General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

NASA TM X- 71015

GALACTIC γ-RAY OBSERVATIONS AND GALACTIC STRUCTURE

F. W. STECKER

NOVEMBER 1975

DEC 1975
RECEIVED
NASA STI FACILITY
INPUT BRANCH

GALACTIC γ-RAY OBSERVATIONS AND GALACTIC STRUCTURE

F. W. Stecker
Theoretical Studies Group
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771

ABSTRACT:

Recent observations of γ-rays originating in the galactic disk together with radio observations, support an emerging picture of the overall structure of our Galaxy with higher interstellar gas densities and star formation rates in a region which corresponds to that of the inner arms. The emerging picture is one where molecular clouds make up the dominant constituent of the interstellar gas in the inner galaxy and play a key role in accounting for the γ-rays and phenomena associated with the production of young stars and other population I objects. In this picture, cosmic rays are associated with supernovae and are primarily of galactic origin. These newly observed phenomena can be understood as consequences of the density wave theories of spiral structure. Based on these new developments, the suggestion is made that a new galactic population class, "Population 0", be added to the standard Populations I and II in order to recognize important differences in dynamics and distribution between diffuse galactic HI and interstellar molecular clouds.

Regarding finer scale galactic structure, the present γ-ray observations have not added significantly to our knowledge of the details of the galactic features such as spiral arms.

GALACTIC γ-RAY OBSERVATIONS AND GALACTIC STRUCTURE

The pioneering work of Kraushaar, Clark and Garmire[1] 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 of Fichtel et al.,[2] we have our sharpest view yet of the galaxy in γ-rays. Although this view is still too blurred to give us many of the answers we want, it is still good enough 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.

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[3,4] 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, i.e. more energetic.

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 (see figure 1).

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.

4) There are indications of more fine-scale structure in the observations (Figure 1) 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.

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^0 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.

For the γ-ray region above 100 MeV, it is easy to show that π^0 decay γ-rays dominate over bremsstrahlung γ-rays in the galaxy since one knows the relevent cross sections and the estimates of the cosmic ray electron-nucleon ratio are good enough for this conclusion to be reached.[4] (Of course, the reverse is true for lower energy γ-rays since the π^0 decay differential spectrum turns over at ~ 70 MeV). The above conclusion is valid independent of the gas density distribution in the galaxy since both production processes are proportional to the total gas density and one would therefore expect similar emissivity distributions in the galaxy in both cases.

A comparison of the π^0-decay and Compton processes is not as straight-forward since, in this case, the former process scales like the gas density and the latter scales like the low-energy photon density in the galaxy. There are, however, four reasons for concluding that pion decay dominates over Compton production of γ-rays in most of the galaxy (with the exception of the region near the galactic center). a) theoretical estimates based on cross sections, cosmic ray intensities and target densities lead to this conclusion,[4] b) if the Compton process were domi-nant, a sharper peak would be expected in the longitude distribution of galactic γ-rays than that observed[5] c) with the peak emissivity of γ-rays in the galaxy implied by the SAS-2 results to lie 4 to 5 kpc from the sun[6-9] the γ-ray disk appears to have a width of less than 210 pc consisent with the gas disk[10] whereas the Compton process would predict a disk width of $\sim$ 500 pc or more. d) The energy spectrum of γ-rays, even in the direction toward galactic center appears to indicate that π^0 decay is the dominant production mechanism.[2,6] 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 two significant point sources have been found by SAS-2 which are relatively nearby pulsars, moreover <u>they have steeper spectra than the general galactic γ-radiation</u>, 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 <u>after they have left their sources</u> and are in interstellar space rather than when they are still at the source.

