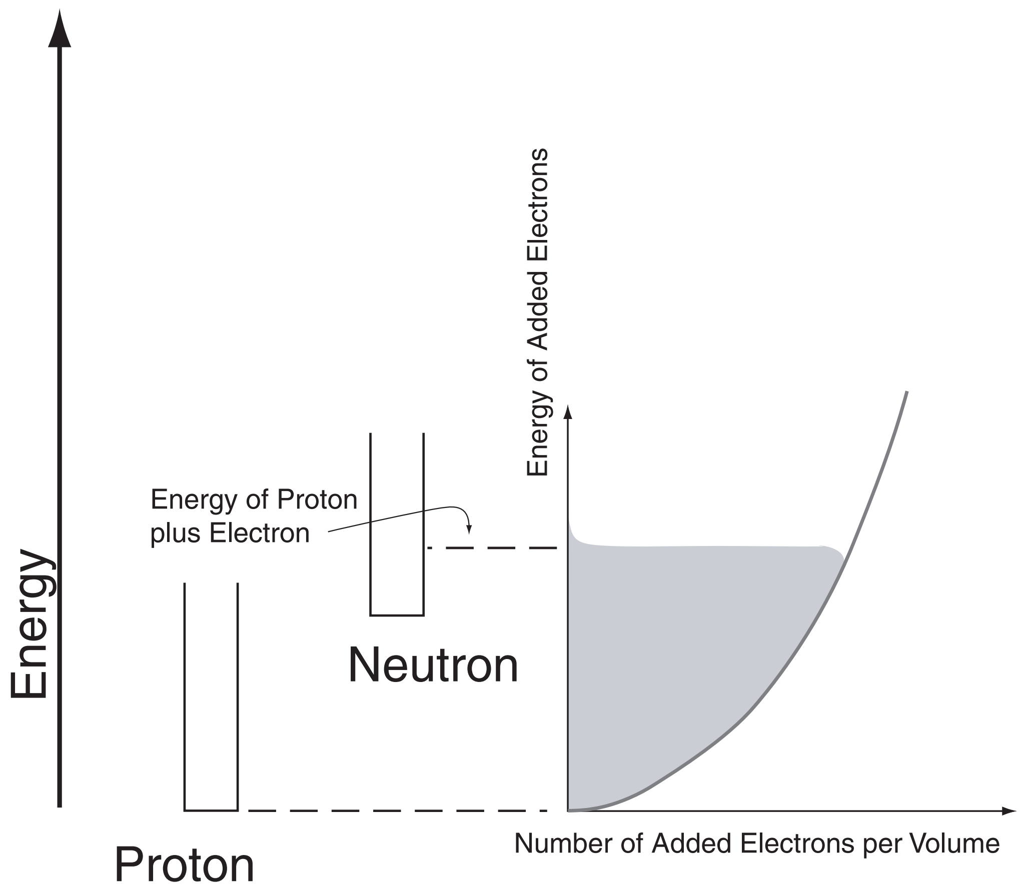
The formation of neutron stars or black holes

The laws of special relativity cause the density at the center of the white dwarf of increasing mass or the quantum pressure supported core of a red giant evolving to the top of the red giant branch to increase without bound. As a consequence, the radius of such an object tries to become zero while the density tries to become infinite. These limits cannot actually be reached and other physical effects intervene. The key new things that happen are:

