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BeppoSAX observation of NGC 7674: a new reflection-dominated Seyfert 2 galaxy

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Abstract. The Seyfert 2 galaxy NGC 7674 has been observed within the BeppoSAX Core Programme with the onboard narrow field instruments between 0.1 and 100 keV. The broad-band spectrum shows four most relevant spectral components: a) a soft excess below ∼2 keV; b) a prominent (EW∼1 keV) Fe line; c) a flat ($\Gamma_{obs} \sim 1.1$) 2–10 keV continuum; d) a 4.5σ detection above 13 keV. The flat power law spectrum can be very well explained within the current AGN unified models assuming a steep ($\Gamma \sim 2$) intrinsic spectrum scattered by warm gas for the low energy band and totally reflected by optically thick cold matter (plausibly a molecular torus) for the high energy band. The case of NGC 7674 adds to the increasing number of so called "Compton-thick" Seyfert 2 galaxies in which the direct emission is totally absorbed and the X-ray luminosity is thus at least one or two orders of magnitude larger than what inferred from the observed flux.

Key words: X-rays: galaxies – galaxies: Seyfert – galaxies: individual: NGC 7674

1. Introduction

Unification models of Seyfert galaxies, at least in their simplest formulation, postulate the presence of a geometrically and optically thick gas and dust torus which, at a distance of several to several tens of parsecs from the nucleus (Krolik, Madau, and Zycki 1994), hides the primary source and the broad line forming region (BLR). The orientation of the torus is independent of the host galaxy, and the observed differences between Seyfert 1 and Seyfert 2 nuclei are thus to be ascribed simply to the angle formed by the line of sight direction and the axis of the torus. After the seminal work by Antonucci & Miller (1985) various pieces of evidence have been accumulating in favour of the unification model of Seyfert galaxies (see Antonucci 1993 for a review of the subject): detection of broadened emission lines in optical spectropolarimetry observations of several Seyfert 2 galaxies (Antonucci & Miller 1985; Miller & Goodrich 1990; Tran 1995; Young et al. 1996) interpreted as scattering of the BLR emission by warm material placed above the torus; biconical structures in the light of the forbidden [OIII] line at 5007 Å (e.g. Tadhunter and Tsvetanov 1989) which is expected if the ionizing radiation field from the nucleus is anisotropic; large (10^{23} cm^{-2} or greater) absorbing column densities observed in the hard X-ray spectra of Seyfert 2 galaxies (Awaki 1997).

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In the optical and UV bands the nuclear emission is visible only if the line of sight does not intercept the torus. In the X-ray band, the interaction between electromagnetic radiation and matter is dominated by photoelectric absorption up to $\simeq$ 10 keV and by Compton scattering at higher energies. When the line of sight intercepts the torus (Seyfert 2) primary X-rays are able to leak through it (Compton thin source) if the column density N_H is less than $\sim 1.5 \times 10^{24}$ cm^{-2}. When $N_H >$ few $\times 10^{24}$ cm^{-2} the primary X-rays cannot escape and are either promptly absorbed via photoelectric interaction, or first Compton downscattered and eventually photoabsorbed making the nucleus invisible (Compton thick source) in direct emission.

Emission from Compton thick Seyfert 2 galaxies can be detected by means of the reflection caused by the visible inner surface of the torus and/or via scattering by the material responsible for producing the broad lines observed in polarized light. The detection of these sources in X–rays is hampered because of their faintness ($\lesssim$ few $\times 10^{-12}$ erg cm^{-2} s^{-1}) and only a few of them are currently known (Matt 1997 and references therein). Their expected observable features in X-rays are: a 2–10 keV continuum flatter than the canonical slope observed for

Seyfert 1, a strong (equivalent width (EW) $\sim$ 1 keV or higher when measured against the reflected continuum) Fe K_α feature around 6.4 keV, and a reflection "hump" at energies $>$ 10 keV (e.g. Ghisellini, Haardt, and Matt 1994).

