Rev. Mexicana Astron. Astrof., 5, 131-133 (1982)

MEASUREMENT OF THE 0.511 MeV γ-RAY LINE FROM THE GALACTIC CENTER

J.O.D. Jardim, J.L. Benson,[1] M.V.A. Jardim, and I.M. Martin

Instituto de Pesquisas Espaciais-INPE
Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq
Brasil
Received 1981 March 27

RESUMO

A detecção do fluxo da linha de aniquilação eletron-positron em 0.511 MeV proveniente da direção do Centro Galático fornece condições de estimar a taxa de produção de positrons e de testar algumas fontes de positrons teóricas. Neste trabalho apresentamos o resultado de medidas da linha 0.511 MeV, obtidas com um experimento para medir raios gama à bordo de um balão estratosférico. O ângulo de visada do detetor observou o disco galático no intervalo de longitude $-31° < \ell^{II} < +41°$. O fluxo observado é $(6.70 \pm 0.85) \times 10^{-3}$ fótons cm^{-2} s^{-1}, o qual concorda muito bem com o valor de fluxo calculado supondo-se que o Centro Galático é uma fonte linear emitindo uniformemente.

ABSTRACT

The detection of the 0.511 MeV electron-positron annihilation line coming from the Galactic Center can provide the means to estimate the rate of positron production and to test some theoretical sources of positrons. In this work we present the result of the measurements of the 0.511 MeV line flux made in a gamma-ray experiment on board a stratospheric balloon. The detector field of view looked at the galactic longitude range $-31° < \ell^{II} < +41°$. The observed flux is $(6.70 \pm 0.85) \times 10^{-3}$ photons cm^{-2} s^{-1}, which is in good agreement with the expected flux when assuming that the Galactic Center is a line source emitting uniformly.

Key words: COSMIC RAYS – GALACTIC NUCLEI – GAMMA RAYS

I. INTRODUCTION

The search for the 0.511 MeV electron-positron annihilation line flux emitted from the Galactic Center (GC) region has been a difficult task to achieve by the few groups working in gamma ray spectroscopy since the observation made by Johnson and Haymes (1973). In that case, however, statistical drift in the channels has occurred and the observed line was centered at (0.476 ± 0.024) MeV thus leading to confusion about its origin (Johnson and Haymes 1973).

Further, Haymes *et al.* (1975) using data obtained with a telescope flown in Argentina reported a flux coming from $-4° < \ell^{II} < +6°$ galactic longitude interval as $(8.0 \pm 2.3) \times 10^{-4}$ photons cm^{-2} s^{-1} for the 0.511 MeV line. Their telescope had a full width at half-maximum (FWHM) of about 13°.

Later, Leventhal *et al.* (1978) flew a telescope from Alice Springs (Australia) with $\cong 15°$ FWHM angular resolution and using a large high-purity (HP) Ge detector of 130 cm^3. They reported a 0.511 MeV line flux of $(1.22 \pm 0.22) \times 10^3$ photons cm^{-2} s^{-1} coming from the GC.

Due to a Brazilian-French collaborative program, a telescope using a large Ge (Li) crystal of 140 cm^3 has flown from Guaratinguetá (Brazil), in 1977, on board a stratospheric balloon (Albernhe *et al.* 1977). Da Costa (1980), analyzing the data obtained from two flights, calculated an intensity of $(4.19 \pm 1.56) \times 10^{-3}$ photons cm^{-2} s^{-1} for the 0.511 MeV line flux from the Galactic Center.

In 1979 the same telescope from Sandia/Bell Labs group was launched again from Alice Springs (Australia).

Leventhal *et al.* (1980) using the data obtained in that flight calculated a flux intensity for the electron-positron annihilation line from the Galactic Center as being $(2.35 \pm 0.71) \times 10^{-3}$ photons cm^{-2} s^{-1}.

In this paper we report the measurement of the electron-positron annihilation line emitted from the GC disk in the $-31° < \ell^{II} < +41°$ longitude interval using the upper NaI (T1) detector of a balloon borne telescope.

The payload was launched from Cachoeira Paulista (22°40'S 45°W), Brazil, in March 29, 1980.