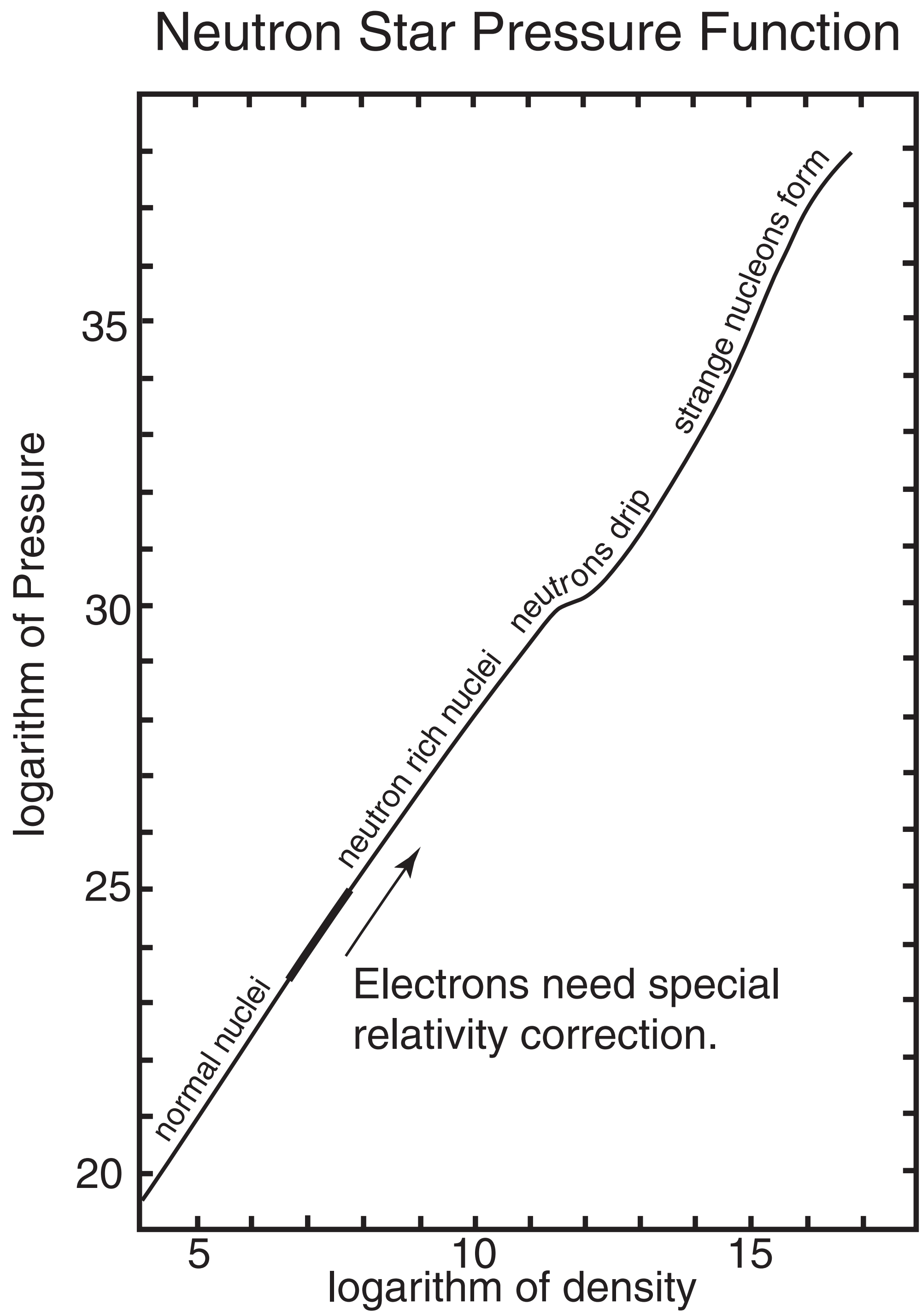
- The increasing energy of the electrons providing the quantum pressure modifies the nature of other nuclear species.
- At first some protons inside the dominant nucleus, which by this time is Iron, capture some of the high energy electrons and become converted to a neutron rich form of Strontium.
- Continued increase in the density produces ever more neutron rich nuclei to form leading to very high mass isotopes of the elements.
- At some point the neutron rich nuclei begin to drip neutrons out into the remaining space between the nuclei.
- Further increases in density yield a neutron gas which itself experiences the quantum pressure effect.
- For a range of masses, the quantum pressure from the neutrons can yield a stable star called a Neutron Star.
- The neutron star has the same special relativity effect on the neutron quantum pressure so that it too decreases its radius as its mass increases.
- The neutron star is very close to another critical radius called the Schwarschild Radius where no particle can escape. This critical radius is where a Black Hole forms.

