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The AGN Population in Nearby Galaxies

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Abstract. In order to determine the incidence of black hole accretion-driven nuclear activity in nearby galaxies, we have compiled radio data for the LINERs, composite LINER/HII and Seyfert galaxies from a complete magnitude-limited sample of bright nearby galaxies (Palomar sample). Our results show an overall radio detection rate of 54% (22% of all bright nearby galaxies) and we estimate that at least ∼50% (∼20% of all bright nearby galaxies) are true AGN. By comparing the radio luminosity function of the LINERs, composite LINER/HII and Seyferts galaxies in the Palomar sample with those of selected moderate-redshift AGN, we find that our sources naturally extend the radio luminosity function of powerful AGN down to powers of about 10 times that of Sgr A*.

1. Introduction

The search for low-luminosity active galactic nuclei (LLAGN) in nearby galaxies has been the subject of many optical surveys. The Palomar survey [10,11,12] has been very useful in this regard by providing a sensitive magnitude-limited (B_T <12.5 mag) sample of almost 500 bright nearby galaxies. About half of the sources are emission-line nuclei, classified as Seyferts, LINERs or composite LINER/HII galaxies, the last category displaying both LINER and HII properties. However, characterizing the powering mechanisms of the sources is not straightforward, particularly in low-luminosity sources. Many of these galaxies possess circumnuclear star-forming regions which blend with and may even drown out the presence of a weak active galactic nucleus (AGN).

Optimally it is necessary to pick spectral regions where the contrast between any hypothetical LLAGN component and circumnuclear stellar component is maximized. X-rays are very useful in this regard as shown by the hard X-ray studies of LLAGN [13,23,24,25]. In the absence of spectral AGN signatures such as a Seyfert or quasar-type continuum or broad emission lines, radio observations can offer an alternative method for determining the LLAGN incidence in nearby galaxies. Measurements of radio flux, compactness, radio spectral index[1] and brightness temperatures provide the necessary diagnostic tools for determining the nature of the radio emission.

Several important radio surveys have been conducted on the magnitude-limited Palomar bright, nearby galaxy sample [10,11,12], revealing a large fraction of radio cores (Figure 1). In

[1] $F_\nu \propto \nu^{-\alpha}$ throughout.

a recent Very Large Array (VLA) 5 and 1.4 GHz, 1" resolution survey of the low-luminosity Seyferts of the Palomar sample [14], it was found that over 80% of the sources harbour a radio core. A VLA, 15 GHz, 0.25" resolution survey of a distance-limited sample of low-luminosity Seyferts, LINERs and composite LINER/HII galaxies [18,19,20] revealed that ~40% of the objects harbour subarcsecond-scale compact radio cores. A recent Multi-Element Radio-Linked Interferometer Network (MERLIN) 5 GHz, 0.1" resolution survey of a subsample of LINERs [5] detected several new subarcsecond-scale radio cores. A similar study with the VLA, at 8.4 GHz, 2.5" resolution of all the composite LINER/HII galaxies in the Palomar sample [7,8], revealing radio cores in ~25% of the sample sources.

