

# ASTR 333/433 - Dark Matter

Prof. McGaugh - Spring 2024

## Course Description

This course will systematically explore the evidence for dark matter in the universe. Necessary physical theory and astronomical concepts will be developed as appropriate. Topics to be covered include gravitational dynamics, gravitational lensing, and hydrostatic equilibrium as probes of the gravitational potentials of extragalactic systems. Examples include the rotation curves of spiral galaxies, the Oort discrepancy in the local galactic disk, the dynamics of pressure supported dwarf and giant elliptical galaxies, and the Local Group timing problem. In clusters of galaxies, the mass discrepancy is illustrated separately by measured velocity dispersions, the hydrostatic equilibrium of the hot intracluster medium, and both strong and weak gravitational lensing. On cosmic scales, the course will address evidence from the gravitating and baryonic mass content of the universe, the growth of large scale structure from the initially smooth cosmic microwave background, and the existence of large voids and large scale bulk flows. The course will describe the various dark matter halo models commonly employed and introduce the techniques of mass modeling. We will examine hypotheses for the nature of dark matter, both baryonic and non-baryonic, and discuss strategies for experimental detection of plausible dark matter candidates. Theories that seek to explain the observed mass discrepancies by means of modifying the law of gravity rather than invoking dark matter will be explored as time permits.

Offered as ASTR 333 and ASTR 433. Prereq: ASTR 222 or PHYS 310 or permission of instructor.

Please also see the [course web page](http://astroweb.case.edu/ssm/ASTR333/), <http://astroweb.case.edu/ssm/ASTR333/>  
*This web page is the main reference for this course, not Canvas*

## ASTR 333/433 - Dark Matter

### 1. Introduction

- Overview of the evidence and dark matter candidates
- Historical Context: Oort & Zwicky; Disk Stability

### 2. Galaxy Dynamics

- Spiral galaxies
  - Photometric properties of galaxies
  - Baryonic content: stars & gas
    - Stellar populations and their mass-to-light ratios
    - The interstellar medium of galaxies
  - Rotation curves
  - Laws of galactic rotation
  - Mass modeling; halo models
- Elliptical galaxies
  - Tracers & orbit anisotropy
- Dwarf galaxies
  - Dwarf irregulars
  - Dwarf Spheroidals

### 3. Groups & clusters of galaxies

- Timing argument in the Local Group
- Velocity dispersions and the turn-around radius
- X-ray gas and hydrostatic equilibrium
- Gravitational lensing

### 4. Gravitational Lensing

- Weak lensing; galaxy statistics
- Strong lensing in galaxies & clusters
- Microlensing

### 5. Cosmological Context

- Dynamical estimates of the mass density
- Big bang nucleosynthesis
- The growth of large scale structure
- The cosmic microwave background

### 6. Dark Matter Candidates & Searches

- Baryonic Dark Matter
  - Candidates
    - brown dwarfs and other very small rocks
    - HI scaling; cold molecular gas
    - Missing baryon problem
    - hot ionized gas (the WHIM & CGM)
  - Detection Strategies
    - Direct observational searches
    - MACHO-type searches
    - Opacity of baryonic dark matter candidates
- Non-baryonic Dark Matter
  - Candidates
    - Neutrinos; sterile neutrinos
    - WIMPs & axions
    - Others: warm DM, self-interacting DM, etc.
  - Detection Strategies
    - Direct laboratory searches
    - Indirect searches
    - Collider evidence

### 7. Modified Gravity

- Generic constraints: non-viable theories that can be immediately excluded
- the acceleration scale
- MOND, MoG, Conformal Weyl Gravity

## **Course Work**

Course work will consist of

- Problem sets (at least 4)
- 2 exams: a midterm and a final
- Students enrolled in 433 will encounter additional problems on the homeworks and exams over and above what is required for 333.

Assignments will be posted on the course web page <http://astroweb.case.edu/ssm/ASTR333/>.

You are welcome and encouraged to discuss assignments with your fellow students. However, your submitted work must be your own original work - no copying, plagiarizing, or utilizing oracles such as Chegg or AI like ChatGPT. Please, no sacrifices to religious diets, major or minor. Demons are surprisingly bad at math.

## **Late Homework Policy**

*Don't be.*

Late homeworks suffer a minimum 20% mark down.

Further arbitrary and capricious penalties will apply to homeworks that are more than one day late.

## **Missed Exam Policy**

*Don't.*

If there is an extraordinarily good reason to miss the scheduled exam, arrangements must be agreed with Prof. McGaugh prior to the exam date.

## **Grades**

Course grades will be based on the weighting scheme in the table:

Problem Sets	50%
Midterm	20%
Final	30%

Final grades will be curved: there is no absolute standard. Those who score highest according to the tabulated weighting scheme will get the highest grades, and vice-versa.

Grades for ASTR 333 will be whole letter grades.

Grades for ASTR 433 will have +/- values.

*You will receive the grade that you earn.*

## **Learning Outcomes**

After taking this course, students should be able to

- Explain what is meant by "dark matter"
- Discuss the empirical evidence for dark matter
- Describe the major candidates for dark matter
- Quantitatively compute dynamical mass estimates and compare with observed masses
- Read and comprehend papers on dark matter in the scientific literature
- Pose relevant questions in scientific discussions of dark matter (e.g., colloquia)
- Critically evaluate hypothesized dark matter candidates
- Distinguish between empirical evidence and theory
- Distinguish between dark matter candidates and modified gravity theories