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High Energy Neutrons from Sgr A East: detection perspectives for the AUGER observatory

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Sgr A East is a supernova remnant located few parsecs away from the Galactic Centre (GC). There are good reasons to believe that this object is the source of the gamma-ray excess detected by HESS in the direction of the GC meaning that Sgr A East is likely to be an efficient Cosmic Ray (CR) accelerator. Due to the presence of strong magnetic fields in that region, the maximal energy of shock accelerated nuclei may be larger than the EeV. We show that, if this is case, EeV neutrons should be effectively produced by the photo-disintegration of Ultra High Energy nuclei onto the IR background (with temperature ~ 40 K) in which Sgr A East is embedded. Neutrons with this energy can reach the Earth before decaying and may be detectable under the form of a CR point-like excess in the direction of the GC. We determined the expected energy spectrum and the amplitude of this signal showing that it may be measurable by the AUGER observatory.

1. Introduction

It is generally accepted that the bulk of Cosmic Rays (CRs) in our Galaxy are shock accelerated in the supersonic outflow of galactic SuperNova Remnants (SNRs). What is the maximal energy reached in these astrophysical accelerators, however, is much more uncertain. The continuity of the CR spectrum up to ankle of the CR spectrum ($E_{\rm ankle} \sim 6 \times 10^{18}$ eV) suggests that the origin of the CRs above the knee ($E_{\rm knee} \sim 3 \times 10^{15}$ eV) is closely related to that at lower energies meaning that the maximal energy reached in some SNRs may be as large as the EeV. A possible direct observational association of EeV CRs with some galactic SNR would provide a precious confirmation of such a scenario. Unfortunately , even EeV protons are significantly deflected in the galactic magnetic field so that the angular correlation between the arrival direction of these particles and the position of their sources is expected to be spoiled. A possible way out may however be found if EeV secondary neutrons are efficiently produced by the scattering of the more energetic primary nuclei with the matter and the radiation surrounding the SNR. Interestingly, neutrons with such an energy can travel over galactic distances without undergoing significant decay as the survival probability is

$$P_{\rm sur} = \exp\left\{ -\frac{(8\ {\rm kpc}) m_n}{1\ {\rm EeV}\ c\tau_n} \right\} \simeq 0.43\ , \tag{1}$$

where, as a benchmark, we considered the Galactic Centre (GC) distance. Although high energy neutrons and protons give rise to indistinguishable showers in the atmosphere, a galactic neutron source may be recognised by the extensive air shower experiments under the form of a localised excess of CRs with energy $\gtrsim 1$ EeV.

The SNRs which are the most promising sources of EeV neutrons are those residing in the densest regions of the Galaxy, where strong magnetic fields as well as thick radiation and gas targets can presumably be found. Active SNRs in the proximity of the Galactic Center and/or in the nearby of dense molecular clouds are natural candidates to the role of EeV neutron factories. A particularly interesting SNR in that region is Sgr A East [1]. Detailed X-ray observations, performed mainly by the Chandra observatory [2], allowed to establish that this is the remnant of a single type II SN explosion which took place about 5×10^4 years ago (the light propagation time is subtracted) less than 3 pc away from the GC, i.e. at a distance of 8 kpc from the Earth. The explosion released about 10^{51} erg in the form of kinetic energy of the ejecta. Chandra found that 1% of this energy has been converted into thermal energy of the gas in the inner region of the remnant. This SNR is embedded within a dense ionised gas halo and in a background of Infrared (IR) radiation due to dust emission at the temperature $T \sim 40$ K [3]. Furthermore, the expanding Sgr A East radio shell is interacting with a dense molecular cloud. Strong magnetic fields, as large as few milliGauss, have been observed in that region [4] which may allow the acceleration of nuclei up to ultra-high energies ($E > 10^{18}$ eV).

A γ-ray emission has been also recently observed by the HESS Cerenkov telescope in the direction of the GC [5]. Although the limited angular resolution reachable by HESS (about 1' corresponding to 2.3 pc at the GC distance) did not allow a firm identification of the source of this emission, several arguments points to Sgr A East as the most plausible source. The most convincing among these arguments is based on the energetic of the emission observed by HESS. Indeed, in [6] we showed that by assuming that the CRs accelerated in Sgr A East are in energy equipartition with the gas thermal energy (corresponding to a 1% acceleration efficiency) the γ-ray flux expected from the decay of neutral pions produced in the hadronic collisions of the CR with the surrounding gas practically coincides with that measured by HESS. On the basis of this argument we assume that Sgr A East accelerates nuclei with a power law spectrum with index equal to that of the γ-ray excess observed by HESS.

