P415 General Relativity & Cosmology

Instructor: Adam Ritz
Office: Elliott 118
Office hours: Mondays 2:30-3:30pm
Email: aritz@uvic.ca
Lectures: 1:00-2:30pm, Mon & Thurs
Prerequisites: PHYS 321A, PHYS 326, MATH 346

This is a 4th year course introducing Einstein's general relativistic theory of gravity, and covering the following broad areas:

- Special relativity and spacetime
- Equivalence principle and gravity as geometry
- Curved spacetime geometry, geodesics, curvature
- Einstein's equations, the Schwarzschild geometry, and solar system tests
- Applications: Black Holes, Gravitational waves, Cosmology

See the course syllabus for further details.

Territory Acknowledgement: *We acknowledge and respect the Lək̓ʷəŋən (Songhees and Esquimalt) Peoples on whose territory the university stands, and the Lək̓ʷəŋən and W̱SÁNEĆ Peoples whose historical relationships with the land continue to this day.*

Syllabus | Texts | Materials | Assessment | Learning Outcomes | Other Resources

This is a 4th year course on general relativity, and (time permitting) will cover the following topics. The chapter references refer to the text by Hartle.

- Overview (Week 1)
  - Introduction, review of Newtonian gravity and Galilean relativity
- Special Relativity and Spacetime [Ch. 4,5] (Weeks 2-4)
  - Lorentz transformations and 4-vectors
  - Energy-momentum and its conservation
  - Lagrangian for a probe particle
- Equivalence Principle and Gravity as Geometry [Ch. 6,7,8] (Weeks 5-7)
  - Inertial and gravitational mass
  - The equivalence principle; Pound-Rebka experiment
  - gravity as geometry, geodesic motion
  - Newtonian gravity in geometric form, post-Newtonian corrections
- Spacetime Geometry and Einstein's Equations [Ch. 9,10 (plus 20,21,22 which are more advanced)] (Weeks 8-10)
  - Tensors and general covariance
  - Covariant derivatives, curvature
  - Einsteins equations
  - Schwarzschild solution
  - Solar system tests
- Applications (Weeks 11-12)
  - Black holes [Ch. 12,13]
    - Orbits, cooridnate systems
    - Astrophysical evidence
  - Gravitaitonal Radiation [Ch. 16]
    - Wave solutions
    - Polarization
  - Cosmology [Ch. 17,18]
    - Homogeneous, isotropic spacetimes
    - FRW metric, thermal history
    - Lambda CDM cosmology

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Syllabus | **Texts** | Materials | Assessment | Learning Outcomes | Other Resources

The (optional) course text is:

- *Gravity: An Introduction to Einstein's General Relativity*, J.B. Hartle

This is an excellent introductory text from one of the well-known names in the subject. Hartle takes a very physical approach, adding new mathematical content only when required, and incorporating many up-to-date applications and examples. Although we will not always follow the same order of topics, this text would make a very useful complementary source to the lectures.

There are of course many (many!) other texts which introduce general relativity. Most follow a slightly more mathematical route than Hartle. Some good course texts which are at a similar or somewhat higher level than this course include:

- *A First Course in General Relativity*, B.F. Schutz
- *General Relativity*, I.R. Kenyon
- *Spacetime and Geometry: An Introduction to General Relativity*, S.M. Carroll

For more advanced material (generally well above the level of this course), standard references are:

- *Gravitation and Cosmology* , S.W. Weinberg
- *General Relativity*, R.M. Wald

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Syllabus | Texts | **Materials** | Assessment | Learning Outcomes | Other Resources

Further online material for the course, including:

- course notes
- assignment sheets
- sample solutions

will be available at the PHYS 415 course page in Brightspace

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Syllabus | Texts | Materials | **Assessment** | Learning Outcomes | Other Resources

The course will be assessed according to the following three components:

- Assignments: 35%
- Mid-term quiz: 25%
- Final exam: 40%

There will be 5 assignments during the semester, and you will generally have ~1.5 weeks to complete each of them. The cumulative assignment grade will be computed from the top 4, with the lowest grade discarded. Assignments form an integral part of the course, used to expand on the material in the lectures in various ways. Investing time in them is beneficial for understanding the novel concepts involved in the theory of general relativity, and a key to success in this course.

