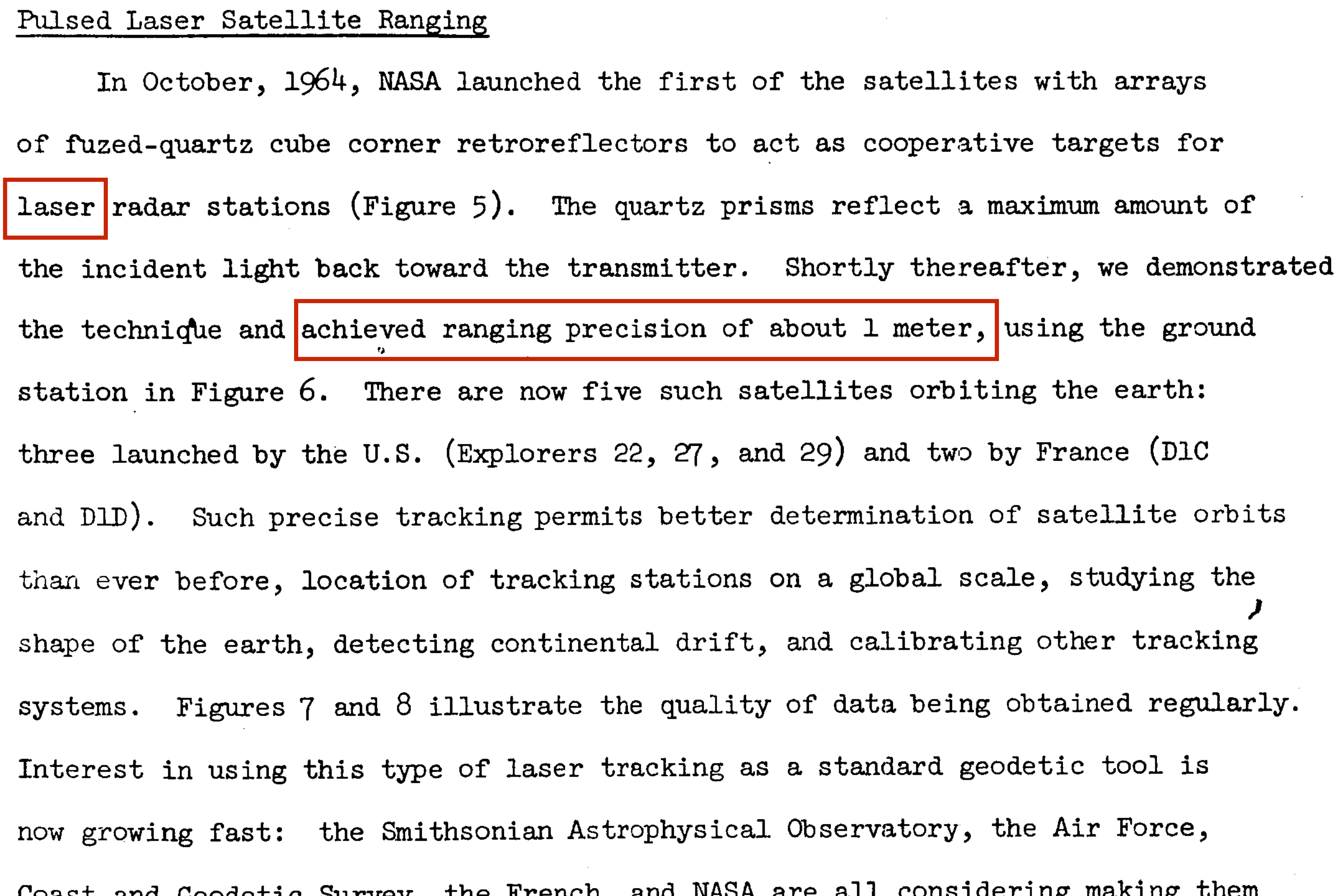
Dicke (1957): maybe Mach’s Principle implies Dirac’s conjecture: maybe the strength of gravity is controlled by the concentration of matter, with both decreasing as the universe expands. Dicke sought to check for the effect by, among other things, precision measurements of the Moon’s orbit.

Henry Plotkin, NASA, in recollections at the 19th International Workshop on Laser Ranging, Annapolis, 2014

1960

meters. Two months earlier, as Fritz and I were making our farewells before leaving New Jersey for Goddard, we visited Princeton and discussed our plans with Dicke and his group. Bill Kaula and Caroll Alley were also at that little meeting. Bob Dicke was developing a new general theory of relativity and he was looking for sensitive tests that would verify his theory rather than Albert Einstein's. He believed that tracking the moon or other high satellites with high precision and over a very long time would ultimately distinguish between the two theories. He suggested that when I get to NASA I consider putting cube corners on the moon or launching cube corners into space orbits and photographing reflections from powerful searchlight illumination.

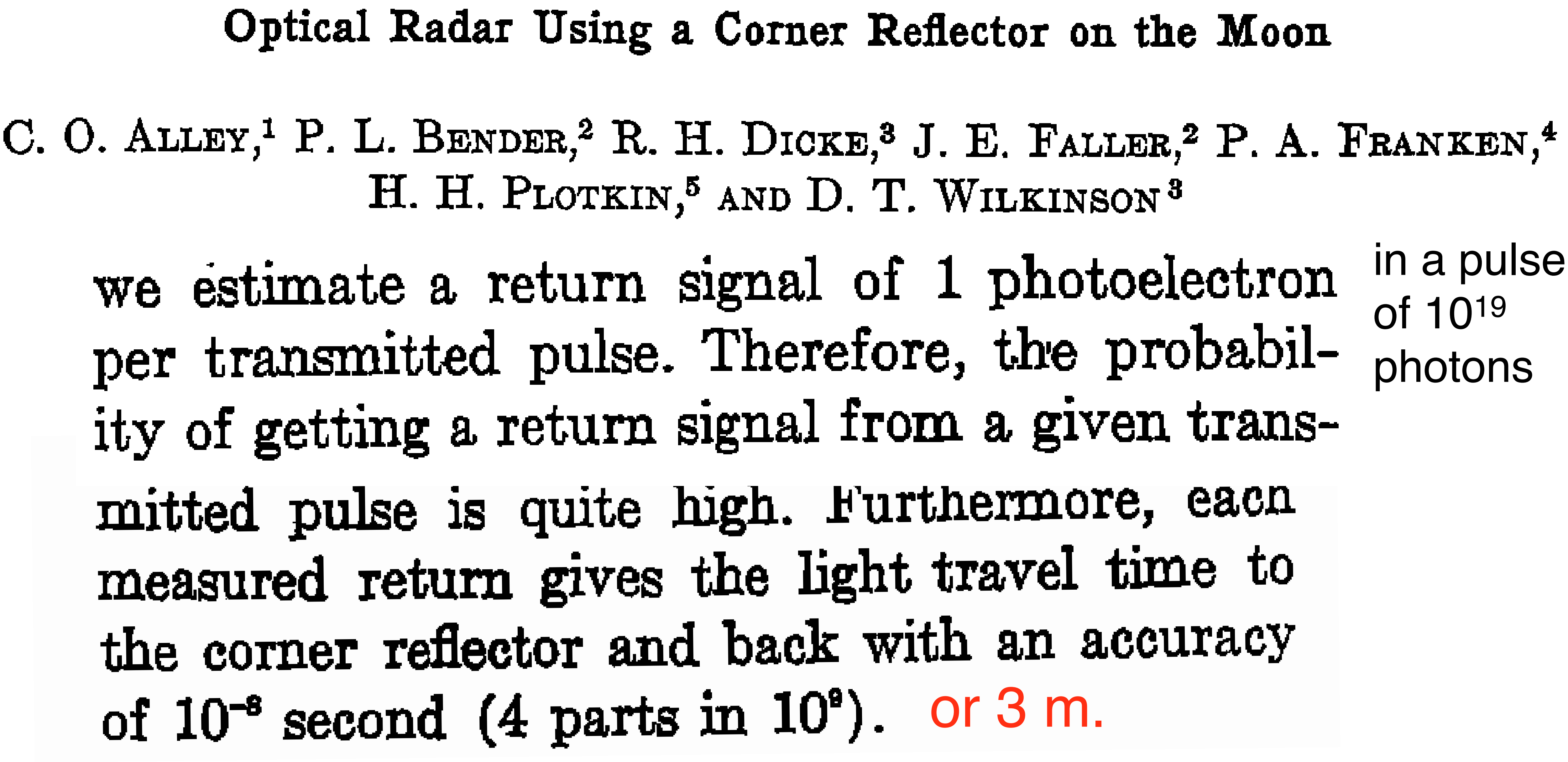
Henry Plotkin, in a NASA report (I can't find the date):



