ON THE EXISTENCE OF GLUEBALLS *

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Lattice gauge calculations require the existence of glueballs. In particular a scalar glueball is firmly predicted at a mass of 1700 MeV. This prediction has led to an intense study of scalar isoscalar interactions and to the discovery of several states. The number of scalar states observed seems to exceed the number of states which can be accommodated in the quark model. None of these states has a decay pattern which is consistent with that of a pure glueball but mixing of scalar $\bar{q}q$ states with the scalar glueball provides for a reasonable interpretation of the data. In this paper we scrutinize the evidence for these states and their production characteristics. The $f_0(1370)$ — a cornerstone of all $\bar{q}q$-glueball mixing scenarios — is shown to be likely of non-$\bar{q}q$ nature. The remaining scalar states then do fit into a nonet classification. If this interpretation should be correct there would be no room for resonant scalar gluon-gluon interactions, no room for the scalar glueball.

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1. Introduction

The non-abelian structure of quantum chromodynamics (QCD) implies that not only quarks carry the triple-valued charge named color but that also the exchange bosons of strong interactions, the gluons, are colored. The superposition principle of quantum electrodynamics does hence not hold; gluons interact with each other with 3-point and 4-point interaction vertices. Since color is confined, two (or more) gluons should be bound thus forming hadronic matter composed primarily of gluons. Such states are called glueballs. They were predicted soon after QCD was formulated [1,2], and meson spectroscopy focused on the search for this new type of hadrons.

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However, QCD is not a solvable theory of strong interactions, at least not at low energies; therefore models have to be developed simulating QCD in the confinement region. This requires close contact between theory and experiment as we do not know the most significant features of unperturbative QCD. QCD on the lattice claims the highest creditability. In the limit of small lattice spacing it is believed to approach the QCD continuum. With the increase in computer power, glueball mass predictions became increasingly more precise. Recent values for the masses of lowest scalar, tensor and pseudoscalar glueballs are 1.73 ± 0.10, 2.40 ± 0.12, and 2.60 ± 0.13 GeV, respectively [3]. Such values are supported by other models, like bag models flux tubes, or QCD sum rules. A excellent review of the field can be found in [4].

2. Scalar mesons and the scalar glueball

2.1. Scalar meson survey

Table I shows the spectrum of scalar mesons below 2 GeV [5].

TABLE I

1: generated by meson exchange dynamics and/or $\bar{K}K$ molecules [6–10]; 2: $^3P_0$ $\bar{q}q$ states; 3: two $^3P_0$ $\bar{q}q$ states mixing with the lowest-mass scalar glueball.

I = 1/2	I = 1	I = 0
		$f_0(400-1200)^1$
	$a_0(980)^1$	$f_0(980)^1$
		$f_0(1370)^3$
$K_0^*(1430)^2$	$a_0(1470)^2$	$f_0(1500)^3$
		$f_0(1710)^3$

The lowest-mass entry is a f_0(400–1200) representing the scalar isoscalar $\pi\pi$ interactions, often called σ-meson. The $\pi\pi$ interactions in this mass range saturate unitarity. Also at energies above 1.2 GeV, the inelasticity is small. At 980 MeV a dip is observed corresponding to the $f_0(980)$ which has large coupling to $\bar{K}K$. A second dip is suggested at 1500 MeV corresponding to the $f_0(1500)$. The amplitude reaches maxima at positions which correspond to the old $\sigma(600)$ which plays an important role in one-boson-exchange-potentials, and to the the old $\epsilon(1300)$. The dips are associated with additional rapid phase motions. The background amplitude and its phase motion are correctly reproduced by t-channel ρ exchange [6, 7].

Adding further t-channel amplitudes for ω, Φ and K* exchange, Speth and collaborators describe both the $f_0(980)$ and the $a_0(980)$ as generated by t-channel exchange dynamics [8] with the $\bar{K}K$ system forming a bound state in isoscalar but not in isovector interactions. Related is the interpretation of these two resonances at the $\bar{K}K$ threshold as $\bar{K}K$ molecules [9]. These states can also be understood as $\bar{q}q$ mesons with properties governed by the $\bar{K}K$ threshold [10]. And they are discussed as $qq\bar{q}\bar{q}$ resonances [11].

