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NORFOLK, VIRGINIA

AN EXPERIMENTAL/ANALYTICAL PROGRAM TO ASSESS THE UTILITY OF LIDAR FOR POLLUTION MONITORING

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By

Frank S. Mills

Earl C. Kindle, Principal Investigator

Progress Report

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

Under
Research Grant NSG 1343
September 1, 1976 - April 30, 1977
G. Burton Northam, Technical Monitor
Environmental and Space Sciences Division

August 1977

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Submitted by the
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Norfolk, Virginia 23508

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AN EXPERIMENTAL/ANALYTICAL PROGRAM TO ASSESS THE UTILITY OF LIDAR FOR POLLUTION MONITORING

by

Frank S. Mills[1]

The primary effort in this phase of the program involved an analytical program to assess the utility of LIDAR for pollution monitoring. The work on this program was conducted in four phases:

A. Analysis of data for plume characterization studies
B. Field measurements of aerosol mixing heights
C. Assembly, checkout, and calibration of an infrared differential absorption lidar system
D. Development, assembly, and calibration of an ultraviolet differential absorption lidar system.

Progress on each of these phases will be described briefly in this report.

Phase A: Plume Characterization Studies

The experimental portion of this program was conducted during four one-week periods during September and October 1976. Analysis of the data from the experiment is nearing completion. An oral paper describing the experiment and the data analysis was prepared for presentation at the Eighth International Laser Radar Conference, June 6-9, 1977, in Philadelphia. When the data analysis is complete, a report describing the experiment and the data analysis will be prepared.

Phase B: Field Measurements of Aerosol Mixing Heights

From October 1976 through February 1977, NASA/Langley Research Center and Old Dominion University assisted the Virginia State

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Air Pollution Control Board in an investigation of the diurnal air quality patterns in Region VI. Measurements were made during one 48-hour period each month. In October, the mobile 12-inch lidar at NASA Langley was used to measure mixing layer height from midnight to 8:00 AM during the 48-hour measurement period. NASA/Langley investigators used the mixing layer height measurements along with data from other instruments to gain a better understanding of air quality patterns.

The mobile 12-inch lidar could not be used in the rest of the investigation since it was not operational, however, other techniques were available for inferring mixing height.

Phase C: Infrared Differential Absorption Lidar System (IR DIAL)

Assembly of the infrared DIAL system has been delayed because of difficulties encountered by the laser supplier. At this time, delivery of the laser is expected in November or December 1977. Other work on the system is proceeding, however. Detectors for the absorption cells have been tested for linearity, and a gas handling manifold for the absorption cells has been designed and built. Development of software for the data system is proceeding.

The effect of transient digitizer errors on DIAL measurements has been investigated experimentally. This has application to any DIAL system which uses transient digitizers to record the lidar returns. An oral paper describing the effect of transient digitizer errors on DIAL measurements was prepared for presentation at the Eighth International Laser Radar Conference, June 6-9, in Philadelphia.

Phase D: Ultraviolet Differential Absorption Lidar System (UV DIAL)

Significant progress has been made in the development of the UV DIAL system. ODU researchers working with NASA personnel have designed and constructed the two-wavelength UV laser. The laser, telescope and detector package have been mounted on a platform and installed at the Langley calibration facility. The data system for the lidar is complete and software for the data system is being developed and checked out. Calibration of the lidar and tests to determine sensitivity and range have begun.

CURRENT STATUS AND PLANS

Mixing layer height measurements for the Virginia Air Pollution Control Board study are complete.

Field measurements for the plume characterization study have been completed and analysis of the data is nearing completion. It is expected that the data analysis will be completed and the report on the study will be prepared by the end of the grant period.

Because of the delay in the delivery of the infrared tunable laser, assembly, checkout, and calibration of the IR DIAL will not be completed under this grant. Tests of some components of the system have been completed, however, tests of the complete IR DIAL system would have to be conducted under a subsequent grant.

The laser, telescope, and detector package for the UV DIAL system have been assembled on a platform and calibration tests have begun at the Langley calibration range. The data system for the lidar is complete and software for the data system is being developed. It is expected that by the end of the grant period, the lidar system will be complete, and calibration tests of the lidar with SO_2 will be complete. In the following year, the system will be mounted on the mobile lidar van and used to monitor SO_2 in a smokestack plume. ODU expects to be involved in this program.

