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Abstract

In this presentation, I will discuss the power of using synoptic galactic surveys in many wavelength bands in order to obtain a more complete picture and a better understanding of the dynamics of the interstellar medium and to study galactic structure and evolution on a large scale. In particular, I will discuss the implications of the picture presented by mm-wave CO, far infrared and γ-ray surveys of the Galaxy.

I. Introduction:

In the past decade new techniques, in addition to 21 cm surveys of HI gas, have been developed to trace and study the spatial distribution of interstellar gas, particularly molecular (H_2) clouds. These new survey techniques involve the use of mm-wave far infrared and γ-ray telescopes. They have told us much about that component of the interstellar gas, molecular clouds (MC) and giant molecular clouds (GMC), which is most directly connected to extreme Population I phenomena in general (see Fig. 1).

The new surveys have their different strengths and weaknesses and also give complimentary information. For example, most mm-wave surveys are undersampled and are made with a very small field of view (beam width) on a galactic scale. In addition, there are presently no mm-wave data over almost half of the galactic plane which is only accessible from the Southern Hemisphere. On the other hand, the γ-ray data encompass a large, completely sampled, field of view and include the entire galactic plane, however their limitations are poor angular resolution (1°-2°) and no velocity data. The mm-wave measurements involve uncertainties of the order of a factor of two in determining H_2 abundances from other molecular abundances, e.g. ^{13}CO and CH_2O. On the other hand, γ-ray data measure the product of cosmic-ray intensity and total gas density. As we will see, most probably the cosmic-ray intensity does not vary significantly over a scale of $\frac{1}{2}$-1 kpc, but there does appear to be a large scale (~ 5 kpc) gradient in the galactic cosmic-ray intensity (Stecker 1975; Stecker, Solomon, Scoville and Ryter 1975; Stecker 1977; Stecker and Jones 1977). The far infrared (FIR) surveys trace the dust in molecular clouds (Fazio and Stecker 1976). They yield no velocity data and are particularly temperature sensitive ($I_{FIR} \propto T^6$). The point is that by making use of <u>all</u> of the surveys, we can minimize the shortcomings of the individual studies and reach a more complete understanding of Population I phenomena and galactic structure.

II. γ-Ray Studies:

The flux of (>100MeV) γ-rays expected from interactions of cosmic rays in a cloud of mass M at distance R is

$$F \approx 10^{19}\left(\frac{M}{M_{\odot}}\right)\left(\frac{I}{I_{loc}}\right)\left(\frac{1pc}{R}\right)^{2} q_{loc} \qquad (1)$$

where I_{loc} and q_{loc} are the local cosmic ray intensity and γ-ray emissivity per H atom. Recently, the European COS-B collaboration has mapped the γ-ray emission from the Orion region (Caraveo, et al. 1980). The COS-B map indicates a distinct correlation between the γ-ray and CO maps with particular γ-ray enhancements associated with the Orion A, Orion B and Mon R2 complexes (see Figure 2). Using eg. (1) and assuming $(I/I_{loc}) = 1$, i.e. cosmic-rays freely penetrate the clouds and they have the same intensity as in our part of the Galaxy, using $M = (1.5\text{-}2) \times 10^{5} M_{\odot}$ for the Orion A and B regions (Blitz 1980) and R = 500 pc, we obtain a calculated flux

$$F_{cal} = (1.3 \pm 0.4) \times 10^{-6} cm^{-2} s^{-1} \qquad (2)$$

as compared with the observed flux

$$F_{obs} = (2 \pm 0.5) \times 10^{-6}\ cm^{-2} s^{-1}. \qquad (3)$$

The observations of γ-radiation in the Orion region are thus consistent with assumptions of a uniform cosmic ray flux penetrating the clouds with roughly the local intensity. Data from the ρ Oph complex and other regions support this conclusion (Lebrun and Paul 1978, Wolfendale 1981). We may also infer that since cosmic rays penetrate the cloud complexes, magnetic fields also penetrate them, connecting them to the ambient gas. This would support the picture of cloud dynamics proposed by Elmegreen (1981 and this workshop). We may also conclude that, at least within ~1kpc of the sun, γ-ray surveys can be used to trace the total mass of interstellar gas complexes. This provides support for the idea of using large scale galactic γ-ray surveys to trace the total gas (atomic plus molecular) in different regions of the Galaxy - as originally indicated by the excellent correlation between mm-wave CO surveys and γ-ray surveys (see references in part I). A particularly prominent feature in the CO, γ-ray, and new far infrared surveys is the 5 kpc Ring or Great Galactic Ring (Stecker 1977; 1978)(see Figure 3).

