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Reply to "Comment on 'Neutron Star Masses as a Constraint on Nuclear Compression Modulus' "

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DISCLAIMER

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The authors of the comment evidently believe that the referenced article claims that neutron star masses depend, *per se*, on the curvature of the equation of state at saturation. Nothing could be farther from the truth. It depends on the equation of state throughout the entire density range spanned by the star. This misunderstanding and all other points of contention can be traced to the fact that they parameterize the equation of state, and I employ a theory of matter to calculate it. Because they refer to their parameter γ as "a truly free second parameter to describe the high density behavior" one infers that they believe it to be a merit of their approach that the curvature of the equation of state at saturation and its high density behavior are isolated from each other. However this is not true of any comprehensive theory of matter, since the equation of state is *everywhere* determined by the coupling constants of the theory. And since we believe that nature is not capricious, but is described by some, possibly not yet discovered theory, the equation of state of matter in one region is related to that in all others. It is precisely this fact that is exploited in my analysis. I will return to this below.

Their choice of a family of curves to represent the equation of state is largely arbitrary. This is illustrated by their own indecision as to the form of their Eq. (1), which contrary to their assertion, is not the same as that of their ref. (2). The one possesses a zero pressure point and therefore a bound state, and the other does not. Similarly their formula Eq. (2) is different from the corresponding one that they published in their ref. (2). This is so because, even with the same parameters K and γ, the coefficient of $(\rho/\rho_0)^\gamma$ is different. For this reason also, it is meaningless to apply their formula Eq. (2) to my equation of state.

The advantage of the approach that is used here is that it is based on a theory of matter, a theory that a number of authors have shown accounts for the properties of nuclear matter as well as a growing number of properties of finite nuclei [1]. This success attests to the appropriateness of the structure of relativistic nuclear field theory as an effective theory of matter in the hadronic phase.

The properties of the theory at saturation and at any other density depend on the coupling constants. These can be fixed by the bulk properties of nuclear matter, among them the symmetry energy. One and the same theory defines also the properties of neutron star matter, it being the solution of the *same* field equations but with subsidiary conditions of charge neutrality and beta equilibrium. It is for this reason that one can characterize the equation of state of both nuclear matter, *and* neutron star matter by the bulk properties of symmetric nuclear matter.

The authors of the comment claim that they can represent the effects of pions, electrons and the baryon species necessary to assure β-equilibrium by absorbing these effects into their K_0 and γ. These effects are not small as they say, but are large as have shown elsewhere [2]. The hyperon populations reduce the limiting star mass by 1/2 $M_\odot$, which is a large effect since the scale on which it is to be measured is of the order of one solar mass. The softening effect of pions and hyperons at their thresholds is quite visible in the equation of state [3], and cannot be represented by the smoothe behavior of their two parameter curve.

It is **not** true that my equation of state can be characterized as a polytrope of constant γ in the density domain of neutron stars, nor can the other theories to which they refer, so their analysis in this connection is invalid.

This brings us to the last point. We agree entirely with the authors of the comment that the limiting neutron star mass does not depend simply on the curvature of the equation of state at saturation. Nor can the rich physics of nuclear matter at saturation much less at high density be characterized by their two parameters. In the theory we employ, there are six coupling constants, five of which can be determined by five properties of matter at saturation. (The sixth is the relative coupling strength of nucleons and hyperons to the mesons for which we adopt the value of Moszkowski, based on quark counting [4].) Because of the recent controversy over the stiffness of the equation of state at high density, we vary this through a variation in the coupling constants which leaves the well known bulk properties fixed, with the exception of the controversial K. We get a lower bound on K not because the neutron star mass depends *per se* on the curvature of the equation of state at saturation, but because in a theory of matter, and in nature too, the equation of state in one domain is related to every other, and in addition to the fact that an appreciable fraction of the star's mass is composed of matter at less than twice saturation density.

References

[1] c.f. B. D. Serot and J. D. Walecka, *The Relativistic Nuclear Many-Body Problem*, in Advances in Nuclear Physics, 1986.

[2] N. K. Glendenning, Z. Phys. A **326** (1987) 57.

[3] N. K. Glendenning, Z. Phys. A **327** (1987) .

[4] S. A. Moszkowski, Phys. Rev. **D9** (1974) 1613.

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