**AST386C, Properties of Galaxies**
**Syllabus**
Fall 2020 — Unique ID #46650
TTh 11:00am-12:15pm
Hosted on Zoom

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**Learning Objectives:**

The primary aim of this course is to establish a strong foundation of knowledge and techniques used to interpret the properties and characteristics of galaxies, including our own Milky Way Galaxy, galaxies in the nearby Universe, and galaxies in the distant Universe. By the end of the course students should be able to:

- build a simple stellar population synthesis model for galaxies' integrated starlight
- diagram stellar orbits in a galaxy's gravitational potential
- identify different characteristics and origins of galaxies' components
- describe the evolution of gas across different temperatures, densities, and scales
- formulate and pose fundamental questions about galaxy formation and evolution

**Practice Goals:**

In addition to the primary learning objectives listed above, this course's philosophy is based on the empirically validated idea that the best learning happens through applied practice. Therefore the primary mode of assessment in this course will not be through memorization of material, but rather through the application of knowledge and understanding to applied detailed research problems. By the end of this course, students should be able to:

- be proficient in discussing the tools of an observational astronomer
- solve problems computationally, and make appropriate approximations as needed
- read and synthesize material from review papers with present-day literature
- share, talk and express informed opinions about galaxies with colleagues

**Pre-requisites and Core Requirements:**

This is a core graduate course, targeted at astronomy graduate students who wish to gain a practical knowledge of the study of galaxy formation and evolution. I will assume that students have a general knowledge of stellar evolution and a rudimentary understanding of cosmology. I will also assume students have a strong grasp on basic computer programming (the language does not matter), calculus, and mathematical modeling.

**Course format:**

The course will be a mix of lecture, Q&A, informal presentation/discussion, and solving problems in class. Your grade will be determined by homework problem sets (40%), in-class presentations/discussions (30%), class attendance (20%), and one 30 minute one-on-one "practice qual" discussion with me near the end of term (10%). The different elements of the course are described below. The final grade in the course will not be curved and will be based on the following scale:

| | | |
|---|---|---|
| 93.00—100% = A | 80.00 — 82.99% = B- | 67.00 — 69.99% = D+ |
| 90.00 — 92.99% = A- | 77.00 — 79.99% = C+ | 63.00 — 66.99% = D |
| 87.00 — 89.99% = B+ | 73.00 — 76.99% = C | 60.00 — 62.99% = D- |
| 83.00 — 86.99% = B | 70.00 — 72.99% = C- | 0 — 59.99% = F |

*1. Homework Problem Sets*

You will be given four homework problem sets throughout the semester which will require somewhat substantial time and effort to complete (these are in lieu of in-class exams). These will require you to use both analytical and computational methods. You are expected to turn in your own original work though you are encouraged to work together and help each other solve each problem. Due dates are on the schedule given at the end of this syllabus. <u>No late work will be accepted</u>, so it is advised you start each problem set as soon as possible.

*2. In-class Presentations and Discussions*

This class will involve quite a bit of active participation and discussion, specifically you will be expected to participate in the following, which are weighted equally toward your class participation grade:

> **A. <u>Review paper round-up:</u>** every class day one of you will be picked at random to present a brief calculation or concept you found most interesting from a review paper that we will be actively discussing that day. Your presentation of the calculation or concept should be informal, and you should draw what you need on a piece of paper to show on the camera via zoom, or on a slide to share via zoom, and only supplement with a plot from the paper only when necessary (cartoon plots are preferred over the original real ones!). You should provide context of the calculation or concept, work done to-date, as well as a description of how this concept can advance science <u>*in the future*</u>, beyond the work of the review paper. Then you should be prepared to field questions about the calculation from the rest of class. These summaries should last 10-15 minutes. If you are called on to present and are not prepared that day, or you are late to class and not there when your name is called, you'll only earn half credit for the day's attendance. <u>*Be respectful of others: do not be late to class.*</u>
>
> **B. <u>Class Discussions:</u>** throughout the course we will have informal discussions in class, and you will have plenty of opportunity to ask questions that lead to more fruitful, prolonged discussions. If questions do not regularly occur to you, you are still expected to think carefully about material and practice posing questions even when you think you know the answer (sometimes it's not what you expect), or when you have no idea what's going on (please, say so!). If one of us is left behind, we are all left behind. Asking well-informed questions takes mindful practice and is an important skill for professional astronomers and so this is emphasized as an important part of your 'presentation' grade.
>
> **C. "<u>Argue-for-your-science" Presentation:</u>** toward the end of the semester, you will present and argue for a scientific study to be carried out with one of three types of cutting-edge observatories (Keck/VLT, ALMA, or *HST*/*JWST*) within the realm of topics covered by this class. Starting mid-semester, you will begin to prepare this science case as part of your homework problems, which will culminate in a final proposal write-up, class presentation, and group critique / mini-TAC process. Your peers will help evaluate the effectiveness of your argument.

