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DETECTION OF X-RAY EMISSION FROM GALAXIES INSIDE AND TOWARDS THE NEARBY VOIDS

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ABSTRACT

We searched for X-ray emission from the 665 galaxies inside and towards the nearby voids by analyzing the ROSAT All-Sky Survey (RASS) data as well as the ROSAT pointed observations (PSPC). As a result we have detected six X-ray emitting galaxies. Two (UGC 10205 and NGC 7509) are in the high density region in the local void, three (UGC 749, MCG +11-10-073, and Mrk 464) are towards the nearby voids, and UGC 32 is located in the low density region. We carried out a timing analysis for both Mrk 464 and UGC 32, and a spectral analysis for Mrk 464. The light curve of Mrk 464 shows the possibility of periodic X-ray flux variation and UGC 32 shows weak, but rapid variation.

Key words : galaxies: active – galaxies: Seyfert – X-rays: galaxies – galaxies: structure

I. INTRODUCTION

As the most prominent feature of the large-scale structure in the Universe, voids are important in understanding the formation and evolution of galaxies in low density environments. Voids have also been used to examine various cosmological models. Since the discovery of the Bootes Void by Kirchner et al. (1981, 1987), voids have caught the attention of the astronomical community (for a review, see Rood, 1988). The Bootes Void has been the most widely and continuously investigated through the observations for different wavelength region. Since Moody et al. (1987) listed eight emission-line galaxies inside the Bootes Void, all 27 galaxies were listed by Cruzen, Weistrop, Hoopes (1997, hereafter CWH). Interestingly, all are emission-line galaxies.

All these galaxies were found through objective prism surveys (Tifft et al, 1986; Moody et al, 1987; Sanduleak, Pesch 1982; Pesch, Sanduleak 1989), the IRAS Point Source Catalog (PSC, 1985; Strauss, Huchra 1988) and the HI survey (Sozomoru, 1994) (see the references for the identification and redshift of these galaxies in Table 1 by CWH). Spectroscopic survey of emission-line galaxies in the Bootes Void was also followed by Cruzen, et al. (1996, 2002). CWH conducted a photometric survey of 27 galaxies in the Bootes Void and found that approximately 40% of galaxies exhibit unusual or disturbed morphologies. Similar conclusion had already been reached by Moody et al (1987), in earlier times. Therefore the unusual nature of these galaxies has been questioned.

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In spite of the various investigations of galaxies inside the Bootes Void, there have been no searches in the X-ray wavelength region, except Mrk 845, which was listed as a Seyfert 1 galaxy, in the X-ray All-Sky Survey with the HEAO 1, by Della Ceca, et al. (1990). Thus, we developed a project in order to identify all X-ray emission sources inside the Bootes Void using the ROSAT All-Sky Survey (RASS) data. Then we have detected nine X-ray emitting void galaxies, found that three of these nine galaxies are active galactic nuclei (see, Kim, et al. 2001, hereafter Paper I). This is the second paper presented on the detection of X-ray galaxies inside and towards other nearby voids.

II. SEARCH WITH THE ROSAT ALL-SKY SURVEY

We have searched a total of 665 galaxies inside and towards the nearby voids with ROSAT All-Sky Survey (RASS, Voges et al. 1996) data, as well as with ROSAT pointed observations(PSPC, HRI) data. All 296 galaxies within and around the three prominent voids searched by the Center for Astrophysics Redshift Survey (see, Grogin & Geller 1999, 2000, hereafter GG99, GG00) were investigated. In addition, 84 nearby dwarf galaxies towards the Local Void in Hercules-Aquila listed by Karachentseva, et al (1999), 82 galaxies in low density regions by Vennik, et al. (1996), and 203 emission-line galaxies towards the nearby voids by Popescu, et al. (1998) were included in our investigation.

