The last Gamma Ray Burst in our Galaxy? On the observed cosmic ray excess at 10^{18} eV

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Abstract

Here we propose that the excess flux of particle events of energy near 10^{18} eV from the direction of the Galactic center region is due to the production of cosmic rays by the last one or two Gamma Ray Bursts in our Galaxy. The basic idea is that protons get accelerated inside Gamma Ray Bursts, then get ejected as neutrons, decay and so turn back into protons. These meander around the inner Galaxy for some time, and then interact again, turning again to neutrons to be observed at our distance from the Galactic center region, where most star formation is happening in our Galaxy. We demonstrate that this suggestion leads to a successful interpretation of the data, within the uncertainties of cosmic ray transport time scales in the inner Galaxy, and in conjunction with many arguments in the literature.

1. Introduction

For some time now, the detection of an excess in 10^{18} eV cosmic rays from the general direction of the Galactic center by the air shower array AGASA [7] has been a special riddle in Galactic cosmic ray research. This excess has been supported at the time by the air fluorescence detector Fly's Eye [3], and is now roughly confirmed in a recent analysis of data from the air shower array SUGAR, [2]. Although the SUGAR results disagree with that of AGASA in details, they confirm the gross features of the excess.

Gamma Ray Bursts have long been argued to produce high energy cosmic rays. Here we will show what the observational signature should be and try to demonstrate that the AGASA excess can be attributed to the last one, or last few Gamma Ray Bursts in our inner Galaxy.

Already the AGASA team concluded, that the energy and the spatial correlation suggested that these particles are neutrons, implying an energy per nucleon of again 10^{18} eV. The flux of the observed excess particles can be turned

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into a luminosity of particles beyond 10^{18} eV of about 4×10^{30} erg/s. Since AGASA cannot observe the entire region, this inferred luminosity must be a lower limit, with the true luminosity possibly being a factor of 3 - 10 larger.

There are three main mechanisms and respective sites to accelerate particles in the Galaxy: supernova explosions either in the interstellar medium, in young and hot star bubbles, or in massive star winds. In any of the three cases such an energy per nucleon cannot be reached for any reasonable parameter of shock velocity and/or magnetic field. The only way to accelerate particles to such an energy per nucleon in a normal galaxy as ours is relativistic shocks. Such relativistic shocks are, for example, produced in Gamma Ray Bursts (GRBs) [10],[8].

As shown in Rachen & Mészáros, [9], because of adiabatic losses, the highest energy particles that emerge from a GRB are mostly neutrons; protons are captive in the magnetic field and so suffer extensive adiabatic losses on the way out. These neutrons will decay after they travel their corresponding decay distance, turning into protons, which are then caught by the magnetic field in the Galaxy, and rumble around with a rather short residence time scale. There is a small, but finite probability that they will produce a neutron again in interactions with the interstellar medium. These secondary neutrons then could travel undeflected to us to be observed. We will try to follow the neutrons originally ejected from a Gamma Ray Burst.

2. The last GRB event in our Galaxy

We estimate the remaining traces of any activity of cosmic rays ejected and/or produced by Gamma Ray Bursts.

The expected flux today, from the last GRB occurring 10^6 yrs ago is now given by 10^{51} ergs, per 10^6 yrs, down by 300 (from the proton diffusion out from the Galaxy), down by 20 (from the interaction probability to make neutrons again from protons), down by 3 (from the geometry), down by 100 (at 10^{18} eV, for an injection spectrum of $E^{-2.2}$, [1]), and down by 2 (from the direction of pointing), and so 10^{31} erg/s. This is just above what is observed, and so allowing for uncertainties mainly due to the limited sky coverage of AGASA, a very plausible estimate to explain the data.

The observed spectrum would be completely dominated by the two step propagation of the secondary neutrons in such a picture. Therefore the spectrum is the folding of the production spectrum, with the decay probability inside the available space, so a hump from the minimum distance to get any neutrons, to the maximum energy possible from GRB productions, usually estimated to be near to or above 10^{19} eV.

We conclude that the observed distribution is rather likely to be the result of one or two GRB events in the Galactic center region.

3. Predictions and tests

Large numbers of photons, electrons and neutrinos are produced the collisions that give rise to the second generation neutrons in such a picture. It is convenient to express the secondary particle spectra in terms of the primary proton spectrum by multiplying it with appropriate reduction factors. Simulations using the Monte Carlo event generator SIBYLL 2.1 [6],[5] predict the following reduction factors: for secondary protons and antiprotons 0.27, for neutrons and antineutrons 0.09, for photons 0.11, for electron-positron pairs 0.05, and for neutrinos (all flavours) 0.13. All these numbers are normalized to a primary proton spectrum, using a powerlaw of $E^{-2.2}$, and the energy range 10^{17} - 10^{18} eV. These numbers are the ratio of the fluxes far below the upper energy cutoff. Observable is the ratio of the uncharged components, e.g., the ratio of neutrons to gamma-rays, which is here close to 1; however, near to the upper cutoff the photons drop off earlier than the neutrons. Given a reliable spectrum, we could infer the upper energy cutoff from an observed ratio of neutron flux to photon flux. The curves will look the same relative to maximum energy (here 10^{18} eV with a following exponential cutoff).

To see an appreciable flux of neutrons peaking near 10^{18} eV with a visible extension to 2×10^{18} eV requires that the primary proton/neutron flux extends to at least about 6×10^{18} eV. A measurement of the ratio of neutrons to photons, with a simultaneous determination of the injected powerlaw slope, would then allow to estimate the real cutoff energy of the injected proton/neutrons.

It is interesting to consider the time evolution of such a neutron flux: There is a last phase, when we pass the diffusive reservoir time of about 10^5 years, the flux begins to decay with $t^{-5/2}$, as protons leak out from the probable interaction volume.

4. Conclusions

We have shown that it is rather plausible that the observed AGASA excess of events near 10^{18} eV energies coming to us from the Galactic center region is due to the last one or two Gamma Ray Burst events in the Galaxy. We predict a corresponding flux in photons and neutrinos.

In fact, if the predicted details can be confirmed, we will have established i) that GRB cosmic ray signature can be detected, ii) the cosmic ray production of Gamma Ray Bursts to be of order 10^{51} erg, iii) that their particle energy extends to at least 6×10^{18} eV, iv) that the maximum particle energy can be estimated with a measurement of both neutrons and photons, as well as the slope of the injection spectrum, and v) that their contribution to the overall energetics of Galactic cosmic rays is minor. To check this will be a major contribution of the Pierre Auger Observatory whose southern part is ideally located to observe the

Galactic center region and is currently under construction [4]. The combination of fluorescence and surface detectors of this experiment allow measurements in the energy region from several 10^{17} eV to the highest energies.

5. Acknowledgements

Work with PLB is mainly being supported through the AUGER theory and membership grant 05 CU1ERA/3 through DESY/BMBF (Germany); further support for the work with PLB comes from the DFG, the DAAD, the Naumann-Foundation, and the Humboldt Foundation (all Germany), grant 2000/06695-0 from FAPESP (Brasil) through G. Medina-Tanco, KOSEF (Korea) through H. Kang and D. Ryu, ARC (Australia) through R.J. Protheroe, a NATO-grant (with S. Moiseenko, Russia) and European INTAS/ Erasmus/ Sokrates/ Phare grants. GMT is also supported through grants from FAPESP and CNPq (Brasil). GP wishes to thank ESO for the kind hospitality. The authors appreciate comments from Alan Watson. PLB also wishes to acknowledge comments from T. Kellmann.

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