AGN SURVEYS
ASP Conference Series, Vol. 284, 2002
R.F. Green, E.Ye. Khachikian, D.B. Sanders

Spectroscopic and Variability Surveys for AGN in the Groth Survey Strip

Vicki Sarajedini

Department of Astronomy, University of Florida, Gainesville, FL 32611

Abstract. Preliminary results are presented for a spectroscopic survey of the Groth Survey Strip (GSS), a 30 by 3 arcminute region of the sky imaged with HST, for which several hundred galaxy spectra have been obtained as part of the DEEP project (http://deep.ucolick.org). At least 6 broad-line AGNs (primarily Seyfert 1s) have been detected as well as several narrow-line Seyfert 2 candidates. The seyfert galaxies detected in our survey have integrated absolute magnitudes extending to $M_B\sim$-17.5, probing fainter magnitudes and higher redshifts than existing optical spectroscopic surveys. We also discuss a variablity study of the GSS using the original HST images from 1994 and new images obtained in 2001. The high resolution obtained with HST allows us to isolate and measure variable galactic nuclei too faint to be detected from the ground, reaching nuclear magnitudes of $M_B\sim$-16 in galaxies to z$\sim$0.8. The combination of these techniques provide a powerful probe of the population of low-luminosity AGNs at moderate redshifts.

1. Introduction

To better understand the nature of any class of extragalactic object, an accurate knowledge of the luminosity function (LF) over a wide range of absolute magnitudes and covering a range of redshifts is necessary. The AGN LF is populated by quasars at the brighter, primarily high redshift end and Seyfert galaxy nuclei, considered to be their intrinsically fainter counterparts, at the low luminosity, low redshift end (Cheng et al. 1985; Huchra & Burg 1992; Maiolino & Rieke 1995). See Wizotski (2002, this volume) for a discussion of the current state of the AGN LF. While bright QSOs are easily observable at all redshifts, fainter seyfert nuclei become increasingly difficult to detect at redshifts much beyond the local universe. Understanding how the faint end of the AGN LF evolves is of particular importance for determining the frequency and total space density of AGNs at earlier epochs.

The purpose of this paper is to show how the increased light gathering capabilities of large (i.e. 10-meter) telescopes and the high spatial resolution achieved with space-based telescopes allows for the detection of these lower luminosity AGN at higher redshifts. In Sections 2 and 3, we describe preliminary results of a spectroscopic survey for AGN using the Keck telescope. Section 4 outlines plans for a variability survey for AGN in this same region of the sky using Hubble Space Telescope images separated by 7 years. A summary of this research is presented in the final section.

2. The DEEP Project

The Deep Extragalactic Evolutionary Probe (DEEP; Koo et al. 1996; Simard et al. 2001) is a project designed to study the formation and evolution of distant field galaxies by combining images from HST with spectroscopic data from the Keck telescope. The Groth Survey Strip (Groth et al. 1994) is one of the fields targeted by DEEP for spectroscopic follow-up. The GSS is comprised of 28 contiguous WFPC2 fields located at 14h17m+52 imaged in the F606W and F814W filters. Optical spectra have been obtained through multi-slit masks with the Keck/Low Resolution Imaging Spectrograph for 775 objects in the GSS between 1995 and 1999. Of the 683 spectra with high enough S/N to identify spectral features and determine redshifts, 634 are galaxies and 49 are galactic stars. The galaxies extend to $I_{AB}\sim24$ with a mean redshift of $z\simeq0.8$. The typical exposure time is one hour with some of the fainter targets being exposed for up to a few hours. Since the majority of galaxies at these redshifts have sizes comparable to the seeing resolution ($\sim1''$), spatial spectral information is not available in most cases and a one-dimensional spectrum has been produced for each object by summing several pixels along the spatial axis.

3. Spectroscopic Identification of AGN

Active Galactic Nuclei can be detected in galaxy spectra through the presence of broad, permitted lines covering a wide range of ionization. Optical spectra for the galaxies studied in this survey display broad H balmer series lines or singly ionized MgII emission (at rest $\lambda2800\mathring{A}$ for higher z objects) when a Seyfert 1 nucleus or QSO is present in the galaxy. Narrow-line Seyfert 2 or LINER galaxies are defined by the property that their forbidden lines and permitted lines have similar, narrow widths with line ratios indicating a more energetic ionizing source than hot stars alone can provide (although in the case of LINERs, this is still under discussion (see Ho 2002, this volume)).

At the present date, a subsample of 235 spectra from the GSS spectroscopic survey (those obtained between 1995 and 1997 with high enough S/N to discern spectral features) have been analyzed to search for AGN. Of these objects, 7 are galactic stars and 7 additional galaxies are high-z galaxies ($z\gtrsim2.8$) not considered in this analysis for the sake of sample uniformity.

