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

Hartmut Schulz¹, Stefanie Komossa² and Jochen Greiner³

¹ Astronomisches Institut der Ruhr-Universität, 44780 Bochum, Germany
² Max–Planck–Institut für extraterrestrische Physik, Giessenbachstraße, 85740 Garching, Germany
³ Astrophysikalisches Institut, 14482 Potsdam, Germany

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 $kT$ ~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 FeK line 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 $L_{0.1-2.4 keV} = 10^{42-43}$ 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.

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 ($\sim 7$ keV) or a powerlaw with the canonical photon index $-1.9$ or slightly flatter.

These models yield a total luminosity of several $10^{42}$ erg/s in the ROSAT band (corroborating an earlier value given in Frick & 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 $2 \times 10^{42}$ 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 $20''$ (7 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 ($\leq 4''$ in radius) X-ray source to 30% or $\sim 50\%$ 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

Fig. 3. Locus of NGC 6240 in the $L_X - L_{\text{blue}}$ 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.)
the FeKα blend, with a $\sim 2$ keV equivalent-width more common for an AGN rather than a starburst.

An AGN induced hard component has to be compact which limits its contribution to the ROSAT band to $\leq 2.5 \times 10^{42}$ erg/s. At higher energies, the hard component emits $L_{2-10\text{keV}} \approx 4 \times 10^{42}$ erg/s which has to be multiplied by a scattering factor $s_x$ to get the intrinsic X-ray luminosity $L_{\text{hx-int}}$ 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 ($N > \sim 10^{23}$ cm$^{-2}$) photoionized gas (cf. Fig. 5 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 $s_x \sim 10^2$, leading to $L_{\text{hx-int}} \sim 10^{44}$ erg/s, which implies for a typical AGN continuum $L_{\text{bol}}(\text{AGN}) \sim 10^{45}$ erg/s. Hence, the AGN contributes an appreciable fraction of the total $L_{\text{bol}}(\text{NGC 6240}) = 4 \times 10^{45}$ erg/s. With $L_{\text{bol}}(\text{AGN}) \sim L_{\text{Edd}}$ a black hole mass of $M_{\text{bh}} \sim 10^7 M_\odot$ 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 $M_{\text{bh}} \approx 0.002 M_{\text{gal}}$ (Lauer et al. 1997) for the evolved elliptical the black hole has still to grow by an order of magnitude which 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. 5), 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
produced 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.

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; 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 the 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 of the evolution of the extended X-ray sources around ellipticals suggests alternative possibilities. E.g., we have 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.

Acknowledgements. St.K. and J.G. acknowledge support from the Verbundforschung under grant No. 50 OR 93065 and 50 QQ 9602 3, respectively.

References

Barbieri C., Rafanelli P., Schulz H., Komossa S., 1994, Astron. Ges. Abstr. Ser. 10, 217
Barbieri C., Rafanelli P., Schulz H., Komossa S., Baruffolo A., 1995, in 17th Texas Symp. on Relativistic Astrophysics and Cosmology, MPE Report 261, W. Voves et al. (eds.)
Brown B.A., Bregman J.N., 1998, ApJ 495, L75
Buote D.A., Fabian A.C., 1998, MNRAS 296, 977
Canizares C.R., Fabbiano G., Trinchieri G., 1987, ApJ 312, 503
Ciotti L., D’Ercole A., Pellegrini S., Renzini A., 1991, ApJ 376, 380
Colbert E.J.M., Wilson A.S., Bland-Hawthorne J., 1994, ApJ 436, 89
Ferland G., 1993, Univ. Kentucky, Phys. Dept., Int. Report
Friaca A.C.S., Terlevich R.J., 1998, MNRAS 298, 399
Fricke K.J., Papaderos P., 1996, in MPE Report 263, 377
Fried J., Schulz H., 1983, A&A 118, 166
Heckman T.M., Armus L., Miley G.K., 1990, ApJS 74, 833
Iwasawa K., 1998, astro-ph/9808343, to appear in MNRAS
Joseph R.D., Wright, G.S., 1985, MNRAS 209, 111
Keel W.C., 1990, AJ 100, 356
Kii T., Nakagawa T., Fujimoto R. et al., 1997, in X-ray Imaging and Spectroscopy of Hot Plasmas, eds. F. Makino and K. Mitsuda, (Universal Academy Press: Tokyo), 161
Komossa S., Schulz H., Greiner J., 1998, A&A 334, 110
Komossa S., Schulz H., 1998, A&A in press
Lauer T.R., Faber S.M., Tremaine S. et al., 1997, ASP Conf. Ser. 116, 113
Lester D.F., Gaffney N.I., 1994, ApJ 431, L13
Lutz D., Genzel R., Sternberg A. et al., 1996, A&A 315, L137
Mac Low M-M., McCray R., 1988, ApJ 324, 776
Mitsuda K., 1995, in press
Mitsuda, (Universal Academy Press: Tokyo), 161
Fiske J., Schulz H., 1983, A&A 118, 166
Lauer T.R., Faber S.M., Tremaine S. et al., 1997, ASP Conf. Ser. 116, 113
Lester D.F., Gaffney N.I., 1994, ApJ 431, L13
Lutz D., Genzel R., Sternberg A. et al., 1996, A&A 315, L137
Mac Low M-M., McCray R., 1988, ApJ 324, 776
Mitsuda K., 1995, in 17th Texas Symp. on Relativistic Astrophysics and Cosmology, eds. H. Bühringer, G.E. Morfill, J.E. Trümper, Ann.N.Y.Acad.Sc. 759, 213
Netzer H., Turner T.J., George I.M., astro-ph/9803205, to appear in ApJ
Ricke G.H. et al. 1985, ApJ 290, 116
Schmitt H.R., Bica E., Pastoriza M.G., 1996, MNRAS 278, 965
Schulz H., Komossa S., Berghöfer T., Boer B., 1997, A&A 330, 823

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.
Shier L.M., Fisher J., 1997, ASP Conf. Ser. 116, 502
Solomon P.M., Downes D., Radford S.J.E., Barrett J.W., 1997, ApJ 478, 144
Trümper J., 1983, Adv. Space Res. 2, 241
Ueno S., Mushotzky R.F., Koyama K. et al., 1994, PASJ 46, L71
van der Werf P.P., Genzel R., Krabbe A., et al., 1993, ApJ, 405, 522
Wright G.S. et al., 1984, Nat 309, 430