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CRYPTONS: A STRINGY FORM OF DECAYING
SUPERHEAVY DARK MATTER, AS A SOURCE OF THE
ULTRA HIGH ENERGY COSMIC RAYS

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Cryptons metastable bound states of matter in the string hidden sector, with dynamically determined masses $M\chi \sim 10^{12}$ GeV and lifetimes $\tau\chi \geq 10^{18}$ yr, may be generated, through inflation, with an abundance close to that required for a near-critical universe. Their decay debris *may* be responsible for the most energetic particles striking Earth's atmosphere. Recent developments of this *astonishing hypothesis* are reviewed, indicating that NESTOR or the PIERRE AUGER project *may* be able to confirm or refute the existence of cryptons.

Introduction

Our present understanding of the universe, as it is encoded in the Big Bang Cosmology, suggests that there are *at least* two major contributions in the energy density of the universe. One, is that of *baryonic* or *shiny* matter (p,n), and the other is that of *dark* matter. The rotational velocities of galaxies, the dynamics of galaxy clusters and theories of structure formation suggest that most of the matter in the universe is invisible and largely composed of non-baryonic matter. The exact nature of dark matter is still not known and not due to lack of candidates. From massive neutrinos to axions to the lightest supersymmetric particle (LSP) to more exotic possibilities, we indeed have an *impressive list* to choose from. While every and each of the above dark matter candidates is plausible and originates in particle physics, the way that they form dark matter is sharply different from the way that they form shiny matter. One then may wonder if it is possible to replicate the way that shiny matter is constructed, but at a higher mass scale, so that we would have then a unified, simple explanation for the origin of matter

in the universe both shiny dark! Actually, as I will discuss in this talk, such a unified explanation is possible in the framework of string theory and *cryptons* (1), which are (meta)stable bound states of matter in a hidden sector of string theory, are the corresponding dark matter “baryons”, but superheavy, so that when they eventually decay, their decay products may compose (2,3) the most energetic particle striking the Earth’s atmosphere – the ultra high energy cosmic rays (UHECR). A detailed discussion of the data and the experimental accounts may be found in recent reviews (4).

Baryons and Cryptons

Let us take things from the beginning. Let us remind ourselves how baryonic or shiny matter has been constructed. There are two kinds of fundamental fermions, quarks (q) and leptons (l). They form doublets under the electroweak gauge symmetry $SU(2)_X U(1)$ e.g. (u,d) (ν_e, e^-), while quarks carry fractional charges $q_u=2/3, q_d=-1/3$. One way to proceed from here is to reinvent strong interactions, i.e. Quantum ChromoDynamics (QCD), in the following way: there are no observed free fractionally-charged particles in nature. That means that u and d quarks cannot float around freely. One then introduces a new interaction, the strong interaction, as expressed by QCD, only for quarks, such that it confines the quarks in color-less integer-charged particles like pions, protons, neutrons and the likes. Actually there is a strong correlation between the 3 of the $SU(3)$ and the (-1/3) or (2/3) fractional charges as quarks form $\underline{3}$ of $SU(3)_{color}$, and we need three quarks to form color-singlet, integer charged baryons (p,n,...) which they may even be called *trions*. Furthermore, we may get information about the characteristic mass scale of color-singlet particles in the following way. The non-Abelian nature of $SU(3)_{color}$, and the observed number of quark flavors, six, allow for the diminishing of the strong interaction coupling constant $a_3(Q^2)$ as Q^2 increases, thus allowing at very high energies the electroweak couplings $a_2(Q^2)$ and $a_1(Q^2)$ to catch up and unify, at scale $O(10^{16} \text{ GeV})$ as observed at LEP, in a supersymmetric framework (5). In a way, quark confinement is related to grand unification through its antipodal property of asymptotic freedom. Thus, given at very high energies the common unified coupling constant, a_{GUT} ($\sim 1/25$), one can trace back, through standard Renormalization Group Equations the energy scale when $a_3(Q^2)$ becomes $O(1)$ i.e. it confines. One finds that $\Lambda_{QCD} \approx O(300 \text{ MeV})$ as the generic characteristic mass scale for color-singlets, in agreement with the observed hadron mass spectrum. So that’s the way that protons and neutrons are formed, and that’s how we, more or less, determine dynamically what is their mass range. In other words, that’s how baryonic or shiny matter is constructed, the “shiny” due, of course, to the left-over, Van der Waals type, nuclear interactions. Actually, we know a bit more. One may prove a simple theorem (6) in the perturbative framework of the Standard Model (SM), that is of the conservation of the global Baryon (B) and Lepton

