Internal Constitution of Neutron and Strange Stars*

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The weakest force—gravity—binds a nucleon in a neutron star 10 times more strongly than the strong force binds a nucleon in a nucleus. In doing so it works against the strong short-range repulsion of the nuclear force and against the Fermi pressure. Gravity therefore brings the Pauli principle into play in distributing the conserved baryon number of the star over many baryon species so as to reach the ground state of charge neutral matter. The name "neutron star" therefore has to be understood as a generic name for a star populated by many baryon species, also by quarks and also a mixed phase of confined and deconfined matter, that as I will discuss, arranges itself in a very intricate pattern in the deep interior of the star.

I will discuss several consequences of the rich constitution of compact stars: (1) a mechanism for the formation of low-mass black holes ($M \sim 1.5 - 2M_\odot$), (2) a multi-layered crystalline structure of confined and deconfined quark phases and (3) the effect of a quark core on the braking index of pulsars as well as the general effect of rotational distortion on the inferred magnetic fields and spin-down times of millisecond pulsars.

In this paper we explore possibilities—not certainties. The properties of matter at densities higher than nuclear are essentially unknown, although they are the subjects of investigation at several ultra high energy accelerators. Essentially all we can be fairly confident of are: (1) the equation of state of dense matter obeys the condition of causality, (2) the equation of state also obeys the condition of microscopic stability ($dp/d\rho \geq 0$) known as Le Chatelier's principle and (3) at sufficiently high density, asymptotic freedom of quarks is achieved. Beyond this, a theory of dense matter ought to be firmly anchored to what is known at nuclear density. Within these constraints we explore what is allowed by the laws of physics, in the belief that the laws of nature are likely to be realized in many if not all possible ways in the universe. The vehicle for the exploration is a covariant nuclear field theory that embraces the above constraints [I].

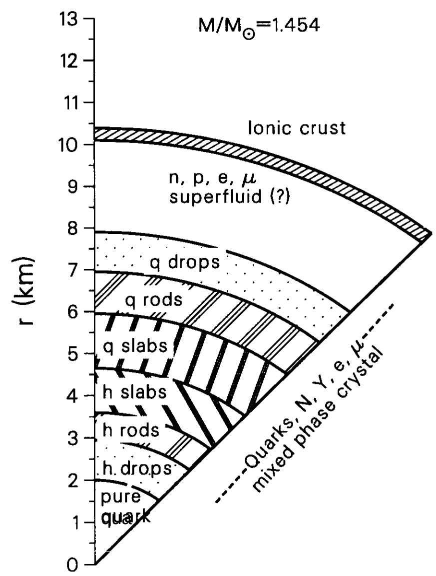

Figure 1: Pie section of a hybrid star (nuclear matter outer region enclosing a solid mixed phase and pure phase of quark matter) showing regions of quantum liquid (white areas) and solid regions of various geometric phases [2]. Notation 'q drops' means quark droplets immersed in nuclear matter, etc.

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[1] N. K. Glendenning, Astrophys. J. **293** (1985) 470.

[2] N. K. Glendenning, *COMPACT STARS, Nuclear Physics, Particle Physics, and* General Relativity (Springer–Verlag New York, 1997).