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CENTAUROS FROM CYGNUS X-3

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ABSTRACT

We show that the measured Centauro events can be explained in terms of strange quark matter primaries ejected by Cygnus X-3, supposing that the pulsar is a strange quark star. We put limits on the efficiency of acceleration mechanism. The spectrum of the ejected strange quark matter is related with the Centauro properties giving rise to a distribution at the source of the Zeldovich type.

Centauro events(1) are characterized by the fragmentation of the primary in hundreds of baryons and practically nothing else and cannot be explained by cosmic-rays of ordinary nuclear matter. A candidate for such events is any sort of stable quark matter that can develop the appropriate baryon number $A \simeq 10^3$. Strange quark matter (SQM)(2), because its stability for virtually any value of A ($10^2 \leq A \leq 10^{57}$) can possibly account for the baryon content of the Centauro primaries(3,4).

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SQM, produced in the phase transition that the Universe undergoes at $T \simeq 200$ MeV, red-shifted by the expansion of the Universe, has not the energy per baryon of the measured Centauro events $\epsilon = E/A \simeq 10$ TeV. One must look for astrophysical production of SQM with the desired properties. One candidate could be Cygnus X-3[5] if the pulsar of the binary system is a strange quark star[6,7]. It is assumed that the core of a neutron star, due to the high density is composed by ordinary quark matter; by changing its flavour composition via the weak interactions u,d ⟶ s, ordinary quark matter can lower its Fermi energy, transforming into the more stable SQM. Ordinary nucleons that enter the SQM region lose their nature liberating their quark content; the more energetically favorable flavour composition is reached through weak interactions. It has been calculated that a neutron star will transform in a strange quark star in roughly one year[6], the properties of a quark star being very similar to those of a neutron star[8].

In this letter we show that the powerful source Cygnus X-3 can account for the properties of Centauro events in terms of nuclearites[3] or strange quark lumps ejected from the strange quark pulsar of the binary system; the spectrum of ejected SQM can be related with the Centauro properties giving rise to a Zeldovich distribution of the origin.

We assume that SQM of all sizes is ejected from the pulsar of Cygnus X-3 with an unknown spectrum. SQM, like ordinary nuclei, develops a positive charge

$$Z \simeq 6 \times A^{1/3} \tag{1}$$

and, when ionized by the ambient photons, can be accelerated by the usual mechanism present in the system. It can be shown[9] that a SQM droplet with radius $\lesssim 10^{-2}$ Å or equivalently $A \lesssim 10^{9}$ can be completely ionized.

We will consider two standard mechanisms of acceleration of charged particles by the pulsar magnetic field, namely Deutch wave[10] and D.C.[11] acceleration; when applied to SQM the maximum energy available is[7]:

$$E_{max} \simeq 3\times10^{3}\ A^{5/9}\ \text{TeV} \quad \text{(Deutch wave acc.)} \tag{2.a}$$

$$E_{max} \simeq 4\times10^{5}\ A^{1/3}\ \text{TeV} \quad \text{(D.C. acc.).} \tag{2.b}$$

Because the energy per baryon of the Centauro events is $\epsilon \simeq E/A \simeq 10$ TeV, eqs.(2) show that the mechanisms are effective for $A \lesssim 10^{7}$-10^{8}. We note that in this region R(droplet) < 10^{-2} Å.

Nuggets of SQM must travel a distance 10 Kpc before they reach the Earth and will suffer collisions with the galactic matter. Taking the strong interaction cross section between strange quark lumps and protons $\sigma \simeq 3A\sigma_{qq} \simeq 30$ A mb., the SQM mean free path will be

$$l = (\sigma \cdot n)^{-1} \simeq \frac{10^{27}}{3} A^{-1} \cdot n^{-1} \text{ cm} \qquad (3)$$

where n is the number density of galactic material, which runs from $n \simeq 1\text{-}2$ cm^{-3} into the galactic spiral arms to $n \simeq 0.2\text{-}0.3$ cm^{-3} between them. We note that only strange quark nuggets whose baryon number is restricted by (3) are free of collisions and can reach the Earth. Taking $n = 1$ cm^{-3} and equating l in (3) to the distance from Cygnus X-3 (~ 10 kpc) we obtain that the possible baryon number of the strange quark primaries are $10^2 \lesssim A \lesssim 10^4$, where the lower bound is due to the intrinsic stability of SQM. The energy per baryon of the Centauro primaries $\epsilon \simeq 10$ TeV, by eqs.(2), translates into a value of the efficiency of the mechanisms of acceleration in the pulsar mentioned above, namely $\sim 10^{-1}$ (Deutch wave acc.); $\sim 10^{-2}$ (D.C. acc.).

If Cygnus X-3 is the source of Centauros it must be capable to produce a flux $F_c \simeq 10^{-2}$ m$^{-2} \cdot$ y^{-1} of primaries with baryon number $A_c \simeq 10^3$ and energy per baryon $\epsilon_c = E_c/A_c \simeq 10$ TeV. In fact, this is the case. The total power of the source is $P \gtrsim 10^{39}$ erg sec^{-1} with an integral spectrum in the measured γ rays of the E^{-1} type; the fraction of the total power that reach the Earth is:

$$\frac{P_\oplus}{P} = \frac{1}{4}\left(\frac{R_\oplus}{D}\right)^2 \qquad (4)$$

where $D \simeq 10$ kpc is the distance between Cygnus X-3 and the Earth; this converts to a flux $F \simeq 2/3$ erg$\cdot$cm$^{-2} \cdot$ y^{-1}. The measured power in Centauros is $F_c \simeq 10^{-2}$ erg$\cdot$cm$^{-2} \cdot$ y^{-1}. Let us assume that the spectrum of different baryon number nuggets at generation is of the exponential form $\propto A^{-\alpha}$; if Cygnus X-3 must account for the Centauro flux $F_c/F \simeq A^{-\alpha}$ which implies that $\alpha \simeq 2/3$ showing a distribution close to the Zeldovich type[12].

The flux of photon measured pointing to Cygnus X-3[13] shows a spectrum $\Phi_\gamma(E_\gamma) \simeq \beta E_\gamma^{-2}$; if photons are mainly produced by SQM lumps and supposing $E_A/A \simeq 10\, E_\gamma$ we obtain a spectrum for the strange quark nuggets $\Phi_A(E_A) \simeq \beta\, 10^2\, A(E_A)^{-2}$, where E_A is the energy of the nugget. The integral flux will be $\Phi_A(>E_A) \simeq \beta\, 10^2 A(E_A)^{-1}$. The two mechanisms of acceleration in the pulsar mentioned above have a dependence from the baryon number given by eqs.(2) which translates in a distribution:

$$\Phi_A(>E_A) \propto A^{-5/9} \qquad \text{(Deutch wave acc.)} \qquad (5.a)$$

$$\Phi_A(>E_A) \propto A^{-1/3} \qquad \text{(D.C. acc.)} \qquad (5.b)$$

In view of eqs.(5) the Deutch wave acceleration mechanism is more close to the above mentioned Zeldovich spectrum than the D.C. one. In fact this can be the case for Cygnus X-3; the D.C. acceleration can be strongly reduced by the pair creation in the strong magnetic field on the vicinity of the pulsar[14]; on the other hand, the recently reported period of the pulsar of Cygnus X-3 of 12.6 ms[15] favours the Deutch wave mechanism due to the extreme youth of the pulsar.

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