UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

SYLLABUS DEL CORSO

Dynamics of Planetary Interiors

2627-1-F7402Q050

Aims

The course introduces students to the study of the structure, composition, evolution and dynamics of planetary interiors, with particular reference to bodies of the Solar System. The main processes governing the internal evolution of planets will be addressed, including accretion, differentiation, core formation, mantle convection, heat transfer, phase transitions, core dynamics and the generation of magnetic fields.
Particular attention will be devoted to the relationships between chemical composition, high-pressure and high-temperature mineralogy, the physicochemical properties of materials and the internal structure of planets. Part of the course will also focus on the experimental and analytical methods used to study materials under extreme conditions, including high-pressure and high-temperature techniques, spectroscopies, X-ray diffraction and measurements at large synchrotron radiation facilities.
The course also aims to develop skills in critical analysis, interpretation of experimental and modelling data, and scientific communication, including through seminars in English. The teaching programme may conclude with an educational visit to a large synchrotron radiation facility.

Knowledge and understanding
By the end of the course, students will know the main processes controlling the structure and evolution of planetary interiors, and will understand the relationships between chemical composition, mineralogy, pressure-temperature conditions and the physicochemical properties of deep planetary materials.

Applying knowledge and understanding
The students will be able to apply the acquired knowledge to the analysis and interpretation of experimental, geochemical, geophysical and modelling data related to planetary interiors. They will also be able to relate phase transitions, equations of state, density, elastic properties and heat flows to the structure and evolution of planets.

Making judgements
The students will be able to critically evaluate theoretical models, experimental results and geophysical interpretations concerning planetary interiors. They will also be able to select the most appropriate experimental, analytical or modelling approaches to address simple scientific questions on the composition and internal dynamics of planets.

Communication skills
By the end of the course, students will have acquired an appropriate technical vocabulary to describe the physical, chemical and mineralogical processes characterising planetary interiors. Seminar activities in English will contribute to developing the ability to present and discuss scientific papers clearly and concisely.

Learning skills
The students will acquire an autonomous and critical learning method to further explore topics in geology, geophysics, geochemistry, mineralogy and planetary sciences, with skills transferable to materials research, space technologies and the analysis of experimental and modelling data.

Contents

The course introduces the main processes controlling the structure, composition and evolution of planetary interiors, starting from the formation of the Solar System, the accretion and differentiation of planetary bodies.

The interiors of terrestrial planets, the Moon and giant planets will be discussed, with particular attention to phase transitions, mantle convection, thermal evolution, core dynamics, generation of magnetic fields and the role of volatile elements.

The final part of the course will be devoted to the experimental and analytical methods used to study planetary materials under extreme conditions, including an introduction to high-pressure and high-temperature techniques, diffraction, spectroscopies and measurements at large synchrotron radiation facilities.

Detailed program

Lectures (4 CFU, 28 hours)

1. Foundations for the study of planetary interiors
   1.1. Basics of cosmogeochemistry and elemental abundances in the Solar System
   1.2. Meteorites and the reconstruction of the early history of the Solar System
   1.3. Classification of meteorites and constraints on the composition of planetary bodies
   1.4. Formation of the Solar System: accretion, radiogenic heating and differentiation
   1.5. Magma oceans, core segregation and formation of planetary internal layers
   1.6. General principles of the thermal evolution of planetary bodies

2. Terrestrial planets
   2.1. The deep Earth: internal structure, PREM, crust, mantle and core
   2.2. Phase transitions in the Earth's mantle: olivine, wadsleyite, ringwoodite, bridgmanite and ferropericlase
   2.3. Seismic discontinuities, transition zone, core-mantle boundary and the D? region
   2.4. Heat flow, mantle convection and thermal evolution of the Earth
   2.5. Deep cycles of water, carbon and sulfur; volatiles in the mantle and core
   2.6. Reactions at the core-mantle boundary and interaction between deep reservoirs
   2.7. The Moon: formation, differentiation, internal structure and thermal evolution
   2.8. Mars: seismological constraints from the InSight mission, internal structure, mantle mineralogy, core and heat flow
   2.9. Mercury and Venus: density, moment of inertia, gravitational constraints, state of the core and dynamo

3. Giant planets
   3.1. Chemical composition of giant planets and constraints from Solar System formation

3.2. Equations of state of H-He mixtures and light materials under extreme conditions
3.3. Metallization of hydrogen and implications for internal structure
3.4. Helium rain, phase separation and internal structure of Jupiter and Saturn
3.5. Possible diamond rain in icy giant planets
3.6. Differentiation and composition of Jupiter, Saturn, Uranus and Neptune
3.7. Water-, ammonia- and methane-rich layers in Uranus and Neptune
3.8. Conductivity, planetary dynamos and non-axial magnetic fields

4. Experimental techniques for the study of planetary interiors
   4.1. Diamond anvil cells and generation of high static pressures
   4.2. Laser heating and in situ measurements at high pressure and temperature
   4.3. X-ray diffraction and spectroscopies under extreme conditions
   4.4. Dynamic compression: laser shock, gas gun experiments and equations of state
   4.5. Large-scale facilities: synchrotrons, free-electron lasers and advanced experimental infrastructures
   4.6. Analytical techniques under ambient and non-ambient conditions applied to planetary materials

Practical classes (1 CFU, 12 hours)

The practical classes include seminar and hands-on activities.

