COURSE UNIT (MODULE) DESCRIPTION

Course unit (module) title	Code
(Physical) Cosmology	

Lecturer(s)	Department(s) where the course unit (module) is delivered
Coordinator: Thomas Gajdosik **Other(s):**	Teorinės fizikos ir astronomijos institutas

Study cycle	Type of the course unit (module)
Master studies	lecture

Mode of delivery	Period when the course unit (module) is delivered	Language(s) of instruction
Lecture	Fall / Spring semester	English

Requirements for students	
Prerequisites: Special Relativity	**Additional requirements (if any):**

Course (module) volume in credits	Total student's workload	Contact hours	Self-study hours
5	140	56	84

Purpose of the course unit (module): programme competences to be developed		
Students should learn the basic mathematical formulations that are necessary for Special and General Relativity, i.e. vector calculus and differential geometry. Based on that ground work, the student should understand the mathematical formulation of the evolution of the universe from the earliest understood time, the era following cosmic inflation.		
Learning outcomes of the course unit (module)	**Teaching and learning methods**	**Assessment methods**
Special Relativity and its astronomical relevance	Lecture and reading (self study)	home work, exam
General Relativity: General covariance, Riemannian geometry, and Einstein equations	Lecture and reading (self study)	exam
Vacuum solutions to Einstein equations (Schwarzschild, Reissner-Nordstroem, Kerr-Newman)	Lecture and reading (self study)	exam
Symmetric solutions (de Sitter, anti de Sitter, FLRW) and their time evolution: Big Bang, Inflation, Cosmic Microwave Background	Lecture and reading (self study)	home work, exam
Particle content of the Standard Model	Lecture and reading (self study)	home work, exam
Supersymmetry (SUSY)	Lecture and reading (self study)	exam
Dark Matter from SUSY, particle detection and Dark Matter Searches	Lecture and reading (self study)	exam

Content: breakdown of the topics	Contact hours							Self-study work: time and assignments	
	Lectures	Tutorials	Seminars	Exercises	Laboratory work	Internship/work	**Contact hours**	**Self-study hours**	**Assignments**

1. Special Relativity introduction: Invariants, Lorentz transformations [1, 2];	2		2				**4**	**3** **1**	Repeating, reading Homework 1 (1.9 %)
2. Special Relativity: general Lorentz transformations and consequence for astronomical observations: redshift, stellar aberration, relativistic beaming and the kinematic model of a Milne universe	2		2				**4**	**3** **3**	Repeating, reading Homework 2 (3.2 %)
3. Mathematical background for differential geometry: vectors, tensors, vector space, manifolds, tangent and cotangent space, affine connection, exterior derivative, Lie derivative, and the metric.	2		2				**4**	**7** **2**	Repeating, reading Homework 3 (2.5 %)
4. Differential Geometry: the concept of Riemannian geometry in a curved space-time; using the metric and the Levi-Civita connection I derive the Riemann tensor, describing the curvature of space-time. Orthonormal coordinates motivate the spin connection.	2		2				**4**	**7**	Repeating, reading
5. Applying Riemannian geometry allows the derivation of the Einstein equations by discussing the geodesic motion. Vacuum solutions to the Einstein equations: Schwarzschild, Reissner-Nordström, Kerr-Newman.	2		2				**4**	**7**	Repeating, reading
6. Symmetric non-vacuum solutions of the Einstein equations: flat, de Sitter and anti de Sitter space. Freedman-Robertson-Walker-Lemaitre cosmological models together with their respective time evolutions.	2		2				**4**	**7** **6**	Repeating, reading Homework 4 (8 %)
7. Hot Big Bang: Introducing the thermodynamic description of particle densities that were formed in the beginning of our universe, the Boltzmann equation coupled to the Einstein equations to describe the dynamic expansion of the universe.	2		2				**4**	**7**	Repeating, reading
8. Cosmological inflation: initial conditions and arguments for the assumption of an inflationary era to explain the homogeneity and isotropy of the initial conditions that start the time evolution governed by the Boltzmann-Einstein equations. Introducing the concepts of fields describing particles allows a short overview over the Lagrangians that are used to build models for the inflationary epoch.	2		2				**4**	**7**	Repeating, reading
9. Cosmic microwave background radiation as a well measured consequence of today's cosmological model. Big Bang Nucleosynthesis (BBN) as another probe of the Big Bang.	2		2				**4**	**7**	Repeating, reading
10. Special Relativity: the algebra of the Poincaré group allows the introduction of spinors and the understanding of particles.	2		2				**4**	**4** **2**	Repeating, reading Homework 5 (4.4 %)
11. The Standard Model: Particle content [9 - 19] An overview over the Standard Model (SM) and its particles	2		2				**4**	**6**	Repeating, reading
12. Supersymmetry: the unique extension of the Poincaré algebra; allows the construction of a supersymmetric field theory; the minimal extension of the SM (MSSM) offers a dark matter candidate	2		2				**4**	**4**	Repeating, reading
13. Dark Matter: arguments for particle dark matter; particle detection in principle; dark matter detection experiments	2		2				**4**	**3**	Repeating, reading
14. Gravitational Waves	2		2				**4**	**2**	Repeating, reading
Preparing the seminar presentation								**2**	
Total	**28**		**28**				**56**	**84**	

