A possible contribution of companion galaxies to intra and extra-cluster UHE cosmic rays

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Abstract

Pulsars are considered possible sources of cosmic rays up to energies of about 4×10^{19} eV ($10^{19.6}$ eV). If this hypothesis will be confirmed, intra and extra-cluster galaxies might play a very important role on cosmic-ray observations near the Earth between 10^{19} and $10^{19.6}$ eV. In particular, it is discussed the contribution of companion galaxies such as the Magellanic Clouds.

1. Introduction

The observed cosmic-ray energy spectrum shows a power-law trend with a varying spectral index above a few GeV. The spectral index is -2.7 between 10^{10} eV and 3×10^{15} eV (knee) and approximately -3.0 above this energy up to 5×10^{18} eV (ankle). Between 10^{19} eV and $10^{19.7}$ eV a bump can be observed and above these energies the spectrum seems to become flatter. The composition is proton rich up to the knee, heavy rich up to the ankle and proton rich again above 10^{19} eV.

In this paper we want to focus on the energy range between 10^{19} eV and $10^{19.7}$ eV where it is expected that:

(I) the diffusion coefficient (D) of cosmic-ray particles increases as a function of the energy above 10^{19} eV and, in particular, it becomes 10^{34}-10^{35} cm^2 s^{-1} between 10^{19} eV and 10^{20} eV in the cluster medium and 10^{35}-10^{36} cm^2 s^{-1} in the same energy interval in the intra-cluster medium [1].

(II) Photo-pion production from proton interactions on microwave background photons occurs above 5×10^{19} eV and

(III) 4×10^{19} eV is the maximum energy of primary cosmic rays accelerated by pulsars [2].

It will be shown here that in case the hypotheses I, II and III listed above will be found correct, part of Ultra High Energy Cosmic Rays (UHECR) observed near the Earth might have been generated by pulsars in other cluster and extra-cluster galaxies. In particular, it is estimated the role of companion galaxies. Above 4×10^{19} eV the cosmic-ray spectrum includes particles with energies higher than the pulsar acceleration limit: the origin of these extreme energy events won't be discussed here.

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Table 1. Major Milky Way companion galaxies characteristics.

Galaxy	Distance from MW (ly)	Dimensions (ly^2)	Mass (Solar masses)
MW	0	100000^2	10^{11}
SagDEG	50000	5000 x 11000	6.04×10^7
LMC	179000	29000 x 34000	2×10^{10}
SMC	195000	10000x30000	2×10^9

2. Pulsar population in Milky Way companion galaxies

The Milky Way (MW) presents a dozen of companion galaxies. The closest and largest are Sagittarius Dwarf Elliptical Galaxy (SagDEG) and the Large (LMC) and Small (SMC) Magellanic Clouds. SagDEG is the MW closest galaxy. The Large and Small Magellanic Clouds are two irregular galaxies located in the southern sky. The characteristics of SagDEG, LMC and SMC have been summarized in Table 1.

In order to discuss the role of pulsars for cosmic-ray (CR) production (observations above 3×10^{18} eV near Earth are reported in Fig.1), it has to be taken into account that the pulsar population presents large variations in different galaxies and therefore the cosmic-ray characteristics result galaxy-dependent.

Approximately 10^9 pulsars are supposed to belong to the Milky Way (10^5 active), but only about 10^3 are known. Young pulsars are candidate UHECR accelerators. A survey of the Magellanic Clouds has revealed [3] a total of 8 radio pulsars. This number is consistent with what is calculated on the basis of various models by assuming a pulsar birthrate 1.6 larger in the companions of the Galaxy with respect to the local solar environment (1 kpc from the Sun).

The X-ray survey of the SMC carried out by the RXTE, ASCA and SAX experiments has revealed a density of X-ray pulsars at least twenty times higher than that of the Milky Way. In fact, 25 X-ray pulsars have been observed [4] while the number expected for a galaxy of approximately 2×10^9 solar masses is less than 1 since only 70 are known in the MW.

It has been suggested, on the basis of the typical X-ray binary system development, that a major star burst occurred about 5 million years ago. The phenomenon that caused this major star burst formation is unknown. Tidal forces generated in a close encounter among the MW and the Magellanic Clouds might have produced the higher star birthrate.

