XMM Observations of an IXO in NGC 2276

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ABSTRACT

We present the results from a ~53 ksec XMM observation of NGC 2276. This galaxy has an unusual optical morphology with the disk of this spiral appearing to be truncated along the western edge. This XMM observation shows that the X-ray source at the western edge is a bright Intermediate X-ray Object (IXO). Its spectrum is well fit by a multi-color disk blackbody model used to fit optically thick standard accretion disks around black holes. The luminosity derived for this IXO is 1.1×10^{41} erg s^{-1} in the 0.5 - 10 keV band making it one of the most luminous discovered to date. The large source luminosity implies a large mass black hole if the source is radiating at the Eddington rate. On the other hand, the inner disk temperature determined here is too high for such a massive object given the standard accretion disk model. In addition to the IXO we find that the nuclear source in this galaxy has dimmed by at least a factor of several thousand in the eight years since the *ROSAT* HRI observations.

Subject headings: Galaxies: spiral, x-ray – X-rays: galaxies

1. Introduction

A new class of X-ray emitting objects has recently been revealed in nearby galaxies which are more luminous than normal X-ray binaries or supernova remnants but do not attain the luminosities of conventional AGN. These objects (intermediate luminosity objects: IXOs, Ptak 2002; ultraluminous X-ray sources: ULXs, Makishima et al. 2000) are generally found

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off-center of their host galaxy where supermassive objects are not thought to reside. The variability seen in these objects indicate that they cannot be a collection of more normal sources such as X-ray binaries or supernova remnants and therefore must be a compact object.

The X-ray properties of IXOs distinguish them from the more common point-like X-ray sources in spiral galaxies. They have luminosities above that of most discrete compact sources in nearby galaxies. They do not lie at the dynamic center (Long 1982; Fabbiano 1989; Marston et al. 1995, Colbert & Mushotzky 1999; Makishima et al. 2000) and have luminosities well in excess of that from an accreting Neutron star. These sources have luminosities in the range of 10^{39} – 10^{41} erg s^{-1} (0.5 – 10 keV), intermediate between X-ray binaries accreting at the Eddington luminosity and most nuclear sources.

While the basic emission mechanism is thought to be accretion, there is an open question of whether these sources emit isotropically or if the emission is beamed. If the emission is isotropic then the relation between the X-ray luminosity and mass for a black hole accreting at the Eddington rate is

$$L_{\rm B} = 1.5 \times 10^{38} M/M_{\odot}\,{\rm erg\,s^{-1}}$$

when the opacity is dominated by electron scattering in gas with solar abundances. Interpreting this simply would imply that for the most luminous IXOs the mass of the black hole must exceed 100 $M_{\odot}$. The implication for very large mass black holes can be avoided if the emission from the source is beamed in our direction (King et al. 2001). In this case the mass of the central object can be reduced so that normal accreting black holes or X-ray binaries can be the source of the radiation. However, producing beamed emission from these types of objects is still being investigated. For instance thick accretion disks with a central funnel may radiate in excess of the Eddington luminosity but a major theoretical question remains: is beaming a natural consequence of high accretion rates in these objects?

Here we present evidence for one of the more luminous IXOs known. This object is located in the peculiar spiral galaxy NGC 2276 which is undergoing intense star formation along the western edge of the galaxy (Davis et al. 1997). This activity is thought to have been triggered by a gravitational interaction with the elliptical galaxy NGC 2300 (Gruendl et al. 1993; Davis et al. 1997). This object has the properties of a "classical" IXO: it is located out in the spiral arms of the galaxy away from the nucleus, has a super Eddington luminosity, and exhibits long term time variability. Below we discuss the XMM observation, the imaging and spectral analysis of the source. Then we review the archival data for the source from the Einstein, *ROSAT*, and *ASCA* missions, and discuss the time variability of the object.

2. Observations

NGC 2276 was observed for ~53 ksec with XMM. The pointing center for this observation was the center of the NGC 2300 group which is approximately 7′ to the east of the elliptical NGC 2300. We analyze only the MOS1 and MOS2 data here since the source fell in a CCD gap on the PN camera. Flares can be a significant problem with XMM data so we searched for flares in the light curve for the full field and found only minor flares near the end of the observation. So for this analysis we use the entire dataset.

The data were reduced and extracted using SAS 5.2, and the spectra are analyzed using XSPEC 11.0.1. The latest calibration products were used to determine the response files for the spectral analysis. The extracted spectra are binned so that each channel has a minimum of 25 counts and the energy range is restricted to between 0.5 and 6.0 keV.

3. X-ray Image

The XMM observation clearly resolves the emission from NGC 2276 into several components; the bright source to the west of the nucleus (the IXO), two other point sources and a more diffuse component from the galactic disk of NGC 2276. Conspicuously absent is the nuclear source seen in the *ROSAT* HRI data (Davis et al. 1997). We have checked the astrometry of the XMM field using the position of the nucleus of NGC 2300. We use the NED position of NGC 2300 as the reference and find that we need to shift the XMM MOS data to the north by 1.″5. The XMM data in the 0.5 – 10 keV band are shown as smoothed contours overlaying the DSS image (Fig 1) and HST WFPC2 image of NGC 2276 (Fig 2). The brightest source, the IXO, lies in the western side of the galaxy near the truncated edge. In this observation we find no evidence for a point source near the nucleus. For the combined dataset our upper limit for the nucleus is $\sim 7.3\times10^{-14}$ erg cm^{-2} s^{-1} or $\sim 2.4\times10^{39}$ erg s^{-1} in the .5-10 keV band. This relatively large upper limit is due to the intense diffuse emission from In the center of the galaxy. We assume the distance to the group is 45.7 Mpc.

The source at $7^h\ 26^m\ 49.^s2$ $+85°\ 45'\ 55.''2$, (the IXO) which we call the western source following Davis et al. (1997), may be slightly elongated to the southwest. However, this elongation may be due to emission from the stellar complex seen in the HST image but is much weaker than the primary source. Figure 1 shows a wider field of view which includes the sources XMMUJ 072718.8+854636 and XMMUJ 072816.7+854436.

