GALACTIC γ-RAY SOURCES, SNOBs, AND GIANT HII REGIONS

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I. INTRODUCTION

A significant progress towards understanding the nature of the COS-B galactic γ-ray sources is allowed by two recent developments:

a) The existence of extensive wide-latitude CO surveys, from the Northern hemisphere, as well as from the Southern hemisphere (Dame and Thaddeus 1985, Cohen et al. 1985), allowing to know more precisely the molecular cloud population of the Perseus, Sagittarius, and Carina spiral arms;

b) The study of the time variability of γ-ray sources by the Caravane Collaboration, in γ-rays but also at other wavelengths, leading to the recognition of 4 new variable sources ("Geminga", and 3 other sources displaying long-term variations) in addition to the already known Crab and Vela pulsars (Bignami and Hermsen 1983; Bignami, Caraveo, and Paul 1984, Vigroux et al. 1985; Pollock et al. 1985).

As a result, three classes of γ-ray sources emerge to date: variable sources, "active" sources (variable or not), and "passive" sources (Pollock et al 1985; see also Montmerle 1979a).

II. VARIABLE SOURCES

It has been argued (Bignami, Caraveo, and Paul 1984) that "Geminga" (= 2CG195+04) is probably a binary system, consisting of a G subdwarf primary and a neutron star secondary, at less than 100 pc from the Sun. Including the two pulsars alredy mentioned, we have therefore 3 γ-ray sources identified with compact objects.

In addition, 3 sources (2CG054+01 and the newly found 083+03, Pollock et al. 1985; 2CG356+00, Bignami and Hermsen 1983) have displayed significant flux variations between separate COS-B observations. The timescale for the observed variations (years, typically) limits the source size to a fraction of a pc. No identification has been proposed so far for these three sources; they are likely to be compact objects as well.

III. NON-VARIABLE SOURCES

In the first galactic quadrant, in which matched CO and γ-ray data have been compared (Lebrun et al. 1983; see also Arnaud et al. 1982), it is possible to compare, point by point, the γ-ray flux at Earth I_o expected on the basis of a "normal" CO/H_2 ratio (or, more precisely, a "normal" $N(H_2)/W_{CO}$ ratio, see Lebrun et al. 1983) and a "normal" cosmic-ray density, with the γ-ray flux actually observed, I_γ.

Writing $I_\gamma = f_\gamma I_o$, one finds 3 sources for which $f_\gamma = 1$, i.e., "passive" sources. These γ-ray sources appear as such only because of a particular matter enhancement along the line of sight (Pollock et al. 1985).

On the other hand, 5 other sources in the same region are seen to imply an extra γ-ray flux: they are "active" sources (Pollock et al. 1985), two of them being variable (see preceding §). All these sources have $f_\gamma \gg 1$.

The γ-ray excess seen along the line of sight towards non-variable sources may be either a coincidence, for instance a compact object on the same line of sight (as <u>is</u> the case for variable sources), or be really <u>linked physically</u> with the gas -hence presumably non-compact-, and extended if not too far away.

IV. NON-COMPACT ACTIVE SOURCES

The most straightforward link between the gas and γ-ray sources in the second and third galactic quadrants, where H_2 is the main component of the gas, is via molecular clouds. An additionnal ingredient is however required: a supernova shock (e.g., Montmerle 1979b, Morfill and Tenorio-Tagle 1983), a stellar wind shock (e.g., Cassé and Paul 1980) etc. (For reviews, see Morfill, Forman, and Bignami 1984, Cesarsky and Montmerle 1983.) On this basis, specific identifications have been proposed, and a few studied in detail: 2CG078+01 and 2CG006-00 with the SNRs G78.2+2.1 (= DR3+DR4) and W28, respectively, see Pollock 1985; 2CG288-00 with the Carina Nebula, Montmerle and Cesarsky (1981). (We note that none of the good "SNOB" candidates in the list of Montmerle 1979b has turned out so far to correspond to a variable γ-ray source.)

Along these lines, a systematic search has been undertaken to look for spatial coincidences with either "supergiant" HII regions, or giant HII region complexes, or "subgiant" HII regions in which some active agent could be found: SNRs, or stars with strong stellar winds, for reasons discussed below. For the sake of homogeneity in the sample, we have used the Georgelin and Georgelin (1976) catalogue of giant HII regions. Supergiant HII regions correspond to their "b" regions, giant and subgiant HII regions to their "m" and "f" regions, respectively.

The Table summarizes the results: out of 14 γ-ray sources known as non-variable, non-passive, and having a low galactic latitude, 10 may be associated, on a one-to-one basis, with the HII regions defined above; up to 4 contain SNRs.