Neutron Star Formation

The effect of the electrons on the state of Protons and Neutrons.



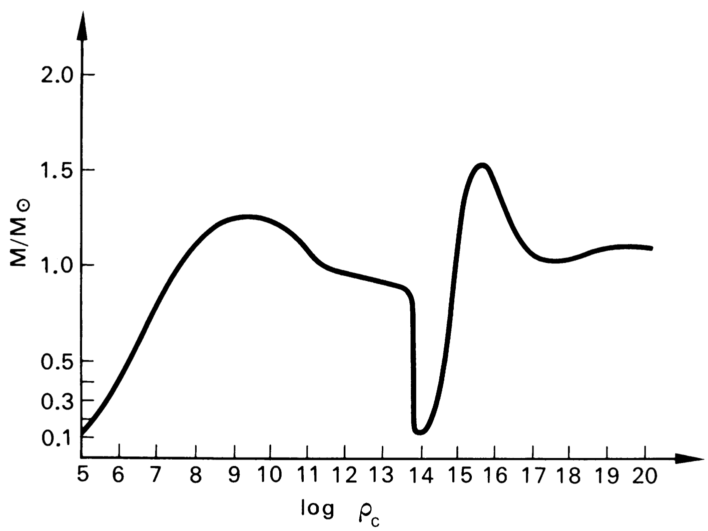
When the electrons have enough energy they can force the protons to become neutrons. This ultimately leads to the formation of Neutron Stars.



This plot shows the growth of the pressure as the density increases. The change is the slope across the boundary where special relativity effects influence the electron pressure is slight but is enough to produce the drop toward zero radius. The neutron drip is a big change and causes the rapid collapse of the star. At the upper end, the strange particle effects are poorly understood and the curve becomes very uncertain.

The Relationship between Mass of a Quantum Pressure Supported Star and the Density at its Center

The pressure as a function of density is a unique relationship as long as the temperature is small. Consequently, for each central density we can calculate the mass of the star which would be a white dwarf or neutron star. This result is shown below:



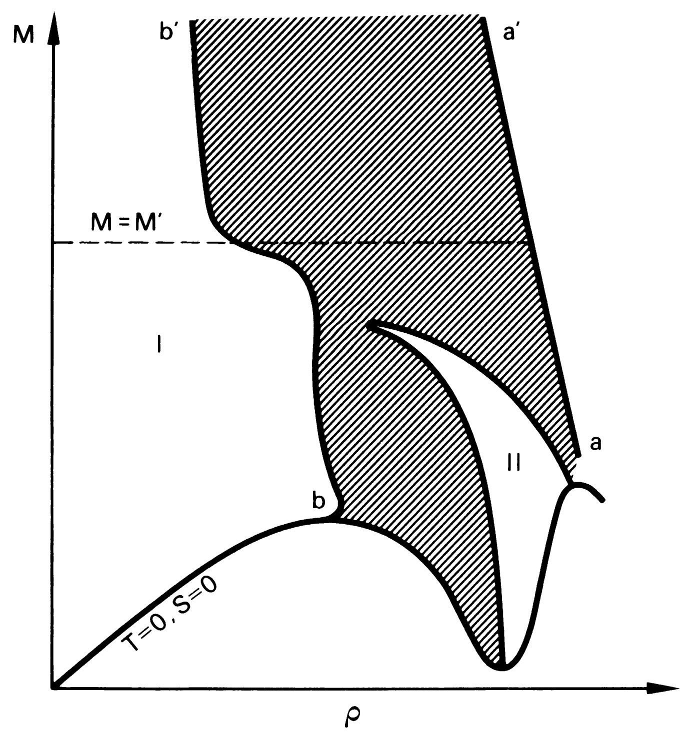
- The mass grows as the central density increases for the White Dwarfs which are found on the left.
- The curve turns over at its first peak because the electrons are being removed by forming neutrons. This means there are few electrons per gram of matter leading to less pressure.
- When the neutrons begin to drip out, there is a rapid conversion of the remaining electrons and the pressure drop leads to a zone of very low mass stars.
- In the region where the mass of a stable star decreases as the density increases, the star is unstable and will contract very quickly, essentially as a free fall.
- The return of the pressure support from the neutron quantum pressure leads to another group of objects which are the neutron stars.

