

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

Hypernovae – 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