Inspection of the remaining 221 galaxy spectra has revealed only two objects with broad lines representing $\sim1\%$ of the galaxies. These galaxies have redshifts of 1.15 and 1.22, each displaying broad MgII emission. Initial inspection of the most recently obtained spectra has revealed at least 4 more broad-lined galaxies with redshifts ranging between 0.6 and 1. The inclusion of the additional spectra are consistent with the finding that $\sim1\%$ of the GSS galaxies appear to be Seyfert 1/QSOs. The integrated luminosities for these galaxies range from $-19.5\gtrsim M_B\gtrsim-22.8$, just below the nominal dividing line between QSOs and seyferts. Since these are integrated magnitudes, the actual nuclear magnitudes are likely to be even fainter.

The majority of the galaxies display narrow emission lines. AGN can be differentiated from star-forming galaxies based on the emission-line ratios of the most prominent optical lines such as [OII]λ3727Å, [OIII]λ4959,5007Å, [NII] λ6548Å, [SII]λ6717,6730Å, Hα and Hβ (e.g. Veilleux & Osterbrock 1987). For the large fraction of galaxies in the GSS, however, many of these lines are redshifted out of the optical range. In addition, our spectra, like many large, multislit spectroscopic surveys, are not flux calibrated. For these reasons, traditional line ratio diagnostics are not applicable to our survey.

A new emission line diagnostic (Rola, Terlevich & Terlevich 1996) is being employed to differentiate AGN and star-forming galaxies in our survey spectra. This technique is based only on the equivalent widths of [OII] and Hβ, allowing for classification of galaxies to z$\simeq$0.8 with optical spectra and avoiding the necessity of flux calibration. Two distinct zones define the AGN region of the diagram, at EW(Hβ)<10 and EW(OII)/EW(Hβ)>3.5. Using a sample of local emission line galaxies, Rola et al. (1996) find that 87% of the AGN reside in these regions with 88% of the HII galaxies falling in the remaining region. Although this technique does not perfectly separate the two object classes, it does a fairly good job of identifying the majority of AGNs in a sample of emission line galaxies.

Of the 221 galaxy spectra in our subsample, 90 have both the [OII] and Hβ lines in the optical spectrum range. Out of those 90 galaxies, only 44 show both lines in emission. We plot these on the Rola diagram in Figure 1 with appropriate error bars. We note the importance of correcting the Hβ EW measurements for the underlying stellar continuum absorption. Without the detection of the Hα emission line for these galaxies, we can only estimate the amount of Hβ absorption in the continuum. We have chosen a moderate value of 3 Å for the underlying stellar absorption (Kennicutt et al. 1992, Tresse et al. 1996). This correction has the effect of pushing objects into the HII region of the diagram. The filled circles represent those galaxies clearly in the HII galaxy region. The open circles are those in the AGN region but with error bars extending into the HII region. The asterisks are those galaxies clearly in the AGN region of the diagram. If the probability that these galaxies are AGN is 88%, our lower-limit estimate on the total number of narrow-line AGN in the GSS out to z$\simeq$0.8 is 10%. If we include the additional 11 objects which lie in the AGN region but have error bars allowing them to be placed in either the AGN or HII regions, our fraction increases to 20%.

The AGN candidates in our survey have integrated absolute magnitudes extending to $M_B \simeq -17.5$, with nuclei that may be up to a magnitude fainter. This demonstrates the strength of the Keck telescope in probing activity in galaxies at much fainter luminosities and higher redshifts than previously possible. Our completed survey for AGN in the GSS will extend the AGN LF several magnitudes fainter at z$\sim$0.8.

A few other diagnostics are available to identify narrow-line AGN in our survey such as the strength of [NeIII]λ3869 and the presence of [NeV]λ3426. A few additional candidates have been detected through the presence of these emission lines. A full analysis of the complete sample of GSS galaxy spectra to detect AGN is presented in a future paper (Sarajedini et al. 2002).

https://doi.org/10.1017/S0252921100030487 Published online by Cambridge University Press

