COSMIC GAMMA RAYS — EXPERIMENTAL (*)

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RÉSUMÉ. — *Aucune expérience faite jusqu'à présent sur la Terre ou dans l'espace n'a apporté mieux que des limites supérieures du flux de rayons cosmiques d'énergie supérieure à quelques MeV. Mais ces résultats ont permis d'apporter des limites à certaines caractéristiques des particules énergétiques dans l'espace interstellaire ou intergalactique. La plus faible des limites supérieures trouvées soit* $3\ 10^{-4}$ *cm*$^{-2}$ *s*$^{-1}$ *sterad*$^{-1}$ *(Explorer XI) est environ 20 fois supérieure aux prévisions basées sur la création de rayons par collisions rayons cosmiques-hydrogène interstellaire. Les prévisions pour les sources radio discrètes émettant du rayonnement synchrotron dépendent beaucoup du modèle fournissant des chiffres nettement plus faibles que les limites supérieures existantes qui sont de* 3.10^{-4} *cm*$^{-2}$ *s*$^{-1}$ *pour* $E > 5.10^{7}$ *ev et de* 5.10^{-11} *cm*$^{-2}$ *s*$^{-1}$ *pour* $E > 5\ 10^{12}$ *eV.*

ABSTRACT. — *As yet no experiment, satellite-borne, balloon-borne or earth-based has provided compelling evidence for more than upper limits to the intensity of cosmic gamma rays of more than a few MeV energy. Even these upper limits have been useful in blocking in some of the large scale properties of energetic particles in interstellar and intergalactic space. Nevertheless, the smallest upper limit set on the intensity of diffuse gamma rays* 3.10^{-4} *cm*$^{-2}$ *s*$^{-1}$ *sterad*$^{-1}$ *(from the satellite experiment in Explorer XI) is a factor of about 20 above the intensity prediction which can be made with rather good confidence for gamma rays made in cosmic ray collisions with interstellar atomic hydrogen.*

Predictions of the gamma ray flux from the various discrete-source emitters of synchrotron radio noise are model-sensitive and in general appreciably smaller than existing upper limits. These upper limits are in the 3.10^{-4} *cm*$^{-2}$ *s*$^{-1}$ *region for gamma rays of* $E > 5.10^{7}$ *eV and in the* 5.10^{-11} *cm*$^{-2}$ *s*$^{-1}$ *region for gamma rays of* $E > 5.10^{12}$ *eV.*

Резюме. — Никакой опыт проведенный до сих пор на земле или в пространстве не принес более чем верхние пределы потока космических лучей с энергией превышающей несколько МэВ. Но эти результаты позволили внести ограничения некоторым характеристикам энергетических частиц в пространстве межзвездном или межгалактическом. Самый слабый из найденных верних пределов, т.е. 3.10^{-4} см$^{-2}$ сек$^{-1}$ смер$^{-1}$ (Эксплорер XI) превышает приблизительно в 20/раз предвидения основанные на создании лучей путем соударений космических лучей — межзвездного водорода.

Превидения для дискретных радиоисточников с сихротронным излучением намного зависят от модели, доставляя числа явно более низкие чем существующие верхние пределы, которые равны 3.10^{-4} см$^{-2}$ сек$^{-1}$ для $E > 5.10^{7}$ эВ и 5.10^{-11} см$^{-2}$ сек$^{-1}$ для $E > 5.10^{12}$ эВ.

While it is the purpose of this contribution to summarize the available experimental data on cosmic gamma rays, the summary is necessarily a peculiar one. Cosmic gamma rays must certainly exist at some intensity level [1-5] yet no experiment, in the author's opinion, has supplied data from which can reasonably be inferred more than upper limits to the cosmic gamma ray intensity (for $E \geqslant 1$ MeV) from any region of thesky outside the solar system. Possible sources fall into two classes, diffuse and discrete. By diffuse we mean those processes which occur in interstellar space, the galactic halo or possibly inter galactic space. Gamma rays from these regions should arrive more or less isotropically. By discrete we mean possible unresolved sources of which the strong radio sources are likely candidates.

