Teaching Plan

1. Cosmology and Fundamental Astrophysics – 2 CFU

Lauro Moscardini (UNIBO-DIFA) – 10h; **Francesca Pozzi** (UNIBO-DIFA) – 10h

The aim of this module is to obtain a general understanding of most important astrophysical topics, from stars to modern cosmology. The first part of the lectures be dedicated to acquire an astronomical language and to present the most relevant astrophysical systems, from stars to galaxies, both from an observational and a physical perspective. The second part of the lectures will allow the students to acquire the basic knowledge of the modern cosmology, based on the Hot Big Bang model and on the theory of formation of cosmic structures, paying attention to observational data that can be used to constrain them (cosmic microwave background, large-scale structure of the universe, ...).

The learning objectives are:

- Fundamental astronomical quantities and the astronomical language;
- How radiation propagates through cosmic space: the radiative transfer equation. Continuum and line emission/absorption processes;
- Stars: classification, the HR diagram, their structural and evolutionary properties;
- Galaxies: our MW galaxy, Spiral and Elliptical galaxies
- Friedmann models
- The Hot Big Bang model and the thermal history of the Universe
- The formation of cosmic structures

The main cosmological observables: the cosmic microwave background radiation and the large-scale structure of the universe.

2. High-energy Astrophysics and Astroparticle Physics – 2 CFU

Marcella Brusa (UNIBO-DIFA) – 10h, **Maurizio Spurio** (UNIBO-DIFA) – 10h

High Energy Astrophysics can be studied through processes that involve electrons and protons/nuclei. The first part of these lectures focuses on processes induced by electrons, which lead to electromagnetic emission from keV to GeV/TeV energies from populations of Galactic and extra-galactic sources. Results from X-ray and gamma-ray space telescopes will be discussed. The second part focuses on the production and acceleration of protons and nuclei and the problem of missing antimatter in the Universe. The method of multimessenger observations of astrophysical objects in the framework of space experiments is finally presented.

The learning objectives are:

- Emission mechanisms: blackbody/bremsstrahlung/synchrotron/Compton scattering and Inverse Compton scattering. Eddington limit and accretion discs;
- Compact sources: X-ray binaries, Active Galactic Nuclei and accreting supermassive black holes, Gamma Ray Bursts
- Extended sources: Clusters of galaxies; the Galactic Center
- Particles and antiparticles in the Universe observed from satellites
- Cosmic rays and the connection with supernovae
- Production of nuclei in the periodic table of elements from different processes
- Multimessenger observations of gravitational waves, gamma-rays and other electromagnetic radiations.

3. Planetology and Astrobiology – 2 CFU

Roberto Orosei (INAF-IRA) – 10h, **Barbara Cavalazzi** (UNIBO-BIGEA) – 10h

The first part of this module presents a general introduction to the solar system objects, their physical properties and thei formation and evolution. The second part presents the main concepts regarding the search for life in the Universe, and how they developed through time. Lectures will then focus on the development of habitability and life on Earth in the context of its geological evolution. Identification of past signatures of life and life in extreme environments will then be discussed. The module will then introduce the current concepts about the origin and evolution of the Universe, the origin of chemical species and the formation of the Solar System. Characteristics and geologic history of planets and minor bodies will be examined, and their potential for habitability discussed. The search for extrasolar planets will be described.

The module will provide students with the basic notions needed to understand the status and trend in the search for life beyond Earth. The high-level learning objectives are:

- The solar system: general properties and evolution of planets, moons and minor bodies;
- How and when planet Earth became home for life;
- Origin and evolution of life on Earth;
- Physical limits of life on Earth and extreme environments;
- Characteristics of planets and moons with respect to their potential to host life;
- Current trends in Solar System and exoplanetary exploration.

4. Fundamental Physics of the Solid Earth – 2 CFU

Alberto Armigliato (UNIBO-DIFA) – 10h, **Alessandra Borghi** (INGV) – 10h

In the module *Introduction to Seismology and Volcanology* the student acquires an understanding of some of the basic concepts of the solid Earth's dynamics with special focus on earthquakes and volcanoes and their physical observables. The module enables students to comprehend the physical processes that are responsible for the generation of earthquakes and of volcanic eruptions, the main characteristics of the measurable deformations induced by earthquakes on the Earth's free surface, the main properties of the volcanic eruptions. An overview on the physics of the generation of other hazards connected to earthquakes and volcanic eruptions, such as landslides and tsunamis, will be given at the end of the module.

