A sample of 27 unabsorbed Seyfert 2 galaxies with and without hidden broad line region

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Abstract. We have compiled a sample of 27 nearby unabsorbed Seyfert 2 type galaxies ($N_H < 10^{22}cm^{-2}$) to investigate them for a hidden broad line region (HBLR). We have derived the ratio $(N_{ph}/N_{ion})_{h\nu>55eV}$ of the number of N_{ph} traced by the [OIII] λ5007Å emission line to the number N_{ion} of high ionizing photons $h\nu > 55eV$ emitted by the central AGN source for all sample's objects. This ratio is a probe of the collimation hypothesis of the Unified model and it is considerably larger than 1 in the anisotropic case. Following our results about a half of the sample's objects have $(N_{ph}/N_{ion})_{h\nu>55eV} > 1$ and some of them possess a HBLR. The Eddington ratios L_{Bol}/L_{Edd} are calculated for 17 objects. There is a critical value of the Eddington ratio, 10^{-3}, below which there is not a HBLR. According to this condition, only 4 objects of our sample possess a HBLR and they also have $(N_{ph}/N_{ion})_{h\nu>55eV} \gtrsim 1$.
Key words: galaxies: active, X-rays: galaxies, galaxies: Seyfert, polarization

Извадка от 27 Сийфърт-2 галактики с ниско поглъщане със и без скрита област на широките крила на линиите

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Направихме извадка от 27 близки Сийфърт 2 галактики с ниско поглъщане в рентгеновия диапазон на спектъра ($N_H < 10^{22}cm^{-2}$), за да ги изследваме за наличие на скрита област на широките крила на линиите. Получихме отношението $(N_{ph}/N_{ion})_{h\nu>55eV}$, което представлява броят на фотоните N_{ph}, проследени от емисионната линия [OIII] λ5007Å, съотнесен към броя N_{ion} на йонизиращите фотони с $h\nu > 55eV$, излъчени от централния източник. Това отношение представлява оценка за анизотропията на полето на лъчение в рамките на хипотезата на Обединения модел. В анизотропния случай това отношение е значително по-голямо от 1. Според нашите резултати, около половината от обектите от извадката имат $(N_{ph}/N_{ion})_{h\nu>55eV} > 1$, някои от които притежават скрита област на широките крила на линиите. Изчислихме Едингтоновите отношения L_{Bol}/L_{Edd} за 17 обекта. Съществува критична стойност на Едингтоновото отношение, 10^{-3}, под която обектите не притежават скрита област на широките крила на линиите. Съобразно това условие установихме, че само 4 обекта от нашата извадка притежават такава област и имат $(N_{ph}/N_{ion})_{h\nu>55eV} \gtrsim 1$.

1 Introduction

The standard theory of active galaxies is based on the idea of an accretion disk around a massive black hole. This theory predicts the presence of a hard X-ray continuum from a central engine, that is strong enough to photoionize the Broad Line Region (BLR, close to the source) and the Narrow Line Region (NLR, at < 100 pc from the nuclear engine).

Seyfert galaxies are divided into two types: Seyfert 1 and Seyfert 2. The Unified model is orientation-based unification scheme. According to this model, the two types Seyferts are actually the same objects but they differ only in their orientation. Like Seyfert 1 type galaxies, Seyfert 2 also possess a BLR but it is obscured by a molecular torus.

In fact, there are some exceptions from this model. Not all Seyfert 2 galaxies have a BLR in polarized light, and not all Seyfert 2 galaxies have column densities higher than $10^{22}cm^{-2}$. Normally, the X–ray column density of neutral hydrogen N_H in type 2 Seyferts is significantly higher than this in type 1 objects because of the torus around the nucleus which is on the line of sight. However, there are some Seyfert 2 galaxies, which are X–ray unabsorbed and their measured column densities are $N_H < 10^{22}cm^{-2}$ (Panessa and Bassani 2002).

In this paper we have used a sample of 27 nearby unabsorbed Seyfert 2 type galaxies to check their Compton thin nature and probe them for a HBLR, using the Eddington ratio L_{Bol}/L_{Edd} as a criterion for existence of a HBLR . We have also calculated the ratio $(N_{ph}/N_{ion})_{h\nu>55eV}$ for our objects to find a relation between this ratio and the presence of a HBLR.

