Gravitational wave detection using precision interferometry

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Gravitational waves are a prediction of Einstein's general theory of relativity. Detection of these waves would further our understanding of gravity, however, the predicted amplitude is extremely small. A typical strain predicted from an astronomical source of gravitational waves measured on the Earth is about 10^{-21}. Detectors are currently operating around the world, including two locations in the US in Louisiana and Washington state, to look for these waves.

To detect such a tiny strain, precision interferometry with very long arms is used. The detectors consist primarily of Michelson interferometers. Every optic is supported by vibration isolation stacks to reduce disturbances from seismic noise. Each optic is suspended in a wire pendulum, for additional isolation from seismic noise and so the mirror is free to interact with the gravitational wave in the sensitive direction of the interferometer. The arms of each interferometer are 4 kilometers long to increase the motion of the free-hanging mirrors from the given wave's strain. Each arm has an additional mirror at the input, forming a Fabry-Perot cavity. This allows the laser power which measures the position of the mirrors to be higher, increasing the signal. The output port is held at a dark fringe, so a further mirror at the bright port is used to reflect light back into the interferometer, further increasing power. Limiting noise sources are seismic motion at low frequencies (below about 40 Hz), thermal vibrations of the suspensions (between 40 Hz and 200 Hz), and shot noise from the laser at high frequencies (above 200 Hz). Noise from other sources, including laser frequency and amplitude noise, scattered light, and electronics, are reduced to below these levels. The operating detectors in the US are currently within a factor of two in most bands of achieving these goals.

Even with such an ambitious detector, an actual detection of a gravitational wave may not be likely until second generation interferometers are built. Noise in all frequency bands is planned to be reduced leaving thermal vibrations of the mirrors themselves as the limiting noise source in the most sensitive band. Much of this thermal noise comes from mechanical loss in the optical coatings of the mirrors. Development of low mechanical loss mirrors, while preserving the low optical loss, low scatter, and high reflectivity necessary for the interferometry is an area of active research. Doping with titania of silica/tantala dielectric optical coatings has shown the most promise of satisfying all of these requirements. Annealing, different coating conditions, and additional materials and dopants are also being researched to improve the coatings.