Supernovae, and the Fate of the Universe

Syllabus

Week 1 (Feb. 3): *Supernovae: An Overview*

Topics covered – The cosmos, and the fundamental role of supernovae. Review of basic physics: Newtonian dynamics and mechanics; gravitation; gravitational self-binding energy.

Required Reading:
Course Reader: *Messages in Starlight*, by Laurence Marschall. *Guest Stars*, by Murdin & Murdin.
Carroll & Ostlie: Chapter(s)/section(s) 2.2 (p.31 - 43); 10.3 (partial; p.329 - 330)

Optional Background Material:
Abell: Chapter(s)/section(s) 3
Hewitt: 2-10, 12, 13
Ohanian: 2-9
Halliday: 2-8, 15

Week 2 (Feb. 10): *Light: It's all We Have*

Topics covered – An astronomical toolkit: Flux, luminosity, magnitude scale, distance modulus, ''standard candles'', the angstrom unit, color index, *UBVRI* photometry filters. The best way to measure distances: trigonometric parallax. Light: wave nature, electromagnetic spectrum, blackbody radiation, Planck function, Wien's displacement law, the Stefan-Boltzmann equation. A thermal supernova spectrum.

Required Reading:
Course Reader: Begin *On Supernovae*, by Baade & Zwicky (1934; end at equation [15]).
Carroll & Ostlie: Ch. 3 (p.63 - 87)

Optional Background Material:
Abell: 7.1, 7.2, 21.1, 21.2, 22.1, 22.2
Hewitt: 27 & 31
Ohanian: 36 & 39
Halliday: 21.7, 38, 40

Week 3 (Feb. 17): *Special Relativity*

Topics covered – Einstein's postulates and their implications: time dilation, length contraction, and the downfall of simultaneity. Doppler shift; redshift and blueshift; relativistic energy.

Required Reading:
Course Reader: Finish *On Supernovae*, by Baade & Zwicky.
Carroll & Ostlie: Ch. 4 (p.93 - 118)

Optional Background Material:
Abell: 8, 27.2
Hewitt: 15, 16 (excellent introduction to special relativity)
Ohanian: 41
Halliday: 8.8, 42

Week 4 (Feb. 24): *The Fingerprints of the Elements*

Topics covered – Spectral lines; Kirchhoff's Laws; photons; the hydrogen atom; Pauli exclusion principle and degeneracy; introduction to supernova spectral classification.

Required Reading:
Course Reader: *Spectra of Supernovae*, by Minkowski (1941). *Types of Supernovae*, by Murdin & Murdin.
Carroll & Ostlie: Ch. 5 (lightly, in sections; p.125 - 158).

Optional Background Material:
Abell: 7.3, 7.4
Hewitt: 28.11
Halliday: 43

Week 5 (March 2): *Understanding Supernova Spectra*

Topics covered – Brief introduction to stellar spectra; Maxwell-Boltzmann distribution function; Hertzsprung-Russell Diagram: an empirical classification scheme; opacity; line blanketing; mean free path; optical depth; photosphere; radiative transfer in moving atmospheres: the anatomy of a P-Cygni line profile.

Required Reading:
Course Reader: Begin *Spectra of Supernovae*, by David Branch (1990).
Carroll & Ostlie: 8.1 (partial; p.223 - 240); 8.2 (p.241 - 250); 9.2 (partial; p.261 - 272); 9.3 (partial; p.276 - 279) p.470 (P-Cygni line profile).

Optional Background Material:
Abell: 22.3, 22.4, 24.2
Halliday: 21.7

Week 6 (March 9): *Why Stars Explode I*

Topics covered – Stellar energy sources; overview of main sequence and post main sequence stellar evolution; Kelvin-Helmholtz, free-fall, and nuclear timescales; the neutrino; binding energy per nucleon; white dwarfs: the fate of stars with $M \lesssim 8M_{\odot}$; core-collapse supernovae: the fate of stars with $M \gtrsim 8M_{\odot}$; explosion mechanism in core-collapse supernovae; radioactive-decay powered light curves; brief introduction to pulsars; SN 1987A.