(L) numbers. In other words there has to exist a stable baryon which happens to be the proton! Furthermore, either non-perturbative effects or beyond-standard model interactions, e.g. as exist in grand unified theories violate B and L quantum numbers, thus turning proton to a metastable particle, with a lifetime $\tau_p \geq O(10^{33} \text{ yrs})$, rather long-lived baryonic or shiny matter. So, here are the main steps in the formation of baryonic matter:

- Existence of fractionally-charged particles that necessitate the
- Existence of a confining gauge interaction, non Abelian in nature, with a dynamically determined confining scale, due to the asymptotically-free property of the non-Abelian interaction that is partially responsible for the Grand Unification of all gauge coupling constants at very large energies $O(10^{16} \text{ GeV})$ with $a_{GUT} (\sim 1/25)$, that may lead to the
- Metastability of the lightest relevant particle and with an appropriate relic abundance.

Clearly, all the above is a tall order to fulfill in the case of dark matter, especially for the superheavy dark matter (i.e. heavier than 1 TeV) where the danger exists that a large relic abundance would overclose the universe. The question of abundance of superheavy relics has recently been revisited (7,8,9). In particular, a gravitational mechanism was suggested (8,9) whereby cosmological inflation may generate a desirable abundance of such massive and weakly interacting massive relic particles. Numerical analysis indicates that the process may be largely independent of details of the models considered for most properties of the dark matter constituent, as well as of details of the transition between the inflationary phase and the subsequent thermal radiation-dominated phase. In the light of this new proposal, it is interesting to revisit the possibility that cryptons or other superheavy string relics may constitute an important part of the astrophysical dark matter.

String theory and cryptons

String theories have historically been analyzed in the weak-coupling limit, where there is an observable sector containing the known gauge interactions and matter particles, and a hidden sector that is expected to become strongly interacting and may play a rôle in supersymmetry breaking. In addition to the states that are massless before this and subsequent stages of symmetry breaking, such string models also contain Kaluza-Klein excitations with masses related to the scales at which surplus dimensions are compactified. In the weakcoupling limit, all these states would have masses comparable to the Planck mass $M_{Pl} \sim 10^{19}$ GeV, beyond the range favoured by (8,9). However, the string mass estimate may be revised downwards in the strong-coupling limit described by M theory, requiring a revised discussion as provided below. We now discuss in more detail a specific string and M theory possibility.

Heterotic-string ($k=1$) *models*: These have been the most studied vacua of string theory. The possibility of building explicit models and carrying out detailed computations makes possible a precise analysis. A well-established prediction of this class of compactifications is the existence of light (massless at the string scale) states which are singlets under $SU(3)_c$ and carry fractional electrical charges, that appear generically in the hidden gauge-group sector (10,11). Such particles cannot be free, because the lightest of these particles would have to be stable and present in the Universe with a large abundance. There are very stringent upper limits on the abundance of such a fractionally-charged relic, from successors of the Milliken experiments, which are many orders of magnitude below the critical density. However, theoretical expectations for their abundance on Earth are about ten orders of magnitude above these limits (12). Thus the only viable string vacua are those where these charges are confined by a “hidden” group G , as in QCD. The integer-charged lightest singlet bound states of such a hidden-sector group may be stable or metastable, providing the dark-matter candidates termed *cryptons* (1).