Among 296 galaxies which were surveyed by GG99 and GG00, the number of galaxies which lay in regions below, and above, the mean survey density is 151 and

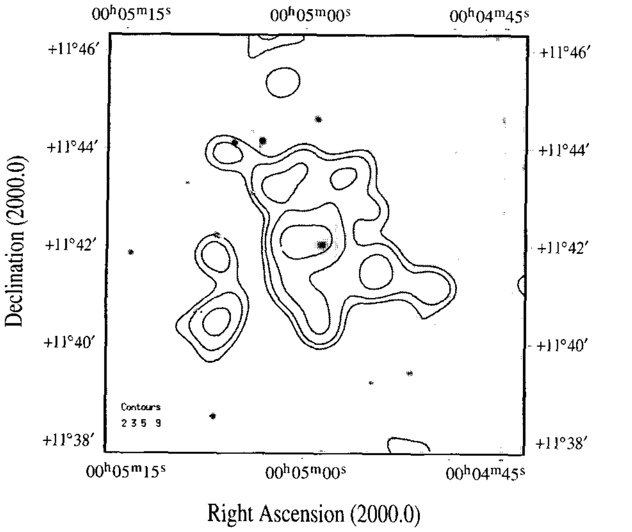

Fig. 1.— X-ray contour lines obtained from the ROSAT All-Sky Survey for UGC 32 overlaid on an image taken from the Digitized Sky Survey. The x-ray emission from UGC 32 is clearly associated with the optical galaxy. Contour levels indicate σ confidence levels above the background.

145 (OVER) respectively. 250 galaxies are located on the periphery of three voids. Among 151 void galaxies, 47 and 104 galaxies are the lowest density (LDVS) and higher density (HDVS) sub-samples, respectively. We have detected two sources of UGC 10205 and NGC 7509 among the HDVS samples, but no source was identified for the LDVS and OVER samples. On the other hand, there had been no detection of X-ray sources for 84 galaxies listed by Karachentseva, et al (1999). We have detected one strong source of UGC 32 among 82 galaxies searched by Vennik, et al. (1996). One faint source of UGC 749, and two strong sources of MCG +11-10-073 and Mrk 464 have been detected among 203 emission-line galaxies listed by Popescu, et al. (1998).

Table 1 presents a list of the six galaxies detected using the RASS data, and Figure 1 to 6 shows the X-ray contour lines obtained from the ROSAT All-Sky Survey for detected galaxies, overlaid on an image taken from the Digitized Sky Survey. The contour lines are given in sigma levels above the background. The X-ray emission from all six sources is clearly associated with the optical galaxy.

(a) UGC 32

UGC 32 is an elliptical galaxy and also a radio source of 34 mJy at 4.85 GHz (Condon et al., 1991). Using the ROSAT HRI data, timing analysis was performed. UGC 32 was observed on December 15 1996 (JD 2448088.649) and the total exposure time of this source was 6066 seconds. The RASS HRI light curve is shown in Figure 7 and it is evident that UGC 32 varied considerably. The lowest and highest count rates are 0.01 $\pm$ 0.01counts s^{-1} and 0.17 $\pm$ 0.18 counts s^{-1} on JD 2448088.737 and JD 2448089.029 , respectively.

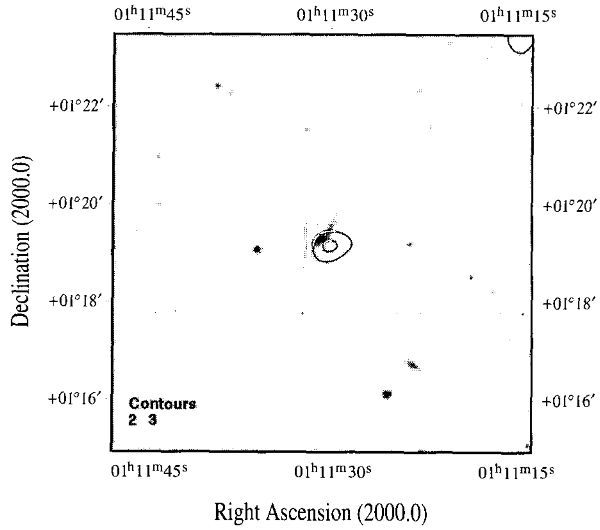

Fig. 2.— X-ray contour lines for UGC 749.

