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UPPER LIMITS TO THE HIGH-ENERGY X-RAY FLUX FROM 16 X-RAY SOURCES AND 10 PULSARS*

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ABSTRACT

On 1972 April 5–6, we carried out balloon X-ray observations from Australia. From these observations we have derived upper limits to the flux (in the energy range above 17 keV) from 16 *Uhuru* sources and 10 radio pulsars, including the Vela pulsar (PSR 0833—45).
Subject headings: pulsars — spectra, X-ray — X-ray sources

During a 24-hour balloon flight from Alice Springs, Australia, on 1972 April 5, we carried out X-ray observations of the Large and Small Magellanic Clouds and of regions along the galactic plane. We used a 45 cm^2 NaI(Tl) scintillation detector surrounded by a NaI(Tl) anticoincidence jacket, mounted in an altazimuth configuration. A tungsten slat collimator defined a slit field of view of $\sim 1.^\circ 4 \times 11^\circ$ FWHM. A balloon with a volume of 46 million cubic feet (1.3×10^6 m^3), manufactured by Winzen Research Incorporated, was used to carry the instruments. The payload reached a maximum altitude of ~151,000 feet (46 km) (1.3 g cm^{-2}), while the lowest float altitude reached during the night was ~133,000 feet (40.5 km) (2.8 g cm^{-2}). The data were both recorded on board and transmitted to a ground-based station. X-rays were recorded in eight energy channels covering the range from 17 to 115 keV. Arrival time of the individual X-rays is known to an absolute accuracy of 1 ms. Aspect during the night is known to $\sim 10'$ (star photography), during the day it is known to $\sim 20'$ (Sun sensors, magnetic sensors). In-flight calibrations with a ^{241}Am source demonstrated no change of any significance in the energy channel boundary settings. Eight scans were performed during the flight. For each scan the telescope was oriented toward a particular direction in the sky (in terms of azimuth and elevation), and the diurnal motion of the Earth caused sources to move through the field of view in 20 to 30 minutes. For more details see Lewin, Ricker, and McClintock (1971) and McClintock *et al.* (1971).

The upper limits (2 σ) to the 17–42 keV and 42–115 keV flux from 3U sources (Giacconi *et al.* 1974) are shown in table 1. A source is included in the table only if the following requirements are satisfied: (1) The effective detector exposure to the source exceeds 8000 cm^2 s^{-1}; (2) the source is not a known eclipsing binary;[1] and (3) the number of source counts in excess of background has a statistical significance of less than three standard deviations.[2]

The upper limits to the pulsed 17–42 keV flux from 10 radio pulsars are listed in table 2. In our calculations we used the known pulsar periods and pulse durations (Terzian 1973). When the latter was not known, it was arbitrarily assumed to be 30 ms.

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[1] Our observations of eclipsing binaries will be discussed in another publication.

[2] Results on sources that have been observed at a statistically significant level will be discussed in another publication.

TABLE 1

2 σ UPPER LIMITS TO THE HIGH-ENERGY X-RAY FLUX FROM 16 *Uhuru* SOURCES

SOURCE NAME, 3U CATALOG	OTHER NAME	OBSERVATIONS UT 1972 APRIL 5 (s)	2 σ UPPER LIMITS TO FLUX* Channel 17–42 keV (keV cm^{-2} s^{-1})	Channel 42–115 keV (keV cm^{-2} s^{-1})
0521—72	LMC X-2	23000	0.33	0.66
0532—66	LMC X-4	22000	0.37	0.55
0539—64	LMC X-3	22000	0.51	0.77
0540—69	LMC X-1	23500	0.24	0.40
0833—45	Vela X	39000	0.54	0.34
1134—61		47400	0.65	0.40
1538—52		53400	0.48	0.87
1543—47†		54600	0.82	0.37
1543—47		64700	0.25	0.80
1624—49		56700	0.64	0.69
1630—47		57200	0.49	0.65
1636—53		56700	1.4	1.4
1642—45	GX 340+0	58200	0.44	1.3
1658—49†	GX 339—4	58700	0.45	0.80
1658—49	GX 339—4	69700	0.70	0.74
1702—42		59700	1.3	0.63
1705—44		59700	1.1	0.55
1735—44†	GX 346—7	61400	0.45	0.31
1735—44	GX 346—7	69900	0.42	0.60

* The source energy spectrum is assumed to be $J(E) \propto E^{-1.5}$ (for different assumptions see table 3).

