22. 'LOCAL' THEORIES OF THE X-RAY BACKGROUND

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Abstract. Recent theories of the origins of diffuse-background X-rays are reviewed, with emphasis on theories of the soft flux in the galactic plane and at the poles. This is probably partly galactic and partly extragalactic in origin. Failure to observe absorption by the Small Magellanic Cloud and by galactic gas in neighboring directions may be due to sources in the Cloud and to statistical fluctuations in galactic emission and absorption. Several models for numerous low-luminosity sources in the Galaxy are available. True 'diffuse' emission seems unnecessary. Absorption by Galactic gas seems to agree roughly with theory. The soft extragalactic component may arise in a hot intergalactic medium.

The existence of a 'diffuse' galactic-plane excess in 1–100 keV is in some doubt. Low-luminosity sources may contribute to this as well.

For isotropic X-rays in 1 keV – 1 MeV, superposition theories involving clusters of galaxies, Seyfert galaxies, etc. over a cosmological path length are now roughly viable. Simple 'metagalactic' Compton theories seem excluded if the break at 40 keV is sharp, but this is now in doubt. A very hot intergalactic medium at $T \approx 3 \times 10^8$ K would give the possibility of a sharp break.

A recent upper limit on the line source strength of 100-MeV photons in the galactic plane may create some difficulties for cosmic-ray theory. The spectral shape of π-γ photons has become a matter of theoretical dispute.

1. Introduction

My task in this review is to deal with 'local' theories and interpretations of the background X-rays and γ-rays, where by local I refer to notions of galactic sources as well as of 'metagalactic' contributions out to a distance roughly equal to the Hubble radius. In the next paper Dr Rees will discuss models involving redshifts $\gg 1$, strongly evolutionary cosmologies, and the early universe. In the time available I cannot even mention all the recent papers on my subject, and I wish to apologize in advance to those authors who will get short shrift. It seemed wise to select a few important and timely topics for major comment. I have been asked to give particular attention to the soft X-rays. Figure 1 shows a recent compilation of diffuse background data. Developments at this Symposium suggest that the observed 'structure' in this curve, especially around 40 keV and 1 MeV, may be rather evanescent. I will, however, deal with some of the recent attempts to explain this structure, as befits a theorist. I will start at low photon energies and work my way up.

2. Soft X-Rays, $h\nu < 1$ keV

The flux below 1 keV appears to exceed the extrapolation from higher energies. There is great diversity of views concerning these very soft X-rays. In trying to arrive at an understanding of the data I will lean most strongly on a recent preprint by the Naval Research Laboratory group (Davidsen *et al.*, 1972). This observation employed two windows, whose effective transmission energies are about 280 and 680 eV. Figure 1 of Friedman *et al.* (this volume, p.215) compares '280-eV' fluxes in

Bradt and Giacconi (eds.), X- and Gamma-Ray Astronomy, 258–275.

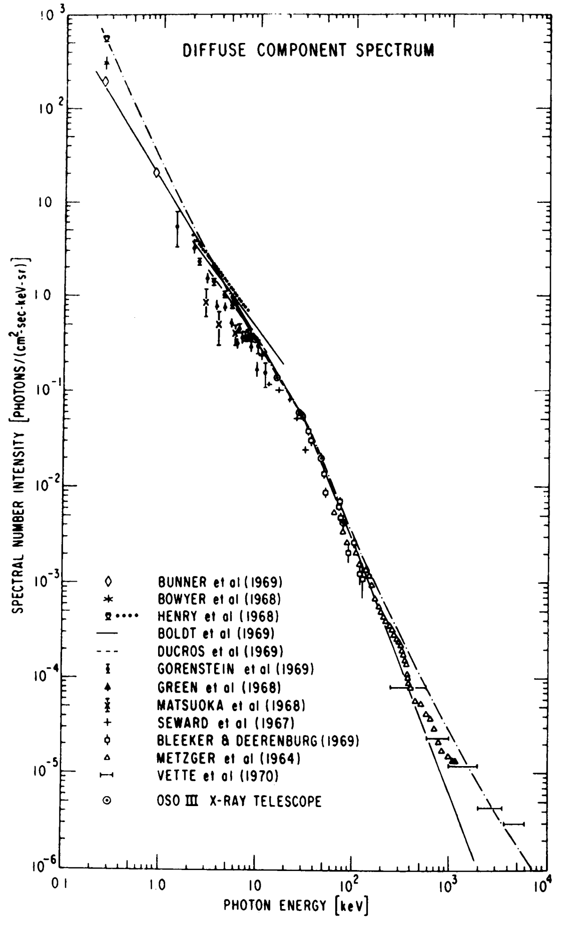

Fig. 1. Collected data on the spectrum of diffuse-background X-rays (Peterson, 1971).

this observation, plotted in galactic coordinates, with neutral-hydrogen column densities N_H. In general the soft X-ray flux rises at the poles, where N_H is low. There are even rises in the count rate at some specific low-N_H features, e.g. $l^{\mathrm{II}} \approx 210°$, $b^{\mathrm{II}} \approx 20°$, though the matchup is far from exact. The rise toward the poles suggests strongly that most of this radiation comes from outside the absorbing disk of gas. This need not mean that there is an isotropic extragalactic component; we might have a disk of sources with a scale height z_s greater than that of the gas, $z_H \approx 120$ pc. Davidsen *et al.* (1972) assumed such a model, without an extragalactic component, and analysed the b^{II}-dependence of the data as a function of $h\nu$. The value of τ_p, the absorption optical thickness in the polar directions, is of critical importance; let us treat this as a free parameter. At 280 eV, as we dip away from a pole toward the plane, we must have $z_s > z_H$ to get a flux decrease, and we must *not* have $\tau_p \gg 1$ if the decrease is to be *significant*. On the other hand, if $\tau_p \ll 1$, we will get an increase! We find that $\tau_p \simeq 2$ gives a good fit to the observed decrease by a factor $\simeq 2$ from a pole to plane, provided

$z_s/z_H \simeq 5$, i.e. $z_s \simeq 600$ pc (Figure 3 of Friedman *et al.* in this volume). The value $\tau_p \simeq 2$ is about twice what we would expect from the observed N_H and the absorption calculations of Brown and Gould (1970) for cosmic abundances, which give

$$\sigma(h\nu) \simeq 0.7 \times 10^{-22} (h\nu/1 \text{ keV})^{-3} \quad \text{up to 532 eV} \tag{1}$$

for the cross section per H atom; the main contribution comes from He. Abundances are adjustable, and we cannot reject this model by use of the 280-eV data alone.

