ASTR378

General Relativity

S2 Day 2016

Dept of Physics and Astronomy

Contents

General Information

Unit convenor and teaching staff
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Credit points
3

Prerequisites
PHYS202 and MATH235

Corequisites

Co-badged status

Unit description
This unit presents Einstein's theory of general relativity. The unit begins with a review of the ideas of geometry, and the presentation of special relativity from a geometric perspective, gravity as geometry, and the equivalence principle. Curved spacetime, metrics, geodesics, and Schwarzschild geometry, are then introduced. Only then is tensor analysis and the full description of space-time curvature developed and used in the derivation of Einstein's field equations. Applications to classical tests of relativity, the Schwarzschild metric, black holes, and gravitational radiation are considered.

Important Academic Dates

Information about important academic dates including deadlines for withdrawing from units are available at https://www.mq.edu.au/study/calendar-of-dates

Learning Outcomes

On successful completion of this unit, you will be able to:

Have an appreciation of the impact of relativity theory on our understanding of the nature of space and time.
Gain an understanding of the nature of gravity.
Gain experience in interpreting and applying the mathematical tools and abstract concepts that underlie the special and general theories of relativity.
Develop an appreciation of the astrophysical and cosmological importance of general relativity.

General Assessment Information

This unit has a hurdle requirement, specifying a minimum standard that must be attained in an aspect of the unit. To pass this unit you must obtain a mark of at least:

- 50% in the unit overall

as well as

- 40% in the final examination

Note: To achieve 50% in the unit overall, any below 50% outcome in one or more components of the assessment must be compensated for by appropriately weighted above 50% performance in the other assessment tasks.

Assessment Tasks

Name	Weighting	Due
Assignments (6)	25%	See below for dates
Weekly exercises	15%	Weekly
2 mid-session + final exam	60%	See below for dates

Assignments (6)

Due: **See below for dates**
Weighting: **25%**

As is usual with all physics courses the assignments are an integral part of the unit and aid your understanding of the material in the unit. The assignments will be set as follows:

- There will be six assignments set during the session.
- The proposed schedule for the assignments is as in the following table. Assignments should be submitted in lecture on the due date, or via the assignment box diagonally opposite E7B 207 by 5pm on the due date.

Assignment No. Available on iLearn on or before To be submitted for marking by 1 5 August 19

August 2 19 August 2 September 3 2 September 16 September 4 30 September 14 October 5 14 October 28 October 6 28 October 11 November
Return: To the extent that it is possible, marked assignments will be returned no later than a week after they have been handed in by the students.

On successful completion you will be able to:

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- Develop an appreciation of the astrophysical and cosmological importance of general relativity.

Weekly exercises

Due: **Weekly**
Weighting: **15%**

At the end of each week a set of exercises consisting of short sharp questions involving the direct application in simple calculations, or clear restatement, of basic principles covered in lectures will be provided on iLearn. The solutions will be handed in at the Wednesday class of the following week.

On successful completion you will be able to:

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- Gain an understanding of the nature of gravity.
- Gain experience in interpreting and applying the mathematical tools and abstract concepts that underlie the special and general theories of relativity.
- Develop an appreciation of the astrophysical and cosmological importance of general relativity.

2 mid-session + final exam

Due: **See below for dates**
Weighting: **60%**

As a wide range of physical and mathematical skills have to be understood in this unit, rather than relegating the bulk of the examination to the end of the semester, two 50 minute mid-term tests will be given. Each midterm will be worth 15% each, and will be applied in such a way as to only improve the final overall grade for the unit. Thus, the midterms can be worth from 0% to 30% of the final grade, and the exam from 30% to 60% of the final grade.

Mid-session exam dates:

The exact dates for these exams is to be determined, but will be held in or near week 6 and week 10.

Final exam:

This will be a two hour exam.

You are expected to present yourself for examination at the time and place designated in the University Examination Timetable. The timetable will be available in draft form approximately eight weeks before the commencement of the examinations and in final form approximately four weeks before the commencement of the examinations. Exam timetables are available at http://www.timetables.mq.edu.au/exam.

The combined grade of examination plus mid-terms is a hurdle requirement. You must obtain a mark of at least 40% to pass the unit. If your mark in the final examination is between 30% and 39% inclusive then you will be a given a second and final attempt at the final, two hour exam, to attain the required level of performance.

On successful completion you will be able to:

- Have an appreciation of the impact of relativity theory on our understanding of the nature of space and time.
- Gain an understanding of the nature of gravity.
- Gain experience in interpreting and applying the mathematical tools and abstract concepts that underlie the special and general theories of relativity.
- Develop an appreciation of the astrophysical and cosmological importance of general relativity.

Delivery and Resources

Classes

All classes will be lectures or tutorials presented as white-board/black-board/computer-generated slides.

