Chapter 2

# HOW ARE AGN FOUND?

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**Abstract** We discuss the very different methods in each wavelength band for selecting and finding Active Galactic Nuclei (AGN). We briefly review the history of the different techniques for finding AGN and compare and contrast the advantages and difficulties of selection in different wavelength bands. We stress the strong selection effects in each wavelength band and the difficulty of defining complete samples. Of all the techniques presently used, we conclude that selection in the hard X-ray band via imaging and spectroscopy is the most complete and allows the best estimate of the number and evolution of active galaxies. However, all of the techniques have difficulties at low luminosities where emission due to stellar processes can have similar sizes and luminosities.

## 2.1 Introduction

Looking at the 60 year history of observations of active galaxies, it is clear that the definition of what they are has strongly influenced the methods of finding them. From our present perspective, many of the techniques used over the past 40 years are not truly appropriate and are more in the line of the famous joke of the drunk looking under the lamp post for his lost car keys. In this chapter, I will use the words Active Galactic Nuclei (alias AGN or quasars) to be the equivalent of radiating supermassive black holes, even though this perspective is very recent.

The difficulty in finding AGN is defining what makes the observed[1] radiation different from that due to other processes, in particular those

[1]While very frequently the inferred emitted radiation is rather different from that intrinsically produced by the region around the black hole, the nature of surveys is such that we must rely on the observed properties of these sources in order to find and identify them.

related to normal stars and stellar evolution (e.g., supernovae).[2] This has often been a process of exclusion; that is, the emission does not resemble that from stars or stellar processes. Dust, high-luminosity emission from starbursts, and the possible effects of unusual types of stars complicate the issue. The strong effects of observing in different spectral ranges also need to be taken into account; for example, at $R = 22$ there are only 100 "optically-selected" AGN per square degree, but at the equivalent flux level in the $2 - 10$ keV X-ray band of $3 \times 10^{-15}$ ergs cm$^{-2}$ s$^{-1}$, there are 1000 deg$^{-2}$. Finally, it is clear that the "non-stellar" signature has a wide variety of forms that gives rise to the "zoo" of names for active galaxies. The spectral energy distributions, optical emission-line properties (strengths, widths, and nature), line of sight column densities, time variability characteristics, and bolometric luminosities of Seyfert 1 galaxies, Seyfert 2 galaxies, BL Lacertae objects, LINERs (Low-Ionization Nuclear Emission Regions), and quasars (to use the names of the largest samples of objects) are all rather different (see, e.g., Risaliti & Elvis, this volume).

It has taken many years and a large amount of effort to finally come to the realization that all these classes are manifestations of the same underlying physical process—emission from near to a supermassive black hole. However, even today it is not certain if all of these sources are driven solely by accretion, or whether there is also energy extraction from the spin of the black hole (see Armitage, this volume). It is also not clear if the energy production is dominated by radiation, relativistic particle production, or bulk motion of material. It is entirely possible that there is a simple relation between the "names" of the sources and their physical natures, but at present this seems very complex and not unique. As opposed to stellar classifications, there is not a one-to-one relationship between the class of the object and its physical nature. However, there are some clear distinctions: for example, in BL Lacertae objects, the observed radiation is dominated by emission from relativistic particles in a jet in our line of sight, and in Seyfert 2 galaxies, the line of sight to the central source is blocked by large amounts of dust and gas (see Hewett & Foltz 1994 for an earlier review and a detailed discussion of the many systematic effects in quasar surveys).

Before discussing the field in general, it is important to consider what a survey really is. As Hewett & Foltz (1994) point out, there are three

[2] To date, all the surveys for AGN have relied on detection of radiation across the electromagnetic spectrum. Perhaps in the distant future we will be able to search for AGN via neutrinos, gravitational waves, or even very high-energy cosmic rays, but this is still quite uncertain.

types of surveys: (1) those that find objects, (2) those that find objects consistently, and (3) those with well-defined selection criteria that allow probabilities to be assigned for selection as a function of survey parameters. Surveys of the first type are the easiest, since the goal is only to provide sources for study that meet some criteria. Surveys of the second type are homogenous in their properties, but completeness is not important. Many of the issues discussed below are more or less important depending on which type of survey is being performed. It is only surveys of the third type that allow comparisons to be made of different wavelength regimes and different survey techniques. While these surveys are the most scientifically important, they are also the most difficult to do.

### 2.1.1 A Short History of AGN Search Techniques

From a historical perspective (e.g., Osterbrock 1991), the first indications of "non-stellar" activity in the nuclei of galaxies came from the discovery of strong, broad emission lines in NGC1068 (Fath 1913; Slipher 1917) and the discovery of the jet in M87 (Curtis 1917). The spectral features found in NGC1068 are almost never found in stars or supernovae remnants and thus were an indication of some new phenomena occurring. It took 50 years before the morphology of the "jet" in M87 was related to non-stellar processes.[3] The first "sample" of non-stellar activity was that of Seyfert in 1943, who found a wide variety of strong "broad" lines in the nuclei—but not elsewhere—of several otherwise "normal" galaxies. It was clear from this early paper that there was something quite unusual about these sources and that they must be fairly common, but it took almost 20 more years for significant progress to be made.

This next step occurred with the discovery of extragalactic radio sources and attempts to find optical counterparts for them. The discovery of low to moderate redshift "active galaxies" as the optical counterparts to several bright radio sources (Baade & Minkowski 1954) showed a new type of "active galaxy". It was clear even in 1958 (Minkowski) that there was tremendous scatter in the optical properties of the identifications at a fixed radio flux. Schmidt (1963), Greenstein & Matthews

[3] We now know that jets can also occur in stellar processes (for example, in Herbig-Haro objects, young neutron stars [e.g., see the *Chandra* image of the Vela pulsar], supernovae remnants [e.g., see the *Chandra* image of Cassiopeia A], and the X-ray and radio emission from some luminous galactic X-ray sources [e.g., Cygnus X-3]). It seems as if the jet phenomenon is related to the emission of large amounts of energy over a short period of time and into a restricted volume.

(1963), and Schmidt & Matthews (1964) discovered that the optical counterparts of several luminous radio sources were stellar-looking sources at large redshifts, and thus were very luminous, compact, extragalactic sources with non-stellar spectra. They were subsequently named "quasars" for quasi-stellar radio sources. The optical properties of these radio sources were very similar to each other, indicating that a class of objects had been found. Sandage (1965) realized that there were sources with the same general optical properties as quasars that were not radio sources. These sources had blue colors, meaning a large ultraviolet (UV) flux relative to the classical optical band, fairly high variability in their continuum intensity, and most had strong, broad emission lines over a wide range of ionization.

It was rapidly realized that the nuclei of some "Seyfert galaxies" had similar properties to quasars (Woltjer 1959; Burbidge, Burbidge, & Sandage 1963), and for the last 30 years, these sources have been grouped under the name Active Galactic Nuclei or AGN (I think that the first use of this name in the literature is from Burbidge 1970). However, even early on, it was clear that not all AGN resembled quasars. There were Seyfert 2 galaxies, which do not have broad lines or strong non-stellar continua but do have strong, narrow forbidden lines that could not be produced by ionization from normal stars. Also, there were BL Lacertae objects, which usually do not have optical or UV emission lines but do have a very strong non-thermal continuum and a wide variety of optical colors. It was thus clear from the start that identifying complete samples of AGN would require a wide variety of techniques and criteria.

Outside of trying to identify the optical counterparts to the radio sources (it took over 30 years to completely identify all of the sources in the 3CR survey, the first large radio survey; Spinrad et al. 1985), the first systematic search for AGN that I can find in the literature was the realization (Arp et al. 1968) that the Markarian survey of compact galaxies with blue stellar colors contained a large number of sources with the properties of Seyfert galaxies. At almost the same time, Sargent (1970) used similar critieria for sources from the Zwicky survey and also found numerous AGN. These two early works, combined with the radio surveys, set the standard for AGN surveys: using photographic techniques to find sources with compact, blue nuclei and following up with optical spectroscopy (see Weedman 1977 for an early review). However, these searches were completely empirical; i.e., they were looking for sources that had the properties of sources that one already knew were active galaxies.

It is clear that AGN have a very wide range of relative parameters, from the line strengths and line widths (ranging down to sources without any emission lines at all; e.g., BL Lacertae objects), to the continuum colors, to the amplitudes and timescales of variability. Thus, having an inclusive definition is very difficult. It is fair to say that most workers have had a difficult time coming up with an AGN definition that is totally complete and not subject to noise and strong selection effects. Recent large optical surveys, such as the Two Degree Field (2dF) and the Sloan Digital Sky Survey (SDSS), have focused on well-defined color or line strength criteria that allow them to be well defined but clearly incomplete.

