Lectures of the Erasmus Mundus IRAP PhD program, September 2010
Park Valrose, University of Nice Sophia Antipolis

	09:00-10:15	10:15-10:30	10:30-11:45	11:45-13:00	12:30-16:00	16:00-17:15	17:15-17:30	17:30-18:45
06.09	**Opening**		Einasto	Hütsi		Mignard		Mignard
07.09	Kerr/Bini		Einasto	Hütsi		Rueda		Koppitz
08.09	Kerr/Bini		Einasto	Hütsi		Rueda		Koppitz
09.09	Kerr/Bini		Einasto	Hütsi		Rueda		Koppitz
10.09	Kerr/Bini		Einasto	Hütsi		Rueda		Koppitz
13.09	Bianco		Frontera	Kobayashi		Palmkvist		Koppitz
14.09	Amati		Frontera	Kobayashi		Palmkvist		Koppitz
15.09	Amati		Frontera	Farinelli		Damour		Koppitz
16.09			Bianco	Kobayashi		Damour		Koppitz
17.09	Damour	Coffee break	Bianco	Kobayashi	Lunch	Palmkvist	Coffee break	Koppitz
20.09	Belinski		Della Valle	Kleinert		Vereshchagin		Chakrabarti
21.09	Belinski		Della Valle	Kleinert		Vereshchagin		Chakrabarti
22.09	Belinski		Della Valle	Della Valle		Della Valle		Chakrabarti
23.09	Belinski		Rosati	Vereshchagin		Rosati		Chakrabarti
24.09	Vereshchagin		Rosati	Belinski		Rosati		Chakrabarti **Concluding remarks**

Opening by:
President of the University of Nice Sophia Antipolis Prof. Albert Marouani
Director of the IRAP Erasmus Mundus PhD Prof. Remo Ruffini
Coordinator of the IRAP Erasmus Mundus PhD Prof. Pascal Chardonnet

Concluding remarks:
Director of the IRAP Erasmus Mundus PhD Prof. Remo Ruffini

Cosmological Singularity
Vladimir Belinski
ICRANet

Lecture 1
Synchronous reference system. Definition of the general solution. Physical and fictitious singularities.

Lecture 2
Kasner solution and its inhomogeneous generalization. Instability of Kasner dynamics.

Lecture 3
Orthogonal frames. Homogeneous spaces. Bianchi classification.

Lecture 4
Bianchi II model. Transition to the new Kasner regime. Diagonal Bianchi IX model. Oscillatory regime. Stochasticity.

Lecture 5

Non-diagonal Bianchi IX model and its inhomogeneous generalization. Rotation of Kasner axis. Orthogonal frame axis. Iwasawa decomposition. Freezing phenomenon.

Lecture 6
Influence of matter. Perfect liquid. Stiff matter state. Scalar field. Electromagnetic field. Yang-Mills fields.

Lecture 7
Multidimensional space. Pure Gravity.

Lecture 8
Supergravity models. Influence of p-forms and dilatons.

Lecture 9
Cosmological billiard. Coxeter simplex. Kac-Moody Lie algebra. Hidden symmetry conjecture.

Lecture 10
Dynamical systems approach. Mixmaster attractor.

Multivalued Fields in Condensed Matter, Electromagnetism, and Gravitation

Hagen Kleinert
Free University of Berlin

Relativistic Kinetic Theory and its Applications in Astrophysics and Cosmology

Gregory Vereshchagin
ICRANet

Lecture 1. Introduction and basic concepts

Density of particles in the phase space. Averaging, macroscopic quantities. One particle distribution function. Moments of DF, entropy flux and hydrodynamic velocity. Boltzmann equation with binary collisions. Cross-section.

Lecture 2. Conservation laws and equilibrium

Conservation laws. H-theorem. Local and global equilibrium. Number density, energy density and pressure in equilibrium.

Lecture 3. Gases and plasmas

Klimontovich DF for many-body systems. Liouville theorem and BBGKY hierarchy. Physical scales and approximations. Binary collisions and equilibrium in gases. Landau collision integral for plasmas. Collisionless Vlasov equation. Landau damping

Lecture 4. Pair plasma

Pair plasma in GRBs. Interactions in hot dense plasma. Collision integrals. Kinetic and thermal equilibria. Relaxation timescales evaluation. Relaxation timescales for the pair plasma with proton admixture.

