ARP 299: A SECOND MERGING SYSTEM WITH TWO ACTIVE NUCLEI?

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ABSTRACT

Recent *Beppo*SAX observations of Arp 299, a powerful far-IR merging starburst system composed of IC 694 and NGC 3690, clearly unveiled for the first time in this system the presence of a strongly absorbed AGN. However, at the spatial resolution of the *Beppo*SAX instruments the system was not resolved. Here we present the analysis of archival *Chandra* and XMM-*Newton* observations, that allow us to disentangle the X-ray emission of the two galaxies. The detection of hard X-ray emission and strong Fe lines in both the spectra suggests the presence of an AGN in both nuclei. This would be the second discovery of two AGNs in a merging system after NGC 6240.

Subject headings: galaxies: active – galaxies: individual (Arp 299, IC 694, NGC 3690) – galaxies: nuclei – galaxies: starburst – X-rays: galaxies

1. INTRODUCTION

Arp 299 is a powerful merging system located at D = 44 Mpc (Heckman et al. 1999). The far-IR luminosity of the system, $L_{43-123\,\mu\mathrm{m}} = 2.86 \times 10^{11}\,L_{\odot}$, dominates the bolometric output. The system consists of two galaxies in an advanced merging state, NGC 3690 to the west and IC 694 to the east, plus a small compact galaxy lying to the northwest (Hibbard & Yun 1999). The centers of the two merging galaxies are separated by only $\sim 22''$ (Heckman et al. 1999), corresponding to a projected distance of 4.6 kpc. In the IR range, IC 694 shows a compact site of activity in the central region, while NGC 3690 is resolved into a complex of sources without a clear central nucleus (Wynn-Williams et al. 1991; Alonso-Herrero et al. 2000). Optical spectroscopy presented in Coziol et al. (1998) shows that IC 694 can be classified as a pure starburst galaxy, while NGC 3690 have line properties at the borderline between starburst and LINER.

We observed Arp 299 with *Beppo*SAX in the context of a project aimed at investigating the startburst-AGN connection in relatively nearby systems, where the detection threshold is sufficiently low to detect AGN activity even if not dominant. The observations unveiled for the first time in this system a strongly absorbed AGN ($N_H \simeq 1.5 \times 10^{24}$ cm^{-2}, with an intrinsic luminosity $L_{0.5-100\ \mathrm{keV}} \simeq 1.9 \times 10^{43}$ erg s^{-1}; Della Ceca et al. 2002). At the spatial resolution of the *Beppo*SAX instruments, however, the system was not resolved; so we were unable to establish in what galaxy the AGN resides.

Arp 299 was the target of both *Chandra* and XMM-*Newton* observations, now available from the archives. Here we present the analysis of these data discussing the evidence that both galaxies in the interactive system are active. After NGC 6240 (Komossa et al. 2003) this would be the second case of two AGN in a merging system.

In this Letter, we assume H_0 = 75 km s^{-1} Mpc^{-1} and q_0 = 0.5.

2. OBSERVATIONS AND DATA REDUCTION

Chandra observed Arp 299 on July 7, 2001 for a total of 26.5 ksec, corresponding to a net exposure of 24.2 ksec. The observation was performed in FAINT mode with the target centered on the aimpoint S1 of the ACIS-I detector. Screened events produced by the mission team (evt2 files) have been used while data analysis has been performed using the mission specific software CIAO version 2.3[1] and the package ds9[2].

We show in Fig. 1 the X-ray contours obtained from the *Chandra* ACIS-I data in the 0.5 – 2 keV (panel a), 2 – 10 keV (panel b), and 6.3 – 6.9 keV (panel c) energy ranges overimposed to the HST WFPC2 image obtained with the F814W filter ($\lambda_{eff} \simeq 8203$ A, $\Delta\lambda \simeq 1758.0$ A) applied.

The *Chandra* 0.5 – 2 keV emission is clearly extended and associated with the two merging galaxies. Three emission knots are visible within the diffuse emission. The north-east and fainter knot is clearly centered on IC 694 while the two others are associated with NGC 3690. Also the 2 – 10 keV emission is diffuse, though in this case it is strongly concentrated around the three knots. When observed in the 6.3 – 6.9 keV energy range (the range where Fe-Kα line(s), an important spectral signature of an AGN, resides), the emission is much more concentrated; besides, the north-west knot in NGC 3690 disappears.