Pulsed Laser Satellite Ranging

In October, 1964, NASA launched the first of the satellites with arrays of fuzed-quartz cube corner retroreflectors to act as cooperative targets for laser radar stations (Figure 5). The quartz prisms reflect a maximum amount of the incident light back toward the transmitter. Shortly thereafter, we demonstrated the technique and achieved ranging precision of about 1 meter, using the ground station in Figure 6. There are now five such satellites orbiting the earth: three launched by the U.S. (Explorers 22, 27, and 29) and two by France (D1C and D1D). Such precise tracking permits better determination of satellite orbits than ever before, location of tracking stations on a global scale, studying the shape of the earth, detecting continental drift, and calibrating other tracking systems. Figures 7 and 8 illustrate the quality of data being obtained regularly. Interest in using this type of laser tracking as a standard geodetic tool is now growing fast: the Smithsonian Astrophysical Observatory, the Air Force, Coast and Geodetic Survey, the French, and NASA are all considering making them

1965



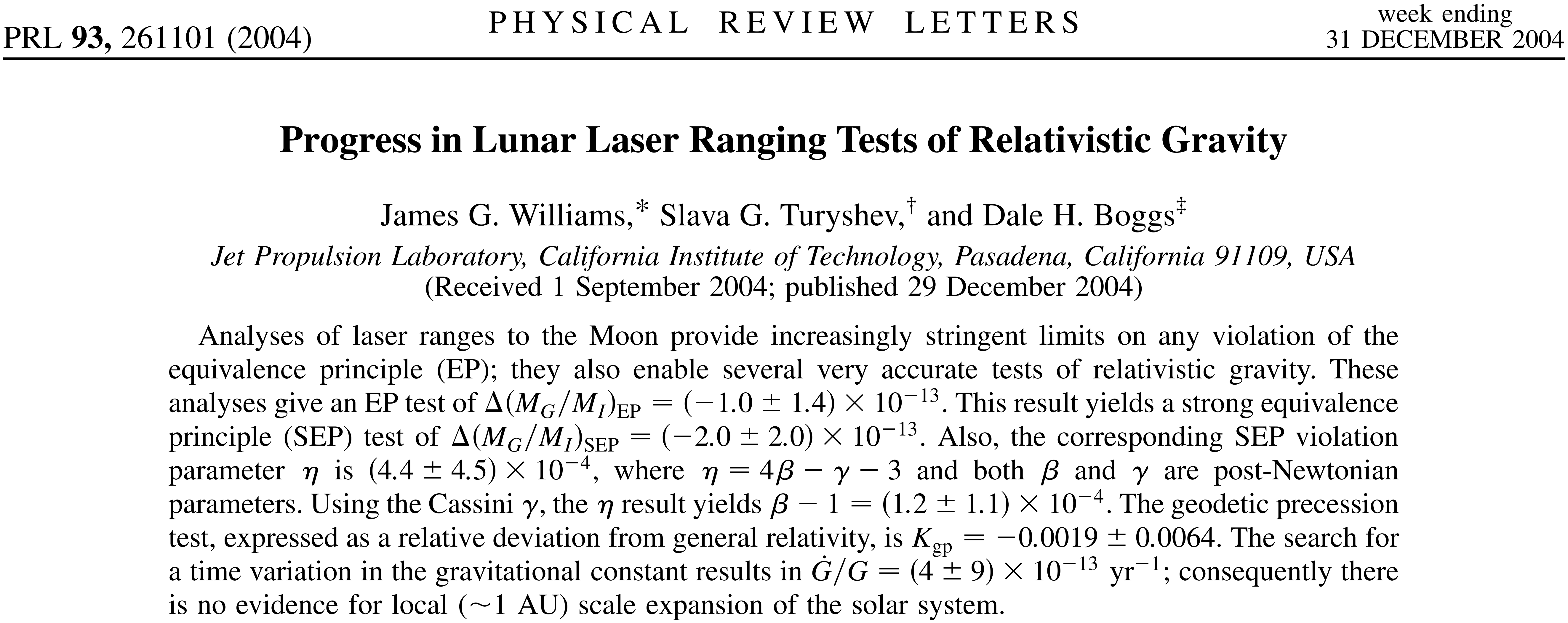
Optical Radar Using a Corner Reflector on the Moon

C. O. ALLEY,[1] P. L. BENDER,[2] R. H. DICKE,[3] J. E. FALLER,[2] P. A. FRANKEN,[4] H. H. PLOTKIN,[5] AND D. T. WILKINSON[3]

we estimate a return signal of 1 photoelectron per transmitted pulse. Therefore, the probability of getting a return signal from a given transmitted pulse is quite high. Furthermore, each measured return gives the light travel time to the corner reflector and back with an accuracy of 10^{-8} second (4 parts in 10^{8}). or 3 m.

in a pulse of 10^{19} photons

Alley, Bender and Faller were former Dicke graduate students, Wilkinson was an assistant prof in Dicke's group, Plotkin led the early NASA satellite ranging, and Frankin at U Michigan was a expert in optics, linear and nonlinear.



PRL **93,** 261101 (2004) PHYSICAL REVIEW LETTERS week ending 31 DECEMBER 2004

Progress in Lunar Laser Ranging Tests of Relativistic Gravity

James G. Williams,* Slava G. Turyshev,† and Dale H. Boggs‡
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109, USA

(Received 1 September 2004; published 29 December 2004)

Analyses of laser ranges to the Moon provide increasingly stringent limits on any violation of the equivalence principle (EP); they also enable several very accurate tests of relativistic gravity. These analyses give an EP test of $\Delta(M_G/M_I)_{\mathrm{EP}} = (-1.0 \pm 1.4) \times 10^{-13}$. This result yields a strong equivalence principle (SEP) test of $\Delta(M_G/M_I)_{\mathrm{SEP}} = (-2.0 \pm 2.0) \times 10^{-13}$. Also, the corresponding SEP violation parameter η is $(4.4 \pm 4.5) \times 10^{-4}$, where $\eta = 4\beta - \gamma - 3$ and both β and γ are post-Newtonian parameters. Using the Cassini γ, the η result yields $\beta - 1 = (1.2 \pm 1.1) \times 10^{-4}$. The geodetic precession test, expressed as a relative deviation from general relativity, is $K_{\mathrm{gp}} = -0.0019 \pm 0.0064$. The search for a time variation in the gravitational constant results in $\dot{G}/G = (4 \pm 9) \times 10^{-13}$ yr^{-1}; consequently there is no evidence for local (∼1 AU) scale expansion of the solar system.

$$\dot{G}/G = (4 \pm 9) \times 10^{-13}\ \mathrm{yr}^{-1}$$

Dicke’s vision of demanding tests of gravity physics by precision measurement of the lunar orbit has been realized, in abundance.