## 2.2 AGN Spectral Energy Distribution and How One Finds AGN

By definition, emission from a black hole does not resemble that from an ensemble of normal stars. It has a different broadband spectral shape (the Spectral Energy Distribution or SED), a very high-luminosity density, and very different time variability properties. Roughly speaking, the broadband spectrum of an optically-selected AGN can be represented by a power law with roughly equal energy per decade from $10^{13} - 10^{20}$ Hz (Elvis et al. 1994). This is much broader than the ensemble of spectra from stars, which is roughly the sum of blackbodies with an effective temperature of $10^3 - 10^5$ K. Superimposed on this power-law form are strong optical and UV lines from hydrogen, highly ionized C, N, and O, and a complex of low-ionization Fe lines. Thus, selecting sources on the basis of either their similarity to an AGN SED or their difference from a stellar SED is rather productive.

While the SED for optically-selected AGN is well studied, that for radio, infrared (IR), and X-ray–selected sources is much less well documented. Many of the radio-selected and hard X-ray–selected AGN show no indications of non-stellar colors in ground-based UV/optical/IR observations, and, thus, the use of the SED in these bands as an AGN indicator will not find the objects.

### 2.2.1 Optical Color Selection and the Presence of a Semi-stellar Nucleus

It was originally realized by Sandage (1971) that the optical colors of an AGN (modeled as a power law plus broad emission lines) and the starlight from a host galaxy deviated in a systematic way from pure stellar colors as a function of power-law index, redshift, and the fraction of total light in the non-thermal continuum. Using this technique and multicolor data, it is possible to construct color ratios that efficiently select objects with unusual colors (e.g., Koo & Kron 1988). These are then candidates for follow-up optical spectroscopy and radio and X-ray observations. This technique has reached its present apogee with the SDSS, which finds objects by their deviations in five-color space (Fan 1999; Richards et al. 2001). The technique is essentially "trained" on known objects, and the colors of the quasars so obtained are sufficiently narrowly distributed that photometric redshifts can be estimated. While there are claims of "completely unbiased" optical samples (Meyer et al. 2001), this reviewer believes that they are rather overstated. In particular, X-ray images with the *XMM-Newton* and *Chandra X-ray Observatories* of the 2dF fields find many AGN not detected by this optical survey (see Fig. 2.1).

Over the last 30 years, there have been a large number of programs (see Hartwick & Schade 1990) that selected AGN using Schmidt's (1969) criteria for selecting quasars:

- Sources that do not have the colors of normal stars in their nuclei at any redshift. These AGN are found by "exclusion".
- Sources that have a luminous semi-stellar nucleus (see Weedman 1977 for a description of a Seyfert 1 galaxy, and Sarajedini et al. 1999 for recent results).
- Sources that show time variability. It is well-known that virtually all AGN vary (Schmidt 1969; Cannon, Penston, & Brett 1971).
- Sources that show strong, relatively broad UV/optical emission lines.
- Stellar sources that lack proper motion. This criterion has recently been revived by analyses of deep *Hubble Space Telescope (HST)* images.
- Luminous high-redshift sources that are selected by their optical colors via the Lyman break.

These criteria are optimized for quasar-like sources and will not select Seyfert 2-like sources very well. (Seyfert 2 galaxies have lines that are not as strong or as broad, nuclei that are not as bright, and they show little or no time variability in the optical bands.) The realization that AGN bolometric luminosity may not be well correlated with galaxy luminosity (Urry 2003) indicates that low-luminosity AGN are very difficult to find in massive galaxies via optical selection techniques. Essentially, the starlight dilutes the signatures of the AGN, reducing the equivalent

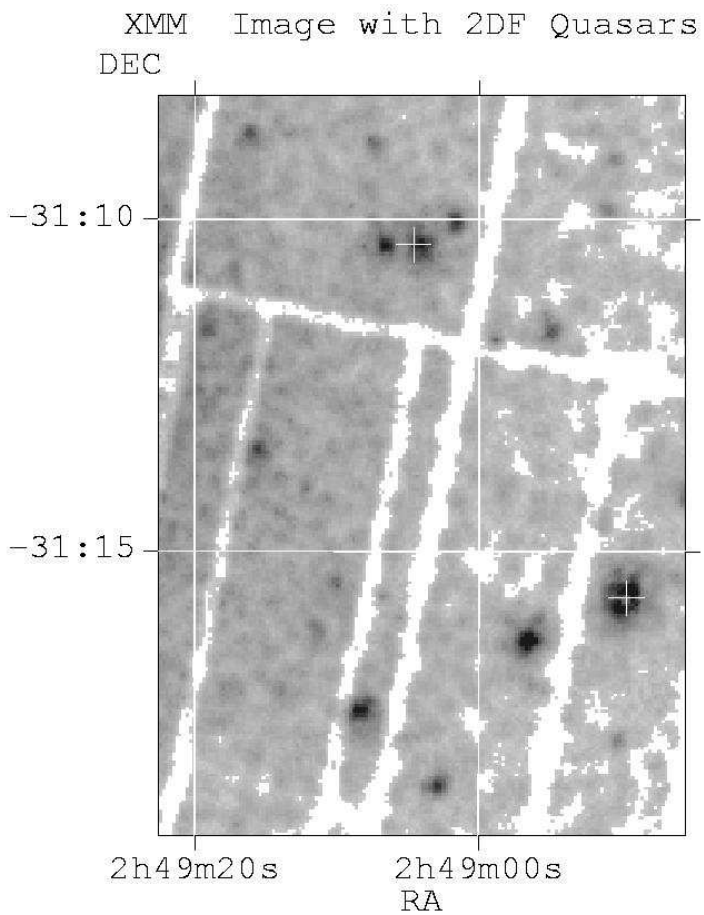


*Figure 2.1.* *XMM-Newton* image of a 2dF quasar field with the 2dF quasars marked by crosses. Notice the large numbers of X-ray point sources, virtually all AGN, that are not identified in the 2dF.

widths of all of the lines; at moderate redshifts ($z > 0.2$), the starlight reduces or eliminates the color signatures of the nucleus.

Hartwick & Schade (1990) review the results of many of these surveys and provide an excellent summary of optical AGN selection techniques. However, they do not compare the results to techniques obtained via other methods. It is somewhat amusing to find stated in the Hartwick & Schade (1990) paper that the samples found by these optical techniques are a complete sample of quasars. As we shall see below, optical techniques miss most radio-selected AGN and a large fraction of IR and X-ray–selected AGN.

The presence of a semi-stellar nucleus was one of the original defining criteria for quasars. However, this criterion is highly sensitive to the angular resolution of the telescope and to the relative contrast of the nucleus and the host galaxy. It also finds bright super star clusters and other compact objects. Sarajedini et al. (1999) searched for stellar nuclei in a relatively large sample of galaxies serendipitously observed by *HST* and found that $\sim 10\%$ show unresolved semi-stellar nuclei that contribute more than 5% of the total optical light. So far, this is the best optical survey for low-luminosity AGN-like activity at moderate redshifts.

While optical techniques are very powerful, they have several problems. Their use requires that the nuclei either be bright enough to outshine the stars in the photometric extraction region or have sufficiently different colors to be recognizable. The effects of copious star formation on the optical colors are considerable. For example, in the Byurakan surveys, which selected objects by searching for blue continua, 90% of the objects found are starbursts rather than Seyferts. Thus, this selection technique is only five times more efficient than a blind survey. The effect of stellar dilution has been quantified for the SDSS by Richards et al. (2001), who noticed that more luminous objects are bluer at a fixed redshift due presumably to the increased importance of starlight in lower luminosity objects. At an absolute magnitude in the Sloan $g$ band of $-23$ (or an optical luminosity of $6 \times 10^{44}$ ergs s$^{-1}$), this effect seems to go away, indicating that the effects of starlight are minimal for these extremely luminous objects. Thus, there are strong selection effects with the luminosities of the nuclei and of the host galaxies, and with redshift. In principle, these selection effects are quantifiable, but in practice, this only works at low redshifts, where one can properly model the host galaxy and remove the starlight (Moran, Filippenko, & Chornock 2002; see also Moran, this volume). Because there is no simple relation between the host galaxy and the nucleus properties, the problem is rather intractable. There are also large color selection terms because of the varying contrast between a "typical" stellar spectrum and the SED of an AGN with redshift.

Color selection is a very efficient technique, and with a large database like the SDSS, produces copious samples of AGN over a wide redshift range. However, such methods must be evaluated carefully because of the large ratio of stars to quasars. At $m \sim 18$ there are $\sim 500$ stars to every quasar, and thus the classification accuracy must be better than 0.2% to avoid severe contamination! Therefore, techniques have focused on stellar "rejection" rather than on "finding all the quasars", unless extensive spectroscopic follow-up is also available for the survey.

In addition, since it is now well-known (see discussion in §2.3) that many (most?) AGN have large amounts of dust and gas in the line of sight, the effects of extinction can be very large and have to be very well modeled to produce reliable samples. The effects of extinction can be partially ameliorated via the use of near-IR data, but only up to some limit. It has been known for very many years that the reddening curve in AGN is different from that in the interstellar medium of the Milky Way (Maiolino et al. 2001), and thus it is not at all clear how to "de-redden" the AGN spectrum to derive reliable optical fluxes.

