CONSTRAINT ON QUASAR NUMBER COUNTS FROM THEIR CONTRIBUTION TO THE X-RAY BACKGROUND

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Abstract

Observations with the Einstein X-ray telescope show that quasars, as a class, are luminous X-ray emitters. By coupling our X-ray observations with quasar optical number counts, we can show that the quasars contribute significantly to the diffuse X-ray background. In fact, the X-ray data strongly suggest that somewhat above 20^m the slope of the optical counts must flatten.

Prior to the launch of the Einstein Observatory, there were three known X-ray emitting quasars: 3C273 (Bowyer et al. 1970), 2A 2251-179 (Ricker et al. 1978), and 4U02141+61 (Apparao et al. 1978). Using the Einstein X-ray Observatory we are undertaking a study of the X-ray properties of quasars with a sensitivity of up to 10^3 times greater than that previously achieved.

We have now detected over 30 quasars. The most distant (or highest redshift) object detected so far in the Center for Astrophysics' program is QSO 0420-388 at z = 3.12. As reported by Ku in this Joint Discussion, the most distant quasar known, OQ 172, has also been detected. If the emission line redshifts can be used as distance indicators, then the 0.5 to 4.5 keV X-ray luminosities range from 10^{43} erg s^{-1} to 10^{47} erg s^{-1}. The details of our observations of quasars as of June 1, 1979, are given in Table 1 (from Tananbaum et al. 1979).

Our observations so far have many biases, such as X-ray brightness, and an underrepresentation of radio quiet quasars. Thus we cannot construct an X-ray luminosity function. Eventually we should be able to generate an unbiased complete sample of X-ray selected quasars.

In the meantime we can use optical counts which are hopefully complete and a tentative correlation between the optical and X-ray

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TABLE 1. Quasar Observations