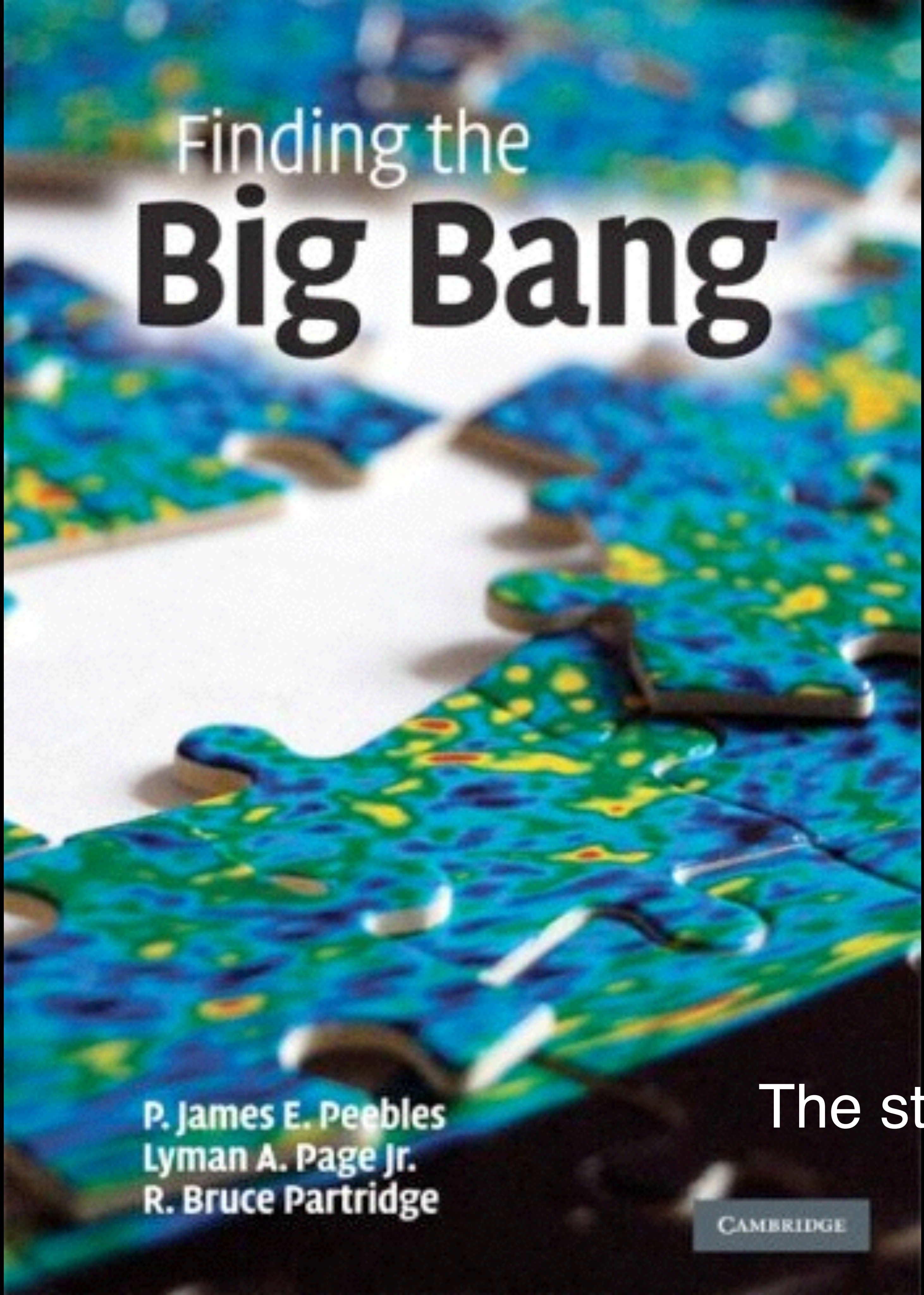
His vision of a better theory than GR has not been realized.

The Hot Big Bang

The four 1955 to 1961 international GR conferences do not take note of what proved to be an exceedingly productive idea.

Imagine a cold very early universe that contains only neutrons. As the density falls and phase space allows neutrons to decay the protons would be radiatively captured by neutrons to form deuterons that readily combine by particle exchange reactions to form helium. Almost all the hydrogen would be eliminated, a Bad Thing.

Solutions: assume
1. a failure of GR
2. degenerate neutrinos
3. Gamow's (1948) choice: a hot Big Bang



The story is here

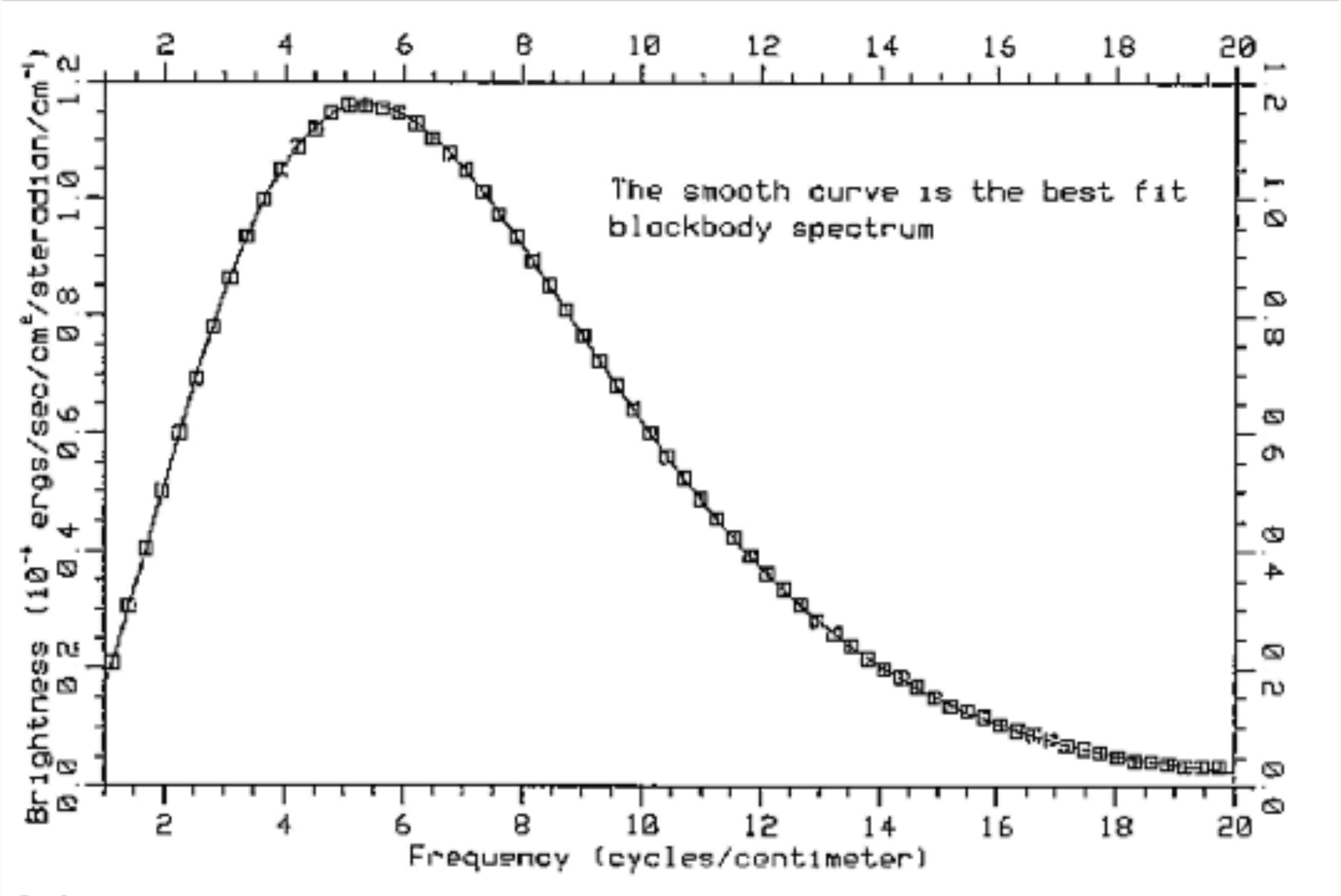
1944 or so: Dicke invents the microwave radiometer
1946: Dicke et al. use it to limit “radiation from cosmic matter at radiometer wave-lengths” (1.0~to 1.5~cm) to 20K
1948: Gamow’s hot Big Bang with baryon density n ~ 10^{18} cm^{-3} at T = 10^9 K produces substantial but not unacceptable helium
1948: Alpher and Herman translate Gamow’s condition to present temperature T ~ 5K
1950: Fermi & Turkevich: Gamow’s conditions make lots of helium
1959: Bell telecommunications experiments detect excess noise
1961: Osterbrock and Rogerson: maybe high helium is from the Big Bang
1964: Penzias & Wilson use Dicke switching to show the noise is not instrumental
1964: Hoyle and Taylor: : maybe high helium is from the Big Bang
1964: Dicke suggests that Roll and Wilkinson build a Dicke Radiometer to search for fossil thermal radiation
1965: Bell and Princeton make contact
1970: the spectrum is shown to be close to thermal longward of 3 mm, but measurements at shorter wavelengths are confused
1990: Mather *et al.* and Gush *et al.* independently show the spectrum is very close to thermal, a profoundly important result