NGC 7674 is a z = 0.029 Seyfert 2 nucleus hosted in a face on spiral galaxy (Sab) with asymmetrical arms and a tidal connection to a nearby compact elliptical galaxy. Broad H_α and H_β components in polarized flux were first observed by Miller & Goodrich (1990), and then by Young et al. (1996). The spectropolarimetric observations suggest that NGC 7674 is the only known Seyfert 2 galaxy with hidden broad line region for which dust scattering is the dominant cause of the observed nuclear polarization (Tran 1995).

Preliminary analysis of the GINGA observation of NGC 7674 (Awaki et al. 1991) gave a flat ($\Gamma \sim 1.5$) 2–10 keV spectrum with no indication for a Fe line (EW $<$ 110 eV). However, subsequent analysis indicated that the observed count rate was below the 3σ rms fluctuation of the Cosmic X-Ray Background between 2 and 10 keV in the eight detectors of the Large Area Counter onboard GINGA (Smith and Done 1996). As a consequence, the 2–10 keV flux of 4×10^{-12} erg cm^{-2} s^{-1} previously reported by Awaki et al. (1991) has to be considered only as a 2σ upper limit (Smith, private communication). In the following, detailed measurement of the X-ray spectral characteristics of NGC 7674 obtained by BeppoSAX is reported.

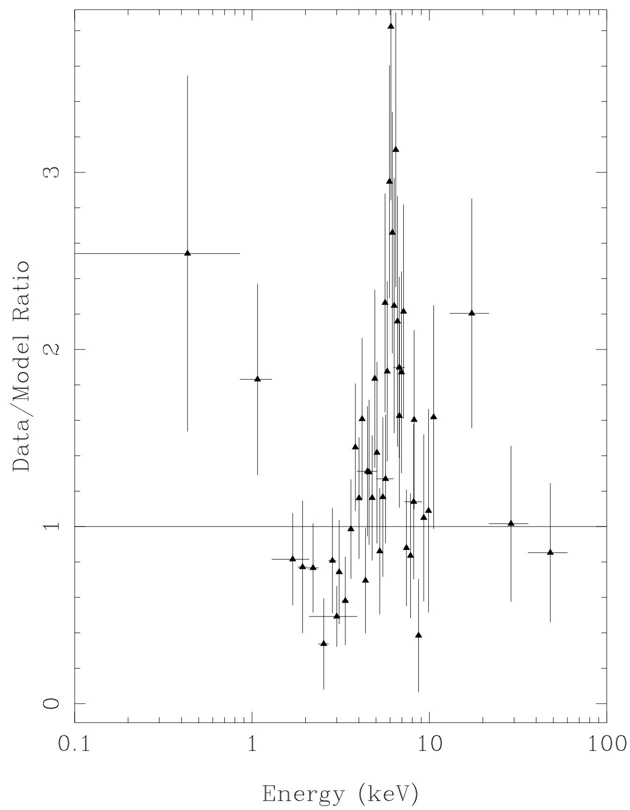

Fig. 1. Data to model ratio in the 0.1-100 keV energy band for a single power law model.

2. Observation and data reduction

The BeppoSAX X-ray observatory (Boella et al. 1997a), a major programme of the Italian Space Agency with participation of the Netherlands Agency for Aereospace Programs, was launched on April 30th 1996 from Cape Canaveral in Florida. The payload instruments are characterized by a wide spectral coverage and consist of four co-aligned Narrow Field Instruments (NFI) plus two Wide Field Cameras perpendicular to the axis of the NFI and looking in opposite directions.