SagDEG has been orbiting the MW halo in the last billion years where it is presently suffering a process of disruption. This galaxy might be experiencing (or to have experienced in the past) an analogous high star birthrate. X-ray binaries are also considered efficient cosmic-ray accelerators (limit for cosmic-ray energy about 10^{16} eV). Consequently, the cosmic-ray equilibrium spectrum

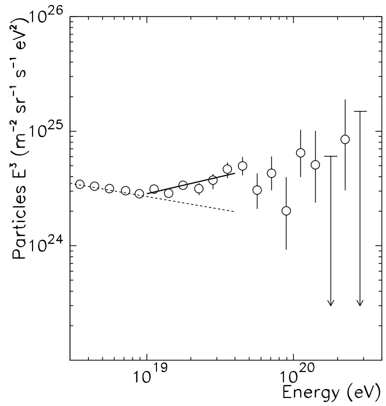

Fig. 1. UHECR data measured by the AGASA experiment. The meaning of the dashed and continuos lines is reported in paragraph 3.

in companion galaxies is enhanced compared to that observed in galaxies with the Milky Way characteristics. The contribution of companion galaxies has to be taken into account in order to estimate the cosmic-ray equilibrium spectrum in the intergalactic medium (IGM). Low energy extragalactic cosmic rays do not reach the Earth from large distances since the bulk of cosmic rays reaching the Earth have origin within one Kpc from the solar system [5]. Conversely, in the energy range studied in this paper an extragalactic component can play an important role.

3. Estimate of an extragalactic contribution to UHECR observations near the Earth between 10^{19} eV and $10^{19.6}$ eV

In order to estimate the extragalactic cosmic-ray component in the observed CR spectrum near the Earth above 10^{19} eV, we use the AGASA experiment data [6] reported in Fig.1. It can be noticed that the first five data points seem to indicate a power-law trend of -3.2 (dashed line in Fig.1). Approximately the same shown between the knee and the ankle.

The flux becomes increasingly higher as a function of the energy above 10^{19} eV with respect to the indicated trend. We have best fitted the data (continuos line in Fig.1) up to $4{\times}10^{19}$ eV. It is found that the component in excess with respect to the power-law trend amounts to 23% between 10^{19} eV and 4 10^{19} eV, ranging from a few to 46% at the extremes. This evidence can be interpreted as an increasing extragalactic component of cosmic rays above 10^{19} eV. In [1] and references therein, it was suggested that below 10^{19} eV the cosmic-ray diffusion coefficient in the cluster medium ranges between 10^{33} and 10^{35} cm^2 s^{-1}. By assuming D=10^{33} cm^2 s^{-1} and about 13 billion years (t) as the time that cosmic rays could diffuse through the cluster and intra-cluster media after star formation, it results that the maximum distance, R, that these particles could travel is ($R^2 \simeq 2Dt$) about 9 Mpc, corresponding to less than the distance of the Virgo cluter from the Local Group of Galaxies. This would imply that below 10^{19} eV UHECR are mainly of galactic origin. However, above 10^{19} eV, D becomes more properly 10^{34} cm^2 s^{-1} in the cluster medium and 10^{35} cm^2 s^{-1} in the intra-cluster medium [1]. Consequently, above 10^{19} eV the maximum distance that UHECR particles can diffuse through is about 30 Mpc (typical cluster dimensions are of a few Mpc) in the cluster medium and 90 Mpc in the intra-cluster medium. Therefore, UHECR would have been able to reach the MW from other cluster and extra-cluster galaxies since the time of star formation. As an example, (beyond Virgo) Pegasus, Cancer and Coma Berenice clusters are, respectively, 45, 55 and 85 Mpc away from the MW. The MW companion galaxies are richer of radio pulsars with respect to the Galaxy (of about a factor of 2). By assuming a similar behaviour for all companion galaxies, their contribution to the extragalactic cosmic-ray flux between 10^{19} and $10^{19.6}$ would be about 10%-15% of the total. This estimate can be obtained by considering that 20-30% of the galaxies [7] have companion galaxies and by assuming for the satellite galaxies characteristics similar to those of the MW companions (see Table 1).

4. Conclusions

We have suggested that the bump observed in the cosmic-ray measurements between 10^{19} eV and $10^{19.6}$ eV is consistent with the hypothesis of UHECR acceleration in radio pulsars in our and other clusters of galaxies. The extragalactic cosmic-ray component between 10^{19} eV and $10^{19.6}$ eV is estimated to be about 23% of the total observed sample. If all companion galaxies present a pulsar formation rate similar to that observed in the MC, their contribution to CR in the above energy range at the IGM is approximately 10%-15% of the total.

5. References

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