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Comment on "Intrinsic and dynamically generated scalar meson states"

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The scalar-meson assignments of Shakin and Wang in a generalized Nambu–Jona-Lasinio model are contradicted by recent experimental information. Also the strict distinction made by these authors between "intrinsic" and "dynamically generated" states is contested.

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In Ref. [1], Shakin and Wang (SW) reexamine a generalized Nambu–Jona-Lasinio (NJL) model, recently applied to light [2] and scalar [3] mesons, so as to present what the authors claim to be additional evidence for their model assignments of scalar-meson resonances. Essential for the interpretation of scalar mesons in SW's model is the distinction between what they call "intrinsic" or "preexisting" (IP), and "dynamically generated" (DG) scalar states, only the former ones corresponding to $q\bar{q}$ quark-model states that should form nonets. In contrast, the DG states, not necessarily forming nonets, are supposed to be the result of *t*- and *u*-channel meson exchange in *S*-wave meson-meson scattering, giving rise to the $\sigma(500\text{–}600)$ [or $f_0(400\text{–}1200)$] and, together with threshold effects in the $q\bar{q}$ T matrix, also the—not yet established—$\kappa(900)$ [or $K_0^*(700\text{–}1100)$]. In this Comment, we want to point out that not only is there quite compelling experimental evidence against some of the assignments of SW, but also their strict distinction between IP and DG is a model-dependent simplification which may be quite misleading.

Starting with the assignments, SW right away present a dubious argument against placing the $a_0(1450)$ and the $K_0^*(1430)$ in the same nonet, arguing that one would expect the $K_0^*(1430)$ to be more massive than the $a_0(1450)$. While this could be true in a very naive quark-model picture, it is very dangerous to apply such a line of reasoning to broad resonances like the scalar mesons under consideration, which are subject to strong unitarization effects, as advocated by, e.g., Maltman [4]. Moreover, by the same token one could argue that the $f_0(1370)$, which is interpreted by SW as an $s\bar{s}$ state lying in the same nonet as the $K_0^*(1430)$, should be the more massive one. Clearly, naive arguments are inadequate to understand the scalars, as the large mass shifts for the f_0s and a_0s in SW's work, due to a short-range NJL interaction, already indicate. Let us just add to this point that it seems much more natural and appealing to place all the scalars below 1 GeV in one nonet, which was accomplished by us in previous work [5,6], as well as by several other authors [7–10], besides Schechter and co-workers (see, e.g., Ref. [11] and references in Ref. [1]). In this picture, the scalar mesons between say 1.3 and 1.5 GeV belong to another nonet, and so forth. If this can be achieved by unitarization only without having to resort to rather *ad hoc* interactions besides the confinement mechanism, which is indeed the case in the Nijmegen unitarized meson model (NUMM) of two of us [6,12], all the better.

Let us now analyze in more detail the interpretation SW attribute to some well-established scalar mesons, i.e., the $f_0(980)$, $f_0(1370)$, and $f_0(1500)$.

$f_0(980)$

This isoscalar scalar meson is described by SW as the lowest nonstrange $n\bar{n}$ state. However, as early as in 1989, the DM2 Collaboration [13] not only confirmed the σ meson as an *S*-wave two-pion resonance in the decay process $J/\psi \to \omega\pi\pi$, with higher statistics than the equivalent and already quite revealing Mark I experiment over a decade earlier [14], but also produced a clear indication that the $f_0(980)$ is *not* mainly $n\bar{n}$. The point is that in the same $\pi\pi$ mass distribution where a huge σ bump shows up only a tiny $f_0(980)$ peak is observed (Ref. [13], Fig. 13), hinting at a dominant $s\bar{s}$ structure for this resonance. Moreover, the very recently measured weak decay rate [15]

$$\Gamma(D_s^+ \to f_0(980)\pi^+) = (2.39 \pm 1.06) \times 10^{-14}\ \text{GeV} \quad (1)$$

is clear evidence for the $f_0(980)$ being mostly $s\bar{s}$, since we have shown [16] that this rate can be perfectly reproduced through a standard W^+-emission process (see Fig. 1), provided one assumes a dominantly $s\bar{s}$ configuration for the $f_0(980)$, possibly with a small $n\bar{n}$ admixture.