We measured an intensity of $(6.70 \pm 0.85) \times 10^{-3}$ photons cm^{-2} s^{-1} for the 0.511 MeV line coming from the GC direction.

II. THE EXPERIMENT AND THE FLIGHT

The telescope is made up of two 10.16 cm × 10.16 cm cylindrical NaI (T1) crystals separated vertically by 90 cm and a 20 cm diameter cylindrical lead (Pb) shield,

1. Present address: Max-Planck Institut für Aeronomie, Lindau, FRG.

5 cm thick, placed in between the detectors. Each detector is surrounded by an aluminum powder shield and has a 1.5 cm thick NE102A plastic scintillator in front of the crystal in order to reduce some of the charged particle background.

The array defines an aperture angle of 30° FWHM at about 1.2 MeV when we take the differences in counting rate between the upper and lower detector as a function of angle.

Each detector is connected to a RCA 8054 photomultiplier and to a 128 channels SEIN encoder in order to provide the spectra in the 0.3 to 3.0 MeV energy interval.

A complete description of the telescope will be given by Benson *et al.* (1981).

The payload was carried aloft by a stratospheric balloon (74 000 m^3) which was launched at 02:07 UT in March 29, 1980.

The balloon reached the ceiling of about 4 milibars at 04:04 UT and the flight duration was 15 hours, as it was discontinued by a pyromechanical device for purposes of recovery.

The pressure data was obtained using a Rosemount pressure sensor.

The encoded signals, pressure and temperature data as well as azimuthal directions obtained from two crossed fluxgate magnetometers were telemetered to the ground via FM-FM telemetry.

We observed the transit of the GC through the field of view of the telescope.

To calculate the flux at the 0.511 MeV line due to the GC we used only the upper detector assembly (FWHM ≅ 72°) for which the setting was about 25 KeV/channel. If we had used the telescope in its present electronic configuration for this purpose it would have been difficult to locate the peak position with confidence.

The measured energy resolution is 14% at 0.511 MeV for the 4″ X 4″ NaI (T1) crystal.

III. RESULTS AND CONCLUSIONS

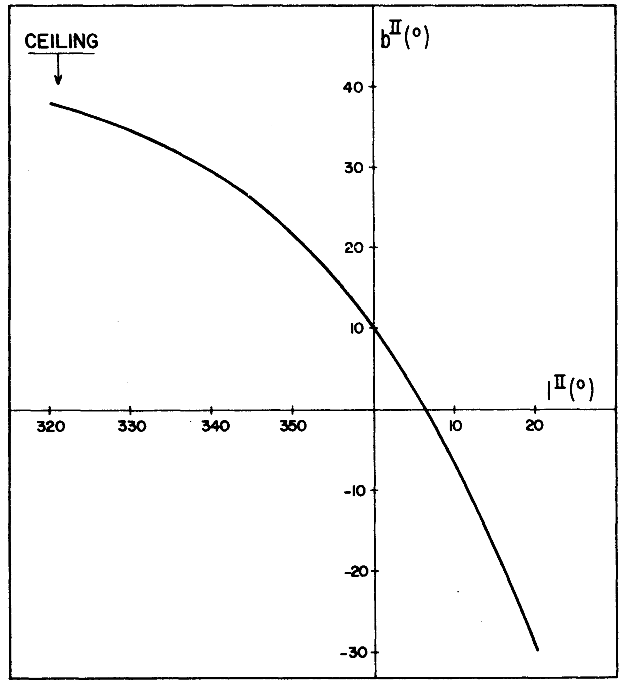
In Figure 1 is shown the path of the balloon in galactic coordinates after the payload reached the ceiling.

We show in Figure 2 the average fluxes for the background (BKD) and for the region where the axis of the telescope was looking toward the galactic coordinates $\ell^{II} = 5.54°$ and $b^{II} = +1.92°$, i.e., when the region in galactic latitude ranging from −31° up to +41° was within the FWHM of the upper detector.

In Figure 3 we show the spectrum for the GC region superimposed on the spectrum for the BKD region (dashed line) for the same integration time.

