

# Exotic baryon states in topological soliton models

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## Abstract

The novel observation of an exotic strangeness  $S = +1$  baryon state at 1.54 GeV will trigger an intensified search for this and other baryons with exotic quantum numbers. This state was predicted long ago in topological soliton models. We use this approach together with the new datum in order to investigate its implications for the baryon spectrum. In particular we estimate the positions of other pentaquark and septuquark states with exotic and with non-exotic quantum numbers.

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## 1 Introduction

In a quite recent paper [1], Nakano et. al. report on an exotic strangeness  $S = +1$  baryon state observed as a sharp resonance at  $1.54 \pm 0.01$  GeV in photo-production from neutrons. The confirmation of this finding would give formidable support to topological soliton models [2, 3] for a description of baryons in the non-perturbative regime of QCD. Higher multiplets containing states carrying exotic quantum numbers arise naturally in the  $SU(3)$  version of these models. These were called *exotic* because, within quark models, such states cannot be built of only 3 valence quarks and additional quark-antiquark pairs must be added. So, the terms *pentaquark* and *septuquark* characterize the quark contents of these states. Strictly, in soliton models there is nothing exotic about these states, they just come as members of the next higher multiplets.

Indeed, beyond the minimal  $\{8\}$  and  $\{10\}$  baryons, also a  $\{\overline{10}\}$  baryon multiplet was mentioned early by Chemtob [4]. Within a simple  $SU(3)$  symmetric Skyrme model Biedenharn and Dothan [5] estimated the excitation energy of the  $\{\overline{10}\}$  with spin  $J = 1/2$  to be only 0.60 GeV (sic!) above the nucleon. This multiplet and a  $\{27\}$  with spin  $J = 3/2$  both contain low lying  $S = +1$  states, called  $Z$  and  $Z^*$  in the following. First numbers for these exotic states taking the configuration mixing caused by symmetry breaking into account were given in [6], albeit some 0.1 GeV

too high if the value found in [1] proves correct. Diakonov, Petrov and Polyakov [7] postulated the experimental  $P11(1.71)$  nucleon resonance a member of the  $\{\overline{10}\}$  multiplet and by this the  $Z$  again with low excitation energy (0.59 GeV). Weigel [8] showed that similar low numbers (0.63 GeV) may be obtained in an extended Skyrme model calculation, which includes a scalar field.

It should be added, that the excitation energies of similar exotic states have been estimated for arbitrary baryonic numbers [9]. It turned out, that all these states appear to be above threshold for the decay due to strong interactions. In general the excitation energies for the  $B > 1$  systems are comparable to those for baryons, e.g. the  $S = 1$  dibaryon state belonging to the  $\{\overline{35}\}$  multiplet was calculated, to be only 0.59 GeV above  $NN$ -threshold [10].

In this paper we address the following questions concerning the  $B = 1$  sector. Is an exotic  $Z$  at 1.54 GeV as reported in [1] compatible with soliton models and the known baryon spectrum? Provided the  $Z$  is actually located at this position, what does it imply for the other exotic states?

## 2 $SU(3)$ soliton model

There exists a large number of different soliton models, pure pseudoscalar ones, models with scalar fields and/or vector and axial-vector mesons and even models which include quark degrees of freedom. There comes also a vast number of possible terms in the effective action for each of these models, partly with free adjustable parameters. However, the  $SU(3)$  symmetric part always leads to the same collective hamiltonian with only 2 model dependent quantities determining the baryon spectrum (section 2.1). Unfortunately the situation for the symmetry breaking part is less advantageous, but still there appears one dominating standard symmetry breaker which will be the third model dependent quantity needed (section 2.2). Thus, instead of referring to a specific model (which comes with a number of free parameters as well) we are going to adjust these 3 quantities to the known  $\{8\}$  and  $\{10\}$  baryon spectra and to the just reported  $Z$  [1]. Using this input, we try to answer the questions posed in the introduction. It will also be shown that the values needed for the three quantities are not too far from what may be obtained in a standard Skyrme model.

In the baryon sector, the static hedgehog soliton configuration located in the non-strange  $SU(2)$  subgroup is collectively and rigidly rotated in  $SU(3)$  space. There are other approaches like the soft rotator approach and the bound state approach, but probably for  $B = 1$  the rigid rotator approach is most appropriate.

