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MASTER

TITLE ION CHAMBER GAMMA BURST DETECTOR

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ION CHAMBER GAMMA BURST DETECTOR

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ABSTRACT

A gamma ray burst detector of x-ray photons 2 to 10 keV is designed to maximize area, 100 m^2, and sensitivity, 10^{-10} ergs cm^{-2} s^{-1}, modest directionality, 2×10^{-4} sr, and minimize thickness, 3 mg cm^{-2}, as a plastic space balloon ion chamber. If the log N - log S curve for gamma bursts extends as the -3/2 power, the sensitivity is limited by gamma-burst peak overlap in time so that the question of the size spectrum and isotropy is maximally tested. Supernova type I prompt x-ray bursts of ≅ 3-ms duration should be detected at a rate of several per day from supernova at a distance greater than 100 Mpc.

INTRODUCTION
ASTROPHYSICS

There are several reasons to attempt to extend the sensitivity of detection of gamma bursts to lower levels. The first is the tantalizing question of the origin of gamma bursts. The astrophysical circumstance is reflected in the log N - log S curve (N observed number, S observed burst size) coupled with the angular distribution function. A galactic distribution should show a galactic structure anisotropy at a burst level corresponding to a departure from a linear 3/2 power of the log N, log S curve. There is almost universal expectation that gamma bursts originate from neutron stars; in which case we expect a galactic distribution which reflects the higher velocity and hence higher galactic latitude associated with neutron stars. On the other hand, most likely, only neutron stars of low velocity such as those that would retain either a companion star for mass accretion or planets for comet or asteroid accretion are responsible. It is a tantalizing question of astrophysics to resolve these questions.

Precise locations of the site of the largest gamma bursts give the maximum probability of "seeing" an associated object because regardless of the distribution function at the origin, the largest bursts will be most likely the closest; this despite the controversy of the location of the so-far singular event (March 5) in the Magellanic Cloud. Furthermore, the obtaining of detailed spectra is biased towards large and presumably close events. It is an unsafe but a practical hypothesis to assume that the spectral properties are only weakly dependent on burst size. This assumes that the distribution n of an event source size, SS, at the origin is more abruptly limited, $P(n) < (SS)^{-3/2}$, than the spatial distribution for the isotropic part of the angular distribution. On the other hand, if the number of events at a given source increases rapidly for decreasing event size as for instance asteroid or comet collisions where $P(n) \propto (SS)^{-2}$ to $^{-3}$, then we would expect to see, at very low flux level, primarily a subset of nearby isotropic sources. If the temporal and spectroscopic characteristics vary as a function of source size, as would be expected, then detectability may also be affected, changing the log N - log S curve. In general, a smaller event at the source is likely to be softer in spectra and shorter in time. Hence, a burst detector that has the maximum sensitivity for soft photons and short time has the highest probability of seeing events that depart from the log N versus log S curve because of source characteristics. In addition, the maximum sensitivity detector regardless of spectral or temporal bias has the maximum probability of detecting departures from log N - log S and isotropy.

SUPERNOVA

There are numerous predictions of x-ray bursts from supernova that depend upon the then favored mode of supernova origin as well as presupernova structure. The early detection of SN by any means would greatly increase the probability of understanding SN and being able to use SN as a standard candle to measure the size scale of the universe (Colgate 1979).

The size of the expected x-ray burst depends upon the heat radiated from the outer layers of the SN just after the explosion shock reaches the surface. The competition between expansion cooling and radiation diffusion determines the x-ray pulse. The extended envelope models of type II SN by Falk and Arnette (1977) give a long time, (radius/velocity ≅ several hours) very soft ($\langle h\nu \rangle \cong 100$ eV) x-ray burst with significant total energy, approximately 10^{48} ergs, or a flux of 10^{44} ergs sec^{-1}. Because of the softness, the fraction of photons above typical x-ray detection threshold (1 to 2 keV) is greatly reduced leading to a low probability of detection. Recently two SN type II's have been observed in ultraviolet spectra (Benvenute 1981) and confirming the very extended envelope model, i.e , a pre-SN stellar wind (larger in one case than in the other) as well as a late time (several weeks to a month) x-ray emission in the second case. The early x-ray pulse for these models is expected to be small because of x-ray absorption blanketing by the tenuous external stellar wind.