From the measurements and after taking into account the atmospheric absorption (Figure 2) we calculated the flux coming from the GC direction as being (6.70 ± 0.85) X 10^{-3} photons cm^{-2} s^{-1}.

If we assume that the galactic disk is a line source emitting uniformly the 0.511 MeV line radiation we can use the results from Johnson and Haymes (1973), Haymes *et al.* (1975), Leventhal *et al.* (1978) and da Costa (1980) and take into account their angular field of view to estimate the flux that our detector would observe.



Fi. 1. Path of the balloon in galactic coordinates after reaching the ceiling.

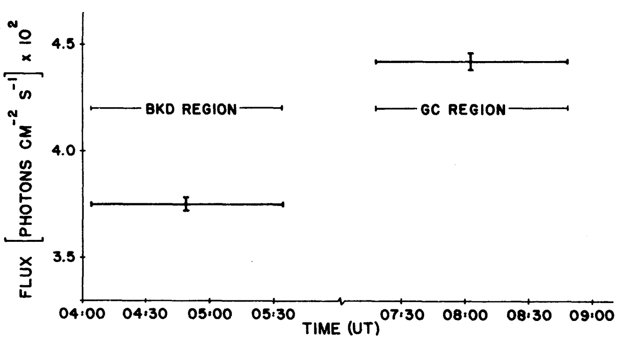


Fig. 2. Average fluxes for background and for the region where the GC was within the field of view.

Using this procedure we calculated an expected line flux of (6.55 ± 0.83) X 10^{-3} photons cm^{-2} s^{-1}, in very good agreement with our measurement.

Mandrou *et al.* (1980) observed the region $-45° < \ell^{II} < +45°$ using a telescope with 90° FWHM which was launched in 1977 from Guaratinguetá, Brazil. They give a 1σ upper limit for the 0.511 MeV line flux as 9.7 X 10^{-3} photons cm^{-2} s^{-1}.

Figure 4 shows the results from measurements of the flux intensity of the 0.511 MeV line as a function of the aperture angle of the telescopes.

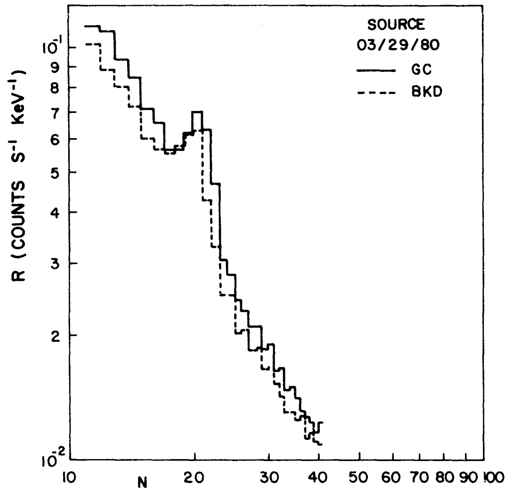


Fig. 3. Spectrum for the GC region superimposed on the BKD spectrum for the same integration time.

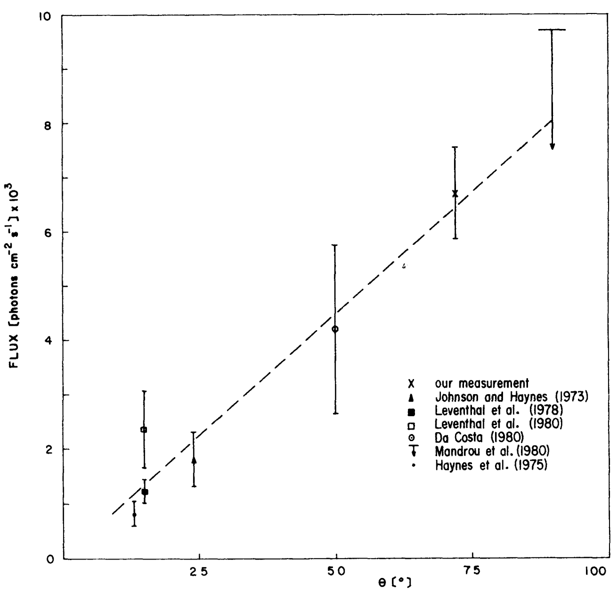


Fig. 4. Measured fluxes for the annihilations line as a function of the angular response of the telescopes.

