The *Suzaku* X-ray spectrum of NGC 3147. Further insights on the best “true” Seyfert 2 galaxy candidate

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**ABSTRACT**

**Context.** NGC 3147 is so far the most convincing case of a “true” Seyfert 2 galaxy, i.e. a source genuinely lacking the Broad Line Regions.

**Aims.** We obtained a *Suzaku* observation with the double aim to study in more detail the iron line complex, and to check the Compton-thick hypothesis for the lack of observed optical broad lines.

**Methods.** The *Suzaku* XIS and HXD/PIN spectra of the source were analysed in detail.

**Results.** The line complex is composed of at least two unresolved lines, one at about 6.45 keV and the other one at about 7 keV, most likely identified with Fe XVI/XIX, the former, and Fe XXVI, the latter. The high-ionization line can originate either in a photoionized matter or in an optically thin thermal plasma. In the latter case, an unusually high temperature is implied. In the photoionized model case, the large equivalent width can be explained either by an extreme iron overabundance or by assuming that the source is Compton-thick. In the Compton-thick hypothesis, however, the emission above 2 keV is mostly due to a highly ionized reflector, contrary to what is usually found in Compton-thick Seyfert 2s, where reflection from low ionized matter dominates. Moreover, the source flux varied between the *XMM-Newton* and the *Suzaku* observations, taken 3.5 years apart, confirming previous findings and indicating that the size of the emitting region must be smaller than a parsec. The hard X-ray spectrum is also inconclusive on the Compton-thick hypothesis. Weighting the various arguments, a “true” Seyfert 2 nature of NGC 3147 seems to be still the most likely explanation, even if the “highly ionized reflector” Compton-thick hypothesis cannot at present be formally rejected.

**Key words.** Galaxies: active – X-rays: galaxies – Galaxies: Seyfert – Galaxies: individual: NGC 3147

1. Introduction

NGC 3147 (\(z = 0.009346\)) is at present the most convincing example of a “true” Seyfert 2 galaxy (Bianchi et al. 2008; Shi et al. 2010; Tran et al. 2011). In such sources the lack of detection of broad emission lines in the optical/UV spectra cannot be explained by the obscuration of the Broad Line Regions (BLR) - as it is the case for “normal” Seyfert 2s in the so far very successful Unification models (Antonucci 1993) - but requires their absence.

In fact, *simultaneous* X-ray and optical spectroscopy have demonstrated that in this source the BLR is lacking at the same time when the nucleus is seen unobscured (Bianchi et al. 2008). The X-ray *XMM-Newton* observation, albeit rather short (less than 20 ks), was good enough to put a tight constraint on the column density of any obscuring material along the line-of-sight. The same observation also indicated complex iron line emission, but the short exposure time did not permit a detailed analysis.

It has been suggested (Nicastro 2000; Nicastro et al. 2003; Elitzur & Shlosman 2006) that at low accretion rates (and thence low luminosities) the broad line regions (BLR) cannot form. Indeed, NGC 3147 is a low (even if not extremely so) luminosity source accreting at a low rate (bolometric luminosity \(L \approx 5 \times 10^{42}\) erg s\(^{-1}\), \(L/L_{\text{Edd}} \approx 10^{-4}\), Bianchi et al. 2008).

A possible alternative explanation for the peculiar characteristics of NGC 3147 is that the source is Compton-thick. In fact, the simultaneous lack of BLR and absorption can be explained if the absorber is so thick to completely obscure the nuclear emission below 10 keV. In this case, the observed emission should be due to reflection off circumnuclear matter, but X-rays could pierce through the absorbers above 10 keV. The hard X-ray coverage offered by *Suzaku* is the best tool at present to test it.

With the dual goal of studying in more detail the iron line emission and to check the Compton-thick explanation for this source, we asked for, and obtained, a long (150 ks) *Suzaku* observation.

The paper is organized as follows. The observation and data reduction are described in Sec. 2, while the data analysis is presented in Sec. 3. Results are discussed and summarized in Sec. 4.

2. Observation and data reduction

NGC 3147 was observed by *Suzaku* on May 24, for 150 ks (obsid 705054010). X-ray Imaging Spectrometer (XIS) and Hard X-ray Detector (HXD) event files were reprocessed with the latest calibration files available (2011-06-30 release), using *xrcons* 6.11 and *Suzaku* software Version 18, adopting standard filtering procedures. Source and background spectra for all the three XIS detectors were extracted from circular regions with radius of 167 pixels (\(\approx 175\) arcsec), avoiding the calibration sources. Response matrices and ancillary response files were generated using xis-
3. Data analysis and results

The light curve is shown in Fig. 1. No significant variability is detected. For the spectral analysis, therefore, we used spectra integrated over the whole observation.