V. DISCUSSION

A giant HII region is ionized by early O stars. In turn, these stars -and in particular their Wolf-Rayet descendants- suffer a very intense mass loss (up to 10^{-6} $M_\odot$ yr^{-1}, with a terminal velocity of order 2-3 000 km s^{-1}), creating as a result a hole in the ionized gas. HII regions around OB associations are therefore always hollow and thick (a few pc; at least in their early stages of evolution, see Dorland, Montmerle, and Doom 1985), with nebulae as the Rosette or Carina as prototypes. Under these conditions, it has been shown that, provided particle acceleration by stellar winds takes place, wave scattering in the thick ionized shell leads to an enhanced cosmic-ray density (up to 100 times the value in the vicinity of the Sun) and, if enough mass is present, to a γ-ray source (Montmerle and Cesarsky 1981, Cesarsky and Montmerle 1983), after traversal of ~ 10 g.cm^{-2}.

TABLE. Non-variable, active γ-ray sources in the galactic plane (*)

name (2CG)	proposed id.	ref.	d (kpc)	HII region	opt. diam.	exc. class	most active star	SNR
006-00	M8	(1,2)	1.5	G6.0-1.2	90'	f	WR	W28
013+00	W33 complex	(*)	4.2	G12.8-0.2		m	n.a.	-
			5.8	G13.2+0.0		f	n.a.	-
			4.0	G14.6+0.1		f	n.a.	-
075+00	-	(*)	5.7	G75.8+0.4		f	n.a.	-
078+01	DR3+DR4	(1,2)	5.0	G78.5+2.1 (+)		f	n.a.	DR3+DR4
121+04	-	-	-	-		-	-	-
135+01	IC1805	(1,3)	2.3	G134.8+1.0	150'	m	O4If	-
218-00	-	-	-	-		-	-	-
235-01	-	-	-	-		-	-	-
284-00	RCW49	(*)	4.7	G284.3-0.3	90'	b	n.a.	-
288-00	Carina complex	(4)	2.6	G287.9-0.8 ...	180'	b	WR	-
311-01	SGMC (++)	(*)	15.5	?		?	?	G311.5-0.3
333+01	RCW106 complex	(1)	4.2	G333.6-0.1 ...	35'	b	WR	MSH16-51
342-02	-	-	-	-		-	-	-
359-00	W24? (§)	(*)	10.0	G0.5-0.0 ...		m	n.a.	-

NOTES. (*) Not including already known identifications : 2CG363-02 = Vela, 2CG184-05 = Crab, 2CG353+16 = ρ Oph (see Montmerle 1985), 2CG195 +04 = Geminga. Restricted to $|b| < 5°$.

(+) Smith et al. (1978)

(++) "Supergiant" molecular cloud (Cohen et al. 1985). This cloud is by far the most massive cloud in the Carina arm ($M = 7.8 \times 10^6\ M_\odot$). Position of SNR G311.5-0.3 highly uncetain (see Clark and Caswell 1976). Size of cloud $\sim$ 1 sq. deg.

(§) Identification doubtful. From Smith et al.(1978), Astr.Ap. 66, 65

REFERENCES. (*) This work. (1) Montmerle 1979b. (2) Pollock et al. 1985. (3) Strong 1977. (4) Montmerle 1981, Montmerle and Cesarsky 1981.

The considerations of the preceding sections seem to encourage such an approach; furthermore, particle acceleration by stellar winds, a subject of controversy (see Völk and Forman 1981) appears now to be better established (White 1985). On the other hand, the concept of "thick cosmic-ray sources" associated with Carina-like HII regions is helpful to solve the excess antiproton problem in galactic cosmic rays (see Lagage and Cesarsky 1985).

And more quantitative approach is therefore warranted (Montmerle, in preparation), but cannot be complete at the present time: the exciting stars of only 30% of the giant HII regions are known; masses of these HII regions are often unreliable or unknown (if deduced from H109α surveys for instance, sensitive only to "hot spots" of emission, underestimates by factors up to 10 are not impossible).

On the other hand, no giant HII region is needed when a SNR is present, since the sole compression of the molecular cloud may lead to a γ-ray source (Blandford and Cowie 1982); here, the HII region may act only as a tracer of a massive molecular cloud.

As a final remark, we note that all the HII regions proposed as counterparts of γ-ray sources belong to spiral arms; this is consistent with the conclusions of works such as Godfrey (1983), or Lebrun et al.(1983) that, given the structure of the galactic diffuse γ-ray emission, the source distribution must be predominantly linked with the spiral structure.

By contrast, most of the SNOB candidates of Montmerle (1979b) belong to interarm regions. The fact the most of them turn out not to be seen as γ-ray sources by COS-B may mean that the mass of the associated molecular clouds is in general too small. Indeed, CO data show that no giant molecular clouds are present between the arms, even if a disk population of molecular clouds exists (Solomon, Sanders, and Rivolo 1985). From this point of view, the links between γ-ray sources and giant HII regions, if confirmed, may shed some light on the respective distribution of H_2 inside, and between, spiral arms.

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