The NFI include a Low Energy Concentrator Spectrometer (LECS; Parmar et al. 1997), three Medium Energy Concentrator Spectrometers (MECS; Boella et al. 1997b), a High Pressure Gas Scintillation Proportional Counter (HPGSPC; Manzo et al. 1997), and a Phoswich Detector System (PDS; Frontera et al. 1997). LECS and MECS are instruments with imaging capabilities (angular resolution $\sim 1'$) and operate in the 0.1–10 keV and 1.5–10 keV spectral bands respectively. In the overlapping energy interval the effective area of the LECS is about one third of the three MECS (which is around 150 cm^2 at 6 keV). HPGSPC and PDS are instruments functioning via rocking collimators and cover the 4–120 keV and 15-300 keV energy bands respectively. In the overlapping energy band PDS is the most sensitive (by a factor $\sim 4 - 8$) while HPGSPC is optimized for spectral resolution.

BeppoSAX NFI pointed at NGC 7674 from November 25th to November 26th 1996 for about 1.1×10^5 s of effective observing time. The on-source time for the LECS was $\sim$40 ksec since this instrument is switched on only during satellite night time, while the on-source time for PDS and HPGSPC was $\simeq$50% of the effective time due to rocking collimator functioning.

LECS and MECS good time intervals were selected imposing the minimum elevation angle above Earth's limb to be $> 5°$ and the instrument to be in its nominal configuration[1]. Given the weak 2–10 keV source flux (see next section) LECS and MECS spectra were extracted from a $2'$ radius region around the centroid of the source and the appropriate response matrices were generated. The same region was used to extract background spectra from blank sky observation files. The use of local instead of blank sky backgrounds did not make significant difference.

The PDS consists of four phoswich units. They operate in collimator mode, with two of them pointing to the source while the other two point $\pm 210'$ away. The two pairs switch on and off source every 96 seconds. The net source spectra have been obtained by subtracting the 'off' to the 'on' counts. PDS source data have been multiplied by a factor 1.42 to account for the mismatch in the absolute normalization with the MECS (Matt et al. 1997, and references therein). Leaving this number free to vary would only slightly change the best fit parameters, without affecting the main results of the present analysis. The net source count rate in the PDS was 0.13 ± 0.03 cts/s between 13 and 60

[1] Information regarding background subtraction and BeppoSAX NFI data reduction can be obtained from *http://www.sdc.asi.it/software/*

keV, which gives a significant detection also after conservative subtraction of the systematic residuals which are currently evaluated $\simeq 0.02$ cts/s in the 13–200 keV band (Guainazzi and Matteuzzi 1997).

The net source count rate (in units of 10^{-3} cts/s) was 2.9 ± 0.3 in the LECS (0.1–9 keV), 4.7 ± 0.3 in the three MECS (2–10 keV), while it was below detection limit in the HPGSPC. Neither the soft (∼0.1–2 keV) nor the hard (2–10 keV) energy band data show significant variability. Statistical χ^2 tests against constancy gave a probability greater than 25%, thus consistent with a constant source. The spectra were thus extracted from the overall observing period and were rebinned to have a minimum of 20 counts in each channel.

3. Spectral analysis

The spectral analysis has been performed by means of the XSPEC 9.0 package, and using the instrument response matrices released by the BeppoSAX Science Data Centre in January 1997. Figure 1 shows the ratio of the broad band spectrum between 0.1 and 100 keV to a simple power law ($\Gamma \simeq 0.5$) model. Residuals indicate the presence of a significant soft excess below 2 keV, a strong line emission around 6.4 keV, and excess emission in the 13–30 keV band. These clear spectral features make NGC 7674 an interesting case for investigating and testing reflection models. All the quoted errors correspond to 90% confidence intervals for one interesting parameter ($\Delta\chi^2$ of 2.71).

3.1. The 2-10 keV spectrum

The MECS spectral data in the 2–10 keV energy band were first fitted with an absorbed power law model, plus a Gaussian narrow (σ = 0 fixed) line to take into account the 6.4 keV feature, with all other parameters left free to vary. The best fit (model #1 in Table 1) parameters are a photon index $\Gamma \simeq 1.1$, an absorption column density $N_{\rm H} \simeq 6 \times 10^{22}$ cm^{-2}, and a gaussian line centered (in the reference frame of the emitting source) around 6.4 keV with an equivalent width of ∼1 keV. The fit improves significantly (>98% via F-test) if the line is allowed to broaden and gives a width of $\sigma \simeq 0.4$ keV and an equivalent width of ∼2 keV (model #2). Unless extreme iron abundances are assumed (about an order of magnitude larger than the cosmic value), the observed iron emission line intensity cannot be explained by transmission through the measured absorption column density which would predict an EW<100 eV (Makishima 1986, Ptak et al. 1996). Such a strong line, together with the unusual flatness of the continuum, is therefore a very strong evidence that the observed hard X-ray spectrum is reflection-dominated.