The confining group G must be such that singlet bound states of $SU(3) \times G$ have integer electric charges. For $G = \prod SU(N) \times \prod SO(2n)$, this condition states that (11,13):

$$\sum_N \frac{i_N(N - i_N)}{2N} + \sum_n \begin{cases} 0 & \text{for } j_n = 0 \\ 1/2 & \text{for } j_n = 2 \\ n/8 & \text{for } j_n = 1 \end{cases} \quad (1)$$

must be a non-vanishing integer, where for every N , i_N is some integer between 0 and $N - 1$. Thus the electric charge of a state transforming in the representation N or \bar{N} of $SU(N)$ and/or $2n$ of $SO(2n)$ must be:

$$q = \pm \sum_N \frac{i_N}{N} + \sum_n \frac{j_n}{2} \text{ mod } 1, \quad (2)$$

with \pm corresponding to representations N or \bar{N} .

The case where G is a product of semi-simple factors presents the advantage, compared to a large unique semi-simple group, of generally giving rise to a smaller number of fractionally-charged states that have to be included in the running of the supersymmetric Standard-Model gauge couplings. Note also that, because of these states, the G gauge sector is not completely “hidden”. This may even be advantageous, if supersymmetry is broken when the coupling of G becomes strong, and an F term is generated. This supersymmetry breaking would be mediated to the observable sector not only by gravitational interactions involving the graviton supermultiplet, but also

through the usual Standard-Model gauge interactions via the supermultiplets of fractionally-charged states (14).

We now review an explicit example of a string model whose hidden sector contains such metastable *crypton* bound states. This model was originally constructed in the weak-coupling limit (15), but we expect that it may be elevated to an authentic *M*-theory model in the strong-coupling limit. This model has the gauge group $SU(5) \times U(1)^4 \times SO(10) \times SU(4)$, with the latter two factors yielding strong hidden-sector interactions. The following Table lists the matter content of this hidden sector.

$\Delta_1^0(0, 1, 6, 0, -\frac{1}{2}, \frac{1}{2}, 0)$	$\Delta_2^0(0, 1, 6, -\frac{1}{2}, 0, \frac{1}{2}, 0)$
$\Delta_3^0(0, 1, 6, -\frac{1}{2}, -\frac{1}{2}, 0, \frac{1}{2})$	$\Delta_4^0(0, 1, 6, 0, -\frac{1}{2}, \frac{1}{2}, 0)$
$\Delta_5^0(0, 1, 6, \frac{1}{2}, 0, -\frac{1}{2}, 0)$	
$T_1^0(10, 1, 0, -\frac{1}{2}, \frac{1}{2}, 0)$	$T_2^0(10, 1, -\frac{1}{2}, 0, \frac{1}{2}, 0)$
$T_3^0(10, 1, -\frac{1}{2}, -\frac{1}{2}, 0, \frac{1}{2})$	$T_4^0(10, 1, 0, \frac{1}{2}, -\frac{1}{2}, 0)$
$T_5^0(10, 1, -\frac{1}{2}, 0, \frac{1}{2}, 0)$	

$\tilde{F}_1^{+\frac{1}{2}}(1, 4, -\frac{1}{4}, \frac{1}{4}, -\frac{1}{4}, \frac{1}{2})$	$\tilde{F}_2^{+\frac{1}{2}}(1, 4, -\frac{1}{4}, \frac{1}{4}, -\frac{1}{4}, -\frac{1}{2})$
$\tilde{F}_3^{-\frac{1}{2}}(1, 4, \frac{1}{4}, \frac{1}{4}, -\frac{1}{4}, \frac{1}{2})$	$\tilde{F}_4^{+\frac{1}{2}}(1, 4, \frac{1}{4}, -\frac{1}{4}, -\frac{1}{4}, 6 - \frac{1}{2})$
$\tilde{F}_5^{+\frac{1}{2}}(1, 4, -\frac{1}{4}, \frac{3}{4}, -\frac{1}{4}, 0)$	$\tilde{F}_6^{+\frac{1}{2}}(1, 4, -\frac{1}{4}, \frac{1}{4}, -\frac{1}{4}, -\frac{1}{2})$
$\tilde{F}_1^{-\frac{1}{2}}(1, 4, -\frac{1}{4}, \frac{1}{4}, \frac{1}{4}, \frac{1}{2})$	$\tilde{F}_2^{-\frac{1}{2}}(1, 4, -\frac{1}{4}, \frac{1}{4}, \frac{1}{4}, -\frac{1}{2})$
$\tilde{F}_3^{+\frac{1}{2}}(1, 4, -\frac{1}{4}, -\frac{1}{4}, \frac{1}{4}, -\frac{1}{2})$	$\tilde{F}_4^{-\frac{1}{2}}(1, 4, -\frac{1}{4}, \frac{1}{4}, \frac{1}{4}, -\frac{1}{2})$
$\tilde{F}_5^{-\frac{1}{2}}(1, 4, -\frac{3}{4}, \frac{1}{4}, -\frac{1}{4}, 0)$	$\tilde{F}_6^{-\frac{1}{2}}(1, 4, \frac{1}{4}, -\frac{1}{4}, \frac{1}{4}, -\frac{1}{2})$

