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GAMMA RAYS, COSMIC RAYS AND GALACTIC STRUCTURE

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ABSTRACT

Working primarily from the recent SAS-2 observations of galactic γ-rays, the relation of these observations to the large scale distribution of cosmic rays and interstellar gas in the galaxy is reviewed and re-examined. Starting with a discussion of production rates, the case for π° decay being the predominant production mechanism in the galactic disk above 100 MeV is reestablished and it is also pointed out that Compton γ-rays can be a significant source near $\ell = 0°$. To facilitate discussion, the concepts of four distinct galactic regions are defined, viz. the nebulodisk, ectodisk, radiodisk and exodisk. Bremsstrahlung and π° decay γ-rays are associated with the first two (primarily the first) regions and Compton γ-rays and synchrotron radiation are associated with the latter two regions. On a large scale, the cosmic rays, interstellar gas (primarily H_2 clouds in the inner galaxy) and γ-ray emissivity all peak in a region between 5 and 6 kpc from the galactic center. This correlation is related to correlation with other population I phenomena and is discussed in terms of the density wave concept of galactic structure. The singular nature of the HI distribution has led to the concept of population 0. The deduced cosmic-ray distribution appears to follow the supernova remnant and pulsar distributions in the galaxy. This fact, together with the fall-off of cosmic rays in the outer galaxy favors a galactic origin theory for most cosmic rays.

Correlations with arm features do not appear to be evident at longitudes $0° \leq \ell \leq 180°$. Between 180° and 360° some evidence for correlation with arm features may or may not exist but arguments against confinement of cosmic rays in spiral arms (with $I_{CR} \propto n_{gas}$) are given on the basis of γ-ray evidence, lifetime of cosmic rays, isotropy, etc. The galactic γ-ray and non-thermal radio distribution are compared with similarities and differences noted. Finally, the contribution of high-latitude γ-rays to the observed cosmic background is discussed and this contribution is shown to reasonably account for the observed spectrum of high-latitude γ-rays between 35 and 200 MeV.

1. Introduction. The pioneering work of Kraushaar, et al. (1972) with their OSO-3 satellite experiment showed that the Milky Way dominates the sky at γ-ray wavelengths and that the galactic γ-radiation is much more intense in directions toward the galactic center than away from it. With the advent of the successful SAS-2 satellite detector (Fichtel et al. 1975) we have our sharpest view yet of the galaxy in γ-rays. In addition, new data from the European COS-B satellite is now becoming available. Although we still do not have many of the answers we want regarding galactic γ-rays we are now in a position to allow us to start asking questions about what γ-ray astronomy tells us about the galaxy and to begin answering them in a cautious way. In order to find plausible answers, we must consider the new information provided by the γ-ray observations together with related information from other branches of astronomy. I will attempt here a review and reexamination of some of these questions in order to basically clarify some of the answers.

2. Data. We start with a summary of the general features of the SAS-2 observations which are as follows:

(1) On a large scale, the cosmic γ-ray radiation can be considered as consisting of two components; there is a general cosmic background radiation coming from all directions which may be cosmological in origin (Stecker 1971, 1975a, Stecker et al. 1971) and also a bright band of radiation coinciding with the galactic plane or Milky Way which is, relative to the background components, both much more intense and harder.

(2) The galactic γ-radiation is most intense in the region within ±40° from the galactic center where it is almost an order of magnitude stronger than in directions away from the galactic center.

(3) Two young nearby pulsars, viz., the Vela pulsar and the Crab Nebula pulsar (NP0532) stand out strongly in the observations at galactic longitudes 264° and 185° respectively. In addition, another γ-ray source, as yet unidentified has been reported at 193° longitude (Knifien et al. 1975).[1]

(4) There are indications of more fine-scale structure in the observations possibly due to such causes as (a) more distant discrete sources such as pulsars, (b) "hot spots" due to supernova remnants and gas clouds, and (c) possible general correlations due to spiral structure.

[1]Evidence for γ-ray emission from two other pulsars, PSR 1747-46 and PSR has now been reported by the SAS-2 group (see Thompson, these proceedings).

In order to arrive at an understanding of these observations, we must first plausibly establish what the predominant mechanism is which produces the observed galactic γ-rays. In addition to the production of γ-rays in discrete galactic objects such as pulsars, there are three main mechanisms by which high energy (greater than 100 MeV) radiation is produced by high energy interactions involving cosmic rays in interstellar space. These processes which produce what may be called "diffuse galactic γ-rays" are (a) the decay of π° mesons produced by interactions of cosmic ray nucleons with interstellar gas nuclei, (b) the bremsstrahlung radiation produced by cosmic-ray electrons interacting in the Coulomb fields of nuclei of interstellar gas atoms, and (c) Compton interactions between cosmic ray electrons and low energy photons in interstellar space.

3. Production Mechanisms and Spectra. For the γ-ray region above 100 MeV, it is easy to show that π° decay γ-rays dominate over bremsstrahlung γ-rays in the galaxy since one knows the relevant cross sections and the estimates of the cosmic ray electron-nucleon ratio are good enough for this conclusion to be reached (Stecker 1968, 1971, 1975). (Of course, the reverse is true for lower energy γ-rays since the π° decay differential spectrum turns over at $\sim$70 MeV.) The above conclusion is valid independent of the gas density distribution in the galaxy if the cosmic ray electrons and nucleons have similar distributions since both production processes are proportional to the total gas density. Thus, one would therefore expect similar γ-ray emissivity distributions in the galaxy in both cases.

Using recent estimates of the demodulated cosmic-ray electron spectrum in the solar vicinity of the galaxy (Goldstein, et al. 1970, Daugherty et al. 1975, Daniel and Stephens 1975) and a cannonical total mean hydrogen density in the solar vicinity of $n_H = 1\ \mathrm{cm}^{-3}$, the integral and differential production rates of γ-rays at 10 kpc from the various processes have been calculated and are shown in Figures 1 and 2. The π° decay production rate is taken from Stecker (1970). The bremsstrahlung and Compton production rates have been calculated using the formulas for a $KE^{-\Gamma}$ differential electron spectrum

$$q_B(E_\gamma) = \frac{4.33 \times 10^{-25}}{\Gamma - 1}\ n_H\ KE^{-\Gamma}\ \mathrm{cm}^{-3}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1} \qquad (1)$$

and

$$q_c(E_\gamma) = \frac{8\pi}{3}\ \sigma_T \rho_{ph} (m_e c^2)^{1-\Gamma} \left(\frac{4}{3}\langle\epsilon\rangle\right)^{(\Gamma-3)/2} KE_\gamma^{(\Gamma+1)/2} \qquad (2)$$

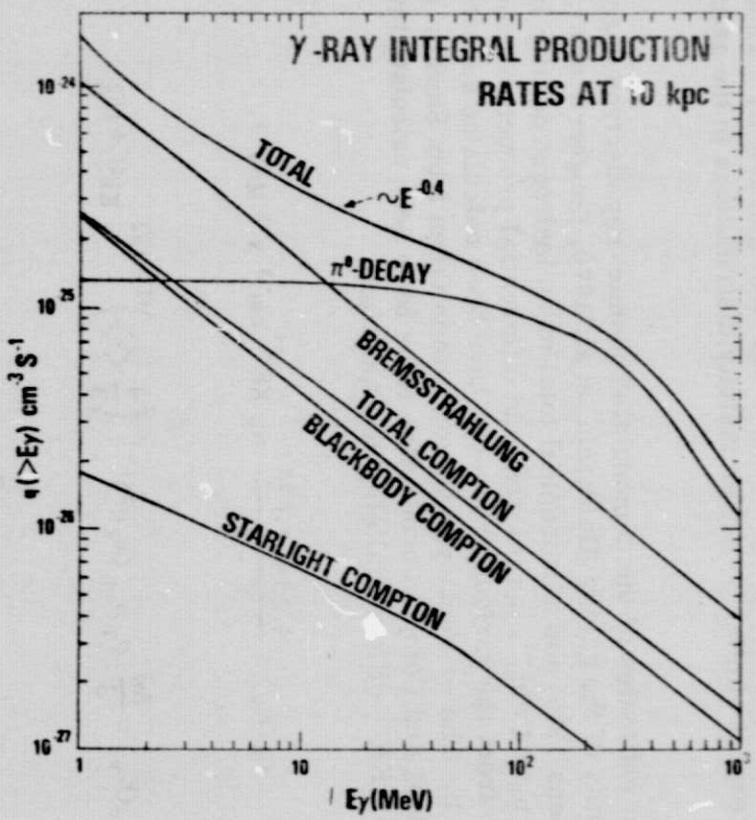

Figure 1. Local galactic γ-ray integral production for a local total gas density of 1 atom per cm^3 and starlight radiation density of 0.44 eV/cm^3. The π^0-decay rate is from Stecker (1970).

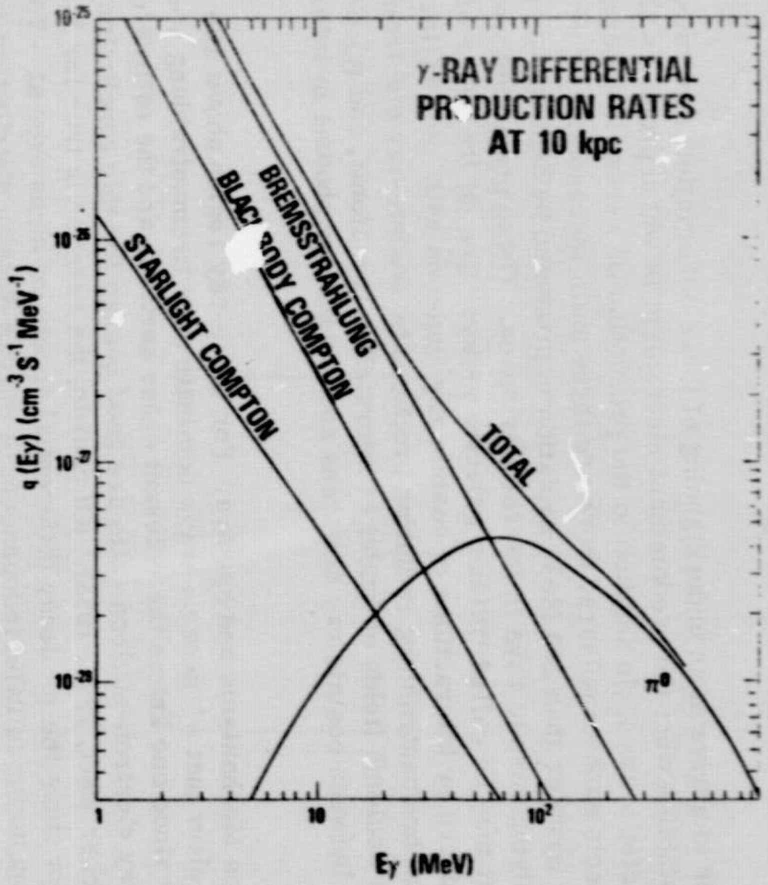

Figure 2. Local galactic γ-ray differential production rate for a total gas density of 1 atom per cm^3 and starlight radiation density of 0.44 eV/cm^3. The π^0-decay rate is from Stecker (1970).