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SEMI-ANNUAL PROGRESS REPORT, July-December 1976

for

NASA Contract NGR-05-002-256*

"Research on Experimental Tests of Gravitation Theory"†

Section I. Prepared in January 1977

Report Submitted August 5, 1977

by

Kip S. Thorne, Principal Investigator

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(NASA-CR-154233) RESEARCH ON EXPERIMENTAL TESTS OF GRAVITATION THEORY Semiannual Progress Report, Jul. - Dec. 1976 (California Inst. of Tech.) 9 p

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9.

I. SUMMARIES OF PROGRESS ON VARIOUS PROJECTS

1. New Laboratory Experiments to Test Post-Newtonian Gravity

Braginsky, Caves, and Thorne got together in Italy, in September, and there they completed their work on ideas for new laboratory experiments to test Post-Newtonian gravity. These new experiments are made possible by the recent development of sensing systems (torsion oscillators, microwave cavities, and massive sapphire crystals) with very low levels of dissipation.

Experiments using torsion oscillators include the following: (1) A measurement of spin-spin gravitational coupling. Here a torsion oscillator (period $\tau_o \simeq 10^4$ sec and damping time $\tau^* \simeq 10^{13}$ sec) is driven at resonance by spin-spin gravitational coupling between a 10 g test mass attached to the oscillator and a 3×10^4 g spinning body with modulated angular velocity ($v_{max} \simeq 5 \times 10^4$ cm/sec, $\tau_{mod} = \tau_o$). (2) A new, improved-accuracy Eötvös-Dicke experiment. (3) A direct measurement of the time-rate-of-change of the gravitation constant, with expected accuracy $|\dot{G}/G| \lesssim 10^{-11}$/yr. In this experiment the restoring force of the oscillator is the gravitational attraction between the oscillator's test masses and several nearby masses. (4) A measurement of the gravitation produced by stresses. In this experiment the source is a solenoidal magnetic field $B_o \simeq 2 \times 10^5$ gauss which is turned on and off at the eigenfrequency of the torsion oscillator. For a magnetic field, stresses are of the same size as energy density. These experiments all require very low temperature ($T \lesssim 4\ ^oK$) to keep Nyquist noise under control. The dominant source of noise is seismic vibrations of the oscillator support. They may be so serious as to necessitate doing the experiments in space.

An experiment using a microwave cavity is the following frame-dragging experiment: A 5×10^6 g mass with modulated spin ($\tau_{mod} \simeq 6 \times 10^5$ sec) is encircled by a standing $\lambda \simeq 1$ mm wave in a torodial microwave cavity with superconducting mirrors. The spinning mass drags inertial frames in the cavity and thereby drags the intensity pattern of the wave form. The most serious sources of noise are seismically-induced rotations of the cavity, and statistical fluctuations in measurements of the intensity pattern, due to the finite number of quanta in the cavity.

A sapphire crystal would be used in the following experiments: (1) A "preferred-frame" experiment. A prolate spheroid, rotates around its shortest principal axis with angular velocity ω, and a cylinder of monocrystal sapphire is placed at rest directly above the axis of rotation. The entire apparatus is rotated with angular velocity $\Omega \ll \omega$ relative to the external universe. In many theories of gravity, but not in general relativity, the crystal experiences a "preferred-frame gravitational force" that drives dipole modes of oscillation at a frequency $\omega_{PN} = \omega \pm 2\,\Omega$. One of these frequencies is tuned to a dipole normal mode of the crystal, and the resulting preferred-frame force changes its amplitude and phase. (2) A Faraday experiment to measure the "electric-type" gravity induced by changing "magnetic-type" gravity. In this experiment the source is a disc rotating about its axis of symmetry. The detector is an axially-symmetric sapphire crystal whose symmetry axis is coincident with that of the source. The source is moved up and down along the axis of symmetry. The induced "electric-type" gravity drives a torsional mode of the detector.

A paper discribing these experiments has been completed and will be submitted for publication soon.