We will show that if this spectrum extends steadily up to few EeV an observable secondary flux of EeV neutrons should be originated in that SNR.

2. High energy neutrons from nuclei photo-disintegration

High energy nucleus can be effectively dissociated into lighter nuclei and one, or more, nucleons when colliding with photons. If the centre of mass energy is $\ll 30$ MeV the photo-disintegration (PD) is dominated by the giant dipole resonance giving rise to a single, or at most a pair, of free nucleons each carrying a fraction $1/A$ of the primary nucleus energy. This is indeed the regime of interest in the present context. In fact, since the Lorentz factor required to produce EeV neutrons is $\gamma_* \sim 10^{18}$ eV$/m_n \sim 10^8$, and the mean energy of thermal photons with $T \simeq 40$ K is $\epsilon \simeq 10^{-2}$ eV, the corresponding c.m. energy is $\gamma_* \epsilon \simeq 1$ MeV.

In [6] we applied the general results found in [7, 8] to determine the PD rate of ultra-relativistic nuclei in the environment of Sgr A East. ¿From this we found the neutron production rate to be

$$R_A(\gamma T) \simeq R_0 \, \xi_A \left(\frac{T}{40 \text{ K}} \right)^3 \Phi_A(\gamma T) \tag{2}$$

where $R_0 \simeq 5 \times 10^{-10}$ s^{-1} and ξ_A is an order one parameter. The function $\Phi_A(\gamma T)$, was plotted in [6] for several nuclear species. For all most abundant species generally present in a type II SNR (^{4}He, ^{12}C, ^{16}O, ^{56}Fe) this function peaks approximatively at the same value of the product of the Lorentz factor with the photon background temperature, namely, $\gamma k T \approx 4$ MeV, corresponding to the energy $E_A^{\rm peak} \simeq A \times 10^{18} \left(\frac{T}{40 \text{ K}} \right)^{-1}$ eV. The maximal value of $R_A(\gamma T)$, however, varies for the different nuclear species and, in several cases, it exceeds the inverse of the SNR age. It is important to observe that when this happens for a give nuclear species, further acceleration of that species is inhibited by the PD losses. We found that, among the most abundant species expected to be present in Sgr A East, only the ^{4}He can reach the energy sufficient to produce EeV neutrons.

The two main quantities on which the flux of secondary neutrons depends on, are the photon density in the

Sgr A East region, which as we discussed in the Introduction it is just given by a black-body with $T = 40$ K, and the spectrum of primary ^{4}He nuclei accelerated in that SNR. As we mentioned in the Introduction, we estimated the latter quantity under the assumption that the CR energy in Sgr A East is in equipartition with the thermal energy of the X-ray as observed by Chandra [2], i.e. $E_{\rm CR} \simeq E_{\rm gas} \simeq 10^{49}$ erg.

Under these hypothesis we found that the differential neutron flux reaching the Earth from Sgr A East should be

$$\frac{dF(E_n)}{dE_n} \simeq 2 \times 10^{-27} \left(\frac{f_A}{0.1}\right) \left(\frac{R_0 \xi_A \Phi_A(E_n, T)}{10^{-12}\ {\rm s}^{-1}}\right) \left(\frac{E_{\rm CR}}{10^{49}\ {\rm erg}}\right) \left(\frac{d}{8\ {\rm kpc}}\right)^{-2} \left(\frac{T}{40\ {\rm K}}\right)^3 \exp\left(-\frac{d\, m_n}{E_n\, c\tau_n}\right) \left(\frac{AE_n}{10^9\ {\rm GeV}}\right)^{-2.2} {\rm GeV}^{-1}{\rm cm}^{-2}{\rm s}^{-1}\ . \tag{3}$$

This is plotted in Fig. 1 for a reasonable value of the relative ^{4}He/H abundance: $f_4 = 0.2$.