3.1. The XIS spectra

We first analyzed the XIS spectra. A simple power law model (plus Galactic absorption, \(N_{\text{H,G}}=3.64\times10^{20} \text{ cm}^{-2}\), Dickey & Lockman 1990) gives a poor fit (\(\chi^2/d.o.f.=604.1/482\)). The most prominent features in the residuals are apparent at the energies of the iron line complex (see Fig. 2). We therefore added two narrow emission lines, with energies free to vary around 6.4 and 7 keV (see next section), which improves significantly the quality of the fit (\(\chi^2/d.o.f.=496.4/478\)). The power law index is 1.745\pm0.014. The inclusion of either a warm absorber or a Compton reflection component is not required by the data (\(\Delta \chi^2=-2.4\) and -2.8, respectively), while addition of a second power law improves the fit quality (\(\chi^2/d.o.f.=481.3/476\); the improvement is significant at the 99.94\% confidence level, according to the F-test). The power law indices are 3.50\,(^{+0.42}_{-0.69}) and 1.689\,(^{+0.022}_{-0.018}). The 0.5-2 (2-10) keV flux is 8.39\times10^{-13} (1.64\times10^{-12}) \text{ erg cm}^{-2} \text{ s}^{-1}, corresponding to a (absorption corrected) luminosity of 1.8\times10^{41} (3.2\times10^{41}) \text{ erg s}^{-1}.

Finally, no intrinsic absorption is detected. The upper limit to the column density of any neutral absorber at the redshift of the source is 5\times10^{20} \text{ cm}^{-2}.

3.1.1. Comparison with the XMM-Newton results

We then compared the Suzaku spectrum with the XMM-Newton results (Bianchi et al. 2008). XMM-Newton observed NGC 3147 on 2006, October 6 (i.e. about three and half year earlier), with a net exposure time of 14 ks in the EPIC-pn instrument. We re-extracted the spectrum with the same procedure described in Bianchi et al. (2008), but using the latest version of SAS (11.0.1) and of the calibration files.

According to Bianchi et al. (2008), we fitted the spectrum with a power law absorbed by both Galactic and intrinsic matter, and two narrow gaussian lines. The fit is good (\(\chi^2/d.o.f.=93.6/106\)). The power law index is 1.62\pm0.05, the column density of the local absorber is \(<3.2\times10^{20} \text{ cm}^{-2}\), the energies of the two lines are 6.471\,(^{+0.089}_{-0.065}) \text{ keV} and 6.798\,(^{+0.083}_{-0.072}) \text{ keV} and their fluxes are 2.8\,(^{+1.6}_{-1.5})\times10^{-6} \text{ ph cm}^{-2} \text{ s}^{-1} (\text{EW of 189 eV}) and 2.4\,(^{+1.5}_{-1.5})\times10^{-6} \text{ ph cm}^{-2} \text{ s}^{-1} (\text{EW of 172 eV}), respectively. All these values are consistent within the errors with those of Bianchi et al. (2008). The 0.5-2 (2-10) keV flux is 5.78\times10^{-13} (1.43\times10^{-12}) \text{ erg cm}^{-2} \text{ s}^{-1}.

Comparing the XMM-Newton and Suzaku results, a variation, most prominent in the soft band, is found. This is shown in Fig. 3.1.1 where the XMM-Newton best fit model is superposed to the Suzaku/XIS1 spectrum. The variation can be explained either as a steepening of the power law component or, better, with different variations of the soft and hard X-ray component, the
fit is good (single power law plus three narrow (Kα, Kβ, Ne Kα) absorption lines). We therefore fitted the spectrum with a model composed by a power law plus a broad Gaussian profile, with rest-frame energies fixed at 6.4 keV (neutral iron, Kα) and 7.06 keV (neutral iron, Kβ). The fit is good ($\chi^2/d.o.f. = 116.2/120$), but some wiggles are apparent in the residuals around the Kα neutral iron line. Letting the energy of that line free to vary, a significantly better fit is found ($\chi^2/d.o.f. = 99.5/119$), with a line energy of about 6.45 keV. No improvement, instead, is found letting the width of that line free to vary ($\sigma < 63$ eV), nor including the Ne Kα line (upper limit to the flux of $5.5 \times 10^{-7}$ ph cm$^{-2}$ s$^{-1}$, corresponding to an equivalent width of 35 eV). Not surprisingly, given the narrowness of the line, no improvement is found with a relativistic profile (diskline model), and the inner disc radius is very large (hundreds of gravitational radii). Even in the relativistic line model, an intrinsic line energy at 6.45 keV is strongly preferred by the fit.

