The ULIRG NGC 6240: Luminous extended X-ray emission and evidence for an AGN

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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 double-nucleus ultraluminous infrared galaxy (ULIRG) NGC 6240. The *ROSAT* spectrum can be well fit by emission from two components in roughly equal proportions: a thermal optically thin plasma with $kT \sim$0.6 keV and a hard component that can be represented by a canonical AGN powerlaw. Source counts appear to have dropped by 30% within a year. Altogether, these findings can be well explained by a contribution of radiation from an AGN essentially hidden at other wavelengths. Fits of *ASCA* spectra, conducted by various groups, corroborate this result, revealing a high-equivalent width FeKα blend which again is straightforwardly interpreted by scattered AGN light.

If radiating at the Eddington limit, the central black hole mass does not exceed $\sim 10^7 M_\odot$. We discuss implications for the formation of this AGN. However, the luminosity in the remaining extended thermal component is still at the limits of a pure starburst-wind-induced source. We suggest that the deeply buried starburst has switched to a partially dormant phase so that heating of the outflow is diminished and a cooling flow could have been established. This flow may account for the extended shock heating traced by LINER-like emission line ratios and the extremely luminous H_2 2.121 μm emission from the central region of this galaxy. Next-generation X-ray telescopes will be able to test this proposal.

1. Introduction

Among known galaxies, the peculiar 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 $\sim 10^{12} L_\odot$ (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., Fosbury & Wall 1979, 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: Lester & Gaffney 1994) suggest that it is a merging system of disk galaxies near to forming an elliptical galaxy. Like other ULIRGs, the object contains a compact ($\sim 10^2$ pc), luminous CO(1-0) emitting core of molecular gas with a mass of $10^{10} M_\odot$ (Solomon et al. 1997). Within this core most of the ultimate enigmatic power source of the FIR radiation appears to be hidden.

The most popular scenario to explain the huge IR power is based on a superluminous starburst (Joseph & Wright 1985, Rieke et al. 1985, Heckman et al. 1990). Although starburst tracers are lacking in the optical (Keel 1990, Schmitt et al. 1996) this picture has recently been supported by ISO-SWS spectra (Lutz et al. 1996). However, our optical evidence for the presence of an AGN (Barbieri et al. 1994, 1995) supplemented by X-ray evidence (Mitsuda 1995) suggested that a starburst only generates part of the power. Subsequently, in the *ROSAT* band we found it difficult to attribute the observed $L_{0.1-2.4\rm keV} = 10^{42-43}$ erg/s to starburst-induced soft X-ray generation via superwind-supershell interaction (Schulz et al. 1998). A buried AGN helps to supply part of the X-ray luminosity and may also contribute to the FIR emission via dust heating. However, even then an appreciable remaining thermal X-ray luminosity has to be generated. It is the purpose of the present contribution to review and extend our earlier discussions (Schulz et al. 1998, Komossa et al. 1998) on these issues.

Observed luminosities given here were derived via plain application of the Hubble law with $H_0 = 50$ km s^{-1} Mpc^{-1} yielding a distance of 144 Mpc for NGC 6240.

2. Observations

The data on which our results are based were taken with the PSPC and HRI on board of the X-ray satellite *ROSAT* (Trümper 1983). NGC 6240 was observed twice with the PSPC summing up to a total exposure time of about 8

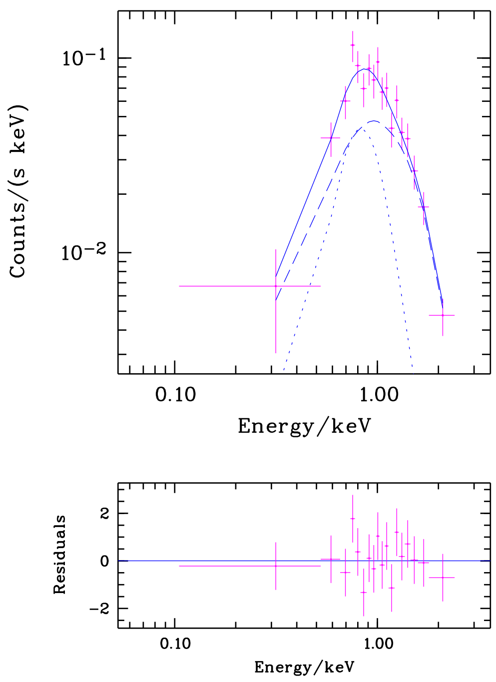

Fig. 1. Two-component fit to the *ROSAT* PSPC spectrum of NGC 6240 consisting of a powerlaw (dashed line) and a Raymond-Smith model (dotted line). The lower panel displays the fit residuals.