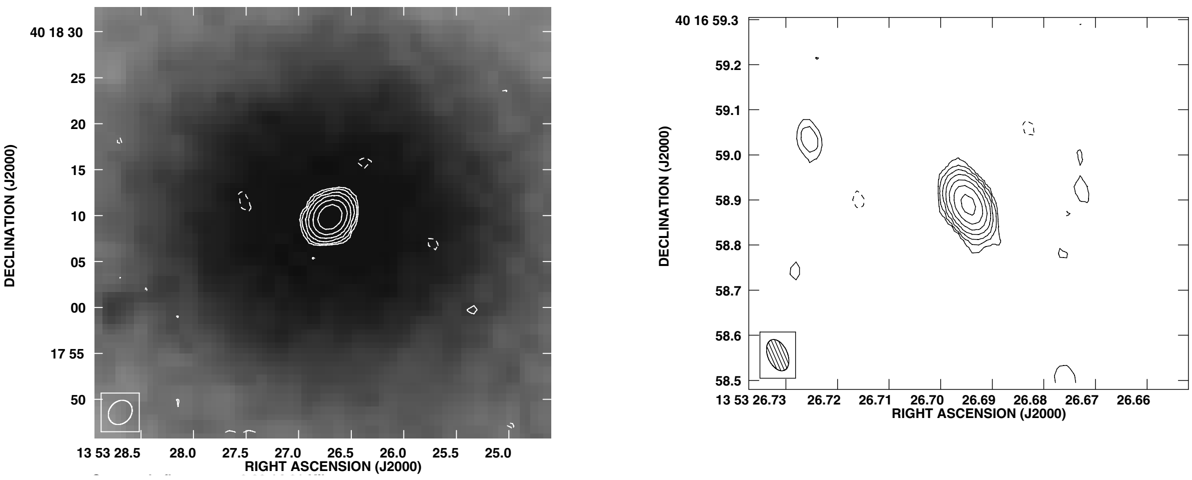

Figure 1. Examples of the radio observations *Left:* The radio contours of the composite galaxy NGC 5354 obtained with the VLA at 8.4 GHz and 2.5" resolution, superimposed on the DSS image [8]. *Right:* The radio contours of the LINER galaxy NGC 5353 obtained with MERLIN at 5 GHz and 0.1" resolution [5].

However, although the radio core emission in these sources is consistent with the presence of a LLAGN, we cannot exclude a stellar origin from the brightness temperature figures ($T_B < 10^5$ K; [3]) obtained at these resolutions. As conclusive judgement requires Very Long Baseline (VLBI)-resolution, multi-wavelength Very Long Baseline Array (VLBA) and European Very Long Baseline Interferometer Network (EVN) observations have been obtained for selected subsamples of low-luminosity Seyferts, LINERs and composite LINER/HII galaxies that showed arcsecond- or subarcsecond-scale radio cores [1,4,6,9,18,19,26]. In sources with subarcsecond- or arcsecond-scale radio peak emission above 2.5 mJy, results reveal a 100% detection rate of high-brightness temperature ($T_B > 10^8$ K), compact, flat spectrum ($\alpha < 0.5$) radio cores, enforcing the LLAGN scenario for the radio emission [1,6,18,26]. Their low radio luminosities suggest we are probing the very faint end of the AGN population.

Unambiguously determining the physical nature of the nearby galaxy radio cores is more than of mere phenomenological interest. If they truly contain an accretion-powered nucleus, then they obviously need to be included in the AGN population. Their non-trivial numbers impact on several astrophysical problems ranging from the cosmological evolution of the AGN luminosity function to their contribution to the X-ray background.

2. The Radio Data

In order to construct a representative AGN radio luminosity function (RLF) of the local Universe, we have used the emission-line (excluding HII) sources in the Palomar sample. All of these sources have now been observed at 2.5” resolution or better. We shall refer to the 196 LINERs, composite sources and Seyferts which satisfy both the magnitude (B_T <12.5 mag) and declination criteria (δ >0 degrees) of the Palomar survey as the ‘LTS sources’ for brevity (LTS meaning LINER-Transition-Seyfert); these sources constitute the present sample.

Ideally, we would like to have a homogeneous set of radio observations. But lacking such a survey, we have assembled a list of radio measurements used to derive the RLF for the LTS sample sources. Radio observations at different frequencies have been converted to 5 GHz assuming a spectral index of 0.7 and also corrected for different cosmologies if necessary. When multiple observations of the same galaxy were available, by order of preference we choose HU01 for Seyferts, the radio observations in [7,8], and [18,19,20] for composite galaxies, [18,19,20] and MERLIN observations in [5] for LINERs.

We caution that the radio-detection rate will depend strongly on observing frequency, resolution and sensitivity. At higher frequencies, many sources may escape detection because spectral indices are not always flat and instrumental sensitivities will also be lower. Furthermore, the source may suffer resolution effects. With this in mind, the [18,19,20] samples, and [5,7,8] observations provide only lower limits to the radio-detection rate in LTS sources.

3. Statistics

3.1. Radio Detection Rate

Galaxies are considered detected if their radio flux density is above 5σ, where σ is the typical noise associated with the respective survey. 82%, 43%, and 49% of the Seyferts, LINERs, and composite galaxies were detected in the radio at 2.5” or less. This is equivalent to an overall radio-detection rate of 54% in all LTS sources or 22% of all bright nearby galaxies (Palomar sources). For Type 1 and 2 LTS sources, the radio detections are 89% and 46%, respectively. Of the Type 1 radio-detected sources (which must be genuine AGN), 59% are classified as Seyferts and 35% are LINERs. Both broad-lined composite galaxies (Type 1.9 NGC 1161 and NGC 2985) were detected. 100% of Type 1 Seyferts and 67% of Type 1 LINERs were detected. 46%, 68%, and 94% of the Type 2 radio-detected sources are Seyferts, LINERs, and composite galaxies, respectively.