Arp 299 was observed by XMM-*Newton* on May 6, 2001 for a total of about 20 ksec, in full frame mode and with the thin filter applied. In this paper we will use only EPIC-pn data since the MOS data does not have enough statistic above 6 keV. The XMM-*Newton* data have been cleaned and processed using the Science Analysis Software (SAS version 5.4), and analysed using standard software packages (FTOOLS version 4.2, XSPEC version 11.2). Event files produced from the pipeline have been filtered from high-background time intervals and only events corresponding to pattern 0 – 4 have been used (see the XMM-*Newton* Users' Handbook; Ehle et al. 2001); the net exposure time after data cleaning is $\sim$ 14 ksec. The latest calibration files released by the EPIC team have been used. We have also gen-

[1] See http://cxc.harvard.edu/ciao/
[2] See http://hea-www.harvard.edu/RD/saotng/

erated our own response matrices at the position of the system using the SAS tasks *arfgen* and *rmfgen*. No statistically significant flux variation has been detected during the XMM-*Newton* observation.

The XMM-*Newton* image in the $2-10$ keV energy range shows two sources of comparable brightness corresponding to the two interacting galaxies (see Fig. 1, panel d). To compare the EPIC-pn spectrum with that obtained by *Beppo*SAX we extracted the source counts from a circular region of radius $28.5''$, which includes the whole merging system. The background spectrum was extracted from a nearby source-free circular region of $\sim 79''$ radius. The net count rate ($0.5-10$ keV energy range) of the total merging system is 0.4822 ± 0.0063 counts s^{-1} and represents about 98.8% of the total counts in the source extraction region. To perform the spectral analysis, source counts have been rebinned to have a number of counts greater than 20 in each energy bin.

In order to derive the spectra of the two sources separately, we selected two smaller regions pointed at their X-ray centroid positions (IC 694: $ra = 11:28:33.9$, $dec = +58:33:43.9$; NGC 3690: $ra = 11:28:29.8$, $dec = +58:33:43.9$). In the case of NGC 3690 the spectrum was extracted from a circle of radius $18.75''$ (limited in size by the presence of the other nucleus). For IC 694 we used a smaller radius of $14.25''$ because of the proximity of the CCDs gap. The regions of extraction used are shown in Fig. 1, panel d. The background spectra were extracted from two source-free circular regions close to the individual sources of radius $32.5''$ and $27.5''$, respectively. The net count rate ($0.5-10$ keV energy range) of IC 694 (NGC 3690) is 0.1686 ± 0.0044 counts s^{-1} (0.2291 ± 0.0049 counts s^{-1}) and represents about 97.5% (98.3%) of the total counts in the source extraction region. Source counts have been properly rebinned.

All the models discussed here have been filtered through the Galactic absorption column density along the line of sight ($N_{H,Gal} = 9.92 \times 10^{19}$ cm^{-2}; Dickey & Lockman 1990); all the errors are at 90% confidence level for 1 parameter of interest ($\Delta\chi^2 = 2.71$). The reported line positions refer to the source rest frame; the metallicity of the used thermal component(s) was fixed to the solar one.

3. SPECTRAL ANALYSIS

3.1. *The total system: comparison with previous* Beppo*SAX results*

Arp 299 was pointed by *Beppo*SAX about seven months after the observations of XMM-*Newton*; the *Beppo*SAX MECS and XMM-*Newton* EPIC-pn $2-10$ keV flux obtained assuming a simple power law model are comparable within the uncertainties. In order to check the consistency of our previous results, the XMM-*Newton* EPIC-pn spectrum of the whole system Arp 299 (see previous section) was analysed jointly with the *Beppo*SAX data. We applied the *Beppo*SAX best-fit model (see Della Ceca et al. 2002 for details), composed by a soft thermal component, a "leaky-absorber" model (an unabsorbed power law + an absorbed power law with the same photon index Γ) and two Gaussian emission lines (at $E \sim 6.4$ keV and $E \sim 3.4$ keV, respectively), to the data in the $0.3-40$ keV energy range. During the analysis, the LECS to MECS and PDS to MECS normalization factors were allowed to vary in the range suggested by the *Beppo*SAX Cookbook (Fiore et al. 1999).