$f_0(1370)$

Although the different hadronic branching fractions of this resonance are not very well known experimentally, the

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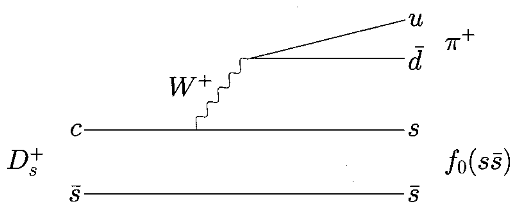

FIG. 1. Contribution of W^+ emission to the weak decay $D_s^+ \to f_0(s\bar{s})\pi^+$.

dominant decay modes involve two and four pions [15], indicating that the $f_0(1370)$ is mostly $n\bar{n}$. In particular, the available data give a branching ratio $\Gamma(K\bar{K})/\Gamma_{\text{total}} = 0.35 \pm 0.13$ [17], which is in accordance with a mainly nonstrange $f_0(1370)$, while SW classify it as an $s\bar{s}$ state. Also very recent data support the $n\bar{n}$ interpretation of the $f_0(1370)$, namely the failure to observe the process $D_s^+ \to f_0(1370)\pi^+ \to K^+K^-\pi^+$ [18] (see also [16]), and the dominance of $J/\psi \to \phi f_0(1370) \to \phi\pi\pi$ over $J/\psi \to \phi f_0(1370) \to \phi K\bar{K}$ [19].

$f_0(1500)$

For this resonance, we can again apply the W^+-emission graph of Fig. 1, since the weak decay $D_s^+ \to f_0(1500)\pi^+$ has been observed very recently, with the rate $(3.7 \pm 2.1) \times 10^{-15}$ GeV [15]. If we assume a pure $s\bar{s}$ configuration for the $f_0(1500)$, we obtain a theoretical decay rate of 3.3×10^{-15} GeV. Of course, the large experimental error perfectly allows for some $n\bar{n}$ admixture in the $f_0(1500)$, but a pure $n\bar{n}$ assignment as advocated by SW seems highly unlikely. As for the hadronic decays of the $f_0(1500)$, the different branching fractions are even less well known than in the $f_0(1370)$ case. Nevertheless, the dominant decay modes of the $f_0(1500)$ involve ηs and η's, having nonzero strange-quark contents, and not pions like for the $f_0(1370)$, which also hints at a dominant $s\bar{s}$ structure for the $f_0(1500)$. At this point we should mention that the relatively small width of the $f_0(1500)$ and its tiny branching fraction into $K\bar{K}$ [17] are often invoked as being evidence for a glueball interpretation of this resonance. However, these peculiar properties can be understood instead by assuming the $f_0(1500)$ to be close to a flavor-octet configuration, but still dominantly $s\bar{s}$ [20,12]. This would give rise to destructive interference between the $s\bar{s}$ and $n\bar{n}$ components, leading to a strong suppression of the $K\bar{K}$ mode, which would be among the dominant decay modes if the $f_0(1500)$ was purely $s\bar{s}$. As we have observed above, the large experimental error for the weak decay $D_s^+ \to f_0(1500)\pi^+$ can easily accomodate a significant $n\bar{n}$ admixture in the $f_0(1500)$, so that the octet hypothesis is plausible.

Summarizing, the experimental data do not favor SW's $n\bar{n}$ assignment for the $f_0(980)$, nor their $s\bar{s}$ and $n\bar{n}$ classifications of the $f_0(1370)$ and $f_0(1500)$, respectively. As for the latter two resonances, these are also not in agreement with the recent lattice calculations of Lee and Weingarten [21] for that matter, as mentioned by SW. In contrast, the NUMM predictions for the $f_0(1370)$ and $f_0(1500)$ [6] do agree with Ref. [21].

