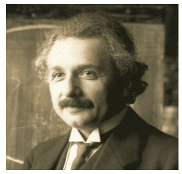
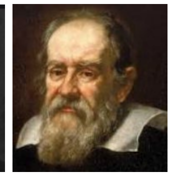
Syllabus: PHYS 5392 Relativity-II






Course Information

PHYS 5392 Relativity-II: General Relativity. Spring 2021: Tues & Thurs 11:30-12:45

Professor Contact Information

Dr. Mustapha Ishak-Boushaki, Professor of Physics and Astrophysics
Office: SCI3.257K in Science Building
Email: mishak@utdallas.edu. URL for research web page: http://www.utdallas.edu/~mishak/
Office hours: Thursdays from 12:45 to 13:45 and additional by appointment.
TA: Anish Agashe anish.agashe@utdallas.edu Office hours: Tuesdays from 10:00 to 11:00.

Course Modality and Expectations

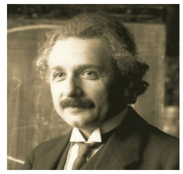
Instructional Mode	**Remote/Online/Virtual:** Synchronous online learning at the day and time of the class. The instructor delivers the instruction from home or the office. Students complete the course at a distance. All lectures will also be recorded and made available on eLearning.
Course Platform	MS Teams. Conference ID: 489 973 860#. Invitations sent directly to all registered students. Office hours are also provided via MS Teams. We will also use wonder,me platform for discussions and interactions.
Expectations	Attend live lectures remotely and contribute actively to class discussions. Attend office hours with instructor and TA.
Asynchronous Learning Guidelines	Lectures will be recorded and uploaded to eLearning. See more info at Asynchronous Access for Spring 2021 FAQ webpage.

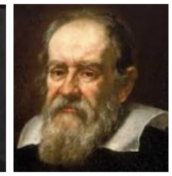
COVID-19 Guidelines and Resources

The information contained in the following link lists the University's COVID-19 resources for students and instructors of record. Please see http://go.utdallas.edu/syllabus-policies.

Class Participation

Regular class participation is expected regardless of course modality. Students who fail to participate in class regularly are inviting scholastic difficulty. A portion of the grade for this course is directly tied to your participation in this class. It also includes engaging in group or other activities during class that solicit your feedback on homework assignments, readings, or materials covered in the lectures (and/or labs). Class participation is documented by faculty. Successful participation is defined as consistently adhering to University requirements, as presented in this syllabus. Failure to comply with these University requirements is a violation of the Student Code of Conduct.





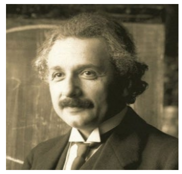

Class Recordings

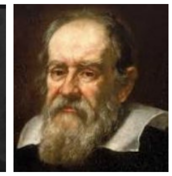
Students are expected to follow appropriate University policies and maintain the security of passwords used to access recorded lectures. Unless the Office of Student Accessibility has approved the student to record the instruction, students are expressly prohibited from recording any part of this course. Recordings may not be published, reproduced, or shared with those not in the class, or uploaded to other online environments except to implement an approved Office of Student Accessibility accommodation. Failure to comply with these University requirements is a violation of the Student Code of Conduct.

The instructor may record meetings of this course. Any recordings will be available to all students registered for this class as they are intended to supplement the classroom experience. Students are expected to follow appropriate University policies and maintain the security of passwords used to access recorded lectures. Unless the Office of Student Accessibility has approved the student to record the instruction, students are expressly prohibited from recording any part of this course. Recordings may not be published, reproduced, or shared with those not in the class, or uploaded to other online environments except to implement an approved Office of Student Accessibility accommodation. If the instructor or a UTD school/department/office plans any other uses for the recordings, consent of the students identifiable in the recordings is required prior to such use unless an exception is allowed by law. Failure to comply with these University requirements is a violation of the Student Code of Conduct.

