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STRANGE MATTER, DETONATIONS AND SN 1987A

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RESUMEN. Para vencer las dificultades presentes en el mecanismo de explosión de supernovas del tipo II (el cual creemos tiene un origen profundamente físico y no computacional) proponemos un escenario inducido por una formación de materia extraña en un medio de material de alta densidad nuclear. Esto muestra que la energía de materia extraña puede bastar para impulsar una onda de detonación que alcance $\sim 10^{51}$ erg la cual es del orden de magnitud esperado para la energía emitida por estos eventos. La emisión de neutrinos de SN 1987A detectada por el grupo de Kamiokande se interpreta naturalmente como una señal del proceso bosquejado. Se discute la presencia de una estrella extraña en lugar de una estrella de neutrones como un remanente compacto para supernovas de tipo II y su compatibilidad con el descubrimiento de un inesperado pulsar rápido PSR 1987A. Si este mecanismo operaba en supernovas de tipo II, las estrellas de neutrón no existen, sino que estos objetos están compuestos de materia extraña.

ABSTRACT. In order to overcome the present difficulties of the type II supernova explosion mechanism (that we believe have a deep physical and not computational origin) we propose a scenario driven by strange matter formation in a high density nuclear matter medium. It is shown that strange matter energetics could suffice to drive a detonation wave that carries $\sim 10^{51}$ erg which is the right order of magnitude expected for the energy outputs of these events. The SN 1987A's neutrino emission detected by Kamiokande group is naturally interpreted as the signal of the sketched process. The presence of a strange star instead of a neutron star as a compact remnant for type II supernovae, and its compatibility with the discovery of the unexpectedly fast pulsar PSR 1987A is discussed. If this mechanism operated in type II supernovae, neutron stars do not actually exist, but these objects are instead composed of strange matter.

Key words: SHOCK WAVES — STARS-SUPERNOVAE

I. INTRODUCTION

Up to now there are two plausible mechanisms that can be responsibles for type II (massive progenitors) supernova explosions. These are the prompt shock (hydrodynamical bounce of infalling matter, Colgate and Johnson 1960) and the delayed shock (revival of the stalled prompt shock by neutrino heating, Bethe and Wilson 1985). Neither one has been conclusively successful in numerical simulations, and their final success is critically dependent on some physical properties of matter which are not straightforwardly deduced from available experimental data, Typically, the reports of simulations that render strong explosions are followed by negative reports when more careful analysis and input physics are considered. Therefore, this suggests that it is not only a matter of the acurateness of the complex numerical simulation, but it may well happen that the included physics is not complete.

We have proposed (Benvenuto, Horvath and Vucetich 1989) that the physical process originating the successful shock is the deconfinement of quarks at high density, forming an hypothetical self-bound state known as strange matter (Witten 1984). Strange matter is a collection of up, down and strange quarks, gluons and electrons whose energy per particle is very likely to be lower than nuclear matter one, thus being a preferred state at any density and temperature and opening the possibility of an energy source of subnuclear origin when deconfinement occurs. Ordinary matter would not turn into strange matter because of the difficulty for creating many strange quarks by simultaneous decays, but the formation of the lower energy state is very likely as we compress the normal matter, raising the Fermi levels μ_i until the strangeness barrier is overcomed. Once formed, strange matter will convert all the surroundings to more of itself releasing $E_b \sim 10$ - 20 MeV per converted particle (Farhi and Jaffe 1984).

II. THE MODEL

How this phase change can help to blow off the outer layers of a massive star is depicted in the following sequence of diagrams.

