SEARCH FOR POSITRON ANNIHILATION LINE AND CONTINUUM RADIATION FROM THE GALACTIC CENTER

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ABSTRACT

Our balloon-borne germanium γ-ray telescope was flown over Alice Springs, Australia, on 1984 November 20 to search for the 511 keV positron annihilation line from the Galactic Center. The measured line flux at Earth was (0.6 ± 4.4) $\times 10^{-4}$ ph cm^{-2} s^{-1} indicating that the source was still in a "low" or "off" state.

1. Introduction. A series of 12 balloon and satellite experiments dating back to 1970 and involving six different scientific groups has established the existence of a powerful, compact, and variable source of 511 keV positron annihilation line radiation within a few degrees of the Galactic Center (GC). Surprisingly, the source was observed to "turn off" rather abruptly at the beginning of this decade (see reference 1 for a review of the observations). Three previous balloon flights of the joint Bell/Sandia gamma-ray astronomy group's high resolution Ge telescope have played an important role in discovering the source and confirming its variability (2,3,4). We report here the results of our fourth flight which indicate that the source was still in an "off" or "low" state in late 1984.

2. Experiment. The instrument was essentially the same as that described originally by Leventhal, MacCallum, and Watts (5). It is built around a single large (~200 cc), high-purity Ge detector operated at cryogenic temperature and surrounded by ~200kg of NaI in active anticoincidence. The entrance aperture in the NaI shield defines the field of view, ~15° FWHM at 511 keV. The energy resolution of the system in the laboratory has been improved to 2.1 keV FWHM at 511 keV by changes in electronics.

The flight took place over Alice Springs, Australia on 1984 November 20. Observations of the GC direction (RA = 265.6°, decl = -29.0°) were made at a mean atmospheric depth of 3.3 g/cmsq. Data were accumulated in alternate ~15 minute target-background pair segments with the telescope maintained at the same zenith angle but rotated 180° in azimuth for the background measurements. Consequently, the background observations swept over the celestial sphere, paying no special attention to any particular point. A total of 7.5 hours of useful GC data and background data were accumulated in this fashion. For each segment, data were accumulated into 8192 energy channels each of width 0.798 keV. There was a gain drift totalling about two channels at 511 keV during the course of the flight, which was monitored by means of three calibration lines from a weak onboard ^{207}Bi source that were visible in every segment spectrum.

3. Results. The data were searched for a possible astronomical line superimposed on the instrumental line at 511 keV, using the maximum likelihood method advocated by Cash (6) applied to Poisson-distributed variables. With only ~5 counts/channel/segment, Poisson statistics seemed likely to be more reliable than Gaussian statistics. Furthermore, the determination of parameter error bounds stands on firmer theoretical footing in the Cash method, which is no more difficult to implement than the more familiar "minimum chi-square" methods. (Nevertheless, in this case, we found a least-squares weighted estimate based on Gaussian statistics gave much the same answer.) For each of 26 segments, a set of 30 channels centered on 511 keV were analyzed under the assumption that a uniform instrumental continuum background plus an instrumental line at 511 keV were present, at the same strengths in both segments of a target-background pair. In addition, an astronomical line was assumed to be present in each target segment, at a constant strength (modified appropriately for atmospheric attenuation). All lines were assumed to have the same width and to be centered on 511 keV. The various parameters were then determined by the maximum likelihood method, and "one-sigma" error bounds were determined for the astronomical line strength by finding that value for it that increased the Cash statistic C ($C = -2\ell nP$, P = maximum likelihood probability maximized wrt all other parameters) by unity. The result for the 511 line flux was $(0.6 \pm 4.4)\times10^{-4}$ ph cm^{-2}s^{-1}. The error bound is slightly worse than our 1981 result, largely due to a small decrease in the effective area of our detector (now = 10.3 cmsq at 511 keV).

Figure 1 shows two spectra in the neighborhood of 511 keV. One is the sum of all target segments, divided by total live time; the other is the same for background segments. A rough energy calibration has been performed simply by centering on the peak channel of each segment. The comparison is illustrative only, in that no consideration is given to variations in atmospheric attenuation or background rates, but the comparison clearly illustrates the lack of a visible astronomical signal.

Continuum radiation from the Galactic Center direction was clearly detected below ~250 keV. This can be seen in Fig. 2, which is the same as Fig. 1 but centered at a lower energy, ~110keV. First indications are that the continuum spectrum is softer than when measured in 1977-81, but the detailed analysis is still in progress.

4. Discussion. When fully on the GC positron source was truly a remarkable object, calling for ~10^{43} annihilations/sec (corresponding to ~10^{38} ergs/sec) if isotropic and located at the GC distance of ~10 Kpc. Nothing like this has been seen anywhere else in the sky. It was easily the brightest gamma-ray object in the Milky Way in annihilation radiation alone. Because of its unique nature it is tempting to locate it within the central parsec of the Galaxy. If so, it would amount to

about 0.1% of the total bolometric luminosity of the nuclear region and would obviously be an important clue to the nature of this source (7).