## 2.1 $SU(3)$ symmetric part

The  $SU(3)$  symmetric effective action leads to the collective Lagrangian [11]

$$L^S = -M + \frac{1}{2}\Theta_\pi \sum_{a=1}^3 (\Omega_a^R)^2 + \frac{1}{2}\Theta_K \sum_{a=4}^7 (\Omega_a^R)^2 - \frac{N_C B}{2\sqrt{3}} \Omega_8^R. \quad (1)$$

depending on the angular velocities  $\Omega_a^R$ ,  $a = 1, \dots, 8$ . It is generic for all effective actions whose non-anomalous part contains at most two time derivatives, the term linear in the angular velocity depends on the baryon number  $B$  and the number of colors  $N_C$  and it appears due to the Wess-Zumino-Witten anomaly.

The soliton mass  $M$ , the pionic and kaonic moments of inertia  $\Theta_\pi$  and  $\Theta_K$  are model dependent quantities. The latter two are relevant to the baryon spectrum, the soliton mass  $M$ , subject to large quantum corrections, enters the absolute masses only. With the right and left angular momenta

$$R_a = -\frac{\partial L^0}{\partial \Omega_a^R}, \quad L_a = \sum_{b=1}^8 D_{ab} R_b, \quad (2)$$

which transform according to Wigner functions  $D_{ab}$  depending on the soliton's orientation, the hamiltonian obtained by a Legendre transformation

$$H^S = M + \frac{1}{2\Theta_\pi} \mathbf{R}^2 + \frac{1}{2\Theta_K} (C_2(SU(3)) - \mathbf{R}^2 - N_C^2 B^2/12) \quad (3)$$

may be expressed by the second order Casimir operators of the  $SU(3)$  group and its nonstrange  $SU(2)$  subgroup

$$C_2(SU(3)) = \sum_{a=1}^8 R_a^2, \quad \mathbf{R}^2 = \sum_{a=1}^3 R_a^2. \quad (4)$$

The eigenvalues of these operators for a given  $SU(3)$  irrep  $(p, q)$  with dimensionality  $N = (p+1)(q+1)(p+q+2)/2$  are

$$\begin{aligned} C_2(SU(3))| \{N\}(p, q), (Y_R J J_3) \rangle &= \left[ \frac{p^2 + q^2 + pq}{3} + p + q \right] | \{N\}(p, q), (Y_R J J_3) \rangle \\ \mathbf{R}^2 | \{N\}(p, q), (Y_R J J_3) \rangle &= J(J+1) | \{N\}(p, q), (Y_R J J_3) \rangle, \end{aligned} \quad (5)$$

where  $(Y_R J J_3)$  denote the right hypercharge and the baryon's spin. The latter relation is due to the hedgehog ansatz which connects the spin to the right isospin. The states are still degenerate with respect to the left (flavor) quantum numbers  $(Y T T_3)$  suppressed here. The constraint  $R_8 = N_C B / 2\sqrt{3}$  fixes  $Y_R = N_C B / 3$  [11] and is written as triality condition [5]

$$Y_{max} = \frac{p+2q}{3} = B + m, \quad (6)$$

with  $Y_{max}$  representing the maximal hypercharge of the  $(p, q)$  multiplet. Thus, baryons belong to irreps of  $SU(3)/Z_3$ . With the octet being the lowest  $B = 1$  multiplet, the number of colors must be  $N_C = 3$ . It also follows a spin-statistics-baryon number relation  $(-1)^{2J+B} = 1$ , which for  $B = 1$  allows for half-integer spins only [5].

From a quark model point of view, the integer  $m$  must be interpreted as the number of additional  $q\bar{q}$  pairs present in the baryon state [9]. When  $B = 1$ , we obtain for  $m = 0$  the minimal multiplets  $\{8\}$  and  $\{10\}$ , for  $m = 1$  the family of pentaquark multiplets  $\{\overline{10}\}$ ,  $\{27\}$ ,  $\{35\}$ ,  $\{28\}$ , and for  $m = 2$  the septuquark multiplets  $\{\overline{35}\}$ ,  $\{64\}$ ,  $\{81\}$ ,  $\{80\}$  and  $\{55\}$  (Fig. 1). For the masses of the multiplets  $\{8\}$   $J = 1/2$ ,  $\{10\}$   $J = 3/2$ ,  $\{\overline{10}\}$   $J = 1/2$ ,  $\{27\}$   $J = 3/2$  and  $\{\overline{35}\}$   $J = 3/2$  simple relations

$$\begin{aligned}
M_{\{10\}} - M_{\{8\}} &= 3/2\Theta_\pi, \\
M_{\{\overline{10}\}} - M_{\{8\}} &= 3/2\Theta_K, \\
M_{\{27\}} - M_{\{10\}} &= 1/\Theta_K, \\
M_{\{\overline{35}\}} - M_{\{10\}} &= 15/4\Theta_K
\end{aligned}
\tag{7}$$

hold. It is noticed that the mass difference of the minimal multiplets depends on  $\Theta_\pi$  only <sup>1</sup>, whereas the mass differences between minimal and non-minimal multiplets depend on  $\Theta_K$  and  $\Theta_\pi$ . With values  $\Theta_\pi \simeq 5 \text{ GeV}^{-1}$  and  $\Theta_K \simeq 2.5 \text{ GeV}^{-1}$  from

