Annexe A: New/Revised Course Content in OBTL+ Format

Course Overview

The sections shown on this interface are based on the templates UG OBTL+ or PG OBTL+
If you are revising/duplicating an existing course and do not see the pre-filled contents you expect in the subsequent sections e.g. Course Aims, Intended Learning Outcomes etc. please refer to Data Transformation Status for more information.

Expected Implementation in Academic Year	AY2025-2026
Semester/Trimester/Others (specify approx. Start/End date)	Semester 1
Course Author * Faculty proposing/revising the course	Leek Meng Lee
Course Author Email	mlleek@ntu.edu.sg
Course Title	Astrophysics and Cosmology
Course Code	PH3403
Academic Units	3
Contact Hours	39
Research Experience Components	Not Applicable

Course Requisites (if applicable)

Pre-requisites	PH1107, PH2101, PH2103
Co-requisites	
Pre-requisite to	
Mutually exclusive to	
Replacement course to	
Remarks (if any)	

Course Aims

This is a first course in cosmology which covers some advanced astrophysical phenomena and fundamental aspects of standard cosmology. The required background tools such as Special and General Relativity are covered to make the module self-contained. The advanced astrophysics topics covered include coalescing binaries which emit gravitational waves. Then we will expand to the discussion of the evolution of the entire universe which is known as cosmology. The topics covered in cosmology include the discussion of the cosmological principle that leads to the derivation of the Friedmann-Robertson-Walker (FRW) metric. Then the kinematics and dynamics of the FRW metric will be discussed and the course closes with the problems in the FRW model and a brief mention of the solutions by postulating an inflationary era during the early evolution of the universe. Throughout this course, you will also appreciate the multi-disciplinary nature of this subject.

Course's Intended Learning Outcomes (ILOs)

Upon the successful completion of this course, you (student) would be able to:

ILO 1	state and explain how Einstein arrived at the various equivalence principles.
ILO 2	state and explain how non-uniform gravitational field can be viewed as curved spacetime.
ILO 3	manipulate tensors in the context of special relativity.
ILO 4	explain the geometrical construction of tensors on differentiable manifolds
ILO 5	state and explain the concept of parallel transport on differentiable manifolds
ILO 6	explain and derive the geodesic equation
ILO 7	state the Bianchi Identity and derive the contracted Bianchi Identity which gives the left-hand-side (LHS) of Einstein equation
ILO 8	state and explain the conservation law of the energy-momentum tensor on curved spacetime which gives the right-hand-side (RHS) of Einstein equation
ILO 9	derive the Einstein equation by combining the LHS and RHS of Einstein equation with physical justifications
ILO 10	derive the Newtonian limit of Einstein equation
ILO 11	derive the basic properties of a static, spherically symmetric black hole from the Schwarzschild metric
ILO 12	state and derive the equations for gravitational waves emitted from orbiting/coalescing neutron stars/black holes
ILO 13	state and explain how the cosmological principle leads to the FRW metric.
ILO 14	derive the kinematical properties of the FRW metric
ILO 15	derive the dynamical equations of the FRW metric by assuming a perfect fluid
ILO 16	derive several analytical models of cosmology
ILO 17	deduce the problems that exist in the standard FRW models of cosmology

ILO 18	explain qualitatively how these problems can be resolved by postulating an inflationary era during the early stage of the evolution of the universe

Course Content

Equivalence principles
Parallel transport
Geodesic equation
Einstein equation
Event horizon of a black hole
Gravitational waves
Cosmological principle
FRW geometry
Friedmann equations
Cosmic expansion and big bang theory
Age of the universe
The horizon problem
Inflationary era

Reading and References (if applicable)

a. Hobson, Michael Paul, George P. Efstathiou, and Anthony N. Lasenby. *General relativity: an introduction for physicists*. Cambridge University Press, 2006, ISBN: 0521829519

b. Carroll, Bradley W., and Dale A. Ostlie. *An introduction to modern astrophysics*. Cambridge University Press, 2017, ISBN: 1108422161

c. Ryden B.S., An introduction to cosmology, Addison-Wesley, 2003, ISBN: 0805389121

d. Baumann, Daniel. *Cosmology*. Cambridge University Press, 2022, ISBN: 978-1-108-83807-8

e. Dodelson S., Modern Cosmology, Academic Press, 2003, ISBN: 0122191412

The above readings comprise the foundational readings for the course and more up-to-date relevant readings will be provided when they are available.

Planned Schedule

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
1	Introduction and course overview, Introduce the physics of General Relativity which are the equivalence principles. Recasting special relativity into the language of tensor calculus	1,2,3	References and lecture notes	In-person	
2	Basic differential geometry and construction of tensors on differentiable manifolds	4	References and lecture notes	In-person	
3	Concept of parallel transport and derivation of geodesic equation	5,6	References and lecture notes	In-person	
4	Curvature tensor and its Bianchi identity. Then the contracted Bianchi identity is derived.	7	References and lecture notes	In-person	

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
5	Energy-momentum tensor and its conservation in curved spacetime. Justification for Einstein equation and checking its Newtonian limit.	8,9,10	References and lecture notes	In-person	
6	Remnants of stellar evolution: black holes	11	References and lecture notes	In-person	Midterm I
7	Gravitational waves from orbiting/coalescing neutron stars/black holes	12	References and lecture notes	In-person	
8	Cosmological principle leading to the construction of the FRW metric	13		In-person	
9	Kinematical properties of the FRW metric	14		In-person	
10	Dynamical properties of the FRW metric (under the assumption of a perfect fluid)	15	References and lecture notes	In-person	
11	Derive several analytical models of cosmology	16	References and lecture notes	In-person	