4

(see, e.q. Ginzburg and Syrovatskii 1964, Stecker, 1971, 1975a). The bremsstrahlung rate is given specifically for the cosmic mixture of H and He based on the cross sections for these elements given by Dovzhenko and Pomanskii (1964). In the equations n_H is the hydrogen atomic density, σ_T is the Thomson cross section equal to 6.65×10^{-25} cm^2, ρ_{ph} is the photon energy density and $\langle\epsilon\rangle$ is the mean photon energy such that

$$\frac{4}{3} \langle\epsilon\rangle = 3.1 \times 10^{-4} T(\mathrm{eV}) \tag{3}$$

Equations (1) and (2) are accurate to within a few percent. For the Compton process, Ginzburg and Syrovatskii (1963) give a correction factor $f_c(\Gamma)$ dependent on the differential electron spectral index Γ, such that $f_c(2) = 0.86$, $f(3) = 0.99$ and $f_c(4) = 1.4$. For bremsstrahlung, using the formulas given by Blumenthal and Gould (1970), I find the correction factor to be

$$f_B \simeq 1 - \frac{2}{3} \frac{(\Gamma - 2)}{\Gamma(\Gamma + 1)} \tag{4}$$

so that $f_B(2) = 1$, $f_B(2.5) = 0.96$ and $f_B(3) = 0.94$. (The local bremsstrahlung rate calculated here is similar to that given by Fichtel et al. (1976) and Ramaty and Westergaard (1976)). The Compton production rate was calculated for a 2.7K blackbody background and a two component starlight model of total radiation density 0.44 eV cm^{-3} (Allen 1973) consisting of a 10^4K graybody component of energy density 0.22 eV cm^{-3} and a 5×10^3K graybody component of equal energy density 0.22 eV cm^{-3} (Lillie, quoted by Greenberg 1971). The 10^4K component will hereafter be referred to as the Population I component since it is due primarily to Population I stars and the 5×10^3K component will be referred to as the Population II component. Although these components contribute approximately equally at a galactocentric distance of 10 kpc, it is expected that the Population I component will be negligible at the galactic center region, which, we will see, is the only region where Compton interactions are expected to play a significant role (Stecker et al 1975).

The Population I component produces a break in the starlight Compton spectrum at a critical energy $E_{C,I} \simeq 60$ MeV, for the Population II component, $E_{C,II} \simeq 30$ MeV. The total starlight Compton spectrum is shown in the figures.

A comparison of the pion-decay and Compton processes throughout the galaxy is not as straightforward as the comparison with bremsstrahlung since, in this case, the Compton process scales like the low-energy photon density in the galaxy whereas the pion-decay process [illegible] like the gas density distribution. There is also the possibility, pointed out by Cowsik and Voges (1975), that Compton production takes place throughout a greater volume of the galaxy since starlight is expected to exist at higher distances from the galactic plane than gas. Therefore, for the purposes of further discussion, I will introduce the useful concepts of various galactic disk regions with different thicknesses as shown in Figure 3. These disks are defined as follows:

(a) The nebulodisk is defined as the region where most of the dust clouds and molecular clouds are found. Its thickness is of the order of 130 pc (Scoville and Solomon 1975, Burton and Gordon 1976).

(b) The ectodisk is the domain of the more diffuse atomic hydrogen (HI). Its thickness is of the order of 260 pc (Burton et al. 1975).

(c) The radiodisk, about 500 pc thick, is the region from which most of the synchrotron emission in the galaxy originates according to the interpretation of Ilovaisky and Lequeux (1972) of the 150 MHz data of Landecker and Wielbinski (1970). For conceptual purposes, I will consider this as the diffusion-trapping region of most cosmic rays. Trapping in a more extensive "halo" will tend to wipe out radial gradients in the cosmic-ray intensity which are necessary to an explanation of the γ-ray measurements (Stecker 1975b, Dodds et al. 1975, Stecker et al. 1975), as will be discussed in more detail in section 8. In any case, recent observations appear to rule out significant trapping in a halo-type region (Webster 1975).

(d) The exodisk, here tentatively identified with a disk about 2 kpc thick from which some synchrotron emission is also occurring according to the interpretation of Ilovaisky and Lequeux. I call this the exodisk because cosmic rays may be escaping from the galaxy primarily from this region (see the discussion of Jokipii 1976).

Using this language, γ-rays from bremsstrahlung and pion decay originate in the nebulodisk and ectodisk whereas those from Compton scattering originate in the radiodisk and exodisk. Even so, the theoretical estimates shown in Figures 1 and 2 indicate that in typical regions of the galactic disk (excluding the galactic nuclear region we will be discussing separately) pion-decay dominates over Compton scattering even if the Compton-producing disk is an order of magnitude thicker than the gas disk. Furthermore, the latitude distribution of galactic γ-rays obtained by SAS-2 shows that the galactic γ-ray disk is thinner than the radiodisk whereas dominant Compton production would imply that the γ-ray disk should be comparable in width to the radiodisk. Stronger evidence for the thinness of the γ-ray disk has been reported by Samami et al. (1974)

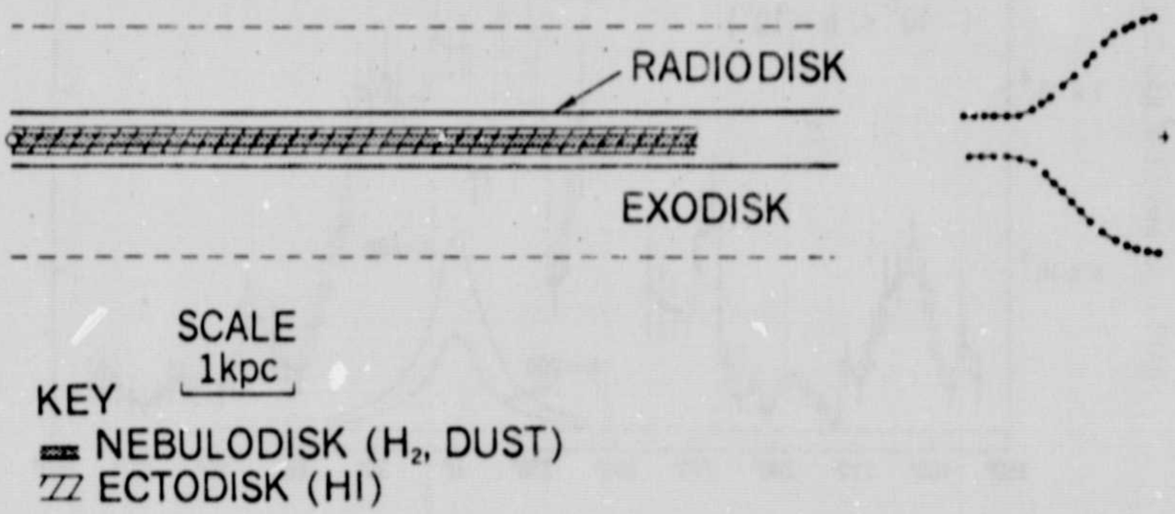

Figure 3. Regions of the galaxy as defined in the discussion given in the text.

which place this width at 3° whereas the SAS-2 resolution can only place an upper limit of about 6° on this width.[2] The asymmetry in the latitude distributions of γ-rays in the center and anticenter directions is further found to correlate well with the gas distribution again arguing for the dominance of pion-bremsstrahlung processes (Fichtel et al. 1975, Stecker et al. 1975, Puget et al. 1976).

4. Compton γ-Rays from the Galactic Center. The observed angular distribution of galactic γ-rays does not exclude the possibility of a significant Compton component being produced near the galactic center which is far enough away so that only a small angle is subtended by the galactic bulge. With a half angle of 0.1 rad (~5°), a source of 2 kpc thickness will be consistent with the γ-ray observations at the galactic center. Assuming that the starlight radiation density varies as the total mass distribution of Perek (1962) as suggested by Cowsik and Voges (1974), but with the radiation density at 10 kpc taken to be 0.44 eV/cm^3 (Allen 1973), I have recalculated the galactic Compton γ-ray flux as a function of galactic longitude assuming a cosmic-ray electron flux equal to its value at 10 kpc. The results are shown in Figure 4 for two different values of the γ-ray disk half-width h as indicated. For γ-ray production in the inner galaxy, where the detector beam covers the whole source, the line intensity is simply proportional to h and is given by

$$I_\gamma(\ell) = \frac{h \cos \ell}{2\pi} \int_{\sin^2 \ell}^{(R_m/10)^2} \frac{2x\,dx\,Q_\gamma(x)}{(1 - x^2)\,(x^2 - \sin^2 \ell)^{1/2}} \quad \text{where } x = R/10. \qquad (5)$$

R is the galactic radius in kpc and R_m is taken to be ~9 kpc. (Puget and Stecker 1974).

[2]The COS-B results in the 300-2000 MeV range reported here place an upper limit of 4° on this width.

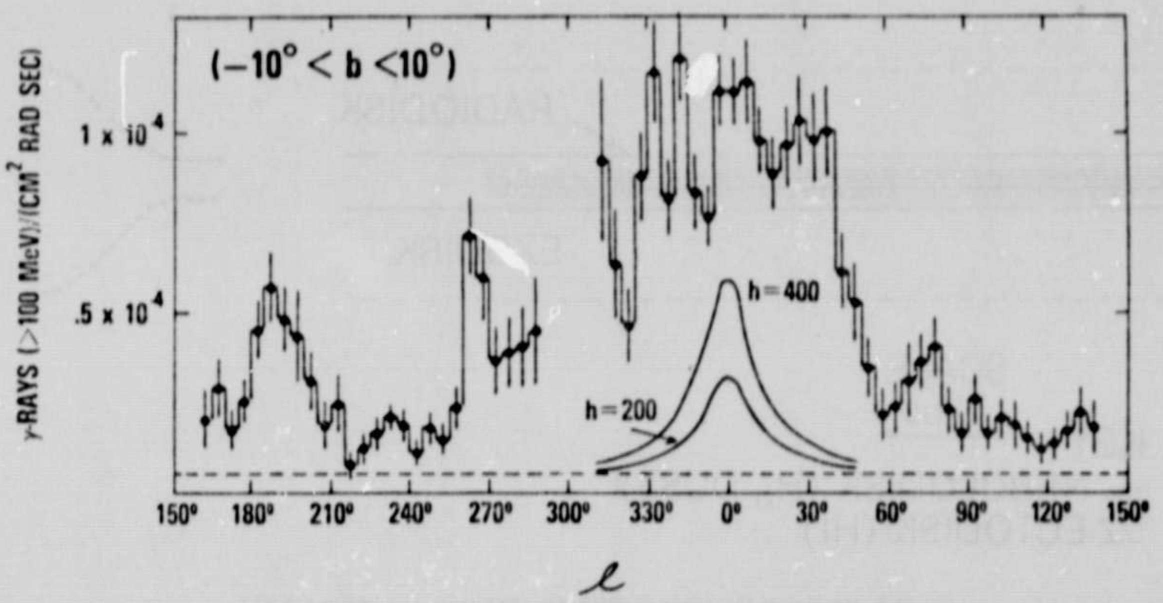

Figure 4. Compton production rate calculated using the method of Puget and Stecker (1974) for two values of half-thickness of the production disk h = 200 pc and 400 pc. These rates are shown together with the SAS-2 data reported by Fichtel et al. (1975).