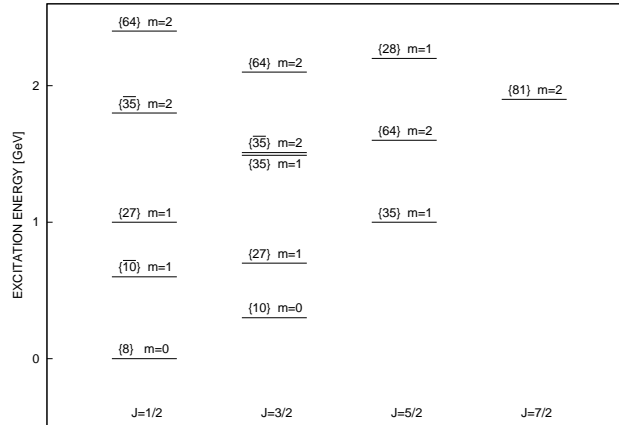


Figure 1:  $B = 1$  baryon multiplets with less than 2.5 GeV excitation energy for  $\Theta_\pi = 5 \text{ GeV}^{-1}$  and  $\Theta_K = 2.5 \text{ GeV}^{-1}$ . The number  $m$  of additional  $q\bar{q}$  pairs is also given.

<sup>1</sup>It was shown for arbitrary  $B$  [9] that coefficient of  $1/2\Theta_K$  in (3),  $C_2(SU(3)) - \mathbf{R}^2 - 3B^2/4 = 3B/2$  for any minimal multiplet with  $p + 2q = 3B$ ;  $N_c = 3$ .

a naive Skyrme model the estimate  $M_{\{\overline{10}\}} - M_{\{8\}} \simeq 0.60$  GeV [5] was obtained, according to (7). The mass of the  $\{27\}$  lies then  $\simeq 0.10$  GeV higher. In Fig. 1 we show the spectrum of all baryon multiplets with an excitation energy up to 2.5 GeV using these moments of inertia for illustration. The sequence of the lowest baryon multiplets

$$\{8\} J = \frac{1}{2}, \quad \{10\} J = \frac{3}{2}, \quad \{\overline{10}\} J = \frac{1}{2}, \quad \{27\} J = \frac{3}{2}, \quad \{35\} J = \frac{5}{2} \dots \quad (8)$$

turns out to be unique within a large range of moments of inertia  $\Theta_\pi/3 < \Theta_K < \Theta_\pi/2$ , covering many realistic cases. Diagrams for the lowest non-minimal baryon multiplets  $\{\overline{10}\}$  and  $\{27\}$  which accommodate the interesting  $S = +1$  states are depicted in Fig. 2.