Table: The spectrum of hidden matter fields that are massless at the string scale in the revamped flipped $SU(5)$ model. We display the quantum numbers under the hidden gauge group $SO(10) \times SO(6) \times U(1)^4$, and superscripts indicate the electric charges.

Analysis of the calculable superpotential in this model shows that most of these fields acquire heavy masses just below the string scale from couplings with singlet fields that acquire vacuum expectation values to cancel the *D*-term of the anomalous $U(1)$. The only light states that survive to have lower masses are the T_3 , Δ_3 , $\tilde{F}_{3,5}$ and $\tilde{\tilde{F}}_{3,5}$. Analysis of the renormalization-group β functions of $SO(10)$ and $SO(6)$ suggest that their confinement scales might lie at $\Lambda_{10} \sim 10^{14-15}$ GeV for $SO(10)$ and $\Lambda_4 \sim 10^{11-12}$ GeV for $SU(4)$ (16). This indicates that the states in the $SU(4)$ representations Δ_3 , $\tilde{F}_{3,5}$ and $\tilde{\tilde{F}}_{3,5}$ will form the lightest bound states.

In addition to meson and baryon bound states as in QCD, one expects quadrilinear *tetron* bound states specific to $SU(4)$ (1). The mesons comprise $T_i T_j$, $\Delta_i \Delta_j$ and $\tilde{F}_i \tilde{F}_j$ bound states, which are all short-lived, as they decay through order $N=3, 4$ or 6 non-renormalizable operators. The baryons have the constituents $\tilde{F}_i \tilde{F}_j \Delta_k$ and $\tilde{F}_i \tilde{F}_j \tilde{F}_k$ are also short-lived. Finally, there are *tetrons* composed of four \tilde{F}_i s, of which the lightest have the forms $\tilde{F}_i \tilde{F}_j \tilde{F}_k \tilde{F}_l$ and $\tilde{F}_i \tilde{F}_j \tilde{F}_k \tilde{F}_l$, where $i, j, k, l=3, 5$. As in the case of QCD pions, one may expect the charged states to be slightly heavier than the neutral ones, due to electromagnetic energy mass splitting. No non-renormalizable interaction capable of enabling this lightest bound state to decay has been found in a search up to eighth order. We therefore consider that this lightest neutral *tetron* is a *perfect candidate* for a superheavy dark matter particle. A rough lower bound on the lifetime of this lightest tetron is of the order:

$$\tau_X \sim \frac{1}{M_X} \left(\frac{m_k}{M_X} \right)^{10}, \quad (3)$$

which is very sensitive to M_X and the scale m_k of suppression of the non-renormalizable terms. For $m_k \sim 10^{17-18}$ GeV, and a tetron mass $M_X \sim 10^{12}$ GeV, we find that $\tau_X > 10^{7-17}$ years. This is a lower bound, and the actual lifetime may well be considerably longer if the leading decay interaction is of significantly higher order.