While the predicted gamma ray flux from the strong radio sources is in general small and model-dependent, the *minimum* intensity from interstellar space, although by no means large, can be estimated with fair confidence. That is, given the measured interstellar atomic hydrogen distribution, one needs only assume the cosmic ray intensity to predict the gamma ray intensity to be expected from π^0-decay processes. (Meson production cross-sections by particles of cosmic

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ray energies are now rather well known.) It is very difficult to see how the cosmic ray intensity in the galactic disc can be appreciably *less* than the intensity near the solar system. If one assumes, then, that the atomic hydrogen as measured by the radio astronomical 21 cm measurements is bombarded by cosmic rays of intensity equal to that found locally, the predicted gamma ray energy spectrum from this source alone, averaged over all directions, is as shown by the broken line of Fig. 1. It must be emphasized that this is a minimum estimate and many possible but unproven circumstances can lead to higher estimated intensities. There may be appreciable amounts of molecular hydrogen in association with the observed atomic hydrogen [6] ; the average cosmic ray intensity may be larger in the Galaxy in general than it is near the solar system ; cosmic rays and energetic electrons may exist in intergalactic space and produce gamma rays by collision processes and by inverse Compton collisions with optical photons [7]; there may be many discrete sources that combine to make a large unresolved and apparently diffuse intensity. In short, should the actual gamma ray intensity prove eventually to have a level near that of the existing upper limits, many possible explanations can be put forward. Fortunately, further experimentation could, at least in principle, distinguish between most hypotheses.

The more recent measured upper limits are shown in Fig. 1. The measurement of ARNOLD *et al* [8] was really a differential (energy) measurement and in order to show the measurement on this integral energy plot, we have assumed an energy spectrum of the form $E^{-\gamma}$ with $\gamma = 2$. This experiment was aboard a Ranger moon probe and was a scintillation spectrometer. The points labelled Rochester [9] and CLINE [10] are from balloon-borne counter experiments and the intensity was obtained from extrapolation to zero atmospheric depth. The Explorer XI point refers to the satellite counter experiment of the M. I. T. group. The KIDD [11] and Bristol [12] points are from balloon-borne emulsion experiments and BASJE [13] refers to the mountain-based, Bolivian Air Shower Joint Experiment in which a search was made for cosmic ray air showers " poor " in μ mesons.

These gamma ray measurements are difficult because the intensity is small in both an absolute sense (the Explorer XI instrument recorded only one quanta every several hours), and compared to the charged cosmic ray intensity which of

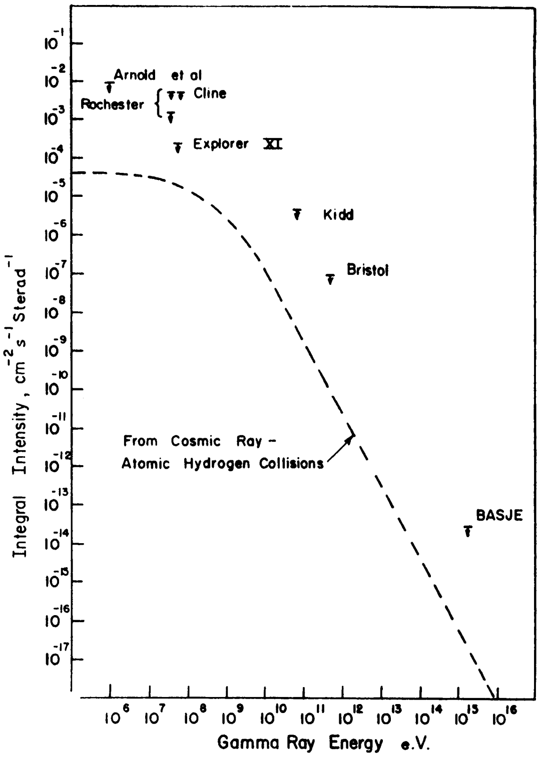

FIG. 1. — Recent experimental values of upper limits to the diffuse gamma ray intensity. The broken line represents the contribution from cosmic ray collisions with galactic atomic hydrogen.

course is continuously incident upon the apparatus and which is a serious potential source of background. We have examined many features of our Explorer XI data in attempts to settle the question as to whether our measured apparent intensity was real or background. Two of the most crucial tests are discussed below. These Explorer XI results are in part from our already published reports [4, 14] and in part from a forthcoming paper which covers the completed data analysis.

