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AGN SURVEYS VIA OPTICAL VARIABILITY, X-RAY, AND MID-IR DETECTION IN HST FIELDS

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RESUMEN

En los campos de imágen profunda del Hubble (HST), los núcleos activos de galaxias (AGN) son seleccionados usando diversas técnicas en diferentes longitudes de onda. Este trabajo compara las muestras de AGN seleccionadas de los campos del Hubble a través de la variabilidad óptica, de los rayos-X y del mediano infrarrojo. Resultados recientes del campo HST-GOODS-South muestran que el 57% de los AGN seleccionados por su emsión conjunta en los rayos-X y en el mediano infrarrojo, varían en la región del óptico. Algunos AGN seleccionados sólo en rayos-X y unos cuantos de los seleccionados sólo del mediano infrarrojo también son variables en el óptico. Investigamos la naturaleza de los AGN que hemos identificado y el papel que juega el oscurecimiento al utilizar estas diferentes técnicas de selección.

ABSTRACT

AGN are identified in deep HST surveys via a number of selection techniques and wavelengths. This work compares the samples of AGN selected via optical variability, X-ray and mid-IR indicators in HST survey fields. Recent results from the HST GOODS-South field reveal that 57% of X-ray and mid-IR selected AGN are also optical variables. Several X-ray-only AGN are variables as well as a few mid-IR-only selected sources. We investigate the nature of the identified AGN and the role of obscuration among the various selection techniques.

Key Words: galaxies: active — surveys

1. INTRODUCTION

Active galaxies manifest themselves at a range of wavelengths and via different observing techniques. The first active galaxies were identified based on their extreme luminosities, emission line properties and ability to vary in luminosity over short time periods. Active galaxies display significant optical flux changes on timescales of months to several years. Variability has been a popular technique to identify quasars (Koo et al. 1986; Hook et al. 1994), the more luminous class of active galactic nuclei (AGN). However, lower-luminosity AGN, such as Seyfert galaxies, have also been shown to vary in broad-band photometric surveys (e.g. Peterson et al. 1998). A survey for variable sources in SA57 revealed many optically extended, Seyfert-like galaxies (Bershady et al. 1998) which generally had higher variability amplitudes than the more luminous QSOs. Recent results from the Sloan Digital Sky Survey confirm this anti-correlation between AGN luminosity and optical variability amplitude (Vanden Berk et al. 2004).

Active galactic nuclei (AGN) are also bright X-ray sources, due to the extreme temperatures of material as it accretes onto the blackhole. X-ray emission has the added advantage of being less affected by obscuring material, which may enshroud many AGN. Active galaxies are also often bright in the mid-infrared. If there is a significant amount of obscuring dust, the light at shorter wavelengths will be reprocessed via the dust and emitted in the mid-infrared. Thus mid-IR surveys are often successful in identifying heavily obscured AGN.

In this proceedings, I report on several optical variability surveys to identify intrinsically faint ($M_B \geq -22$) AGN in deep, Hubble Space Telescope image fields. Most galaxies in these fields have redshifts around z≃1. Thus, these surveys probe the fainter population of AGN at significant distances and look-back times. Knowledge of the space density of faint AGN at earlier epochs is of particular importance for determining their role in AGN and galaxy evolution. The sources identified via variability are then compared with X-ray and mid-IR AGN selection techniques to understand the role of obscuration in variability surveys.

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2. VARIABILITY SURVEYS IN HST FIELDS

The Hubble Deep Field North (HDF-N) was the first deep HST field to be re-imaged several years after the initial observations. The first epoch of data was obtained in 1995 and the second epoch in 2000. Our technique is to exploit the high resolution of HST to isolate and detect varying nuclei within galaxies. To do this, the photometric apertures are set slightly larger than the seeing FWHM to measure light primarily from the nuclear, unresolved component of the galaxy while avoiding the non-varying galaxy component. For the HDF-N, an aperture size of r=0.075″ was used. A difference measurement of the magnitude of each galactic nucleus was then determined for 217 galaxies to $V_{nuc} \leq 27.5$, the completeness limit of our survey. We identified 16 galaxies with significantly varying nuclei in the HDF-N (Sarajedini, Gilliland, & Kasm 2003) comprising 8% of the galaxies in this field.