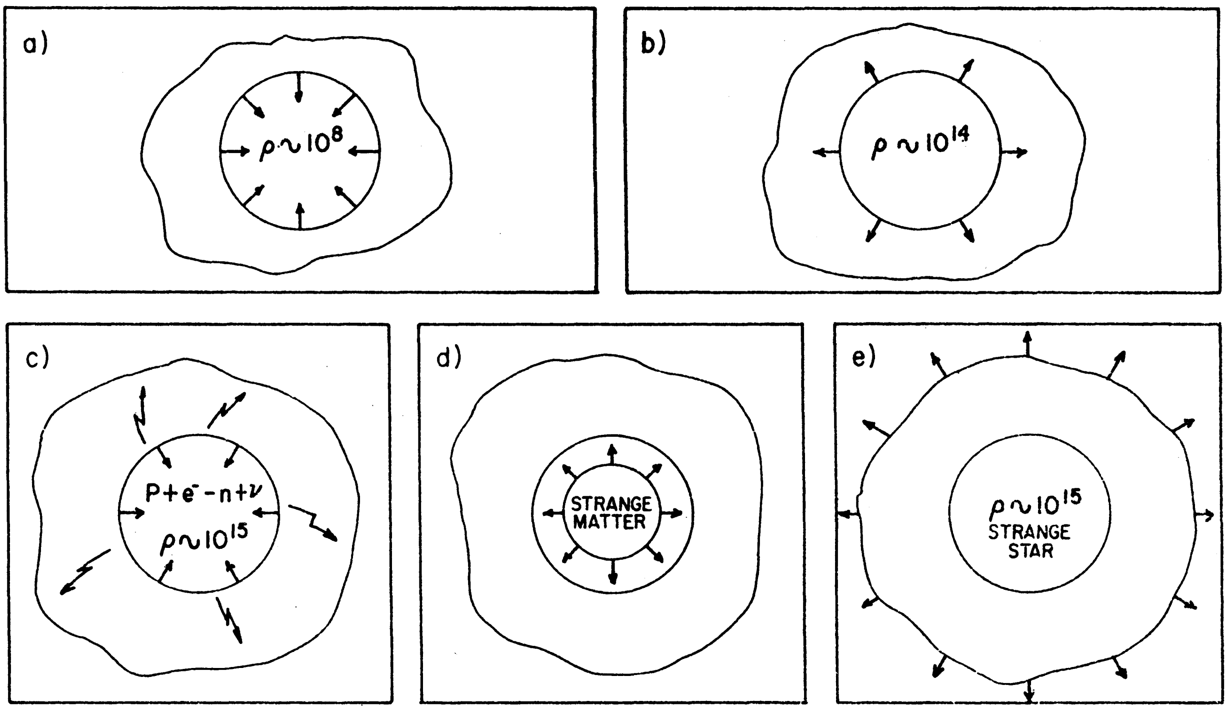

Fig. 1. a) Beginning of collapse; b) failed prompt shock; c) Neutrino emission, recollapse and full neutronization; d) phase transition and detonation; e) Supernova outburst.

Each stage of the evolutionary process (which lasts ~ 10 sec) is briefly described as follows.

Stage 1: When the ^{56}Fe core exceeds the Chandrasekhar mass (~ 1.4 M$_\odot$), the collapse starts until the central region of the star reaches densities above the saturation one ($2.7\ 10^{14}$ gr/cm^3)

Stage 2: Due to the stiffening of the nuclear matter equation of state, a shock discontinuity builds at mass coordinate 0,8 M$_\odot$ as a result of the bounce of matter falling onto the stiff inner core. The shock begins to propagate outwards and finds iron nuclei in its path. The break up of this highly bounded nuclei ($1.7\ 10^{51}$ erg for each 0.1 M$_\odot$ of iron) plus the energy loose by neutrino diffusion quickly damps the shock which stalls outside the inner core at R$\sim$100 Km.

Stage 3: The huge energy release in the form of neutrinos ($\sim 10^{53}$ erg) diffusing out the central region helps to avoid a recollapse that would form a black hole, Meanwhile, as the escang neutrinos cease to contribute to the pressure inside the iron core, the density raises subs ntially and a full neutronization is achieved.

age 4: Either by a direc crossing of the deconfinement threshold or by quantum fluctuations at locally enhace the value of the density, a two flavor (up and down) quark matter appears, laxing on a weak interaction timescale to strange matter with the consequent energy release. e small converted region has nevertheless a large pressure difference with respect to the nor l matter surroundings. It can be shown (Landau and Lifshitz 1959) that this situation trigg- s the propagation of a detonation wave (fast combustion mode) outwards. In this process, very r from equilibrium, neutrons are eaten by the detonation front and the released E_b helps to rther propel the propagation. Due to conservation laws it can be shown that the detonation nnot propagate when the density is lower than 1.8 times the saturation one, thus becoming a andard shock wave in neutron matter.

age 5: When this shock reaches the edge of the original iron core, collides with the stalled ompt shock transferring enough energy to sweep off the mantle and envelope of the star. The mpact remnant is completely converted to strange matter by turbulent convection (Horvath and nvenuto 1988) and after a short transient it settles down as a strange star (possibly a stran pulsar, see Benvenuto and Horvath this proceeding).

I. THE SN 1987A DATA AND THE MODEL

Simple analytical models of this process support the presented sequence and show at a full numerical simulation is likely to render a successful type II explosion. It should noted that this theory predicts a time gap between the prompt neutrino signal (stage 3) and e neutrinos arising from the reactions

$$d \longrightarrow u + e^- + \nu_e$$

$$u + e^- \longrightarrow d + \nu_e$$

ring stage 4 which stream out in the stage 5. The detections from Kamiokande group (Hirata et . 1987) do show a time gap of 7 sec between first and late events which has no explanation in andard collapse models (although it has been claimed that this gap is due to small number sta stics, Arnett et al. 1989). This cannot be interpreted as a definitive proof in favor of our cture but may give some support to it until a galactic type II supernova can be observed. As e neutrino detection scales as R^{-2} with the distance to the source, a galactic supernova whe $\sim 10^4$ neutrinos should be detected will be enough to confirm or dismiss a bimodal temporal stribution as the predicted by this model (Benvenuto and Horvath 1989).

Further evidence for an unexpected behaviour of the high density matter has been ported by Kristian et al. (1989). The detection of an ultrafast pulsar in SN 1987A puts seve constraints on the nuclear matter equation of state in order to explain this observation as e rotation of a compact star. In fact it has been shown that only extremely soft equations state can stand such rotation (Friedman, Ipser and Parker 1989), but are marginally succes- l to explain the observed mass of the slowly rotating binary pulsar PSR 1913+16 (1.444 $M_\odot$) d cannot explain the 1.85 ± 0.30 $M_\odot$ mass of 4U0900-40. Moreover, the central densities of the- models are all above 12 times the saturation density, far in excess the neutron close pack nsity, and thus cannot be composed of neutron matter (Glendenning 1989). It has been shown at strange matter models of pulsars can support a 0.5 msec period of rotation and this means at the confirmation of the pulsar observation would be a strong evidence in favor of strange tter inside this object and therefore support for the presented origin.

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