### 2.2.2 Optical Emission Lines, Variability, and Zero Proper Motion Selection

There have been a wide variety of AGN surveys relying on low-resolution optical spectra. These techniques select AGN on the strength of the UV/optical emission lines (see Osmer & Hewett 1991 for a summary of this technique, and Salzer et al. 2000 for the latest application with the Kitt Peak National Observatory International Spectroscopic Survey). While this method essentially has no "false" detections, its completeness is very difficult to evaluate, since the signal-to-noise depends on the equivalent widths of the lines. Since the lines observed in the optical depend on the redshifts of the objects (e.g., from H$\alpha$ to Ly$\alpha$) and vary in intrinsic strength by over an order of magnitude, it is very difficult to evaluate the completeness of the sample. Furthermore, the effects of redshifting make the effective band smaller by $(1+z)$, such that at $z = 3$, only 1400 Å in the rest-frame are covered by the total ground-based optical wavelength band ($3200 - 8900$ Å). The limit of this technique (Ho, Filippenko, & Sargent 1995) is to obtain high signal-to-noise spectra of the nucleus of every object in a complete sample. However, even this method runs into the difficulty of removing absorption lines due to stars in the relatively low-luminosity AGN spectra and requires extreme care.

Variability can also be used as a survey technique (Usher & Mitchell 1978; Brunzendorf & Meusinger 2002; Dobrzycki et al. 2003), since on long enough timescales, virtually all AGN are variable (Veron & Hawkins 1995; Giveon et al. 1999). This method requires a large number of observations and seems to produce a lower areal density of objects than other techniques. However, this method also finds large numbers of variable stars and supernovae and must be combined with other selection criteria.

Similarly, since AGN are at great distances compared to bright stars, the absence of proper motion can be a guide to AGN selection. However, this technique has not been widely used and fails at faint magnitudes, where most of the stars also do not show proper motion. This technique will be resurrected when large solid angle astrometric data sets are available.

### 2.2.3 Radio Selection

Radio selection was the original way to find AGN. It is very powerful, since almost all luminous radio sources are AGN in our definition of radiating supermassive black holes—the only contamination is at lower luminosities, where there can be significant radio emission from rapidly star-forming regions. Thus, for most luminous objects, mere detection in the radio indicates the presence of an AGN. Radio surveys are also rather sensitive, and the positions are extremely accurate. The morphological information is also important, since all radio sources showing double-lobe or jet-like structures are AGN.

However, radio surveys are very incomplete, since less than 10% of AGN have luminous radio emission (White et al. 2000), the ratio of bolometric luminosity to radio luminosity varies by a factor of $10^5$, and the fraction of the total energy radiated in the radio is small. While it is true that most "radio-quiet" AGN have some radio emission, the relative intensity is very low, making searches for these objects in the radio very difficult. Even the early radio samples found objects with a wide range of optical properties and a wide redshift distribution. The absence of a correlation of radio flux with redshift indicated a broad luminosity function.

It was noted in the 1960s that a significant fraction of the radio sources did not have broad lines or had no lines at all and that their optical colors were not unusual (Kristian, Sandage, & Katem 1974). To quote from Ulrich (1971), "Comparison of the optical and radio properties of nuclei of galaxies shows that galaxies with compact nuclear radio sources are more likely to have optical spectra with emission lines than are galaxies without central radio sources", thereby indicating the relative rareness of broad or strong lines in radio-selected AGN. This has been quantified recently in a combined study of the 2dF survey with a southern radio survey (Sadler et al. 2002; Magliocchetti et al. 2002), as well as in SDSS and FIRST (Faint Images of the Radio Sky at Twenty-cm) data (Ivezic et al. 2002). In these data, over 60% of nearby radio galaxies show no evidence for strong emission lines of any width, and their optical continua show weak or no evidence for non-thermal activity. This is also true at higher redshifts, where the radio sources are not even found to be X-ray sources (Cowie et al. 2004a). In the SDSS data, only 10% of the optical counterparts of radio sources show evidence for strong AGN-like emission lines. However, in several of the nearby objects for which no obvious nucleus or broad lines exist in ground-based data, *HST* imaging finds evidence for weak non-thermal continua (Chiaberge et al. 2003). In fact, the absence of strong lines in the radio galaxies made optical spectral identification so hard that it required more than 30 years to completely identify the first radio catalog (Spinrad et al. 1985). It is quite interesting that the vast majority of radio AGN would never be selected by optical techniques. This was the first indication that different selection techniques tend to find different objects. To rephrase this, while only 10% of optically-selected AGN are "radio loud", less than 30% of radio-selected AGN are "optically loud".

The "radio" colors of AGN allow discrimination against other sources of radio emission for luminous objects. Almost all flat-spectrum, compact radio sources are AGN. In addition, the strong correlation of mid-IR with radio flux found for star-forming galaxies allows the detection of AGN by exclusion, if one also has IR data (Yun, Reddy, & Condon 2001). That is, the objects with low IR-to-radio luminosity ratios are almost all AGN (Condon, Anderson, & Broderick 1995), and those objects that lie in a narrow range of high IR-to-radio luminosity ratios are starbursts (or radio-quiet AGN). This technique has been used to show that many of the objects thought to be starbursts in the *ROSAT* All-Sky Survey data were really previously uncataloged AGN (Condon et al. 1998). However, inspection of a large sample of X-ray–selected objects (the most famous of which is NGC1068) shows many of them with "star formation" IR-to-radio ratios, indicating that most of the IR and radio luminosities are not AGN related. It thus requires a good deal of care (Miller & Owen 2001) to select the AGN, which tend to have lower relative far-IR–to–radio luminosities and larger scatter in the correlation than those seen for star-forming galaxies.

In an unbiased survey of radio-selected objects using the SDSS (Ivezic et al. 2002), the number of starburst galaxies outnumbers those objects with AGN-like optical spectra by 5:2, and the number of objects without any unusual optical properties dominate the optically-active AGN by 12:1. It thus seems that deep radio surveys have a large contamination factor from non-AGN populations but discover lots of AGN that would not be selected with classical optical criteria.

Most radio data have fairly accurate positions (better than $45''$ for the largest radio survey, the NRAO VLA Sky Survey or NVSS, and better than $7''$ for the most sensitive large solid angle survey, FIRST), allowing counterparts in other wavelength bands to be readily identified. However, only $\sim 8\%$ of optically-selected AGN (Ivezic et al. 2002) are radio "loud" and selectable in radio surveys.

### 2.2.4 Infrared Selection

The use of IR techniques to measure AGN continua started in the 1970s with the advent of the first sensitive IR detectors (Low & Kleinmann 1968). However, the IR "colors" of Seyfert galaxies are only subtly different than those of normal galaxies (Kuraszkiewicz et al. 2003), and the equivalent widths of the IR lines are not sufficient to use as a finding mechanism. Thus, IR color surveys can have a large fraction of "false" AGN, unless great care is taken.

The first large-scale attempt to find AGN in the IR was based on *Infrared Astronomical Satellite (IRAS)* data. De Grijp, Lub, & Miley (1987) showed that AGN had systematically different $60\mu$m/$25\mu$m colors than normal galaxies. An alternative approach (Spinoglio & Malkan 1989) is to obtain optical spectra of every IR-selected galaxy. This is a follow-up of the idea of Huchra & Burg (1992) to obtain optical spectra of every optically-selected galaxy, but it is not really a survey technique. The latest use of the IR to find active galaxies is with the Two Micron All Sky Survey (2MASS; Cutri et al. 2002). In this survey, $\sim 60\%$ of the objects with $J-K > 2$ are found to have the optical properties of AGN. This selection criterion is bootstrapped by using the near-IR colors of known radio and optically-selected AGN (Elvis et al. 1994), and thus will tend to find objects with similar properties. The large space density of these IR-selected objects makes them a major contributor to the AGN population.

One of the main potential advantages of the IR is that, at least for known AGN, the mid-IR ($3-10$ $\mu$m) seems to be a "pivot point" in the SED. That is, objects of the same bolometric luminosity have rather similar mid-IR luminosities but very variable radio, optical, UV, and soft X-ray luminosities. Exactly how to use this information in a survey via color-color plots has been investigated by Andreani et al. (2003) and potentially seems to be quite powerful. However, to avoid large numbers of false detections, IR selection requires very broadband, precision IR photometry from $4-100$ $\mu$m. Because of the large ratio of normal to "active" galaxies, there can be "leakage" in the selection criteria, unless photometric errors are small.

It has been demonstrated (de Grijp et al. 1987) that most optically-selected AGN have a "mid-IR excess" and are "warmer" compared to normal galaxies. This also seems to be true for radio-selected AGN. The effect is very subtle, however, with AGN tending to have a "hotter" mid-IR effective dust temperature. However, based on *Infrared Space Observatory (ISO)* colors of AGN (Haas et al. 2003), it is not clear how complete this technique is, since the mid-IR slopes span a range from

$0.9 - 2.2$, and the relative brightness of the mid-IR AGN component to the stellar continuum and star-heated dust spans a wide range. At long IR wavelengths, the contribution from normal stars fades, and there is emission from AGN and star formation-heated dust.