Leaving out the 3 states $f_0(400–1200)$, $f_0(980)$ and $a_0(980)$, we remain with a decuplet of states and not with nine states as expected in the quark model, see Table I. The three scalar isoscalar states $f_0(1370)$, $f_0(1500)$ and $f_0(1750)$ cannot possibly belong to one nonet. On the other hand, none of the three states has a decay pattern as expected from a pure glueball. These observations have led Amsler and Close [12] to the conclusion that a glueball has introduced the world of quarkonia, mixing with them and thus producing the 3 observed resonances.

2.2. Decay widths of scalar isoscalar states

In such a situation it is of course important to identify all three isoscalar states in as many as possible reactions and to determine their decay modes. The largest part of new information on the $f_0(1370)$ and $f_0(1500)$ comes from the Crystal Barrel experiment at LEAR in which these mesons also were discovered. Table II lists the partial decay widths of these two states assuming that all decay modes are now known.

TABLE II

Partial widths Γ_i (in MeV) of $f_0(1370)$ and $f_0(1500)$. From U. Thoma, this conference.

	$f_0(1370)$	$f_0(1500)$
Γ_{tot}	275 ± 55	130 ± 30
$\Gamma_{\sigma\sigma}$	120.5 ± 45.2	18.6 ± 12.5
$\Gamma_{\rho\rho}$	62.2 ± 28.8	8.9 ± 8.2
$\Gamma_{\pi^*\pi}$	41.6 ± 22.0	35.5 ± 29.2
$\Gamma_{a_1\pi}$	14.10 ± 7.2	8.6 ± 6.6
$\Gamma_{\pi\pi}$	21.7 ± 9.9	44.1 ± 15.4
$\Gamma_{\eta\eta}$	0.41 ± 0.27	3.4 ± 1.2
$\Gamma_{\eta\eta'}$		2.9 ± 1.0
$\Gamma_{\bar{K}K}$	(7.9 ± 2.7) to (21.2 ± 7.2)	

Central production is a rich source of meson resonances; in the limit of high momenta and low momentum transfers the process is dominated by Pomeron Pomeron scattering. Pomerons contain a large fraction of glue; hence central production is a good place to search for glueballs or for mesons with a large glueball component. Mesons with a given mass can be produced at smaller or larger momentum transfers; Close and Kirk pointed out [21] that the production rates of well-established $\bar{q}q$ mesons fall off fast with decreasing momentum transfer while the production rates of mesons which are suspect of being non-$\bar{q}q$ objects remain large even for small momentum transfer. The choice of small momentum transfer for mesons in central production is therefore called *glueball filter*. The two Pomerons like to fuse to form a glueball. If this conjecture is correct, a glueball wave function should be more extended spatially than that of a $\bar{q}q$ state. This has to be contrasted to the prediction of lattice gauge calculations that glueball wave functions are more localized than those of $\bar{q}q$-mesons.

Data on the $f_0(1750)$ depend crucially on the existence of a $f_2(1710)$. WA102 reports ratios of decay rates given in Table III.

TABLE III

Decay fractions of scalar mesons from the WA102 experiment.

$f_0(1370) \to \eta\eta / f_0(1370) \to 4\pi$	=	0.0047 ± 0.0020
$f_0(1500) \to \eta\eta / f_0(1500) \to \pi\pi$	=	0.18 ± 0.03
$f_0(1500) \to \eta\eta / f_0(1500) \to \bar{K}K$	=	0.54 ± 0.12
$f_0(1710) \to \eta\eta / f_0(1710) \to \bar{K}K$	=	0.48 ± 0.15

2.3. Mixing of scalar mesons with the lightest glueball

Several authors have suggested scenarios in which a scalar glueball mixes with two $\bar{q}q$ states [12–17]. The mixing angles were (partly) determined from partial decay widths of the scalar states. Only Gutsche [17] includes the 4π decays into the analysis.

Not shown in the Table IV is the mixing scenario suggested by Narison [18] who finds that all three states share the glueball in approximately equal portions. Anisovich *et al.* [19] believe 5 states to exist below 1.8 GeV which they identify with the 1^3P_0 and 2^3P_0 $\bar{q}q$ states and a very broad underlying component which they interprete as scalar glueball.

