Advanced Interferometric Gravitational-wave Detectors

Outline of Chapter 1

1) Overview of the state of the field and prospects for the field (*2 pages*)

1a) The gravitational wave spectrum and measurement methods

Primeaval gravitational waves: B modes of CMB polarization: periods of 10Gyears
Massive black hole formation, binary coalescences in galaxy collisions: pulsar timing: periods of years
Black hole coalescences across the universe, white dwarf binaries in our galaxy: space interferometry: periods hours to minutes
Gravitational wave astronomy: compact binary coalescences, supernova and other transients, galactic periodic sources : ground based long baseline interferometry: periods 0.1 seconds to 0.1 milliseconds

1b) Range of science

Fundamental physics: strong field gravitation, tests of general relativity, gravitational wave kinematics, nuclear physics equation of state

Astrophysics: stellar evolution and population statistics, internal dynamics of supernova explosions, internal dynamics of neutron stars, another means of establishing the cosmic distance scale

2) Book dedicated to the techniques and technology associated with gravitational wave astronomy using ground based long baseline interferometry. Chapter serves as introduction to the book by touching on the basic concepts and noise sources, referring forward for details. (*3 pages*)

2a) Current state of the large baseline projects: VIRGO, LIGO, GEO : sensitivities, duty cycles achieved in the initial instruments, noise budgets, where understood and where not. Projections for the advanced detectors. This will serve as an introduction to the various subsystems and their noise sources discussed more thoroughly later in the book.

3) Basic concepts (*15-20 pages*)

3a) Given the metric for a gravitational wave show how time of flight measurements between free masses establishes h. How a Michelson geometry exploits the polarization of the wave. All done by identifying the four vectors of the events associated with the measurement of the arrival and departure of the light at mirrors that ride with the wave. This was done in the NSF bluebook and removes the ambiguities of what is being changed by the gravitational wave. Add the interferometer and finally cavities as a way of gaining sensitivity. Show the formulation for when the scale of the system is smaller than the gravitational wavelength and when it is larger. (Need to think about short discussion of detecting scalar waves with the same instrument.)

3b) An interesting alternate but equivalent view of the interaction of a gravitational wave with an electromagnetic wave, is to solve the Maxwell equations in the metric of the gravitational wave and note that sidebands to the electromagnetic wave at + and – the gravitational wave frequency are generated by the interaction. The mirrors act as stationary reflectors in this formulation.

3c) Some estimates to establish the timing differences (phase shifts) induced by plausible gravitational waves from sources discussed in the beginning. The need to make long baselines and why this field has become dependent on understanding and controlling the noise sources. The characterization of the noise sources as those that affect the measurements of the time (or phase shifts) and those that exert stochastic forces on the mirrors. The scaling of the noise sources with length. Detailed explanations are in the book, in this chapter discuss the physics of the fundamental noise sources: thermal noise and the fluctuation dissipation theorem , quantum noise, some discussion of seismic noise and Newtonian gravitational noise from local sources but these are not as fundamental as the prior two, nevertheless have significant impact on the technology. Have to think where to put scattering, again not fundamental, but places a real limit on the research and drives the optics, and the need for a vacuum.

3d) Tricks of the trade to approach the fundamental noise sources: feedback with quiet reference points to cool and damp systems (mechanical electronic and optical), modulation to move signals from noisy to less noisy frequencies, techniques to use symmetries to remove excess noise (common and differential mode signals). Diagnostic techniques to measure the instrument sensitivity to a noise followed by subtraction by sensors sensitive to the noise source, the general approach to measure the correlation between different instrument variables to remove noise in critical signal channels (diagonalization using new basis signal channels), where applicable the technique of feed forward from an auxiliary instrument specifically sensitive to a noise source.