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Sgr A* as a potential source of galactic PeV neutrinos

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Introduction

Pev protons in the galactic center (GC) was detected by H.E.S.S. collaboration [1]. The highest possible energy of the proton from the Sgr A* is proposed to be 170 PeV [2]. Proton having this much energy will interact with the molecular hydrogens present in plenty near the origin and background photons. The time scale of p-p interaction is very small compared to the p-γ interaction time scale [3]. Also plenty molecular hydrogen presents in the Galaxy makes the p-p channel more efficient than other posible channels. p-p interactions will generate pions (π^o, π^+, π^-). Neutral pions will decay into gamma rays, where as charged pions produces various neutrinos and anti neutrinos. In the mechanism $p \to \pi^o \to 2\gamma$ and $p \to \pi^\pm \to 3\nu$, the number ratio $\gamma : \nu \sim 1 : 3$ and the corresponding energy ratio is $\frac{E_\gamma}{E_\nu} \sim 2$ [4]. So maximum possible gamma energy and neutrino energy in this process will be $[E_\gamma \sim \frac{1}{10}E_p]$ 17 PeV and $[E_\nu \sim \frac{1}{20}E_p]$ 8.5 PeV respectively.

π production

High energy protons which are accelerated via LLCD mechanism[5], interacts with the cold ambient ISM, gives rise to γ and ν through the decays of produced pions. We considered isotropic distribution of the accelerated proton $dn(E_p)/dE_p$, which gives rise to π^o emissivity given by [4], $Q^{pp}_{\pi^o}(E_{\pi^o}) =$

$$cn_H \int_{E_p^{th}}^{E_p^{max}} \frac{dn(E_p)}{dE_p} \frac{d\sigma_{pp}(E_{\pi^o}, E_p)}{dE_{\pi^o}} dE_p \quad (1)$$

where n_H is the ambient hydrogen number density. The energy dependent pp crossection expressed by [3] $\sigma_{pp} = 34.3 + 1.88 ln(E_p/1TeV) + 0.25(ln(E_p/1TeV))^2$ mb.

E_p-independent approximations in scalling model with a parameterization of the differential cross section gives,[4]

$$\frac{d\sigma_{pp}(E_{\pi^o}, E_p)}{dE_{\pi^o}} \simeq \frac{\sigma_{pp}}{E_{\pi^o}} f_{\pi^o}(x) \quad (2)$$

where, $x \equiv E_{\pi^o}/E_p$ and $f_{\pi^o}(x)$ is expressed as [3, 4]

$$f_{\pi^o}(x) = 8.18x^{1/2} \left(\frac{1 - x^{1/2}}{1 + 1.33x^{1/2}(1 - x^{1/2})} \right)^4 \times \left(\frac{1}{1 - x^{1/2}} + \frac{1.33(1 - 2x^{1/2})}{1 + 1.33x^{1/2}(1 - x^{1/2})} \right) \quad (3)$$

Using all those parameterization π^o emissivity can be rewritten as,

$$Q^{pp}_{\pi^o}(E_{\pi^o}) = cn_H \sigma_{pp} \frac{dn(E_p)}{dE_p} \times Z_{p\pi^o}(\alpha) \quad (4)$$

here α is the spectral index of the cosmic-ray spectrum and $Z_{p\pi^0}(\alpha)$ is the spectrum-weighted moment of the inclusive cross section, also named as Z-factor and is given by[4],

$$Z_{p\pi^0}(\alpha) = \int_0^1 x^{\alpha-2} f_{\pi^o}(x) dx \quad (5)$$

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PeV neutrino and gamma ray flux

The emissivity for the production of gamma ray from pp interaction is expressed by the following [4] equation,

$$Q^{pp}_{\gamma}(E_{\gamma}) \simeq Z_{\pi^o\gamma}(\alpha) Q^{pp}_{\pi^o}(E_{\pi^o}) \quad (6)$$

here, $Z_{\pi^o\gamma}(\alpha) = 2/\alpha$, let us term this as Z_0.