All mixing schemes agree in that the scalar glueball manifests itself in the scalar meson sector and that it has a mass, before mixing, of about 1600 MeV. Hence all authors agree that lattice gauge theories are doing well in predicting a scalar glueball at this mass. The mixing schemes disagree how the glueball is distributed between the three experimentally observed states. Some of the models assign very large $s\bar{s}$ components to the $f_0(1370)$ or $f_0(1500)$; this is certainly not compatible with data.

TABLE IV

Decomposition of the wave function of 3 scalar isoscalar states into their quarkonium and glueball contribution in various models.

Amsler and Close [12]						
$f_0(1370)$	=	$0.86\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	+	$0.13\ s\bar{s}$	−	0.50 glueball
$f_0(1500)$	=	$0.43\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	−	$0.61\ s\bar{s}$	+	<u>0.61</u> glueball
$f_0(1750)$	=	$0.22\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	−	$0.76\ s\bar{s}$	+	<u>0.60</u> glueball
Lee and Weingarten [13]						
$f_0(1370)$	=	$0.87\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	+	$0.25\ s\bar{s}$	−	0.43 glueball
$f_0(1500)$	=	$-0.36\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	+	$0.91\ s\bar{s}$	−	0.22 glueball
$f_0(1750)$	=	$0.34\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	+	$0.33\ s\bar{s}$	+	<u>0.88</u> glueball
De-Min Li *et al.* [14]						
$f_0(1370)$	=	$-0.30\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	−	$0.82\ s\bar{s}$	−	0.49 glueball
$f_0(1500)$	=	$+0.72\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	+	$0.53\ s\bar{s}$	−	0.45 glueball
$f_0(1750)$	=	$-0.63\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	+	$0.22\ s\bar{s}$	+	<u>0.75</u> glueball
Close and Kirk [15]						
$f_0(1370)$	=	$-0.79\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	−	$0.13\ s\bar{s}$	−	0.60 glueball
$f_0(1500)$	=	$-0.62\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	+	$0.37\ s\bar{s}$	+	<u>0.69</u> glueball
$f_0(1750)$	=	$0.14\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	+	$0.91\ s\bar{s}$	+	0.39 glueball
Celenza *et al.* [16]						
$f_0(1370)$	=	$0.01\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	−	$1.00\ s\bar{s}$	−	0.00 glueball
$f_0(1500)$	=	$0.99\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	−	$0.11\ s\bar{s}$	+	0.01 glueball
$f_0(1750)$	=	$0.03\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	+	$0.09\ s\bar{s}$	+	<u>0.99</u> glueball
Gutsche [17]						
$f_0(1370)$	=	$0.94\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	+	$0.07\ s\bar{s}$	−	0.34 glueball
$f_0(1500)$	=	$0.31\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	−	$0.58\ s\bar{s}$	+	<u>0.61</u> glueball
$f_0(1750)$	=	$0.15\frac{1}{\sqrt{2}}\,(u\bar{u}+d\bar{d})$	+	$0.81\ s\bar{s}$	+	<u>0.57</u> glueball

3. The scalar isoscalar resonances

The interpretation of two resonances, of the $f_0(980)$ and the $f_0(1370)$, plays a decisive role in the meson–glueball mixing scenarios. Also, the nature of the $f_0(400–1200)$ is unclear. We discuss these 3 states in some detail.

3.1. The $f_0(980)$ and $a_0(980)$

At LEP, the fragmentation of quark- and gluon-jets has been studied intensively [22]. In particular the inclusive production of the $f_0(980)$ and $a_0(980)$ provides new insight into their internal structure. The OPAL collaboration searched for these and other light meson resonances in a data sample of 4.3 million hadronic Z^0 decays. For the $f_0(980)$ a coupled channel analysis was made by simultaneously fitting the inclusive $\pi\pi$ and $\bar{K}K$ mass spectra. Some total inclusive rates are listed in Table V.

TABLE V

Yield of light mesons per hadronic Z^0 decay.