There is a long-running discussion in the IR community about how to separate out dusty AGN from starburst galaxies based on optical and IR data (see Veilleux 2002 for an excellent summary of the present situation). In this reviewer's opinion, it is basically impossible without IR spectroscopy. In the mid-IR, the presence and absence of IR emission features associated with polycyclic aromatic hydrocarbons (PAHs) and high-ionization IR lines (Laurent et al. 2000) provide strong AGN diagnostics. However, there have not been any wide-angle IR spectroscopic surveys designed to find active galaxies. This will change with the *Spitzer Space Telescope*. Because of a lack of data, it is not known if there are mid-IR "quiet" AGN.

Infrared observations of X-ray–selected (Kuraszkiewicz et al. 2003) and optically-selected (Haas et al. 2003) AGN samples show a very wide range of IR to X-ray SEDs and considerable variation in the IR colors of AGN, making the use of IR colors somewhat problematic in an AGN survey. The IR spectral parameters do not correlate with the optical spectral slope, nor with the IR luminosity, nor with the mid-IR–to–far-IR luminosity ratio, nor with inclination-dependent extinction effects in the picture of a dusty torus.

### 2.2.5 High-Energy Selection

The other two techniques used to find active galaxies are X-ray and $\gamma$-ray–selection. Like radio emission, luminous, compact X-ray and $\gamma$-ray emission is an almost certain indicator of the existence of an AGN and does not need "confirmation" by data in other wavelength bands. The relatively low signal in most X-ray surveys makes X-ray spectroscopic redshift determinations difficult, and for most objects one must rely on optical redshifts. However, in a few recent cases, X-ray redshifts have been determined (Hasinger 2004). The need to obtain optical redshifts has driven the entire field of "optical identification", in a fashion similar to that of the identification of radio surveys.

It was realized in the early 1970s (Pounds et al. 1975) that about one-quarter of the high-latitude X-ray–selected objects in the *Ariel-V* X-ray survey could be identified with previously known AGN. Given the large uncertainties in the positions of these objects ($\sim 0.5 - 2$ deg$^2$), this was quite surprising. Detailed follow-up work of the unidentified, high-latitude X-ray sources in the early surveys (Ward et al. 1980; Wilson 1979) discovered that most of them were previously unknown AGN with properties that "hid" them from optical surveys. This work was strengthened with the first accurate X-ray positions (Griffiths et al. 1979), which confirmed that objects with rather weak or narrow optical lines and no evidence for a non-thermal continuum could be luminous X-ray sources. The advent of X-ray imaging with the *Einstein Observatory* in 1979 vastly increased the efficiency and accuracy of X-ray surveys, but, with the exception of low-redshift objects, the positions were still not accurate enough to have an unique optical counterpart. This drove a very large program of identification (the *Einstein* Medium-Sensitivity Survey or EMSS; Gioia et al. 1990), which took several years to complete.

A major difference in the early X-ray and optical surveys was the redshift distribution, with optical selection criteria finding many objects over a wide redshift range out to $z \sim 3$, while X-ray samples were much more concentrated at $z < 1$. Even the early X-ray samples found very little correlation of redshift with flux.

So far, while $\gamma$-ray emission is certainly an almost unique feature of high-latitude active galaxies, the positions are too poor to allow the identification of the objects. Based on correlations with radio data, most of the identified AGN are blazars or flat-spectrum radio sources, and very few, if any, classical Seyfert 1 galaxies or quasars are found in the *Compton Gamma-Ray Observatory* surveys.

It has been known for over 35 years that the vast majority of high-latitude, point-like "hard" X-ray sources are AGN[4] (Pounds 1979), and this is one of the most efficient and least "error prone" ways of selecting AGN. At the present time, there are very few, if any, known AGN that are not also luminous X-ray sources. However, because of the wide variance in the SEDs of AGN, there are many objects which do not have sufficiently sensitive X-ray data to decide if they really are X-ray "quiet" objects (Leighly, Halpern, & Jenkins 2002; Gallagher et al. 2001). There are classes of AGN (in particular, broad absorption-line quasars and strong FeII objects; Lawrence et al. 1997) that have rather low soft X-ray–to–optical ratios. At present, this is thought to be due to the high column densities in these objects (see §2.3), but work is still proceeding on this. Recent results suggest that there is a class of IR-selected AGN with broad optical emission lines that are X-ray "weak" (Wilkes et al. 2002).

[4]In a historical point, before the *Ariel-V* results, there were strong indications from *Uhuru* data of a class of "unidentified high galactic latitude X-ray sources" (Holt et al. 1974). Arguments—later proved false—were put forward that they could not be Seyfert galaxies.

The efficiency of X-ray surveys is very high, finding considerably more AGN at a fixed optical magnitude than other techniques. The asymptotic limit of optical surveys is $\sim$ 130 AGN deg$^{-2}$ at $B < 23$ mag (Palunas et al. 2000), while the *Chandra* surveys find $\sim 1000$ deg$^{-2}$ at $r < 24$ mag. This relative efficiency is true even for very optically-bright samples; for example, Grazian et al. (2000) finds three times more AGN with $v < 14.5$ in the *ROSAT* All-Sky Survey than does the color-selected Palomar-Green (PG) bright quasar survey (Schmidt & Green 1983). In the $2-8$ keV band at fluxes between $10^{-15}$ to $10^{-10}$ ergs cm$^{-2}$ s$^{-1}$, essentially all of the point-like sources are AGN. At lower fluxes, the fraction of star-forming galaxies increases, but the X-ray counts are still dominated by AGN over the range to which *Chandra* has so far reached.

It is only recently with *Chandra* and *XMM-Newton* data that the X-ray/optical/near-IR distribution of normal galaxies has been measured, and thus an estimate of the AGN "contamination factor" derived. The bottom line is that all compact X-ray sources with a luminosity above $\sim 10^{42}$ ergs s$^{-1}$ ($2-10$ keV) are considered to be AGN. The main interlopers are "ultraluminous X-ray sources" (ULXs; Colbert & Ptak 2002), which are objects with X-ray luminosities between $4\times10^{39}$ and $10^{42}$ ergs s$^{-1}$ and do not reside in the nuclei of the host galaxies. While easily recognized at low redshifts, *Chandra* imaging is required to separate these out at $z > 0.1$ (Hornschemeier et al. 2003). At X-ray luminosities below $10^{42}$ ergs s$^{-1}$, there is always the possibility that a nuclear source might really be an ULX rather than an AGN, as is apparently the case in M33 (Long, Charles, & Dubus 2002). However, it is not clear if the distinction is meaningful if the ULXs turn out to be supermassive black holes. Starburst galaxies have a considerably lower X-ray–to–optical flux ratio than AGN, and while they frequently harbor ULXs (Grimm, Gilfanov, & Sunyaev 2003), their total luminosities rarely reach $10^{42}$ ergs s$^{-1}$ and are well correlated with their IR luminosities (Ranalli, Comastri, & Setti 2003).

For "typical" soft X-ray–selected AGN, the X-ray–to–$B$-band flux ratio is $\sim 1$, with a full range of $\sim 100$ and a variance of $\sim 6$ (Mushotzky & Wandel 1989; Anderson et al. 2003). In the $2-10$ keV X-ray band, there is a broader range of X-ray–to–optical flux ratios, with a significant tail of very high X-ray–to–optical ratios that extends out to $> 10^4$ (Akiyama et al. 2003; Barger et al. 2003b; Comastri et al. 2003; see also Comastri, this volume).

Because of the broad wavelength coverage of the X-ray band (about a factor of 100 in wavelength), there is a significant difference between soft-band ($0.2-2$ keV), hard-band ($2-6$ keV), and very hard-band ($5-10$ keV) surveys. The soft-band surveys can suffer from the same extinction effects as UV and optical surveys, while in the harder bands, absorption is a much smaller effect. Based on *ROSAT* and *Chandra* data, the soft and hard X-ray selection tends to find different objects. The soft X-ray selection preferentially finds broad-line quasars and narrow-line Seyfert galaxies (these objects tend to have a bright, soft spectral component, in addition to a flat, high-energy, power-law spectrum). The hard X-ray selection finds, in addition to the classical Seyfert 1 galaxies and quasars, large numbers of objects with weak or absent optical emission lines and lacking non-thermal nuclei. It is believed that this selection effect may be related to the presence of absorbing material, but other possibilities exist (see §2.3). Large follow-up programs for X-ray–selected AGN find other selection effects. The median value of the soft X-ray–to–optical flux ratio changes by a factor of $2-3$ over four orders of magnitude in optical flux (Anderson et al. 2003). Thus, high-luminosity objects are somewhat weaker in the X-ray band for a given optical luminosity. On the other hand, radio-loud AGN have a factor of three higher X-ray–to–optical flux ratio than radio-quiet objects (Worrall 1987). Thus, soft X-ray selection compared to optical selection is biased towards radio-loud, lower luminosity objects. While there is a fair range in the X-ray spectral slopes of AGN (the variance is $\Delta\alpha \sim 0.2$), there is no correlation of slope with luminosity or redshift (Vignali et al. 2003; Reeves et al. 1997).

