The Southern Crab Nebula (He2-104), a planetary nebula (left), and the Crab Nebula (M1; right), a supernova remnant.
Once the giant phase of a medium-mass star ends, it exhales its outer layers, making a planetary nebula. The degenerate core is a white dwarf star.
In 1844 F. W. Bessel was investigating the proper motion and parallax of Sirius. He predicted that it had a faint, unseen companion.

In 1862 Alvan Graham Clark discovered this faint companion. It was the first known white dwarf star.
Sirius A and B at optical wavelengths (top left), and in X-rays (left).
In 1930 the young Indian physicist Subrahmanyan Chandrasekhar (1910-1995) discovered that a white dwarf star can have a mass no greater than 1.4 solar masses.
A white dwarf star is comparable in size to the Earth. More massive white dwarfs are smaller than less massive white dwarfs.
Three routes to an end state:

less than 0.4 solar masses – because they are fully convective, they use up all their mass slowly converting H to He. Do not become red giants.

0.4 to 8 solar masses – lose mass due to stellar winds during giant phase, exhale atmospheres (which become planetary nebulae), leave white dwarf remnant at center of planetary nebula.

8 or more solar masses – explode as Type II supernovae, leaving behind black holes, neutron stars, or pulsars.
Occultation of Venus by the Moon, 19 June 2020
Somehow or other, intermediate mass stars “know” they must shed sufficient mass to have less than 1.4 solar masses.

Ferrario et al. (2005)
This nearly spherical planetary nebula has a low-luminosity outer envelope and a highly excited inner region.
Ring Nebula in Lyra (M 57). Note white dwarf in center.
Slow stellar wind from a red giant

The gases of the slow wind are not easily detectable.

Fast wind from exposed interior

We see a planetary nebula where the fast wind compresses the slow wind.
Three lovely planetary nebulae.
More planetary nebulae.
Close binary stars have different evolution than single stars. Mass can be passed from one star to the other.
As the more massive star swells to become a red giant, a lot of mass can be transferred to the formerly less massive star. Ironically, the originally less massive star can be the one to reach its end state first.
The star Algol (β Persei, marked with pink arrow) is an eclipsing binary in which the original less massive star has evolved to become a red giant, which the original more massive star is still on the main sequence.
Material from the accretion disk in a nova (or dwarf nova) settles onto the white dwarf. This can lead to periodic explosions in the system.
SS Cygni is a dwarf nova that has an outburst just about every 52 days. In the upper image at left it is in its faint stage. In the lower image at left it is having an outburst.
Stars with 8 or more solar masses end up with a many-layered structure, eventually with an iron core.
The Crab Nebula in Taurus is a SN remnant of an object visible in the year 1054.
Iron is the mostly tightly bound nucleus. Nuclear reactions to form heavier atoms would use up more energy than they would produce. The outer layers squeeze down onto the iron core and the star explodes as a Type II supernova.
SN 1987A was the explosion of blue supergiant star in the Large Magellanic Cloud, a satellite galaxy of our Milky Way.

*Neutrinos* from this explosion were detected on the Earth.

As the ejecta of the SN plow into the interstellar medium, an expanding ring of shocked gas is observed.
Spectrum of the Type II SN 2003hn. At least four emission lines due to atomic hydrogen are visible.
Infrared and optical light curves of the Type II-P SN 2003hn.
We can find many supernova remnants in our Galaxy.
There are two basic ways to make a supernova:

1) explosion of a single massive star

2) mass transfer to a white dwarf star (If the mass of the WD approaches 1.4 solar masses, the star explodes.)

Supernovae with hydrogen emission in their spectra are called Type II. They are explosions of single, massive stars.

Supernovae without hydrogen emission, but with silicon absorption are Type Ia SNe. They are explosions of C-O white dwarf stars.
Note how similar the spectra of these two Type Ia supernovae are!
Type Ia supernovae have very similar light curves in the B-band and V-band. But the objects that are brighter at maximum light have light curves that decline more slowly.
Optical light curves of the Type Ia supernova 2004S
The “decline rate” is the number of magnitudes that a Type Ia supernova gets fainter in the blue band over the first 15 days after maximum brightness. Faster decliners are less luminous. The objects are standardizable candles.
The absolute magnitude of Type Ia SNe is correlated with two measures of the “decline rate”.

Burns et al. (2018)
The top 4 SNe shown here are intrinsically brighter than the bottom two. The top 4 peak in the near-IR a couple days prior to the time of $B$-band max. Note the different strengths of the secondary maxima.
Because Type Ia supernovae are so bright (4 billion times brighter than the Sun!) and because we can determine their absolute magnitudes, we can use them to determine distances to galaxies halfway across the visible universe.