The ratio of XMM-*Newton* EPIC-pn data to the best fit model discussed above shows a deficit of photons at $E < 0.8$ keV, that was present but not statistically significant in the *Beppo*SAX data (due to the poor LECS statistics at low energies). This requires an additional absorption in front of the soft thermal component, having a column density of $N_{H,soft} \sim 1.5 \times 10^{21}$ cm^{-2} (consistent with the absorption found for several Seyfert 2 galaxies having a circum-nuclear starburst, see Levenson et al. 2001a, b). With this modification the overall model proposed by Della Ceca et al. (2002) reproduces well the XMM-*Newton* + *Beppo*SAX observations; the values found for the most relevant parameters ($N_{H,hard} = 2.6 \times 10^{24}$ cm^{-2}, $\Gamma = 1.89$, $kT = 0.64$ keV, $E = 6.41$ keV; χ^2/d.o.f. = 607.1/542) are in good agreement with those obtained previously. The presence of a Gaussian line at 3.4 keV is not required by the XMM-*Newton* data. Also the absorbed fluxes and the intrinsic (i.e. unabsorbed) luminosity are consistent with our previous results, confirming our earlier conclusion about the presence of a deeply buried AGN in the system.

3.2. *X-ray emission from the two galaxies*

Using only the EPIC-pn data we then have studied the X-ray emission produced by the two merging galaxies. Their $0.5-10$ keV band emission can be well described by a thermal component + a power law + a Gaussian emission line model, with soft X-ray absorption in addition to the Galactic one. Apart from the energy and equivalent width of the emission lines (see below), the best fit parameters are very similar for the two galaxies ($kT \sim 0.66$ keV, $\Gamma \sim 1.9$ and $N_{H,soft} \sim 1.5 \times 10^{21}$ cm^{-2}). Furthermore the two galaxies contribute to the $2-10$ keV emission of Arp 299 with similar intensities.

As expected, at energies smaller than 2 keV the dominant contribution is due to the thermal emission, associated with the starburst component. The luminosity of this thermal component in the $0.5-2$ keV energy range is $L_{0.5-2\ \mathrm{keV}} = 1.37 \times 10^{41}$ erg s^{-1} for NGC 3690 and $L_{0.5-2\ \mathrm{keV}} = 1.08 \times 10^{41}$ erg s^{-1} for IC 694.

In order to study the nuclear X-ray emission of NGC 3690 and IC 694, we now concentrate on the $2-10$ keV energy range, where the contribution from the soft thermal component is negligible.

In Fig. 2 we show the ratio of the XMM-*Newton* data to a single unabsorbed power law fit ($\Gamma = 1.89$ for NCG 3690 and $\Gamma = 1.97$ for IC 694); for both the sources, the residuals suggest the presence of line-like features at energies between 6.3 keV and 7 keV. In fact, adding a Gaussian emission line to the simple power law model we obtain in both cases fit improvements significant at the 99% according to the F–test; the results of our analysis are reported in Table 1 and are shown in Fig. 3.

The main difference between the two objects is the position and the equivalent width of the emission lines. In the case of IC 694 the energy of this feature is consistent with He-like Fe-Kα, while in the case of NGC 3690 the energy of the line is consistent with Fe-Kα from neutral Fe.

The XMM-*Newton* EPIC-pn data and in particular the properties (energy position and equivalent width) of the two observed features, as well as the power-law nature of the continuum, seem to suggest *the simultaneous presence of two AGNs in the merging system*. This evidence is also supported by the point-like appearance of the galaxies around the Iron line(s).

4. DISCUSSION

The $2-10$ keV spectrum derived for NGC 3690 from the XMM-*Newton* data argues strongly for the presence in this galaxy of the absorbed AGN inferred from the *Beppo*SAX observation. In fact the observed line is due to cold Fe-Kα, as expected if produced by transmission through the neutral material that is reponsible for the absorption measured by *Beppo*SAX. No sign of absorption is apparent in the XMM-*Newton* spectrum of NGC 3690, implying a column density of the order of 10^{24} cm^{-2}; in the energy range covered by XMM-*Newton* the primary emission is then totally absorbed and reprocessed to our line of sight via reflection and/or scattering. Assuming that NGC 3960 produces the whole hard X-ray flux observed by the *Beppo*SAX PDS, the continuum observed by XMM-*Newton* in the $2-10$ keV energy range is only $\sim 3\%$ of the emitted one.