It can be seen that, given an increased cosmic-ray electron intensity near the galactic center or a large enough value of h, it is possible for Compton scattering to provide a significant, or even major portion of the γ-ray flux near the galactic center as suggested by Cowsik and coworkers, contrary to the conclusions of Shukla et al. (1975). However, at longitudes less than 10° or 15° from the galactic center, the Compton contribution to the galactic γ-ray flux becomes relatively unimportant. This calculation is essentially in agreement with that of Dodds et al. (1975) for h = 115 pc. Stecker et al. (1975) pointed out that because of the relative lack of both HI and H_2 gas inside of 3 kpc (except at the galactic nucleus) not enough pion-decay and bremsstrahlung γ-rays could be produced to account for the flux at the galactic center but pointed out that the inclusion of Compton γ-rays could adequately account for the observed flux distribution and intensity.

One may ask whether the observed spectrum of γ-rays coming from the galactic center region can tell us the production source. Using a 5×10^3 K (Population II) photon field in the central region of the galaxy, and based on the radio synchrotron data, one would expect a differential γ-ray spectral index of 1.8 from Compton produced γ-rays in the 35-200 MeV energy range. The pion-bremsstrahlung spectrum shown in Figures 1 and 2 has an average index of 1.4 in this energy range. The observations (Fichtel et al. 1975) yield a mean index of about 1.65 ± 0.25 which is, unfortunately, not accurate enough to tell us whether Compton or pion-bremsstrahlung γ-rays provide the dominant contribution.

5. γ-Rays in the Galactic Disk. As was discussed earlier, it is expected that cosmic-ray-gas interactions (pion-bremsstrahlung) are more important than Compton interactions in producing γ-rays in most of the galactic disk. There remains the question of whether most of the galactic γ-rays are produced by diffuse processes or point sources. Here, the lines are not clearly drawn but two arguments seem to favor diffuse processes (a) only three significant point sources have been found by SAS-2, two of which are relatively nearby pulsars; moreover they have steeper spectra than the general galactic γ-radiation, and (b) by analogy with the case of the nonthermal radio radiation from cosmic ray electrons in the galaxy, one may argue that it is expected that the γ-rays also should be produced mainly by cosmic rays after they have left their sources and are in interstellar space rather than when they are still at the source (Lequeux 1971).

Since, therefore, it is most likely that most galactic γ-rays with energy above 100 MeV result from the decay of π°-mesons which were produced in interstellar interactions of cosmic-ray nucleons with interstellar gas nuclei, it follows that by studying the γ-ray emissivity distribution in the galaxy, one may learn about the distribution of cosmic-rays, mainly 1-10 GeV protons (Stecker 1973), and gas in the galaxy. We thus turn our attention, in the rest of this article, to a discussion of the implication of the SAS-2 observations of galactic γ-rays for determining new information about the distribution and origin of cosmic rays and about the structure and composition of the galaxy.

It was first deduced by Stecker et al. (1974) (later supported in calculations by Puget and Stecker (1974), Strong (1975), and Puget et al. (1976)) that the SAS-2 observations imply that γ-ray emission is highly nonuniform in the galaxy and that the emissivity distribution peaks in the region of the galaxy about halfway between the sun and the galactic center. My analysis of the latest version of the SAS-2 data with more events and smaller longitude bins (see paper of Kniffen, these proceedings) using the method of Puget and Stecker (1974) places this peak emissivity in the region between 5 and 6 kpc from the galactic center for the positive longitude side of the galaxy ($0° \leq \ell \leq 180°$) and at $\sim$5 kpc for the "negative" longitude side ($180° \leq \ell \leq 360°$) (See Figures 5 and 6 and section 7). The correlation between the and γ-ray distribution is excellent for the range $0° \leq \ell \leq 180°$; unfortunately, there is presently no CO data yet available for the range $180° \leq \ell \leq 360°$. The new γ-ray unfolding is in good agreement with that of Puget et al. (1976) for the range $0° \leq \ell \leq 180°$, however there are some differences in the range $180° \leq \ell \leq 360°$ due mainly to differences in the data used and the subtraction of a pulsar contribution at 345°.

It was noted by Solomon and Stecker (1974) that the γ-ray emissivity distribution bears a strong similarity to the distribution of molecular clouds in the

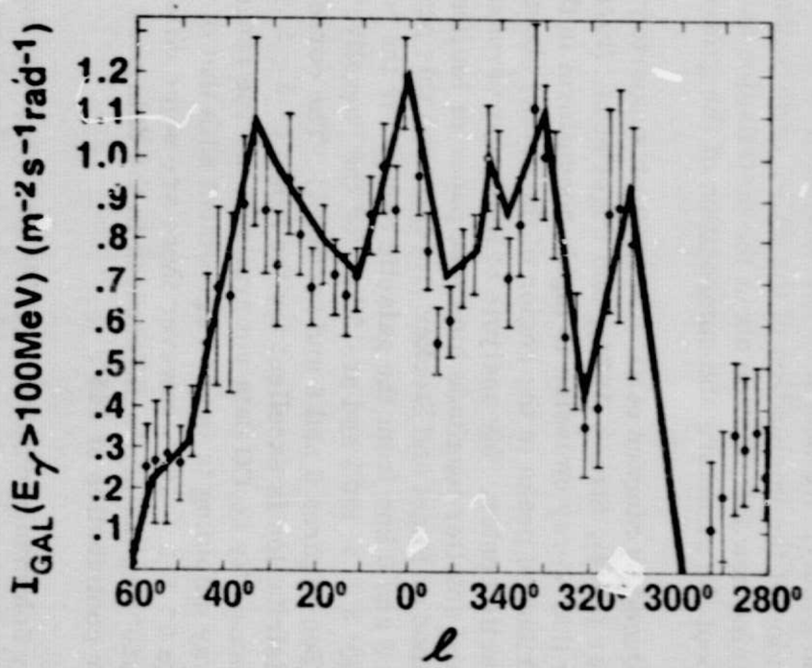

Figure 5. Most recent SAS-2 longitude data with more events reported in 2.5° longitude bins shown for the inner region of galactic longitude with the two points shown by the open circles having the contribution of pulsar PSR 1747-46 subtracted out (Kniffen, personal communication). The solid line shows the approximation to the distribution used in the unfolding calculation, the results of which are given in Figure 6.

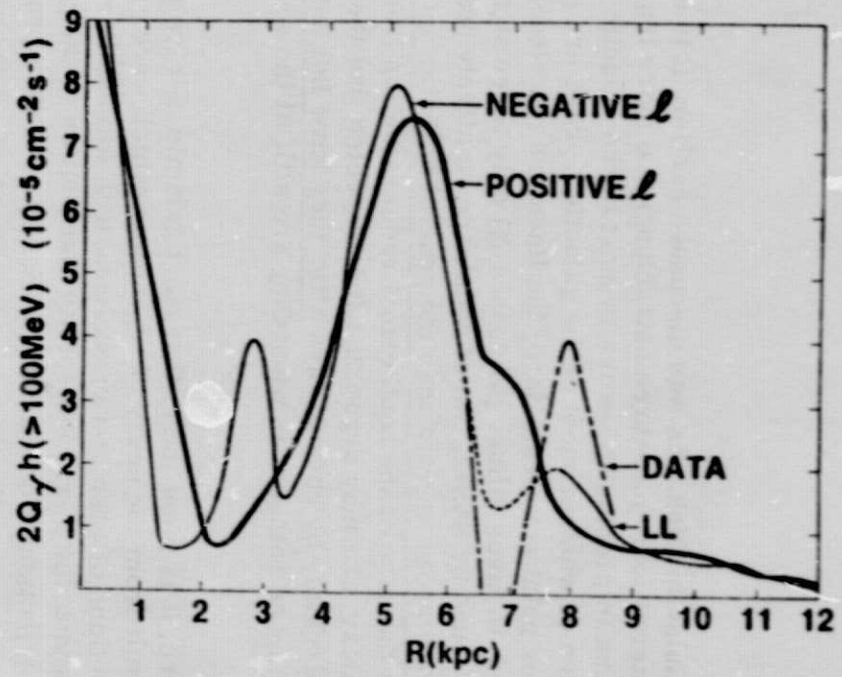

Figure 6. Radial distribution of galactic γ-ray emission obtained from unfolding the longitude distribution of Figure 5 for the ranges $0° \leq \ell \leq 180°$ (positive longitudes and $180° \leq \ell \leq 360°$ (negative longitudes). For negative ℓ, the unfolding using the data points in the range $310° \leq \ell \leq 317.5°$ is shown by the dot-dashed curve; that obtained using the lower limits to the statistical error bars is shown by the curve marked LL. The emissivity at the galactic center (R = 0) is approximately $1.5 \times 10^{-4}\ cm^{-2}\ s^{-1}$.

galaxy which also peaks in the 5 to 6 kpc region (Scoville and Solomon 1975, Burton et al. 1975). This similarity, coupled with the lack of enough gas in atomic form to explain the γ-ray measurements led to the supposition that H_2 is far more abundant in the inner galaxy than HI and that H_2 plays the major role in producing galactic γ-rays (Solomon and Stecker 1974, Burton et al. 1975, Stecker et al. 1975). In fact a γ-ray emissivity which scales like the more uniform HI distribution will not explain the observations. An alternative explanation for the γ-ray observations is to assume that the cosmic rays increase by more than an order of magnitude in intensity in the inner galaxy (Stecker et al. 1974) but this alternative encounters difficulties in producing instability in the galactic gas disk (Wentzel et al. 1975). The remaining problem has been to determine the absolute amount of H_2 in the galaxy as well as its distribution. This can be estimated both by using the UV observations of H_2 in the local galactic neighborhood as typical of the H_2 at a galactocentric distance of 10 kpc and by using the infrared and x-ray absorption measurements in the direction of the galactic center to estimate the total column density of gas in that direction. Stecker et al. (1975) used the data shown in Table 1 to estimate a total column density of $\sim 7 \times 10^{22}$ cm^{-2}. Gordon and Burton (1976) worked directly from their CO data to determine the H_2 density. Both these methods yield consistent results and indicate that the volume averaged density of H_2 is of the order of 2 molecules per cm^3 in the 5 to 6 kpc region (Stecker et al. 1975, Gordon and Burton 1976) and drops off dramatically inside of 4 kpc and in the outer galaxy. At 10 kpc, at least half of the interstellar gas is probably in atomic form and there is a negligible amount of H_2 in the outer regions of the galaxy (Scoville and Solomon 1975, Burton et al. 1976). The gas distributions obtained are shown in Figures 7 and 9. A subsequent deduction of the implied cosmic ray distribution indicates that the cosmic rays increase (relative to the local intensity) by about a factor of two (Stecker et al. 1975) or slightly more (Puget et al. 1976) at a maximum coinciding with the maximum in the gas density in the 5 to 6 kpc region and that the cosmic rays drop off rather rapidly in the outer galaxy (Stecker et al. 1975, Dodds et al. 1975). Dodds et al. (1975) have calculated the latitude distribution of γ-rays in detail under the "extragalactic" hypothesis (uniform cosmic ray intensity) and "galactic" hypothesis (reduced cosmic ray intensity in the outer galaxy) and compared the results with the SAS-2 observations as shown in Figure 9.

