THE SOFT X-RAY EXCESS IN QUASARS AND DEEP X-RAY SURVEYS

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Abstract. We examine the surface density of quasars expected in the *ROSAT* PSPC surveys, using quasar optical luminosity functions and model continuum spectra including a soft X-ray excess. We show that the surface density is a sensitive function of the characteristic energy of the soft excess, and the absorption within the quasar as well as the interstellar medium. Comparision of the predicted surface density with the results of various surveys allows useful constraints to be put on the nature of the soft excess.

Key words: *ROSAT, Quasars, Soft X-ray Excess*

1. Introduction

It is now well established that in the continuum spectrum of quasars and AGN, there is excess emission in the soft X-ray region with $\leq 0.5\,\text{keV}$, over the extrapolation of the power-law spectrum which is observed in the $\sim 1 - 10\,\text{keV}$ region. This excess has been observed directly as residuals from power-law fits to the spectrum of 3C273 (Turner *et al.* 1990) and a few other quasars and Active Galactic Nuclei (AGN). Indirect evidence for the ubiquitous presence of the soft excess is also available from spectral fits to *EINSTEIN* IPC and *EXOSAT* data. Many objects in these samples show X-ray measured coloumn density N_H lower than the galactic line-of-sight-value (Wilkes and Elvis 1987, Turner *et al.* 1989), an obvious explanation for which is the presence of excess soft X-ray emission. The energy resolution presently available at soft X-ray energies is however too poor for the spectral shape to be determined, or even to constrain the parameters of a given model.

The optical luminosity function of quasars is now well determined to a reshift $z \simeq 3$, and given a continuum spectrum which extends from the optical to the X-ray region, this can be used to predict the number of quasars per unit area of the sky expected to appear in an X-ray survey. We will show that the predicted surface density, as a function of the flux in the soft X-ray region, depends sensitively on the assumed soft X-ray excess. Comparision with the results of recent deep X-ray surveys (Hasinger *et al.* 1992, Shanks *et al* 1989) then allows constraints to be put

T. J.-L. Courvoisier and A. Blecha: Multi-Wavelength Continuum Emission of AGN, 217–220.

on parameters which define the excess, and to see their relationship with other factors which determine the broad-band shape of the continuum spectrum.

2. The Continuum Spectrum

In the optical and $\sim 1 - 10\,\mathrm{keV}$ X-ray regions, the continuum spectrum is reasonably well represented by a simple power law, with spectral indices $\alpha_{op} \simeq 0.5$ and $\alpha_{xh} \simeq 0.7$ respectively. In order to keep the number of free parameters to the minimum, we represent the soft excess by a simple exponential with characterstic energy E_{xs}, and express the continuum by

$$L(E) = B_{op}E^{-\alpha_{op}}exp(-E/E_{xs}) + B_{xh}E^{-\alpha xh}, \qquad (1)$$

where B_{op} is determined given the optical luminosity, and B_{xh} using the spectral index α_{ox} which connects the emission at $2500\mathring{A}$ with that at $2\,\mathrm{keV}$. This spectrum clearly reduces to a power-law in the optical and $\sim 1 - 10\,\mathrm{keV}$ regions as required, and has excess emission at $E \simeq E_{xs}$. The excess can also be represented by a Planckian, but in this case there is an extra parameter.

3. The Quasar Optical Luminosity Function

Large complete samples of quasars, selected in ultra-violet excess (UVX) or multi-colour surveys, have become available over the last several years, and using these it has been established that the optical luminosity distribution of quasars may be be represented as a power-law which is relatively flat at low luminosities and steep at high luminosites; the characteristic luminosity at which the change in slope occurs increases with redshift, leading to pure luminosity evolution. We will use the luminosity function of Boyle *et al.* (1991), which is based on a UVX sample, augmented by quasars found using other techniques for $2.2 < z < 2.9$. The sample is complete to $m_B < 21$ in the redshift range $0.3 < z < 2.9$, and the derived luminosity function fits the observed surface density very well except at the bright apparent magniude. The form of the function is

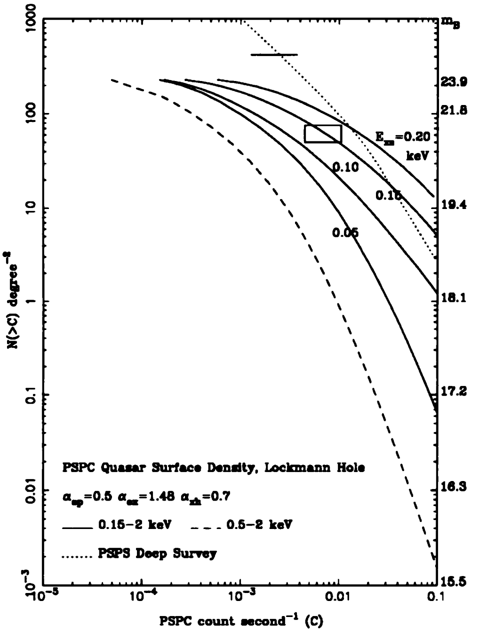
$$\Phi(M_B, z) = \frac{\Phi^*}{10^{0.4[M_B - M_B(z)](\alpha+1)} + 10^{0.4[M_B - M_B(z)](\beta+1)}}, \qquad (2)$$

