A NEW ASPECT OF GALACTIC RIDGE X-RAY EMISSION —SNRs IN A TENUOUS MEDIUM ? —

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ABSTRACT. Thin thermal natures of a plasma temperature of several keV are observed in the diffuse X-ray spectra from the galactic ridge region by the Tenma satellite. Within the constraints imposed by the observational results, possible origins of the ridge X-ray emission are discussed. We show that unidentified young supernova remnants in a tenuous medium could be a significant contributor to the ridge emission.

1. INTRODUCTION

The first systematic survey of the diffuse galactic ridge X-ray emission above 2 keV was carried out by the HEAO-A satellite (Iwan et al. 1982, Worrall et al. 1982). Most of the X-ray emission was found to come from point sources. However, an excess emission, which is not resolved into point sources was also observed along the galactic plane. The origin of this diffuse X-ray emission is still unknown.

Recently Tenma and EXOSAT satellites confirmed this finding with better energy resolution (Tenma) and better spatial resolution (EXOSAT) (Koyama 1984, Warwick et al. 1985 , Koyama et al. 1986a). The diffuse emission is concentrated near the inner galactic disk known as the galactic ridge. In this paper, we report on the observational results by the Tenma gas scintillation proportional counters (GSPC) and try to give a new interpretation on the origin of the ridge emission.

2. X-RAY SPECTRUM FROM THE GALCTIC RIDGE

The observed positions were selected so as to exclude cataloged X-ray sources and radio supernova remnants. Figure 1 shows the observed positions in the galactic coordinate. Here, large circles show the full field of view of the detector(GSPC); small open circles indicate cataloged X-ray sources (Forman et al. 1978, Wood et al. 1984) with intensity greater than 2 m Crab ; and small closed circles indicate radio supernova remnants (Clark and Caswell 1976).

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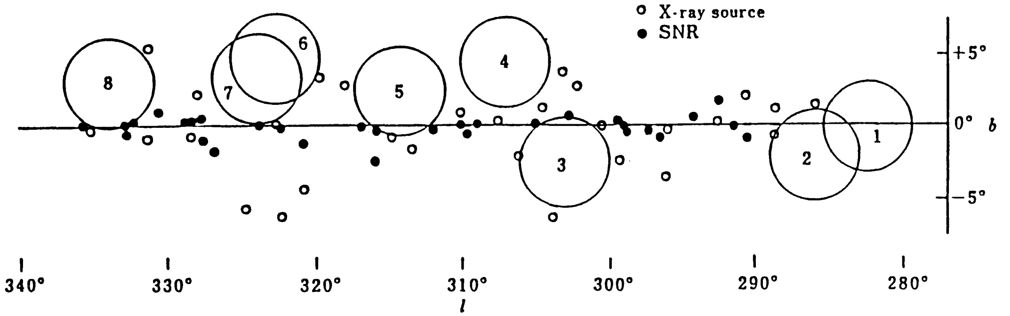
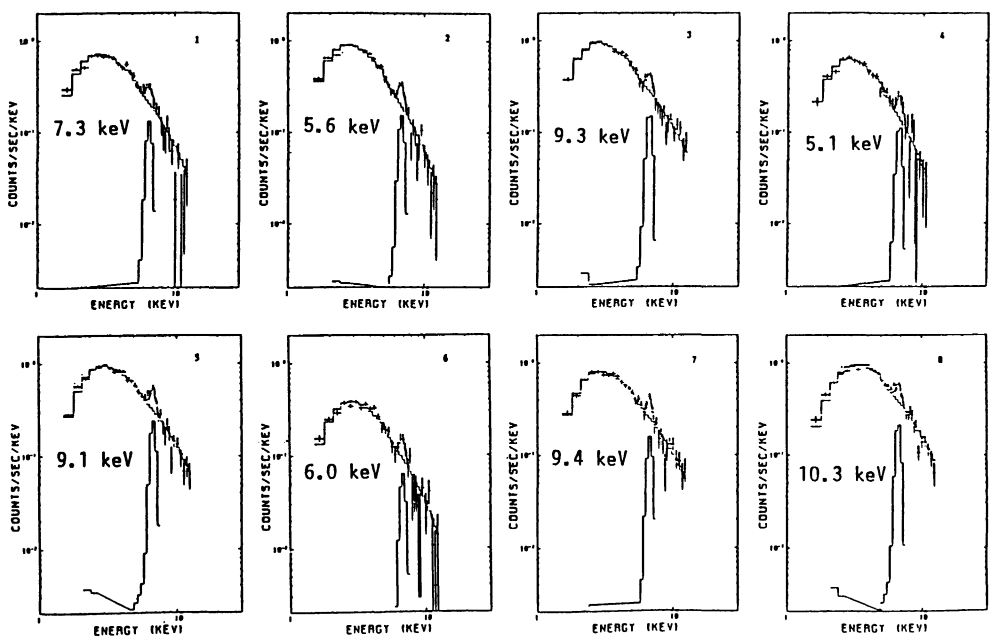
Fig.1