Since, therefore it is most likely that most galactic γ-rays with energy above 100 MeV result from the decay of π^0-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[11]) 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.[6] (later supported in calculations by Puget and Stecker[7] and Strong[8]) 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. Analysis of the final SAS-2 data places this peak emissivity in the region between 5 and 6 kpc from the galactic center.[9] It was noted by Solomon and Stecker[12] that the γ-ray emissivity distribution bears a strong similarity to the distribution of molecular clouds in the galaxy which also peaks in the 5 to 6 kpc region.[13,14] This similarity, coupled with the lack of enough gas in atomic form (HI) 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.[12,13,15] 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[6] but this alternative

encounters difficulties in producing instability in the galactic gas disk.[16] 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[17] 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. Both these methods yield consistent results and indicate that the volume averaged density of H_2 is of the order of 2 to 3 molecules per cm^3 in the 5 to 6 kpc region and drops off dramatically inside of 4 kpc and in the outer galaxy so that 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. A deduction then of the implied cosmic ray distribution indicates that the cosmic rays increase (relative to the local intensity) by about a factor of two[15] or slightly more[9] 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.[15,18] 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[19] and pulsars.[20] 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 supernovae either in the explosion or the resulting pulsars.[21]

On an overall large scale, therefore, 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.[22] 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 these components is natural can been seen in Figure 2. 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.[23,24] 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 enhancement in the flux of subrelativistic cosmic rays may help lead to a strengthened enhancement in the amount of ionized gas in the region around 5 kpc as indicated in recent surveys.[25]

Whereas all of the above components of the galaxy 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 kpc region.[14,26] 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.[27]

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* 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

*approximately 95%

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.[28]

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.[29] The galaxies with well developed arms and high surface brightness with an implied high star formation rate are found to satisfy the condition $(W_{\perp}/a) > 1$ where $W_{\perp}$ 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 $(W_{\perp}/a) > 1$ and in the outer regions, zones of weak linear compression where $(W_{\perp}/a) < 1$ Burton[30] has estimated the interface between these two zones in our own Galaxy to occur at a galactocentric radius $R \sim 10$ kpc.

Figure 3 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.,[14] where the H_2 density is normalized according to the methods of Stecker et al[15] with a scale height of ~ 50 pc for the molecular clouds. Also shown are the regions of weak and strong compression.[30] 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*prompt us to suggest the following changes in the standard 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.

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 *'e 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, synchrotron and π^0-decay γ-radiation from molecular clouds. This population is expected to predominate in regions of the galaxy where $(W_1/a) > 1$ (strong compression).[14,29,30]

III) 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 $(W_1/a) < 1$ (weak compression). The main distinction between populations 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 1.

---

*see also the summary and discussion of Burton[30]

TABLE 1

	Scale height perpendicular to plane	Galactocentric Radius of Maximum Surface Density
Population I	∿ 40 to 70 pc	5 to 6 kpc
Population 0	≥ 110 pc	12 to 13 kpc

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.[28] The above classification, with population 0 removed from a primary role in the star formation process, naturally accommodates this hitherto somewhat mysterious fact.

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.[29,33] 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 γ-ray telescope and the ambiguous interpretation of data from other types of astronomical observations as to the character of the spiral features of our Galaxy.[31,32] 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[34] with large arm-interarm
ratios of both gas and cosmic rays.[35,36]

Unfortunately, these attempts have ignored or downplayed the
implications of recent molecular cloud observations[13,14] with regard
to the importance of the galactic H_2 component in the inner galaxy. They
have therefore required one to postulate unrealistically high amounts of
HI at locations which have been attributed to arm features (see Figure 4)
and equally large amounts of cosmic rays relative to the solar intensities
in order to obtain fluxes of γ-rays large enough to compare with the
observations in the range $|\ell| \lesssim 40°$. They have also assumed that H_2 is
proportional to HI everywhere in the galaxy so that $(n_{H_2} + n_{HI})/n_{HI} = K$
with (in the recent case of reference 36) $K = 2$. Then

$$I_\gamma \propto (Kn_{HI})^2 \propto 4n_{HI}^2 \ .$$

With this sensitive density dependence, the questionable assumptions
about n_{HI} shown in Figure 4 take on critical importance.