3.2. AGN Fraction

We can also estimate the fraction of these radio-detected LTS sources that are likely to be genuine AGN. In the absence of unambiguous optical spectral signatures of AGN activity (e.g., broad emission lines), the radio regime provides an alternative and complementary diagnostic. Although not a necessary condition for the presence of an AGN, a compact, flat-spectrum radio core is indicative of synchrotron self-absorption, which is associated with jet emission from AGN. However, there are several caveats. First, ground-based optical spectra and VLBI-resolution radio images typically sample very different spatial, and presumably temporal, scales. Thus, optical and radio signatures of AGN activity need not occur concurrently. Second, because the mechanism of jet formation is still uncertain, radio emission cannot be regarded as an inevitable by-product of AGN activity. Finally, empirical evidence suggests that there is a radio flux density threshold of 2 mJy below which the sources become difficult to detect at milliarcsecond-scale resolution using current facilities [4,9,18]. Known sources with submilliJansky radio cores and/or hard X-ray detections (e.g., NGC 660 and NGC 7331; [7,9]), which are likely to be genuine AGN, or sources that are highly radio variable can be missed by these relatively shallow, milliarcsecond-scale resolution observations. We therefore caution that our estimate based on radio detection is a lower limit to the true AGN fraction in LTS sources. For the sake of homogeneity, we will restrict ourselves to observations of <1" resolution. With the above caveats in mind, we conclude that at least 80% of the Seyferts [14], 40% of the LINERs [5,18,19,29] and 20% of the composite sources [5,18,19,20] are likely AGN. Based on the presence of compact radio emission, the total fraction of LTS sources and bright nearby galaxies harbouring AGN is therefore ∼50% and ∼20%, respectively.

According to classical AGN unification schemes [2], Type 2 objects are simply Type 1 AGN seen edge-on, whereby the molecular torus blocks the direct view of the broad-line region (BLR). However, in the case of LLAGN it is not entirely clear that unification schemes are readily applicable. There is growing evidence that not all low luminosity Seyferts, LINERs and composite sources possess a BLR and when they do the BLR is weak; there are only twelve sources in the Palomar sample [11] classified as Type 1.0-1.8 and all are Seyferts. We can then conservatively argue that all Type 1 sources, which exhibit broad-line emission in their spectra, are genuine AGN. Therefore, based solely on the presence of broad-line emission, we can estimate that at least 20% of the LTS sources and 10% of all bright nearby galaxies harbour an AGN.

4. The Local Radio Luminosity Function

Because the sample sources are nearby (median D = 17 Mpc), we have considered a flat, Euclidean Universe with q_0=0.5 and H_0=75 km s^{-1} Mpc^{-1} for the subsequent calculations. The V/V_{max} method [22] was applied in order to construct the RLF at 5 GHz. The main constraints arise from the magnitude limit of the Palomar survey, which is taken to be B_{limit}=12.5 mag (Ho, Filippenko & Sargent 1995), and the radio flux limit of the survey from where the radio luminosity of the LTS source was obtained. Moreover, only galaxies with positive declination were observed, which restricts the survey area covered to 2π. The calculation of the RLF is then performed over equal bins in log of radio power (0.4 dex). Statistical errors associated with the space densities were assigned assuming Poisson statistics.

