CEN A OBSERVATION AT MEV-ENERGIES

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ABSTRACT

During a balloon flight with the MPI Compton telescope from Uberaba/Brasil gamma-ray emission from the direction of Cen A was observed at MeV-energies. The observed flux connects to the x-ray spectrum of Cen A beyond 0.7 MeV and has a statistical significance of 4.1σ. The extension beyond 3 MeV has a significance of 3.8σ. Possible interpretations of the energy spectrum are discussed.

1. Introduction. The bright radio galaxy Cen A is the nearest active galaxy at a distance of 4.4 Mpc. Existing hard x-ray and low energy gamma-ray measurements extend to about 1 MeV (Ref 1-6). At these energies the spectrum follows a power law dependence. The x-ray emission is highly variable in intensity and spectral shape on the timescale of months or even days. Above 35 MeV only upper limits to the gamma-ray intensity exist (Ref 7, 8). In this paper new results on the gamma-ray emission from the direction of Cen A in the energy range 0.7 to 20 MeV are presented. The results were derived from a balloon flight observation of Cen A during a flight on Oct. 31, 1982 from Uberaba/ Brasil with the MPI Compton-telescope. The balloon reached the float altitude of 3.5 to 4 g/cm^2 residual atmosphere at 14.4 h UT, 30 minutes after the transit of Cen A. Cen A was within the field of view of the telescope for about two hours; its closest angular distance to the telescope axis was 23^o.

2. Data Analysis and Results. The Compton telescope of the MPI and its performance are described in detail in ref. 9. The telescope characteristics are determined mainly by two detector layers. In each layer the position of the interaction and the energy deposit of the infalling gamma-ray are measured. The connection between the two interaction points defines the direction of the scattered gamma-ray: its projection onto the celestial sphere may have the coordinates α_s, δ_s. From the two energy deposits the Compton scattering angle $\bar{\varphi}$ can be calculated. For each measured gamma-ray event a probability distribution of arrival directions is determined, which may be called the "event cake", because it looks like a donut centered around the direction of the scattered gamma-ray.

Fig. 1 shows a likelihood sky map obtained from all flight data at float altitude (3 hours). For each point of the map the probability $\bar{p}_s$ was calculated (by multiplication of all event-cakes) that no measured gamma-rays came from that point. A corresponding probability $\bar{p}_m$ was then determined for the mirror position of this selected celestial point. The mirror point is defined by telescope symmetries, it has the same background response as the source point; its position on the sky changes during the flight. The contour lines in Fig. 1 represent the ratio $\bar{p}_m/\bar{p}_s$. This ratio shows a maximum at α = 206^o, δ = -43^o. The likelihood for the existence of a source is greatest at this position. The asymmetry of the source profiles is caused by the large off-axis angles of the source and is understood as instrumental effect from Monte Carlo calculations.

The statistical significance of the excess was determined in the following way: For each event the derived Compton scatter angle $\bar{\varphi}$ was subtracted from the angle φ_G which is the difference between the direction of the scattered gamma-ray and the assumed direction of the source. The quantity $\varrho = \bar{\varphi} - \varphi_G$ may be called the "angular residual" of an event. The distribution of residuals for a source at the position of Cen A (no background) was calculated by a Monte Carlo simulation for actual balloon flight conditions. If the distribution of residuals of the same Cen A-events around the mirror point is subtracted, then the resulting distribution shows a maximum at $\varrho = 0^o$ (lower half of Fig. 2). In the upper half of Fig. 2 the distribution of residuals around Cen A ($\alpha = 201^o$, $\delta = 43^o$) and its mirror position are derived from the real flight data (including background). As can be seen the difference between both distributions indeed shows an excess at $\varrho = 0^o$ and has the overall shape as expected from the Monte Carlo simulation. The excess in the interval $-5^o < \varrho < +5^o$ (corresponding roughly to the FWHM angular resolution of the telescope) contains 112 events and has a statistical significance of 4.1σ. Fig. 3 shows the differential count rate spectrum of the source events. This count rate spectrum was converted into a photon spectrum using the Monte Carlo simulation code. The resulting gamma-ray spectrum is shown in Fig. 4, where comparison is made with previous measurements in the adjacent energy ranges. The statistical significances of the observed values are 2.9σ, 0.3σ, 3.3σ, and 1.9σ in the energy ranges 0.7-1.5, 1.5-3, 3-8 and 8-20 MeV, respectively. As can be seen the derived gamma-ray spectrum is an extension of the x-ray spectrum of Cen A beyond 0.7 MeV. This fact together with the position of the excess in Fig. 1 is taken as indication that the observed gamma-ray emission is related to Cen A.