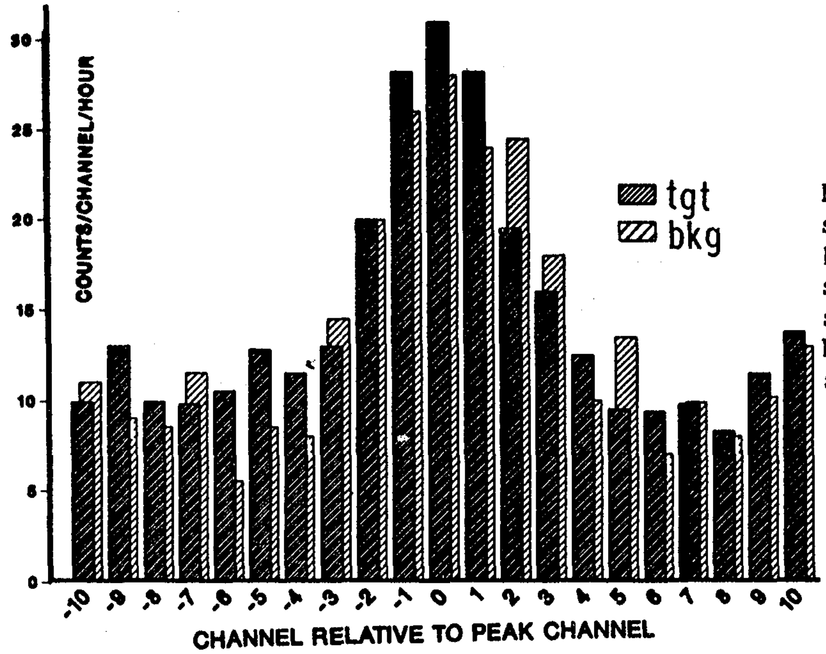

Fig. 1 Channel spectra around 511 keV for sum of tgt segments and for sum of bkg segments. No astronomical signal is apparent.

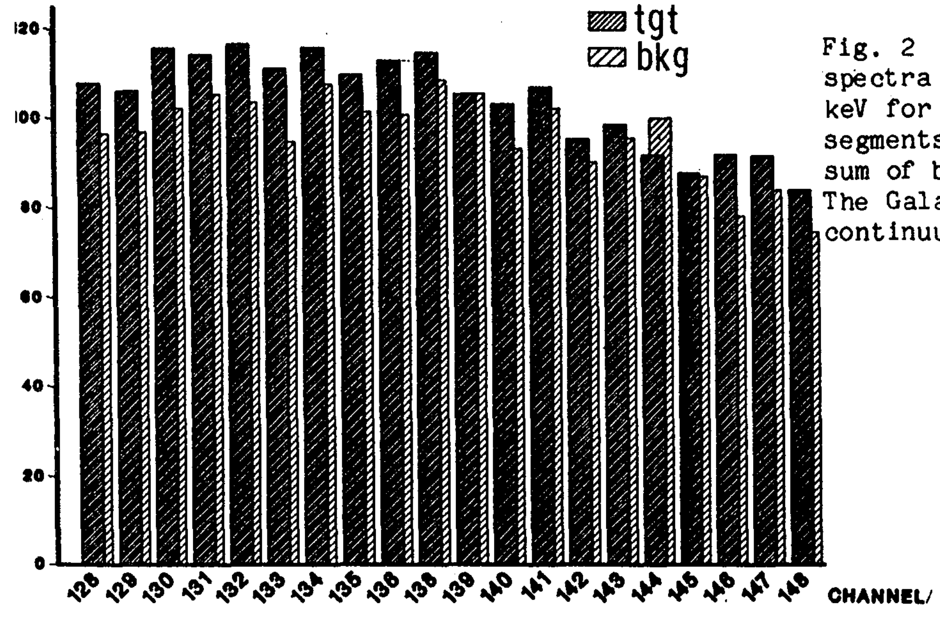

Fig. 2 Channel spectra around 110 keV for sum of tgt segments and for sum of bkg segments. The Galactic Center continuum is evident.

Considerable theoretical effort has gone into modeling the source of positron annihilation radiation. Various black hole models are favored (8,9,10), although supernova (11) and pulsar (12,13) models have also been considered. It would appear that only the black hole models can easily and naturally account for the large flux, rapid variability, and the absence of other nuclear gamma-ray lines. In these models the variability arises from changes in either the rate of accretion or the dynamics of the interaction between an emitted positron beam and a stopping cloud. In recent years considerable support for the presence of such an object at the GC has come from the more conventional branches of astronomy (14,15,16,17,18). However this is sure to remain a controversial issue for years to come.

It does not seem possible to predict with any certainty when the positron annihilation radiation might reappear. We intend to monitor the Galactic Center periodically in the future with a more sensitive gamma-ray telescope in the hope of once again detecting this source.

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