Astronomy 48200: Dark Energy and Cosmic Acceleration
Spring Quarter, 2009
Class: Wednesdays, Fridays, some Mondays 1:30-2:50 pm, AAC 123
Instructor: Josh Frieman (frieman@fnal.gov), AAC 032
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- **Introduction and Background:**

- The Expanding Universe:
  - FRW Cosmology: Cosmological Principle, Expansion, Redshift, the Hubble Law
  - Cosmological Dynamics I: Newtonian limit, Matter-dominated Universe

- Historical Perspective:
  - CDM model: age of the Universe, pre-history of acceleration discovery
  - The Cosmological Constant and its effects
  - Energy-momentum conservation
  - Dark Energy and the Equation of State parameter
  - The Ω_Λ - Ω_m plane; deceleration parameter
  - Evidence for acceleration from Supernovae, Large-scale Structure (BAO), and the CMB

- Brief Introduction to General Relativity:
  - The Equivalence Principle and bending of light; geometric view of gravity
  - Principle of General Covariance: Tensors, Covariant Differentiation
  - Geodesic equation of motion
  - Curvature
  - Newtonian Limit and the Field Equations of General Relativity
  - Addition of the Cosmological Constant

- Friedmann-Robertson-Walker Cosmology:
  - The metric for homogeneous and isotropic Universes
  - Friedmann equations from General Relativity
  - Distances and the Hubble diagram; lookback time; volume element
  - Linear growth of structure and ΛCDM

- **Theoretical Approaches to Cosmic Acceleration:**

- The Cosmological Constant:
  - Role of Λ in cosmology
  - Vacuum energy density

- Observable effects of vacuum energy: Casimir effect, etc
- Expectation from Quantum Field Theory
- The Cosmological Constant Problem and proposed solutions
- Does vacuum energy gravitate?

• Light Scalar Fields:
- Classical Scalar Fields in Cosmology: inflation
- Classes of Models and their behaviors: approaches to Cosmic Coincidence
- Naturalness
- Scalar Field Perturbations
- Coupling of Dark Energy - Topological Defect models
- Phantom Dark Energy

• Modifications of Gravity:
- Braneworld models and extra dimensions
- $f(R)$ models and their behaviors: linear and non-linear regimes

• Inhomogeneous cosmologies and apparent acceleration:
- Backreaction effects
- Lemaitre-Tolman-Bondi models

• Characterizing Dark Energy:
- Parametrizing the Equation of State
- Reconstructing Dark Energy
- Principal Component Analysis
- Parametrizing Linear Growth
- Kinematic Descriptions

• **Evidence for and Probes of Acceleration:**

• Supernovae:
- Type Ia SNe as Calibrated Candles
- Light-curve fitting methods: MLCS, SALT,...
- Dust extinction and other systematics
- Current results

• CMB:
- CMB anisotropies and structure formation
- Features in the angular power spectrum
- WMAP constraints on cosmological parameters
- Expectations from Planck

- Large-scale structure:
  - Baryon Acoustic Oscillations
  - Predictions for BAO from N-body and Perturbation Theory
  - Effects of non-linearity, bias, and redshift distortions
  - Redshift Distortions as a probe of the growth rate

- Clusters:
  - Counting Clusters: probing geometry and growth
  - Cluster probes: X-ray, SZ, Optical, WL
  - Galaxy counts
  - Mass-observable relation, selection effects, systematics
  - The f_{gas} method

- Weak Gravitational Lensing:
  - Introduction to Gravitational Lensing and Shear
  - Cosmic Shear Tomography as a probe of geometry and growth
  - Shear systematics

- Photometric Redshifts:
  - Photo-z requirements for Dark energy probes
  - Photo-z errors and systematics

- Other Probes:
  - Strong gravitational lensing
  - Integrated Sachs-Wolfe effect
  - CMB Lensing
  - Gravitational Wave Sirens
  - Measuring the change in expansion over time

- Expansion Rate and Growth Factor:
  - Probing Dark Energy vs. Modified Gravity

- Forecasting Constraints:
  - Fisher matrix
  - Monte Carlo simulations, MCMC, etc.
  - Figures of Merit

- Dark Energy Projects:
  - Ground- and space-based experiments

- Open Issues:

Required Work

Work will include oral reports in class on a subject area, e.g., a presentation/explication of a paper or set of papers on a particular topic. Short, original write-ups exploring a particular DE topic, e.g., theory, data analysis, simulation, or forecast, will be due at the end of the quarter.

Useful References

We'll make reference to the original literature thoughout. The following reviews are useful in different contexts:

Frieman, Lectures on Dark Energy and Cosmic Acceleration, in Graduate School in Astronomy: XII Special Courses at the National Observatory of Rio de Janeiro, AIP Conf. Series, Vol. 1057, pp. 87-124 (2008): I will post these online.

Frieman, Turner, and Huterer, ARAA, 46, 385 (2008); astro-ph/0803.0982: general review

Copeland, Sami, and Tsujikawa, IJMP, D15, 1753 (2006); astro-ph/0603057; theory focus

Peebles and Ratra, RMP, 75, 559 (2003); astro-ph/0207347

Caldwell and Kamionkowski, ARNP (2009); astro-ph/0903.0866

Linder, astro-ph/0801.2968

Uzan, GRG, 39, 307 (2007); astro-ph/0605313

Albrecht, etal, Dark Energy Task Force Report, astro-ph/0609591

Albrecht, etal, Figure of Merit Science Working Group Report, astro-ph/0901.0721

Class Schedule:

Mon. April 6
Wed. April 8
Fri. April 10
Mon. April 13
Wed. April 15
Mon. April 20
Wed. April 22
Fri. April 24
Fri. May 1
Mon. May 4
Wed. May 6
Fri. May 8
Wed. May 13
Fri. May 15
Mon. May 18
Wed. May 20
Fri. May 22
Mon. June 1
Wed. June 3
Fri. June 5