Topics at the Frontier of astrophysics

AST 353: unique course id – 48310; carries Quantitative Reasoning Flag

Professor Pawan Kumar

T-Th 12:30 P.M. – 2:00 P.M.

Online (Welch 2.310)

- **INSTRUCTOR:** Pawan Kumar – Professor of astrophysics, specializing in exploding stars
  Email: pk@astro.as.utexas.edu **Web:** surya.as.utexas.edu
  Office hour: Tuesday 2-3 pm PMA 17.204
- **TA**: Bryce Hobbs, graduate student, Astronomy; Email: brycehobbs@utexas.edu
  Office hours: Wednesdays 1:00 pm to 2:00 pm (PMA 15.216B)
- **Grader**: Arnav Shah (undergrad student majoring in astro/phy)

Books (none of these are required)

1. Astrophysics in a Nutshell, Dan Maoz (suggested)
2. Cosmology: The science of the universe, Edward Harrison (suggested)
3. An Introduction to Modern Cosmology, Andrew Liddle (suggested)

Course Description

The goal of this course is to learn about exciting discoveries in astronomy and topics at the forefront of current research. The list of topics we plan to explore together are –

- Cosmology: the big bang origin of the universe, expansion and the future of the universe, dark matter and dark energy, the theory of cosmic inflation and what happened before the big bang, formation of stars and galaxies etc. [12 lectures]
- Einstein's theory of gravity or general relativity, black holes and gravitational waves [8 lectures]
- Powerful explosions and transients: gamma-ray bursts (the death and explosions of massive stars), stars falling into black holes (TDE) and the last signals we have detected from these catastrophic events, fast radio bursts from exotic objects [5 lectures]
- Exoplanets: finding planets outside the solar system, their properties and the search for life around other stars [2 lectures]

Grading

There will be one Final Exam in this course. The grade will be based on homeworks (20%), pop quizzes and class participation (25%), **two term papers** (40%), final exam (15%)

The term paper should explore a current topic in astrophysics in depth. The length of the term paper is expected to be between 7 and 10 typed pages, single spacing. **The due date for the first term paper (initial draft) is October 12, and the final draft of the first term paper will be due on October 31. The head-TA will provide comments on the first draft and a tentative grade. The 2nd and the final draft of term paper 1 will be assigned the final grade. The due date for the second term paper (the 1st and the final drat) is December 1.**

- **HW submissions and late submission policy:**

  Please upload your HW solutions (pdf files) to canvas under the appropriate Assignments. The official solutions will be posted on Canvas one week after the due date. The percentage of HW grade lost when a submission is late by ”Nd” days is 15*Nd.

- **Review process for term papers:**

  For the first term paper, the head-TA will provide feedbacks and tentative grades (via Canvas) within a week after the due date of the term paper. Late submissions (of the first draft) are not considered for review. You can improve your term-paper grade by submitting a revised version to the head-TA before the deadline for the final draft. Please make sure that you describe all the changes you have made to the term paper to address the comments/feedbacks provided by the head-TA; these changes should be described in a typed letter addressed to the head-TA, and attached to the front of the revised term paper. BTW this is a standard practice all scientists follow when they submit their manuscripts to a journal for peer review and publication of their discovery. Beacuse of the end of the semester time crunch no feedback for term paper number 2 will be provided.

Plus/minus grading will be used for the final grade: 59.0 – 63.6 D-, 63.7 – 66.6 D, 66.7 – 69.6 D+, 69.7 –72.6 C-, 72.7 –76.6 C, 76.7 – 79.6 C+, 79.7 – 82.6 B-, 82.7 – 85.6 B, 85.7 – 88.6 B+, 88.7 – 92.0 A-, >92.0 A; **this is only an approximate guideline – the final grade will be based on the class performance curve at the end of the semester when all the numerical grades are available.**

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Guidelines for writing term papers

