HARD X-RAY EMISSION FROM THE GALACTIC RIDGE

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ABSTRACT

We present results[1] of a study of the Galactic ridge X-ray emission (GRXE) in hard X-rays performed with the IBIS telescope aboard INTEGRAL. The imaging capabilities of this coding aperture telescope make it possible to account for the flux from bright Galactic point sources whereas the wide field of view permits to collect large flux from the underlying GRXE. Extensive study of the IBIS/ISGRI detector background allowed us to construct a model that predicts the detector count rate with $\sim 1-2\%$ accuracy in the energy band 17-60 keV. The derived longitude and latitude profiles of the ridge emission are in good agreement with the Galactic distribution of stars obtained from infrared observations. This, along with the measured hard X-ray spectrum of the Galactic ridge emission strongly indicates its stellar origin. The derived unit stellar mass emissivity of the ridge in the energy band 17-60 keV, $(0.9-1.2)\times10^{27}$erg s^{-1} $M_{\odot}^{-1}$agrees with that of local (in the Solar neigborhood) accreting magnetic white dwarf binaries - dominant contributors to the GRXE at these energies. In addition, the shape of the obtained GRXE spectrum can be used to determine the average mass of white dwarfs in such systems in the Galaxy as $\sim 0.5M_{\odot}$. The total hard X-ray luminosity of the GRXE is $L_{17-60\mathrm{keV}} = (3.7\pm0.2)\times10^{37}$erg s^{-1}in the 17–60 keV band. At energies 70–200 keV no additional contribution to the total emission of the Galaxy apart from the detected point sources is seen.

Key words: galaxy: structure – galaxy: bulge – galaxy: disk – X-rays: diffuse background – stars: white dwarfs.

1. INTRODUCTION

Broad band studies of the radiative output of the Galaxy demonstrate that different physical mechanisms contribute to the brightness of the Galaxy in different energy bands. In the near-infrared and optical spectral bands the bulk of the emission is provided by different types of stars. In the high energy ($h\nu >$GeV) band the Galactic emission is likely a result of interactions of cosmic rays with interstellar matter [e.g. 21, 35, 36, 18, 16].

From the first all sky surveys in X-rays ($\sim$ 2-10 keV) it became clear that in this energy band the emission of the Galaxy as a whole is dominated by the contribution from bright point sources, mainly accreting black holes and neutron star binaries. However, there was also discovered emission that was not resolved into separate point sources – the Galactic ridge X-ray emission (GRXE, e.g. Worrall et al. 44). Even the significant increase of the sensitivity of X-ray instruments over the last decades has not led to resolving all the Galactic ridge emission into discrete sources [38, 14, 11]. This was considered as an indication of a truly diffuse origin of the Galactic ridge emission.

Latest studies of the morphology and volume emissivity of the GRXE in the energy band 3-20 keV provide convincing evidence that the majority of the GRXE consists of a large number of stellar type X-ray sources, namely white dwarf binaries and coronally active stars [30, 32].

In particular for the energy band $>$20 keV this means that the GRXE must be dominated by the contribution of magnetic white dwarf binaries – intermediate polars (IP) and polars (P).

The GRXE spectrum above $>$20 keV is not yet accurately measured [e.g., 29, 34, 17]. The most recent results on GRXE were obtained with the instruments aboard INTEGRAL observatory [45]. [23] and [41] using IBIS telescope [42] have shown that although bright point sources dominate the emission from the Galaxy at 30 keV, there is a significant unresolved component. [5] and [37] using SPI spectrometer [43] found an unresolved Galactic X-ray emission at energies higher than 50 keV.

In order to determine the origin of the hard X-ray Galactic background it is very important to investigate whether the GRXE in hard X-rays is distributed similar to the stellar distribution, indicating its stellar origin, or it more closely follows the interstellar gas density distribution, thus connecting to the high energy gamma-ray background seen e.g. by EGRET. Does the spectrum of the GRXE have a cutoff at energies $\sim$30-50 keV due to the typical cutoff in spectra of magnetic CVs [e.g. 39], or it has a power law spectral shape up to higher energies as would be ex-

[1]The content of this report is mainly based on paper [22].

pected if the Galactic background emission were induced by cosmic ray electrons [e.g. 36, 25, 31, 33].

Previous attempts to study the hard X-ray component of the GRXE were severely inhibited by the poor angular resolution of the instruments used, which precluded effective subtraction of the contribution of bright point sources. Only now this has become possible thanks to the hard X-ray telescopes aboard the INTEGRAL observatory. The IBIS telescope on INTEGRAL possesses an optimal combination of properties to perform such a study:

- it has a relatively large field of view ($\sim 28^\circ \times 28^\circ$ at zero response) that allows large flux of the diffuse emission to be collected, but not too large to preclude the construction of a GRXE map if the telescope is used as a collimated instrument;
- it has a possibility to detect and subtract the contribution of point sources;
- its sensitivity to point sources for typical exposure times in the Galactic plane regions ~1Ms is $\sim 10^{-11}$ erg s^{-1} cm^{-2}, which for the Galactic Center distance corresponds to a luminosity $\sim 10^{35}$;

  erg s^{-1}. subtraction of sources with luminosities higher than this limit allows one to avoid significant contamination of the GRXE by point sources [see e.g. 32].

