# Talk

## June 13, 2019

## Balaton Limnological Research Institute of the Hungarian Academy of Sciences

Jim Faller

JILA, University of Colorado, and the University of Glasgow

***‘Nature never deals off of the bottom of the deck’.***

***…but she holds all of the aces.***

**“Subtle is the Lord, but malicious He is not.”**

***[“Raffeniert ist der Herrgott aber boshaft ist er nicht.”]***

**A. Einstein**

**…“for in contrast with much of humanity, Nature usually plays fair”…**

***“Experiments and Experiences”***

**R. V. Jones (p. 376)**

# Cavendish Played Fair

XXI. *Experiments to determine the Density of the Earth. By Henry Cavendish, Esq. F.R.S. and A.S.*

Read June 21, 1798.

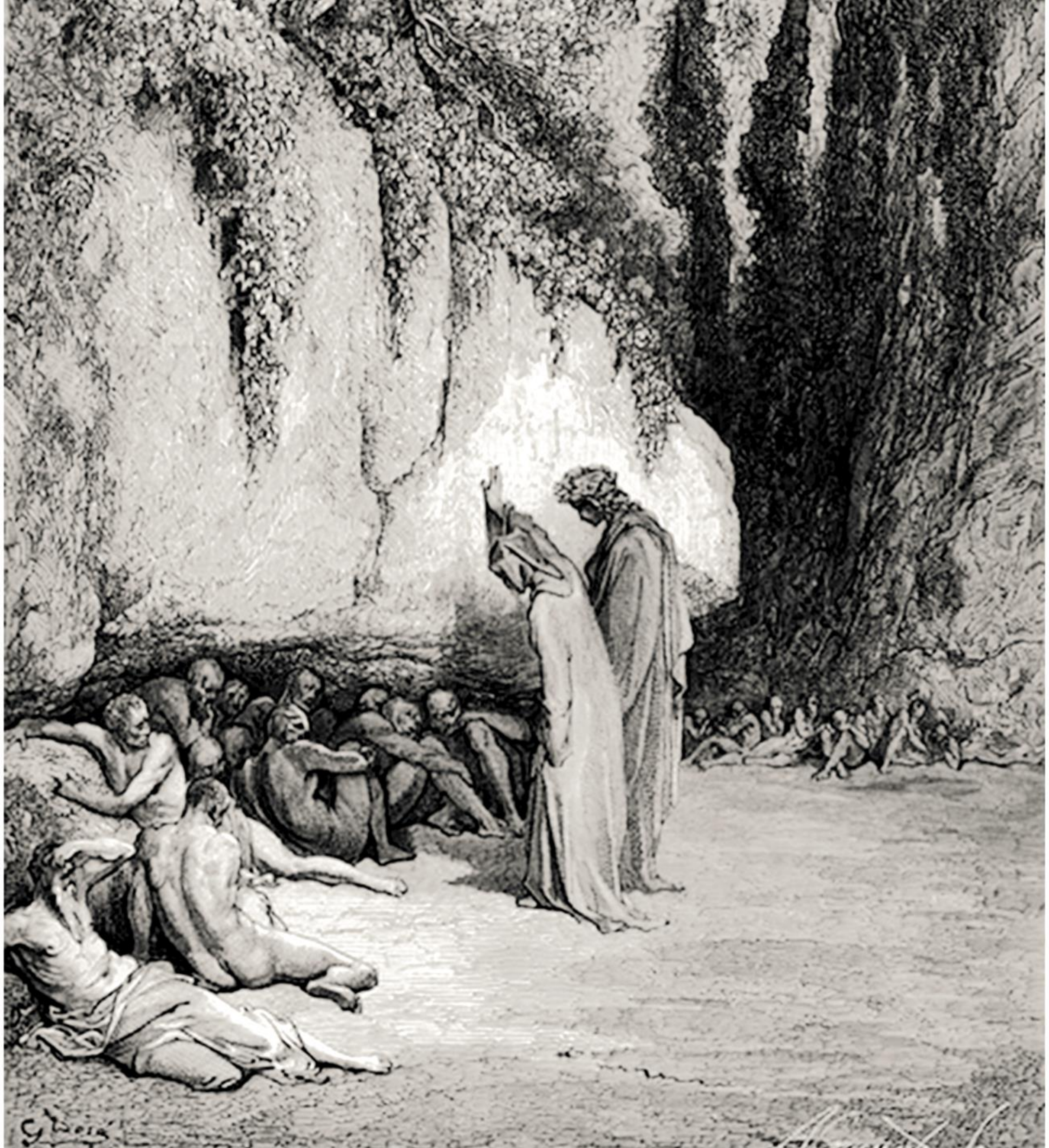
MANY years ago, the late Rev. JOHN MICHELL, of this Society, contrived a method of determining the density of the earth, by rendering sensible the attraction of small quantities of matter; but, as he was engaged in other pursuits, he did not complete the apparatus till a short time before his death, and did not live to make any experiments with it. After his death, the apparatus came to the Rev. FRANCIS JOHN HYDE WOLLASTON, Jacksonian Professor at Cambridge, who, not having conveniences for making experiments with it, in the manner he could wish, was so good as to give it to me.

The apparatus is very simple; ←n.b.

# Measurement capability is the enabler of scientific progress

**By extending the reach of our hands and quickening the response of our eyes, new measurement methods and instrumental capabilities have driven and implemented much of scientific progress.**

How do ***ideas*** come about



*And you're certain that none of you want to learn about science?*

**I have always enjoyed building things…**

# ERECTOR

DEVELOPED AT THE
GILBERT HALL OF SCIENCE

# The Indiana University Period

**Professor Richard J Eden OBE**
**Quantum field theory, nuclear physics, high energy physics, energy studies.**

My answer to Milo Sampson's question,

"Why don't you go to Princeton?"

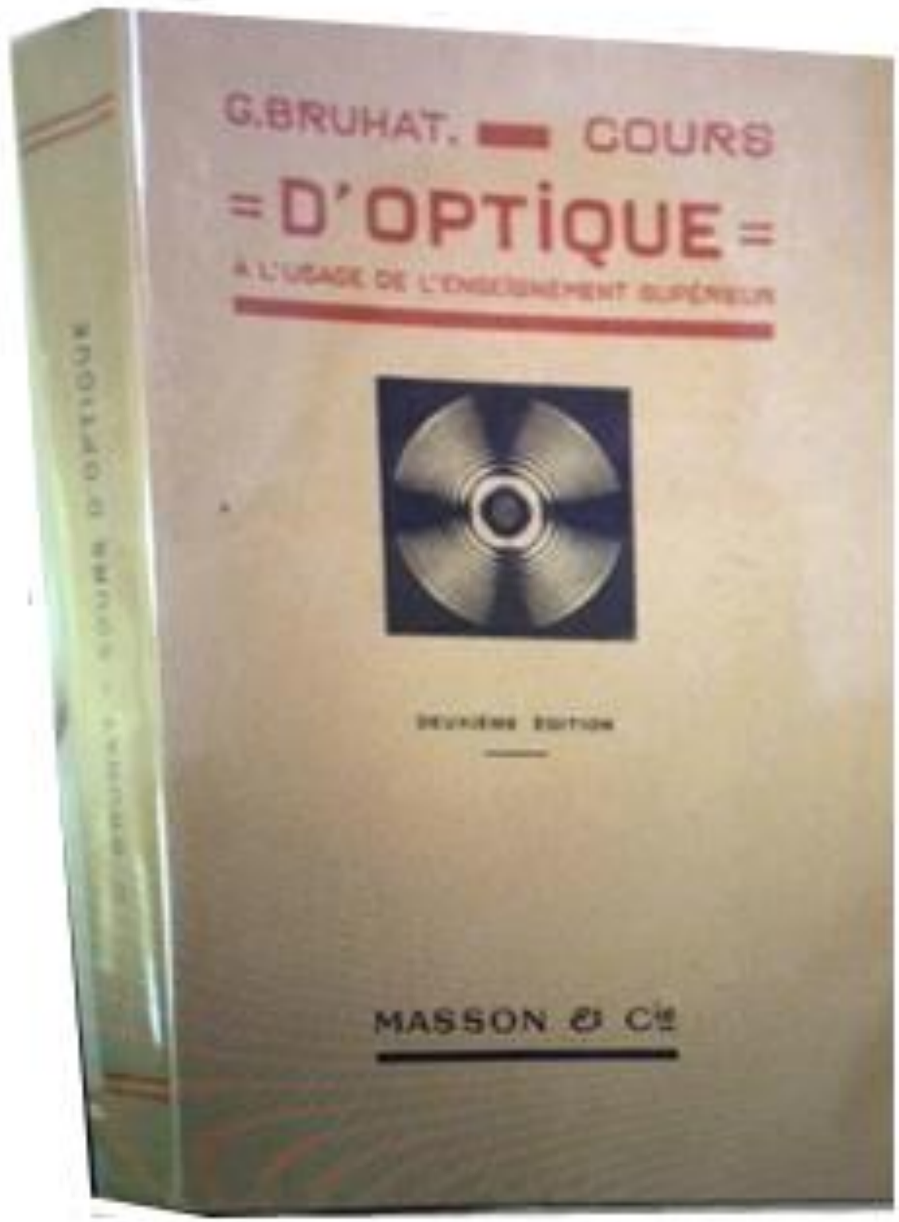
was

Where's that?

# The Princeton Period 1955-1963

Members of the senior faculty in the Department of Physics, Palmer Physical Laboratory, Princeton University, in about 1950: from the left Rubby Sherr, Allen Shenstone, Donald Hamilton, Eric Rogers, Robert Dicke, Walker Bleakney, John Wheeler, Rudolf Ladenburg, and Eugene Wigner.

Shenstone’s Optic’s Text For Use Two Year’s Hence



**Much was learned from Eric Rogers who lived on Mercer Street right next to Einstein house.**


LUCY WHY IS THE SKY BLUE?
BECAUSE IT ISN'T GREEN!!
THAT JUST SHOWS HOW STUPID I AM... I THOUGHT THERE WOULD BE A MORE COMPLICATED REASON...

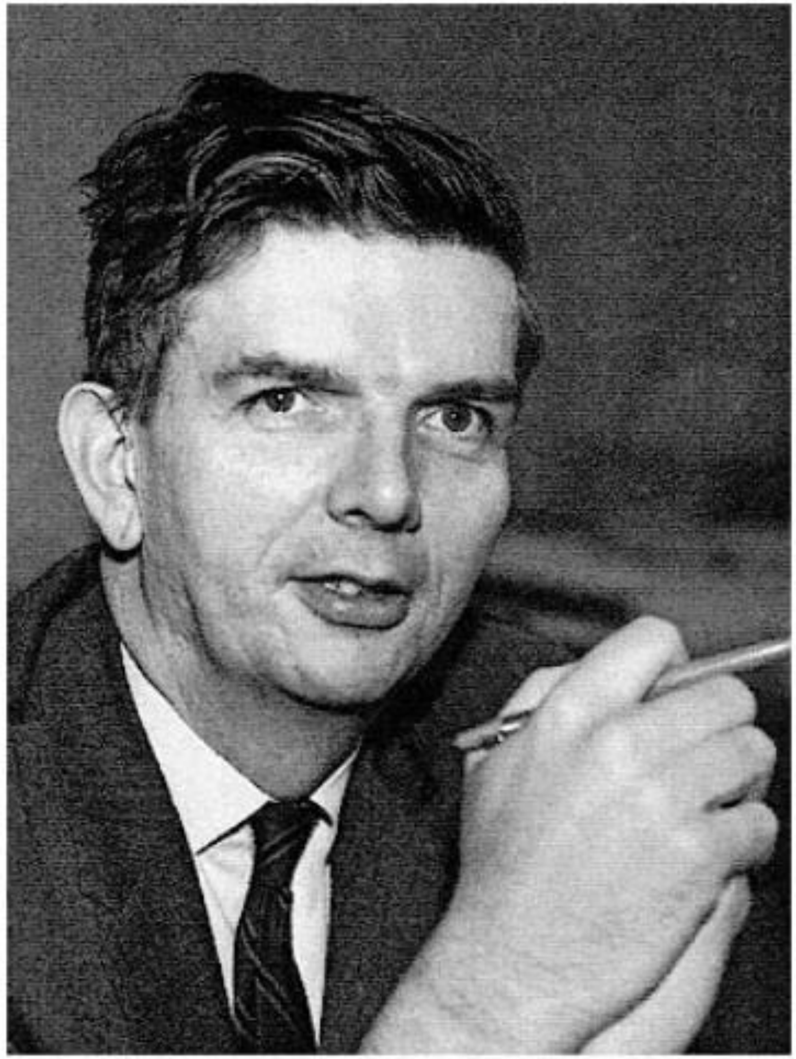
**“It is almost a miracle that modern teaching methods have not yet entirely strangled the holy curiosity of inquiry; for what this delicate little plant needs more than anything, beside stimulation, is freedom.”**

**A. Einstein, Philosopher-Scientist.**
**The Living Philosophers, Inc., Illinois (1949)**

# Science's 'rough' edges

**"The stumbling way in which even the ablest of scientists in every generation have had to fight through thickets of erroneous observations, misleading generalizations, inadequate formulations and unconscious prejudice is rarely appreciated by those who obtain their scientific knowledge from text books."**

**James Bryant-Conant (1940), President of Harvard University; and also a very good chemist.**



Bob Dicke

**Dicke gave the departmental talk to the new graduate students (of whom there were 15).**

**“ No required courses and/or tests…until the ‘General Exam’ which was usually taken in the Spring of one’s second year.  Plan on working hard; this is Princeton.”**

**New students included Paul Condon, Bob Fuller (later  president of Oberlin College),**

**Julio Fermi, and Steven Weinberg (who was drawing fighter planes shooting bullets at each other while Bob was speaking).**

**Many of us were the first generation in our family to go to college.**

**Dicke group's Friday evening discussions—one by one at the black board telling what had been complished the past week, and also what was tried but, for some reason or other, didn't work.**

**Dicke during his sabbatical at Harvard bought a (very good) von Heune tenor recorder…and played it with a small group of us who lingered when the Friday evening physics discussions were over and stayed on to play music together. Bob also had a grand piano in the center of his front room at home on which he (bombastically) played classical piano pieces. He was quite a decent pianist!**

Graduate student research with Dicke, pre-gravity

| Name | Research |
|---|---|
| Alexander Pond | A Experimental Investigation of Positronium (1952) |
| George Newell | A Method for Reducing the Doppler Width of Microwave Spectrum Lines (1953) |
| Bruce Hawkins | The Orientation and Alignment of Sodium Atoms by Means of Polarized Resonance Radiation (1954) |
| Robert Romer | A Method for the Reduction of the Doppler Width of Microwave Spectral Lines (1955) |
| James Wittke | A Redetermination of the Hyperfine Splitting in the Ground State of Atomic Hydrogen (1955) |
| Christopher Sherman | Nuclear Induction with Separate Regions of Excitation and Detection (1955) |
| Lowell White | The Gyromagnetic Ratio of the Electron in the Metastable State of Hydrogen (1956) |
| Peter Bender | The Effect of a Buffer Gas on the Optical Orientation Process in Sodium Vapor (1956) |
| Edward Lambe | A Measurement of the g-Value of the Electron in the Ground State of the Hydrogen Atom (1959) |

Table 2A: Research with Dicke in the Gravity Group

| Name | Status | Research |
|---|---|---|
| Robert Krotkov | post-PhD | Comparison between theory and observation for the outer planets (Krotkov and Dicke 1959) |
| Carl Brans | PhD | Mach's Principle & Varying Gravitational Constant (1961) |
| James Peebles | PhD | Observational Tests and Theoretical Problems with Variable Strength of the Electromagnetic Interaction (1961) |
| Carroll Alley | PhD | Optical Pumping and Optical Detection Involving Microwave & Radio Frequency Coherence Effects (1962) |
| William Hoffmann | PhD | A Pendulum Gravimeter for Measurement of Periodic Annual Variations in the Gravitational Constant (1962) |
| Kenneth Turner | PhD | New Limit on Velocity Dependent Interaction Between Natural Clocks and Distant Matter (1962) |
| James Brault | PhD | The Gravitational Red Shift in the Solar Spectrum (1962) |
| Dieter Brill | post-PhD | Experiments on Gravitation (Bertotti, Brill, Krotkov 1962) |
| James Faller | PhD | An Absolute Interferometric Determination of the Acceleration of Gravity (1963) |
| John Stoner | PhD | Production of narrow balmer spectrum lines in an electron-bombarded atomic hydrogen beam (1963) |
| Henry Hill | post-PhD | Experimental Limit on Velocity-Dependent Interactions of Clocks and Distant Matter (Turner and Hill 1964) |
| Sidney Liebes | post-PhD | Gravitational Lenses (Liebes 1964) |
| Curtis Callan | PhD | Sphericaly Symmetric Cosmological models (1964) |
| Lawrence Jordan | PhD | The velocities of 4 BeV/c pions and 8 BeV/c pions, kaons, and protons (1964) |
| Jason Morgan | PhD | An Astronomical and Geophysical Search for Scalar Gravitational Waves (1964) |
| William Hildreth | PhD | The interaction of scalar gravitational waves with the Schwarzschild Metric (1964) |

## Research with Dicke in the gravity group (continued)

| | | |
|---|---|---|
| Peter Roll | post-PhD | The equivalence of inertial and passive gravitational mass (Roll, Krotkov, Dicke 1964) |
| Rainer Weiss | post-PhD | A Gravimeter to Monitor the $_0S_0$ Dilational Mode of the Earth (Weiss and Block 1965) |
| David Curott | PhD | A Pendulum Gravimeter for Precision Detection of Scalar Gravitational Radiation (1965) |
| David Wilkinson | post-PhD | Cosmic Black-Body Radiation (Dicke, Peebles, Roll, and Wilkinson 1965) |
| Robert Moore | PhD | Study of Low Frequency Earth Noise and New Upper Limit to the Intensity of Scalar Gravitational Waves (1966) |
| Lloyd Kreuzer | PhD | The Equivalence of Active and Gravitational Mass (1966) |
| Barry Block | post-PhD | Measurements in Earth mode frequency, electrostatic sensing & feedback gravimeter (Block and Moore 1966) |
| Mark Goldenberg | post-PhD | Solar Oblateness and General Relativity (Dicke and Goldenberg 1967) |
| Carl Zanoni | PhD | Development of Daytime Astrometry to Measure the Gravitational Deflection of Light (1967) |
| Dennis Heygi | PhD | The Primordial Helium Abundance as Determined from the Binary Star System $\mu$ Cassiopeiae (1968) |
| B. Edward McDonald | PhD | Meridian Circulation in Rotating Stars (1970) |
| Lawrence Cathles | PhD | The viscosity of the Earth's mantle (1971) |
| William Wickes | PhD | Primordial Helium Abundance and Population-II Binary Stars: Measurement Technique (1972) |
| Jeffrey Kuhn | PhD | Global scale photospheric velocity fields: Probes of the solar interior (1980) |
| Ken Libbrecht | PhD | The shape of the Sun (1984) |