Passing on then from the specific form of the interpretation of
reference 35 one may still consider the general question of whether the γ-ray
observations provide evidence of spiral features. In this context, one
may immediately note that the expanding "4 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 $340° \leq \ell \leq 345°$ as proposed by Bignami et al.[13,14]

In any case, sharp structure of that type can be more readily explained
in terms of a possible nearby source (like the peaks due to the Crab and Vela
pulsars) superimposed upon the general increase in the galactic γ-ray

flux in the inner galaxy with some possibility of statistical fluctuations in the data. Another problem with the spiral arm interpretation is the lack of a strong feature at 50^0 from the Sagittarius arm (see figures 1 and 4). A strong Sagittarius arm would also be inconsistent with some γ-ray latitude observations.[10] But this again should not be surprising since even the molecular cloud measurements do not provide evidence for a significant enhancement of gas in that region. The γ-ray enhancement in the Cygnus region ($65^0 \leq \ell \leq 80^0$) has been identified with the Orion arm but the existence of the Orion arm is in serious question from kinematical evidence of HI gas in this region[37] and known clumpiness of gas and supernova remnants in the direction of Cygnus may account for this enhancement. One can see that this is reasonable if one notes that an even larger enhancement in over a 25^0 longitude range in the anticenter direction could not possibly be due to the fact that we are looking tangentially along a spiral arm straight out away from the galactic center. Additional evidence against cosmic-ray confinement in an Orion arm comes from the lack of cosmic-ray anistropy in this direction as well as the long-term constancy of the cosmic ray flux.[38]

Given then our presently existing γ-ray observations of the galaxy, with only 5^0 resolution in longitude, it appears that while the overall matter distribution and H_2/hI ratio distribution in the galaxy are consistent with the concepts of density wave theory, the γ-ray observations have as yet added nothing concrete to the rather ambiguous conclusions from the 21 cm radio data[32] regarding the details of galactic spiral features.

Addendum: In a recent preprint, Fichtel et al. (NASA X-662-75-246) have stated that cosmic rays will not penetrate molecular clouds to produce γ-rays. There is, however, no observational evidence or compelling theoretical argument to support the contention that 1 to 10 GeV cosmic rays will be excluded from these regions. Indeed, the γ-ray evidence supports the opposite point-of-view, since, as pointed out in this paper, interactions of cosmic rays with HI alone cannot explain the high γ-ray emissivity in the inner galaxy. Also, of course, one can note the excellent correlation between γ-rays and molecular clouds on a galactic scale.

REFERENCES

1. Kraushaar, W. L., Clark, G. W., Garmire, G. P., Borken, R., Higbie, P., Leong, V. and Thorsos, T., Astrophys. J. 177, 341 (1972).

2. Fichtel, C. E., Hartman, R. C., Kniffen, D. A., Thompson, D. v., Bignami, G. F., Ögelman, H., Özel, M. F. and Tümer, T., Astrophys. J. 198, 163 (1975)

3. Stecker, F. W., Cosmic Gamma Rays, Mono Book Co., Baltimore Md. (1971)

4. Stecker, F. W., Origin of Cosmic Rays (ed. J. L. Osborn and A. W. Wolfendale) D. Reidel Pub. Co., Dordrecht, Holland (1975)

5. Dodds, D., Strong, A. W., Wolfendale, A. W. and Wdowczyk, J., J. Phys. A. 8, 624 (1975)

6. Stecker, F. W., Puget, J. L., Strong, A. W. and Bredekamp, J. H. Astrophys. J. Letters 188, L59 (1974).

7. Puget, J. L. and Stecker, F. W., Astrophys. J. 191, 323 (1974)

8. Strong, A. W., J. Phys. A. 8, 617 (1975).

9. Puget, J. L., Ryter, C., Serra, A. and Bignami, G. F., Astron. and Astrophys., in press (1976)

10. Baker, P. L., and Burton, W. B., Astrophys. J. 198, 281 (1975)
    Samimi, J., Share, G. H. and Kinzer, R. L., Proc. ESLAB γ-Ray Symp., Frascati, Italy, ESRO-SP-106, 211 (1974).