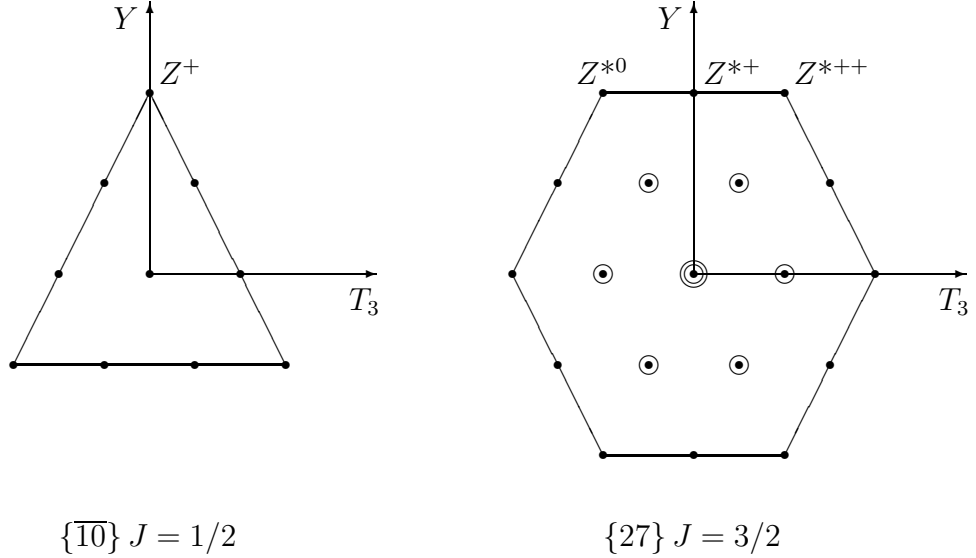


Figure 2: The  $T_3 - Y$  diagrams for the baryon multiplets  $\{\overline{10}\}$  and  $\{27\}$  which include the lowest  $S = +1$  states.

So far we have considered the  $SU(3)$  symmetric case. In order to explain the splitting of baryon states within each multiplet we have to take the explicit symmetry breaking into account.

## 2.2 $SU(3)$ symmetry breaking

The dominant standard symmetry breaker comes from mass and kinetic terms in the effective action which account for different meson masses and decay constants

e.g.  $m_K \neq m_\pi$  and  $F_K \neq F_\pi$

$$L^{SB} = -\frac{1}{2}\Gamma(1 - D_{88}) - \Delta \sum_{a=1}^3 D_{8a} \Omega_a^R + \dots, \quad (9)$$

(first term). There may be further terms of minor importance which depend on the specific effective action used. As an example we will optionally include such a term which arises from  $\rho - \omega$  mixing in vector meson lagrangians (second term). This may serve as a test for the model dependence of our results. The corresponding hamiltonian is

$$H^{SB} = \frac{1}{2}\Gamma(1 - D_{88}) - \frac{\Delta}{\Theta_\pi} \sum_{a=1}^3 D_{8a} R_a + \dots. \quad (10)$$

The quantities  $\Gamma$  and  $\Delta$  are again model dependent quantities, they determine the strength of symmetry breaking. To begin with we consider only the standard symmetry breaker  $\Gamma$ .

It was early noticed that a perturbative treatment of this symmetry breaker leads to a splitting  $(M_\Lambda - M_N) : (M_\Sigma - M_\Lambda) : (M_\Xi - M_\Sigma) = 2 : 2 : 1$  for the  $\{8\}$  baryons [4, 11] in variance with observation. Because symmetry breaking is strong, eq. (10) must be diagonalised in the basis of the unperturbed eigenstates of  $H^S$ . By this procedure the states of a certain multiplet pick up components of higher representations. Nevertheless we will address also the mixed states as  $\{8\}$  states,  $\{10\}$  states and so on, according to their dominant contribution.

The best values for the moments of inertia  $\Theta_\pi$  and  $\Theta_K$  and the symmetry breaker  $\Gamma$  are listed in Table 1 (fit A). Optionally the symmetry breaker  $\Delta$  is also included (fit B). First we show in Fig. 3 the dependence of the  $Z$  and  $Z^*$  energies on the

Table 1: Moments of inertia and symmetry breakers as obtained from a fit to the baryon spectrum including the novel  $Z$  datum.

	$\Theta_\pi[\text{GeV}^{-1}]$	$\Theta_K[\text{GeV}^{-1}]$	$\Gamma[\text{GeV}]$	$\Delta$
fit A	5.61	2.84	1.45	—
fit B	5.87	2.74	1.34	0.40

kaonic moment of inertia  $\Theta_K$  with the other parameters kept fixed. The sensitive dependence expected from eq. (7) persists when symmetry breaking is included. If the experimental datum for  $Z$  proves correct, a relatively large kaonic moment of inertia (Table 1) is required.

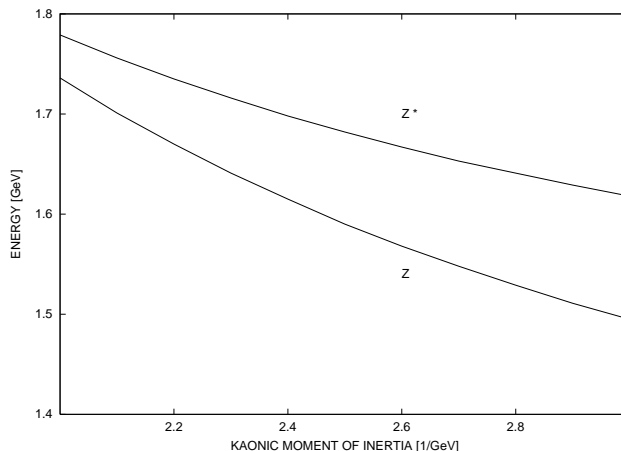


Figure 3: The masses of the  $S = 1$  baryon masses  $Z$  and  $Z^*$  depending on the kaonic moment of inertia.  $\Theta_\pi = 5.87 \text{ GeV}^{-1}$  and  $\Gamma = 1.34 \text{ GeV}$  are kept fixed.

