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THE SPACE MICROWAVE INTERFEROMETER AND THE SEARCH FOR COSMIC BACKGROUND GRAVITATIONAL WAVE RADIATION

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ABSTRACT

Present and planned investigations which use interplanetary spacecraft for gravitational wave searches are severely limited in their detection capability. This limitation has to do both with the Earth-based tracking procedures used and with the configuration of the experiments themselves. It is suggested that a much improved experiment can now be made using a multiarm interferometer designed with current operating elements. An important source of gravitational wave radiation, the cosmic background, may well be within reach of detection with these procedures.

It is proposed to make a number of experimental steps that can now be carried out using TDRSS spacecraft and would conclude in the establishment of an operating multiarm microwave interferometer. This interferometer is projected to have a sensitivity to cosmic background gravitational wave radiation with an energy of less than 10^{-4} cosmic closure density and to periodic waves generating spatial strain approaching 10^{-19} in the range 0.1 to 0.001 Hz.

I. INTRODUCTION

Gravitational wave research lies at the very heart of modern physics. The search for gravitational waves of astrophysical origin is one of the single most outstanding challenges for experimental physics today. This effort is currently being pursued by eminent experimental teams in several parts of the world. After two decades of experimental efforts that have been carried out both on the ground and simultaneously in space, we have reached the point where it is evident that a new generation of detectors is required if detection of gravitational waves is to be successful.

Several proposals have recently been made that aim at the construction of multiarm interferometers in space. These proposals range from direct approaches, which build upon current technologies, to more ambitious projects, which look some distance into the next century.

The situation in gravitational wave physics today is not unlike that in the particle physics community some 60 years ago. At that time, small university basement cyclotrons were just as important to the whole of physics as Fermilab, SLAC, CERN, or SSC are today. Progress and understanding in experimental physics is a methodical game. Each step along the way is supported by different groups, using different techniques, testing different methods, on different equipment.

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*presently at Santa Barbara

II. SMILE

The Space Microwave Interferometer for Low Energy gravitational wave detection, or SMILE, combines our best current experimental knowledge and experience of present day capabilities in space gravitational wave detection. Its goal is the operation of a space multiarm microwave interferometer by the end of this century. By utilizing the most appropriate existing equipment and facilities of the various national space agencies, which are being deployed in space by other programs at considerable expense, we have designed a detection scheme which we believe is the best that can be currently achieved. This interferometer would have 10^4 to 10^5 greater sensitivity to gravitational wave energy than the best interplanetary spacecraft searches (Galileo). It would be the first in a new class of space detectors.

We have identified several experimental steps that can be carried out in the next few years. These early stages would require some new ground equipment of minimal expense but would not, however, require any special additional launch opportunities. The final stage of the proposal would require the deployment of two small probes of scout launch class to implement the full power of the interferometer. If not overburdening, these small probes might, in addition, carry equipment for the test of an even more ambitious interferometer of the next century.

At this time, it seems highly probable that the techniques developed for and utilized in the SMILE interferometer could become a primary method used for the initial set up, adjustment, and monitoring of a future interferometer of greater capability. It can be envisioned that the lessons gained from the techniques developed for SMILE could provide a reliable and necessary first step along the way to an even more highly advanced stage of space interferometry.

III. SPACE MICROWAVE INTERFEROMETER FOR LOW ENERGY GRAVITATIONAL WAVE DETECTION (SMILE)

Current major limitations with spacecraft measurements $\Delta l/l$:

1) Troposphere* (model at best 10^{-16} at 1000 s);
2) Ionosphere* (10^{-13} to 10^{-16} at 100 s S/X band);
3) Clock* (present Vessot operational 10^{-16} at 3000 s);
4) Earth Rotation variation, Polar Motion, Atmosphere, Ocean and Tidal Loading parameters* (model to 10^{-16} at 1000 s); and
5) Plasma (10^{-13} to 10^{-16} at 1000 s S/X band).

SMILE will:

1) Eliminate Troposphere,
2) Eliminate Ionosphere,
3) Eliminate clock,
4) Eliminate Earth Rotation variation, PM, A, O and TL parameter errors,
5) Reduce plasma by 2 orders in $\Delta l/l$,

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*RTLT correlated creating problem for G–wave detection

6) Provide 4 to 5 orders improvement in G-wave energy sensitivity detection over Galileo,

7) Measure a G-wave background energy to less than 10^{-4} cosmic closure density in the range 0.1 to 0.001 Hz, and

8) Measure periodic G-waves generating spatial strain approaching 10^{-19} in the range 0.1 to 0.001 Hz.

The following is a series of experimental steps that have been identified and can now be conducted with the present TDRSS spacecraft for evaluation prior to design commitment of the space interferometer.

Step 1. *Design and carry out a TDRSS open loop tracking experiment.*

Configuration: TDRSS, one antenna, tracking earth orbiting Doppler beacon spacecraft in wideband. Transmit wideband signal to White Sands, record and do open loop recovery and Fourier analysis. Compare with TDRSS discrete Doppler readout. Develop open loop recording and analysis procedures. Develop algorithms and model spacecraft dynamics from data.