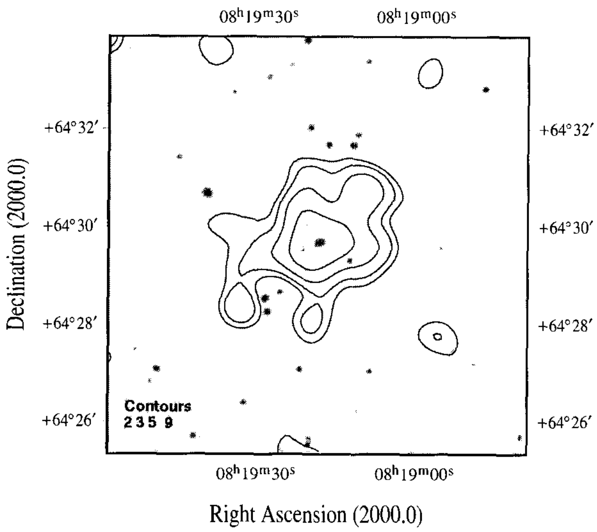

Fig. 3.— X-ray contour lines for MCG11-10-073.

This result indicates that there was a weak but rapid variation. The reality of the highest count rate of 0.17 ± 0.18counts s^{-1} can be doubted because the error bar is too large and also this is the last data point in the left group. If this is real, then the light variation is the order of almost 18 for the duration of about 40 seconds. This looks like a flare event discovered in Mrk 926 (Kim & Boller, 2002) although we do not know the pattern of gradual variation.

(b) MRK 464

Mrk 464 was classified as a Seyfert 1 galaxy by Denisyuk & Lipovertski (1974), but Kalinkov, et al. (1993) classified it as a Seyfert 1.5 galaxy under the investigation of H_β/[OIII]=0.45, H_α/H_β=5.13 and [OIII]/H_α=0.43. On the other hand, JHKL photometry was secured to Mrk 464 by Zitelli, et al. (1993)

TABLE 1
RASS DETECTED X-RAY GALAXIES INSIDE AND TOWARDS THE NEARBY VOIDS

SOURCE NAME	RA(2000)	DEC(2000)	MAG (V)	REDSHIFT	GALAXY TYPE	RASS COUNT RATE[a]	EXPOSURE TIME(S)
UGC 32	00 04 58.9	11 42 05.0	17.0	0.07606	E	0.148	429
UGC 749	01 11 30.6	01 19 14.5	14.3	0.02260	SDM:	0.016	425
MCG +11-10-073	08 19 17.6	64 29 38.8	16.0	0.03900	SY1	0.160	425
MRK 464	13 55 53.3	38 34 27.8	16.5	0.05100	SY1.5	0.172	526
UGC 10205	16 06 40.2	30 05 54.6	14.4	0.02187	SA	0.009	706
NGC 7509	23 12 21.3	14 36 33.4	15.0	0.01627	?	0.019	401

[a] The unit of count rate is counts/s.

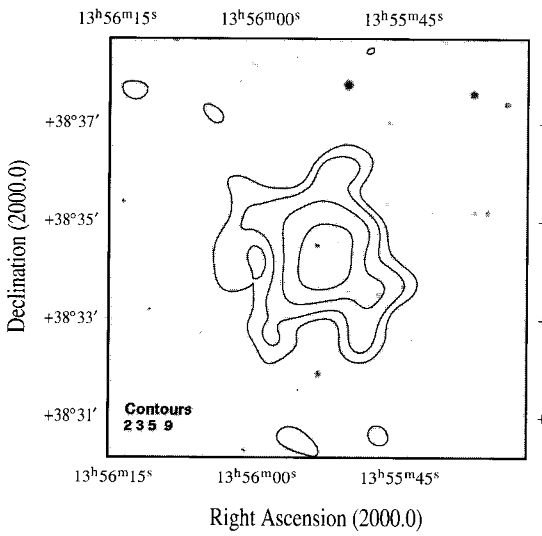

Fig. 4.— Figure 4. X-ray contour lines for Mrk 464.

