

Astronomy 4602B

Gravitational Astrophysics and Cosmology

Winter 2024, Department of Physics and Astronomy, Western University, Canada

This course covers the astrophysics of gravity and cosmology and is aimed at undergraduate students in third and fourth year. I will assume a basic understanding of ordinary differential equations and physics at least at the second-year level. We will cover some aspects of general relativity by following the analysis of binary black hole mergers detected by the Laser Interferometer Gravitational-wave Observatory (LIGO) and learn the standard model of the expanding universe. The latter includes fitting the Type Ia supernova data to find the proposed evidence for an accelerating universe. The course evaluation is primarily through written reports and computational projects.

The motto of this course is **Learning by doing, not learning by listening**. You are now a senior student in a challenging subject area, and it is time to learn by doing projects and giving presentations, as done by professionals in your field. Class time will be used largely to work on projects rather than to listen to extended lectures. I will do a limited amount of lecturing.

Instructor: Prof. Shantanu Basu

Contact: basu@uwo.ca

Email is a useful way to make quick inquiries. Longer discussion should take place in several other ways: in class discussion (use this opportunity (!) because I am not lecturing during most classes), right after class, or during an office hour.

There will be group work on the projects, and you are expected to work on those during class times and other times. Your project marks will include a mark for participation, so attendance is important.

Prerequisites: [Physics 2101A/B](#), [Physics 2102A/B](#), [Calculus 2503A/B](#).

Unless you have either the requisites for this course or written special permission from your Dean's Designate (Department/Program Counsellors and Science Academic Counselling) to enroll in it, you may be removed from this course and it will be deleted from your record. This decision may not be appealed. You will receive no adjustment to your fees in the event that you are dropped from a course for failing to have the necessary prerequisites.

Textbook: There is a curated textbook for the course available through the UWO bookstore. It contains 5 chapters, some of which are taken from published textbooks. There will be additional course readings that are available on the OWL course site. I will also post slides that I present in class. Together, these resources will provide the research material and background needed to perform most tasks in the course.

Some textbooks that provide additional useful content are:

- *Introduction to Cosmology*, Ryden, B. 2003, Addison-Wesley
- *An Introduction to Relativity*, Narlikar, J. V. 2010, Cambridge University Press
- *How Did the First Stars and Galaxies Form?*, Loeb, A. 2010, Princeton University Press
- *Cosmology: A Short Introduction*, Coles, P. 2001, Oxford University Press

OWL Site: Students are responsible for checking the course OWL site (<http://owl.uwo.ca>) on a regular basis for news and updates. This is the primary method by which information will be disseminated to all students in the class.

If students need assistance with the course OWL site, they can seek support on the OWL Help page. Alternatively, they can contact the Western Technology Services Helpdesk. They can be contacted by phone at 519-661-3800 or ext. 83800.

Lecture and Interaction Hour Content: All pdf files of slides (and any possible audio recordings) are copyrighted to me and should not be shared with persons who are not students in the class and should not be posted anywhere.

Evaluation:

Evaluation	Weight	Date or Due Date
Assignment 1	12.5%	Jan 23
Project 1	20%	Feb 6
Project 2	20%	Mar 5
Quiz	10%	Mar 12
Assignment 2	12.5%	Apr 2
Presentation	5%	Apr 8

Final Exam	20%	April Exam period
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The projects will be done working in groups of two people. One report will be handed in by each group. Both persons in a group are expected to contribute equally, and a statement is required from each participant about who performed which tasks.

The final exam is in the university scheduled exam period.

Classes will be mostly collaborative work on the projects, hence bringing your laptop is strongly encouraged.

The computational projects are to be submitted in scientific manuscript style, with an abstract, introduction, methods, results, and conclusions sections, as well as a bibliography. A copy of your numerical code should also be attached. Marks for the project will be based on results as well as the presentation of background material, clarity of derivations, clarity of writing, and clarity of the code. A participation mark is also included.