Let us now turn to the question of IP versus DG scalar states. This is in fact not a new issue, but has already been explicitly addressed by, e.g., Isgur and Speth (IS), in a Comment [22] on the work of Törnqvist and Roos (TR) [7]. Though disagreeing with SW on the nature of the $a_0(980)$ and $f_0(980)$, also IS argue that light scalars owe their existence to "degrees of freedom already present in the meson-meson continuum," i.e., *t*-channel forces, to be contrasted with "intrinsic poles arising from the insertion of a new $q\bar{q}$ degree of freedom." At the same time, IS criticize TR for the omission of *t*-channel meson exchanges, which according to them calls into question TR's analysis. However, in another Comment on the same paper, Harada *et al.* [23] quantitatively demonstrate, in the framework of their own model, that the neglect of ρ-meson exchange in the *S*-wave $\pi\pi$ amplitude, though destroying crossing symmetry, does not destroy the existence of the σ meson, and does not even worsen the quality of the fit, only leading to a moderate (complex) shift of the σ pole. This finding lends support to TR's claim, seconded by us, in their Reply [24] to IS that "a detailed inclusion of all nearby *s*-channel singularities is more important than the inclusion of a few strong *t*-channel exchanges" (see also Ref. [25] for further discussion on the σ, crossing, and chiral symmetry).

We wish to add to this discussion by arguing that the strict separation of IP and DG poles, as advocated by IS and SW, is a model artifact, which is probably a much more serious approximation than the neglect of *t*-channel exchanges in the NUMM [6,12] and the model of TR [7]. The crucial point is that, once one accepts strong three-meson couplings, as IS and SW seem to do, these will inexorably show up also in the scalar → pseudoscalar-pseudoscalar (and scalar → vector-vector) sector. Hence any "intrinsic" scalar state will couple strongly to the "meson-meson continuum," leading to large unitarization effects. This will inevitably give rise to strong mixing of IP and DG states, making a strict identification of either type somewhat meaningless. (Nevertheless, pure DG chiral schemes at the quark level which involve scalar mesons do appear to have merit [26].) In the NUMM, which is a coupled-channel model where the $q\bar{q}$ and meson-meson sectors are treated on an equal footing, unitarization leads to a phenomenon unique to scalar mesons, namely resonance doubling, also observed by TR. So even without including *t*-channel exchanges, extra poles are generated, which can be interpreted as the light scalars and, moreover, allow a reasonably good description, without any free parameters, of *S*-wave meson-meson phase shifts up to about 1.2 GeV in the case of the NUMM [12,6]. But this does not mean that the poles below 1 GeV are of a DG nature, while the ones above 1 GeV are of the IP type. It namely happens that either set of poles can be traced back to the "intrinsic" $q\bar{q}$ bound states (see Ref. [12] for more details and references).

Finally, let us discuss the meson decay constants which SW invoke as apparent support for their scalar-meson assignments. While we do not have any fundamental objection against such a procedure, one should realize that these constants are not observables and, therefore, model dependent. However, we note that SW compare their decay constants with those of Maltman [4], who claims that the values he finds for the $a_0(980)$, the $a_0(1450)$, and the $K_0^*(1430)$ ''suggest a UQM-like (unitarized quark model) scenario for the isovector scalar states,'' a scenario which is clearly not considered by SW, with one exception. Since SW find disagreement with Maltman's value in the $a_0(980)$ case, they admit ''... which suggests that the $a_0(980)$ may have a significant $K\bar{K}$ component.'' Accordingly, they should allow the inclusion of sizable two-meson components, not only for the $a_0(980)$, but also in the case of the other scalar mesons, as naturally happens in UQMs like the NUMM and the model of Ref. [7]. This could considerably change the results for the decay constants.

In conclusion, we believe to have demonstrated in this Comment that the interpretation of scalar-meson states by SW is clearly called into question by experiment. Furthermore, their strict distinction between IP and DG scalar states lacks a consistent theoretical foundation.

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