Students will prepare and present short scientific seminars in English based on papers selected by the lecturer and consistent with the course contents. This activity aims to develop the ability to critically read the scientific literature, synthesize complex results and communicate them effectively.

Practical sessions with software for the analysis and visualization of data derived from experimental techniques applied to the study of planetary interiors are also planned. The software and tools may include GSAS-II, SYNCMoss, Origin or equivalent programs for the analysis of diffraction, spectroscopy and physicochemical property data.

Laboratory activities (1 CFU, 12 hours)

Laboratory activities will be devoted to the introduction and participatory use of experimental methods and analytical techniques employed in the study of planetary materials under extreme conditions.

Activities may include:

- introduction to the use of the diamond anvil cell;
- Raman and spectroscopic techniques applied to geological and planetary materials;
- analysis of experimental data collected under ambient and non-ambient conditions;
- discussion of high-pressure and high-temperature experiments;
- educational visit to a large synchrotron radiation facility, such as Grenoble, to directly observe experiments and advanced techniques applied to the study of planetary materials.

Prerequisites

There are no mandatory prerequisites. However, basic knowledge of mineralogy, petrology, geochemistry and geophysics is recommended.

Students are advised to take this course in combination with other mineralogical-petrographic, geochemical and geophysical courses, such as Instrumental Methods in Mineralogical Investigation, Petrogenesis of Geodynamic Environments, Geochronology and Archaeometry, Industrial and Environmental Mineralogy, and related geophysics courses.

The course is also strongly complementary to Planetary Surface Dynamics, which focuses on atmospheres, surface processes, planetary geomorphology, surface tectonics, impact cratering, remote sensing and the study of planetary surfaces.

Teaching form

The course is taught in English and includes:

28 hours of lectures, 4 CFU, mainly held in the classroom. These lectures will cover the fundamental theoretical aspects of the dynamics of planetary interiors and will include case studies related to the Earth and other bodies of the Solar System.

12 hours of practical classes, 1 CFU, held in person and dedicated to the active participation of students through scientific seminars in English and practical data-analysis activities.

12 hours of laboratory activities, 1 CFU, during which students will participate in the observation and application of experimental methods and analytical techniques used in the study of planetary interiors, possibly including activities in laboratories or at large-scale research facilities.

Textbook and teaching resource

In addition to the course slides and materials provided by the lecturer, also based on direct experience in the laboratory and at large-scale experimental facilities, the following texts are recommended for further study of the topics covered:

Andrew Putnis, Introduction to Mineral Sciences. Cambridge University Press.

Deep Carbon: Past to Present. Cambridge University Press.

Planetary Mineralogy. EMU Notes in Mineralogy, vol. 15. European Mineralogical Union.

Additional scientific papers and up-to-date review articles will be provided by the lecturer during the course and will serve as reference material for the seminar activities.

Semester

The course takes place in the second semester of the first year of the Master’s degree programme, indicatively from early March to late May, with a break during the Easter period.

The educational visit to a large synchrotron radiation facility is indicatively planned for June or July, depending on the availability of the host facility and logistical arrangements.

Assessment method

Assessment will include:

1. preparation of an original project based on a published scientific study, on a topic agreed with the lecturer, possibly hypothetical, integrating the scientific contents and techniques covered during the course;
2. an oral examination focused on the developed project and on the topics discussed during the lectures;
3. evaluation of participation in the practical classes, including the quality of the scientific seminar delivered in English.

The overall assessment will take into account clarity of presentation, ability to synthesize information, scientific accuracy, the ability to connect theoretical, experimental and modelling aspects, as well as originality and critical thinking in framing a research problem.

The ability to interpret experimental or modelling data, the understanding of the physicochemical processes governing planetary interiors, and the ability to communicate complex scientific content effectively will also be assessed.

The course is passed with a minimum final grade of 18/30.

A possible breakdown of the final grade is as follows:

written project or scientific report: up to 15 points;
oral examination on the course topics and the project: up to 10 points;
seminar in English and participation in practical classes: up to 5 points.

Office hours

Every working day during office hours, by appointment, depending on the lecturer's teaching, institutional and off-campus commitments.

Sustainable Development Goals

QUALITY EDUCATION | INDUSTRY, INNOVATION AND INFRASTRUCTURE | CLIMATE ACTION | LIFE ON LAND | PARTNERSHIPS FOR THE GOALS