4 Dark matter and cryptons

The pressing problem we are facing now is how does one explain why superheavy particles such as tetrons are naturally generated with the right abundance so that to form the cold dark matter of the Universe? As I mentioned above this problem was addressed by the authors in (8,9). They suggested that these particles X might be created through the interaction of the vacuum with the gravitational field during the reheating period of the Universe (17). Such a process involves only the gravitational interaction of the particle, and thus is quite independent of the other (weak) interactions that it might have. This scenario leads to the following mass density of the particle X created at time $t=t_e$:

$$\Omega_X h^2 \approx \Omega_R h^2 \left(\frac{T_{RH}}{T_0} \right) \frac{8\pi}{3} \left(\frac{M_X}{M_{Pl}} \right) \frac{n_X(t_e)}{M_{Pl} H^2(t_e)}. \quad (4)$$

where $\Omega_R h^2 \approx 4.31 \times 10^{-5}$ is the fraction of the critical energy density that is in radiation today, and T_{RH} is the reheating temperature.

The numerical analysis of (8) indicates that the correct magnitude for the abundance of the X particle is obtained if its mass lies in the region $0.04 \leq M_X / H \leq 2$, where $H \sim 10^{13}$ GeV is the Hubble expansion rate at the end of inflation, which is expected to be of the same order as the mass of the inflaton. For our purposes, we shall consider the range 10^{11} GeV $\leq M_X \leq 10^{14}$ GeV to be favourable for superheavy dark matter. It is rather remarkable that the dynamically determined (1,16) mass range of the stringy cryptons, $M_X \approx O(10^{12}$ GeV) (or more specifically tetrons), falls just inside the allowed range for superheavy particles to have naturally $\Omega_X h^2 \approx O(1)$!!! We thus have succeeded (1,3) to produce a superheavy dark matter candidate, of purely stringy origin, that follows exactly the same steps as sketched in section 2 that led to the formulation of baryonic or shiny matter but now at a superheavy mass scale. Deliberately, these steps have been presented in a form that applies verbatim both for baryons and cryptons! Thus, as promised, we have provided a realistic example where both shiny and dark matter employ the same type of mechanism in their formation. Furthermore, back in 1991, we evaluated (2) the constraints on cryptons from the possible effects of their decays on the spectrum of the microwave background radiation and the primordially synthesized abundancies of the light elements, from the observation of the diffuse gamma-ray background radiation and from searches for muons and neutrinos in nuclear decay and cosmic ray detectors. We found (2) that cryptons may well have the *cosmological critical density* if their lifetime exceeds $\sim 10^{16}$ yrs as imposed from the limit of high-energy air-showers obtained by Fly's Eye atmospheric fluorescence detector (4). Of course, we didn't have back in 1991 a natural mechanism of why $\Omega_X h^2 \approx O(1)$ as we do now, but it didn't escape our attention (2) the fact that cryptons, with their characteristic masses and lifetimes and of almost critical abundance, would produce ultra-high energy cosmic rays, observable by the Fly's Eye. By a strange twist of fate, our paper (2) was accepted for publication in Nuclear Physics B on 22 Oct. 1991, while the most energetic particle to strike Earth's atmosphere, ever, of energy $(3.0 \pm 0.9)10^{20}$ eV was recorded on 15 Oct. 1991 by the Fly's Eye! (18) In 1993 the AGASA ground array detected a giant air-shower whose primary energy was estimated to be $(1.7-2.6)10^{20}$ eV (19). While innocent and benign looking, these events have created quite a stir in the cosmic ray community (20). Let's see why.

Ultra high energy cosmic rays (uhecr) and cryptons

Cosmic rays with energies up to $O(5 \cdot 10^{18}$ eV) are of predominantly galactic origin, and accept conventional explanations i.e. acceleration by the Fermi mechanism in supernovae remnants (21). Above this energy the spectrum flattens and the composition changes from being mostly heavy nuclei to mostly protons (4). This correlated change in the spectrum and composition, suggests the emergence of a population of cosmic rays from outside the Milky Way. The Galactic magnetic field is too weak to confine protons

above 10^{19} eV but here seems to be no credible astrophysical mechanism, either inside or outside the Galaxy, for accelerating protons to energies above 10^{19} eV! Furthermore, the most energetic cosmic-ray particles would be affected by interactions with the ubiquitous photons of the Cosmic Microwave Background Radiation (CMBR). If the cosmic ray sources were far enough from us and if their energy spectrum extended beyond, say, 10^{20} eV, then the ultra high energy protons and nuclei would interact inelastically with the CMBR photons. As shown by Greisen and Zatsepin and Kuzmin (22) more than thirty years ago the threshold for this energy degrading or sapping interaction is the onset of pion-photon production:

