ASTR-5120: RADIATIVE & DYNAMICAL PROCESSES

CU Boulder Syllabus (Fall 2021)

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Course Times: Mon., Wed., Fri., 4:10–5:00 pm, Duane Physics room E126

Course Web Page: https://stevencranmer.bitbucket.io/ASTR_5120_2021/

Office Hours: Tuesdays, 10:30–11:30 am (in-person & virtual; see Canvas)

SUMMARY

This course is an introduction to radiative and dynamical processes (RDP) aimed at graduate students in astrophysics, space physics, and planetary science. RDP is intended to cover a handful of topics that are central to much of astrophysical and planetary sciences, but are rarely encountered at the undergraduate level. We will cover particle collisions and transport phenomena, magnetohydrodynamics, gravitational dynamics (applied to planetary orbits, stellar binaries, and N-body systems like galaxies), and a macroscopic treatment of radiation fields. This is a core required course for APS graduate students.

COURSE MATERIAL

The primary "required readings" are the lecture notes, which ought to contain everything discussed in class. They will be posted on the course web page as the semester progresses. No one textbook covers all aspects of this class, but here are three rather good ones:

- *Plasma Physics for Astrophysics,* by Russell M. Kulsrud (Princeton Univ. Press, 2005)
- *Galactic Dynamics,* by James Binney & Scott Tremaine (2nd ed., Princeton Univ. Press, 2008)
- *Radiative Processes in Astrophysics,* by George Rybicki & Alan Lightman (Wiley, 1979)

There will also be links to lots of online material (e.g., textbook-length lecture notes from other courses, plus my own Fall 2020 RDP video lectures on YouTube) on this course's web page. Please see me if you have any difficulty in obtaining copies of the recommended materials.

GRADING

The final course grade will be assembled from the following components:

Homework Problem Sets 1–5	50%
Homework 6: choose from three options	10%
Final Exam (take-home)	17%
Participation in Weekly Discussions	12%
Contribution to the "RDQ" Group Term Project	11%

Each graded aspect of this course will be described in more detail below. Graduate students in the APS Department need to earn a grade of B– or higher in this course to meet the *Preliminary Core-Course* requirement (i.e., before moving on to take the Comprehensive Exam for Ph.D. candidacy). If a grade lower than B– is received, there are a variety of other options, including taking the course again or arranging an independent study. Please contact the APS Office for more details. For undergraduates or students in other departments, this does not apply to you, although your department/program may have its own rules about minimum grades.

SCHEDULE OF TOPICS

The dates listed here for each set of topics are approximate. The web page will be kept up-to-date on the topics to be covered in each class session. Also, we will investigate how often we *may* be able to meet at times other than the dreaded 4:10–5:00 pm slot...

Introduction & Overview	Aug 23
I. Plasmas and Collisional Effects	
Random walks & relation to particle diffusion	Aug 25
Binary collisions; mean free paths; collision statistics	Aug 27, 30; Sep 1
Kinetic theory; Liouville's theorem; Boltzmann equation	Sep 3, 8
Fluid moments in a plasma; kinetic origins of thermodynamics	Sep 10, 15
Ideal & resistive MHD; magnetic pressure & tension	Sep 17, 20
Force-free fields and MHD waves	Sep 22, 24
Survey of plasma physics "beyond MHD"	Sep 29; Oct 1
II. Gravitational Dynamics	
Conservative forces: work, energy, Euler-Lagrange formalism	Oct 4, 6
Two-body Keplerian motion & applications	Oct 8, 13, 15
Restricted three-body problem; resonances; tides	Oct 18, 20
N-body Boltzmann stellar dynamics; dynamical friction	Oct 22, 27
N-body gravitational potentials; virial theorem	Oct 29; Nov 1
III. Radiative Processes	
Defining the radiation field; equation of radiation transfer	Nov 3, 5
Review of opacity sources; emission & absorption	Nov 10, 12
RT solutions in useful limits; LTE & the gray atmosphere	Nov 15, 17
Beyond the gray atmosphere: non-LTE & spectral lines	Nov 19; Dec 1, 3
Ionization & recombination; irradiated bodies; radiation pressure	Dec 6, 8