Kelsall Weiss Smoot Hauser Wright Lubin Moseley Mather Gulkis Silverberg Janssesn Boggess Bennett Meyer Murdock Shafer Wilkinson Cheng

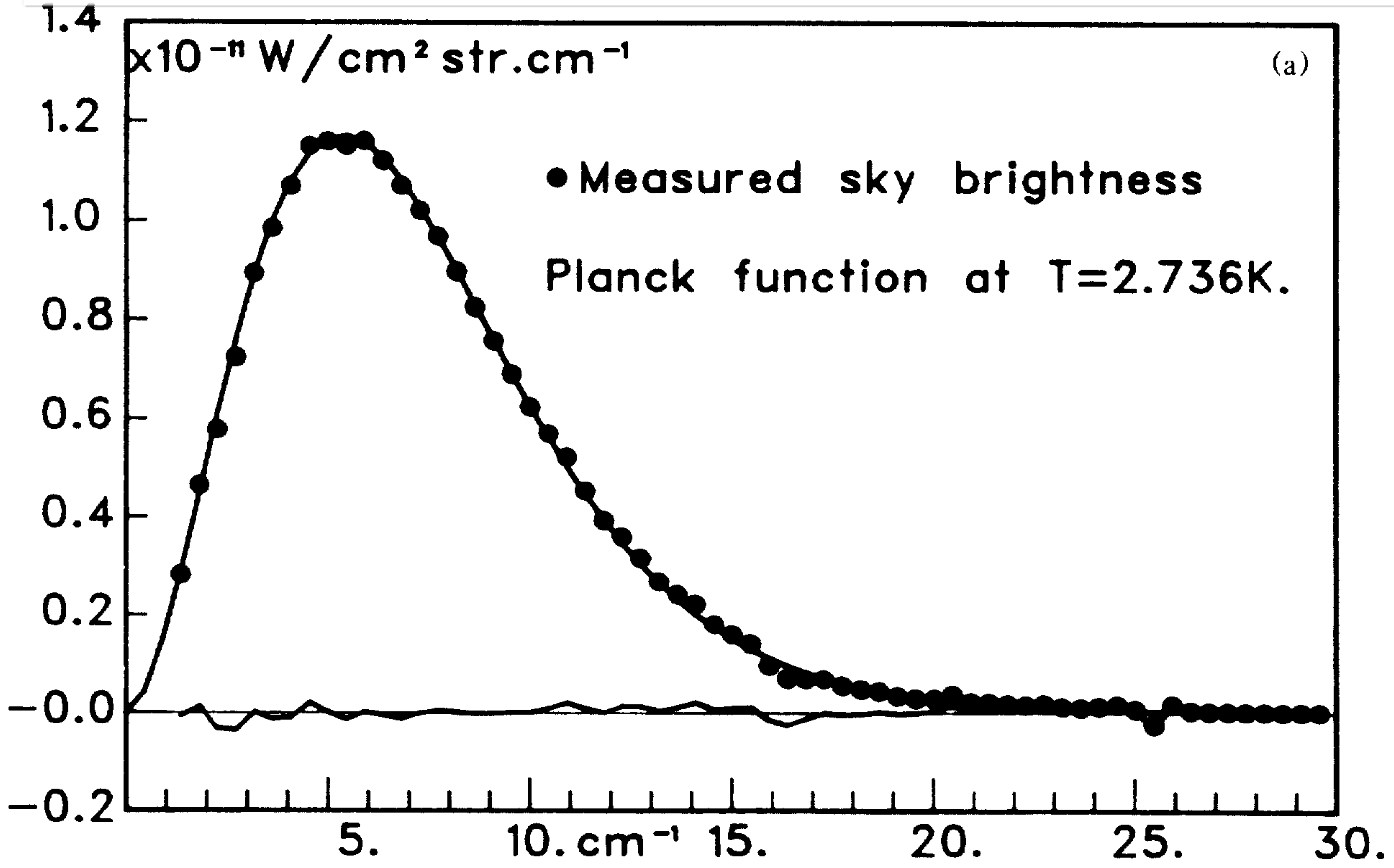
COBE Science Working Group

Herb Gush,
University of British
Columbia

Mark Halpern and Ed Wishnow, UBC

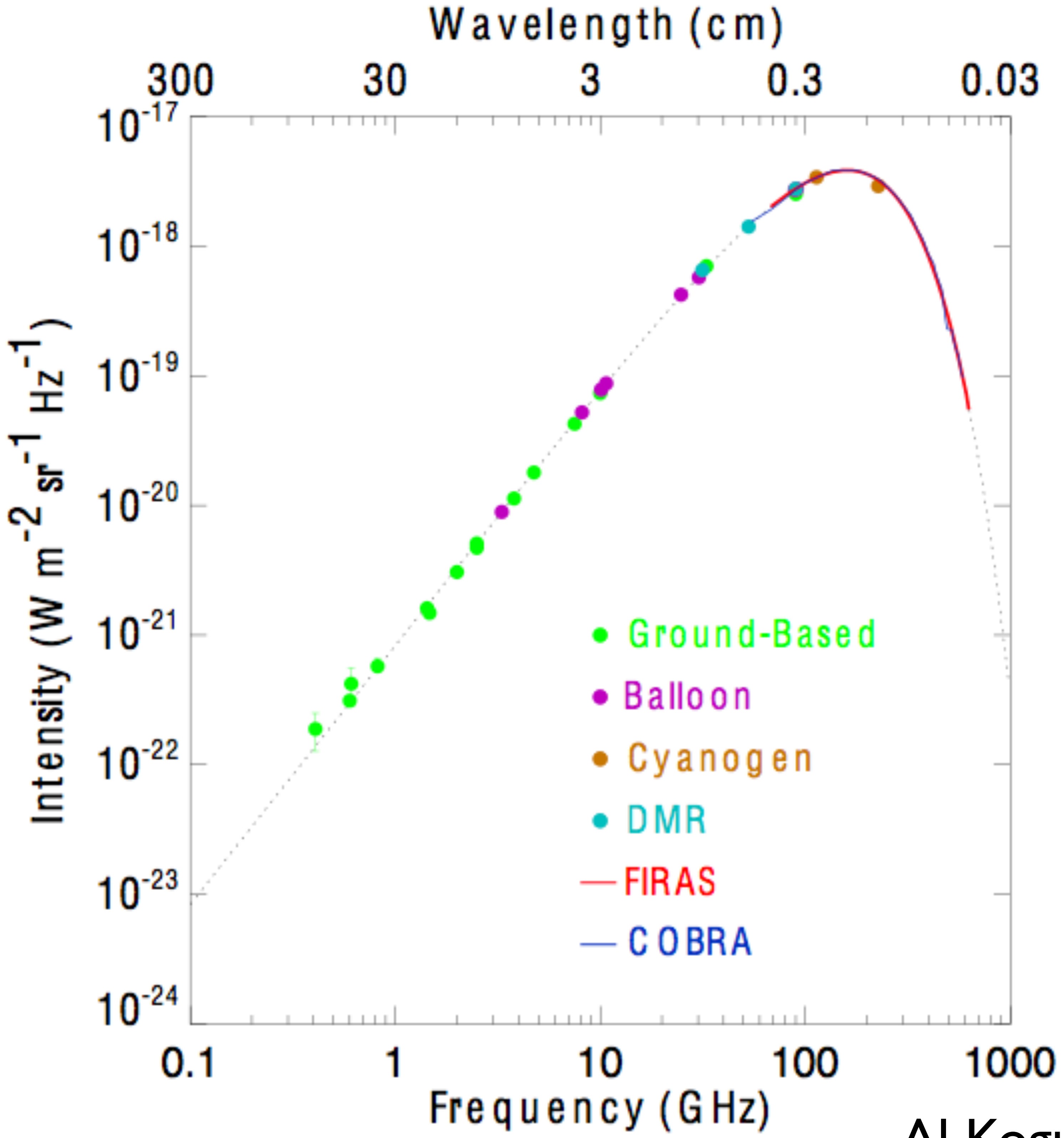