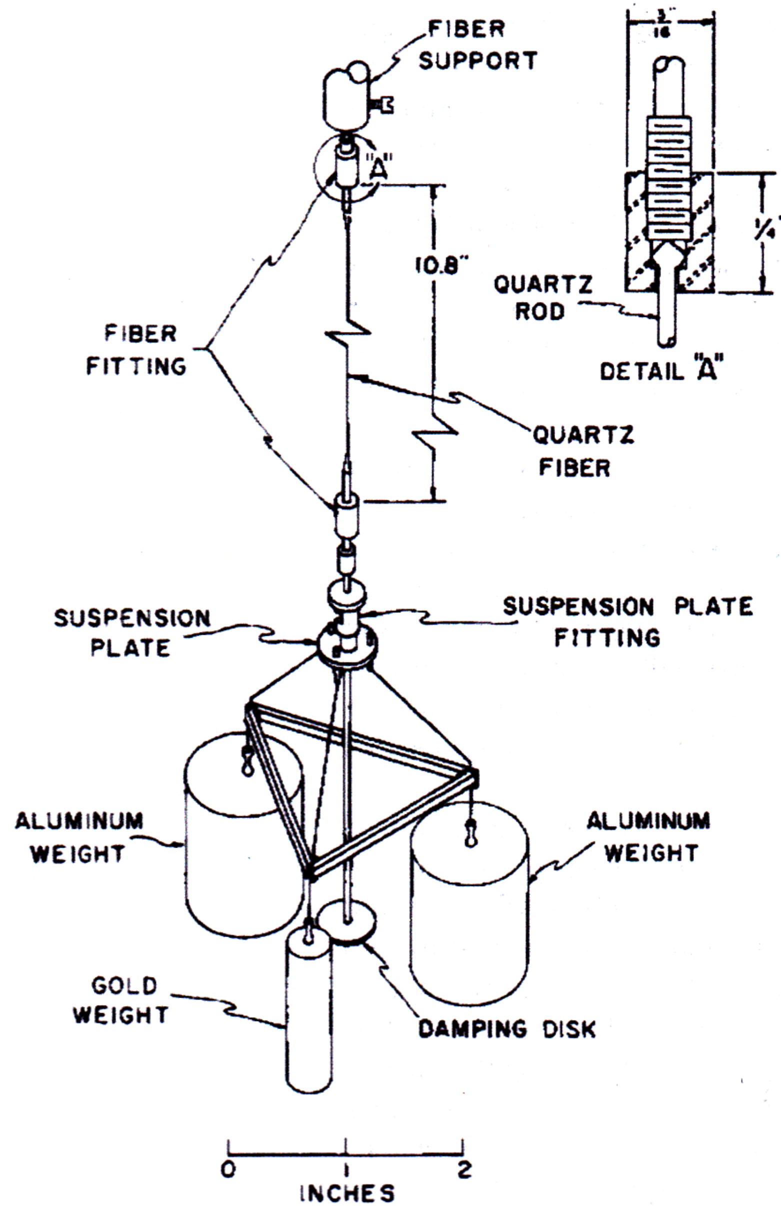
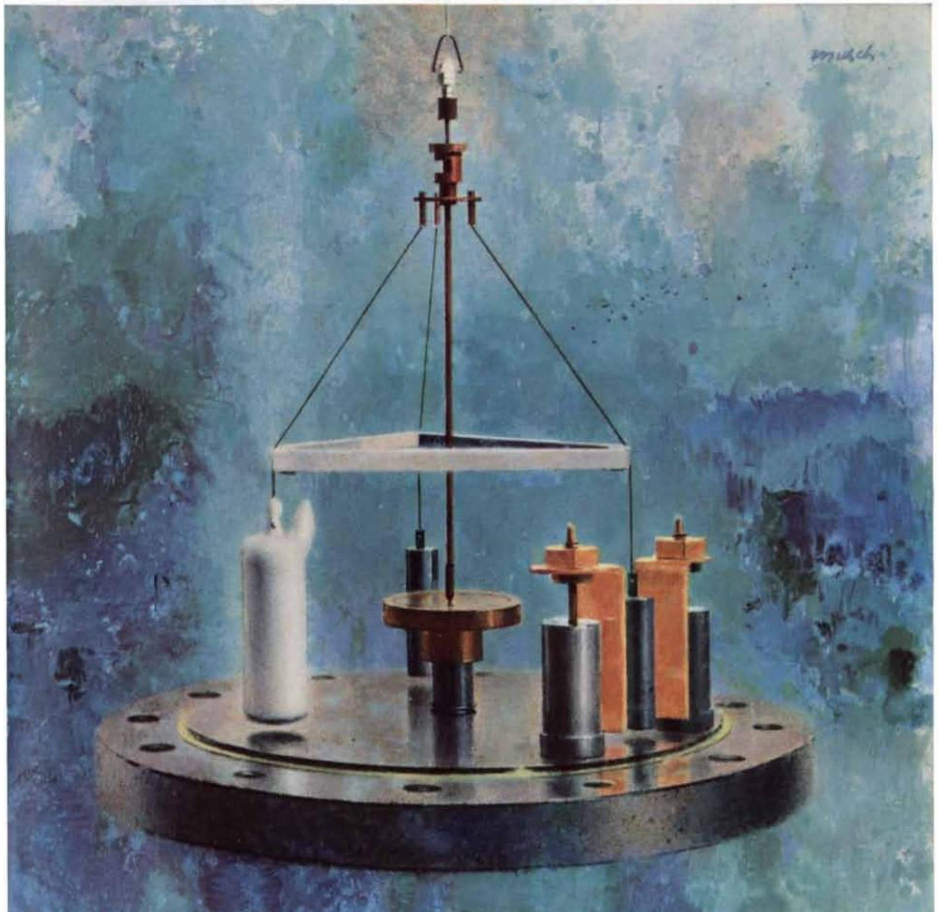



FIG. 3. The torsion balance suspension. The construction of both upper and lower fiber fittings is illustrated in Detail "A."

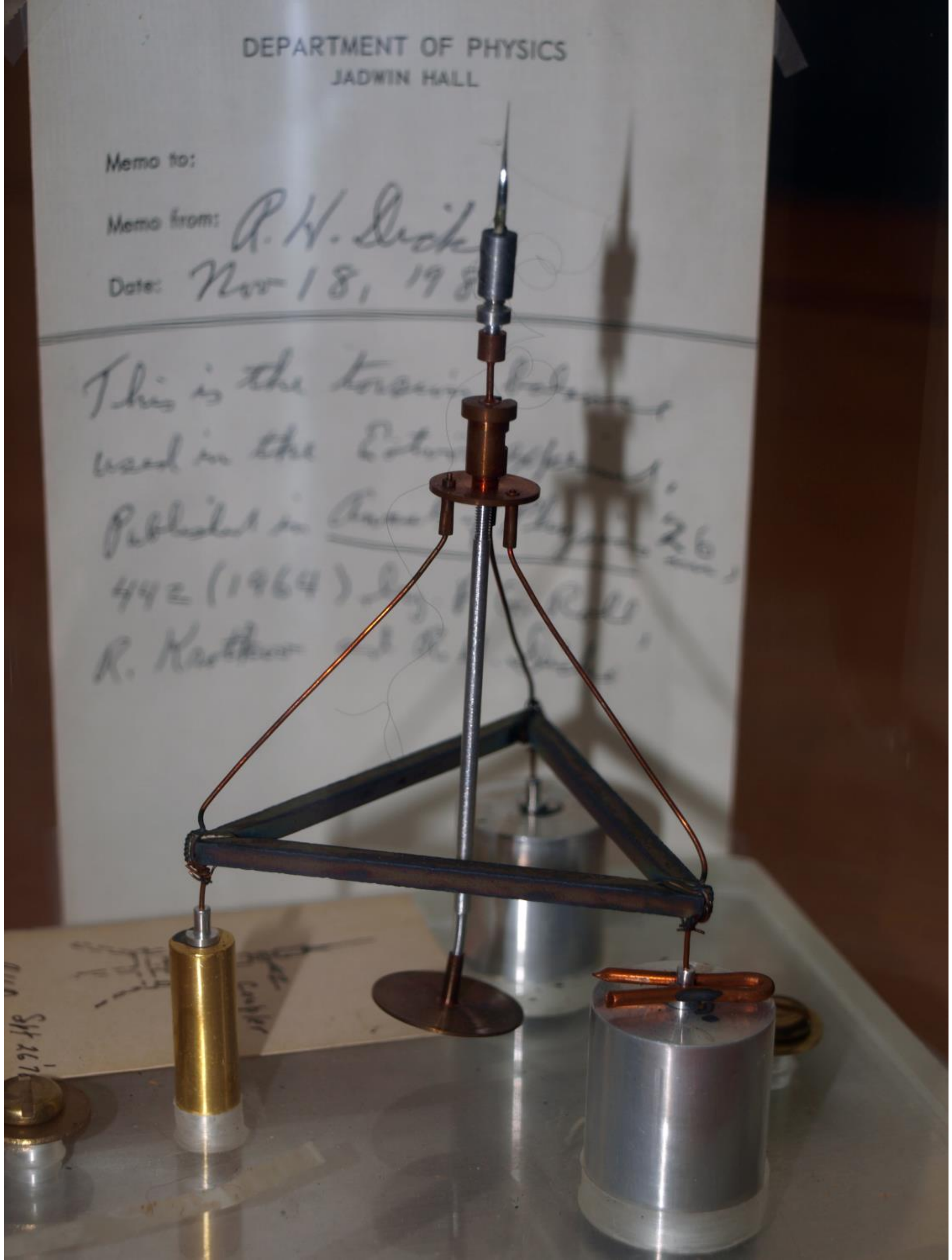
# SCIENTIFIC AMERICAN



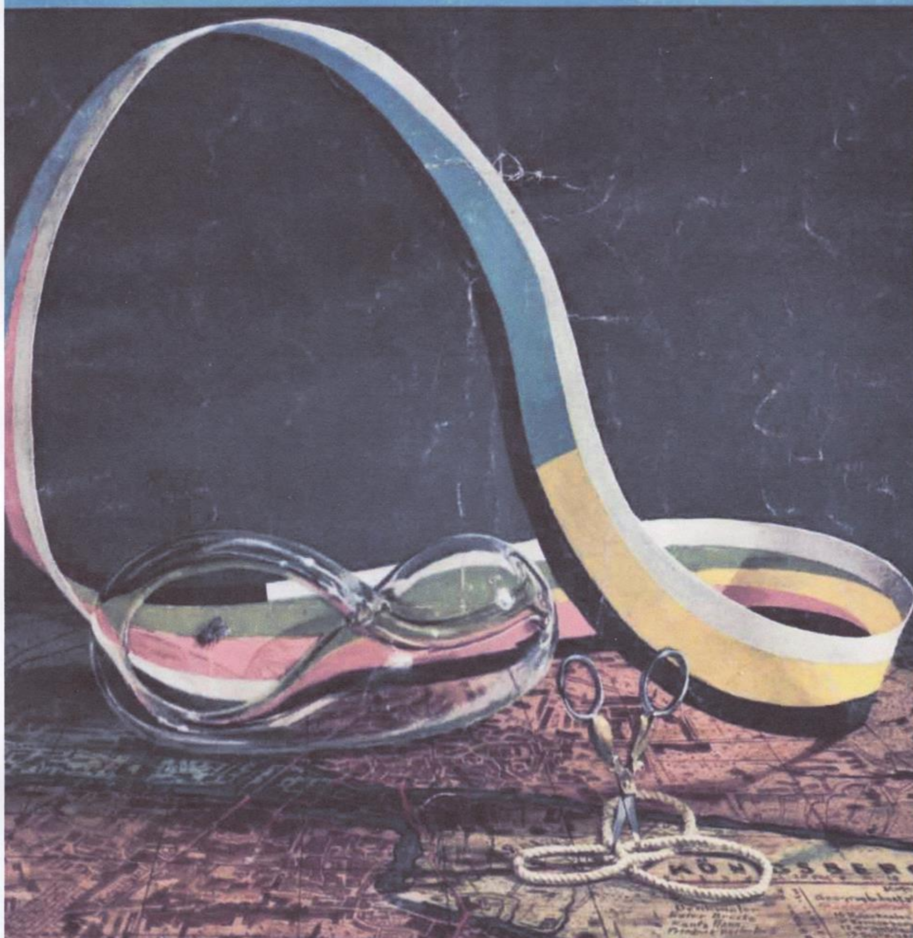
GRAVITY EXPERIMENT

*FIFTY CENTS*

*December 1961*


DEPARTMENT OF PHYSICS
JADWIN HALL
Memo to:
Memo from:
Date:

# SCIENTIFIC AMERICAN



**TOPOLOGY**

**FIFTY CENTS**

*January 1950*

# RATTLESNAKE SEASON ON THE FRONT RANGE

Kirk W. Davidson / Special to The Denver Post

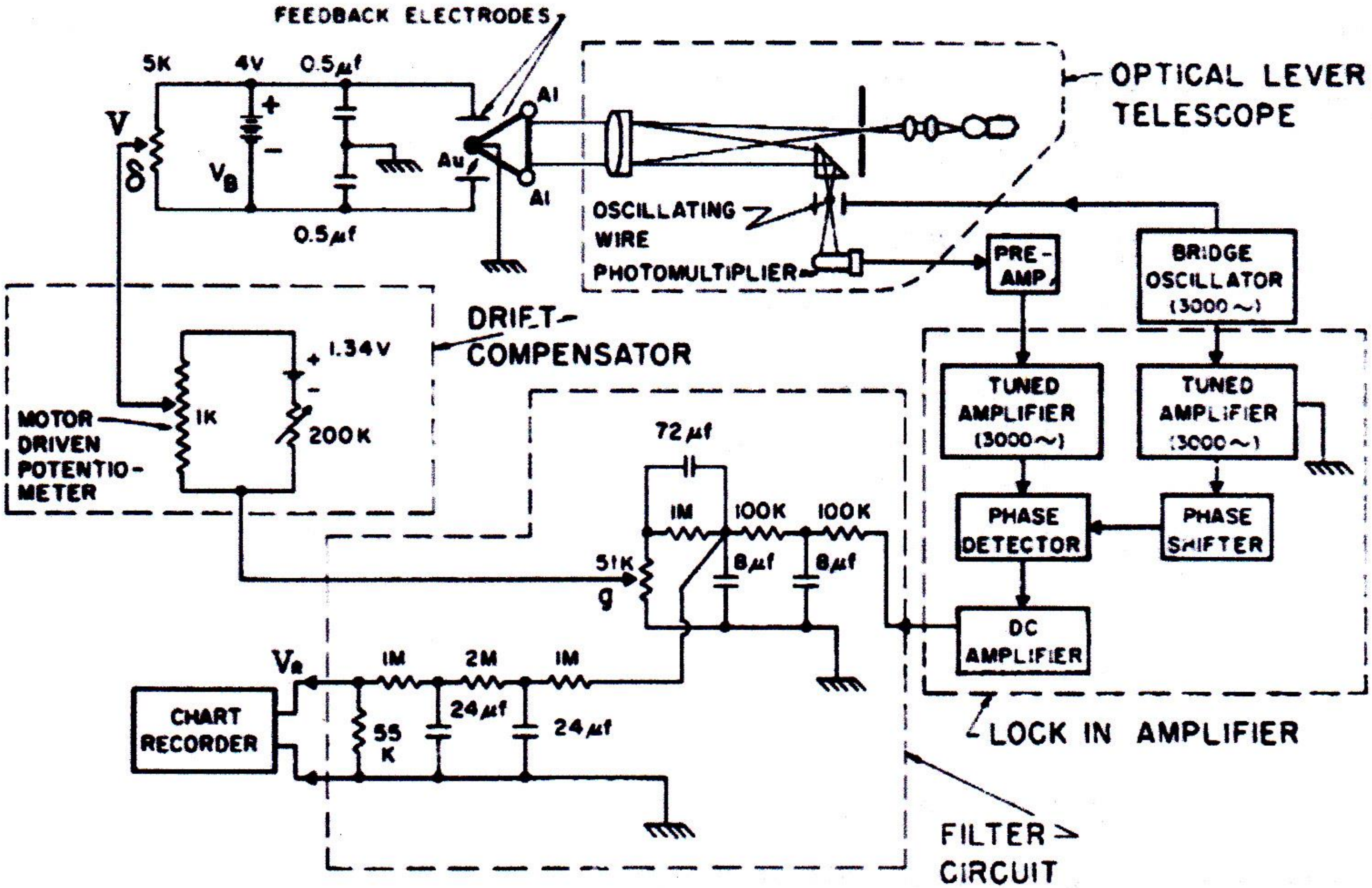


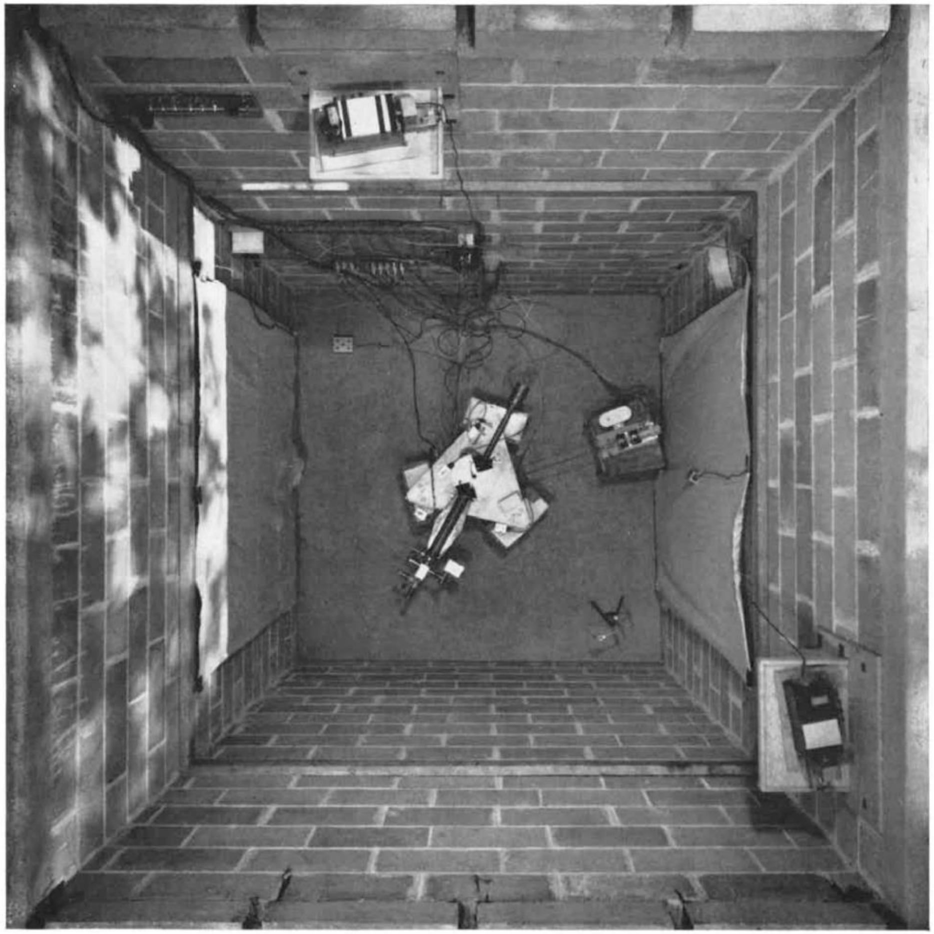

FIG. 6. Block diagram of the optical lever detection system

essential in any case, because there is no air around the balance to provide natural damping.

