Course Number	PH623
Course credit (L-T-P-C)	3-0-0-6
Course title	Introduction to general relativity and cosmology
Learning mode	Offline
Learning objectives	• Understand the basic concepts of general relativity • Learn about various eras of our universe since the earliest known time • Learn about the standard model of cosmology • Know the various experimental or observational methods in cosmology research • Introduction to inflationary cosmology, and open research problems
Course description	This course provides a basic review of general relativity and presents a beginner level introduction to the science of understanding the origin, structure, and evolution of our universe. Based on the introductory text by B. Ryden, this semester-long course is aimed at graduate and undergraduate students with a keen interest in cosmology as a research discipline.
Course content	Brief review of special theory of relativity, equivalence principle, describing curvature – Riemannian spacetime, generalized coordinates, review of tensor algebra and calculus, metric, Christoffel connections, geodesic equation, metric as a classical field, Reimann curvature tensor, Ricci tensor and scalar, Einstein action, Einstein equations, FRW metric, proper distance; Cosmological observations: dark night sky, isotropy and homogeneity, redshift, cosmic particles, cosmic microwave background – overview of the CMB spectrum, recombination, temperature fluctuations; the standard model of the universe (ΛCDM); Friedmann equation, equation of state, cosmological constant, single component universe – spatially flat, radiation, and matter dominated; cosmological parameters – Hubble constant, deceleration parameter; introduction to dark matter; The inflationary universe: flatness problem, horizon problem, monopole problem, the paradigm of inflation, physics of inflation – example of a scalar field driven inflation, advances of inflation model building, confronting inflation models with observation, primordial gravitational waves.
Pre-requisites	• Classical mechanics • Differential equations, PDE, complex algebra
Learning outcomes	After the successful completion of this course, the students will achieve: • Basic understanding of general relativity, and computing covariant derivatives, solving tensor field equations. • An overview of the research field of cosmology, and developments in our understanding of the universe over the past 100 years. • The knowledge of observational aspects of cosmology, particularly the cosmic microwave background, Expansion rate of the universe, Hubble parameter, etc. • Basics of inflationary cosmology, and open problems therein.
Assessment method	Assignments (A), Paper Presentation (PP), MidSem (MS), EndSem (ES). Internal (A+PP)=40%, MS=30%, ES=30%
Textbooks and references	• Introduction to cosmology, B. Ryden, Cambridge Univ. Press, 2016. • Modern cosmology, Scott Dodelson, Academic Press, 2003. • Spacetime and Geometry: An introduction to general relativity, S. Carroll, Cambridge, 2019. Additional references: • Cosmology, D. Baumann, Cambridge, 2022. • A first course in general relativity, B. Schutz, Cambridge, 2009. • Introduction to Cosmology, J. V. Narlikar, Cambridge Univ Press, 2002. • Gravitation and cosmology: Principles and applications of the general theory of relativity, S. Weinberg, Wiley, 1972.

TENTATIVE COURSE PLAN

Week	**Lecture topics**	Evaluation milestones
1	Course introduction, course plan, books and references, paper review groups, introduction to cosmology, research trends in cosmology, online literature resources, introduction to computational resources – mathematica and maple, xAct packages.	
2	Review of STR, equivalence principles – weak and strong, breakdown of Newtonian (and standard) gravity – few recent observational evidence, describing curvature using Riemannian spacetime,	Group forming for paper review
3	generalized coordinates, review of tensor algebra and calculus, metric, Christoffel connections	Assignment 1; pool of research papers
4	geodesic equation, Reimann curvature tensor, Ricci tensor and scalar	
5	metric as a classical field, Einstein action, Einstein equations, FRW metric, proper distance;	Assignment 2
6	Cosmological observations: dark night sky, isotropy and homogeneity, redshift, cosmic particles,	
7	cosmic microwave background – overview of the CMB spectrum, recombination, temperature fluctuations; introducing the standard model of the universe (ΛCDM);	Assignment 3
8	the standard model of the universe (ΛCDM), Friedmann equation, equation of state, cosmological constant,	
9	single component universe – spatially flat, radiation, and matter dominated;	Assignment 4
10	cosmological parameters – Hubble constant, deceleration parameter; introduction to dark matter;	
11	The inflationary universe: flatness problem, horizon problem, monopole problem,	Assignment 5
12	the paradigm of inflation – a brief history of advances in the past four decades, overview of inflation models, the inflation era (pre- and post-)	Paper presentation
13	scalar field driven inflation, scalar, vector and tensor perturbations, confronting inflation models with observation	Assignment 6
14	primordial gravitational waves, calculating observables in the CMB (spectral index and tensor to scalar ratio) if time permits, demo of symbolic computation using mathematica.	

Important points to note about this course:

- This course is designed for 14 weeks or 42 lectures. We have an extra (15^{th}) week this semester, but I will likely take leave for a week in the first week of March. Therefore, we will aim to have 42 lectures in total. If needed, we might arrange one or two additional lectures.
- You may expect an assignment roughly once in two weeks (six or seven in total). This time I will try to go beyond pen-paper based assignments and give you a taste of computational packages.
- Apart from assignments, there will be a paper review and presentation component as well constituting around 20% of the weightage. For this, I will divide the class into groups and each group will choose a research paper out of a pool of papers that I will float in the next two-three weeks. The presentations will be scheduled near the end of the semester, based on which you will be evaluated.
- No quizzes!

Additional resources:

- Mathematica – computational package commonly used to perform symbolic and numerical computation in cosmology and other fields.
- Maple – an alternative to Mathematica (I don't use it often)
- xAct packages for Mathematica – Tensor algebra and calculus for symbolic calculations especially in GR, QFT and cosmology.
    - Try learning about xTensor, xPert packages.
- arXiv.org – Useful opensource archive where thousands of new and revised research papers are uploaded everday in almost every branch of physics, including GR and cosmology (gr-qc, hep-th, astro-ph).
- Inspirehep.net – Online archive exclusively for high energy physics community. All papers on arXiv are also available on inspirehep.net, along with citation, references, and author profiles.
    - Great for tracking researchers and their work.

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