Class times and locations

- Tuesday 2-4 pm W5C 234
- Wednesday 2 pm E6A 109
- Friday 10-11 am W5C 234

Required and Recommended Texts and/or Materials

Required Text

The required textbook for this unit is

- James Hartle: Gravity: An Introduction to Einstein's General Relativity.

Detailed notes to accompany the special relativity lectures will be provided.

Recommended Readings

- Ta-Pei Cheng: Relativity, Gravitation and Cosmology
- Andrew M. Steane: Relativity Made Relatively Easy
- Ian R Kenyon: General Relativity
- Bernard Schutz: A first course in General Relativity

Technology used and required

Unit web page

The web page for this unit can be found at http://ilearn.mq.edu.au

Please check this web page regularly for announcements and material available for downloading. Some learning resources for the unit will be provided in hardcopy rather on-line.

Teaching and Learning Strategy

This unit is taught through lectures and tutorials. We strongly encourage students to attend lectures because they provide a much more interactive and effective learning experience than studying a textbook. Questions during and outside lectures are strongly encouraged in this unit - please do not be afraid to ask, as it is likely that your classmates will also want to know the answer. You should aim to read the relevant sections of the textbook before and after lectures and discuss the content with classmates and lecturers.

You should aim to spend 3 hours per week working on the assignments and exercises. You may wish to discuss your assignment problems with other students and the lecturers, but you are required to hand in your own work (see the note on plagiarism below). Assignments are provided as one of the key learning activities for this unit, they are not there just for assessment. It is by applying knowledge learned from lectures and textbooks to solve problems that you are best able to test and develop your skills and understanding of the material.

Unit Schedule

Schedule of Topics

• **Special relativity** Weeks 1 – 7 lectures and tutorials given by Dr James Cresser covering basic ideas of gravitational physics and of the role of geometry, special relativity from a geometric perspective, the equivalence principle, accelerated reference frames, gravity as geometry.

• **General relativity** Weeks 8 – 13 lectures and tutorials given by Dr Dominic Berry. The ideas of flat spacetime are extended to the idea of curved space-time. The Schwarzschild solution for a spherically symmetric geometry is examined, and black holes, and experimental tests of general relativity are discussed. Then gravity and the equivalence principle, tensors, metric and curvature are studied, leading finally to the Einstein field equations.

Policies and Procedures

Macquarie University policies and procedures are accessible from Policy Central. Students should be aware of the following policies in particular with regard to Learning and Teaching:

Academic Honesty Policy http://mq.edu.au/policy/docs/academic_honesty/policy.html

New Assessment Policy in effect from Session 2 2016 http://mq.edu.au/policy/docs/assessment/policy_2016.html. For more information visit http://students.mq.edu.au/events/2016/07/19/new_assessment_policy_in_place_from_session_2/

Assessment Policy prior to Session 2 2016 http://mq.edu.au/policy/docs/assessment/policy.html

Grading Policy prior to Session 2 2016 http://mq.edu.au/policy/docs/grading/policy.html

Grade Appeal Policy http://mq.edu.au/policy/docs/gradeappeal/policy.html

Complaint Management Procedure for Students and Members of the Public http://www.mq.edu.au/policy/docs/complaint_management/procedure.html

Disruption to Studies Policy http://www.mq.edu.au/policy/docs/disruption_studies/policy.html *The Disruption to Studies Policy is effective from March 3 2014 and replaces the Special Consideration Policy.*

In addition, a number of other policies can be found in the Learning and Teaching Category of Policy Central.

Student Code of Conduct

Macquarie University students have a responsibility to be familiar with the Student Code of Conduct: https://students.mq.edu.au/support/student_conduct/

Results

Results shown in *iLearn*, or released directly by your Unit Convenor, are not confirmed as they are subject to final approval by the University. Once approved, final results will be sent to your student email address and will be made available in eStudent. For more information visit ask.mq.edu.au.

Disruption to Studies

The University recognises that students may experience disruptions that adversely affect their academic performance in assessment activities. Support Services are provided by the University to assist students through their studies. Whilst advice and recommendations may be made to a student, it is ultimately the student's responsibility to access these services as appropriate. Further information is to be found at http://students.mq.edu.au/student_admin/exams/disruption_to_studies/

Academic Honesty Policy

The University has developed an academic honesty policy whose key principles requires all students and staff to undertake their academic work honestly. Dishonest student behaviours by

will be managed by

1. communicating to students that any piece of academic work can be checked at any time using an appropriate process
2. implementing a common remedial and penalty framework across the University
3. establishing and applying appropriate, consistent procedures for detecting and investigating alleged academic dishonesty
4. providing and communicating the appeal process This policy covers such dishonest academic behaviours as

Plagiarism: Using the work or ideas of another person and presenting this as your own without clear acknowledgement of the source of the work or ideas. This includes, but is not limited to, any of the following acts:

– copying out part(s) of any document or audio-visual material or computer code or website content without indicating their origins

– using or extracting another person's concepts, experimental results, or conclusions

– summarising another person's work

– submitting substantially the same final version of any material as another student in an assignment where there was collaborative preparatory work

– use of others (paid or otherwise) to conceive, research or write material submitted for assessment

– submitting the same or substantially the same piece of work for two different tasks (self-plagiarism).