Before the *Chandra* and *XMM-Newton* surveys, X-ray error circles were often large (e.g., $> 15''$), engendering large optical follow-up programs and allowing a bias in the selection of the optical "counterpart". However, *Chandra* and *XMM-Newton* follow-up of *ROSAT* identifications (McHardy et al. 2003) show that virtually all of them were "right", and, thus, this possible selection effect is small.

### 2.2.6 Ultraviolet Selection

While it has long been possible to select high-redshift objects in the rest-frame UV—and this is often the main path to "optical" selection of quasars—until 2003 there has been no large-scale survey in the UV for active galaxies. This will be remedied with the recent successful launch of the *Galaxy Evolution Explorer (GALEX)* satellite. To date, there has not been a rest-frame UV survey for AGN covering a reasonable solid angle with reasonable sensitivity.

## 2.3 Selection Effects

The whole subject of finding and cataloging AGN is dominated by selection effects (see Hewett & Foltz 1994 for an extensive discussion and an excellent summary of the field). The main effects are:

(1) *Dilution of the optical/IR brightness and color by starlight.* This is a large effect for AGN with optical/IR luminosities less than that of an average galaxy (roughly $10^{44}$ ergs $s^{-1}$) at moderate to high redshifts. This effect has made optical selection of Seyfert galaxies at $z > 0.5$ a very difficult process, since it reduces the signal from time variability, color, or emission-line survey techniques. This effect is unimportant for X-ray selection above a luminosity of $\sim 10^{41.5}$ ergs $s^{-1}$ and for radio selection above a power of $10^{24}$ Watts $Hz^{-1}$. The dilution reduces the equivalent widths of all of the lines, as well as the visibility of the non-thermal radiation in the spectral bands where stars are luminous (i.e., optical/near-IR). The magnitude of this effect clearly depends on angular resolution and aperture and is minimized for *HST* data. However, very recent work shows that the brightness of the optical nuclei for the hard X-ray–selected sources in the *Chandra* Deep Field-South are a factor of 20 dimmer than expected based on the *ROSAT* sources (Grogin et al. 2003). It may also be important for luminous AGN at high redshifts, where most galaxies seem to have copious star formation.[5]

(2) *Obscuration.* Based on X-ray and IR surveys, one finds that many (most?) AGN have large column densities of gas and dust in the line of sight (Fabian & Iwasawa 1999). Models of the X-ray and IR backgrounds (Almaini, Lawrence, & Boyle 1999) suggest that more than 70% of all AGN have high column densities ($> 10^{22}$ atoms $cm^{-2}$) in the line of sight, which, for normal dust-to-gas ratios, gives an effective optical absorption of $A_V > 5$, effectively extinguishing the UV/near-IR fluxes. However, the situation is not simple: there are many objects known with (a) high X-ray column densities and luminous UV continua (the most famous being NGC4151), (b) high IR dust emission and low X-ray

[5] Recent work by Comastri et al. (2003) shows that X-ray–to–optical luminosity ratios for objects having only narrow optical lines rise as $L_{2-10\ \mathrm{keV}}$). Note that these may not be the same as classical Seyfert 2 galaxies; for the purposes of this chapter, I follow the nomenclature of the *BeppoSAX* High-Energy Large Area Survey (HELLAS) team and call these optically-obscured type 2 AGN. Thus, at high X-ray luminosities, these objects are X-ray bright rather than X-ray dim.

column densities (e.g., IRAS 1334; Brandt et al. 1997), and (c) very red continua, strong, broad optical lines, and apparently very high X-ray column densities (e.g., Wilkes et al. 2002; for a review, see Comastri et al. 2003). The multivariate distribution functions of each of these is not known at the present time, and thus these effects cannot be corrected for.

In unified models of active galaxies (Antonucci 1993), the physical difference between Seyfert 1 and Seyfert 2 galaxies is that the line of sight to the latter is blocked by optically-thick material in the UV and optical. This accounts for the observed weakness of UV/optical/soft X-ray emission, the lack of short timescale intensity variability, the high optical polarization, and the detailed form of the X-ray spectra. For these objects, the observed UV/soft X-ray continuum is only a small fraction of the emitted radiation, and much of the energy is emitted in the IR. Seyfert 2 galaxies have low soft X-ray luminosities, low optical luminosities, and large IR luminosities. Thus, they are not found in great numbers in soft X-ray or optical color samples.

Both of the above selection biases make it very difficult to directly connect samples derived in different spectral bands and to derive unique values for the bolometric luminosity function and its evolution. It is also not clear if these selection effects are functions of redshift and source luminosity.

Much recent progress has been achieved via *Chandra* and *XMM-Newton* observations of optically well-surveyed fields, with some surprising results. The *Chandra*-selected AGN sample shows that at high X-ray luminosities, almost all AGN show broad optical emission lines, indicating that the effects of obscuration are small, while at low luminosities, the vast majority of AGN show little or no activity in the optical (Steffen et al. 2003). There are also strong indications of evolution in these ratios.

There is another important effect, which, while not a classical selection effect, has important consequences for the nature and completeness of AGN samples. It is clear that the strengths and widths of various UV and optical lines are not random but lie along two eigenvectors (Boroson 2002). These line strengths are strongly correlated with the slope of the X-ray continuum (Brandt & Boller 1998). Thus, in X-ray flux-limited surveys at different energy ranges, or in UV/optical surveys that rely on line widths and fluxes, one will end up with different sets of objects. There also may be evolution in the nature of these eigenvectors. It is speculated that the narrow-line Seyfert 1 galaxies that lie along one of the extrema are radiating near the Eddington limit, and, if so, should be more common at higher redshifts.

## 2.4 X-ray Selection of AGN

The advantages of X-ray selection of AGN include

- High contrast between the AGN and the stellar light (see Figure 2.2).
- Penetrating power of X-rays. Even column densities of $3\times10^{23}$ cm$^{-2}$ (corresponding to $A_V \sim 150$ mags) do not reduce the flux at $E > 5$ keV significantly (see Figure 2.3).
- Great sensitivity of *Chandra* and *XMM-Newton*. Sources in the luminosity range $10^{42} - 10^{46}$ ergs s$^{-1}$ can be detected out to $z \sim 3$, independent of the nature of the host galaxy (e.g., Steffen et al. 2003).
- Accurate positions from *Chandra*. Unique identifications can be made with counterparts in other wavelength bands.
- A relatively large fraction of the bolometric energy ($3 - 20\%$) is radiated in the classical X-ray bands (Ho 1999).
- High areal density of X-ray–selected AGN reaching 400 sources deg$^{-2}$ at $F_X \sim 10^{-15}$ ergs cm$^{-2}$ s$^{-1}$ in the $2 - 8$ keV band (Moretti et al. 2002), a level easily reachable with *Chandra* and *XMM-Newton* in moderate exposures, compared to the maximal value of $\sim 150$ deg$^{-2}$ in optical surveys.
- Large amplitude and frequency of variability in the X-ray band (see Dobrzycki et al. 2003 for an interesting comparison of objects selected by X-ray imaging and optical variability techniques).

In contrast to the optical, where stellar light is a major contributor, or the UV, where light from young massive stars often dominates, or the IR, where dust reradiation from massive stars dominates, or the radio, where emission from HII regions, young supernovae, and other indicators of rapid star formation are often very important, there are very few sources of radiation that can confuse the issue in the hard X-ray band.

Point-like X-ray emission is easy to recognize as being caused by low-luminosity AGN. Using surveys of the low-redshift universe as a guideline, if the total integrated X-ray luminosity of a small ($< 2$ kpc in size) object is greater than $10^{42}$ ergs s$^{-1}$, then the object is almost certainly

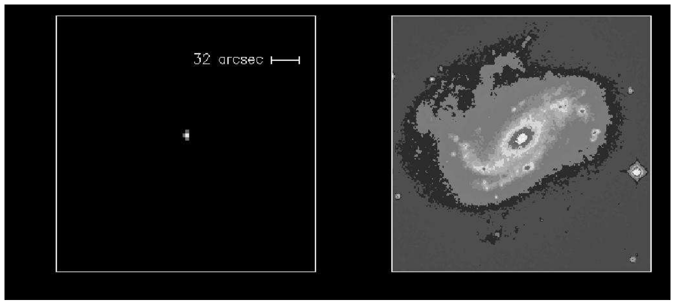


*Figure 2.2.* *(Left panel)* X-ray (*ROSAT* High-Resolution Imager) and (*Right panel)* optical (SDSS) images of the nearby Seyfert galaxy NGC4051. Notice in the X-ray image that essentially the only observed emission is due to the AGN, while the optical image is dominated by starlight. This is one of the original objects identified by Seyfert (1943).

an AGN. In the low-redshift universe, there are no galaxies with a total (non-AGN) luminosity exceeding this level. Thus, even without detailed X-ray spectra or imaging, the identification of the nature of the source is clear.