*3. Class attendance*

To succeed in astronomy (in general and this class in particular) you need to be putting in the effort regularly. Show up to class always, be on time to show respect to your classmates and me, and when you will not be able to attend please let me know in advance as much as possible. If you miss a class, please arrange to consult your classmates on what you missed. You are allowed to miss three class periods without an impact on your attendance grade.

*4. End-of-term one-on-one discussion*

The final assessment of the course will be a 30 minute one-on-one discussion with me to assess your learning over the course of this semester. It will mimic questions for the qualifying exam. I will provide you a list of topics beforehand to practice, which will then become the list of topics used for this course during formal qualifying exams either in the spring 2021 or 2022.

**Resources for Course:**

There is no formal text for the course (though a few textbook titles are provided below this list if you would like to supplement your knowledge). However, there are a number of core review articles we will be using throughout this course, and you should generally read to bolster your knowledge and fill in gaps. It is expected that you become skilled in searching the literature yourselves to learn about techniques, measurements and physical explanations for phenomena, but these review articles can be great starting points to give you background and point you to important non-review papers in the literature. Consult the course schedule for a guide as to which review articles to read in preparation for certain class periods:

- Barnes & Hernquist 1992, "Dynamics of Interacting Galaxies" ARA&A 30, 705
- Bastian, Covey & Meyer 2010, "A Universal Stellar initial Mass Function? A Critical Look at Variations" ARA&A 48, 339
- Bland-Hawthorn & Gerhard 2016 "The Galaxy in Context: Structural, Kinematic, and Integrated Properties" ARA&A 54, 529
- Bolatto, Wolfire & Leroy 2013, "The CO-to-$H_2$ Conversion Factor" ARA&A 51, 207
- Calzetti et al. (2000), "The Dust Content and Opacity of Actively Star-Forming Galaxies" ApJ 533, 682
- Carilli & Walter 2013, "Cool Gas in High-Redshift Galaxies" ARA&A 51, 105
- Casey, Narayanan & Cooray 2014, "Dusty Star-Forming Galaxies at High Redshift" Physics Reports 541, 45
- Chabrier 2003, "Galactic Stellar and Substellar Initial Mass Function" PASP 115, 763
- Condon 1992, "Radio emission from normal galaxies" ARA&A 30, 575
- Conroy 2013, "Modeling the Panchromatic Spectral Energy Distributions of Galaxies" ARA&A 51, 393
- Conselice 2014, "The Evolution of Galaxy Structure over Cosmic Time" ARA&A 52, 291
- Cowie & Songaila 1986, "High-resolution optical and ultraviolet absorption-line studies of interstellar gas" ARA&A 24, 499
- Fabian 2012, "Observational Evidence of Active Galactic Nuclei Feedback" ARA&A 50, 455
- Feltzing & Chiba 2013 "Elemental abundances in the Milky Way stellar disk(s), bulge, and halo" New Astronomy Reviews 57, 80
- Finkelstein 2016, "Observational Searches for Star-Forming Galaxies at $z>6$" PASA 33, 37
- Frebel & Norris 2015, "Near-Field Cosmology with Extremely Metal-Poor Stars" ARA&A 53, 631
- Freeman & Bland-Hawthorn 2002 "The New Galaxy: Signatures of Its Formation" ARA&A 40, 487
- Hodge & da Cunha 2020, "High-redshift star formation in the ALMA era" Royal Society Open Science (arXiv:2004.00934)
- Ivezić, Beers & Jurić 2012, "Galactic Stellar Populations in the Era of the Sloan Digital Sky Survey and Other Large Surveys" ARA&A 50, 251
- Kennicutt & Evans 2012, "Star Formation in the Milky Way and Nearby Galaxies" ARA&A 50, 531
- Kormendy & Ho 2013, "Coevolution (Or Not) of Supermassive Black Holes and Host Galaxies" ARA&A 51, 511
- Kormendy & Richstone 1995, "Inward Bound — The search for Supermassive Black Holes in Galactic Nuclei" ARA&A 33, 581
- Madau & Dickinson 2014, "Cosmic Star Formation History" ARA&A 52, 415
- McQuinn 2016, "The evolution of the Intergalactic Medium" ARA&A 54, 313
- Putman, Peek & Joung 2012, "Gaseous Galaxy Halos" ARA&A 50, 491

