AST 392D: Math Methods (= Order of Magnitude Astrophysics)

Spring 2022

WF 1:30-2:45 ~~Zoom PMA 15.216~~ Zoom

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Office Hours: By appointment (we'll play it by ear)

Course Logistics

Philosophy: Official catalog name aside, the de facto course title is "Order of Magnitude Astrophysics". The goal of this course is to build our skill and experience in quickly taking some knowledge of an astrophysical object/system, and using it to infer other features or behavior of that system. Astronomers call these "Order of Magnitude" calculations because that's often going to be our target precision - estimating something to the nearest factor of 10(ish). You might be surprised by how often this is good enough. The universe is an exponential place, and if you ask a question, the answer is often either 10^{10} or 10^{-10}. When distinguishing between those possibilities, you can get away with a whole lot of simplifying approximations. (The physicists will often use the term "Fermi Problems", since Fermi was reputed to be very fast and adept at these sorts of calculations. We'll get into a probably-apocryphal Fermi story along these lines later in the semester, and maybe take a stab at it ourselves.)

This is an important, but often under-appreciated skill. The most apparent benefit is that it allows you to think in real-time about a broad range of astrophysical topics, which can be useful for critical appreciation of others' talks, answering questions about your own research, and generally participating in discussions with your colleagues about whatever might come up. However, it also will allow you to generate ideas and (approximately) evaluate them much more quickly. I think it's a truism of science, and certainly for my own experience, that one generates a lot of ideas that miss the mark (whether infeasible, based in incomplete understanding of the background astrophysics, or just not able to answer the question) for every idea that's genuinely worth pursuing. If you can winnow the non-starters more quickly, or save yourself from pursuing one of them for days/weeks(/months(/years!)), this makes it easier to identify those genuinely good ideas. For context, I feel like I have one "good idea" for a new project every year or two. To borrow some terminology that we'll be developing this semester, apparently I fall in a regime where this timescale really matters!

The way I think of this is that we'll be studying three types of interlocking topics:

1. Astronomical objects and systems. We're all here because we find the Universe interesting, so my goal is to make sure that we're constantly learning new things about what's out there. I'm more of a local-scale person (stars and planets), but I'll try to make sure we include plenty of galactic and extragalactic astronomy as well.

2. Astrophysics. You can cover a whole lot of ground, or at least reasonably approximate it, using a surprisingly modest portfolio of physical principles that map to the aforementioned wide range of actual astronomical objects/systems.
3. Methodological (or perhaps ”meta”) techniques. This establishes the foundation of the entire course, giving you a toolkit for quickly and quantitatively(ish) understanding the astrophysical effects that operate among astronomical objects and systems. These tools include estimation, scaling relations, dimensional analysis, linearization, approximate statistics, etc.

Format: My expectation is that I'll spend part of our class time introducing concepts under the various umbrellas that I listed before (methodological concepts, physics concepts, astronomical objects). However, a majority of the class time will be spent working to solve (hopefully entertaining) order-of-magnitude questions in small groups. I assume we'll start with four groups of 4 each, and then I'll probably mix things up every few weeks.

Coursework: This will come in a few parts:

A) A key aspect of this process will be to work out math collaboratively within your group, and then share it out with the rest of the class. It is my expectation that for most of the semester, we'll be able to use blackboards/whiteboards in the Astro classroom, and I've also reserved the Edmonds conference room so we can space out. We might need to improvise for the first couple of weeks, though. **One of your first tasks will be to instead figure out your preferred method for being able to do math at whatever location you're currently social-distancing from, and then share it via Zoom.** Having participated in several qualifying exam and thesis defense committees via Zoom now, I've seen various solutions to this, including pointing your webcam at a whiteboard, using a stylus with a tablet, aiming your phone downward toward a sheet of paper, or various online whiteboard apps.

I don't have a preference which of these you choose, or if you find something else, as long as it works for you and allows you to share your work with the rest of the class. But please have one of the strategies ready to go ASAP. And keep in mind that a large fraction of the class grade will be ”participation”, which basically means contributing to solving these problems. So to claim credit, I'll want you to screencap or otherwise take pictures of your group's work and post them on Canvas after each class.

