Exploration of Quantum Physics on Astronomical Scales, Part 1

Lunar interferometry

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A long outstanding mystery in theoretical physics is the apparent conflct between the theories of quantum mechanics (QM) and Einstein's theory of gravity, general relativity (GR). Both theories are well established, and are widely accepted, and have led to many advances, such as the invention of the transistor (QM), to the discovery of black holes (GR) and the global positioning system (both). Both theories have survived 100 years of the most stringent testing the world's leading scientists and accurately predict nature with unprecedented accuracy better than 0.1 parts per billion. It is therefore quite problematic that QM and GR have not yet been unified in a consistent theory. GR is a purely classical theory that does not account for quantum effects that are expected in the early universe or around black holes, etc.

Quantum mechanics is normally applied in the domain of small scales typically less than 10^{-9} meters, e.g. atoms or atomic nuclei. On these small scales, the classical theories of electromagnetism and other forces fail to accurately predict behavior, so QM is an important element of our understanding of the universe. Conversely, general relativity describes the force of gravity and differs from the classical theory of Newtonian gravity especially near regions of high gravitational field (e.g. black holes, etc.) and on stellar to cosmological scales typically greater than 10^{9} meters. The 18 orders of magnitude difference between typical scales for QM and GR make it very difficult to design experiments that probe both at the same time.

Recent proposals [Laurance' paper] describe experiments that can explore the consistency of quantum mechanics and general relativity through astronomical observations. It is suggested that consistency tests could be accomplished with extremely large double-slit interferometers on a solar system scale or larger. At the extreme limits of current technology it may be possible to simulate such an interferometer using two planets such as Mars and Mercury as mirrors for electromagnetic radiation.

As a stepping stone toward solar system interferometry, here we propose a series of new interferometer measurements that making use of the moon as a mirror. By reflecting EM radiation from two different places on the moon at the same time, we can test many of the basic principles behind our solar system interferometer with considerably more ease than on solar system scales. These experiments are also interesting in their own right as we propose building the world's largest double-slit interferometer to date.

The proposed experiments use the Allen Telescope Array, a radio interferometer owned and operated by the SETI Institute in northern California. With this very sensitive radio telescope, it is possible to detect even weak radio signals bounced off the lunar surface (demonstrated, could show figure). In collaboration with a modest HAM radio transmitter on Earth, it is possible to test for the effects of double-slit interferometry under conditions where the "mirrors" are very rough. The lunar surface is rough (as are Mars and Mercury) on length scales of many kilometers. By comparison, the wavelength of radio waves (less than 1 meter) is extremely small and there is some contention, even by astronomers in our group, that rough mirrors are acceptable optical elements for double-slit interferometry. We propose to test double-slit interferometry using the moon as a way of settling this question and preparing the way for future solar system interferometer measurements.

The use of the ATA, moon, and HAM radio transmitters make these experiments very convenient compared to solar system interferometry. For example, there is no need to get any special permits from the FCC for powerful radio transmissions. We do not have to propose for and wait for simultaneous time on the world's largest radar transmitters and radio telescopes to see the effects. Scheduling of the ATA is under direct control by the SETI institute, and we already have offers from several amateur HAMs for the coordinated transmissions required for these measurements.

Description of science goals

The functioning of the solar system interferometer relies on the prediction that even a rough surface like Mars can be effectively used as a mirror for the double-slit experiment. Put technically, the radiation coming from the two slits must be approximately coherent. We describe this point below.

One is familiar with ordinary optical mirrors we all have at home. The principle behind a mirror is to provide an approximately flat surface for the reflection of electromagnetic waves (in this case, light). But not every flat surface can serve as an optical mirror. For example, the wall of a concrete building is quite flat but it scatters light diffusely hence is not a good mirror. To obtain efficient specular reflection it is important that the roughness scale of the mirror be smaller than the wavelength of the EM radiation in question. Since light has a wavelength of around one millionth of a meter, a concrete wall rough on the scale 1 millimeter performs poorly as a mirror. The difficulty of producing a surface flat enough for a household mirror delayed the invention and widespread use of mirrors, with float glass mirrors invented as recently as 1835, less than two hundred years ago.

While the concrete acts poorly as a useful mirror, the principle of superposition of (light) waves predicts that for certain applications the concrete wall will be good enough as a reflector. Since scattering from a stationary rough surface cannot affect the wavelength of the scattered light, a detector positioned far (many wavelengths) from the concrete wall will receive coherent radiation provided that the detector is small enough.[1] This is the prediction of standard electromagnetic wave theory.

However, in practice coherent reflection from a rough surface may not be achievable. The slightest bit of motion between the source, detector, or different areas of the mirror can cancel out this effect. It is not known if transmitters and receivers on Earth and a mirror using lunar surface (or the surface of Mars) is stable enough to reproduce the effect of coherent superposition. After all, the Earth and Moon are both moving and rotating with respect to one another. In the time it takes for the moon to move the distance of one wavelength, the coherence of the reflection will be spoiled. For radio waves of length 20 cm, and lunar motion of about 1 km/s, the coherence time of reflected light is only 100 microseconds or one part in 10,000 of a second. Any detector that responds (integrates) over time periods long than this will observe incoherent radiation, thereby destroying the utility of an interferometer.

So how is it possible that the ATA, in observations lasting from minutes to hours, can detect the effects of double-slit interferometry? Our hypothesis is that the total integration time is not the relevant scale

[1] In theory, the maximum detector size for this experiment is related to the wavelength of the light λ, the roughness scale of the mirror σ, and the distance between the mirror and detector *r* according to $\text{Detector size} <\approx \lambda r \sigma^{-1}$. For the moon at a distance of 384 million meters,

for the detection of double-slit effects. Rather, the coherence time should be compared to the period of the wave. A radio wave at 20 cm wavelength goes through one period of oscillation in the time it takes the wave to travel one wavelength. Since radio waves travel at the speed of light, the period is only 1 nanosecond (10^{-9} seconds) in this case. Since the wave period is much shorter than the coherence time (10^{-4} seconds) we believe that double-slit lunar interferometry is possible.

But this remains to be seen. The utility of a lunar interferometer could fail due to all sorts of experimental difficulties. In a double-slit experiment, we compare waves travel nearly the same distance through the interferometer. If the distance traveled differs greatly along the two paths of the interferometer, interference can be spoiled by uncontrolled frequency variations at the wave source (radio transmitter). Such variations effectively reduce the coherence time of the wave and can spoil the interference. Since lunar roughness limits our control of the path length difference between the two reflected beams to no better than a few kilometers, our experiment is vulnerable to this effect.

Among many experimental conditions such as frequency stability, our lunar interferometry measurements test the practicality of a solar system interferometer. By performing lunar double-slit experimenrts we can test many of the concepts of solar system interferometry with great ease and a low investment of time and financial support.