Gravitation and Cosmology

Lecturer: Dmitri Fursaev

Autumn and spring semesters

This course is intended for 2nd – 3rd-year students of theoretical physics or 4th – 5th-year students of other specialties, including experimental ones. The lecture cycle is aimed at giving students an idea of physical and mathematical foundations of the General Theory of Relativity and acquainting them with the most important experimental data and theoretical concepts of cosmology, black hole physics, and other areas. There are 5 – 10 problems associated with each lecture. Some of the problems are considered during lectures; solutions of the others are submitted by the students to the lecturer.

The program of the course

1. Special theory of relativity

1.1. Historical facts.

1.2. Postulates of the special theory of relativity.

1.3. Accelerated observers in special theory of relativity

1.3. Speed up observers in special theory of relativity.

2. Basics of the general theory of relativity.

2.1. The equivalence principle

2.2. Metrics.

2.3. Simultaneous events and physical distances

3. The basics of mathematical apparatus of GTR.

3.1. Vectors, bases, tensors.

3.2. The parallel transport and covariate derivatives.

4. Geodesics

4.1. Geodesics

4.2. The transport of Fermi-Walker

4.3. Non-relativistic limit

5. Curvature

5.1. Deviation of geodesics

5.2. Riemann tensor, its properties and geometric meaning.

6. Equations of gravity field

6.1. Energy-momentum tensor.

6.2. The Einshtein equations

6.3. Energy conditions and cosmological constant

7. Gravitational field of massive source and basic GTR effects

7.1. The Schwarzschild solution

7.2. The deviation of light rays in the gravitational field

7.3. Shift of the perihelion of planet orbit

8. The gyroscopes precession.

8.1. General equation of precession in GTR.

8.2. Orientation of accelerated observers in the flat space

8.3. Thomas precession

9. Effect Lense-Thirring and geodesic precession

9.1. Weak gravitational field

9.2. Basis defining directions in the field of a revolving source

9.3. Experiment “Gravity probe”

10. Black holes: geometry of Schwarzschild

10.1. What are black holes and do they exist?

10.2. Nonanalyticity and incompleteness of the Schwarzschild coordinates

11. Geometry of the eternal black hole

11.1. The coordinates of Cruskal-Sheckers

11.2. “Geometry as a whole” and Carter-Penrose diagrams

11.2.1. The Minkowski space

11.2.2. The black hole

12. The gravitational collapse

12.1. Static stars model

12.2. Collapse of the spheric shell

13. Description of reference systems in GTR

13.1. Acceleration, rotation and deformation

13.2. The reference system of Killing observers

13.3. Rotation of the reference system

14. The rotating black hole

14.1. The chronometrical system of reference

14.2. The horizon and ergosphere

14.3. The reference system of observers with zero angular momentum

14.4. Extraction of energy from the black hole: the Penrose process

15. Black holes, thermodynamics and quantum theory

15.1. Black holes as thermodynamic systems

15.2. Quantum evaporation of black holes

15.3. The black holes and quantum gravity

16. The gravitational waves I

16.1. Linearization of the Einstein equations

16.2. Influence of gravitational wave on test particles

17. Gravitational waves II

17.1. The quadrupole character of gravity radiation

17.2. The energy and the spin of a gravitational wave

17.3. Modern detectors of gravitational waves

18. Cosmology

18.1. Main characteristics of the observed Universe

18.2. The Friedman model

18.2.1. Equations

18.2.2. Spreading of the photons and the z-factor

18.2.3. "Standard candles" and measuring of distances

19. The dark energy and hidden mass

19.1. Far distance supernovae and acceleration

19.2. The rotation curves of galaxies

19.3. Anisotropy of the relict background radiation

19.4. Cosmological constant, hidden mass and physics of high energies

20. The models of inflation

20.1. Main difficulties of the standard theory of Big Bang

20.1.1 The horizon problem

20.1.2. The problem of size

20.1.3. The problem of flatness

20.2. The key idea of inflation

20.3. The original inflation model, chaotic inflation

21 Some new concepts

21.1 The scale of quantum gravity and of the “world on the brane “ model

21.2. Quantum birth of microscopic black holes on colliders

21.3. The holography principle

21.4. The AdS/CFT correspondence