EXCESS γ-RAYS IN THE DIRECTION OF THE ρ OPHIUCHI CLOUD : AN EXOTIC OBJECT ?

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I. INTRODUCTION.

The COS-B γ-ray data in the direction of the ρ Oph dark cloud show an extended structure (Hermsen 1983); at the same time, the region of highest intensity has a spatial distribution compatible with a localized source : 2CG353+16 (e.g., Bignami and Hermsen 1983), which we designate for short by "Oph-γ" in what follows. The possibility of an excess γ-ray flux over what is expected on the basis of the interaction of average-density cosmic rays with an estimated cloud mass of 2-4 000 $M_\odot$ (at 160 pc) is still open, pending an extended CO survey matching the γ-ray data. Current estimates for this excess factor are in the range 2-4. While the cloud mass may admittedly be underestimated (e.g., Issa and Wolfendale 1981), it should be noted that an excess of the same order appears to be present in the nearby Oph-Sag area, well surveyed in CO with the Columbia dish (e.g., Lebrun 1985).

In the following, we reexamine possible reasons for a γ-ray excess, in view of two recent observational developments : an Einstein X-ray survey (Montmerle et al. 1983, hereafter MKFG), and a VLA radio survey (Montmerle, André, and Feigelson 1985, Montmerle et al., in preparation), both covering the $\sim$2°-diameter "Oph-γ" error box.

Current interpretations link the γ-ray excess to the cloud gas, in which some active agent is present : stellar winds (Cassé and Paul 1980), or interaction with the North Polar Spur (Morfill et al. 1981). However, in view of the existence of γ-ray sources as strange as "Geminga", it seems wothwhile to revisit the problem and examine the possibility that the γ-ray excess may not be associated with the cloud. Two main cases are a priori possible : a compact object, such as a pulsar, or an extragalactic source, lying somewhere along the line of sight to the cloud.

II. COMPACT SOURCES.

In MKFG, it has been argued that no clear signature for a compact object has been found among the 40-plus X-ray sources discovered in the cloud. However, no X-ray source has been found within a $\sim$10'-radius circle containing the cloud core (Wilking and Lada 1983), likely because of absorption caused by a vry high column density ($N_H > 10^{23}$ cm^{-2}). The possibility of an unseen X-ray source within this circle definitely exists, and therefore the existence of a compact source along the corresponding line of sight cannot be ruled out.

III. RADIO SOURCES.

Our VLA survey has been performed at 1.5 GHz in configuration C, the central region of the cloud being surveyed also at 5 GHz and, in part, at 15 GHz (Montmerle, André, and Feigelson 1985; see also Feigelson and Montmerle 1985). The latest analysis yields, at 1.5 GHz, 54 sources within 15' of the pointing directions (< 50% attenuation); in addition, 8 sources are shown to belong to the cloud, on the basis of various identifications at other wavelengths.

However, the strongest source in the survey lies more than 15' away from any pointing direction; its corrected flux density at 1.5 GHz is ~800 mJy. Clearly visible in the 2.3 GHz survey of the Sco-Oph region by Baart et al. (1980), near the HII region S9 surrounding σ Sco, it is identified with the Parkes source PKS1622-253, hereafter simply "PKS" (Wehrle, Morabito and Preston 1984). All the other sources found in our survey have a flux density < 150 mJy. PKS lies at the edge of the nominal error box, but well within the γ-ray isophotes of the area.

IV. 2CG353+16 = PKS1622-253 ?

To solve this strange "equation", we use the data on 3C273, the closest quasar (d = 1 Gpc), associated with the only extragalactic γ-ray source, 2CG289+64 (Bignami et al. 1981).

The data at our disposal to compare PKS and 3C273 are : radio, optical, X-ray, and γ-ray. They have been gathered in the Table; we focus on the derived F_j/F_r ratios of the j-fluxes (j = optical, X-ray, γ-ray) to the radio fluxes. It can be seen that the F_R(red)$/F_r$ and F_X/F_r ratios are quite comparable for the two objects; however, the F_γ/F_r ratio implied by the identification of "Oph-γ" with PKS is about 100 times higher than for 3C 273. (It would be even larger if another of our radio sources were the actual extragalactic counterpart.)

V. DISCUSSION.

a) Compact object ?

