Gamma-ray burst parameters and the fine structure of the Galactic ISM as seen by *AKARI*

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ABSTRACT

Galactic foreground hydrogen column density was estimated from H I 21cm surveys, the *Planck* all-sky and *AKARI* all-sky data in the direction of the long gamma-ray burst GRB 051022, a member of the Large GRB Ring. Intrinsic hydrogen column densities were derived from fitting the X-ray afterglow spectrum using all the various foreground estimates. The resolution of the *AKARI* FIS maps is better than other available all sky survey data on the Galactic ISM. We show, how much that resolution gain matters calculating the actual foreground column densities, and then deriving an intrinsic column density.

Keywords: gamma-ray burst: general, GRB051022, ISM: structure

1. INTRODUCTION

Gamma-ray bursts (GRB) are in the focus of extragalactic astrophysics partly due to recent discoveries of gravitational wave events (see e.g., Goldstein et al. 2017), partly because of their use as signposts of the distant universe. GRBs types according to the duration of the gamma-ray emission are: short and long (Kouveliotou et al. 1993) with average durations of 0.3s and 30s, respectively; intermediate (Horváth 2009; Horváth & Tóth 2016) and ultra-long (Boër et al. 2015) GRBs. Long-duration GRBs are associated with the explosions of massive stars (e.g., Stanek et al. 2003).

An accurate enough estimate of the foreground hydrogen column density $N(\mathrm{H})_{\mathrm{MW}}$ is one of the crucial input parameters calculating the intrinsic (at the GRB location) $N(\mathrm{H})_{\mathrm{GRB}}$ values (Fynbo et al. 2009).

But it is in general a challenge to accurately estimate the extinction by the galactic foreground interstellar medium in the direction of extragalactic sources. We note that parameters of the intrinsic ISM may also be estimated from the optical afterglow spectrum (Elíasdóttir et al. 2009). In this paper we compare various all sky surveys of the Galactic ISM, and show how the difference among the foreground $N(\mathrm{H})_{\mathrm{MW}}$ estimates effect the intrinsic $N(\mathrm{H})_{\mathrm{GRB}}$ derived from fitting the X-ray afterglow spectra. We also demonstrate the use of *AKARI* (Murakami et al. 2007) data.

2. INPUT DATA, ANALYSIS AND RESULTS

2.1. GRB051022

GRB051022 was a long (T90 = 200s), dark GRB (i.e. optical counterpart was not found), and one of the most intense ones with its 30–400 keV energy band fluence of 1.3×10^{-4} erg cm^{-2} (Nakagawa et al. 2007). Precise location was obtained thanks to mm observations (Cameron & Frail 2005). The GRB host galaxy is a red, massive ($2.5 \times 10^{10}\ M_{\odot}$) galaxy, for which a near solar metallicity is measured with emission-line diagnostics.

GRB051022 is on a Giant Ring of GRBs (with a mean angular diameter of 1720 Mpc in the comoving frame) located by Balázs et al. (2015) in the redshift range of $0.78 < z < 0.86$. Adopting their approach that the ring can be a projection of a spheroidal structure, one has to assume that each of the 9 host galaxies of the ring had their GRB rate enhanced in the same relatively short period of 2.5×10^{8} years.

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2.2. Sky surveys and foreground values

We used *AKARI* FIS full sky images at 65 μm, 90 μm, 140 μm and 160 μm by Doi et al. (2015) with a detection limit of about <10 MJy sr^{-1} and a relative photometric accuracy of about < 20%. After smoothing those to 2′ spatial we calculated hydrogen column densities as described in Toth et al. (2017). Further all-sky survey were also used, such as "SFD" based on *IRAS* and *COBE*/DIRBE/SDSS by Schlafly & Finkbeiner (2011) and *Planck* results by Planck Collaboration et al. (2014) and by Planck Collaboration et al. (2016). Column densities of neutral hydrogen were taken from the LAB Survey (Kalberla et al. 2005), and the EBHIS survey (Kerp et al. 2011).

We subtracted 30 × 30□′ and 6.5 × 6.5□° images centered on the position of GRB051022 from the above mentioned all sky surveys, and calculated the $N(\mathrm{H})_{\mathrm{MW}}$ galactic foreground hydrogen column density distribution. The result is shown in Figure 1. The Pearson's correlation coefficient of the various $N(\mathrm{H})_{\mathrm{MW}}$ values is not always high (see Figure 2 and Table 1).