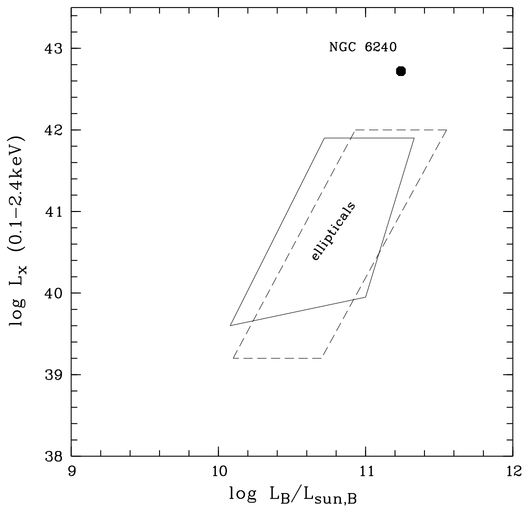

Fig. 3. Locus of NGC 6240 in the $L_{\mathrm{x}} - L_{\mathrm{blue}}$ diagram, compared with two samples of elliptical galaxies (solid line, Canizares et al. 1989; dashed, Brown & Bregman 1998); the X-ray brightest ellipticals are those in the group/cluster environment. Plotted is the total X-ray luminosity of NGC 6240 (cf. Schulz et al. 1998, last row of their Tab. 2.)

ksec and thrice with the HRI yielding a total time of 50 ksec. The data were retrieved from the archive.

Data reduction procedures were carried out in a standard manner (details are given in Komossa et al. 1998 and Schulz et al. 1998).

3. Results and discussion

3.1. Spectral fits

Fitting the *ROSAT* PSPC observations of NGC 6240 we found that, in addition to a soft thermal component ($kT \sim 0.6$ keV), two-component fits of the (0.1–2.4) keV PSPC spectrum require a second *hard* component (Fig. 1) that can be represented either by *very hot thermal* emission ($\simeq 7$ keV) or a *powerlaw* with the canonical photon index -1.9 or slightly flatter.[1]

These models yield a total luminosity of *several* 10^{42} erg/s in the *ROSAT* band (corroborating an earlier value given in Fricke & Papaderos 1996; see also these proceedings). To get an idea of the lower limit for the luminosity we checked a large variety (even physically untenable models) of one- and two-component spectral models (utilizing Raymond-Smith, black-body, bremsstrahlung, warm absorber/reflector and power-law models with fixed or free cold X-ray absorption). Taking into account the uncertainty in the distance of NGC 6240, the most likely lower limit on the (0.1-2.4 keV) luminosity turns out to be $2\,10^{42}$ erg/s, with a conservative lower bound of 10^{42} erg/s. The HRI *images* reveal that part of this huge radiative power arises in a roughly spherical source with strong ($\geq 2\sigma$ above background) emission out to a radius of $20''$(~ 14 kpc) (Fig. 2). Hence, NGC 6240 is the host of one of the *most luminous extended* X-ray sources in isolated galaxies (Fig. 3).

The resolution of the HRI limits the contribution of a centrally concentrated ($< 4''$ in radius) X-ray source to 30% or ~ 50% in flux for the spectral types involved here.

3.2. Interpretation of the hard component

The hard component in the *ROSAT* band is of particular importance because it has been related to scattered AGN radiation in Komossa et al. (1998) and Schulz et al. (1998). Various fits of *ASCA* spectra (e.g., Mitsuda 1995, Kii et al. 1997, Iwasawa 1998, Netzer et al. 1998) revealing the extension of the hard component up to 10 keV support this conclusion; the various fits differ in the description of the soft component(s) and the amount of absorption of the hard component, though. An additional feature is the FeKα blend, with a ~ 2 keV equivalent-width more common for an AGN rather than a starburst.