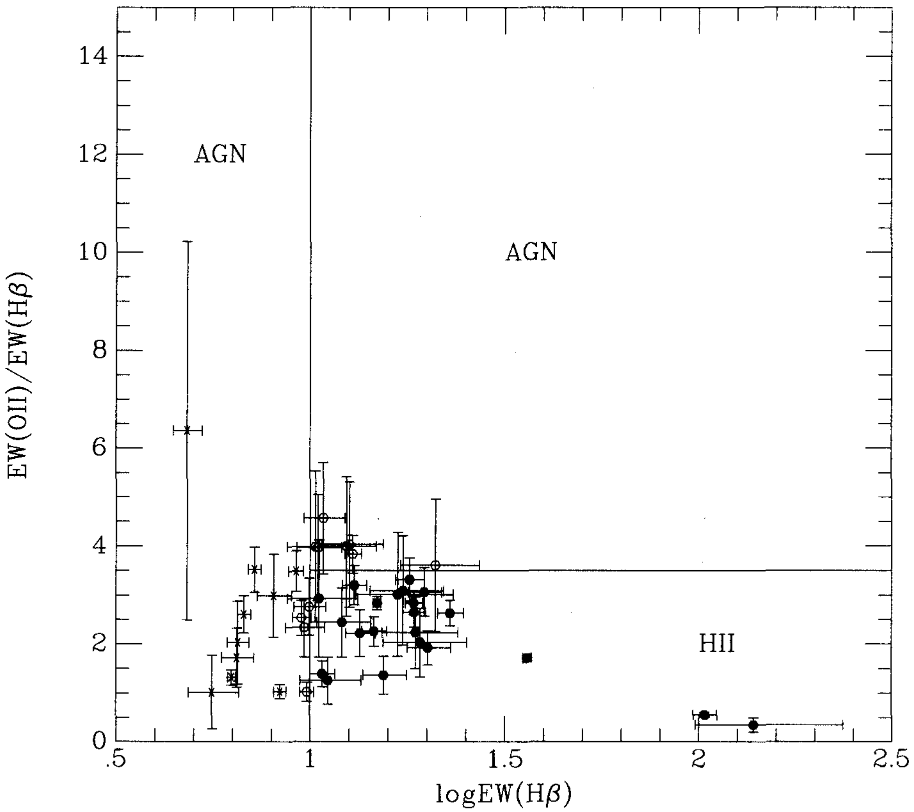

Figure 1. EW[OII]/EW(Hβ) ratio versus EW(Hβ). Solid symbols are those galaxies in the HII region of the diagram. Open symbols are those in the AGN region with error bars extending into the HII region and asterisks are galaxies in the AGN region of the diagram.

4. Detecting AGN through Variability Surveys

Obtaining spectra for as many galaxies as possible in a particular region of the sky is a robust way to find and classify the population of active galaxies. However, this technique requires many nights of observing on large telescopes. A less "expensive" way to detect AGN, and complement the spectroscopic survey, is through the use of multi-epoch images to identify variable sources.

Variability has long been known as an effective way to identify QSOs (e.g. Hawkins 1986) with Koo, Kron & Cudworth (1986) finding ~80% of their spectroscopic and color selected quasars in Selected Area 57 to be variable over an 11 year time period. In addition to quasars, Bershady et al. (1998) detected 14 extended variable objects in this region with Seyfert-like spectral characteristics. The variability amplitude for objects in SA57 was generally higher for active nuclei of lower luminosity, making this technique well suited for the selection of intrinsically faint QSOs and Seyfert-like nuclei.

https://doi.org/10.1017/S0252921100030487 Published online by Cambridge University Press

We are conducting a survey to detect nuclear variabilty for galaxies in the GSS. In addition to the original HST images taken in 1994, a second epoch has been obtained for the entire region in the spring/summer of 2001 (J. Mould, PI). The unique high resolution capabilities of HST are necessary to isolate and measure faint, variable nuclei within brighter host galaxies. We can easily detect and measure structural parameters for galaxies to $V_{606}\simeq25$ with redshifts extending to $z\simeq1$ in the GSS (Simard et al. 1999). Many galaxies in this regime have shown evidence of central point source components in addition to a disk and/or bulge component (Sarajedini et al. 1999). Assuming a typical disk host galaxy with a scale length of $0.25''$, we estimate that nuclei comprising as little as 15% of the host galaxy light can be detected in galaxies down to $V_{606}\simeq23.5$. The advantage of HST is the ability to do accurate photometry within smaller apertures, thus allowing us to probe much lower AGN/host galaxy luminosity ratios than can be done from the ground.

The success of this technique has been demonstrated with the Hubble Deep Field North. Based on observations of the HDF-N separated by two years, we have detected nuclear variability at or above the 3σ level in 8 of 633 galaxies at $I_{814}\leq27.5$ (Sarajedini et al. 2000). Only 2 detections would be expected by chance in a normal distribution. At least one of these 8 has been spectroscopically confirmed as a Seyfert 1 galaxy. Based on the AGN structure function for variability (Trevese & Kron 1990), the estimated luminosities for the varying nuclear components extend to $M_B\simeq-16$ providing an interesting comparison with the population of local Seyfert galaxies at similar luminosities.