The whole apparatus is mounted at the bottom of a pit 12 feet deep not far from the Princeton football stadium. When an experiment is in progress, the top of the pit is sealed by a four-foot plug of thermal insulation.

In an experiment lasting several months, whose results were analyzed this past summer, we found no significant rotation of the suspended weights. Surprisingly, with all our modern techniques we have been able to improve on the accuracy of the Eötvös results only by a factor of 50. With an accuracy of about one part in $10^{10}$ we can say that the gravitational acceleration of lead and copper are equal. We hope that in a new run, soon to be started, we can extend this accuracy by another factor of 10.

Contemplating all the potential sources of error besetting such an experiment—gravitational gradients, thermal and magnetic disturbances and optical limitations—it seems almost incredible that Eötvös could have achieved the accuracy he claimed. Still, it would be a mistake, and uncharitable as well, to underestimate the technical skill that a dedicated investigator can develop through years of experience with familiar pieces of apparatus. The new experiment might have shown Eötvös to be in error, and it has not.



EXPERIMENTAL CHAMBER for the author's gravity investigation is a solidly constructed pit 12 feet deep, not far from the Princeton football stadium. The torsion balance, within its vacuum housing (all within a second chamber), rests on the center of triangular base at the bottom of the pit. The long tube projecting toward the lower left of the photograph is a telescope; the tube directly opposite is a counterweight. The whole apparatus can be rotated. The electric blankets on the walls were used to test the temperature sensitivity of the equipment. When the experiment itself is in progress, the top of the pit is sealed by four feet of thermal insulation.

# Saturday Mornings in the Lab

# *‘Introduction to Quantum Mechanics’*

Robert Henry Dicke and James P. Wittke

# One Saturday Morning with Bob Dicke
# Sum the series, 1 + 1/2 + 1/4 + 1/8 +…

**Physicist's Way (You can always have more…) and after an infinite number of requests you end up being given a total of 2 potatoes (the solution to the above sum)!**

**Mathematician's Way (Algebra)**

$$S \text{ (Sum)} = 1 + 1/2 + 1/4 + 1/8 + 1/16 + \ldots$$

$$= 1 + 1/2\,(1 + 1/2 + 1/4 + 1/8 + 1/16 + \ldots)$$

**S = 1 + 1/2 S, whose solution is S = 2.**

**In a conversation one Saturday morning, Bob Dicke told me that the first person to come up with the idea of a lock-in amplifier (phase sensitive detector) was a physics professor from Bryn Mawr College in Philadelphia and who had published this idea in the "*American Journal of Physics*."**

**(Shades of Cavendish!)**

**Why does the reflectivity of light from a flat dielectric or metal surface go to 100% as the incident light approaches grazing incidence?**

(Without appealing to Maxwell's equations)

**Dicke, one day, walking with me up the stairs (from the 1st to 2nd floor of Palmer Lab) said, “Jim, I wonder if you know how one gets into the National Academy of Sciences as I’d like to know this.”**

## APPEAR TO BE SERIOUS?

### ONE THOUGHT IN ANSWER TO THE PREVIOUS QUESTION

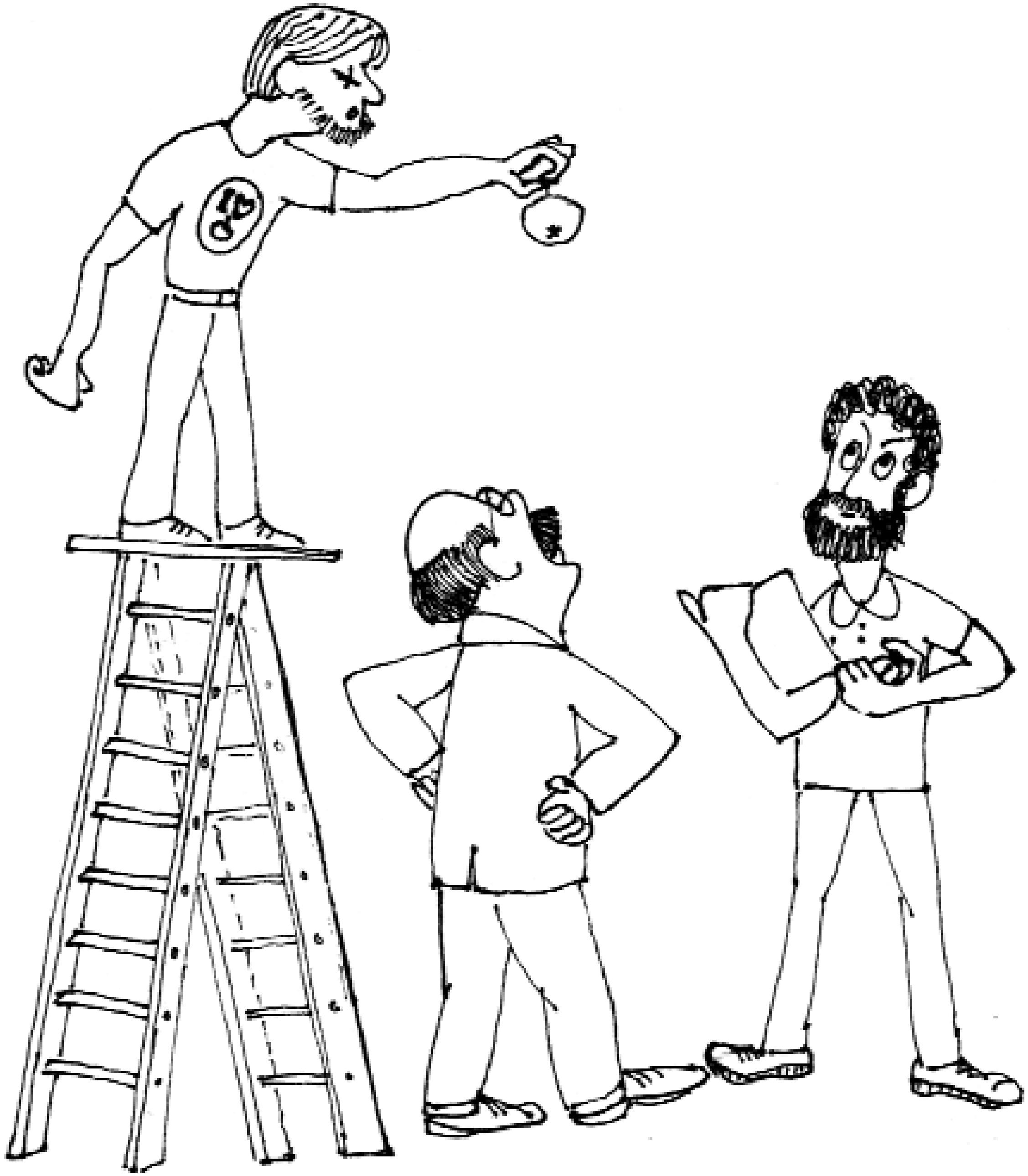
**"It took me 20 years of studied self-restraint, aided by the natural decay of my faculties, to make myself dull enough to be accepted as a serious person by the British public."**

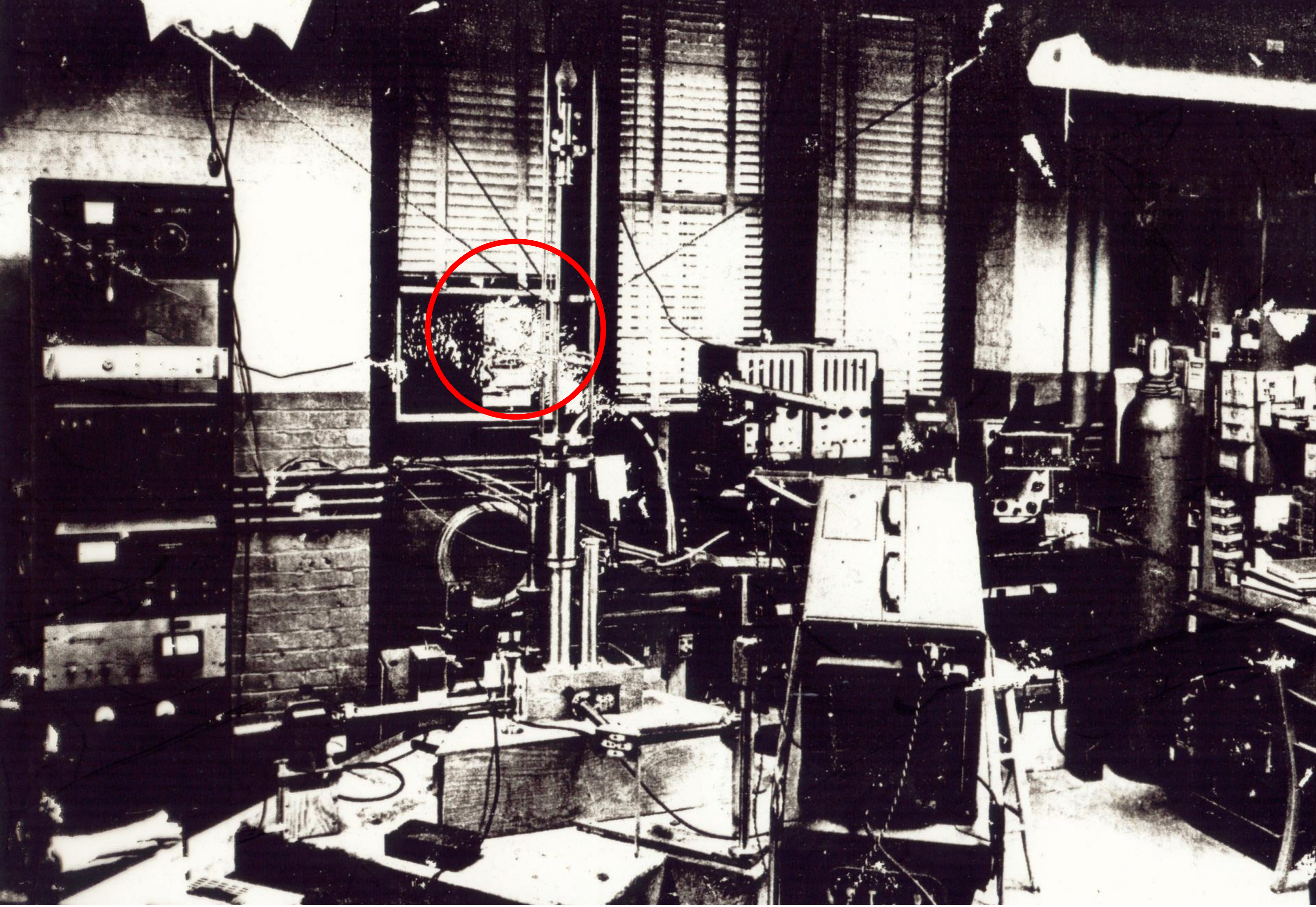
**George Bernard Shaw**

# Are scientists human?

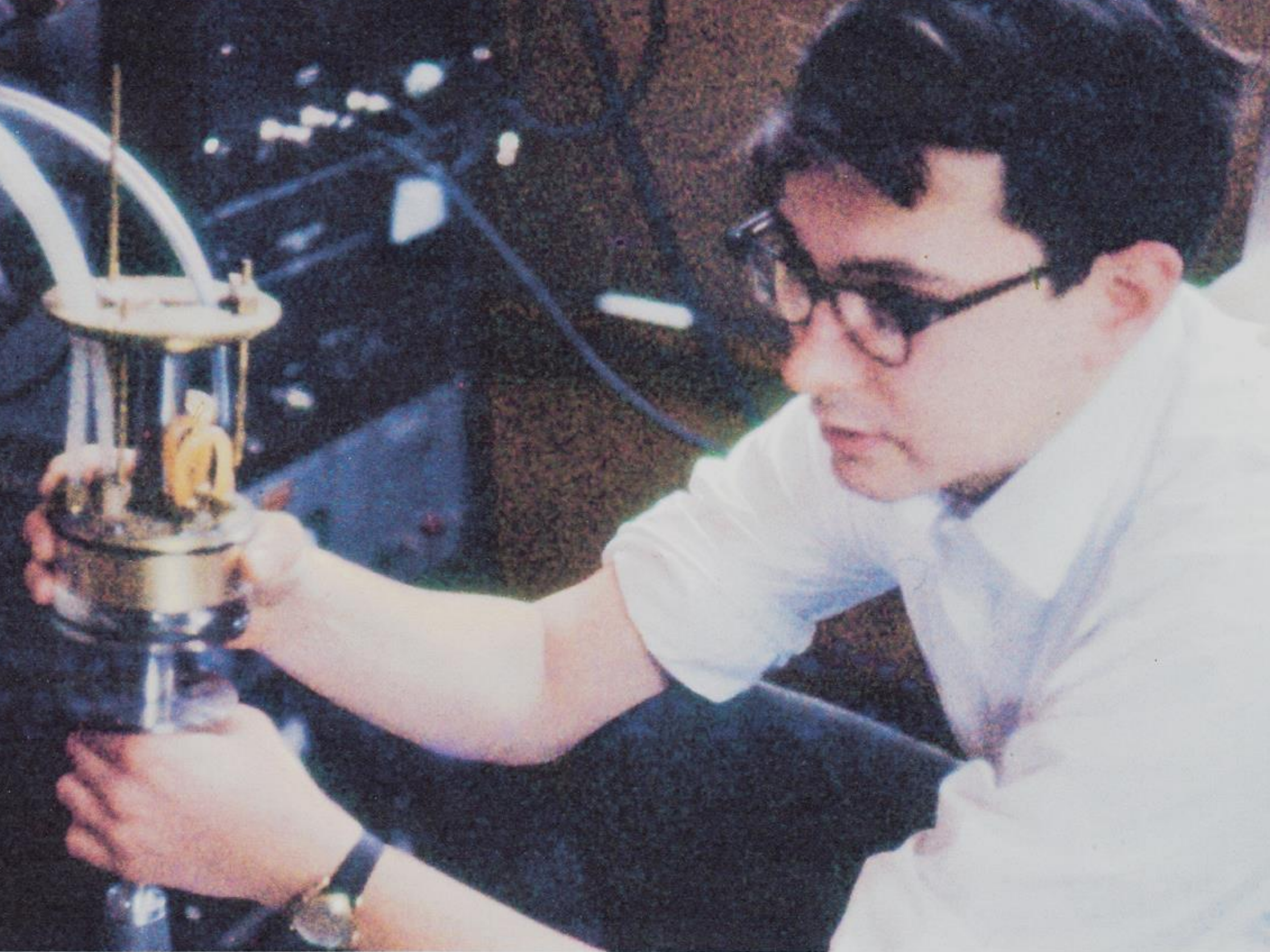
**I believe they are…for they desperately want to be seen getting the ‘right’ answer.**