2 The sample

Our sample contains 27 nearby unabsorbed Seyfert galaxies and most of them are classified by NED as Seyfert 2 type, but others as type 1.8 - 1.9. For the sake of simplicity, we generally call them Seyfert 2. All objects have $N_H < 10^{22}cm^{-2}$. We adopt the cosmological constant H_0= 75 km s^{-1} Mpc^{-1}.

The observed hard X-ray (2-10 keV) flux $F_{2\text{–}10keV}$, the extinction-corrected flux $F_{[OIII]}$ λ5007 and the far-infrared flux F_{IR} are given in Table 1.

F_{IR} is calculated from the equation:

$$F_{IR} = F_{25\mu m} \times \nu_{25\mu m} + F_{60\mu m} \times \nu_{60\mu m} \ , \tag{1}$$

where $F_{25\mu m}$ and $F_{60\mu m}$ are the IRAS fluxes, $\nu_{25\mu m}$ and $\nu_{60\mu m}$ are the frequencies at 25 and 60 microns. This definition of the far-infrared flux was used by Mulchaey et al. [1994].

We have investigated the Compton thin nature of our objects. For this purpose we have used the fluxes ratios: $F_{2\text{–}10keV}/F_{IR}$, $F_{2\text{–}10keV}/F_{[OIII]}$ and $F_{[OIII]}/F_{IR}$. These three ratios provide an independent way to establish which is the dominant component between AGN or Starburst. At the same time they are a powerful tool in the detection of Compton thick sources when an X-ray spectral analysis is not sufficient (see Panessa and Bassani 2002). Starburst galaxies show a value $F_{[OIII]}/F_{IR} < 10^{-4}$ while AGNs show a value $F_{[OIII]}/F_{IR} > 10^{-4}$. Typically type 1 AGNs and Compton thin type 2 show ratios $F_{2\text{–}10keV}/F_{IR} \sim 0.1$, while Compton thick type 2 objects show ratios lower than 5×10^{-4}.

The $F_{2\text{–}10keV}/F_{[OIII]}$ ratio has been studied in a large sample of Seyfert 2 galaxies (Panessa and Bassani 2002): all Compton thin Seyferts show ratios higher than ~ 1, while Compton thick sources show ratios below this value.

The objects of our sample, shown in Fig.1 and Fig.2, belong to the area of Compton thin sources. Only NGC 4501 lies in the Starburst region, but

Table 1. Observed and calculated data for 27 unabsorbed Seyfert 2 galaxies

Name	z	LogN_H	Γ	$F_{2-10keV}$	$F_{[OIII]}$	F_{IR}	$F_{25\mu m}$	$F_{60\mu m}$	N_{ph}/N_{ion}
MRK 273x	0.458000	21.15	1.66	0.01	0.00014	-	-	-	0.15
MRK 334	0.021945	20.64	2.00	1.366	0.2	34.30	1.05	4.34	-
IRAS F01475-0740	0.017666	21.59	2.06	0.075	0.0625	16.76	<0.959	1.05	2.52
IRAS 20051-1117	0.031498	<21.60	1.92	0.24	0.0152	7.64	0.174	1.11	0.31
ESO 540-G001	0.026845	20.28	1.99	0.08	0.024	25.93	0.557	3.85	1.15
CGCG 303-017	0.037132	21.56	1.71	0.215	0.0126	14.69	0.299	2.22	0.56
CGCG 551-008	0.023616	<20.60	2.09	0.031	0.0047	7.14	<0.250	0.828	0.41
MCG 03-05-007	0.019927	<20.48	1.85	0.069	0.0102	12.67	0.252	1.93	0.90
UGC 03134	0.028710	21.23	1.34	0.019	0.0065	5.04	<0.122	0.716	8.24
IC 1631	0.030841	<21.50	2.10	1.00	0.052	6.86	<0.134	1.05	0.14
NGC 2992	0.007710	21.95	1.70	7.4	0.680	54.11	1.57	7.34	0.90
NGC 3147	0.009407	<20.46	1.94	0.22	0.009	44.39	0.674	7.26	0.19
NGC 3660	0.012285	20.26	1.83	0.236	0.0593	12.04	0.224	1.87	1.64
NGC 3941	0.003095	≤21.00	2.1	0.004	0.00329	-	-	-	2.17
NGC 4472	0.003326	21.48	1.61	0.038	0.0003	0.91	<0.049	<0.065	0.10
NGC 4501	0.007609	21.30	1.5	0.011	0.0054	83.86	1.28	13.7	8.44
NGC 4565	0.004103	20.11	1.7	0.02	0.006	42.03	0.732	6.65	2.95
NGC 4579	0.005067	20.39	1.88	0.52	0.009	28.25	0.379	4.74	0.10
NGC 4594	0.003416	21.23	1.5	0.16	0.007	21.51	0.497	3.11	0.75
NGC 4698	0.003342	20.91	1.91	0.10	0.0024	3.14	<0.157	0.258	0.12
NGC 5033	0.002919	20.01	1.7	0.28	0.017	82.8	1.15	13.8	0.60
NGC 5929	0.008312	20.76	1.7	0.135	0.0408	65.14	<0.300	<1.00	2.97
NGC 5995	0.025194	21.94	1.81	2.89	0.66	28.56	0.859	3.65	1.59
NGC 6221	0.004999	22.04	1.9	1.4	0.00214	-	-	-	0.01
NGC 6251	0.024710	21.88	1.83	0.14	0.057	1.32	0.100	<0.023	2.66
NGC 7590	0.005255	<20.96	2.29	0.12	0.017	44.52	0.831	6.91	0.19
NGC 7679	0.017139	20.34	1.75	0.60	0.1083	50.85	1.15	7.41	1.52