These results demonstrate the strength of this technique in probing faint AGN at $z\simeq1$. Extending this search to the GSS should produce a much larger sample of faint AGN. Based on several different estimates for the number of AGN in the local universe (e.g. Huchra & Burg 1992; Maiolino & Rieke 1995; Ho et al. 1997) we expect to find at least $\sim$45 Seyfert-like nuclei in the entire GSS (assuming no evolution to z=1) or $\sim$120 if mild number density evolution has occurred. With this much larger sample, we will have the ability to not only determine number density evolution with statistical significance, but also study any changes with redshift in the shape of the LF for low-luminosity AGN.

5. Summary and Conclusions

With the aim of studying the evolution of AGN in the low-luminosity regime, we are conducting two different yet complementary surveys of galaxies in the GSS. We present the preliminary results of our spectroscopic search to identify broad and narrow-line AGN based on their spectral characteristics. Six broad-line AGN have currently been detected, representing about 1% of the galaxies for which spectra have been obtained as part of the DEEP project. A larger number (10 to $\sim$20) of narrow-line AGN candidates have been detected using a new emission line diagnostic to identify Seyfert 2s and LINERs based on the equivalent widths of [OII] and $H\beta$. This represents between 10 and 20% of the galaxies to $z\simeq0.8$ in which these lines could be detected. The absolute magnitudes of these galaxies extend to $M_B\simeq-17.5$ with a mean redshift of $\sim$0.8.

We have also outlined a program to search for variable nuclei in GSS galaxies using HST images separated by 7 years. The high resolution capabilities of HST

https://doi.org/10.1017/S0252921100030487 Published online by Cambridge University Press

will allow us to detect and measure faint nuclei using small aperture photometry, probing lower nuclear/host galaxy ratios than possible from the ground. Using this technique on HDF-N images separated by 2 years, we have shown that varying nuclei as faint as $M_B \simeq -16$ may be detected for galaxies out to $z \simeq 0.8$.

The results of these surveys will be used in conjunction with GSS observations in other wavelengths such as X-ray (XMM; Griffiths et al. 2000), infrared (SIRTF), radio (VLA FIRST) and sub-millimeter (SCUBA) to better understand the nature of the AGN and their host galaxies.

Acknowledgments. VS would like to acknowledge the many members of the DEEP Team (UC Santa Cruz) for work in obtaining and reducing spectral data presented here. Financial support for part of this work comes from NASA grants through the Space Telescope Science Institute, operated by AURA, Inc. under NASA contract NAS5-26555.

References

Bershady, M. A., Trevese, D. & Kron, R. G. 1998, ApJ, 496, 103

Cheng, F. Z., Danese, L., De Zotti, G. & Franchesini, A. 1985, MNRAS, 212, 857

Griffiths R. E., Miyaji, T. & Ptak, A. 2000, BAAS 197, 5606

Groth, E. J., Kristian, J. A., Lynds, R., O'Neil, E. J., Balsano, R., Rhodes, J., & the WFPC-1 IDT. 1994, BAAS, 185, 5309

Hawkins, M. R. S. 1986, MNRAS, 219, 417

Ho, L. C., 2002, this volume

Ho, L. C., Filippenko, A. & Sargent, W. L. W. 1997, ApJS, 112, 315

Huchra, J. & Burg, R. 1992, ApJ, 393, 90

Kennicutt, R. C. 1992, ApJS, 79, 255

Koo, D. C. et al. 1996, ApJ, 469, 535

Koo, D. C., Kron, R. G. & Cudworth, K. M. 1986, PASP, 98, 285

Maiolino, R. & Rieke, G. H. 1995, ApJ, 454, 95

Rola, C. S., Terlevich, E. & Terlevich, R. J. 1996, MNRAS, 289, 419

Sarajedini, V. L., Green, R. F., Griffiths, R. E., & Ratnatunga, K. 1999, ApJ, 514, 746

Sarajedini, V. L., Gilliland, R. L. & Phillips, M. M. 2000, AJ, 120, 2825

Sarajedini, V. L. et al. 2002, in preparation

Simard, L., Koo, D. C., Faber, S. M., Sarajedini, V. L., Vogt, N. P., Phillips, A. C., Gebhardt, K., Illingworth, G. D., & Wu, K. L. 1999, ApJ, 519, 563

Simard, L. et al. 2001, ApJ, submitted

Tresse, L., Rola, C. S., Hammer, F., Stasinska, G., Le Fevre, O., Lilly, S. J. & Crampton, D. 1996, MNRAS, 281, 847

Trevese, D. & Kron, R. G. 1990, in Variability of Active Galactic Nuclei, ed. H.R. Miller & J.P. Witta (Cambridge: Cambridge University Press), 72

Veilleux, S. & Osterbrock, D. E. 1987, ApJS, 63, 295

Wisotzki, L. 2002, this volume