Let us compare with what is obtained from a standard Skyrme model [2, 3] (the only parameter of this model  $e = 4.05$ ) with mass and kinetic symmetry breakers included with mesonic parameters. There appear time derivatives in the kinetic symmetry breaker which were neglected in [6] (adiabatic approximation) with the argument that they are suppressed by two orders in an  $1/N_C$  expansion and there should come many other symmetry breaking terms at this order which are also not taken into account. This leads to  $\Theta_\pi = 5.88 \text{ GeV}^{-1}$ ,  $\Gamma = 1.32 \text{ GeV}$  and a relatively small kaonic moment of inertia  $\Theta_K = 2.19 \text{ GeV}^{-1}$  (connected with larger  $Z$  and  $Z^*$  masses, Fig. 3). However, the non-adiabatic terms in the kinetic symmetry breaker are not really small, giving a sizeable contribution to the kaonic moment of inertia  $\Theta_K = 2.80 \text{ GeV}^{-1}$  together with symmetry breaking terms and even terms non-diagonal in the angular momenta. Since the latter were never properly treated, these numbers should be compared with reservation to those given in Table 1. Nevertheless, it seems that the standard Skyrme model potentially may provide values close to fit B. Relative to fit A, the standard symmetry breaker from the Skyrme model appears too weak indicating that an important symmetry breaking piece is missing in this model. Concluding this discussion, it should be stressed, that the non-adiabatic terms in the kinetic symmetry breaker are of course not the only possibility to arrive at larger kaonic moments of inertia. The inclusion of other degrees of freedom or the consideration of additional terms in the effective action sensitively influences this quantity. In this respect the position of the exotic  $Z$  baryon proves an important constraint on soliton models.

The resulting baryon spectrum is shown in Fig. 4. It is noticed that for fit A,

with the standard symmetry breaker alone, (i) the  $\Sigma - \Lambda$  mass difference is too large, (ii) the splitting in the  $J = 1/2$  multiplets relative to that in the  $J = 3/2$  multiplets is overestimated, and (iii) the corresponding  $SU(2)$  symmetry breaker may account only for half the neutron-proton split (not shown here, see e.g.[6]). Essentially all three deficiencies may be cured by including the second symmetry breaker, fit B. This does of course not mean, that the additional symmetry breaker must be exactly of the form (10), other operator structures are possible. As mentioned, we include fit B mainly to get a notion of the model dependence of our results. It seems that the

