

Sun

Atmosphere – Observations via *SOHO*

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

Distances

Parallax $p = 1/d$

Parsec, Lightyear

Absolute Magnitude

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
- 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
 - 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)
- 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

- 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 – RS Oph

High Mass Stars (greater than 8 solar masses)

- Mass loss

 - Bipolar outflow

 - Strong winds

- Supergiants

 - 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 I - White Dwarf pushed over Chandrasekhar limit

 - Type II - Large Mass star core collapse

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 – depends only on mass

- Tidal effects

- Detection of black holes

Unusual objects

PSR 1913+16

- Neutron Star binary system

- Confirms general relativity

Cygnus X-1

- X-ray source

- Accretion disk

- Likely black hole

XTE J0929-314

- “Black Widow” system

Magnetars

Quark/Strange Stars