Since its launch in 2002 INTEGRAL/IBIS has collected a large amount of observational data on different sky regions, and in particular on the inner Galactic plane where most of the GRXE is located.

In this work we will study the spectral and morphological properties of the GRXE in the hard X-ray energy band 17-200 keV. At higher energies the positronium annihilation continuum of the Galactic Center [e.g. 24, 12, 8, 19] should be carefully taken into account, which requires a different approach from the one used in this work (which is especially related to the detector background modeling). For this reason we leave the study of the Galactic background emission at energies higher then 200 keV for a separate paper.

2. ANALYSIS

For our analysis we used all the IBIS data available to us, including public data, some proprietary data (Galactic Center observations and Crux Spiral arm deep exposure observations) and data available to us through the INTEGRAL Science Working Team. In total we analyzed ~33 Msec of the data (deadtime corrected value of exposure). We considered only the data of the ISGRI detector of the IBIS telescope, which provides data in the energy band $\sim 17-1000$ keV with high sensitivity in hard X-rays (17-200 keV) and has sufficient angular resolution ($\sim 12'$) for studying crowded fields like the Galactic Center region.

The method of the sky reconstruction employed in the IBIS telescope (coded mask imaging) does not allow one to study directly diffuse structures that are significantly larger that the size of the mask pixels. Therefore, in order to study large scale structures, such as the GRXE ($\sim 100^\circ \times 5^\circ$) , we should use IBIS/ISGRI as a collimated instrument. The detector collects photons from point sources and diffuse emission. Measurement of the point sources contribution to the total detector count rate makes it possible to recover the flux of the GRXE. The success of such approach strongly depends on the accuracy of the instrumental background modelling.

At any given time the detector count rate of IBIS/ISGRI consists of:

- Cosmic X-ray Background (CXB),
- emission from point sources,
- Galactic ridge X-ray emission, if the field of view of the telescope is directed towards the Galactic plane,
- detector internal background, caused by different processes including activation of different elements of the spacecraft, interaction of the detector material with cosmic-rays, etc. [e.g. 7, 40].

The Cosmic X-ray Background contributes ~0.5 Crab in the energy band 17-100 keV and can be considered very uniform over the sky. Taking into account the IBIS/ISGRI field of view, we can expect that CXB flux variability over the sky for ISGRI will not exceed $\sim 1\%$ [e.g. 9]. Therefore, the contribution of the CXB to the detector count rate can be considered as independent of observation orientation and can be estimated from observations at high Galactic latitudes. The contribution of point sources to the detector count rate can be almost perfectly predicted using the telescope coded mask imaging technique (more on this below). The list of detected sources used in our subtraction procedure includes more than 360 sources on the entire sky. Typically the detection limit for regions near the Galactic plane is at the level of ~ 1 mCrab. The complete list of sources will be presented elsewhere.

To predict the detector count rate not caused by photons arriving from the sky one should use a background model.

We followed two different approaches to study the ridge morphology and its energy spectrum. For the study of the energy spectrum we used only specially performed INTEGRAL observations for which the systematical uncertainties are minimal (see description below, model 2), whereas for the study of the ridge emission distribution in the Galaxy we used all the available observations.

Model 1: Background model using tracers

We chose the ISGRI detector count rate in the energy band $600-1000$ keV as a main tracer to keep track detector variability with time. At these energies the effective area of the ISGRI detector is very small (< 40 cm^2) and the detector count rate is expected to be dominated by the internal detector background. Our model of the ISGRI background consists of a linear combination of the $600-1000$ keV detector count rate H and the gain variations of the ISGRI detector G. To make allowance for possible long-term variations of the ISGRI detector background we also included time (T) in the cubic polynomial form. The model coefficients for the 17-60 keV energy band were calculated using observations pointed away from the Galactic Center and away from the inner Galactic plane, where the GRXE is negligible [30] (hereafter we consider only the detector count rates after removal of the contribution of point sources). In the $17-60$ keV energy band estimated accuracy of the model is $1-2\%$ from observed detector count rate which approximately corresponds to a flux ~ 10 mCrab for a Crab-like spectrum.