Dates for the mid-term quiz and final exam are TBA.

The final grade will follow the University's percentage grading scheme given in the University Calendar, with the following universal conversion between letter and percentage grades:

- A+ (90-100)
- A (85-89)
- A- (80-84)
- B+ (77-79)
- B (73-76)
- B- (70-72)
- C+ (65-69)
- C (60-64)
- D (50-59)
- E (TBD)
- F (0-49)

If the application of this scheme would result in grades deemed by the instructor to be inconsistent with the University's grading descriptions, percentages will be assigned which are consistent with them.

Note on the use of calculators in exams: Calculators are not really required for this course, but a reminder about the general university policy; "On all examinations the only acceptable calculator is the Sharp EL-510R. This calculator can be bought in the Bookstore for about $10. DO NOT bring any other calculator to the examinations."

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Syllabus | Texts | Materials | Assessment | **Learning Outcomes** | Other Resources

After completing the course, you will:

- have detailed knowledge of how special relativity imposes a causal structure on events in space and time, and the associated Minkowski spacetime geometry.
- be able to explain how the equivalence principle leads to a geometric description of gravity, in the form of Einstein's general theory of gravity.
- have detailed knowledge of how space and time are curved around spherically symmetric mass distributions, you can solve practical orbit and trajectory problems in such spacetime geometries, and you know the basic properties of Schwarzschild black holes.
- have acquired basic knowledge of the cosmological concordance model, and how it is based on Einstein's theory of gravity.
- be able to communicate basic principles and complex topics in GR in a clear and pedagogical way.

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Syllabus | Texts | Materials | Assessment | Learning Outcomes | **Other Resources**

This document contains some important information about the department, and a number of UVic resources and supports that could be relevant for your studies.

Here are some additional resources and educational supports:

- Important Dates
  - https://www.uvic.ca/calendar/dates/
- Academic Supports
  - https://onlineacademiccommunity.uvic.ca/LearnAnywhere/academic-supports/
- Accommodations (Centre for Accessible Learning)
  - https://www.uvic.ca/accessible-learning/students/accommodations/index.php
- Learning Strategies
  - https://onlineacademiccommunity.uvic.ca/LearnAnywhere/learning-strategies/
- Well-being
  - https://onlineacademiccommunity.uvic.ca/LearnAnywhere/well-being/
- Policy on Academic Integrity
  - https://www.uvic.ca/students/academics/academic-integrity/index.php

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DEPARTMENT OF PHYSICS AND ASTRONOMY INFORMATION

- **Department Website:** uvic.ca/science/physics/index.php
- **Department General Office:** physgen@uvic.ca
- **Department Undergraduate Advisor:** phast_advising@uvic.ca
- **Department Graduate Advisor:** pkovtun@uvic.ca
- **Department Graduate Program Assistant:** physgrad@uvic.ca

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UNIVERSITY STATEMENTS & POLICIES

- Academic Calendar: Information for All Students
- Creating a respectful, inclusive, and productive learning environment
- Accommodation of Religious Observance
- Accommodation and Access for Students with Disabilities
- Student Conduct
- Non-academic Student Misconduct
- Accessibility
- Diversity / EDI
- Equity Statement
- Sexualized Violence Prevention and Response
- Discrimination and Harassment Policy

STUDENT RESOURCES

POSITIVITY AND SAFETY

The University of Victoria is committed to promoting, providing, and protecting a positive and safe learning and working environment for all its members.

Student Groups & Resources

ACADEMIC RESOURCES

UVic Library - *UVic Library offers many services and resources for undergraduate and graduate students*.

uvic.ca/students/academics/library-services

Learning Resources - *UVic Learn Anywhere is the primary learning resource for students that offers many learning workshops and resources to help students with academics and learning strategies.*

onlineacademiccommunity.uvic.ca/uviclearn/

Centre for Academic Communication - *Offers online and in-person one-on-one tutorials, workshops, and more.*

uvic.ca/learningandteaching/cac

Math & Stats Assistance Centre - *Offers drop-in, face-to-face tutoring and a friendly, collaborative study space for 100- and 200-level math and stats courses.*

uvic.ca/science/math-statistics/current-students/undergraduate/msac

MENTAL HEALTH & WELLNESS

A note to remind you to take care of yourself. Do your best to maintain a healthy lifestyle this semester by eating well, exercising, getting enough sleep, and taking some time to relax. This will help you achieve your goals and cope with stress. All of us benefit from support during times of struggle. You are not alone.