The case of IC 694 is more ambiguous, since the 6.7 keV line from highly ionized Fe could be produced by a high temperature thermal plasma. In fact we have been able to reproduce the $2-10$ keV spectrum of IC 694 (continuum + line) using a thermal (MEKAL) model with $kT \simeq 7$ keV. The resulting temperature is higher than the values tipically found in SNRs, but consistent with that found for instance in the SNR N132D by Behar et al. (2001). Assuming a typical X-ray luminosity of young SNRs of $L_X \sim 10^{37}$ erg s^{-1} and a typical duration of the hot phase of 1000 yr (cfr. Persic & Raphaeli 2002), the measured $2-10$ keV luminosity of IC 694 ($\sim 10^{41}$ erg s^{-1}) implies about 10000 SNRs in the nuclear starburst and a supernovae rate of 10 yr^{-1}; the latter value is about a factor 15 above the supernovae rate estimated in IC 694 from radio and near-IR observations (Alonso-Herrero et al. 2000). Thus, although the data do not allow to definitively rule out the starburst origin of the emission line, this possibility implies rather extreme conditions (number of SNRs and high plasma temperature).

We note that the He-like Fe line at $E \sim 6.7$ keV is firmly detected in the starburst galaxy NGC 253. In order to compare our results with those obtained with *Chandra* for NGC 253 (Weaver et al. 2002) we estimated the central ($\sim 5''$) FIR luminosity of IC 694 using the radio measurement at 1.4 GHz (taken from the FIRST survey) and the well-known radio/IR correlation for star-forming galaxies (Condon 1992). Rescaling the Fe line luminosity of NGC 253 reported by Weaver et al. (2002) using the ratio of the FIR luminosities of the two galaxies we find that the starburst emission could account for about 20% of the observed line in IC 694.

We are therefore lead to consider the possibility that in the nucleus of IC 694 an AGN may be present as was also suggested on the basis of its radio properties (see Gehrz et al. 1983) Note that also NGC 253 may harbor a hidden AGN as suggested by some authors (see e.g. Mohan et al. 2002). Therefore we favor the AGN hypothesis; in this case, the presence of an He-like Fe-Kα emission line suggests that the AGN continuum could be scattered/reflected by a highly ionized gas.

Indeed modelling the reflected emission component as described by Ross & Fabian (1993) (available in XSPEC as a *table* model file; see also Ballantyne, Iwasawa & Fabian 2001) we find a perfectly consistent result. Since the predicted continuum due to reflection by an ionized slab can be characterized by features at low energies, we considered the full $0.5-10$ keV spectrum adding a MEKAL thermal component at low energies to take into account the starburst contribution. This model accounts quite well for the entire spectrum (χ^2/d.o.f.= 201.6/183), with $kT \sim 0.2$ keV, $\Gamma \sim 2$ and a ionization parameter[3] $\xi = 2.6 \times 10^3$.

The absence of neutral Fe-Kα line and the lack of any sign of absorption due to a medium with high column density indicate that the AGN inside IC 694 is not heavily absorbed ($N_H \leq 10^{22}$cm^{-2}). Observing the $2-10$ keV radiation we are probably looking at the direct emission of the central source, an AGN of low luminosity ($L_X \sim 10^{41}$ erg s^{-1}) surrounded by a cloud of highly ionized gas. Taking into account that the FIR luminosity of IC 694 is about 3 order of magnitude greater than the X-ray luminosity of the AGN, the emission from the star-forming nuclear region can completely masks the optical spectrum of a low luminosity active nucleus, preventing us from identifying its real nature (see e.g. Georgantopoulos et al. 2003).

To conclude, the existence of an AGN in each merging galaxy, one highly absorbed ($N_H \simeq 1.5 \times 10^{24}$ cm^{-2}) and of high luminosity ($L_{0.5-100\ \mathrm{keV}} \simeq 1.9 \times 10^{43}$ erg s^{-1}), the other one less luminous ($L_{2-10\ \mathrm{keV}} \simeq 10^{41}$ erg s^{-1}) and surrounded by a highly ionized gas, seems the most plausible hypothesis to explain the X-ray observations. In order to establish the AGN activity in IC 694, hard (> 10 keV) X-ray observations with angular resolution sufficient to disentangle the X-ray emission from the two galaxies would be needed. Such observations are far to come (Constellation X). Alternatively longer and/or repeated XMM-*Newton* observations, providing information on the variability of the X-ray sources, would be at the moment the only means to test the AGN hypothesis in IC 694.

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[3] $\xi \equiv L_{ill}/(nR^2)$, where L_{ill} is the luminosity of the continuum, n is the numerical density (part cm^{-3}) of the illuminated slab and R is the distance between the slab and the illuminating source.