Students must write their papers in their own words. Proper referencing through citations is also expected in the written reports. All required papers may be subject to submission for textual similarity review to the commercial plagiarism detection software under license to the University for the detection of plagiarism. All papers submitted for such checking will be included as source documents in the reference database for the purpose of detecting plagiarism of papers subsequently submitted to the system. Use of the service is subject to the licensing agreement, currently between The University of Western Ontario and Turnitin.com (<http://www.turnitin.com>).

The quiz will be held during the Tuesday class time block (March 12) and be timed for 30 minutes. The quiz will consist of multiple-choice questions.

The date or due dates for each assessment are listed in the Table above. All assessments other than the quiz should be uploaded to your Drop Box on the OWL site. If the projects or assignments are turned in late then they will be assessed a 10% penalty per day that they are late.

Learning Outcomes:

- *Understand the Minkowski metric of Special Relativity and its relation to time dilation and length contraction*
- *Understand Einstein's mass-energy relation and its application to self-gravitating bodies*
- *Learn the Schwarzschild metric of General Relativity for spacetime in the vicinity of a point mass*

- *Calculate the orbit decay of binary black hole systems and the frequency of gravitational wave emission at merger*
- *Learn the case for dark matter*
- *Understand the expanding universe model and the case for dark energy*
- *Understand the origin of the cosmic microwave background and how it is measured*

Equity, Diversity, and Inclusion

The principles of EDI are very meaningful to me, and I will try to foster an atmosphere of respect and inclusion, where all voices can be heard. All class members should treat others with professional respect and equal consideration in both written and spoken communication. We should work to provide an environment that encourages the free expression and exchange of ideas.

Western has historically had EDI challenges and it requires ongoing efforts by all for improvement. I encourage you to read the recent report of the President's Anti-racism Working Group, available at <https://president.uwo.ca/pdf/arwg-final-report-to-president-shepard-fnl.pdf>, and seek out resources available at <https://www.edi.uwo.ca/resources/>.

The Canadian Association of Physicists (CAP) has published a special magazine issue on inclusion available at <https://pic-pac.cap.ca/> and the Canadian Astronomical Society (CASCA) has compiled a list of EDI resources at https://casca.ca/?page_id=17441.

Decolonization Statement

Western sits on the traditional territories of the Anishinaabek, Haudenosaunee, Lūnaapéewak and Chonnocton Peoples. The legacy of colonization and colonialism is felt globally and is imprinted in our educational system. Western is taking some initial steps toward recognizing it. Textbooks can be biased toward a particular cultural narrative. Physics textbooks are no exception. I will strive to include unique content as much as I can, and I seek your feedback. I encourage you to read the following articles and share your ideas on this topic with me and with your colleagues.

<https://news.westernu.ca/2021/06/moving-toward-decolonizing-the-curriculum/>

<https://indigenous.uwo.ca/initiatives/learning/12-ways.html>

Department Policy: Course marks may, in some cases, be adjusted to conform to the meaning of course marks described in the Western Academic Calendar, and to conform to Department policy.

Student Absences

If you are unable to meet a course requirement due to illness or other serious circumstances, please follow the procedures below.

The presentation, due on April 8, is worth 5% of your mark. If you need academic consideration to miss that you can talk to me. The accommodation, if granted by me, would be that the marks are added to the final exam, to make the final exam worth 25% instead of 20%.

By policy, academic considerations for work totalling 10% or more of the final course grade can be granted only by the student's Faculty of Registration (typically by their academic counsellors). In such cases, students should be directed as follows.

For work totalling 10% or more of the final course grade, you must provide valid medical or supporting documentation to the Academic Counselling Office of your Faculty of Registration as soon as possible. For further information, please consult the University's medical illness policy at

https://www.uwo.ca/univsec/pdf/academic_policies/appeals/academic_consideration.pdf.

The Student Medical Certificate is available at

https://www.uwo.ca/univsec/pdf/academic_policies/appeals/medicalform.pdf.

Absences from Final Examinations

If you miss the Final Exam, please contact the Academic Counselling office of your Faculty of Registration as soon as you are able to do so. They will assess your eligibility to write the Special Examination (the name given by the University to a makeup Final Exam).