One important feature of the γ-radiation is the low intensity of the γ-ray emission from the outer galaxy. Using the 21cm measurements to set a lower limit on the amount of gas in the anticenter direction, the low γ-ray fluxes indicate that the cosmic ray intensity must fall off by at least a factor of two in the outer galaxy, indicating a large scale radial radient in the galactic cosmic ray distribution and showing that most cosmic rays are of galactic origin (Dodds, Strong and Wolfendale 1975; Stecker 1975). Indications of a significant amount of H_2 in the outer parts of the Galaxy not seen in 21 cm (Kutner and Mead, 1981 and Blitz, this workshop) would strengthen this conclusion by indicating that the cosmic ray flux may fall off by as much as a factor of 4-6 in the region 15-20 kpc from the Galactic center.

Turning toward the inner parts of the Galaxy, we find that the cosmic ray intensity flux is $I(5\text{kpc}) \approx (2-5)\ I_{loc}$ in the 5-kpc ring using a volume-averaged value for the H_2 gas density $\langle n_{H_2} \rangle \approx 1.5-2\ cm^{-3}$ (Gordon and Burton

1976; Solomon and Sanders 1980). The galactic radial distribution of cosmic rays I(R) mimics the distribution of supernova remnants on a scale of kiloparsecs, consistent with the hypothesis that supernovae (or other Pop I related phenomena) produce most galactic cosmic rays (Stecker 1975, 1977) and consistent with simple models for galactic cosmic ray diffusion (Stecker and Jones 197.).

Other Population I phenomena track with the radial distribution of CO, exhibiting the 5-kpc maximum. The pulsar and γ-ray distributions are remarkably similar (Harding and Stecker 1981). The distribution of HII regions and ionized gas (Lockman 1976) also falls into this category as does the distribution of far infrared emissivity (Cheung 1980; Cheung, Fazio Stecker, Sanders and Solomon 1981). All these data lend support to the idea that the H_2 cloud component of the interstellar medium plays the active dynamical role in Population I star formation processes and in participating in the dynamical processes which result in the observable structural characteristics of spiral galaxies (Burton 1976, Stecker 1976).

III. The FIR data:

Following this idea, Fazio and Stecker (1976) predicted that the galactic far infrared (FIR) distribution should also exhibit a characteristic form correlated with the CO distribution and having a pronounced peak at $R_{gal} \approx$ 5kpc. This has indeed proved to be the case. Fazio and Stecker proposed a simple model for predicting the FIR emissivity by assuming a constant gas/dust ratio of 100:1, and a dust temperature (Goldreich and Kwan 1974) $T_d \approx 2\, T_{kin} \approx 2T_{exc,CO}$. The advent of better determination of H_2 column densities from ^{13}CO surveys (Solomon, Scoville and Sanders 1979) and kinetic temperatures from ^{12}CO data (Solomon and Sanders 1980) have led to a fine tuning of the Fazio-Stecker model which has been compared with new FIR survey data from the

Goddard Space Flight Center infrared group led by M. Hauser. Preliminary analysis of this data (Cheung 1980) has revealed an excellent qualitative and quantitative (within a factor of 2) agreement between model and observation (Cheung, Fazio, Stecker, Sanders and Solomon 1981), supporting the general conclusion of the previous section (see Figure 4). In this case, the far infrared (100 μm - 2000μm) emission is from the reradiation of dust associated with and located within the specific H_2 complexes seen in large scale CO surveys (as well as in HII regions). The correlation between CO, FIR and γ-ray emission, together with the large enhancement of γ-ray emissivity in the 5-kpc region (Stecker 1977) leads to the conclusion the H_2 is the dominant form of the interstellar gas in the inner galaxy and that the numbers for $\langle n_{H_2} \rangle$ obtained by Gordon and Burton (1976) and Solomon and Sanders (1980) are fairly accurate. Much lower values for $\langle n_{H_2} \rangle$ in the 5 kpc region, as advocated by Cohen, et al. (1980) are in <u>prima facie</u> conflict with the γ-ray results. If $\langle n_{H_2} \rangle \approx \langle n_{HI} \rangle$ at 5-kpc, an explanation of the γ-ray enhancement would require $I_{cr}(5\text{ kpc}) \gg I_{loc}$, creating severe instabilities in the interstellar gas disk owing to the imbalance which such a large cosmic ray pressure would create. Thus, it is the gas which is signicicantly enhanced in the 5-kpc region. Since $n_{HI}(5\text{-kpc}) \approx n_{HI,loc}$, the value for n_{H_2} must increase significantly in the 5-kpc region in order to account for the γ-ray emissivity there. Thus, one can see how taking a "synoptic" viewpoint in looking at this Galaxy and the interstellar medium can be most helpful. The reader is referred to the references for more details of the work discussed here.