Model 2: Rocking mode

Part of the Galactic Center region observations – Galactic Center Latitude scans (March 2005 – March 2006) – were taken by INTEGRAL using a specially designed pattern, which presents considerable advantages from the point of view of the study of the Galactic ridge energy spectrum. The pointing direction of INTEGRAL instruments were moved across the Galactic Center region on a time scale ~ 10 hours, which is smaller than that of significant changes of the INTEGRAL/IBIS/ISGRI instrumental background. This mode of observations turns the IBIS/ISGRI instrument into some kind of a rocking collimator experiment. Therefore, the prediction of the ISGRI/IBIS instrumental background in this mode of observations was calculated using interpolation between ISGRI flux measurements done at high ($|l| > 20°$) Galactic latitudes, where the surface brightness of the Galactic background emission is negligible [e.g. 30]

We checked the quality of the ISGRI instrumental background subtraction in high energy channels (> 600 keV) where the instrumental background totally dominates. We found that the systematical uncertainties of the background subtraction using the employed technique ($\sim 0.5\%$ of the detector count rate) do not exceed the statistical uncertainties of the ~ 1 Msec dataset used. In particular, for energy channels ~100-200 keV this means approximately 7 times better quality of the background subtraction than when using the method described in previous paragraphs (model 1) – ~15 and ~100 mCrab correspondingly.

Thus for the construction of the Galactic ridge energy spectrum we used only these observations. Unfortunately this method cannot be used for studying the whole Galaxy because the special pattern of observations (Galactic latitude scans) is available only for the Galactic Center region.

3. RESULTS

Using the method described above for each INTEGRAL/IBIS/ISGRI observation we obtain two numbers in any considered energy channel: 1) the summed detector count rate caused by resolved point sources and 2) the detector count rate left after subtraction of the contribution of point sources and modeled detector background.

The possible remaining contribution of undetected point sources on the detector can be estimated using the luminosity function of Galactic X-ray sources [13, 32]. The majority of the inner Galactic plane was observed by INTEGRAL/IBIS for more than 0.5-0.8 Ms. Such an exposure corresponds to an IBIS/ISGRI detection sensitivity ~ 1 mCrab $\sim 10^{-11}$ erg s^{-1} cm^{-2} in the energy band 17–60 keV, which in turn corresponds to a source luminosity $\sim 10^{35}$ erg s^{-1} for the Galactic Center distance. The contribution of sources brighter than this limit was subtracted from the detector count rate. Therefore, from Fig.12 of [32] we can conclude that the contribution of undetected point sources does not significantly affect the emission of the GRXE.

3.1. Morphology

We constructed longitude and latitude profiles of the integrated emission from point sources and of the hard X-ray Galactic ridge emission (Fig.1). The latitude (longitude) profile was obtained by averaging those GRXE flux measurements made when the IBIS telescope was directed within $|l| < 5°$ ($|b| < 5°$).

In order to extract information about the three-dimensional structure of the Galactic ridge in hard X-rays we have compared the profiles of GRXE proxies (with known properties) with those obtained by us from INTEGRAL/ISGRI data. In particular, the current understanding of the GRXE morphology implies that the best tracer of the GRXE is the near infrared surface brightness [30].

The map of the Galaxy in the near infrared spectral band was obtained using data of COBE/DIRBE observations (zodi-subtracted mission average map provided by the LAMBDA archive of the Goddard Space Flight Center, http://lambda.gsfc.nasa.gov). In order to reduce the influence of the interstellar reddening we considered DIRBE spectral band 4.9μm.

The map of the NIR intensity was then convolved with the IBIS/ISGRI collimator response function. The resulting longitude and latitude profiles of the COBE/DIRBE NIR intensity are shown by the solid line on Fig.1. We also constructed a map of the IBIS/ISGRI surface brightness distribution of the GRXE in the $17-60$ keV energy band (see Fig.2). The map of the NIR intensity is shown by contours.

It is clearly seen that the GRXE intensity distribution very closely follows the NIR intensity distribution and thus

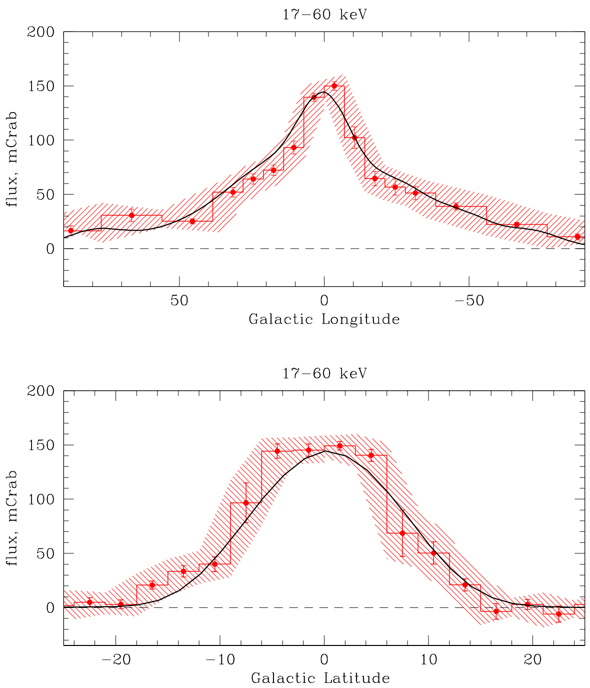

Figure 1. Longitude (upper panel) and latitude (bottom panel) profiles of the GRXE measured by INTEGRAL/IBIS/ISGRI (histogram and shaded region) in the 17-60 keV energy band along with the intensity profile of the Galactic NIR emission obtained by COBE/DIRBE at 4.9 μm (solid line). The NIR map was convolved with the IBIS collimator response. Normalization of the NIR profile is determined from X-ray-NIR correlation function (see Fig.4).