Seven of the 16 variables (44%) were detected in the 2Ms Chandra X-ray survey (Alexander et al. 2003). About half of these X-ray sources have considerably lower F_x/F_{opt} ratios than typical AGN and would not have been classified as AGN based on X-ray properties alone. Thus, variability can be an important descriminant on the nature of the dominant X-ray-emitting source in some galaxies.

We have also analyzed optical variability in a larger, but shallower HST field known as the Groth Survey Strip (GSS; Sarajedini et al. 2006). This region is 28 times larger in area than the HDF-N. Twenty-six galaxies with variable nuclei (4.5%) were detected in this field down to a limiting magnitude of $V_{nuc} \leq 27$. A lower percentage of variables was identified in this field (as compared to the HDF-N) due to the poorer repeatability of the second epoch images (i.e. pointing errors) coupled with the WFPC2 CCD charge transfer efficiency losses. Thus, the GSS variability threshold was significantly higher than that obtained for the HDF-N. A comparison with X-ray observations found that 25% of the variables were associated with X-ray sources from the Chandra and XMM surveys (Nandra et al. 2005; Miyaji et al. 2004).

3. GOODS-SOUTH FIELD VARIABILITY OF PRE-SELECTED AGN CANDIDATES

The Great Observatories Origins Deep Survey (GOODS) consists of a North and South field with a total area of 320 □′ imaged with the HST Advance Camera for Surveys (ACS). The data were obtained in 5 epochs separated by 45-day intervals. We are currently carrying out a systematic search for variable nuclei in both fields to identify AGN candidates via their variable nuclei.

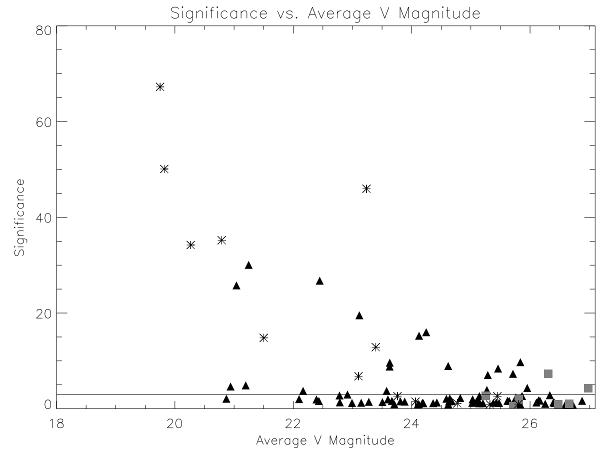

Fig. 1. Significance vs. average nuclear (r=0.125″) V magnitude. Black triangles represent objects detected only in X-rays, gray squares are objects selected via IR power-law behavior, and asterisks are objects that are both X-ray and mid-IR selected. The solid line delineates 3-sigma variability significance.

We have recently completed a variability analysis of several AGN candidates selected via X-ray and IR properties (Klesman & Sarajedini 2007). These sources appear to have a range of obscuration levels, from soft X-ray sources to highly obscured mid-IR sources lacking X-ray emission. The AGN candidates consist of 22 mid-IR power-law sources from Alonso-Herrero et al. (2006) and 104 X-ray sources from Alexander et al. (2003). The mid-IR sources are galaxies whose Spitzer IRAC band fluxes reveal a power-law SED in the mid-IR, which is often indicative of an AGN. The X-ray sources were detected in the Chandra 0.2–8 keV survey. Each sample was constrained to those galaxies which fell within our optical survey and above our photometric magnitude limits. There are 14 objects which are both X-ray and mid-IR power-law sources.