Stecker (1975b) has shown that the cosmic-ray distribution deduced using the γ-ray observations in conjunction with the deduced variation of total gas (HI + H_2) in the galaxy is, within experimental error, identical to the distribution of supernova remnants (Ilovaisky and Lequeux 1972, Kodaira 1974) and pulsars (Lyne 1974, Hulse and Taylor 1975, Sieradakis, these proceedings). The similarity of the deduced cosmic ray distribution and the distribution of supernova remnants provides our strongest evidence to date that the observed cosmic ray nucleons, which make up 99% of the cosmic rays, originate in galactic super novae either in the explosion or the resulting pulsars. It supports other evidence

Table 1. Column Densities of Hydrogen at $\ell = 0°$ Excluding the Galactic Nucleus ($\times 10^{-22}$) (cm^{-2}) ($N_{G.C.,\infty}$)

$\langle N_{HI} \rangle$ from 21 cm radio	$\gtrsim$ 0.6 to 1.5	Daltabuit and Meyer (1972)
	~ 2	Kerr and Westerhout (1965)
	$\leq$ 1.2	Clark (1965)
$\langle 2N_{H_2} \rangle$ from CO	3 to 10	Scoville and Solomon (1975)
$\langle 2N_{H_2} + N_{HI} \rangle$ from SAS-2 γ-ray flux	$\lesssim$ (11.5 ± 2)	this work ($I_{CR} \gtrsim I_{\odot}$)
$\langle 2N_{H_2} + N_{HI} \rangle$ from x-ray absorption	6.5 to 9	$\sigma_{H_2}/2\sigma_{HI} \leq 1.7$ (Kaplan and Markin 1973) as verified by the measurements of Crasemann et al. (1974).
$\langle 2N_{H_2} + N_{HI} \rangle$ from IR absorption	5 to 7.5	Ryter, et al. (1975)

from measurements of abundance ratios of heavy nuclides (see, e.g. Reeves, 1975).

Figure 9 shows the rough distributions of supernova remnants and total gas in the galaxy and Figure 10 shows the implied γ-ray longitude distribution calculated by Stecker (1975b) with Compton interactions included at the galactic center. Also shown is the observed longitude distribution (Fichtel et al. 1975).

6. Implication of the Large-Scale Galactic Distributions. On an overall large scale, there appears to be an excellent correlation between several important constituents of the galaxy in terms of their distributions as a function of galactocentric distance. These constituents are molecular clouds, HII regions (ionized hydrogen), cosmic rays, γ-rays, supernova remnants and pulsars. All of these constituents of the galaxy seem to be most dense in the 5 to 6 kpc region and appear to drop off sharply inside of 4 kpc and in the outer galaxy. They all can be associated with the formation and evolution of the so-called Population I stars in the galaxy and are known to have a Population I distribution. They are associated with the formation and destruction of hot young O and B stars in the galaxy which delineate arms in other spiral galaxies. That the correlation of

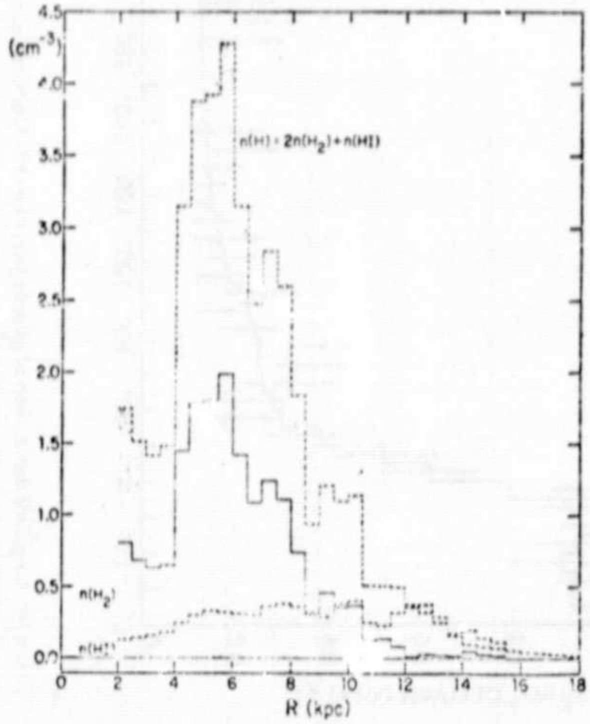

Figure 7. Volume density of interstellar hydrogen as a function of galactic radius given by Gordon and Burton (1976).

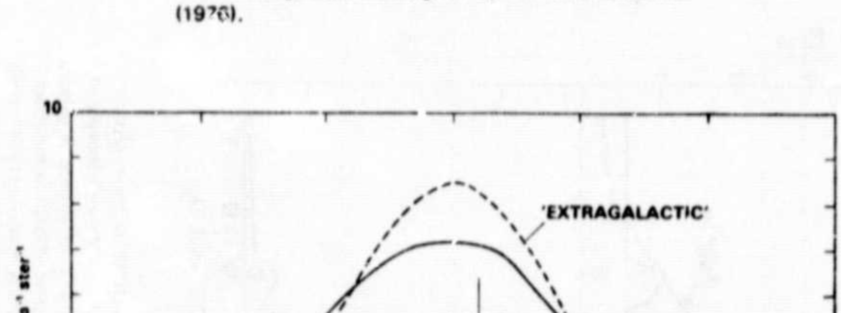

Figure 8. Calculated galactic latitude distributions of γ-rays for the "extragalactic" (uniform cosmic-ray flux) and "galactic" (falloff of cosmic rays in the outer galaxy) hypotheses as given by Dodds et al. (1975) together with SAS-2 data of Fichtel et al. (1975).

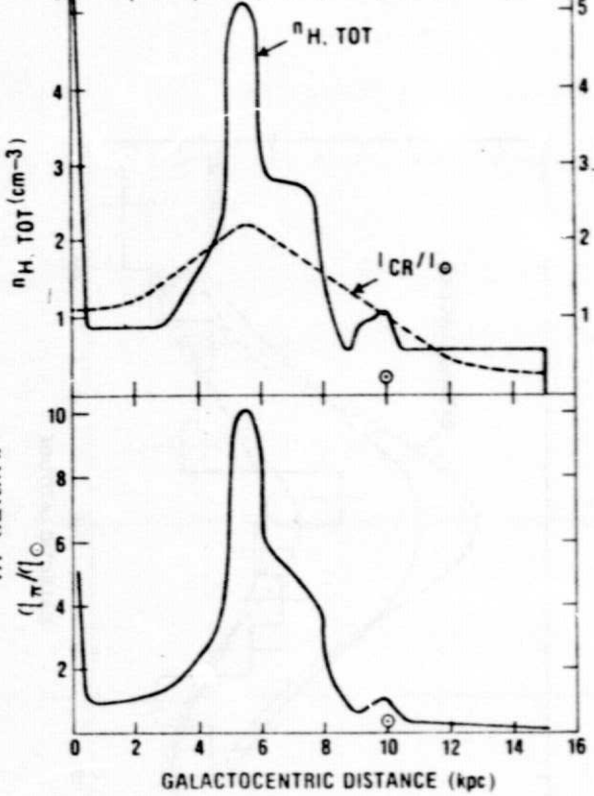

Figure 9. Volume density of interstellar hydrogen given by Stecker (1975) as deduced using the CO data of Scoville and Solomon (1975) together with the relative large-scale galactic cosmic-ray distribution, assumed proportional to the supernova remnant distribution deduced by Kodaira (1974) (top); the implied relative γ-ray emissivity from π^0-decay is also shown (bottom).

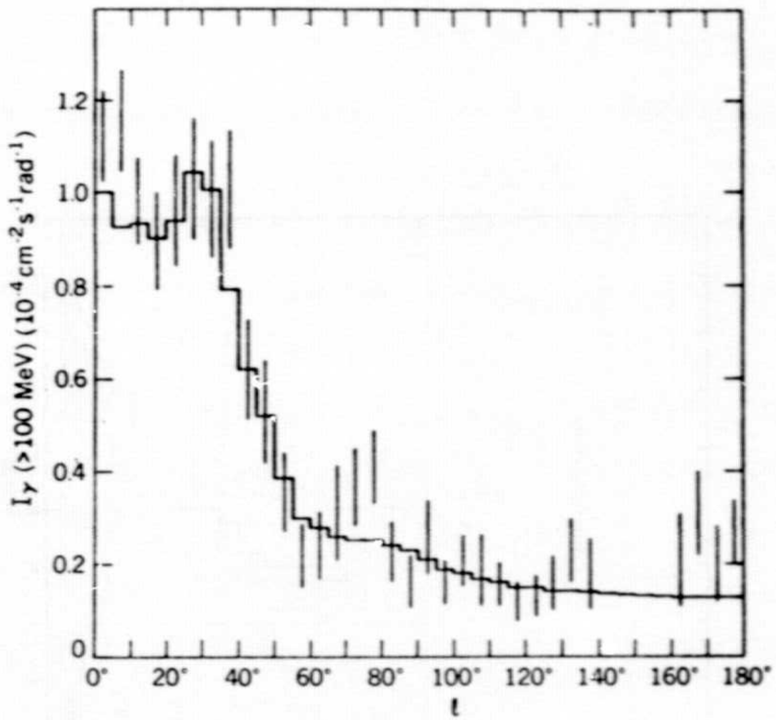

Figure 10. Longitude distribution of galactic γ-rays for $-10^{\circ} \leq b \leq 10^{\circ}$ averaged over 5° intervals calculated using the π^0-decay emissivity distribution given in Figure 9 and including effectsof bremsstrahlung from secondary electrons and Compton γ-rays at the galactic center (Stecker 1975). The Compton contribution at the galactic center, calculated using a local electron flux and a value of h = 100 pc, may be underestimated. The calculations are only valid for $0^{\circ} \leq \ell \leq 180^{\circ}$ and are shown by the histogram together with the data given by Fichtel et al. (1975), shown by the vertical lines.

these components is natural can be seen in Figure 11. The gravitational collapse of molecular clouds is expected to lead to the formation of OB associations containing the massive, hot, short-lived O and B stars whose ultraviolet radiation causes the formation of zones of ionized gas around them (HII regions). The massive O and B stars, after a few million years, terminate their existence as supernovae which in turn leads to the generation of cosmic rays. It has also been suggested that the supernova explosions can trigger the formation of new OB associations in a feedback effect (Öpik, 1953, Ögelman and Maran 1975). The compound effect of cosmic rays and molecular clouds being enhanced in the same region of the galaxy then leads to an even stronger enhancement in the γ-ray emissivity in the enhanced region. In addition, an increase in the flux of subrelativistic cosmic rays may help lead to an additional increase in the amount of ionized gas in the region around 5 kpc as indicated in recent surveys (Mezger 1970, Lockman 1976).

As a final note, Hayakawa et al. (1976) have recently reported a correlation between their observed 2.4 μm infrared flux and CO emission on a galactic scale. The shape of the longitude distribution given by Hayakawa et al. (see Figure 12) implies a strong maximum near 5 kpc which, one can argue, points to the emission originality in very young Population I objects. Thus, one may speculate that a major contribution comes from circumstellar shells surrounding pre-main sequence stars such as T Tauri stars or close surrounding Be stars (see e.g., the review of Neugelbauer, et al. 1971). A similar galactic distribution of diffuse far-infrared (100 μm–300 μm) emission originating in dust in molecular clouds has been predicted by Fazio and Stecker (1976).