with $M_B(z) = M_B^* - 2.5k_L \log(1+z)$. The values of the constants are $\alpha = -3.8$, $\beta = -1.6$, $M_B^* = -22.6$, $k_L = 3.45$ and $\Phi^* = 6.5 \times 10^{-7}$. A similar function has been proposed by Warren *et al.* (1993) at higher redshifts. It follows from their luminosity function that the space density of quasars decreses rapidly beyond $z \simeq 3$, so that their contribution to the surface density of the X-ray sources is not considerable.

4. Quasar Surface Density in the X-ray Band

The PSPC on *ROSAT* has a large collecting area and extremely low intrinsic background, and is especially sensitive at soft X-ray energies, which makes it ideally suited to detect a soft X-ray excess. The number of counts per second produced in some energy band of the PSPC by a quasar is determined by the form of the luminosity as a function of energy given in Equation (1), its redshift and the effective area of the detector as a function of energy. The surface density of quasars as a function of the count rate can be found by : (1) finding the number of quasars in small ranges of M_B and z from their luminosity function, (2) finding their PSPC count rate and (3) repeating the procedure over the range of M_B and z required.

The results of such a calculation are summarized in the Figure below, where we have shown the integral surface density of quasars as a function of the count rate in the $(0.15 - 2\,\text{keV})$ band of the PSPC.



The numbers on the right edge of the box indicate the apparent blue magnitude at which the integral surface density of quasars shown on the left edge is reached. The surface density depends most sensitively on the characteristic energy E_{xs} of the soft excess and the hydrogen coloumn density N_H. The ROSAT Deep Survey (Hasinger *et al.*, 1993) was carried out in the region of the *Lockmann Hole* with $N_H = 5.7 \times 10^{19}\,\text{cm}^{-2}$, which is the minimum value known in the sky. Qusars as

https://doi.org/10.1017/S0074180900175060 Published online by Cambridge University Press

a class are not known to have significant intrinsic N_H, and therefore we choose N_H as in the Deep Survey. Results of the Deep Survey have been reported in the $(0.5 - 2\,\mathrm{keV})$, energy band, which misses the soft X-ray photons. The translation of count rate from this band to ours depends on the shape of the spectrum and redshift, and for the range of these parameters being considered, 1 PSPC count in the $(0.5-2\,\mathrm{keV})$ band corrsponds to 10 ± 0.04 counts in the $(0.15-2\,\mathrm{keV})$band. The horizontal line in the diagram shows the surface density of $443\,\mathrm{deg}^{-2}$ of all X-ray sources at the limit of the Deep Survey observed by Hasinger *et al.* , translated to our band. The dotted line shows the integral surface density of X-ray sources in the Deep survey as a function of the count rate, and it is clear that quasars contribute only a fraction of the sources, especially at the faintest limits obtained through fluctuation analysis. A direct constraint on the soft excess is provided by the results of Shanks *et al.* (1991) who carried out an optical identification programme to obtain a surface density of 63 ± 12 quasars deg^{-2} at the limiting $0.5 - 2\,\mathrm{keV}$ flux of $\sim 10^{-14}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$. The observed surface density, together with the 1σ error-bar translates in our band to the small rectangle shown in the figure. It is clear that soft X-ray emission with $\mathrm{E_{xs}} > 0.15\,\mathrm{keV}$ would produce an excess of quasars, while emission with $\mathrm{E_{xs}} < 0.05\,\mathrm{keV}$ would lead to a deficit relative to this limit. The allowed range of E_{xs} depends upon the value of α_{ox} with the bound $E_{xs} < 0.1\,\mathrm{keV}$ for $\alpha_{ox} = 1.38$, $E_{xs} < 0.13\,\mathrm{keV}$ for $\alpha_{ox} = 1.48$ and $E_{xs} < 0.15\,\mathrm{keV}$ for $\alpha_{ox} = 1.58$. If the excess is represented by a black-body spectrum, the temperature which leads to a surface density consistent with observation is $kT \simeq 40\,\mathrm{keV}$, but this value depends upon the total energy present in the black-body radiation.

At the flux limit of the Deep Survey, quasars contribute only a fraction of all the sources. Since the surface density of quasars at this level is close to the total surface density of quasars, it is clear that other populations will be making an increasing contribution at the faint levels. We have shown (Kembhavi and Fabian, 1993) that Seyfert galaxies contribute at most several hundred sources per square degree, so that the remaining sources, most of which are extragalactic (Hasinger *et al.*, 1992), should be liners, starburst galaxies or normal galaxies.

Acknowledgements AK wishes to thank Professor D. Lynden-Bell, Director, Institute of astronomy, Cambridge for funding a visit during which much of this work was done. ACF acknowledges the Royal Society for financial support.

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