Space Astrophysics (ASTR 3161)

Spring Semester 2020

Course and Contact Information

Department and Course:	Physics, ASTR 3161
Semester:	Spring 2020
Time:	Monday and Wednesday 12:45 PM - 02:00 PM
Location:	Corcoran Hall 404A
Course Web Site:	http://blackboard.gwu.edu

Instructor:	Prof. Oleg Kargaltsev
Campus address:	Corcoran Hall 407 (office)
Phone:	202-994-7225 (office)
E-Mail:	kargaltsev@gwu.edu
Office Hours:	Tuesday, 2:30 PM - 3:30 PM
	Wednesday, 3:00 PM - 4:00 PM
	(or by appointment)

ASTR 3161 — Space Astrophysics

Week	Date	Homework Due or Exam	Topics
1	Monday Jan 13		A Brief History of High-Energy (X-ray & Gamma-Ray) Astronomy. Basic terminology.
1	Wednesday, Jan 15		Radiation I: Electromagnetic Radiation and Basic Radiation Processes and Quantities.
2	Monday Jan 20		Martin Luther King Jr. Day (no class)
2	Wednesday, Jan 22		Radiation II: Electromagnetic Radiation: Radiation quantities. Thermal equilibrium. Blackbody. Optical depth.
3	Monday Jan 27		Radiation III: Thermal Bremsstrahlung. Line emission. Absorption in ISM.
3	Wednesday, Jan 29	HW#1	Radiation IV: Cyclotron radiation.
4	Monday Feb 03		Radiation V: Synchrotron and Curvature Radiation.
4	Wednesday, Feb 05		Radiation VI: Thomson and Compton Scattering. Basic Special Relativity.
5	Monday, Feb 10	HW#2	Basic plasma physics.
5	Wednesday, Feb 12		Basic MHD.
6	Monday, Feb 17		President's Day (no class)
6	Wednesday, Feb 19		MHD. Reconnection. Dynamo.
7	Monday, Feb 24		Shock waves. Particle acceleration.
7	Wednesday, Feb 26		Telescopes and Detectors for X-rays and, Gamma-rays. Basics of measurements. Final project intro.
8	Monday, Mar 02	HW#3	Sources of High-Energy Emission: Evolution of massive stars.
8	Wednesday, Mar 04		Sources of High-Energy Emission: Supernovae
9	Monday, Mar 09		Sources of High-Energy Emission: Supernova Remnants. REVIEW FOR EXAM #1
9	Wednesday, Mar 11		EXAM #1
10	Monday, Mar 16		SPRING BREAK

10	Wednesday, Mar 18		SPRING BREAK
11	Monday, Mar 23		Sources of High-Energy Emission: White Dwarfs. Isolated Neutron Stars. Pulsars. Pair production.
11	Wednesday, Mar 25		Sources of High-Energy Emission: Pulsar wind nebulae. Neutron star zoo.
12	Monday, Mar 30	HW#4	Accretion. White Dwarfs and Neutron Stars in Binary Systems.
12	Wednesday, Apr 01	Final project topic is due	Isolated Black Holes. Black holes in binaries.
13	Monday, Apr 06	Final project outline is due	Astrophysics and observational manifestations of supermassive Black Holes, AGNs.
13	Wednesday, Apr 08		Gamma-ray Bursts.
14	Monday, Apr 13	HW#5	Fast Radio Bursts.
14	Wednesday, Apr 15		EXAM #2
15	Monday, Apr 20	Final project Progress Report is due	Gravitational waves.
15	Wednesday, Apr 22		Cosmic Rays, High-Energy Particle Astrophysics, Neutrino Astrophysics.
16	Monday, Apr 27		Practical demonstration: data from Chandra X-ray Observatory and Hubble Space Telescope. Last minute questions about final project questions.
16	Wednesday, Apr 29	Final project is due, at 5:00 pm	No class unless there is a need to make-up for canceled class.

Detailed Course Description

COURSE DESCRIPTION: In this survey course you will learn about high-energy radiation processes, the 4th state of matter (plasma), extreme states of matter and space (neutron stars and black holes), basic astronomy and lives of stars, modern X-ray and gamma-ray observatories, and basics of statistical data analysis.

PREREQUISITE: PHYS 1022 (University Physics II), MATH 1231 (Calculus I), MATH 1232 (Calculus II) or equivalent. You need to know material from these courses well to be successful in ASTR 3161 course.