3.2. The soft excess

The low statistics at energies below $\simeq$2 keV do not allow to firmly discriminate among different models tested. In fact, the excess detected in the LECS data at $E < 2$ keV is well modeled both by a steep ($\Gamma \sim 2.9$) power law absorbed by the galactic column density in the direction of the source ($N_{\rm H} = 5.31 \times 10^{20}$ cm^{-2}; Dickey and Lockman [1990]) and by a Raymond-Smith model with solar abundance and kT∼0.9 keV (models #3a and #3b). Moreover, an acceptable fit is also obtained assuming an electron scattering model with $\Gamma_{\rm soft} \equiv \Gamma_{\rm hard}$ (model #4). The possible implications of the scattering model are discussed in Sect. 4.

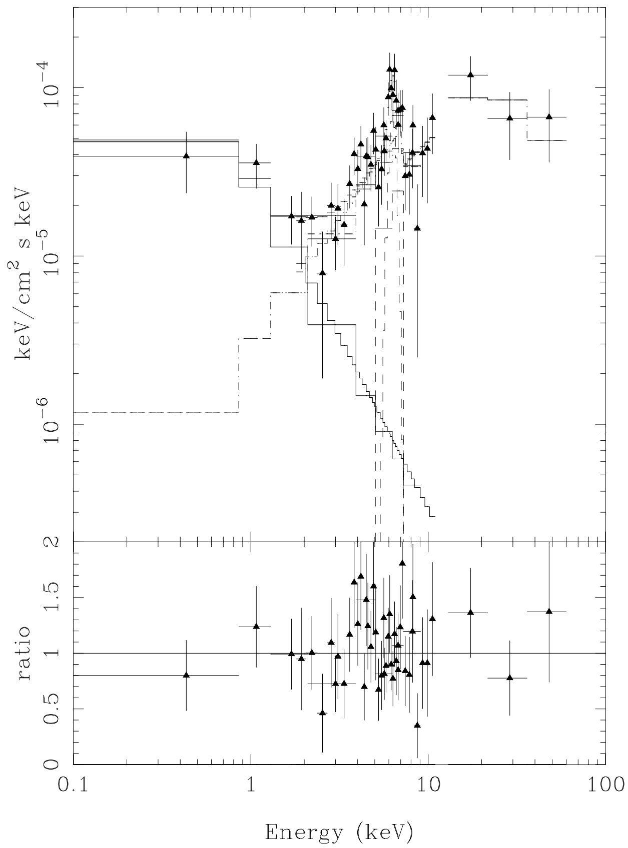

Fig. 2. Unfolded best fit model (model #3a) consisting of a steep power law at low energies plus a "pure" reflection component and associated FeK line at higher energies.

3.3. The broad-band reflection-dominated spectrum

The broad band (0.1–100 keV) spectrum has been fitted with a soft component (see Sect. 3.2) plus a pure reflection continuum resulting from a power law illumination of cold and thick material plus a gaussian line. The use of this model is justified by the fact that the emission line centroid energy is consistent with K shell fluorescence from neutral Iron and has an EW of the order of what is expected in the case of a pure reflection continuum (e.g. Matt, Perola, and Piro 1991; Ghisellini, Haardt, and Matt 1994; Krolik, Madau, and Zycki 1994). In this reflection model (PLREFL in XSPEC) the only free parameter is the relative normalization of the reflected component to the direct one. If this parameter is left free to vary, only a lower limit ($\simeq 40$) is obtained, thus confirming that the observed spectrum is dominated by reflection. Therefore a purely reflected spectrum (i.e.