Supernova type II on the other hand are now known not to have the very extended envelope, $R \cong 10^{14}$ cm, because the recent early (near maximum light) ultraviolet measurements on SN (Benvenute 1981) show an ultraviolet flux that is $\lesssim 1\%$ of the expected Planck spectrum extrapolated from the visible spectrum at the derived temperature of 15,000° K. Since the lack of hydrogen in the spectra is so well confirmed, it is reasonable to expect an initial compact structure typical of a white dwarf. In this case, the surface layer will be shocked to a relativistic energy and the radiation pulse will be short because of size and velocity. This pulse was calculated in the extreme limit of a small size presupernova, radius = 2×10^{8} cm and large ejected relativistic mass giving a kinetic energy of 10^{49} ergs (Colgate and Petschek 1978). The radiated energy is then a very small fraction of the kinetic energy, 10^{-6} or 10^{43} ergs per logarithmic decade of photon energy. This very small fraction of radiation energy is caused by the same phenomena that restricts gamma bursts to circumstances requiring a strong magnetic field, i.e., the rapid surface blowoff, expansion, and cooling before radiation can diffuse out of the previously shocked hot surface layers. This radiation pulse extends from the highest gamma energies of 10^{12} eV down to the visible and contains roughly 10^{43} ergs per logarithmic decade. The characteristic time of each energy interval is inversely proportional to the energy such that the 3 keV photon band is emitted in ≅ 3 ms. If the presupernova star has a larger envelope, the prompt radiation pulse will be more energetic, $\propto R^2$, and last longer, $\propto R$, and so increases detectability.

The detection of the radiation pulse would serve two important astrophysical objectives: it would be the strongest confirmation of the so-far theoretical estimate of the relativistic ejecta and hence possible origin of cosmic rays and, secondly, it would allow the early localization of an expected optical SN type I. A localized optical search should then find an SN type I and the observation of the early SN light curve becomes a distinct possibility. The early light curve becomes critical in understanding the SN phenomenon itself as well as using SN type I as a standard candle for measuring the scale of the universe (Colgate 1979).

Weak gamma bursts as well as SN bursts lead to very small radiation pulses; current detectors see down to several × 10^{-7} ergs cm^{-2} per pulse, or one 100 keV photon cm^{-2} per pulse. Hence to gain adequate statistics one needs a large area and a sensitivity to a low photon energy. (Present spectra would indicate comparable total energy per logarithmic photon energy internal for both gamma bursts as well as for theoretical SN early bursts.)

DETECTOR CONSIDERATIONS

One then asks what would a detector look like that is optimized for both these qualities. For maximum area and low photon energy one wants the thinnest window material and lowest weight per unit area. The thinnest detector window material that is easily manageable and available in large quantities is Mylar in a thickness range of ¼ mil, i.e., 2.5 × 10^{-4} in. thick. Only a gas ionization detector can be made as thin as the window. A gas detector also requires high strength in the window material which is satisfied by Mylar. Mylar has an x-ray photon absorption coefficient such that ¼ mil (10^{-3} g cm^{-2}) corresponds to an energy threshold (e-fold attenuation) of 2 keV. At 3 keV the transmission is roughly 75%. In turn a gas filling of A, Ne, K, and Xe, and thickness of 10^{-3} g cm^{-2} will result in 75% absorption for photons of 3 to 6 keV. We, therefore, expect 50% photon absorption in the gas of the thinnest detector made of standard ¼-mil Mylar and an equal mass (one Mylar layer) of noble gas filling. The critical question is whether the Mylar strength is adequate to contain this gas pressure. Novick (1981) successfully built Mylar-scrim inflatable as long ago as 1965.

