A study of the X- and gamma-ray emission characteristics of Seyfert 2 galaxies(*)

G. MALAGUTI([1]), L. BASSANI([1]), G. DI COCCO([1]) and G. PALUMBO([1])([2])

([1]) *Istituto TESRE/CNR - Bologna, Italy*
([2]) *Dipartimento di Astronomia, Università di Bologna - Bologna, Italy*

(ricevuto il 5 Dicembre 1996; approvato il 27 Febbraio 1997)

Summary. — We have undertaken a study of X- and gamma-ray characteristics of a sample of Seyfert 2 galaxies observed by Ginga. A number of these sources are already included in our catalogue of AGN spectra. We plan to integrate these data at low energy with ROSAT and Einstein data, while at high energy above 50 keV observations have been performed and are planned with the instruments onboard the Compton observatory. The results obtained so far are presented.

PACS 98.52 – Normal galaxies; extragalactic objects and systems (by type).
PACS 96.40 – Cosmic rays.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

Seyfert galaxies are classified as type 1 or 2 (hereafter Sey 1 and Sey 2) according to the presence or absence of broad emission lines in their optical spectra. Generally speaking, type 1 have strong keV X-ray emission and type 2 do not. Strong X-ray emission has also been detected from a few objects with narrow emission lines very similar to Sey 2 galaxies; these are X-ray selected objects, defined as narrow emission line galaxies (NELG) and are now thought to be strongly related to Sey 2.

The discovery by Antonucci and Miller (1985) of a "hidden" Sey 1 spectrum in the polarized light of the archetype Sey 2 galaxy NGC 1068 has revived the longstanding hope that the two classes of galaxies could be unified according to a simple model. This unified model (Antonucci 1993 and references therein) assumes that an optically thick torus of gas and dust surrounds the active nucleus absorbing much of the radiation from optical/UV to several keV, including the broad emission lines. If the viewing angle to the galaxy is such that the nucleus is hidden by the torus, then the source is classified as type 2, otherwise as type 1. Consequently, the different properties of the two classes are simply due to the

(*) Paper presented at the VII Cosmic Physics National Conference, Rimini, October 26-28, 1994.

TABLE I. – *Seyfert* 2 *and* NELG X-*ray data available. The* 2–10 keV *fluxes have been taken from* GINGA; *the* 0.2–4 keV *fluxes have been taken from Einstein. F is in* ($\times10^{-12}$ erg cm^{-2} s^{-1}), *while* $N_{\rm H}$ *in* ($\times10^{22}$ atoms cm^{-2}).