4. Spectral Fits

The spectrum of the IXO source has a total of 2344 source counts and we fit the spectrum using an absorbed power law with the power law index, normalization and foreground absorption as free parameters. This fit results in an unacceptably high value of χ^2 which is due primarily to excess soft emission. Examination of figure 2 reveals that there is diffuse emission associated with the disk of NGC 2276. Instead of attempting to remove this spatially complex component by modifying the background spectra we instead model the disk emission as thermal emission from a plasma and fit that component with the MekaL model in XSPEC, letting the temperature and intensity be free parameters and fixing the abundance at the solar value. One consequence of this additional spectral complexity is that we have to fix the total line-of-sight column density to the Galactic value for the Milkyway (5.32×10^{20} atom cm^{-2}; Dickey & Lockman 1990) to obtain a stable fit for the temperature of the thermal component. Given the position of the X-ray source in NGC 2276, in the outer disk and in the star forming regions of this morphologically peculiar galaxy, we also explore models of emission from accreting black holes. Following Colbert & Mushotzky (1999) we fit the data with an absorbed power law and multi-color disk models (diskbb in XSPEC). The power law model with the addition of the soft thermal component is a substantial improvement over the simple absorbed power law. The multi-color disk model with the addition of the soft thermal component is a better fit to the spectrum than a power law with reduced χ^2=1.05 (Figure 3) and no systematic residuals. The luminosity of the MCD model for this source is 3.2×10^{40} erg s^{-1} in the 0.5 – 2.0 keV band, which is unusually luminous for black hole sources in nearby galaxies (Colbert & Mushotzky 1999).

We also fit the source XMMUJ 072718.8+854636 with a power law and the multi-color disk model discussed above. With 437 source counts either model fits the data but the derived parameters for the power law model are rather unusual for luminous galactic sources with ($N_h = 2.3\times10^{21}$, Γ=3.5 and $\chi^2_\nu = 1.3$ for 9 d.o.f.) and thus we only discuss the MCD model here. The best fit MCD model has a reduced χ^2 of 0.8. The luminosity of the MCD model for this source is 4.2×10^{39} erg s^{-1} in the 0.5 – 10.0 keV band (3.8×10^{39} erg s^{-1} in the 0.5 – 2.0 keV band). For the source XMMUJ 072816.7+854436, with 424 source counts, we only fit a power law, which is often used to characterize the spectra of weak sources and using the best fit we find that the luminosity in the 0.5 – 10 keV band is 1.1×10^{39} erg s^{-1} and 9.4×10^{38} erg s^{-1} in the 0.5 – 2.0 keV band assuming that both sources are at the distance of NGC 2276. Table 1 summarizes the fitting results.

5. Source Variability

We have extracted the light curve for the western source from the XMM MOS2 data. We selected these data because the MOS2 is the only detector for which all of the emission from this source lies entirely on the chip. With this restriction we do not have to allow for possible rate variations due to different amounts of flux falling in the CCD gaps during the long pointing. We extract the count rate data for the western source and show the data grouped in 4600 second bins (figure 4). To search for periodicity in the lightcurve we examined the power spectrum of the lightcurve with frequency binning from 1 Hz to 3.3×10^{-4}Hz. Besides detecting the CCD readout time of 2.6 seconds (Ehle et al. 2001) no other significant period was detected.

To investigate the long term behavior of this object we have searched the HEASARC database for archival observations and table 2 lists the observations we use to investigate the long term trends for this object. The Einstein IPC observed the NGC 2300 group for only 1940 seconds and this exposure time was insufficient to detect the spiral galaxy. We determine an upper limit of 2.0 $\times10^{40}$ erg s^{-1} in the 0.5 – 2.0 keV band during that time.

The *ROSAT* PSPC data, with its poorer resolution than the *ROSAT* HRI or the XMM data, potentially suffers from confusion with other sources in the galaxy. However, the location of the peak of the emission is distinct from the nucleus and consistent with the XMM and HRI position of the IXO. During the *ROSAT* PSPC observations the luminosity of this source in the 0.5 – 2.0 keV band was 2.5×10^{40} erg s^{-1} in the initial observation in 1992 and 2.2×10^{40} erg s^{-1} in the first of the two observations in August 1993, an interval of 1.3 years. This is consistent with no change between April 25 1992 and Aug 22 1993. The count rate in the PSPC data for the second 1993 observation shows that the source luminosity increased by a factor of roughly 2 between observations separated by only $\sim$3.25 hours to 4.4×10^{40} erg s^{-1}. These luminosities are determined using the best fit XMM MCD model fit to the PSPC spectra with only the normalizations allowed to vary. The hard and soft band data show that the hardness ratio did not change appreciably between these observations.

The *ROSAT* HRI data originally analyzed by Davis et al. (1997) were a combination of two HRI observations separated by about six months. In the first observation the luminosity of the IXO is 3.7×10^{40} erg s^{-1}. By the second observation it had decreased in luminosity to 2.4×10^{40} erg s^{-1} in the 0.5 – 2.0 keV band. Even given the assumptions that are needed to convert the HRI count rate to flux, e.g. similar disk temperature at that epoch, this is clear evidence that the source had dimmed significantly since the 1993 PSPC observations.

We have also examined the *ASCA* GIS data for signs of variability from NGC 2276 and find variability of about a factor of 4 between the different observations. Unfortunately, with the GIS spatial resolution ($\approx 0.9'$ at 2 keV with large wings) we cannot isolate the western source so the luminosities are totals for the galaxy. As we point out below the nuclear region in the galaxy is also variable, so that the variability during this time may be the IXO, the nucleus, or some combination of the two. The best fit MCD model to the XMM data yields a luminosity of 3.2×10^{40} erg s^{-1} in the same band for the GIS data.

The archival data clearly show that this source is variable and that while the flux may remain fairly constant for long periods of time this IXO can change luminosity by a factor of 2 in a short time and factors of 2 or 3 over a year or more. Figure 5 summarizes the source variability. In addition to the western source the nuclear source has also varied. The *ROSAT* HRI data show that the nuclear region had an X-ray luminosity of $\sim2.0\times10^{40}$ erg s^{-1} in the 0.5 - 2.0 keV band for both observations. The XMM upper limit of the flux from the nuclear region is $<1.4\times10^{39}$ erg s^{-1} in the same band.

6. Discussion

The X-ray luminosity, variability, spectral fits, and position of the source in the galaxy indicate that this is another example of an IXO. Interpreting this source as a young X-ray bright supernova remnant or a remnant evolving in a dense medium (Franco et al. 1993) is problematic. The HST image (figure 2) does not show that the source is clearly associated with a diffuse source. The luminosity of this source is 1.1×10^{41} erg s^{-1} extrapolated to the 0.5 – 10 keV band (3.2×10^{40} erg s^{-1} in the 0.5 - 2.0 keV band) which is consistent with the luminosity of the source in March 1994 in the *ROSAT* HRI data (3.7×10^{40} erg s^{-1} in the 0.5 - 2.0 keV band). Yet the X-ray luminosity of supernova remnants are expected to evolve strongly over such a timescale (Chevalier 1982). The PSPC and *ASCA* data indicate that the luminosity of the source is not simply declining but shows variability on time scales of both hours and years consistent with this being a compact source rather than a SNR.