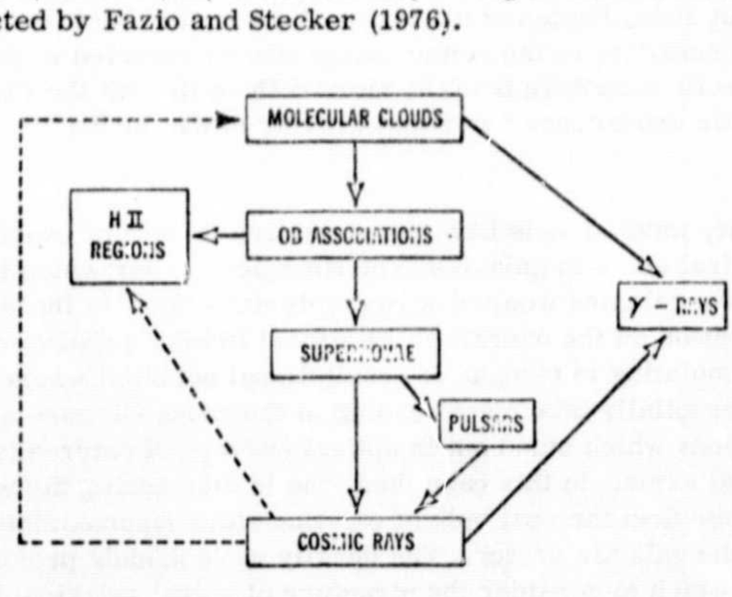

Figure 11. Plausible generic relations between various "Population I" galactic constituents (Stecker 1976).

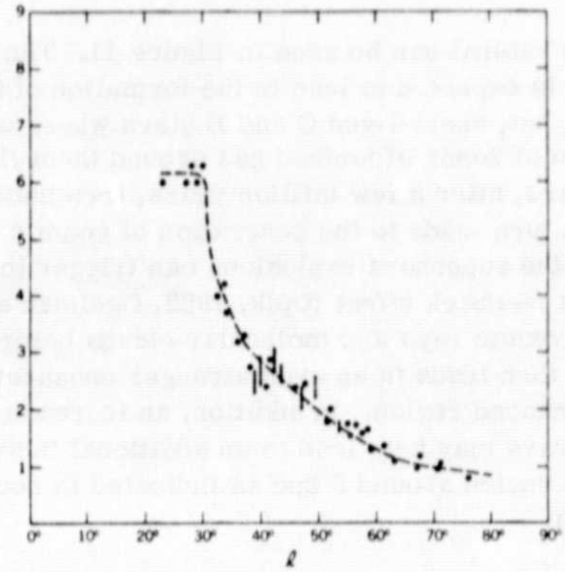

Figure 12. Gclactic longitude distribution of 2.4 μm infrared mission reported by Hayakawa et al. (1976).

Whereas all of the components of the galaxy just discussed have correlated large-scale galactic distributions with maximum densities in the 5 to 6 kpc region, 21 cm radio observations of HI indicate a relatively constant overall density distribution of atomic hydrogen between 4 and 14 kpc from the galactic center with no evidence for a significant enhancement in the 5-6 region (Kerr and Westerhout 1965, Burton et al. 1975). This implies that the H_2 distribution is much more sensitive to the compression effects expected in density wave models of galactic structure than the more diffuse HI with the ratio H_2/HI having a radial galactic dependence somewhat similar to that of HII/HI as discussed by Shu (1973).

The density wave models have the attractive feature of explaining the persistence of spiral arms in galaxies over time periods for which the differential rotation of these galaxies would destroy material arms. In these models, a spiral perturbation on the overall gravitational field of a galaxy results in excess gas accumulating in troughs of gravitational potential where star formation will then preferentially take place leading to the young OB associations and associated HII regions which stand out in optical surveys of external galaxies and delineate spiral arms. In this case then, one is only seeing the wave of new star formation rather than the real bulk of existing stars (approximately 95% as they move around the galactic center. The density wave models provide a plausible framework in which to consider the structure of spiral galaxies, but they are not complete in that they do not explain the origin of the spiral wave pattern itself or the energy input required to maintain it. In the context of the density wave theories, however, a crowding of the wave pattern and an increase in the frequency of gas shocking in the region of the inner arms would naturally lead to an increased density of molecular clouds, young stars, supernovae and HII regions in the 5 to 6 kpc region. The question of the details of spiral structure in the Galaxy is, however, more difficult. Our Galaxy apparently shares with other spiral galaxies a lack of gas of all types in the innermost region (radius less than 4 kpc with the exception of the galactic nucleus). Similar structural characteristics have been found in other spiral galaxies (Roberts 1974).

However, there is a large variation in structural details among spiral galaxies. This range of detail, from those with long thin well developed arms and high surface brightness (van den Bergh type I) to those with only a bare hint of arm structure (van den Bergh type V) has been incorporated into the general framework of density wave theory by Roberts et al. (1975). The galaxies with well developed arms and high surface brightness with an implied high star formation rate are found to satisfy the condition $(W_{10}/a)>1$ where W_{10} is the velocity component of basic rotation normal to the spiral arms and a is the effective acoustic speed of the interstellar gas. Within galaxies themselves there can exist in the inner regions, zones of strong nonlinear compression where $(W_{10}/a)>1$ and in the outer regions, zones of weak linear compression where $(W_{10}/a)<1$ Burton (1976) has estimated the interface between these two zones in our own Galaxy to occur at a galactocentric radius $R \sim 10$ kpc (see paper of Roberts, these proceedings).

Figure 13 shows the smoothed radial distribution of mean surface density of the atomic and molecular components of interstellar gas in our Galaxy based on recent data of Burton et al. (1975) where the H_2 density is normalized according to the methods of Stecker et al.(1975) with a scale height of ~ 65 pc for the molecular clouds (Scoville and Solomon 1975, Burton and Gordon 1976). Also shown are the regions of weak and strong compression. It can be seen that the transition region near 10 kpc is one in which the total surface density is roughly constant but where larger and larger amounts of gas are converted from HI to H_2 as R decreases.

All of these recent observational and theoretical developments regarding galactic structure[3] prompted Stecker (1976) to suggest the following changes in the Baade (1944) classification scheme for galactic objects:

(I) The classification "Population II" which consists of old disk stars ("high velocity" stars) nuclear bulge stars, halo stars and globular cluster stars stays the same.

[3]See also the summary and discussion of Burton (1976).

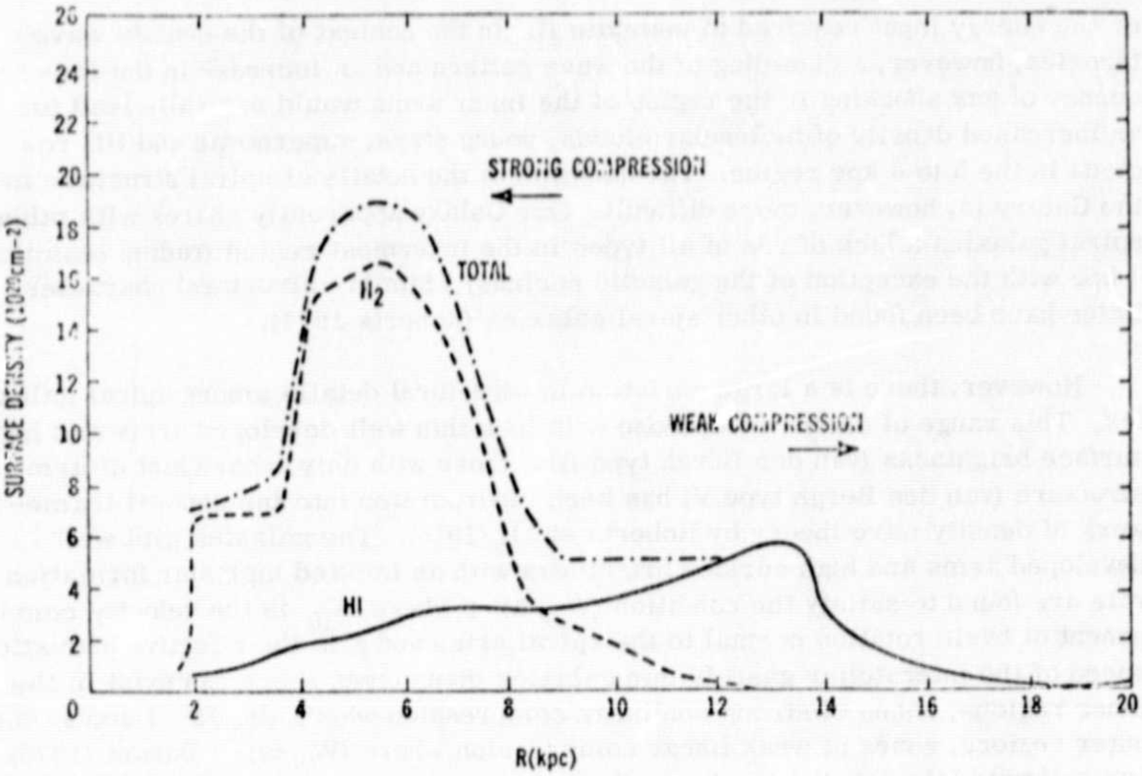

Figure 13. Surface density distribution of HI, H_2 and total gas, derived as described in the text, shown with regions of weak (linear) and strong (nonlinear) density wave compression as determined by Burton (1976). The figure is from Stecker (1976).

(II) The classification "Population I" should be expanded to include all galactic objects narrowly confined to the galactic plane and associated with the formation of Population I stars. Thus the set of galactic population I objects will include molecular clouds, OB associations, HII regions, dark nebulae, dust, supernovae and even associated radiation fields such as infrared (Fazio and Stecker 1976) synchrotron and π°-decay γ-radiation from molecular clouds. This population is expected to predominate in regions of the galaxy where $(W_{10}/a) > 1$ (strong compression).

(III) I define a new population class, "Population 0" consisting of the more diffuse atomic hydrogen which is now considered not to play a primary role in star formation. (In the case of some of the denser HI clouds there may be some blurring of definition). This population will be important in regions where $(W_{10}/a) < 1$ (weak compression). The main distinction between population 0 and I stems from the effects of compression and with the higher compression stemming from the nonlinear density waves. Two basic differences between the galactic distributions of the population I and Population 0 components are shown in Table 2.

Table 2

Population	Scale height perpendicular to plane	Galactocentric Radius of Maximum Surface Density
Population I	$\sim$ 50 to 70 pc (nebulodisk)	5 to 6 kpc
Population 0	$\gtrsim$110 pc (ectodisk)	12 to 13 kpc

The population I component is thus associated with the nebulodisk and the population 0 component with the ectodisk. It is found that in late-type spiral galaxies it is characteristic for the neutral hydrogen density to peak well outside the visible radius of the galaxy. (Roberts 1974). This is illustrated by Figures 14 and 15 from the work of Rots and Shane (1975) which shows clearly that for M81 the 21 cm emission peaks outside the optical disk of the galaxy. The above classification, with population 0 removed from a primary role in the star formation process, naturally accommodates this hitherto somewhat mysterious fact.

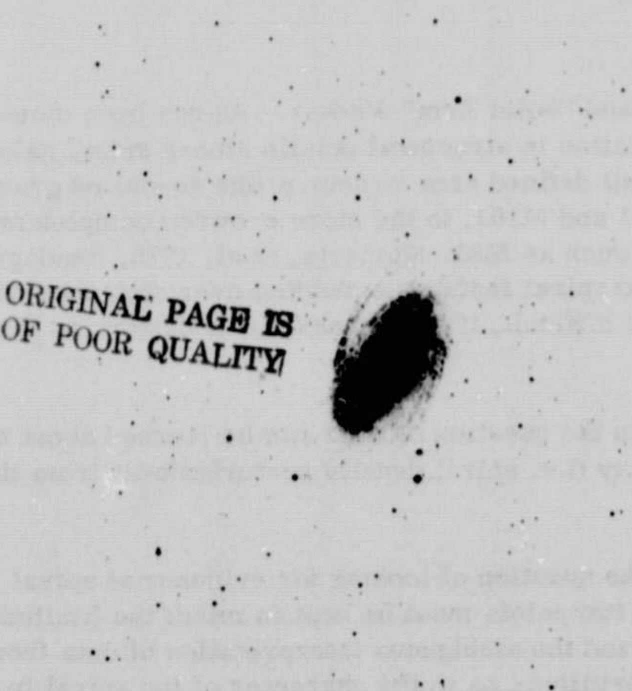

Figure 14. Optical image of M81 together with 21 cm contours (Rots and Shane 1975).