Source name	α_{1950}	δ_{1950}	z	$F_{2-10\ \rm keV}$	$F_{0.2-4\ \rm keV}$	$N_{\rm H}$
0024+159	00 24	+15 54		<22.6		
MKN 553	00 33 50.5	+02 54 33	0.029	6.24		
MKN 957	00 39 09.7	+40 04 51	0.073	<14.3		
MKN 348	00 46 04.9	+31 41 05	0.015	10.15	0.36	
0052−709	00 52 06.4	−70 54 19	0.069	<26.2		
UM296	00 56 30.1	+00 43 55		27.94		
IRAS 01065−4644	01 06 32.0	−46 44 30	0.033	<10		
0107−038	01 07 13.7	−03 48 22		<17.4		
0111+849	01 11 58.5	+84 56 09		<9.66		
Fairall 294	01 13 47.0	−50 27 12	0.017	<37.8		
NGC 526A	01 21 38.0	−35 19 42	0.019	6.06	39.6	0.76
MKN 573	01 41 22.9	+02 05 56	0.017	<3.9	0.34	
Fairall 377	02 09 01.4	−49 56 03	0.046	<7.24		
3C 67	02 21 18.1	+27 36 37	0.310	<11.43		
NGC 1068	02 40 07.1	−00 13 31	0.003	6.75	1.5	
MKN 372	02 46 31.4	+19 05 49		2.0	0.87	
MKN 1058	02 46 46.9	+34 46 53	0.017	3.74		
MKN 1066	02 56 49.9	+36 37 21	0.020	0.93		
MKN 607	03 22 17.8	−03 13 04	0.009	<6.79		
MKN 612	03 28 10.2	−03 18 28	0.021	<4.46		
NGC 1365	03 31 41.0	−36 18 24	0.006	4.77	1.50	
0338−712	03 38 01.0	−71 13 18		<31.17		
MKN 617	04 31 35.5	−08 40 56	0.016	17.41	0.43	
0438−084	04 38 43.2	−43 38 54	0.015	2.37		
NGC 1672	04 44 55.0	−59 20 18	0.004	3	0.76	
NGC 1667	04 46 10.5	−06 24 24	0.015	7.44		
0457−756	04 57 36.0	−75 37 00	0.018	10.93		
NGC 1808	05 05 58.6	−37 34 37	0.003	8.10		
NGC 2110	05 49 46.4	−07 28 02	0.008	10	3.33	2.35
0557−579	05 57 05.5	−57 58 44		<12.1		
MKN 3	06 09 48.4	+71 03 11	0.014	6	0.78	30
0629−664	06 29 11.4	−66 27 51		<254.8		
0631−640	06 31 41.7	−64 03 39		<6.37		
4U0708−49	07 08 31.1	−49 53 53	0.041	<6.1		
MKN 78	07 37 56.8	+65 17 42	0.037	<4.65	0.35	
0930+682	09 30 34.5	+68 13 55		<9.12		
NGC 2992	09 43 17.7	−14 05 43	0.008	40	27.5	0.8
MCG −5−23−16	09 45 28.4	−30 42 57	0.008	44.7	21.0	1.24
IRAS 10329−1352	10 32 57.9	−13 51 58	0.016	8.8		
1040+706	10 40 32.1	+70 40 04		11.53		
ARP 107	10 49 30.0	+30 20 00		<12.87		
MKN 745	11 37 20.6	+17 13 55	0.011	<4.43		
MKN 1457	11 44 42.5	+52 43 39	0.048	<14.12		
WAS 32	11 45 30.2	+22 06 24	0.027	<2.17		
NGC 3982	11 53 52.3	+55 24 12	0.004	<3.49		
AKN 347	12 01 56.3	+20 35 40	0.022	<1.11		
WAS 45 nar.	12 02 10.2	+31 27 20	0.025	3.25		

TABLE I. – *Continued.*

Source name	α_{1950}	δ_{1950}	z	$F_{2-10\ \mathrm{keV}}$	$F_{0.2-4\ \mathrm{keV}}$	N_{H}
NGC 4117	12 05 14.2	+43 24 17	0.003	<19.13		
NGC 4388	12 23 14.6	+12 56 17		21.0	0.81	27
NGC 4507	12 32 55.0	−39 38 00	0.012	16	0.53	50
1242+165	12 42 13.2	+16 32 52		<0.81		
NGC 4945	13 02 31.0	−49 12 12	0.002	50		
NGC 4968	13 04 24.0	−23 24 42	0.009	<3.90		
1305−241	13 05 58.7	−24 06 52	0.014	<12.06		
WAS 66	13 13 42.3	+29 38 43	0.037	<0.85		
NGC 5135	13 22 56.5	−29 34 26	0.013	<5.03	0.29	
MKN 789	13 29 55.4	+11 21 44	0.032	<61.9		
1331−234	13 31 54.0	−23 25 30		<5.33		
1331−231	13 31 54.4	−23 11 27		6.95		
MKN 266A	13 36 15.0	+48 31 54	0.028	<0.70		
MKN 268	13 38 54.0	+30 37 49	0.024	<8.99	<0.186	
1350−383	13 49 57.6	−38 21 33		8.61		
NGC 5347	13 51 05.0	+33 44 11	0.008	<7.74		
MKN 273	13 42 51.7	+56 08 13	0.038	<1.3	0.57	
MKN 463	13 53 39.9	+18 36 57	0.051	<3.9	0.194	
WAS 87	13 58 46.0	+21 28 54	0.027	7.54		
IRAS 14095−2652	14 09 31.0	−26 52 24	0.023	<2.3		
NGC 5506	14 10 39.1	−02 58 26	0.006	79.7	18.5	3.2
NGC 5643	14 29 28.0	−43 57 12	0.004	<5	1.10	
NGC 5674	14 31 22.5	+05 40 38	0.025	10	0.45	27.6
1443+272	14 43 26.8	+27 14 36	0.029	<14.34		
MKN 822	14 43 54.1	+16 18 18	0.054	<67.38		
1454+491	14 54 08.1	+49 06 37		<5.79		
WAS 96	15 08 58.0	+31 39 48	0.033	<5.46		
NGC 5929	15 24 18.9	+41 50 41	0.008	<6.53		
3CR 321	15 29 32.8	+24 14 33	0.096	<2.67		
ARP 220	15 32 47.0	+23 40 08	0.018	<0.86	0.40	
MKN 1102/1103	15 55 27.7	+41 41 11	0.035	<5.41		
NGC 6217	16 35 05.1	+78 18 05	0.005	16.8		
NGC 6251	16 37 58.5	+82 38 19	0.024	<180.5		
PKS 1718−649	17 18 46.1	−64 57 48		<118.9		
NGC 6300	17 12 18.0	−62 45 54	0.003	13.67		
1729+596	17 29 40.1	+59 40 30	0.028	11.16	0.24	
1733−595	17 33 11.0	−59 54 42		<29.87		
1734+493	17 34 51.1	+49 20 21		<33.04		
MKN 507	17 48 55.8	+68 43 05	0.056	<4.89	0.598	
AKN 539	18 27 34.3	+50 20 18	0.017	5.49		
IRAS 1832−594	18 32 32.5	−59 26 40	0.019	29.75		
ESO 103−G35	18 33 22.0	−65 28 18	0.013	20.7	<20.58	
I 4777	18 44 10.0	−53 12 12	0.018	<11.09		
1845+721	18 46 15.7	+72 07 43		11.93		
OW 637	20 21 13.3	+61 27 18	0.227	<41.69		
IC 5063	20 48 12.8	−57 15 32	0.011	10		
IRAS 21116+0158	21 11 39.9	+01 58 11	0.013	<0.88		
3C 433	21 21 30.5	+24 51 15	0.103	<6.90		