π^0	$9.55 \pm 0.06 \pm 0.75$
η	$0.97 \pm 0.03 \pm 0.11$
η'	$0.14 \pm 0.01 \pm 0.02$
$a_0(980)^{\pm}$	$0.27 \pm 0.04 \pm 0.10$
$f_0(980)$	$0.141 \pm 0.007 \pm 0.011$
$\Phi(1020)$	$0.091 \pm 0.002 \pm 0.003$
$f_2(1270)$	$0.155 \pm 0.011 \pm 0.018$

First we notice that the three mesons η', $f_0(980)$ and $a_0(980)$ — which have very similar masses — also have production rates which are nearly identical (the two charge modes of the $a_0(980)^{\pm}$ need to be taken into account). Hence there is primary evidence that the three mesons have the same internal structure, that they are all three $\bar{q}q$ states. This conclusion can be substantiated by further studies. Very detailed studies have been carried out on the production characteristics of the $f_0(980)$ which are compared to those of $\mathrm{f}_2(1270)$ and $\Phi(1020)$ mesons, and with the Lund string model of hadronization [23], within which the $f_0(980)$ is treated as a conventional meson. No difference is observed in any of these comparisons between the $f_0(980)$ and the $\mathrm{f}_2(1270)$ and $\Phi(1020)$.

Two-photon decays provide insight into the internal structure [24]. The ratio [5]

$$R_{\gamma\gamma} = \frac{\Gamma_{f_0(980)\to\gamma\gamma}}{\Gamma_{a_0(980)\to\gamma\gamma}} = 1.38 \pm 0.63 \qquad (1)$$

is related to the scalar mixing by

$$R_{\gamma\gamma} = \frac{1}{3}\left(\sin\Theta + 3\sqrt{2}\cos\Theta\right)^2 . \qquad (2)$$

There are two solutions: $\Theta = (75.4 \pm 7)^\circ$ and $\Theta = (-48.9 \pm 7)^\circ$. Only the first value is compatible with the result obtained in [24]. The angle $\Theta = 60^\circ$

corresponds to a wave function

$$f_0(980) \sim \sqrt{\frac{1}{9}}\frac{1}{\sqrt{2}}(u\bar{u}+d\bar{d}) + \sqrt{\frac{8}{9}}s\bar{s} \tag{3}$$

which has a larger $s\bar{s}$ content than a isosinglet state would have, likely due to the $\bar{K}K$ threshold.

The $\Phi \to \gamma f_{0(980)}$ ratio is surprisingly large [25]. Predictions [27] assuming different structures for the $f_0(980)$, $\bar{q}q$, $\bar{K}K$ or four-quark, all are well below the recent experimental value [25]. The rate for $\Phi{\to}\gamma a_0(980)$ is smaller by a factor ~ 4 than the rate for $\Phi{\to}\gamma f_0(980)$ which seems difficult to reproduce if both mesons are $\bar{K}K$ molecules. The decay chain $\Phi{\to}\gamma f_0(980); f_0(980){\to}\pi\pi$ should be much larger than $\Phi{\to}\gamma a_0(980)$; $a_0(980){\to}\eta\pi$ if the $f_0(980)$ has a structure as given in (3) and the $a_0(980)$ is $\frac{1}{\sqrt{2}}(u\bar{u}\text{-}d\bar{d})$. Isospin-breaking mixing between $f_0(980)$ and $a_0(980)$ due to the mass splitting between the $K^+\boldsymbol{K}^-$ and $\boldsymbol{K}^0K^0$ thresholds [26] could be responsible for the large $\Phi{\to}\gamma a_0(980)$ rate.

D_s decays into three pions provide further insight into the spectrum of isoscalar scalar resonances. The comparatively large rate for three-pion production is surprising: consider the reaction $D_s^+{\to}2\pi^+\pi^-$. The quark content of the D_s^+ is $u\bar{c}$. In the decay, the $\bar{c}$ undergoes a transition to an $\bar{s}$, the W^+ converts into a π^+. Hence a $s\bar{s}$ state is produced which decays into $\pi^+\pi^-$. This is OZI rule violating, and the OZI violation is strong:

$$\frac{\Gamma_{\pi^+\pi^-\pi^0}}{\Gamma_{K^+K^-\pi^0}} = 0.23 \pm 0.04\,. \tag{4}$$

The three-pion Dalitz plot has moderate statistics only, but the $f_0(980)$ is clearly seen and the partial wave analysis finds a second scalar state at $f_0(1470)$ which we identify with the $f_0(1500)$. The two states $f_0(980)$ and $f_0(1500)$ then both decay into $\pi^+\pi^-$.