11. Stecker, F. W., Astrophys. J. 185, 499 (1973).

12. Solomon, P. M. and Stecker, F. W., Proc. ESLAB γ-Ray Symposium, Frascati, Italy, ESRO-SP-106, 253 (1974).

13. Scoville, N. Z. and Solomon, P.M., Astrophys. J. Letters 187, 167 (1975).

14. Burton, W. B., Gordon, M. A., Bania, T. M. and Lockman, F. J., Astrophys. J., in press (1975).

15. Stecker, F. W., Solomon, P. M., Scoville, N. Z. and Ryter, C. E., Astrophys. J. 201, 90 (1975).

15
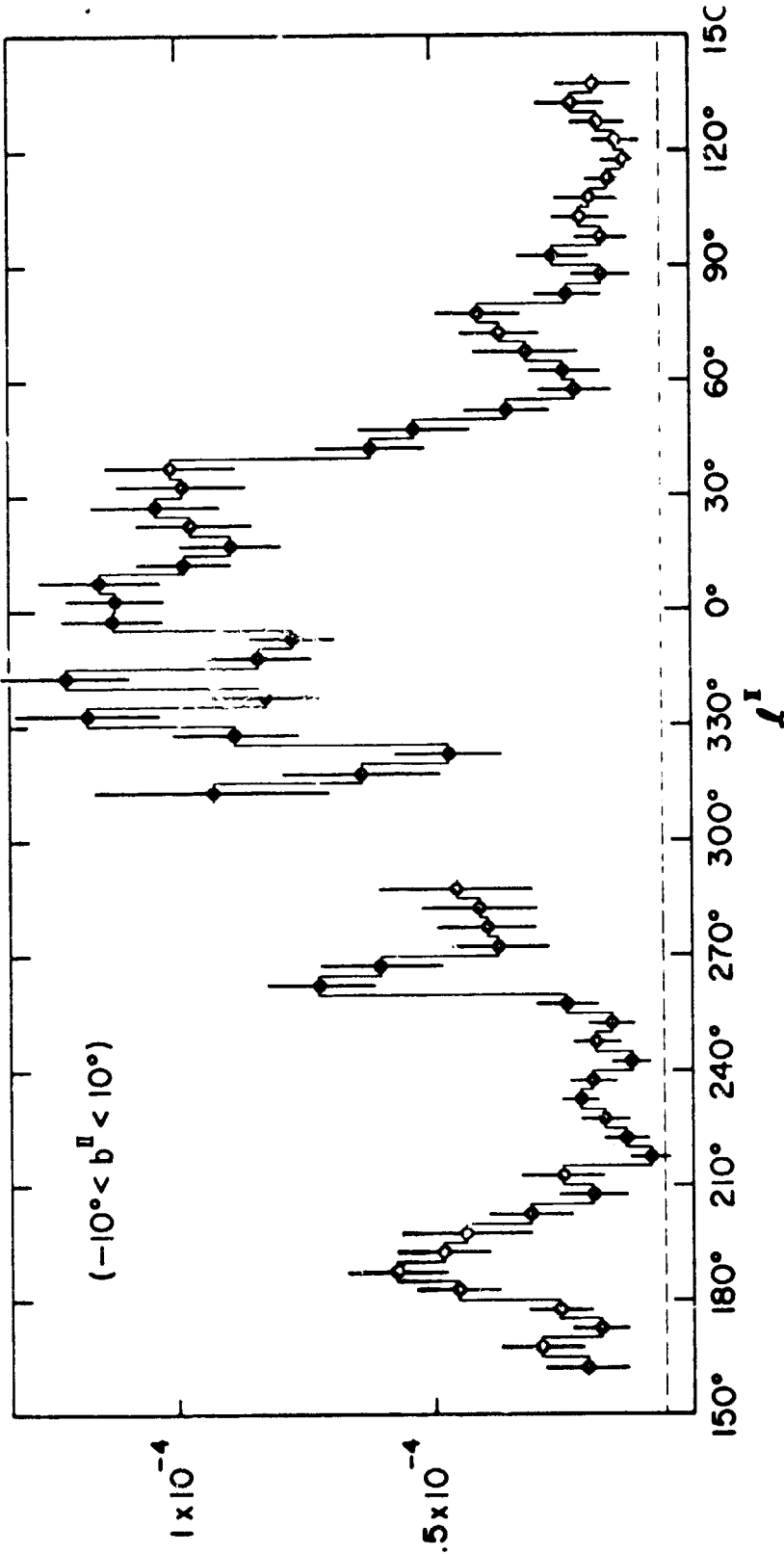
16. Wentzel, D. G., Jackson, P. D., Rose, W. K. and Sihha, R. F., Astrophys. J.
       Letters 201, L5 (1975).