B) This class also offers a great opportunity to practice asking such questions, in addition to answering them. As such, we're also going to have another component that runs parallel to actual class time, and constitutes most of your “homework”. Starting in week 3, then for every class meeting, one of you is going to record a $\sim$20 minute talk about your research and post the link on Canvas. Think of this as a seminar-level talk, and feel free to borrow content from other past talks about your work. Every other member of the class will then be tasked with posting a question for you on Canvas, ideally one that allows for an order-of-magnitude answer. The speaker will then spend some time in class the following week answering one of these questions. Note that nothing here is running realtime, which is intended to give you time to be deliberate (and not have that unpleasant sensation of being on stage). People can record their talks (and even do retakes) at whatever pace they want, then others can mull over questions as long as they need, and the speaker can choose a question and formulate their answer ahead of time and then just demonstrate it for the class. The point here isn't to test you (and hence the grading will be very lax). The point is to give you an opportunity for deliberate practice, thinking about process as you go, and learning as others also do this. By learning to formulate quantitative questions for others (and seeing how others do it), you'll build experience in asking yourself those questions and being able to hold such conversations in the future. And as part of this, I'd also like for each speaker to watch their talk themselves, identify at least one thing they did well and one thing they'd like to improve, and think about how to go about addressing the latter. Let's fully commit to the meta-cognition in this class!

C) Also along these lines, for each class after the first couple of weeks, one of you will be assigned to go back into the literature in your area of expertise and find an example of a paper that used an order-of-magnitude calculation. Each class, one of you will then spend a few minutes in class describing the motivation for the authors' use of the "quick" calculation and how that answer contrasts with the "real" answer. The expectation isn't that you'll replicate it or even go into the fine details of the calculation, but rather to describe it at a high level and judge their effectiveness. I suspect your best source for this will be to look at old theory papers - in the 20th century, people made entire careers out of writing OoM papers! And it's definitely still doable today, even if a lot of the low-hanging fruit has been explored.

D) Finally, one more piece - near the end of the semester, I'd like you to develop an exercise-level Order of Magnitude question in your area. Emulating what I do, you'll spend about 5-10 minutes contextualizing the background, then pose the question. I don't think we'll have time for people to go through the solutions live, but you'll then post the solution on Canvas.

Text: There is no single textbook, per se - we'll be assembling written supplemental materials from a variety of sources. However, we'll start by basing our first few weeks on an excellent Order of Magnitude Physics textbook available online (written as somebody's PhD thesis!):

`http://www.inference.org.uk/sanjoy/thesis/thesis-letter.pdf`

Chapters 2 and 3 outline the core philosophy of courses like this, and then we'll draw specific topics from Chapters 4–6 as they fit into the overall plan.

I'll keep you updated on other sources as we add them, in part driven by the demand from the class on what topics we cover. For the astrophysics topics, I suspect most of the material will ultimately be found in the highly recommended "Modern Astrophysics" textbook by Caroll & Ostlie. (AKA, the "Big Orange Book"). The entire conceit of this course is to be practicing calculations that can be finished fairly quickly on a blackboard, so we're more likely to be going broad than deep.

Web page: See Canvas for announcements, documents, readings, and assignments. We'll be making fairly heavy use of its discussion forum as a complement to our in-class exercises and for carrying out assigned exercises.

Grading

Course grades will use the plus/minus system, along with the standard cutoffs. There will be no rounding. The course grade will be driven largely by participation with a couple of other modest sources:

- A pre-recorded "research talk", plus an in-class demonstration of answering somebody's Order-of-Magnitude question based on that: 10%. There's an oft-repeated saying in academia that if you want to ask a few good questions, start by asking a lot of questions. So the idea here is to give you an opportunity to practice asking questions about others' research, as well as answering questions about your own research, in a low-stakes environment. Starting in week 3, we'll rotate through the class and each day, one person (starting with me!) will post a $\sim$15 minute pre-recorded summary of the research they're doing right now, or at least one piece of it. Each other person in the class will then have three days to post an Order-of-Magnitude question about the research talk to Canvas (in a discussion forum thread), and then the speaker will choose one of those questions (in consultation with me) and come back the next week (7 days later) to walk us through the Order-of-Magnitude solution during class time.