- Sanders & Mirabel 1996, “Luminous Infrared Galaxies” ARA&A 34, 749
- Shapley 2011, “Physical Properties of Galaxies from z=2-4” ARA&A 49, 525
- Solomon & vanden Bout 2005, “Molecular Gas at High Redshift” ARA&A 43, 677
- Somerville & Davé 2015, “Physical Models of Galaxy Formation in a Cosmological Framework” ARA&A 53, 51
- Stark 2016, “Galaxies in the First Billion Years After the Big Bang” ARA&A 54, 761
- Tokunaga & Vacca (2005), “The Mauna Kea Observatories Near-Infrared Filter Set. III. Isophotal Wavelengths and Absolute Calibration” PASP 117, 421
- van der Kruit & Freeman 2011, “Galaxy Disks” ARA&A 49, 301

Like everything, they aren’t perfect because they are written by humans who have their own biases and background knowledge that doesn’t cover everything. The best astronomers will try to digest as much of the literature as possible (within reason) and form their own opinions.

If you would like to supplement the material in these review papers, some relevant “classic” textbooks are:

- Binney & Merrifield, Galactic Astronomy 1998
- Binney & Tremaine, Galactic Dynamics, Second Edition 2008
- Mo, van den Bosch & White, Galaxy Formation & Evolution 2010
- Longair, Galaxy Formation, Second Edition 2008

**Expectations for students in an online environment:**

The COVID-19 situation is unusual and teaching this class online is new territory for me, and learning in an online environment from the start of the semester may be new to you. Below are a list of expectations to ensure that we maximize the experience and all get the most out of our time together. Please adhere to the following guidelines for online participation in this class:

- Find a quiet work station with good lighting.
- As it would be for an in-person class, do not browse the internet, email or social media during class.
- Given that this is a small class requiring interaction, I would prefer for all cameras to be turned on during the entire class period so I can see everyone while I teach and you can see each other. If this is problematic for any reason, please contact me so we can discuss.
- To avoid sound feedback, students should be muted while not speaking.
- There will be discussions in breakout rooms, akin to small group discussions in class. These breakout room discussions should be structured and on topic. Take turns sharing ideas without any single person dominating the discourse. I will randomly drop in to listen to the discussion, answer, or ask questions.
- Students are welcome to use appropriate virtual backgrounds. If no virtual zoom background is used, please be sure there is nothing inappropriate in the background while on camera.
- All classroom norms apply when in a zoom session. If you wouldn’t do something in a physical class setting, don’t do it in an online classroom.

**Accommodations for disabilities and/or family responsibilities:**

If you have any kind of disability, whether apparent or non-apparent, learning, emotional, physical, or cognitive, and you need some accommodations please feel free to talk to me and discuss reasonable accommodations for your access needs. Students with disabilities may also request appropriate accommodations from the Division of Diversity and Community Engagement, and from UT’s Services for Students with Disabilities. The official wording provided by the university is: The University of Austin provides upon request appropriate academic accommodations for qualified students with disabilities. For more information, contact the Office of the Dean of Students at 471-6259, 471-6441 TTY or Division of Diversity and Community Engagement, Services for Students with Disabilities, 512-471-6259, www.utexas.edu/diversity/ddce/ssd.

Aside from disabilities, I recognize that students with children or family care responsibilities might require special accommodations on occasion, and they should contact me by email regarding missed or late work.

