Identifying a zero-range exchange of vector mesons as the driving force for the s-wave scattering of pseudo-scalar mesons off the baryon ground states, a rich spectrum of hadronic nuclei is formed. We argue that chiral symmetry and large-$N_c$ considerations determine that part of the interaction which generates the spectrum. We suggest the existence of strongly bound crypto-exotic baryons, which contain a charm-anti-charm pair. Such states are narrow since they can decay only via OZI-violating processes.

**Keywords**: hadrogenesis, coupled-channel systems, hadronic nuclei, chiral dynamics

**PACS numbers**: 12.38 Cy, 12.38 Lg, 12.39 Fe

1. **Introduction**

The existence of strongly bound crypto-exotic baryon systems with hidden charm would be a striking feature of strong interactions\(^1\). Such states may be narrow since their strong decays are OZI-suppressed\(^2\). Indeed, a high statistics bubble chamber experiment performed 30 years ago with a $K^-$ beam reported on a possible signal for a hyperon resonance of mass 3.17 GeV of width smaller than 20 MeV\(^3\). About ten years later a further bubble chamber experiment using a high energy $\pi^-$ beam suggested a nucleon resonance of mass 3.52 GeV with a narrow width of $7^{+20}_{-7}$ MeV. In Fig. 1, we recall the measured five body ($p K^+ K^0 \pi^- \pi^-$) invariant mass distribution\(^6\) suggesting the existence of a crypto-exotic nucleon resonance.

It is the purpose of the present talk to review a study addressing the possible existence of crypto-exotic baryon systems\(^7\). In view of the highly speculative nature of such states it is important to correlate the properties of such states to those firmly established, applying a unified and quantitative framework. We extended previous works Ref.\(^11\)\(^,\)\(^12\) that performed a coupled-channel study of the s-wave scattering processes where a Goldstone boson hits a baryon ground state. The spectrum of $J^P = \frac{1}{2}^-$ and $J^P = \frac{3}{2}^-$ molecules obtained in Ref.\(^9\)\(^,\)\(^10\)\(^,\)\(^11\)\(^,\)\(^12\) is quite compatible with the so far observed states. Analogous computations successfully describe the spectrum of zero and open-charm mesons with $J^P = 0^+$ and $1^+$ quantum numbers\(^13\)\(^,\)\(^14\)\(^,\)\(^15\). These developments were driven by the hadrogenesis conjecture: meson
and baryon resonances that do not belong to the large-$N_c$ ground state of QCD should be viewed as hadronic nuclei. Generalizing those computations to include $D$- and $\eta_c$-mesons in the intermediate states offers the possibility to address the formation of crypto-exotic baryon states (see also Ref. 18, 19, 20, 21).

The results of Ref. 9, 10, 11, 12 were based on the leading order chiral Lagrangian, that predicts unambiguously the s-wave interaction strength of Goldstone bosons with baryon ground states in terms of the pion decay constant. Including the light vector mesons as explicit degrees of freedom in a chiral Lagrangian gives an interpretation of the leading order interaction in terms of the zero-range t-channel exchange of light vector mesons 22, 23, 24, 25, 26. The latter couple universally to any matter field in this type of approach. Based on the assumption that the interaction strength of $D$- and $\eta_c$-mesons with the baryon ground states is also dominated by the t-channel exchange of the light vector mesons, we performed a coupled-channel study of crypto-exotic baryon resonances 27, 28.

2. S-wave baryon resonances with zero charm

The spectrum of $J^P = \frac{1}{2}^-$ baryon resonances as generated by the t-channel vector-meson exchange interaction via coupled-channel dynamics falls into two types of states. Resonances with masses above 3 GeV couple strongly to mesons with non-
zero charm content. In the SU(3) limit those states form an octet and a singlet. All other states have masses below 2 GeV. In the SU(3) limit they group into two degenerate octets and one singlet. The presence of the heavy channels does not affect that part of the spectrum at all (see Ref. [7]). We reproduce the success of previous coupled-channel computations of Ref. [9, 10], which predicts the existence of the s-wave resonances \( N(1535), \Lambda(1405), \Lambda(1670), \Xi(1690) \) unambiguously with masses and branching ratios quite compatible with empirical information. These states are omitted from Table 1.

