PRECISION LONG-PATH INTERFEROMETRY AND ITS APPLICATION TO GEOPHYSICS AND ASTROPHYSICS

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We are currently operating a 30-meter Fabry-Perot interferometer as a strainmeter in an unworked gold mine near Boulder, Colorado. The interferometer is illuminated by a 3.39 m single mode helium-neon laser. The laser is locked to one of the transmission maxima of the Fabry-Perot by means of a servo loop which tunes the laser so as to maximize the power transmitted through the long path. The tuning is accomplished by mounting one of the laser mirrors on a piezoelectric ceramic and by applying a suitable voltage to the ceramic.

The 30-meter interferometer has a finesse of 50 so that the full width at half maximum of a transmission fringe is 100 kHz. The signal to noise ratio is about 500 to 1 for a one millisecond integration time enabling us to pick the fringe center to one part in a thousand in a few milliseconds.

The wavelength of the transmission maxima is approximately given by

$$\lambda_n = \frac{2L}{n}$$

where L is the length of the interferometer and n is an integer. Thus

$$\frac{\Delta\lambda_n}{\lambda_n} = \frac{\Delta L}{L} = \frac{-\Delta f_n}{f_n}$$

where f_n is the frequency corresponding to λ_n, i.e.,

$$f_n \lambda_n = c$$

where c is the velocity of light. Thus a measurement of either $\Delta f_n / f_n$ or $\Delta\lambda_n / \lambda_n$ yields the strain change in the long path directly without any calibrations or adjustments.

We choose to measure the fractional frequency fluctuations by heterodyning the laser with a second 3.39 m laser which is stabilized using saturated absorption in methane. We extract the difference frequency between the two lasers and record it as a function of time.

The fluctuations of the beat frequency are directly related to fluctuation in the strain in the rock on which the interferometer is mounted. These strain fluctuations are driven both from terrestrial sources such as earthquakes and nuclear explosions and from extra terrestrial sources such as the fluctuations of the gravitational attraction of the sun and the moon. This latter effect is commonly known as the earth tides and long term high quality tidal records can provide surprisingly detailed insight into the makeup of the earth's crust.

We are also investigating the possibility of detecting periodic fluctuations in the strain field driven by gravitational waves emitted by pulsars or by rapidly rotating binary stars. Our data to date suggests that we could detect fluctuations in the strain field as small as 5 parts in 10^{-17} at pulsar frequencies. This represents the most sensitive geophysical measurement to date, but may not be sufficiently sensitive to detect gravitational waves from pulsars because the earth is a very poor receiver of gravitational waves. Only a small fraction of the incident gravitational energy is converted to elastic energy at the earth's surface. It is this poor conversion efficiency which make gravitational wave experiments so difficult.

We are also working on other experiments including a measurement of the power spectrum of the earth in the normal mode band (1 to 30 cycles per hour). A measurement of the normal mode power spectrum following large earthquakes can be used to infer the source mechanism, while such measurements during quiet earth periods can be used in a search for gravitational radiation.

Our preliminary measurements suggest that our noise level in the normal mode band is on the order of 5×10^{-23} $(\Delta L/L)^2$ per cycle per hour.