Mather et al. 1990



Gush et al. 1990

Selected Measurements of CMB Spectrum



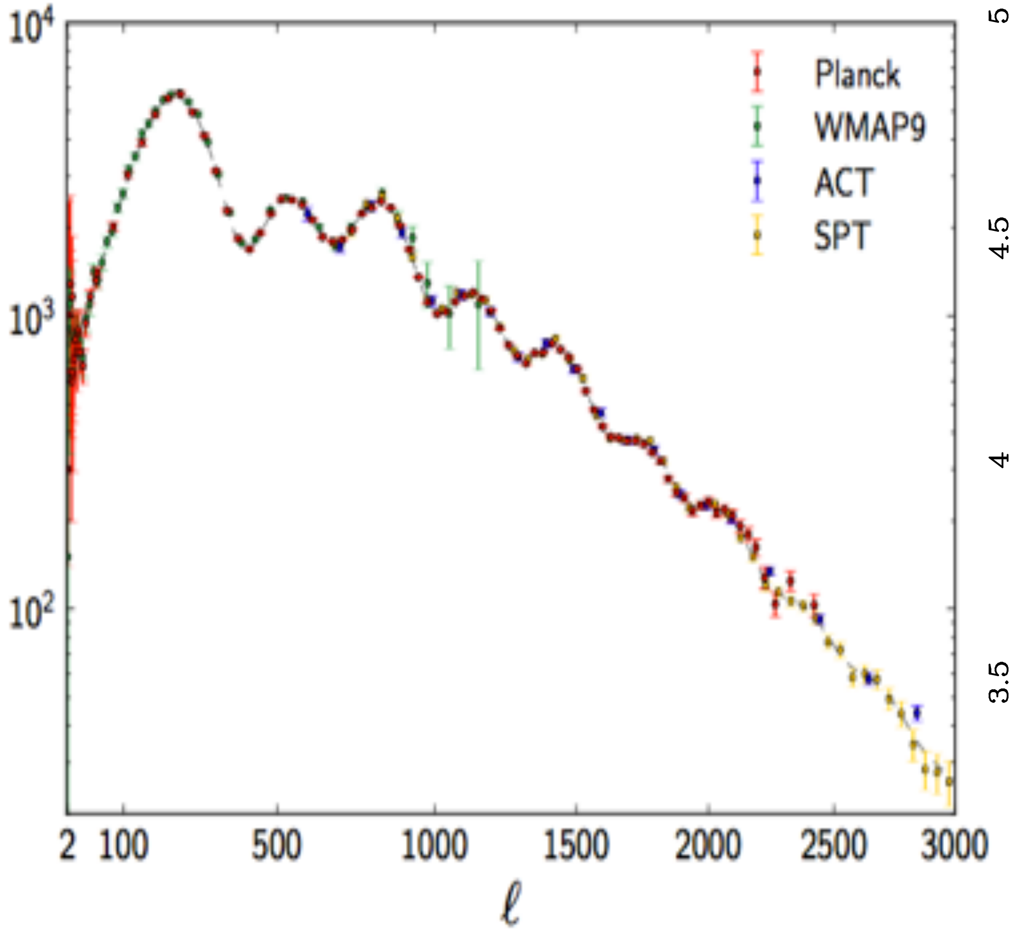
This is evidence that our universe evolved from a very different state,

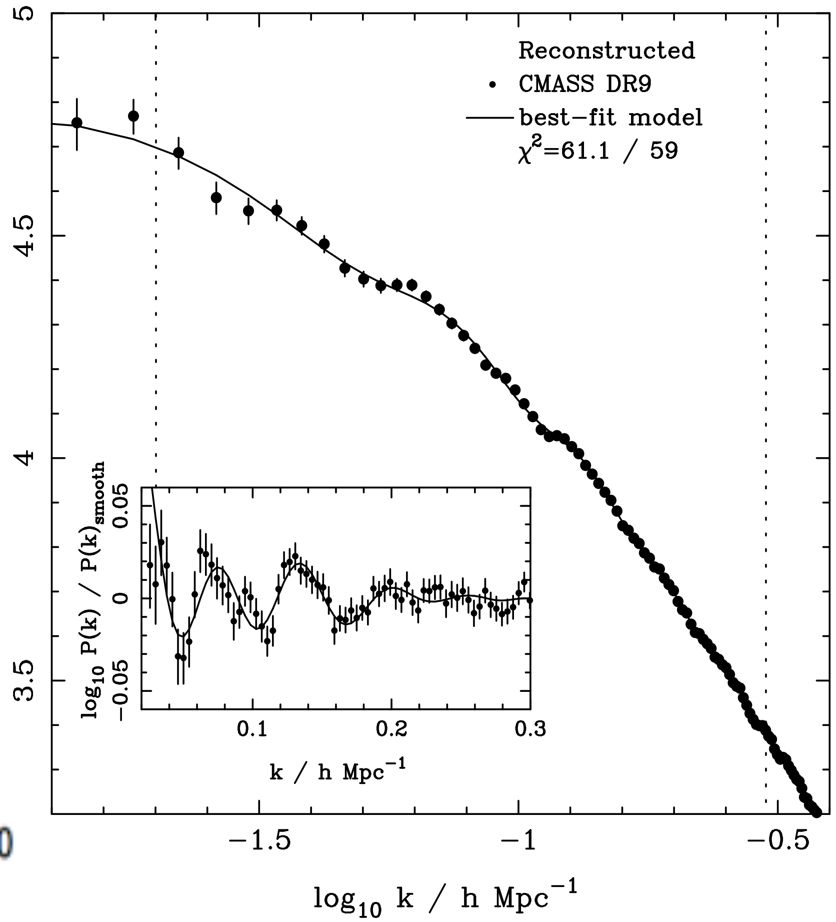
hot and dense enough to have relaxed to thermal equilibrium.