The unabsorbed luminosity of this source (1.1×10^{41} erg s^{-1} in the 0.5 – 10 keV band) makes this one of the most luminous IXOs known to date. Typical luminosities for these sources are 10^{39} – 10^{40} erg s^{-1} in the 0.5 – 10 keV band while the most luminous of these sources seems to be the one in M82 with a maximum luminosity of $\sim10^{41}$ erg s^{-1} (Matsumoto et al. 2001). However these objects are strongly variable with the X-ray luminosity changing by an order of magnitude or more over a timescale of a few years. In fact the source in NGC 2276 has varied by a factor of $\sim$2 between the *ROSAT* HRI observation and the XMM observation. We have also searched for short term variability in the XMM data by constructing a power density spectrum (PDS). We binned the data with a bin width of 300 s, 500 s and 3000 s. Using the powspec tool from the FTOOLS version 5.1 we found no significant structure in the PDS for the source over the timescale of the XMM observation.

6.1. Spectral Results

The spectrum of this source is well fit by a multi-color disk model (Mitsuda et al. 1984). This is typical for such sources (Colbert & Mushotzky 1999; Makishima et al. 2000; Wang 2002) although a power law spectrum seems to be more appropriate in some cases (Strickland et al. 2001). The multi-color disk model (Mitsuda et al. 1984) assumes a standard optically thick accretion disk with the inner disk edge located at the last stable orbit for a Schwarzchild black hole. The spectrum is a superposition of multiple blackbody spectra up to a maximum temperature (T_{in}). This maximum temperature is expected to occur at the inner edge (R_{in}) of the accretion disk. Under these assumptions the temperature at R_{in} can be used to infer the radius of the last stable orbit and thus the mass of the black hole. Using the measured temperature for the MCD model of 2.05 keV and the definition of the XSPEC diskbb model norm $K = ((R_{in}/km)/(D/10kpc))^2 * cos(\theta)$, where D is the distance to the source and θ is the inclination angle of the accretion disk. Solving this for R_{in} and using eq 8 of Makishima et al. (2000) we can estimate the mass of the black hole as $M = 516(K/\alpha^2 cos^2(\theta))^{1/2} M_{\odot}$, where K is the normalization of the XSPEC MCD model, θ is the inclination of the accretion disk, and α is the ratio of the inner disk radius to that of the last stable orbit for a Schwarzchild black hole. Given that the XSPEC normalization is 1.26×10^{-3} and assuming that α=1, a Schwarzchild black hole, then from the spectral data we can estimate that the mass of the black hole is $18.3(\cos(\theta))^{-1/2}$ $M_{\odot}$. Modeling the effects of the strong gravitational field near the black hole shows that for a Schwarzschild singularity the cosine law is approximately valid but for a Kerr black hole $\cos(\theta)$ is restricted to about 0.17 – 0.4 (Zhang et al. 2001). So, for a rapidly rotating Kerr Hole the estimated mass range is (30 – 40 $M_{\odot})\alpha^{-2}$. For a Schwarzschild singularity with a viewing angle of 45° then the mass is a more modest 22 $M_{\odot}$. For either case the observed luminosity of the source exceeds the Eddington luminosity for the masses derived above by factors of 10 to 40 if α=1. The requirement that we match both the temperature of the inner disk and the luminosity of the source requires that $\alpha \lesssim$ 0.26, consistent with a Kerr Black Hole.

Looking at the correlation between T_{in} and L_x (Makishima et al. (2000)) we find that this source lies well above the correlation found for the ASCA sources at the high temperature end. It is an order of magnitude more luminous for its temperature than the ASCA sources and therefore is the most discrepant object yet discovered from the theoretical prediction between luminosity-mass and temperature.

The origin of the unusual luminosity in IXO's is still uncertain. The proposed models fall into two main categories: beamed models and unbeamed models. For the beamed models the prediction is that this is a short-lived evolutionary phase and should be associated with young stellar populations (Taniguchi et al. 2000; King et al. 2001). The position of this IXO in the star forming regions along the truncated edge of NGC 2276 is consistent with that interpretation.

6.2. Emission Models

One of the possible explanations for the incredible luminosity of the IXOs is that the radiation is geometrically beamed. Essentially this means that the true solid angle of the radiation is less than 4π sr. One method of achieving this is to have a thick disk partially block the radiation and redirect a fraction of the initially isotropic emission into a smaller solid angle. In this scenario some of the x-ray radiation is absorbed by the thick disk and re-radiated in other wavelength bands and some is scattered into our line of sight. We stress that no physically reasonable scattering region will be a perfect mirror and thus a substantial fraction of the intrinsic luminosity will be absorbed and re-radiated. The most likely spectral regions to observe this re-radiated energy would be either the optical or infrared band. Thus in nave geometrical beaming models one expects a luminous optical-IR counterpart to the IXO.

We estimate the amount geometrical beaming using the thick accretion disk model of Madau (1988). While this model is not unique it does allow one to calculate the expected luminosity in other wavelength bands and is the only one that we are aware of that calculates the opening angle expected in a thick accretion disk. Using figure 9 from Madau (1988) we see that the beamed radiation is most intense within a half opening angle of $\sim 20°$ of the rotation axis of the torus and predicts that an observer inside that half angle infers that the source is radiating at roughly 20 times the "true" rate. Assuming that we are observing the source down the rotation axis of the funnel then the implied observed flux is 16 times that of the true isotropically radiated emission e.g the observed flux would be enhanced by a factor of 20 compared to the true flux, which is simply the ratio of the opening angle to the total solid angle assuming two cones. Thus using this model the true isotropic luminosity of the IXO in NGC2276 is 6×10^{39} erg s^{-1} consistent with a black hole mass of 45 $M_{\odot}$.

