

# Exotic pion like states as "infra-red" Regge Trajectories and a new view about nuclear physics

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## Abstract

There is considerable evidence for what might be called "infrared" Regge trajectories having interpretation in terms of string with string tension considerably lower than hadronic string tension. This article was motivated by a finding new evidence for pion like state in the decays of long-lived kaon. The discussion of these findings leads to a more detailed formulation of nuclear string model in terms of IR Regge trajectories of nucleons allowing to understand the successes of harmonic oscillator model but with totally different interpretation. Also the nuclear binding energy can be understood at rather quantitative level in the model. Nuclear physics would reduce to that for the magnetic body of nucleon.

## 1 Introduction

TGD based view about non-perturbative aspects of hadron physics (<http://tinyurl.com/y8semjtv>) relies on the notion of color magnetic flux tubes. These flux tubes are string like objects and it would not be surprising if the outcome would be satellite states of hadrons with string tension below the pion mass scale. One would have kind of infrared Regge trajectories satisfying in a reasonable approximation a mass formula analogous to string mass formula. What is amazing that this phenomenon could allow new interpretation for the claims for a signal interpreted as Higgs at several masses (115 GeV by ATLAS, at 125 GeV by ATLAS and CMS, and at 145 GeV by CDF). They would not be actually statistical fluctuations but observations of states at IR Regge trajectory of pion of  $M_{89}$  hadron physics!

Years after writing this new evidence for pionlike state(s) as final state in the decay of long-lived kaon emerged. The detailed consideration of the situation lead to fascinating possibility. I realized that the IR Regge trajectories allow a much more detailed view about nuclear string model allowing to reinterpret the rather successful harmonic oscillator model in terms of the IR Regge trajectories assignable to 3 - possibly electromagnetic - flux tube bonds between 3 quarks forming nucleon. 3 integers label the energy eigenvalues just like in the case of 3-D harmonic oscillator. In harmonic oscillator model nucleons are effectively free: now they are free apart from constraint from belonging to the nuclear string. Also the nuclear binding energy and its behavior can be understood at rather quantitative level in terms of nuclear string model. Nuclear physics would reduce to that for the magnetic body of nucleon, which would mean enormous simplification.

## 2 IR Regge trajectories

Consider first the mass formula for the hadrons at IR Regge trajectories.

1. There are two options depending on whether the mass squared or mass for hadron and for the flux tubes are assumed to be additive. p-Adic physics would suggest that if the p-adic primes characterizing the flux tubes associated with hadron and hadron proper are different then mass is additive. If the p-adic prime is same, the mass squared is additive.

2. The simplest guess is that the IR stringy spectrum is universal in the sense that  $m_0$  does not depend on hadron at all. This is the case if the flux tubes in question correspond to hadronic space-time sheets characterized by p-adic prime  $M_{107}$  in the case of ordinary hadron physics. This would give for the IR contribution to mass the expression

$$m^2 = \sqrt{m_0^2 + nm_1^2} .$$

3. The net mass of hadron results from the contribution of the “core” hadron and the stringy contribution. If mass squared is additive, one obtains  $m(H_n) = \sqrt{m^2(H_0) + m_0^2 + nm_1^2}$ , where  $H_0$  denotes hadron ground state and  $H_n$  its excitation assignable to magnetic flux tube. For heavy hadrons this would give the approximate spectrum

$$m(H_n) \simeq m(H_0) + \frac{m_0^2 + nm_1^2}{2m(H_0)} .$$

The mass unit for the excitations decreases with the mass of the hadron.

4. If mass is additive as one indeed expects since the p-adic primes characterizing heavy quarks are smaller than hadronic p-adic prime, one obtains

$$m(H_n) = m(H_0) + \sqrt{m_0^2 + nm_1^2} .$$

For  $m_0^2 \gg m_1^2$  one has

$$m(H_n) = m(H_0) + m_0 + n \frac{m_1^2}{2m_0} .$$

If the flux tubes correspond to p-adic prime. This would give linear spectrum which is same for all hadrons.