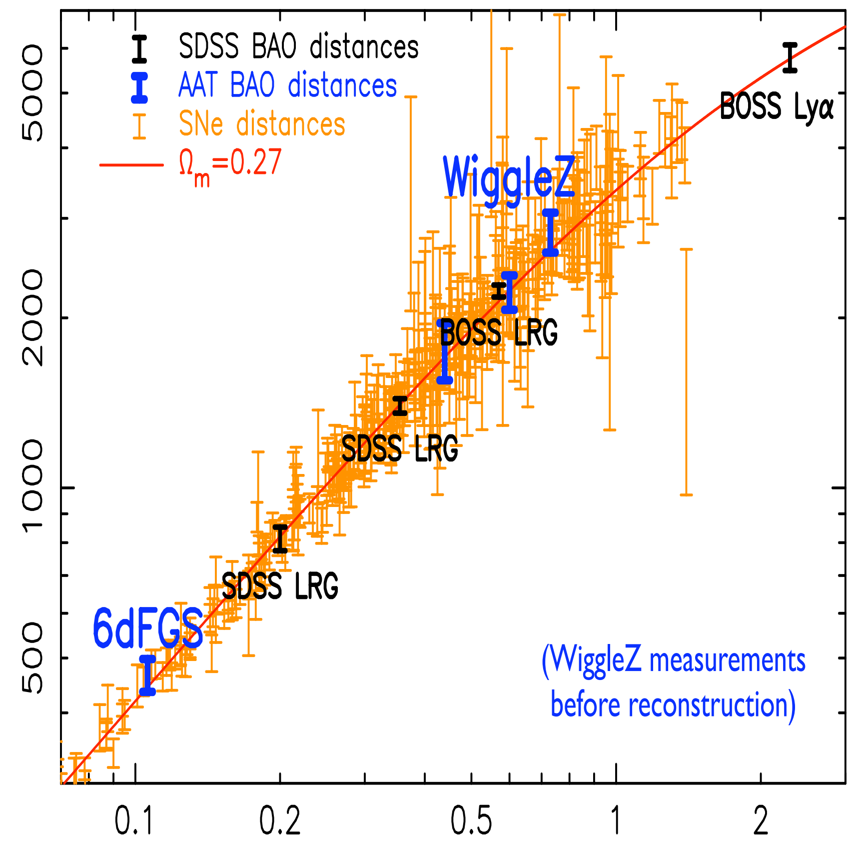
The case summarized in this figure is about as good as it gets in natural science.

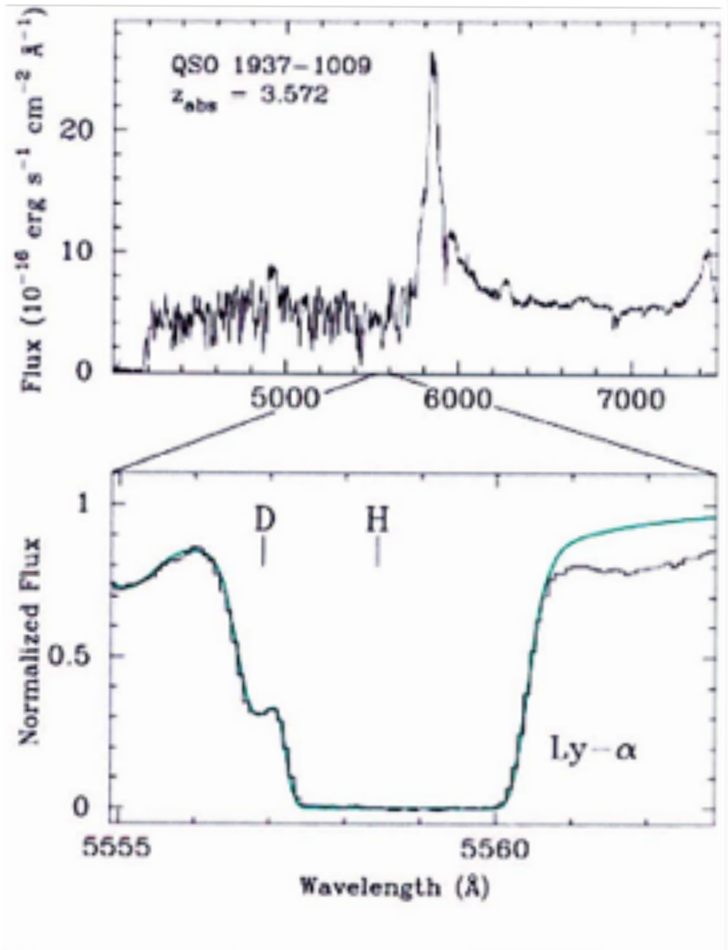
This figure ought to be more broadly celebrated.