TABLE I. – *Continued.*

Source name	α_{1950}	δ_{1950}	z	$F_{2-10\ \mathrm{keV}}$	$F_{0.2-4\ \mathrm{keV}}$	N_{H}
NGC 7172	21 59 07.6	−32 06 42	0.008	41.68		
NGC 7314	22 33 00.0	−26 18 36	0.006	36.70		
NGC 7496	23 06 59.0	−43 42 00	0.005	<8	0.46	
2306+050	23 06 01.8	+05 05 13		<9.89		
ESO 148−IG02	23 12 51.0	−59 19 36	0.044	<2.72		
NGC 7582	23 15 38.0	−42 38 36	0.005	50	3.7	20
NGC 7672	23 24 59.8	+12 06 38	0.013	<28.61		
NGC 7674	23 25 24.4	+08 30 13	0.029	8.2		
MKN 930	23 29 29.5	+28 40 18	0.018	<11.12		
2353+299	23 53 12.4	+29 56 11		48.37		
I 1515	23 53 30.2	−01 16 10		<9.37		

inclination of the torus axis with respect to the line of sight.

Observation of absorbed objects in the hard-X / soft-gamma energy band can offer important tests of the unified model, because of the penetrating power of the radiation that at these frequencies can escape column densities of up to $10^{23-24}\ \mathrm{cm}^{-2}$.

In our work we have started from a sample of Sey 2 and NELG observed by Ginga. These data have been integrated with our AGN high-energy spectral catalogue (Malaguti *et al.* 1994) and are being currently integrated with ROSAT observations. At higher energies (above 50 keV) the database is being improved with observations, some of them already performed, made with the instrumentation aboard the Compton Observatory. In this contribution we present and discuss the results so far obtained.

2. – The X-ray data and the sample

During the manoeuvering operation, Ginga covered about 30% of the sky for about 3 years. Analysis of these data produced an enlarged list of Sey 2 and NELG observed in the 2–10 keV range: 88 objects were in the instrument field of view among which 29 were positive detections (18 new sources). From the available X-ray data we have compiled a list (see table I) of Sey 2 and NELG observed in the medium (2–10 keV) X-ray band. This sample contains all objects for which a measurement (positive detection or upper limit) of the flux is available in the 2–10 keV band.

