Lower Limit to Stellar Masses $\geq 0.08 \text{ Msun}$

Substellar objects – Brown Dwarfs
Evolution of Low Mass Stars -- like the Sun $< 2 - 3$ Msun
Post Main Sequence Evolution -- the Red Giant Stage
The Sun as a red giant

Comparison in size of Sun as a main sequence star and a red giant

Sun as a main sequence star

Sun as a red giant, $R = 100 \ R_\odot$

The Sun

The Earth

Red Giant
Second Red Giant Stage -- the Asymptotic Giant Branch (AGB)
Post AGB, Planetary Nebulae and White Dwarfs -- final stage for the Sun
White Dwarf stage – Nuclear reactions extinguished, weight of star supported by electron degeneracy.
Observations – Sirius A and B
White Dwarf Properties

Sun as a WD  \(~ 0.5 – 0.7\) Msun

Size  \(~ 2\) R earth

Density  \(10^6\) gm/cm\(^3\)

Compare with

Mean density of Sun  \(1\) gm/cm\(^3\)

core of Sun  \(100\) gm/cm\(^3\)

density Earth  \(5.5\) gm/cm\(^3\)

Chandrasekhar Limit  \(1.4\) Msun  -- upper mass limit for electron degeneracy

Size depends on mass of WD
Novae – white dwarfs in a close binary system

Companion either red giant or red dwarf
Evolution of the Most Massive Stars -- \( \sim \geq 10 \) Msun

He-burning begins as a red supergiant, no electron degenerate core

He \( \rightarrow \) C, O, C, O \( \rightarrow \) heavier elements up to Fe, as a red supergiant or successive transits across HR diagram
Most massive stars are unstable, lose mass, some in high mass loss events.
Massive Stars – final stages (days!)
Enrichment of the Interstellar Medium – abundances of the elements

Thousands of SNe seen 1936 – 2014 but in other galaxies

Rate 1 -2 /galaxy/100 yrs

Relative abundance of the elements in the Universe. Abundances are scaled so that silicon (Si) = 10000. From Mason (1968).
Historical Supernovae in Milky Way and supernova remnants

Crab Nebula – 1054
Tycho’s 1572
Kepler’s 1604
Supernovae remnants

The Veil Nebula

The Crab Nebula -- 1054

Cas A – Tycho’s
Naked-eye supernova – 1987A -- not in our galaxy --- LMC
The Importance of the Crab Nebula