Most spectacular are the resonances with hidden charm generated above 3 GeV. The multiplet structure of such states is readily understood. The mesons with \( C = -1 \) form a triplet which is scattered off the \( C = +1 \) baryons being members of an anti-triplet or sextet. We decompose the products into irreducible tensors

\[
3 \otimes \mathbf{3} = 1 \oplus 8, \quad 3 \otimes \mathbf{6} = 8 \oplus 10.
\]

The coupled-channel interaction is attractive in the singlet for the anti-triplet of baryons. Attraction in the octet sector is provided by the sextet of baryons. The resulting octet of states mixes with the \( \eta' (N, \Lambda, \Sigma, \Xi) \) and \( \eta_c (N, \Lambda, \Sigma, \Xi) \) systems. A complicated mixing pattern arises. All together the binding energies of the crypto-exotic states are large. This is in part due to the large masses of the coupled-channel states: the kinetic energy the attractive t-channel force has to overcome is reduced.

The states are narrow as a result of the OZI rule. The mechanism is analogous to the one explaining the long life time of the \( J/\Psi \)-meson. We should mention, however, a caveat. It turns out that the width of the crypto-exotic states is quite sensitive to the presence of channels involving the \( \eta' \) meson. This is a natural result since the \( \eta' \) meson is closely related to the \( U_A(1) \) anomaly giving it large gluonic components. The latter works against the OZI rule. We emphasize that switching off the t-channel exchange of charm or using the SU(4) estimate for the latter, strongly bound crypto-exotic states are formed. In Table 1 the zero-charm spectrum insisting on SU(4) estimates for the couplings is shown in the 3rd and 4th column. The mass of the crypto-exotic nucleon resonance comes at 3.33 GeV in this case. Its width of 160 MeV is completely dominated by the \( \eta'/N \) decay. The properties of that state can be adjusted easily to be consistent with the empirical values claimed in Ref. [6]. The \( \eta' \) coupling strength to the open-charm mesons can be turned off by an appropriate SU(4) breaking. As a result the width of the resonance is down to about 1-2 MeV. It is stressed that the masses of the crypto-exotic states are not affected at all. The latter are increased most efficiently by allowing an OZI violating \( \phi_D D \bar{D} \) vertex. All together it is possible to tune the mass and width of the crypto-exotic nucleon at 3.52 GeV and 7 MeV. The result of this scenario is shown in the last two rows of Table 1. Further crypto-exotic states, members of the aforementioned octet, are predicted at mass 3.58 GeV \((0, -1)\) and 3.93 GeV \((1, -1)\). The multiplet is completed with a \((\frac{1}{2}, -2)\) state at 3.80 GeV. The decay widths of these states center around \( \sim 7 \) MeV. This reflects the dominance of their decays into channels involving the \( \eta' \) meson. The coupling constants to the various channels are included.
Table 1. Spectrum of $J^P = \frac{1}{2}^-$ baryons with charm zero. The 3rd and 4th columns follow with SU(4) symmetric 3-point vertices. In the 5th and 6th columns SU(4) breaking is introduced as explained in the text. Only states with hidden charm are shown, for a complete list see Ref. 7.