The main topics covered by the module are:

- generalities on the internal structure of the Earth and on plate tectonics;
- the seismic source and its representation;

- deformations of the Earth's surface induced by earthquakes: co-seismic and post-seismic deformations;
- phenomenology of volcanism: volcanism on the Earth and on other planets in the Solar System, types of eruption on Earth and associated energy;
- genesis and properties of magma, mechanics of magma ascent and its measurable physical properties (composition of the gas emissions, thermal properties, change in shape of the volcanic edifice);
- other hazards possibly connected to earthquakes and volcanic eruptions: landslides and tsunamis.

In the module *Introduction to Satellite Geodesy*, the student acquires an understanding of some of the basic concepts related to the geometric shape and dimension of the Earth and its gravity and magnetic fields. The module enables students to comprehend the physical concepts underlying the definition of reference surfaces, as the geoid and the reference ellipsoid, and of the coordinate systems, the origin and properties of the Earth's gravity and magnetic fields.

The main topics covered by the module are:

- Introduction to Geodesy
- Geometrical geodesy: the reference and coordinate systems, measurements of the position of points on the Earth surface and its change over time (GNSS techniques)
- Physical Geodesy: origin of the gravity field, definition of the gravity anomalies, its observation by satellite (CHAMP, GRACE and GOCE satellite missions)
- The terrestrial magnetic field and its measurement by satellite (Swarm mission).

5. Fundamental Physics of the Fluid Earth – 1 CFU

Federico Porcù (UNIBO-DIFA) – 6h, **Francesco Trotta** (UNIBO-DIFA) – 4h

In the module *Introduction to Physical Oceanography*, the student acquires the understanding of some of the basic concepts of ocean dynamics solving the classical problems of the wind driven ocean circulation for the world open ocean areas. The module enables students to comprehend the physical processes that govern ocean circulation: the interaction of the ocean with the atmosphere, and the distribution of oceanic winds, currents, heat fluxes, and water masses.

The main topics covered by the module are:

- Physical and chemical properties of seawater;
- Distribution of water characteristics in the world ocean and in the Mediterranean;
- Principles of dynamical oceanography: equation of continuity, equations of motion; main approximations used in geophysical fluid dynamics;
- Large scale circulation in the ocean: surface and thermohaline circulation, the global ocean conveyor belt
- Ocean general circulation models. The main community models.

In the module *Introduction to Atmospheric Physics*, the physical characteristics of the atmosphere are presented, focusing on the attributes that are able to impact on the radiative transfer and earth surface observation. Moreover, the basic physical process occurring in the atmosphere are introduced, discussing the capability of remote sensing for studying and monitoring.

The student acquires the basic knowledge to link meteorological processes and their signature in satellite observation. The main topics covered by the module are:

- Structure of the Atmosphere;

- Thermodynamic and dynamical processes;
- General circulation and large scale features.

6-7. Space Missions – I & II – 6 CFU

Paolo Tortora (UNIBO-DIN) – 20h, **Dario Modenini** (UNIBO-DIN) – 20h, **Marco Zannoni** (UNIBO-DIN) – 20h

In the first part of the module, the student acquires fundamentals on systems engineering of space systems and the key aspects of spacecraft systems design. He/she will also learn the design considerations which come into play in laying out a space mission and its preliminary design. In the second part of the module, students are taken step-by-step through an example of the design of a space mission, learning how to use the on-board instrumentation requirements and the general sizing criteria for all subsystems.

The module will enable students to design and engineer a scientific space mission. Therefore, the high-level learning objectives are:

- Knowledge of the main aspects of satellite missions;
- Understanding the usage of systems engineering methods and practices;
- Expertise in the elements and architecture of a spacecraft mission;
- Capability to present and defend their design of an element in the architecture of a spacecraft mission;
- Familiarity with current trends in space industry and space science mission research.

8. Space Telescopes and Radiation Detectors – 1 CFU

Beatrice Fraboni (UNIBO-DIFA) – 5h, **Carlotta Gruppioni** (INAF-OAS)–5h

In the first part of the module, the students acquire fundamentals on radiation detectors for astrophysics. Basic concepts on radiation-matter interactions will be surveyed together with the different active materials and operating principles required for the detection of electromagnetic radiation spanning from far infrared to gamma-rays and particles.

In the second part of the module, the students are introduced to the main properties of the space telescopes, with particular focus on the Infrared Space Telescopes by ESA and NASA and their technological evolution with time. They will learn how the astrophysical observations depend on the main telescope components through examples and comparisons of improved instrument performances.

