Lahore University of Management Sciences

PHY 242 – Exploring Black Holes
Summer 2023

Instructor	Moeez Hassan
Room No.	9-111A
Office Hours	After every class + TBA; or by appointment
Email	syed_hassan@lums.edu.pk
TA	TBA
TA Office Hours	TBA
Course URL (if any)	LMS

Course Teaching Methodology
• Teaching Methodology: Lectures will be in-person on-campus. All Covid related SOPs are to be strictly followed in the classroom. Unless medically exempted, all students sitting in the class must be fully vaccinated (i.e., they must have received the final dose of their vaccine at least 14 days prior to the start of classes).

Course Basics				
Credit Hours	3			
Lecture(s)	Nbr of Lec(s) Per Week	4	Duration	110 minutes
Recitation/Lab (per week)	Nbr of Lec(s) Per Week	1	Duration	110 minutes
Tutorial (per week)	Nbr of Lec(s) Per Week		Duration	

Course Distribution	
Core	No
Elective	Yes
Open for Student Category	All
Close for Student Category	None

COURSE DESCRIPTION
What is a black hole? Does it swallow everything around it? Can you go near one? If so, how close can you get? What happens if you fall in? Do they actually exist? Can we 'see' a black hole? Where can I find one? Have you ever been interested in these questions but …were too afraid to ask? …the mathematics of general relativity felt just a bit much? …always found popular opinions online but no satisfactory scientific answer to these questions? Well, worry not! This *introductory* (yet at the same time rigorous) course may just be for you! Come, join us, as we explore the fascinating world of black holes through mathematics, physics, videos, interactive simulations and games!

COURSE PREREQUISITE(S)	
• • •	PHY 101 – Mechanics AND; PHY 104 – Modern Physics AND; MATH 101/101H – Calculus-I.
• Anti Req	Anti-Requisite: PHY 442/642 / MATH 466 – General Relativity (You *cannot* take this course if you have already taken 'General Relativity'. You *can* go on to take 'General Relativity' later if you take this course).

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COURSE OBJECTIVES	
•	The aim of this course is to develop an introductory mathematical and physical understanding of black holes.

Course Learning Outcomes	
	Students should be able to: 1. Understand the geometrical formulation of special relativity and apply it. 2. Solve simple problems related to curved geometry. 3. Understand what black holes are and compute relevant physical quantities. 4. Calculate trajectories of objects moving around black holes.

Grading Breakup and Policy

Component	Weightage	Description
Assignments	20%	• There will be ~8 assignments (2 per week). • There will be an N-2 on assignments.
Lab Tasks	40%	• There will be a fun and interactive 'lab' every week to help you understand and visualize the concepts taught in class. • There will be 4 lab tasks (one for each lab) with 10% weightage each. • These are to be completed within the lab time.
Final Exam	40%	• Comprehensive final exam. • Closed book, closed notes.

- The instructor reserves the right to vary these grade assignments or add new instruments by upto 10%.
- In the event that the course has to be shifted online, this grading breakup (and the details) may be substantially revised.
- **University policy for cheating/unfair means will be applicable on <u>all</u> grading instruments. You must submit your own work. If any evidence of plagiarism is found, these cases will be forwarded straight to the School DC.**

<u>COURSE POLICIES (READ CAREFULLY):</u>

- All Covid related SOPs are to be strictly followed in the classroom. Unless medically exempted, all students sitting in the class must be fully vaccinated (i.e., they must have received the final dose of their vaccine at least 14 days prior to the start of classes).
- **All emails** sent to the instructor or TAs must have a **subject line** of the following format: "PHY 242 – subject line".
- **All emails** must be signed with name and **roll-number**.
- If you email me asking me a question that is already answered in the outline, I will not answer your email.
- All announcements will be posted on LMS (with an email notification). **It is your responsibility** to regularly check the LMS site for this course.
- Please come on time. No talking/disturbance during class. No cell-phones, laptops etc. during class.
- **An approved petition from the OSA will be required for any missed components.**
- **For HWs: N-2 is there to cater for any unforeseen circumstances.**
- **For Lab Tasks: Either student's own average in the remaining lab tasks will be applied, or student will be asked to complete it later on their own (Instructor's decision).**

Examination Detail	
Midterm Exam	Yes/No: **No** Combine Separate: Duration: Preferred Date: Exam Specifications:

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Final Exam	Yes/No: **Yes** Combine Separate: Duration: 3 hours Exam Specifications: **Closed book/notes**