Note. The columns contain, as follows: the name of the galaxy; redshift z as reported in NED; N_H in units of cm^{-2} (from other references); photon index Γ (from other references); observed hard X-ray (2-10 keV) flux in units of 10^{-11} ergs s^{-1} cm^{-2} (from other references); extinction-corrected flux of [OIII] λ5007 emission in units of 10^{-11} ergs s^{-1} cm^{-2} (observed F[OIII] is from other references); far-infrared flux in units of 10^{-11} ergs s^{-1} cm^{-2}; $F_{25\mu m}$ [Jy] and $F_{60\mu m}$ [Jy] (IRAS fluxes from NED); N_{ph}/N_{ion} ratio.
The data in this table is taken from: Bassani et al. [1999], Bian and Gu [2007], Cappi et al. [2006], Dadina [2007], Gu and Huang [2002], Gu et al. [2006], Lumsden and Alexander [2001], Moran et al. [1996], Mulchaey et al. [1994], Panessa and Bassani [2002], Panessa et al. [2006], Polletta et al. [1996], Shu et al. [2007], Tran [2003], Wang and Zhang [2007].

close to the boundary between the two regions. This galaxy lies also in the area of Compton thick sources in Fig.1, but in Fig.2 it belongs to the area of Compton thin sources. NGC 4501 is classified as a Compton thin object in the other papers (Panessa and Bassani 2002, Shu et al. 2007, Wang and Zhang 2007) and we believe that is true.