(1) Name	(2) Redshift	(3) Detector	(4) Net Counts Observed	(5) Uncertainty in Net Counts	(6) Exposure Time (s)	(7) Energy Band $E_1 - E_2$ (keV)	(8) Flux erg/cm^2 s	(9) Luminosity[a] 0.5-4.5 keV erg/s	(10) α_{ox}	(11) L_x/L_{opt}
4U0241+61	0.044	Uhuru/SAS-3				2 - 11	4.0×10^{-11}	2.4×10^{44}	1.66	0.06
2A 2251-179	0.068	Ariel V/SAS-3				2 - 11	2.5×10^{-11}	3.6×10^{44}	1.30	0.56
Mkn 205	0.07	HRI	367	19	4437	0.1 - 4.5	1.4×10^{-11}	2.8×10^{44}	1.21	0.97
PG 1351+640	0.088	IPC	10	4	803	0.47 - 3.7	3.0×10^{-13}	1.2×10^{43}	1.86	0.02
PG 0026+129	0.142	IPC	79	9	428	0.45 - 2.9	3.9×10^{-12}	5.5×10^{44}	1.40	0.30
QSO 1635+119	0.146	IPC	277	19	3472	0.37 - 3.8	2.3×10^{-13}	2.5×10^{44}	1.20	1.02
3C 273	0.158	HRI	68510	262	75240	0.1 - 4.5	1.5×10^{-10}	1.7×10^{46}	1.19	1.09
GQ Com	0.165	IPC	701	27	2804	0.47 - 3.6	5.2×10^{-12}	8.2×10^{44}	1.28	0.63
V 396 Her	0.175	IPC	14	5	734	0.43 - 3.8	7.0×10^{-13}	1.2×10^{44}	1.48	0.19
QSO 1028+313	0.177	IPC	1088	34	5924	0.47 - 3.6	3.9×10^{-12}	7.2×10^{44}	1.14	1.47
3C 61.1	0.184	IPC	12	4	1094	0.44 - 4.0	2.3×10^{-13}	4.2×10^{43}	1.27	0.67
OX 169	0.213	HRI	47	8	15060	0.1 - 4.5	5.3×10^{-13}	1.1×10^{44}	1.71	0.05
4C 13.41	0.240	IPC	< 13		1305	0.44 - 3.4	$<3.0 \times 10^{-13}$	$<1.1 \times 10^{44}$	>1.80	< 0.03
4C 25.40	0.268	IPC	78	11	2414	0.44 - 3.3	5.2×10^{-13}	2.3×10^{44}	1.58	0.10
3C 351	0.371	IPC	87	11	1737	0.25 - 3.1	6.5×10^{-13}	5.7×10^{44}	1.68	0.06
3C 47	0.425	IPC	589	26	4172	0.39 - 2.4	2.9×10^{-12}	4.7×10^{45}	0.95	4.70
QSO 1548+115a	0.436	HRI/IPC[b]	72	9	815	0.44 - 3.3	2.4×10^{-12}	3.1×10^{45}	1.18	1.17
1E 0438-1635	0.5	HRI/IPC[b]	91	17	12560	0.43 - 3.2	1.5×10^{-13}	2.8×10^{44}	1.24	0.81
1E 1227+0224	0.5	HRI	124	15	75240	0.1 - 4.5	4.4×10^{-13}	5.6×10^{44}	1.13	1.56
3C 279	0.536	IPC	500	23	2233	0.32 - 2.9	5.2×10^{-12}	1.2×10^{46}	1.31	0.55
Ton 156	0.549	IPC	≤35		2531	0.24 - 3.0	$\leq 3.2 \times 10^{-13}$	$\leq 6.9 \times 10^{44}$	≥1.61	≤0.09
3C 263	0.652	IPC	25	5	160	0.31 - 2.6	3.4×10^{-12}	1.3×10^{46}	1.24	0.81
3C 138	0.760	IPC	42	8	2547	0.20 - 2.4	2.2×10^{-13}	1.2×10^{45}	1.43	0.26
3C 175	0.768	IPC	19	5	1150	0.25 - 2.5	2.7×10^{-13}	1.5×10^{45}	1.73	0.04
PHL 891	0.874	IPC	< 36		6229	0.32 - 2.3	$<1.6 \times 10^{-13}$	$<1.3 \times 10^{45}$	>1.47	<0.20
PHL 892	0.911	IPC	< 36		6229	0.21 - 2.3	$<1.3 \times 10^{-13}$	$<1.1 \times 10^{45}$	> 1.49	<0.18
3C 208	1.110	IPC	35	7	1268	0.30 - 2.1	2.9×10^{-13}	4.5×10^{45}	1.46	0.22
3C 204	1.112	IPC	<10		165	0.23 - 2.3	$<1.1 \times 10^{-12}$	$<1.6 \times 10^{46}$	>1.12	<1.65
4C 10.43	1.358	IPC	37	9	2329	0.19 - 1.8	9.3×10^{-14}	2.6×10^{45}	1.51	0.16
3C 446	1.404	IPC	213	15	1248	0.23 - 1.8	2.7×10^{-12}	8.4×10^{46}	1.03	2.84
3C 298	1.439	IPC	58	9	1771	0.17 - 2.0	4.7×10^{-13}	1.5×10^{46}	1.44	0.25
1E 1711+7116	1.6	HRI	29	9	46490	0.1 - 4.5	1.6×10^{-13}	3.4×10^{45}	1.65	0.07
Ton 155	1.703	IPC	≤35		2531	0.18 - 1.7	$\leq 2.8 \times 10^{-13}$	$\leq 1.5 \times 10^{46}$	≥1.49	≤0.18
QSO 1548+115b	1.901	HRI/IPC[c]	< 20		1717	0.1 - 4.5	$<1.7 \times 10^{-12}$	$<5.3 \times 10^{46}$	> 1.01	< 3.20
1E 0438-1638	1.96	HRI/IPC[b]	58	16	12140	0.23 - 1.5	1.3×10^{-13}	1.2×10^{46}	1.48	0.19
1E 1704+7101	2	HRI/IPC[b]	80	30	87730	0.21 - 1.6	3.4×10^{-14}	3.1×10^{45}	1.78	0.03
3C 9	2.012	IPC	60	12	6626	0.21 - 1.6	2.0×10^{-13}	1.8×10^{46}	1.34	0.45
QSO 2357-348	2.070	IPC	22	6	1594	0.23 - 1.4	2.0×10^{-13}	2.3×10^{46}	1.50	0.17
B2 1225+31	2.2	IPC	183	17	6265	0.11 - 1.5	4.0×10^{-13}	4.7×10^{46}	1.58	0.10
PKS 0537-286[d]	3.11	IPC	555	28	20850	0.15 - 1.1	2.9×10^{-13}	1.3×10^{47}	0.94	4.87
QSO 0420-388[d]	3.12	IPC	336	23	20450	0.16 - 1.2	1.9×10^{-13}	7.8×10^{46}	1.49	0.18
QSO 0938+119[d]	3.19	IPC	<25		5880	0.10 - 1.0	$<7.3 \times 10^{-14}$	$<3.8 \times 10^{46}$	>1.31	< 0.55

(a) $H_o = 50$ km s^{-1} Mpc^{-1}, $q_o = 0$.