TABLE 1

RESULTS OF THE SPECTRAL ANALYSIS (EPIC-PN 2 – 10 KEV): PARTIALLY ABSORBED POWER LAW + NARROW GAUSSIAN LINE.

	Power Law		Line						
	Γ	Norm[(a)]	E (keV)	Norm[(b)]	EW (eV)	$N_{H,soft}^{(c)}$ (10^{21} cm^{-2})	Flux[(d)] (10^{-13} erg cm^{-2} s^{-1})	Luminosity[(e)] (10^{41} erg s^{-1})	χ^2/d.o.f.
IC 694	1.95±0.20	$1.52^{+0.43}_{-0.32}$	$6.69^{+0.12}_{-0.09}$	$3.02^{+1.40}_{-1.46}$	818^{+380}_{-396}	2.35	4.33	1.02	40.62/45
NGC 3690[(f)]	$1.80^{+0.44}_{-0.32}$	$1.29^{+1.46}_{-0.49}$	$6.36^{+0.27}_{-0.14}$	$1.92^{+1.20}_{-1.31}$	422^{+262}_{-288}	5.56	4.37	1.06	50.45/50

NOTE: Errors are quoted at the 90% confidence level for 1 parameter of interest ($\Delta\chi^2 = 2.71$).
The net count rate in the 2 – 10 keV energy range is 0.0363 ± 0.0031 counts s^{-1} for IC 694 and 0.0401 ± 0.0031 counts s^{-1} for NCG 3690 (about 97.6% and 97.3% of the total counts, respectively).

[(a)] In units of 10^{-4} photons keV^{-1} cm^{-2} s^{-1} @1 keV.

[(b)] In units of 10^{-6} photons keV^{-1} cm^{-2} s^{-1} in the line.

[(c)] Column density of neutral hydrogen in addition to $N_{H,Gal} = 9.92 \times 10^{19}$ cm^{-2}.

[(d)] Observed X-ray fluxes.

[(e)] Observed X-ray luminosities.

[(f)] The line profile appears marginally broad ($\sigma = 0.32^{+0.64}_{-0.25}$ keV). This can be due to the blending of several lines: if the 2 – 10 keV continuum is produced by a “warm mirror” which scatters the primary radiation of the central source, than we would expect emission lines from highly ionized Fe. The present statistics does not allow us to be conclusive about this point.