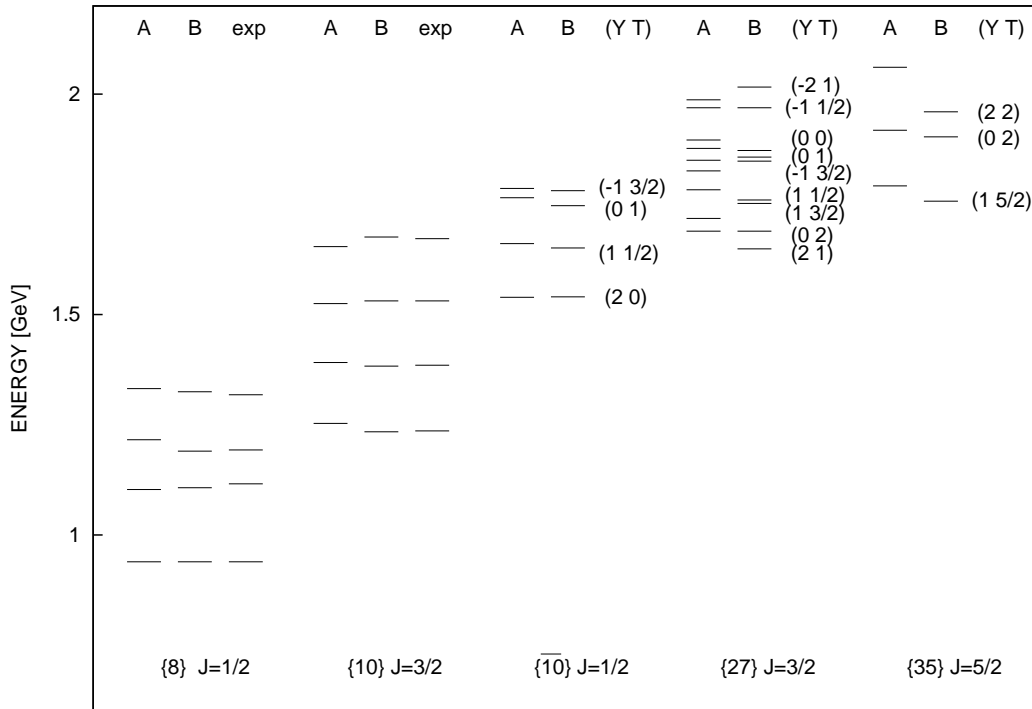


Figure 4: Lowest rotational states in the  $SU(3)$  soliton model for fits A and B. The experimental masses of the  $\{8\}$  and  $\{10\}$  baryons are depicted for comparison. Not all states of the  $\{35\}$  are shown.

levels of the  $\{\overline{10}\}$  are relatively stable in contrast to the  $\{27\}$  whose states depend sensitively on the specific form of the symmetry breakers such that even the ordering of the levels gets changed.

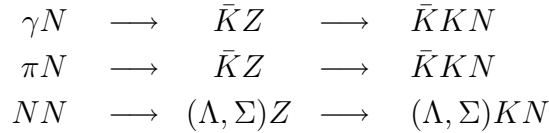
The lowest states of the  $\{\overline{10}\}$  and  $\{27\}$  are listed in Tables 2 and 3. We distinguish states with exotic quantum numbers from those with non-exotic quantum numbers  $-2 \leq Y \leq 1$  and  $T \leq 1 + Y/2$ . Generally, the former are "cleaner", because they

cannot mix with vibrational excitations (apart from their own radial excitations). Because additional vibrations on top of these states can only enhance the energy,

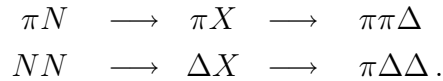
Table 2: Rotational states of non-minimal multiplets with exotic quantum numbers below 2 GeV including all members of  $\{\overline{10}\}$  and  $\{27\}$ . The experimental  $Z$  datum enters the fits. The lowest exotic  $Y = \pm 3$  baryon states are also included.

		$J$	$Y$	$T$	decay modes	estimated energy [GeV]	
						A	B
$Z$	$\{\overline{10}\}$	$\frac{1}{2}$	2	0	$KN$	1.54	1.54
$Z^*$	$\{27\}$	$\frac{3}{2}$	2	1	$KN$	1.69	1.65
	$\{27\}$	$\frac{3}{2}$	0	2	$\pi\Sigma, \pi\Sigma^*, \pi\pi\Lambda$	1.72	1.69
$X$	$\{35\}$	$\frac{5}{2}$	1	$\frac{5}{2}$	$\pi\Delta, \pi\pi N$	1.79	1.76
	$\{\overline{10}\}$	$\frac{1}{2}$	-1	$\frac{3}{2}$	$\pi\Sigma, \pi\Sigma^*, \bar{K}\Sigma$	1.79	1.78
	$\{27\}$	$\frac{3}{2}$	-1	$\frac{3}{2}$	$\pi\Sigma, \pi\Sigma^*, \bar{K}\Sigma$	1.85	1.85
	$\{35\}$	$\frac{5}{2}$	0	2	$\pi\Sigma, \pi\Sigma^*$	1.92	1.90
	$\{35\}$	$\frac{5}{2}$	2	2	$K\Delta, K\pi N$	2.06	1.96
	$\{27\}$	$\frac{3}{2}$	-2	1	$\pi\Omega, \bar{K}\Xi, \bar{K}\Xi^*$	1.99	2.02
	$\{35\}$	$\frac{5}{2}$	-3	$\frac{1}{2}$	$K\Omega, KK\Xi$	2.31	2.36
$Z^{**}$	$\{\overline{35}\}$	$\frac{3}{2}$	3	$\frac{1}{2}$	$KKN, KK\Delta$	2.41	2.38

these turn out to be really the lowest states with exotic quantum numbers starting with the  $S = 1$  baryon states  $Z$  and  $Z^*$ . The latter are experimentally accessible via the reactions



and in  $KN$  scattering. The novel measurement [1] was a photo-production experiment of the first type. The  $S \neq 1$  exotics are more difficult to measure, e.g. the  $X$  of Table 2 via the reactions



We included also the lowest exotic states with strangeness  $S = +2$  and  $S = -4$

Table 3: Rotational states of higher multiplets with non-exotic quantum numbers below 2 GeV including all members of the  $\{\overline{10}\}$  and  $\{27\}$ .