We can observed an intense emission line at about 6.7 keV from every position. This emission line is, without doubt, K-emission line from helium-like iron. Therefore this observation strongly supports the interpretation of of a thin thermal origin for the ridge emission. Furthermore, the continuum spectrum can be fit by a thermal bremsstrahlung model of several keV as is given in the solid curve in figure 2. The best-fit temperatures are also given in the figure.

Fig.2



From this, we are able to draw the following conclusion:

(1) The ridge emission mainly comes from thin hot plasma of several keV.

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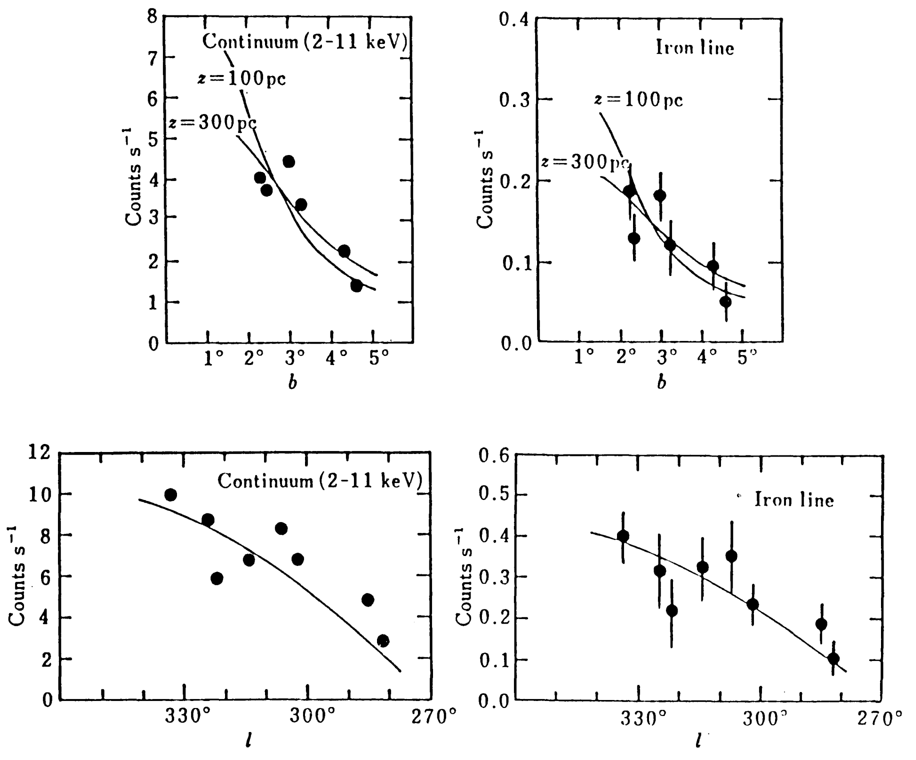
3. SIZE OF THE EMISSION REGION AND TOTAL LUMINOSITY

In figure 3, the intensity of iron line and continuum emission are plotted as a function of angular distance from the plane. Solid lines are the estimated curve assuming disk-like emission of 10 kpc radius with scale height of 100 and 300 pc. The lower graph shows the longitudial distribution of iron and that of continuum intensity. Again the solid curves assume the same disk-like emission as that assumed in the upper graph. From this figure, we can conclude that the emission comes from the inner galactic disk at a radius of about 10 kpc and a scale height of about 100 pc. Thus, we can estimate a total luminosity of about 10^{38} erg/sec. Therefore we are able to draw a second conclusion:

(2) The ridge emission is concentrated near the inner disk and has a total luminosity of about 10^{38} erg/sec.

This conclusion is consistent with the results of both HEAO-A and EXOSAT.

Fig.3



The third conclusion that we can draw based on the results shown in the figure 2 is ;

(3) The observed plasma temperature differs from place to place.