Assuming, however, that the *ratio* $\tau_p(280)/\tau_p(680)$ should be as given by Brown and Gould, τ_p is small at 680 eV, and at this energy the same model then predicts a *rise* in the X-ray flux as we go away from the pole, which is not observed (Figure 3 of Friedman *et al.* in this volume). The NRL group conclude that a purely galactic origin for the soft X-rays is excluded. Now for consistency the ratio $\tau_p(280)/\tau_p(680)$ should perhaps also be left free in this discussion, because if we abandon the cosmic abundance ratios, so as to make $\tau_p(280)$ free, we lack a physical model for the absorption. τ_p (280) is probably due mainly to He, $\tau_p(680)$ to O. But the simplest thing we could do to obtain the large $\tau_p(280) \simeq 2$, viz. adding more He, would *increase* the ratio $\tau_p(280)/\tau_p(680)$ above the Brown and Gould value, pushing $\tau_p(680)$ downwards for fixed $\tau_p(280)$ and strengthening the case made by Davidsen *et al.* (1972).

Rejecting this purely galactic model, these authors consider also a purely extragalactic source, and find that the best fit for such a model implies that τ_p is about $\frac{1}{3}$ the theoretical value. This confirms the result of Bowyer *et al.* (1968), which stimulated all the discussion about 'cloudiness' corrections to the X-ray absorption. But this purely extragalactic model fails, because it cannot explain the sizable residual X-ray intensities near the plane in regions of large N_H (Figure 2). This removes the necessity for 'cloudiness' or other subtractive corrections to τ_p, for when it is recognized that the X-rays on the right-hand side of Figure 2 are of galactic origin, and the exponential-absorption line is drawn to fit the left-hand side only, an absorption $\tau_p(280) \simeq 1$ is obtained, in accord with theory. It still is not clear why these X-rays in the plane were not seen by Bowyer *et al.* (1968). Recent observations have all detected them.

Following through on this two-component model, Davidsen *et al.* find that the best fit (Figure 2) is indeed obtained for $\tau_p(280) \simeq 1$ and $z_s/z_H \lesssim 1$, implying $z_s \lesssim 120$ pc. About $\frac{2}{3}$ of the 280-eV flux received at the poles, i.e. about 200 photons (cm^2 s sr keV)$^{-1}$, is extragalactic in origin. Interesting information about the sources in the galactic disk can be derived from the data obtained near the plane. The fact that counts are observed in each $10° \times 10°$ box implies that there are many faint sources of soft X-rays rather than a few bright ones. One source per $\lesssim (7 \text{ pc})^3$, or a number density $n \gtrsim 3 \times 10^{-3}$ pc^{-3}, is what is required if they are point sources, but if they are extended the number can be smaller. If the sources are uniformly distributed and there are many in the beam, it is a good approximation to say that the emission is continuously intermixed with the absorbing gas. The specific intensity I_ν received in the plane, where $\tau \gg 1$, is then just the source function $\mathscr{S}_\nu$:

$$I_\nu = \mathscr{S}_\nu = \frac{S_x}{4\pi n_{\mathrm{H}} \sigma}, \tag{2}$$

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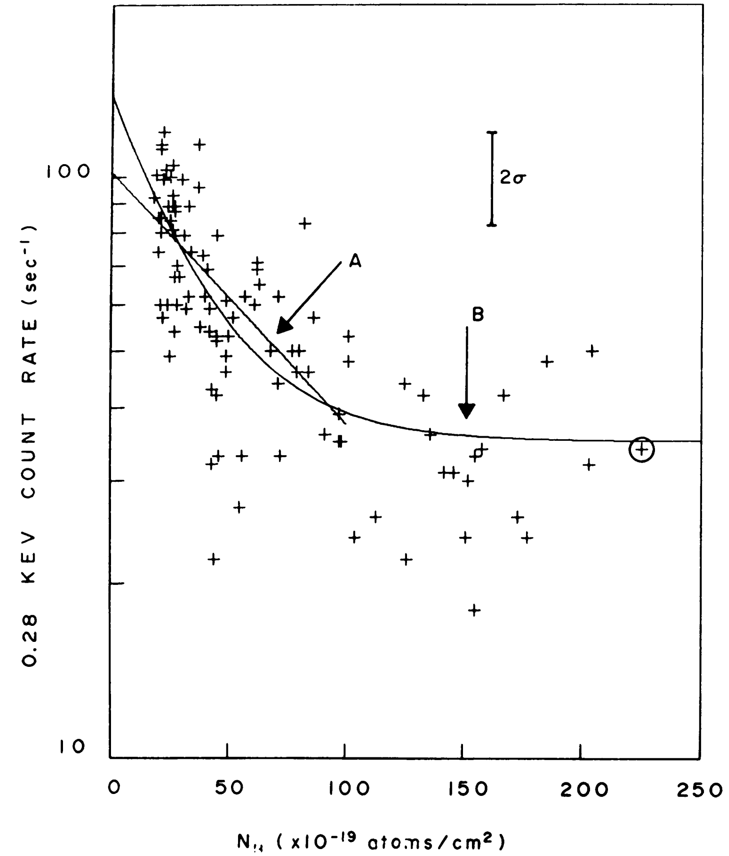

Fig. 2. Correlation plot of the log of the 280-eV count rate versus the hydrogen column density. The encircled point is the average intensity within 10° of the galactic plane and is plotted at an arbitrary column density. Curve A is an attempt to represent these data by a pure-extragalactic source model; Curve B is for a two-component model (Davidsen *et al.*, 1972).

where S_x is the X-ray emissivity and σ is the absorption cross section per H atom (Brown and Gould, 1970). Since $\sigma(h\nu) \mathrel{\approx\!\!\!\!\propto} \nu^{-3}$ apart from absorption edges, the spectrum of the sources in the plane must be

$$S_x \mathrel{\approx\!\!\!\!\propto} \nu^{-3} I_\nu; \tag{3}$$

the sources are softer than the radiation as received. Assuming thermal bremsstrahlung, Davidsen *et al.* found $T \simeq (2\text{–}3) \times 10^6$ K for the disk sources. The extragalactic component is somewhat harder, $T \simeq 4 \times 10^6$ K.

In the NRL paper it is not always clear when the counter windows have been treated as monochromators and when the efficiency curves have been folded into the calculations. Efficiency curves are not given in the preprint, though they are included in the present volume (Friedman *et al.*, p.215). Nevertheless this preprint offers the most coherent picture to date of the soft X-rays.