Interstellar atomic hydrogen is of course concentrated near small galactic latitudes, and so the collision π^0-decay gamma rays should be similarly concentrated. The dependence of our measured intensity upon galactic latitude is shown in Fig. 2. Also shown is the predicted dependence account having been taken of the broad angular response of the detector. The ratio of the intensity for $l > 20^o$ to that for $l < 20^o$ is 1.6 ± 0.6, whereas the predicted ratio is 4. This test alone, then, can by no means eliminate the possibility that our entire measured intensity is background. It is possible of course, that the galactic latitude dependence is present but masked by gamma rays

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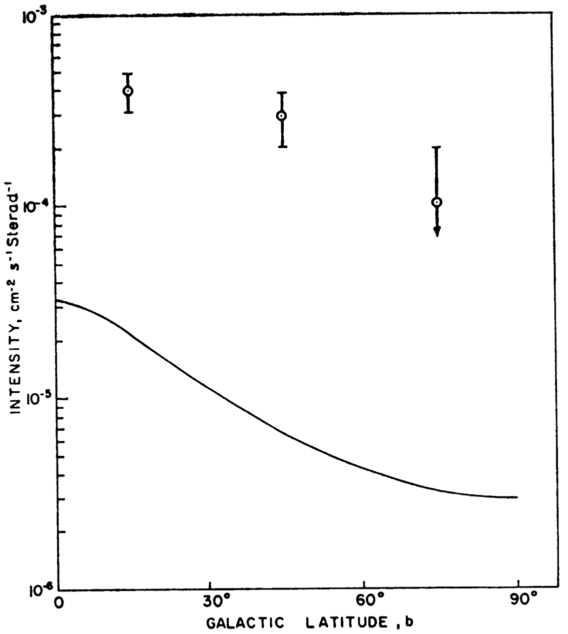

FIG. 2. — Intensity as measured by Explorer XI as a function of galactic latitude. The solid curve represents the calculated distribution from cosmic ray — atomic hydrogen collisions.

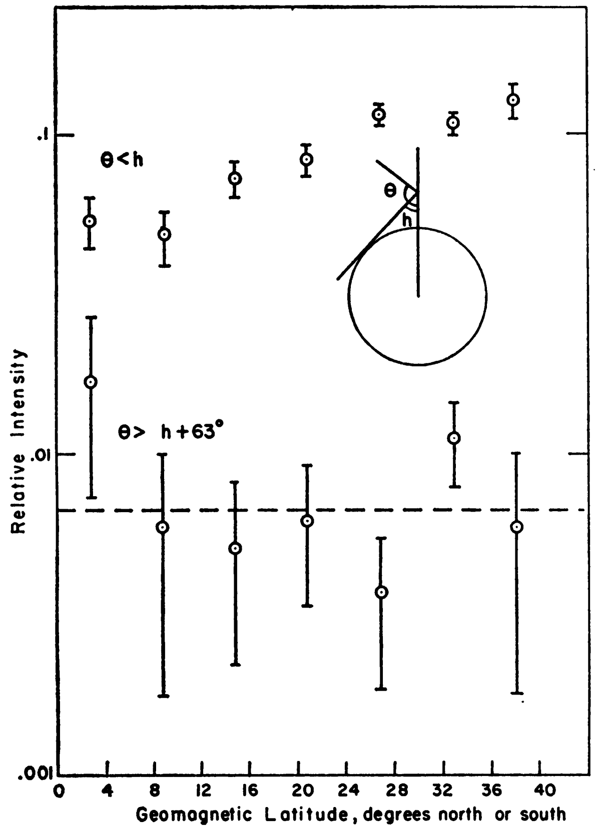

FIG. 3. — Relative intensity of gamma rays from the earth (upper set of data points) and from the sky (lower set of data points) as measured by Explorer XI as functions of the geomagnetic latitude of the satellite at the time of observation.

from another source that is essentially isotropic.