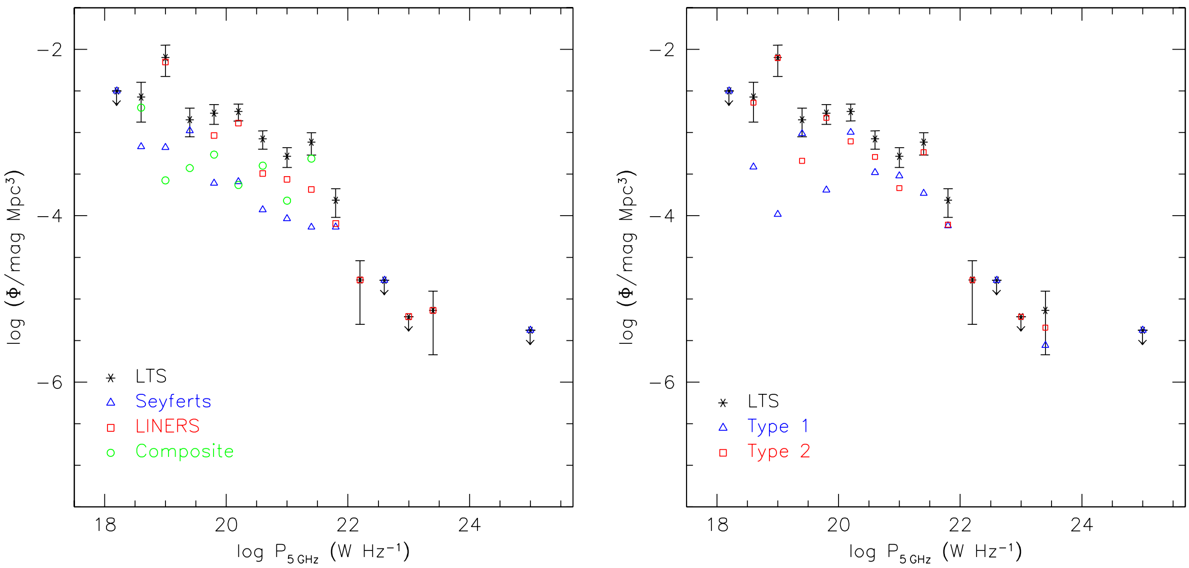

Figure 2. *Left:* The radio luminosity function for the LTS, Seyferts, LINERs and composite galaxies in the Palomar sample. *Right:* The radio luminosity function for the LTS, Type 1 and Type 2 sources in the Palomar sample.

5. Discussion

Figure 2 contains the derived RLF for the radio-detected LTS sample sources, together and separately for Seyferts, LINERs, composite sources and then also for Type 1 and Type 2 objects (with and without broad lines, respectively). It is worth mentioning that, particularly on the low-power end, the RLF is irregular; this is the most likely due to density inhomogeneities in our local volume.

Inspection of the plots shows that space densities of LTS sources continue to rise with decreasing radio power, with some evidence of flattening below 10^{20} W Hz^{-1}, partly due to incompleteness of the radio survey (see also discussion in [18]). At all radio powers the space densities are clearly dominated by the LINER galaxies, in particular at the high radio power end ($> 10^{22}$ W Hz^{-1}). Both Seyfert and LINER galaxies contribute to the steady rise in space densities. On the other hand, the space densities of composite sources appear relatively flat in the range 19<log $P_{5\,\mathrm{GHz}}$ <21 W Hz^{-1}.

For Type 1 and Type 2 sources, at all radio powers the space densities are dominated by the more numerous Type 2 sources, although 56% of the Type 2 sources were not detected on scales <2.5". They do, however, span the same radio power range as Type 1 sources and appear to turn over at a power of 10^{21} W Hz^{-1}. Type 2 sources roughly mimic the composite source and Seyfert behaviour in its flattening below log $P_{5\,\mathrm{GHz}}$ =21 W Hz^{-1}.

It is possible that Type 2 or (equivalently composite sources and some LINERs) are a mixed case, whereby only a small fraction of these are genuine AGN. However, various lines of evidence, as stated above, suggest that we are underestimating the number of LLAGN in the LTS sample. Long integration X-ray and radio observations should prove useful in this regard to provide a complete survey with uniform sensitivity and resolution. If there is a significant population of submillijansky LLAGN that we cannot detect with the present observations, then by including them in the RLF, we should expect higher space densities, in particular at the low-luminosity end of the RLF.

Furthermore, because we have compiled radio measurements from surveys with different resolutions, is it likely that in some cases we are overestimating radio flux densities. Many of these sources are known to suffer from resolution effects [7,8,9,19,20]; the radio power of the underlying AGN may be an order of magnitude or so lower than given by the arcsec-scale observations. The overall effect would be to shift the RLF to lower radio luminosities.

It is interesting to compare our results with available published surveys. In [18] the authors have derived a RLF for a distance-limited sample of Palomar sources. Comparison between our analysis and theirs shows that the results are in rough agreement, within the errors. In particular, the larger sample of the LTS sources presented in this study (our 106 versus their 68 radio-detected sources) allows us to confirm the low-power turnover seen in the RLF.