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
12	Discussion of the problems within the standard FRW framework	17	References and lecture notes	In-person	Midterm II
13	Qualitatively understand how these problems are resolved by introducing an inflationary era in the early stage during the evolution of the universe	18	References and lecture notes	In-person	

Learning and Teaching Approach

Approach	How does this approach support you in achieving the learning outcomes?
Problem solving (tutorial and lecture)	Develop competence and perseverance in solving physics problems
Peer Instruction (during lecture)	Develop communication skills and competence in physics.
Lectures	Warm-up questions will be raised first, followed by lectures that further explain the physics based on the questions. Then wrap-up questions will also be provided.
Tutorial	You will review main concepts learned in lectures. This helps them to digest and understand better.
Homework	The homework comprises standard textbook practice questions that are covered during tutorial.

Assessment Structure

Assessment Components (includes both continuous and summative assessment)

No.	Component	ILO	Related PLO or Accreditation	Weightage	Team/Individual	Rubrics	Level of Understanding
1	Summative Assessment (EXAM): Final exam(This is a 2hr 30 min written paper assessing the student's understanding of the entire course.)	All	Not Applicable	40	Individual	Analytic	Relational
2	Continuous Assessment (CA): Test/Quiz(Midterm Test I is a 1hr 15min written paper to assess student's understanding of the first part of the course.)	Range 1-10	Not Applicable	20	Individual	Analytic	Relational
3	Continuous Assessment (CA): Test/Quiz(Midterm Test II is a 1hr 15min written paper to assess the student's understanding of the second part of the course.)	Range 11-16	Not Applicable	20	Individual	Analytic	Relational
4	Continuous Assessment (CA): Assignment(This component is made up of 5 homework sets where students will work on problems that enforce and enhance their understanding.)	All	Not Applicable	20	Individual	Analytic	Relational

Description of Assessment Components (if applicable)

Formative Feedback

Formative feedback is given through discussion within tutorial lessons, a discussion after the midterm, and an examiner’s report for the final exam.

NTU Graduate Attributes/Competency Mapping

This course intends to develop the following graduate attributes and competencies (maximum 5 most relevant)

Attributes/Competency	Level
Curiosity	Intermediate
Problem Solving	Intermediate
Sense Making	Advanced

Course Policy

Policy (Academic Integrity)

Good academic work depends on honesty and ethical behaviour. The quality of your work as a student relies on adhering to the principles of academic integrity and to the NTU Honour Code, a set of values shared by the whole university community. Truth, Trust and Justice are at the core of NTU's shared values. As a student, it is important that you recognize your responsibilities in understanding and applying the principles of academic integrity in all the work you do at NTU. Not knowing what is involved in maintaining academic integrity does not excuse academic dishonesty. You need to actively equip yourself with strategies to avoid all forms of academic dishonesty, including plagiarism, academic fraud, collusion and cheating. If you are uncertain of the definitions of any of these terms, you should go to the academic integrity website for more information. On the use of technological tools (such as Generative AI tools), different courses / assignments have different intended learning outcomes. Students should refer to the specific assignment instructions on their use and requirements and/or consult your instructors on how you can use these tools to help your learning. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Policy (General)

You are expected to complete all assigned pre-class readings and activities, attend all lectures, tutorial classes punctually and take all scheduled assignments and tests by due dates. You are expected to participate in all tutorial discussions and activities.

Policy (Absenteeism)

Absence Due to Medical or Other Reasons
If you are sick and unable to attend your class / Mid-terms, you have to:

1. Send an email to the instructor regarding the absence and request for a replacement class and make-up mid-terms.
2. Submit the original Medical Certificate* or official letter of excuse to administrator.
3. Attend the assigned replacement class (subject to availability) and make-up mid-terms.

* The medical certificate mentioned above should be issued in Singapore by a medical practitioner registered with the Singapore Medical Association.

Policy (Others, if applicable)

Diversity and inclusion policy

Integrating a diverse set of experiences is important for a more comprehensive understanding of science.

It is our goal to create an inclusive and collaborative learning environment that supports a diversity of perspectives and learning experiences, and that honours your identities; including ethnicity, gender, socioeconomic status, sexual orientation, religion or ability.

To help accomplish this:

- If you are neuroatypical or neurodiverse, have dyslexia or ADHD (for example), or have a social anxiety disorder or social phobia;

- If you feel like your performance in the class is being impacted by your experiences outside of class;
- If something was said in class (by anyone, including the instructor) that made you feel uncomfortable;

Please speak to your teaching team, our school pastoral officer or a peer or senior (either in-person or via email) about how we can help facilitate your learning experience.

As a participant in course discussions, you should also strive to honour the diversity of your classmates. You can do this by: using preferred pronouns and names; being respectful of others opinions and actively making sure all voices are being heard; and refraining from the use of derogatory or demeaning speech or actions.

All members of the class are expected to adhere to the NTU anti-harassment policy. if you witness something that goes against this or have any other concerns, please speak to your instructors or a faculty member.