From the X-ray data, we can only look for an object located within the central 10' of the cloud. If it is a pulsar, from the work of Arnaud and Rothenflug (1980), there are 5 pulsars in a 5° strip within $10° \lesssim b \lesssim 20°$ and $300° \lesssim l \lesssim 360°$; the probability to find a pulsar aligned with the center of the ρ Oph cloud is thus $P_p = 4\ 10^{-4}$.

Another possibility is that of a Geminga-like object, an a priori serious possibility since Geminga is thought to be less than 100 pc away from the Sun (e.g., Caraveo et al. 1984). We estimate the probability of identification as follows. Out of 26 γ-ray sources (the 25 2CG sources, and 083+03, Pollock et al. 1985), 7 are known : (1 quasar), 2 pulsars, 3 "passive" sources (Pollock et al. 1985), and Geminga itself. In addition, Montmerle (1985) has proposed 10 identifications with "active" giant HII regions. On the other hand, 3 sources are variable (hence probably compact) 5 are unidentified. The last one is "Oph-γ", which we assume here is not associated with the ρ Oph cloud. In all, 1 (if "Oph-γ") to 9 sources can be Geminga-like. Assuming the HII region identifications are correct, the probability P_1 of identification of "Oph-γ" with a source of this (galactic) type is therefore $P_1 = 1/24$ to $P_1 = 9/16$. The probability of finding an X-ray-obscured Geminga-like source (which does not display detectable radio emission) is $P_2 = (10'/2°)^2$. The final identification probability

$P_G = P_1P_2$ of identifying "Oph-γ" with a Geminga-like source is thus:

$$3\ 10^{-4} \lesssim P_G \lesssim 4\ 10^{-3}.$$

In both cases above, it turns out that the probabilities P_p and P_G are quite low, the upper limit of $P_G \simeq 0.4\%$ being probably quite strong, since it implies that all the unidentified γ-ray sources are Geminga-like -an unlikely possibility in view of their latitude distribution.

b) Extragalactic object ?

No statistical argument applies here. We note only that the condition $F_\gamma/F_r(\text{PKS}) \gtrsim 100\ F_\gamma/F_r(\text{3C273})$ is extremely constraining, since the other flux ratios have comparable values. The γ-ray emission from 2C273 is already somewhat difficult to explain (see Morrison, Roberts, and Sadun 1984).

VI. CONCLUSION.

Perhaps not too surprisingly, we find that to interpret the excess γ-ray flux associated with 2CG353+16 in terms of objects not associated with the ρ Oph cloud is indeed difficult. The possibility of invoking exotic objects cannot be strictly ruled out, but all in all, if the excess is real, the most probable identification remains that of the interaction of the North Polar Spur with the cloud, as proposed by Morfill et al. (1981). In fact, the same interaction probably accounts also for the γ-ray excess, of the same order as in ρ Oph, found in the nearby Oph-Sag region.

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TABLE. Compared properties of 3C273 and PKS1622-253

spect. range	γ-rays 100MeV-1GeV erg $cm^{-2}s^{-1}$	X-rays 0.2-0.4 keV erg $cm^{-2}s^{-1}$	opt.(Red) 0.6μ -0.8μ erg $cm^{-2}s^{-1}$	radio 1.4-5.0 GHz erg $cm^{-2}s^{-1}$	F_γ/F_r	F_X/F_r	F_R/F_r
3C273	$2.5\ 10^{-10}$	10^{-11}	$2\ 10^{-11}$	$1.4\ 10^{-12}$	$1.8\ 10^{2}$	7	14
PKS	$4.5\ 10^{-10}$	$3\ 10^{-13}$	$2\ 10^{-13}$	$2.8\ 10^{-14}$	$1.6\ 10^{4}$	11	7
Notes	(1)	(2)	(3)	(4)			

NOTES. (1) PKS : flux if identification with 2CG353+16 assumed; 3C273 : from Bignami and Hermsen (1983).

(2) PKS : upper limit from MKFG = 10^{-2} cts s^{-1}. In the area, $N_H \lesssim 10^{-21}$ cm^{-2}, $A_V \lesssim 0.5$ mag; F_X assumes integral spectrum with index $\lesssim 0.5$. 3C273 : from Worrall et al.(1979).

(3) PKS and 3C273 : from PSS red print; we estimate m_R(3C273) = 13.0, m_R(PKS) = 18.0 .

(4) PKS : based on a 1.4 GHz flux desity of 0.8 Jy (this work), assuming a non-increasing spectrum between 1.4 GHz and 5.0 GHz. 3C273 : based on a constant flux density of 40 Jy (1.5-5.0 GHz).