The one large piece of contrary evidence is the Small Magellanic Cloud (SMC) observation by the Wisconsin group (McCammon *et al.*, 1971). They examined the SMC and a surrounding region of high b^{II} and unusually low galactic obscuration ($N_H \simeq 1 \times 10^{20}$ cm$^{-2} \Rightarrow \tau(280) \simeq 0.3$). They could not see any drop when they scanned across the SMC (where τ is probably very large) (region 5 in Figure 3A), and they concluded that less than one-fourth of their observed flux of $\simeq 400$ photons (cm^2 s sr keV)$^{-1}$ at 280 eV could be coming from beyond the SMC or, roughly speaking, that the observed flux *drops* by at most 100 when the detector is pointed at the SMC.

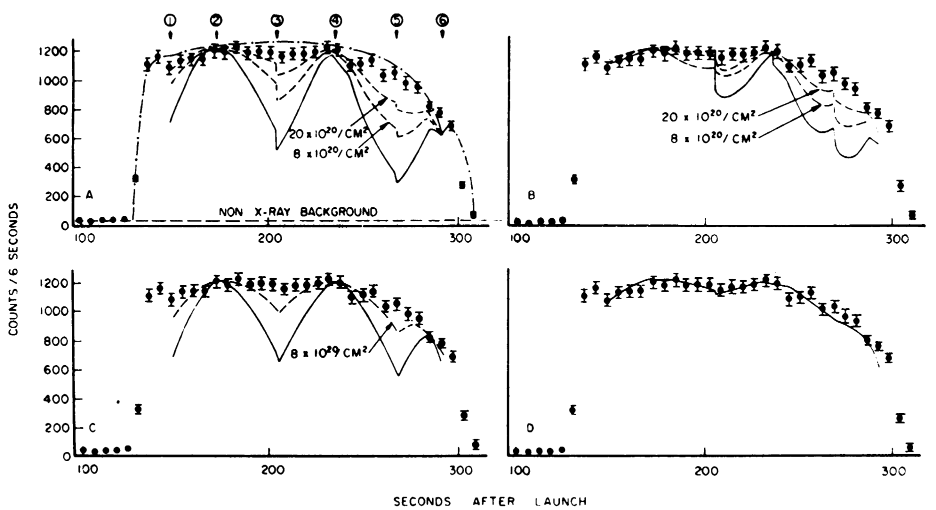

Fig. 3. Total counting rates in the 120–450 eV range as a function of time during the flight (McCammon *et al.*, 1971). The curves show expected behavior on various models. The models shown in Figure 3a assume that all the flux comes from beyond the SMC. *Solid curve*, absorption predicted if all the gas detected at 21 cm (i.e. the gas associated with the Galaxy-SMC system) is uniformly distributed. *Dashed curves*, cases where the absorbing gas is clumped into clouds of 8 and 20×10^{20} cm^{-2} thickness. *Dot-dash curve* includes only the effects of the Earth's atmosphere. For clarity, all models are normalized to the same point. Models in Fig. 3B assume absorption only by gas associated with the SMC, and those in Figure 3C assume absorption only by gas associated with the Galaxy. Curve in Figure 3D is the predicted absorption assuming that only an $E^{-1.4}$ photon spectrum fit to the 2–10 keV data is extragalactic, with the remainder of the observed flux coming from some *local* source.

Does this observation imply that the extragalactic flux is very weak, and is it inconsistent with the picture presented by the NRL group? NRL swept the matter under the rug. When we look at the center of the SMC, the I_ν we see should be the source function $\mathscr{S}_\nu$. In the Galaxy $\mathscr{S}_\nu$ is $\simeq 120$ in the units above, from the work of Davidsen *et al.* If it were $\simeq 300$ in the SMC, then, since 400-300 = 100, all 400 units above could be extragalactic, and the counts absorbed in the SMC could be filled in by SMC emission! McCammon *et al.* (1971) noted this and pointed out a bigger difficulty: that their count rate also failed to drop much when they scanned across a region of higher *galactic* absorption (region 3 in Figure 3A). In order to fill *this* in, the *galactic* $\mathscr{S}_\nu$ in this direction would have to be several times its general value for $b^{II} \simeq 0$. Three comments are in order:

(1) $\mathscr{S}_\nu$ is the ratio of two quantities which are not necessarily related, and it might vary *systematically* from place to place;

(2) If S_x is due to stars, for example, then there must be *statistical* variation in it. A cone of 8° FWHM looking through 100 pc of the galactic disk ($\tau \simeq 1$) contains $\sim$20 sources if their density is $n \sim 3 \times 10^{-3}$ pc^{-3}. But half the radiation received comes from the nearest 50 pc of the cone, and the mean number of sources in this portion is only $\sim$2, so the statistical fluctuations can be quite large. We might have a lower n and even larger fluctuations.

(3) The discussion is sensitive to the actual value of τ in the regions of lowest obcuration. If $\tau \ll 1$, then the received flux can actually *rise* when we move the line of sight onto a galactic cloud, because we pick up additional (galactic) sources in the cloud, and τ, while it might double, is still small. If He were to be either underabundant or doubly ionized in particular clouds, the absorption would be much reduced.*

We should not try to make much out of little by constructing a general model of soft X-rays in the Galaxy from a few observations in particular directions; in likely cases the lumpiness may frustrate us. The NRL approach of averaging data over large portions of the Galaxy is a good one. As the data accumulate, more can be done, e.g., the X-ray flux should be plotted against N_H for regions at *constant* b^{II} and vice versa; this would help us separate out the effects of galactic sources and perceive attenuation of the extragalactic radiation.

The latest report from the Wisconsin group (Coleman *et al.*, 1972) says that at *low* b^{II} the soft X-ray flux is not correlated with N_H. This is certainly expected, because in the plane we see just the constant $\mathscr{S}_\nu$, apart from statistical variations.