Deception: includes, but is not limited to, false indication of group contribution, false in- dication of assignment submission, collusion, submission of a work previously submitted, creating a new article out of an existing article by rewriting/reusing it, using the same data to form the same arguments and conclusion, presenting collaborative work as one's own without acknowledging others' contributions, cheating in an examination or using others to write material for examination.

Fabrication: includes, but is not limited to, creating fictitious clinical data, citation(s), or referee reports.

Sabotage: includes, but is not limited to, theft of work, destruction of library materials. Full details of the academic honesty policy can be found on http://www.mq.edu.au/policy/docs/academic_honesty/policy.html

Extensions

Assignments: As a general rule, no extensions will be granted. Late tasks will be accepted up to 72 hours after the submission deadline. There will be a deduction of 10% of the total available marks made from the total awarded mark for each 24 hour period or part thereof that the submission is late (for example, 25 hours late in submission – 20% penalty). This penalty does

not apply for cases in which an application for disruption to studies is made and approved.

Exercises: No extensions. Late tasks will not be accepted.

Student Support

Macquarie University provides a range of support services for students. For details, visit http://students.mq.edu.au/support/

Learning Skills

Learning Skills (mq.edu.au/learningskills) provides academic writing resources and study strategies to improve your marks and take control of your study.

- Workshops
- StudyWise
- Academic Integrity Module for Students
- Ask a Learning Adviser

Student Services and Support

Students with a disability are encouraged to contact the Disability Service who can provide appropriate help with any issues that arise during their studies.

Student Enquiries

For all student enquiries, visit Student Connect at ask.mq.edu.au

IT Help

For help with University computer systems and technology, visit http://www.mq.edu.au/about_us/offices_and_units/information_technology/help/.

When using the University's IT, you must adhere to the Acceptable Use of IT Resources Policy. The policy applies to all who connect to the MQ network including students.

Graduate Capabilities

Creative and Innovative

Our graduates will also be capable of creative thinking and of creating knowledge. They will be imaginative and open to experience and capable of innovation at work and in the community. We want them to be engaged in applying their critical, creative thinking.

This graduate capability is supported by:

Learning outcome

- Gain experience in interpreting and applying the mathematical tools and abstract concepts that underlie the special and general theories of relativity.

Assessment tasks

- Assignments (6)
- 2 mid-session + final exam

Commitment to Continuous Learning

Our graduates will have enquiring minds and a literate curiosity which will lead them to pursue knowledge for its own sake. They will continue to pursue learning in their careers and as they participate in the world. They will be capable of reflecting on their experiences and relationships with others and the environment, learning from them, and growing - personally, professionally and socially.

This graduate capability is supported by:

Learning outcomes

- Have an appreciation of the impact of relativity theory on our understanding of the nature of space and time.
- Gain an understanding of the nature of gravity.
- Gain experience in interpreting and applying the mathematical tools and abstract concepts that underlie the special and general theories of relativity.

Assessment tasks

- Assignments (6)
- Weekly exercises

Discipline Specific Knowledge and Skills

Our graduates will take with them the intellectual development, depth and breadth of knowledge, scholarly understanding, and specific subject content in their chosen fields to make them competent and confident in their subject or profession. They will be able to demonstrate, where relevant, professional technical competence and meet professional standards. They will be able to articulate the structure of knowledge of their discipline, be able to adapt discipline-specific knowledge to novel situations, and be able to contribute from their discipline to inter-disciplinary solutions to problems.

This graduate capability is supported by:

Learning outcomes

- Have an appreciation of the impact of relativity theory on our understanding of the nature of space and time.
- Gain an understanding of the nature of gravity.
- Gain experience in interpreting and applying the mathematical tools and abstract concepts that underlie the special and general theories of relativity.

Assessment tasks

- Assignments (6)
- Weekly exercises
- 2 mid-session + final exam

Critical, Analytical and Integrative Thinking

We want our graduates to be capable of reasoning, questioning and analysing, and to integrate and synthesise learning and knowledge from a range of sources and environments; to be able to critique constraints, assumptions and limitations; to be able to think independently and systemically in relation to scholarly activity, in the workplace, and in the world. We want them to have a level of scientific and information technology literacy.