Lecture 5. Collisionless and selfgravitating systems

Plasma instabilities. Collisionless shocks. Lynden-Bell violent relaxation. Jeans instability in collisionless system. Hierarchical clustering and dark matter halos.

Numerical Relativity

Michael Koppitz
Max-Planck-Institut füür Gravitationsphysik
Albert-Einstein-Institut

During the last few decades numerical relativity has become one of the most important analysis tools in general relativity. Dynamical solutions such as the two-body problem have attracted special attention and led to major advances in the numerical treatment of Einstein's equations. Especially new gauge choices found recently created a breakthrough and have ignited a wave of new results and both fundamental understanding and astronomical applications.

During the lecture we will address the basic ideas such as the 3+1 split, re-formulations of the equations, the importance of gauge choices, and a selection of analysis tools together with recent results.

1. Motivation / Introduction

2. The 3+1 Split
2. 1. Electrodynamics
2. 2. Einstein's Equations

3. Evolution Systems
3. 1. The ADM equations
3. 2. The BSSN equations

4. Initial data
4. 1. The York-Lichnerowicz Decomposition
4. 2. Misner, Brill-Linquist, Bowen-York, and Puncture Data
4. 3. The Thin Sandwich Decomposition

5. The Gauge Choices
5. 1. The Importance of Slicing Conditions
5. 2. The Shift Vector

6. Gravitational Waves
6. 1. Linearized Einstein Equations
6. 2. Weyl-Tensor and Newman-Penrose quantities

7. Horizon Finding
7. 1 Event Horizons
7. 2 Apparent Horizons
7. 3 Isolated Horizons

8. Things we didn't talk about
8. 1. Matter
8. 2. Boundary Conditions
8. 3. Alternative Formulations
8. 4. NUmerical Issues

9. Visualizations

Open Issues in High Energy Astrophysics and Needed X/Gamma-Ray Instrumentation

Filippo Frontera
University of Ferrara

The lectrures will concern an excursus of the instrument development since the first discovery of Sco-X1 by Giacconi et al. (1962) up to the nowday isntrumentation.
I will argument the instrumentation development excursus by discussing the science objectives that stimulated the new developments, and, conversely, the instrumentation that stimulated the science objectives.

Introduction to X-ray Binaries and Accretion processes around black holes and neutron stars

Sandip Chakrabarti
S.N. Bose National Center for Basic Sciences

1. Formation and classification of X-ray Binaries
2. Properties of X-ray binaries
3. Relativistic hydrodynamics around black holes and neutron stars
4. Radiations emitted from accreting matter: Observations vs. theory

Introduction to Cosmology

Gert Hütsi
(Tartu Observatory, ICRANet)

PART I: the homogeneous and isotropic Universe (Lectures 1-3)

Cosmological Principle. Hubble's law. Metrics of the homogeneous-isotropic space-times. Kinematics: distances, horizons etc. Dynamics: Friedmann equations. Matter-energy content of the Universe. Probes of the homogeneous isotropic expansion. Thermal history of the early Universe: baryogenesis, neutrino decoupling, e± annihilation, Big Bang nucleosynthesis, recombination. Problems with the Big Bang model. Inflation.

PART II: the clumpy Universe (Lectures 4-5)

Initial conditions. Linear evolution. Quasi-nonlinear evolution. Nonlinear evolution. Probes of cosmic fluctuation fields.

Numerical methods in Astrophysics

Shiho Kobayashi
Astrophysics Research Institute, Liverpool John Moores University

In the series of lectures, we discuss basic numerical algorithms for solving ordinary differential equations and partial differential equations (mainly wave equations) in astrophysical context. I first explain how to numerically solve equations of motion, and show how it could be used in actual astrophysics research by using an example of Hyper-velocity Stars (Massive black hole - binary interaction). The second part is about wave equations. We examine the advection equation and its mathematical properties. Then we show how such advection algorithms are used for solving the equations of hydrodynamics. Then we proceed with Riemann solver algorithms and relativistic implications (e.g. Gamma-Ray Bursts).