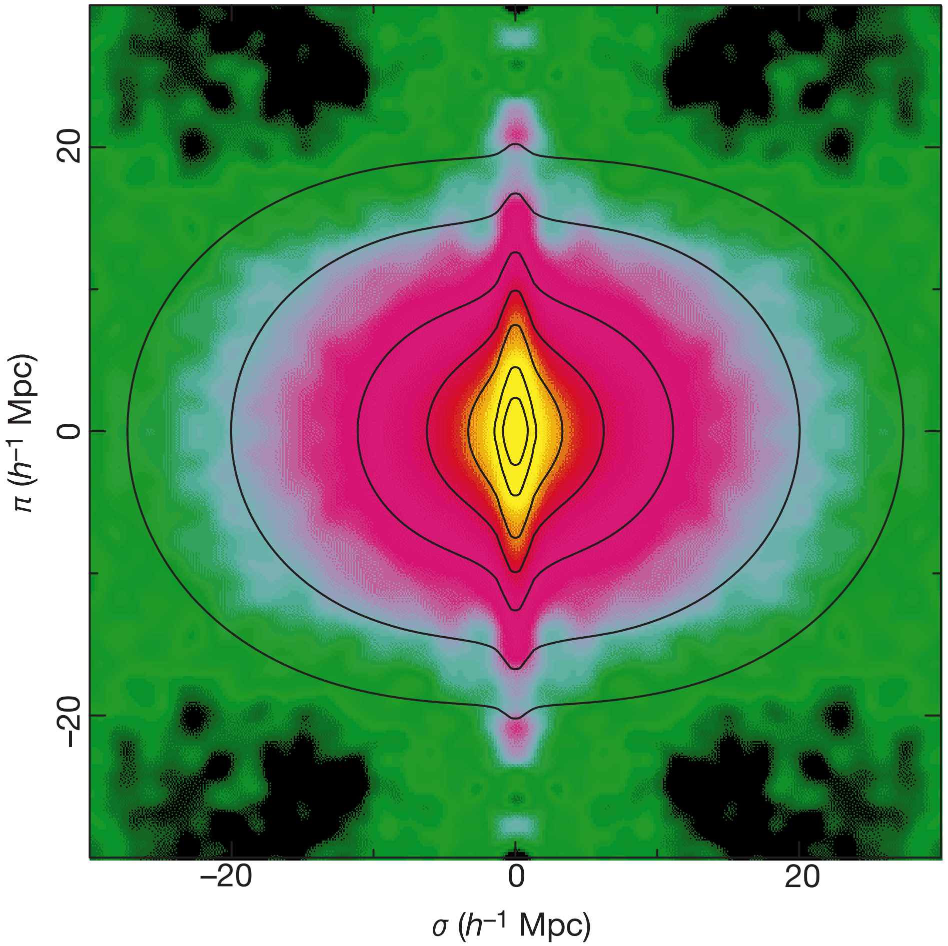
Al Kogut, 2012

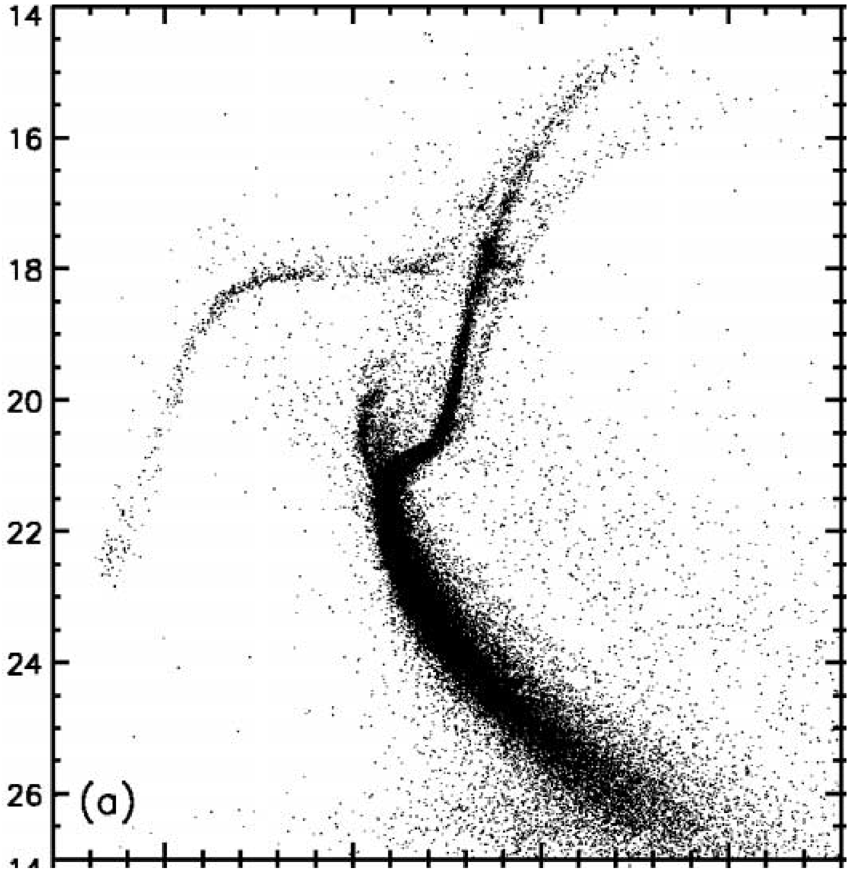

Planck
WMAP9
ACT
SPT
10^4
10^3
10^2
2
100
500
1000
1500
2000
2500
3000
ℓ


Reconstructed
CMASS DR9
best-fit model
χ^2=61.1 / 59
5
4.5
4
3.5
−1.5
−1
−0.5
$\log_{10}$ k / h Mpc^{-1}
$\log_{10}$ P(k) / P(k)$_{\rm smooth}$
0.05
0
−0.05
0.1
0.2
0.3
k / h Mpc^{-1}


SDSS BAO distances
AAT BAO distances
SNe distances
Ω_m=0.27
BOSS Lyα
WiggleZ
BOSS LRG
SDSS LRG
SDSS LRG
6dFGS
(WiggleZ measurements
before reconstruction)
5000
2000
1000
500
0.1
0.2
0.5
1
2


QSO 1937−1009
z_{abs} = 3.572
Flux (10^{-16} erg s^{-1} cm^{-2} Å^{-1})
20
10
0
5000
6000
7000
Normalized Flux
1
0.5
0
D
H
Ly−α
5555
5560
Wavelength (Å)


20
0
−20
π (h^{-1} Mpc)
−20
0
20
σ (h^{-1} Mpc)


14
16
18
20
22
24
26
(a)

Concluding thoughts

The revolution in experimental gravity physics in the US had considerable US military support: acknowledgements include

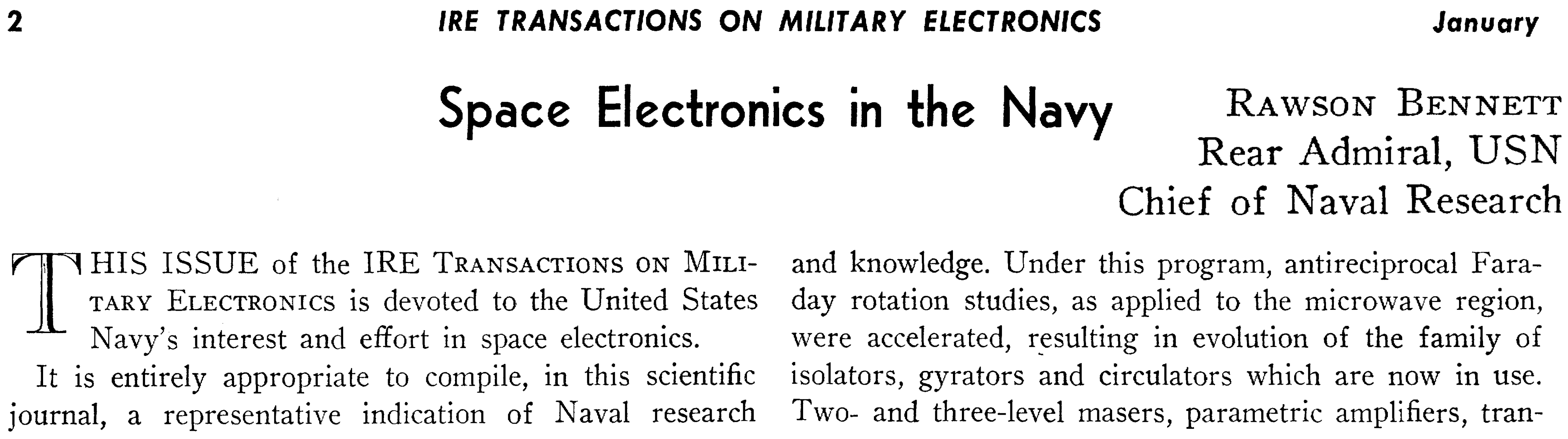
US Army Signal Corps: Townes, Dicke
Office of Naval Research: Townes, Dicke, Pound
Air Research and Development Command: Townes
Atomic Energy Commission: Pound
Air Force: Sapiro, Chapel Hill Conference
Office of Ordnance Research: Chapel Hill Conference

US National Science Foundation: Dicke, Chapel Hill Conference
NASA: Shapiro

The military missions of the 1960s—Cold War, Korea, Vietnam—maybe gained something from this curiosity-driven research, but they had their own considerable resources for that. Long-term payoff was significant, in technology and consulting.

Curiosity-driven gravity research gained a lot: no interference with directions of research that I can see, at trivial expense to the military—apart from Shapiro's radar time delay experiment (Kaiser).

