THE EVAPORATION OF STRANGE MATTER IN THE EARLY UNIVERSE

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A new candidate for the dark matter of the universe is strange matter.[1] This substance consists of roughly equal numbers of up, down and strange quarks confined in a quark phase which is conjectured to have a lower energy per baryon number than ordinary nuclei. Strange matter is absolutely stable, has a density comparable to that of nuclei and can exist in lumps ranging in size from a few fermis to ~ 10 km. If it is distributed in space in lumps larger than ~ 1 cm, it could close the universe without ever encountering the earth and would be astronomically unobservable.[2]

A lump of strange matter contains ordinary quarks (up, down and strange) and gluons plus a small component of electrons to guarantee charge neutrality. The hadronic material is in a "quark phase" in which nucleons and mesons do not exist and the quarks are free to roam within the lump.[3] Witten[1] suggested that this form of matter could be absolutely stable. A detailed study[3] has shown that within the uncertainties inherent in a strong interaction calculation, the existence of stable strange matter is reasonable.

Witten[1] also outlined a scenario for the production of strange matter in the early universe. The production occurred when the universe cooled through the QCD phase transition at a temperature T_C (roughly, 100-200 MeV). Witten's scenario has been criticized[4], but the physics involved is sufficiently complex that a clear determination of the outcome of the QCD phase transition is unlikely to appear soon. We avoided these uncertainties by examining the fate of lumps of strange matter at temperatures below 100 MeV, assuming that strange matter is formed during the transition.

The strange matter efficiently evaporates neutrons and some protons. The evaporation rate is very efficient, being limited primarily by the rate of heating by thermal neutrinos. We are able to strongly conclude that a lump of strange matter can only survive if its baryon number $A \gtrsim 10^{52}$.

This number is large in an important sense cosmologically. If we assume the universe is closed by baryons in either the strange or normal phase, then the mean baryon number in the particle horizon at these early epochs is ~ 10^{55} $(1\ \mathrm{MeV}/T_u)^3$. At T_u = 50 MeV this number is ~ 8×10^{49}, much smaller than the minimum baryon number of a lump which could survive. This means that the process that leads to the formation of strange matter lumps must involve large perturbations in the baryon number on the horizon scale. A mechanism for producing this perturbation is not known to us.

1. E. Witten, *Phys. Rev.* D30, 272 (1984).
2. A. DeRujula and S. Glashow, *Nature* 312, 734 (1984).
3. E. Farhi and R. L. Jaffe, *Phys. Rev.* D30, 2379 (1984).
4. J. Applegate and C. Hogan, Cal Tech preprint GRP032 (1984).

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