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ILT 2 WEEKS 11–12

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1. ON THE WHITE DWARF MASS LIMIT AND S. CHANDRASEKHAR

Subrahmanyan Chandrasekhar (1910–1995) was born into a Brahmin family in Lahore, then India. At the age as early as 21, he was responsible for deriving a theoretical mass limit an ideal white dwarf star can achieve without collapsing in on itself, now referred to as the Chandrasekhar limit, and accepted at 1.39 $M_{\odot}$. This was one of the most important discoveries in the 20th century as it paved the way for better understanding of the processes occurring during the collapses of degenerate stars that may lead to such phenomena as black holes – ingredients crucial for the development of our modern cosmological theories. Without venturing too deep into the underlying physics, Chandrasekhar limit implies that a very massive star at the end of its life will collapse, probably into a then only theoretical black hole, if it exceeds a certain limit. This is explained by the electron degeneracy pressure supporting it from the inside being unable to balance the star's own gravitational force. The limit gave rise to a notable controversy because Sir Arthur Stanley Eddington, famous for embarking on a campaign to popularize relativity at that time, was heavily opposed to the notion of existence of black holes. The first persons to suggest white dwarfs may have a mass limit, however, were Wilhelm Robert Karl Anderson (1880–1940), a German-Estonian astrophysicist born in Minsk, in what is now Belarus, and Edmund C. Stoner (1899–1968), one of the most distinguished theoretical physicists of the 1920's who is principally known for his work on ferromagnetism. Other prominent minds were of no less importance for deriving this limit.

The origins may be traced back to 1924 when Stoner published a paper in *Philosophical Magazine* called "The distribution of electrons among atomic levels" that played an important role in the formulation of the exclusion principle by Wolfgang Pauli. Two years later, a British physicist and astronomer Ralph H. Fowler (1889–1944) suggested that Pauli's principle may explain the extreme density of matter found in stars such as the companion of Sirius. He writes that the density of such "energetic" matter is only limited *a priori* by the "sizes" of electrons and atomic nuclei (Fowler 1926). A new equilibrium should, then, ensue due to the electron degeneracy pressure supporting the white dwarf after all nuclear reactions in its core have ceased. In a paper following that, Stoner (1929) attempts to establish properties of such equilibrium, as proposed by Fowler, and plants the first seeds for the notion of the white dwarf having mass limits by calculating the density limits of degenerate matter in such stars which increases with the square of mass (Nauenberg 2008). In the paper published November the same year, Anderson (1929) indicates that the principle described by Stoner implies a maximum value of the mass and derives a limit of $\sim$0.69 $M_{\odot}$. The figure based on a more solid theoretical grounds followed shortly in the work by Stoner (1930) where he derived correct relativistic equation of state and the limit of 1.10 $M_{\odot}$.

In his paper, Chandrasekhar (1931) refers to works by Fowler and Stoner (of 1929) in the first paragraph where he also declares an attempt of arriving the density limit "from different considerations." This comes from Chandrasekhar's realization that the upper levels of degenerate electron gas are relativistic, that is, a density change $\Delta\rho$ and pressure change Δp are related by $\rho\Delta p/p\Delta\rho = 4/3$, as opposed to nonrelativistic approach (equals 5/3) employed earlier by Fowler (Parker 1997). Another paper of his appearing in *The Astrophysical Journal* derives the limit of 1.10 $M_{\odot}$ which is in perfect agreement to the Stoner's result (Chandrasekhar 1931). While some sources state that Chandrasekhar was a year late, It is worth noting that Chandrasekhar's article is dated November 12, 1930 (Trinity College, Cambridge) that claims more of a simultaneity with the work by Stoner.

Further study on the subject has followed by Chandrasekhar, Stoner, Milne, Landau as the limit has been refined, and it would be difficult to provide a complete overview within this ILT response. It can be concluded that Chandrasekhar has derived the limit from the insight of the relativistic treatment of degenerate matter in white dwarf stars which originates in earlier publications from authors mentioned above (Blackman 2011). Some interesting aspects on Chandrasekhar's biography and character in relation to this period can be found in Miller (2005). In Chandrasekhar's Nobel prize acceptance speech of 1983, no single reference was included to Stoner (Nauenberg 2008).

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