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On the origin of gamma-ray bursts

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Abstract

The conjecture is examined that the predominant source of "gamma ray" bursts are not, in fact, gamma rays. An alternate possibility is that these signals are caused by the most abundant neutral objects in the universe, composite objects: neutral hydrogen atoms. This conjecture satisfies many of the constraints of the observations of these signals. Some models of achieving energetic neutral hydrogen atoms favor compact stellar objects with high magnetic fields like neutron stars or black holes. The problem of their transmission through the interstellar medium is discussed. A short mean free path for transmission could produce an isotropic angular distribution corresponding to experimental observations. The detector sensitivity to neutral atoms and the extent to which they could be mistaken for gamma rays is examined.

1 Introduction

The nature of the sources of gamma-ray bursts has been a problem for > 20 years since their discovery after declassification [K73]. After the initial discovery, much additional data have been gathered by experiments such as BATSE [F93, F94]. Briefly stated, the mysteries are: There are no known sources of this radiation; they do not tend to repeat; the bursts do not look alike in structure; and there do not seem to be corresponding bursts at other energy regions of the electromagnetic spectrum. What are these bursts? Where do they originate?

The most recent data have deepened the mystery by showing almost perfect isotropy of angle and hence no correlation with the galactic plane [M92, A94]. This experimental data seem to point to divergent possibilities which could provide the isotropy: The sources are extragalactic, they are from the halo of our galaxy, or they are from the local vicinity of the solar system. The isotropy which each of these hypotheses could provide: The rest of the universe is, relative to us, quite isotropic; the halo of our galaxy is relatively isotropic to us because its extent from the center of our galaxy, ~35 kpc, is modestly larger than our ~ 10 kpc distance from the center of the galaxy [F91]. The last hypothesis is disfavored because our solar system is not believed to be the "center" of anything in regard to dimensions larger than a few light hours and directions toward the center of our galaxy are expected to be decidedly different from other directions for distance scales of order galactic size.

Since the data give no clue as to absolute distances, none of the hypotheses are eliminated from consideration on the basis of distance. On energy considerations, the necessary power which generates the observed signals from these sources must increase as the square of the distance to the sources. Thus the most isotropic hypothesis (extragalactic) requires enormous power in the sources due to the large distances involved. The hypothesis which would require the least source power apparently provides the least isotropy; namely, for sources relatively close to us. Although the data give no clue as to absolute distances or source power, they do have a limited dynamic range; that is, there is a deficiency of faint bursts from that expected assuming a uniform distribution whose number grows as distance cubed whereas the detected intensity falls off as the inverse of the distance squared. This

increase in the number of low intensity detections to the -1.5 power of the intensity is found in other astrophysical phenomena. The additional fall off of the burst data at low intensities imply that the earth lies at the center of a spherical grouping of burst sources that extend only to a finite distance; the distance scale itself is not solvable from this data.

2 Discussion

Let us examine the conclusion that the number of bursts falls abruptly at low intensity. This conclusion rests on the question of the dynamic range of the detectors and their possible bias against low intensity bursts [R93] (BATSE was designed to detect low intensity bursts with a threshold of ~1E-7 erg/sq-cm). There is a natural bias in intensity; as the signal gets weaker it is more difficult to detect since the low counting rate of the weak sources gives them less statistical significance above background compared to stronger sources. Although the bias is an inherent one, the effects of this bias can be and are corrected; it is assumed that the correction has been performed properly and that the conclusion of a fall-off is a real effect and not just an uncorrected bias.

What about the power requirements of the sources? If they are from the universe, then distance scales of a ~Gpc would imply a typical burst energy of ~1E52 ergs in the source. The associated power level is more than that of the visible, radio, uv, and ir radiation added together. In the absence of any theory of what the sources are, this is of course possible but it puts severe constraints on the theories of sources which are extragalactic. Our halo is expected to have a radius of 35 kpc; since we are some 10 kpc from the center of the galaxy [F91], if the sources had a uniform distribution in the halo we would observe a non-uniformity in angle which exceeds any possible non-uniformity of the data. This discrepancy could be compensated by selective absorption of the signal while looking in directions toward the center of our galaxy. If there is sufficient matching of absorption with increased potential source lengths, then the discrepancy could be eliminated, albeit with difficulty. Energy considerations would yield source energies of ~1E43 ergs for distances ~50 kpc; and a modest ~1E28 ergs for sources as close as ~0.001 pc (for example colliding comets) [F93]. The hypothesis that the sources of the gamma-ray bursts are local demands the least power to generate the signals.

3 A non-gamma carrier of the burst signal

There have been many progenetor models which address the question of these bursts (there is a comprehensive list in Ref. [N94]); this paper is an attempt to add another entry to the list of more than 100 such models. Perhaps the solution to the riddle lies in the idea that the sources of the burst signals are not, in fact, gamma rays at all. Let us consider alternate explanations as to the carrier of these signals; the one we consider here, for an example, is neutral hydrogen atoms. They are certainly familiar objects--there is more hydrogen in the universe than any other particle or composite. This neutral object would be undeflected by the interstellar, solar, and terrestial magnetic fields. The composite would have a natural cutoff in distance-to-source provided by mechanisms which destroy (ionize) the atoms; for example, interactions with interstellar material and electromagnetic radiation. If this ionizing medium were homogenous, then this provides a possible easy answer to two parts of the puzzle at once: It provides isotropy of signal assuming only that the source *density* is radial symmetric about the solar system within a distance of a few mean free paths, and the cutoff in intensity is naturally provided by the fact that sources farther away would be ionized and rapidly lose the coherent character of a "burst." Once ionized, the protons are bent in the interstellar magnetic fields so as to destroy their coherence of direction and they

rapidly become a part of the background radiation; this mechanism thus provides a natural and uniform cutoff in distance away from the detector. The hypothesis thus explains two mysteries: isotropy and intensity distribution.