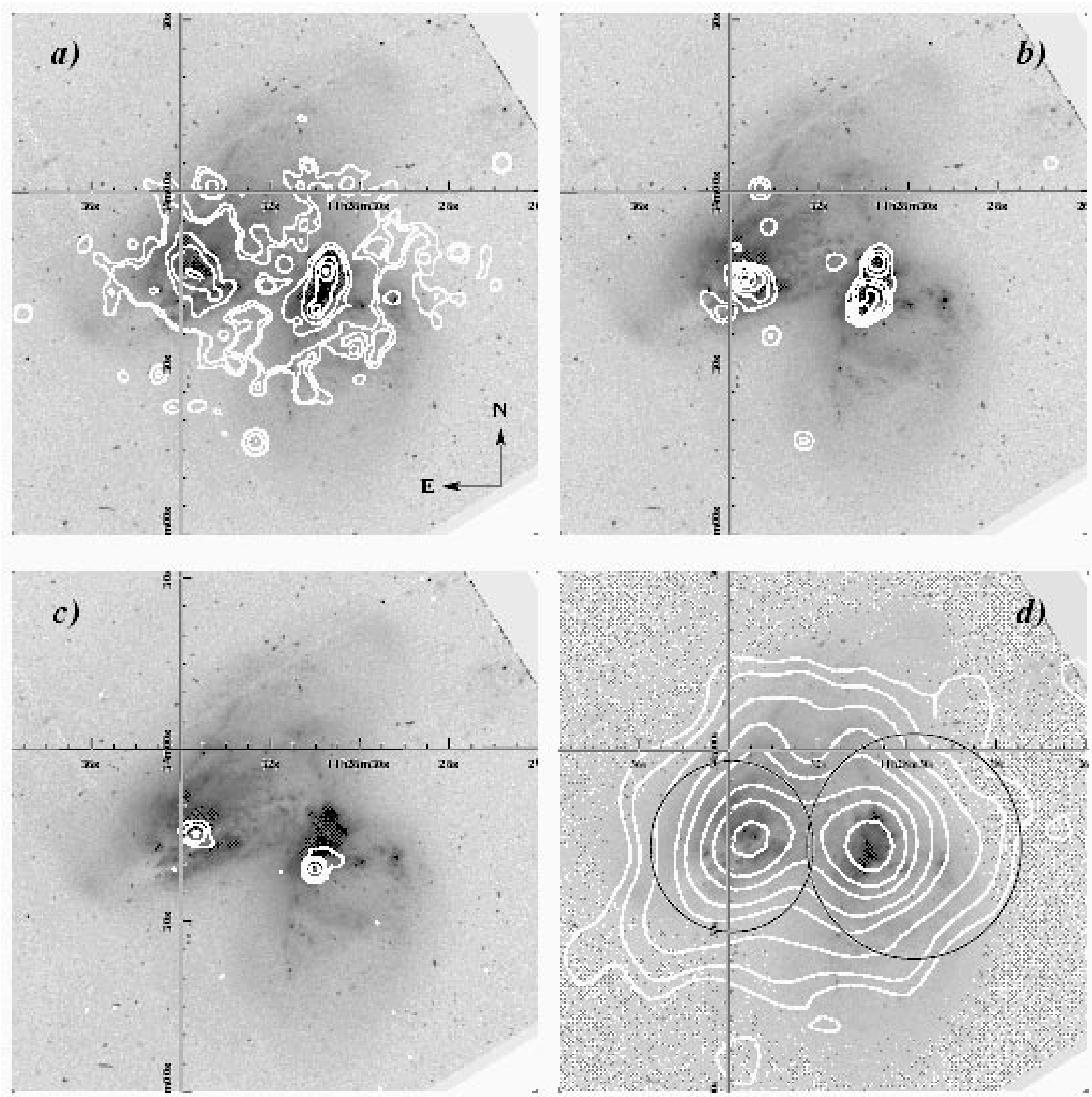

FIG. 1.— X-ray contours derived from the *Chandra* ACIS-I data in different energy ranges overimposed to the HST WFPC2 image; *panel a*: 0.5 − 2 keV (contours corresponding to 2σ, 5σ, 10σ, 20σ, 50σ, 75σ and 100σ above the background), where we detected 284 ± 17, 468 ± 22 and 307 ± 18 net counts within a radius of $3''$ from the emission peaks of the eastern, north-western and south-western knots respectively; *panel b*: 2 − 10 keV (contours corresponding to 2σ, 5σ, 10σ, 20σ and 30σ), where the net counts close ($r<3''$) to the emission peaks are 116 ± 11, 73 ± 9 and 165 ± 13; *panel c*: 6.3 − 6.9 keV (contours corresponding to 2σ, 5σ, 10σ and 20σ), with net counts of 6 for the eastern source and 15 for the western one. *Panel d*: XMM-*Newton* EPIC-pn contours of Arp 299 in the 0.5 − 10 keV band, corresponding to 3σ, 5σ, 10σ, 20σ, 30σ, 50σ, 70σ and 100σ, overimposed to the same image; the circles mark the regions considered for the spectral analysis.

