# A Terrestrial, Atom Interferometer, Experiment Searching for Dark Energy Density and Other Dark Contents of the Vacuum

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## INTRODUCTION

We are constructing at the SLAC National Accelerator Laboratory, an atom interferometer experiment, Fig. 1, incorporating a completely new way to investigate the nature of dark energy and at the same time to look for unknown contents of the vacuum that we refer to as "Dark Contents of the Vacuum" . The concept for this experiment was originated by Holger Meyer and Martin Perl [M. L. Perl, arXiv 1007.1622v1 (2010); M. L. Perl and H. Mueller, arXiv 1001.4061v1 (1010)] This note gives the principle of this experiment and outlines the nature of the sought signal

Figure 1. The vacuium envelope and support sturucture. The apparatus is about 7 feet high and sits on an anti-vibration optical table.

**PRECISION MEASUREMENT OF FORCE USING ATOM INTERFEROMETRY**

Figure 2 illustrates a typical atom interferometer of the type we use. Cesium atoms vertically drop from rest in vacuum under the influence of the earth's gravitational field $F_g$ with the acceleration g=9.8 m/s$^2$. In our experiment the drop is about 1.5 meters. As the Cs atom falls it is excited by laser beams that move the atomic state between the ground state $S_{1/2}$and a low lying excited state $P_{3/2}$. The wavelength of this transition is $\lambda$=852 nm. As shown in Fig.3, the $S_{1/2}$state has two hyperfine levels, F=3,4, and the laser beams put an atom in either of these states.

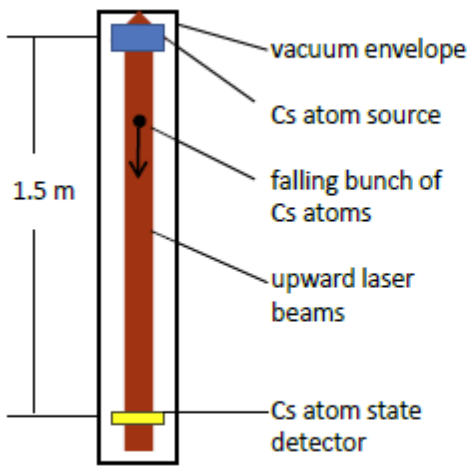


Figure 2

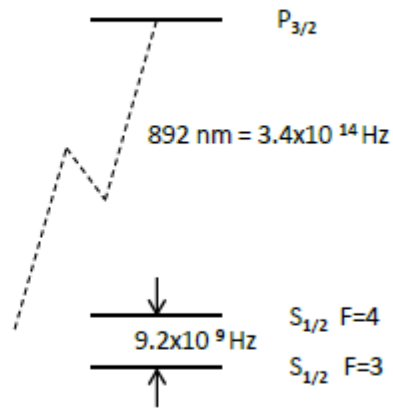


Figure 3

The wave function of the Cs atom has a phase term $e^{i\varphi}$ and $\varphi$ changes as the atom falls through the changing gravitational potential. In most atomic experiments $\varphi$ is ignored because only the absolute value of the square of the wave function is observed. However in an atom interferometer the phase is determined at the detector through interference. In simple interferometers the total change is given by

$$\Delta\varphi = (4\pi/\lambda)gT^2 \text{ radians} \qquad (1)$$

where T is the atom fall time in seconds. In the interferometer illustrated here

$$\Delta\varphi = 4.3 \text{ x } 106 \text{ radians.}$$

Since an interferometer measures $\Delta\varphi$ to a small fraction of a radian, Eq. 1 gives a precise value of g, to $10^{-9}$ precision.

**PRINCIPLE OF THE EXPERIMENT**

Consider, Fig.4, two identical, adjacent interferometers, A and B, of the type in Fig. 2, assume that $F_g$ is the same everywhere and perpendicular to the earth's surface. Then $\Delta\varphi_A = \Delta\varphi_B$ and the difference in phase shift is

$$\Delta\varphi = \Delta\varphi_A - \Delta\varphi_B = 0 \qquad (2)$$

But suppose, as in Fig. 5, there is an additional force on the atoms caused by dark energy, $F_{DE}$ in the vicinity of interferometer A but not in the vicinity of interferometer B. The total phase shift of A is now $\Delta\varphi_A + \Delta\varphi_{DEA}$ .