- To keep the reader's attention, a paper should tell a coherent story with a clearly defined question, an opening (introduction), actions (main body), and resolution (conclusion).
  - To create good storytelling, one needs to highlight the significance of the topic (Why do we care? What can we learn?) and introduce some current challenges (unsolved problems) in the field. This is usually done in the abstract or/and introduction.
  - Related to the above point, although we do not require you to show novel research results in your paper, you are encouraged to explore and discuss the frontier of your chosen topic. A paper is different from a textbook in that it focuses on the unknown and the relation between the unknown and the known, while textbooks usually focus on the known.
  - It is a good practice to make the connections between different sections/paragraphs explicit to guide the reader through your reasoning. (Words like "however/nevertheless", "besides/furthermore/moreover", "on the other hand", "in the light of this", "as a result/therefore/thus", "for instance", and etc., can be used with good effect in scientific papers.)
  - Related to the above point, figures and tables should be numbered and mentioned in the main text, such that the reader can tell what points are made by these data.
- To be reader-friendly, it is a good practice to organize information into a clear hierarchical structure consisting of sections and subsections. You should avoid super long paragraphs that can be hard to follow and keep the reader interested in what you have to say. At the beginning of a (sub)section, you may briefly summarize what is to be covered before going into individual lower-level (sub)sections.
- You should always strive to be self-consistent. For instance, each symbol/term/abbreviation with specific meanings must be defined at the first place it occurs in the paper. The mapping between symbols and physical quantities should always be one to one.
- To avoid plagiarism, we require inline citations. That is to say, you should mention the source (including figures) right at the place it is cited in your paper, and also list all references at the end of the paper.
- General tips for paper preparation:
  - To quickly acquire a basic understanding of a field, one usually starts by reading one or a few review articles. Such papers serve as roadmaps for you to see the big picture and meanwhile identify the focus of your paper for further investigation. You can type "xxx review" in google scholar (Links to an external site.) to obtain them.
  - It is a good practice to first come up with the basic structure of your paper (in terms of an outline). Once the structure is set, with the connections between different parts established in your mind, collecting information, and filling in the materials should be easy.

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Topics for term papers

You will be writing two term papers which will carry 20% each of the total grade.

The expectation is that the length of the term paper should be 7 to 10 pages (single space), and should be written in a way so that any student in the class who has not researched the topic herself/himself can obtain an in-depth understanding of the subject. The report should consist of some background historical information about the topic, self-contained technical discussion of the relevant physics, and the current state of the art of developments in that specialized sub-field of astronomy.

You can choose from the topics listed below for your term papers. The topics on this list are described in general terms, on purpose, so as to give you flexibility to explore specific things that interest you on that topic. In case you find yourself really interested in a topic that is completely different from anything on this list, then you should ask for my approval before deciding to write a term paper on that topic for this class.

1. How measurements of the Hubble constant have changed in the last 100 years: a historical perspective and improvements in distance measurement techniques.

2. Five different methods astronomers have used for the measurement of the Hubble constant, and the current tension between H_0 measured using cosmic microwave background anisotropy and methods that rely on Cepheid variables and supernovae IA.

3. Nucleosynthesis of light elements in the early universe (within the first several minutes).

4. Detection of dark matter in galaxies and clusters of galaxies: different observational techniques used, and the major results discovered.

5. Detection of dark energy in the universe and current experiments to determine whether the dark energy density is evolving with time or not.

6. Cosmic microwave background (CMB) measurements and properties of the CMB. A discussion of what has the CMB anisotropy taught us about cosmological parameters.

7. The dynamics of the universe, the growth of density fluctuations with time and formation of galaxies and large-scale structures in the universe.