Gravitational Radiation and Binary Systems

Thibault Damour
IHES & ICRANet

The course will review several aspects of the theory of gravitational radiation: definition, generation by material systems, propagation, multipolar decomposition, radiation reaction, multipolar post-Minkowskian formalism, asymptotic behaviour, emission by binary systems, interface between analytical relativity and numerical relativity, the effective one body formalism, experimental evidence for the reality of gravitational radiation from binary pulsars,...

Kjell Rosquist
Stocholm University and ICRANet

Lecture 1. Exact solutions of the Einstein equations with rotation, charge and cosmological constant

Physical properties of the most important exact vacuum solutions of the Einstein equations will be discussed. The solutions treated are the charged generalizations of Schwarzschild and Kerr, also including a cosmological constant. Applications for the solar system and for cosmology will also be given.

Lecture 2. The physics of gravitomagnetism

We describe how the gravitational field of a rotating source can be decomposed in gravitoelectric and gravitomagnetic parts. In particular we consider the expansion in multipole moments and how it differs from the Newtonian case. The gravitomagnetic fields of various physical sources will also be discussed.

Large Scale Structure
Jaan Einasto
Tartu Observatory & ICRANet

Introduction to large scale structure
Short history of the Universe. 2-dimensional data on the structure of the Universe. 3-dimensional data on the structure of the Universe. Modern surveys of galaxies.

Methods of the analysis of the LSS
Testing structure formation theories. Correlation function; clustering analysis; percolation test; void probability function. Bias analysis. Luminosity function of galaxies, clusters and superclusters. Luminosity density field and its use to find superclusters.

Dark Matter
Local dark matter and global dark matter. The Dark Matter Story: first detections in clusters of galaxies and in the Galactic disk; galactic models; extended rotation curves; x-ray data, gravitational lensing. Nature of dark matter: density of baryonic matter, CMB data on density fluctuations; Hot Dark Matter (neutrinos), Cold Dark Matter (axions?); alternatives to DM.

Cosmological parameters and Dark Energy
Expansion of the Universe and density of matter. Data from CMB radiation temperature fluctuations, large-scale distribution of galaxies, distant supernova analysis. Evidence for Dark Energy.

Structure formation and evolution
Numerical simulations of the structure formation and evolution. Zeldovich pancake scenarios and Peebles hierarchical clustering scenario. Comparison of models with observations. Luminosity density field and its wavelet decomposition. Formation of first stars and galaxies. Influence of density perturbations of various scales.

Electron-positron pairs creation and dynamics in external electric fields

She-Sheng Xue
ICRANet

Reference: ``Electron-Positron pairs in Physics and Astrophysics: from heavy nuclei to black holes'' R. Ruffini, Gregory Vereshchagin, She-Sheng Xue, Phys. Rep. 481, 1 (2010).

Lecture 1. (45 minutes): relativistic Dirac theory for the electron and position pair, and introduction to the vacuum, pair - creation and annihilation.

Lecture 2. (45 minutes): the WKB-approach to the rate of electron-positron pair-creation in uniform electric fields, generalized to electromagnetic fields by field invariants under Lorentz and duality transformations.

Lecture 3. (45 minutes): the rate of electron-positron pair-creation in non-uniform electric fields. Some applications.

Lecture 4. (45 minutes): back-reaction: the electron-positron oscillation in external electric fields.

Lecture 5. (45 minutes): the electron-positron oscillation and annihilation in external electric fields.

Clusters of Galaxies
Piero Rosati
ESO

- Distribution of Baryons and Dark Matter in clusters
- Determination of cluster masses and mass density profiles; mass determination methods: Gravitational Lensing and hydrostatic equilibrium
- Use of clusters as probe of structure formation and cosmology:
  - formation and evolution of hot (ICM) and cold baryons (cluster galaxies)
  - cosmological parameters from cluster abundance and baryon fraction
- Current and future cluster surveys from the millimeter to X-ray wavelengths

Supernova

Massimo Della Valle
INAF - Astronomical Observatory of Capodimonte

Lecture 1. Historical background
Lecture 2. General Properties
Lecture 3. Explosive Mechanisms
Lecture 4. Supernovae and Gamma-ray Bursts
Lecture 5. Supernovae and Cosmology