In the Madau (1988) model, part of the radiation is scattered and enhances the surface brightness of the funnel walls and part of the radiation is absorbed by the funnel walls; only a small fraction of the intrinsically radiated luminosity is being captured by the scattering cone and most of it is being radiated into the blocking torus. The difference between the isotropic luminosity predicted by the Madau model and that from the geometric argument is the ratio of the luminosity that goes up the funnel and that which is radiated in 4pi sterradians which is a factor of 16 for a double done model. Thus 5×10^{39} erg s^{-1} must be absorbed by the thick accretion disk. Since this x-ray radiation is absorbed by the material in the Torus and it must be re-radiated in some other bandpass. The most likely spectral region would be the optical or far-IR and this would produce a luminosity that would result in an absolute magnitude of $\approx$-11 without any color corrections much brighter than the most luminous stellar objects in any galaxy (excluding supernova) which have absolute magnitudes in the range of -9 to -11 (Humphreys & Davidson 1979; Massey et al. 2000. These extremely luminous stars are similar to Eta Carinae and would be easily identifiable as the counterparts of the IXOs in nearby galaxies. This is driven home by studies of the brightest IXO, the source in M33 (Long, Charles & Dubus 2002), where there is no optical evidence, at the absolute visual magnitude of $\sim$ -5.2, for an unusual counterpart to the $L_x \approx 10^{39}$ erg s^{-1} source. The lack of any such identifications suggests to us that either the absorbed energy is radiated in the far-IR, for which similar surveys have not been done, or that geometrical collimation is not the process responsible for the apparent high luminosities. While the above limits are model dependent the lack of extremely luminous optical counterparts to the IXOs strongly limits any geometrical collimating scenario. It is beyond the limits of this paper to calculate the general restrictions, e.g. abeldo, solid angle of scattered, absorption models and fraction of the luminosity that is intrinsically isotropic but we simply wish to point out that the absence of an extremely luminous optical counterpart strongly limits geometrical beaming models.

The other alternative is true beaming in which the intrinsic radiation field is highly anisotropic. This has been observed in many extragalactic radio sources (e.g. Bl Lac objects) and in several Galactic objects (e.g. SS433 and the X-ray microquasars). In relativistic beaming models (e.g., Urry & Shafer 1984) this is a natural consequence of relativistic motion. The existence of a highly anisotropic radiation field in non-relativitic objects is mainly the subject of theoretical work and so far has not received observational support from the extensive work on Seyfert galaxies and quasars. A natural consequence of relativistic beaming is a connection between the beaming factor Γ and the solid angle of the beam. The luminosity is enhanced by roughly Γ^4 and the solid angle of the beam is of order Γ^{-2}. The number of sources is a strong function of the intrinsic beaming and the intrinsic luminosity function. In reviewing the cases discussed in Urry and Shafer (1984), we were immediately struck by the fact that the beamed luminosity function is the same as the unbeamed luminosity function; however, the sources are more luminous by Γ^4. Using this fact, and the intrinsic luminosity function of X-ray sources in external spiral galaxies having a luminosity function with a slope of ~ -1.5 (e.g. Tennet et al. 2001) we can predict the number of lower luminosity sources from both the beamed and unbeamed populations. Of course at lower luminosities there must be a substantial population of non-black hole sources (e.g. high and low mass x-ray binaries). Given that we have only one IXO in NGC 2276 (or at most three if the other two sources are indeed IXO's) one would predict $\sim$30 times more sources from a beamed component at a luminosity which is one tenth the luminosity of the IXO. This is completely ruled out by the data. In addition to the relativistically beamed sources one must observe the parent population of these sources, those objects whose radiation is not beamed in our direction. While we do not know if there is any unbeamed radiation at all, if Bl Lacs are a guide, there should be many such objects. The intrinsic numbers are roughly Γ^2 larger than the beamed sources. So if we have beaming factors of $\Gamma \sim 2.5$ and thus apparent luminosity enhancements of $\sim$80, reducing the true luminosity to $\sim 10^{39}$ and as such easily accommodated by a $20 M_{\odot}$ black hole, then we expect $\sim$10 times more unbeamed sources of intrinsic luminosity $\sim 10^{39}$. These objects are not seen either. The detailed implications of the beaming scenario are discussed in Körding, Falcke & Markoff (2002) and are in good agreement with the qualitative discussion above. In their figure 1 they show the expected factor of 30 increase in the number density of log $L_x \sim 39.5$ objects over those at log $L_x \sim 40.5$ for the beaming models. This large increase in the number density in NGC 2276 is ruled out by our data. Thus the absence of lower luminosity, ultra-luminous sources strongly constrains the relativistic beaming models for this object.

It is also well known that relativistically beamed objects show very large amplitude variability (e.g. the microquasars and Bl lac objects). In addition, the other sources that are known to be beamed (e.g. BL Lac objects) show large amplitude variability on short timescales and have PDS that can be represented by a power law, $f^{-\alpha}$, with an index α of 2 to 3. (eg. Kataoka et al. 2001). This steep slope in the PDS can be interpreted as variability of the source on short timescales. The PDS for the IXO in NGC 2276 is flat between $\sim 10^{-5}$ and 5×10^{-3} Hz which is quite different from the PDS for Bl Lac objects. If Galactic microquasars are an analog of IXOs then the lack of short term variability may pose a problem. Multi-wavelength monitoring of GRS 1915+105, a Galactic microquasar, shows that this source is very variable in the X-ray band. GRS 1915+105 also demonstrates quasi-periodic flaring on a timescale of about 2700 seconds and also flare activity during periods of more constant luminosity (Ueda et al. 2002). So if the IXO in NGC 2276 is a microquasar viewed along the jet then the lack of short term variability is puzzling. The very low amplitude of short timescale variability in G1915+105 is also seen in the IXO's observed by ASCA (Ueda et al. 2002) and is in strong contradiction to the expectations for relativistically beamed sources.

In addition to the temporal properties of the jets we also look at the spectral properties. As Körding et al. (2001) point out the jet hypothesis requires rather powerful jets with reasonable Lorentz factors or rather large Lorentz factors with less powerful jets. This implies a rather unique spectrum for the jet dominated emission. The only known jet X-ray sources, Bl Lac objects, are fit by power law models with curvature at both low and high energies, a spectral shape very different from the MCD models which fit the IXOs including the source in NGC 2276. Thus models which can produce the X-ray spectra from a jet in the IXOs (Georganopoulos, Aharonian & Kirk 2002) need to be rather different from those that work in Bl Lacs.

If IXOs are radiating isotropically at the Eddington limit, then even for the systems with more typical luminosity, the mass of the accreting object must exceed several hundred $M_\odot$. Previous observations have found evidence for stellar mass black holes with masses $\lesssim$10 $M_\odot$ and for supermassive black holes ($M \gtrsim 10^6$ $M_\odot$) but no clear evidence for intermediate masses. These IXOs may represent the first evidence for intermediate mass black holes as suggested by Colbert & Mushotzky (1999). Assuming the existence of intermediate mass black holes the unbeamed models require a black hole mass of $\geq$100 $M_\odot$ in a binary system (King et al. 2001). One problem with this is that the inferred temperature of the inner disk is inconsistent with such a high mass black hole. The high inner disk temperature can be explained either by having the central source be a Kerr black hole (Makishima et al. 2000) or by assuming non-standard accretion disk model (eg. Watarai et al. 2001).