## 2.1 Evidence for IR Regge trajectories

There is evidence for this kind of states. The experimental claim (see <http://tinyurl.com/ybq323yy>) of Tatischeff and Tomasi-Gustafsson is that pion is accompanied by pion like states organized on Regge trajectory and having mass 60, 80, 100, 140, 181, 198, 215, 227.5, and 235 MeV. means that besides pion also other pion like states should be there. Similar satellites have been observed for nucleons with ground state mass 934 MeV: the masses of the satellites are 1004, 1044, 1094 MeV. Also the signal cross sections for Higgs to gamma pairs at LHC [C3, C4] suggest the existence of several pion and spion like states, and this was the reason why I decided to again the search for data about this kind of states (I remembered vaguely that Tommaso Dorigo had talked about them but I failed to find the posting). What is their interpretation? One can imagine two explanations which could be also equivalent.

The states could be “infrared” Regge trajectories assignable to magnetic flux tubes of order Compton length of  $u$  and  $d$  quark (very long and with small string tension) could be the explanation. Hadron mass spectrum would have microstructure. This is something very natural in many-sheeted space-time with the predicted p-adic fractal hierarchy of physics. This conforms with the proposal that all baryons have the satellite states and that they correspond to stringy excitations of magnetic flux tubes assignable to quarks. Similar fine structure for nuclei is predicted for nuclei in nuclear string model [K2]. In fact, the first excited state for  ${}^4\text{He}$  has energy equal to 20 MeV not far from the average energy difference 17.5 MeV for the excited states of pion with energies 198, 215, and 227.5 MeV so that this state might correspond to an excitation of a color magnetic flux tube connecting two nucleons.

This idea should be made more precise. Color magnetic flux tubes would correspond to ordinary Regge trajectories. The magnetic flux tubes in electro-magnetic sense would correspond to IR Regge trajectories.

A further piece of evidence for scaled variants of pion comes from two articles by Eef van Beveren and George Rupp. The first article [C1] is titled *First indications of the existence of*

a 38 MeV light scalar boson (see <http://tinyurl.com/yat1b97o>). Second article [C2] has title *Material evidence of a 38 MeV boson* (see <http://tinyurl.com/yczo7juy>).

The basic observations are following. The rate for the annihilation  $e^+ + e^- \rightarrow u\bar{u}$  assignable to the reaction  $e^+ + e^- \rightarrow \pi^+\pi^-$  has a small periodic oscillation with a period of  $78 \pm 2$  MeV and amplitude of about 5 per cent. The rate for the annihilation  $e^+ + e^- \rightarrow b\bar{b}$ , assignable to the reaction  $e^+ + e^- \rightarrow \Upsilon\pi^+\pi^-$  has similar oscillatory behavior with a period of  $73 \pm 3$  MeV and amplitude about 12.5 per cent. The rate for the annihilation  $p\bar{p} \rightarrow c\bar{c}$  assignable to the reaction  $e^+ + e^- \rightarrow J/\Psi\pi^+\pi^-$  has similar oscillatory behavior with period of  $79 \pm 5$  MeV and amplitude .75 per cent.

In these examples universal Regge slope is consistent with the experimental findings and supports additive mass formula and the assignment of IR Regge trajectories to hadronic flux tubes with fixed p-adic length scale. There is also consistency with the experiments of Tatitscheff and Tomasi-Gustafsson.

What does one obtain if one scales up the IR Regge trajectories to the  $M_{89}$  hadron physics [K1]?

1. In the case of  $M_{89}$  pion the mass differences 20 MeV and 40 MeV appearing in the IR Regge trajectories of pion would scale up to 10 GeV and 20 GeV respectively. This would suggest the spectrum of pion like states with masses 115, 125, 145, 165 GeV. What makes this interesting that ATLAS reported during last year evidence for a signal at 115 GeV taken as evidence for Higgs and CDF reported before this signal taken as evidence for Higgs around 145 GeV! 125 GeV is the mass of the most recent Higgs candidate. Could it be that all these reported signals have been genuine signals - not for Higgs- but for  $M_{89}$  pion and corresponding spion consisting of squark pair and its IR satellites?
2. In the case of  $M_{89}$  hadron physics the naive scaling of the parameters  $m_0$  and  $m_1$  by factor 512 would scale 38 MeV to 19.5 GeV.