A preprint by Gorenstein and Tucker (1972) describes work similar to that of Davidsen *et al.* (1972), but the conclusions differ. Nevertheless there are many points of contact. They followed the Wisconsin group in assuming *no* extragalactic component. They looked only at the pole/plane intensity ratio instead of the full b^{II}-dependence, and since their planar value seems to involve only a short span of data, one suspects that their statistics are not as good as NRL's. Having removed the extragalactic flux, they naturally found a thicker disk of galactic sources, $z_s \simeq 800$ pc. As in the work of Davidsen *et al.*, the energy bands are somewhat ill-defined, but Gorenstein and Tucker (1972) are apparently a little more sensitive at low $h\nu$. They find that the pole/plane intensity ratio decreases with decreesing $h\nu$ below 280 eV; NRL found it to decrease with *increasing* $h\nu$ *above* 280 eV. Since the X-ray absorption is $\propto \exp(\nu^{-3})$,

* A special word of warning about X-ray absorption calculations: An estimate of the distance to Cygnus X-1 (Gursky *et al.*, 1971) based on N_H and observed X-ray absorption led Kristian *et al.* (1971) to exclude prematurely a candidate that is presently regarded as strong (Bolton, 1972). The distance discrepancy was a factor of 2. I am told that this error involved intrinsic X-ray variation in the source (R. C. Henry, private communication). In any case, it suggests caution. X-ray absorption depends mainly upon He and O, and we should beware of attaching sanctity to fixed abundance ratios for all points in the interstellar medium.

it must be clear that substantial progress in such details will be difficult until we have good spectroscopy with energy resolution $\sim 5\%$, rather than several broad window transmissions. Gorenstein and Tucker (1972) conclude from the observed directional fluctuations that $n \sim 10^{-2}\ \mathrm{pc}^{-3}$, and they estimate T of the sources as $\lesssim 10^6$ K. The value for n is not very different from that given by NRL, but the T is significantly smaller, and perhaps points to an additional population of very soft sources.

A recent report by the Livermore group (Palmieri *et al.*, 1972) suggests that their earlier work (Palmieri *et al.*, 1971), which indicated a systematic *increase* in 280-eV flux from pole to plane, suffered from coarse collimation and ultraviolet contamination. Their new observation reveals a curious 'hump' in the soft X-rays near $l^{\mathrm{II}} \simeq 330°$, $b^{\mathrm{II}} \simeq 15°$. This hump is 10–15° wide (much larger than the Lupus loop, which lies in the same direction), and its soft X-rays are a factor ~ 2 above neighboring regions. Apparently it is *not* merely one or two point sources. If at 50 pc distance this might be a diffuse source ~ 15 pc in diameter. One might imagine several kinds of astronomical structures with such a size, but Ilovaisky and Ryter (1971, 1972) have already proposed that old supernova remnants (SNR) of such dimensions could be responsible for the soft X-rays in the plane. This theory has the advantage that SNR are already known to emit soft X-rays; an extrapolation to larger and older remnants gives the desired result, though arguments from available-energy considerations (Tucker, 1971) have tended to suggest that this extrapolation is too generous. Of course a related phenomenon like the 2×10^5 K 'fossil H II regions' of McCray and Schwartz (1972) may contribute. A detailed study of the energetics, heating and cooling is clearly in order. Ilovaisky and Lequeux (1972) claim that the scale height of the old SNR is $\simeq 90$ pc, which would agree with the NRL model of the galactic sources.

Other astronomical theories for the planar flux are available. Strittmatter *et al.* (1972), in a clever inference from assorted facts, suggest that hot ($T \sim 10^7$ K) coronae of white dwarfs are responsible. The physics in this paper is order-of-magnitude only. Gorenstein and Tucker's criticism that this model is excluded by the short cooling times of the coronae is too hasty; their physical arguments for scale height and electron density are not consonant with those employed in the original paper. Anyway it is not clear that a cooling time shorter than the interval between heat-supplying pulses (implying X-ray pulsations) would be objectionable! Nor is it clear what this characteristic time for heat supply would be if the corona somehow draws its energy from the star's *rotation* rather than pulsation. Gorenstein and Tucker's other criticism, however, seems well founded: A T as low as $\sim 10^6$ K, suggested by the observed spectrum (3) of X-rays in the plane, conflicts with basic assumptions of the model. The model is good in that it makes several predictions, in particular regarding the observability of individual white dwarfs as sources. It implies a high space density of sources, in agreement with the NRL conclusions, and a large (population II) scale height, rather larger than NRL wish to accept.

Ostriker *et al.* (1970) suggested that interstellar gas accreting onto $\sim 10^9$ neutron stars in the Galaxy should be heated to $\sim 10^6$ K. The expected X-ray flux is adequate.

Since the accretion is $\propto v^{-3}$, the high-velocity 'runaway' neutron stars at large z ($\sim$2500 pc) give little contribution, and the effective scale height should be $z_s \leqslant$ 100 pc. This agrees with the NRL picture. Recently, when Gorenstein and Tucker (1972) had inferred $z_s \approx 800$ pc from their observations, one of the authors of the Ostriker *et al.* paper is said to have reversed his field and redirected attention to the runaway neutron stars! This is unsettling; a theorist should be able to say what he expects z_s to be before knowing what it is.

There is another possibility involving neutron stars: blackbody radiation at $\sim 10^7$ K from their surfaces, heated by wobble dissipation of rotational energy (Henriksen *et al.*, 1972). I am not competent to discuss the physics in this paper. z_s would presumably be $\gg 100$ pc in this case, since the runaways should wobble as much as any.

Without minimizing the possible variety of interpretations, let me advance a few hypotheses I believe are suggested by present data. I hope these will be borne out.

(1) The 280-eV flux at the galactic poles is mainly the transmitted portion of an 'isotropic' extragalactic flux, having an intensity (outside the disk) ≈ 500 photons (cm^2 s sr keV)$^{-1}$. (It is possible to account for the b^{II}-dependence of the 280-eV flux by a purely galactic source model, but then the expected b^{II}-dependence at higher $h\nu$ is not in accord with observations. Note that Ilovaisky, in a contributed paper for this Symposium, reached a conclusion contrary to mine, as did Gorenstein and Tucker. He relied heavily on the Livermore data, but as I mentioned, the latest Livermore paper impeached these earlier data somewhat. Dr Hayakawa's conclusion, from his own analysis of data from the Leiden-Nagoya group, is essentially in agreement with mine.)

(2) Failure to observe absorption by the SMC is due to fill-in by sources in the SMC and/or statistical fluctuation in galactic sources in that particular direction. (It will be objected that this is fortuitous, but the alternative of merely abandoning hypothesis (1) would not solve the problem posed by Figure 3C. Perhaps Figure 3D suggests that the soft sources are indeed *extremely* local, e.g. in the outer atmosphere, but I am resisting this conclusion for the moment.)

(3) The X-ray opacity of interstellar gas is approximately as given by Brown and Gould (1970). Any subtractive correction for cloudiness isn't very important in observations to date. (Cloudiness will loom larger at lower $h\nu$ and finer angular resolution.) Incidentally, since interstellar 'clouds' are still not well understood as physical entities, we should not hasten to attribute to the X-ray-absorbing clouds 'known' properties derived from unrelated observations.