Class Materials

The Instructor may provide class materials that will be made available to all students registered for this class as they are intended to supplement the classroom experience. These materials may be downloaded during the course; however, these materials are for registered students' use only. Classroom materials may not be reproduced or shared with those not in class or uploaded to other online environments except to implement an approved Office of Student Accessibility accommodation. Failure to comply with these University requirements is a violation of the Student Code of Conduct.






Course Short Description:

PHYS 5392 Relativity-II: General Relativity (3 semester hours):

This course will cover the following: Overview of Tensor calculus and Riemannian geometry; foundation of general relativity; Einstein's Equations; Schwarzschild solution and black hole; the crucial tests of relativity; the Kerr exact solution and rotating Black Hole; other exact solutions to Einstein's Equations; linearized gravity and gravitational waves; and the Friedmann solutions for cosmology.

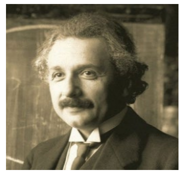
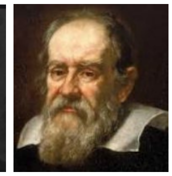
Textbooks and Materials

In this graduate course, I will be using self-contained notes made from various books and my own notes about General Relativity and recent research developments in the field. Below are some books with various styles and levels of depth. I will discuss each of them during the first lecture. My suggestion is to read the corresponding chapter before class and also to review the recordings of lecture afterward in order to re-enforce learning.

Introducing Einstein's Relativity. Ray D'Inverno. (introductory level)
Relativity. Wolfgang Rindler. (introductory level)
An Introduction to General Relativity. Sean Carroll. (introductory level)
Gravitation. Misner, Charles W., Kip S. Thorne, and John Archibald Wheeler. (introductory – extended treatment of the subject)
Gravitation and Cosmology. Weinberg, Steven. (introductory level)
General relativity. Wald, Robert (intermediate level)
Advanced General Relativity. John Stewart (advanced level)

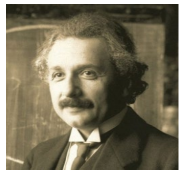
Grading Policy

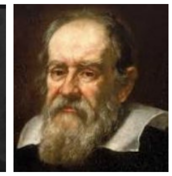
Homework (30%), 2 non-cumulative exams (30%, 30%), presentation (8%), attendance / participation (2%). First exam will be around the middle of the semester (March: exact date to be decided in class). The second exam is fixed by the university to be at the end of the semester. These dates will be discussed in class with students. Exams are based on problems that are similar in scope and difficulty to homework assignments. See page 7 further below on more detailed description of learning assessment.

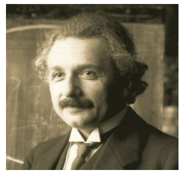
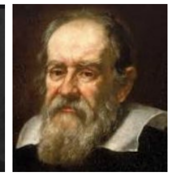
Course content description, schedule and reading chapters

Topic	**Chapter from D'Inverno's book**
Chapter 1: Overview of Special Relativity (itemized description): 1.1 A brief discussion of Special Relativity and flat spacetime. 1.2 The postulates of Special Relativity including a) Constancy of the speed of light in vacuum b) Principle of relativity, and the abolition of absolute space and time. 1.3 Lorentz transformations 1.4 Consequences of Lorentz transformations and invariance.	Read Chap. 2 from the book of D'Inverno
Chapter 2: Overview of Tensor Operations and Riemann Curvature Tensor (itemized description): 2.1 Coordinate Systems 2.2. Einstein Summation Convention 2.3 Scalars; 2.4 Vectors 2.5 Tensors 2.6 Elementary Operations a) Sum/Difference; b) Contraction; c) Outer Multiplication; d) Inner Multiplication; e) Quotient Theorem; f) Symmetric/Anti-Symmetric Tensor; g) Symmetrisation/ Anti-Symmetrisation 2.7 The Metric Tensor (line element, signature etc.) 2.8 Differentiation of Tensors a) Partial derivative b) Covariant Derivative and Connections c) Absolute or Directional Derivative 2.9 The Levi-Civita Connection; The Metric; Christoffel Symbols 2.10 Geodesics, Parallel Transport of Tensors, 4-Acceleration 2.11 Gradient, Divergence and Curl 2.12 Riemann Tensor and Curvature a) Anti-commutation of Parallel Transport along a Closed Path and Detection of Curvature. Flatness of a Manifold b) Properties of Riemann Tensor 2.13 Ricci and Einstein Tensor 2.14 Weyl Tensor	Read Chaps. 5 and 6 from the book of D'Inverno