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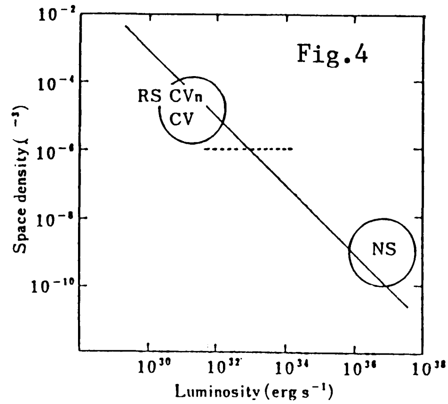
4. ORIGIN OF THE RIDGE EMISSION

The ridge emission is probably an integrated effect of unresolved discrete sources. Given the emission volume and total luminosity of the ridge emission, we are able to relate the luminosity of discrete source to the space density. Figure 4 shows this relation. The candidate source should lie on the solid line. As an example, we show the known class of X-ray sources; neutron star binaries (NS) , RS CVn satrs (RS CVn) and cataclysmic variables (CV).

Since the observed temperature differs from place to place, the space density of the candidate source should not be very large. By a simple calculation, we can conclude that the space density should be lower than the dotted line in the figure. Therefore the luminosity of an individual source should be higher than 10^{33} erg/sec. On the other hand, the luminosity of individual discrete source is required to be less than 10^{36} erg/sec, given the fact that they can not be resolved into point sources.



Thus the proper candidate is characterized by ;

(1) A thin thermal spectrum of several keV with an intense iron line at about 6.7 keV.
(2) An individual luminosity in the range 10^{33} - 10^{36} erg/sec
(3) A total luminosity of 10^{38} erg/sec.
(4) Being spatially concentrated near the inner galactic disk with scale height of about 100pc.

These conditions are depicted graphically in figure 5.

Many authors have suggested M-dwarfs as candidate sources. However this suggestion is inconsistent with several of our findings. For example, X-ray spectrum of M-dwarfs is often very soft, their luminosity is about 10^{28} erg/sec and the scale height is very large. Therefore it is inconsistent with conditions (1) ,(2) and (4).

RS-CVn and Cataclysmic Variable has also been suggested as candidate sources . In this case, the continuum spectrum is marginally consistent with that of the ridge emission. The individual luminosity of these objects is typically 10^{32} erg/sec and their total luminosity may exceed 10^{37} erg/sec. Therefore these X-ray sources could be marginal candidates. The key observation, however, is that of the iron line feature of these objects. A systematic spectral observation of this class of objects would be useful in settling this point.

A third possible candidate is the newly discovered thin thermal source ' star forming region'(Agrawal et al. 1986 , Koyama 1986c). The spectrum , individual luminosity and scale height of this objects is consistent with conditions (1) , (2) and (4). However the total luminosity may be less than 10^{37} erg/sec.

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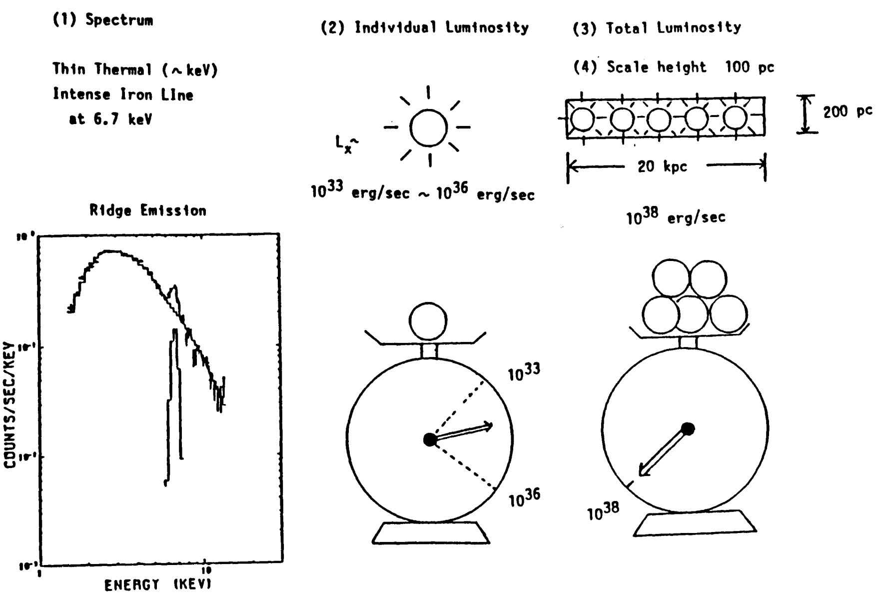
Fig.5