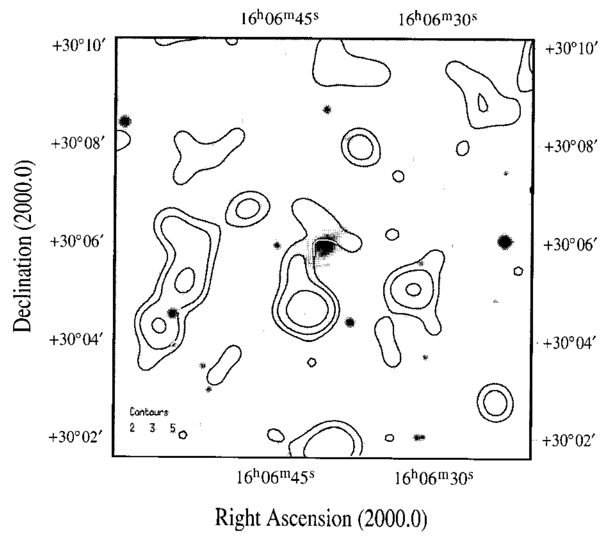

Fig. 5.— X-ray contour lines for UGC 10205.

and it was reported that the profile of Mrk 464 is almost starlike, with a poorly defined hosting galaxy. Mrk 464 is also a quiet radio source (Ulvestad & Wilson 1984 ; Xu, et al. 1999) and X-ray observations were made with the HEAO-1, Ariel V and EXOSAT (ref in Ghosh & Soundararajaperumal, 1992, hereafter GS92).

GS92 analyzed the EXOSAT data and found no low-energy absorption but this result is different from the measurements of X-ray flux by Ariel V and HEAO-1. The 2–10 keV X-ray flux measured by Ariel V and HEAO-1 was decreased by a factor of 3 between 1977 December and 1978 October. They also confirmed the presence of a soft excess and reported a possibility of the presence of the emission line at 6 keV.

Mrk 464 was observed with the ROSAT and is the only source among the sample for which the adequate PSPC data exists to construct a light curve and to analyze a spectrum. Mrk 464 was observed during two epochs : 1991 December 16 (JD 2448786.79) and 1992 July 13 (JD 2448606.13). Timing and spectral analysis were followed for two observations of 700144p and 700781p. The exposure time was 2349 and 2122 seconds respectively.

The background-subtracted RASS light curve is shown in Figure 7 and it is evident that there was a long-term gradual decreasing of the brightness for about six months. The mean counts rate during this interval are 0.37 ± 0.03 counts s^{-1} on JD 2448606.13 and 0.26 ± 0.03 counts s^{-1} on JD 2448786.79. However, if we take into account the RASS count rate of 0.172 counts s^{-1} observed on July 11 in 1990, the variation of flux shows the possibility of a sinusoidal pattern with the period of roughly one year.

The spectrum of Mrk 464 from the PSPC data was extracted using the EXSAS data analysis package of MPE Garching (Zimmermann et al. 1994). The X-ray spectrum was derived from the photon event tables covering the area of the sky around Mrk 464. Source counts were collected in a disk of 260 arcsec radius around the source position. Background counts were from an annular region of inner radius of 300 arcsec and outer radius of 600 arcsec around the object position in the scan direction of the satellite and free of contaminating sources.

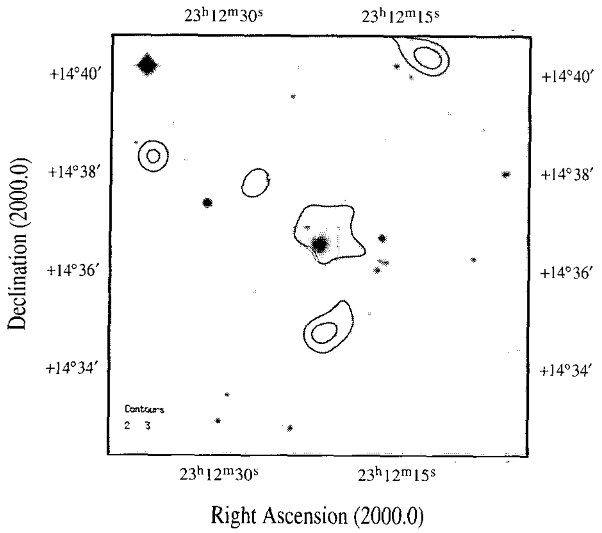

Fig. 6.— X-ray contour lines for NGC 7509.