You may also be eligible to write the Special Exam if you are in a "Multiple Exam Situation" (e.g., more than 2 exams in 23-hour period, more than 3 exams in a 47-hour period).

If a student fails to write a scheduled Special Examination, the date of the next Special Examination (if granted) normally will be the scheduled date for the final exam the next time this course is offered. The maximum course load for that term will be reduced by the credit of the course(s) for which the final examination has been deferred. See the Academic Calendar for details (under [Special Examinations](#)).

Note: missed work can *only* be excused through one of the mechanisms above. Being asked not to attend an in-person course requirement due to potential COVID-19 symptoms is **not** sufficient on its own.

Accommodation and Accessibility

Religious Accommodation

When a course requirement conflicts with a religious holiday that requires an absence from the University or prohibits certain activities, students should request an accommodation for their absence in writing at least two weeks prior to the holiday to the course instructor and/or the Academic Counselling office of their Faculty of Registration. Please visit the Diversity Calendars posted on our university's EDID website for the recognized religious holidays:

<https://www.edi.uwo.ca>.

Accommodation Policies

Students with disabilities are encouraged to contact Accessible Education, which provides recommendations for accommodation based on medical documentation or psychological and cognitive testing. The policy on Academic Accommodation for Students with Disabilities can be found at:

[https://www.uwo.ca/univsec/pdf/academic_policies/appeals/Academic Accommodation_disabilities.pdf](https://www.uwo.ca/univsec/pdf/academic_policies/appeals/Academic_Accommodation_disabilities.pdf).

Academic Policies

The website for Registrarial Services is <https://www.registrar.uwo.ca/>.

In accordance with policy,

https://www.uwo.ca/univsec/pdf/policies_procedures/section1/mapp113.pdf,

the centrally administered e-mail account provided to students will be considered the individual's official university e-mail address. It is the responsibility of the account holder to ensure that e-mail received from the University at their official university address is attended to in a timely manner.

For the final exam, a non-programmable scientific calculator is permitted.

Scholastic offences are taken seriously and students are directed to read the appropriate policy, specifically, the definition of what constitutes a Scholastic Offence, at the following Web site:

https://www.uwo.ca/univsec/pdf/academic_policies/appeals/scholastic_discipline_undergrad.pdf.

All required papers may be subject to submission for textual similarity review to the commercial plagiarism detection software under license to the University for the detection of plagiarism. All papers submitted for such checking will be included as source documents in the reference database for the purpose of detecting plagiarism of papers subsequently submitted to the system. Use of the service is subject to the licensing agreement, currently between The University of Western Ontario and Turnitin.com (<http://www.turnitin.com>).

Support Services

Please visit the Science & Basic Medical Sciences Academic Counselling webpage for information on adding/dropping courses, academic considerations for absences, appeals, exam conflicts, and many other academic related matters: <https://www.uwo.ca/sci/counselling/>.

Students who are in emotional/mental distress should refer to Mental Health@Western (<https://uwo.ca/health/>) for a complete list of options about how to obtain help.

Western is committed to reducing incidents of gender-based and sexual violence and providing compassionate support to anyone who has gone through these traumatic events. If you have experienced sexual or gender-based violence (either recently or in the past), you will find information about support services for survivors, including emergency contacts at https://www.uwo.ca/health/student_support/survivor_support/get-help.html. To connect with a case manager or set up an appointment, please contact support@uwo.ca.

Learning-skills counsellors at Learning Development and Success (<https://learning.uwo.ca>) are ready to help you improve your learning skills. They offer presentations on strategies for improving time management, multiple-choice exam preparation/writing, textbook reading, and more. Individual support is offered throughout the Fall/Winter terms in the drop-in Learning Help Centre, and year-round through individual counselling.

Western University is committed to a thriving campus as we deliver our courses in the mixed model of both virtual and face-to-face formats. We encourage you to check out the Digital Student Experience website to manage your academics and well-being: <https://www.uwo.ca/se/digital/>.

Additional student-run support services are offered by the USC, <https://westernusc.ca/services/>.