UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Astrophysics of Gravitational Waves

2526-1-F5803Q008

Aims

Acquire basic knowledge in the field of gravitational waves, which have recently been confirmed as an extraordinary tool for understanding the universe and the objects that populate it.
At the end of the course the students:
- will know now learn to derive the general formula for the amplitude of a gravitational wave
- will know the main sources of gravitational waves and the type of signals they emit
- will know the main techniques of gravitational waves obervations, and the type of signals they emit
- will understand the basic concepts of Bayesian data analysis relevant to the observation of gravitational waves and to the extraction of the source parameters

Contents

1- theory of gravitational wave emission
2- detection methods: interferometers and pulsar timing
3- astrophysical sources of gravitational waves and their signals
4- the bands of the gravitational wave spectrum and the observers that cover them: LIGO / Virgo, LISA, PTAs
5- basics of gravitational wave data analysis

Detailed program

1- Theory of gravitational wave emission

- linearization of Einstein's equations
- derivation of the strain in the TT gauge

- wave polarizations and effect on a set of free fall masses

2- Gravitational wave signals from binary systems

- practical derivation of the signal for a binary system
- energy carried by the wave and evolution of the binary system
- binary systems as standard sirens
- zoology of binary signals:
- monochromatic sources
- evolving sources (chirps)
- incoherent superposition of signals: stochastic backgrounds

3- Astrophysics of gravitational wave sources

- stellar mass binaries (white dwarfs, neutron stars, black holes)
- massive black hole binaries
- extreme mass ratio inspirals (systems involving a massive black hole and a stellar mass compact object)

4- Detection of gravitational waves from binary systems

- interferometers: observation principle and detector response
- LIGO: observed sources and notable examples: GW150914, GW170817
- LISA (Interferometric laser antenna): sources and expected rates:
- supermassive black hole binaries
- compact galactic objects (binary of white dwarfs, neutron stars and black holes)
- extreme mass ratio inspirals
- pulsar timing array (PTA):
- detection principle
- response to a single source and a stochastic background (Hellings & Downs curve)
- calculation of the signal to noise ratio for the different types of signals.

5- Bayesian data analysis of gravitational wave signals

- signal to noise ratio
- match filtering
- frequentist and Bayesian statistics
- likelihood priors and posteriors
- gravitational wave source parameter estimation

Prerequisites

None, besides the basic classes of the bachelor.

It is advised to take this class after Relativistic Astrophysics. Some of the concepts developed during the course will be easier to understand if the students have attended the General Relativity course. I stress, however, that this is not a needed prerequisite, as the course will be largely self-contained.

Teaching form

28 hours of frontal lectures, mostly at the blackboard, occasionally with the support of slides (4 credits).
20 hours of exercises and supporting activities (2 credits)
Lectures will be in English.
Recording so the lectures (or equivalent lectures from previous years) will be made available to meet the needs of students who might be impeded in personally attending classes.

Textbook and teaching resource

Supporting material will be uploaded on e-learing during the course of the semester, in any case here follows an (incomplete) list of useful references.

1- Gravitational wave emission theory

Valeria Ferrari lecture notes (will be uploaded on e-learning).

2-gravitational wave signals from binaries
S. Phinney, "A Practical Theorem on Gravitational Wave Backgrounds":
A. Sesana, "Gravitational wave emission from binary supermassive black holes":
Michele Maggiore: "Gravitational Waves". Book 2, 2018

3-Gravitational wave detection
Perrodin & Sesana, "Radio Pulsars: Testing Gravity and Detecting Gravitational Waves":
Michele Maggiore: "Gravitational Waves". Book 2, 2018

Semester

Second semester

Assessment method

Oral examination. The student will first be asked to elaborate on a topic of his choice for about 15-20 minutes. In the rest of the exam, the lecturer will ask other questions covering any of the topics treated during class.

The exam will evaluate:
-the acquired knowledge of the topics treated during lectures
-the ability to perform analytical derivations
-the ability to critically tackle problems related to the material studied in class

There will be no intermediate examinations nor marked homework.

Office hours

Open office hour, just send an email to book an appointment.

Sustainable Development Goals

QUALITY EDUCATION | INDUSTRY, INNOVATION AND INFRASTRUCTURE