Vladimir Braginsky (Moscow State Univ.),
Carlton M. Caves, Kip S. Thorne

2. Analysis of Gravitational Experiments

Work has been initiated on classical and quantum-mechanical analysis of noise and fluctuations, especially as applied to gravitational wave antennas and experimental tests of relativity. Also being investigated is the proposed Stanford Eötvös (uniqueness of free fall) experiment. Finally, a search through recent literature on neutron stars and pulsar models has been begun, with the goal of revising the estimates of the gravitational radiation emitted; Press and Thorne's 1972 figures may have been too optimistic.

Mark Zimmermann

3. A Formalism for Analyzing the Response of Microwave Cavities to Gravitational Fields

This project has been set aside temporarily to permit completion of the project described in 1. above.

Carlton M. Caves

4. Distance Dependence of the Gravitational Constant

This project, described in our last progress report (item 3), has been completed and submitted for publication.

David R. Mikkelsen and Michael Newman

5. Large-Scale Gravitation Experiments

In the work of item 4 above, I found that there are no useful experimental determinations of the value of the gravitation constant $G(r)$ for separations r greater than a few meters. Gravitational experiments on larger scales could significantly improve the experimental foundations of gravitation and may provide a better estimate of G on planetary scales than is presently available, so I have begun to study the feasibility of experimentally determining $G(r)$

for distances up to ~ 10 km. Proposed second-generation gravitational radiation detectors with resonant frequencies below 1 kHz might detect time-varying Newtonian gravitational sources at distances of up to ~ 1 km. Work based on discussions with R. W. P. Drever during his recent visit to Caltech suggests that a torsion oscillator may be capable of detecting sources at distances of ~ 10 km.

David R. Mikkelsen

6. Very massive Neutron Stars in Ni's Theory of Gravity

This project has been set aside, temporarily, due to the press of items 4 and 5 above.

7. Noise Study for Gravitational Wave Detection by Doppler Tracking of Interplanetary Spacecraft

Estabrook and Wahlquist at JPL, with some (but not much) input from Thorne, have completed a preliminary study of the noise sources and levels in the doppler tracking system of the Deep Space Network — both at present and in the near future. Their most important conclusion is that to achieve the precision required for detection of waves at the level predicted by Braginsky and Thorne, it is essential to have a 2-way dual-frequency doppler system.

Frank B. Estabrook and Hugo Wahlquist,
with kibitzing from Kip S. Thorne

8. The Luminosity of Pregalactic Black Holes

At the time in the expanding Universe when the temperature dropped low enough for atoms to form, the first large scale condensations of matter became possible. Studies of conditions at this time suggest that many condensations with masses of ~ 10^5 $M_{\odot}$ should have formed. A fascinating possibility, suggested by Paczyński, is that these condensations evolved into 10^5 $M_{\odot}$

black holes which form halos around galaxies and which perhaps comprise the "missing mass" necessary to close the Universe. Thorne has pointed out that gravitational waves from the births of such holes might be detectable by doppler tracking of interplanetary spacecraft.

To decide whether such a hypothesis is tenable we have studied the luminosity such objects would have today due to the heating of gas accreting onto them as they plunge through the disk of our galaxy. We found that these pregalactic black holes could accrete gas more-or-less spherically, or via disk formation. (Which type of accretion depends on the homogeneity of interstellar gas on small length scales.) Luminosities are found to be $\sim 10^{37}$ ergs/sec at wavelengths of $\sim 10\ \mu$ for spherical accretion and at visible wavelengths for disk accretion. In either case observational constraints limit the abundance of such pregalactic objects to be smaller, by at least a factor of 100, than the proposed $10^{12}\ M_{\odot}$ per galaxy. A paper describing this work has been submitted to The Astrophysical Journal.

James R. Ipser, Richard H. Price

9. Gravitational Bremsstrahlung from High-Speed Stellar Flybies

This project has been described in previous progress reports. The derivation of algebraic expressions for the radiation field as a function of time, polarization, and solid angle has been completed; and a manuscript describing that derivation is being written for submission to The Astrophysical Journal. Our final Bremsstrahlung formulae are being compared and contrasted with the work of other authors. Graphs for $v \ll c$ or $v \approx c$, depending on the location of the observer, show that the dimensionless wave amplitudes A_+ or A_x can cause a permanent displacement between two test particles. For the ultra-relativistic case the radiation is highly peaked in a forward cone of half angle ~ $1/\gamma$. Work on the energy and power spectrum in general, and analytic expressions for the ultra-relativistic limits of these is now in progress.

