RevMexAA (Serie de Conferencias), **16**, 194–197 (2003)

THE NATURE OF LOW LUMINOSITY ACTIVE GALAXIES AT $Z\sim1$

V. L. Sarajedini

University of Florida, Department of Astronomy, USA

RESUMEN

Se presentan resultados recientes de mapas espectroscópicos y de imagen destinados a detectar y estudiar las propiedades de galaxias activas hasta corrimientos al rojo 1. Particularmente importantes son la naturaleza y evolución de los AGN de baja luminosidad (i.e., Seyferts y LINERS), cuya observación se hace cada vez más difícil a corrimientos al rojo altos donde el brillo aparente del núcleo se hace más débil y difícil de separar del de la galaxia que lo aloja. El GTC será una potente herramienta con la que estudiar estos tipos de galaxias a los corrimientos al rojo más altos utilizando para ello imagen y espectroscopía para detectar LLAGN a partir de sus firmas espectrales, así como del color, morfología y variabilidad. El objetivo principal de este proyecto es la determinación de la evolución de la función de luminosidad de AGN, lo que tiene importantes implicaciones para nuestro entendimiento de los mecanismos físicos que proporcionan energía a los QSOs y a las galaxias Seyferts, así como el estudio de la naturaleza de las galaxias que alojan AGN y su evolución.

ABSTRACT

Recent results from spectroscopic and imaging surveys to detect and study the properties of active galaxies out to redshifts of 1 are presented. Of particular importance is the nature and evolution of low luminosity AGN (LLAGN, i.e., Seyferts and LINERs), which become increasingly difficult to observe at high redshifts, as the apparent brightness of the nuclear light becomes fainter and difficult to disentangle from the host galaxy light. The GTC will be a powerful tool with which to study these types of galaxies at higher redshifts using both imaging and spectroscopy to detect LLAGN by their spectroscopic signature as well as through color, morphology, and variability. The main goal of this project is to determine the evolution of the AGN luminosity function, which has broad implications for our understanding of the physical mechanisms that power QSOs and Seyfert galaxies, as well as studying the nature of AGN host galaxies and their evolution.

Key Words: **GALAXIES:ACTIVE – GALAXIES : SEYFERT**

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 nuclei, considered to be their intrinsically fainter counterparts, at the low luminosity, low z end (Cheng et al. 1985; Huchra & Burg 1992; Maiolino & Rieke 1995). While bright QSOs are easily observable at all redshifts, fainter Seyfert nuclei become increasingly difficult to detect at redshifts 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 AGN at earlier epochs. This has obvious implications for determining their total contribution to the X-ray, IR and UV backgrounds. Also, the faint end is particularly important in constraining evolution models for the AGN LF such as pure luminosity and luminosity-dependent density evolution (e.g., Hartwick & Schade 1990).

I report on two recent studies to quantify the population of low luminosity AGN at redshifts out to $z \sim 1$. These studies are based on the increased light gathering capabilities of 10 m class telescopes and the high spatial resolution of space-based telescopes (i.e., *HST*), which allow for the detection of these faint AGN at higher redshifts. The future GTC will be essential for imaging and spectroscopic follow-up of the AGN candidates identified in these studies.

2. A SPECTROSCOPIC SURVEY FOR AGN—THE DEEP PROJECT

DEEP (Deep Extragalactic Evolutionary Probe, Koo et al. 1996; Simard et al. 2002) is a project designed to study the formation and evolution of distant field galaxies by combining images from the

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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 comprises 28 contiguous WFPC2 fields located at $14^{\rm h}17^{\rm m}$ +52 and imaged in the F606W and F814W filters. Optical spectra have been obtained through multislit 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 $I_{AB} \sim 24$ with a mean redshift of $z \simeq 0.8$. The typical exposure time is one hour per slit mask with 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 ($\sim 1''$), 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.

Currently, a subsample of 235 spectra from the GSS spectroscopic survey have been analyzed for AGN. Of these objects, seven are galactic stars and seven additional galaxies are at $z \gtrsim 2.8$ and are not considered in this analysis for the sake of sample uniformity. Only two of the 221 remaining galaxy spectra, representing $\sim$1% of the galaxies, have broad lines. These galaxies have redshifts of 1.15 and 1.22, each displaying broad Mg II emission. An initial inspection of the larger sample of GSS spectra is consistent with the finding that $\sim$1% of the galaxies appear to be broad line 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 [O II] λ3727 Å, [O III] λ4959,5007 Å, [N II] λ6548 Å, [S II] λ6717,6730 Å, Hα, and Hβ (e.g., Veilleux & Osterbrock 1987). For a large fraction of galaxies in the GSS, however, many of these lines are redshifted out of the optical range. In addition, our spectra are not flux-calibrated because of the nature of our multislit observing mode. For these reasons, traditional line ratio diagnostics are not applicable to our data.

A new emission line diagnostic (Rola, Terlevich, & Terlevich 1997) is being employed to differentiate between AGN and star forming galaxies in our survey. This technique is based only on the equivalent widths of [O II] 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(O II)/EW(Hβ) > 3.5. Using a sample of local emission line galaxies, Rola et al. (1997) find that 87% of the AGN reside in these regions with 88% of the H II 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 AGN in a sample of emission line galaxies.