LECTURES: The lectures are meant to explain difficult concepts, to expand on the reading material, and to introduce topics not covered in the textbook such as examples from real observations and data. If you do not understand something, you are very much encouraged to ask questions during the lectures. If I am lecturing too fast or something is not clear, please tell me right away. Due to some travel I have over the semester, there may be some guest and make-up lectures. These will be arranged as needed later on. **The lecture content for the previous weeks and for the upcoming week, the reading assignments, and the homework will be listed in the Weekly Activities section of the Blackboad course page. Please check that page frequently, things may change. If needed, that page is updated announcements will be made through the Blackboard Announcements.**

YOUR RESPONSIBILITIES:

1. Reading the textbook(s);
2. Reading any additional materials distributed or assigned otherwise;
3. Participating in discussions during the class;
4. Repeating the any calculations and derivations done in class alone by yourself (with textbook closed);
5. Doing your homework yourself and turning it in time.

At least 6 hrs/week of independent learning is expected in this course. This will help you do well on the exams.

LEARNING OBJECTIVES:

In this course, you will:

1. Acquire basic knowledge about cosmic sources of high-energy radiation;
2. Develop analytical, scientific, and critical thinking skills;
3. Develop the ability to identify the appropriate physics laws/principles and mathematical methods needed to tackle a specific astrophysics problem;
4. Make connections between mathematics, physics and astronomy.

TEXTBOOKS AND OTHER USEFUL BOOKS:

There are two **required** (you need to buy them or get them from the library) textbooks for this course:

*** High-Energy Astrophysics**
F. Melia
Princeton University Press, 2009
ISBN: 978-0-691-14029-2

*** Exploring the X-ray Universe: Second Edition**
F.D. Seward and P.A. Charles
Cambridge University Press, 2010
ISBN: 978-0-521-88483-9

Taken together, these two textbooks give good introduction to high-energy astrophysics. I will provide some additional reading material which will be always available on the course in the Blackboard.

There are other good books on high-energy astrophysics that will be useful for various parts of the course, and you are strongly encouraged to use them as need arises in addition to your lecture notes. Most of them should be also on reserve in the GWU (Gelman) library.

* Frontiers of X-ray Astronomy
A.C. Fabian, K.A. Pounds, and R.D. Blandford
Cambridge University Press, 2004
ISBN: 0-521-53487-9
Good reviews on selected topics in X-ray astronomy.

* Accretion Power in Astrophysics: Third Edition
J. Frank, A. King, and D. Raine
Cambridge University Press, 2002
ISBN: 0-521-620538
The book has excellent coverage of accretion physics.

* High-Energy Astrophysics: Third Edition
M.S. Longair
Cambridge University Press, 2011
ISBN: 978-0-521-75618-1
Extensive coverage of high-energy astrophysics including phenomenological astronomy, physical processes, Galactic and extragalactic sources. An excellent reference resource.

* Plasma Astrophysics: Saas-Fee Advanced Course 24. Lecture Notes 1994.
J.G. Kirk, D.B. Melrose, E.R. Priest (Author)
Springer-Verlag Berlin Heidelberg 2010
ISBN: 978-364-208202-3
An excellent, concise introduction to plasma astrophysics and magnetohydrodynamics

* Radiative Processes in Astrophysics
G.B. Rybicki and A.P. Lightman
Wiley Interscience, 1979
ISBN: 0-471-82759-2
This excellent book is frequently used as a graduate level textbook for the course named alike.

*High Energy Radiation from Black Holes: Gamma Rays, Cosmic Rays, and Neutrinos
Charles D. Dermer & Govind Menon
Princeton University Press, 2009
ISBN: 9780691144085

Great modern graduate level textbook covering broad range of topics in theoretical high-energy astrophysics.

* The Restless Universe: Understanding X-ray Astronomy in the Age of Chandra and XMM-Newton
E.M. Schlegel
Oxford University Press, 2002
ISBN: 0-19-514847-9
Fairly recent, nontechnical, broad review of X-ray astronomy.

* Black Holes, White Dwarfs, and Neutron Stars: The Physics of Compact Objects
S.L. Shapiro and S.A. Teukolsky
Wiley Interscience, 1983
ISBN: 0-471-87316-0
This somewhat old but classic book covers the physics compact objects mentioned in its title. Very well written in places more advanced than undergraduate course.

Gelman Library has copies of most of these books, and I have placed them on reserve for your use. If you are planning a professional career in astronomy/astrophysics, you will need to take a look at these books.

I also strongly encourage you to look through the preprints abstracts http://arxiv.org/list/astro-ph/recent looking for articles relevant for each class. If something catches your attention we can discuss it at the beginning of the class. This will count toward your class participation.