[1] For a recent discussion of the issue of two-component X-ray spectral models of ∼solar abundances in the Raymond-Smith component versus single-component models of very subsolar abundances see, e.g., Buote & Fabian (1998) and Komossa & Schulz (1998).

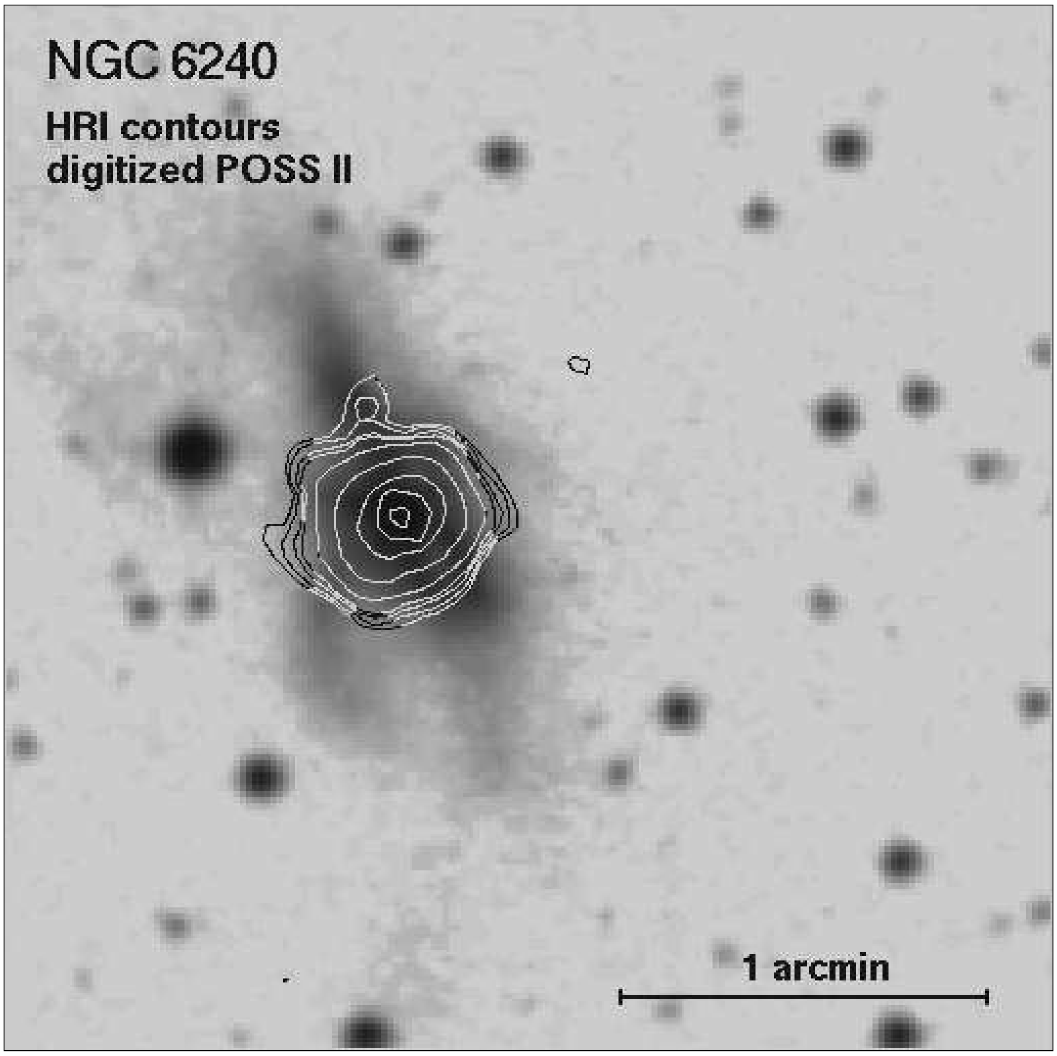

Fig. 2. Overlay of the HRI X-ray contours on an optical image of NGC 6240. The lowest contour is at 2σ above the background.