(4) At 280 eV in the galactic plane, we see $\sim$120 photons (cm^2 s sr keV)$^{-1}$, which is the source function resulting from interstellar absorption mixed with a population of galactic sources. These must be either quite numerous ($n \gtrsim 3 \times 10^{-3}$ pc^{-3}) or quite large in size, otherwise they would already have been resolved. Their scale height may be $\lesssim$100 pc or possibly larger; this requires further work. White dwarfs, neutron stars and SNR are all possibilities; the SNR theory perhaps deserves a slight preference at the moment, because (a) emission has been observed from known resolved SNR, and (b) it contradicts no feature of the background observations. If I_ν is the

received background spectrum in the plane, the intrinsic source spectrum is $\propto \nu^{-3} I_\nu$ at all ν's sufficiently high that many sources are still contributing to I_ν.

3. The Soft Extragalactic Component

What is the origin of the extragalactic excess below 1 keV? It is usual to assume that this is thermal bremsstrahlung, because the exponential spectrum can give a bump at any desired energy if T is chosen appropriately. For 280 eV, $T \sim 10^6$ K is about right. We might postulate hot gas actually within a quasispherical halo ($R \sim 10$ kpc, $n_e \sim 3 \times 10^{-3}$ cm^{-3}) or in the Local group of galaxies ($R \sim 1$Mpc, $n_e \sim 3 \times 10^{-4}$ cm^{-3}) (Silk, 1970; Rees *et al.*, 1968; Hunt and Sciama, contributed paper for this Symposium). But the standard and much-discussed hypothesis is that of an intergalactic medium having the closure density

$$\varrho_{cl} = \frac{3H_0^2}{8\pi G} \tag{4}$$

and some temperature $T \sim 10^6$ K. If $H_0 = 100$ km (s Mpc)$^{-1}$, the extragalactic flux $\simeq 500$ units at 280 eV suggested by Davidsen *et al.* (1972) would be supplied by a Euclidean sphere of 'cosmological' radius (Felten, 1966)

$$R = \frac{1}{2} R_H = \frac{1}{2} \frac{c}{H_0}, \tag{5}$$

filled with hydrogen plasma at $\varrho = \varrho_{cl}$ and $T \simeq 4 \times 10^6$ K. This is also the T which fits the NRL polar data best. But order-of-magnitude astronomers must be cautious in this problem, because in the real universe T must be a function of epoch, and the medium is quite likely to be hotter at large z (because of adiabatic cooling). The emissivity at 280 eV is quite a strong function of T around 10^6 K. Quite a bit of work has been done on thermal histories of the intergalactic medium, most recently by Bergeron (1969, 1970). This will have to be extended as the soft X-ray data develop.

At present I do not see any fatal objection to a hot dense intergalactic medium, with heat sources placed in z so that the thermal history supplies the observed soft X-rays without transgressing upper limits at $h\nu > 1$ keV. Gunn and Gott (1972) think it likely that $\varrho \ll \varrho_{cl}$, but indirect arguments like theirs are seldom ironclad. It has been suggested that observations of neutral hydrogen in the peripheries of external galaxies enable us to reject the hypothesis of an intergalactic soft X-ray flux. This is incorrect (Felten and Bergeron, 1969), essentially because we do not know the outer structure of external galaxies, or even of our own Galaxy, well enough to employ them as photon counters!

4. 'Mainstream' X-Rays from the Disk, $h\nu = 1$ keV-1 MeV

I pass now to a higher energy band, 1 keV–1 MeV, where the spectrum has usually been represented as a power law. It has been claimed (Seward *et al.*, 1967; Cooke *et al.*, 1969) that in 1–10 keV there is a detectable excess brightness associated with the galactic plane. This has been observed again recently (Bleach *et al.*, 1972) in an interarm region of the disk ($l^{II} \approx 60°$); its line intensity is ≈ 3 photons $(cm^2 \text{ s rad})^{-1}$ in 2–10 keV. There is no shortage of diffuse-emission theories to explain this line source (e.g. de Freitas Pacheco, 1970; Ipavich and Lenchek, 1970). Time does not permit me to explore these theories; Ilovaisky has reviewed them in a contributed paper for this Symposium and found that they probably are not adequate to produce the observed flux. Anyway they seem a bit superfluous. Recall that Ryter (1970) and Setti and Woltjer (1970) showed that the *weakness* of this unresolved line source permitted us to infer that most of the then-*resolved* sources were intrinsically quite bright and at distances ~ 10 kpc (not much less) – otherwise the unresolved disk would have been much stronger than it is! Then it is clear that this line source *can* in fact be just unresolved galactic sources, e.g. SNR (Ryter, 1970). Bleach *et al.* (1972) argued that, if so, they must be a new family of smaller z_s than the presently resolved sources, and might be more numerous and of lower luminosity, $\sim 10^{33}$ erg s^{-1}. The scale height implied by their data is $z_s \lesssim 600$ pc. This could perhaps be a little larger, since the effective path length to the edge of the galactic disk may be a little larger than the 10 kpc they assumed. They claim that z_s is significantly *thinner* than the z_s for the *resolved* (UHURU) sources, for which they find $z_s \approx 900$ pc. I am not altogether convinced that this discrepancy is significant.

The fact that Clark (paper in this Symposium, p. 29) *failed* to observe the enhancement in the plane when looking in a different direction (the longitude band $l^{II} \approx 140$–$150°$) may suggest that statistical fluctuations in the line density of these sources are quite large and therefore that they are not really very numerous, or it might simply mean that they are numerous in some parts of the Galaxy (interarm?) but not in others. The Leicester group (K. A. Pounds, private communication) found recently that at least 90% of the disk emission they reported earlier can now be accounted for by resolved sources. The enhancement was also seen in 7–12 keV by OSO-3, integrated over a wide range of l^{II}, but it has not yet been checked whether this can now be accounted for by UHURU sources. As usual, more data are needed. The sources contributing to this disk flux could well be the same ones which give the soft X-rays. If these sources are of thermal-bremsstrahlung character, they may then have hot components, $T \sim 8 \times 10^7$ K, but if power-law they must be rather soft, no flatter than $I_\nu \propto \nu^{-2.2}$ in energy units (Hudson *et al.*, 1971). Flare stars are a possibility (Edwards, 1971; Cavallo and Horstman, 1972); X-ray lines of iron should then be seen.

5. Mainstream X-Rays: Isotropic Component

Away from the galactic plane, the diffuse flux in 1–100 keV at least is isotropic (within $\lesssim 4\%$ around 10 keV) over large portions of the sky (Schwartz, 1970; Fabian and Sanford, 1971; Schwartz *et al.*, 1971). A 'hole' $\simeq 20°$ across and 10% deep is rumored to have been observed by UHURU in the direction of Draco, but this seems doubtful. If it is real, it may be galactic, and associated with the high-velocity clouds in this direction. The general isotropy suggests an extragalactic origin.