X-rays are also rather penetrating. Column densities corresponding to $A_V = 5$ ($N_H \sim 10^{22}$ atoms cm$^{-2}$) only reduce fluxes by $\sim 3$ in the *Chandra* and *XMM-Newton* soft X-ray bands. One can see in the $2 - 10$ keV X-ray surveys that approximately half of the brightest objects are highly reddened in the optical and often invisible in the UV. At $z \sim 10$ the absorber has to be Compton-thick ($A_V \sim 2000!$) to "kill" the X-ray flux (see Fig. 2.3). Thus, there are no dark ages for very high-redshift AGN in the X-ray band caused by the Gunn-Peterson effect. X-rays have a "reverse" Ly$\alpha$ forest effect—redshifting reduces the effects of absorption. Thus, for a fixed flux and column density, high-redshift quasars are easier to detect. This effect is similar, but of smaller magnitude, to that seen for the submillimeter sources.

From a more physics oriented point of view (Mushotzky, Done, & Pounds 1993), the X-ray emission originates from very close to the central black hole, often shows large amplitude rapid variability, and is characterized by a non-thermal spectrum. Thus, the X-ray properties are directly connected to the black hole nature of the AGN and are not due to reprocessing of the radiation

The fundamental properties of black holes should not be functions of metallicity or environment but only of mass, accretion rate, and black hole spin. Since the X-ray flux originates from very close to the event horizon, the X-ray properties of high-redshift "primordial" black holes should be very similar to that of lower redshift objects. This allows a

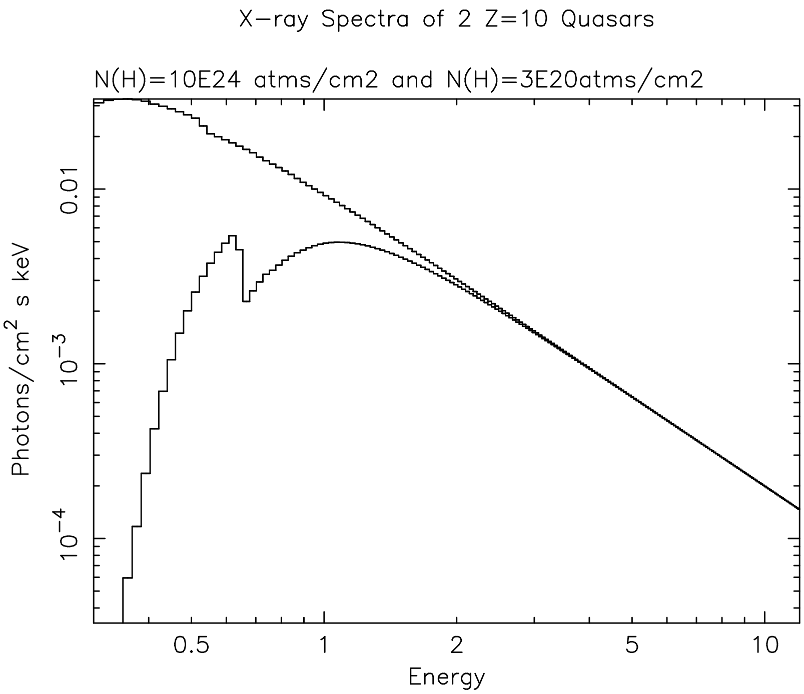


*Figure 2.3.* X-ray spectra of two AGN at $z \sim 10$, one with no absorption, and the other with a line of sight column density of $\sim 10^{24}$ atoms $cm^{-2}$ and pure photoelectric absorption. Note that at energies greater than 2 keV (observer's frame), there is no reduction in the source flux. The effects at lower energies are much larger.

reasonable calculation of their observable properties at high redshifts (Haiman & Loeb 1999; see also Haiman & Quataert, this volume).

### 2.4.1 Early X-ray Surveys

The first large-scale surveys of the X-ray sky were performed by the *Uhuru* (Gursky & Schwartz 1977) and *Ariel-V* (Pounds 1979) small satellites in the $2 - 6$ keV band in the 1970s. These surveyed the sky more or less uniformly above a flux threshold of $\sim 2{\times}10^{-11}$ ergs $cm^{-2}$ $s^{-1}$ and, while non-imaging, were able to derive error boxes small enough to identify many of the sources. One of the early surprises was that approximately half of all the AGN identified by *Ariel-V* had not been identified previously as active galaxies by radio or optical surveys and had rather different properties (weaker non-thermal continua, narrower weak lines, strong reddening) than optically-selected AGN. The last large solid angle survey in the $2 - 10$ keV band was performed by the *HEAO-1* satellite, with the largest samples being from the A2 (Piccinotti et al. 1982) and

A1 (Remillard et al. 1986) experiments. These surveys produced a list of $< 200$ AGN and a complete identification of the Piccinotti et al. (1982) list, which had only 35 AGN.

### 2.4.2 Soft X-ray Surveys

The *Einstein* and, especially, the *ROSAT* surveys have provided very large samples of soft X-ray–selected AGN. There have been extensive discussions of samples obtained by these missions (see Puchnarewicz et al. 1996 for a summary of the pointed observations, and Fischer et al. 2000 and Zickgraf et al. 2003 for the survey data). At moderate X-ray fluxes ($> 10^{-13}$ ergs cm$^{-2}$ s$^{-1}$), there is only $\sim 1$ X-ray source per square degree, and the *ROSAT* PSPC[6] had sufficiently small positional errors that unique identifications could be made for the sources brighter than $m \sim 20$ mag in the $B$ or $V$ bands on the basis of the X-ray positions alone (see Fig. 2.4). However, at lower fluxes, more accurate positions and better angular resolution are often required, and many of the identifications were made on the basis of finding a broad-line object inside the X-ray error circle. Historically, this is how the previous large soft X-ray survey with *Einstein* (the EMSS; Gioia et al. 1990) obtained optical counterparts. At faint X-ray fluxes ($< 10^{-14}$ ergs cm$^{-2}$ s$^{-1}$), very long observations were required to detect the sources (the *ROSAT* Deep Surveys; Hasinger et al. 1998). It is historically interesting that the identifications of most of the *ROSAT* Deep Survey sources were just at the limit of the capabilities of the largest ground-based optical telescopes, with the optical identification of the survey being almost complete at $R \sim 23$ mag (Hasinger et al. 1999).

Soft X-ray surveys find that there is a moderate correlation of optical and X-ray properties (see Fig. 2.5) with a relatively narrow ($\pm 1$ order of magnitude) range in X-ray–to–optical flux ratios, that the X-ray evolution of AGN is similar to that of optically-selected AGN (see Miyaji, Hasinger, & Schmidt 2000), and that most of the objects are broad-line AGN (see Hasinger et al. 1999 for a review). In the shallow *ROSAT* All-Sky Survey (Appenzeller et al. 2000), the median redshift is $z \sim 0.2$, and there are only two objects at $z > 2$. This is to be contrasted with the "shallow" optical Bright Quasar Survey (BQS; Schmidt & Green 1983), which has a much flatter redshift distribution out to $z \sim 2$. However, there is a significant fraction of unusual AGN, some of which have rather

[6] The PSPC is the Position Sensitive Proportional Counter, the workhorse instrument on *ROSAT* with a $15''$ spatial resolution and $3'' - 5''$ positional errors.

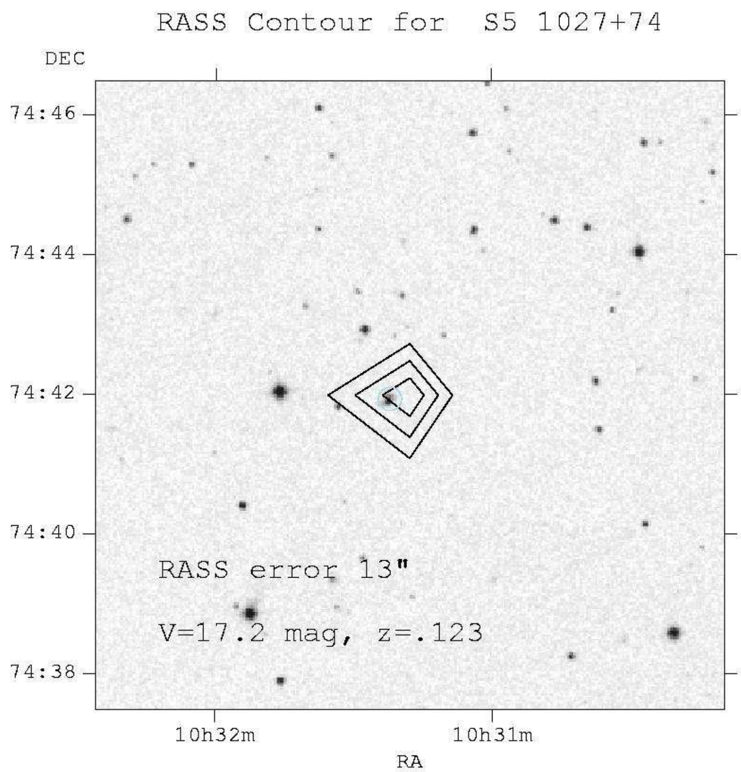


*Figure 2.4.* X-ray contours from the *ROSAT* All-Sky Survey superimposed on a field from the Palomar sky survey for the quasar S51027+74. Note that the *ROSAT* contours are small enough for a high-probability optical identification of the source.

red continuum colors and broad optical emission lines (Puchnarewicz & Mason 1998).