We are thus left either with the idea of King & Puchnarewicz (2002) that a new mechanism must be at work which produces intrinsically beamed non-relativisitic radiation fields or that these objects are truly very massive black holes. If these objects represent a new type of accretion phenomena one might expect other unusual spectral or temporal properties such as seen in the narrow line Seyfert galaxies which have very distinct X-ray spectral and temporal properties from normal Seyfert galaxies (Leighly 1999). One strong test of the idea that these objects are very massive black holes will come from measurement of the PDS of time variability. Recent XTE results on both galactic and extragalactic black holes (Nandra et al. 2000; Uttley, McHardy, Papadakis 2002) show that there is a scaling between the knee of the PDS and the mass of the black hole. If the IXOs are truly $\sim$100-1000 $M_\odot$ black holes then their PDS will be intermediate between those of the 10 $M_\odot$ galactic objects and the 10^6-10^8 $M_\odot$ AGN. This is easily testable with XMM observations of the brightest IXOs.

This set of unusual properties for the X-ray binary population in NGC2276 argues, as suggested by King et al (2001), that individual IXOs may represent rare occurrences of very massive isolated black holes. We note that the situation in the Antenna of several ultra-luminous sources in a individual galaxy is quite rare (Colbert and Ptak 2002) with an expectation value on the basis of XMM and Rosat data of $\lesssim$2 per galaxy and thus the situation in NGC 2276 may be much more common (Foschini et al. 2002). Models which are driven by the high rate of IXOs in some starburst galaxies may not be applicable in general.

6.3. The Central Source

The nucleus of NGC 2276 shows no signs of AGN activity based on the optical colors (Davis et al 1997) or spectra (Kennicutt 1992). However, the strong X-ray variability of the nuclear region of NGC 2276 may be an example of large amplitude variability seen in a few other AGN. While detailed variability studies on times scales of years are only available for the brightest 25 AGNs, it is not unusual for objects to vary by factors of five over time scales of years and factors of ten are not unknown (e.g., Peterson et al. (2000) for NGC4051 and Weaver et al. (1996) for NGC2992). Thus it is not clear if the pattern of variability of the central source in NGC2276 is unusual. However, it is clear that the strong variability confirms that this object is indeed an AGN. In the Rosat all sky survey there were five galaxies that were in outburst, three of which show no signs of nuclear activity in the optical band. Donely et al (2002) conclude that the rate of large-amplitude X-ray outbursts from inactive galaxies in the local Universe is $\sim 9.1 \times 10^{-6}$ galaxy^{-1} yr^{-1}. This rate is consistent with the predicted rate of stellar tidal disruption events in such galaxies. It is entirely possible that the NGC2276 nucleus is another example of this sort of activity.

7. Conclusions

A long $\sim$53 ksec observation of the spiral galaxy NGC 2276 has reveled the presence of a bright IXO at the western edge of the galaxy. The spectrum of this source is fit best with a multi-color disk blackbody with a thermal MekaL model included to account for the X-ray emission from the disk of the galaxy. The inferred temperature of the inner disk is kT = 2.05 keV. This along with the high bolometric luminosity of 1.1×10^{41} erg s^{-1} implies that either the singularity must be rotating or that a non-standard disk model must be employed. In addition, the strong star formation rate seen in this disturbed galaxy lends weight to the proposal by Taniguchi et al. (2000) that intermediate mass black holes can form in regions of intense star formation.

IXO models where the radiation is geometrically beamed also predict that in addition to the direct and reflected radiation, that part of that radiation incident on the thick disk must be absorbed. This radiation must be re-radiated in some energy band. Assuming that the model of Madau (1988) is applicable we find that $\sim 2.4\times10^{40}$ erg s^{-1} must be re-radiated. A source with this level of emission would easily be seen as a extremely luminous optical counterpart to in IXO's associated with nearby galaxies. So either this radiation must be re-radiated at far-IR wavelengths or that geometrical beaming is not at work in IXOs.

The models where IXOs are relatively normal X-ray binary systems that are relativistically beamed in our direction seem to predict that short term variability would be a characteristic of such systems. We searched for short term variability in this source and found none. The power density spectrum for this IXO is flat and shows none of the power law structure seen in other beamed sources. However this IXO does show time variability on timescales of hours and years. On the timescale of years the variability can be up to factors of two or three and it can vary by 20% in only a few hours. Thus models where IXO's are relatively normal X-ray binary systems that are beamed in our direction seem less likely in this case.

A more stringent test to distinguish between various models of IXOs require that accurate positions of the object be known in order for counterparts at other wavelengths to be found. This will also allow for detailed studies of the environment that these objects are found in and presumably formed. For this a more accurate X-ray position from *Chandra* is needed. The combination of the high throughput of XMM combined with the positional accuracy of *Chandra* is vital for the further study of this object.

This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. This research has also made use of data obtained from the High Energy Astrophysics Science Archive Research Center (HEASARC), provided by NASA's Goddard Space Flight Center.

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Table 1. Model fits

Model	Parameters	χ^2 / dof
	Western Source	
Power Law	Γ=$1.30^{+0.09}_{-0.10}$	110/79
	N_H=$5.38^{+2.22}_{-3.10}$	
Power Law	Γ=$1.40^{+0.12}_{-0.17}$	85 / 76
+	kT=$0.31^{+0.10}_{-0.04}$	
MekaL	N_H=$17.8^{+14.8}_{-12.8}$	
Diskbb	T_{in} =$2.05^{+0.27}_{-0.27}$	80 / 76
	$K_{MCD} = 1.26 \times 10^{-3}$	
+	N_H=$0.13^{+9.59}_{-0.13}$	
MekaL	kT=$0.35^{+0.20}_{-0.06}$	
	XMMUJ 072718.8+854636	
Diskbb	T_{in} =$0.45^{+0.20}_{-0.75}$	4.12 / 6
	$K_{MCD} = 3.96 \times 10^{-4}$	
+	N_H=<47.3	
MekaL	kT=$0.35^{+0.20}_{-0.06}$	
	XMMUJ 072816.7+854436	
	N_H=5.32	
Power Law	Γ=$1.40^{+0.67}_{-0.53}$	17.4 / 16

[a]Intrinsic N_H in units of $\times 10^{20}$ atoms cm^{-2}

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Table 2. Observation Log

Mission	Sequence #	Observation Date	MJD	Exposure (s)
Einstein	I6645	1980-03-04	44302	1940
ROSAT	RP900161N00	1992-04-25	48737	5997
ROSAT	RP900512N00	1993-08-22	49221	9029
ROSAT	RP900513N00	1993-08-22	49221	8417
ROSAT	RH600498N00	1994-03-18	49429	52235
ROSAT	RH600498A01	1994-08-29	49593	21731
ASCA	80012000	1993-05-29	49136	19808
ASCA	80013000	1993-05-30	49137	21472
ASCA	85005000	1997-10-31	50752	44128
ASCA	85005010	1997-10-31	50752	37296
XMM	0022340201	2001-03-16	51984	53830