17. Jenkins, E. B., and Savage, B. D., Astrophys. J. 187, 243 (1974).

18. Dodds, D., Strong, A. W. and Wolfendale, A. W., Mon. Nat. R. Astro. Soc. 171,
       569 (1975).

19. Kodaira K., Pub. Astron. Soc. Japan 26, 255 (1974).

20. Lyne, A. G. in Galactic Radio Astronomy (ed. F. J. Kerr and S. C. Simonson III),
       Hulse, R. A. and Taylor, J. H., Astrophys. J. Letters, 201
       (1975), also, J. Sieradakis, private communication.

21. Stecker, F. W., Phys. Rev. Letters 35, 188 (1975).

22. Ilovaisky, A. and Lequeux, J., Aston. and Astrophys. 20, 347 (1972);
       Gordon, M. A., Brown, R. L. and Gottesman, S. T., Astrophys. J. 178,
       119 (1972).

23. Öpik, E., Irish Astro. J. 2, 219 (1953).

24. Ögelman, H. B. and Maran, S. P., preprint (1975)

25. Mezcer, P. A. Proc. IAU Symp. No. 38 Basel, Switzerland (ed. W. Becker
       and G. Contopoulos) Reidel Pub. Co., Dordrecht, Holland, 107 (1970).
       also, Lockman, F. J., private communication

26. Kerr, F. J. and Westerhout, G. in Galactic Structure Stars and Stellar Systems 5,
       167 (ed. A.Blaauw and M. Schmidt), U. Chicago Press (1965).

27. Shu, F. J. in The Interstellar Medium (ed. K. Pinkau) D. Reidel Pub. Co.,
       Dordrecht, Holland, 219 (1973).

28. Roberts, M. S., Science 183, 371 (1974).

29. Roberts, W. W., Jr., Roberts, M. S. and Shu, F. H. 1975, Astrophys. J. 196, 381 (1975)

30. Burton, W. B., Ann. Rev. Astron. and Astrophys. 14 (1976) in press.

31. Simonson III, S. C. Astron. and Astrophys. 9, 163 (1970).

32. Burton, W. B., in Galactic and Extragalactic Radio Astronomy, ed. G. L. Verschuur
       and K. I. Kellerman, Springer-Verlag, New York, 82 (1974)

Sandage, A., The Hubble Atlas of Galaxies, Carnegie Inst., Washington, D. C. (1961).

Simonson III, S. C., Proc. CNRS Symp., Paris, to be published.

Bignami, G. F. and Fichtel, C. E., Astrophys. J. Letters 189, L65.

Bignami, G. F., Fichtel, C. E., Kinffen, D. A., and Thompson, D. J., Astrophys. J. 199, 54 (1975).

Burton, W. B. and Bania, T. M., Astron. and Astrophys. 33, 425 (1974).