4 Burst detector sensitivity to hydrogen atoms

Let us examine the BATSE experiment [F93] as an example of an instrument built to detect bursts. There are eight detectors of identical design deployed on the corners of the CGRO spacecraft. Each is composed of an active scintillation veto counter over the front of a NaI counter which is used to absorb the photons which come through the active veto on the front side. On the rear is a passive shield designed to absorb photons of moderate energies. According to the ionization cross section, hydrogen atoms incident on the front of the veto counter would be ionized near its front and hence would veto with almost full efficiency. Thus for the atoms to make it through from the front would require some malfunction of the anti-electronics, e.g. pileup or jamming at high rate; alternatively, Bethe has neglected radiative corrections to his ionization cross section formula, so it is also possible the present formula overestimates the real ionization cross section by some factor which would allow them to get through the scintillator without ionizing. Another possibility, however, is that the atoms register in the NaI by penetrating the passive shield from the rear direction. Here, even if the atom is immediately ionized, with sufficient energy the proton and/or electron could punch through the remaining material and make it to the NaI with some residual energy; these charges would then register in the NaI and be considered gamma rays. Additional isotropy would be generated by the fact that the direction from which the signal is coming is incorrectly calculated thus generating a more uniform distribution of angles from the randomness of the mistakes.

5 Acceleration mechanisms for neutral composites

If neutral atoms are the source of the signal, then they must be accelerated to the typical energies observed by BATSE and other detectors of these bursts, say ~1 MeV.

5.1 Van Allen radiation belt mechanism Possible models for the acceleration of the atom could include a two-step process by which first, the proton nucleus is accelerated and then, after its acceleration, it acquires the electron while still in the vicinity of the neutron star. One such model would be to consider the neutron star to have a dipole magnetic field and to have, about it, a Van Allen Radiation Belt of protons which are stored in the magnetic bottle of the non-uniform dipole magnetic field. Electrons might be stored in a neighboring region of space outside the protons where the magnetic field is weaker and the bremsstrahlung energy loss of the electrons does not prevent them from having a reasonable storage lifetime. Perhaps a magnetic storm would bring the two regions into overlap for a short time. A large electron capture cross section provides a mechanism for these protons to become neutral atoms. The capture would normally be to a high Rydberg state which would then rapidly decay to the ground state by emitting photon(s). In the ground state the hydrogen's binding energy is enhanced by the presence of the magnetic field thus providing added force to hold the atom together while it exits from the magnetic field.

5.2 Acceleration of hydrogen in a non-uniform magnetic field Another possible mechanism is the acceleration of the neutral hydrogen atom by the force present between the non-uniform magnetic field and the magnetic moment of the neutral hydrogen atom, (mu times grad B) where mu is the magnetic moment of the atom in its ground state and B is the magnetic field [1]. If one integrates this force through the total field, one

obtains an energy of (mu times B) where B is the net change of the field during the acceleration. Perhaps a different mechanism for providing energetic neutral hydrogen atoms is the operative one and the above ideas only interesting possibilities. The precise mechanism is not important for the sake of the arguments in this paper; merely that there are reasonable possibilites for this acceleration. Once the postulate that neutral composite objects can acquire energies and be a significant fraction of the detected burst signals, then the postulate can be examined and tested.

6 Mean free path for interstellar transmission

The next consideration would then be the mean free path for their survival in the interstellar space of our galaxy. One mechanism for the ionizing the atoms is ionization by interstellar material If one assumes a material density of the interstellar medium in the vicinity of the solar system to be 1 atom/cubic-cm and the ionization cross section to be 5E6 barns for a 1 MeV hydrogen atom [A89], then the mean free path from ionization due to interstellar material is 0.2 pc. Possible deviations of the cross section for process (1) could be in the direction so as to increase the mean free path for ionization by this process [P93].

Ionization by interstellar material would provide a mean free path rather isotropic in angle assuming that: the material is isotropic, the density of sources is large enough and isotropic within a few mean free paths; added isotropy would be provided by the randomness of incorrectly calculated angles if the signals were incident from the rear of the detectors. Under scenario (5.1) for energy production, a binary star system would prevent radiation belts to be maintained about the neutron star. If this is the predominant accelerating mechanism, then binary stars systems are ruled out as possible sources. Since there are no data on the density of non-binary neutron stars near the solar system, the simplest conjecture is assumed: There is no preferred direction for their distribution about the solar system and there are a sufficient number of them close enough to provide the number of bursts which are seen. Since it is suspected that the relevant neutron star systems are not binary systems, a lone neutron star would not produce much electromagnetic radiation in the visible part of the spectrum and could, then, escape detection.

7 Conclusion

The ideas presented here are intended to add to the scope of the search for the solution to the puzzles of the bursts which have been under attack for some 25 years. Although only an idea or two presented here may prove correct, perhaps even one could aid in the quest for a solution. This research is supported in part by grants from the Univ. of Notre Dame.

Footnotes and references

[1] Although a static magnetic field cannot accelerate a single elementary particle, this statement does not necessarily hold for a composite object.

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