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The Soft X-ray Excess in Quasars

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Abstract

A soft X-ray excess in the energy range of a few tenths of a keV has been detected in some quasars, and there are indications in the X-ray data which point to the excess being a feature universal to all quasars. The poor energy resolution in the concerned energy band makes it impossible at the present to observationally constrain the excess quantitatively. We show in this paper that the shape of the excess sensitively determines the surface density of quasars as observed by the *Rosat* PSPC. Comparison with the observed surface density therefore allows an assessment of the nature of the excess.

1 Introduction

The X-ray spectrum of a typical high luminosity quasar is rather complex, even though it can be represented by a simple power-law over certain segments of the X-ray band. In the 2-10 keV region, quasars have a power-law spectrum $L_x(E) \propto E^{-\alpha_x}$, with mean spectra index $\langle \alpha_x \rangle = 0.69$ and dispersion $\sigma_{\alpha_x} = 0.16$ (Turner et al. 1989a), while in the range $\sim 0.5 - 3.5$ keV covered by the IPC on Einstein, a power-law is again obtained, but with a wide spread in the power-law index, $-0.2 < \alpha_x < 1.8$.

At soft x-ray energies below the IPC Limit, there are indications of excess energy over the extrapolation of the higher energy power-law spectra to lower energies. The excess has been directly observed in the case of 3C273 (Turner et al. 1990), and convincing evidence of its existence is available from IPC data (Wilkes and Elvis 1987). The energy resolution at present available at soft x-ray energies is however too poor to provide any idea of the shape of the soft X-ray spectrum or to even constrain parameters which define model spectra. We present in this paper a novel method for obtaining such constraints.

2 Quasar X-ray Spectrum and Surface Density

The PSPC detector on *Rosat* has relatively high efficiency at soft X-ray energies (≤ 0.5 keV). As a consequence, the surface density of quasars detected by it is sensitively dependent on the properties of the soft X-ray excess. Our method involves using an assumed X-ray spectrum and the known optical luminosity function of quasars to predict the quasar surface density as a function of PSPC count rate. Comparison with the observed surface density then provides useful constraints on parameters which define the spectrum.

We have experimented with different kinds of spectra, but will in this paper consider a simple model in which the soft-excess is assumed to have an exponential shape. In this model the luminosity of the typical quasar as a function of energy is given by

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

where B_{op} and B_{xh} are normalization constants and E_{xs} is the characteristic energy of the soft excess. The spectrum in (1) reduces to the usual power law form in the optical ($E \ll E_{xs}$) and the 2–10 keV X-ray ($E \gg E_{xs}$) regions. The constants B_{op} and B_{xh} are determined as

$$\frac{B_{op} = 6.60 \times 10^{20-0.4M_B-0.097\alpha_{op}} \text{ erg s}^{-1} \text{ Hz}^{-1}}{E_{4400}^{-\alpha_{op}} \exp(-E_{4400}/E_{xs}) + E_{xh}^{(\alpha_{xh}-\alpha_{op})} E_{4400}^{-\alpha_{xh}} \exp(-E_{xs}/E_{xh})}, \quad (2)$$

and

$$B_{xh} = B_{op} E_{xh}^{(\alpha_{xh}-\alpha_{op})} \exp(-E_{xh}/E_{xs}), \quad (3)$$

where M_B is the absolute blue magnitude and E_{xh} the energy at which the first and second terms on the right hand side of (1) are equal. The PSPC count rate produced by a quasar at redshift z is

$$C = \frac{1}{4\pi \left(\frac{c}{H_0}\right)^2 (1+z)d^2(z)} \int_{E_{01}}^{E_{02}} \frac{L(E_0(1+z))}{E_0} e^{-N_H \sigma(E_0)} A(E_0) dE_0, \quad (4)$$

with

$$d(z) = \frac{[q_0 z + (q_0 - 1)(-1 + \sqrt{1 + 2q_0 z})]}{q_0^2(1 + z)}. \quad (5)$$

Using a sample of 420 ultraviolet excess (*UVX*) quasars, Boyle et. al have obtained an optical luminosity function which is applicable for redshift $z < 2.2$. We use their Model A, for which the number of quasars per unit comoving volume is given by

$$\phi(M_B, z) = \frac{\phi^*}{\left[10^{0.4[M_B - M_B(z)](\alpha+1)} + 10^{0.4[M_B - M_B(z)](\beta+1)}\right]}, \quad (6)$$

$$M_B(z) = M_B^* - 2.5k_L \log(1 + z), \quad M_0^* = -23.1, \quad \alpha = -3.84, \quad \beta = -1.61, \quad k = 3.34, \quad (7)$$

with the cosmological deceleration parameter $q_0 = 0$ and $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$. We have used Eqn. (1), (5) and (6) to obtain the number of quasars per square degree of the sky as a function of C .

3 Results

We have shown in Fig 1 the integral surface density of quasars obtained using $\alpha_{op} = 1$, $\alpha_{th} = 0.7$ and $\alpha_{ox} = 1.48$, which are true for the typical radio- quiet quasars, the last being the nominal optical to X-ray power- law index. It is seen that at a given count rate the surface density increases sharply with E_{xs} . The predicted surface density is to be compared with the observed number of 63 ± 13 quasars per square degree with the PSPC count rate $C > 9 \times 10^{-4} \text{ cts}^{-1}$ in the 0.1 – 2.4 keV region (Shanks et. al. 1991). To facilitate the comparison, we have shown in Fig. 2 the integral surface density at the limit of the Shanks et al survey, for various parameter values. It is clear that for $\alpha_{ox} = 1.48$ (the typical value for radio-quiet quasars), the characterisitic energy $E_{xs} \leq 0.1 \text{ keV}$ in order not to exceed the observed surface density. E_{xs} decreases for smaller values of α_{ox} , and for $\alpha_{ox} < 1.4$, a steep optical power-law spectral index is required if the soft excess is to be present without exceeding the observed surface density. For a black-body form of the soft excess, adequate surface density is produced for $kT \simeq 30 \text{ keV}$. Taking into account the soft excess, it can be shown that the Einstein IPC X-ray luminosity of quasars, obtained using an assumed pure power-law form, may be underestimated by 20 percent.

References

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