Chas Addams



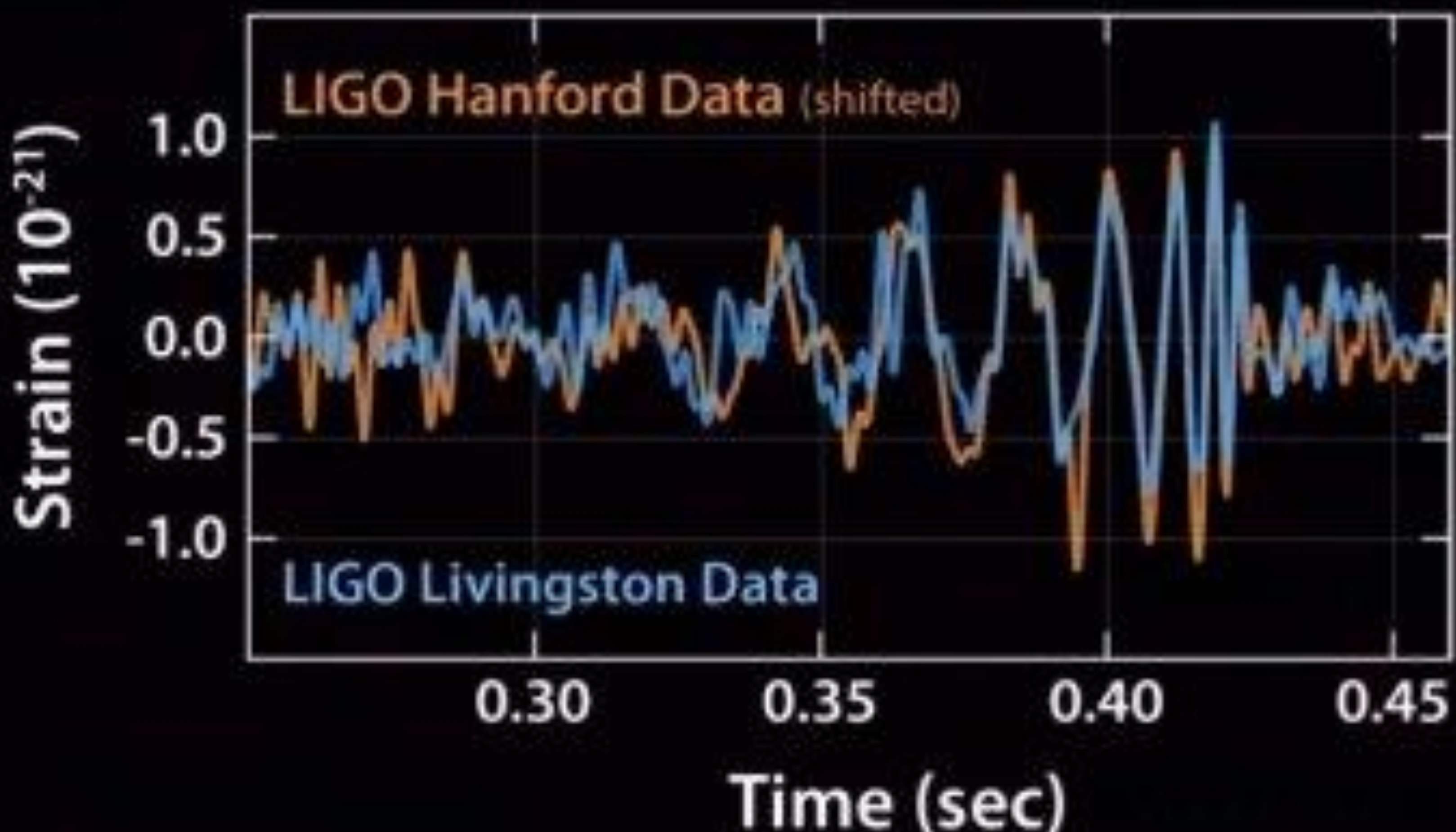


Laboratory scene from the 1950’s (lab photo)

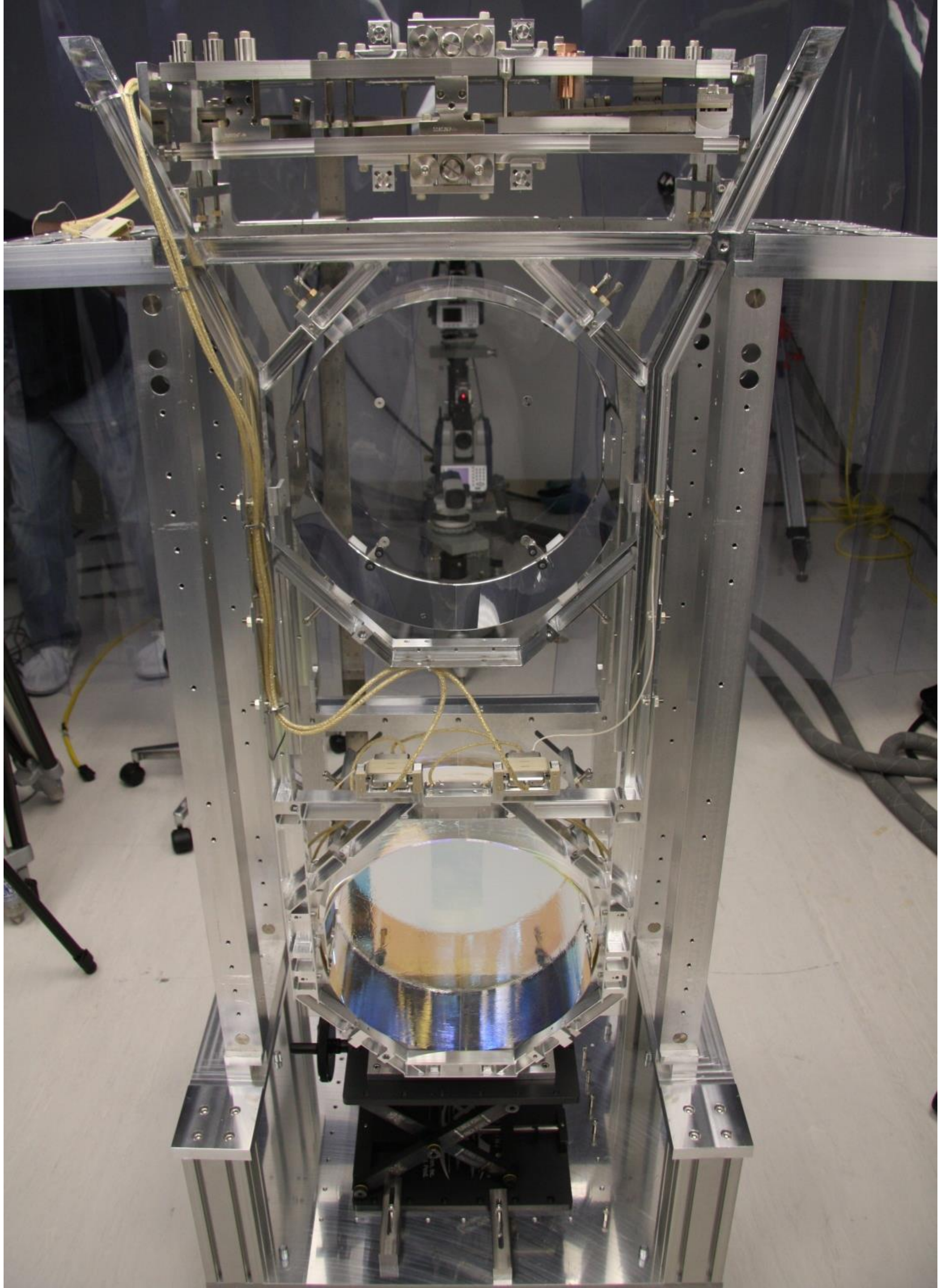


# Remembered Colloquiums

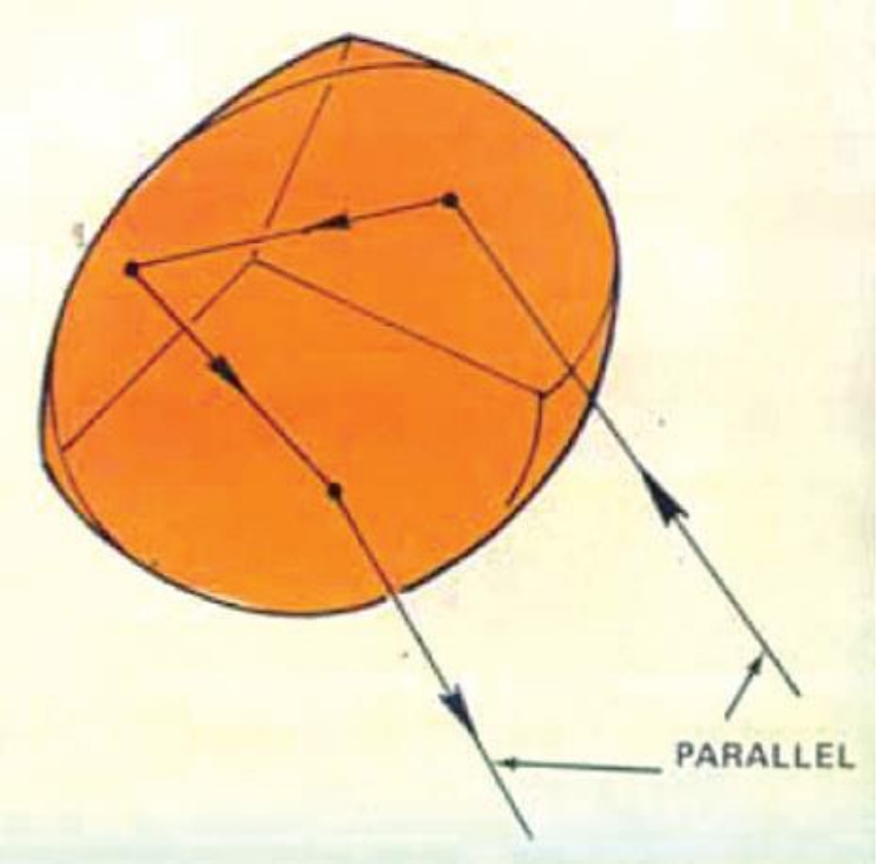
- Wu (Columbia)…Parity Violation
- Weber (Maryland)…Gravity Waves
- R.V. Jones (Aberdeen)…Design of Apparatus
- Bohr (Copenhagen)…
- …
- Javan (MIT)…He-Ne Gas Laser



LIGO Hanford Data (shifted)
LIGO Livingston Data
Strain ($10^{-21}$)
1.0
0.5
0.0
-0.5
-1.0
0.30
0.35
0.40
0.45
Time (sec)




Newport


PARALLEL

Perhaps we could discuss this.
Bob D.

Professor Dicke,
Would you see if this makes any sense.
Jim Faller

A Proposed Lunar Package
(A Corner Reflector on the Moon)

This note describes what is felt to be both a useful and at the same time a practical lunar package. The total weight involved would be only 2 to 3 pounds, and it could be constructed to withstand a rather hard landing. Once there, the only requirement for it to function successfully is that its landing leave it free to bounce and roll until it comes naturally to rest. This lunar package containing an optical corner has been built.

Recently there has been considerable discussion concerning the possibility of bouncing a laser off the moon and detecting the reflected light returning to the earth. This would permit a precise earth-moon distance measurement to be made. (The distance here being measured to one of the larger maria.)

In order for this to be done, a rather large aperature is needed to collect the reflected photons as is seen from the following calculation: 30 joules/laser burst $\sim 10^{20}$ photons/burst

All the photons will hit the moon and scatter back into a solid angle of approx. $2\pi$ steradians. The number of ~~reflected~~ the reflected photons that will be collected is given by

$$\frac{\text{solid } \angle \text{ of collector}}{2\pi} = \left(\frac{30}{4\times 10^{10}}\right)^2 \Big/ 2\pi$$

if we use a 12" (30 cm.) telescope. Assuming 1/10 of the photons which hit the moon are reflected, the number collected by our telescope will be:

$$10^{20} \times \frac{1}{10} \times \frac{30^2}{(4\times 10^{10})^2} \times \frac{1}{2\pi} \sim 1 \text{ photon/laser burst.}$$

which is not very encouraging. (With a 100" telescope one collects ~ 81 photons/laser burst.)

The lunar package proposed here would permit a substancial improvement to be made in the number of returning photons that are collected. First note that for a fixed payload (all other things being equal) it would be best to put a single large corner on the moon rather than a lot of smaller ones. This may be seen as follows: Number of corners $\sim \frac{1}{l^3}$ ($l$ = linear size)

Collecting area for light offered $\sim$ Number of corners $\times\, l^2$ or $\sim \frac{1}{l}$

The size of the sopt on earth resulting from diffraction in the corners affecting the returning photons is given by

$$\left[2 \times \frac{\lambda}{l} \times (\text{Earth-Moon Distance})\right]^2 \sim \frac{1}{l^2}$$

It therefore follows that the efficiency which is proportional to collection area on moon/diffraction area on earth $\propto l$.

Therefore So it is better, so to speak, to put all the photons in one corner. In practice (to minimize the possibilities of landing mishaps) it would be best to place several corners one the moon rather than "the ideal" single corner reflector.

A one-pound corner cube (the one used in the model package) offers a collection area of apporx. 40 cm$^2$. Using a 12" (30 cm.) telescope to set the diffraction size of the spot on the moon (an idealization neglecting practical difficulties both in reference to actual lasers and to atmospheric disturbances), the area on the moon is given by:

$$\left(2 \times \frac{8\times10^{-5}}{30} \times 4\times10^{10}\right)^2 \sim 3\times10^{10}\ \text{cm}^2$$

The number of photons returned will be those collected, namely:

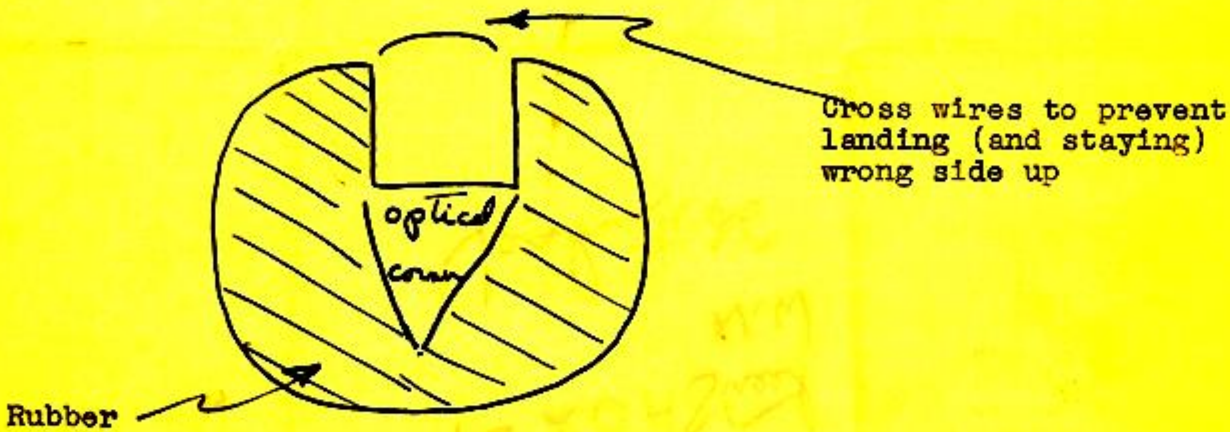
$$\frac{40}{3\times10^{10}} \times 10^{20} \sim 10^{11}\ \text{photons/burst}$$

These will form a larger patch on the earth due to the smaller size of our corner (compared to our 12" telescope), but ~~not~~ now we have a larger photon collecting area. The net effect of this is that we again ~~lose~~ ~~loose~~ lose by the same factor, namely $10^{-9}$ resulting

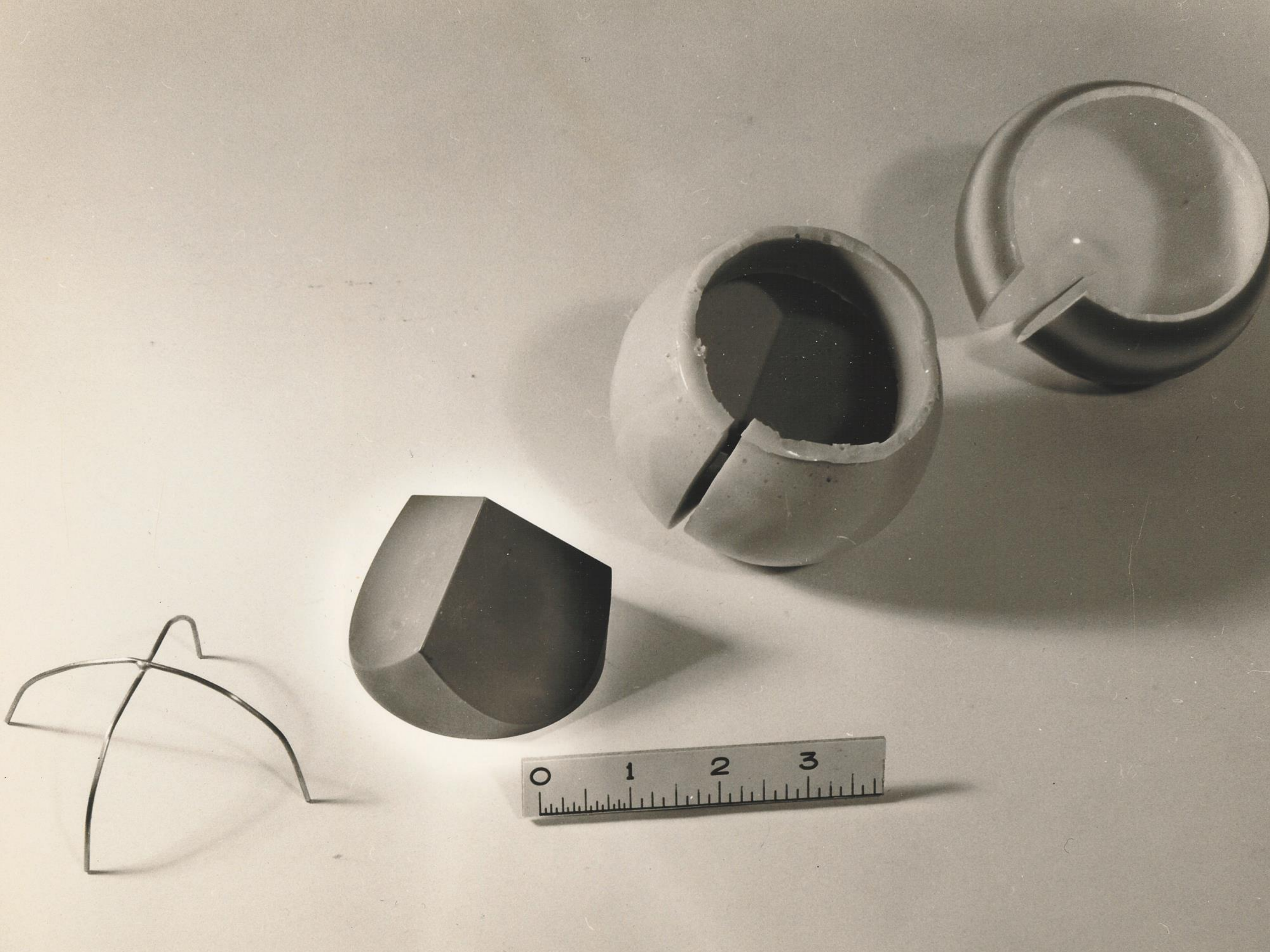
... Here, in principle, the number of photons collected goes as the forth power of the telescope aperature so that going to a larger telescope is even more useful ~~than~~ than in the case of bouncing photons simply off the moon where improvements are only proportional to the square of the aperature.