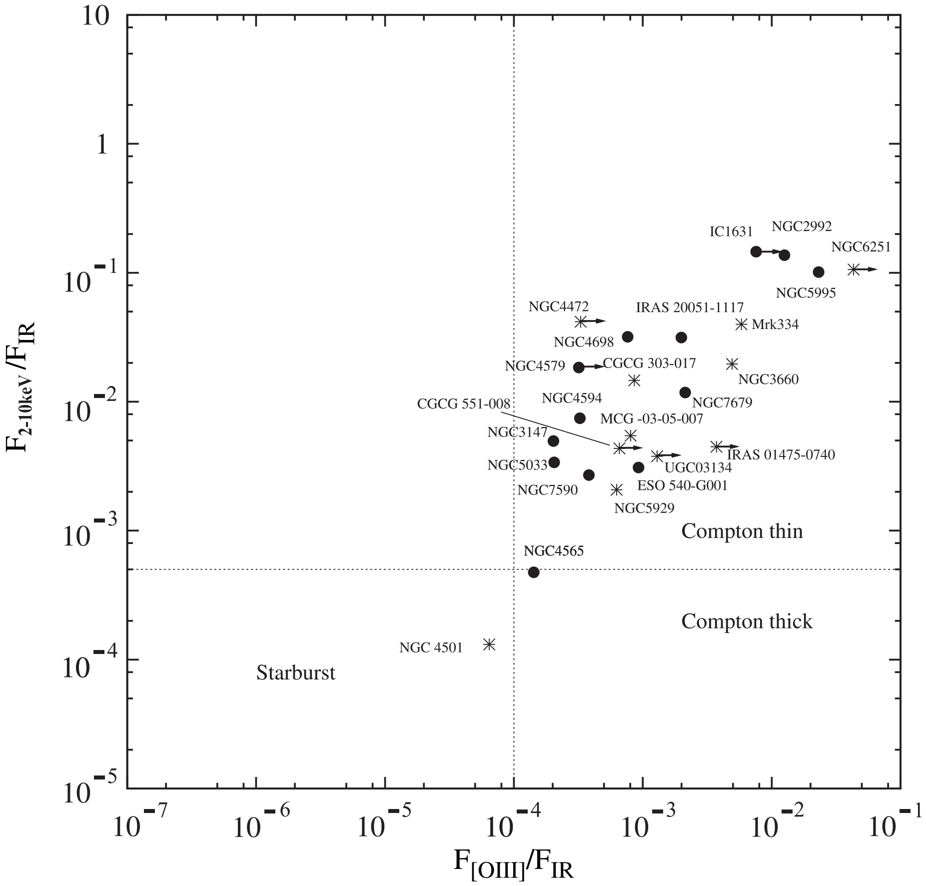

Fig. 1. Diagnostic diagram of $F_{2-10keV}/F_{IR}$ vs. $F_{[OIII]}/F_{IR}$ for the objects of the sample. We separate with dashed lines the Compton thin, Compton thick and Starburst region. The fluxes are listed in Table 1. The objects which are plotted in the same diagram in Panessa and Bassani [2002] are marked with circles; those which are new in this figure are shown with asterisks.

3 Calculations and results

We have calculated $(N_{ph}/N_{ion})_{h\nu>55eV}$ from:

$$N_{ion} = \int_{55eV}^{\infty} \frac{F_\nu^{nt}}{h\nu} d\nu = 4\pi R_G^2 \frac{F_{h\nu=55eV}^{nt}}{h\Gamma},\ F_\nu^{nt} = F_{\nu_0}(\nu_0/\nu)^{\Gamma}, \tag{2}$$

where N_{ion} is the number of ionizing photons with $h\nu > 55eV$ provided by the central AGN source, R_G is the distance to the galaxy, F_ν^{nt} is the flux