Simple superposition theories are basically attractive. The 1–10 keV luminosity of our Galaxy is $L_X \simeq 5 \times 10^{39}$ erg s^{-1} (a generous estimate). The local density of ordinary galaxies in space is $\simeq 3 \times 10^{-2}$ Mpc^{-3} if $H_0 = 75$ Mpc^{-3} (Sandage, 1965; cf. van den Bergh, 1961; Kiang, 1961).* Using $\frac{1}{2}R_H$ as the effective 'cosmological' superposition radius, we find that the 1–10 keV integrated intensity due to ordinary galaxies should be

$$I\,(\mathrm{erg\ cm^{-2}\ s^{-1}\ sr^{-1}}) \simeq \frac{nL_X c}{8\pi H_0} \simeq 2.4 \times 10^{-9}. \tag{6}$$

The intensity (6) is a factor of $\simeq 25$ below the *observed I*, and this factor has spawned most of the pretentious 'cosmic' theories of the background. But there are other superposition possibilities, of which I will mention several. The 1–10 keV luminosity of 3C 273 is $\simeq 10^{46}$ erg s^{-1} (Kellogg *et al.*, 1971), and the local space density of QSO's may be $\sim 10^{-6}$ Mpc^{-3} (Schmidt, 1970). These values for L_x and n would bring (6) up to four times the observed value! But not all these QSO's are necessarily in the same active state as 3C 273; the strong radio QSO's (QSS's) are 10^2–10^3 times rarer. The rich clusters of galaxies in Virgo, Coma and Perseus (Kellogg *et al.*, 1971; Forman *et al.*, 1972) are extended sources at a level high enough to reduce the shortfall of (6) to a factor ~ 10 if all rich clusters are sources. Seyfert galaxies are another possibility. NGC 4151 is detected, and the present data on NGC 1068 and 1275 permit us to assume that the mean X-ray luminosity of Seyferts is as high as $\sim 2 \times 10^{42}$ erg s^{-1}. Since their space density is $\sim 1\%$ of that of normal galaxies (Burbidge, 1970), this would leave (6) short of the observed intensity by a factor only ~ 6. Finally, we could suppose that the *time-average* luminosity of normal galaxies is $\gg$ the *present* L_X of our own Galaxy, because of high X-ray output by supernovae (Tucker, 1970); the time average is clearly the quantity to be used in (6). We see that superposition theories, even in this simple Euclidean form, are not dead. Setti and Woltjer confirm this in more careful calculations for this Symposium (p. 208).

The high isotropy would put constraints on some superposition theories. Schwartz *et al.* (1971) estimate that the number of sources contributing must be $\gtrsim 4 \times 10^6$. Since the total number of galaxies within $\frac{1}{2}R_H$ is only $\sim 1 \times 10^9$, this limit might be quite tight for QSO or supernova theories, depending upon details. Random fluctuations have not been accounted for explicitly in the argument of Schwartz *et al.* (1971), but I will not spend time on this, as I believe Dr Rees intends to develop it in the next paper.

Turning to the 'metagalactic' theories, I will not go through the familiar 'classical' inverse-Compton explanation for the background radiation (Felten and Morrison, 1966; Setti and Rees, 1970). The apparent sharp 'break' in the spectrum at 40 keV (Figure 1) is a stumbling block for this theory. The break (Schwartz *et al.*, 1970; Horstman and Horstman-Moretti, 1971) is in strong dispute at this Symposium;

* Several of the following estimates depend on H_0 in various ways. I will take $H_0 = 75$ to suppress this complication.

I shall assume that it *is* real and discuss the consequences. It will be clear that the existence and shape of this break are of great importance in choosing among theories.

Putting aside any possibility of cosmic far-infrared radiation, I set the photon energy density in intergalactic space equal to

$$\varrho_{bb} \approx a\,(3\,\mathrm{K})^4 \approx 0.4\,\mathrm{eV\,cm^{-3}}. \tag{7}$$

The characteristic time for Compton loss by an electron of energy $\gamma m_e c^2$ is $\propto \gamma^{-1}$. If we want to induce a 'break' in the power-law spectrum of the received Compton radiation, we can do so by postulating another competing loss process with a characteristic time t_L which is, say, the same for all γ, and which therefore acts on the low-energy electrons faster than Compton loss. The resulting break occurs at

$$\varepsilon_0 \sim \frac{2 \times 10^{36}}{[t_L(\mathrm{s})]^2}\,\mathrm{eV} \tag{8}$$

and is 0.5 power (Felten and Rees, 1969). To put this at 40 keV we need $t_L \sim 3 \times 10^8$ yr. There is no physical basis for such a value. For high-energy electrons free in the intergalactic medium, all loss times would be $\gtrsim 10^{10}$ yr. We might suppose that the electrons suffered adiabatic expansion loss with $t_L \sim 3 \times 10^8$ yr in the radio galaxies from which they came. But this is an unreasonably long lifetime for a radio-galaxy outburst, and in any case, confinement this long in the strong magnetic fields of a radio galaxy would cause these electrons to emit much more synchrotron radiation than observations of the background radio brightness will allow. Expanding confinement *near* radio galaxies, in regions of *weak* field, might work; we require $\bar{H} \lesssim 10^{-7}$ G. Perhaps some form of this model still has unexplored possibilities. It can be extended to radio galaxies at large z, and there the constraints are less severe (Bergamini *et al.*, 1967; Felten and Rees, 1969). But further straining at these artifices for producing the break does not seem profitable if the break is indeed sharp, for a reason which will appear shortly.

Brecher and Morrison (1969) obtained a magnificent fit to the bends and curves of the X-ray spectrum (the dashed curve in Figure 1 is theirs) by folding additional complications into the inverse-Compton model. They took normal galaxies rather than radio galaxies as the electron sources, introduced a spectral break arising *in the sources* (and lying at the same energy in each source!) to circumvent the difficulty of the 40-keV break, postulated a distribution of electron spectral indices in the various sources to induce curvature at the two ends of the Compton spectrum, and assumed a very high output of cosmic rays by these 'normal' galaxies, so that our own Galaxy can no longer be taken as an example (Setti and Rees, 1970). Though not all the details in this paper are clear, it is not surprising that a good fit can be obtained with so many degrees of freedom. Notice how well their curve matches the sharp break at 40 keV.

