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The observational signatures of ultra-high energy cosmic rays in the Galactic Center

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The central region of our Galaxy is believed to contain a supermassive black hole coincident with the radio source Sgr A. This region has been observed by several gamma-ray observatories as a source of gammas at energies above 200 GeV, probably extending into the TeV region. In this work we study the propagation of protons inside a model of the magnetic field present in the central 400 parsecs of our Galaxy. The particles are injected in the field with two different configurations, one assuming that their source is located within a sphere of 15 parsecs in the Galactic Center, and other injecting the particles at a spherical boundary surrounding the magnetized bulge. For both cases we study the propagation of 1 EeV protons inside 200 pc from the Galactic Center, their trapping time and estimate the neutron and gamma fluxes resultant from their interaction with the local interstellar medium.

1. Introduction

Within the central hundreds parsecs of our Galaxy a great number of phenomena are taking place due to a myriad of different astrophysical objects. The taxonomy of those objects reveals the presence of a central supermassive blackhole surrounded by stars in formation process, hot X-ray halos, supernova remnants and a great molecular zone of about 200 parsecs in radius lying down in the Galactic Plane [1]. Although the region is obscured at optical and UV wavelenghts, the study of the Galactic Center indicates the presence of gamma ray emmiters (TeV and GeV energy ranges), X-Ray, radio, infrared [1] and, probably, cosmic ray sources [2] as well.

Inside this region the field has been observed or inferred by several different techniques, such as Zeeman effect in maser and radio, infrared polarization and radio synchrotron emission.

The Galactic Magnetic Field (GMF) structure and strength plays a central role in the study of charged particles crossing or trapped in our Galaxy. The regular component of this field inside the Galactic disk has a strength of the order of few μG [3] and may be the result of a large scale S0 dynamo. Furthermore, there are evidences of antisymmetric rotation measurements at high Galactic latitudes which are compatible with a toroidal field in the Galactic halo. This toroidal component possibly extends into the inner Galaxy, inside the central molecular zone [4].

On the other hand, the observation of non-thermal radio filaments in the Galactic center region [1], have long been thought as indicatives of a larger scale poloidal component rooted in a central dipole [5, 6, 8].

The combination of the toroidal and dipole components in the Galactic center region strongly suggests that an A0 dynamo is operating in the halo and bulge of our Galaxy.

According to some observations, the strength of the inner Galaxy fields can reach up to 3 mG [7] at scales of tens of parsecs, perhaps remaining at the level of several tens of μG up to several hundred parsecs from the Galactic center.

Therefore, the extension of the regular magnetic structure observed (or inferred) at large scales into the central few hundred parsec of our Galaxy is potentially interesting for cosmic ray propagation studies since the gyro-radius of particles with energies as high as 10^{19} eV would be much smaller than the characteristic scale of the region (see, Fig. 1), leading to severe bending or even partial confinement and the corresponding build up of a local ultra-high energy cosmic ray excess density.

In this work the propagation of charged particles inside the central 400 parsecs of our Galaxy and its corresponding observational manifestations are analyzed.

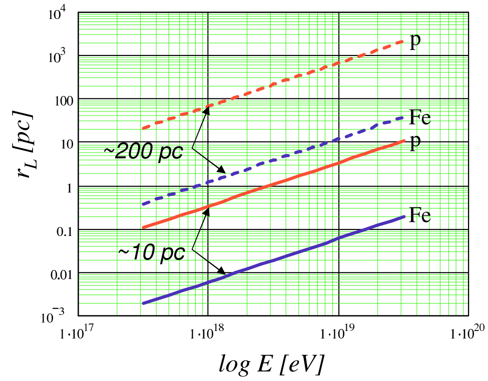

Figure 1. The Larmor radius of proton and Fe nuclei as a function of energy at $\sim$ 10 and $\sim$ 200 pc from the Galactic Center in the vicinity of the Galactic Plane.

2. Propagation at EeV: estimates and simulations

If the intensity of the magnetic field in the central region of the Galaxy is considerably higher than in the rest of the disk, as it seems to be the case, particles coming mainly from the extragalactic cosmic ray flux may be partially confined for a relatively long time. Since the interstellar medium (ISM) in this region is also much denser than in the rest of the Galaxy, cosmic ray particles might have the chance to interact with the ISM and produce neutral particles, neutrons, neutrinos and gammas, that could be detected at Earth.