The main topics covered by the module are:

- Radiation Detectors for Astrophysics: materials, system architectures, relevant figures of merit
- Examples of detectors applied to Space Missions
- Infrared Space Telescopes, properties and design
- Astrophysical observables and their dependence on the telescope components

9. Space Data Transmission – 1 CFU

Marco Chiani (UNIBO-DEI) – 5h, **Enrico Paolini** (UNIBO-DEI) – 5h

In this module, the student acquires knowledge about concepts that play a fundamental role in space digital communication systems. In the first part of the module, the main subsystems composing a wireless digital communication scheme are reviewed and fundamental concepts such as spectrum and bandwidth, modulation and demodulation, symbol rate, bit error rate, are overviewed. In the second part of the module, the above concepts are exploited to introduce and analyze the link budget. The concepts of antenna gain, free space path loss, and signal-to-noise ratio are addressed in the second part of the module. Examples are provided for actual space missions such as Voyager, Rosetta, ExoMars, etc.

The module will enable students to perform a link budget in a scientific space mission. The high-level learning objectives include:

- Understanding the performance metrics in space communication links;
- Understanding the fundamental relationship between the transmitted and the received power in a space link;
- Capability to prepare a link budget and calculate the power margin in a space link;
- Understanding the trade-off between performance and spectral efficiency.

10. Human Flight and Space Medicine – 1 CFU

Gabriele Mascetti (ASI) – 5h, **Matteo Cerri** (UNIBO-DIBINEM) – 5h

The module, in its first part, will provide the student with a panorama on the past, present and future history of the Human Spaceflight. An insight on the current major spaceflight program, the International Space Station, will be provided; key enabling factors enabling human spaceflight will be addressed.

In the second part an overview on health risk and on the adaptation of the human body to the space environment will be presented, with a special focus on the measure that could be used to counteract such effects.

The module will deliver to the students

- Knowledge of the history and main achievements of human spaceflight
- Understanding of the ongoing and planned major programs of human exploration
- Ability to identify key challenges for human spaceflight
- An overview on the physiology of the human body
- An overview on the adaptation of the body in space and the concurrent health risk.
- An overview on the methods that can/could be used to counteract the effects of space on the human body.

11. Management of Space Missions – 1 CFU

Luca Valenziano (IANF-OAS) – 10h

Students will be guided in understanding the end-to-end development of a space mission from the organization point of view. They will learn the basic concepts of project management, with a specific focus on its application to science projects in a multi-partner academic environment. The ECSS standards will be introduced. The complementarity to System Engineering will be presented in the concept of Project Office. The module will enable students to understand the structured development of a space project and to sketch a high-level management approach to science projects.

The high-level learning objectives are:

- Identification of main stakeholders in a space projects: funding agencies, space agencies, research centers, industries, scientific community;

- Knowledge of project management fundamentals: Product Tree, Work Breakdown Structure, Schedule, Risks, Configuration, Documents structure;
- Understanding the different phases of a project: from A to E and the concept of V-development; Technology Readiness Level;
- Learning the hierarchical approach to complex system breakdown and its relation to the review process;
- Familiarity with classical approach to ESA space projects and the new trends in project development in the private sector.

12. Analysis of Astrophysical Data – 2 CFU

Cristian Vignali (UNIBO-DIFA) – 10h, **Michele Ennio Maria Moresco** (UNIBO-DIFA) – 5h, **Alessio Mucciarelli** (UNIBO-DIFA) – 5h

In the first part of the module (led by Prof. C. Vignali), the student will be introduced to the properties of focusing X-ray telescopes. Then he/she will be led through few examples of data analysis with current X-ray telescopes and their interpretation in the light of accretion physics. Finally, the student will be guided to the new windows that forthcoming X-ray facilities will open, with a particular focus on high-resolution spectroscopy.

The high-level learning objectives of this part of the module are:

- Understanding the principle of double grazing incidence;
- Expertise in X-ray data (imaging, timing, and spectral) analysis and their interpretation;
- Familiarity with current and forthcoming X-ray facilities.

In the second part of the module (led by Prof. M. Moresco), the student will be given a general introduction to spectroscopy, discussing the main optical elements and relevant quantities (e.g., prism, grating, grism, spectral resolution, signal-to-noise ratio, ...) and as well the different modes with which spectroscopic data can be acquired (slit, slitless). He/she will learn the basics of spectral analysis and of the fundamental spectral measurements (line, flux, equivalent width, full width half maximum, continuum, error estimate, ...), and how the measurements are performed. Finally, the student will learn the main kinematical and physical quantities that can be derived from spectroscopic data (velocity, velocity dispersion, mass, metallicity, extinction, ...) and the methods to obtain them.

