Astronomy 4602B

Gravitational Astrophysics and Cosmology

Winter 2022, 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 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, much of which will be asynchronous.

Instructor: Prof. Shantanu Basu

Contact: basu@uwo.ca, Office: PAB 258

Email is a useful way to make quick inquiries. Longer discussion should take place during the interaction hours (see below).

Time and Location: Course timetable is Tu 10:30 am – 12:20 pm, Th 10:30 am 11:20 pm. In person classes, if and when available, will be held in the WALS classroom at FNB 2210.

We are starting the term as a fully online course with asynchronous lectures and synchronous interaction hours; the latter are not lectures. Lecture notes and audio files for any week will be posted by the start of that week. The Tuesday time slot is the recommended time to listen to the audio lectures, but you can choose to use another time. In the absence of in-person classes, there will be an interaction hour each Thursday 10:30 am (by Zoom). During some weeks, the Tuesday time slot 10:30 am – 12:20 pm may also be used, for an interaction hour, quiz, or student presentations. There will be group work on the projects, and you are expected to work on those during the Tuesday class times and other times.

Prerequisites: Physics 2101A/B, Physics 2102A/B, Calculus 2503A/B.

Textbook: There is no required textbook, but suitable textbooks that provide some 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. Princeton University Press
- *Astrophysics and the Evolution of the Universe,* Kisslinger, L. S. 2017, World Scientific
- *An Introduction to Modern Astrophysics,* Carroll, B. W., and Ostlie, D. A. 1996, Addison-Wesley
- *The Physical Universe,* Shu, F. H. 1981, University Science Books

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 audio recordings of lectures and pdf files of slides are copyrighted to me and should not be shared with persons who are not students in the class and should not be posted anywhere. You are not permitted to record the recordings. The live Zoom interaction hours should not be recorded by you under any circumstances. They are like an office hour would be in my office, and no recording device is allowed. You may of course take handwritten notes based on the discussion. The interaction hours are conversational and are not lecture sessions.

Evaluation:

Evaluation	Weight	Date or Due Date
Project 1	20%	Feb 4
Project 2	20%	Mar 11
Online quiz	10%	Mar 15
Class presentation	20%	Mar 22, 24, 29
Final Exam	30%	April Exam period

The projects and presentation will be done working in groups of two people. One report or presentation will be handed in by each group. Both persons are expected to contribute equally, and a statement is required from each group about who performed which tasks. The presentation will be in class or through zoom and both persons should contribute equally. Topics for the presentation will be chosen by March 1.

The final exam is in the university scheduled exam period.

If the projects are turned in late then they will be assessed a 10% penalty per day that they are late.

In-person classes will be mostly collaborative work on the projects, hence bringing your laptop is strongly encouraged. If we switch to in-person some portion of the assignment will be done and handed in during class.

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.

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 online and delivered through OWL. It will be held during the Tuesday class time block 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.

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*

Zoom requirement: Completion of this course will require you to have a reliable internet connection and a device that meets the system requirements for Zoom. Information about the system requirements is available at the following link:

https://support.zoom.us/hc/en-us.

* Please note that Zoom servers are located outside Canada. If you would prefer to use only your first name or a nickname to login to Zoom, please discuss this with your instructor in advance of the test or examination.

Website: There is a course website available through OWL (owl.uwo.ca). Course lectures and practice problem sets will be posted there.

Equity, Diversity, and Inclusion Statement: 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.

I encourage all of 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.

Decolonization Statement: The legacy of colonization and colonialism is imprinted in our educational system, and Western is taking some initial steps toward recognizing it. 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 in order to conform to the meaning of course marks described in the Western Academic Calendar, and in order to conform to Department policy.

Academic Consideration for Student Absences

Students who experience an extenuating circumstance (illness, injury or other extenuating circumstance) sufficiently significant to temporarily render them unable to meet academic requirements may submit a request for academic consideration through the following routes:

(i) Submitting a Self-Reported Absence (SRA) form provided that the conditions for submission are met. To be eligible for a Self-Reported Absence:

- an absence must be no more than 48 hours
- the assessments must be worth no more than 30% of the student's final grade
- no more than two SRAs may be submitted during the Fall/Winter term

(ii) For medical absences, submitting a Student Medical Certificate (SMC) signed by a licensed medical or mental health practitioner to the Academic Counselling office of their Faculty of Registration.

(iii) Submitting appropriate documentation for non-medical absences to the Academic Counselling office in their Faculty of Registration.

Note that in all cases, students are required to contact their instructors within 24 hours of the end of the period covered, unless otherwise instructed in the course outline.

Students should also note that individual instructors are not permitted to receive documentation directly from a student, whether in support of an application for consideration on medical grounds, or for other reasons. **All documentation required for absences that are not covered by the Self-Reported Absence Policy must be submitted to the Academic Counselling office of a student's Home Faculty.**

For the policy on Academic Consideration for Student Absences – Undergraduate Students in First Entry Programs, see:

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

and for the Student Medical Certificate (SMC), see:

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

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 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 consult University's list of recognized religious holidays (updated annually) at

https://multiculturalcalendar.com/ecal/index.php?s=c-univwo.

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).

Accommodation Policies

Students with disabilities work with Accessible Education (formerly SSD), 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

The website for Registrarial Services is http://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 his/her official university address is attended to in a timely manner.

A standard calculator of the type that is used in first year physics classes is required for the final exam.

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:

http://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/.

Please contact the course instructor if you require lecture or printed material in an alternate format or if any other arrangements can make this course more accessible to you. You may also wish to contact Accessible Education at (519) 661-2147 if you have any questions regarding accommodations.

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

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