Using our measurement and the fluxes observed by Johnson and Haymes (1973), Haymes *et al.* (1975), Leventhal *et al.* (1978) and da Costa (1980) and the line source assumption to estimate the flux they would have observed we get $(9.1 \pm 0.8) \times 10^{-3}$ photons cm^{-2} s^{-1}.

The positrons are very likely to be produced in supernova remnants and in nearby H II regions (Bussard *et al.* 1979). The observed distribution of these objects (Ilovaisky and Lequeux 1972; Burton 1976) as a function of the galactocentric distance shows a high concentration between the galactic longitudes ±40°, i.e., about 80° wide.

The fact that Mandrou *et al.* (1980) give only an upper limit flux for that line seems to suggest that the extent of the 0.511 MeV emitting region is less than 90° FWHM in longitude, in agreement with the hypothesis of Bussard *et al.* (1979) for the origin of the positrons. The difference between the measured fluxes by Leventhal *et al.* (1978, 1980) using the same telescope seems to indicate the non-uniformity of the galactic disk line source, i.e., the presence of discrete sources which in specific longitudes would increase the contribution to the annihilation line.

On the other hand, the highest estimated value from theoretical models for the intensity of the 0.511 MeV line due to electron-positron annihilation is given by Stecker (1971) as 2×10^{-3} photons cm^{-2} s^{-1} sr^{-1}.

If we use our result and the detector solid angle to transform the flux into the same units used by Stecker (1971) we get 5.58×10^{-3} photons cm^{-2} s^{-1} sr^{-1}, which is about 3 times higher than the theoretical estimate. This suggests that other sources of positrons are needed to explain the observations.

Finally, we calculated the positron annihilation rate in order to maintain the flux observed by us as being of the order of 4×10^{43} annihilation/s, which yields a line luminosity of $\sim 6 \times 10^{37}$ erg s^{-1}.

REFERENCES

Albernhe, F., Boclet, D., Claisse, J., Durouchoux, Ph., Frabel, M., Marques, J., Olivier, E., Pagnier, P., Rocchia, R., and Vedrenne, G. 1977, in *Proc. 12th ESLAB Symp.*, ESA SP-124, p. 293.
Benson, J.L., Jardim, J.O.D., Martin, I.M., Jayanthi, U.B., and Aguiar, O.D. 1981, *Nucl. Instr. Meth.*, **188**, 613.
Burton, W.B. 1976, in *The Structure and Content of the Galaxy and Galactic Gamma Rays*, NASA CP-002, p. 163.
Bussard, R.W., Ramaty, R., and Drachman, R.J. 1979, *Ap. J.*, **228**, 928.
da Costa, J.M. 1980, Ph. D. thesis, INPE.
Haymes, R.C., Walraven, G.D., Meegan, C.A., Hall, R.D., Djuth, F.T., and Shelton, D.H. 1975, *Ap. J.*, **201**, 593.
Ilovaisky, S.A. and Lequeux, J. 1972, *Astr. and Ap.*, **18**, 169.
Johnson, W.N. III. and Haymes, R.C. 1973, *Ap. J.*, **184**, 103.
Leventhal, M., MacCallum, C.J., and Stang, P.D. 1978, Ap. *J. (Letters)*, **225**, L11.
Leventhal, M., MacCallum, C.J., Huters, A.F., and Stang, P.D. 1980, *Ap. J.*, **240**, 338.
Mandrou, P., Bui-Van, N.A., Vedrenne, G., and Niel, M. 1980, *Ap. J.*, **237**, 424.
Stecker, F.W. 1971, in *Cosmic Gamma Rays*, NASA SP-249, p. 167.

J.L. Benson, J.O.D. Jardim, M.V.A. Jardim and I.M. Martin: Instituto de Pesquisas Espaciais–INPE, C.P. 515, 12200 S.J. dos Campos, SP. Brasil.