The results are summarized in Table 1. The line fluxes are consistent within the errors to those derived from the XMM-Newton spectra. While the hydrogen-like line is only marginally detected and the Kβ line is formally an upper limit, this of course does not mean that there is no significant line emission at that energy, but simply that the quality of the data is not good enough to accurately determine the parameters of the lines simultaneously. This is best seen in Fig. 5 where the contour plot of the fluxes of the two lines is shown: a simultaneous lack of emission for the two lines is shown: a simultaneous lack of emission for the two lines is shown: a simultaneous lack of emission for the two lines is shown: a simultaneous lack of emission for the two lines is shown: a simultaneous lack of emission for the two lines is shown.:

3.2. The iron line complex

We then studied in more detail the iron line complex. While the iron line properties in the XMM-Newton and Suzaku observations are roughly consistent, the much better statistics in the Suzaku observation due to the longer exposure time allows for a more detailed analysis. To this end, we limited for simplicity the analysis to the XIS instruments, and the energy range to the 4-10 keV band. In Fig. 4, the data and best fit model are shown, after removal of any emission line from the fit. The presence of two emission lines is clear, one around 6.4 keV, to be attributed to Kα emission from neutral or low ionization iron, the other around 7 keV, likely due to either (or both) hydrogen-like (i.e. Fe XXVI) iron emission or Kβ emission from low ionization iron. We therefore fitted the spectrum with a model composed by a single power law plus three narrow ($\sigma = 0$) emission lines, with rest-frame energies fixed at 6.4 keV (neutral iron, Kα), 6.96 keV (hydrogen-like iron, Kα), and 7.06 keV (neutral iron, Kβ). The fit is good ($\chi^2/d.o.f. = 116.2/120$), but some wiggles are apparent in the residuals around the Kα neutral iron line. Letting the energy of that line free to vary, a significantly better fit is found ($\chi^2/d.o.f. = 99.5/119$), with a line energy of about 6.45 keV. No improvement, instead, is found letting the width of that line free to vary ($\sigma < 63$ eV), nor including the Ne Kα line (upper limit to the flux of $5.5 \times 10^{-7}$ ph cm$^{-2}$ s$^{-1}$, corresponding to an equivalent width of 35 eV). Not surprisingly, given the narrowness of the line, no improvement is found with a relativistic profile (diskline model), and the inner disc radius is very large (hundreds of gravitational radii). Even in the relativistic line model, an intrinsic line energy at 6.45 keV is strongly preferred by the fit.

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3.2.1. The low ionization iron line

The rest-frame energy of the low ionization Kα iron line is significantly larger than (and not consistent with) 6.4 keV, the energy for neutral iron. We are not aware of any major problem in the energy calibration of the XIS detectors and indeed, fitting the Mn Kα doublet and the Kβ in the calibration spectra, we found energies consistent with the intrinsic ones. Letting the
energy of the line free to vary independently in the three XISs, similar values are found. We therefore conclude that the iron is truly ionized.

According to House (1967), the best-fit energy corresponds to Fe XVII/XIX, where iron emission should be suppressed by resonant trapping (Ross & Fabian 1993, Matt et al. 1993, 1996). To avoid this effect, the matter should be very optically thin, which is ruled out by the large EW (almost 200 eV), or very turbulent, so reducing the effective optical depth at the line core. Recent and more refined calculations by Garcia et al. (2011), however, show that suppression is not so efficient and that significant emission from the abovementioned ions is possible. In this case, we do not expect any Kβ line emission, because for those ions the M shell is no longer populated, and therefore the line emission at about 7 keV should be entirely due to the hydrogen-like iron line.

3.2.2. The high ionization iron line

Setting the Kβ line to zero, the H-like line flux is 1.44(±0.59)×10⁻⁶ ph cm⁻² s⁻¹ (see also Fig. 5), with an equivalent width of about 100 eV and χ²/d.o.f. = 101.5/120. An upper limit of 35:100 to the ratio between helium- and hydrogen-like lines (as derived from the respective fluxes) implies high values of the ionization parameter, such that the EW of the hydrogen line should be, for a solar iron abundance, only a few eV with respect to the total continuum (Bianchi & Matt 2002). The required factor of (at least) 10-20 iron overabundance is rather extreme, even if not fully inconsistent with the EW of the low ionization line (which is a factor 2-3 larger than expected for solar abundances, in agreement with the calculations of Matt et al. 1997 for optically thick matter with a similar iron overabundance).

