Gravitational Waves - Academic Year 2012-2013

PROGRAM

- General relativity and the weak field approximation.
- The transverse-traceless gauge.
- Characteristics of gravitational waves (GW).
- Equation of geodesic deviation and interaction of GW with test masses.
- The energy of GW.
- Generation of GW in linearized theory: mass quadrupole radiation.
- Astrophysical sources of GW: the case of coalescing binary systems; overview on other possible sources of GW (Supernovae, neutron stars, black holes);
- The GW stochastic background.
- Experimental observation of GW emission in compact binaries.
- Experiments for the detection of GW.
- Resonant detectors:
  interaction of GW with a resonant body of cylindrical shape; cross section; overview on the instrumentation; main noise sources; spectral sensitivity; spherical detectors (main concepts).
- Interferometric detectors:
  principle of operation; overview on the instrumentation; main noise sources and sensitivity; the network of interferometric detectors (present and advanced interferometers); sources detectability with advanced instruments .
- Laser interferometry for GW research:
  main concepts of geometrical optics; ABCD matrices; aberration theory in brief; thermal lensing effect; wave-front measurement: working principle of the Hartmann sensor; wave-front decomposition into Zernike polynomials; laser working principle; solution to the EM field in a laser beam: fundamental mode and higher order modes (Hermite-Gauss); laser beam propagation through an arbitrary optical system with ABCD matrices; meaning of the M^2 parameter and method to measure it; Michelson interferometer: working principle and optical configuration; how to build a GW interferometric detector; how to run a GW interferometric detector;
- Focusing on applications, exercise 1:
  laser beam characterization: wavelenght measurement through Michelson interferometry, beam quality parameter (M^2) estimate with knife-edge method; flat-flat optic wedge angle measurement with a Michelson interferometer.
- Introduction to data analysis techniques: general concepts.
- Statistic:
  frequentist probability; hypotesis test; false alarm and false dismissal.
- Importance of a network of detectors.
- Projection of the signal on the detector frame (F+, Fx).
- The wavelet transform as a tool for data analysys (concept).
- Background characterization: time shifts, coincidence window, time delay - detection efficiency.
- Notes on the localization of the GW sources.
- Notes on multimessenger analysis with optical, radio telescopes and with neutrinos.
- Characterization of a continuous GW signal emitted by an isolated neutron star:
  signal amplitude, signal frequency and spin-down; spin-down limit; Doppler effect and sidereal modulation due to the Detector Pattern Functions on the received signal.
- Basic tools for data analysis:
  crosscorrelation, autocorrelation and convolution functions; the Fourier Transform (main properties); Parseval theorem; Power Spectrum and Power Spectral density; White noise; Signal to Noise Ratio; Matched Filter (time domain and frequency domain); Matched filter and waveform mismatch; Sampling and the Nyquist condition.
- Basic Tools for data analysis applied to a continuous GW signal:
  simple sinusoidal signal with known and unknown frequency; GW signal with known parameters: frequency, spin-down and sky position (Target Search); discussion on the limit of the Matched Filter.
- Focusing on applications, exercise 2:
  matched filter and bursts, events identification.