We note two aspects: first, the two states $f_0(980), f_0(1500)$ are produced in a similar way and — taking phase space into account — with similar couplings. Second, both mesons do not respect the OZI rule. This is similar to the η and η'. The wave functions of both, $f_0(980)$ and $f_0(1500)$, must contain $u\bar{u}+d\bar{d}$ and $s\bar{s}$ components.

We conclude that there are good reasons to believe that the $f_0(980)$ and $a_0(980)$ should be counted as $\bar{q}q$ 1^3P_0 states. Of course, the vicinity of the $\bar{K}K$ threshold plays a significant role and a large $\bar{K}K$ component is to be expected as part of their wave functions [10].

3.2. The $f_0(1370)$

$\boldsymbol{D_s}$ **decays** into three pions show no evidence for the $f_0(1370)$. Only the two states $f_0(980)$ and $f_0(1500)$ are produced.

Radiative $\boldsymbol{J/\psi}$ **decays.** Glueballs have to show up in radiative J/ψ decays. In these decays, one photon and two gluons are emitted by the annihilating $c\bar{c}$ system, the two gluons interact and must form glueballs — if a glueball exists in the accessible mass range. A most prominent — possibly scalar — signal in radiative J/ψ decays into 2η is the old $\Theta(1690)$, now $f_J(1710)$, which might have a large fraction of glue in its wave function. Three scalar resonances are observed at BES in radiative J/ψ decays into $2\pi^+2\pi^-$ [28]. The results of a partial wave analysis show a slowly rising instrumental background and 3 important contributions with scalar, pseudoscalar and tensor quantum numbers. Of particular importance here is the scalar part. It is seen to contain 3 resonances, at 1500, 1740 and 2100 MeV. This pattern of states was already suggested in a reanalysis of MARKIII data [29]. The $f_0(1500), f_0(1740)$ and the $f_0(2100)$ have a similar production and decay pattern. Neither a $f_0(1370)$ nor 'background' amplitude is assigned to the scalar isoscalar partial wave.

The $\boldsymbol{\eta\eta}$ **invariant mass spectrum** produced in $\bar{p}p$ annihilation in flight into $\pi^0\eta\eta$ [30] exhibits three peaks at $f_0(1500), f_0(1750)$ and $f_0(2100)$ MeV, fully compatible with the findings in radiative J/ψ decays into four pions. The data were not decomposed into partial waves in a partial wave analysis, so the peaks could have $J^{PC} = 0^{++}$ or 2^{++}. If the states would have $J^{PC} = 2^{++}$, their decay into $\eta\eta$ would be suppressed by the angular momentum barrier. The fact that the peaks are seen so clearly suggests 0^{++} quantum numbers, and this is the result of the partial wave analysis of the J/ψ data. Hence we believe that the 3 peaks are scalar isoscalar resonances.

Central production is believed to be a good place for a glueball search. The 4π invariant mass spectra from the WA102 experiment [31] show a large peak at 1370 MeV, followed by a dip in the 1500 MeV region and a further (asymmetric) bump. The partial wave analysis decomposes this structure into several scalar resonances, the $f_0(1370), f_0(1500)$ and $f_0(1750)$ and a new $f_0(1900)$. We note that the partial wave analysis finds that the $f_0(1370)$ decays into $\rho\rho$ but not into $\sigma\sigma$ while the $f_0(1500)$ shows both decay modes. In the Crystal Barrel experiment the $f_0(1370)$ decays into $\rho\rho$ and into $\sigma\sigma$ with similar strength.

TABLE VI

Decay fractions into $\sigma\sigma$ of scalar mesons from the WA102 and CBAR experiments.

$f_0(1370) \to \sigma\sigma / f_0(1370) \to 4\pi$	$=$	≤ 0.23	WA102
$f_0(1500) \to \sigma\sigma / f_0(1500) \to 4\pi$	$=$	$0.23 - 0.50$	WA102
$f_0(1370) \to \sigma\sigma / f_0(1370) \to 4\pi$	$=$	0.51 ± 0.09	CBAR
$f_0(1500) \to \sigma\sigma / f_0(1500) \to 4\pi$	$=$	0.26 ± 0.07	CBAR

The upper limit for $f_0(1370) \to \sigma\sigma$ is not very restrictive. In the partial wave analysis presented in [31] representing the preferred solution, the upper limit for $f_0(1370) \to \sigma\sigma / f_0(1370) \to 4\pi$ is certainly smaller. On the other hand, in $\bar{p}p$ annihilation the $\sigma\sigma$ decay mode is certainly present and strong. This is an important observation and provides a clue for the interpretation of the spectrum of scalar mesons.