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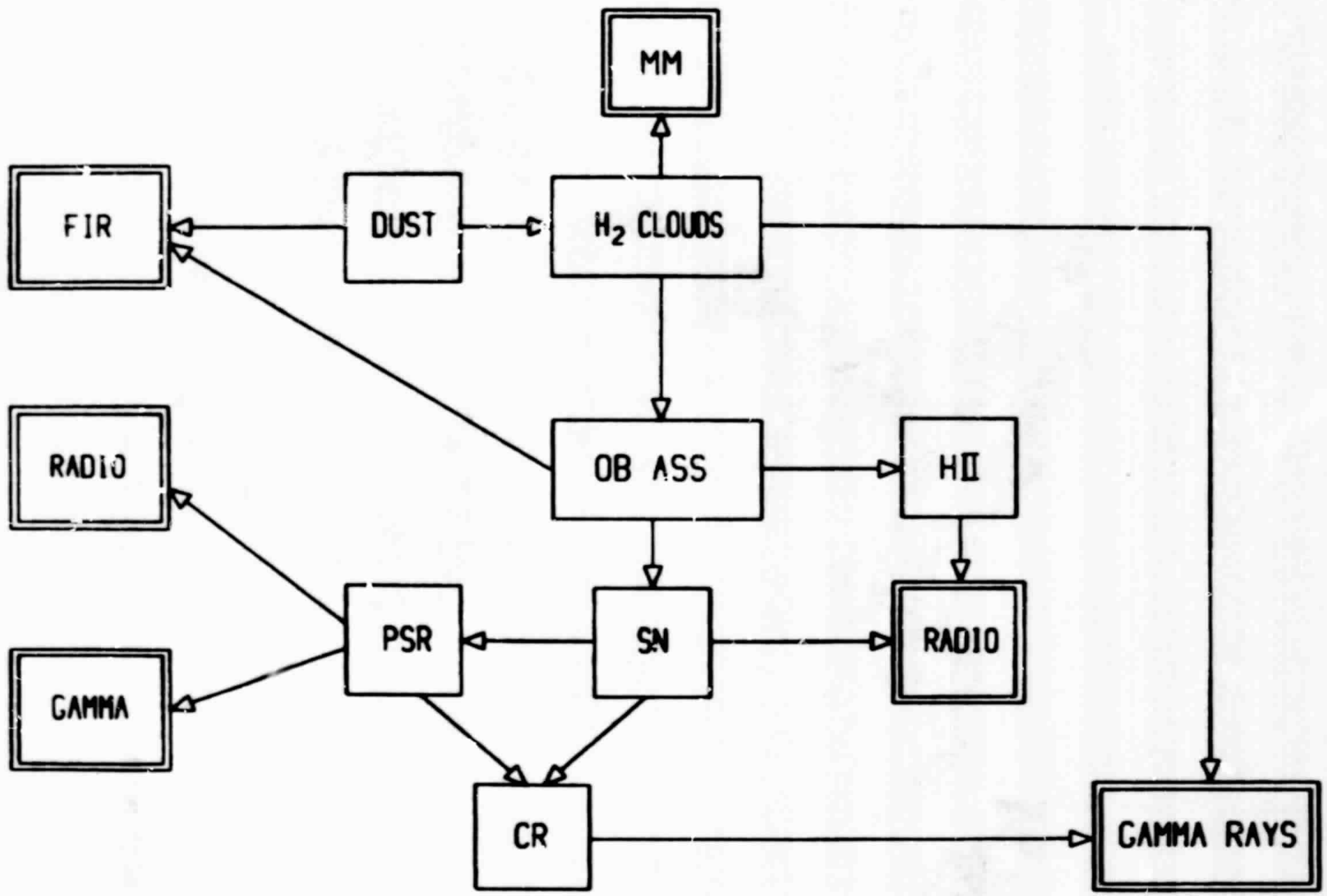
Figure Captions:

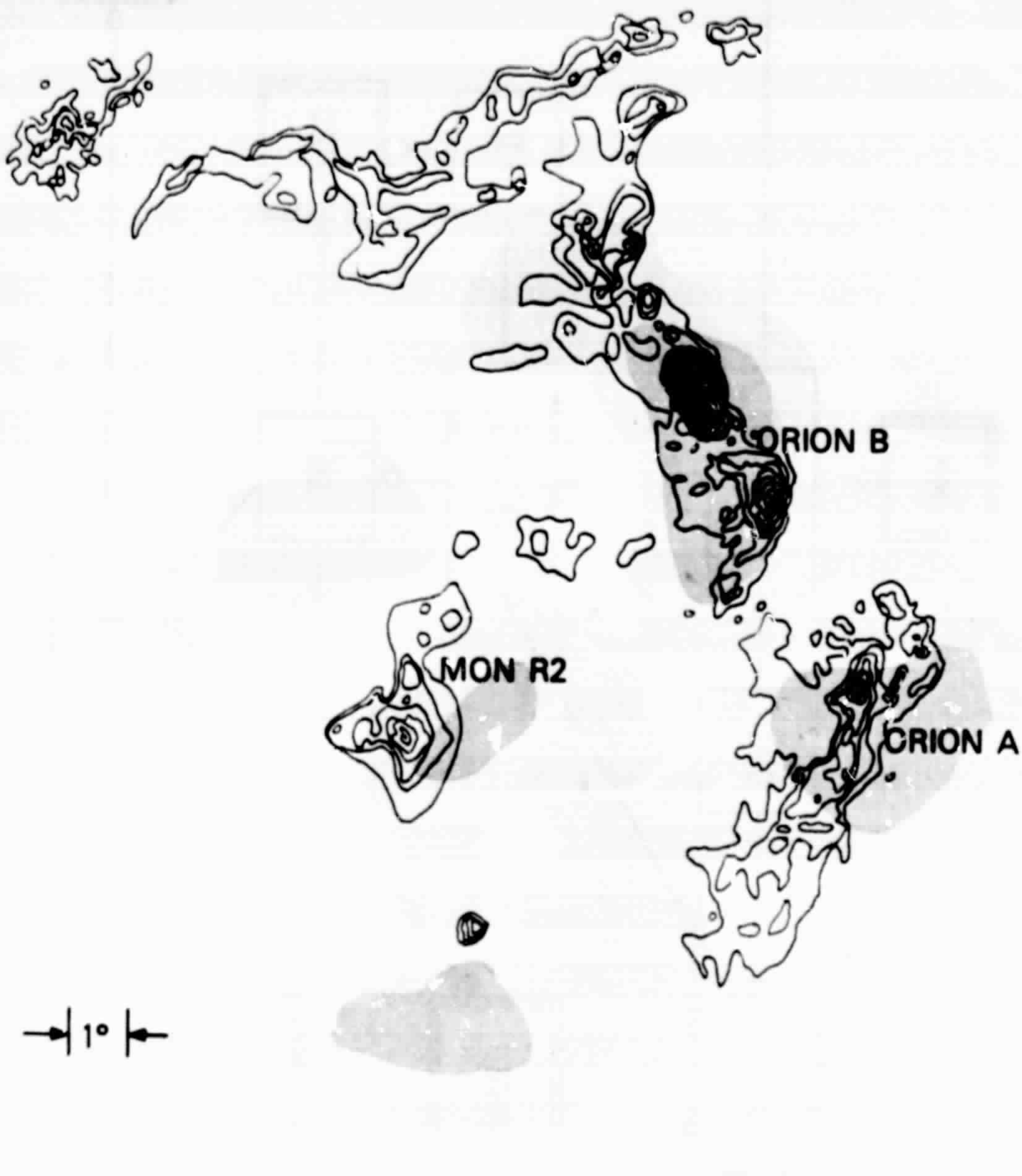
Figure 1. A flow diagram showing the evolution and interaction of various Pop I phenomena (SN = supernova, PSR = pulsar, CR = cosmic rays, OB ASS = OB Association) and resulting radiations in various wavelength regions (double boxes) which can be seen over the galaxy as a whole (low opacity).