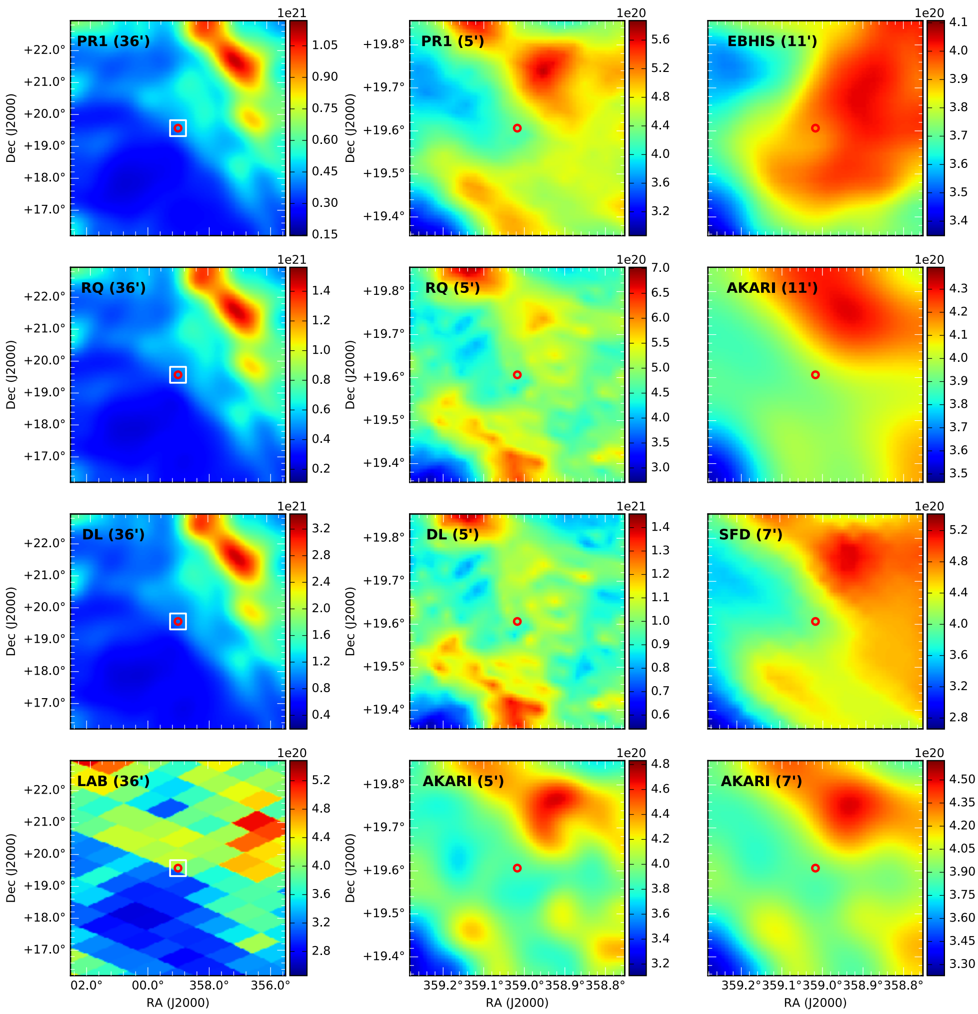

Figure 1. Galactic foreground hydrogen column density distribution in the direction of GRB051022, based on various all sky surveys. Left column: The first three images from top are *Planck* PR1, *Planck* PR2 RQ, and *Planck* PR2 DL based $N(\mathrm{H})_{\mathrm{MW}}$ distributions smoothed to 36′ resolution; the bottom one is the $N(\mathrm{H})_{\mathrm{MW}}$ from the LAB survey. Middle column: All images show the central area of the left column (marked with white box), but with a resolution of 5′. The first three images from top are similar to the left column, the bottom one is based on *AKARI* FIS data. Right column: The first two from the top are $N(\mathrm{H})_{\mathrm{MW}}$ with 11′ resolution based on EBHIS and *AKARI*. The lower two are based on the SFD and *AKARI* with 7′ resolution both. See also text.

