U1-4A Cosmological parameters and large scale structures : birth and fate of the universe

I. Basic description of the cosmological model

- General framework
- Privileged models and main cosmological parameters

II. Constraining the characteristics of the Universe: key methods

a.Testing the growth of structure:

- Initial matter density perturbations
- Dynamical evolution of the large-scale structure and redshift-space distortions
- Weak lensing tomography
- Massive structures, cluster physics and evolution

b. Testing the geometry of the Universe

- Supernovae 1A as standard candels
- Cosmic Microwave Background : physical sources, anisotropy, polarisation
- Baryon acoustic oscillations in the galaxy distribution
- Matter distribution and gravitational lensing

c. Large-scale structure and galaxiy distribution : numerical simulations and analytical prescriptions

- High performance computing and numerical modeling
- From intergalactic to circum-galactic medium
- Modeling physical processes in the ISM: star formation and feedback
- Matching models and obser vations

III. The planned milestones and key projects

- Introduction to the milestones
- Related key projects : present and future

UE1-4B-Formation & Evolution of Galaxies

I Galaxies in the universe: a general introduction

- The Milky Way: recognizing it as a galaxy
- Elliptical and spiral galaxies, rotation curves and dark matter halo
- The general framework of galaxy formation and evolution

II Radiation from galaxies: from the observations to the physical content of galaxies.

- Galaxies at all wavelengths: brief presentation of the whole spectrum
- Star formation rates and stellar mass measurements
- Gaseous and dust components
- The process of star formation

III Detailed view of spiral galaxies and their secular evolution

- Galaxy formation: the primordial disk
- Formation and stability of the disk, orbits in the disk
- Formation of the arms, the bar and the bulge
- Importance of instabilities at high redshift

IV Galaxy evolution within the dark matter structures

- The star formation history and the dark matter structure growth
- The dark matter halos and stellar mass functions: AGN and SN feedback
- impact of the environment, mergers and formation of the elliptical galaxies

V Galaxy evolution from the local to the distant universe

- The local universe and the distant universe
- The stellar mass assembly
- Statistics : spatial distribution, counts, luminosity functions and biases

VI Active Galaxy Nucleii

- What is an active galaxy ? a central black hole as engine, the accrétion disk
- The unification model
- AGN-galaxy co-evolution: quenching of the star formation

VII The Intergalactic medium

- Cosmological reionization, Gunn-Peterson effect
- Clumpy IGM: absorbing systems
- The cosmic web: IGM-galaxy connection

Bibliography:

The structure and evolution of galaxies, S. Phillips, Wiley
Galaxy formation and evolution, Mo, Van den Bosch & White, Cambridge Univ. Press
A panchromatic view of galaxies, Boselli, Wiley
Galaxies in the universe: an introduction, Sparke & Gallagher, Cambridge Univ. Press
Astrophysics of gaseous nebular and active galactic nuclei, Osterbrock, Univ. Science Books

U1-4C : Stars and Stellar Formation : From the Early Universe to Now

I. Observational properties of stars

- Determination of stellar radii, surface temperatures, mass, composition, etc.
- Hertzsprung-Russell diagram and Main Sequence
- Star clusters; distances, ages and stellar populations

II. Star formation

- The viral theorem
- The Jean's mass
- The interstellar medium and molecular clouds
- Observational evidence for star formation
- Initial Mass Function

III Formation of first stars

- Stellar formation with no metals
- Stellar evolution with no metals

IV Stellar interiors

- Concepts of pressure and equation of state
- Hydrostatic equilibrium
- Energy transfer and conservation
- Equations of stellar structure
- Polytropic models
- The sun, a typical star
- Degeneracy pressure and the minimum mass of a star
- Nuclear physics
- Hydrogen burning and the main sequence of the HR diagram

V. Stellar evolution and stellar remnants

- Stellar evolution
- White dwarfs
- Supernovae and neutrons stars
- Pulsars and Supernovae remnants
- Black holes

Bibliography:

Stephen W. Stalher and Francesco Palla, "The formation of stars", Wiley-VCH
R. Kippenhahn and A. Weigert, "Stellar structure and evolution", Springer-Verlag,
Richard Bowerz and Terry Deeming, "Astrophysics I Stars", Jones and Bartlett Publishers, Inc,

UE1-4D Physics and chemistry of the interstellar medium

- **Introduction: phases and processes in the interstellar medium**

- **Ionization, dissociation and radiative processes**
  - Ionization equilibrium
  - Hydrogen recombination and Forbidden emission lines
  - Continuum emission
  - Interstellar absorption lines
  - Radiative transfer and lines and continuum formation
  - High energy radiations

- **Overall equilibrium**
  - Heating and cooling processes
  - Thermal equilibrium

- **Interstellar dust**
  - Extinction
  - Polarization
  - Physical properties of grains

- **Molecules in the Universe**
  - A brief history of molecules detection, the birth of astrochemistry
  - Review of molecular compounds (organic , inorganic, polymer,…)
  - Astrophysical environments and molecules (diffuse, dense, planetary, …)

- **Chemical processes in the interstellar medium**
  - Gas phase chemical reactions
  - Grain chemistry
  - Ice chemistry
  - Chemistry of diffuse clouds, photodissociation regions chemistry
  - Molecular clouds and star formation chemistry
  - Shocks chemistry
  - PAH chemistry
  - Solar bodies and exoplanet chemistry

- **Open questions of astrochemistry (2h)**
  - The evolution of molecular complexity
  - The search for prebiotic molecules (amino-acids, homochirality,…)
  - The search for habitability and biosignatures

Bibliography :

The physics and Chemistry of the interstellar medium, Tielens, Cambridge University press, 2005
The interstellar Medium (Astronomy and Astrophysics Library) Lequeux, Falgarone, Ryter, 2003
Physical processes in the interstellar medium, Spitzer, Wiley Classics library, 1998

UE1-4E Planetary systems

I. Solar System and exoplanet taxonomy (4h)

II. Planetary formation (6h)

- Protoplanetary accretion disks
- Physical chemistry of the protosolar nebula
- From dust to planets
- Migration mechanisms

III. Planetary evolution (7h)

- Tidal interactions and system stability
- Thermal evolution of small bodies
- Internal structures of terrestrial planets
- Geology of terrestrial planets
- Icy bodies (moons, dwarf planets, small mass exoplanets)
- Giant planets interiors
- Mass-radius relationship

IV. Planetary atmospheres (6h)

- Origin and evolution
- Atmospheric Composition: fundamentals
- Radiative transfer and greenhouse effect
- Vertical structure
- Clouds and aerosols

V. Characterization techniques and limitations (4h)

- Search techniques and sensitivities
- Characterization of exoplanet atmospheres
- *In situ* measurements

VI. Astrobiology (3h)

- Life and its origins
- Life on Earth
- Habitable environments in the solar system
- Habitable zone and biosignatures

Bibliography:-

- Protostar and Planet VI (2014):
- Armitage, P. 2011 Dynamics of Protoplanetary Disks ARA&A 513, 57.
- Blum & Wurm 2008 – The growth mechanism of macroscopic bodies ARA&A 46, 21
- Solar System Update – Editors P. Blondel and J. W. Mason – Springer, 2006
- Exoplanet Atmospheres: Physical Processes, S. Seager, Princeton Series in Astrophysics 2010
- Exoplanets, Space Science Series, S. Seager editor, 2010
- Earth: evolution of a habitable world, J. I. Lunine, Cambridge, 2013
- Physics and chemistry of the solar system, J. S. Lewis, Academic Press, 1997
- An introduction to planetary atmospheres, A. Sanchez-Lavega, CRC Press, 2010

UE1-4F2.1 Plasma physics and MHD

I. Basic parameters

- Debye length
- Coulomb collisions
- Collective effects
- Plasma sheath
- Plasma oscillations
- Transport processes
- Statistical properties of the electric microfield

II. Charged particle motion

- Hamiltonian dynamics
- Particle motion in uniform electric and magnetic fields
- Guiding center motion: drifts and invariants

III. Plasma fluid theory

- Distribution functions and related moments
- Derivation of the macroscopic equations
- One- and multi-fluid models
- MHD equations
- Dimensional analysis and approximations (quasi-neutrality, ideal MHD, etc.)
- The energy equation

Bibliography:

F. Chen, Introduction to plasma physics and controlled fusion, Plenum press, New York 1984.
J.-M. Rax, Physique des plasmas, Dunod, Paris 2005.