A Slight Hardening of the Arteries of Natural Science



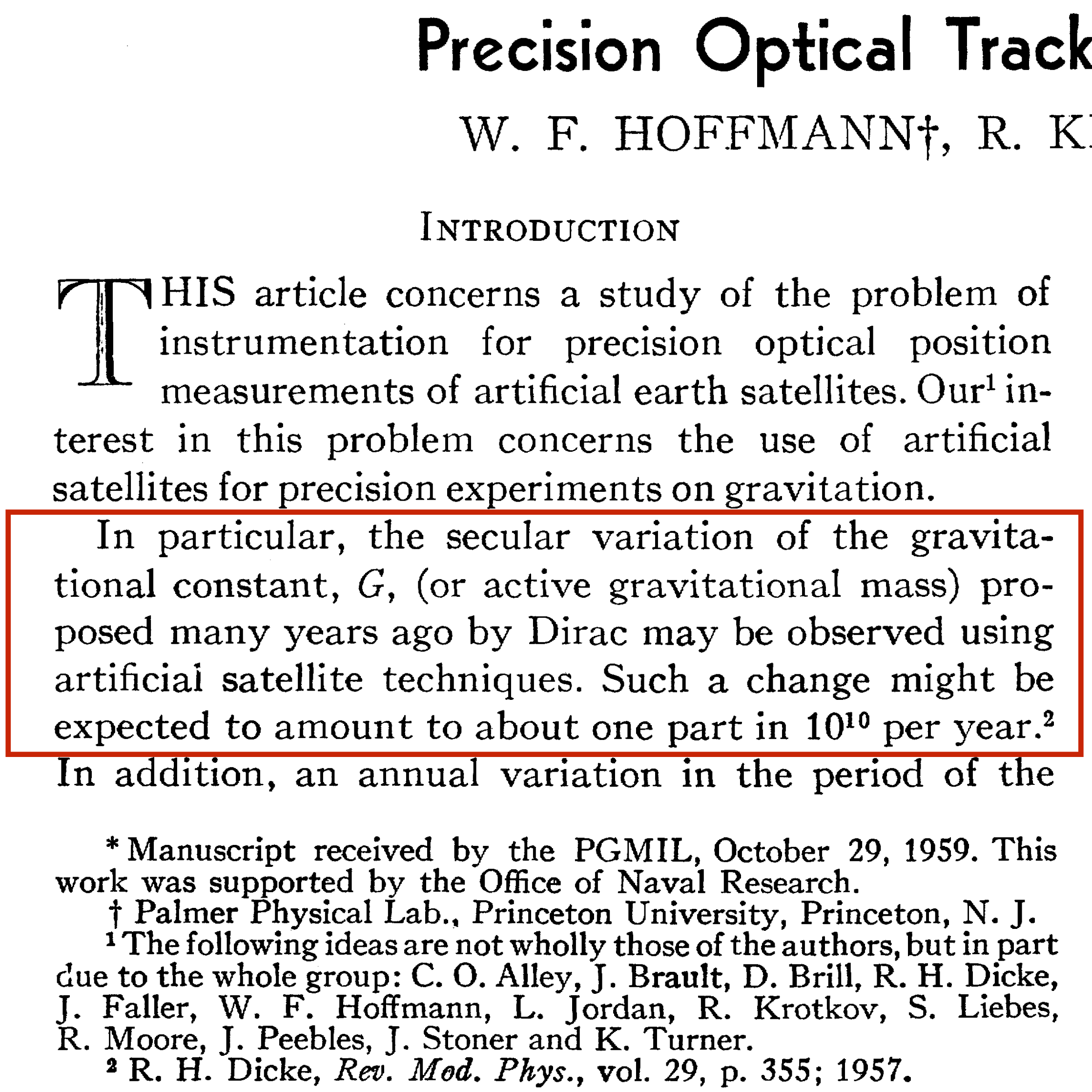
2 IRE TRANSACTIONS ON MILITARY ELECTRONICS January

Space Electronics in the Navy

Rawson Bennett
Rear Admiral, USN
Chief of Naval Research

THIS ISSUE of the IRE Transactions on Military Electronics is devoted to the United States Navy's interest and effort in space electronics.

It is entirely appropriate to compile, in this scientific journal, a representative indication of Naval research and knowledge. Under this program, antireciprocal Faraday rotation studies, as applied to the microwave region, were accelerated, resulting in evolution of the family of isolators, gyrators and circulators which are now in use. Two- and three-level masers, parametric amplifiers, tran-



Precision Optical Tracking of Artificial Satellites*

W. F. HOFFMANN†, R. KROTKOV†, and R. H. DICKE†

Introduction

THIS article concerns a study of the problem of instrumentation for precision optical position measurements of artificial earth satellites. Our[1] interest in this problem concerns the use of artificial satellites for precision experiments on gravitation.

In particular, the secular variation of the gravitational constant, G, (or active gravitational mass) proposed many years ago by Dirac may be observed using artificial satellite techniques. Such a change might be expected to amount to about one part in 10^{10} per year.[2] In addition, an annual variation in the period of the

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* Manuscript received by the PGMIL, October 29, 1959. This work was supported by the Office of Naval Research.

† Palmer Physical Lab., Princeton University, Princeton, N. J.

[1] The following ideas are not wholly those of the authors, but in part due to the whole group: C. O. Alley, J. Brault, D. Brill, R. H. Dicke, J. Faller, W. F. Hoffmann, L. Jordan, R. Krotkov, S. Liebes, R. Moore, J. Peebles, J. Stoner and K. Turner.

[2] R. H. Dicke, *Rev. Mod. Phys.*, vol. 29, p. 355; 1957.

The 1969 Mansfield Amendment ended this practice by prohibiting the Defense Department from funding "any research project or study unless such project or study has a direct and apparent relationship to a specific military function."

The “Great Man Theory:” where would we be without Dicke?

Others, at least in part independently, seized on new technology as it appeared for new tests of gravity physics.

But I wonder whether anyone else would have so thoroughly cast about for tests.

For example, would someone else have had the motivation and influence to persuade NASA or the USSR to put corner reflectors on the moon, and inspire people to spend the time and effort to find the ~1 in 10^{17} detected return photons?

I expect that, without Dicke, we would have the present tight network of precision tests of GR, but not in such broad and searching variety. And gravity physics would have been the poorer.

We see the power of Great Ideas:

GR survives an extrapolation of 14 orders of magnitude to the Hubble length from the length scale of Mercury's orbit, the only demanding test before the revolution.

Mach's Principle led Einstein to the observed large-scale structure of the universe.

But Great Ideas can fail: Mach's Principle has given us nothing more of substance so far.

That is why some, including me, feel less than confident about inflation, the Anthropic Principle, and today's other Great Ideas.

In the 1950s GR was accepted in the gold standard of theoretical physics, Landau and Lifshitz.

Now we have a tight well-checked web of evidence that GR really is a good approximation to many aspects of what actually has been happening, on scales ranging from the laboratory to the edge of our universe.

Which is far better.

Never make predictions, especially about the future.
(Casey Stengel?)

In 1955 GR was was widely accepted as logically compelling. Now inflation is widely accepted as logically compelling.

A serious difference: GR is a theory, inflation a scenario.

A serious similarity: GR in 1955, and inflation in 2015, stand on beauty, and maybe lack of a better idea, with empirical bases considered to be necessarily scanty: “just trust the theory.”

World economies cannot afford many more cycles of revolutionary experimental advances in gravity. But we were surprised by the 1957—1967 revolution, and we’ll likely be surprised again, in some surprising direction.

Professor Dr. Pascual Jordan
Universitat Hamburg
Hamburg 13, Den
Isestrasse 123
Germany

Dear Professor Jordan:

I was delighted to learn that you will be visiting our country again and am looking forward to seeing you. I expect to be on the west coast September 14th through 16th and to be out of town on October 18th. While there will be other conflicts later, these are the only engagements that I presently have in my book.

I was pleased to learn that you are publishing a new book. I think that perhaps you would agree with me that the implications for geophysics and astrophysics of a time rate of change of the gravitational interaction is one of the most fascinating questions that one could consider. I always have my mind open looking for some new fragment of information that could have a bearing on this question. I am curious to know how you could have a time rate of change of gravitation as great as 10^{-9} per year and am looking forward to reading about it in your book.

Sincerely yours,

RHD:mf

R. H. Dicke