The Ginga data have been integrated, where possible (see table I), with redshift, soft (0.2–4 keV) flux taken from Einstein observatory data, and hydrogen column density. This Sey 2 and NELG database is continuously updated with the data coming from the operating observatories.

3. – The hard X- and gamma-ray continuum in Seyfert 2 and NELG

Figure 1 shows the hardness ratio (2–10 keV flux / 0.5–4.5 keV flux) as a function of the hydrogen column density (cm^{-2}) for those objects taken from table I for which N_{H} and soft–X-ray flux measurements are available.

We find evidence for a correlation between the two parameters as expected because the large column densities in the Sey 2 objects will absorb most of the soft–X-ray photons that impinge upon the torus making them underluminous in the soft–X-ray band with respect to the hard X-ray band.

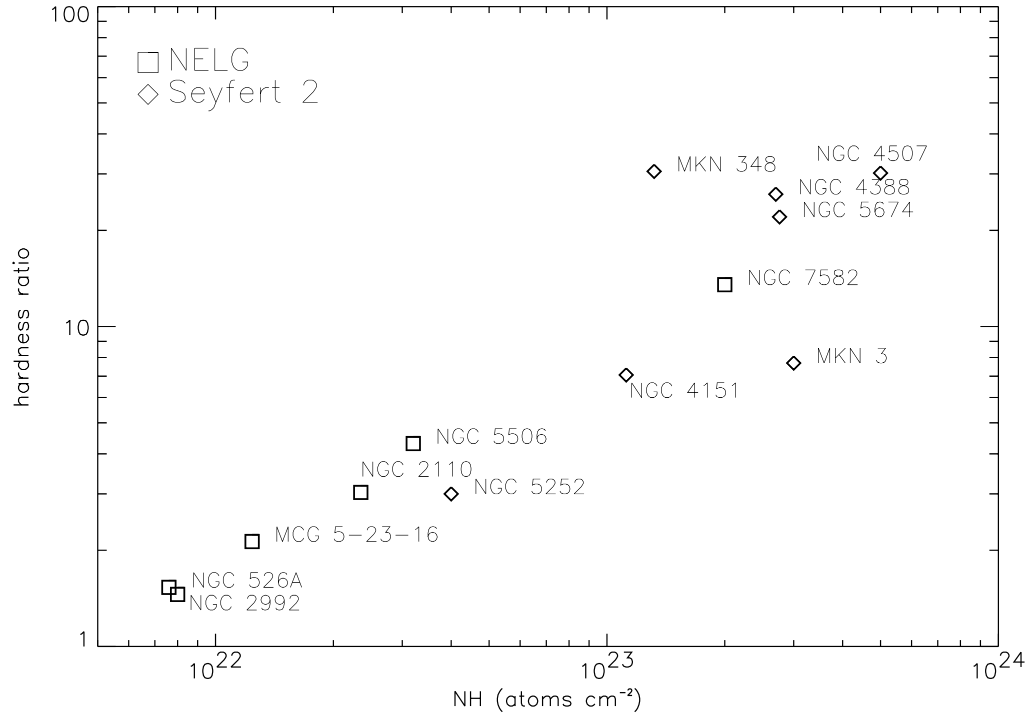

Fig. 1. – Hardness ratio *vs.* hydrogen column density for a list of Seyfert 2 (optically selected) and NELG (X-ray selected). Note the separation between the two classes.

We find a correlation coefficient, R, of 0.76 (the probability of achieving this by chance from a random sample is less than 0.4%); exclusion of Mkn 348 from the sample increases R to 0.90 with a corresponding probability $< 0.1\%$.

However the observed correlation is surprising in view of the fact that part of the soft–X-ray flux is probably due to scattered emission into our line of sight (Awaki 1991) and also to diffuse emission as observed in NGC 4388 (Matt *et al.* 1995) and NGC 1068 (Williams *et al.* 1992). These two effects should weaken the correlation. A larger sample of data together with more detailed spatial and spectral information in the soft–X-ray band is needed to investigate this issue.

It is also interesting to note that NELGs have column densities and hardness ratios lower than Sey 2. This finding coupled with the higher luminosity observed in NELG supports the current idea that they may be characterized by intrinsically thinner torii than Sey 2, or that our line of sight intercepts only the edge of the torus (Mulchaey *et al.* 1992; Krolik *et al.* 1994).