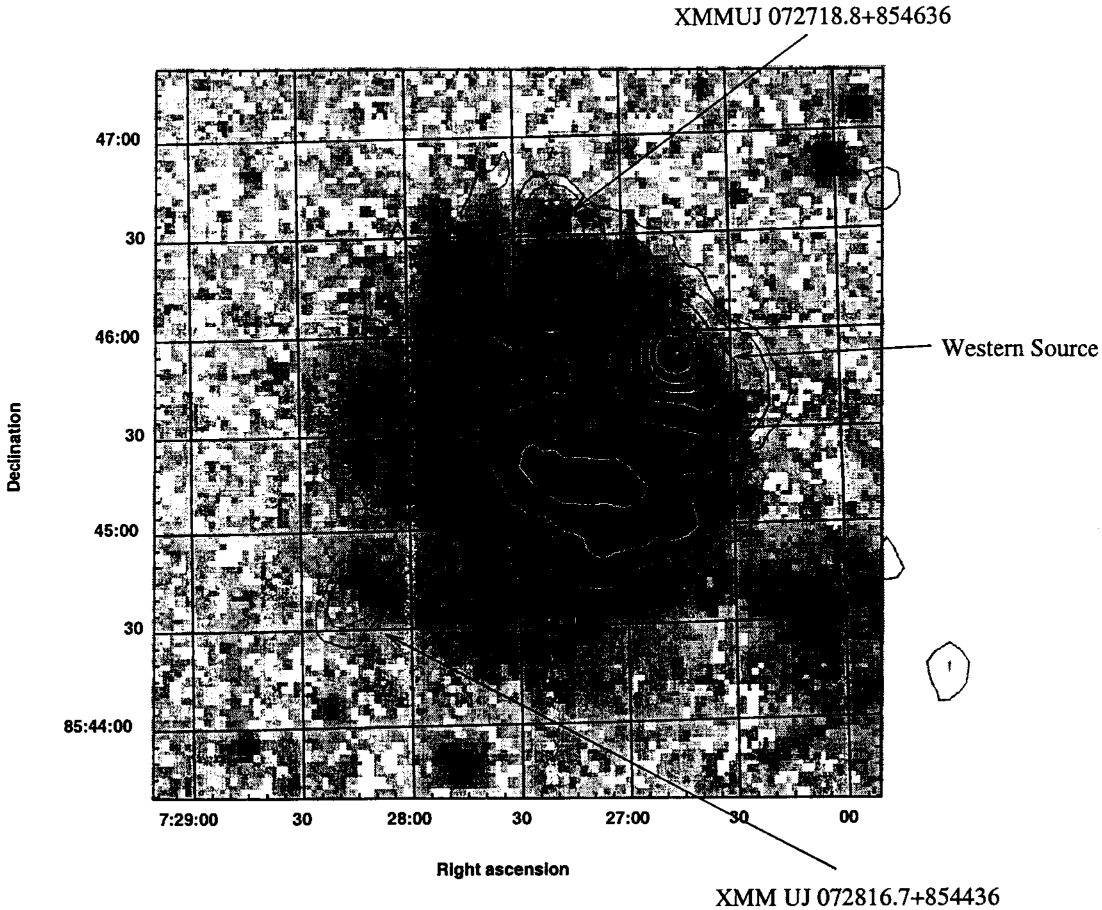

Fig. 1.— The Digital Sky Survey image of NGC 2265 with the XMM X-ray contours overlayed. The XMM data have been smoothed with a $\sigma = 15''$ Gaussian.

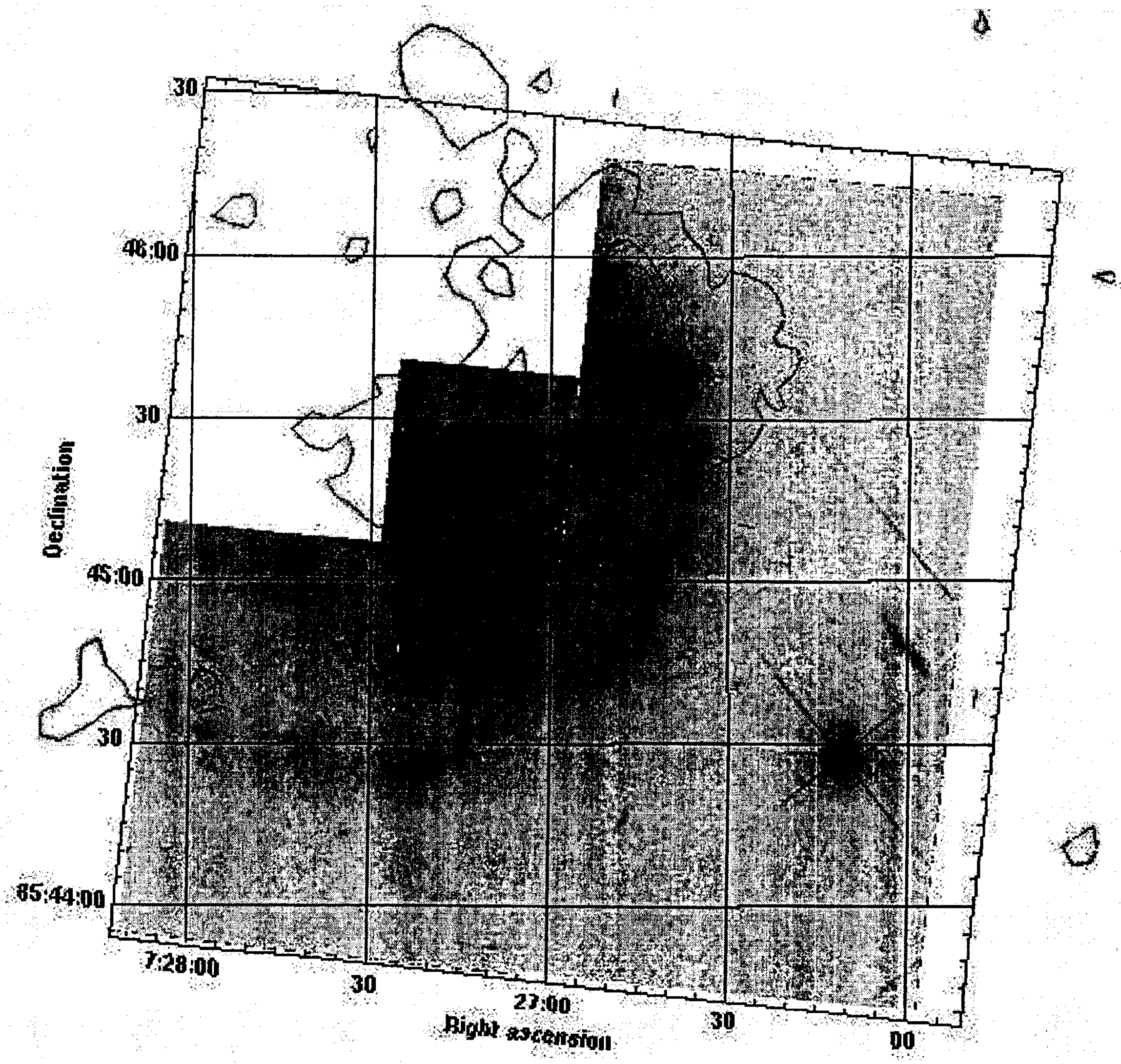

Fig. 2.— The HST image of NGC 2265 with the XMM X-ray contours overlayed. The XMM data have been smoothed with a Gaussian using a $\sigma = 15''$.