**Regarding harassment/assault:**

Title IX makes it clear that violence and harassment based on sex and gender are Civil Rights violations subject to the same kinds of accountability and the same kinds of support applied to offenses against other protected categories such as race, national origin (Title VII), sexuality, and gender identity. Harassment of any sort will not be tolerated in this classroom or related workspaces. If you or someone you know has been harassed or assaulted, you can find the appropriate resources through the University Title IX Coordinator (512-232-3992), UT Austin Campus Police (512-471-4441), the Student Ombuds Services (which can provide *confidential* advice, resources and help; 512-471-3825), and the UT Counseling and Mental Health Center (512-471-3515).

**Academic Dishonesty:**

The minimum penalty for cheating — in any way whatsoever — is receiving a zero on the assignment on which you cheated. I reserve the right to seek a penalty I find appropriate for the given case of academic dishonesty, including failing the class and being reported to Student Judicial Services. If you deny a cheating allegation for which there is sufficient proof, or if the academic honesty is sufficiently serious, I will proceed by filing a formal report to the Judicial Services in the Dean of Students Office as is policy. Judicial Services would decide the final penalty after a hearing on the matter. For more information, read in the General Information Catalog about scholastic dishonesty (i.e. cheating).

**Rough calendar of topics:**

This schedule is only an approximation and may or may not be accurate depending on how the class is moving along at the time.

| Date | Topic Covered | Review Paper to Prepare Prior to Class | HW Due? |
|---|---|---|---|
| **Aug 27** | Class Overview / Brainstorming Activity | NONE | |
| **Sep 1** | Basics of units / conversions / observations | Chabrier 2003 (Tokunaga & Vacca 2005) | |
| **Sep 3** | The IMF and Stellar Population Synthesis | Chabrier 2003 / Bastian et al. 2010 | |
| **Sep 8** | Dedicated Homework Work Time / Caitlin Gone | Bastian et al. 2010 / Conroy 2013 | |
| **Sep 10** | Stellar Population Synthesis Continued | Conroy 2013 | |
| **Sep 15** | Dust Attenuation | Calzetti et al. 2000 | |
| **Sep 17** | Galactic Structure: the Milky Way | Ivezić, Beers & Jurić 2012 | |

| Date | Topic Covered | Review Paper to Prepare Prior to Class | HW Due? |
|---|---|---|---|
| **Sep 22** | Modeling a Galaxy's Gravitational Potential | Freeman & Bland-Hawthorn 2002 | HW1 Due |
| **Sep 24** | Modeling a Galaxy's Gravitational Potential | van der Kruit & Freeman 2011 | |
| **Sep 29** | Dedicated Homework Work Time / Caitlin Gone | | |
| **Oct 1** | Hubble Sequence / Galaxy Types & Relationships | | |
| **Oct 6** | Gas in Galaxies | Putman, Peek & Joung 2012 | |
| **Oct 8** | Gas in Galaxies | Bolatto, Wolfire & Leroy 2013 | |
| **Oct 13** | Star-Formation in Galaxies | Kennicutt & Evans 2012 | HW2 Due |
| **Oct 15** | Star-Formation / AGN | Kormendy & Ho 2013 | |
| **Oct 20** | AGN / How to pose interesting scientific questions | Kormendy & Ho 2013 | |
| **Oct 22** | Designing Observational Programs | Sanders & Mirabel 1996 | |
| **Oct 27** | Exceptional / Quirky Galaxies | Casey, Narayanan & Cooray 2014 | |
| **Oct 29** | Mergers & Interactions | Barnes & Hernquist 1992 | |
| **Nov 3** | Evolution of Galaxies toward high-z: structure | Concelise 2014 | HW3 Due |
| **Nov 5** | High-z Galaxies: Physical Properties | Hodge & da Cunha 2020 | |
| **Nov 10** | High-z Galaxies: Physical Properties | | |
| **Nov 12** | High-z Galaxies: Context of Evolution | Shapley 2011 | |
| **Nov 17** | Open Reionization-Era Questions | Finkelstein 2016 | |
| **Nov 19** | Proposal Prep Time / In-class Q&A / overrun | Stark 2016 | |
| **Nov 24** | Proposal Prep Time / In-class Q&A / overrun | | |
| **Nov 26** | Thanksgiving Break | | |
| **Dec 1** | Presentations of Proposals | | HW4 Due |
| **Dec 3** | TAC Review | | |