No gamma-ray lines at 1.6 MeV and 4.4 MeV are seen in the energy spectrum of Cen A in contrast to those reported in ref. 2. The 2σ-upper limits to both lines are $(3.4 \text{ and } 8.0)\cdot 10^{-4} cm^{-2} sec^{-1}$, respectively. It cannot be excluded that a larger number of unresolved lines (of correspondingly lower intensity) contribute to the total observed flux.

3. Discussion. In spite of the low statistical significance of the source detection a discussion of the implications is in order. However, no firm conclusion can be derived from the energy spectrum yet because of the large uncertainties.

The power law x-ray spectrum as previously measured up to about 1 MeV extends to 10 or 20 MeV. Beyond this value the spectrum must steepen rapidly in order to meet the upper limits set by SAS-2 (Ref 7) and COS-B (Ref 8) above 35 MeV and 50 MeV, respectively (assuming their validity also during the time of the balloon observation). Considering the low statistical significance of the 8 to 20 MeV point (1.9σ), the turnover may be even around 8 MeV.

This steepening may be due to photon-photon absorption, if the source is sufficiently compact. Following Herterich (Ref 10) and assuming the gamma-ray source to lie within a surrounding isotropic x-ray source, the radius of the x-ray source should be $(1.4 \text{ to } 1.9)\cdot 10^{13}$ cm depending on whether the turnover is at 10 or 20 MeV. Assuming the source size to be 10-times the Schwarzschild-radius, the central object should have a mass of order $5\cdot 10^6 M_\odot$. The measured gamma-ray luminosity of $3.9\cdot 10^{43}$ erg/s (1 to 10 MeV) or $7\cdot 10^{43}$ erg/s (0.7 to 20 MeV) would be 7% to 8% of the Eddington limit of this object ($L_E = (6 \text{ to } 8.5)\cdot 10^{44}$ erg/s). If the photon-photon absorption really is responsible for the turnover of the spectrum, then future measurements should find a shift of the turnover to lower (higher) energies, when the x-ray source goes into a higher (lower) intensity state.

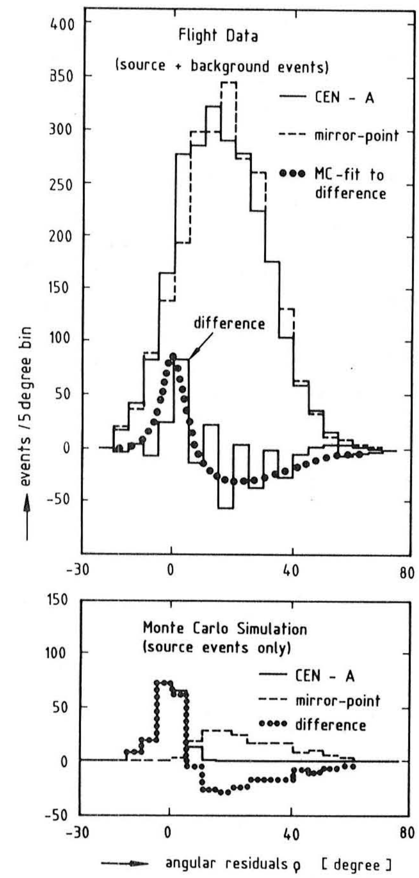

Fig. 2 Distribution of residuals. Lower half: Monte Carlo Simulation of a source at the position of Cen A. Upper half: flight data. The source is identified by the excess between $-5^o < \rho < +5^o$.