As discussed in §2.3, there are significant selection effects in soft X-ray surveys caused by obscuration in the line of sight. Perhaps the most direct example of this is the analysis of *ROSAT* observations of the Piccinotti et al. (1982) hard X-ray survey (Schartel et al. 1997), which shows that approximately half of all the hard X-ray sources are absorbed and thus have significantly lower soft X-ray fluxes—up to 300 times less—than expected if the spectra were not absorbed. A comparison of the hard X-ray properties of a soft X-ray–selected sample has not been done because of the limited sensitivities of large solid angle hard X-ray surveys.

As one goes to higher redshifts, the effect of obscuration in the X-ray band decreases as the spectrum redshifts (Barger et al. 2001), so the

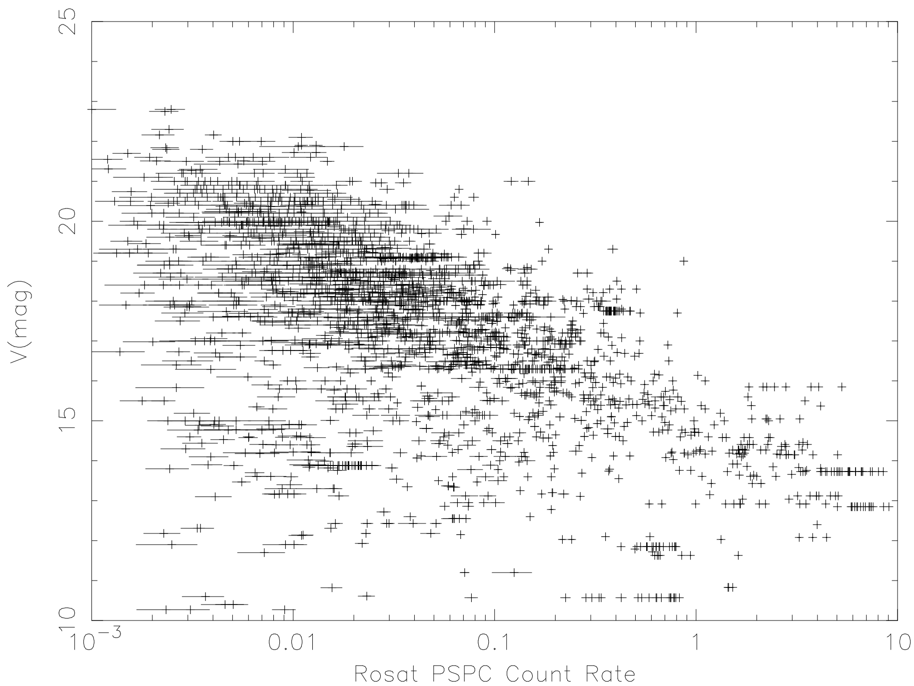


*Figure 2.5.* Correlation of the *ROSAT* All-Sky Survey counting rate and optical magnitude for a large sample of active galaxies. Note that the majority of objects lie in a narrow band in magnitude vs. X-ray counts space.

observed $0.5 - 2$ keV band is much less affected by obscuration effects. This seems to be a rather important effect for the *Chandra* sources, and thus the *ROSAT* soft-band data need to be corrected for the changing effective bandpass.

*ROSAT* also performed a survey in the softest X-ray bands at 0.25 keV (Vaughan et al. 2001). Because of the effect of obscuration by the galactic column density in this low-energy range, only $\sim$ 0.6 sr could be covered. The sample appears to be complete. The identifications are rather different than in other AGN surveys, with one-third of the AGN identifications being BL Lacertae objects and one-quarter being narrow-line Seyfert 1 galaxies. These are relatively large percentages for these two classes of objects compared with surveys in any other wavelength band. Such a survey has a bias towards these objects because of their steep X-ray spectra. The almost disjoint nature of the objects contained in a hard (see §2.4.3) and extremely soft X-ray selection is a warning to the completeness of any survey.

### 2.4.3 Pre-*Chandra* and *XMM-Newton* Hard X-ray Surveys

The most sensitive large solid angle $2-8$ keV surveys have been obtained via serendipitous sources detected by *ASCA* (Akiyama et al. 2003; Nandra et al. 2003) and *BeppoSAX* (Fiore et al. 2000). These satellites had moderate fields of view and moderate sensitivities, reaching $2-10$ keV flux limits of $\sim 2\times10^{-13}$ ergs cm$^{-2}$ s$^{-1}$. At this flux level, there are $5-10$ sources per square degree (Cagnoni, della Ceca, & Maccacaro 1998; Ueda et al. 2001), or roughly one serendipitous source per *ASCA* or *BeppoSAX* pointing. Over its lifetime, *ASCA* obtained $\sim 500$ serendipitous sources over $\sim 100$ deg$^2$, and *BeppoSAX* somewhat fewer. Because of their moderate $\sim 1-3'$ FWHM angular resolutions and $40-100''$ angular accuracies (similar to those of the earlier *Einstein* soft X-ray serendipitous survey), optical follow-up has been tedious, and the number of identified sources is now only $\sim 150$ objects. The difficulty of optical, IR, and radio follow-up seriously delayed the results from these surveys, and they appeared after the initial *Chandra* results, despite the fact that these satellites were launched $5-7$ years earlier. The angular resolution of these surveys limits the fluxes of the optical counterparts to $R<21$ mag for the *BeppoSAX* HELLAS survey and $R<19$ mag for the *ASCA* Large Area Sky Survey, in order to avoid confusion and speed up the identification process. This is about two magnitudes brighter than the *ROSAT* Deep Survey limits. At these levels, $\sim 85\%$ of the sources are identified with fairly high confidence.

The nature of the sources is rather different from the *ROSAT* sources, with approximately one-third not having prominent broad lines (La Franca et al. 2002; Akiyama et al. 2003), while in the bright and faint *ROSAT* samples (Lehmann et al. 2000; Appenzeller et al. 2000), more than 90% of the AGN identifications have broad lines. The hard X-ray surveys find very few narrow-line Seyfert 1 galaxies compared to the large fraction in the *ROSAT* surveys. There are only a very few sources at these hard X-ray flux levels that have "normal" galaxies as optical counterparts.

The range of optical–to–X-ray flux ratios is very large, $\pm2$ dex, which is much larger than in the *ROSAT* bands, $\pm1$ dex. It is believed that there are two main effects in the sample differences: 1) obscuration, and 2) redshift. It has been noted in the deep *ROSAT*, *Chandra*, and *XMM-Newton* samples (see §2.4.4) that there is a strong correlation (Hasinger et al. 1999) between $R-K$ color and optical magnitude, with the fainter optical counterparts of the X-ray sources being systematically redder. Part of this is clearly due to the increasing effect of dust on the rest-frame UV colors of AGN (the same amount of dust is much more significant in the UV than in the optical, and, of course, it is the UV which gets redshifted into the rest-frame optical band for $z > 1$ objects), and part seems to be due to the relative dominance of starlight in many of the faint sources and the steep SED of stellar objects. The mean X-ray spectral indices of the objects flatten as the sources get fainter by about $\Delta\alpha \sim 0.3$ over a factor of $10^3$ in flux (Ueda et al. 1999).

The properties of these sources indicate that a significant fraction of them have highly absorbed spectra, but the absorption is not "simple". The popular "leaky absorber model" (Turner et al. 1997), which fits many of the high signal-to-noise *ASCA* AGN spectra, produces a significant signal for highly absorbed objects in the soft ($0.5 - 2$ keV) band. Recently, results from many *Chandra* and *XMM-Newton* serendipitous fields are becoming available, which will allow a much larger database for the $F_X < 10^{-13}$ ergs cm$^{-2}$ s$^{-1}$ sources, but the solid angles covered will be too small to produce many sources in the $F_X \sim 10^{-12} - 10^{-13}$ ergs cm$^{-2}$ s$^{-1}$ range, for which good X-ray spectra can be obtained.

It is entertaining to note that the recent deep *Chandra* hard X-ray surveys have more objects per pointing than the entire *HEAO-1* or *ASCA/BeppoSAX* data sets.

