

Production mechanisms of multiple primaries for Cosmic Rays Showers

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We investigate the physical mechanism of the GZ-effect that could explain the production of multiple primaries from an event initiated outside the Earth’s atmosphere. In this case, there would correspondingly be multiple extensive air showers in temporal coincidence at ground, even for detectors separated by many kilometers, and also showers initiated by primaries of different energies could consequently have a common source. We analyse the perspectives and limits of some models and discuss the experimental counterparts.

1. Introduction

The history of a Cosmic ray from the production point and through the acceleration sites undergoes many changes in velocity and eventually in chemical structure. The nature of such a primary, either a heavy nucleus or proton or gamma-ray or whatever, influences strongly the byproduct of its interaction with the medium: interstellar matter, Cosmic Microwave Background photons (CMB) or local interstellar/intergalactic/galactic magnetic fields [1, 2, 3, 4, 5]. A great interest is therefore devoted to understanding the abundances of protons and relative chemical composition of the CR’s flux, in terms of other elements or ions.

Among the various kinds of projectiles hitting the Earth’s atmosphere, we will consider the fragments deriving from the photo disintegration of heavy nuclei (for example Fe) when interacting with the solar magnetic field [6]: the crucial aspect of this fragmentation relies in the possibility of detecting on Earth two (or eventually more) of them. In fact, the influence of the solar field permeates the space surrounding the Sun up to distances limited to 3 or 4 AU. This relatively small volume allows the fragments to arrive on Earth almost simultaneously and spaced ranging some up to few thousands Km. Thus, the Extensive Air Showers (EAS) generated by the two projectiles when hitting the atmosphere would be temporally as well spatially correlated and detectable when having many detectors placed at different distances, some closely and some widely spaced.

The arrival rate computed in the present paper heavily depends on the energy of the incoming particles and for this reason we include in our estimate small variations (some units) providing important differences in the expectation values.

What is strongly encouraging in the experimental search for this peculiar phenomena is the possibility of being detected by the new experiment “Extreme Energy Events” (EEE) which is starting in Italy [7]. In fact, the disposition of the particle detectors is planned inside numerous High Schools over all the Italian territory (about 300.000 Km²), more densely inside the cities, from south to north.

2. Heavy primaries and correlation

2.1 Spatial and temporal correlation

The study and the detection of (ultra-)high energy CRs in temporal coincidence is based on the energy of the primaries, the time difference between the two (or more) events, the reconstructed arrival directions, the possible source or set of sources. Each of these patterns is strongly related to the others, and the accuracy in reconstructing a specific air shower puts forward experimental results paired with theoretical shortcomings.

Gerasimova and Zatsepin [6], in the early Sixties, proposed a theoretical prediction on large scale correlations: the so-called GZ effect describes the disintegration of CR nuclei in the field of solar photons, leading to the formation of extended time-correlated EAS pairs with core distances (their estimate) ~ 1 Km.

Medina-Tanco and Watson [8] have re-evaluated the background of solar photons, in view of a simple model for the solar radiation field and of the existing/planned (at that time) experiments (like OWL, AGASA and AUGER). The estimates were limited by the blindness of the detectors during the Earth's day side exposition, which is the condition for higher flux (the former), the smallness of the array (the second) or the small acceptance for showers at large distances for the latter.

2.2 Heavy nuclei and origin of fragments

Basically, multiple correlated showers, temporally as well spatially, can arise either from local astrophysical events, on the distance scale of the solar system, or from exotic phenomena, $E > 10^{15}$ eV air showers, which may require anomalous processes high in the atmosphere.