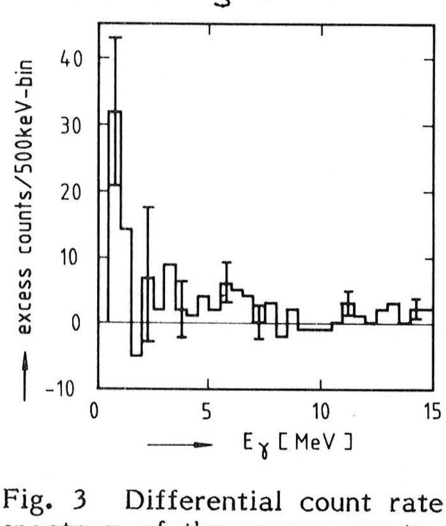

Fig. 3 Differential count rate spectrum of the source events

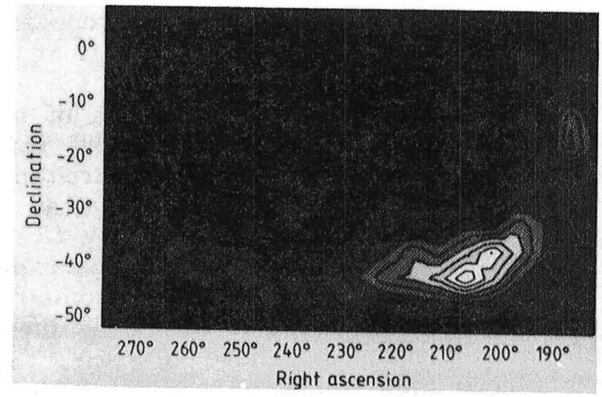

Fig. 1 Sky map of equidistant likelihood contour lines (in steps of 10% of the maximum value). Accepted are all events in the range 0.7 to 20 MeV satisfying $\bar{\varphi} < 37^o$. The likelihood for the existence of a soure is greatest at $\alpha = 206^o$, $\delta = -43^o$.

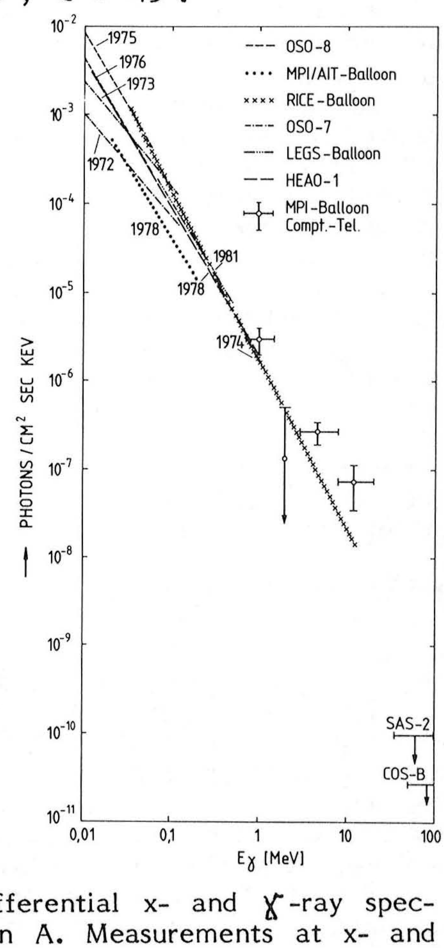

Fig. 4 Differential x- and γ-ray spectrum of Cen A. Measurements at x- and high γ-ray energies are from ref. 1 to 8. Continuum > 1 MeV was seen by ref. 2 with 0.7σ only.

Basically two models have been discussed in the literature, how the power law photon spectrum can be produced: the one is the Synchrotron-Self-Compton Model and the other the Thermal Comptonisation Model.

In the first case the existence of high energy electrons is postulated. These produce infrared or radio photons via the synchrotron process by gyration in magnetic fields. The synchrotron photons are then scattered by the same electrons into the x- and gamma-ray range. A synchrotron-self-Compton model has been suggested by Grindlay (Ref 11) for Cen A. In his model a sharp turnover of the gamma-ray spectrum is predicted at about 5 MeV. Within one decade of energy the gamma-ray intensity should drop by more than 3 decades. The break is caused by the observed turnover of the infrared spectrum at frequencies above 10^{14} Hz. The synchrotron-self-Compton model predicts correlated intensity changes in the infrared and x/gamma-ray range. Due to the energy dependence of the electron life-time the delay in the intensity changes should be smaller at gamma-ray energies than at x-ray energies.

In the Thermal Comptonisation Model low energy photons (e.g. infrared photons) are Compton scattered by thermal electrons, which have a kT-value in the x- or gamma-range. Repeated scatterings of the electrons with the photons result in an approximate power law spectrum, if the number of scattering processes of each photon is sufficiently large. The power law drops off at photon energies of a few kT. In the case of Cen A a value of kT $\gtrsim$ 10 mc^2 would be required together with a small optical thickness for Thompson scattering ($\tau_T \ll 1$) in order to fit the observed spectrum. It has been shown (Ref 12, 13) that in such a case the Comptonised spectrum is bumpy and consists of a superposition of a few individual scattering profiles. It could indeed be that the negative dip in the measured spectrum between 1.5 to 3 MeV - if real - is due to such a negative bump. The present measurement does not allow to derive this conclusion because of the limited statistical accuracy. If, however, the dip is confirmed in an observation with higher sensitivity then this would prove that thermal Comptonisation is operating. No doubt, Cen A will be one of the very interesting objects to be studied by GRO, which will be able to determine its spectrum with high precision.

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