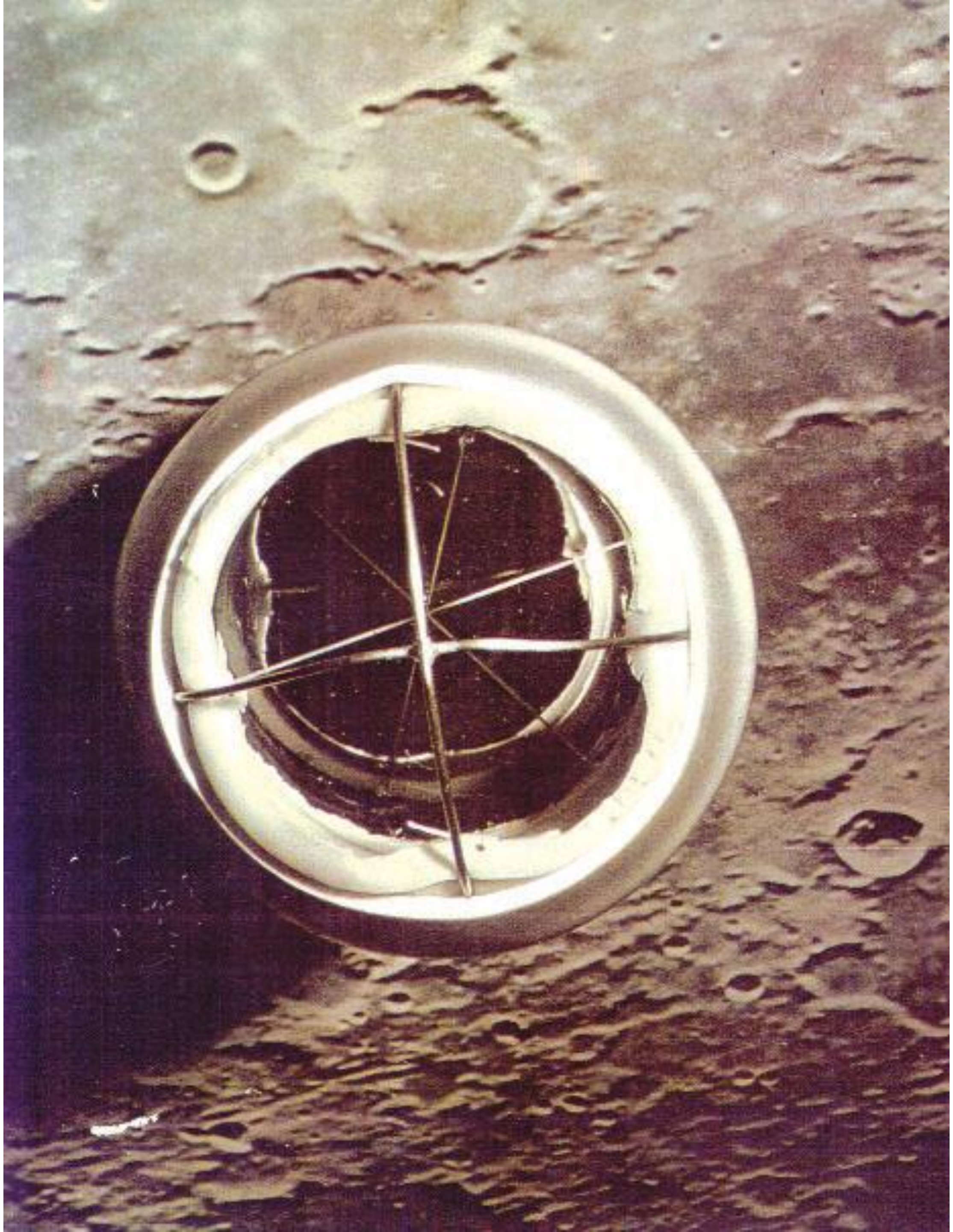
In addition to permitting the afore-mentioned experiment, a group of corners on the moon would provide the long-desired marking stripes on the moon and thereby permit precise period measurements to be made. The moon would then be a precision gravity clock.

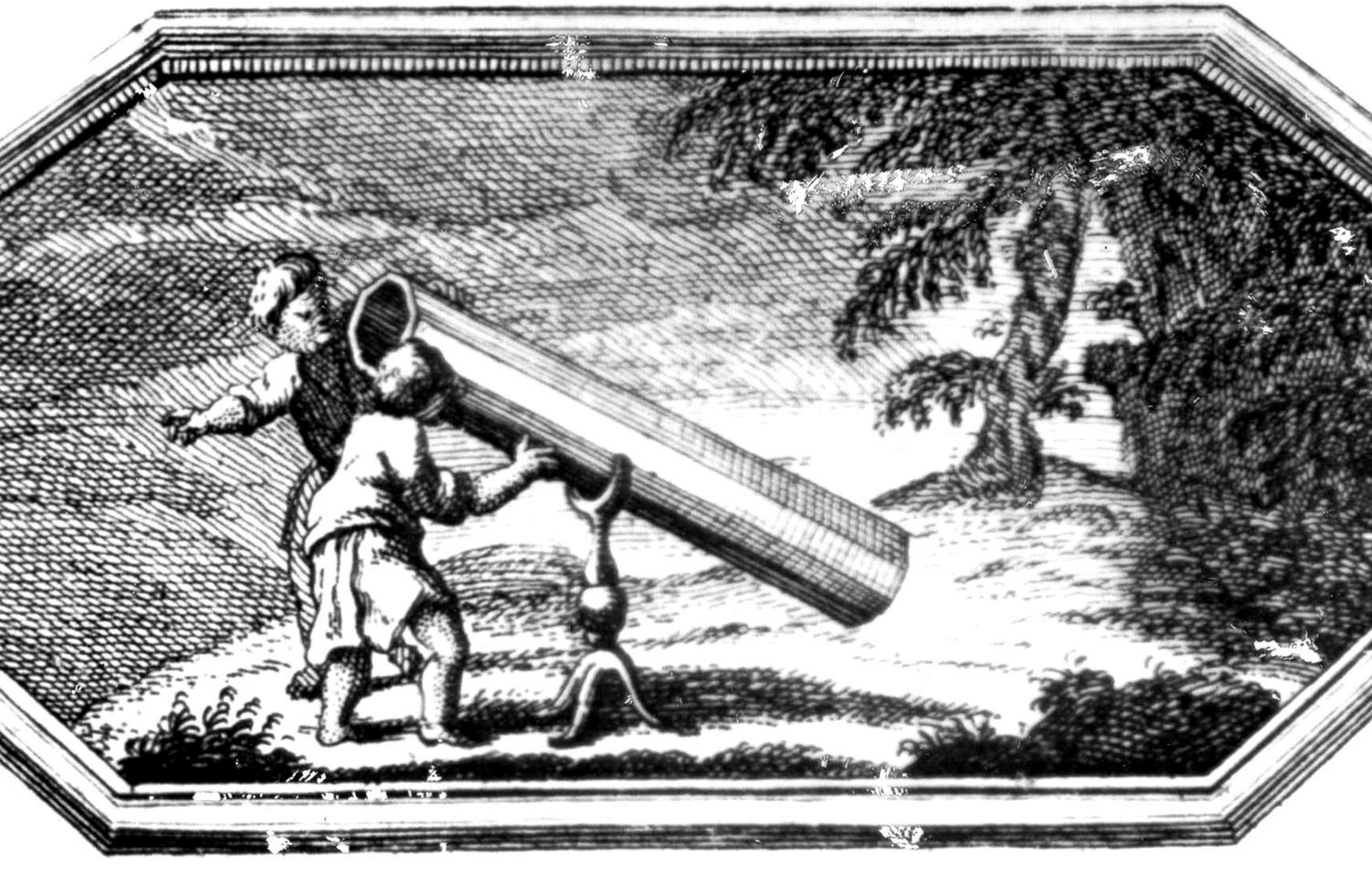
Proposed package (cross section)



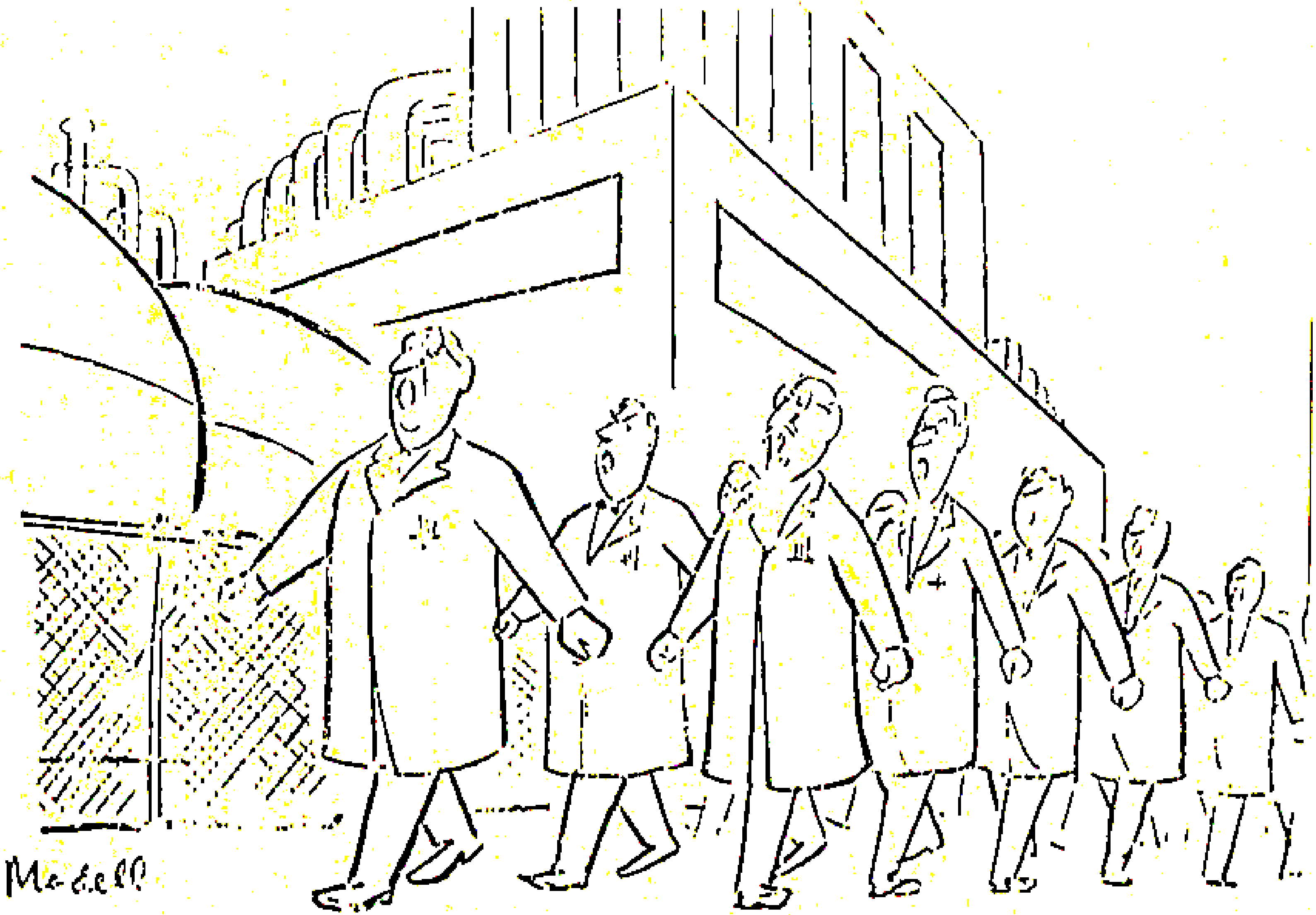

Note that the COM is arranged to be below the center of the ball when the corner is properly positioned, and therefore the package will position itself with the corner pointing up.


0 1 2 3





**The late 1950s and the early 1960's was a great time to be a physicist!**



"From the cyclotron of Berkeley to the labs of M.I.T.
We're the lads that you can trust to keep our country strong and free."

1958

# Post doc at JILA with Peter Bender

- While at JILA started Jim Hammond worked on laser based absolute gravimeter to measure little g to 5 parts in $10^8$ using a just then available commercial Lamb-dip stabilized laser.
- Told Peter and Jan Hall my idea for laser ranging to the moon.
- Started Spencer Weart on eclipse experiment using the moon to get high (seeing-free) height resolution in the solar chromospheres.
- Taught Al Bartlett’s ‘physics for poets and pre-meds’ course while he was on sabbatical at Harvard using Eric Roger’s “Physics for the Enquiring Mind” as the text.  My first teaching attempt was a huge success and there were none of the predicted coke bottles rolling down the isles.
- Started working on the optimum-sized corner-cube array for placement on the Moon.

- And was told by JILA’s NBS Division Chief, Lewis Bransomb, that my research interests didn’t fit into JILA’s  idea of ‘laboratory astrophysics’ so I eventually would have to go.
- Left for Wesleyan three months later and took Ed Williams (a JILA graduate student) with me to work on a high precision test of Coulomb’s law and the photon rest mass experiment.
- Continued LLR as member of LURE team

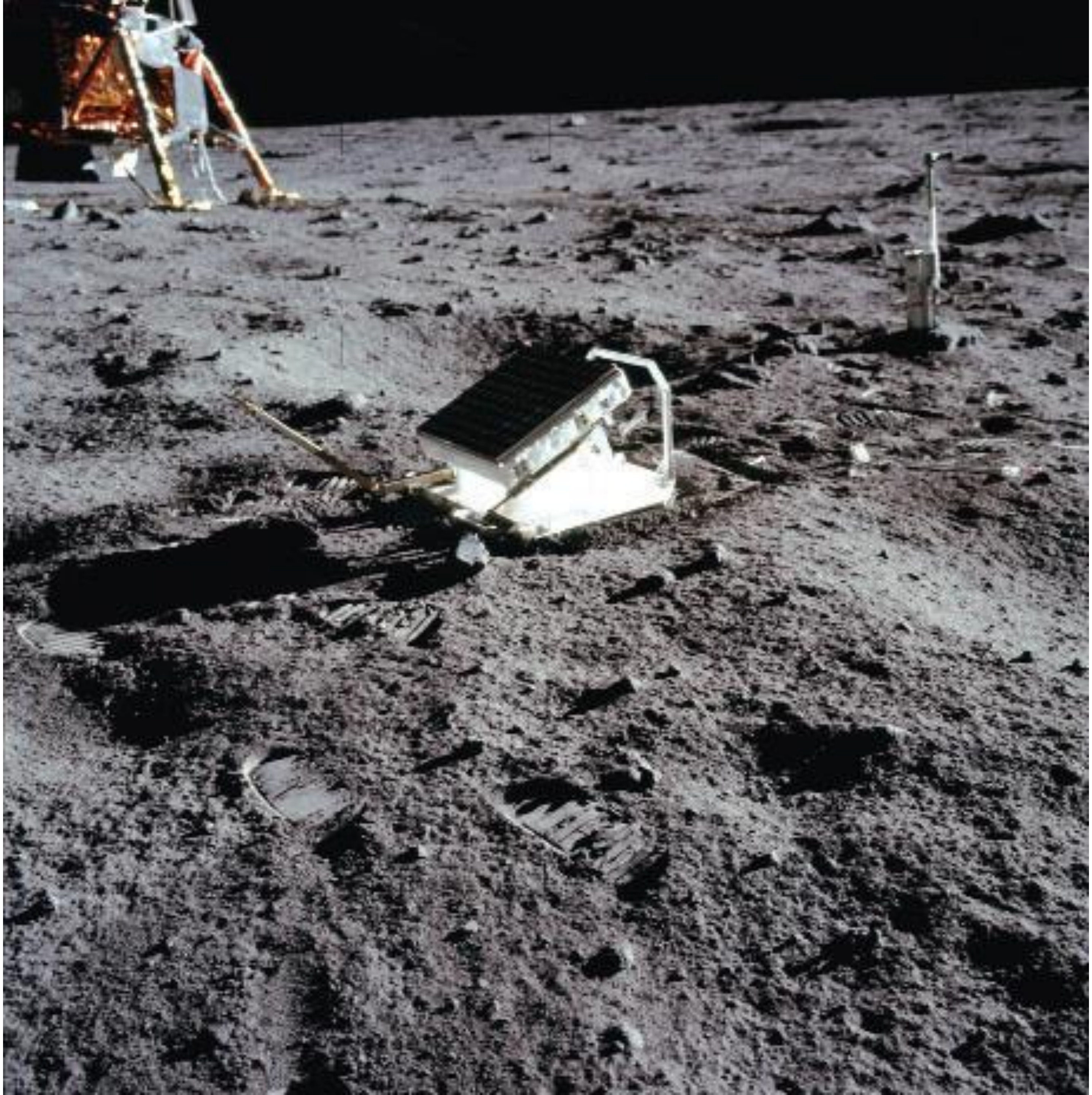
# Wesleyan Period

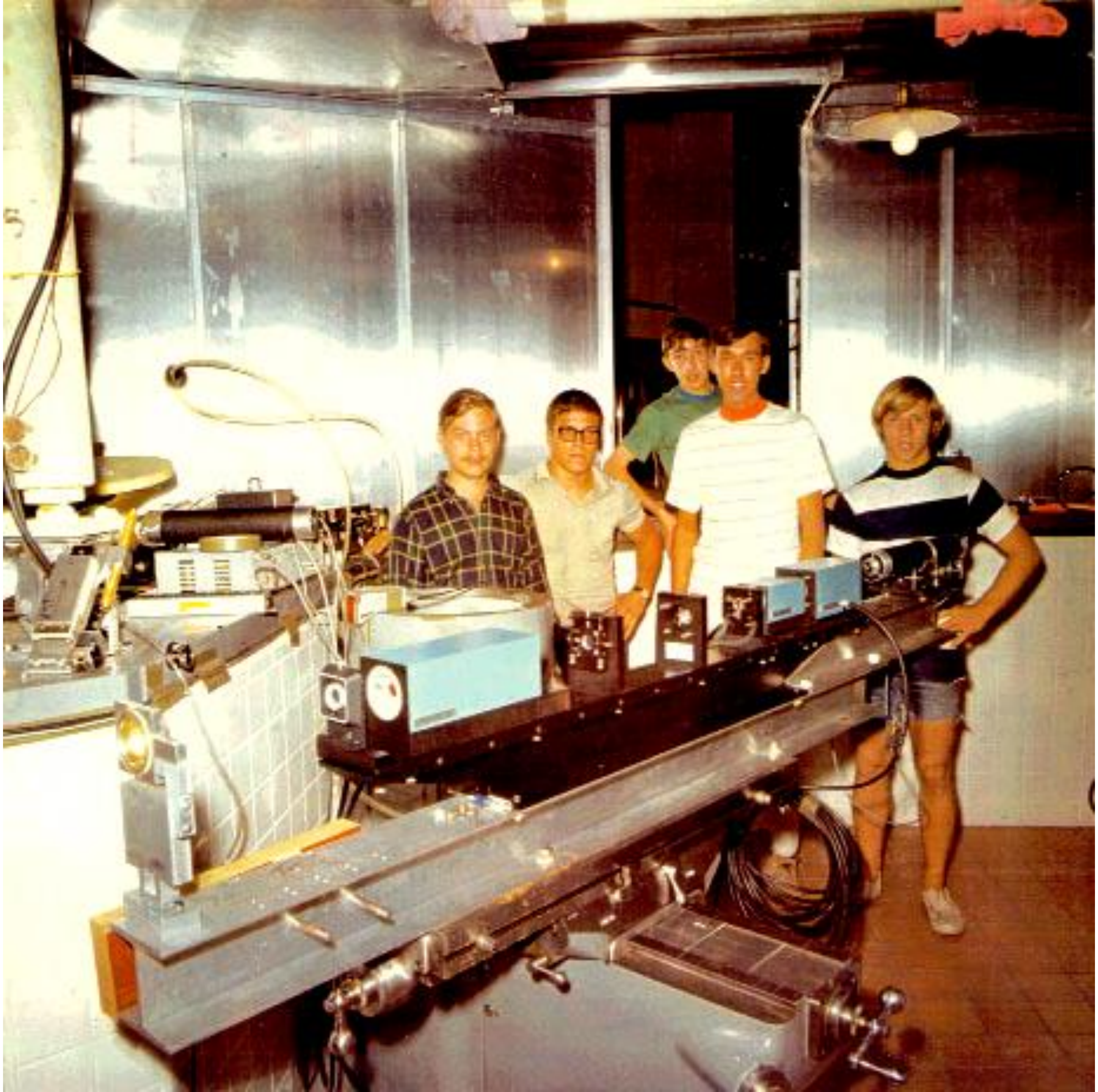
# Don’t Kick The Shits

**Bob Singleton**

**Chair, at that time, of**
**Wesleyan University’s**
**Math Department**

- With Ed Williams and Henry Hill carried out best at that time experimental test of Coulomb’s law.
- Eclipse experiment with Spencer Weart
- Bob Rinker was admitted by Wesleyan but applied to and was accepted CU when he learned I would be returning to JILA
- Completed design for Lunar retroreflector array.