On the other hand, such large equivalent widths could be explained if the source is Compton-thick and the observed emission comes from reflection in two physically distinct mirrors, one at low and the other at high ionization, and no direct emission. To test this hypothesis, we fitted the spectrum with a power law (representing reflection from highly ionized matter), a Compton reflection component (to account for reflection from low ionized matter), plus two gaussian lines, one free to vary around 6.4 keV and the other fixed to 6.96 keV. The value of R, the relative amount of Compton reflection with respect to the power law component, was fixed to 2, which is the value corresponding to the observed EW of the 6.4 keV line. This translates to a 2-10 keV flux from the high ionization reflector 7 times larger than the low ionization component, a quite unusual configuration in Compton-thick sources where it is the low ionization reflection which generally dominates. The fit is good (χ²/d.o.f. = 107.8/120), even if slightly worse than with a simple power law. The H-like line flux is now 0.97(±0.60)×10⁻⁶ ph cm⁻² s⁻¹, corresponding to an EW with respect to the high ionized reflection only of about 80 eV, a value consistent with what is expected from the large ionization parameter values implied by the absence of the He-like line (Bianchi & Matt 2002).

Alternatively, this line may be emitted in a high temperature, optically thin thermal plasma. A 0.5-10 keV fit with the Mekal model (iron abundance fixed to solar) instead of the 7 keV gaussian line is acceptable (χ²/d.o.f. = 485.5/476), giving a plasma temperature of 25(±2) keV. The 2-10 keV luminosity of the thermal component is 1.2×10⁴¹ erg/s. The emission measure, ~

\[ \int n_e^2 dV, \]

is about 7×10⁶³ cm⁻³. Assuming, for self-consistency, that the emitting matter is not optically thick to Thomson scattering, i.e. \( n_H R_{\text{e}} T < 1 \) (with \( R \) the radius of the emitting region, assumed spherical and with constant density), then a lower limit to \( R \) of 7.4×10¹⁴ cm (i.e. about 12 Schwarzschild radii if a value of the black hole mass of 2×10⁸ solar masses is adopted, Dong & DeRobertis 2006), is obtained (corresponding to an upper limit to \( n_H \) of 2×10⁸ cm⁻³). (If the Mekal component is used instead of both the hard power law and the highly ionized iron line the fit is still good, the soft power law gets flatter, \( \Gamma = 2.18(±0.02) \) and the thermal plasma 2-10 keV luminosity is 2.2×10⁴¹ erg s⁻¹).

The origin and nature of this putative thermal plasma is however unclear. The accretion rate of NGC 3147 is low (\( L/Edd \sim 10^{-4} \), Bianchi et al. 2008), and therefore accretion could occur in a radiatively inefficient mode (ADAF, Narayan et al. 1995; RIAF, Yuan et al. 2003), where the X-ray emission is expected to be due to bremsstrahlung radiation. However, in such a mode the ion temperature is expected to be extremely high, and no visible line is expected. The thermal emission may be related to hot gas in a starburst region, but the implied luminosities are quite large, and there is no evidence for such an extreme starburst at other wavelengths. Alternatively, the plasma emitting region may be a compact one, in the innermost regions of the AGN. While there is so far no strong evidence of a significant contribution of such a plasma emission to the X-ray spectrum of Seyfert galaxies, it must be recalled that NGC 3147 is likely a peculiar source.

3.3. The hard X-ray emission

One of the goals of the Suzaku observation of NGC 3147 is to exploit its hard X-ray coverage to test the Compton-thick hypothesis for the unabsorbed X-ray spectrum of this Seyfert 2 galaxy. In fact, if the source is Compton-thick, the spectrum may appear unabsorbed because the primary emission below 10 keV would be completely hidden by the thick absorber, the observed emission being due to reflection from circumnuclear matter. In this scenario, the primary emission could emerge above 10 keV (if the absorber is not too thick, see e.g. Matt et al. 1999) and then be observable with the HXD/PIN. As discussed in the previous section, the observed EWs of the iron lines are consistent with the Compton-thick hypothesis (although in a quite unusual configuration), even if other scenarios are also possible.