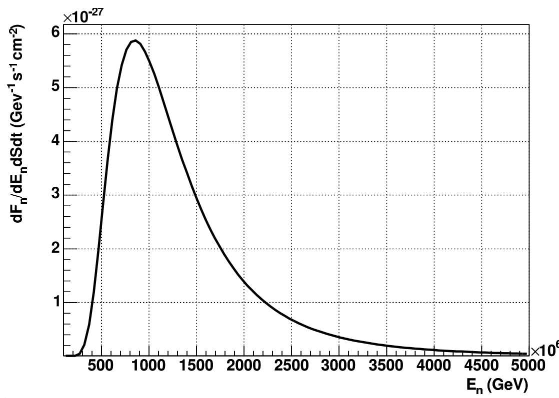

Figure 1. The differential flux reaching the Earth of neutrons produced by the photo-disintegration of ^{4}He nuclei in Sgr A East

3. Expected signal at AUGER

The Pierre AUGER Observatory is an Extensive Air Shower detector under construction in Argentina [9]. When completed, it will consist of 1600 Water Cherenkov elementary Detectors (WCDs) covering an area of about 3000 km^2 overlooked by a set of four florescence telescopes. An Engineering Array of WCDs has been in operation since 2002 and the detection of several showers with energy of the primary $\sim 10^{18}$ eV has already announced at the ICRC 2003 [10]. The AUGER acceptance will be $A\Omega \approx 4700$ km^{2}sr, for a zenith angle $\theta < 45^o$. The array trigger efficiency at the EeV has been estimated to be $\eta \simeq 0.25$ [10].

The geographic position of AUGER is ideal for observing a UHECR excess in the direction of the GC. Since the angular size of Sgr A East is few primes, the neutron emission from this object should give rise to a point-like signal in AUGER. The isotropic background of ordinary CRs gives rise to an unavoidable noise. The CR spectrum in the energy range $4 \times 10^{17} < E < 6.3 \times 10^{18}$ eV is

$$J_{\rm CR}(E) = (9.23 \pm 0.65) \times 10^{-28} \left(\frac{E}{6.3 \times 10^{18}}\right)^{-3.20 \pm 0.05} ({\rm GeV\ sr\ cm^2\ s})^{-1}\ . \tag{4}$$

Therefore the maximal (at 95%C.L.) differential flux around 10^{18} eV incident onto the expected AUGER angular bin is

$$F_{\rm CR}^{\rm max}(E) \simeq 3 \times 10^{-27} \left(\frac{E}{10^{18}\ {\rm eV}}\right)^{-3.3} \left(\frac{\delta}{2.5^o}\right)^2 \ {\rm GeV}^{-1}{\rm cm}^{-2}{\rm s}^{-1} \ . \quad (5)$$

It is comforting that the expected neutron flux from Sgr A East produced by the photo-disintegration of ^{4}He nuclei (see Eq. 3) is comparable to the isotropic CR flux around the EeV incident over the AUGER angular bin. As a consequence, AUGER may observe a significant UHECR excess in the angular bin corresponding to the position of the GC.

As a benchmark, we give here the expected rates of showers incident over an angular bin of 2.5^0, in the energy range $1 \times 10^{18} < E < 3 \times 10^{18}$ eV, due to the PD neutrons (accounting for the AUGER trigger efficiency) versus the CR background rate in the same angular and energy bins

$$\dot{N}_{\rm PD} \simeq 130\ {\rm yr}^{-1}\ , \qquad \dot{N}_{\rm CR} \simeq 440\ {\rm yr}^{-1}\ . \quad (6)$$

$\dot{N}_{\rm PD}$ has been computed assuming the ^{4}He relative abundance $f_4 = 0.2$. Since the expected signal is a sizeable fraction of the background a significant excess should be detectable in the direction of the GC.

4. Conclusions

Although Sgr A East is an ordinary SNR, we showed (see [6] for more details) that its particular location, within a region with strong magnetic fields and rich of infrared radiation, makes it a plausible factory of EeV neutrons. Here we only considered the photo-disintegration channel as in [6] we showed that in order to produce EeV neutrons by *pp* scattering a too high mean proton energy ($\gtrsim 2 \times 10^{19}$ eV) is required. Although we showed that the expected neutron flux from Sgr A East should be detectable by AUGER, from our analysis it follows that this source can hardly be responsible for the CR anisotropies claimed by AGASA[11] and SUGAR [12] experiments in two different directions in the nearby of the GC around the EeV.

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