traces the stellar mass density in the Galaxy. In order to show that the correlation of the hard X-ray GRXE with the cosmic–ray induced gamma–ray background emission is not nearly as good as its correlation with the NIR intensity, we present Fig.3. Here one can see the distributions (convolved with the IBIS/ISGRI collimator response function) of the EGRET gamma–ray background, Galactic neutral hydrogen (HI), and molecular gas (CO emission)[2].

We can conclude that the emissivity profile of the GRXE in hard X-rays (17-60 keV) supports the finding of Revnivtsev et al. [30] that the GRXE traces the stellar mass distribution. This allows us to estimate the emissivity of the GRXE in hard X-rays using the known NIR luminosity measured with COBE/DIRBE observations.

The ratio of NIR- and hard X-ray intensities averaged over the whole Galaxy is $F_{17-60\rm keV}/F_{4.9\mu\rm m} = (7.52 \pm 0.33) \times 10^{-5}$ (Fig.4). We have also shown that there is no statistically significant difference in the obtained ratios for the bulge and disk regions separately.

[2]EGRET gamma–ray background map, HI and CO data were obtained from Skyview (http://skyview.gsfc.nasa.gov/) facility supplied by NASA/GSFC.

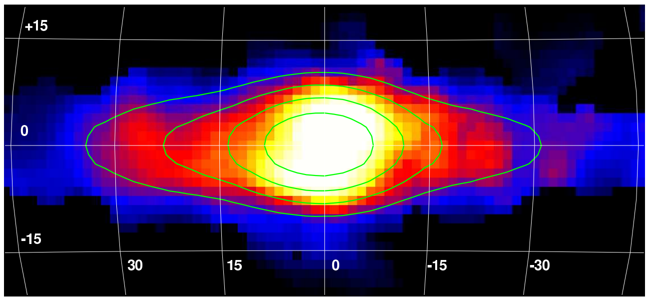

Figure 2. Map of the Galactic diffuse emission observed by INTEGRAL/IBIS/ISGRI in the energy band $17-60$ keV. Contours represent the near infrared intensity measured by COBE/DIRBE at $4.9\mu m$. NIR contours were convolved with the IBIS collimator response function. The contour levels correspond to $1.0, 1.4, 1.8, 2.2 \times 10^{-5}$ erg s^{-1} cm^{-2}per IBIS FOV.

Using the $4.9\mu m$ luminosity of the Galactic bulge [10] and obtained NIR-to hard X-ray flux ratio we can estimate the 17-60 keV luminosity of the Galactic bulge as $(1.23 \pm 0.05) \times 10^{37}$erg s^{-1}.

Assuming a Galactic bulge mass of $M_{\rm bulge} = 1 - 1.3 \times 10^{10} M_\odot$ (e.g. Dwek et al. 10), we can estimate the unit stellar mass hard X-ray emissivity of the GRXE as $L_{17-60\rm keV}/M_{\rm bulge} = 0.9 - 1.2 \times 10^{27}$ erg/s/$M_\odot$.

Taking the disk-to-bulge mass ratio to be ~ 2, we can estimate that the total hard X-ray (17-60 keV) luminosity of the Galaxy in the ridge emission is $(3.7 \pm 0.2) \times 10^{37}$ erg s^{-1}.

3.2. Spectrum

After we showed that hard GRXE volume emissivity traces the stellar mass density in the Galaxy, we can construct a broad-band unit stellar mass spectrum of the GRXE. For this purpose we have used the data from Galactic latitude scans, which have the smallest systematic uncertainties of the ISGRI background subtraction. We obtained ratios of hard X-ray surface brightness in each energy band to NIR surface brightness. NIR surface brightness was obtained after convolution of reddening-corrected COBE/DIRBE 4.9μm measurements with the IBIS collimator response function in appropriate energy bins. Using the obtained ratios and unit stellar mass 4.9μm luminosity we calculated the unit stellar mass hard X-ray spectrum of the GRXE (Fig.5).

Note that after subtraction of bright point sources detected by IBIS/ISGRI we do not detect any additional hard X-ray emission at energies ~60-200 keV. Our 2σ upper limit on such emission is ~ 60 mCrab for the IBIS field of view and for the energy band $57 - 86$ keV.