Table 1. Upper panel: MECS fit with a power law plus different models; lower panel: pure reflection fits.

2–10 keV – Single absorbed power-law model						
Model #	Γ	N_H ($\times 10^{22}$ cm^{-2})	E(FeK) (keV)	σ(FeK) (keV)	EW(FeK) (eV)	χ^2/ν
1	$1.12^{+0.34}_{-0.32}$	$6.4^{+7.3}_{-4.5}$	$6.39^{+0.18}_{-0.13}$	$0_{\rm (fixed)}$	1030^{+790}_{-431}	32.4/28
2	$1.06^{+0.37}_{-0.32}$	$4.6^{+7.6}_{-3.8}$	$6.51^{+0.19}_{-0.17}$	$0.41^{+0.27}_{-0.16}$	2070^{+1450}_{-930}	26.1/27
0.1–100 keV – Soft component + Pure reflection component						
Model #	$\Gamma_{\rm soft}$ kT	$\Gamma_{\rm hard}$	E(FeK) (keV)	σ(FeK) (keV)	EW(FeK) (eV)	χ^2/ν
3a	$2.87^{+0.53}_{-0.49}$	$1.92^{+0.21}_{-0.21}$	$6.45^{+0.18}_{-0.17}$	$0.26^{+0.27}_{-0.22}$	900^{+470}_{-299}	36.5/38
3b	$0.85^{+0.55}_{-0.27}$ keV	$2.06^{+0.23}_{-0.23}$	$6.45^{+0.23}_{-0.17}$	$0.23^{+0.27}_{-0.23}$	757^{+423}_{-252}	37.3/38
4	$1.92^{+0.28}_{-0.27}$	$\Gamma_{\rm hard} \equiv \Gamma_{\rm soft}$	$6.48^{+0.21}_{-0.17}$	$0.31^{+0.26}_{-0.19}$	1070^{+740}_{-448}	39.5/39
5	$2.91^{+0.60}_{-0.67}$	$1.97^{+0.27}_{-0.16}$	$6.33^{+0.14}_{-0.16}$ $6.90^{+0.60}_{-0.70}$	$0_{\rm (fixed)}$ $0_{\rm (fixed)}$	524^{+224}_{-194} 260^{+111}_{-97}	35.9/37
6	$2.88^{+0.56}_{-0.58}$	$1.93^{+0.22}_{-0.21}$	$6.40_{\rm (fixed)}$ $7.06_{\rm (fixed)}$	$0_{\rm (fixed)}$ $0_{\rm (fixed)}$	831^{+263}_{-232} 103^{+74}_{-38}	36.4/39

no direct component) was chosen. The best fit gives in this case (model #3a) an intrinsic photon index $\Gamma \simeq 1.9 \pm 0.2$ consistent with the average values of Seyfert 1 galaxies (Nandra and Pounds 1994). The $2-10$ keV observed flux is 5×10^{-13} erg cm^{-2} s^{-1} corresponding to an observed luminosity of 2×10^{42} erg s^{-1}. The observed $\sim$ 6.4 keV emission feature can also be fitted with a more complex model. An acceptable fit (model #5) is in fact obtained by adding to the Fe neutral line a second emission feature. The best-fit energy centroid of this second line (6.90 keV) is consistent both with H-like Fe (6.97 keV) or with a blend of He- (6.70 keV) plus H-like Fe. This indicates that, certainly, reflection from thick cold matter plays an important role. Nonetheless, contribution from reflection caused by ionized matter cannot be ruled out on the basis of the present data. Finally, an acceptable fit (model #6) is also obtained assuming both K_α and K_β emission to be present in the form of narrow lines. The best-fit equivalent widths are consistent with the K_β/K_α ratio expected for neutral iron (0.135 [Weast 1987]).

