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PRODUCTION OF METASTABLE STRANGE-QUARK DROPLETS IN RELATIVISTIC HEAVY-ION COLLISIONS

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ABSTRACT

Of enormous consequence is the theoretical possibility that not only may multiquark S droplets with large strangeness be metastable, but large extended S matter might be absolutely stable. If indeed, the energy/baryon < 938 MeV for S matter, then this would provide the ultimate energy source. Thus the detection of the metastable S droplets in relativistic heavy-ion collisions would be of great interest. We have calculated the production probability of S droplets in heavy-ion collisions by fragmentation of quarks following formation of hot quark-gluon droplets. We proposed a very sensitive detection scheme (for the present fixed target heavy-ion BNL and CERN facilities) in which an S droplet interacts in a secondary target to produce many Λ's, a striking, readily identified signature. Here, we also discuss detectable consequences of neutron stars being S matter with essentially no crust, in particular, the possibility of a pulsed $\bar{\nu}_e$ flux from fast pulsars.

INTRODUCTION

Considerable theoretical interest[1-6] has focused on the intriguing possibility that not only may nuclear-density multiquark droplets (S droplets) with large strangeness be very long-lived[3] but large bodies of strange matter (S matter) might be absolutely stable[5,6]. Roughly, neglecting the strange-quark mass, m_s, the number of strange quarks n_s should be ≈ A, the baryon number, since $n_s = n_u = n_d$ in order to lower the Fermi energies of the u and d quarks. Chin and Kerman[3] calculated (using the MIT bag model) that S droplets with $A \gtrsim 10$ and $n_s/A \gtrsim 0.8$ would be metastable with lifetimes $\tau_s \gtrsim 10^{-4}$ sec. They proposed producing S droplets in relativistic heavy-ion collisions. Recently Witten[5] suggested that extended S matter with $n_s/A \sim 1$ might be absolutely stable, i.e., the energy/A < 938 MeV. Farhi and Jaffe[6] then, using a Fermi-gas model with α_c QCD corrections, showed that for a range of parameters (α_c and m_s) S matter could be stable. It seems certain that in the forseeable future QCD calculations will not be accurate enough to give a definitive prediction on the stability of S matter. Thus experimental tests are crucial and must be done since the consequences are of such enormity. A (positively charged) large A stable chunk of S matter would be the ultimate energy source; it would readily gobble up neutrons, increasing its size and giving off energy. Liu and I[7] calculated the production probability of S droplets in relativistic heavy-ion collisions. We proposed a very sensitive detection scheme (for the present fixed target relativistic heavy-ion facilities at BNL and CERN) in which an S droplet produced in the primary collision interacts in a secondary target to produce many Λ's The study of the properties of metastable S droplets should shed considerable light on the stability of S matter.

As noted by Witten[5], a consequence of the stability of S matter would be that "neutron" stars are really S matter with essentially no crust. Benford, Silverman and I[8] have shown that a fast strange matter pulsar would emit an observable ν flux. Metastable S drops stripped from the pulsar (and accelerated) by electrodynamic fields yield a $\bar{\nu}_e$ flux by sequential decays of the S drops. These decays may be rapid enough to see the pulsar frequency in the neutrino signal in future, large detectors. Possible relevance to Cygnus X-3 is discussed. If indeed the contraversial secondary muons observations[9-12] from Cygnus X-3 are correct, then some new physics would appear to be involved. A good candidate might be a long-lived neutral S droplet.[13,14] In fact we suggest that light, long-lived, neutral S droplets might be coming from all fast pulsars.

PRODUCTION OF S DROPLETS IN HEAVY-ION COLLISIONS

The process for S droplets production was considered in two steps: We assumed that in a relativistic heavy-ion collision with a large A fixed target nuclei, a high density, hot quark-gluon (qg) droplet[15] (or perhaps two) is formed with probability P_{qg}. Note that P_{qg} could be fairly small, and also that a real phase transition to a qg plasma is not necessary for our proposal. In the second step, we calculated[7] the emission of mesons and baryons in several processes from the hot, expanding qg droplet leading to an S droplet. By far the dominant process was the emission of a high momentum u or d quark from the surface of the qg droplet which fragments and picks up an $\bar{s}$ quark leaving behind an s from an $s\bar{s}$ pair. We found that the probability P of producing the metastable S droplet with $n_s/A > .8$ from the initial qg droplet is quite model dependent, but highly favoring small A droplets where it may be very large. Although very many particles <u>will</u> be produced in each primary interaction, and <u>even</u> if the probability of producing an S droplet, $P_{qg} \cdot P$, is <u>extremely</u> small, it should be readily detected in a <u>secondary</u> collision. Our scheme is summarized in Fig. 1.

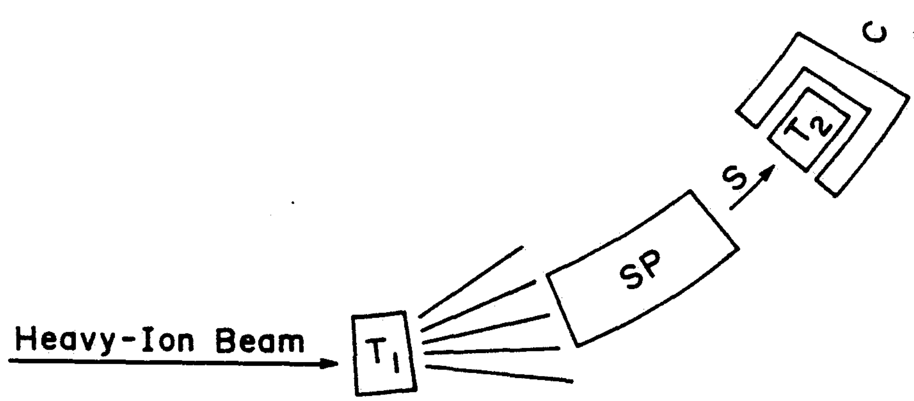

Fig. 1 Schematic diagram of a proposed[7] experiment to detect the quasistable S droplets. The relativistic heavy-ion beam hits a thin Pb target T_1 designed so that produced S droplets suffer no secondary collisions. From the huge number of particles produced in each primary collision, the spectrometer SP would tend to separate out S droplets by passing fragments with $A \gtrsim 10$ and Z/A small or negative. The observation of multiple Λ's, in counters C, emitted in the interaction of an S droplet in target T_2 would be a striking, readily observed signature.