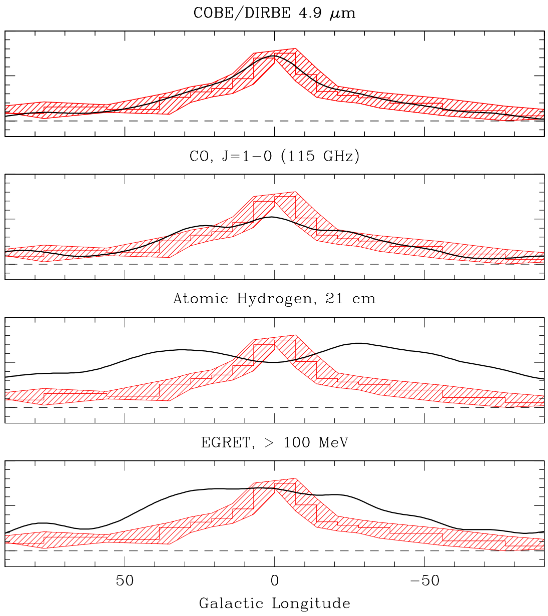

Figure 3. Profile of the GRXE in hard X-rays (17-60 keV) observed by IBIS/ISGRI along with the profiles of EGRET gamma–ray background, neutral hydrogen (HI) emission, and molecular gas (CO) emission. All the profiles were convolved with the IBIS/ISGRI collimator response function and arbitrary normalized for better visibility.

4. DISCUSSION

The obtained spectrum of the GRXE can now be compared with a composite spectrum of known types of weak Galactic X-ray sources. Unfortunately we do not have broad band spectra of all sources that were used in the construction of the luminosity function of weak Galactic X-ray sources [32]. Therefore we tried to obtain some ”toy” composite spectrum that would posess the main properties of the ideal sample of sources.

As the input templates of spectra of individual classes of sources we take: the spectrum of V711 Tau as an RS CVn binary, AM Her as a polar, and SU UMa as a dwarf nova. For the spectrum of intermediate polars, which are the dominant contributors in hard X-rays, we adopt the model spectrum of [39] with the white dwarf mass $M_{\rm wd} = 0.5M_{\odot}$.

The important difference of this ”toy” composite spectrum from that used in the work of [30] is the value of the white dwarf mass in the intermediate polar binary system. The temperature of the optically thin plasma emitting X-ray radiation in the case of accreting magnetic CVs (in particular - in intermediate polars, which dominate in hard X-rays) strongly depends on the mass of the white dwarf [e.g. 1]. In the range of masses $\sim 0.3 - 1.0M_{\odot}$ the optically thin plasma temperature, which is a measure of the virial temperature of protons near the white dwarf, is approximately $kT \propto M^{1.6-1.7}$ [see e.g. WD

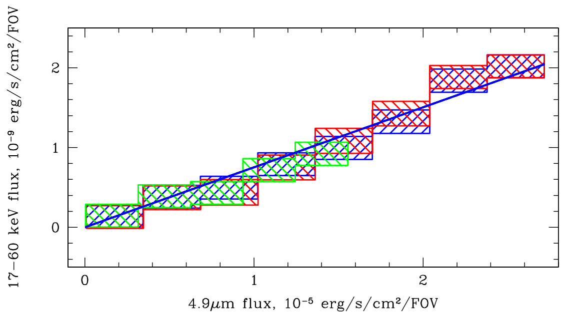

Figure 4. The linear correlation between NIR and hard X-ray fluxes measured using all GRXE observations $F_{17-60\rm keV}/F_{4.9\mu m} = (7.52 \pm 0.33) \times 10^{-5}$ (shown in blue, shaded region and fit). NIR- and hard X-ray correlation $(7.73 \pm 0.34) \times 10^{-5}$ and $(6.53 \pm 0.72) \times 10^{-5}$ measured in the Galactic bulge ($|l| < 10°$, red boxes) and Galactic disk ($|l| > 20°$, green boxes) regions correspondingly.

mass-radius relation in 26]. Therefore, it would be more reasonable to use the average mass of the white dwarfs in the Galaxy rather than some peculiar mass value. [30] used the spectrum of the binary system V1223 Sgr, which harbors a white dwarf with mass $M_{\rm wd} \sim 1M_{\odot}$ [e.g. 39], while the average mass of white dwarfs in the Galaxy is apparently considerably smaller – $M_{\rm wd} \sim 0.5M_{\odot}$ [e.g. 3, 4, 20, 27]. Therefore, the hard X-ray part of the true spectrum of the GRXE if it were composed of $\sim 0.5M_{\odot}$ white dwarfs is expected to be significantly softer than shown in Fig.8 of [30]. For illustration the spectrum generated for the lower end of the possible WD mass range ($M_{\rm wd} = 0.3M_{\odot}$) is also shown in Fig.5. In order to demonstrate spectrum for the lower possible white dwarf mass we have also genereated model spectrum assuming $M_{\rm wd} = 0.3M_{\odot}$.