4. Discussion

The 2-10 keV flat spectrum together with the high equivalent width of the Fe line strongly suggest that the observed spectrum of the Seyfert 2 galaxy NGC 7674 is reflection dominated. The observed luminosity, $L_{\rm Obs}^{2-10\ \rm keV} = 2 \times 10^{42}$ erg s^{-1} is, therefore, expected to be much lower than the intrinsic one. Assuming a scattering model (model #4), the best fit luminosity of the soft component extrapolated in the 2–10 keV band is $L_{\rm Scatt}^{2-10\ \rm keV} \simeq 4 \times 10^{41}$ erg s^{-1}. If the material that electron-scatters the nuclear radiation is confined in a cone-shaped region above the torus, then $L_{\rm Scatt}$ is linked to the nuclear intrinsic luminosity $L_{\rm Int}$ by the relation $L_{\rm Scatt} = L_{\rm Int}\tau(\Omega/2\pi)$, where τ and Ω are the mirror optical depth and subtended solid angle respectively. Assuming NGC 1068 values of $\simeq 10^{-3}$ and 0.25 for τ and $\Omega/2\pi$ respectively (Iwasawa, Fabian, and Matt 1997), then $L_{\rm Int}$ is estimated to be $\sim 10^{45}$ erg s^{-1}. It is interesting to note that this value is very close to the intrinsic [OIII] luminosity of $\sim 6 \times 10^{44}$ erg s^{-1} evaluated from the observed flux corrected for the reddening in the narrow line region (Maiolino, private communication). The fact that also the far infrared integrated $8-120\,\mu$m luminosity $L_{FIR} = 1.6\times10^{45}$ erg s^{-1} (Spinoglio and Malkan 1989) is of the same order of magnitude suggests that both $L_{[OIII]}$ and and L_{FIR} can be good indicators of the intrinsic X-ray luminosity.

If the reflection is caused by cold materials at the inner surface of the torus (Ghisellini, Haardt, and Matt 1994; Krolik, Madau, and Zycki 1994), then only a fraction f_R of the reflecting surface is visible. This fraction can be estimated from the intrinsic luminosity. Using the notation of Iwasawa, Fabian, and Matt (1997), the observed luminosity can be written as $L_{Scatt} = f_R \eta L_{Int}$ where η is the albedo for a isotropic illumination. Using the above values for L_{Scatt} and L_{Int} and assuming $\eta = 0.022$, f_R becomes equal to $\sim$0.1, which is consistent within a factor of 2 of what found for NGC 1068.

Pure reflection spectra have been observed in X-rays by the ASCA satellite in at least few other Seyfert 2 galaxies such as NGC 6552 (Fukazawa et al. 1994; Reynolds et al. 1994), NGC 6240 (Kii et al. 1997), the Circinus galaxy (Matt et al. 1996), and NGC 1068 which has also been confirmed by BeppoSAX (Matt et al. 1997, and references therein). In NGC 7674, even if some contribution from a warm reflection component cannot in principle be excluded, as demonstrated by the acceptable fit obtained with a blend of ionized lines (model #5), the observed X-ray emission is certainly dominated by reflection from cold matter. In fact, on statistical basis (better χ^2_ν, see Table 1) and self-consistency arguments, the most convincing explanation for the possible higher energy line is K_β emission from neutral iron (model #6). This is contrary to what observed in NGC 1068 and NGC 6240 where the ionized reflection component is much stronger, but similar to what observed in the Circinus galaxy and NGC 6552. Such differences may have different physical interpretations. They could be ascribed to an orientation effect (more face-on than NGC 1068 and NGC 6240) with respect to the line of sight of the torus, or to the condition (e.g. low scattering efficiency) of the warm mirror itself. In conclusion, the case of NGC 7674 adds to the increasing number of Compton-thick Seyfert 2 galaxies, thus suggesting that a dedicated study of a complete sample of optically selected Seyfert 2 galaxies may allow the discovery of a significant number of Compton-thick objects as indicated by recent BeppoSAX results (Salvati et al. 1997; Maiolino et al. 1997).

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