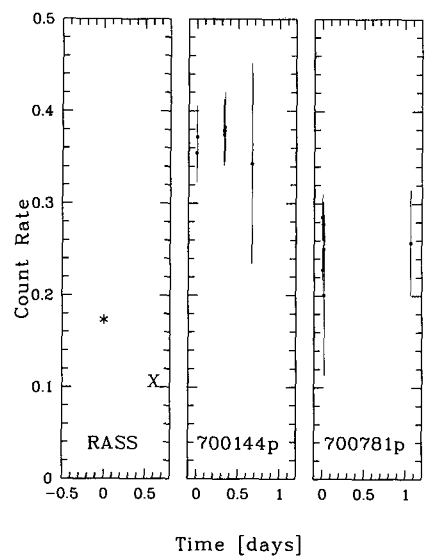

Fig. 7.— Light curve of UGC 32. Time is in units of days since the initial observation on 1990 July 16. The ROSAT HRI (0.1–2.4 keV) count rate is given in units of counts s^{-1}.

This spectrum was fitted with a simple power law plus absorption model. The photon index is 2.18 ± 0.27 and 2.00 ± 0.37 for 700144p and 700781p respectively as well as the column density of neutral hydrogen along the line of sight of 2.78 and 2.28 H-atom 10^{20} cm^{-2}. These values are larger than the galactic absorption of 1.02 H-atom 10^{20} cm^{-2} from Dicky & Lockman (1990) which means there is an internal absorption by Mrk 464 itself. The normalization at 1 keV is 11.8 and 8.12 $\cdot 10^{-4}$. From this an unabsorbed flux of 3.77 and 2.62 $\cdot 10^{-12}$ergcm^{-2} s^{-1} are derived. A more realistic model (e.g., a combination of thermal and non-thermal components) was not attempted due to the rather low signal -to-noise ratio of the spectral data. Using the relation of Schmidt & Green (1986), we derive luminosities of 4.36x10^{43} and $3.00x10^{43} erg\ s^{-1}$. This value is not much different from 1.62x10^{43} and 4.56x10^{43}erg s^{-1} determined similar type Seyfert 1 galaxy of Mrk 926 inside the Bootes Void.

(c) UGC 10205

As an edge-on disk galaxy, UGC 10205 was classified as a Sa spiral by Nilson (1973) and by de Vaucouleurs et al. (1991). Vega et al. (1997) found the presence of three kinematically distinct gaseous components in the nucleus. UGC 10205 is also a peculiar galaxy, with a weak asymmetric envelope and strongly non-circular gas motions in the nuclear region from detailed photometric studies by Reshetnikov & Evstigneeva (1999). They reported that the overall photometric and kinematic characteristics are consistent with those of a normal giant early-type (S0/a-Sa) galaxy, and the peculiarities of this galaxy could be explained using a numerical model in which an early stage is observed in the capture and tidal disruption of a small type E/S0 companion by the massive central galaxy. UGC 10205 is also a weak radio and IR source (3.4 mJy at 1.4 GHz ; 0.394 Jy at 60 μm) by Miller & Owen (2001). As a void galaxy, UGC 10205 was identified as a weak X-ray source in our investigation.

III. SUMMARY AND DISCUSSION

We have searched for X-ray emission from galaxies inside and towards the nearby voids using the ROSAT RASS database. Actually we wanted to investigate only void galaxies and, therefore, only galaxies in low density regions were selected. However, no X-ray source for all 47 galaxies in lowest region was detected, but two (UGC 10205 and NGC 7509) among 104 galaxies in the highest density region were detected inside the local voids listed by Grogin & Geller (1999, 2000). Only one (UGC 32) among 82 galaxies in the low density regions searched by Vennik (1996) was detected. Hence the identified total number of X-ray galaxies inside local voids are only three among 378 galaxies. Detection of only three void galaxies can not be compared with the detection of nine X-ray galaxies among 27 emission-line galaxies inside the Bootes void in our first paper (Kim & Boller, 2002).

Direct comparison of the detection rate in the Bootes Void and local voids is meaningless due to the different volume size of voids, different limiting magnitude of investigated galaxies, different galaxy types, etc. However, searching emission-line galaxies is much more efficient to increase the detection rate of X-ray galaxies inside voids. Because it is difficult to compare the X-ray characteristics of galaxies in different voids due to a low detection rate, we decided to include all galaxies towards the local voids in addition void galaxies. We investigated all 84 and 203 galaxies towards the local voids listed by Karachentseva, et al. (1999) and by Popescu, et al. (1998) respectively, but only three X-ray galaxies (UGC 749, MCG +11-10-073 and MRK 464) were detected.