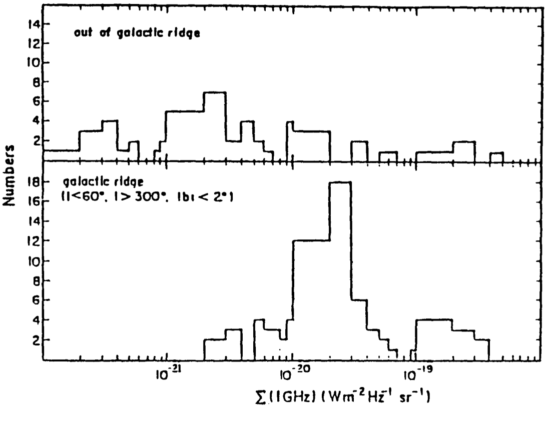
5. CONTRIBUTION OF SUPERNOVA REMNANTS

The spectrum of young SNR is similar to the ridge emission. Therefore, uncataloged SNRs may also be possible candidate sources of the ridge emission (Koyama et al 1986b).

Figure 6 shows the number distribution of radio SNR as a function of surface brightness in the ridge region and other regions (following Milne 1979). From this figure, we note that there could be lots of radio SNRs on the ridge below the current detection limits about 10^{-20} ($Wm^{-1}Hz^{-1}sr^{-1}$).

We will estimate the X-ray luminosity from these uncataloged radio SNRs. We derived the surface brightness of radio SNRs semi-empirically as a function of density (n/cc) of the interstellar medium and the diameter of the SNR (D pc) (Tomisaka et al. 1980).

Fig.6



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$$\Sigma(1\mathrm{GHz}) = 2.88 \times 10^{-14}\, D^{-3.8}\, n^{2} \qquad (\mathrm{Wm^{-2}Hz^{-1}sr^{-1}})$$

Assuming a simple Sedov model (1959) with an initial explosion energy of 10^{51} erg, the diameter of the SNR is given as a function of density and age (year);

$$D = 0.62 \times n^{-0.2}\, E_{51}{}^{0.2}\, \tau^{0.4} \qquad (\mathrm{pc})$$

Then the condition that these radio SNRs escape from the current survey is:

$$n\, \tau_3{}^{-0.55} < 0.11 \times E_{51}{}^{0.28} \qquad (1)$$

This relation is given in figure 7 on the density (n/cc) and age (τ year) plane.

The X-ray luminosity and temperature of the SNR are given as functions of density and age using the Sedov model.

$$Lx = 1.6 \times 10^{34}\, n^{1.2}\, E_{51}{}^{0.8}\, \tau^{0.6} \quad (\mathrm{erg/sec}),$$

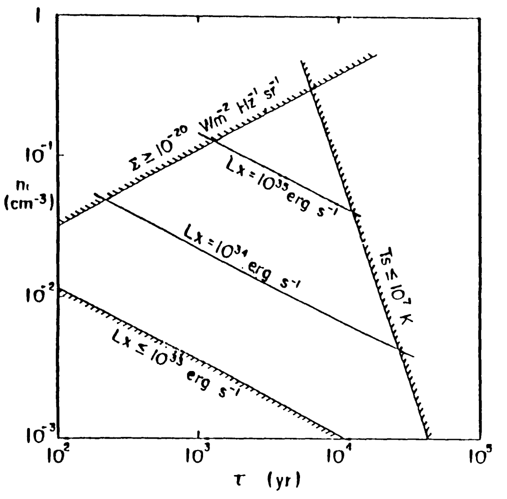
$$T = 2.0 \times 10^{11}\, n^{-0.4}\, E_{51}{}^{0.4}\, \tau^{-1.2} \quad (\mathrm{K}).$$

The observations require that the luminosity be in the range 10^{33} - 10^{36} ergs/ sec, and that the temperature be higher than 1 keV. We therfore arrive at the following conditions;

$$n\, \tau_3{}^{3} < 57 \times E_{51} \qquad (2),$$

$$10^{-3}\, E_{51}{}^{-0.8} < n^{1.2}\, \tau_3{}^{0.6} < E_{51}{}^{0.8} \qquad (3).$$

Fig.7



The conditions (1), (2) and (3) are given in the n - τ plane (figure 7), where hatched sides are forbidden region. Based on an inspection of this figure, we can conclude that SNRs in a tenuous medium less than 0.1 /cc and age of 1000-10000 year could be candidate sources of the ridge emission. The total luminosity can be given as a function of t_{10}, where t_{10} is the interval of supernova explosion in units of 10 years.