	$J$	$Y$	$T$	candidate	estimated energy [GeV]	
					A	B
$N^* \{\overline{10}\}$	$\frac{1}{2}$	1	$\frac{1}{2}$	$NP11(1.71)***$	1.66	1.65
$\Sigma^* \{\overline{10}\}$	$\frac{1}{2}$	0	1	$\Sigma P11(1.77)*$	1.77	1.75
$\Delta^* \{27\}$	$\frac{3}{2}$	1	$\frac{3}{2}$		1.83	1.75
$\{27\}$	$\frac{3}{2}$	1	$\frac{1}{2}$	$NP13(1.72)****$	1.78	1.76
$\{27\}$	$\frac{3}{2}$	0	1	$\Sigma P13(1.84)*$	1.90	1.86
$\Lambda^* \{27\}$	$\frac{3}{2}$	0	0	$\Lambda P03(1.89)****$	1.88	1.87
$\{27\}$	$\frac{3}{2}$	-1	$\frac{1}{2}$	$\Xi ?? (1.95)**$	1.97	1.97

with main components in the  $\{\overline{35}\}$  and  $\{35\}$  multiplets respectively. The  $S = +2$  state  $Z^{**}$  still can be produced in binary reactions, e.g.  $K^0 p \rightarrow K^- Z^{**,++}$ , but the energy of this state is already quite considerable,  $\simeq 2.4$  GeV. On the other hand, the  $S = -4$  state is more difficult to produce, but detection seems to be simpler because final  $\Omega^-$  and  $K^-$  are easy to see.

In contrast, the states with non-exotic quantum numbers in Table 3 mix strongly with vibrational excitations of the  $\{8\}$  and  $\{10\}$  baryons. For example the  $N^*$  rotational state, identified with the nucleon resonance  $P11(1.71)$  in [7], mixes strongly with a  $2\hbar\omega$  radial excitation which may even lead to a doubling of states as found in [8]. This situation renders an easy interpretation difficult. Probably the cleanest of these states with non-exotic quantum numbers is the one called  $\Lambda^*$  which predominantly couples to the *non-resonant* magnetic dipole mode. But even here it is not excluded that the good agreement with the position of the experimental  $\Lambda$  resonance  $P03(1.89)$  is accidental. Also, there is not even a candidate for the rotational state called  $\Delta^*$  listed by the PDG in the required energy region with the empirical  $\Delta$  resonance  $P33(1.92)$  lying  $\simeq 0.1$  GeV too high. On the other hand in 5 cases we do have candidates close to the estimated energies. There is certainly some evidence that the numbers presented are not unreasonable.

It should be added that the energies for the  $\{\overline{10}\}$  baryons presented here differ substantially from what was obtained in ref.[7] using simple perturbation theory. Their  $\{\overline{10}\}$  splitting is overestimated by more than a factor of 1.5 .

### 3 The $S = 1$ baryon spectrum

So far we have considered rotational states only. The real situation is complicated by the fact that there is a whole tower of vibrational excitations connected with each of these rotational states. We will briefly address this issue on a quite qualitative level particularly for the  $S = 1$  sector. Possibly this may be of help for experimentalists in search for further exotic baryons.

The lowest states in the  $S = 1$  sector are the rotational states  $Z$  and  $Z^*$  discussed in the previous section. As mentioned, we believe that the energies of these 2 states should be close to each other with that of  $Z^*$  somewhat larger ( $\simeq 0.10 - 0.15$  GeV). Such rotational states appear as sharp resonances with small widths relative to the broader vibrational states. The width of  $Z$  was given in [1] to be smaller than 25 MeV, and that of  $Z^*$  should be somewhat larger due to phase space arguments. Probably the  $Z^*$  will be the next exotic state detected.