The high-level learning objectives of this part of the module are:

- Knowledge of the basics of spectroscopic data;
- Expertise in the fundamental techniques to perform spectral measurements;
- Understanding of the physical and kinematical information that can be obtained from spectral measurements, and of the available techniques and methods to extract these.

In the third part of the module (led by Prof. A. Mucciarelli), the student will be introduced to the main techniques concerning the photometric data, with a particular interest to the analysis of data from space telescopes.

The lectures of this part of the module will present

- the basic concepts concerning the photometric data (point-spread function and its description, photometric filters, seeing versus diffraction-limited data);
- the main techniques to measure magnitudes (aperture photometry and PSF-fitting), fluxes, positions and proper motions from photometric data;

- the presentation of some (current and future) space facilities (Hubble Space Telescope, Gaia, James Webb, Euclid) and the impact of their photometric data related to some specific astrophysical science cases.

13. Detectors for Astroparticles and Data Analysis – 1 CFU

Laura Patrizii (INFN) – 10h

This module will complement the one on Astroparticle Physics by providing the fundamentals of particle's interaction with matter, detection techniques and their application in spaceborne experiments. It is organized in three units:

1. Particle interaction with matter:

- heavy charged particles
- fast electrons
- gammas
- electromagnetic/hadronic showers

2. Particle detectors: general properties (energy/space/time resolution; efficiency, …)

- ionization detectors, scintillators, Cherenkov detectors, silicon detectors
- particle identification: tracking detectors, transition radiation detectors, time-of-flight, magnetic spectrometers, electromagnetic calorimeters

3. Space experiments: overview (PAMELA, AMS-02, FERMI-LAT, DAMPE, ...).

- Data analysis: measurement of anti-protons; the B/C ratio; the positron anomaly

14. Earth Observation Techniques and Data Analysis – 4 CFU

Gabriele Bitelli (UNIBO-DICAM) – 20h, **Emanuele Mandanici** (UNIBO-DICAM) – 10h, **Bianca Maria Dinelli** (CNR-ISAC) – 10h

Module 1: Earth Observation systems, data and applications (G. Bitelli, E. Mandanici, 20h + 10h)

The course provides both theoretical knowledge and practical skills in Earth Observation techniques and their adoption inside Geographical Information Systems (GIS). Students will acquire the fundamentals on the use of satellite remote sensing imagery to derive qualitative and quantitative information about the territory (at urban, basin and regional scale). Students will also develop practical skills through examples and exercises of EO data processing and thematic map generation.

The main learning objective are:

- Understanding of the main characteristics of multispectral satellite images;
- Main EO satellite missions, with emphasis on Copernicus program;
- Basics of the effects of the atmosphere on multispectral images, spectral profiles of main land cover types;
- Skills on basic pre-processing of images (radiometric and geometric);
- Knowledge of the potential and limitations of the main image classification techniques;
- Familiarity with the integration of EO data with modern Geomatics techniques on GIS platforms.

Module 2 (B.M. Dinelli, A. Bonazza, 6h + 4h)

The module will be divided into two parts. The first part will be focused to the basic concepts of satellite measurements of the atmospheric and surface properties. All the aspects (from the principal measurement techniques to the data analysis methods) will be treated, dealing mainly with observations in clear sky condition. In the second part an introduction of the basics of pollution and climate change impact on cultural heritage will be illustrated, followed by an analysis of satellite data for the protection and management of built heritage and landscape at risk, by presenting showcases of application.

1st part on satellite atmospheric measurement techniques and data analysis (Bianca M. Dinelli, 6h)

- Radiative transfer in atmosphere in clear sky and molecular spectroscopic properties.
- Inversion methods to obtain the atmospheric status from remote sensing measurements. Error evaluation of the obtained quantities
- Description of the main measurement techniques used to observe the atmospheric status (temperature and composition) and examples of satellite instruments for the atmospheric measurement and their products.
- 2nd Part on satellite data for the protection of cultural heritage (Alessandra Bonazza, 4h)
- Impact of pollution and climate change on cultural heritage: assessment methodologies and still existing gaps in research
- Matching Copernicus services portfolio with Cultural Heritage user requirements
- Showcases of satellite data application for risk assessment of built heritage and landscape exposed to climate extreme events.