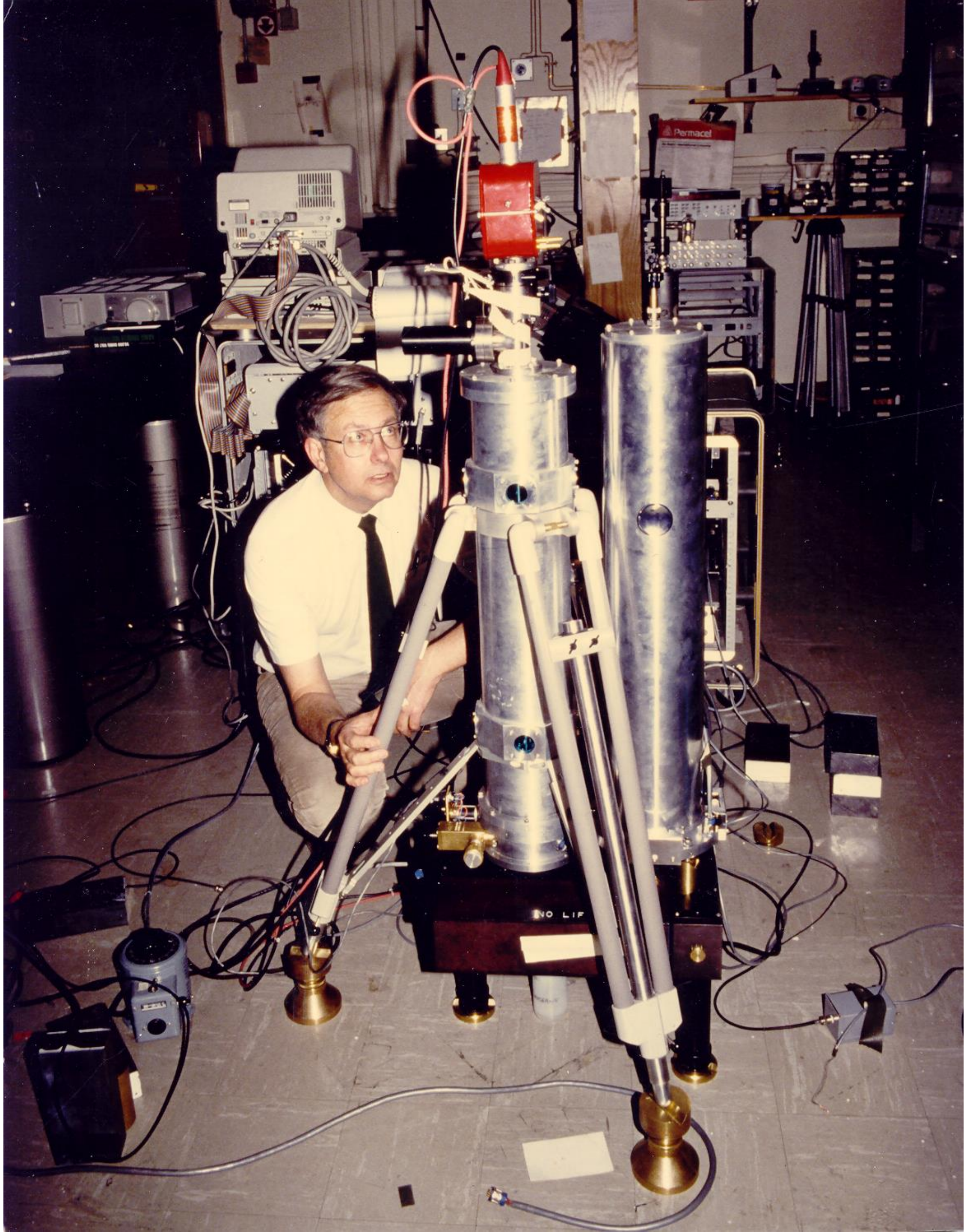


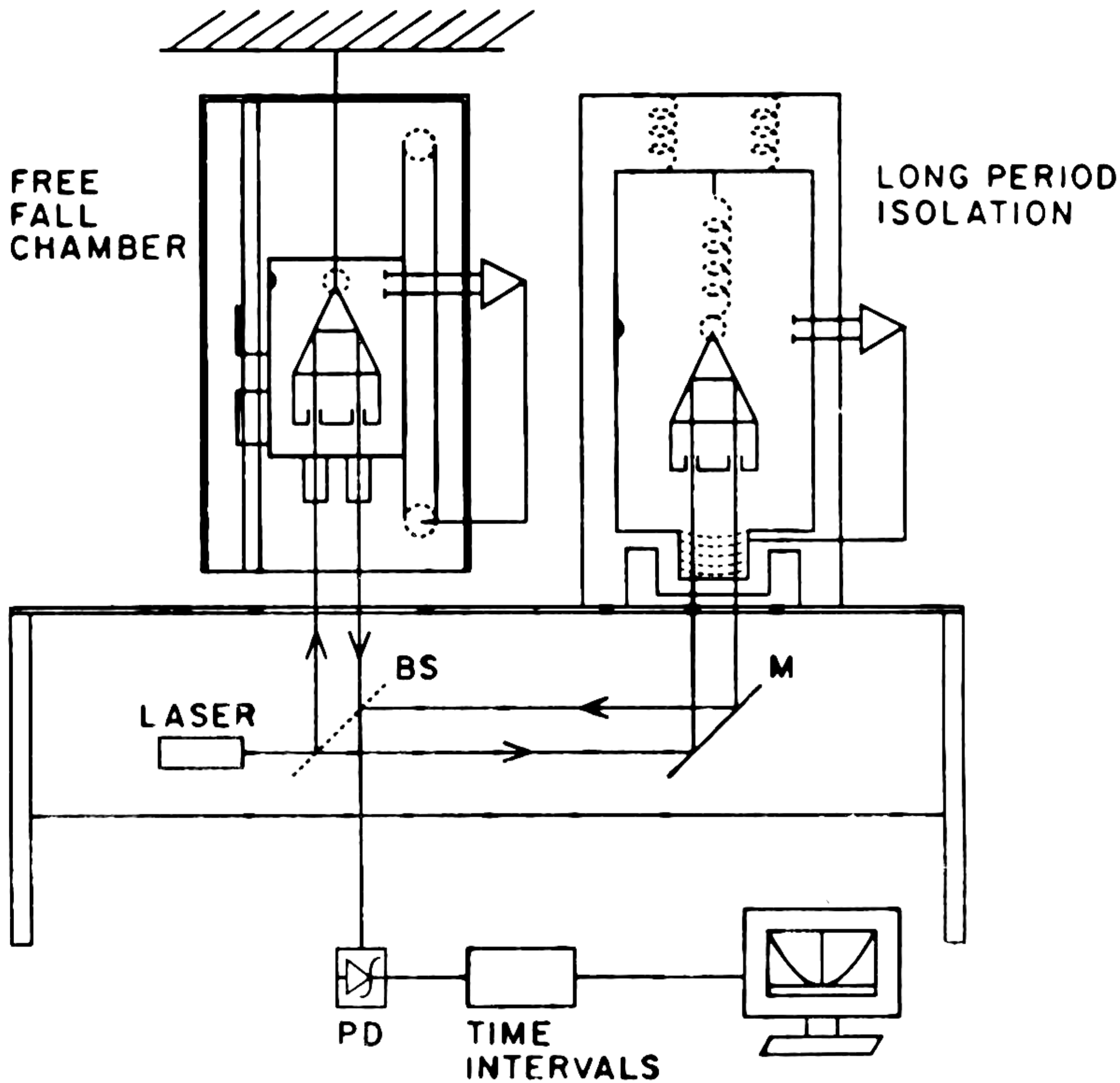
Lick successfully ranged to the retro-reflector array on the Moon on August 1, 2019.

- **Was called some three years after leaving JILA by Lewis Branscomb who told me he had made a mistake…and would I come back to JILA.**
- **In 1971 returned to JILA**

# Back to JILA

1971

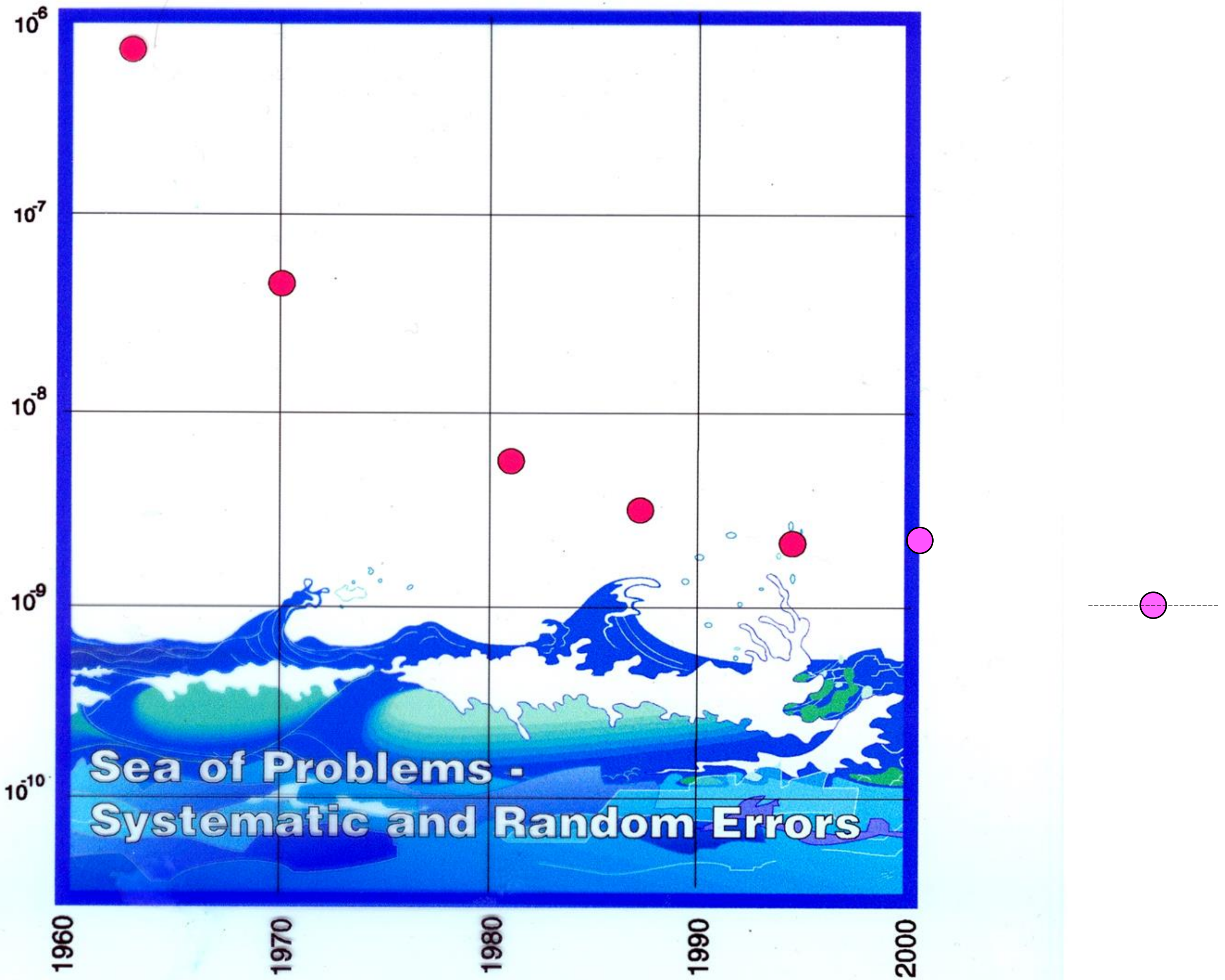

Permacel


FREE
FALL
CHAMBER
LONG PERIOD
ISOLATION
BS
M
LASER
PD
TIME
INTERVALS

# SUPER SPRING

**Though the Super Spring concept was initially developed to provide isolation for the reference arm corner cube in absolute gravimeters, it has since served as the basis for various isolation tables including the isolation tables used in the LIGO gravitational wave detection—though they forgot to reference our contribution!**

# Measurement Accuracy of Little g Versus Time



**Universities and National Institutions are like game preserves.  They provide an environment where certain types of people can survive far better than they would survive in the "real world". But, given this, the inhabitants of these preserves owe something in return to those who pay for the "fence."**

# At Washington AP
# APS Meeting
# I Lied to Dicke—Only Time
# “Have you eaten yet?”

…

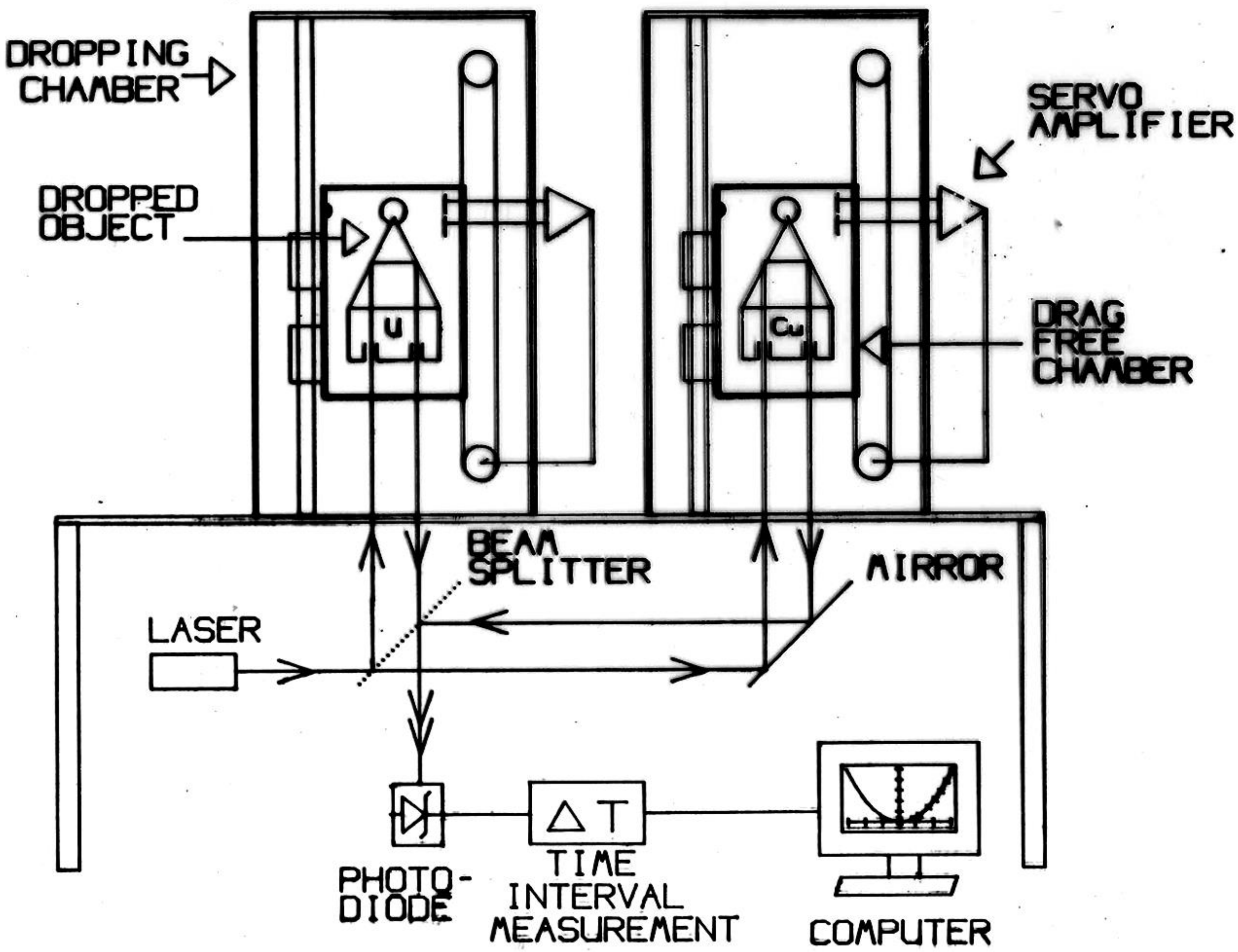
‘Oh no sir’