The Formation of Neutron Stars with Higher Mass Stars

We have discussed those stars dominated by quantum pressure. These tend to have lower initial masses. For the higher mass case, the nuclear conversion follows the same sequence: Hydrogen ⟶ Helium ⟶ Carbon/Oxygen/Neon ⟶ Magnesium/Silicon ⟶ Iron. After the production of Iron, there is no additional source of fuel and the mass of the central region is quite large.

The compression of the central region raises the temperature and causes the Iron to evaporate into its constituent parts which are mostly Helium nuclei.

The loss of the thermal energy due to Iron evaporation causes an immediate collapse of the core toward very high densities. We encounter the same neutron star pressure function and have to consider again the mass as a function of central density. This time the gas is hot and we can get some new results:

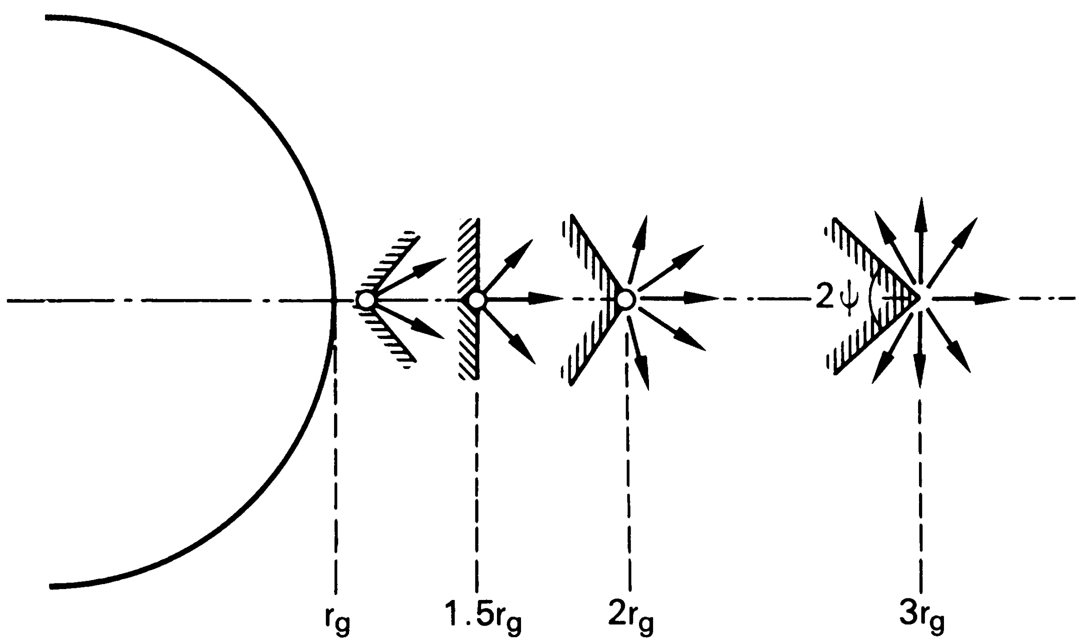


The finger of white area extending to higher mass represents a set of stable hot stars. The collapse of the star center can bounce off this solution and cause the supernova outburst.

The Formation of Black Holes

- The bounce at the center of a collapsing massive star is not assurred.
- Uncertainties in the pressure at the highest densities make it possible for the collapse to overrun the support density and become a black hole.
- The outer layers of the star may be blown off in either case.

Near the black hole, we can describe the motions of photons as below:



The sketch shows the directions that photons emitted by a point outside the black hole can escape to free space. As the point gets closer to the Schwarzschild Radius, the cone of escape narrows until finally it closes and no photons can escape.