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 $\sim 0.5 - 0.7$ Msun
Size $\sim 2$ R earth
Density $10^6$ gm/cm$^3$

Compare with
Mean density of Sun 1gm/cm$^3$
core of Sun 100gm/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 -- \( \geq 10 \) 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
Betelgeuse

Antares

Sun (1 pixel)

Jupiter is invisible at this scale

Sirius

Pollux

Arcturus

Rigel

Aldebaran
Most massive stars are unstable, lose mass, some in high mass loss events.
Massive Stars – final stages (days!)

Supernova!
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