### 2.4.4 Deep *Chandra* and *XMM-Newton* Hard X-ray Surveys

Because the *ROSAT* Deep Surveys resolved most of the soft X-ray background, much of the emphasis with *Chandra* and *XMM-Newton* has been on hard X-ray surveys[7]. It also seems that at the faintest fluxes reached by *Chandra* ($\sim 10^{-16}$ ergs cm$^{-2}$ s$^{-1}$ in the $2-10$ keV band, corresponding to 10 counts in the deepest $2 \times 10^6$ s exposures), the relative fraction of objects which are AGN declines rapidly (Hornscheimer et al. 2003), indicating that one has reached the "end of AGN-ness", similar to what is seen in the deep radio surveys.

The major advantage of the *Chandra* data is that, to very faint optical magnitudes ($I \sim 28$), there is almost always an "unique" optical identification (or lack thereof, Barger et al. 2003a; Koekemoer et al. 2004). Thus, as opposed to almost all other surveys (with the exception of radio data), the identifications are certain, and one does not need to rely on optical spectroscopy to confirm the identification.

[7]For the most recent update on the *Chandra* and *XMM-Newton* surveys, see Barcons (2003).

The nature of the hard *Chandra* sources has been rather surprising (Mushotzky et al. 2000; Barger et al. 2001; Alexander et al. 2001). As summarized in Barger et al. (2003b), less than 30% of the optical counterparts have strong broad lines or a non-thermal continuum, and many of the other 70% are pure absorption-line objects. Most of the light from these sources is due to stars in both the optical (Barger et al. 2002) and IR (Crawford et al. 2001) bands; even with *HST* images, the nuclei are almost invisible (Grogin et al. 2003; Cowie & Barger, this volume). Most of these objects have stellar luminosities near $L^*$ or brighter in the $K$-band. Given the very high areal density of the *Chandra* sources (more than 3000 deg$^{-2}$ at $F_X \sim 10^{-16}$ ergs cm$^{-2}$ s$^{-1}$ in the 2−8 keV band), this makes these "optically-dull" (a nomenclature first used by Elvis et al. 1981) objects the most numerous class of AGN. Similar results are seen in the *XMM-Newton* surveys (Barcons et al. 2002). Comparison of the optical colors of the *XMM-Newton* sources shows that only about half are consistent with the region used by the SDSS to find AGN (Richards et al. 2002).

The exquisite *Chandra* positions have allowed the detection of the X-ray–selected AGN population that (a) dominates the AGN numbers, (b) are not found by standard optical selection criteria, and (c) would not have been found in previous X-ray surveys. This is a stunning example of the "lamppost effect" alluded to in the introduction and should open our eyes to the possibility of even more such surprises when IR selection techniques are well developed.

### 2.4.5 Comparison of X-ray and Optical Surveys

So the question arises as to what is the difference between the X-ray and optically-selected samples? Since, as discussed above, there are strong selection effects in soft X-ray, UV, and optical samples, especially at luminosities less than $10^{44}$ ergs s$^{-1}$, it is not a great surprise to found that the major differences between these two surveys occur at this luminosity and less (Steffen et al. 2003). Clearly, optical-selection techniques are much less sensitive to low-luminosity objects, where the effects of stellar dilution can be large (Moran et al. 2002; Moran, this volume).

Stellar dilution reduces the amplitude of optical variability. In one of the very few direct comparisons of optical variability versus X-ray selection, Dobrzycki et al. (2003) found a ratio of X-ray to variability-selected quasars of $\sim 5:1$ at $V < 20.5$. Similar effects are seen in a comparison of objects in the SSA13 field, where Cowie et al. (1996) found only three obvious quasars, and a moderately deep *Chandra* observation found $> 20$ active galaxies in the same solid angle. Similar results are obtained in the Hubble Deep Field-North (HDF-N) and Flanking Fields, where Liu et al. (1999) found an areal density of $B < 21$ quasars of 30 deg$^{-2}$ (rather typical of optical quasar surveys), while there are $>$ 1000 *Chandra* AGN deg$^{-2}$ in the same field.

Detailed analyses of several of the "optically-dull" galaxies (including the famous first one, 3C264) show that dilution, while important (Watanabe et al. 2002), is often not enough to remove an obvious AGN signature (Severgnini et al. 2003), and the optical continuum and emission lines must be reduced in strength if these objects have the same ratio of H$\alpha$ or $B$-band flux to X-rays as "normal" AGN. A large fraction of the "optically-dull" galaxies have hard X-ray spectra indicative of column densities $> 10^{22}$ atoms cm$^{-2}$, but this is primarily derived from hardness ratios, rather than directly from X-ray spectral fitting.

Alternatively, it is possible that the "optically-dull" galaxies are intrinsically weak in the optical band, as seen in many LINERs, which have the same properties: high X-ray–to–optical ratios, absent or very weak optical continua, no broad lines, and weak total emission-line flux (Ho 1999). This reviewer suspects that all three effects are important but that many of the *Chandra* "optically-dull" galaxies are higher luminosity versions of LINERs, which are not cataloged in the low-redshift universe, since such objects would probably only be found in the low-redshift universe via a large solid angle sensitive hard X-ray survey. There are recent indications from the SDSS that such objects are quite common (as indicated in the Ho et al. 1995 work), but without X-ray measurements, their true luminosities are difficult to estimate.

Because of the absence of measurable optical nuclear light in these objects, the bolometric correction factors are not known, and thus the contribution of these objects to the mass density of black holes is difficult to estimate (see, however, Cowie & Barger, this volume). The recent *HST* observations of *Chandra* sources (Grogin et al. 2003) indicate that the observed nuclear light is $\sim 20$ times less than anticipated on the basis of the X-ray flux and the X-ray–to–optical ratios of the *ROSAT* sources.

One of the unexpected features of the distribution of the *Chandra* sources was their strong concentration in large scale structures (Barger et al. 2003b; Gilli et al. 2003; Yang et al. 2003), in contrast to optically-selected samples, which have the same correlation functions as normal galaxies. I suspect that this can be understood as a matter of the higher space density of X-ray–selected AGN that allows them to be traced on smaller length scales not possible with optical samples.

Theoretically, this result is perhaps unexpected. It is believed that there is a strong correlation between the mass of the black hole and the mass of the galaxy. Therefore, luminous AGN should be in massive galaxies, which are more strongly clustered than other galaxies. However, the mean bolometric luminosity of the *Chandra* AGN sources is considerably less than that of objects in optically-selected surveys, especially at $z > 0.2$. Thus, one might naively expect X-ray–selected AGN to be more weakly correlated than optically-selected objects.

It is likely that the X-ray luminosity is strongly correlated with the black hole mass, with a scatter of roughly 50 (Grupe 2004). This sort of correlation is apparently not seen with the bolometric luminosity (Woo & Urry 2002). Thus, the correlation of X-ray luminosity with the optical luminosity of the host galaxy seen in the *Chandra* fields (Fig. 22 in Barger et al. 2003b) indicates that a very large fraction of the "medium luminosity" *Chandra* AGN lie in massive galaxies that are strongly correlated (Barger et al. 2001; Cowie et al. 2004b). I believe the true question should be: why does the optically-selected sample not show a stronger correlation function?

### 2.4.6 Very High Energies

The detection of luminous $E > 10$ keV emission from several nearby, apparently low-luminosity objects (e.g., NGC4945; Done et al. 2003) shows that even the $2 - 8$ keV band can suffer from selection effects. The *BeppoSAX* survey of Seyfert 2 galaxies (Risaliti, Maiolino, & Salvati 1999) shows that the distribution of column densities is flat in log space from $10^{21}$ to $3 \times 10^{24}$ atoms cm$^{-2}$. While very high column density objects may be absent from the *Chandra* samples, the argument put forward by Fabian (2000) that three-fifths of the nearest AGN have very high column densities has, in my opinion, strong merit. The absence of a large solid angle sensitive $E > 10$ keV survey means that the statistics of such objects are hard to constrain, but it certainly seems possible that the number of low to moderate-luminosity objects at $z < 0.5$ with very large column densities may be similar to that of less absorbed objects. The fundamental question is whether "absorbed" accretion is a major component to the total AGN luminosity. It is not clear how, absent a new X-ray mission[8], to proceed to answer this question.

[8] It seems as if *INTEGRAL* is not sensitive enough to perform a survey of AGN in the $10 - 30$ keV band; the sensitivity of *SWIFT* is not yet clear, but it may provide the best hard X-ray survey yet performed.

## 2.5 Conclusions

The wide variety of techniques to detect AGN has resulted in a vast array of objects with an enormous variety of selection effects. At high luminosities, optical and X-ray selection seem equally sensitive. At lower luminosities, beam dilution, absorption, and the possible existence of optically-quiet AGN seem to make X-ray selection more reliable. While it may be premature, it seems as if hard X-ray emission is a fundamental observational property of AGN and that the most unbiased samples of AGN are found in $E > 2$ keV X-ray surveys. This field is rapidly changing, and I anticipate that we will soon have direct comparisons of very sensitive techniques in the X-ray, optical, radio, and IR bands in exactly the same places in the sky to allow the first full view of the AGN phenomena.

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