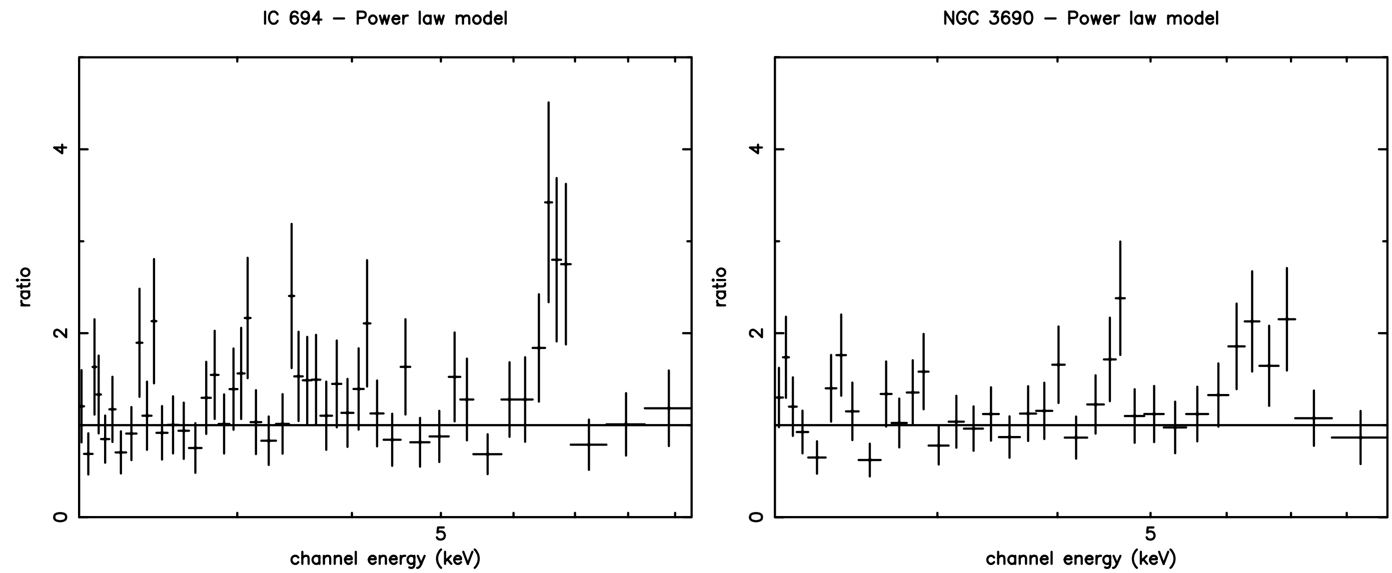

FIG. 2.— Ratio of the simple power-law model to the XMM-*Newton* EPIC-pn data for IC 694 and NGC 3690. For a graphic purpose, data of NGC 3690 have been binned to have a number of counts greater than 15 in each energy bin.

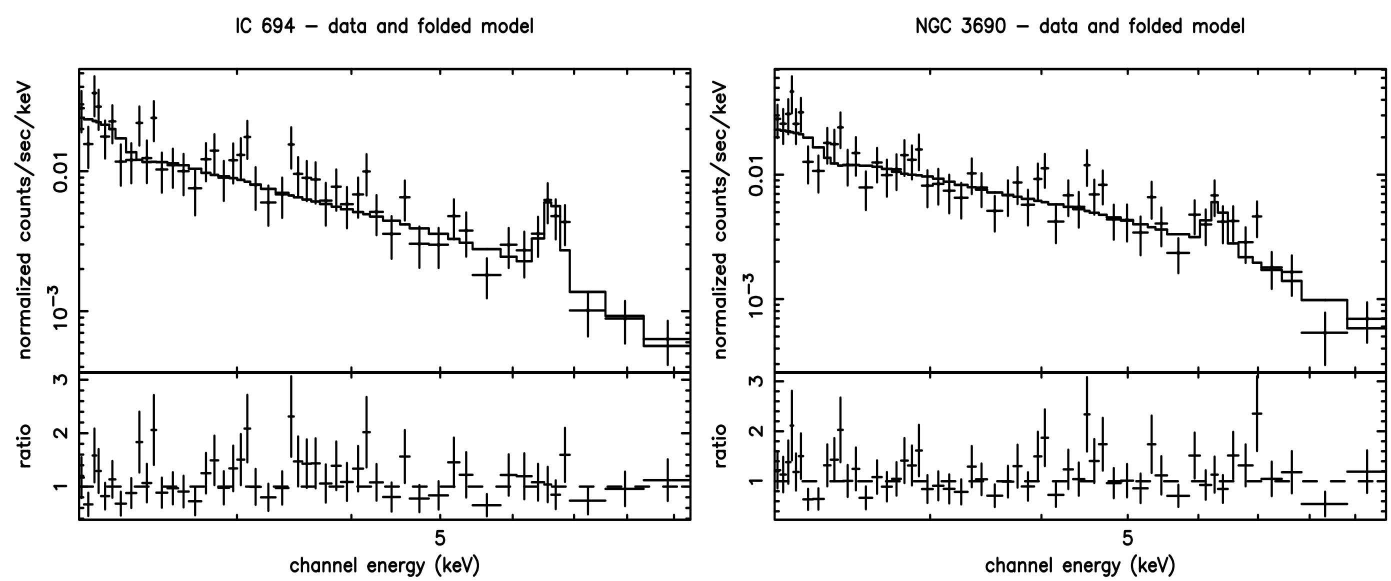

FIG. 3.— XMM-*Newton* EPIC-pn data fitted with a power law component and a Gaussian line.