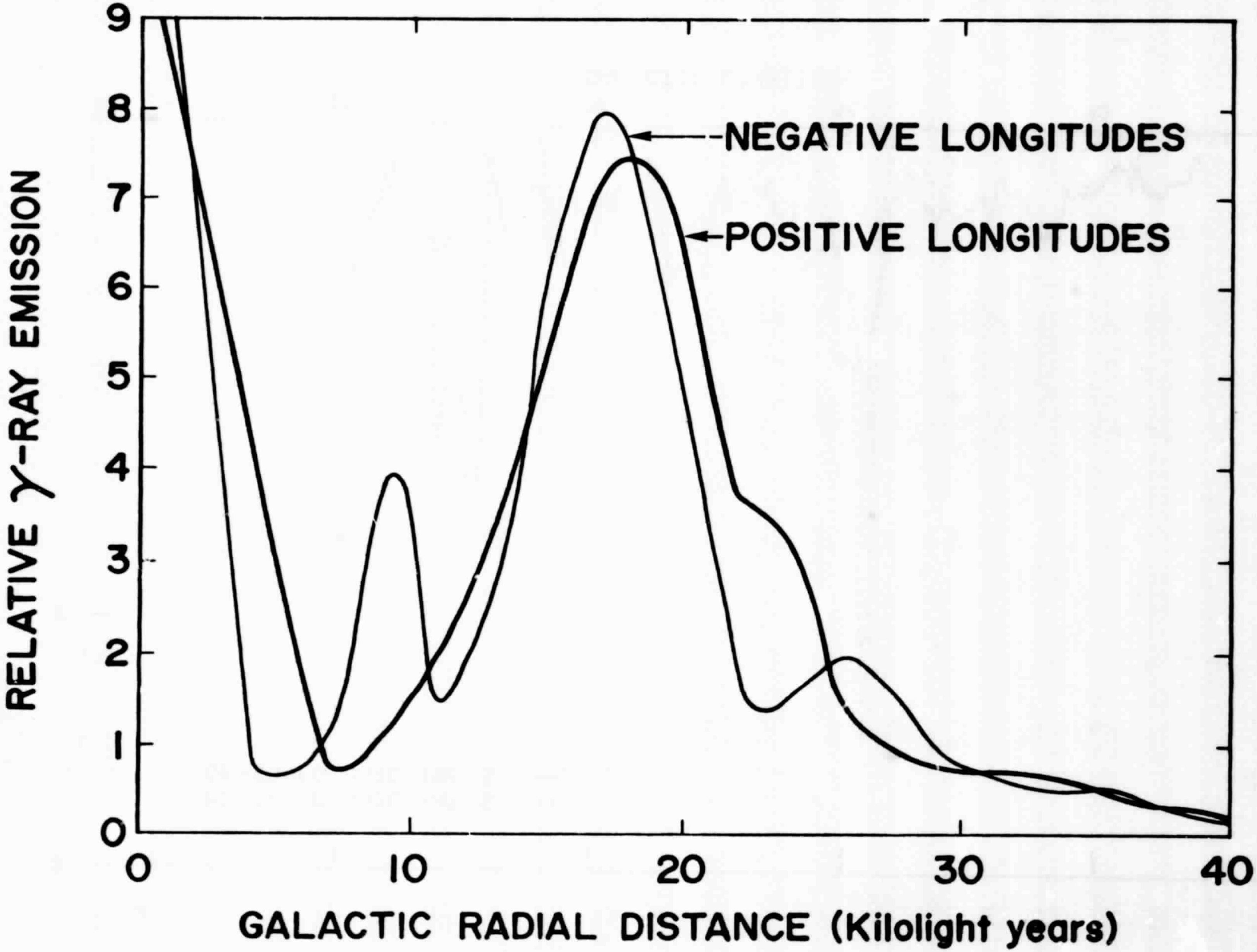
Figure 2. A map of the Orion region shown in CO (contour lines) and 100 MeV γ-ray emission (shading) after Caraveo, et al. (1980). The mid-level shading corresponds to the observed flux used in equation (3) (see text).