Note than according to the above reasoning *the shape of the GRXE spectrum in hard X-rays can be used to determine the average mass of the white dwarfs in accreting magnetic CVs in the Galaxy*. The exact determination of the average WD mass is subject to uncertainties of relative contribution of different types of Galactic X-ray sources, but our first estimate shows that it is approximately consistent with $\langle M_{\rm wd,IP}\rangle \sim 0.5M_{\odot}$.

At the energies 60-200 keV we did not detect any hard X-ray emission of the Galaxy apart from the contribution of a relatively small number of bright point sources visible by IBIS/ISGRI.

At energies higher than 100-200 keV a more detailed study of the IBIS/ISGRI detector background is needed in order to recover the properties of the unresolved emission in the Galaxy. In addition to the instrumental problems at these energies there is a strong contribution of the diffuse positronium continuum in the Galactic Center region, which should be carefully taken into account. We plan to study the unresolved Galactic continuum at these high energies in our future work.

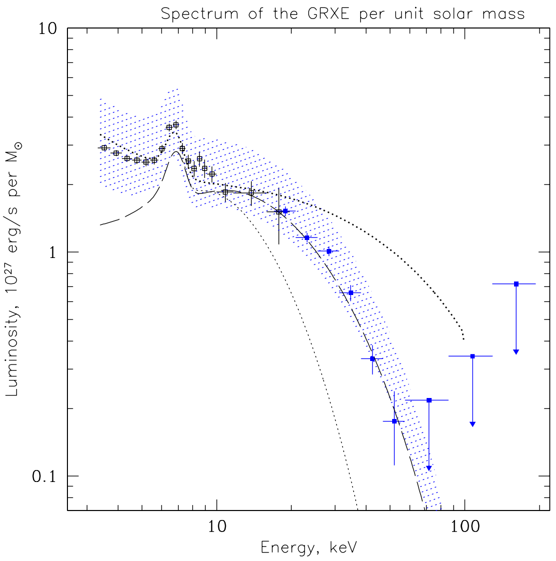

Figure 5. Broad band spectrum of GRXE per unit stellar mass. Blue points represent result of this work. Shaded region represents a "toy" composite spectrum of weak Galactic X-ray sources with weights according to [32]. For the input template spectrum of intermediate polars we adopted a white dwarf mass $M_{\rm wd} = 0.5 M_\odot$. The approximate (due to uncertainties in the relative weights of CVs and coronally active stars) contribution of magnetic CVs (intermediate polars and polars) to the GRXE emissivity is shown by the dashed curve. For comparison the thin and thick dotted lines show the composite GRXE spectra calculated assuming the white draft masses of 0.3 and 1 Msun respectively.

5. CONCLUSION

1) We have shown that the surface brightness distribution of the GRXE in the energy band 17-60 keV very closely follows the near infrared surface brightness distribution throughout the Galaxy. This strongly supports the conclusion of [30] based on lower energies (3–20 keV) data. The surface brightness distributions of the gamma–ray background (EGRET data, 30 MeV-10 GeV), neutral interstellar matter (HI map), and molecular interstellar gas (CO map) do not show such correspondence with the hard GRXE intensity. The hard X-ray (17–60 keV) emissivity of the Galactic ridge, recalculated per unit stellar mass is $(0.9 - 1.2) \times 10^{27}$ erg s^{-1} M$_\odot^{-1}$. This value is in good agreement (after correction for the energy band) with the unit stellar mass X-ray emissivity of weak Galactic X-ray sources [32, 30]. The total Galactic hard X-ray luminosity of the GRXE is $(3.7 \pm 0.2) \times 10^{37}$ erg s^{-1}in the 17–60 keV energy band.

However, we should note that the difference in the morphology of the EGRET Galactic gamma–ray background and hard X-ray (17-60 keV) ridge emission observed by IBIS/ISGRI cannot by itself be considered as a strong argument against the hypothesis of the cosmic ray origin for the GRXE. Indeed, if the hard X-ray background emission of the Galaxy were dominated by bremsstrahlung of low energy ($\lesssim 0.5$MeV) cosmic ray electrons [see e.g. 36, 25, 31, 15], then these electrons might be confined to an almost immediate vicinity of their birthplace if the interstellar magnetic field is sufficiently tangled. This would happen because electrons at these energies have very small mean free paths in the presence of tangled interstellar magnetic field [e.g. 46]. If the places of origin of such electrons somehow followed the stellar mass distribution in the Galaxy, then the hard X-ray background, induced by such cosmic–rays would also follow the NIR intensity distribution.