Sándor J. Kovács, Kip S. Thorne

10. The Gravitational Scattering of Massless Plane Waves

De Logi and Kovács have calculated the differential scattering cross section $d\sigma/d\Omega$, for gravitational scattering of massless plane waves of spin 0, 1, and 2 by the linearized Schwarzschild and Kerr geometries in the long-wavelength, weak-field limit (wavelengths of incident radiation $\gg$ radius of scatterer $\gg$ mass of scatterer). The calculation utilizes Feynman diagram techniques. The results explicitly show 1) conservation of helicity (spin-1 scattering), 2) differential focussing (spin 1 or 2 scattered by Kerr), and 3) helicity is not conserved for spin-2 wave scattering.

Walter de Logi (Electrical Engineering)
Sándor J. Kovács

11. Supercritical Accretion

Icke has finished calculations begun in Cambridge on the structure of accretion flow onto black holes at or above the Eddington limit — an issue of some importance for observational aspects of black holes in binary systems and galactic nuclei. He has found a family of self-similar solutions which include the effects of gas pressure, radiation pressure and viscosity. These solutions make it possible to determine to what extent the Eddington limit prevails for cylindrically symmetric, instead of spherical, flow. An article describing this work has been submitted to Nature.

Vincent Icke

II. PUBLICATIONS SUPPORTED PARTIALLY OR WHOLLY BY THIS GRANT

A. Publications submitted previously but published in the current half year

A1. Gravitational-Wave Astronomy: Where Do We Stand Now?
Kip S. Thorne
Relativity, Fields, Strings and Gravity, ed. C. Aragone (University Simón Bolivar, Caracas, 1976)

B. Publications submitted in the current half year

B1. Recent JPL Work on Gravity Wave Detection and Solar System Relativity Experiments
H. D. Wahlquist, J. D. Anderson, F. B. Estabrook, and K. S. Thorne
Proceedings of the International Symposium "Experimental Gravitation"
Pavia, Italy, September 1976

B2. Accretion onto Pregalactic Black Holes
James R. Ipser and Richard H. Price
Astrophys. J.

B3. Constraints on the Gravitational Constant at Large Distances
David R. Mikkelsen and Michael J. Newman
Phys. Rev. D

B4. Radiative Acceleration of Gas Above a Luminous Disk
Vincent Icke
Nature

III. LECTURES DESCRIBING, WHOLLY OR IN PART, RESEARCH SUPPORTED BY THIS GRANT

Summer Lecture Program, Arecibo Observatory, Arecibo, Puerto Rico, August 11 and 12, 1976

Gravitational-Wave Astronomy
K. S. Thorne

Colloquium, Department of Physics, Glasgow University, Glasgow, Scotland, September 7, 1976

New Laboratory Experiments to Test General Relativity
K. S. Thorne

Colloquium, DAMTP, Cambridge University, Cambridge, England, September 10, 1976

New Laboratory Experiments to Test General Relativity
K. S. Thorne

International Symposium on Experimental Relativity, Pavia, Italy, September 17-20, 1976

Proposal for New Laboratory Experiments to Test Relativistic Gravity
V. B. Braginsky, C. M. Caves, and K. S. Thorne

Seminar, Niels Bohr Institute, Copenhagen, Denmark, September 30, 1976

Laboratory Experiments to Test Relativistic Gravity
C. M. Caves

IAA Symposium, Anaheim, California, October 10-16, 1976

Sources of Very-Low-Frequency Gravitational Radiation
K. S. Thorne

Spacecraft Gravitation Experiments Using a Torsion Oscillator
V. B. Braginsky, C. M. Caves, and K. S. Thorne

Office of Naval Research 30th Anniversary Symposium, Washington, D.C., October 28, 1976

Probing the Universe — Big Bang, Black Holes, Neutrinos, and Gravitational Waves
K. S. Thorne

Physics Coloquium, Department of Physics, University of Utah, Salt Lake City, Utah, December 6, 1976

Quantum Non-Demolition Measurements: Can they be Made?
K. S. Thorne