The electromagnetic size N_e and the muon number N_μ of a shower, depend differently on the energy and mass of the primary: these allow an estimate of E and A for each shower. Qualitatively, since $N_\mu \sim K' A^{1-\beta/\alpha} N_e^{\beta/\alpha}$ with $\alpha > 1$, $\beta < 1$, heavy primaries can be selected choosing muon rich showers. Evaluating N_e , a proton shower can be associated to a small muon number, while the highest muon multiplicities are related to iron nuclei, therefore the measurement of A for the single EAS would be the definitive signature for the observation of a fragmentation process event. The photo disintegration [2] of heavy nuclei with a photon background are dominantly in the channels $A + \gamma \rightarrow (A - 1) + N$, or $\rightarrow (A - 2) + 2N$ being N a nucleon, and most of the absorption cross section results in the emission of only single nucleons, either protons or neutrons, while pair production processes will not give rise to multiple primaries. The fragmentation process goes through the photo nuclear interaction with an individual nucleon, and refers to measurements and values of the nuclear-collision cross sections at energies lower than CRs', so that could need corrections when applied to CRs photo disintegration.

The energy change is related to that of the atomic number as $\Delta E/E = \Delta A/A$ hence, for example, a Fe nucleus losing a proton diminishes its energy of less than 2%. The most evident effect for single or multiple disintegrations off photon backgrounds (of different kinds) is a wide richer variety in chemical composition of CRs flux, together with the protons' one.

2.3 Current searches and methods

The look for correlations between CRs aims to distinguish some common features, such as the sources or their number and distribution, and the characteristics of the propagation to the Earth. The first unusual simultaneous increase in the CRs shower rate has been reported in 1983 [9]; an experiment devoted to the search for correlations between primaries has been proposed by Carrel and Martin in 1994 [10] who wanted (with no success) to measure showers arising from multiple primaries originated by a hypothetical single (or multiple) event far from the Earth.

Many experiments are running looking for UHECRs, but to date there are no stringent data about spatial or temporal clustering, apart from few signals from AGASA [11] and low statistics for anisotropies [12]. A recent search for time correlated events is given by the CHICOS project [13], currently running in California High Schools, covering an area of about 400 Km², providing one observed candidate event, yet compatible with an accidental coincidence of independent showers. The Large Area Air Shower (LAAS) [14] in Japan has a shower array of about 130.000 Km² area; the group reported one pair of EAS with a very small time and angular difference. They found [15], four coincident event candidates, though with very low significance.

3. Gerasimova-Zatsepin effect

The photodisintegration process can happen at various distances from Earth, ranging about 0.04 AU up to 4 AU off the solar magnetic field [8]. Given a nucleus of mass M and mass number A , the Lorentz factor is $\gamma = E/(Am_p c^2)$. Then, an isotropic emission of nucleon(s) in the reference system of the parent nucleus would result in a cone with aperture of $\sim 1/\gamma$ around the original direction of propagation, when viewed in the reference system of the Earth. For high values of the Lorentz factor ($\gamma > 10^7$), both fragments have exactly the same direction as the incoming nucleus, after the interaction with the photon: the fragments will proceed on their way almost parallel and will be deflected under the action of the magnetic field, depending on their charge, producing a core separation expected at Earth that can be of the order of many kilometers. The further the disintegration takes place, the larger will be the distance between the fragments (and of the produced showers) when entering the atmosphere.

We re-evaluate the rate of secondary CRs, allowing a small energy variation of the parent primary and scanning all directions in the sky, night-side and day-side (much more favorable), in view of ongoing and new experiments, such as EEE [7], which, once in operation, can allow a consistent source of investigation for simultaneous showers over a wide range of distances, up to hundreds of kilometers away.

Given the mean free path of a nucleus against photo disintegration, the ratio $\eta_{GZ} = \Phi_{GZ}/\Phi_\infty$ between the flux Φ_{GZ} of the GZ fragment pairs and the unperturbed incoming one Φ_∞ is related to the parameter δ , the average separation between the showers' cores when arriving on the Earth, spanning from about 1 to 2000 Km. Small values of δ refer to events originating in the vicinity of the Earth, larger values refer to further distances. The EEE project [7] will cover a surface $A_{EEE} \cong 3 \cdot 10^5 \text{ Km}^2$. In principle, since the GZ effect is for well spaced showers (of the order of Km or tens of), the whole array does not need to be very dense.