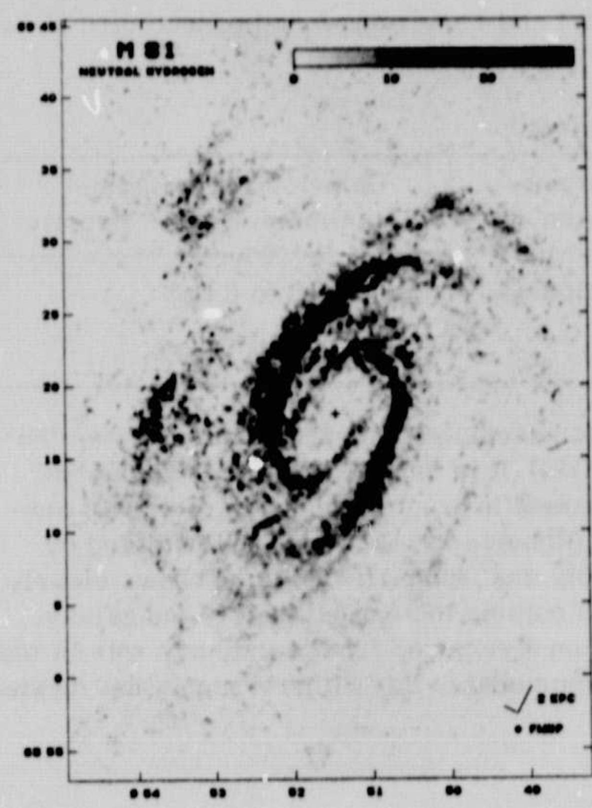

Figure 15. 21 cm radio map of M81 showing regions of neutral atomic hydrogen. The scale is the same as for Figure 14. It can be seen that the peak HI density lies at the outside of the optical image of the galaxy. (Rots and Shane 1975.)

7. Spiral Features and "Solid Arm" Models. As has been discussed above, there is a large variation in structural details among spiral galaxies, ranging from a bright and well defined arm structure (the so-called grand design) in galaxies such as M51 and M101, to the more crowded complex and nondescript features of galaxies such as M33. (Roberts, et al. 1975, Sandage 1961). In the latter cases, ordered spiral features extending over distances of the order of several kpc would be difficult, if not impossible to determine from a point within the galactic disk.

This brings us to the question of what can be learned about the "small scale" structure of the galaxy (i.e. spiral density perturbations) from the recent γ-ray observations.

In considering the question of looking for evidence of spiral structure in the γ-ray observations, two points must be kept in mind: the limited resolution of the SAS-2 telescope and the ambiguous interpretation of data from other types of astronomical observations as to the character of the spiral features of our Galaxy (Simonson 1970, Burton 1974). Burton (1974) has pointed out that 21 cm features associated with spiral arms could be due mainly or in part to kinematic effects. Therefore, while the overall distribution of "Population I" material can be understood in terms of density wave models of the Galaxy, one is on much shakier ground when it comes to analyzing the detailed structural features such as reconstructing spiral arms.

Attempts have been made to interpret the SAS-2 γ-ray data based on grand-design spiral models of the galaxy (Simonson 1976) with large arm-interarm ratios of both gas and cosmic rays (Bignami and Fichtel 1974), Bignami et al. 1975, Paul et al. 1976).

Because of the lack of CO data at negative longitudes, Bignami et al. constructed models based on 21 cm studies of atomic hydrogen. These models did not fully utilize the emerging implications of recent molecular cloud observations with regard to the galactic H_2 component in the inner galaxy. The models of Bignami et al. had therefore required unrealistically high amounts of HI at locations which have been attributed to arm features (see Figure 16) and proportionally large amounts of cosmic rays relative to the solar intensities ($I_{CR} \propto n_H$) in order to obtain fluxes of γ-rays to compare with the observations in the range $|\ell| \leq 40°$. These models also assumed that H_2 was proportional to HI everywhere in the galaxy so that $(n_{H_2} + n_{HI})/n_{HI} = K$ with (in the recent model of Bignami et al. (1975)) K = 2. Then since the γ-ray emissivity is proportional to the product $I_{CR} n_H$ with I_{CR} assumed proportional to n_H, $I_\gamma \propto (Kn_{HI})^2 \propto 4n_{HI}^2$. With this sensitive density dependence, the assumptions about n_{HI} shown in Figure 16 with $\langle n_{HI} \rangle$ above the recently observed values took on critical importance. Therefore, Kniffen et al. (these proceedings) have reexamined this model including the implications of the recent CO data. The model of Paul et al. (1976) has sought to relate the radio data to the γ-ray data by making the additional assumptions $I_{CR} \propto I_e \propto n_H \propto B^2$. They themselves point out, however, that the b distribution of the radio-synchrotron and γ-ray emission are different (see Figure 17). Also, there is only a rough relation between the longitude distributions of the two components which mainly reflects the overall structural features discussed earlier (see also section 9).

Passing on then from specific spiral arm models one may still consider the general question of whether the γ-ray observations provide evidence of spiral features. In this context, I previously noted that the expanding "3 kpc" arm, observed by its distinct separation on velocity-longitude plots of both HI and CO emission, has insufficient material either in atomic or molecular form to account for the largest peak in the observed galactic γ-ray distribution at $340° \leq \ell \leq 345°$ shown in Figure 4 as proposed by Bignami et al. The new longitude distribution reported here no longer has such a prominent feature as shown in Figure 5 with a ~5% contribution from PSR 1747-46 subtracted out (see Hartman, these proceedings). The unfolding of the new SAS-2 data shown in Figure 6 is compatible with emission from the 3 kpc feature, however, the explanation of a superimposed nearby source together with statistical fluctuations cannot be ruled out.

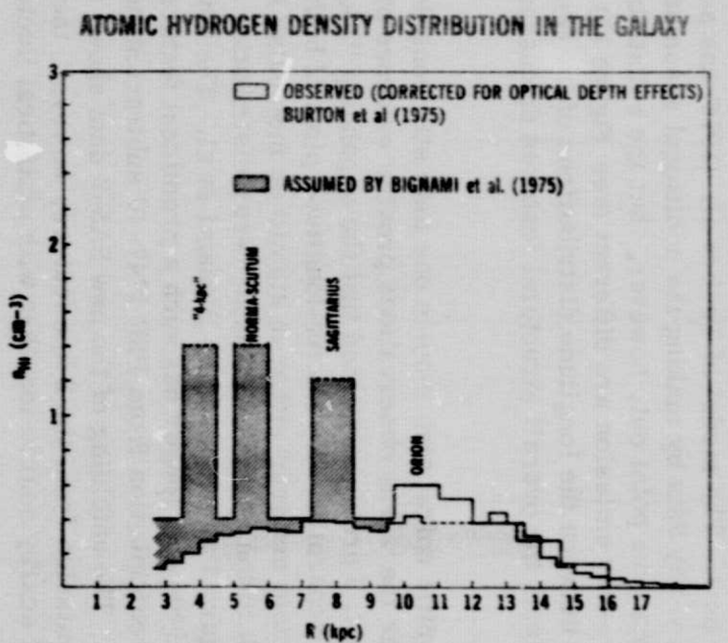

Figure 16. Mean HI density as a function of galactic radius as obtained from 21 cm surveys (Burton et al. 1975) and assumed in the recent spiral arm model of Bignami et al. (1975). This model further assumes that H_2 has the same galactic distribution as HI (contrary to the observations of Scoville and Solomon (1975) and Burton et al. (1975)). It is assumed in the model that $n_{TOT} = KN_{HI}$ with K = 2 (Bignami et al. (1975)). Circular symmetry is not assumed in the model and the figure only represents typical positions for the arm features. The model appears to overestimate the volume averaged density of HI (regardless of structural details) as determined by the 21 cm observations (see Stecker et al. (1975) for further discussion).

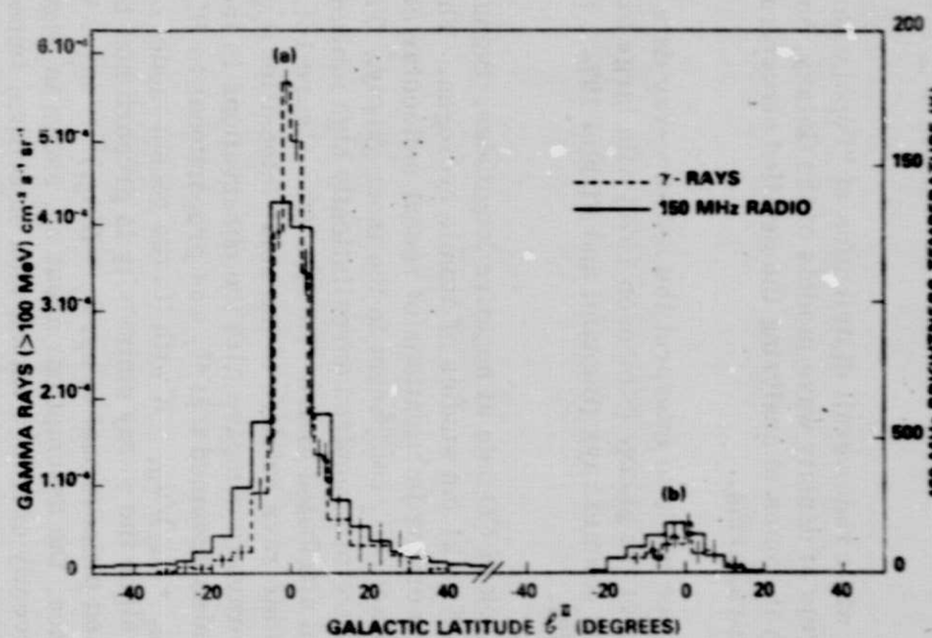

Figure 17. Comparison of latitude distribution of γ-rays (unresolved) and 150 MHz nonthermal emissions in the galaxy for the center (a) and anticenter (b) directions (Paul et al. 1976).

The large peak in the data in the range $310° \leq \ell \leq 315°$ has been associated by the SAS-2 group (Fichtel et al. 1975) with the "Scutum arm" feature as interpreted by some 21 cm observers. However, the narrow profile of this feature is hard to reconcile with that expected from a spiral arm. An ideal uniform spiral arm will fill in at longitudes closer to the galactic center than the tangential longitude so that it traces out a characteristic longitude distribution shaped somewhat like a shallow letter M. The inside slope of this pattern as calculated by the SAS-2 group in this model should be shallower than that actually observed. Looking at it another way, if one tries to unfold the longitude data for $180° \leq \ell \leq 360°$, it requires a negative γ-ray emissivity for $R \simeq 7$ kpc (see the dot-dashed curve in Figure 6) in order to obtain the steep slope inside of 315° on the longitude distribution. Since this is clearly nonphysical, one must look for an alternate explanation. One such explanation is to assume that the true flux is near the low end of the statistical error bars. The unfolding then results in the solid line shown in Figure 6 with a relatively small arm type feature at $R \simeq 7.7$ kpc which may be associated with the "Scutum arm." Such a feature is compatible with the mean gas density falling outside of 6 kpc. Another possibility is point source contamination. In order to truly resolve this problem and the whole problem of gas density on the "negative longitude" side of the galaxy, we must await further γ-ray observations with better statistics near 310° and filling in the data gap in the range $290° \leq \ell \leq 315°$. We also need CO observations from a millimeter wave facility in the southern hemisphere which will have access to this half of the galactic plane, and we also could make use of related far infrared observations (Fazio and Stecker, 1976).