| $C = 0$ : $(I, S)$ | state | $M_R$ [MeV] | $\Gamma_R$ [MeV] | $|g_R|$ | $M_R$ [MeV] | $\Gamma_R$ [MeV] | $|g_R|$ |
|-------------------|-------|-------------|----------------|------|-------------|----------------|------|
| $(\frac{1}{2}^-, 0)$ | $\pi N$ | 0.1 | 0.07 | | | | |
| | $\eta N$ | 0.1 | 0.11 | | | | |
| | $\Lambda K$ | 0.1 | 0.08 | | | | |
| | $\Sigma K$ | 3327 | 0.1 | 3520 | 0.08 | | |
| | $\eta' N$ | 156 | 1.4 | 7.3 | 0.22 | | |
| | $\eta_c N$ | 0.7 | 1.0 | | | | |
| | $\bar{D} K_c$ | 5.7 | 5.3 | | | | |
| | $D_{\Sigma_c}$ | 5.0 | 5.0 | | | | |
| | $D_{\Xi_c}$ | 0.1 | 0.01 | | | | |
| $(0, -1)$ | $\pi N$ | 0.04 | 0.04 | | | | |
| | $\eta N$ | 0.03 | 0.03 | | | | |
| | $\Lambda K$ | 0.03 | 0.03 | | | | |
| | $\Xi K$ | 0.04 | 0.04 | | | | |
| | $\eta' \Lambda$ | 0.08 | 0.57 | 0.01 | | | |
| | $\eta_c \Lambda$ | 0.6 | 0.04 | | | | |
| | $\bar{D} K_c$ | 3.2 | 3.0 | | | | |
| | $D_{\Xi_c}$ | 5.0 | 5.0 | | | | |
| | $D_{\Sigma_c}$ | 0.1 | 0.01 | | | | |
| $(0, -1)$ | $\pi \Sigma$ | 0.06 | 0.06 | | | | |
| | $\eta \Sigma$ | 0.01 | 0.01 | | | | |
| | $\Lambda K$ | 0.01 | 0.01 | | | | |
| | $\Xi K$ | 0.1 | 0.07 | | | | |
| | $\eta' \Lambda$ | 0.07 | 0.93 | | | | |
| | $\eta_c \Lambda$ | 0.01 | 0.02 | | | | |
| | $\bar{D} K_c$ | 0.1 | 0.02 | | | | |
| | $D_{\Xi_c}$ | 3.8 | 4.9 | 0.20 | | | |
| | $D_{\Sigma_c}$ | 0.6 | 0.36 | | | | |
| | $D_{\Xi_c'}$ | 5.6 | 5.3 | | | | |
| $(1, -1)$ | $\pi \Sigma$ | 0.1 | 0.08 | | | | |
| | $\eta \Sigma$ | 0.04 | 0.04 | | | | |
| | $\Lambda K$ | 0.2 | 0.12 | | | | |
| | $\Xi K$ | 0.1 | 0.06 | | | | |
| | $\eta' \Sigma$ | 0.1 | 0.06 | | | | |
| | $\eta_c \Sigma$ | 0.1 | 0.06 | | | | |
| | $\bar{D} K_c$ | 1.2 | 1.8 | | | | |
| | $D_{\Xi_c}$ | 0.6 | 0.11 | | | | |
| | $D_{\Sigma_c}$ | 4.6 | 3.6 | | | | |
| | $D_{\Xi_c'}$ | 2.9 | 2.4 | | | | |
| $(\frac{3}{2}, -2)$ | $\pi \Xi$ | 0.1 | 0.08 | | | | |
| | $\eta \Xi$ | 0.1 | 0.04 | | | | |
| | $\Lambda K$ | 0.1 | 0.04 | | | | |
| | $\Sigma K$ | 0.1 | 0.04 | | | | |
| | $\eta' \Xi$ | 0.0 | 0.01 | | | | |
| | $\eta_c \Xi$ | 1.4 | 0.22 | | | | |
| | $\bar{D} K_c$ | 1.0 | 1.2 | | | | |
| | $D_{\Xi_c}$ | 0.6 | 0.10 | | | | |
| | $D_{\Xi_c'}$ | 3.3 | 2.9 | | | | |
| | $D_{\Omega_c}$ | 4.3 | 4.0 | | | | |

They confirm the interpretation that the crypto-exotic states discussed above are a consequence of a strongly attractive force between the charmed mesons and the baryon sextet.

A crypto-exotic SU(3) singlet state is formed due to strong attraction in the $(\bar{D}_s \Lambda_c)$, $(\bar{D} \Xi_c)$ system. Its nature is quite different as compared to the one of the octet states. This is because its coupling to the $\eta' \Lambda$ channel is largely suppressed. We identify this state with a signal claimed in the $K^- p$ reaction, where a narrow hyperon state with 3.17 GeV mass and width smaller than 20 MeV was seen \[7\]. Using values for the coupling constants as suggested by SU(4) the state has a mass
and width of 3.148 GeV and 1 MeV (see 3rd and 4th column of Table 1).

3. $J^P = \frac{3}{2}^-$ resonances with zero charm

We turn to the resonances with $J^P = \frac{3}{2}^-$. The spectrum falls into two types of states. Resonances with masses above 3 GeV couple strongly to mesons with non-zero charm content. In the SU(3) limit those states form an octet. All other states have masses below 2.5 GeV. In the SU(3) limit they group into an octet and decuplet. The presence of the heavy channels does not affect that part of the spectrum at all. We reproduce the previous coupled-channel computation 10. Again an octet of resonances with hidden charm above 3 GeV is formed. The multiplet structure of such states is readily understood. The mesons with $C = -1$ form a triplet which is scattered off the charmed baryons forming a sextet, the decomposition into irreducible tensors is the same as in (1). The interaction is attractive in the crypto-exotic octet and repulsive in the decuplet. For the formation of the states the charm-exchange processes are irrelevant. This holds as long as the SU(4) estimates for the coupling constants are correct within a factor of three. Thus the crypto-exotic sector may be characterized by the decomposition

$$\frac{1}{4 \pi^2} \sum_{V \in [9]} C_V^{(C=0)} = C^{\text{crypto}}_{[8]} - 2 C^{\text{crypto}}_{[10]},$$

(2)

where we assume chiral and large-$N_c$ relations for the three-point vertices again. The binding energies of the crypto-exotic states are large.