Let us consider a primary Fe nucleus with energy varying between $E \sim 10^{17}$ and $E \sim 10^{19}$ eV. On the basis

δ (Km)	η_{GZ}	event rate
	$\times 10^{-5}$	
2 ÷ 5	0.08	66 - 112
5 ÷ 6	0.40	330 - 562
> 6	0.4	33 - 56
		$\times 10^3$
< 250	1.6	1.3 - 2.2
250 ÷ 400	2.5	2.1 - 3.5
400 ÷ 600	5.0	4.2 - 7.1
600 ÷ 1000	13	10.5 - 17.8
1000 ÷ 1500	32	26.2 - 44.6
> 1500	50	41.6 - 70.7

Table 1. GZ events rate for various δ , with primary's energy $3.2 \div 7.9 \cdot 10^{17}$ eV, integrated over A_{EEE} , in one year.

δ (Km)	η_{GZ}	event rate
	$\times 10^{-8}$	$\times 10^{-2}$
$\gg 50$	50.1	0.8 - 19.5
> 50	20.0	0.3 - 7.8
30 ÷ 50	7.9	0.1 - 3.1
20 ÷ 30	3.2	0.05 - 1.2
10 ÷ 20	5.0	0.08 - 1.9
5 ÷ 10	2.0	0.03 - 0.7
< 5	1.3	0.02 - 0.5

Table 2. GZ events rate for various δ , given a primary's energy ranging $1.0 \div 6.3 \cdot 10^{19}$ eV, integrated over A_{EEE} , in one year.

of the fraction η_{GZ} of the total CRs flux, we compute the integral flux, over A_{EEE} and for one year. One can look at different separations between the fragments at Earth, taking in mind that the spacing depends slightly also from the incoming direction in the sky. The range given for the event rate is due to allowing η_{GZ} being the same for slight variations of the primary's energy. For example, in Table 1 we consider the two values of E , 3.2 and $7.9 \cdot 10^{17}$ eV: correspondingly, we find the event rates for different ranges of δ . Similarly, for the interval of energy $1.0 - 6.3 \cdot 10^{19}$ eV, and $2.5 - 3.9 \cdot 10^{18}$ eV we have the rates reported in Table 2 and Table

3, respectively.

δ (Km)	η_{GZ}	event rate
	$\times 10^{-6}$	
20 ÷ 60	1.58	4 - 10
60 ÷ 80	2.51	6 - 17
60 ÷ 80	6.31	15 - 42
80 ÷ 100	15.8	38 - 104

Table 3. GZ events rate for various δ , with primary's energy $2.5 \div 3.9 \cdot 10^{18}$ eV, integrated over A_{EEE} , in one year. Note that the two rows with equal δ refer to different directions in the sky.

4. Discussion and conclusions

The event rates are strongly dependent on the primary energy, as can be seen in the case of a very energetic one, since the flux varies accordingly by orders of magnitude. The fragments can generate showers over a wide range distances between them, from few to thousands Km, thus not requiring a peculiarly spaced array of detectors, but moreover a large area. If we consider primaries with a given E and flux, our calculations split essentially in two classes: the first relies on the events characterized by a large separation of fragments on Earth $\delta > 200$ Km, i.e. events originated closer to the solar influence, at distances of order $> 2 AU$ from the Earth; the second is given by a smaller separation of the fragments $\delta < 15$ Km, corresponding to primaries photo disintegrated at distances $< 2 AU$.

Considering a relatively modest variation for the incoming particle energy (about few units) and for the values computed for η_{GZ} , we find that the rate of GZ events expected can be effectively high (see Tables), leaving very promising work for the observation of the GZ effect.

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