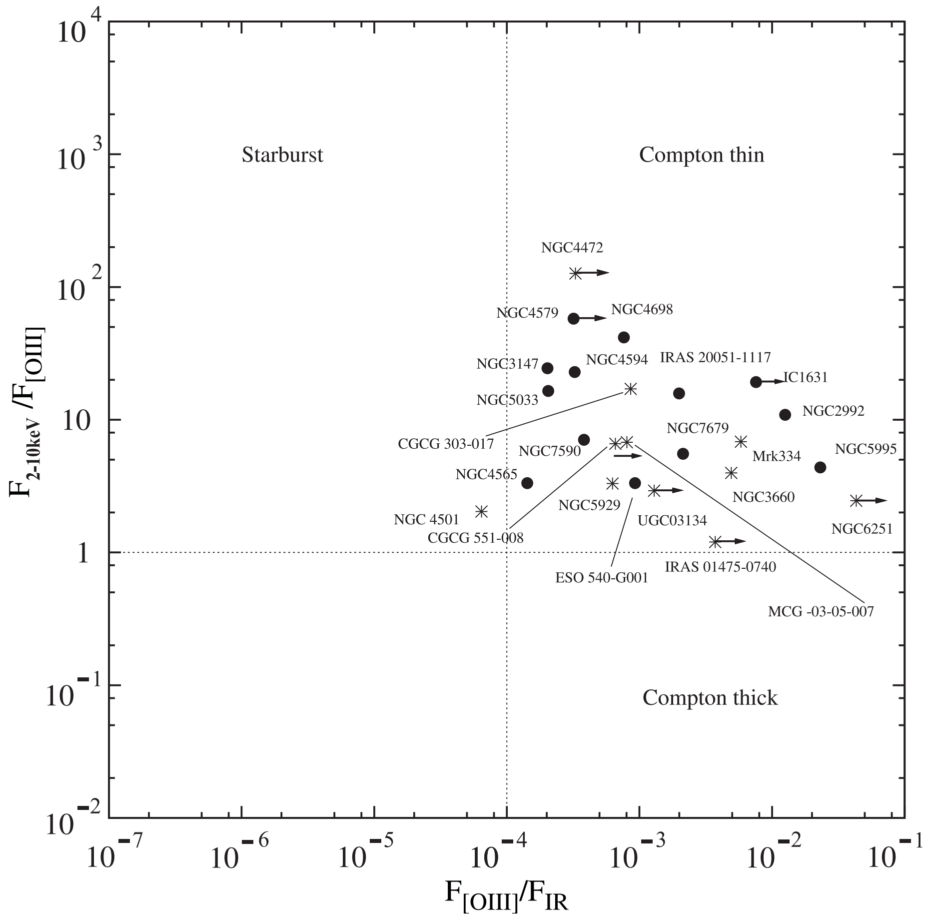

Fig. 2. Diagnostic diagram of $F_{2-10keV}/F_{[OIII]}$ vs. $F_{[OIII]}/F_{IR}$ for the objects of the sample. We separate with dashed lines the Compton thin, Compton thick and Starburst region. The fluxes are listed in Table 1. The objects which are plotted in the same diagram in Panessa and Bassani [2002] are marked with circles; those which are new in this figure are shown with asterisks.

from the central source, F_{ν_0} is the flux at $h\nu_0 = 13.6eV$ and Γ is the photon index,

$$N_{ph} = \frac{\alpha_G(O^{+2}, T_e)L^{corr}([O^{+2}]\lambda 5007)CF^{-1}}{\alpha_{5007}^{eff}(n_e, T_e)h\nu_{5007}}; \tag{3}$$

Table 2. Black hole masses and Eddington ratios for galaxies with measured stellar velocity dispersions

Name	$\sigma[km\,s^{-1}]$	$M_{BH}(\times 10^7)[\mathcal{M}_\odot]$	$Log(L_{Bol}/L_{Edd})$
MRK 334	79*	0.3	-0.08
NGC 2992	166.1	6.4	-1.55
NGC 3147	261.3	39.5	-3.70
NGC 3660	95*	0.7	-1.67
NGC 3941	168.7	6.8	-5.64
NGC 4472	291.1	61.0	-5.55
NGC 4501	160.9	5.6	-4.33
NGC 4565	136.0	2.9	-4.32
NGC 4579	154.4	4.8	-2.94
NGC 4594	241.1	28.6	-4.57
NGC 4698	132.7	2.6	-3.75
NGC 5033	131.4	2.5	-3.41
NGC 5929	120.6	1.8	-2.66
NGC 6221	111*	1.3	-1.95
NGC 6251	310.7	79.3	-3.35
NGC 7590	99*	0.8	-2.77
NGC 7679	96*	0.7	-0.99

Note. The columns contain, as follows: the name of the galaxy; σ – stellar velocity dispersion of the galaxy (the data for most of the objects is taken from the archive LEDA. The values marked with asterisks are taken from Gu et al. [2006]); M_{BH} – black hole mass; Eddington ratios (L_{Bol}/L_{Edd}).

N_{ph} is the total number of ionizing photons that must be available to produce the observed [OIII] λ5007 emission, $L^{corr}([O^{+2}]\lambda 5007)$ is the luminosity corrected for extinction, $\alpha_G(O^{+2}, T_e) = 5.1 \times 10^{-12} cm^3 s^{-1}$ is the recombination coefficient at $T_e \approx 10^4 K$, $\alpha_{5007}^{eff}(n_e, T_e) = 0.7 \times 10^{-9} cm^3 s^{-1}$ is the effective recombination coefficient at $n_e = 3 \times 10^5 cm^{-3}$ and $T_e = 10^4 K$. The covering factor is $CF = 0.07$ (Yankulova et al. 2007). Calculated (N_{ph}/N_{ion}) ratios are listed in Table 1. In the meantime, we have used the empirical relation $M_{BH} - \sigma$ from Wang and Zhang [2007] to estimate the mass of the central massive black hole for each object of our sample:

$$M_{BH} = 1.35 \times 10^8 \mathcal{M}_\odot (\sigma/200 km\ s^{-1})^{4.02}, \tag{4}$$

where σ is the central stellar velocity dispersion of the galaxy.

The Eddington ratio is estimated from:

$$(L_{Bol}/L_{Edd}) = 0.1\, (\frac{L_{Bol}}{1.4 \times 10^{44} erg\ s^{-1}})\, (\frac{M_{BH}}{10^7 \mathcal{M}_\odot})^{-1}, \tag{5}$$

where the bolometric luminosity is $L_{Bol} = 30\, L_{2\text{–}10keV}$ (Panessa et al. 2006); see Table 2.