$$E_{thres} \approx \frac{m_p m_\pi}{E_\gamma} \approx 5 \cdot 10^{19} \text{ eV} \quad (5)$$

for $E_\gamma \approx 2$ meV corresponding to $T_0 = 2.7^{\circ}$ K. The smooth power law cosmic ray energy spectrum would therefore be abruptly cut off near $5 \cdot 10^{19}$ eV the GZK cut off (22). The existence therefore of UHE cosmic ray events a-la Fly's Eye (18) and AGASA (19) discussed above create a rather serious problem in the following sense. Because these UHECR events go well beyond the GZK cut off, their sources must be within ~ 50 Mpc from us, thus by cosmological standards in the well-scrutinized local neighborhood. But there are few such sources so close to us and no definite correlations have been found between the locations and arrival directions of the most energetic events. It is worth recalling that above 10^{19} eV, the proton trajectory is so nearly straight in the Galactic and intergalactic magnetic fields that one would have hoped, with sufficient statistics, to pin down the sources on the celestial sphere. So what's going on? What is the source(s) of the UHECR events?

Clearly, one is encouraged to look (3,9,23) for a more exotic or daring resolution of this basic problem, namely to identify the UHECR events with the decay products of superheavy dark matter particles like cryptons. In other words instead for looking for grotesque acceleration mechanisms of low-energy protons, let us use the most natural source of superenergetic particles, the decay of a superheavy particle. Indeed, as I mentioned above cryptons with $\Omega_X h^2 \approx 1$ would provide (2) observable UHECR events at the cosmic ray detectors like Fly's Eye, AGASA etc. Recently with the new developments in string theory, where non-perturbative effects become tractable and specifically in the framework of the 11-dimensional M-theory, it has been a natural reconciliation (24) between the natural string scale M_{string} and the unification scale $M_{LEP} \sim O(10^{16}$ GeV) thus evading a severe problem of string phenomenology (25). This fact in conjunction with the existence of a natural mechanism (8,9) discussed above providing $\Omega_X h^2 \approx 1$ for a suitable mass range of superheavy particles triggered us to revisit crypton physics (3). Indeed, we did reproduce our old results, now standing on firmer ground, i.e. the existence of metastable, superheavy cryptons (more accurately tetrons)

or masses $O(10^{12} \text{ GeV})$ and lifetimes $O(\geq 10^{18} \text{ yrs})$ dynamically determined, and of the right abundance $\Omega_\chi h^2 \approx 1$ to be identified as the missing dark matter. We also argued that tetrons would be prime candidates for producing, through their decays, the UHECR events of Fly's Eye and AGASA. The mass range of cryptons, 10^{12} GeV or 10^{21} eV , and lifetime $\geq 10^{18} \text{ yrs}$ seem to naively fit with the observed UHECR events. Since such superheavy particles would behave as cold dark matter and cluster efficiently in all gravitational potential wells, their abundance in our galactic halo would be enhanced above their cosmological abundance by a factor of $O(10^4)$. The UHECR would mainly come from decaying cryptons in our galactic halo, thus crossing distances smaller than say $O(100 \text{ kpc})$, evading the GZK cut off. It is going without saying that the GZK cut off is replaced by the kinematic cut off $E \leq O(M_{\text{crypton}} \sim 10^{12} \text{ GeV})$. A few weeks after our paper (3) appeared, Birkel and Sarkar came out with a paper (26) that they were working for months. They did show, in very elaborated way, that cryptons are indeed "what the doctor ordered" as the UHECR events. They calculated the expected proton and neutrino fluxes from decays of the superheavy metastable particles, using the HERWIG QCD event generator. They noticed that the predicted proton spectrum accounts for the observed spectrum of the UHECR beyond the GZK cut off, in shape and absolute magnitude if the decaying superheavy particle has a mass of $O(10^{12} \text{ GeV})$ and a lifetime $O(\geq 10^{20} \text{ yrs})$, if such particles constitute all of dark matter!!! In other words if cryptons hadn't been suggested before, Birkel and Sarkar (26) would have to invent them. They went further (26) and calculated also the expected ratio of the proton to neutrino flux. They found that the predicted neutrino flux exceeds the proton flux for $E \geq 10^{19} \text{ eV}$ and $E \geq 3 \cdot 10^{20} \text{ eV}$ while the ratio $\frac{I_p}{I_\nu}$ has a characteristic peak at about $2 \cdot 10^{20} \text{ eV}$, a rather careful diagnostic of the decaying crypton hypothesis for future experiments such as the *Pierre Auger* project. Furthermore, since the neutrino flux dominated over the proton flux at low energies, the bulk of the energy released by the decaying cryptons end up as neutrinos. This should sound like music to the ears of the NESTOR project people, because NESTOR is sensitive to neutrino fluxes of TeV energies and the expected neutrino flux of the cryptons decays should be something like:

