IDS 160 B

George F. Smoot

Spring Semester 1995

Required Text for 160B: Gerhard Borner, The Early Universe: Fact and Fiction, 2nd ed. (1992). Supplementary texts (for reserve and for the use of the instructor in preparing lectures): Rowan-Robinson, The Cosmological Distance Ladder (1985); Longair, High Energy Astrophysics, 2nd ed. (1992–93); Shapiro and Teukolsky, Black Holes, White Dwarfs and Neutron Stars (1983 — paperback addition available); J. Frank, A.R. King and D.J. Raine, Accretion Power in Astrophysics, 2nd ed. (1992 — paperback edition available); Alan Lightman et al, Problem Book in Relativity and Gravitation (1975)

IDS 160B. Relativistic Astrophysics and Cosmology (4) Three hours of lecture and one hour of discussion per week. Prerequisites: Senior standing in Astronomy or in Physics, or permission of the instructor. IDS160A, Physics 112, and either Physics 110A-B or Physics 137A-B. A prior knowledge of Astrophysics comparable to that offered in Astronomy 7 is useful but not required. Elements of general relativity. Physics of pulsars, cosmic rays and black holes. The cosmological distance scale, elementary cosmological models, properties of galaxies and quasars. The mass density and age of the Universe. Evidence for dark matter, and concepts of the early Universe and of galaxy formation. Reflections on astrophysics as a probe of the extrema of physics.

Syllabus

IDS 160B: Relativistic Astrophysics and Cosmology - 45 lecture hours — 30 lectures — 4 units 3 hours/week lecture, 1 hour/week discussion

Elements of General Relativity (3 lectures)
- Equivalence principle
- Coordinate transformations and local Minkowski frames
- Geodesic motion, gravitational redshift and gravitational lensing
- Statement of Einstein equations
- Schwarzschild and Robertson-Walker Metrics
- Gravitational Lenses

Pulsars and Synchrotron Nebulae (2 lectures)
- Radio, O, X and Observations
- Synchrotron Nebulae
  - Synchrotron Radiation
  - Nebulae - Relativistic Power Input by Pulsars
- The Magnetized Neutron Star Model
  - Clock Stability
  - $\dot{P} > 0$
  - Magnetized Spin Down model
    - Vacuum and Non-vacuum Models (Magnetospheric Voltage)
  - Magnetic Fields of Neutron Stars
    - Field Strengths - Normal and Millisecond Pulsars
- Outstanding Problems (High Energy Particle Acceleration, Pulsar Emission)

Cosmic Rays (2 lectures)
- Observations
  - Total Spectrum
  - Composition: propagation effects and lifetime
- Cosmic Ray Origins
  - Supernova Remnants (qualitative)
  - Shock Acceleration (qualitative)

Black Holes (2 lectures)
  - Basic Structure
  - Particle orbits
  - Reality of singularities
- Summary of other black hole physics
  - Evaporation

Disk accretion onto Black Holes
The Expanding Universe (2 lectures)
Observational Motivations
Redshift (naive Doppler, relativistic effects)
Hubble/Quasar controversy
Evidence for a Hot Big Bang
2.73K Background Radiation
Primordial Element Abundances
Homogeneity and Structure
Friedman-Lemaitre Universes
Roberston-Walker Metric, Friedman equations, Newtonian analog
Evolution of Scale parameter in pressureless Universe
Critical density, open and closed Universes
Causality, horizon
Cosmological constant
Determination of Cosmological Parameters (5 lectures)
The Hubble Parameter — Cosmological Distance Ladder (3 lectures)
Trigonometric Methods
Methods from Stellar Physics
Main sequence
Cepheids
Supernovae of type Ia
Planetary Nebulae
Methods from Galaxy Physics
Basic Properties of Galaxies
Tully-Fisher
D-
Surface Brightness fluctuations
The Basic Uncertainties
The Density of the Universe (3 lectures)
Depth of Potential Wells
Virial Methods
Temperature of cluster gas
Gravitational lensing
Dynamical Methods
Principle: Observed velocity =
Inputs:

- Velocity flows
  - Deviation from Hubble flow
  - Conversion of radial velocities to 3D velocities
- Large scale structure
- Growth of density fluctuations

Various Estimations of

Uncertainties

Direct Geometric Measurement

- Measurements of curvature
  - Definitions of distances
  - Volume element
- Luminosity vs. redshift (Sandage, SN Ia)
- Number counts
- Volume element evolution
  - Evolutionary diffculties

Conclusion: 90

The Age of the Universe (1 lecture)

- Radioactive dating
- Age of globular clusters
- White dwarfs
- Is the cosmological constant nonzero?

Gravitational Radiation (2 lectures)

- Weak Field Approximation, polarization, nature
- Quadrupole Radiation
- Binary Pulsar and Orbit Decay

Quasars (3 lectures)

- Phenomelogy of Radio quiet, jet free QSOs
- Phenomenology of Radio loud QSOs with jets
- Black Hole in a Galaxy model for QSOs
  - Large scale disks
  - X-Ray and UV emission - blue bump
  - Disk Outflows - Jets
    - Observations of jets
      - Superluminal motion
      - Termination of jets in radio sources
    - Equilibrium jet models

High brightness temperature radio sources - relativistic effects on T_b

QSO Emission lines

QSO Absorption Lines — Probes of the Universe at High Redshift

Gunn-Peterson Effect

Lyman- forest —early galaxies?

The Early Universe (6 lectures)

Thermodynamics in an Expanding Universe

Radiation Dominated Universe

Number of Degrees of Freedom

Evolution of Temperature

Fossil Radiation

Decoupling of Relic Radiation

Transparency $\Rightarrow RelicBackgrounds$

Electromagnetic Radiation

Neutrinos

Gravitational Waves

Phase Transitions

Inflationary episodes

Topological singularities

The Microwave Background

Experimental Techniques

Spectrum

Large Scale Anisotropy

Dipole

Causality, horizon, inflation

Small scale anisotropy — predictions and current efforts

Conclusions — Fundamental intial conditions for galaxy formation

The Number of Baryons in the Universe

Baryon-antibaryon asymmetry

Experimental absence of antimatter

Potential explanation from particle physics

Expected large photon to baryon ratio

Primordial nucleosynthesis

Experimental determinations

Nucleosynthesis theory

            - Ratio of baryons to photons, cosmological limits on the number of neutrino families
            - Density of the Universe in baryons
    - The Nature of Dark Matter
        - Baryonic Dark Matter
            - Constraints
            - The search for dark massive objects: gravitational lenses and MACHOS
        - Non-baryonic dark matter
            - Summary of evidence and theoretical prejudices
            - Thermal equilibrium cases
                - Freeze out and relic abundance
                - Light massive neutrinos
                - Weakly interacting massive particles (WIMPS): current searches
            - Other candidates
- Philosophical Remarks (1 lecture)
    - The Union of the large and small
    - Extremes of the behavior of mass-energy
    - The Big Bang to the formation of stars and planets
        - Origin of Life
            - Current ideas
            - Searches
    - Do we live in a special Universe?
        - Copernican principle
        - Anthropic principle
    - Cosmology and Mythologies