Hence

$\Delta\varphi = \Delta\varphi_{DEA}$.

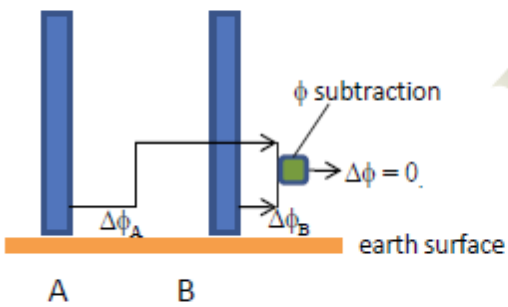


Figure 4

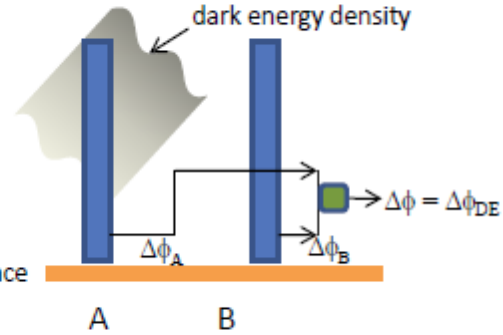


Figure 5

$F_{DE}$ can be detected by this double interferometer method under two assumptions:

- Dark energy exerts a force on atoms. This force must be larger than the equivalent gravitational force from the dark energy density.

- The dark energy density must be inhomogeneous. Atom interferometry depends on a non –uniform potential. If the dark energy density and hence its potential is the same everywhere in the universe this search method will not work. If the cosmological constant explanation of dark energy is correct, this experiment will give a null signal.

**NATURE OF THE SOUGHT SIGNAL**

Our interferometers fixed to the earth are moving through space at about 400 km/s with reference to the frame of the cosmic microwave background . While we know little about the distribution of dark energy density, it is certainly not fixed to the earth or the solar system. Comparing 400 km/s to our sampling rate of the order of 1 Hz we realize that the phase measurements are averaged over space distances of hundreds of kilometers. We do not record $\Delta\varphi$ which will average to zero, we record the root mean square $\Delta\varphi$ rms. We can then determine the dark energy equivalent acceleration, $g_{DE}$

We expect to be able to detect the dark energy equivalent acceleration, $g_{DE}$ with a precision of

$$10^{-15}\ m/s^2$$

As shown in a forthcoming paper by Adler, Mueller and Perl to be submitted to Physical Review D

## EXPERIMENTAL DESIGN

The experimental configuration incorporates the two interferometers in one vacuum envelope as shown schematically in Fig. 6. This reduces problems from common mode noises such as vibrations. Our design uses drop sources for simplicity.

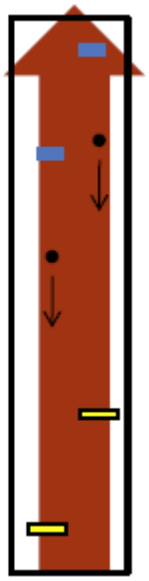

Figure 6 Incorporation of two interferometers in one vacuum envelope. The sources are staggered vertically so that the total phase change for each atom is measured during the Same velocity period.

## SEARCHING FOR OTHER DARK CONTENTS OF THE VACUUM

Are there unknown contents of the vacuum that can exert a force on matter, as yet undetected because the force is much small than terrestrial gravitation? The detection of dark energy density detection discussion applies to these forces. In general this experiment is the beginning of a new exploration of the nature of the vacuum.

Incidentally, this experiment is not relevant to the perennial zero-point energy problem.

## THIS EXPERIMENTAL SEARCH METHOD USING AN EARTH ORBIT SATELLITE.

There is continuing interest in the substantially increased precision obtained by carrying out atom interferometry experiments in the microgravity environment of an earth orbit satellite. There are special advantages using an earth orbit satellite for atom interferometry searches for dark energy and other dark contents of the vacuum –the nulling of g is easier and the atoms can be held longer in the measurement mode.