## 2.2 New particle having no interpretation in standard model discovered?

A new piece of evidence for IR Regge trajectories years after writing the above text - thanks for Wilhelmus de Wilde for a link. The popular article in Schitechdaily (<http://tinyurl.com/wb98u6u>) tells about completely unexpected finding by a team led by professors Tacemichi Okui and Kohsaku Tobioka. The decay of longlived kaon  $K_L$  suggests the existence of new longlived particle with quantum numbers of axion - or equivalently pion. The finding is published in Physical Review Letters [C5] (<http://tinyurl.com/v2rwh3e>). Standard model cannot explain this kind of particle.

A rough estimate for mass is not far from pion mass. There exists earlier evidence that pion has mass spectrum. Could an excitation of pion be involved?

This is actually not new. The experimental claim [C6] (see <http://tinyurl.com/ybq323yy>) of Tatischeff and Tomasi-Gustafsson is that pion is accompanied by pion like states organized on Regge trajectory and having mass 60, 80, 100, 140, 181, 198, 215, 227.5, and 235 MeV means that besides pion also other pion like states should be there. Similar satellites have been observed for nucleons with ground state mass 934 MeV: the masses of the satellites are 1004, 1044, 1094 MeV. Also the signal cross sections for Higgs to gamma pairs at LHC suggest the existence of several pion and spion like states, and this was the reason why I decided to again the search for data about this kind of states. Their possible interpretation in TGD framework is discussed in [K1] (<http://tinyurl.com/rk7b3dd>).

One explanation could be that the states correspond to "infrared Regge trajectories" of pion related to the structure of its magnetic body. Genuine Regge trajectories would have slope of about GeV and now the slope less than 10 per cent of this, which conforms with the ratio of fine structure constant to coupling strength. IR trajectories would be associated with the electromagnetic body and ordinary Regge trajectories with the color magnetic body. One can also consider p-adically scaled down variant of color interactions.

It is interesting to look the situation quantitatively.

1. It is clear that the masses in question do not fit to a single Regge trajectory. One can however restrict the consideration to Regge trajectory  $M^2 = M_0^2 + nT(\pi)$ , where  $T(\pi)$  denotes

string tension. Since the masses obey approximately linear formula one can assume linear approximation  $\Delta M^2 = 2M\Delta M$  at pion mass  $M_1 = m(\pi) = .140$  GeV and consider the mass squared difference for pion and its predecessor with  $M_0 = .100$  GeV so that one has  $\Delta M = .040$  GeV.

One obtains  $\Delta M^2 = M_1^2 - M_0^2 = T(\pi)$ . This would give for the string tension  $T(\pi) = 0.96 \times 10^{-2} T_H \simeq .96 \times 10^{-2}$  GeV<sup>2</sup>, where  $T_H \simeq 1$  GeV<sup>2</sup> is hadronic string tension assignable to color interactions.

2. What about the value of  $M_0^2$ ? In string models it tends to be negative but one can assume that the values of mass squared for physical states are negative. Also in TGD the value is negative in  $p$ -adic mass calculations. One must require that several values for pion mass below  $m(\pi)$  are possible. The formula  $m(\pi)^2 = M_0^2 + nT(\pi)$  gives formula  $M_0^2 = (m(\pi)^2 - nT(\pi))$ . For  $n(\pi) = 2$ , which looks rather reasonable guess, one has  $M_0^2 = .04$  GeV<sup>2</sup>, which corresponds to  $M_0 = 20$  MeV.

There is actually a lot of confusion about the value of hadronic string tension.

1. In early models hadronic string tension was taken to be 1 GeV. Much smaller values for the string tension smaller by a factor or order  $x \times 10^{-2}$  GeV<sup>2</sup>,  $x$  in the range 2-11.1 for mesons and in the range 2.2-4.55 for baryons are however suggested by the study of hadronic spectrum (<http://tinyurl.com/s5jwawx>). Intriguingly, the lower bounds is twice the above estimate  $T(\pi) \simeq .01$  GeV<sup>2</sup> obtained above. Does this mean that the  $p$ -adic prime involved is about 2 times smaller or is this factor due to a numerical factor 1/2 related to the difference between  $N$ -S and Ramond type representations of Super-Virasoro algebra.
2. The reason for the confusion about string tension could be simple: besides the string tension 1 GeV assignable to color flux tubes there are string tensions assignable to possible scaled down color flux tubes and possible electromagnetic and even weak flux tubes. Several  $p$ -adic length scales could be associated coming in powers of 2 by  $p$ -adic length scales hypothesis are involved.

