THE NATURE OF THE LUMINOUS X-RAY EMISSION OF NGC 6240

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1. Abstract
We briefly review and extend our discussion of the ROSAT detection of the extraordinarily luminous (>10^{42} erg/s) partly extended (>30 kpc diameter) X-ray emission from the ultraluminous infrared galaxy NGC 6240. The ‘standard’-model of starburst outflow is contrasted with alternatives and a comparison with the X-ray properties of ellipticals is performed.

2. Introduction
The double-nucleus galaxy NGC 6240 is outstanding in several respects: its infrared H$_2$ 2.121µm and [FeII] 1.644µm line luminosities and the ratio of H$_2$ to bolometric luminosities are the largest currently known (van der Werf et al. 1993). Its huge far-infrared luminosity of ≈ 10^{12}L$_\odot$ (Wright et al. 1984) comprises nearly all of its bolometric luminosity. Hence, owing to its low redshift of z=0.024, NGC 6240 is one of the nearest members of the class of ultraluminous infrared galaxies (hereafter ULIRGs). Its optical morphology (e.g., Zwicky et al. 1961, Fried & Schulz 1983) and its large stellar velocity dispersion of 360 km/s (among the highest values ever found in the center of a galaxy: e.g., Doyon et al. 1994) suggest that it is a

1We continue to refer to NGC 6240 as ULIRG but note that, owing to the method to integrate over the IRAS bands and the adopted value of $H_\alpha$, most authors now attribute an IR luminosity $< 10^{12}$ $L_\odot$ to NGC6240 rendering it a LIRG instead of a ULIRG.
merging system on its way to become an elliptical. Like other ULIRGs, the object contains a compact, luminous CO(1-0) emitting core of molecular gas (Solomon et al. 1997). Within this core most of the ultimate power source of the FIR radiation appears to be hidden.

There is now growing evidence that LIRGs are predominantly powered by star-formation and that the AGN contribution increases with FIR luminosity (e.g., Shier et al. 1996, Lutz et al. 1998a, Rigopolou et al. 1998; see Sanders & Mirabel 1996 and Genzel et al. 1998 for recent reviews) while essentially all of the HyLIRGs contain QSOs (e.g., Hines et al. 1995 and these proceedings). In the ‘transition region’ around \( L_{\text{FIR}} \approx 10^{12} L_\odot \) it then requires a careful object-by-object analysis to find out the major power source. Concerning NGC 6240, at least four scenarios have been suggested: Heating of dust by a superluminous starburst, by an AGN, by an old stellar population, and by UV radiation from molecular cloud collisions. In particular, previous hints for an AGN included (i) the strength of NIR recombination lines (de Poy et al. 1986, depending on the applied reddening correction, though), (ii) the presence of compact bright radio cores (Carral et al. 1990 but see Colbert et al. 1994), (iii) the discovery of a high-excitation core in the southern nucleus with HST (Barbieri et al. 1994, 1995, Rafanelli et al. 1997), and the detection of the \([\text{OIV}] 25.9\mu m\) emission line with ISO (Lutz et al. 1996 – but see Lutz et al. 1998b who discovered this line in a number of starburst galaxies; Egami, this meeting).

X-rays are a powerful tool to investigate both, the presence of an AGN and starburst-superwind activity. It is the aim of the present contribution to review briefly and discuss our findings of evidence for a hard X-ray component in the ROSAT PSPC spectrum of NGC 6240 (Schulz et al. 1998, SKBB hereafter) and the detection of luminous extended emission based on ROSAT HRI data (Komossa et al. 1998) in combination with the discovery of an FeK line and hard X-ray component by ASCA (first reported by Mitsuda 1995).

Luminosities given below were calculated using \( H_0 = 50 \text{ km/s/Mpc} \).

3. Scenarios to explain the luminous X-ray emission of NGC 6240

3.1. SPECTRAL PROPERTIES AND ORIGIN OF THE HARD COMPONENT

In our analysis of ROSAT PSPC data of NGC 6240 we tested a large variety of models to explain the X-ray spectrum (SKBB). One-component fits turned out to be unlikely. E.g., a single Raymond-Smith model requires a huge absorbing column along the line-of-sight, the consequence being an intrinsic (absorption corrected) luminosity of \( L_{X,0.1-2.4} \approx 4 \times 10^{43} \text{ erg/s} \), almost impossible to reach in any starburst-superwind scenario. The one
model that does not require excess absorption is a single black body. Although physically implausible, this description does allow to derive a lower limit on the intrinsically emitted X-ray luminosity which any model has to explain: \( L_X \gtrsim 2.5 \times 10^{42} \text{ erg/s} \) in the (0.1-2.4) keV band (Fricke & Papaderos 1996 obtained \( 3.8 \times 10^{42} \) erg/s by fitting a thermal bremsstrahlung model and allowing for some excess absorption). Successful two-component models require the presence of a hard X-ray component, in form of either very hot thermal emission (\( kT \simeq 7 \text{ keV} \)) or a powerlaw.\(^2\)

Due to its large luminosity of several \( 10^{42} \) erg/s we interpret the hard component to arise from an AGN. Both, the essential lack of non-X-ray evidence for an unobscured AGN, and the high equivalent width of the FeK