GRADING: Your grade will be based on homework (20%), exam #1 (20%), exam#2 (20%), class attendance/participation (20%), term project paper (20%). Lectures are mandatory and active class participation is expected (part of the grade). If you missed any lectures because of medical reasons you must bring a note from your doctor stating that you have been sick on that day.

The grading scale for the course is as follows:

106.00 - 94.000	A
93.999 - 90.000	A–
89.999 - 86.000	B+
85.999 - 82.000	B
81.999 - 78.000	B–
77.999 - 74.000	C+
73.999 - 70.000	C
69.999 - 66.000	C–
65.999 - 61.000	D+
60.999 - 55.000	D
54.999 - 50.000	D–
49.999 - 0.000	F

HOMEWORK AND TEAM WORK POLICY: Homework assignments will be distributed and collected **BEFORE** class starts on the **specified day** (see pages 2-3). The homework problems will also be available through the Problem Sets section of the course in the Blackboard. Any homework turned in late will be assigned only half of the credit. Please start working on your homework early and do not postpone it till the last day! If you have a medical excuse, you must contact me as soon as possible (e.g. by e-mail) to arrange a new due date for the HW.

In this class you are expected to learn how to think independently and creatively and how to solve problems by yourself. You are required to work by yourself (alone) on each problem for an hour before you discuss it with anyone or come to office hours. Feel free to consult the textbooks and lecture notes but *do not Google the solution* and paste it. I am aware of what is online and will notice it. After you have made an honest attempt to solve the homework problem for at *least 1 hour*, you may discuss it with other students or come see me during the office hours. Any substantial use of online resources must be clearly indicated in your homework. Should a particular problem cause troubles for majority of students in the class, I will review the solution at the beginning of my next lecture.

It is VERY important to write you homework solution in a detailed and clear way. If I cannot follow your solution, I cannot assign any credit for it. A detailed, well-structured solution will usually get higher score. Please, do not substitute the numbers into the equations until the very end, whenever possible. Clearly number the problems in your solution in the same way they are numbered in the homework assignment. A partial credit for the homework (or exam) problem can be earned even if you got a wrong answer but demonstrated understanding of underlying physics. Staple your homework before handing it in. Some homework sets may include challenging problems for those who plan to go on to become professional astrophysicists or would like to earn a little extra credit.

Each qualitative problem (homework or exams) will be graded in the following way: 20% is awarded if you demonstrate understanding of the physical processes associated with the problem. Another 20% is awarded if you use the correct equations (assuming equations are needed). Another 40% are awarded for the correct solution of equations. Final 20% is

awarded if the numerical answer (if it is required) is correct. You may get some points if you got the wrong numerical answer but realized this and wrote why you think it is unreasonable.

If you disagree with your homework grade, you must e-mail your appeal to me **within 1 week** from the date when graded homework was returned to you. The appeal must include your name, it should clearly identify the issue in question, contain a detailed explanation of what you think is wrong or unfair, and your original homework must be included as a part of the appeal. The same procedure applies to the exams.

EXAMS: There will be one **two** exams in this course. **The exams will be based solely on the material covered during the lectures, assigned reading, and in the homeworks.** You are responsible for knowing the material presented in class as well as material from the assigned readings (including the textbook material and the distributed in class materials, unless the material is marked as optional). The exams will be closed book and closed notes (except for those distributed with the exam). You may use standard, non-programmable calculators on the exams. Cell phones, laptops, Ipads, and calculators that can store equations and text are not allowed. A violation of this policy will cost you half the exam score. A table with physical constants (in cgs units) will be provided during the exam.

Each exam will have 4-5 problems (each problem may have multiple simpler parts). Questions may include definitions, physical explanations, brief calculations, and brief derivations. You should work efficiently to score as many points as possible. Do not get stuck with a single question for the entire exam period. Incomplete solution can get partial credit so please write at least something reasonable. To get full or partial credit, your written answers must be written legibly, and your writing must show your reasoning clearly. Please provide your solutions in the same order in the problems are given to you.

No makeup exams are planned. If you have a medical excuse, you must contact me as soon as possible regarding this matter to discuss possible solutions.