We interprete of 4π mass spectra of the WA102 experiment in the following way: we assume that Pomeron–Pomeron scattering can also precede via ρ exchange in the t-channel. This t-channel amplitude interferes with the production of the $\bar{q}q$ state $f_0(1500)$ producing a dip, very much alike the dip seen at 980 MeV in $\pi\pi$ scattering. Isospin conservation does not allow $\sigma\sigma$ production from ρ exchange in the t-channel for Pomeron–Pomeron scattering. In contrast, $\bar{p}p$ annihilation may also start from $\bar{p}p \to \sigma\sigma\pi$ which then converts via ρ exchange in the t-channel into $\sigma\sigma$. Note that there should be $f_0(980) \to \rho\rho$ coupling. Hence the phase of the $\rho\rho$ scattering amplitude should raise from 980 to 1500 MeV by 180°. Due to the $\rho\rho$ threshold and the destructive interference with the $f_0(1500)$ the $\rho\rho$ scattering amplitude has a peak between 1000 and 1500 MeV: the most natural and economic description is by use of a Breit–Wigner resonance. But its true nature is of molecular character.

We conclude that the $f_0(1370)$ is not produced in hard processes like J/ψ radiative decays, D_s decays or $\bar{p}p$ annihilation in flight, it is seen only in peripheral processes. The production and decay pattern in central production suggests that it is a t-channel phenomenon originating from meson-meson interactions.

3.3. The red dragon or $f_0(1000)$

The $\pi\pi$ scattering amplitude exhibits a continuously and slowly rising phase and a sudden phase increase at 980 MeV. The rapid phase motion is easily identified with the $f_0(980)$, the slowly rising phase can be associated with a s-channel resonance which was called $f_0(1000)$ by Morgan and Pennington [32]. It extends at least up to 1400 MeV. Minkowsky and Ochs [24] suggested that this broad enhancement which they call *the red dragon* is the scalar glueball.

We do not follow this interpretation since we believe it to be incompatible with data on radiative J/ψ decay into two pions and on D_s decays into three pions. In radiative J/ψ decays the scalar isoscalar intensity vanishes up to 1 GeV [33] and gives two enhancements at 1430 and 1700 MeV. The enhancement at 1430 MeV could have contributions from the $f_0(1370)$ and $f_0(1500)$. Similarly, the measured scalar $\pi\pi$ mass in D_s decays is 1470 MeV. Both values are 1σ compatible with the mass 1488 MeV determined from $\bar{p}p$ annihilation in flight into $\pi\eta\eta$. Hence both these reactions provide no support for an interpretation of the $f_0(1000)$ as glueball.

3.4. The scalar $\bar{q}q$ states

Thus we arrive at an interpretation of the spectrum of scalar mesons as suggested in Table VII. Two nonets of scalar mesons are identified; the lower nonet coincides with the results of an analysis of Minkowsky and Ochs [24]. The spectrum of scalar isoscalar mesons agrees very well with predictions of an instanton-based model [34].

TABLE VII

1: generated by meson exchange dynamics [6–10]; 2: 1^3P_0 $\bar{q}q$ states; 3: 2^3P_0 $\bar{q}q$ states.

I = 1/2	I = 1	I = 0
		$f_0(400-1200)^1$
	$a_0(980)^2$	$f_0(980)^2$
		$f_0(1370)^1$
$K_0^*(1430)^2$	$a_0(1470)^3$	$f_0(1500)^2$
		$f_0(1750)^3$
$K_0^*(1950)^3$		
		$f_0(2100)^3$

3.5. Where is the scalar glueball?

The above interpretation of scalar isoscalar interactions leaves no room for a glueball. Even worse, intensity and the full phase motion are assigned to $\bar{q}q$ states. If true, this view of the scalar meson spectrum implies that present-day lattice gauge calculations involving gluons only are not relevant for the glueball discussion. It is well known that QCD on the lattice does not match with requirements of chiral dynamics; Goldstone bosons do not survive the lattice. Obviously, chiral dynamics plays a very important role in low-energy QCD and for the question if a scalar glueball exist as scalar isoscalar resonance.

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