- A brief in-class description of an order-of-magnitude calculation from some relatively old source in the literature: 10%. We'll start on these a little later, exact date TBD.

- : A contextualized order-of-magnitude exercise that you've created and presented to your colleagues, plus the solution to it: 15%. These will be scheduled near the end of the semester.

- Participation: 70%. This is earned in equal amounts each day, and you can assume you've earned it unless I tell you otherwise. You earn this by attending class, participating in the group problem-solving exercises, and posting your relevant questions for your colleagues' research summaries. Among other things, to claim this I will expect pictures or screen caps of your work to be uploaded onto Canvas.

This may not add up to 100%, but the order of magnitude seems close enough...

I know that even without travel being allowed this semester, events can stop people from being able to attend class - observing runs, conferences, grad school visits, etc. Please check in with me ahead of time, and if it's for a justifiable reason, then it won't affect the participation grade.

Approximate Course Schedule

TBD. I have a more firm schedule for the front half of the class, but it gets fuzzier after that because I want to be able to respond to the interests of the class. My ideas are:

- Week 1: Estimation 101. (Number counts, sizes, time/size/velocity scales, etc.)

- Week 2: Scaling Relations (starting with OoM Applications of Kepler's Laws)

- Week 3: Dimensional Analysis

- Week 4: Cross-sections

- Week 5: Interaction Rates
- Week 6: Accretion Rates & Accretion Luminosities
- Week 7: Energy Content, Densities, & Timescales
- Week 8: Linearized Differential Equations, Pressure & Density Scale Heights
- Week 9: Equilibrium Temperatures, Radiation Pressure, & Quantum Heating
- Week 10: Thomson Scattering & Eddington Luminosities
- Week 11: Compton Scattering, Relativistic Interactions, Time Dilation
- Week 12: Statistics (Poisson, Binomial, & Otherwise)
- Week 13: Observational Planning
- Materials physics (chemical bonding, densities, etc)
- Degenerate matter physics
- Wave Physics
- Virial theorem & applications
- Other topics requested by the class

The instructor reserves the right to change the course content as needed to match the pace of the class or to tell the class about breaking astronomical news.

Class Policies

- Canvas will be updated with announcements, reading assignments, and deadlines. It is your responsibility to check these on a regular basis. Please come to class prepared, having read the required reading assignments, since understanding the lectures and being able to take good notes will be crucial for doing well on homework and exams.
- Don't pack up or leave class early (or consistently come in late) unless you have talked to me in advance, as a consideration to me and your fellow students. There are only $\sim$15 of you. I notice these things.
- Phones/tablets/laptops: We're all using some kind of computer for the early weeks, of course. I normally say that phone use during class is not allowed, and I'll emphasize that texting and social media are off limits. This is 2022, though, and we'll be talking about things where none of us necessarily knows the answer. Googling relevant topics is allowed. If you find something interesting on the Internet, by all means, share.

Academic Dishonesty

University of Texas Honor Code: The core values of The University of Texas at Austin are learning, discovery ,freedom, leadership, individual opportunity, and responsibility. Each member of the university is expected to uphold these values through integrity, honesty, trust, fairness, and respect toward peers and community. Students who violate University rules on scholastic dishonesty are subject to disciplinary penalities, including the possiblity of failure in the course and/or dismissal from the University. Standards for Academic Integrity are posted at http://deanofstudents.utexas.edu/sjs/acint_student.php.

In other words, you should turn in work that is your own. Everybody should make a good-faith effort to contribute equally to group work.

Documented Disabilities

Please notify me of any modification/adaptation you may require to accommodate a disability-related need. The University of Texas at Austin provides upon request appropriate academic accommodations for qualified students with disabilities. For more information, contact Servies for Students with Disabilities at 471-6259 (voice) or 232-2937 (video phone) or http://www.utexas.edu/diversity/ddce/s

Email

Email is recognized as an official mode of university correspondence, so you are responsible for reading your email for university and course-related information and announcements. Please check your email regularly and frequently.