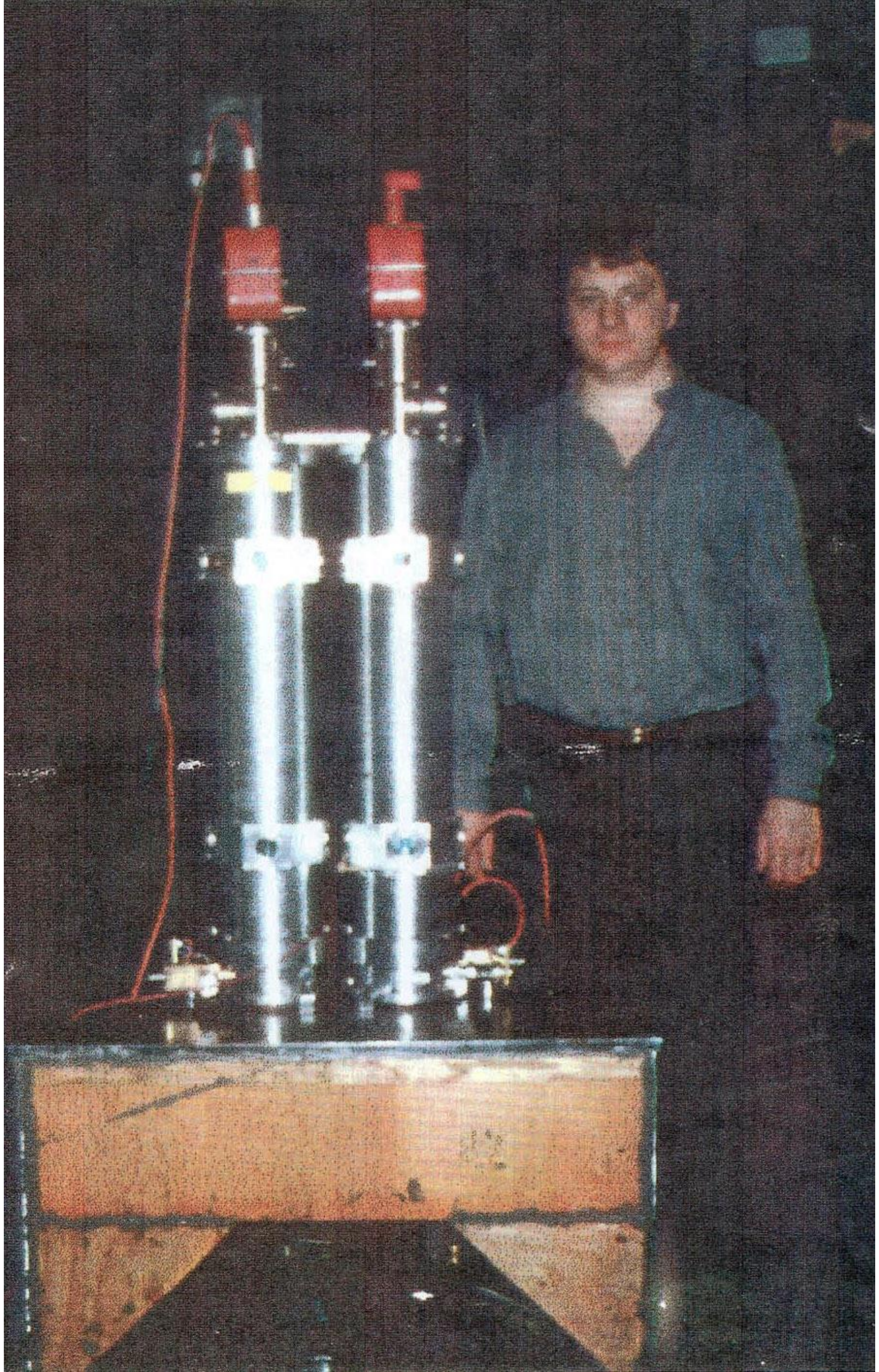
Had diner with Bob and Hans Dehmelt

In Washington D.C. Fish Restaurant

# Two JILA-based Eötvös Experiments

# GALILEAN APPARATUS





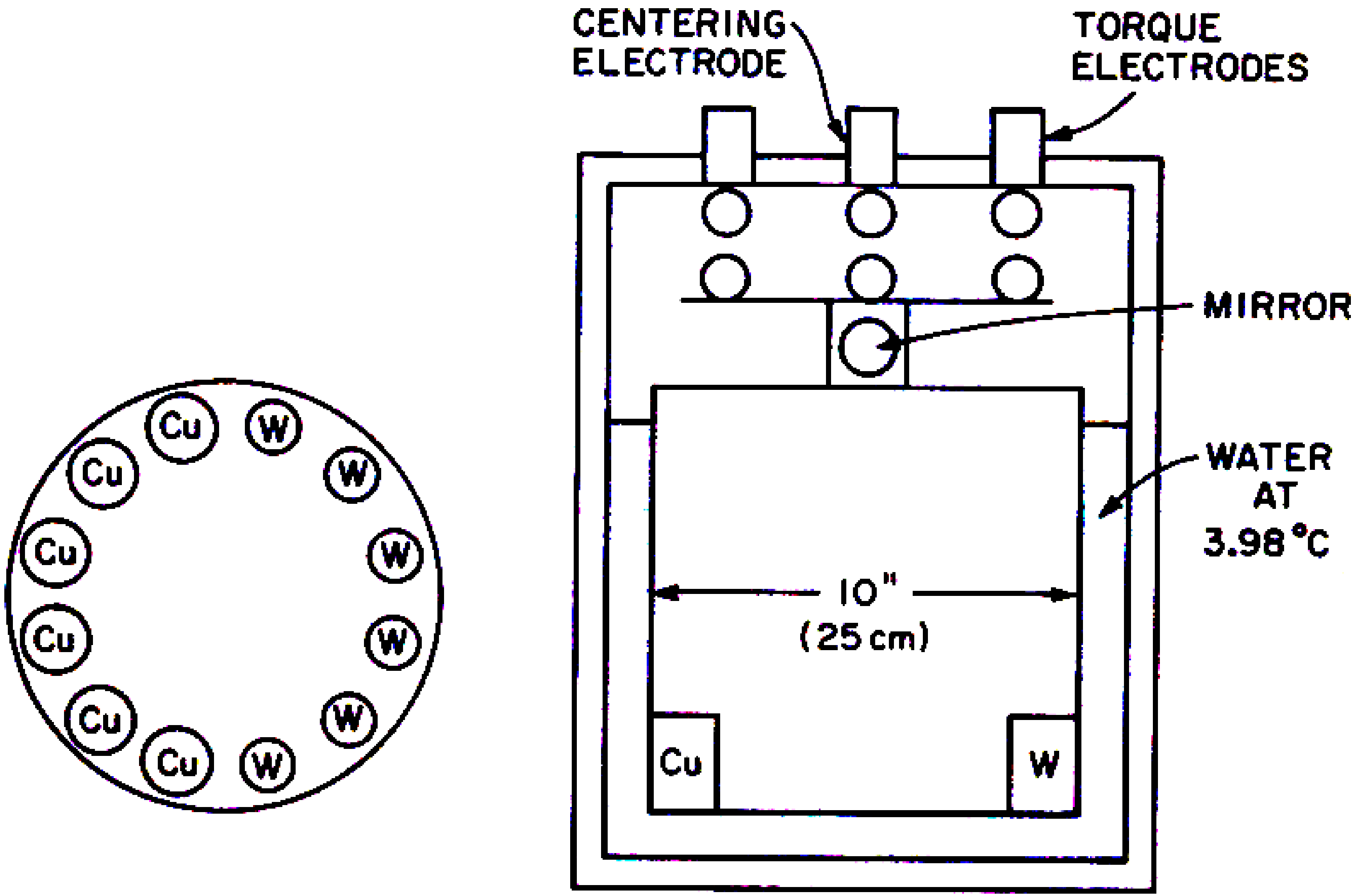
)CEEDINGS OF THE SECOND MARCEL GROSSMANN
..EETING ON GENERAL RELATIVITY
R. Ruffini (editor)


# EÖTVÖS EXPERIMENT WITH A FLUID FIBER

G. M. Keiser[*†] and J. E. Faller[‡]

Joint Institute for Laboratory Astrophysics
University of Colorado and National Bureau of Standards
Boulder, Colorado 80309

Recent work aimed at an improved Eötvös experiment is described. Copper and tungsten test masses are contained in a cylindrical float supported by the buoyancy of water which is held at its maximum density point. Electrostatic forces are used to keep the float centered and to provide the torsion constant. Sources of noise associated with convection currents, magnetic fields, seismic noise, changing gradients in the gravitational field, long term drifts in the position detector, and Brownian motion are described, and recent experimental results are presented.



Cu
Cu
Cu
Cu
Cu
Cu
W
W
W
W
W
W
CENTERING ELECTRODE
TORQUE ELECTRODES
MIRROR
WATER AT 3.98 °C
10"
(25 cm)
Cu
W

$$\eta = 0.6 \text{ +/- } 2 \times 10^{-11}$$

$$\eta = 0.6 \text{ +/- } 4 \times 10^{-11}$$

**Spoke at**

PRINCETON UNIVERSITY 's

# *Dicke Day*

8 MAY 1976

SIXTIETH BIRTHDAY
SYMPOSIUM IN HONOR OF
ROBERT HENRY DICKE

*The evolution of physical science is marked by bursts of activity as the time becomes ripe for new techniques and new directions of research. How much there is to be done if only one can think how to go about it! No happier example does physics provide of one who dreams, designs, and does, than Robert Dicke, some of whose many contributions to modern physics form the topics of this symposium.*

## PARTICIPANTS

Carroll O. Alley, Jr.
Peter L. Bender
E. R. Beringer
Carl Brans
James Brault
Dieter Brill
Curtis Callan
Thomas Carver
Thomas Coor
Robert H. Dicke
James E. Faller
Val L. Fitch
Marvin L. Goldberger
H. Mark Goldenberg
Edward Groth
W. Bruce Hawkins
Paul Henry
Henry Hill
Robert Krotkov
Edward Lambe
Edward Loh
B. Edward McDonald
Charles W. Misner
R. Bruce Partridge
P. James E. Peebles
Alexander Pond
William H. Press
Edward M. Purcell
I. I. Rabi
George T. Reynolds
Allen G. Shenstone
Rubby Sherr
Claudio Teitelboim
Kip S. Thorne
Kenneth C. Turner
Rainer Weiss
John A. Wheeler
Milton G. White
William Wickes
David T. Wilkinson
James P. Wittke

## PROGRAMME

### I. ELECTRONICS, ATOMIC PHYSICS AND PRECISION MEASUREMENTS

9:30 a.m. Professors' Room, 218 Jadwin Hall

*Edward M. Purcell* — A Report from Group 41, M.I.T. Radiation Laboratory

*James P. Wittke* — The Early Years at Princeton

*Peter L. Bender* — A New Generation of Clocks?

12:00 Noon Lunch, Presidential Dining Room, Prospect

### II. GRAVITY PHYSICS

2:15 p.m. Professors' Room, 218 Jadwin Hall

*Kip S. Thorne* — The Theoretical Significance of Experimental Gravitation

*Robert Krotkov* — The Eötvös Experiment

*H. Mark Goldenberg* — Reflections on Solar Oblateness

*David T. Wilkinson* — The Microwave Background

*P. James E. Peebles* — The Search for Variation of the Fine Structure Constant

*James E. Faller* — Lunar Ranging: Status and Results

*Rainer Weiss* — Experimental Relativity: Prospects

5:30 p.m. 30 Maxwell Lane, off Mercer Street Road, cocktails and buffet supper

# Fine Hall Graffiti

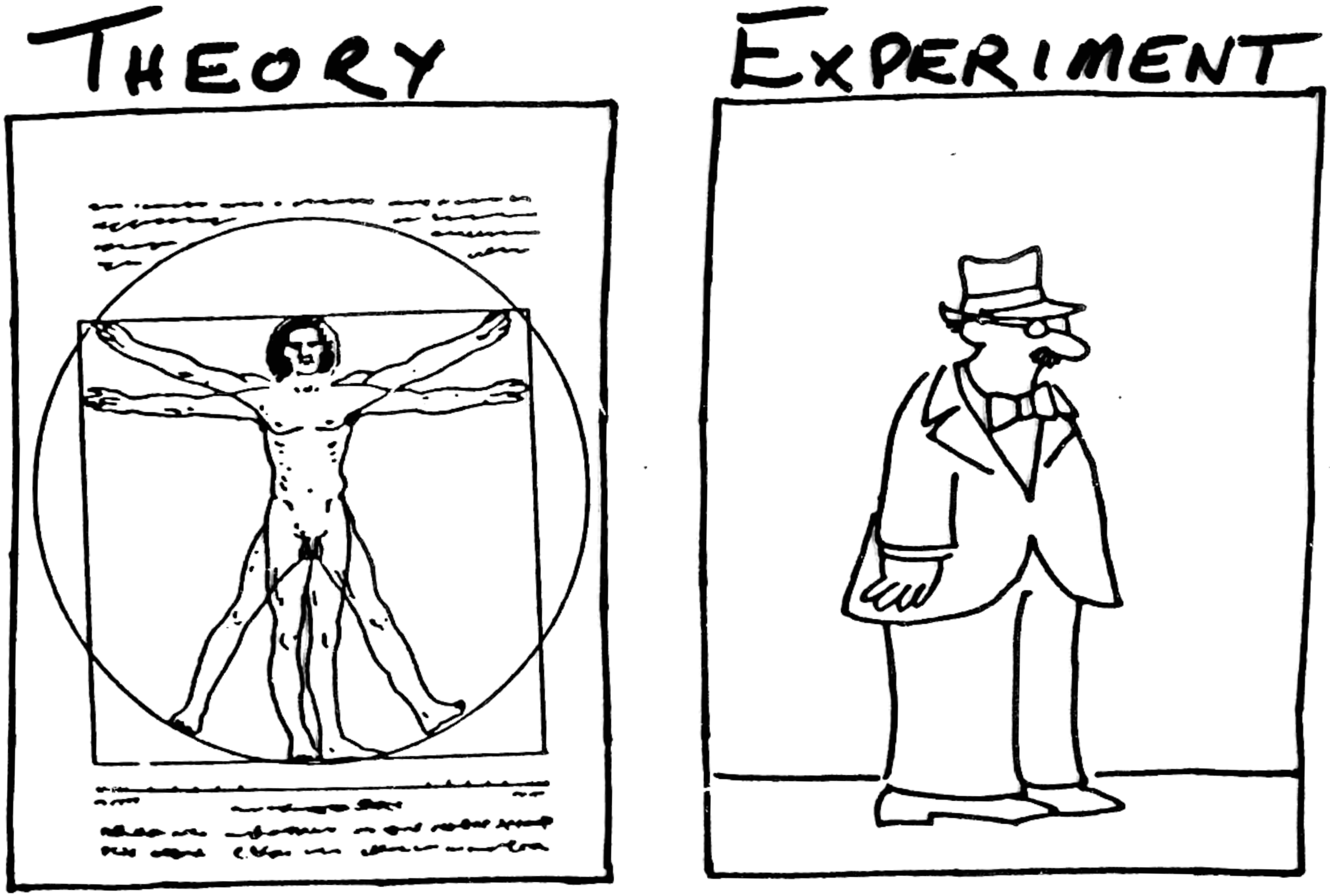
(Men’s Room, Princeton Mathematics Department circa 1960)

$$2+2 = 5$$

…for large values of 2

# Benedictory (Closing) Thoughts

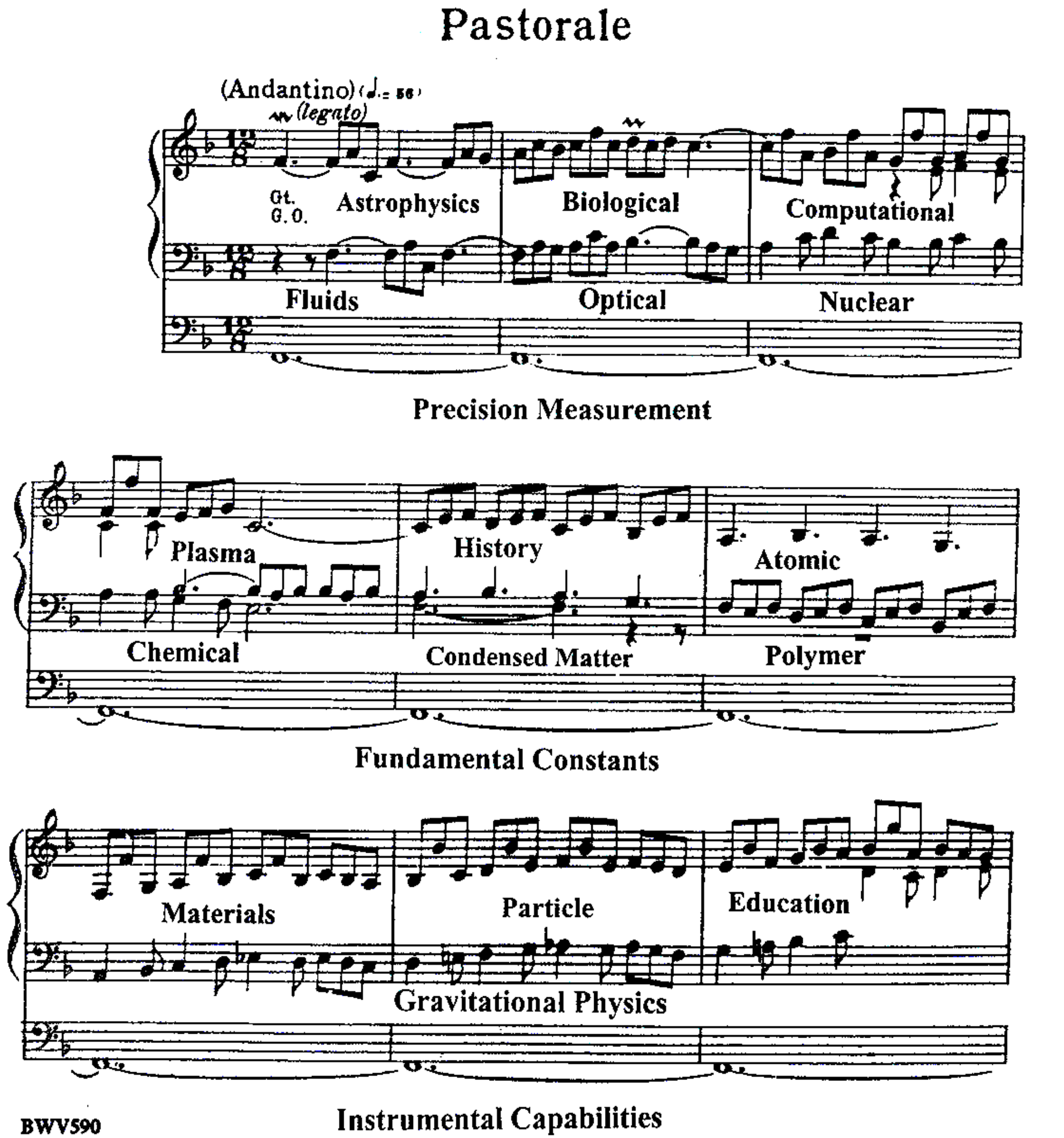

220


THEORY
EXPERIMENT


**It is oftentimes difficult to recognize the source of a problem!**

**“More things are known than are actually true.”**

**J. R. Pierce**




**Embellished Pastorale in F (Johann Sebastian Bach)**

**“A month or two in the laboratory will save you an hour in the library”**

**Experimental Physicist’s Motto**

"I have little patience with scientists who take a board of wood, look for its thinnest part, and drill a lot of holes where drilling is easy."