2) Subtracting the flux of detected point sources from the total IBIS aperture sky flux we have obtained the spectrum of the GRXE. Its shape well agrees with the spectral shape of accreting magnetic white dwarfs, which are expected to provide a dominant contribution to the Galactic X-ray emission in this energy band. The shape of the spectrum of the GRXE allows us to estimate the average mass of accreting magnetic white dwarfs in the Galaxy $\langle M_{\rm wd} \rangle \sim 0.5 M_\odot$.

3) We have shown that the Galactic background emission is undetectable in the energy range ~60-200 keV. The signal that was previously ascribed to the Galactic background emission at these energies was most likely due to emission of unresolved point sources.

4) Our results fit in the model in which the Galactic ridge X-ray emission in energy band 3-100 keV originates as superposition of weak Galactic point sources. This suggests that at energies $\gtrsim$ 200 keV a change of the nature of the unresolved Galactic emission to cosmic–ray induced background should occur. In order to illustrate this we present a scheme of the luminosity spectrum of unresolved emission of the whole Galaxy in Fig.6. One should remember that according to our model the ratio of the γ-ray to X-ray unresolved background luminosities strongly varies across the Galaxy, therefore the presented broad-band spectrum should be considered as only a schematic representation of the real luminosity spectrum of the whole Galaxy.

As the Galactic Center region at energies 200-500 keV contains a powerful diffuse emission of the positronium continuum that is very hard to disentangle from the cosmic-ray induced radiation we anticipate that an answer to the question where the cosmic-ray induced radiation begins to dominate can be obtained only either by studying regions away from the Galactic Center or at energies 0.5-10 MeV.

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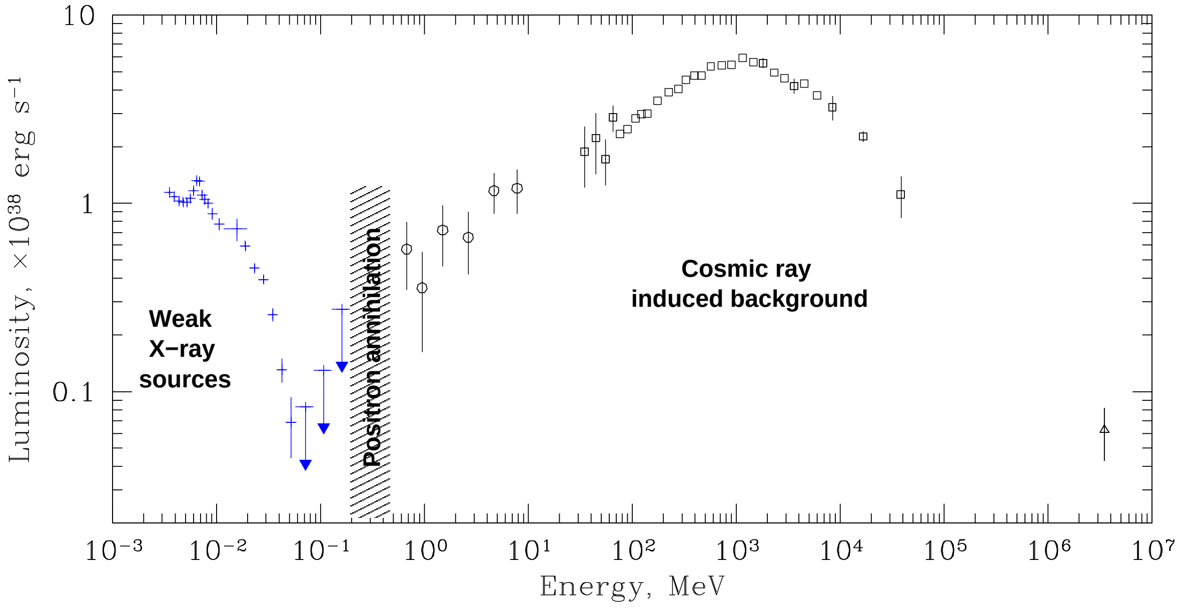

Figure 6. Schematic luminosity spectrum of "unresolved" emission of the Galaxy in the energy band 3 keV – 4 TeV. In the X-ray energy band the luminosity spectrum was scaled from the GRXE unit stellar mass emissivity spectrum (Fig. 5) assuming a mass of the Galaxy of $3.9 \times 10^{10} M_{\odot}$. *For scaling the* γ*-ray part of the spectrum we adopted a value of the total Galactic luminosity at* > 100 *MeV of* $L_{>100\mathrm{MeV}} = 2 \times 10^{39}$ *erg/s [6]. Measurements in* γ*-rays by CGRO/OSSE and CGRO/EGRET are adopted from [17], the measurement at TeV energies is rescaled from [2, 28]. The shaded region at energies ∼200-500 keV denotes the area where positron annihilation radiation in the Galactic Center region strongly dominates.*