$$\left(\frac{10^{20} \text{ eV}}{1 \text{ TeV}}\right) (flux)_{UCHR} \approx 10^8 \cdot \left(\frac{1 \text{ event}}{\text{km}^2 \cdot \text{century}}\right) \approx \left(\frac{10^6 \text{ events}}{\text{km}^2 \cdot \text{year}}\right) \quad (6)$$

Moreover the neutrinos should be correlated in both time and arrival direction with the cosmic rays since the path length in the galactic halo is $\leq 100 \text{ kpc}$. In addition, since we are not living in the center of our Galaxy, but about 8.5 kpc away, with sufficient event statistics one should be able to discover the small anisotropy which should result from the distribution of decaying cryptons in the galactic halo (27). I believe that

all the above phenomenological analysis/predictions have taken cryptons out of the fancy realms of string theory and brought them into direct contact with the fact-based world of Experimental Physics. We may know soon if cryptons have been found.

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ΠΕΡΙΛΗΨΗ

**Κρυπτόνια: Μια νέα μορφή σκοτενής ύλης και πηγή τῶν “μυστηριωδῶν”
ὑπερενεργειακῶν κοσμικῆς ἀκτίνων.**

Τὰ κρυπτόνια εἶναι μία νέα μορφή “μετασταθούς” ὕλης προερχομένης ἀπὸ τὸν λεγόμενο “κρυφὸ τομέα” τῶν ὑπερχορδῶν. Ἡ μάζα τους, $M_X \sim 10^{12}$ GeV καὶ ὁ χρόνος ζωῆς τους $\tau_X \geq 10^{18}$, προσδιορίζονται δυναμικὰ ἐνῶ ἡ κοσμικὴ ἐνεργειακὴ πυκνότητά τους, πλησιάζει φυσιολογικὰ τὴν “κριτικὴ πυκνότητα”. Τὰ προϊόντα διασπάσεώς τους περιέχουν πρωτόνια, ποὺ ὑπὸ μορφή Ὑπερενεργειακῶν κοσμικῶν ἀκτίνων φθάνουν στὴν γῆ. Τελευταῖοι ὑπολογισμοὶ δείχνουν ὅτι τὰ κρυπτόνια μποροῦν πράγματι νὰ εἶναι ἡ πηγή τῶν πιδ ὑπερενεργειακῶν κοσμικῶν ἀκτίνων ποὺ “κτύπησαν” ποτὲ τὴν γήινη ἀτμόσφαιρα, ὅπως παρατηρήθηκαν ἀπὸ τοὺς ἀνιχνευτὲς Fly’s Eye καὶ AGASA.

Τὰ κρυπτόνια δίνουν πολὺ συγκεκριμένες ροὲς πρωτονίων καὶ νετρίνων παρατηρήσιμες ἀπὸ τοὺς ὑπὸ κατασκευὴ καινούργιους κοσμικοὺς ἀνιχνευτὲς, ὅπως ὁ ΝΕΣΤΩΡ, στὴν Πύλο καὶ ὁ PIERRA AUGER.