### 2.3 New view about nuclear physics provided by IR Regge trajectories

This picture led to an unexpected development in the nuclear string model that I constructed more than 2 decades ago [K2] (<http://tinyurl.com/rc4umgv>). The key assumption - very natural in TGD, where monopole flux tubes prevail in all scales - is that nucleons form nuclear strings. Nuclear radius satisfies  $R \propto A^{1/3}$ ,  $A$  mass number, so that nuclei have constant density in good approximation (<http://tinyurl.com/rtc9jdh>) so that the flux tube would fill the entire volume. I have proposed that also blackholes and other final states of stars are flux tube spaghetti of this kind [L1].

The basic objection against the model is that the harmonic oscillator model for nuclear works surprisingly well. The justification for this model is that one can reasonably well describe nucleus as motion of nucleons in an effective nuclear potential, which in linearization becomes harmonic. Nucleons themselves have no mutual interactions in this approximation.

Could nuclear string model allow to understand harmonic oscillator model of nuclei as an approximation?

1. It is best to start from the problems of the harmonic oscillator model. The first problem is that the description of nuclear binding energies is poorly understood. For instance, nuclear binding energies have scale measured in MeVs. The scale is much smaller than energy scale of hadronic strong interactions for which pion mass is a natural scale. Rather remarkably, the ratio of the scales is roughly the ratio of fine structure constant to color coupling strength. Could one imagine that electromagnetic interactions somehow determine the energy scale of nuclear binding energies and excitations?
2. As noticed, also nucleons are reported to have IR Regge trajectories. The first guess is that the trajectories have same string tension as in the case of pion. TGD suggests a model of nuclei as three nucleons connected by color flux tubes characterized by hadronic string tension

$T_H \simeq 1 \text{ GeV}^2$ . Besides color flux tubes hadrons are expected to have also electromagnetic and perhaps also weak flux tubes with a smaller value of string tension. Em flux tubes should give a contribution to the energy, which is of the order of Coulomb energy of nucleon about  $\alpha/L^c(p) \simeq 7.5 \text{ MeV}$ . Intriguingly, this is of same order of magnitude as nuclear binding energy: could IR Regge trajectories correspond to em interaction so that the spectrum of nuclear binding energies and excitation energies would be determined by electromagnetic interactions?

3. If the value of  $p$ -adic prime  $p \simeq 2^k$  corresponds to  $k = 113$  assumed to characterize nuclei in nuclear string model, hadronic string tension would be scaled down by factor  $2^{107-113} = 1/64$  to  $T_H/64$ , which corresponds to a mass of  $125 \text{ MeV}$ , which is somewhat larger than the value about  $96 \text{ MeV}$  obtained from the above estimate. For  $\Delta M^2 \simeq 2M\Delta M = nT(\pi)$  this gives  $\Delta M \simeq 7.8 \text{ MeV}$  for  $\Delta n = 1$ , which corresponds to the maximal nuclear binding energy per nucleon do be denoted by  $e_B$ . This string tension is naturally assignable to em flux tubes assignable nuclei as 3 -quark states. Color flux tubes would be responsible for the hadronic string tension  $T_H$ .

**Remark:** Flux tubes carry all classical gauge fields, which are induced from the spinor connection of  $CP_2$  but it seems that one can assign to given flux tube quanta of particular interaction.

4. In the case of baryons one would have 3 color flux tubes and and 3 em flux tubes. For large mass excitations one would have in linear approximation for  $M^2$  harmonic oscillator spectrum! Could linearization of mass squared formula replace linearization of effective potential function leading to harmonic oscillator model? The dimension  $D = 3$  for the nuclear harmonic oscillators would correspond to the fact that nucleons consist of 3 quarks. The free nucleon approximation would have simple justification: in good approximation one can treat the nucleons of nuclear strings as independent particles!
5. Could the nuclear  $e_B$  correspond to a reduction of the value of  $n$  for the IR Regge trajectory of free nucleon? The mass squared formula for IR trajectory would be  $M^2 = M_0^2(N) + nT(\pi)$ . This mechanism requires that the one has  $M_0 \leq m(N)$  so that one has  $n > 0$  for nucleons. For  $\Delta n = -1$  one has  $\Delta M = T(\pi)/2m(N) \simeq 7.8 \text{ MeV}$ .

