How a Star Evolves to Become a Core-Collapse Supernova

- Born onto the main sequence with $M > 8 \, \text{M}_\odot$.
- Lives a short main-sequence life (< 40 million years).
- Evolves to become a supergiant (i.e., Betelgeuse).
- Very rapidly fuses heavier and heavier elements until a core of iron is formed, perhaps $\sim 1.5 \, \text{M}_\odot$, size of Earth.
- Iron nucleus (26 protons) is the most stable nucleus; no further fusion to heavier elements is possible.
- Core supported by electron degeneracy pressure and thermal (heat) pressure.
- Incredibly high core densities are reached, squeezing protons and electrons together to form neutrons and releasing neutrinos: $p^+ + e^- \rightarrow n + \nu_e$.
- With electron degeneracy pressure no longer supporting core, catastrophic collapse ensues, in less than a second collapsing down to size of small city.
- Neutron degeneracy pressure halts collapse of inner core.
- Collapsing outer regions slam into core, a shock wave develops that somehow manages to eject stellar envelope as a supernova.

Core-collapse (Type II) Supernovae

- Result from the core collapse and subsequent envelope ejection of massive stars (stars with initial main-sequence masses > 8 $\, \text{M}_\odot$).
- Produce a tremendous optical display, rivaling the optical light output of an entire galaxy for a short time.
- Release an enormous number of neutrinos at the moment of core collapse:

$$p^+ + e^- \rightarrow n + \nu_e$$

- Leave behind a very compact object, the dense corpse of the core of the once-massive star. This object is thought to be EITHER:

**Neutron star:** A star of extremely high density composed almost entirely of neutrons. Mass < 3 $\, \text{M}_\odot$. Thought to be produced by stars with initial mass < 40 $\, \text{M}_\odot$.

**Black hole:** A completely gravitationally collapsed object; a region of space from which neither matter nor radiation can escape. Thought to be produced by stars with initial mass > 40 $\, \text{M}_\odot$. 
Initial Observations of SN 1987A

• 1987 Feb. 23, 7:36 UT: Neutrinos observed.
• 1987 Feb. 23, 9:30 UT: Albert Jones, amateur astronomer observes LMC and sees nothing unusual.
• 1987 Feb. 23, 10:30 UT: Robert McNaught photographs LMC; when plate is developed, SN 1987A is there.

→ 20 hours later, Ian Shelton discovers SN 1987A.

Neutrinos arrived 2-3 hrs before optical light.

Types of Supernovae

Type Ia

Progenitor: Accreting white dwarf in binary system, nearing Chandrasekhar limit.
Explosion Mechanism: Thermonuclear runaway.
What remains: Disturbed companion star.

Type II

Progenitor: Red supergiant at end of nuclear-burning life.
Explosion Mechanism: Core–collapse and rebound.
What remains: Compact object, either a neutron star or, perhaps, a black hole.