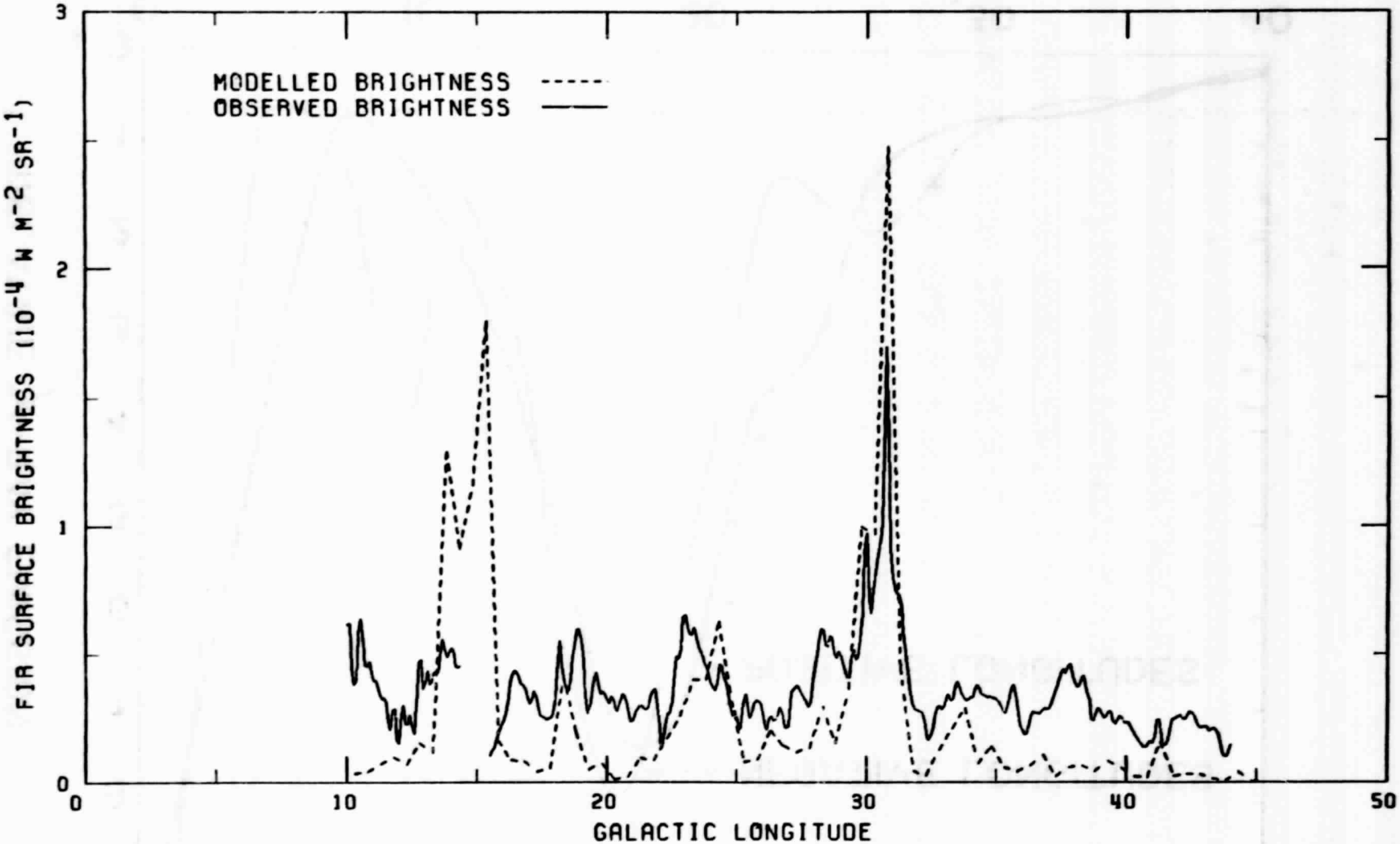
Figure 3. Radial distribution of galactic γ-ray emissivity (1 kly = 3.26 kpc) shown for the galactic longitude ranges $0^{\circ} < \ell < 180^{\circ}$ (positive) and $180^{\circ} < \ell < 360^{\circ}$ (negative).

Figure 4. Galactic far infrared brightness distribution as observed by the Goddard Space Flight Center infrared survey (see text) and as obtained from the theoretical model described in the text.


MM
FIR
DUST
H_2 CLOUDS
RADIO
OB ASS
HII
PSR
SN
RADIO
GAMMA
CR
GAMMA RAYS


ORION B
MON R2
ORION A
1°


NEGATIVE LONGITUDES
POSITIVE LONGITUDES
RELATIVE γ-RAY EMISSION
GALACTIC RADIAL DISTANCE (Kilolight years)
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40



MODELLED BRIGHTNESS
OBSERVED BRIGHTNESS
FIR SURFACE BRIGHTNESS (10^{-4} W M^{-2} SR^{-1})
GALACTIC LONGITUDE
0
1
2
3
0
10
20
30
40
50