# Reply to "Comment on 'Intrinsic and dynamically generated scalar meson states'"

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We suggest that a QCD-based chiral model, such as our generalized Nambu–Jona-Lasinio model, provides the best context in which one may study the structure of the $q\bar{q}$ states which are coupled to the meson continuum and that give rise to a resonance such as the $f_0(980)$. Our characterization of this resonance is intimately related to the chiral symmetry of the Lagrangian of our model. In our model the 't Hooft interaction leads to an excellent description of the decay constants and mixing angles of the $\eta(547)$ and $\eta'(958)$. In our recent work we have found that the $f_0(980)$ is a flavor singlet.

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The quark structure of the scalar mesons has been discussed for at least two decades and is still a matter of some controversy [1]. In this comment we do not attempt to discuss the problems in determining $q\bar{q}$ configurations of scalar states using experimental data. (A significant problem is the importance of channel coupling via final-state interactions, such as $\pi\pi\to K\bar{K}$ or $K\bar{K}\to\pi\pi$, so that the observation of the mesons in a particular decay channel does not provide definitive information concerning the $q\bar{q}$ configuration of the resonance.) However, we will discuss various theoretical calculations and describe their implications.

The Lagrangian of our model may be found in Ref. [1]. There the coupling constants $G_S$, $G_D$ and $G_V$ appear. (The value of $G_V$ has been obtained in an earlier study of vector mesons.) The parameters $G_S=11.84\,\mathrm{GeV}^{-2}$ and $G_D\approx-220\,\mathrm{GeV}^{-5}$ have been determined in a recent study of the $\eta(547)$, $\eta'(958)$ and their radial excitations [2]. Here, $G_D$ parametrizes the 't Hooft interaction, which plays an important role in breaking the $U_A(1)$ symmetry and allows us to fit the energy of the $\eta'(958)$. The resulting fit to the masses of the $\eta(547)$, $\eta'(958)$, $\eta(1295)$ and $\eta(1440)$ mesons is good. We also provide a very good fit to the singlet and octet decay constants of the $\eta(547)$ and $\eta'(958)$, as well as the mixing angles of these mesons, $\theta_\eta$ and $\theta_{\eta'}$ [4]. Once the parameters of the model, including the constituent quark masses, have been fixed in our study of the pseudoscalar mesons, there are no free parameters in our study of the scalar-isoscalar mesons. (The parameters used in our calculations, $G_{00}$, $G_{88}$ and $G_{08}$, for either the pseudoscalar or the scalar mesons are given in terms of $G_S$, $G_D$ and the quark vacuum condensates [3].) We find the lowest $f_0$ state at 915 MeV and the lowest $s\bar{s}$ state at 1477 MeV. There is a $2\ ^3P_0$ state at 1554 MeV. Mixing with the scalar glueball allows us to provide a reasonable fit to the mass values of the $f_0(980)$, $f_0(1370)$, $f_0(1500)$, and $f_0(1710)$ mesons [5].

Recently, Anisovich had described the result of a very extensive study of the scalar mesons [6]. The result of interest to us is that the $f_0(980)$ may be about 50% $n\bar{n}$ and 50% $s\bar{s}$. That is, if one writes $f_0(980)=n\bar{n}\cos\varphi+s\bar{s}\sin\varphi$, the preferred solution has $\varphi=-48°\pm6°$, although $\varphi=85°\pm4°$ is a possible value [6]. At the present stage of development, our formalism does not contain a mechanism for creating that degree of $n\bar{n}$-$s\bar{s}$ mixing in the case of scalar mesons, in contrast to the excellent results obtained for such mixing in the case of the $\eta(547)$ and $\eta'(958)$ [2]. In our recent work [7,8] we have found that the $f_0(980)$ is a flavor singlet and, therefore, has a significant $s\bar{s}$ component.

Our program differs from that of other researchers who attempt to construct wave functions of the scalar mesons using experimental data. It would be of interest to perform a coupled-channel calculation of meson scattering, in which the $f_0$ resonances are excited, making use of the parameters determined in our comprehensive fit to the properties of the eta mesons [2] and other light mesons.

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