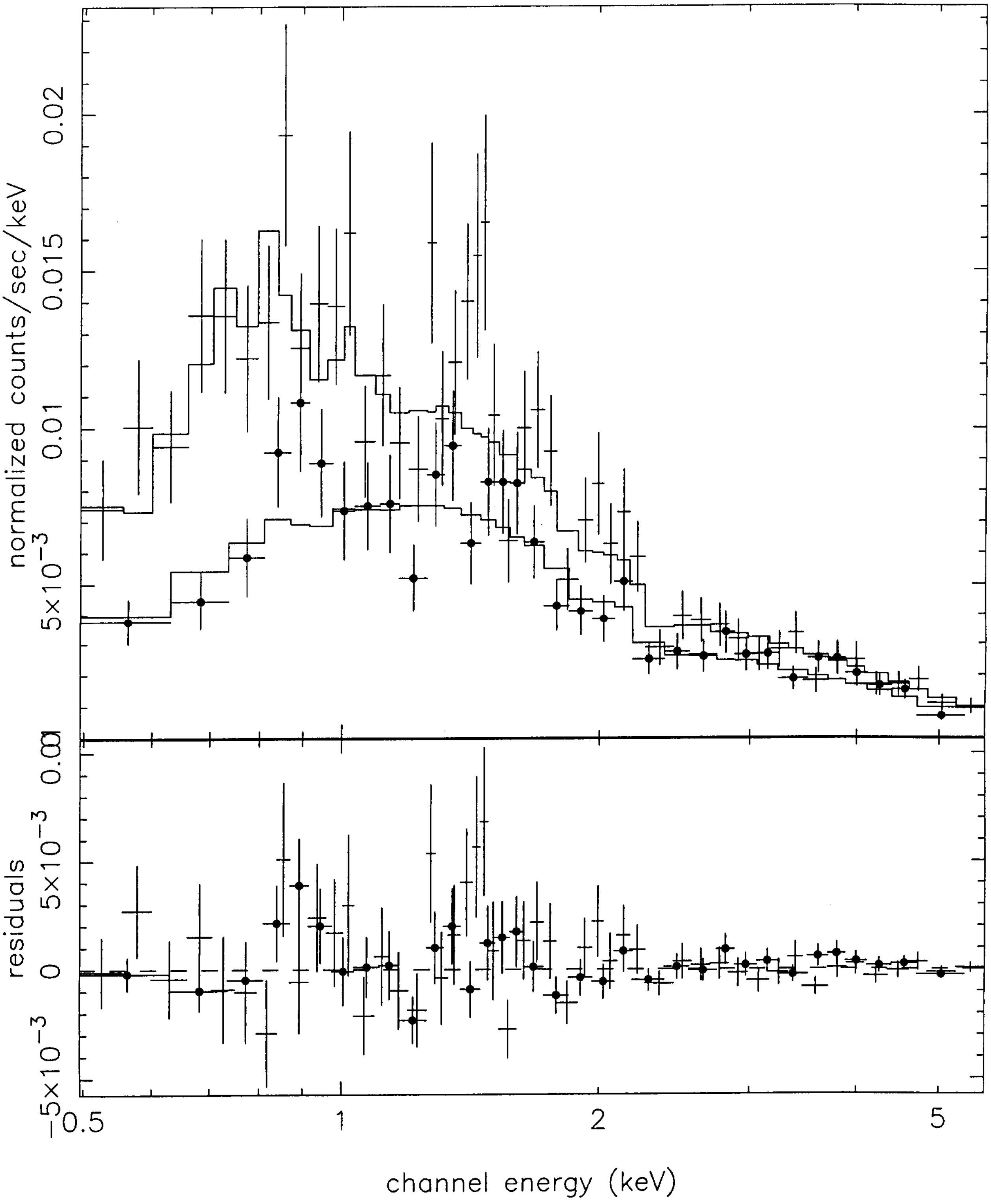

Fig. 3.— The extracted XMM MOS1 and MOS2 (solid points) and the fitted XSPEC diskbb model.