A further confirmation of the unified model comes from the observation of the optically selected Seyfert 2 NGC 4507. We have performed this observation with the instrument OSSE (Johnson *et al.* 1993) onboard the Compton observatory. The source has been detected with a spectrum which is well described by an exponential model of the form $e^{-(E/kT)}$, with $kT = 50.7^{+13.0}_{-9.8}$ and a 100 keV intensity of $(5.2 \pm 0.7)\ 10^{-6}$ photons cm^{-2} s^{-1} keV^{-1} (Bassani *et al.* 1995). Comparison between NGC 4507 and other Seyfert galaxies indicates that although at low energies a difference between type 1 and 2 objects is possible (*e.g.*, Zdziarski *et al.* 1995), at high energies the observed shapes are indeed similar. We interpret this as evidence that the primary source emission (*i.e.* not re-processed by material in the source) is the same for both types.

4. – Future works

On the basis of the available data we selected from tableI a set of sources to be studied with the instrument BATSE onboard the Compton observatory. This proposal has been accepted and the selected sources were observed by BATSE in 1995 and 1996, whereas occultation data so far collected will be searched in order to find useful data for the remaining sources. We have chosen BATSE both for its operative energy range which covers the region between hard X-rays and soft–γ-rays where the opacity of the material is minimum, and also because this instrument is capable to produce images of the sky using the Earth occultation technique (Zhang *et al.* 1993).

One of the problems with the AGN unified scheme is the lack of type 2 quasars so far discovered. In order to confirm if they are really rare or have so far eluded observations, we have proposed to observe with OSSE two bright X-ray emitting active galaxies, namely 3C 109 and NGC 7172, which have not been scheduled for observations up to now. Both objects belong to the class of highly obscured type 2 AGN: one (NGC 7172) represents an example of a nearby and the other (3C 109) a faraway type 2 source. In particular, 3C 109 could well be the first absorbed QSO observed at high energies. We have chosen the instrument OSSE onboard the Compton observatory since its sensitivity ensures detectability of both sources in a standard observation time. This proposal has been accepted and the two sources are scheduled for observation within the first six months of 1995.

Note added in proofs. – Analysis of BATSE data of a sample of 17 Seyfert 2 galaxies has yielded a number of positive detection in the 20–100 keV band: NGC 7172, MCG−5−23−16, NGC 5506, NGC 4388, NGC 4507, NGC 7582, MKN 463 have all been detected at more than 5σ (Bassani *et al.* 1996). NGC 7172 has been observed by OSSE and detected in the 50–200 keV range at more than 5σ, while no detection has been obtained from 3C 109. A catalogue of X-ray selected Seyfert 2 has been recently compiled. This catalogue is complemented with data from radio to X-ray frequency (Polletta *et al.* 1996).

REFERENCES

ANTONUCCI R. R. J., *Annu. Rev. Astron. Astrophys.*, **297** (1993) 621.
ANTONUCCI R. R. J. and MILLER J. S., *Astrophys. J.*, **297** (1985) 621.
AWAKI H., Ph. D. Thesis, Nagoya University (1991).
BASSANI L. *et al.*, *Astrophys. J.*, **444** (1995) L73.
BASSANI L. *et al.*, *Astron. Astrophys. Suppl.*, **120** (1996) 559.
JOHNSON W. N., *Astrophys. J. Suppl.*, **86** (1993) 693.
KROLIK J. H., *Astrophys. J.*, **420** (1994) L57.
MALAGUTI G. *et al.*, *Astrophys. J. Suppl.*, **94** (1994) 517.
MATT G. *et al.*, *Astron. Astrophys.*, **292** (1994) 13.
MULCHAEY J. S., MUSHOTZKY R. F. and WEAVER K. A., *Astrophys. J.*, **390** (1992) L69.
POLLETTA M. *et al.*, *Astrophys. J. Suppl.*, **106** (1996) 399.
WILLIAMS O. R. *et al.*, *Astrophys. J.*, **389** (1992) 157.
ZHANG S. N. *et al.*, *Nature*, **366** (1993) 245.
ZDZIARSKI A. A. *et al.*, *Astrophys. J. Lett.*, **438** (1995) 63.