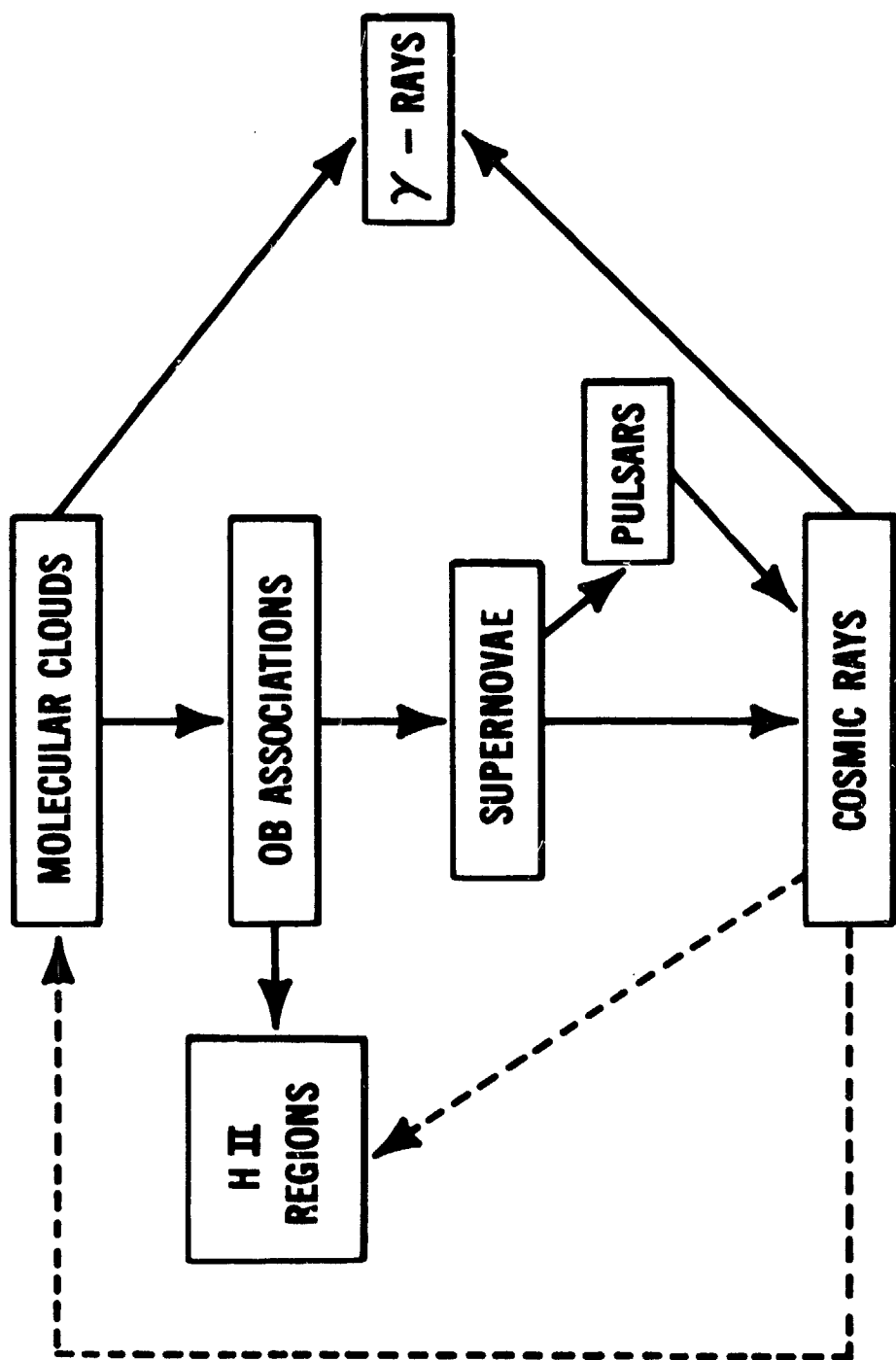Brecher, K. and Burbidge, G. R., Astrophys. J. 174, 253 (1972).

FIGURE CAPTIONS

Figure 1   Longitude distribution of γ-rays with energy greater

than 100 MeV summed over $\pm 10^0$ in galactic latitude (Ref. 2).

Figure 2   Relationship between various "population I" galactic components.

Figure 3   Surface density distribution of HI, H_2 and total gas as

a function of galactocentric radius based on a smoothing

of data given in Reference 14 using methods outlined in

Reference 15. The H_2 data are slightly different than those

given in reference 13, but can be considered qualitatively the

same for the purpose of the present discussion. The graph

illustrates the general separation of HI and H_2 components in

the galaxy and the correlation of these components with

the weak compression and strong compression regions of the

galactic disk respectively.

Figure 4   Mean density of HI as a function of galactocentric radius

as determined from recent 21 cm observations[14] and as assumed

in two recent "spiral arm" models of galactic γ-ray emission.[35,36]