Step 2. *Design and carry out a TDRSS open loop tracking experiment.*

Configuration: TDRSS, two antennas, both tracking simultaneously same earth orbiting spacecraft in wideband. Transmit both wideband signals to White Sands, record and do open loop recovery of both signals, Fourier analysis and comparison. Model complex spacecraft dynamics.

Step 3. *Design and carry out a TDRSS White Sands frequency standard H-maser experiment using transmit through and receive on TDRSS with wideband reception.*

Configuration: TDRSS, one antenna, tracking earth orbiting transponder spacecraft. Use TDRSS precise Doppler transmit mode. Transmit wideband to White Sands, record and do open loop recovery, Fourier analysis.

Step 4. *Design and carry out a TDRSS White Sands frequency standard H-maser experiment using transmit through and receive on TDRSS with wideband reception on two antennas.*

Configuration: TDRSS, two antennas, both tracking simultaneously same earth-orbiting transponder spacecraft. Use TDRSS precise Doppler transmit mode. Transmit both wideband signals to White Sands, record and do open loop recovery of both signals, Fourier analysis and comparison. Evaluate system in detail.

DISCUSSION

SCHUMAKER: In a previous vu-graph you said that plasma noise entered in at levels 10^{-13} - 10^{-16}. You gain by a factor of 10 going from X to KA-band, and another factor of ten between 100-S and 1000-S arms. Is this factor of 100 what allows you to expect a sensitivity of 10^{-18}? And, if so, isn't this optimistic, and only appropriate for directions away from the sun?

ANDERSON: Yes, it is a realistic value. The full range of 10^{-13} to 10^{-16} to $\Delta L/L$ equivalent effect for X-band was primarily to indicate the vast range of plasma effects over the whole solar angle and solar cycle period. The experiment would be so configured as to minimize the plasma effects and periods of operation at $\Delta L/L$ of 10-18 is realistic (see comment by Hellings).

HELLINGS: The increase in sensitivity in the interferometer comes from a factor of 10 due to the change from X to K band and another factor of about 5 from the fact that the round-trip light-times will be only 100 seconds compared to the 10^4 seconds in the interplanetary spacecraft. The plasma noise is stronger at low fourier frequencies, and the shorter light time avoids these low fourier components.

SHAPIRO: The uncertainty of theoretical predictions in this field notwithstanding, what is the theoretical basis for your assumption that the gravitational stochastic background will match the power in the microwave background?

ANDERSON: I believe it is correct to say that there is no other measurement which comes within 2 or 3 orders of setting a limit of 10^{-4} closure density for G-wave energy in this waveband. There are a lot of potential sources in this waveband making the accumulated incoherent gravitational wave energy flux a major source. Estimates of the incoherent flux from close binaries in our own galaxy, for example, indicate a total summed flux causing spatial strain around 10^{-18} $\Delta L/L$ in a broad band throughout this waveband. Therefore I believe the chance of detecting this incoherent background with these methods is very good.

TREUHAFT: Your estimate of tropospheric fluctuations of 10^{-16} at 1000 sec seems between one and two orders of magnitude too low. From the recent TDRSS experiment, the earth-based baseline (Japan-Australia) was much more stable then baselines to TDRSS. How do you plan to get around satellite motion, or whatever is determined to be the ultimate cause of the low coherence on TDRSS baseline (for times >500 sec)?

ANDERSON: (1) In my first overhead I have purposely indicated the most optimistic values, that is, those that are the best possible. Those for the troposphere are for high desert sites, and are based partly upon measurements inferred from the VLA for spatial coherency as reported by Armstrong, 1981, in Radio Science. Armstrong concluded that about 10% of the time data taken was equivalent to plasma + troposphere disturbance at 5 parts in 10^{15} or better. The experiment itself was unable to set an absolute smaller limit beyond this number. I have therefore noted for brevity on the overhead that spacecraft tracking experiments done from earth tracking stations are limited by unmodellable tropospheric disturbances at 10^{16} and very unlikely to ever be better than this number using our current methods of measurement and present understanding. Your objection that you cannot do well by modelling is probably correct using current methods. (2) Concerning the TDRSS experiment itself, we would not do the classical VLBI experiment, which measures baseline length, but rather we would measure Doppler and we believe this can be done at about 3 orders more accurate. Appropriate tests using TDRSS can be carried out to confirm this estimate.

BERTOTTI: What is the level at which you need to measure or to control the non-gravitational accelerations in your final experiment?

ANDERSON: In this experiment there are two approaches. The first one is to beat down the noise in the detector by building up a large number of observations, spectrally separating the general broadband noises caused by individual members of the interferometer from the specific gravitational wave autocorrelation signature. To reach a level of $10^{-18}\ \Delta L/L$ for this detection we would need about 20 days of data. The second approach is to limit the broadband noises. Here the payoff would only be commensurate with the other characteristics of the system being improved at the same time. In this experiment unmodelled drag forces of 10^{-9} to 10^{-10} g in the waveband of the detection are tolerable.