The neutrino emissivity for different flavours takes these form [4],

$$Q^{pp}_{\nu_\mu}(E_{\nu_\mu}) \simeq 2[Z_{\pi^o\nu_\mu}(\alpha) + Z_{\mu\nu_\mu}(\alpha)] Q^{pp}_{\pi^o}(E_{\pi^o}) \quad (7)$$

$$Q^{pp}_{\nu_e}(E_{\nu_e}) \simeq 2 Z_{\mu\nu_e}(\alpha) Q^{pp}_{\pi^o}(E_{\pi^o}) \quad (8)$$

factor 2 in the above equation implies that we are considering the sum of the neutrino and antinutrino emissivity. let us name $Z_{\pi^o\nu_\mu}(\alpha)$ as Z_1, $Z_{\mu\nu_\mu}(\alpha)$as Z_2 and $Z_{\mu\nu_e}(\alpha)$as Z_3. These are the Z-factor corresponding to ν_μ production from pion decay,muon decay and ν_e production from muon decay. They are evaluated following the equations[4] :

$$Z_1 = \frac{(1-r)^{\alpha-1}}{\alpha} \quad (9)$$

$$Z_2 = \frac{4[3-2r-r^{\alpha}(3-2r+\alpha-\alpha r)]}{\alpha^2(1-r)^2(\alpha+2)(\alpha+3)} \quad (10)$$

$$Z_3 = \frac{24[\alpha(1-r)-r(1-r^{\alpha})]}{\alpha^2(1-r)^2(\alpha+1)(\alpha+2)(\alpha+3)} \quad (11)$$

where, $r = (m_\mu/m_\pi)^2 = 0.467$

From eq. 4 the total neutrino emissivity for all flavours combined can be written as,

$$Q_\nu = c n_H Z \sigma_{pp} \frac{dn(E_p)}{dE_p} \times Z_{p\pi^o}(\alpha) \quad (12)$$

where, $Z = 2[Z_1 + Z_2 + Z_3]$

Now, $N_p = \frac{4\pi}{c} J_p$ is the steady state density $= \frac{dn(E_p)}{dE_p}$ and $R_{eff} \equiv \int dV/(4\pi r^2)$ is the effective radius, which is calculated to be between 1kpc to 10 kpc depending the shape of the halo considered around the galactic center[6]. The observed neutrino flux can be drived using[6],

$$J_\nu = J_\nu(E_\nu) = \frac{1}{4\pi}\int_0^1 dV \frac{Q_\nu}{4\pi r^2} = \frac{R_{eff}}{4\pi} \times Q_\nu \quad (13)$$

from equation 12 and 13 we derived the equation for the calculation of the neutrino flux,

$$J_\nu = n_H \sigma_{pp} Z R_{eff} J_p \times Z_{p\pi^o}(\alpha) \quad (14)$$

The gamma ray flux is expressed by,

$$J_\gamma = n_H \sigma_{pp} Z_0 R_{eff} J_p \times Z_{p\pi^o}(\alpha) \quad (15)$$

Results

$n_H = 1cm^{-3}$[3, 6] is considered. Although in various paper GC region ISM density is cosidered to be much higher $n_H = 120cm^{-3}$ [7]. J_p is calculted from cosmic ray spectra[8] comes $\frac{2\times10^3}{E^{2.6}}$ in $GeV^{-1}cm^{-2}s^{-1}sr^{-1}$

TABLE I: Flux calculation for different values of n_H and R_{eff} with spectral index value 3.

n_H [a]	R_{eff} [b]	J_ν [c]	$E_\nu{}^2 J_\nu$ [d]	$E_\gamma{}^2 J_\gamma$ [d]
1	1	2.7×10^{-28}	2×10^{-14}	9.3×10^{-14}
120	1	3.2×10^{-26}	2.3×10^{-12}	1.1×10^{-11}
1	10	2.7×10^{-27}	2×10^{-13}	9.3×10^{-13}
120	10	3.2×10^{-25}	2.3×10^{-11}	1.1×10^{-10}

[a] in cm^{-3}
[b] in kpc
[c] in $GeV^{-1}cm^{-2}s^{-1}sr^{-1}$
[d] in $GeV cm^{-2}s^{-1}sr^{-1}$

Conclusions

Higher flux value is observed for lower spectral index values. Sgr A* can be a source of PeV neutrinos. Much higher sensitive detector may detect those neutrinos in near future.

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