We have also derived a RLF for the Markarian [17] and CfA Seyferts [15] (2" resolution VLA radio data from [16]), converting flux densities to 5 GHz assuming $\alpha = 0.7$ (Fig. 3; left). We caution that the Markarian Seyferts have been observed with the Westerbork Radio Synthesis Telescope (WRST) and nuclear radio flux densities may be over-estimated. The RLFs are consistent with the Palomar Seyfert RLFs for powers above 10^{21} W Hz^{-1}. The rising of the LTS and Palomar Seyfert RLF towards lower powers demonstrates that the LTS sample contains fainter and more local sources than those in the Markarian and CfA samples. This result is in agreement with that found in VLA/N05 and in HU01, considering the difference in RLF frequency and binning.

Similarly, we can compare our RLF with the AGN sources in the 2dF Galaxy Redshift Survey [21] (2dF/NVSS AGN sample). Galaxies in this sample have been classified as AGN according to their spectral characteristics; they show either an absorption-line spectrum like that of a giant elliptical, an absorption spectrum with weak LINER-type emission lines or stellar continuum dominated by nebular emission lines of [OII] or [OIII], which are strong compared to any Balmerline emission. The sample has been cross-correlated with the NVSS catalog. We have converted the flux densities to 5 GHz assuming an $\alpha = 0.7$ and corrected for different cosmologies. The resulting RLF is plotted along with the LTS RLF in Figure 3 (right).

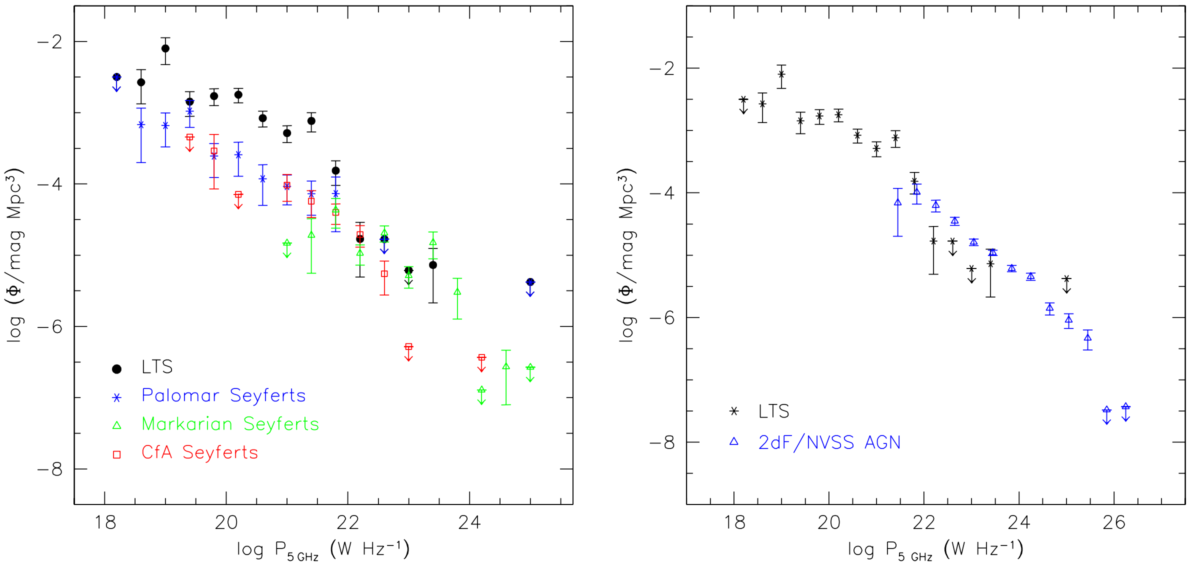

Figure 3. *Left:* The radio luminosity function for the LTS sources compared to the Palomar, Markarian [17] and CfA [15,16] Seyferts. *Right:* The radio luminosity function for the LTS sources compared to the 2dF/NVSS AGN sample [21].