In Tab. 2 the spectrum of crypto-exotic baryons is shown. The charm-exchange contributions are estimated by a SU(4) ansatz for the 3-point vertices. The octet of states is narrow as a result of the OZI rule. The precise values of the width parameters are sensitive to the SU(4) estimates. In contrast to the $J^P = \frac{3}{2}^-$ states, channels that involve the $\eta'$ meson do not to play a special role in the d-wave spectrum. This is in part a consequence that the $\eta'$ channels decouple from the crypto-exotic sector in the SU(3) limit. It is interesting to observe that a narrow nucleon resonance is predicted at 3.42 GeV. One may speculate that the crypto-exotic resonance claimed at 3.52 GeV in 6 may be a d-wave rather than s-wave state. If so its decay into the $\eta'N$ channel should be suppressed. Given the uncertainties of the claim 6 we refrain from fine tuning the model parameters as to push up the $(\frac{1}{2}, 0)$ state.

The results collected in Tab. 2 are subject to large uncertainties. The evaluation of the total width as well as a more reliable estimate of the binding energies of the crypto-exotic states requires the consideration of further partial-wave contributions. The large binding energy obtained suggest a more detailed study that is based on a more realistic interaction taking into account in particular the finite masses of the t-channel exchange processes.
Table 2. Spectrum of $J^P = \frac{3}{2}^-$ baryons with charm zero. Here all columns follow with SU(4) symmetric 3-point vertices. Only states with hidden charm are shown, for a complete list see Ref. 8.

| $C = 0 : (I, S)$ | state  | $M_R$ [MeV] | $\Gamma_R$ [MeV] | $|g_R|$ |
|------------------|--------|-------------|-----------------|--------|
| $(\frac{1}{2}, 0)$ | $\pi \Delta$ | 3430 | 0.05 | |
|                  | $K \Sigma$ | 0.50 | 0.04 | |
|                  | $D \Sigma_c$ | 5.6 | 0.04 | |
| $(0, -1)$        | $\pi \Xi$ | 3538 | 0.05 | |
|                  | $K \Xi$ | 0.63 | 0.05 | |
|                  | $D \Xi_c$ | 5.5 | 0.04 | |
| $(1, -1)$        | $\pi \Sigma$ | 3720 | 0.03 | |
|                  | $K \Delta$ | 0.83 | 0.01 | |
|                  | $\eta' \Sigma$ | 0.20 | |
|                  | $D_\pi \Sigma_c$ | 4.5 | |
|                  | $D_\eta \Xi_c$ | 2.8 | |
| $(\frac{1}{2}, -2)$ | $\pi \Xi$ | 3742 | 1.1 | 0.03 |
|                  | $K \Omega$ | 0.06 | |
|                  | $\eta' \Xi$ | 0.16 | |
|                  | $D_\pi \Xi_c$ | 3.2 | |
|                  | $D_\eta \Omega_c$ | 4.2 | |

4. Summary

We reviewed coupled-channel studies of crypto-exotic s-wave and d-wave baryon resonances with charm 0. The dominant interaction is defined by the exchange of light vector mesons in the t-channel. All relevant coupling constants are obtained from chiral and large-$N_c$ properties of QCD. Less relevant vertices related to the t-channel forces induced by the exchange of charmed vector mesons were estimated by applying SU(4) symmetry. Most spectacular is the prediction of narrow baryons with charm zero forming below 4 GeV. Such states contain a $c\bar{c}$ pair. Their widths parameters are small due to the OZI rule, like it is the case for the $J/\Psi$ meson. We predict octets of crypto-exotic s-wave and d-wave states. The s-wave resonances decay dominantly into channels involving an $\eta'$ meson. An even stronger bound crypto-exotic SU(3) singlet s-wave state is predicted to have a decay width of about 1 MeV only.

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