In summary, neither the γ-ray nor CO observations provide clear evidence of arm features at positive longitudes, but an overall larger scale structure, fairly symmetric vis-a-vis positive and negative longitudes, indicating a maximum emissivity in the 5 to 6 kpc region is seen (see Figure 6). Possible evidence of arm features if found at negative longitudes (Fichtel et al. 1975) which may be associated with the complex distribution of HII regions at those longitudes (Puget et al. 1976) but which does not correspond to the flat $\langle n_{HI} \rangle$ distribution seen in 21 cm observations, even modulated with a large arm-interarm ratio. Such a model will not give the proper intensity or distribution of galactic γ-rays unless the H_2 cloud distribution is taken into account (Stecker et al. 1975). Further evidence for this may be seen in the lack of a "Sagittarius arm" feature at $\ell = 50°$ which is absent in both the CO observations (Scoville and Solomon 1975, Burton et al. 1975) and the SAS-2 γ-ray observations (Fichtel et al.1975). A strong Sagittarius arm would also be inconsistent with the γ-ray latitude observations of Samimi et al.(1974). The small γ-ray enhancement in the Cygnus region ($65° \leq \ell \leq 80°$) has been identified with the Orion arm by the SAS-2 group, however, the existence of the Orion arm is in serious question from the kinematical evidence of HI gas in that region (Burton and Bania 1974) and known clumpiness of gas with relatively large amounts of CO emission in that region, together with supernova remnants in that direction may help account for the observed γ-ray enhancement.[4] Additional evidence against cosmic ray confinement in a local ("Orion") arm comes from the lack of cosmic-ray anisotropy in this direction as well as the long-term constancy of the cosmic ray flux (Brecher and Burbidge 1972). New evidence of a possible 2×10^7 yr lifetime for cosmic-rays in the solar neighborhood (Garcia-Munoz et al. 1975) would rule out strict cosmic-ray confinement in arms with a γ-ray production rate proportional to n_H^2 as suggested by Bignami and Fichtel (1974) and Paul et al. (1976). Such a lifetime, although still uncertain (O'Dell et al. (1973), Hagen et al. 1975), would argue for diffusion of cosmic-rays in a larger region of the galaxy (Jokipii 1976) as will be discussed in more detail in the next section, and will support a weaker cosmic-ray correlation with larger scale galactic features as argued by Stecker et al. (1975) on the basis of the CO data.[5] These authors note that an approximate relation $I_{CR} \propto n_{TOT}^{\alpha}$ holds in the inner galaxy where $n_{TOT} \simeq n_{H_2}$ and $0.2 \leq \alpha \lesssim 0.5$.

8. Implications of a 20 My Lifetime for Cosmic-Rays on Interpretation of the γ-Ray Data. It has been established earlier that there must be a positive overall correlation between cosmic-rays and matter in the galaxy in order to explain the γ-ray production rate. On the other hand, should it be established that cosmic rays have a mean lifetime $\sim 2 \times 10^7$ yr. as obtained by Garica-Munoz et al. (1975), this would imply a relatively small mean gas density seen by cosmic-rays throughout their lifetime. Studies of cosmic-ray secondaries have revealed that cosmic rays travel through an average of 1.5 to 3×10^{24} atoms/cm^2 throughout their lifetime in the galaxy. Taking that lifetime to be 6×10^{14}s implies

$$\langle n_H \rangle_{\substack{\text{cosmic ray} \\ \text{confinement volume}}} = \frac{(1.5 - 3) \times 10^{24}\ \text{cm}^{-2}}{(3 \times 10^{10}\ \text{cm/s})\ (6 \times 10^{14}\ \text{s})} \simeq 0.1 - 0.2\ \text{cm}^{-3} \quad (6)$$

Jokipii (1976) has pointed out that the γ-ray evidence argues against their being trapped in "tunnels" in the galactic disk as suggested by Scott (1975). The other alternative, arguing against confinement in spiral arms, is that the cosmic rays spend considerable time in regions where $n_H \lesssim 0.2$ cm^{-3} as well as those where $n > 0.2$ cm^{-3}, and in a region thicker than the gas disk such as the radio-disk or exodisk (see Figure 3). Confinement in a large halo would require a $\sim 10^8$ yr trapping time (Ginsburg and Syrovatskii 1974) and appears not to be

[4] Much of the Cygnus enhancement has now been associated with Cygnus X-3 (Thompson, these proceedings).

[5] Arm effects in the γ-ray longitude profile can, of course, be caused by density and source perturbations alone without invoking cosmic-ray confinement.

consistent with the radio evidence (Webster 1975). In addition confinement in such a large region would tend to wipe out any radial gradient in the cosmic-ray flux as suggested by the γ-ray observations (Stecker 1975, Dodds et al. 1975). Thus, one might presently favor an "exodisk" concept as suggested by Jokipii (1976) and as perhaps as illustrated by the radiodisk studies of some spiral galaxies in the observation of Ekers and Sancisi (1976). An example from these observations is NGC4631 shown in Figure 18. As can be seen from the figure, a fat disk or flat halo type region of synchrotron emission surrounds NGC4631; such a region may also exist around our own galaxy. An even more apt example may be the spiral NGC891 which shows a radiodisk of thickness ~ 4 kpc (Van der Kruit and Allen 1976) and a gas disk, seen in 21 cm, of thickness $\lesssim 500$ pc (Sancisi, quoted by Ekers 1975). (See paper of Baldwin, these proceedings).

9. Comparison of Radio and γ-Ray Longitude Distributions. Paul et al. (1976) have constructed a model of γ-ray emission in our Galaxy based in part on the assumption of the relation $I_e B^2 \propto I_{CR} n_H$ which implies $I_{sync} \propto I_\gamma$. It is my own philosophy that one should eliminate such a priori assumptions and work from the data as much as possible. One can learn from comparisons of the distributions of various galactic emissions, both from their similarities and their differences. It has already been remarked that the 150 MHz radio and γ-ray emissions have different latitude distributions. Figure 19 shows that similarities and differences also exist in the longitude distributions. The SAS-2 γ-ray data is shown by the histogram and the radio data is taken from Price (1974) with the positions of the tangents of 21 cm features shown by the arrows. Note that the γ-ray distribution is generally wider in the inner galaxy than the radio distribution. Both are enhanced in the Cygnus region ($\ell \simeq 80°$) and in the longitude range near 310°. Note, however, that in the later case, the reported γ-ray emission is relatively much more intense than the 150 MHz emission, supporting the suggestion made earlier in this paper regarding the 310° feature (see Figure 6). The peak in the γ-ray distribution at $\sim 260°$ can be attributed to the Vela pulsar and the enhancement in the anticenter direction is due primarily to the Crab pulsar and another γ-ray source at $\ell \simeq 193°$.

10. The Galactic Contribution to the High-Latitude γ-Ray Background. The revised Apollo data shown in Figure 20 (Trombka et al. 1976) are consistent with other data in the ~ 1 MeV range and are consistent with cosmological redshifted π^0-decay processes proposed by the author in the past (Stecker 1969, 1971, Stecker et al. 1971, Stecker 1974, 1975a) which predict a shelf-like feature near ~ 1 MeV and a steep spectrum $\sim E^{-3}$ above 10 MeV. At energies between 35 and 200 MeV, the observed spectrum at high galactic latitudes ($b > 30°$) appears to be flatter than at lower energies, $\sim E^{-(2.4 \pm 0.2)}$ (Fichtel et al. 1975). This can be readily explained as high latitude galactic background emission due to the finite thickness of the galactic γ-ray disk. Taking a typical SAS-2 path length

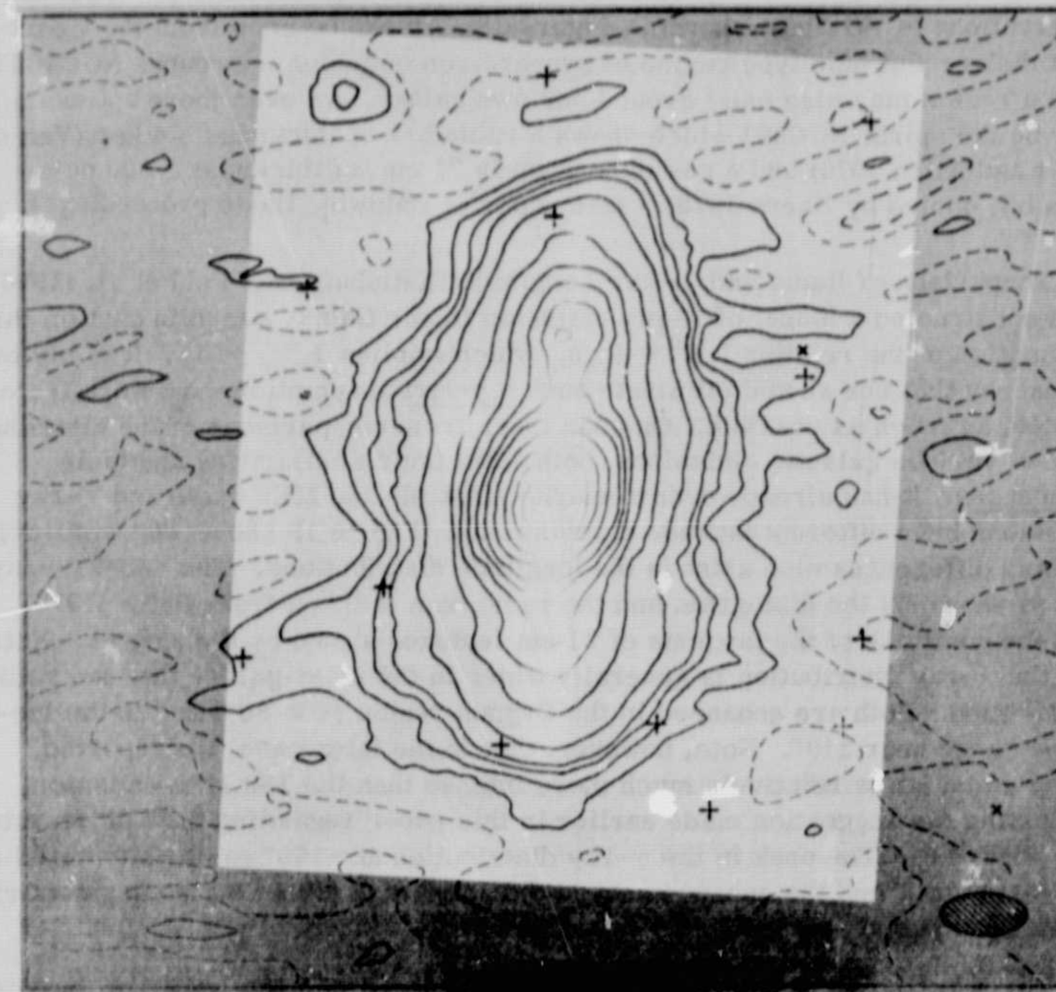

Figure 18. Optical image of the edge-on spiral galaxy NGC 4631 together with preliminary 50 MHz radio contours obtained with the aperture synthesis array at Westerbork by Ekers and Sancisi (personal communication).