We assume that the thermal environment cannot be significantly altered from earth-solar equilibrium or 300° K. Hence, the gas pressure for a thickness $\Delta = 10^{-3}$ g cm^{-2} and a spacing d will be

$$P_{gas} = \frac{\Delta}{d\rho_{air}} \frac{A_{air}}{A_{gas}} \text{ atmospheres} \quad .$$

The stress τ in stringers of thickness w = Mylar thickness = 6.2×10^{-4} cm spaced periodically equal to the spacing between window layers, d, becomes

$$\tau = \frac{P_{gas}\, d}{w} = \frac{\Delta}{w\, \rho_{air}} \frac{A_{air}}{A_{gas}} \text{ atmospheres} \quad .$$

If we use a heavy gas mixture such that $A_{gas}/A_{air} = 3$, then

$$\tau = 1/3/(w\, \rho_{air}) = 1.3 \times 10^{3} \text{ atmospheres}$$

$$= 20{,}000 \text{ psi} \quad .$$

This is a near maximum working stress for Mylar whose yield stress is 60 to 100×10^{3} psi and so some compromise in gas filling may be necessary. However, scrim threads can greatly increase the strength.

One notes that the stress limitation is independent of the spacing between layers d because we have assumed a spacing d of the stringers equal to that of the spacing between window layers, figure 1. We can, therefore, make our detector with an arbitrary aspect ratio of L/d, i.e., a thin plane of large area L^2.

GEOMETRY

We therefore envision three mutually orthogonal large planar detectors, gas-filled balloons, similar to air mattress construction made of aluminized Mylar. The three planes will have different projected areas (as well as detectability) as a function of viewing angle of an incoming radiation pulse and so give direction, limited by the aspect ratio, d/L, and statistical variation within the signal on each plane.

A very large area would be $L^2 = 100$ m^2 or 10^6 cm^2 and L = 10 meters. Then statistical variations will limit the useful directionality of $L/d < 100$ or $d \lesssim 10$ cm. On the other hand, the spacing d should be as large as possible to ease construction complexity.

We then obtain a balloon-like air mattress 10-cm thick, 10 × 10 meters in dimension and filled with 1/30 atmosphere of a noble gas mixture.