Recent work by Cowsik and Kobetich (1972) reveals a serious difficulty with the Brecher and Morrison spectrum. To make this clear let me first show a figure from Blumenthal and Gould (1970) (Figure 4). The solid curve is the *number* spectrum in energy of photons Compton-scattered by an electron of energy $\gamma m_e c^2$ moving in an isotropic flux of monoenergetic photons, energy E_0. The abscissa is in units of the kinematic maximum energy, $4\gamma^2 E_0$. I have sketched in (dotted curve) the corresponding *energy* spectrum. This is strictly a physical problem, and no astronomical assumptions are involved. Note that the width at half-power points is large, a factor

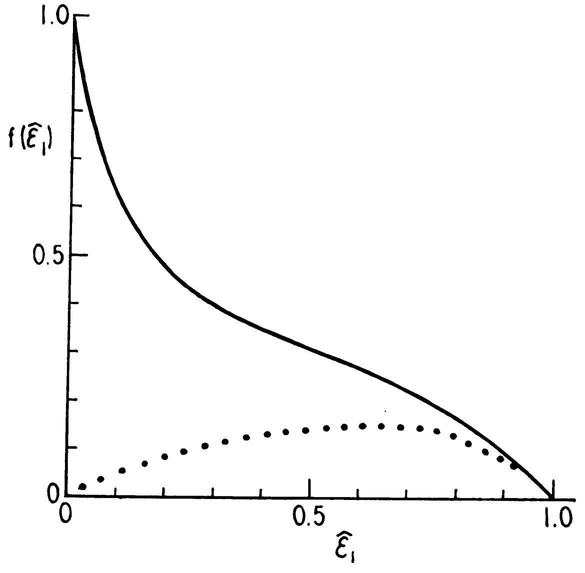

Fig. 4. Differential *number* spectrum of Compton-scattered photons produced by monoenergetic electrons in an isotropic monoenergetic photon flux (Blumenthal and Gould, 1970). Ordinate units are arbitrary. The dotted line (sketched) shows the corresponding energy spectrum. The point 1.0 at right corresponds to the kinematic maximum energy $4\gamma^2 E_0$.

$\sim$6 in energy, although the *reacting photons and electrons are monoenergetic*. Then when an electron spectrum having a 'break', even a sharp break, is folded with an isotropic photon flux (monoenergetic, or *a fortiori* blackbody) it is clear that a sharp break will *not* be obtained in the radiated Compton spectrum. Figure 5 shows the results of integrations by Cowsik and Kobetich (1972). 'L_{BM69}' shows the Brecher and Morrison (1969) spectrum, with the sharp break given by a delta-function approximation. 'L_2' shows the accurate result for the Compton spectrum radiated by a simple power-law electron spectrum with one abrupt break, interacting with blackbody photons. The width of the knee is seen to be a factor $\sim$10. 'L_{ig}' is an even *less* 'angular' Compton spectrum which Cowsik and Kobetich (1972) obtain by introducing additional smearing assumptions, some rather arbitrary, which I will not discuss here. The important point is that an electron power law with a break, even a sharp break, will not produce a Compton spectrum with a break any sharper than L_2, and it is doubtful whether L_2 is an acceptable fit to the 40-keV data. This cuts strongly against all inverse-Compton theories, not just that of Brecher and Morrison

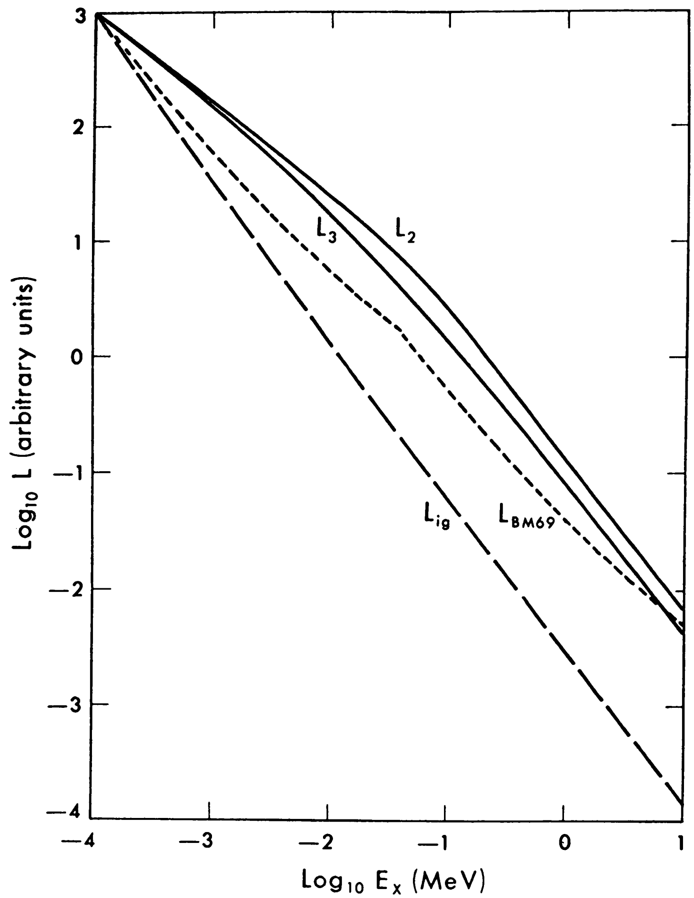

Fig. 5. Shapes of expected 'breaks' in Compton spectra (Cowsik and Kobetich, 1972). See text.

(1969). Of course it would be possible to patch this up by introducing additional components, e.g. a suitably shaped 'hump' in the electron energy distribution. But then the inverse-Compton theory loses its basic appeal of simplicity.

We are left with the problem of explaining the sharp (?) 40-keV break. I will show you one more figure from Cowsik and Kobetich (1972) (Figure 6). Here these authors have plotted the observed diffuse X-rays compared with their smooth (kneeless) Compton spectrum and with a model spectrum for extragalactic γ-rays from white dwarfs, concocted by Cowsik (1971). (This model involves the dubious assumption that most of the galactic *cosmic rays* are also produced by white dwarfs). In their view, the *soft* X-rays come from inverse Compton effect, and the only X-ray band not fitted adequately by these two components is the range from 3 to 100 keV, containing the knee. Therefore, they suggest a third component, namely thermal bremsstrahlung from a very hot intergalactic plasma at $T \simeq 3.3 \times 10^8$ K ($kT \simeq 30$ keV). The advantage of this is that the bremsstrahlung exponential function has an almost