CLASS PARTICIPATION

Once a week (likely on Mondays) we will devote half a class to a recitation/discussion session that will be led mostly by the students. To prepare, there will be a Canvas discussion board where you will respond to specific prompts. In those responses, you can ask questions about the lectures or homework, point out steps you didn't understand, correct any errors of mine, or recommend cool new RDP-relevant papers you've seen on arXiv. Answering another student's question counts as a valid response, too. Over the semester, there will be 13 of these sessions, each with 3 to 4 prompts (so somewhere between 40 and 50 total prompts). To receive the full credit for this "participation" component of the course grade, each student will need to submit at least 30 responses.

HOMEWORK PROBLEM SETS

There will be five primary problem-set based homeworks, each worth 10% of the course grade. A detailed schedule of distribution and due dates will be posted on the web page. Either hardcopy or online (Canvas) submission is fine, though if you choose the latter, please compile your submission into a single PDF. Problems will be due on the dates listed, but one late submission can be arranged if necessary (for a maximum delay of 1 week), as long as the arrangement is made at least 1 class prior to the due date. Other late problem sets will incur a penalty of a 5% lower grade per weekday that it is late. Submissions are no longer possible after answer keys are distributed (usually about 1 week after the due date).

HOMEWORK 6

The sixth homework (which may end up being assigned as the 4th or 5th in the sequence, rather than last) will allow you to choose one of three options:

- You can create and write up two new homework problems (with answer keys) of similar size and scope as the existing homework problems for this course.
- You can choose a relevant paper (from a journal or arXiv) and review it with two written components: (a) a brief pedagogical summary, as if you were preparing lecture notes to teach it to a new class of RDP students, and (b) a mock referee's report, which includes criticism for the authors that is as specific and constructive as possible.
- You can choose a relevant paper (from a journal or arXiv) and reproduce some of its key results. This is likely to involve some combination of writing code, re-deriving equations, downloading data, and making figures. Your write-up will contain your versions of the results as well as insights about how straightforwardly "reproducible" the original paper was.

More information about these options will be provided soon, and we will provide lists of example papers for the 2nd an 3rd options above. Also, ideas for interesting journal/arXiv papers may come from the weekly recitation/discussion sessions.

FINAL EXAM

The format will be a take-home exam with problems having a similar scope as the homework problem sets; the primary difference being the **no-collaboration** aspect of an exam. The final exam will comprehensively cover material from the entire course. Completed exams will be due 48 hours after they are given to you, and exact dates will be given on the course web page.

GROUP TERM PROJECT: "RDQ"

The APS Department aims for these courses to be relevant to your research, and we always want to keep optimizing in that direction. Thus, we're trying something new. Over the semester, the class will work to assemble a document that lists and describes a number of major unanswered *Radiative & Dynamical Questions* (RDQ). The goal is to assemble a sourcebook containing dozens (hundreds?) of potential ideas, projects, and future research directions that can be used for inspiration over the remainder of your time as students—and beyond? More details will be provided, but for now I can give some initial thoughts:

- The goal is to keep the topics relevant to the scope of this course. However, because RDP covers many different fields, we will have to make some judgement calls about what to include and/or exclude.
- For the end-product, let's aim high and envision something comparable to the National Academies Decadal Survey reports or the Science Plans put out by NASA's Science Mission Directorate. (Okay, maybe not as *long* as those doorstop-sized documents.) It's possible that a better format may end up being a Wiki or some other online, hyperlinked thing that's easier to navigate and keep up-to-date.
- There are some well-known lists like this already, but our goal will be to delve deeper. We'll aim to include relevant equations, details about how present-day observations, theory, and simulations prevent us from solving these problems, and (most importantly) suggestions about paths forward.
- I'm also envisioning that, every other week, we will devote half a class to RDQ discussions. There will be a sign-up sheet for students to rotate through various tasks (i.e., researching the week's topics, leading each discussion, taking notes, and writing up the results). The final product will be due on Monday, December 6, 2021.