These models further assume that H_2 has the same galactic distri-

bution as HI (contrary to the main point of the present work)

so that $n_{tot} = Kn_{HI}$ with K = 1.5 in reference 35 and K = 2

in reference 36. In the case of reference 36, circular

symmetry is not assumed and the figure only represents typical

positions for the arm features. The models both appear to over-

estimate the <u>volume averaged</u> density of HI (regardless of

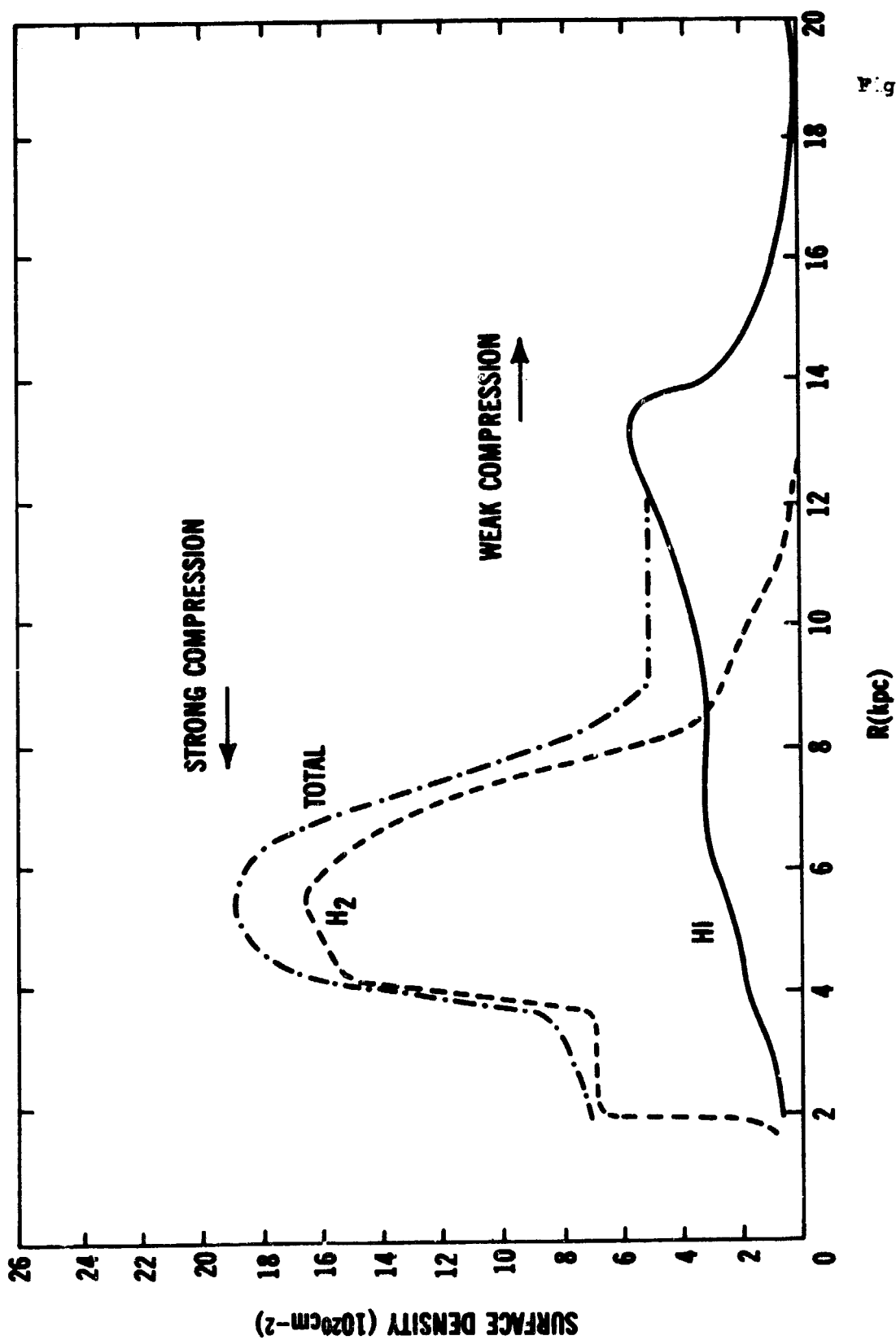structural details) as determined from 21 cm measurements.

Fig.1

$(-10° < b^{II} < 10°)$

γ-RAYS (>100 MeV)/(CM RAD SEC)

Fig.2

Fig.3

Fig.4

ATOMIC HYDROGEN DENSITY DISTRIBUTION IN THE GALAXY