Background, if it exists in our measurement, almost certainly arises in some fashion from the laıge incident cosmic ray flux. Cosmic rays, being charged, are partially excluded by the earth's magnetic field and so the cosmic ray intensity has a minimum at small geomagnetic latitudes. Gamma rays produced in the earth's atmosphere by cosmic rays should and do exhibit a pronounced dependence upon geomagnetic latitude as shown by the upper set of data points of Fig. 3. True cosmic gamma rays should show no geomagnetic latitude dependence. Our data, the lower set of points of Fig. 3, indeed shows no such dependence. But the argument is unfortunately not statistically convincing. We have separated the data into two parts, one for geomagnetic latitudes more than 20° from the geomagnetic equator and one for geomagnetic latitudes within 20° of the geomagnetic equator. For those gamma rays from the earth

$$\frac{R\,|\lambda| > 20}{R\,|\lambda| < 20} \doteq 1.65,$$

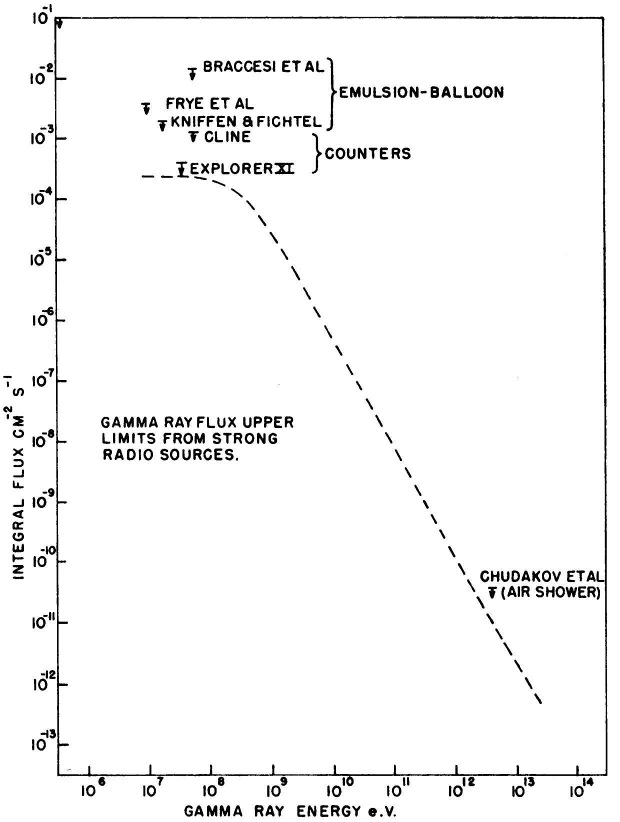

FIG. 4. — Recent experimental values of upper limits to the gamma ray flux from strong radio sources. The broken line is a typical π^0-decay spectrum and has arbitrary normalization.

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while for those apparently from the sky.

$$\frac{R\,|\lambda| > 20}{R\,|\lambda| < 20} = 1.16 \pm 0.44.$$

In Fig. 4 is shown a number of the more recent upper limit measurements of the gamma ray flux from possible discrete sources. One source has not been distinguished from another in this figure as the intent was to indicate the state of the art. The points labelled Braccesi *et al*., [15] Frye *et al*, [16] and Kniffen and Fichtel [17] are all from balloon-borne emulsion experiments, and the point labelled Chudakov *et al*. [18] is from a ground-based shower experiment in which the Čerenkov light from the shower electrons was detected against the background light of the night sky. The broken curve is a typical π^0-decay gamma ray spectrum with arbitrary normalization.

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