## Astrophysics

# Softening of neutron stars

*from Philip J. Siemens*

ADVANCES in particle physics in the past decade have not only clarified our view of the structure of matter and vacuum at very tiny distances but have also revolutionized our picture of the cosmos. The most striking implications have been drawn from studying the first microsecond of the Universe, before the fundamental quanta—quarks and gluons—coalesced into the heavy neutrons and protons which, with the lighter electrons and photons, make up most of the matter in our world today. In a recent paper[1], astrophysicists from Copenhagen, Krakow and Illinois extend these implications to include current dynamic processes in our Universe. They conclude that supernovae are more likely to produce black holes than had been thought, and less likely to produce the more readily observed pulsars or neutron stars. Indeed, pulsars are observed in only a few supernova remnants[2].

Kutschera, Pethick and Ravenhall trace the paucity of neutron stars to the inability of their material to resist the crushing force of gravity[1]. A neutron star is formed when a star about ten times as massive as our Sun has burned all its nuclear fuel. Without the outward pressure of heat and light from nuclear power to counteract the inward pull of its own gravity, the star collapses until the neutrons and protons in its interior bump into each other. Their collisions produce a shock-wave of pressure which travels outwards through the star, blowing the surrounding material into space in a spectacular explosion known as a supernova. About a tenth of the star's mass is left in the middle of the explosion, within a radius of about ten kilometres. Whether this remnant becomes a pulsar or a black hole depends on its mass and on the strength of the material of which it is made. If the neutrons and protons are able to resist being crushed into each other by the enormous gravitational pressure, the remnant will become a neutron star (eventually, nearly all the protons absorb electrons to become neutrons), its rapid rotation giving rise to the pulses of radiation by which the pulsar is identified. If gravity wins, the remnant keeps on collapsing until its gravity becomes so intense that it becomes a black hole, cut off from the rest of the universe. For the heaviest remnants, gravity wins; for remnants as light as our Sun, the neutron star is stable. The new study places the dividing line at about 1.5 solar masses compared to about 2 estimated from previous work.

The conclusion that neutron-star matter is softer than previously believed follows from a new picture of what happens when neutrons are crushed together under pressure. This, in turn, is based on a radical concept of neutrons. In older theories, a neutron is either taken as a fundamental, indivisible particle or (more recently) as a group of three such particles (quarks), bound together by strong interaction fields of force (gluons). In each case the particles are specified while their interactions are described by wave-fields of force around them. In the new picture, the fields are the main 'objects', while the particles are solitons or solitary waves, representing kinks in the field. These kinks arise as localized singularities when the field, which extends over all space, is thought of as a mapping of each point in space and time into a manifold characterizing the field. This manifold consists of all possible combinations or various mixtures of the different kinds of 'flavours' of field. The solitons are places where the fields change abruptly. Various types of solitons are possible, depending on the topology of the manifold of fields. The neutron-star computation uses a theory with four fundamental fields, known as the chiral field theory; together with its equations of motion and the identification of its singularities as neutrons, protons and other particles, this theory is known as the 'chiral soliton model'. It was invented over 25 years ago by T.H.R. Skyrme[3,4] and chiral solitons are now sometimes known as 'skyrmions'.

Considered a mere curiosity when it was introduced, the chiral soliton model has drawn much attention since Witten[5] connected it to the modern gauge-field theory of quarks and gluons, known as quantum chromodynamics or QCD. This has many more fields than the chiral soliton model and has its own elementary particles as well; nevertheless, Witten showed that Skyrme's model is a correct approximation to QCD for experiments which do not probe too deeply into the interior of the neutron. Unfortunately, another approximation has to be made to obtain Skyrme's model, which corresponds to setting the pi meson's mass to zero. True pi mesons, the primary agents that bind atomic nuclei together, are, however, not massless.

Many nuclear theorists are working to improve the model so that it accounts correctly for the attractive forces that bind nuclei as well as the repulsion that stabilizes neutron stars. The computation of neutron-star matter using skyrmions shows how to apply QCD to the Universe's largest nuclei, neutron stars. It is an important step towards an understanding of the structure of atomic nuclei. □


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## Primatology

# First fossil tarsier from Africa

*from R. D. Martin*

IN THE evolutionary tree of primates, the tarsiers (*Tarsius* spp.) occupy a special position. These diminutive, nocturnal primates, weighing approximately 150 g, are generally thought to be intermediate between the other prosimian primates (lemurs and lorises) and the simian primates (monkeys, apes and man). There is, therefore, considerable interest in their ancestry and in the relationship between surviving and fossil tarsioids. In that respect, a fossil described on page 475 of this issue comes as a major surprise to primate palaeontologists.

Hubrecht, the father of modern comparative embryology, noted in 1908 that tarsiers share with simians a particular form of invasive (haemochorial) placentation. Ever since, evidence has gradually accumulated to suggest that tarsiers and simians share a specific common ancestor. Living tarsiers share with living simians a whole suite of morphological similarities, including features of the brain, major sense organs and skull structure. It has also been found that tarsiers resemble simians in chromosomal and biochemical terms.

In a major review of the morphological evidence in 1981, Pocock noted that whereas lemurs and lorises, like other mammals, have an area of naked, moist skin (the rhinarium) surrounding the nostrils, tarsiers and simians (alone among land-living mammals) have lost all visible trace of this structure; their nostrils are surrounded by hairy skin and there is a true face. Pocock suggested a fundamental division of the primates into Strepsirhini (lemurs + lorises) and Haplorhini (tarsiers + simians). Although it is still not universally accepted that tarsiers are the closest living relatives of simians, the consensus of opinion is increasingly moving in that direction and numerous authors have found it convenient to split the living primates, at least, into 'strepsirhines' and 'haplorhines'.

Despite their particularly interesting intermediate position in the primate evolutionary tree, tarsiers are still quite poorly known, largely because of their very limited geographical distribution. The three