Student Wellness Centre - *Our team of practitioners offers a variety of services to support students' mental, physical, and spiritual health.*

uvic.ca/student-wellness

Counselling Services - *Counselling Services can help you make the most of your university experience. They offer free professional, confidential, inclusive support to currently registered UVic students.*

uvic.ca/student-wellness

Health Services - *University Health Services (UHS) provides a full-service primary health clinic for students and coordinates healthy student and campus initiatives.*

uvic.ca/student-wellness

ACCESSIBILITY

Students with diverse learning styles and needs are welcome in this course. In particular, if you have a documented disability or health consideration that may require accommodations, please feel free to approach me and/or the Centre for Accessible Learning (CAL) as soon as possible.

Centre for Accessible Learning - *The CAL staff are available by appointment to assess specific needs, provide referrals and arrange appropriate accommodations. The sooner you let us know your needs the quicker we can assist you in achieving your learning goals in this course.*

uvic.ca/accessible-learning

ADVISING

For academic advising-related questions, students in Physics and Astronomy are also encouraged to meet with one of the PHAST Undergraduate Advisors (phast_advising@uvic.ca) as well as an academic advisor in the Academic Advising Centre early in their studies to help map out a plan to declare a major and complete university program requirements.

Academic Advising Centre - *Academic advice and support is currently available by phone, email and virtual or in-person appointments*. uvic.ca/services/advising

Ombudsperson - *The ombuds office is an independent, impartial, and confidential resource for undergraduate and graduate students and other members of the University of Victoria community. The ombudsperson helps resolve student problems or disputes fairly.* uvicombudsperson.ca

ACADEMIC CONCESSION

You can request an academic concession if your course requirements are affected by unexpected and unavoidable circumstances, or conflicting responsibilities. Concession requests can be for an in-course extension, deferral, withdrawal under extenuating circumstances, or an aegrotat. Please speak to an advisor at the Academic Advising Centre if you have questions on how requesting a concession will affect your academic program.

Undergraduate Academic Concessions - uvic.ca/students/academics/academic-concessions-accommodations

EQUITY AND HUMAN RIGHTS AT UVIC

EQHR is a resource for students, staff, and faculty who have experienced sexualized violence, discrimination, and/or harassment and are looking for informal and/or formal resolution options as well as advice, coaching, and/or education. We are available for confidential consultations so that you can ask questions and learn your options.

EQHR – By email at eqhr01@uvic.ca or in-person (Sedgewick C115). uvic.ca/equity

Sexualized Violence Resource Office – *If you have been directly or indirectly impacted by sexualized violence, reach out to the SVRO for information, advice, and resolution options (restorative and disciplinary) as well as support options and referrals. The SVRO is both survivor-centred and trauma-informed in their approach. You can reach us by phone at 250-721-8021 or by email at eqhr01@uvic.ca to book either an in-person (Sedgewick C119) or online appointment.* uvic.ca/sexualizedviolence

RESOURCES FOR INTERNATIONAL STUDENTS

International Centre for Students - *The primary office supporting international students on campus at the university-wide level*. uvic.ca/international-experiences

UVic Global Community Initiative - *Provides various supportive programming, including a Mentorship Program and Conversation Partner Program*. uvic.ca/international-experiences/get-involved/uvic-global-community

RESOURCES FOR INDIGENOUS STUDENTS

Indigenous Student Support - *UVic offers holistic services to Indigenous students throughout their academic journey.* uvic.ca/students/info-for/indigenous-students

Elders in Residence - *The Office of Indigenous Academic and Community Engagement (IACE) has the privilege of assembling a group of Elders from local communities to guide students, staff, faculty, and administration in Indigenous ways of knowing and being.* uvic.ca/iace/