An AGN induced hard component has to be compact which limits its contribution to the *ROSAT* band to $\leq 2.5\,10^{42}$ erg/s. At higher energies, the hard component emits $L_{2-10\mathrm{keV}} \sim 4\,10^{42}$ erg/s which has to be multiplied by a scattering factor s_{x} to get the *intrinsic* X-ray luminosity $L_{\mathrm{hx-int}}$ of the hidden AGN. The precise efficiency and covering fraction of the mirror are highly uncertain, but plausible models, either a *warm scatterer* – near-nuclear high-column-density ($N \gtrsim 10^{23}$ cm^{-2}) photoionized gas (cf. Fig. 4 and Komossa et al. 1998) – or $\sim 10^2$ pc extended plasma (Schulz et al. 1998) or a comparison with NGC 1068 (Ueno et al. 1994) suggest $s_{\mathrm{x}} \sim 10^2$, leading to $L_{\mathrm{hx-int}} \sim 10^{44}$ erg/s, which implies for a typical AGN continuum $L_{\mathrm{bol}}(\mathrm{AGN}) \sim 10^{45}$ erg/s. Hence, the AGN contributes an appreciable fraction of the total $L_{\mathrm{bol}}(\mathrm{NGC\,6240}) = 4\,10^{45}$ erg/s. With $L_{\mathrm{bol}}(\mathrm{AGN}) \sim L_{\mathrm{Edd}}$ a black hole mass of $M_{\mathrm{bh}} \sim 10^7 M_{\odot}$ 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 $M_{\mathrm{bh}} \approx 0.002\,M_{\mathrm{gal}}$ (Lauer et al. 1997) for the evolved elliptical the black hole has still to grow by an order of magnitude which requires another 10^9 yrs of accretion while the merger is settling down.

3.3. Interpretation of the thermal soft component

The *ROSAT* X-ray luminosity of the extended source of NGC 6240 is outstandingly large (Fig. 3), even after subtracting the hard component. Komossa et al. (1998) and Schulz et al. (1998) found it to be at the limits for simple supernova driven superwind models. 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-

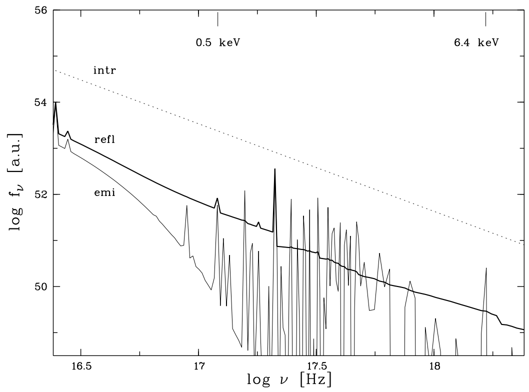

Fig. 4. Spectral components of a 'warm scatterer', calculated with Ferland's (1993) code *Cloudy*. The incident continuum is shown as dotted line. The thin solid line corresponds to the emitted spectrum and the thick solid line to the reflected spectrum. The abscissa brackets the energy range 0.1 – 10 keV.

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; Friaca & 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 $L_{\rm x}$ 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).

Admittedly, so far there is not enough information to tell from a back-of-the-envelope estimate which of the possibly competing processes dominates (merger induced shocks or cooling flow induced shocks) but shape and luminosity of the X-ray source suggest that more than a bipolar starburst outflow is going on.

4. Conclusions

NGC 6240, a merger on its way to become an elliptical galaxy, is found to harbour an exceptionally luminous extended X-ray source. A spectral decomposition of the X-ray flux leads to a hard component most likely interpreted by scattered radiation from an otherwise obscured AGN that significantly contributes to the FIR of the galaxy.

As we proposed earlier, the remaining extended X-ray source might be explained via starburst-driven outflow, but this scenario has been pushed to its limits and only rather detailed models could clarify whether it is sufficient. A comparison with the evolution of the extended X-ray sources around ellipticals suggests alternative possibilities. E.g., we here conjectured that the inner X-ray bubble may have currently switched to an inflow phase which would alleviate the X-luminosity requirements and help to understand the extended central shock excited regions seen in the optical and in the near infrared. Whether this new picture is tenable can be further scrutinized with the next-generation X-ray telescopes.

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