The hard X–ray spectrum of Compton–thick Seyfert 2 galaxies and the synthesis of the XRB

Giorgio Matt¹, Fulvio Pompilio¹, Fabio La Franca³

¹Dipartimento di Fisica, Università Roma Tre, Via della Vasca Navale 84, I–00146 Roma, Italy.

Abstract. A synthesis model for the cosmic X–ray Background (XRB) is presented, which includes a proper treatment of Compton scattering in the absorbing matter for type 2 AGN. Evidence for a decrease of the relative importance of type 2 AGN at high redshift is found, which may be due either to a decrease of the relative number of obscured sources, or (more plausibly) to an increase of the fraction of Compton–thick absorbed sources. The XRB spectrum, soft X–rays and hard X–rays source counts can be simultaneously fitted only if the XRB normalization as derived from BeppoSAX/MECS measurements ([12]) is adopted.

1 Modeling the X–ray absorption in Compton–thick source

BeppoSAX observations have shown that a large fraction (at least 50%) of nearby Seyfert 2 galaxies are Compton–thick, i.e. the nucleus is obscured by matter with $N_H \geq \sigma_T^{-1} = 1.5 \times 10^{24} \, \text{cm}^{-2}$ ([5], [10]). Because Seyfert 2s outnumber Seyfert 1s by a large factor, this means that Compton–thick Seyfert 2s are the most common type of AGN in the local Universe. It is possible that heavily obscured sources were even more common in the past ([3]), and then Compton–thick sources should be an important ingredient in XRB synthesis models, despite their low flux.

It is therefore important to model in detail the X–ray spectrum emerging from such a thick absorber. We have calculated transmitted spectra by means of Monte Carlo simulations assuming a spherical geometry, with the X–ray source in the centre. All relevant physical processes: photoelectric absorption, Compton scattering (with fully relativistic treatment), and fluorescence (for iron atoms only), have been included in the code. More details can be found in [7].

To illustrate the importance of a proper treatment of the transmission spectrum, in Figure 1 the case for $N_H = 3 \times 10^{24} \, \text{cm}^{-2}$ is shown. For comparison, we also plot the spectrum obtained with only photoelectric absorption (an unphysical situation) and photoelectric plus Compton absorption (neglecting scattering, which corresponds to obscuring matter with small covering factor, an unlikely situation given the large fraction of Compton–thick sources). The differences between the three curves are large, and fitting real data with the inappropriate model can make a big difference in the derived parameters. Let us discuss as an
Figure 1: The X-ray transmitted spectrum for $N_H = 3 \times 10^{24}$ cm$^{-2}$. The solid line is for the complete spherical model discussed in \cite{7}. The dashed line refers to absorption by matter with small covering factor, while the dotted line is computed in the unphysical assumption of only photoelectric absorption, and is shown here only for the sake of illustration.

example the case of the Circinus Galaxy. The BeppoSAX observation revealed the nuclear radiation transmitted through a Compton–thick absorber (\cite{8}). When fitted with the “small cloud” absorber, the best fit value for the column density is $6.9 \times 10^{24}$ cm$^{-2}$, and the 2–10 keV extrapolated luminosity is $1.5 \times 10^{44}$ erg s$^{-1}$, a surprisingly large value when compared to the IR luminosity. If the spectrum is instead fitted with the spherical model (then including Compton scattering), the column density is $4.3 \times 10^{24}$ cm$^{-2}$, and the 2–10 keV luminosity reduces to a much more reasonable value of $10^{42}$ erg s$^{-1}$.

2 The XRB synthesis model and the evolution of AGN

We developed a synthesis model for the XRB based on the standard assumption that the XRB is mostly made by a combination of type 1 and 2 AGN (\cite{11}, \cite{2} and references therein). Below we schematically summarize the main assumptions of the model. Further details can be found in \cite{9}.

1. AGN spectra
(a) type 1 (AGN1) spectrum:
- power law ($\alpha = 0.9$) + exponential cut-off ($E_c = 400$ keV);
- Compton reflection component (accretion disk, $\theta_{obs} \sim 60^\circ$);

(b) type 2 (AGN2) spectrum (\cite{7}):
- primary AGN1 spectrum obscured by cold matter:
  $10^{21} \leq N_H \leq 10^{25}$ cm$^{-2}$,
  $\frac{dN}{d(\log N_H)} \propto \log N_H$;
- Compton scattering within the absorbing matter fully included.

2. Cosmological parameters
(a) PLE ($\Phi^*(z=0) = 1.45 \times 10^{-6}$ Mpc$^{-3}(10^{44}$ erg s$^{-1})^{-1}$);
(b) power law evolution for the break-luminosity:
  $L^*(z) \propto (1 + z)^k$ up to $z_{max} = 1.73$, with
  $L^*(z = 0) = 3.9 \times 10^{44}$ erg s$^{-1}$ and $k = 2.9$ (model H of \cite{1});
(c) the redshift integration is performed up to $z_d = 4.5$.

2.1 The $R(z)$ model
The best-fit to the high energy (3-50 keV) XRB HEAO-1 data (\cite{1}), but with a
$\sim$30 % higher normalization (according to the BeppoSAX/MECS results below
10 keV, \cite{12}) is performed by a $\chi^2$-minimization procedure. The inclusion of a
redshift–dependent term in the number ratio of the two types of sources (i.e.
$R(z) = N(type2,z)/N(type1,z)$) results in an improvement of the fit at the 99%
confidence level. Our best solution is shown in Figure 2 and is described by the
following analytical form:

$$R(z) = R_0 \times (1 + z)^{k_1} e^{k_2 z}$$

with $R_0 = 4$ (according to \cite{5}). The best-fit parameters are $k_1 = 2.8 \pm 0.2$ and
$k_2 = -1.5 \pm 0.1$. It is worth noticing that this result does not necessarily imply
that the actual number of Seyfert 2s diminishes with $z$, but rather that their
contribution to the XRB diminishes. This may well be due to a larger fraction of
obscured objects being Compton–thick in the past, as proposed by \cite{3}. Hopefully,
\textit{Chandra} and \textit{XMM} surveys will be able to check this intriguing possibility.

2.2 The source counts
While there is no much difference in the goodness of the fit to both the XRB
spectrum and the soft X-ray source counts if the HEAO–1 normalization is or
not readjusted to match the BeppoSAX results, it makes a large difference in the
fitting of the hard X-ray source counts. In particular, the BeppoSAX (\cite{4} and
Comastri, this conference) 5–10 keV source counts can be simultaneously fitted
by our model only if the higher normalization is used.
Figure 2: The type 2/type 1 number ratio as a function of redshift.

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