Could one understand the qualitative features of the nuclear binding energy spectrum on basis of this picture?

1.  $e_B$  is below  $3 \text{ MeV}$  for nuclei lighter than  ${}^4\text{He}$  and has tendency to increase up to Fe. For the most abundant stable isotope of Fe with  $(Z,A)=(26,56)$  it is  $8.78 \text{ MeV}$ . For heavier nuclei neutron number  $N$  increases and  $e_B$  starts to decrease.
2. For  $D$  one must have  $\Delta n = 0$  and  $p$ - $n$  pairing would be somehow responsible for the binding. For  $T$  the total binding energy is  $8.478 \text{ MeV}$  and could involve  $\Delta n = -1$  for one nucleon.  ${}^3\text{He}$  has total binding energy  $7.715 \text{ MeV}$  and also now one nucleon could have  $\Delta n = -1$ .  ${}^4\text{He}$  has  $e_B = 7.07 \text{ eV}$ . This suggests that  $p$ - $n$  pairing causes reduction  $\Delta n = -1$  for all nucleons in  ${}^4\text{He}$  units proposed to be building bricks of nuclei.

For nuclei with odd  $Z$  and nuclei there are would be also deuteron sub-unit present and also  $|A - Z|$  unpaired neutrons. This would reduce the binding energy. The prediction is that for nuclei with  $N=Z$  with even  $Z$  the binding energy exceeds that for  ${}^4\text{He}$ . For heavier nuclei this can happen also for odd  $Z$  and also for  $N$  different from  $Z$ .

3. The pairing of to  $D$  subunits should be rise to binding energy  $2.223 \text{ MeV}$  per deuteron unit. Why the value is so small? Could deuteron unit correspond to a smaller string tension: perhaps corresponding to  $k = 9$  instead of  $k = 6$  as the ratio of  ${}^4\text{He}/D$  binding energies per nucleon would suggest. The ratio of the maximal binding energy  $8.7892 \text{ MeV}$  per nucleon to deuteron binding energy is rather precisely 8, which supports the interpretation.
4. What causes the increase of  $e_B$  up to Fe? Attractive potential energy does not look like an elegant interpretation in TGD framework. Some repulsive interaction should reduce the binding energy per nucleon for lighter nuclei than Fe from the value  $8.8 \text{ MeV}$ . The increase from  ${}^4\text{He}$  to Fe is about  $1 \text{ MeV}$ . Why does this repulsive contribution decrease up to Fe?

Does it start to increase after that or is the presence of surplus neutrons the reason for the reduction? Or are both mechanisms involved?

The IR Regge trajectories considered are not the only ones as already the findings of Tatischeff and Tomasi-Gustafsson suggest and there might be trajectories with smaller string tension. The value of  $k = 9$  with string tension  $T(\pi)/8$  assignable to  $D$ , which corresponds to a  $e_B$  of about 1 MeV and this is roughly the total variation of the  $e_B$  from  ${}^4\text{He}$  to Fe. Could both  $k = 6$  and  $k = 9$  flux tubes be present for given nucleon. Could the reduction of  $n$  for  $k = 9$  flux tubes take place also for  ${}^4\text{He}$  units as nuclei become heavier. What happens in nuclei heavier than Fe? Could the increase of neutron surplus reduce  $e_B$ ?

Nuclear string has tension and reduces total binding energy  $e_B$  a contribution proportional to the length  $L$  of the string. Constant density for nuclei gives  $R = r_0 A^{1/3}$ ,  $r_0 = 1.2$  fm for the nuclear radius and  $L \propto A \propto R^3$  for  $L$ . From this the contribution of string energy per nucleon is proportion to  $L/A = \text{constant}$ . The 20 per cent variation of  $r_0$  is due the variation of  $e_B$  and cannot explain the variation of  $e_B$ .

To sum up, nuclear string model would reduce nuclear physics that for the magnetic body of the nucleon - obviously an enormous simplification.

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