\(^2\)The requirement of a second component in the ROSAT band can be omitted if strongly depleted metal abundances are allowed for. This has been reported for other objects as well and the low inferred X-ray abundances are quite puzzling given that other methods yield much higher abundances (as also stressed by Netzer at this meeting). A recent discussion of this issue is given in Komossa & Schulz (1998) and Buote & Fabian (1998) who give arguments in favour of two-component X-ray spectral models of \(~\text{solar}\) abundances in the Raymond-Smith component instead of single-component models of very subsolar abundances. In particular, Buote & Fabian conclude that the necessity of a second X-ray component cannot be circumvented by details of the modelling of the FeL emission.
Figure 2. Position of NGC 6240 in the $L_x$–$L_{\text{blue}}$ diagram, compared with two samples of elliptical galaxies (solid line: Canizares et al. 1987, dashed: Brown & Bregman 1998); the X-ray brightest ellipticals are those in the group/cluster environment. The open circle gives the minimum observed (0.1-2.4 keV) X-ray luminosity of NGC 6240, the filled circle the one for the favoured two-component model (Sect. 3.1; see SKBB, last row of their Tab. 2.) The open triangle corresponds to Arp 220 with $L_x$ from Heckman et al. (1996).

Line observed by ASCA (e.g., Mitsuda et al. 1995) suggest we see the AGN mainly in scattered light. Indeed, the X-ray spectrum can be successfully described by a ‘warm scatterer’ (cf. Fig. 4 of Komossa et al. 1998), highly ionized material seen in reflection which could also explain the strong FeK line seen by ASCA. Our model, which was suggested to explain the hard component, is quite similar to the one suggested by Netzer et al. (1998) who, however, explained the whole ASCA spectrum in terms of scattering. In this respect, we emphasize that the widely extended X-ray component detected with the ROSAT HRI (Komossa et al. 1998; cf. next Sect.) is likely of different origin, given the low efficiency of a hugely extended scattering mirror (SKBB).

With an X-ray luminosity in scattered emission of a few $10^{42}$ erg/s one obtains an intrinsic luminosity of order $10^{44-45}$ erg/s, depending on the covering factor of the scatterer. Various fits of ASCA spectra (e.g., Mitsuda 1995, Kii et al. 1997, Iwasawa 1998, Netzer et al. 1998, Nakagawa, these proceedings) revealing the extension of the hard component up to 10 keV support this conclusion; the various approaches differ in the description of the soft component(s) and the amount of absorption of the hard component, though. In any case, the AGN contributes an appreciable fraction of the total $L_{\text{bol}}$(NGC 6240) = $4 \times 10^{45}$ erg/s. If $L_{\text{bol}}$(AGN) $\simeq L_{\text{Edd}}$ a black hole mass of $M_{\text{bh}} \approx 10^7 M_\odot$ results. NGC 6240 is expected to form an $L_*$ elliptical galaxy rather than a giant elliptical after having completed its merging epoch (Shier & Fischer 1997). However, to match the relation $M_{\text{bh}} \approx 0.002 M_{\text{gal}}$ (Lauer et al. 1997) for the evolved elliptical the black hole has still to grow by an order of magnitude which would require another
$10^9$ yrs of accretion while the merger is settling down. Alternatively, the present accretion rate could be below the Eddington rate.

The inferred X-ray luminosity is an appreciable fraction of the FIR luminosity, suggesting that both, the starburst (e.g., Lutz et al. 1996) and the AGN power the FIR emission of this ULIRG.

### 3.2. EXTENDED EMISSION

The HRI images (Komossa et al. 1998) reveal that part of the huge X-ray luminosity arises in a roughly spherical source with strong ($\geq 2\sigma$ above background) emission out to a radius of $20''$ ($\sim 14$ kpc; Fig. 1). Hence, NGC 6240 is the host of one of the most luminous extended X-ray sources in isolated galaxies (see Fig. 2 where $L_X$ is compared with a sample of elliptical galaxies and Arp 220). Analytical estimates based on the Mac Low & McCray (1988) models show that the extended emission can be explained by superwind-shell interaction from the central starburst (SKBB). A puzzle is the high circular symmetry of the X-ray bubble, in contrast to the bicone-symmetry expected in a wind-driven supershell scenario so that it seems worthwhile to look for further potential contributors to the X-ray emission.

An additional small contribution may come from a wind induced by the large velocity dispersion of 350 km/s (Lester & Gaffney 1994) leading to shocks in the gas expelled by the red giant population. Another interesting point is that the extended X-ray bubbles around elliptical galaxies are usually brighter in the inflow phases or ‘when caught in the verge of experiencing their central cooling catastrophe’ (Ciotti et al. 1991, Frick & Terlevich 1998). Although time scales and details for an ongoing merger are certainly different, it is conceivable that NGC 6240 experiences a lack of heating when a major starburst period has ended. In this case, a cooling flow would commence boosting $L_X$ and presumably shock heating the ISM in the central kiloparsecs. Due to fragmentation, shock velocities could be enhanced causing the LINER like line ratios in the two nuclei (gravitational centers) and, with lower velocities, excite the molecular cloud complex between the nuclei leading to the extreme $H_2$ luminosity found there (van der Werf et al. 1993).

Its exceptional X-ray properties make NGC 6240 a prime target for future X-ray satellites like XMM and AXAF.

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