Particles produced in the initial collision in (a thin Pb) target T_1 pass through a spectrometer SP that tends to separate S droplets by passing fragments with baryon number $A \gtrsim 10$ and small or negative electric-charge ratio Z/A. The secondary collision of the relativistic S droplet in T_2 will have center-of-mass energies >> the binding energy of the S droplet and will then disintegrate into a huge number of hypersons. The observation of multiple Λ decays would be a readily detected and striking signature. Such an experiment should be extremely sensitive. For example, the BNL heavy-ion facility will have a 16 GeV/A beam with $\sim 10^{10}$ oxygen ions per pulse, giving $\sim 10^{14}$ per day. Thus sensitivities of detecting an S droplet produced per 10^{10} collisions should be possible.

PULSED $\bar{\nu}_e$ BEAMS FROM STRANGE MATTER PULSARS

If indeed S matter is stable, Witten[5] noted that "neutron" stars would really be S matter (one huge bag of u, d and s quarks) with essentially no crust. Benford, Silverman and I[8] then proposed that a fast S matter pulsar would emit an observable, possibly pulsed $\bar{\nu}_e$ beam. Metastable S droplets stripped from the pulsar (and accelerated) by electrodynamic fields yield mainly $\bar{\nu}_e$'s by sequential decays.

A pulsar rapidly rotates (period P) and carries its huge magnetic field B with it. As a result, a surface gap (height h) in charge density must exist, and the pulsar must emit a current to supply the corotation charge. This outward flowing ion beam (charge Z, baryon number A) excavates matter at a rate[16]

$$F \approx 2 \times 10^{-3}\ A(ZP)^{-1}(B/10^{12}G)\ \mathrm{g\ cm^{-2}s^{-1}} \qquad (1)$$

from the polar cap. It is understood[17] that a TeV electron-positron cascade is produced in the charge gap and these electrons hitting the polar cap excavate the ions. We[8] propose that this self-consistent picture[16,17] could liberate S droplets (along with more conventional ions) without necessarily breaking them up. (A TeV electron hitting the polar cap could produce a high energy pion which rapidly distributes its energy in a small volume). These S droplets would perhaps have $30 \lesssim A \lesssim 10^4$, some with lifetimes >> 10^{-4}s. The charge density gap will accelerate the ions to a maximum energy[18]

$$E_{max} \sim 3 \times 10^{15}\ Z(B/10^{12}G)(P/10\ ms)^{-\frac{5}{2}}\ (h/10\ km)\ eV. \qquad (2)$$

These accelerated high-energy S droplets would undergo a chain of decays. Silverman[19] has shown that for a range of parameters consistent with Farhi and Jaffe[6] that an S droplet by the end of its decay sequences emits roughly a number of $\bar{\nu}_e \sim A$. Thus a S matter fast pulsar should be an incredible source of high-energy ($\gtrsim$ 10 GeV) $\bar{\nu}_e$'s. It also appears that the decay times of S droplets might be such that the $\bar{\nu}_e$ beam displays the pulsar frequency. This would be a great help in rejecting a signal from background. As a bonus, note that separate measurement in future, large detectors of μ ane e events from the (mainly) $\bar{\nu}_e$ beam would be an extremely sensitive test of neutrino oscillations. Not only would the appearance of $\bar{\nu}_\mu$'s test Δm_ν^2 to $\sim 10^{-16}$ eV^2, but would be simultaneously sensitive to small mixing angles. A larger, fully instrumented version of the presently planned DUMAND[20] would be necessary for this accuracy.

CONCLUSION

One of the most exciting conjectures[5] in physics is that S matter might be absolutely stable, i.e., have energy/A < 938 MeV. A chunk of stable S matter would then provide the ultimate energy source. Although, compatible[6] with QCD, no forseeable calculations can settle the question of whether S matter is stable. Thus experimental tests are crucial. We have suggested two relevelant experiments: We have proposed[7] that metastable S droplets be produced in reltivistic heavy-ion collisions at the present BNL and CERN fixed target facilities, both beginning operation by the end of this year. The observation of multiple Λ's emitted in the interaction of an S droplet in the secondary target (see Fig. 1) would be a striking, readily identified signature. A second proposal[8] is that an S matter pulsar would have S droplets stripped from its polar cap (and accelerated) by electrodynamic fields. These high-energy S droplets would undergo a sequence of decays yielding a measurable $\bar{\nu}_e$ flux in future, large detectors. We further note the possibility of there existing a very-long lived ($\gtrsim$ 1 year) electrically neutral, light S droplet and it being produced in these sequential decays of the S droplets. This might be relevant to Cygnus X-3. If the contraversial[9-12] secondary muon observations from Cygnus X-3 are correct, then new physics seems to be needed. A good candidate might be a long-lived neutral S droplet.[13,14] We strongly suggest that it would be much larger A than the proposed A=2 H particle.[14] Finally, we suggest that such light, long-lived, ($\gtrsim$ 1 year) neutral S droplets may be coming from all fast pulsars (no companion, as for Cygnus X-3, is necessary).

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