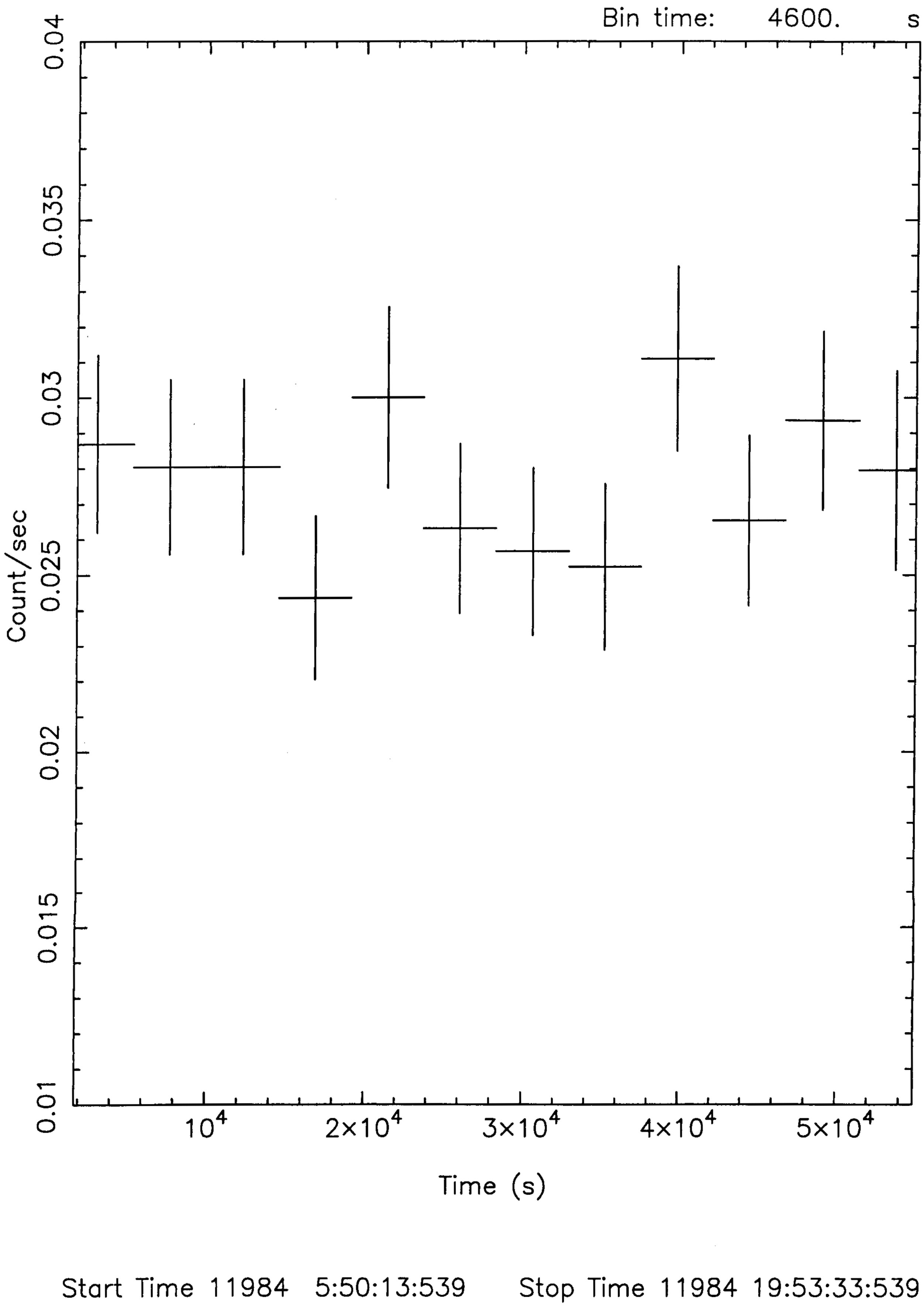

Fig. 4.— The extracted XMM MOS2 lightcurve for the western source (IXO) with 4600 second bins.

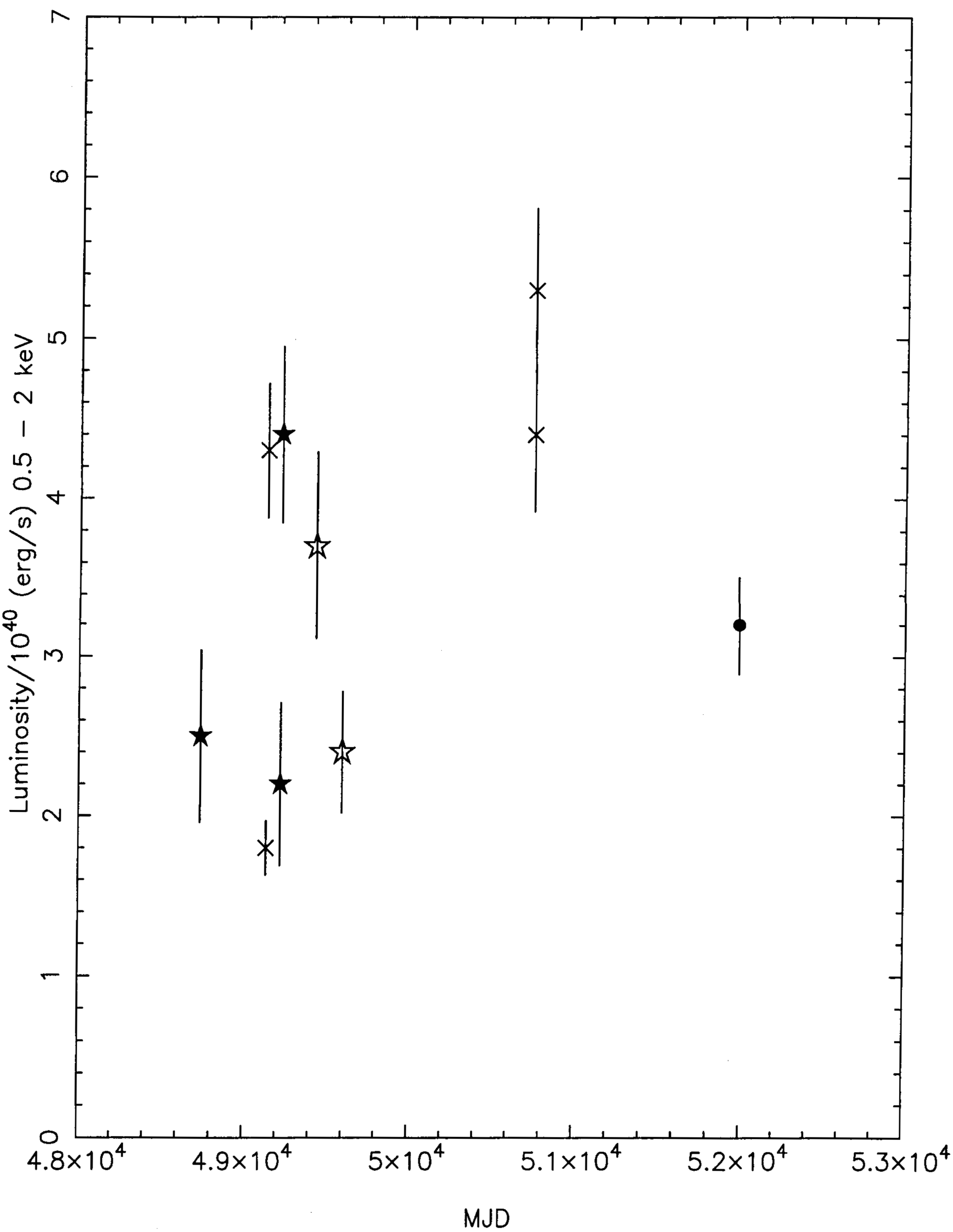

Fig. 5.— The long term lightcurve for the IXO in NGC 2276. The solid stars are the *ROSAT* PSPC data, the open stars are the *ROSAT* HRI data. The *ASCA* GIS data are denoted by the crosses and the XMM luminosity is shown with the solid circle. The flux is in units of 10^{40} erg s−1 in the 0.5 – 2.0 keV band. The plotted error bars are 1 σ. It should be noted that while the ASCA data does not isolate the IXO we assume that the preponderance of the X-ray emission is from the IXO. The upper limit for the Einstein IPC data is not shown here for clarity.