2.3. Intrinsic hydrogen column densities

We assume that the best available estimate of $N(\mathrm{H})_{\mathrm{MW}}$ is the one we obtain calibrating the *AKARI* based $N(\mathrm{H})_{\mathrm{MW}}$ with *Planck* PR2 RQ data. The $N(\mathrm{H})_{\mathrm{GRB}}$ intrinsic hydrogen column density was calculated fitting the X-ray afterglow spectrum of GRB051022 taken from the *Swift-XRT* GRB Catalogue[1], using Xspec[2] (Arnaud 1996) but varying the $N(\mathrm{H})_{\mathrm{MW}}$ value

[1] maintained by the UK Swift Science Data Centre (UKSSDC)
[2] Xspec is part of the HEASOFT Software package of NASA's HEASARC

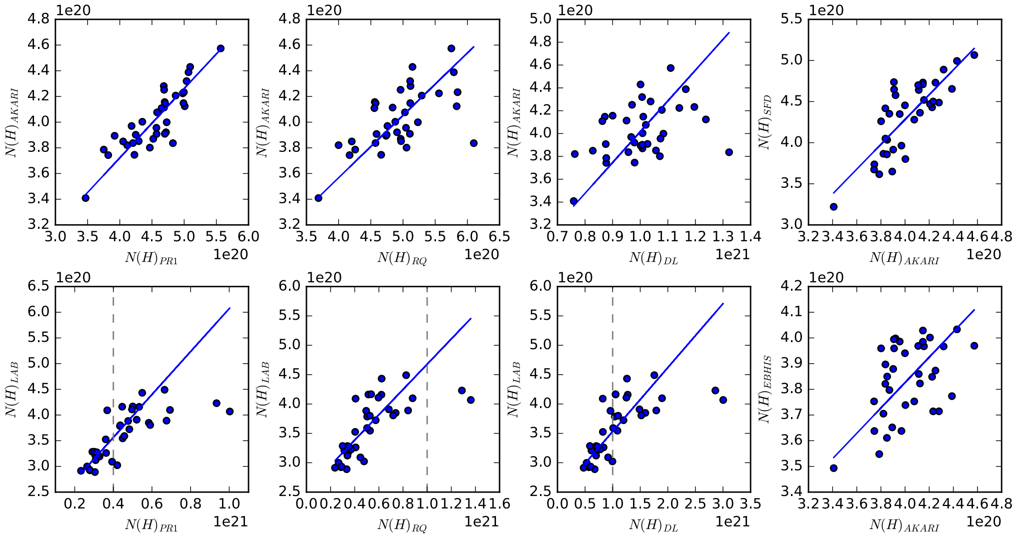

Figure 2. Correlation plots of the estimated galactic foreground hydrogen column densities in the direction of GRB051022, based on various all sky surveys. Top row from left to right: *AKARI* vs. *Planck* PR1; *AKARI* vs. *Planck* PR2 RQ; *AKARI* vs. *Planck* PR2 DL; SFD vs. *AKARI*. The bottom row: LAB survey vs. *Planck* PR1; LAB survey vs. *Planck* PR2 RQ; LAB survey vs. *Planck* PR2 DL; EBHIS vs. *AKARI*. Ordinary least square fitted lines are drawn. The Pearson's correlation coefficients and the least square fits were calculated only at the linear parts of the correlation plots with H I data, the limits are indicated with dashed lines.