Figure 1 shows the variability significance, the standard deviation of the nuclear optical flux divided by the RMS of the photometric errors, versus the average nuclear V magnitude for all objects. The solid line is the 3-sigma variability significance threshold. We find a total of 29 galaxies with variable nuclei (26%). Eight of the 14 galaxies which are mid-IR and X-ray selected AGN candidates show significant optical variability (57%). Many of these are also the brightest optical sources. These are most likely luminous AGN with some dust/obscuring material present to reprocess a portion of the light and re-emit it in the infrared. Most of the other variables are X-ray-only selected AGN candidates. These sources may contain little dust and thus do not reveal AGN signatures in the mid-IR. Two of the variables are IR-only selected AGN candidates. These sources are likely to be obscured AGN, where much of the X-ray, UV and optical light is reprocessed into the mid-IR. Their extremely faint optical magnitudes are consistent with this interpretation. In total, 45% of all mid-IR AGN and 26% of all X-ray AGN exhibit significant optical variability.

A closer look at the X-ray emission reveals some clues to help quantify the types of AGN selected via optical variability. We compute the band ratio (BR) for X-ray sources as the hard X-ray flux (2–8 keV) divided by the soft X-ray flux (0.5–2 keV). The band ratio provides a measure of the level of obscuring material around the AGN, with small band ratio values representing sources with the least obscuration. Considering only the softest X-ray sources (BR<0.5) we find the percentage of optical variables to be 51%. X-ray sources with intermediate band ratios reveal 16% as optical variables. There are no optical variables among those with the hardest X-ray emission (BR>2), indicating the greatest levels of obscuration.

If the cause of AGN variability is related to instabilities in the accretion disk (e.g. Pereyra et al. 2006), then it is not surprising that less obscured AGN, those where the accretion disk and surrounding area are directly visible to the observer in the unified theory, are more likely to display optical variability. Likewise, since much of the optical light is absorbed/scattered by dust, measuring optical variability should become increasingly difficult in more obscured AGN. Nonetheless, this study reveals that high-resolution multi-epoch optical imaging with HST can detect optical variability for faint galactic nuclei and can even detect significant variability for some heavily obscured AGN, albeit with a lower success rate than for unobscured AGN.

4. SUMMARY AND FUTURE WORK

We have found that optical variability of galactic nuclei can be a powerful probe to detect low-luminosity, Seyfert-like AGN in $z \simeq 1$ galaxies on timescales of months to several years. Depending on the repeatability of the imaging survey and the subsequent threshold to detect variability, multi-year surveys with HST (such as the HDF-N and GSS) find that between ∼4% and 8% of galaxies contain a variable nucleus. The majority of these are likely to be AGN. A significant fraction of the variables are X-ray detected (25% to 44%). Of those sources displaying power-law SEDs through the mid-IR IRAC bands, 45% are optically variable in the GOODS-S field. Additional analysis of the X-ray and mid-IR properties of sources in the GOODS-S field indicate that optical variability identifies most unobscured AGN. However, those objects with significant amounts of obscuration based on X-ray band ratio or mid-IR selection can also display optical variability, but with a lower detection rate.

Spectroscopic data are particularly helpful in identifying and classifying AGN and determining their redshifts for evolutionary studies. While optical spectroscopic surveys have been conducted in many of the fields analyzed here, the optical wavelength range often misses important emission features for higher redshift AGN ($z \geq 1.2$). We plan to conduct a near-IR spectroscopic survey to study the nature of AGN selected via multi-wavelength and multi-technique surveys. The Flamingos II near-IR multi-object spectrograph will soon be available on the Gemini South telescope, with access to the GOODS-S field. In the near future, the EMIR spectrograph will be available on the Gran Telescopio Canarias for spectroscopic follow-up of AGN candidates in GOODS-N and the Extended Groth Survey Strip. Together, these instruments will provide the necessary spectroscopic information to fully study the properties of AGN in higher redshift galaxies (out to $z \simeq 3$) and better understand the evolution of AGN and their relationship to galaxy evolution.

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