Certainly, in soliton models there exist radial excitations (breathing modes) for each rotational state. For most of the  $\{8\}$  and  $\{10\}$  baryons such excitations correspond to wellknown resonances as e.g. the Roper resonance for the nucleon. A breathing mode excitation energy  $\simeq 0.45$  GeV for the  $Z$  was calculated in [8], and that of  $Z^*$  should be considerably smaller because the latter object is more extended due to centrifugal forces connected to a larger spin (similar situation as for Roper and the  $\Delta$  resonance  $P33(1.60)$ ). Therefore we may expect excited  $P01$  and  $P13$  states close together as indicated in Fig. 5 (the order may be reversed!). In addition,

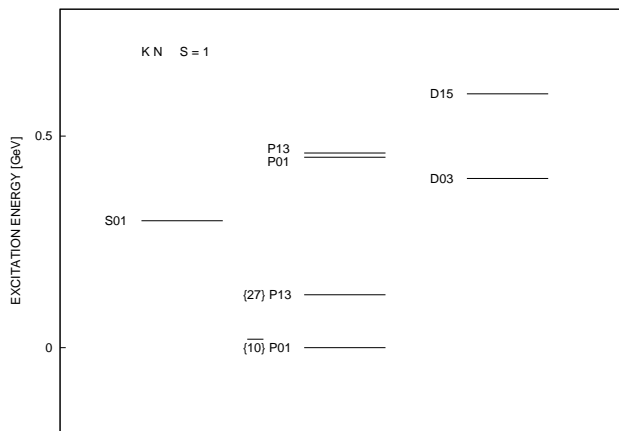


Figure 5: Tentative baryon spectrum for the  $S = 1$  sector.

there will be strong quadrupole excitations as those obtained in soliton models [12] and seen empirically in the well studied  $S = 0$  and  $S = -1$  sectors (with roughly 0.4 and 0.6 GeV excitation energy). In these sectors there appear also a number of

S-wave resonances through  $\bar{K}N$ ,  $K\Lambda$ ,  $K\Sigma$  and  $K\Xi$  bound states just below the corresponding thresholds [12]. Although such an interpretation seems less clear in the  $S = 1$  sector, a low lying  $S_{01}$  resonance is nevertheless expected, just by inspection of the other sectors.

Tentatively, this leads to a  $S = +1$  baryon spectrum depicted in Fig.5. The T-matrix poles  $P_{01}(1.83)$ ,  $P_{13}(1.81)$ ,  $D_{03}(1.79)$  and  $D_{15}(2.07)$  extracted from early  $KN$  scattering experiments [13] qualitatively would fit with such a scheme, the spacings however are considerably smaller than in Fig.5. So, in case these T-matrix poles prove correct, a strong quenching of the spectrum shown in Fig. 5 has to be understood. The existence of such poles, particularly in the  $D$ -waves, would likewise favour a  $Z$  located considerably below these resonances compatible with the datum 1.54 GeV.

## 4 Conclusion

We have shown that a low position of the exotic  $S = +1$  baryon  $Z$  with quantum numbers  $J = 1/2$  and  $T = 0$  at the reported 1.54 GeV is compatible with soliton models and the known baryon spectrum. For all members of the  $\{\bar{10}\}$  and  $\{27\}$  multiplets with non-exotic quantum numbers we find candidates close to the estimated energies, with one exception: the empirical  $\Delta$  resonance  $P_{33}(1.92)$  lies  $\simeq 0.1$  GeV too high. There will be a strong mixing of these states with vibrational modes of the  $\{8\}$  and  $\{10\}$  baryons, which may lead to considerable energy shifts and even to a doubling of states. Also the T-matrix poles of early  $KN$  scattering experiments favour a low  $Z$  sufficiently below these resonances, with the caveat, that when these poles are correct a strong quenching of the  $S = 1$  baryon spectrum compared to other sectors has to be explained.

However, the soliton model by itself does not exclude a  $Z$  baryon at higher energies. Therefore the confirmation of this datum, which proves a stringent constraint on these models, is most important.

Under the assumption, that the exotic  $Z$  is actually located at the reported position, we have estimated the energies of other exotic baryons. First of all, there will be a further  $S = +1$  baryon  $Z^*$  with quantum numbers  $J = 3/2$  and  $T = 1$ , some 0.10 – 0.15 GeV above the  $Z$ . This will probably be the next state to be discovered in similar experiments also as a sharp resonance with a somewhat larger width yet. Moreover there will be a tower of vibrational excitations built on these two exotic states, which should appear as broader resonances several 0.1 GeV above these energies.

There are also several low lying  $S \neq 1$  baryons with exotic isospin, starting with a  $J = 1/2$  state with quantum numbers  $S = 0$  and  $T = 2$  at  $\simeq 1.7$  GeV. These states are more difficult to access experimentally. The lowest  $S = +2$  and  $S = -4$  baryon states may also be of some interest although they are already expected at

high energies  $\simeq 2.3 - 2.4$  GeV.

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