† Source observed and listed twice.

TABLE 2

2 σ UPPER LIMITS TO THE PULSED X-RAY FLUXES FROM 10 RADIO PULSARS

Pulsar	Heliocentric Period (s)	Pulse Duration (ms)	Observation UT 1972 April 5 (s)	2 σ Upper Limit to Flux of Pulsed Spectrum* (time averaged) 17–42 keV (keV cm^{-2} s^{-1})
0833—45	0.08922	2	37500	0.10
1154—62	0.40052	30†	49000	0.24
1530—53	1.36885	25	52800	0.25
1556—44	0.25705	30†	55600	0.31
1558—50	0.86419	30†	54900	0.25
1601—52	0.65795	30†	54800	0.37
1641—45‡	0.45496	30†	58100	0.19
1641—45	0.45496	30†	67500	0.40
1727—47‡	0.82968	30	60300	0.19
1727—47	0.82968	30	71000	0.36
1747—46‡	0.74235	20	61700	0.10
1747—46	0.74235	20	71500	0.09
1749—28	0.56255	6	75500	0.10

* The pulsed energy spectrum is assumed to be $J(E) \propto E^{-1.5}$ (for different assumptions see table 3).

† The radio pulse duration is not known; assumed pulse duration 30 ms.

‡ Source observed and listed twice.

TABLE 3

CONVERSION FACTORS APPLICABLE TO THE UPPER LIMITS AS LISTED IN TABLES 1 AND 2 FOR VARIOUS SPECTRA

Energy Channel (keV)	Power Law, $J(E) \propto E^{-\alpha}$ $\alpha = 0$	$\alpha = 1.5$	$\alpha = 3$	Exponential, $J(E) \propto e^{-E/kT}$ $kT = 20$ keV	$kT = 5$ keV
17–42	0.7	1	1.4	1	2
42–115	1	1	1	1	0.7

The fluxes listed in both tables are obtained by using corrections for atmospheric absorption and detector response under the assumption that the primary energy spectrum of the source is of power-law form $J(E) \propto E^{-\alpha}$ with $\alpha = 1.5$. Upper limits for different spectra can be derived by multiplying the results of tables 1 and 2 with the conversion factors as listed in table 3. As an example: For an assumed exponential energy spectrum of form $J(E) \propto e^{-E/kT}$, with $kT = 5$ keV, the 2 σ upper limit of the flux from 3U 1630—47 in the energy range 42–115 keV is $0.7 \times 0.65 = 0.46$ keV cm^{-2} s^{-1}.

Vela pulsar, PSR 0833—45.—Harnden and Gorenstein (1973) have recently reported soft X-ray pulsations from the Vela pulsar, PSR 0833—45. Combining their data with the upper limits reported here implies $kT < 25$ keV for an exponential primary energy source spectrum, or $\alpha > 0.9$ for a power-law spectrum.

Harnden, Johnson, and Haymes (1972) reported 3 σ evidence for hard X-ray pulsations from the Vela pulsar, with a time-averaged pulsed flux of 0.12 ± 0.04 keV cm^{-2} s^{-1} in the range 23–80 keV. Data obtained during our flight yields a 2 σ upper limit of 0.12 keV cm^{-2} s^{-1} for the time-averaged pulsed flux in the same energy range (23–80 keV). Less than 3 days after our observations, on 1972 April 8, 2^h33^m UT, the heliocentric period of PSR 0833—45 was 89.221082 ms (Reichley 1972). We have corrected this period for slowdown (28 ns) and for the Earth's motion (3.02 μs), and we have searched for a pulsed X-ray flux over a range of periods extending 500 ns on each side of the apparent period as derived by us.

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