8. Formation of the first stars, and their expected properties.
9. Cosmic inflation theory: why we need it? What are its predictions, and what observational evidences do we have that the universe underwent this exponential phase of expansion?
10. The physics of baryon acoustic oscillations and how it is being used to determine the evolution of the dark energy.
11. Reionization: What are the major observational techniques for probing the epoch of reionization? What are the sources of UV photons responsbile for reionizing the universe between the redshifts of 6 and $\sim$10?
12. High redshift universe ($z > 3$): how do astronomers determine star formation rate and galaxy properties at high redshifts? What do we know about how galaxies, quasars and star formation rates have evolved as the universes has aged?
13. Einstein's theory of gravity and a discussion of at least five different predictions it made that have been experimentally verified.
14. Current efforts to detect dark matter in underground laboratories and the constraints these experiments have provided on the nature of dark matter particles.
15. Detection of stellar-mass black holes in the Galaxy, and a discussion of the origin of these black holes.
16. Detection and properties of supermassive black holes at the centers of galaxies, and our current understanding of their origin.
17. Particle and photon orbits in Schwarzschild geometry, i.e. in the presence of a black hole. How is the motion modified if the black hole is rotating?
18. Stellar evolution, and formation of white dwarf stars, neutron stars, and stellar-mass black holes.
19. Classification of supernovae and the origin of Superluminous supernovae.
20. Taking the photograph of a black hole: how was it done (some technical discussion) and what has it taught us about the validity of Einstein's theory and black holes?
21. Gravitational waves: detection technique and what have we learned from these detections? The report should include at least a brief discussion of the recent, very interesting, event GW 190521 (and why is this event interesting?).
22. Graviational waves and electromatic radiation from merging binary neutron stars detected in 2017, and what did we learn from that spectacular event?

23. Observational evidences for stars falling into super-massive black holes (also called tidal disruption events or TDEs), and the rich variety of physical processes involved in these encounters.

24. The mystery of gamma-ray bursts (GRBs): the multiwavelength follow up observations of these events, and our current understanding of what causes GRBs.

25. The enigmatic fast radio bursts (FRBs): their surprising discovery, observational properties, and physical models.

26. Exoplanets: a discussion of the major techniques used by astronomers to observe planets outside the solar system, and properties of the thousands of exoplanets discovered thus far. The report should also describe the work done in the last few years on imaging of exoplanets by people in the astronomy department at UT.

27. Exoplanets: our current understanding of the process by which exoplanets form, and how well they do to explain their observed properties.

28. Exoplanets: observations of habitable planets, and search for life outside the solar system.

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Extra credits

- **Seminars:**

  You can earn extra credit by attending astronomy colloquia and seminars at UT. Each time you attend a talk, please send the head-TA a summary of the talk and the main points you learned from it (1-2 page) within one week after the talk. The maximum credit you can earn for attending an astronomy seminar is equivalent to the total of all quizzes in one AST-353 lecture. The information regarding Astronomy Department seminars are posted on this Page https://astronomy.utexas.edu/colloquium-and-research-seminars

- *Extra credit for Astronomy Outreach:*

  If you give a lecture or presentation on any topic in astrophysics connected to or covered in this course to an audience such as elementary or secondary school students, community college students, or the general public, you may send the slides and, if possible, an audio recording of your talk to Professor Kumar. He will review it and award you extra credit for popularizing astronomy to people outside UT. Please make sure to include in your submission the date and place of your talk, a brief description of the audience, and the number of people who attended your lecture. The expectation is that your audience size is greater than 3. Depending on the length, depth, and quality of your lecture, you can earn up to 5% credit toward your final grade.

  Note: Presenting your current or past astronomy research work to a university audience, whether at UT or another university, will not qualify for this extra credit. Similarly, any presentations you make in other classes you are currently taking or have taken in the past will not qualify for extra credit in AST 353.

- **Credit for designing HW problems:**

  We encourage you to come up with HW problems. If a problem is adopted by us, the author of the problem can earn extra credit (about 2% of the final grade).

- **Summary of the course**

  If you provide a good summary of the main topics covered in this course (20-25 pages long – single space), you can earn up to 10% credit, i.e. about one-half of one term paper worth of credit for writing the summary.

Please note that submissions for extra credit will only be accepted until the last day of Fall semester classes.