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Nuclear matter low lying collective modes in a finite size model of nucleons

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Abstract. We study the effects of finite size of nucleons on the relativistic equation of state of symmetric nuclear matter. The Landau parameters and the low lying collective modes at zero temperature are examined within a model of composite nucleons.

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1. Finite Volume Corrections and Landau Parameters

In a previous paper we have included finite volume corrections, generalizing the original Quark Meson Coupling (QMC) model [1]with a Van der Waals-like normalization of the fields, to study hadronic matter at very high densities [2]. There it was shown that this normalization, which simulate strong short ranged correlations in dense matter, prevents the overlapping of the quark confining volume, even at the center of neutron stars. We refer to [2] for further details. Other related works on finite volume effects are given for instance in [3]. Our aim here is to apply excluded volume corrections (EVC) to collective properties of symmetric nuclear matter, using the relativistic extension of Landau's Fermi-liquid theory.
As described in [2], EVC renormalize the nucleon fields Ψ^b $(b = n, p)$

$$\Psi^b(x) = (V\,\vartheta)^{-1/2} \sum_{\vec{k},s} [\, a^b(\vec{k}, s)\, u^b(\vec{k}, s)\, e^{-ik^\mu x_\mu} + b^{b\dagger}(\vec{k}, s)\, v^b(\vec{k}, s)\, e^{\,ik^\mu x_\mu}\,] \qquad (1)$$

where $\vartheta = (1 - \sum_b n^b v_b)$. The nucleon density is $n^b = \vartheta\, {k_{Fb}}^3/(3\pi^2)$, and $v_b = 4\sqrt{2}\, {R_b}^3$ is the effective nucleon volume. In the QMC model, the total mean field energy density for symmetric nuclear matter is $(\hbar = c = 1)$ [2]
$\epsilon = (1/2){m_\sigma}^2\, {\sigma_0}^2 + (1/2){m_\omega}^2\, {\omega_0}^2 + 2\,\vartheta/\pi^2 \int_0^{k_F} dk\, k^2 \sqrt{{M^*}^2 + k^2}$.
The nucleon effective mass M^* can be expressed within QMC in terms of the

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quark energies [1]. The Landau parameters F_0 and F_1, defined in terms of second derivatives of ϵ [4, 5], are related to the compressibility, sound velocities, and quadrupolar excitation energy. Here we focus on the low lying collective modes propagating in symmetric matter, whose dispersion relations are solutions of the equation $0 = 1 + [F_0 + F_1 Q^2/(1 + F_1/3)]\,\Phi(Q)$, with $\Phi(x)$ the Lindhard function, and $Q = \omega E_F/(|\vec{p}|p_F)$. Results are displayed in Fig.1.

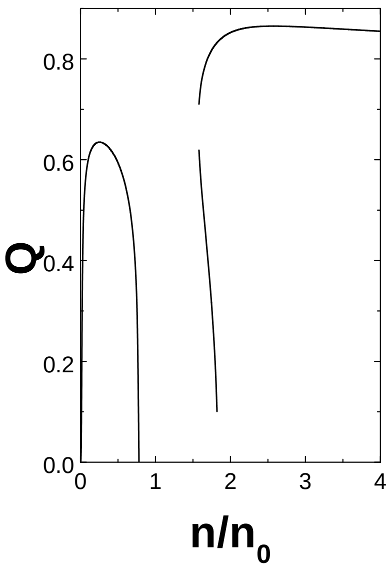

Fig. 1. The dispersion relation for low lying collective modes in terms of the nuclear density. A characteristic instability mode is found at low densities, and two branches of damped zero sound mode at densities higher than 1.5 times the normal nuclear density n_0.

Excluded volume effects could be the cause of the fast evanescence of one of the zero sound branches, and the lack of undamped modes. In a forthcoming paper, a more wide discussion referred to hypermatter will be given [5].

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