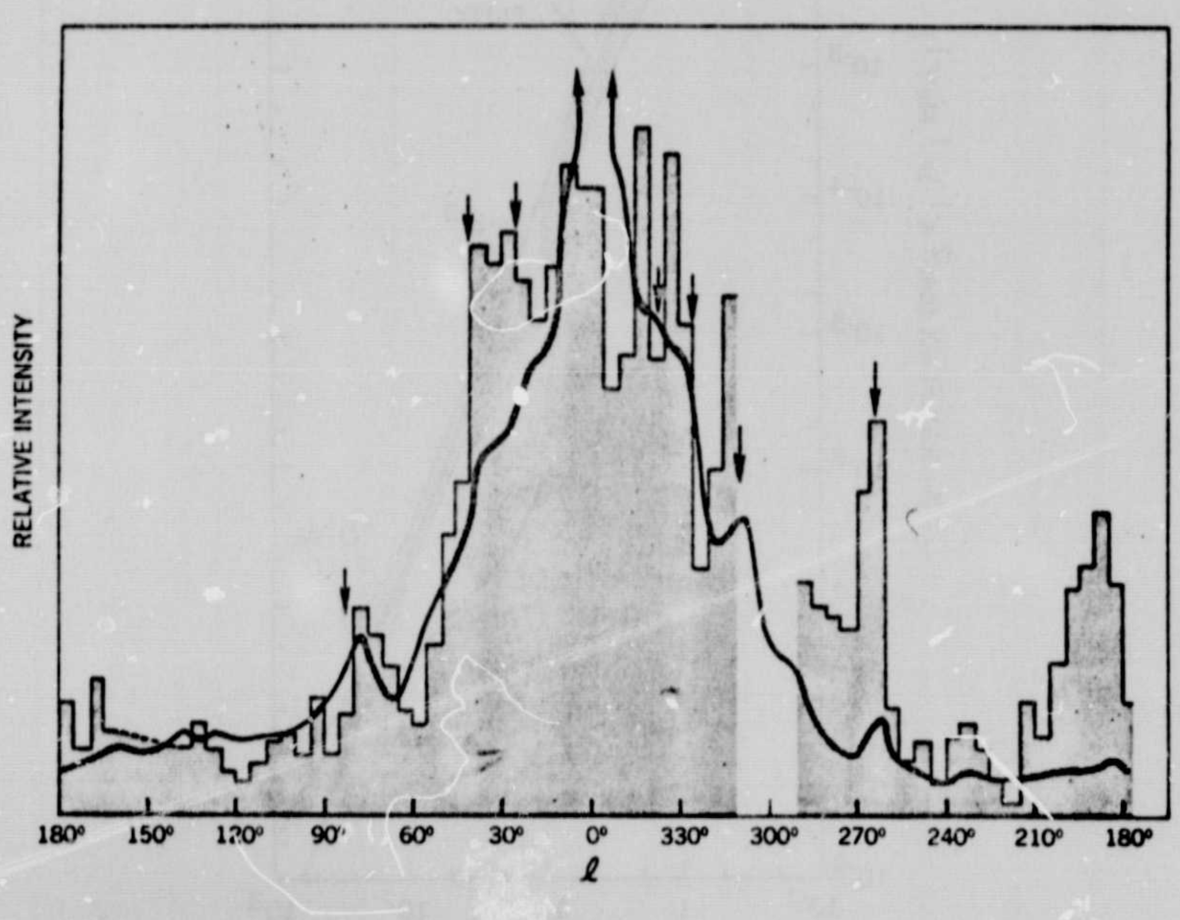

Figure 19. Comparison of longitude distributions of γ-rays (Fichtel et al. (1975) and 150 MHz radio emission (Price 1974).

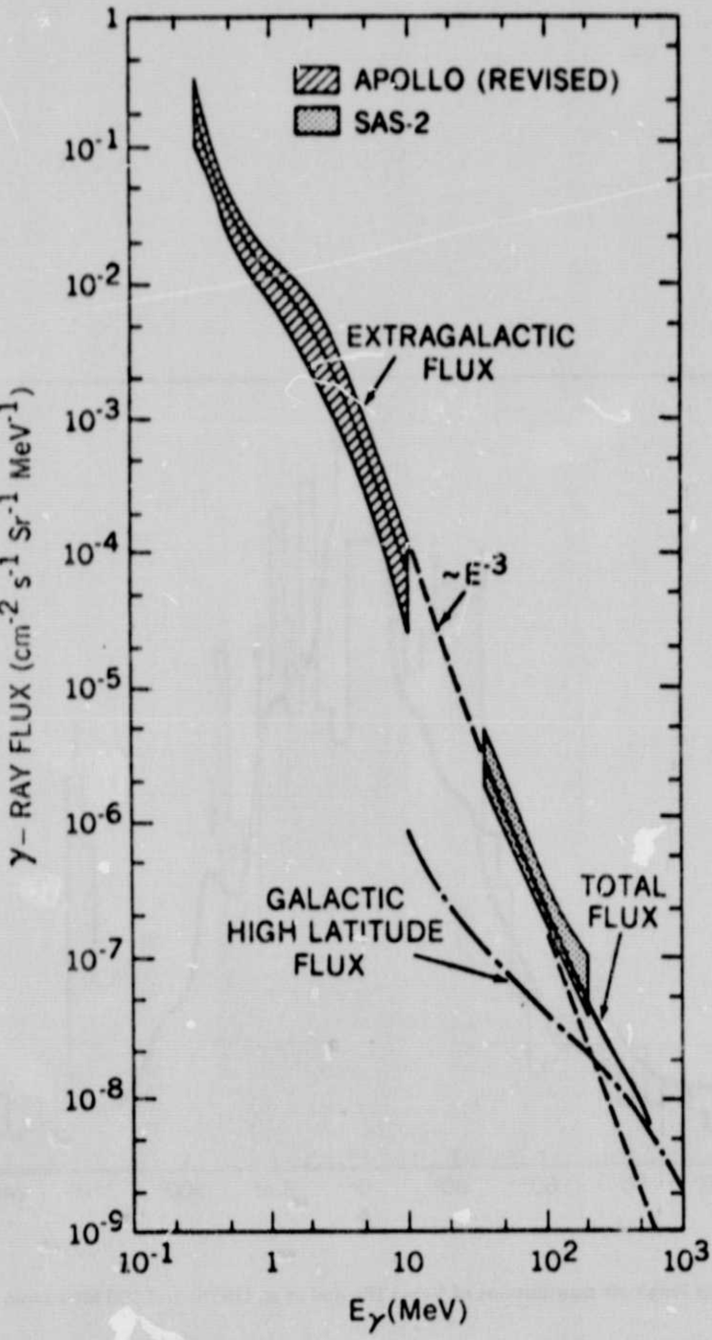

Figure 20. Revised background γ-ray observations from Apollo 15 (re-corrected for intrinsic spurious events (Trombka, personal communication) and high latitude SAS-2 observations (Fichtel et al. 1975). The cosmological background is expected to have a E^{-3} form above $\sim$ 10 MeV from the π^0-decay models (see Stecker 1975 for discussion and review). The contribution from the high-latitude galactic flux, as calculated in this work, is sufficient to flatten the total spectrum to the shape observed by SAS-2 with an approximate $E^{-2.4}$ form at energies between 35 and 200 MeV. The galactic Compton contribution at high latitudes used here may be underestimated (a larger scale height may be more appropriate.) But this does not significantly change the total flux or shape of the spectrum calculated.

of 3×10^{20} csc b cm^{-2} (Falgarone and Lequeux 1973) with $b \sim 40°$, and using the differential production rate shown in Figure 2. Choosing an E^{-3} power law above 10 MeV which runs through both the SAS-2 and Apollo data (shown in Figure 20 by a dashed line) and adding in the galactic flux, the total flux expected is shown by the solid line. This can be seen to be flatter than the pure extragalactic background component and consistent with the SAS-2 data. The effect of the galactic contamination can be reduced ideally by ~33% by making observation at $b = 90°$. However, it should be noted that the galactic background can still be expected to dominate at energies above 300 MeV making a proposed test (Stecker 1974, 1975) between the cosmological π^0-decay models of the γ-ray background invalid.[6]

11. γ-Rays and Galactic Structure: An Approach for the Future. The early optimistic hope of 21 cm observers to delineate the spiral structure of the Galaxy has been dimmed by complications in the analysis of even the most thorough velocity-longitude plots due to kinematic (velocity streaming) effects, nonuniformities within arm features (fragmentation, branching, etc.) and strong non-circular gas velocities as evidenced at $\ell = 0°$. At the same time, high-resolution 21 cm surveys of external spirals, such as the Rots and Shane (1975) work on M81 shown in Figure 14, have shown that large-scale spiral structure exists in the gas in spiral galaxies, as we know it exists in other components such as dust clouds, HII regions and OB associations. The CO observations of our Galaxy, which should reflect arm structure in young molecular clouds even more strongly than the 21 cm observations, have not revealed such structure in the $0° \leq \ell \leq 180°$ range. However, they have excitingly revealed a larger scale overall galactic structure which shows a broad maximum in the 5-6 kpc region. The existence of this structure is supported by the γ-ray observations. Strong correlations with other Population I phenomena in the galaxy suggest that a new picture of overall galactic structure is emerging and will lead to new understandings of the nature of the Galaxy.

Some γ-ray observers have exhibited the optimism shown in the early 21 cm work in looking for spiral features. However, it should be remembered that γ-ray observations provide even more disadvantages in their analysis than 21 cm observations. Three important disadvantages inherent to the γ-ray observations and not the 21 cm observations are (1) no velocity information to help determine from where in the galaxy emission at a specific longitude originates, (2) relatively poor angular resolution in the present data, which restricts fine-scale structure studies and (3) the fact that the γ-ray emission is proportional to the product of gas density and cosmic-ray intensity integrated along the line-of-sight so that assumptions must be made to separate these two quantities or, preferably, other observations must also be used to determine the gas density.

[6]Theoretical difficulties have arisen with regard to various aspects of the Omnes model for baryon-antibaryon separation in the early universe. At present, the author considers these difficulties to be intrinsically no worse than those with the standard "big-bang" cosmology (see e.g., Gunn and Tinsley 1975). The possibility of some mechanism of baryon separation on a large scale as an explanation for the γ-ray background should not be prematurely discarded at this time.

Of course, the γ-ray observations have their advantages. Optical depth corrections are entirely unnecessary. And, to the extent that the gas density distribution can be obtained by other means (using as much of the electromagnetic spectrum as possible, e.g., radio, microwave and far-infrared observations Fazio and Stecker (1976)) the galactic cosmic-ray nucleon distribution can then be deduced. Indeed, 100 MeV γ-ray observations are unique in their potential for determining information about the large-scale distribution of galactic cosmic-ray nucleons. Using the above approach, large-scale structure in both the interstellar gas and the cosmic-ray distributions is now becoming apparent. Higher resolution γ-ray observations should enable us to study important unresolved questions about small-scale and spiral structure features. A concerted "synoptic" approach to galactic surveys by observers at all wavelengths should enable us in the future to take advantage of complementary observations and improve our understanding of the structure and dynamics of the galaxy.

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