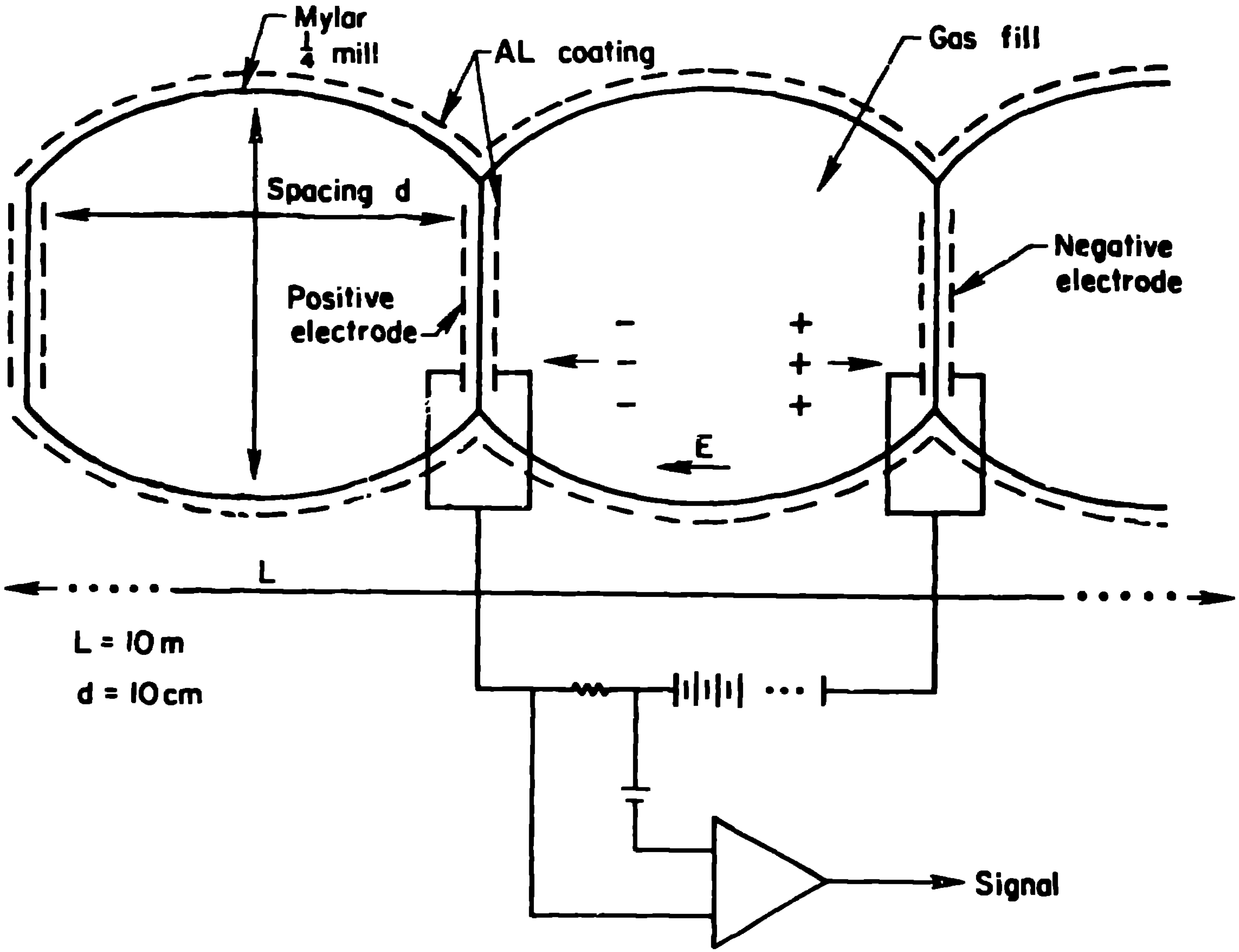

Fig. 1. Schematic design of ion chamber gamma burst detector.

COLLECTION MODE, ION CHAMBER, OR PROPORTIONAL COUNTER

The large area implies a large background counting rate because of cosmic rays and x-ray background. We assume an orbit that avoids the radiation belts and we also assume that the detector is most useful when the earth shields the solar x-fay flux, i.e., ½ the observing time. This strategy has the serendipitous advantage of maximizing the gas filling because of reduced temperature on the night side and also offers the possibility of optical identification of SN, if detected. At 2 keV the isotropic x-ray flux is just the cosmic ray flux of 1 sr cm^{-2} s^{-1} (Peterson 1975). Discrete sources, such as Sco-X1 and the Crab will double this x-ray background and so will correspond to just the CR background or a total of 2 counts $sterrad^{-1}$ cm^{-2} s^{-1}. Furthermore, a CR proton at minimum ionization will deposit the same energy (dE/dx) w = 2 keV as an x-ray photon. Therefore, the pulse rate for 2π steradians, i.e., half shielded by the earth and assuming the earth shine above 2 keV is less than the space flux, then results in 10^7 pulses s^{-1} per detector plane. A proportional counter taking into account collection time could probably discriminate against CR's, but for only a reduction of 2 in background. This is hardly worth the complexity of 10^7 s^{-1} event analyses.

Instead, we integrate the ionization signal for a characteristic time Δt that is determined by collection time, bit rate, storage, transmission, etc.

The collection time of an ionization pulse is the drift time in the chamber. The ions will contribute the same as the electrons unless proportional counter gain is needed. If we exclude the complexity of proportional counter gain, then the collection time becomes $\Delta t_{col} = d/v_d = d\ P_{gas}/2E$ where E is the electron field in volts cm^{-1}, P_{gas} in atmospheres, and d in cm. Then for P_{gas} = 1/30 atmosphere and E = 150 V cm^{-1}, i.e., ¼ of the breakdown field, then Δt ≅ 1 ms. This is adequate time resolution but shorter could be an advantage. A shorter collection time is possible using a smaller spacing, d, and constant (P_{gas}/E), but the complexity of the structure becomes greater. Hence Δt = 1 ms and d = 10 cm is a reasonable compromise. The background rate of 10^7 s^{-1} then becomes 10^4 events per time resolution interval of 10^{-3} s. The 5σ detection pulse presumably observable in each of the other 3 planes for 50% detection efficiency becomes 2 × 500 photons = 10^3 photons or 10^{-3} photons cm^{-2} or 3 × 10^{-12} ergs cm^{-1} per pulse.