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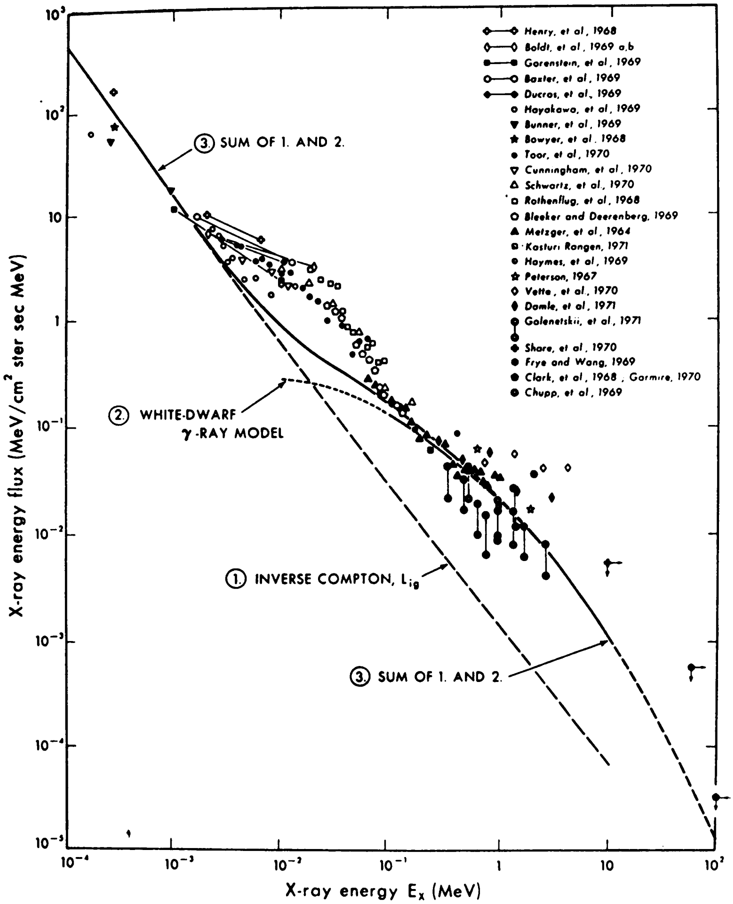

Fig. 6. Three-component model for the diffuse X-ray background (Cowsik and Kobetich, 1972). See text.

unique capability of giving the sharp break. If $H_0 = 100$, a density $\varrho = \varrho_{cl}$ would give ~ 10 times more flux than is observed in the break region, but since the product $\varrho_{cl}^2 R_H \propto H_0^3$ when H_0 is varied, Cowsik and Kobetich (1972) set $H_0 \simeq 55$ as suggested by recent data (Sandage, 1971) and then find that $\varrho = \varrho_{cl}$ ($n_e \sim 3 \times 10^{-6}\ \mathrm{cm}^{-3}$) is quite consistent with the X-ray flux! Thus something like the 'hot universe' of Gold and Hoyle (1959) is resuscitated by the new value of H_0, which should not, however, be taken as firmly established. This new twist to the problem of the hot intergalactic medium is intriguing. Of course it is no great achievement to fit an observed spectrum by a three-component model with many adjustable parameters.

6. γ-Rays, $h\nu > 1$ MeV

I have time for only a few remarks about γ-rays. The reality of the turnup near 1 MeV has been disputed (Anand *et al.*, 1970), and is in severe doubt at this Symposium, though an independent group has obtained the same turnup (Vedrenne *et al.*, 1971). Several theoretical models have been proposed (Silk, 1970; Sunyaev, 1970), all extragalactic and some resorting to large z. Indeed the indication now is that these photons *are* isotropic (Damle *et al.*, 1972).

In the 100-MeV range, Cavallo and Gould (1971a) have recalculated the expected flux of '$\pi-\gamma$' photons due to decay of π^0's produced by galactic cosmic rays, assuming that the cosmic-ray density throughout the galactic disk is the same as its local value and using observed neutral-hydrogen column densities. With the recent renormalization of the observational data, they find reasonably good agreement with the observed 'line source' in the plane, except at the galactic center, where an additional source is required. This may be supplied by Compton scattering of the dense infrared radiation at the galactic center by cosmic-ray electrons (Stecher and Stecker, 1970). Since the predicted '$\pi-\gamma$' fluxes are conservative, there may be serious consequences to cosmic-ray theory if the galactic 'line source' turns out not to be there, as a high-resolution observation suggests (Browning *et al.*, 1972).

An attractive feature of the $\pi-\gamma$ process is that its spectrum can be predicted on physical grounds, without astronomical hypotheses. Figure 7 (Cavallo and Gould, 1971a) shows this spectrum (photons s^{-1} MeV^{-1}); it has a flat top and is symmetrical about $\frac{1}{2}m_{\pi^0}c^2=67.5$ MeV. An earlier result by Stecker (1970) is also shown. The difference between these curves has become a matter of dispute (Stecker, 1971; Cavallo and Gould, 1971b). It appears that the Cavallo and Gould curve may be more nearly correct, although the matter is not as simple as they tried to make out. A third independent calculation would be useful; Goldsmith and Levy (1971) have undertaken this, at least in part. Observations (Fichtel *et al.*, 1972) indicate that the

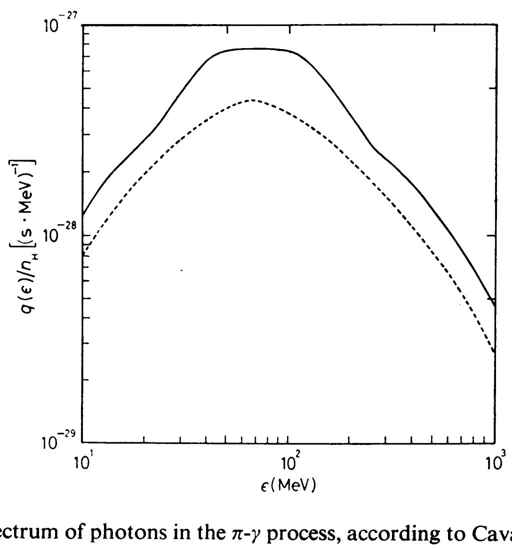

Fig. 7. Production spectrum of photons in the π-γ process, according to Cavallo and Gould (1971a). The dashed curve is a result given earlier by Stecker (1970).

photons coming from the galactic-center direction are indeed as hard as a $\pi - \gamma$ origin would imply.

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The reviews by Setti and Rees (1970) and Silk (1970) have been helpful, as have conversations with K. Brecher, P. Morrison, M. J. Rees, P. A. Strittmatter and W. H. Tucker. A referee kindly made the Cowsik and Kobetich figures available to me, together with some comments. Preparation of this manuscript at Steward Observatory has been supported partially by the University Science Development Program of the U.S. National Science Foundation.

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