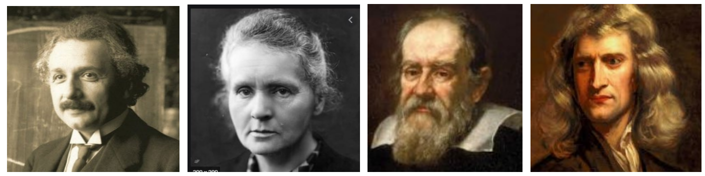





Chapter 3 Gravitation and Einstein's Field Equations (EFEs) (itemized description): 3.1. Introduction a. From SR to GR – Guidelines and Key Insight b. Experimentally Validated Theory with Applications – From Cosmology to GPS devices 3.2 Equivalence Principles and Universality of Gravity a. Weak Equivalence Principle (WEP) b. Einstein Equivalence Principle (EEP) c. Strong Equivalence Principle (SEP) 3.3 Einstein's Field Equations (EFEs) a. Guiding Requirements b. Mathematical Forms of the EFEs c. The Energy-Momentum Tensor 3.4 Overview of Exact Solutions to EFEs a. Mathematical solutions b. Physical Solutions and Relevance to Astrophysics	Read Chaps. 9 and 10 from the book of D'Inverno
Chapter 4: The Schwarzschild vacuum solution to EFEs (itemized description): 4.1. Spherically symmetric solutions 4.2 Schwarzschild vacuum solution 4.3. Birkhoff theorem 4.4. Schwarzschild de Sitter solution (Kottler metric) 4.5. Geodesics from a Lagrangian 4.6. Geodesics in the Schwarzschild spacetime 4.7. Perihelion advance or precession of planets 4.8. Relativistic light bending 4.9. Shapiro time delay 4.10. Gravitational shift (redshift)	Read Chaps. 14 and 15 from the book of D'Inverno
Exam 1: in March (exact date TBD in class)	
Chapter 5: Schwarzschild Black Hole (itemized description): 5.1. Coordinates, potentials and orders of magnitudes 5.2 . Singularities of the Schwarzschild spacetime 5.3. Incompleteness of the Schw solution and the notion of extensions 5.4. Eddington-Finkelstein coordinates 5.5. Event Horizon and radially infalling particles 5.6. Maximal extension to the Schw metric: the Kruskal spacetime 5.7. Charged Schw metric: the Reisner-Nordstrom spacetime	Read Chaps. 16 and 17 from the book of D'Inverno



Topic	Chapter from D'Inverno's book
Chapter 6: Kerr axially symmetric vacuum solution and the Kerr Black Hole (itemized description): 6.1 The Kerr metric 6.2 General properties 6.3 Singularities and horizons 6.4 Null geodesics and stationary limit surface 6.5 Summary	Read Chap. 19 from the book of D'Inverno
Chapter 7: The Friedmann exact cosmological solution (itemized description): 7.1 Friedman-Lemaitre-Robertson-Walker (FLRW) metric 7.2 Friedmann equations with no cosmological constant 7.3 Friedmann equations with a cosmological constant 7.4 Conservation and continuity equations 7.5 Evolution of the energy density for various matter species 7.6 Cosmological evolution with no cosmological constant 7.6 Cosmological evolution with a cosmological constant 7.7 The question of an infinite universe	Read Chap. 22 from the book of D'Inverno
Chapter 8: Gravitation radiation – gravitational waves (itemized description): 8.1 Linearized Einstein equations 8.2 Perturbed Einstein Equations 8.3 Gravitational waves solution to the perturbed Einstein's equations	Read Chaps. 20 from the book of D'Inverno. See also Chap. 7 from the book of Carroll
Exam 2 End of semester – date fixed by UTD registrar – TBD	