Because the 2dF/NVSS AGN sample is relatively nearby (median z=0.2), it allows a direct comparison with the LTS source RLF. We caution, however, that because this sample has been cross-correlated with NVSS data, the radio flux densities may be slightly over-estimated. The plot shows that there is an overlap in radio luminosities for the LTS and 2dF/NVSS AGN RLF in the regime log $P_{5\,\mathrm{GHz}} \approx 21$ and 23 W Hz^{-1}. In this region of overlap, both the normalization and slope of the two RLFs are roughly similar, within the errors. The LTS sources naturally extend the 2dF/NVSS AGN RLF to lower luminosities. To emphasize the extreme low powers sampled by our RLF, we note that the lowest power LTS sources are only ~10 times more powerful than Sgr A*. The overall shape and the smooth transition from the 2dF/NVSS AGN RLF to the LTS RLF, suggest a luminosity continuation between these two source populations. It is natural to view the LTS sources as the low-redshift, low-luminosity counterparts of the AGN as sampled by the 2dF/NVSS AGN survey.

6. Conclusions

We have compiled radio observations for the non-stellar emission-line sources – low-luminosity Seyferts, LINERs and composite LINER/HII galaxies – in the magnitude-limited Palomar survey. Our results reveal a radio-detection rate of 54% (or 22% of all bright nearby galaxies), with a more than 50% detection rate (or 20% for all bright nearby galaxies) of low-luminosity active nuclei. The radio detection of the Seyferts, LINERs and composite LINER/HII sources in the Palomar survey allow the construction of a local radio luminosity function. Our results show that the Seyferts, LINERs and composite LINER/HII sources form a smooth luminosity transition from higher redshift, more luminous AGN as sampled by the Markarian and CfA Seyfert and 2dF/NVSS AGN survey.

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References

[1] Anderson, J. M., Ulvestad, J. S., & Ho, L.C. 2004, ApJ, 603, 42
[2] Antonucci, R. 1993, ARA&A, 31, 473
[3] Condon, J. J. 1992, ARA&A, 30, 575
[4] Falcke, H., Nagar, N. M., Wilson, A. S., & Ulvestad, J. 2000, ApJ, 542, 197
[5] Filho, M. E., Barthel, P. D., & Ho, L. C., 2006, A&A, 451, 71
[6] Filho, M. E., Barthel, P. D., & Ho, L. C. 2002b, A&A, 385, 425
[7] Filho, M. E., Barthel, P. D., & Ho, L. C. 2002a, ApJS, 142, 223
[8] Filho, M. E., Barthel, P. D., & Ho, L. C. 2000, ApJS, 129, 93
[9] Filho, M. E., Fraternali, F., Markoff, S., Nagar, N. M., Barthel, P. D., Ho, L. C., & Yuan, F. 2004, A&A, 418, 429
[10] Ho, L. C., Filippenko, A. V., & Sargent, W. L. W. 1997b, ApJ, 487, 568
[11] Ho, L. C., Filippenko, A. V., & Sargent, W. L. W. 1997a, ApJS, 112, 315
[12] Ho, L. C., Filippenko, A. V., & Sargent, W. L. W. 1995, ApJS, 98, 477
[13] Ho, L. C. et al. 2001, ApJ, 549, L51
[14] Ho, L. C., & Ulvestad, J. S. 2001, ApJS, 133, 77
[15] Huchra, J. & Burg, R. 1992, ApJ, 393, 90
[16] Kukula, M. J., Pedlar, A., Baum, S. A., & O'Dea, C. P. 1995, MNRAS, 276, 1262
[17] Meurs E. J. A. & Wilson A. S. 1984, A&A, 136, 206
[18] Nagar, N. M, Falcke, H., & Wilson, A. S. 2005, A&A, 435, 521
[19] Nagar, N. M, Falcke, H., Wilson, A. S., & Ulvestad, J. S. 2002, A&A, 392, 53
[20] Nagar, N. M, Falcke, H., Wilson, A. S., & Ho, L. C. 2000, ApJ, 542, 186
[21] Sadler, E., et al. 2002, MNRAS, 329, 227
[22] Schmidt, M. 1968, ApJ, 151, 393
[23] Terashima, Y., Ho, L. C., & Ptak, A. F. 2000, ApJ, 539, 161
[24] Terashima, Y., Ho, L. C., Ptak, A. F., Mushotzky, R. F., Serlemitsos, P. J., Yaqoob, T., & Kunieda, H. 2000, ApJ, 533, 729
[25] Terashima, Y., & Wilson, A. S. 2003, ApJ, 583, 145
[26] Ulvestad, J. S., & Ho, L. C. 2001b, ApJ, 562, L133