For a typical gamma burst where the resolution time might be several seconds, the 5σ detection level becomes × 30 larger, or 10^{-10} ergs cm^{-2}. These limits are to be compared to current detectors, the Mazets experiment of 10^{-7} ergs cm^{-2} and the proposed BASTE experiment of 5 × 10^{-8} ergs cm^{-2} for a several second burst. The electrical charge collected per millisecond signal of 5σ n ≅ 3 × 10^4 ions, or well above simple amplifier noise.

EXPECTED BURST RATE

If the log N - log S curve is extended down to this burst level, we expect a frequency $\dot{\varepsilon}$ of one half the basic rate $\dot{\varepsilon}_{01}$ event per year of 10^{-5} ergs cm^{-2} × $(gain)^{3/2}$ = $\frac{1}{2}(10^{-5}/10^{-10})^{3/2}$ = 1.5×10^7 per year or 0.5 s^{-1}. This exceeds the effective burst time of several seconds and so only bursts of ≅ 2×10^{-10} ergs would be time resolved.

Supernova on the other hand perhaps give rise to pulses of 10^{43} ergs in 3×10^{-3} s at 3 keV. At a distance of 100 Mpc, the pulse size becomes

$$S_{100} = \frac{10^{43}}{4\pi(3 \times 10^{26})^2} = 10^{-11} \text{ ergs cm}^{-2}$$

or 10σ. The rate of events assuming 1 per 200 years per standard galaxy and 0.05 standard galaxies per Mpc^3, is 10^3 per 4π sr or 500 per year per half sky. This is an event rate of several per day, or one per semishielded night-timeintervals per orbit day. The maximum optical brightness will be about 16^{th} to 17^{th} magnitude with roughly 100 candidate galaxies in the resolution field of 2×10^{-4} sr.

HEAVY COSMIC RAYS

A significant source of bkg will be very heavy cosmic rays - iron nuclei with a flux of 5.57×10^{-2} m^{-2} $sterard^{-1}$ s^{-1} above the earth's atmosphere corresponding to a low orbit (Webber 1981). The ionization signal proportional to Z^2 is 640 times larger. This signal is 6 times larger than our statistical bkg of 100 photons. This rate is 35 s^{-1} per plane detector (2π sr) and so becomes a serious background. On the other hand each plane detector must be divided into several sections for redundancy insurance against a gas leak or electrical failure. Hence a relatively simple signal processing can remove heavy CR nuclei pulses by coincidence analysis. This requires a processing rate of 12 bits per millisecond per detector of 10^5 baud or well within microprocessor capabilities. The storage or transmission requirement is roughly 1 event per second which is also modest.

LAUNCH MODE

This experiment is adaptable to the shuttle mode of launch and retrieval resulting in several days in orbit.

In summary, a large area, thin wall, and small mass (10 kg + electronics) ionization chamber gamma burst detector is designed that can extend the log N - log S curve down to a presumed temperal confusion limit and also detect an expected prompt type I supernova in galaxies at 100 Mpc at a rate of one per day.

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REFERENCES

Benvenuti, P., Panagia, N., and Wamsteker, W. 1981, private communication, NATO-ASI Conference on Supernovae June 29-July 11, 1981, Cambridge, England.

Colgate, S. A. 1979, Ap. J., 232, 404-408.

Colgate, S. A., and Petschek, A. G. 1978, "Supernova Type I Luminosity," Supernovae and Supernova Remnants, Memorie Della Societá Astronomica Italiano, 49, No. 2-3, 417, Aprile-Settembre, 1978. ISSN:0037-8720.

Falk, S. W. and Arnett, W. D. 1977, Ap. J. Suppl., 33, No. 4, 515.

Novick, R. 1981, private communication.

Peterson, L. E., 1975, Ann. Rev. of Astron. & Astro. Phys. 13, 423.

Webber, W. R., 1981, 17th ICCR, OG1, 1.6, p. 80.

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