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. <u>Cosmological Context</u>
    - Dynamical estimates of the mass density
    - Big bang nucleosynhtesis
    - The growth of large scale structure
    - The cosmic microwave background

6. <u>Dark Matter Candidates & Searches</u>
    - 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. <u>Modified Gravity</u>
    - Generic constraints: non-viable theories that can be immediately excluded
    - the acceleration scale
    - MOND, MoG, Conformal Weyl Gravity

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 inctracluster 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.

Course Work

Course work will consist of

- Problem sets (at least 4)
- 2 exams: a midterm and a final
- A course project (433 only - see below)
  Students enrolled in 433 will enounter 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/.

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:

Work	ASTR 333	ASTR 433
Problem Sets	50%	40%
Midterm	25%	25%
Final	25%	25%
Project	-	10%

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.

Course Project

The project will explore some current aspect of the mass discrepancy problem: observational clues, experimental searches, or theoretical developments. It will culminate in an oral presentation on it to the class. Prior to the presentation, you will write an absract for distribution to the class. Presentations will be scheduled towards the end of the semester.

Projects must be selected in consultation with Prof. McGaugh.

Ideas for projects (this list is meant to be suggestive. It is neither complete nor exclusive.)

- Dark Matter candidates (hypotheses & motivations)
  - WIMPs & Supersymmetry
  - Axions
  - Strange Nuggets
  - MACHOs
  - Cold molecular gas
  - &c.
- Dark Matter detection experiments
  - Direct detection, e.g., CDMS, LUX, DAMA, etc.
  - Indirect detection, e.g., Fermi (γ-rays); Ice Cube (neutrinos)
  - Microlensing searches for MACHOs
  - Collider constraints (i.e., should the LHC see evidence for DM particles)
  - &c.
- Astronomical constraints
  - *There are many, many possibilities here*
  - Individual galaxies
  - Classes of galaxies (e.g., dwarf Spheroidals)
  - Clusters of galaxies
  - Gravitational lensing
  - Large scale structure
  - The cosmic microwave background
  - &c.
- &c.