As an example, let us consider particles n the energy range 1–2 $\times 10^{18}$ eV and a confinement region of $L \sim 100$ pc. If the diffusion coefficient can be approximated by $D \sim r_L c/3$ the diffusion time scale across the region would be $\Delta t \sim L^2/D$, while the light travel time is $\tau_{LT} \sim L/c$, and one can estimate a density enhancement factor inside this region with respect to the original cosmic ray density as $f \sim \Delta t/\tau_{LT} \sim cL/D$ which, for our example, would amount to $f \sim 10^3$.

The ISM density at the Galactic center, on scales of tens of parsecs is difficult to estimate, but a conservative value is $n_{ISM} \sim 10^2$ cm^{-3}. The column density along the size of the region, L, is $\lambda \sim \mu m_p n_{ISM} L \sim 4.5 \times 10^{-2}$ gm/cm^2, and the mass traversed by a typical cosmic ray at 1 EeV would be $\Lambda \sim f\lambda \sim 45$ gm/cm^2. Since the proton-proton interaction length, $\lambda_{pp} \sim 40$ gm/cm^2, is comparable, almost every cosmic ray proton would have at least one interaction with the ISM during confinement.

Since the cosmic ray flux at 1 EeV is of the order of $E^3 \times J(10^{18} eV) \sim 10^{24.5}$ m^{-2} sec^{-1} sr^{-1} eV^2, one can estimate the number of particles with energies between 1 and 2 EeV entering a confinement region of size $L \sim 100$ pc as $\Phi(E = 10^{18}, \Delta E = 10^{18}) \sim 10^{27}$ sec^{-1}. Each one of these particles will experience, on average, 1 interaction with the ISM.

Therefore, since the multiplicity for neutron production in p-p interaction is $\sim 1/4$, the number of neutrons per year reaching Auger from this "point-like" source would be $\Psi^N_{\delta\theta} \sim (1/4) \times \Phi \times (\Delta\Omega_{Auger}/4\pi) \sim 30$

neutrons/yr. In the same area of the sky, the background arriving to the detector would be $\Psi_{\delta\theta}^{ALL} \sim 10^6 \times \big((\Delta\theta)^2/2\pi\big) \sim 20 \text{ yr}^{-1}$.

These numbers were estimated for the particular case of $L \sim 100$ pc but, for $L < 100$ pc they can be scaled as: $\Psi_{\delta\theta}^{N}(10^{18}) \sim 30 \times (L/100pc)^{7/2}$ neutron/yr and $\Psi_{\delta\theta}^{ALL}(10^{18}) \sim 20 \times (L/100pc)^2$ particles/yr. These fluxes are plotted in figure 2 as a function of the size of the region, L_{GC}.

It can be seen that, if the size of the high magnetic field intensity region is some tens of pc, the Galactic center should be detectable above the background after few years of integration by an experiment like Auger. Inverting the argument, the detection of such a source, should allow to infer the characteristic fields in the innermost regions of our Galaxy.

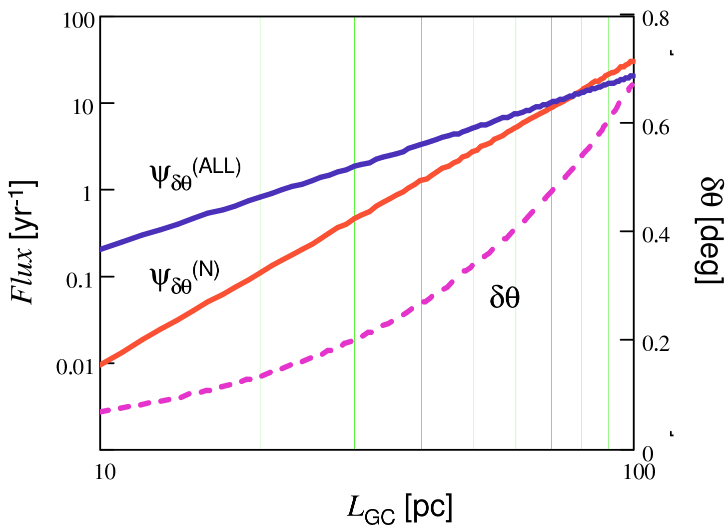

Figure 2. Left vertical axis: secondary neutron flux arising from a confinement region of size L_{GC}, $\Psi_{\delta\theta}^{N}$, as a function of L_{GC} in the 1 to 2 EeV range expected at a 3000 km^2 array like Auger (units are particles per yr). Also shown for comparison is the all particle flux expected in the same region of the sky, $\Psi_{\delta\theta}^{ALL}$. Right vertical axis: angular size subtended by the neutron source as a function of its size.