ACADEMIC INTEGRITY

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the Honor Code. Violations of the policy may include: plagiarism, cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course without permission from all course instructors involved, and aiding academic dishonesty. All incidents of academic misconduct will be reported to the Honor Code (honor@colorado.edu; 303–492–5550). Students found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code as well as academic sanctions from the faculty member. Additional information regarding the Honor Code academic integrity policy can be found at the Honor Code website.

For this course, I encourage you to discuss the assignments and topics with your fellow students. However, everything that is written up and submitted must be your own independent work. If you do collaborate with other students, a good time to split off from the group is when you start to write up your answers. If someone were to ask you questions about your work, you should be able to explain everything about how & why you did it the way you did.

ACCOMMODATION FOR DISABILITIES

If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to your faculty member in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment, but please contact me to discuss how I can help even for conditions not on their list. Information on requesting accommodations is located on the Disability Services website. Contact Disability Services at 303–492–8671 or by email at dsinfo@colorado.edu for further assistance. If you have a temporary medical condition or injury, see the guidelines for Temporary Medical Conditions on the Disability Services website.

I try to provide a positive and supportive learning environment for everyone, and it's always helpful for me to hear what works best for you.

RELIGIOUS OBSERVANCES

Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all students who, because of religious obligations, have conflicts with scheduled exams, assignments, or required attendance. For full details, see the campus policy regarding religious observances.

DISCRIMINATION AND HARASSMENT

The University of Colorado Boulder (CU Boulder) is committed to fostering a positive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, or protected-class discrimination or harassment by members of our community. Individuals who believe they have been subject to misconduct or retaliatory actions for reporting a concern should contact the Office of Institutional Equity and Compliance (OIEC) at 303–492–2127 or by email at cureport@colorado.edu. Information about the OIEC, university policies, reporting options, and the campus resources can be found on the OIEC website. Please know that faculty and instructors have a responsibility to inform OIEC when made aware of incidents of sexual misconduct, dating and domestic violence, stalking, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about their rights, support resources, and reporting options.

PREFERRED STUDENT NAMES AND PRONOUNS

CU Boulder recognizes that students' legal information doesn't always align with how they identify. Students may update their preferred names and pronouns via the student portal; those preferred names and pronouns are listed on instructors' class rosters. In the absence of such updates, the name that appears on the class roster is the student's legal name.

CLASSROOM BEHAVIOR

Both students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote, or online. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political philosophy. For more information, see the policies on classroom behavior and the Student Conduct & Conflict Resolution policies.

The policy of the Department of Astrophysical and Planetary Sciences is to ban any use of electronic devices (cellphones, tablets, laptops) in class except as an approved accommodation granted by Disability Services, or as explicitly authorized by the instructor. *In this course* I authorize the use of tablets and laptops for note-taking, but students doing so must do their best to seat themselves with nobody behind them.

REQUIREMENTS FOR COVID–19

As a matter of public health and safety due to the pandemic, all members of the CU Boulder community and all visitors to campus must follow university, department, and building requirements and all public health orders in place to reduce the risk of spreading infectious disease. Students who fail to adhere to these requirements will be asked to leave class, and students who do not leave class when asked or who refuse to comply with these requirements will be referred to Student Conduct and Conflict Resolution. For more information, see the policy on classroom behavior and the Student Code of Conduct. If you require accommodation because a disability prevents you from fulfilling these safety measures, please follow the steps in the "Accommodation for Disabilities" statement on this syllabus.

As of August 13, 2021, CU Boulder has returned to requiring masks in classrooms and laboratories regardless of vaccination status. This requirement is a temporary precaution during the delta surge to supplement CU Boulder's COVID-19 vaccine requirement. Exemptions include individuals who cannot medically tolerate a face covering, as well as those who are hearing-impaired or otherwise disabled or who are communicating with someone who is hearing-impaired or otherwise disabled and where the ability to see the mouth is essential to communication. If you qualify for a mask-related accommodation, please follow the steps in the "Accommodation for Disabilities" statement on this syllabus. In addition, vaccinated instructional faculty who are engaged in an indoor instructional activity and are separated by at least 6 feet from the nearest person are exempt from wearing masks if they so choose.

Students who have tested positive for COVID-19, have symptoms of COVID-19, or have had close contact with someone who has tested positive for or had symptoms of COVID-19 must stay home.