This graduate capability is supported by:

Learning outcomes

- Have an appreciation of the impact of relativity theory on our understanding of the nature of space and time.
- Gain an understanding of the nature of gravity.
- Gain experience in interpreting and applying the mathematical tools and abstract concepts that underlie the special and general theories of relativity.

Assessment tasks

- Assignments (6)
- 2 mid-session + final exam

Problem Solving and Research Capability

Our graduates should be capable of researching; of analysing, and interpreting and assessing data and information in various forms; of drawing connections across fields of knowledge; and they should be able to relate their knowledge to complex situations at work or in the world, in order to diagnose and solve problems. We want them to have the confidence to take the initiative in doing so, within an awareness of their own limitations.

This graduate capability is supported by:

Learning outcomes

- Have an appreciation of the impact of relativity theory on our understanding of the nature of space and time.
- Gain an understanding of the nature of gravity.
- Gain experience in interpreting and applying the mathematical tools and abstract concepts that underlie the special and general theories of relativity.

Assessment tasks

- Assignments (6)
- Weekly exercises
- 2 mid-session + final exam

Effective Communication

We want to develop in our students the ability to communicate and convey their views in forms effective with different audiences. We want our graduates to take with them the capability to read, listen, question, gather and evaluate information resources in a variety of formats, assess, write clearly, speak effectively, and to use visual communication and communication technologies as appropriate.

This graduate capability is supported by:

Learning outcome

- Develop an appreciation of the astrophysical and cosmological importance of general relativity.

Assessment task

- Weekly exercises

Changes from Previous Offering

Dr Dominic Berry will be taking the second half of the unit.

The final exam will be two hours long rather than three hours.

In response to students' concerns expressed in the 2015 Student Liaison Committee meeting regarding the assignment/weekly exercises workload, closer attention will be paid to the content of the `weekly exercises' tasks which in 2015 drifted away from their `short sharp' question format and became comparable in length and difficulty to the assignments as the semester progressed. These exercises have been well-received in earlier years, and are intended to not require much time to complete, so efforts will be made to maintaining the `short sharp' question format throughout the unit.

Feedback

Student Liaison Committee

The Physics Department values quality teaching and engages in periodic student evaluations of its units, external reviews of its programs and course units, and seeks formal feedback from students via focus groups and the Student Liaison Committee. Please consider being a member of this committee, which meets once during the semester (lunch provided), with the purpose of improving teaching via student feedback. The class will be asked to nominate two students as representatives for the ASTR378 unit on the student liaison committee. This nomination process will be conducted during lectures and the lecturer will forward the names to the Head of

Department. The SLC meetings are minuted and student representatives receive copies of the minutes from the two preceding SLC meetings prior to the meeting. An update on the responses that have been made by the department to the feedback obtained at the two preceding SLC meetings are reported by the Head of Department at the beginning of each SLC meeting. These responses are also minuted. The feedback is acted upon in a number of ways mostly initiated via Department of Physics and Astronomy meetings, where decisions on actions are taken.

For responses to the 2015 SLC meeting comments on ASTR378, see `Changes from previous offering'.

Standards Expectation

Grading

An aggregate standard number grade (SNG) corresponding to a pass (P) is required to pass this unit.

High Distinction (HD, 85-100%): provides consistent evidence of deep and critical understanding in relation to the learning outcomes. There is substantial originality and insight in identifying, generating and communicating competing arguments, perspectives or problem solving approaches; critical evaluation of problems, their solutions and their implications; creativity in application.

Distinction (D, 75-84%): provides evidence of integration and evaluation of critical ideas, principles and theories, distinctive insight and ability in applying relevant skills and concepts in relation to learning outcomes. There is demonstration of frequent originality in defining and analysing issues or problems and providing solutions; and the use of means of communication appropriate to the discipline and the audience.

Credit (Cr, 66-74%): provides evidence of learning that goes beyond replication of content knowledge or skills relevant to the learning outcomes. There is demonstration of substantial understanding of fundamental concepts in the field of study and the ability to apply these concepts in a variety of contexts; plus communication of ideas fluently and clearly in terms of the conventions of the discipline.

Pass (P, 50-65%): provides sufficient evidence of the achievement of learning outcomes. There is demonstration of understanding and application of fundamental concepts of the field of study; and communication of information and ideas adequately in terms of the conventions of the discipline. The learning attainment is considered satisfactory or adequate or competent or capable in relation to the specified outcomes.

Fail (F, 0-49%): does not provide evidence of attainment of all learning outcomes. There is missing or partial or superficial or faulty understanding and application of the fundamental concepts in the field of study; and incomplete, confusing or lacking communication of ideas in ways that give little attention to the conventions of the discipline.