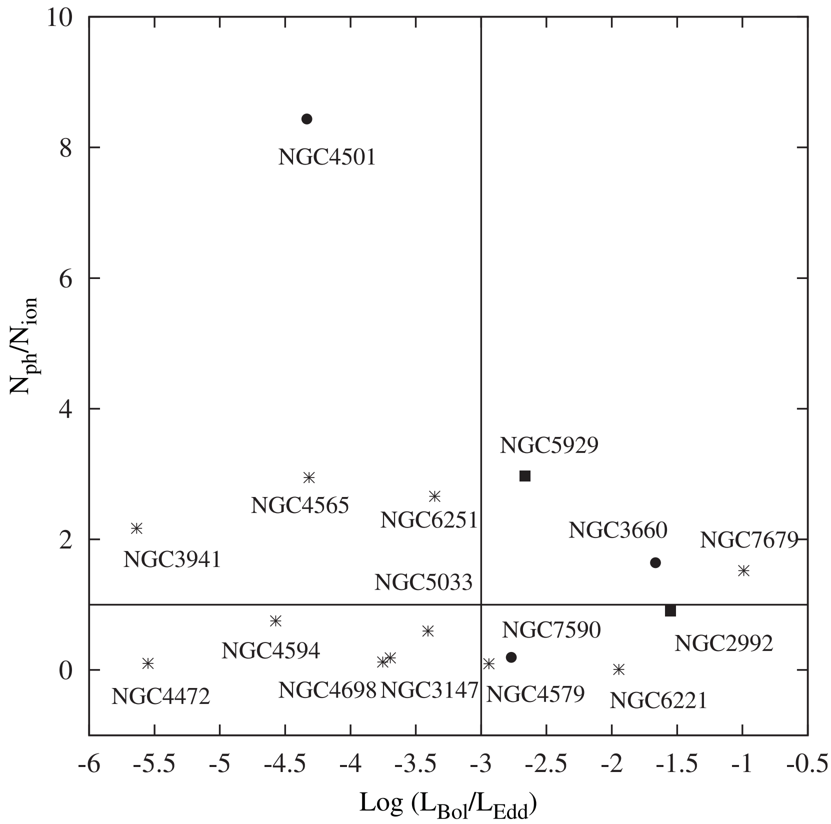

Fig. 3. (N_{ph}/N_{ion}) vs. $Log(L_{Bol}/L_{Edd})$. (N_{ph}/N_{ion}) is an anisotropy parameter. The horizontal line $(N_{ph}/N_{ion} = 1)$ shows the boundary between the objects with hidden AGN source $(N_{ph}/N_{ion} > 1)$ and those without hidden central engine (Nph/Nion $<$ 1). The vertical line $((L_{Bol}/L_{Edd}) = -3)$ shows the critical value of the Eddington ratio, below which Seyfert 2 galaxies do not have a HBLR (Nicastro et al. 2003). The objects which have polarized broad lines from observations (see Shu et al. 2007) are marked with squares in the figure; those without polarized broad lines from observations are shown with circles; asterisks denote the galaxies which are not observed in polarized light and are not specified about existence of a HBLR.

The unabsorbed Seyfert 2 galaxies are divided into two sub-classes: non-HBLR Seyfert 2 and HBLR Seyfert 2 galaxies. There is a critical value of the Eddington ratio 10^{-3} (the vertical line in Fig.3), below which there is no HBLR (Nicastro et al. 2003). But when the Eddington ratio is $\geq 0.2 - 3$, the broad lines also disappear. It is obvious that in Fig.3 there are 9 objects below the critical value of Nicastro and these galaxies do not have a HBLR.

Our sample contains 4 objects which have polarized broad lines (IRAS F01475-0740, NGC 2992, NGC 5929, NGC 5995) and also 4 objects without polarized broad lines (MRK 334, NGC 3660, NGC 4501, NGC 7590) - see Shu et al. [2007]

Conclusion

We proved the Compton thin nature of the galaxies of our sample. According to the results about a half of the sample's objects have $(N_{ph}/N_{ion})_{h\nu>55eV} > 1$ and some of them possess a HBLR.

The Eddington ratios L_{Bol}/L_{Edd} are calculated for 17 objects. Using the critical value of the Eddington ratio, 10^{-3}, below which there is not a HBLR, we found that only 4 objects of our sample possess a HBLR and they also have $(N_{ph}/N_{ion})_{h\nu>55eV} \gtrsim 1$.

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