Sun

Atmosphere – Observations via SOHO, SDO
- Photosphere
  - “surface”, 6000 K
  - Granules, granulation, convection
- Spectra
- Chromosphere
  - Pinkish
  - 10,000 K
  - UV source
- Corona
  - Visible during eclipses
  - 1-2 million K, x-ray source
  - solar winds, aurora

Sunspots
- Umbra, Penumbra, sunspot groups
- Solar rotation – differential rotation
- Sunspot cycle
  - 11 years – peak number of spots
  - location of spots – Maunder butterfly diagram
- Magnetic Field
  - Zeeman effect
  - 22 year cycle – full sunspot cycle
  - Polarity of spots in each hemisphere – flips with next cycle

Solar Activity
- Flares, Prominences
- Coronal Mass Ejections
- Spicules
- Helioseismology

Stars
- Apparent Magnitude, m
- Distances
  - Parallax \( p = 1/d \)
  - Parsec, Lightyear
- Absolute Magnitude, M
- Luminosity
  - Stefan-Boltzmann Law and Surface area
    \( L = R^2 T^4 \) (in solar units)
  - Black body properties
- Temperature determination
  - Wien's Law
  - Photometry
- Spectra
  - Spectral Classification System – OBAFGKMLT
  - Temperature scale
H-R diagram
  Main Sequence
  Red Giants
  Supergiants
  White Dwarfs
  Spectroscopic parallax

Mass Determination
  Binary Stars
    Kepler’s Laws
    Center of Mass
    Optical Binaries
  Physical Binaries
    Visual Binary - Mass determination
    Spectroscopic Binary - Mass determination
    Eclipsing Binary - Mass, Radius determination

Mass – Luminosity relation (for Main Sequence)

Star formation
  Large Scale Star Formation
    Giant Molecular Clouds
    Types of stars formed
    H II regions – Orion Nebula, proplyds

Small Scale Star Formation
  protostars
  T Tauri Stars
  H-H objects – Jets, bipolar outflow

Main sequence properties
  Energy production – Fusion in the Core
    Einstein's Special Theory
    Proton - Proton Chain
      protons = hydrogen atoms
      helium, energy (gamma ray), neutrino, positron
      deuterium
    CNO cycle
  Radiative Zone
    Random Walk
  Convective Zone

Stellar Interiors
  Helioseismology, asteroseismology
  Neutrino detectors
  Computer models
    Hydrostatic Equilibrium
    Conservation of Energy
    Conservation of mass
    Energy transport laws

Zero-age Main Sequence (ZAMS)
  Time on Main Sequence – Mass of star relation
Main sequence characteristics
Range of mass, temperature, luminosity, lifetime of stars on MS

Stellar Death
Very low mass – Brown dwarf, not even stars
Medium Mass – up to 8 solar masses
   Helium core
   Hydrogen shell fusion
   Thermal energy
   Red Giant
      Electron degenerate core
      Helium Flash
      Helium fusion
         Triple alpha process - produces Carbon, Oxygen
      Helium shell flashes, thermal pulses
Planetary Nebula Stage
   Helium shell flashes, Winds,
   Mass loss – bipolar outflow, other ejection shapes
White Dwarf
   Electron Degenerate
   Chandrasekhar Limit = 1.4 solar masses
Black Dwarf
White Dwarf Binary
   Close binary
   Roche Lobe
   Mass transfer
   Accretion disk
   Nova
   Recurrent nova – U Scorpii
High Mass Stars (greater than 8 solar masses)
Mass loss
   Bipolar outflow
   Strong winds
Supergiants – Red or Blue
   More fusion stages - C, O, Ne, Si etc
   Iron (Fe) fusion
   Core collapse
   Neutron degenerate core – neutron star
Supernova
   Bright
   Forms neutron star or black hole
   Release of neutrinos
   Shockwave
   Production of Heavy elements
Two types of Supernova
   Type Ia - White Dwarf pushed over Chandrasekhar limit
   Type II - Large Mass star core collapse
Hyperfueva – gamma-ray bursts

Historical Supernovae & Supernovae Remnants

1054 Supernova
Tycho’s & Kepler’s Supernovae
Cas A, Crab Nebula, Gum Nebula

Supernova 1987A
Feb 1987
In the Large Magellanic Cloud
Pre-supernova star = Sanduleak -69 202
Detection of Neutrinos
Detection of heavy element production
Ring structures around it

Neutron stars
Discovery – Jocelyn Bell

Pulsars
Link between pulsars, supernova = Crab nebula/pulsar
Conservation of Angular momentum
Magnetic fields
Synchrotron Radiation – non-thermal radiation

Black Holes
Special Theory of Relativity
Speed of light is constant
Nothing goes faster than light
Effects due to velocities close to the speed of light

General Theory of Relativity
Matter warps space
Warped space influences matter, light in it
Mercury’s orbital precession
Sun’s deflection of light

Black hole characteristics
Mass
Singularity
Schwarzschild Radius/Event horizon – depends only on mass
Tidal effects
Detection of black holes

Unusual objects
PSR 1913+16
PSR J0737-3039A
Cygnus X-1
XTE J0929-314
Magnetars
Quark/Strange Stars
Gamma-ray sources