In Fig. 6 (left panel), the PIN spectrum is added to the already analyzed XIS spectra, and a clear excess with respect to the extrapolation of the XIS-only best fit model is apparent (the result is basically the same if a high temperature thermal plasma is used to account for the hydrogen-like iron line). No confusing source is known in the PIN field of view, according to the existing catalogs of bright X-ray sources. Assuming that the excess is due to the nuclear radiation piercing through a Compton-thick absorber, we included in the model the transmission and scat-

### Table 1. Best-fit parameters for the iron lines.

| Line      | E (keV) | Flux (10⁻⁶ ph cm⁻² s⁻¹) | EW (eV) |
|-----------|---------|--------------------------|---------|
| Low ionized Kα | 6.452±0.012 | 3.27±0.61 | 195±36 |
| H-like     | 6.96    | 0.93±0.89               | 63±60   |
| Low ionized Kβ | 7.06    | < 1.61                  | < 111   |
The cosmic X-ray background is also highly variable, up to 10%, from place to place on scales of 1 sq degree (Barcons et al. 2000). However, the CXB is only 5% of the total PIN background (Fukazawa et al. 2009).

4. Conclusions

Based on a short XMM-Newton observation, there were good arguments against the Compton-thick hypothesis for NGC 3147 (Bianchi et al. 2008): the X-ray/[OIII] ratio is typical of unobscured objects, as well as the X-ray spectrum: in Compton-thick sources the 2-10 keV emission is usually much harder, being dominated by the Compton reflection component from low ionization matter and with a neutral iron line of about 1 keV EW.

However, if reflection is from highly ionized matter the spectrum is steeper, but in this case emission from He- or H-like ions is also expected (Matt et al. 1996). Our Suzaku observation suggests the presence of a strong H-like line. Indeed, the overall line and continuum spectrum below 10 keV is consistent with a Compton-thick scenario in which reflection is mostly (but not entirely) due to a highly ionized mirror. Interestingly, if this is the case, the absorber may not be the torus, which in this source is claimed by Shi et al. (2010) to be seen almost face-on.

Strong highly ionized reflectors in Compton-thick Seyfert 2s are rare, and even when observed, as in NGC 1068, their relative importance with respect to the low ionization reflector is lower (Iwasawa et al. 1997, Matt et. al. 2004). NGC 3147 would therefore be rather extreme. It is worth noting that a larger-than-usual amount of highly ionized reflection may at least partly explain the unusually (for a Compton-thick source) high X-ray/[OIII] ratio, as well as the low primary-to-reflection ratio.

On the other hand, it must also be stressed that alternative hypotheses, like e.g. large iron overabundance or a line emission from a very hot (temperature of about 20 keV), optically thin plasma cannot be ruled out. These characteristics would be unusual in Seyfert galaxies, but NGC 3147, if confirmed as a “true” Seyfert 2 galaxy, would be a peculiar source anyway.

A strong argument against the Compton-thick scenario is provided by the observed flux variation between the Suzaku and the XMM-Newton observations, obtained 3.5 years apart. Flux variations on yearly time scales were also found comparing earlier observations with ASCA, BeppoSAX and Chandra. These variations indicate that we are looking at an emitting region with a size smaller than a parsec. On the other hand, the argument, albeit strong, is still not decisive. Variations on similar or even smaller time scales have been claimed for NGC 1068, the archetypal Compton-thick Seyfert 2 (Guainazzi et al. 2000, Colbert et al. 2002). Interestingly, in NGC 1068 the variations...
Fig. 7. Contour plot of the putative Compton-thick absorber column density vs. normalization of the primary power-law.

seems to concern the highly ionized reflector, which in that source is prominent only above about 2 keV (reflection from less ionized matter, possibly related to the Narrow Line Regions, dominates at lower energies). Moreover, there is evidence in some sources, most notably NGC 1365 (Risaliti et al. 2005), of Compton-thick material very close to the central black hole.

If the source is moderately Compton-thick, we expect that the direct emission would pierce through the absorber in hard X-rays. Using the standard background subtraction, an excess in the PIN is observed, which however disappears - becoming consistent with the SWIFT/BAT upper limit - assuming that the background is higher than usual by 3.5%, a not uncommon variation. Therefore, this observation is unfortunately not decisive in this respect.

To conclude, after the new Suzaku observation the “true” Seyfert 2 nature of NGC 3147 remains the most probable hypothesis. On the other hand, the ionized iron line is best explained in the “highly ionized reflector” Compton-thick scenario, which is still a viable option. Future sensitive hard X-ray observations with NuStar and/or high spectral resolution observations with Astro-H are needed to definitely settle the issue.

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