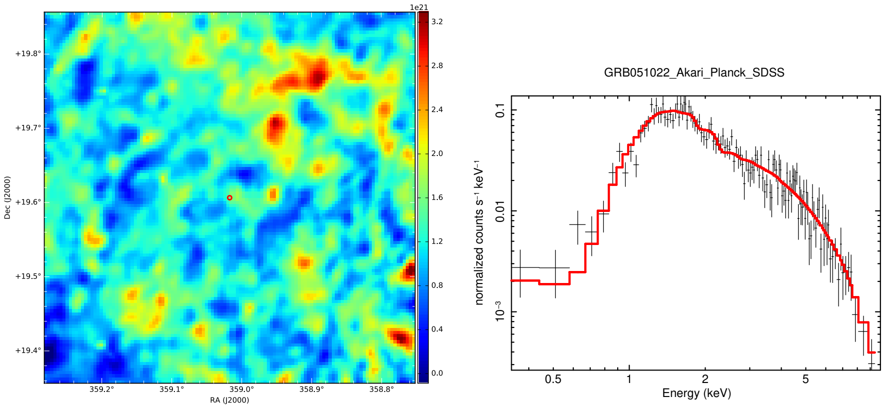

Figure 3. Left: *AKARI* $N(\mathrm{H})_{\mathrm{MW}}$ map calibrated with *Planck* DR2 RQ, position of GRB051022 is marked with red circle at the centre. Right: XRT spectrum of GRB051022 fitted with Xspec (Arnaud 1996) using the *AKARI* based Galactic foreground.

Table 1. Results of correlating N(H) maps, with the Pearson's correlation coefficient r; and least square linear fits $y = ax + b$.

		r	a	$b/10^{20}$			r	a	$b/10^{20}$
Planck PR1	*AKARI*	0.8593	0.5391	1.5658	*Planck* PR1	LAB	0.5958	0.4178	1.8924
Planck RQ	*AKARI*	0.6222	0.4855	1.6253	*Planck* RQ	LAB	0.7849	0.2152	2.5255
Planck DL	*AKARI*	0.4118	0.2696	1.3202	*Planck* DL	LAB	0.4978	0.1089	2.4424
SFD	*AKARI*	0.8033	1.5093	−1.7552	EBHIS	*AKARI*	0.4834	2.0261	−3.7525

as shown in Table 2. We see, that $N(\mathrm{H})_{\mathrm{MW}}$ is slightly higher in the direction of GRB051022, than around it. That is why it is one of the few directions where the high resolution foreground estimate is slightly higher than the value used by UKSSDC, and as a consequence the intrinsic $N(\mathrm{H})_{\mathrm{GRB}}$ value became slightly lower, than the former estimate was.

Table 2. The $N(\mathrm{H})_{\mathrm{MW}}$ Galactic foreground hydrogen column density; the $N(\mathrm{H})_{\mathrm{GRB}}$ intrinsic column density (from Swift XRT spectral fit); and the χ^2 of the XRT fit for various estimates of the foreground.

	HPBW [arcmin]	$N(\mathrm{H})_{\mathrm{MW}}$ [10^{20} cm^{-2}]	$N(\mathrm{H})_{\mathrm{GRB}}$ [10^{20} cm^{-2}]	χ^2
AKARI (calibrated with *Planck* PR1)	2	4.9	$565.2^{631.5}_{502.6}$	804.5
AKARI (calibrated with *Planck* PR2 DL)	2	10.8	$538.8^{605.0}_{476.3}$	804.3
AKARI (calibrated with *Planck* PR2 RQ)	2	5.4	$563.3^{629.6}_{500.7}$	804.5
Smoothed *AKARI* (calibrated with *Planck* PR1)	5	4.3	$568.2^{634.4}_{505.5}$	804.5
Smoothed *AKARI* (calibrated with *Planck* PR2 DL)	5	9.5	$544.7^{610.9}_{482.2}$	804.4
Smoothed *AKARI* (calibrated with *Planck* PR2 RQ)	5	4.6	$566.6^{632.8}_{503.9}$	804.5
Planck PR1	5	4.3	$568.1^{634.4}_{505.5}$	804.5
Planck PR2 DL	5	9.9	$543.0^{609.2}_{480.4}$	804.4
Planck PR2 RQ	5	4.7	$566.1^{632.4}_{503.5}$	804.5
Smoothed *Planck* PR1	36	4.4	$567.5^{633.8}_{504.9}$	804.5
Smoothed *Planck* PR2 DL	36	9.9	$542.7^{608.9}_{480.2}$	804.5
Smoothed *Planck* PR2 RQ	36	4.9	$565.5^{631.8}_{502.9}$	804.5
LAB (from observation)	36	4.0	$569.6^{635.7}_{506.9}$	804.5
UKSSDC NH (based on LAB)	36	4.5	$567.1^{633.4}_{504.5}$	804.5
EBHIS	10.8	3.9	$569.7^{636.1}_{507.1}$	804.5
SFD	7-14	4.1	$569.2^{635.5}_{506.5}$	804.5

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