UE1-4F2.2 Radiation-matter interactions and spectroscopy

I. Complete thermodynamic equilibrium

- Equilibrium between different ionization states in a plasma: Saha law
- Atomic populations and the Boltzmann law
- Maxwell velocity distribution
- Planck law: a historical perspective

II. Radiative transfer

- Einstein coefficients and relations
- Radiative transfer in a two-level system
- Optically thin and thick sources
- Radiation and energy

III. Elementary processes in gases and plasmas

- Collisional processes
- Radiative processes
- Calculations of cross sections : bremsstrahlung
- Local thermodynamic equilibrium, coronal and collisional-radiative models

IV. Introduction to spectroscopy

- Energy and power spectra
- Autocorrelation function of a wave train
- Damping of the classical oscillator
- Doppler broadening
- Collisional broadening with the Lorentz model

Bibliography:

D. Mihalas, Stellar Atmospheres, W. H. Freeman and Company, San Francisco, 1978.

UE1-4G Instrumental technics in astronomy

I. Astronomy, telescopes and focal instruments

- Astrophysical context
- Information messengers
- Photon detection: multi-wavelength observational technics
- Introduction to telescopes and detector: from radio wavelengths to γ rays
- Telescope families (Newton, Cassegrain, Schmidt, Schmidt-Cassegrain, Ritchey-Chrétien…)
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II. Spectro-imaging : spectroscopes, spectrographs and spectrometers

- Observational parameters: spatial, spectral and temporal information, bidimensionnal detectors, data cube.
- Adequation between scientific objectives and spectroscopic facilities
- Path light analysis
- Image dissector
- Examples of spectro-imaging systems

III. Active & adaptative optics

- Effects of atmospheric turbulence
- Adaptative and active optics: principles and technics
- Wavefront analysis: concept and analysis
- Direct and inverse problems: wavefront reconstruction, deconvolution
- Applications

IV. Introduction to optical systems

- Electronics: control command, components, modulation, amplification etc…
- Signal processing: probablilities, signal description, sampling etc..
- Opto-mechanics: mechanics and thermics of structures
- Systems ingineering

Bibliography :

- Observational Astrophysics, Pierre Lena, Daniel Rouan et al., Springer.
- Detection and Spectrometry of Faint Light, J. Meaburn, Astrophysics and Space Science Library
- Optics – Eugene Hecht – Adelphi University
- Astronomical Optics 2nd ed - D. Schroeder – Academic Press
- Astronomical Instrumentation, Matthew Griffin, Peter A. R., Series in Astronomy and Astrophysics

UE5-Inititation to observations

Initiation to a complete run of observations in a professional context

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I. Preparation of observations

- Coordinates systems
- Astronomical instrumentation
- Definition of the observational program
- Remote night observation with the IRIS telescope

II. Observations: 4 nights at OHP

- Telescope T80: imaging, interferometry
- T120: imaging and low resolution spectroscopy
- T193: high resolution spectroscopy
- pre-reduction of the data

III. Data analysis

- Calibration
- Scientific analysis
- Redaction of a research note and oral presentation of the results

Bibliography

* Observational Astronomy: Edmund C. Sutton, Cambridge University Press.
* Astrophysique, Méthodes Physiques de l'observation : Pierre Léna, Savoir actuel, CNRS éditions

UE7 Numerical physics

- Introduction to Fortran 90 programming
- Code parallelization
- Numerical simulations
- Integration
- Classical equations of motion
- Monte-Carlo method
- Molecular dynamics
- Schrödinger equation
- Plasma microfield

Bibliography:

H. Gould and J. Tobochnik, An introduction to computer simulation methods, Addison-Wesley, Reading 1996.
F. Vesely, Computational physics, Plenum press, New York 1994.