FINAL PROJECT: This is your independent research project. You will need to write and submit to the instructor by the specified date a research paper (a proposal to observe a particular high-energy source or your own in-depth investigation of an astrophysical phenomen/object relevant to the course, using available literature). Each student should hand in *a one-paragraph outline of the project*, on **Monday, April 6**. This outline should include the goal of the project, the data to be used, and a list of six or more relevant references to the journal articles. Here is a great place to search: http://adsabs.harvard.edu/abstract_service.html. A *Progress Report will be due* on **Monday, April 20**. This is an expansion of the outline and should include your work to date, as well as any problems you are encountering with your project. ***Your final project report should include***: a cover page with a title and abstract, introduction describing the question you have posed and would like to investigate, available data and literature, brief description of any relevant analysis methods or proposed observations, tabular/graphical results, images, conclusions, suggestions for future work, and reference list. The total length of the report (including figures) should not exceed ten pages using 11pt font, double spaced. Electronic copy of your term project **must be e-mailed to me** by **5:00 pm Wednesday, April 29.** If you do not understand what you should do for the final

project or you are having other difficulties with your term project, you must let me know in advance and come to see me during the office hours. Late reports will not be accepted unless there is a valid (i.e. medical) reason.

CLASS ATTENDANCE AND PARTICIPATION: The class attendance and participation is important. To do well, you should (1) come to class and pay attention, (2) answer questions when they are posed by the instructor, (3) ask questions in class when you don't understand the lecture, (4) perform simple tasks when requested by the instructor, (5) be courteous and friendly to your fellow students and the instructor, and (6) follow the general points on classroom conduct given below. You must also make sure that everything taught is clear to you. Please feel free to ask questions regarding the previous class material at the beginning of the next class.

GENERAL CLASSROOM CONDUCT: Please turn off cell phones and Ipads before the start of each class. No food consumption during the lecture unless required for medical reasons (must notify instructor ahead of the lecture). Please respect your classmates and do not talk during the class unless asked by the instructor.

OFFICE HOURS AND QUESTIONS: You are strongly encouraged to come to my office during the office hours for help with the course material. If you cannot make the appointed times, please e-mail to make an appointment. If you are unhappy about something in the course please let me know, I will discuss it with you and try to fix it.

University Policies

University policy on observance of religious holidays:

In accordance with University policy, students should notify faculty during the first week of the semester of their intention to be absent from class on their day(s) of religious observance. For details and policy, see: provost.gwu.edu/policies-procedures-and-guidelines

Academic integrity code:

Academic dishonesty is defined as cheating of any kind, including misrepresenting one's own work, taking credit for the work of others without crediting them and without appropriate authorization, and the fabrication of information. For details and complete code, see: studentconduct.gwu.edu/code-academic-integrity

Support for students outside the classroom:

Disability Support Services (DSS) 202-994-8250
Any student who may need an accommodation based on the potential impact of a disability should contact Disability Support Services in Rome Hall, 801 22nd Street, NW, Suite 102, to establish eligibility and to coordinate reasonable accommodations. For additional information see: disabilitysupport.gwu.edu

Counseling and Psychological Services 202-994-5300
GW's Colonial Health Center offers counseling and psychological services, supporting mental health and personal development by collaborating directly with students to overcome challenges and difficulties that may interfere with academic, emotional, and personal success. For additional information see healthcenter.gwu.edu/counseling-and-psychological-services

Safety and security:

• **In an emergency**: call GWPD 202-994-6111 or 911

• **For situation-specific actions:** review the Emergency Response Handbook: safety.gwu.edu/emergency-response-handbook

• **In an active violence situation:** Get Out, Hide Out or Take Out: go.gwu.edu/shooterprep

• **Stay informed**: safety.gwu.edu/stay-informed

Miscellaneous

***Blackboard* system:** The *Blackboard* courseware system will be used for the ASTR 3161 class. The address for the *Blackboard* web site is: **http://blackboard.gwu.edu**

After entering *Blackboard*, it is necessary for you to click on the ASTR 3161 course. You are *automatically* subscribed within the *Blackboard* system to the courses for which you are registered (but you also must have a GW e-mail address!). The web access provided by *Blackboard* is a valuable resource for all aspects of the class. It includes course announcements, lecture notes, homework solutions, discussion forums, and other useful features. You should consult it frequently!

ABOUT YOUR INSTRUCTOR: Dr. Oleg Kargaltsev is an Associate Professor in the Department of Physics. He works extensively with Chandra X-ray Observatory (NASA) the X-ray Multi-Mirror Mission-Newton (ESA), Suzaku X-ray Observatory (JAXA) and Hubble Space Telescope (NASA) to study the physics, evolution, and properties of neutron stars and black holes. He is an author of >200 research papers and Principle Investigator of many observing programs on the various space observatories. Kargaltsev's other interests include science philosophy and policy, logical (especially recursive) puzzles, and science fiction.