(b) IPC counts, fluxes, and luminosities are quoted.

(c) HRI counts, fluxes, and luminosities are quoted.

(d) Observations part of collaborative effort with M. Smith, R. Weymann, P. Strittmatter, J. Condon, and J. Liebert.

fluxes to proceed. We define
$\alpha_{ox} \equiv - \log \{\ell(\nu_x)/\ \ell(\nu_o)\}/\ \log \{\nu_x / \nu_o\}$, where $\ell(\nu)$ is the monochromatic luminosity at emitted frequency ν (erg s^{-1} Hz^{-1}). We have computed monochromatic X-ray luminosities at 2 keV assuming a power law spectrum with photon index 1.5. The optical monochromatic luminosities at 2500 Å have been computed according to the formulae given by Schmidt. The values of α_{ox} range from 0.94 to 1.86 (Table 1, Column 10) corresponding to a factor of 250 in the ratio of X-ray to optical luminosity. It is important to note that α_{ox} does not appear to vary systematically with redshift or with optical luminosity.

The average value of the X-ray to optical luminosity has been computed using both the positive detections and upper limits given in Table 1 by the method described by Avni et al. (1979). This method calculates the maximum likelihood probability distribution for α_{ox} and from that the average value of the X-ray to optical luminosity ratio $< L_x/L_{opt} >$. The effective α_{ox}, defined by

$$< L_x/L_{opt}> \equiv 10^{-2.605 \ \alpha_{ox}^{eff}} \text{, is } 1.26 \pm 0.10 \ (2\sigma).$$

Due to possible biases in the sample selection, the true uncertainty in α_{ox} may be larger than the above statistical uncertainty.

We now want to combine this α_{ox}^{eff} with the optical number counts to estimate the contribution of the quasars to the X-ray background. Braccesi et al. (1979), analyzing all the available data on optically selected quasars, conclude that the counts can be described from $m_B = 15.5$ to $m_B = 21.4$ by

$$\log N\ (< m_B) = a \left(\frac{m_B - m_o}{2.5}\right) \quad \text{where } a = 2.16 \text{ and } m_o = 18.33$$

and $N\ (< m_B)$ is the number of objects per square degree with magnitude less than m_B.

The background contribution is then proportional to

$$(10^{-2.605\ \alpha_{ox}^{eff}})\ (1 + z_{eff})^{\alpha_o - \alpha_x}\ (\frac{a}{a-1})\ 10^{\frac{a-1}{2.5}(m_{Lim} - \frac{a}{a-1} m_o)}$$

where α_o and α_x are the optical and X-ray energy indices (taken to be 0.7 and 0.5) and z_{eff} is the redshift of the "typical" quasar contributing to the X-ray background. The above formula is strictly valid only if there is no spread in the spectral indices and if all quasars are at z_{eff}. Since $\alpha_o - \alpha_x \simeq 0$ our failure to properly average over spectral indices and integrate over redshift is not too important. Using $z_{eff} = 1.5$, and the values of α_{ox}^{eff}, α_o, α_x, and m_o given previously, results in a computed background that exceeds that actually observed if the optical counts extend beyond $20^{m}.3$. This result is weakened if α_{ox}^{eff} is larger than we assumed. This could be the case if radio quiet quasars, which make up most of the total, but are under-represented in our sample, are less luminous X-ray emitters than the radio observed.

The above calculation shows that the diffuse X-ray background plus the observed emission from quasars will ultimately be useful for setting limits on the maximum number of faint quasars. Our data already strongly suggest that the slope of the optical counts does not exceed 2.16 and also that somewhat above 20^{m} the slope must flatten.

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