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REFERENCES

[1] Aizu K., 1973, PThPh, 49, 1184

[2] Atkins R., et al., 2005, PhRvL, 95, 251103

[3] Bergeron P., Saffer R. A., Liebert J., 1992, ApJ, 394, 228

[4] Bergeron P., Liebert J., Fulbright M. S., 1995, ApJ, 444, 810

[5] Bouchet, L., Roques, J. P., Mandrou, P., Strong, A., Diehl, R., Lebrun, F., & Terrier, R. 2005, ApJ, 635, 1103

[6] Bloemen J. B. G. M., Blitz L., Hermsen W., 1984, ApJ, 279, 136

[7] Bloser P. F., Narita T., Jenkins J. A., Perrin M., Murray R., Grindlay J. E., 2002, SPIE, 4497, 88

[8] Churazov E., Sunyaev R., Sazonov S., Revnivtsev M., Varshalovich D., 2005, MNRAS, 357, 1377

[9] Churazov et al., et al., 2006, astro, arXiv:astro-ph/0608250

[10] Dwek E., et al., 1995, ApJ, 445, 716

[11] Ebisawa, K., et al. 2005, ApJ, 635, 214

[12] Gehrels N., Barthelmy S. D., Teegarden B. J., Tueller J., Leventhal M., MacCallum C. J., 1991, ApJ, 375, L13

[13] Grimm H.-J., Gilfanov M., Sunyaev R., 2002, A&A, 391, 923

[14] Hands A. D. P., Warwick R. S., Watson M. G., Helfand D. J., 2004, MNRAS, 351, 31

[15] Harris M. J., Share G. H., Leising M. D., Kinzer R. L., Messina D. C., 1990, ApJ, 362, 135

[16] Hunter S. D., et al., 1997, ApJ, 481, 205

[17] Kinzer R. L., Purcell W. R., Kurfess J. D., 1999, ApJ, 515, 215

[18] Kniffen D. A., Bertsch D. L., Morris D. J., Palmeira R. A. R., Rao K. R., 1978, ApJ, 225, 591

[19] Knödlseder, J., et al. 2005, A&A, 441, 513

[20] de Kool M., 1992, A&A, 261, 188

[21] Kraushaar W. L., Clark G. W., Garmire G. P., Borken R., Higbie P., Leong V., Thorsos T., 1972, ApJ, 177, 341

[22] Krivonos, R., Revnivtsev, M., Churazov, E., Sazonov, S., Grebenev, S., & Sunyaev, R. 2007, A&A, 463, 957

[23] Lebrun F., et al., 2004, Natur, 428

[24] Leventhal M., MacCallum C. J., Stang P. D., 1978, ApJ, 225, L11

[25] Mandrou P., Bui-van A., Vedrenne G., Niel M., 1980, ApJ, 237, 424

[26] Nauenberg M., 1972, ApJ, 175, 417

[27] Politano M., 1996, ApJ, 465, 338

[28] Prodanovic T., Fields B. D., Beacom J. F., 2006, astro, arXiv:astro-ph/0603618

[29] Purcell W. R., et al., 1996, A&AS, 120, 389

[30] Revnivtsev M., Sazonov S., Gilfanov M., Churazov E., Sunyaev R., 2005, astro, arXiv:astro-ph/0510050

[31] Sacher W., Schoenfelder V., 1984, ApJ, 279, 817

[32] Sazonov S., Revnivtsev M., Gilfanov M., Churazov E., Sunyaev R., 2006, A&A, 450, 117

[33] Skibo J. G., Ramaty R., 1993, A&AS, 97, 145

[34] Skibo J. G., et al., 1997, ApJ, 483, L95

[35] Stecker, F. W. 1973, ApJ, 185, 499

[36] Stecker F. W., 1977, ApJ, 212, 60

[37] Strong, A. W., Diehl, R., Halloin, H., Schönfelder, V., Bouchet, L., Mandrou, P., Lebrun, F., & Terrier, R. 2005, A&A, 444, 495

[38] Sugizaki M., Mitsuda K., Kaneda H., Matsuzaki K., Yamauchi S., Koyama K., 2001, ApJS, 134, 77

[39] Suleimanov V., Revnivtsev M., Ritter H., 2005, A&A, 435, 191

[40] Terrier R., et al., 2003, A&A, 411, L167

[41] Terrier R., Lebrun F., Belanger G. et al. 2004, Proceedings of the 5th INTEGRAL Workshop, Munich 16-20 February 2004. ESA SP-552, astro-ph/0405207

[42] Ubertini P., et al., 2003, A&A, 411, L131

[43] Vedrenne, G., et al. 2003, A&A, 411, L63

[44] Worrall D. M., Marshall F. E., Boldt E. A., Swank J. H., 1982, ApJ, 255, 111

[45] Winkler C., et al., 2003, A&A, 411, L1

[46] Zwickl R. D., Webber W. R., 1978, JGR, 83, 1157