As listed in Table 1., among the six X-ray galaxies, three (MCG +11-10-073, UGC 32 and Mrk 464) have previously been identified as AGNs. We performed an X-ray timing analysis for Mrk 464 and UGC 32, and we have discovered a possible long-term X-ray periodic flux variation for Mrk 464, and weak, but rapid variation for UGC 32. A long-term X-ray variation for AGNs has not yet been well studied. This phenomenon for active galaxies was investigated for 3C 273 and Mrk 926 by Kim (2001) and Kim & Boller (2001) using the ROSAT PSPC data. In the case of 3C 273, a periodic variation within the period of roughly one year was confirmed, with a maximum variability of a factor of two. On the other hand, Mrk 926 located inside the Bootes Void is a Seyfert 1 galaxy, and the light curves showed a gradual decrease of brightness for a time scale of 36 months, with the exception of a possible single flare event superimposed on the gradual variation of brightness.

Is the variability pattern of Mrk 464 periodic or a gradual decreasing as in the case of 3C 273 and Mrk 926, respectively? Both interpretations can be possible. If the maximum count rate in Figure 8 is a flare event, then Mrk 464 shows a gradual increment of brightness as in the case of Mrk 926. With only three data sets, a complete periodic cycle can not be figured. But, there is a possibility that the brightness variation of Mrk 464 can be periodic with the period of roughly one year, as is the case of 3C 273. If the X-ray flux variation with a one year period for 3C 273 and Mrk 464 is real, this can be an important clue to understanding the so-called AGN phenomenon. It is difficult to explain the long-term gradual variation. One possibility is a change in the accretion rate of radially infalling matter onto the central massive black hole. One plausible explanation for the periodic variation is a periodic accretion rate variation.

The rapid variation discovered in UGC 32 is even rare among Seyfert 1 galaxies, and only a few examples have been reported in the literature (e.g. IRAS 13224-3809 (Boller et al. 1997) and PHL 1092 (Brandt et al. 1999). Therefore, although UGC 32 has been classified as a E type galaxy, rapid X-ray variation can classify it as one of the active galaxies. Relativistic flux boosting effects might be a plausible explanation for this type of variability.

We like to point out one thing that our main purpose of this paper is the identification of as many as possible X-ray void galaxies. The study of X-ray void galaxies is under early stage, i.e., only 15 sources including six detected in this paper were identified up to the present. Therefore the number of sources is too small to search any common or different characteristics of them especially comparing with other non X-ray void galaxies. For example, we tried to compute the IR and X-ray correlation between the void and the non-void galaxies to check the presence of excessive star formations. Our results show negative results, i.e. we could not find the differences between these two groups. May be the number of X-ray void galaxies are a few to search for such correlations.

The X-ray properties of the three galaxies seem not to be different from that of other ordinary active galaxies. Further population studies of void galaxies in the X-ray region are necessary to understand the nature, the properties, and also possible differences of galaxies inside voids compared to normal field galaxies. It is absolutely necessary to investigate the long-term X-ray variation for as many AGNs as possible. We plan to investigate the SLOAN Survey data and expect to identify more X-ray void galaxies.

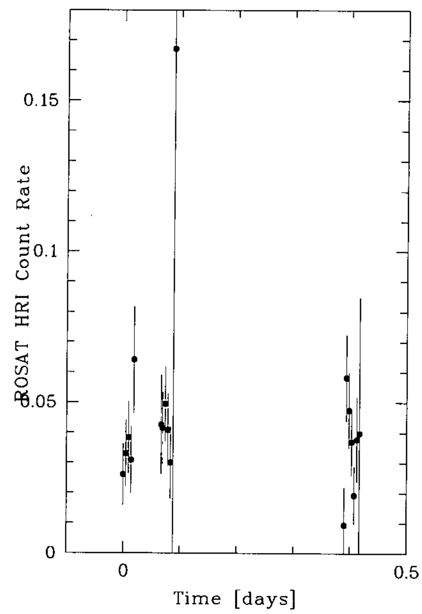

Fig. 8.— Light curve of Mrk 464. Time is in units of days since the initial observation on 1991 December 16. The ROSAT PSPC (0.1–2.4 keV) count rate is given in units of counts s^{-1}. Data are binned in intervals between 24 and 100 seconds.

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