Albert Einstein

**Gravitational Physics**
**and**
**Precision Measurement**
**are both a**
***very* thick board.**

# Lunar Laser Ranging

This experiment made it possible, for the first time, the equivalence of free fall of gravitational energy with other types of energy/matter. They all fall at the same rate!

Einstein would be pleased but I think not surprised.

And what role did the Lick observations play…? They contributed the important and essential "existence theorem" that the array was working! Additionally where it was precisely located on the moon, and also its range.

“I would have been disappointed had mere physical strength ever proved superior to skill and maneuverability”…in an other words ‘grace’.

John Wooden

On ‘how to do physics’… following UCLA’s defeat of Kentucky in the 1975 NCAA basketball final dark. The time seemed to pass very quickly with all the party. Kate went first, leaning upon her brother's arm, and talking with him and Mr. Frank Cheeryble; and Mrs. Nickleby and the elder gentleman followed at a short distance, the kindness of the good merchant, his interest in the welfare of Nicholas, and his admiration of Kate, so operating upon the good lady's feelings, that the usual current of her speech was confined within very narrow and circumscribed limits. Smike (who, if he had ever been an object of interest in his life, had been one that day) accompanied them, joining sometimes one group and sometimes the other, as brother Charles, laying his hand upon his shoulder, bade him walk with him, or Nicholas, looking smilingly round, beckoned him to come and talk with the old friend who understood him best, and who could win a smile into his care-worn face when none else could.

Pride is one of the seven deadly sins; but it cannot be the pride of a mother in her children, for that is a compound of two cardinal virtues—faith and hope. This was the pride which swelled Mrs. Nickleby's heart that night, and this it was which left upon her face, glistening in the light when they returned home, traces of the most grateful tears she had ever shed.

There was a quiet mirth about the little supper, which harmonised exactly with this tone of feeling, and at length the two gentlemen took their leave. There was one circumstance in the leave-taking which occasioned a vast deal of smiling and pleasantry, and that was, that Mr. Frank Cheeryble offered his hand to Kate twice over, quite forgetting that he had bade her adieu already. This was held by the elder Mr. Cheeryble to be a convincing proof that he was thinking of his German flame, and the jest occasioned immense laughter. So easy is it to move light hearts.

In short, it was a day of serene and tranquil happiness; and as we all have some bright day—many of us, let us hope, among a crowd of others—to which we revert with particular delight, so this one was often looked back to afterwards, as holding a conspicuous place in the calendar of those who shared it.

Was there one exception, and that one he who needed to have been most happy?

Who was that who, in the silence of his own chamber, sunk upon his knees to pray as his first friend had taught him, and, folding his hands and stretching them wildly in the air, fell upon his face in a passion of bitter grief?

## CHAPTER XLIV.

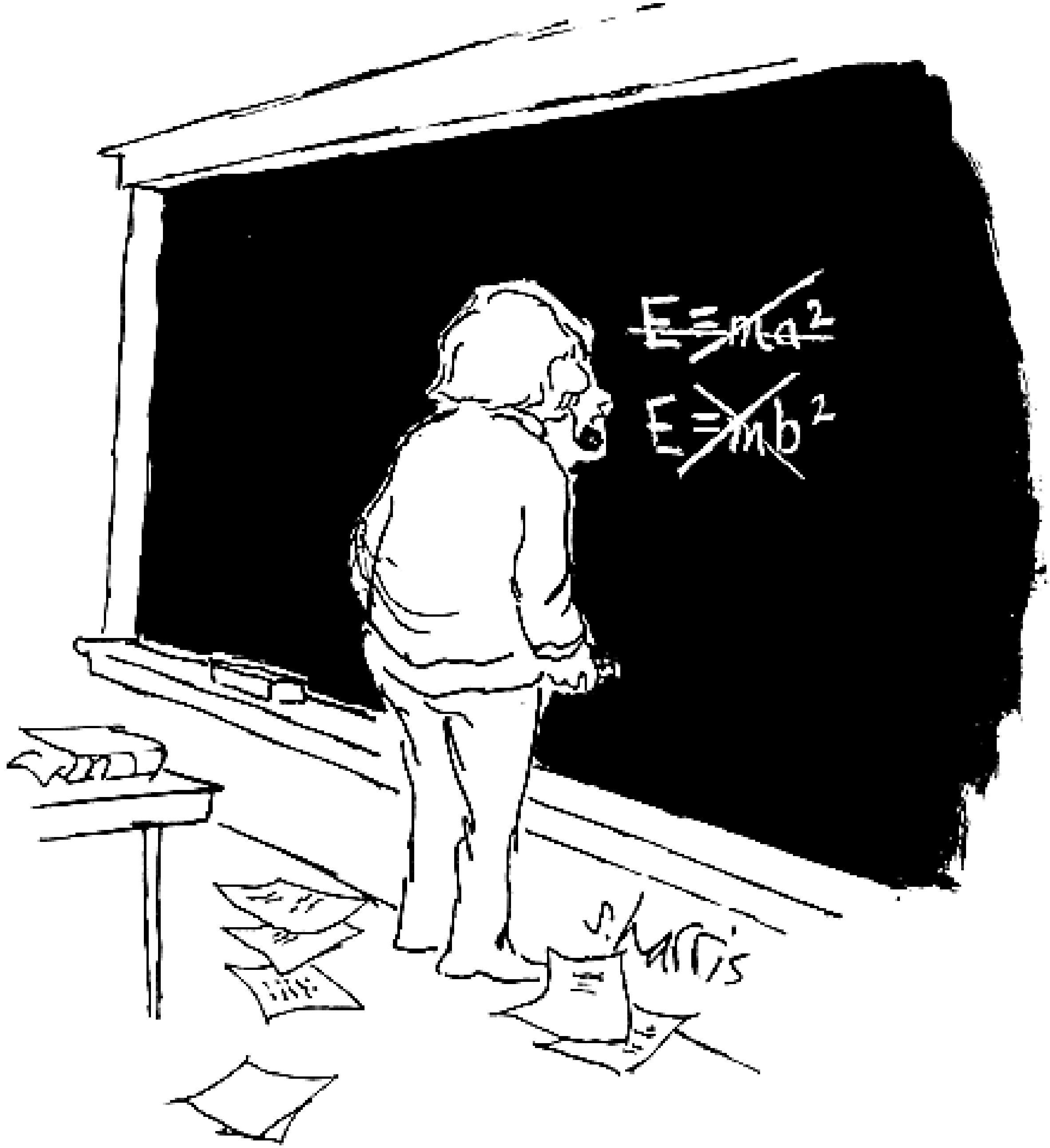
MR. RALPH NICKLEBY CUTS AN OLD ACQUAINTANCE. IT WOULD ALSO APPEAR, FROM THE CONTENTS HEREOF, THAT A JOKE, EVEN BETWEEN HUSBAND AND WIFE, MAY BE SOMETIMES CARRIED TOO FAR.

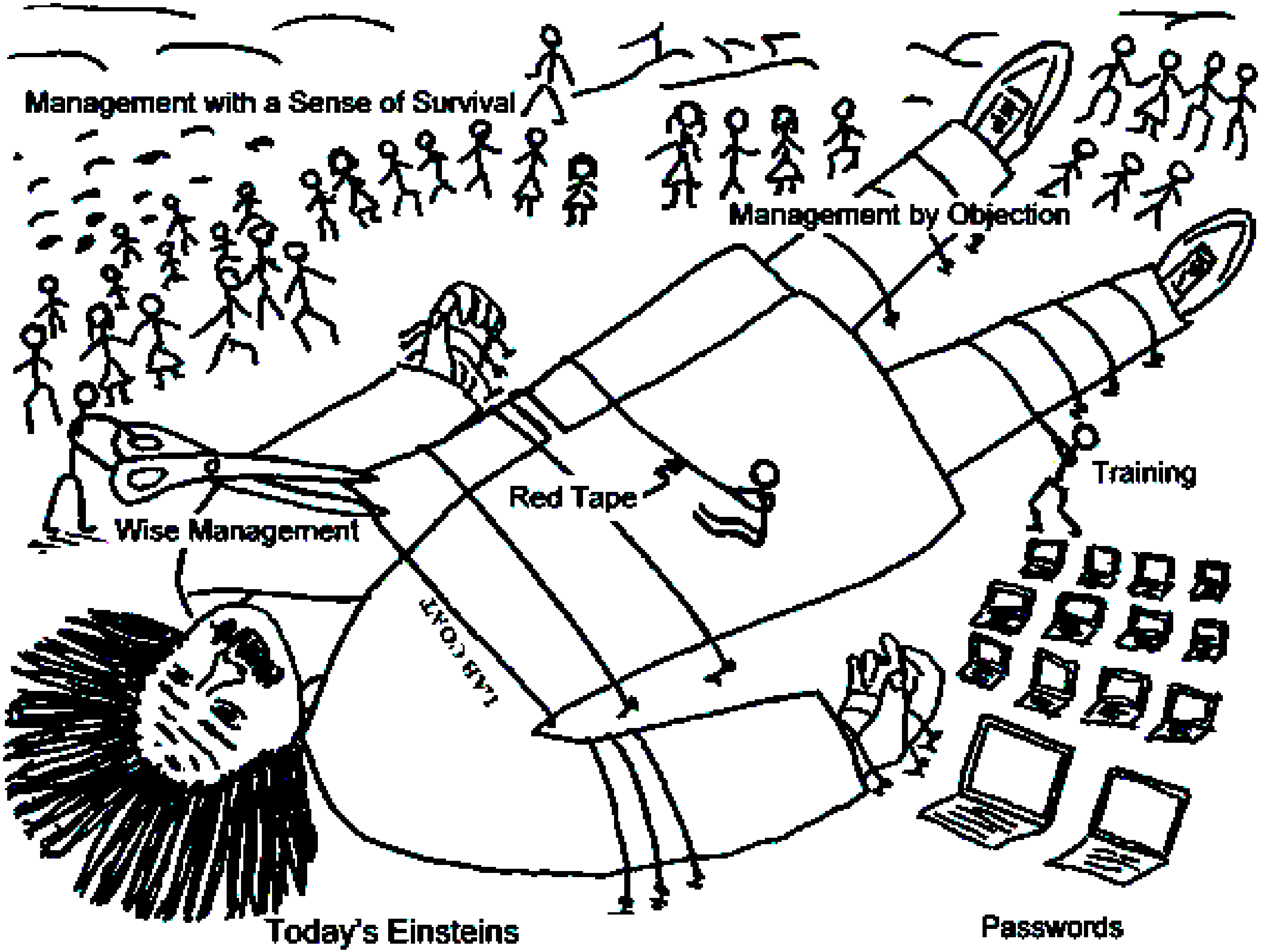
THERE are some men who, living with the one object of enriching themselves, no matter by what means, and being perfectly conscious of the baseness and rascality of the means which they will use every day towards this end, affect nevertheless—even to themselves—a high tone of moral rectitude, and shake their heads and sigh over the depravity of the world. Some of the craftiest scoundrels that ever walked this earth, or rather—for walking implies, at least, an erect position and the bearing of a man—that ever crawled and crept through life by its dirtiest and narrowest ways, will gravely jot down in diaries the events of every day, and keep a regular debtor and creditor account with Heaven, which shall always show a floating balance in their own favour. Whether this is a gratuitous (the only gratuitous) part of the falsehood and trickery of such men's lives, or whether they really hope to cheat Heaven itself, and lay up treasure in the next world by the same process which has enabled them to lay up treasure in this—not to question how it is, so it is. And, doubtless, such book-keeping (like certain autobiographies which have enlightened the world) cannot fail to prove serviceable, in the one respect of sparing the recording Angel some time and labour.

Ralph Nickleby was not a man of this stamp. Stern, unyielding, dogged, and impenetrable, Ralph cared for nothing in life, or beyond it, save the gratification of two passions: avarice, the first and predominant appetite of his nature, and hatred, the second. Affecting to consider himself but a type of all humanity, he was at little pains to conceal his true character from the world in general, and in his own heart he exulted over and cherished every bad design as it had birth. The only scriptural admonition that Ralph Nickleby heeded, in the letter, was, "Know thyself." He knew himself well, and, choosing to imagine that all mankind were cast in the same mould, hated them; for, though no man hates himself, the coldest among us having too much self-love for that, yet most men unconsciously judge the world from themselves, and it will be very generally found that those who sneer habitually at human nature, and affect to despise it, are among its worst and least pleasant samples.

"Pride is one of the seven deadly sins; but it cannot be the pride of a mother in her children, for that is a compound of two cardinal virtues – faith and hope."

Nicholas Nickleby


$E=ma^2$
$E=mb^2$
S. Harris




**Gullivarian Constraints on Today's Einsteins (Cartoon by J. Faller)**

**If at all possible, choose to measure a frequency rather than an angle or a displacement.**

**More things are known than are actually true.**

**J. R. Pierce**

**Bob's comment to me while we were walking down the basement hall in Swain Laboratory,**

# "Jim, I don't think I can have any more students. I just can't think of anything worthwhile that a graduate student can do in three years."

I'M THINKING OF STARTING SOME NEW HOBBIES..
THAT'S A GOOD IDEA, LUCY.. THE PEOPLE WHO GET MOST OUT OF LIFE ARE THOSE WHO REALLY TRY TO ACCOMPLISH SOMETHING...
ACCOMPLISH SOMETHING?!
I THOUGHT WE WERE JUST SUPPOSED TO KEEP BUSY!
SCHULZ

# And Finally Bob's Benediction on Lunar Laser Ranging

**ROBERT H. DICKE**
**PRINCETON UNIVERSITY**
**Department of Physics**
**JOSEPH HENRY LABORATORIES**
**JADWIN HALL**
**Post Office box 700**
**PRINCETON, N.J. 08544**

## LUNAR LASER RANGING REMINISCENCES

**"While on leave at Harvard in 1954-55, I considered the experimental basis of general relativity, Einstein's theory of gravitation. I concluded that the observational basis was thin and that much more was needed, particularly a modern high precision version of the Eotvos experiment. This experiment was started at Princeton in 1955. Problems were encountered and many students, post docs and faculty contributed to their solutions.**

**Among the interests of our research group was Dirac's Cosmology and its implication of a decreasing gravitational constant. Mach's principle and the scalar-tensor theory [were] developed in collaboration with Carl Brans.**

**The gravitational research group would meet in the evening once a week to discuss research ideas, some wild and some not so wild. One night testing for a decreasing gravitational constant was proposed using a zero drag satellite orbiting the Earth and reflecting a light pulse from a corner reflector carried on the satellite. The laser had not yet been developed and we had in mind using a flash lamp for illumination. With the development of the laser it became feasible to eliminate the artificial satellite and use the Moon instead. Jim Faller first suggested this and I remember that he brought a corner reflector mounted in a rubber ball to one of the evening meetings to show how the experiment might be done. The ball could be dropped from a**

lunar lander [at that time the Surveyor program] and the ball would roll to point the reflector upward.

Some years later, after several members of the group had left Princeton, a number of us met at a Physical Society meeting to discuss the possibility of proposing such an experiment to NASA. We decided that some one person should take the responsibility of proposing the experiment and Carroll Alley was urged to do this. [At that meeting, the rationale for having Carroll do this was 'since he was at the University of Maryland, and therefore close to NASA headquarters, he would be in a better position to coordinate and interface the group's efforts with NASA.'] Alley was successful. Later an advisory committee was established with members from both inside and outside the Princeton group. [The LURE (Lunar Ranging Experiment) Team initially consisted of (in alphabetical order): Carroll O. Alley, Jr., University of Maryland; Peter L. Bender, National Bureau of Standards; D.G. Currie, University of Maryland; R. H. Dicke, Princeton University; James E. Faller, Wesleyan University; Henry H. Plotkin, Goddard Space Flight Center; David T. Wilkinson, Princeton University; J. D. Mulholland, Jet Propulsion Laboratory; William M. Kaula, University of California, Los Angeles; and Gordon J. F. MacDonald, University of California, Santa Barbara]

A high point in my memory of the Lunar Laser Ranging program is the night that reflected optical pulses were first observed. After the first set of corner reflectors had been left on the Moon at the time of the first lunar landing, attempts were made at two different observatories to observe light pulses from the reflectors, using large telescopes, especially instrumented for the job. One of these efforts, directed by Jim Faller [and Joe Wampler of Lick] used the large telescope of the Lick observatory on Mt. Hamilton. The other directed by Carroll Alley, used a large telescope of the University of Texas.

For several days neither team was successful. The situation was desperate for the allotted time at the Lick observatory was nearly exhausted. I had not been involved with either group but happened to be spending a month at the Lick observatory on the Santa Cruz campus. On our last night, I visited the telescope. Jim showed me the instrument details and he convinced me that everything was well tested and working. [This "convincing" was accomplished during an intensive two to three hours of my showing Bob *every* aspect of what we had done and answering *all* of his many questions.] I spent the rest of the night in the control room looking for photon counts above the noise in the range channels. I like to believe that, in some small way, my good luck contributed to the success of that night's observation." [As did also the thought and energy that Bob put into the weekly group meetings that taught a generation of Princeton physicists how to do experiments.]

Thanks for Listening