Student Learning Objectives/Outcomes

- Learn tensor calculus aspects and be able to perform the needed calculations for General Relativity
- Understand the fundamental concept of Riemann tensor and to use it to calculate the curvature of spacetime
- Understand the structure of the Einstein Field Equations (EFEs) and be able to apply them to gravitational, astrophysical and cosmological situations
- Understand the framework of the Schwarzschild exact solution to EFEs and be able
  - to calculate trajectories of planets and stars,
  - to calculate the deflection angle of light by gravitational masses
  - to compare these results to real astronomical observations
- Understand the concepts of Black Holes, their internal structure and be able to use such knowledge to interpret the observed accreting material around Black Holes present at the center of spiral galaxies
- Understand the Friedmann cosmological exact solution and be able to apply its calculations to current observational data from our expanding universe
- Understand gravitational wave radiation theory and be able to use it to interpret the recently detected gravitational wave signals.

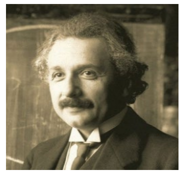
Assessment:

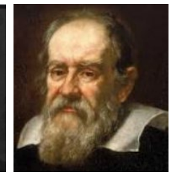
a) Homework assignments:

Students are expected to understand each of the topics above and be able to analyze how they apply corresponding real astrophysical situations and phenomena. This will be assessed during the semester via given questions as homework assignments that align with each chapter material as listed above. Assignments will be announced in class and on posted on eLearning. Students are encouraged to discuss the homework assignments with their peers but must complete their assignments individually.

b) Classroom short presentations about scientists who were influential in General Relativity

Each student will make a presentation of 8 minutes plus 2 minutes for questions and answers. Students are expected to be able to conduct a focused bibliography search about the biography and most important scientific contributions of an influential relativist. Students are expected to be able to compile and summarize the information into an informative but concise presentation before the class. Students will be given instructions in class on bibliography search and successful presentation delivery resources. These objectives will be assessed via the content and delivery of the presentation. Feedback will be given to students in private about their presentation content and style by the instructor.






A note about presentations: Students should follow the instructions and hints given in class on how to make effective and successful presentations. Whether for a simple class requirement, a talk at a professional conference or an important job talk, learning the skills of presenting your work is an important element of your training as a graduate student. Here are some links on how to make successful presentations:
http://www.apa.org/science/about/psa/2010/04/presentation.aspx
http://crosstalk.cell.com/blog/tips-for-giving-a-successful-scientific-presentation
http://www.sciencemag.org/careers/2017/05/how-get-most-out-attending-conferences

c) Exams:

Two non-cumulative exams will be given. Problems will be similar in scope and difficulty to the typical homework problems but will be adjusted to fit within the exam limited time frame. Students must bring with them a valid picture ID to the exam. Scientific calculators that have trig functions will be allowed in the exam but graphing calculators and programmable calculators will not be allowed. Makeup exams will be offered in the case of very good and documented medical reasons (or exceptional and documented personal reasons.) All exams will be closed book and a formula sheet will be provided with the exam. Exams will be given online and using the proctoring system Honorlock during the classroom time. More information will be provided about Honorlock system during class and posted to eLearning.

Comet Creed

This creed was voted on by the UT Dallas student body in 2014. It is a standard that Comets choose to live by and encourage others to do the same:

"As a Comet, I pledge honesty, integrity, and service in all that I do."

Academic Support Resources

The information contained in the following link lists the University's academic support resources for all students.

Please go to Academic Support Resources webpage for these policies.

UT Dallas Syllabus Policies and Procedures

The information contained in the following link constitutes the University's policies and procedures segment of the course syllabus.

Please go to UT Dallas Syllabus Policies webpage for these policies.