In order to make a more reliable assessment of this and other effects, we explicitly tracked protons of different energies injected in the central region of our Galaxy at two different positions. In the first simulation group, the protons were injected at random positions over the surface of a 15 parsecs radius sphere centered in the Galactic Center. Those particles were generated with random directions. This first picture represents the central 15 parsecs of our Galaxy as the source of those protons. As the magnetic field in this region is probably very tangled, the momentum of the protons that succeed in escaping from that region points completely random directions.

The second scenario considers the extragalactic flux of protons impinging on an artificial spherical boundary surrounding the inner magnetized region of the Galactic bulge.

The model assumed for the magnetic field at the center of the Galaxy takes into account the observed values for this field and the regular structure inferred from polarimetric and radio studies. We estimate the total field as a composition of a large scale dynamo, a dipolar field acting in the innermost region and a magnetic field created by a flat 2D ring of electric current located in the galactic plane.

Initial results confirm the confinement effect at $\sim$ 1 EeV, see fig. 3, and the neutron flux estimated above. Further details will also be presented about neutrino and gammas fluxes.

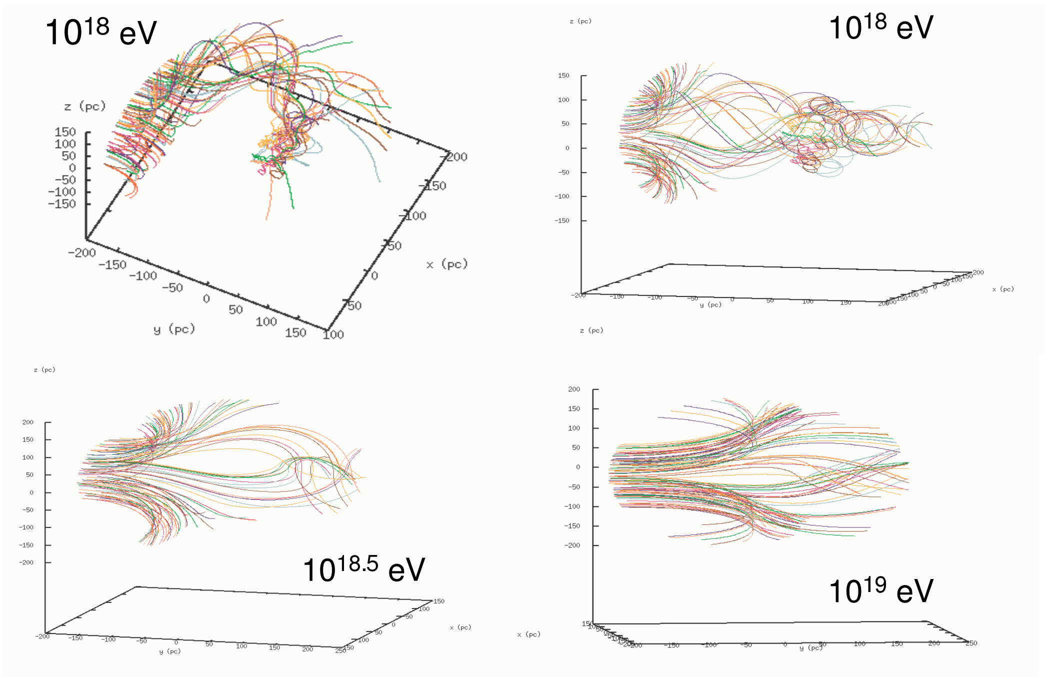

Figure 3. Tracks of some few protons injected with parallel momenta at three different energies, at the border of the central bulge region. The particle orbits show the possibility of some degree of confinement at scales of tens of parsec at energies as high as $10^{18.25}$ eV. This does not preclude confinement at higher energies in a smaller central region depending on details of the magnetic field structure there.

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References

[1] Morris M., E. Serabyn, Annu. Rev. of Astron. and Astrophys. 34, 645 (1996)
[2] Hayashida N. et al., Astropart.Phys. 10, 303 (1999)
[3] Beck R., et al., Annu. Rev. of Astron. and Astrophys. 34, 155 (1996)
[4] Novak G., et al., Astrophys. J, **583**, L83 (2003)
[5] Yusef-Zadeh F., Morris M. (1987) Astrophys. J. 320, 545
[6] Sofue Y., Reich W., Inoue M., Seiradakis J.H. (1987) Publ. Astron. Soc. Japan 39, 95.
[7] Chuss D. T., et al., Astron. Nachr. 324, No S1, 173 (2003)
[8] Sofue Y., C. Lang, The Central Parsecs of the Galaxy, ASP Conference Series, Vol. 186 (1999)