AST1420: Galactic structure and dynamics

Fall 2020

(last updated: September 15, 2020; rev. 85c968c)

Course description

This graduate-level course provides an introduction to galaxies and their properties. The focus of the course is on the physical understanding of the fundamental processes that shape galaxies and their constituents and much attention will go to various manifestations of the gravitational force, arguably the most important force shaping galaxies. We will also focus on learning the basic theoretical tools and observational data sets used in the study of galaxies.

Logistics

- **Meeting time:**
  - *Lectures*: Asynchronous, videos posted Tue morning at MS Stream (see website)
  - *Weekly Q&A*: tentative time **Thu 12:10 – 1:30 pm** on Zoom (Meeting ID: 914 5982 0306; Password: 333891);
    URL: `https://dunlap.zoom.us/j/91459820306?pwd=WmdVeHlGT0xEQmlUbUxVcHRrYWd5dz09`
- **Instructor:** Jo Bovy.
- **Email:** jo.bovy@utoronto.ca
- **Office hours:** by appointment.
- **Course website:** `https://github.com/jobovy/AST1420`.
- **Slack channel:** `#ast1420-fall2020` on the `Astro@UofT` slack.

Learning objectives

After this course you should understand

- the different constituents of galaxies, their typical properties (density, morphology, kinematics, etc.), and their relation to one another.
- the basic dynamical properties of mass distributions: dynamical time, relaxation time, circular velocity, escape speed, and the important differences between spherical, axisymmetric, and triaxial mass distributions.
- the basic properties of orbits for spherical, axisymmetric, and non-axisymmetric mass distributions; the importance of conservation laws and integrals of the motion in characterizing orbits and galaxies.
- the properties of close-to-circular orbits (epicycle approximation) and the dynamics of the solar neighborhood.
- rotation curves and the distribution of dark matter in galaxies.

- equilibrium states of spherical, axisymmetric, and triaxial stellar systems and how to use these to observationally measure the mass and orbital distributions of galaxies.
- the formation and structure of dark matter halos in the ΛCDM paradigm.
- N-body modeling.
- basic galactic chemical evolution.
- how and why bars and spiral structure forms; how galaxies form and grow through violent relaxation, phase-mixing, gas accretion, mergers, and dynamical friction.
- how we think disk and elliptical galaxies form.
- how we know that every galaxy has a supermassive black hole at its center.

Reading

A set of lecture notes will be posted on the course website throughout the semester. For additional reading, we will mostly be using

- Binney & Tremaine, *Galactic Dynamics, 2nd Edition*, 2008, Princeton University Press. Errata can be found here.
- Binney & Merrifield, *Galactic Astronomy*, 1998, Princeton University Press. Errata can be found here.
- Mo, van den Bosch, & White, *Galaxy Formation and Evolution*, 2010, Cambridge University Press. Errata can be found here.

Grading scheme

- **Assignments:** 30 % over three assignments; see course website for due dates.
- **Participation in the Q&A:** 20 %
  - Each student should send at least one question about the weeks' material to jo.bovy@utoronto.ca by the end of the workday the day before the Q&A.
- **Presentations:** 20 %
- **Take-home final + oral exam:** 30 %

  You are allowed to (and are encouraged to!) work together with classmates on the assignments, but each student must hand in an independent write-up of their solutions. The take-home final should be your own work. Solutions must be written up in a detailed enough manner to demonstrate that you understand each step. The oral exam will consist of a discussion of the take-home final with follow-up questions.

Academic integrity

From Appendix D of the Academic Integrity Handbook:

> Academic integrity is one of the cornerstones of the University of Toronto. It is critically important both to maintain our community which honours the values of honesty, trust, respect, fairness, and responsibility and to protect you, the students within this community, and the value of the degree towards which you are all working so diligently.
>
> According to Section B of the University of Toronto's Code of Behaviour on Academic Matter (`http://www.governingcouncil.utoronto.ca/policies/behaveac.htm`) which all students are expected to read and by which they are expected to abide, it is an offence for students to:
>
> - Use someone else's ideas or words in their own work without acknowledging explicitly that those ideas/words are not their own with a citation and quotation marks, i.e. to commit plagiarism.
> - Include false, misleading, or concocted citations in their work.
> - Obtain unauthorized assistance on any assignment.
> - Provide unauthorized assistance to another students. This includes showing another student your own work.
> - Submit their own work for credit in more than one course without the permission of the instructors.
>
> There are other offenses covered under the Code, but these are the most common. You are instructed to respect these rules and the values that they protect.

Schedule

- **Week 1:** Class logistics; Introduction to galactic structure; overview of background knowledge.
- **Week 2:** General properties of gravitational potentials; properties and examples of spherical mass distributions; basics of classical mechanics; orbits in spherical potentials.
- **Week 3:** Galaxies as collisionless sytems; equilibrium configurations of spherical systems; virial theorem; collisionless Boltzmann equation; spherical Jeans equations; spherical distribution functions; applications: masses of spherical systems.
- **Week 4:** Properties of disky mass distributions; orbits in axisymmetric potentials; dark matter; rotation curves; gas kinematics in the Milky Way.
- **Week 5:** Asymmetric drift; the dynamics of the solar neighborhood; Spheroidal and triaxial mass distributions; orbits in these mass distributions; surfaces of section; chaos; Schwarzschild modeling.
- **Week 6:** Numerical methods; N-body modeling.
- **Week 7:** Formation and evolution of dark matter halos; violent relaxation; phase-mixing.
- **Week 8:** Chemical evolution of galaxies; age–abundance relations in the solar neighborhood; stellar population synthesis.
- **Week 9:** Internal structure of elliptical galaxies; supermassive central black holes; stability of stellar systems; bars; spiral arms.

- **Week 10:** Student presentations.
- **Week 11:** Mergers and dynamical friction; tides.
- **Week 12:** Review.

What's going on this week? What's due?

Week	Dates	Topic	Due on Thu?
1	Sep 14 – Sep 18	Introduction to galactic structure	
2	Sep 21 – Sep 25	Gravitation, classical mechanics, spherical orbits	
3	Sep 28 – Oct 02	Dynamical equilibria, masses of spherical systems	
4	Oct 05 – Oct 09	Galactic disks, galactic rotation	
5	Oct 12 – Oct 16	Disk equilibria, spheroidal mass distributions	Assignment 1
6	Oct 19 – Oct 23	Numerical methods	Presentation topic
7	Oct 26 – Oct 30	Dark matter halos	
8	Nov 02 – Nov 06	Chemical evolution	Assignment 2
	Nov 09 – Nov 13	**Reading week, no class**	
9	Nov 16 – Nov 20	Elliptical galaxies, stability	Assignment 3
10	Nov 23 – Nov 27	**Presentations**	
11	Nov 20 – Dec 04	Mergers and dynamical friction	
12	Dec 07 – Dec 11	Review	