COURSE OVERVIEW			
Lecture	Topics	Recommended Readings	Objectives/ Application
Lec 1	Introduction, Review of Special Relativity	**Class notes (see below)**	**CLO 1**
Lec 2	Geometric formulation of Special Relativity		**CLO 1**
Lab 1	*'Seeing Relativity with your own eyes'*		**CLO 1**
Lec 3	Vectors and the Metric in Special Relativity, Light cones		**CLO 1**
Lec 4	Accelerated observers in Special Relativity		**CLO 1**
Lec 5	Curved spaces (metric, distances, areas, …)		**CLO 2**
Lec 6	Review of Newtonian gravity, Introduction to General Relativity (Einstein's Equivalence Principle: Acceleration = Gravity!)		**CLO 2**
Lab 2	*'Exploring curvature'* *($\pi = 2$? Yes! But how?)*		**CLO 2**
Lec 7	Introducing Black Holes, The Schwarzschild metric, Gravitational time dilation, redshift		**CLO 3**
Lec 8	Singularities, Horizons, Coordinates, Light cones		**CLO 3**
Lec 9	Particles (and you and me) moving around a black hole, can we fall in?		**CLO 4**
Lec 10	Light moving around a black hole, can it orbit? The bending of light		**CLO 4**
Lab 3	*'Exploring motion around black holes'* *(the SAB–GHOOMo app)*		**CLO 4**
Lec 11	Falling in a black hole – I: Vertical free fall		**CLO 4**
Lec 12	Falling in a black hole – II: As seen by someone far away, Tidal forces		**CLO 4**
Lec 13	Do black holes exist? – I: Astrophysical black holes, detection		**CLO 3**
Lec 14	Do black holes exist? – II: The first picture		**CLO 3**
Lab 4	*'Seeing a Black Hole with your own eyes'*		**CLO 3**
Lec 15-16	[Time Permitting] Gravitational Waves		

Textbook(s)/Supplementary Readings

There is no single course textbook. The primary and most useful resource – along with regularly and punctually attending classes – will be lecture notes.

I will take material from the following resources (these should be treated as supplementary reading if you are interested and want to complement and enhance your learning):

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- Exploring Black Holes by Wheeler, Taylor and Bertschinger [Available at: https://archive.org/details/exploringblackholes]
- Black Holes & Time Warps: Einstein's Outrageous Legacy by Kip Thorne
- Gravity: An Introduction to Einstein's General Relativity by James Hartle
- A First Course in General Relativity by Bernard Schutz
- Notes on Relativity and Cosmology by Donald Marolf [Available at: https://web.physics.ucsb.edu/~marolf/MasterNotes.pdf]
- Lecture Notes on General Relativity by Matthias Blau [Available at: http://www.blau.itp.unibe.ch/GRLecturenotes.html]

Academic Honesty

The principles of truth and honesty are recognized as fundamental to a community of teachers and students. This means that all academic work will be done by the student to whom it is assigned without unauthorized aid of any kind. Plagiarism, cheating and other forms of academic dishonesty are prohibited. Any instances of academic dishonesty in this course (intentional or unintentional) will be dealt with swiftly and severely. Potential penalties include receiving a failing grade on the assignment in question or in the course overall. For further information, students should make themselves familiar with the relevant section of the LUMS student handbook.

Harassment Policy

SSE, LUMS and particularly this class, is a harassment free zone. There is absolutely zero tolerance for any behaviour that is intended, or has the expected result of making anyone uncomfortable and negatively impacts the class environment, or any individual's ability to work to the best of their potential.

In case a differently-abled student requires accommodations for fully participating in the course, students are advised to contact the instructor so that they can be facilitated accordingly.

If you think that you may be a victim of harassment, or if you have observed any harassment occurring in the purview of this class, please reach out and speak to me. If you are a victim, I strongly encourage you to reach out to the Office of Accessibility and Inclusion at oai@lums.edu.pk or the sexual harassment inquiry committee at harassment@lums.edu.pk for any queries, clarifications, or advice. You may choose to file an informal or a formal complaint to put an end of offending behavior. You can find more details regarding the LUMS sexual harassment policy here.

To file a complaint, please write to harassment@lums.edu.pk.

SSE Council on Equity and Belonging

In addition to LUMS resources, SSE's **Council on Belonging and Equity** is committed to devising ways to provide a safe, inclusive and respectful learning environment for students, faculty and staff. To seek counsel related to any issues, please feel free to approach either a member of the council or email at cbe.sse@lums.edu.pk

Rights and Code of Conduct for Online Teaching

A misuse of online modes of communication is unacceptable. TAs and Faculty will seek consent before the recording of live online lectures or tutorials. Please ensure if you do not wish to be recorded during a session to inform the faculty member. Please also ensure that you prioritize formal means of communication (email, lms) over informal means to communicate with course staff.