15. Applications of Geospatial Information – 2 CFU

Elisabetta Carfagna (UNIBO-STAT) – 20h

This course addresses the main methodological aspects behind the use of geospatial technology for monitoring agriculture and agri-environment and for producing reliable and timely agriculture and agri-environmental statistics. Advantages, constraints and requirements of the use of geospatial technology are highlighted. Various statistical aspects are analysed, such as main types of probability sample surveys based on area sampling frames and corresponding estimation methods, the use of remote sensing data at the design level (area frame construction and stratification) as well as at the estimator level. Finally, the impact on estimates of spatial resolution, change of support and transformations of spatial data is addressed.

1. Elements of statistical inference and sampling techniques

- Elements of estimation theory
- Design based sampling techniques

2. Probability sample surveys for exploiting geospatial information

- List and area sampling frames
- Area frame construction and stratification
- Optimisation of area sample designs
- Sample allocation
- Multiple frame sample surveys
- Master sampling frames

3. Estimation methods using geospatial information

- Associating segments with reporting units
- Sampling circles and farms by points and related estimators
- Multiple frame estimators

4. Statistical issues of classification of Sentinel data

- Accuracy assessment of classification of Sentinel data
- Analysis of stability, robustness and bias of classification methods

5. Improving the precision of estimates with classified satellite data as auxiliary variables

- Regression and calibrating estimators
- Small area estimators
- Yield estimation models

6. Impact on estimates of spatial resolution, change of support and transformations of spatial data

16. Satellite Monitoring of the Climate and Ocean Systems – 2 CFU

Tiziano Maestri (UNIBO-DIFA) – 10h, **Nadia Pinardi** (UNIBO-DIFA) – 5h, **Marco Zavatarelli** (UNIBO-DIFA) – 5h

Module 1 (T. Maestri, 10h)

In the first part of the module, the student acquires the fundamentals of radiative transfer in planetary atmosphere and remote sensing of surface and clouds/hazes/aerosols. He/she also learns the main techniques to derive optical, geometrical and physical information from satellite observation of scattering layers. The module enables students to interpret atmospheric radiance spectra and the link to the retrieved products for the climate system understanding and monitoring.

The main topics covered by the module are:

- Radiative transfer at shortwave and longwave wavelengths: observing the Earth system with spectro-radiometers and sounders.
- Surface reflection and emissivity. Land characterization, retrieving land surface temperature and properties. Fires detections.
- Scattering phenomena in the atmosphere; remote sensing in multiple scattering environments. Clouds and aerosols from space.
- Cloud identification and properties retrievals.
- Radiation and climate. Clouds and aerosols properties databases.

Module 2 (N. Pinardi, 5h - M. Zavatarelli, 5h)

In the module section dedicated to the satellite remote sensing of the ocean, the student acquires knowledge of fundamentals of ocean optics and the basic functioning of the sensors carrying out observations. They will also explore the data available through the European Earth Observation Program “COPERNICUS”. Subsequently, they will operate data analysis procedures applied on the most important ocean properties remotely observed trough satellite. In particular the work will be based on:

- Scatterometer data (surface winds)
- AIS data (sea surface altimetry)
- SAR data (oil spills)
- AVHRR (sea surface temperature)
- Ocean Color (surface phytoplankton concentration and light extinction coefficient)

17. Image Processing and Data Analysis – 4 CFU

Alessandro Bevilacqua (UNIBO-DISI) – 40h

In the first part of module, the student learns the fundamentals of a computer vision system, made of a camera and image processing and analysis software, to be used for metrology and quantitative analyses. The student acquires the basic principles of optics and radiometry useful to understand the image formation on the sensing device and the basics of image processing operations and image analysis. The student knows the principles of 3D imaging. Some commercial and open source software for image processing and analysis will be presented.

Therefore, the high-level learning objectives are:

- Basic knowledge of optics, radiometry and image sensing
- Understanding the process of image formation
- Expertise in image processing – point, local and global operations
- Capability to design a simple computer vision system
- Capability to extract radiometric and geometric measures from images
- Understanding the principle of 3D imaging

In the second part of module, the student will learn the fundamentals of pattern recognition and machine learning, that is, how to automatically extract meaningful information from images and dataset. The student acquires the expertise to accomplish this task using either parametric or nonparametric models, in a supervised or unsupervised manner. The student knows how to setup and validate a model, learning the concepts of overfitting and generalizability. Useful examples exploiting 1D signals, images and multi-feature data will be employed.

Therefore, the high-level learning objectives are:

- Principles of pattern recognition and machine learning
- Understanding descriptive and statistical inference
- Expertise in parametric and nonparametric regression
- Capability to explore data relations to extract meaningful features
- Knowledge of supervised and unsupervised learning
- Understanding model validation