$$Lx \sim 10^{38}/t_{10} \quad \mathrm{erg/sec} \qquad (n = 0.1)$$

$$Lx \sim 10^{37}/t10 \quad \mathrm{erg/sec} \qquad (n = 0.01)$$

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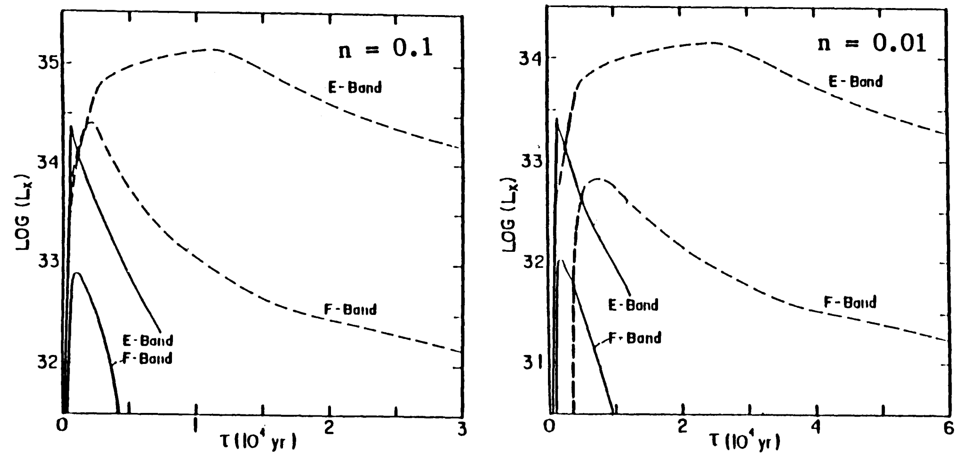
In order to estimate the luminosity more accurately, we carried out a numerical calculation of a supernova explosion in a tenuous medium of 0.1 and 0.01 /cc. The results are given in figure 8 with solid lines (X-ray luminosity from the ejecta) and dashed lines (blast wave), where E- band and F-band indicate the energy range 1.5-8 keV and 8-25 keV, respectively. The total luminosity above 1.5 keV is then given as:

$$Lx \sim 1.5 \times 10^{38}/t_{10} \quad \text{erg/sec} \quad (n = 0.1)$$

$$Lx \sim 0.5 \times 10^{38}/t_{10} \quad \text{erg/sec} \quad (n = 0.01)$$

Fig.8

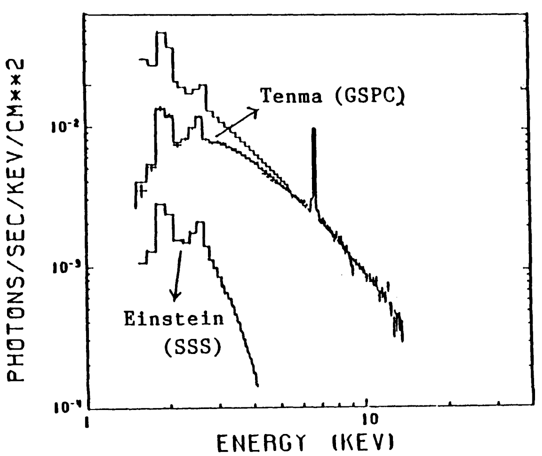


Therefore, the current rate of one explosion per 30-50 years already contributes significantly to the ridge emission. If the rate is as high as one ten years, then we can explain the total ridge emission.

In any case, we can say that there are many uncataloged SNRs on the galactic ridge.

The surface brightness of the X-ray SNRs in a tenuous medium is less than 10^{-13} erg/s/cm^2/arcmin.^{2}. This value may be at the detection limit of the Einstein medium survey. Furthermore, on the galactic ridge, the heavy

Fig.9



interstellar absorption on the galactic ridge makes it difficult to detect young X-ray SNR, because the Einstein Observatory has high sensitivity only in the low energy band.

We show the efficiency of both the Tenma (GSPC) and the Einstein Observatory (SSS) assuming an N_H value of 3 x 10^{22} H/cm^2 using the observed ridge spectrum. Figure 9 shows that the current detection limit of X-ray SNRs by the Einstein Observatory is still limited. If we were able to combine Einstein's spacial resolution and Tenma's effective area above several keV, then the resulting sensitivity would be about 10-100 times larger than that achieved in the current survey of the Einstein Observatory. We would then able to locate many SNRs on the galactic ridge.

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DISCUSSION

D. Helfand: In the Magellanic Clouds, we see a total population of over 40 SNRs and the sample is complete to 10^{35} ergs s^{-1}, but there are none with a temperature as high as that of your diffuse emission. I believe you should consider the alternative of Be star binaries which have a scale height, luminosity range, galactic population and harder spectrum consistent with your requirements.