Required Reading:
Course Reader: Begin *Why Stars Explode*, by Laurence Marschall (1988); *Supernovae, Type II, Theory and Interpretation*, by Stan Woosley (1992); *The Making of a Neutron Star*, by Murdin & Murdin (1985).
Carroll & Ostlie: 10.3 (partial; p.331 - 334, 348 - 350); 12.2 (partial; p.451, homologous collapse); 13.1 (partial; p.489 - 490); 13.2 (partial; p.504 - 509); 13.3 (p.510 - 528).

Optional Background Material:
Abell: 27, 29, 30
Hewitt: 40
Halliday: 47.5, 48.6, 48.7

Week 7: *Spring Break*

Topics covered – Matter at rest.

Week 8 (March 23): *Why Stars Explode II*

Topics covered – The light curves and spectra of core-collapse supernovae: Types II-P, II-L, IIn, Ib, and Ic; ''hypernovae''; Physics of degenerate matter; white dwarfs; Chandrasekhar limit; Type Ia supernovae.

Required Reading:
Course Reader: Finish *Spectra of Supernovae*, by David Branch (1990); *New Types of Supernovae*, by J. Craig Wheeler (1992); *Review on the Observed and Physical Properties of Core Collapse Supernovae*, by Mario Hamuy (2003); Finish *Why Stars Explode*, by Laurence Marschall (1988).
Carroll & Ostlie: 15.1 - 15.4 (p.577 - 591); 17.4 (partial, p.719 - 723).

Optional Background Material:
Abell: 30

Week 9 (March 30): *Fun With Supernovae*

Topics covered – Explosion geometry from polarization studies; time-dilation from studies of Type Ia supernovae; the supernova-gamma-ray-burst connection.

Required Reading:
Course Reader: *Supernova Light Curves*, by Bob Kirshner (1990); *Spectropolarimetric Observations of Supernovae*, by Alex Filippenko & Doug Leonard (2003); *Time Dilation in the Light Curve of the Distant Type Ia Supernova SN 1995K*, by Bruno Leibundgut et al. (1996), p.168-171.
Carroll & Ostlie: Ch. 25.4 (lightly, p.1141 - 1147).

Optional Background Material:
Abell: 25

→**Midterm Examination (first half of class).**

Week 10 (April 6): *Supernovae as Distance Indicators*

Topics covered – Type Ia supernovae as standard candles; Type II-P supernovae as primary distance indicators through the expanding photosphere method; the extragalactic distance scale; interstellar extinction.

Required Reading:
Course Reader: *The Absolute Magnitudes of Type Ia Supernovae*, by Mark Phillips (1993)
Carroll & Ostlie: Ch. 12.1 (partial, p.437 - 441); 14.1 (p.541 - 548); 25.1 (partial, p.1097 - 1102).

Week 11 (April 13): *The Expansion of the Universe*

Topics covered – Hubble's law; Newtonian cosmology: cosmological principle, dust-filled universe, critical density, look-back time, deceleration parameter.

Required Reading:
Carroll & Ostlie: Ch. 25.2 (p.1110 - 1118); 27.1 (p.1221 - 1236)

Optional Background Material:
Abell: 33

Week 12 (April 20): *Relativistic Cosmology*

Topics covered – Brief introduction to the general theory of relativity; Schwarzschild metric; Robertson-Walker metric; Friedmann equation; the cosmological constant.

Required Reading:
Course Reader: Begin *The Cosmological Constant* by Carroll et al. (1992).
Carroll & Ostlie: Ch. 16.1 & 16.2 (lightly, p.633 - 661); 27.3 (partial, p.1249 - 1264).

Optional Background Material:
Abell: 31

Week 13 (April 27): *The Accelerating Universe*

Topics covered – Observational cosmology; luminosity distance and Mattig's formula; observations of Type Ia supernovae; basics of error analysis, confidence limits; the supernova discovery.

Required Reading:
Course Reader: *Supernova Explosions in the Universe* by Adam Burrows (2000); Finish *The Cosmological Constant* by Carroll et al. (1992); *Error Analysis* by Ben Mathiesen (1997); *Confidence Limits* by Press et al. (1992).
Carroll & Ostlie: 27.4 (partial, p.1264 - 1273)

Week 14 (May 4): *Ending it All*

Topics covered – The effects of a nonzero cosmological constant; WMAP results; the fate of the Universe.

Course Reader: *The Accelerating Universe and Dark Energy: Evidence from Type Ia Supernovae* by Alex Filippenko.

Week 15 (May 10 - 14) *Exam Week*: *The Last Word*

→Final student presentations.