Assessment strategy	Weight,%	Deadline	Assessment criteria
Participation in the lecture and discussion during the seminars	14 %		Active participation
Homeworks	20 %	As announced in the syllabus:	Turning in the homework and correcting it
Seminar presentation	15 %		Giving a presentation
Exam	51 %		Passing the written and the oral part

Author	Year of public ation	Title	Issue of a periodical or volume of a publication	Publishing place and house or web link
Compulsary reading				
1. Davig Hogg	1997	Special Relativity		http://cosmo.nyu.edu/hogg/sr/sr.pdf
Strongly suggested reading				
2. Sean M. Carroll	1997 2004	Lecture Notes on General Relativity; Spacetime and geometry: An introduction to general relativity		arXiv: gr-qc/9712019 San Francisco, USA: Addison-Wesley (2004) 513 p
Optional reading				
3. B. F. Schutz,	1985	A First Course In General Relativity		Cambridge, Uk: Univ. Pr. (1985) 376p
4. C. W. Misner, K. S. Thorne and J. A. Wheeler	1973	Gravitation		San Francisco 1973, 1279p
5. T. P. Cheng	2010	Relativity, Gravitation, And Cosmology: A Basic Introduction		Oxford, UK: Univ. Pr. (2010) 435 p
6. P. J. E. Peebles	1993	Principles of physical cosmology		Princeton, USA: Univ. Pr. (1993) 718 p
7. D. H. Perkins	2003	Particle astrophysics		Oxford, UK: Univ. Pr. (2003) 256 p
8. S. Dodelson	2003	Modern cosmology		Amsterdam, Netherlands: Academic Pr. (2003) 440 p
9. Daniel Baumann	2022	Cosmology		Cambridge University Press, 2022, ISBN 978-1-108-93709-2, 978-1-108-83807-8 doi:10.1017/9781108937092
Optional reading about particle physics:+				
10. David Griffiths	1987	Introduction to Elementary Particles		John Wiley & Sons, Inc.; ISBN 0-471-60386-4 (1987).
11. Particle Data Group	2014	The particle adventure:		http://www.particleadventure.org/
12. A. Zee	2003	Quantum Field Theory in a Nutshell		Princeton University Press; ISBN 0-691-01019-6 (2003).
13. P. B. Pal	2010	Dirac, Majorana and Weyl fermions		arXiv:1006.1718 [hep-ph]
14. I. J. R. Aitchison and A. J. G. Hey	2013	Gauge theories in particle physics: A practical introduction. Vol. 1: From relativistic quantum mechanics to QED		Bristol, UK: IOP (2003) 406p
15. I. J. R. Aitchison and A. J. G. Hey	2014	Gauge theories in particle physics: A practical introduction. Vol. 2: Non-Abelian gauge theories: QCD and the electroweak theory		Bristol, UK: IOP (2004) 454 p

16. Warren Siegel	2017	Fields		http://arxiv.org/abs/hep-th/9912205 or http://insti.physics.sunysb.edu/~siegel/Fields4.pdf
17. S. Weinberg	1995	The Quantum Theory of Fields, I and II,		Cambridge University Press; ISBN 0-521-58555-4
18. S. Weinberg	2000	The Quantum Theory of Fields, III		Cambridge University Press; ISBN 0-521-66000-9