Of the 221 galaxy spectra in our subsample, 90 have both the [O II] and Hβ lines in the optical spectral 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 1992; Tresse et al. 1996). This correction has the effect of pushing objects into the H II region of the diagram. The filled circles represent those galaxies clearly in the H II galaxy region. The open circles are those in the AGN region but with error bars extending into the H II 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 eleven objects which lie in the AGN region but have error bars extending into the H II region, our fraction increases to 20%.

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. Future modeling of the galaxy light profile will allow for an accurate determination of the true AGN magnitude (i.e., Sarajedini, Gilliland, & Phillips 1999). This demonstrates the strength of 10 m class telescopes like the Keck telescope and the future GTC to probe 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 $z \sim 0.8$.

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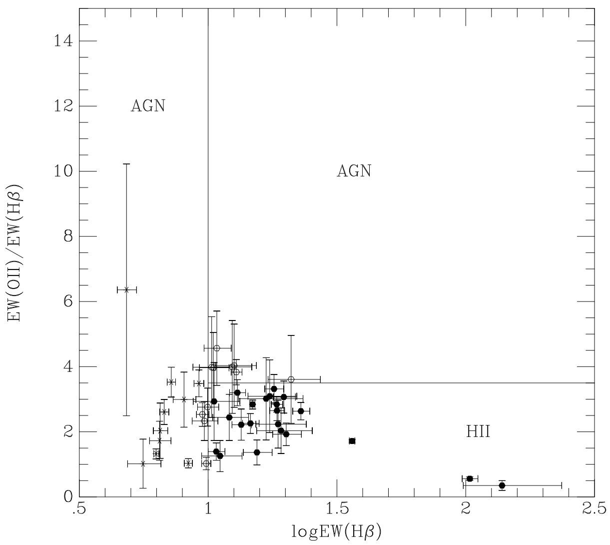

Fig. 1. EW[O II]/EW(Hβ) ratio versus EW(Hβ). Solid symbols are those galaxies in the H II region of the diagram. Open symbols are those in the AGN region with error bars extending into the H II region and asterisks are galaxies in the AGN region of the diagram.

3. A VARIABILITY SURVEY FOR AGN

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, Trevese, & Kron (1998) detected fourteen 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.

A variability survey of the Groth Survey Strip is now being carried out using the original *HST* images taken in 1994 and a second epoch obtained in the spring 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. 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 this field separated by two years, we have detected nuclear variability at or above the 3σ level in eight of 633 galaxies at $I_{814} \leq 27.5$ (Sarajedini et al. 2000). Only two detections would be expected by chance in a normal distribution. At least one of these eight 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 AGN at similar luminosities (e.g., Londish et al. 2000).

The GSS should yield a much larger sample of faint AGN at redshifts comparable to those detected in the HDF-N. We expect to find at least ~45 Seyfert-like nuclei in the entire GSS (assuming no evolution to $z = 1$) or ~120 if mild evolution has occurred. With this much larger sample, we will have the ability to not only trace the evolution of faint AGN with statistical significance, but also quantify changes in the LF morphology with redshift.

4. SUMMARY AND FUTURE WORK

Two projects to identify and study the population of low luminosity AGN to $z \sim 1$ have been described. The spectroscopic survey is sensitive to integrated (AGN + host galaxy) magnitudes of $M_B \sim -17.5$. The variability survey has the benefit of being able to probe lower AGN/host galaxy luminosity ratios, extending the search to AGN with $M_B \sim -16$. The combination of these two surveys over the same region of sky has many advantages. Since the variability survey will probe fainter nuclei, we can use this sample to test the completeness limitations for the spectroscopic survey and determine the AGN/host galaxy luminosity ratio to which we are spectroscopically complete. We would expect all spectroscopic AGN to be detected as variable sources since the spectroscopic flux limit will be higher. However, any spectroscopic AGN not detected as a variable sources will allow us to assess variability selection incompleteness as a function of AGN type, something for which little information currently exists in the literature.

A key aspect of this program will be accurate classifications for the AGN candidates identified in these studies. The galaxies detected in the variability survey will require high S/N spectroscopic follow-up to verify their AGN nature and classification. A 10 m class telescope like the GTC will be necessary with a multiobject spectrograph to efficiently obtain spectra for several candidates at once.

While the spectroscopically detected broad line AGN are clear cases, the narrow line AGN candidates identified in Figure 1 would benefit from additional evidence of their AGN nature. Spectroscopic follow-up in the near IR would allow for the detection of several important emission lines traditionally used for AGN classification (i.e., Hα, [N II], [S II], [O III]). These line fluxes could then be used to firmly differentiate between the narrow line Seyfert 2s/LINERs and the starbursting galaxies.

The multiobject spectrographs planned for the GTC will be ideal for obtaining the necessary follow-up spectroscopy for these AGN candidates. OSIRIS (Optical System for Imaging and Low-Resolution Integrated Spectroscopy) can be used to obtain follow-up spectra for candidate AGN identified in the variability survey. Higher redshift ($z \gtrsim 0.3$) narrow line AGN candidates identified in the spectroscopic survey will benefit from spectral follow-up with EMIR (Espectrografo Multiobjeto Infrarrojo) in the near IR. These observing programs could be done in conjunction with other projects requiring spectroscopy of a large number of field galaxies in the optical and NIR, making this science an ideal component of a galaxy evolution key project with the GTC.

VS thanks 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 the NSF through grant AST-9529098 and from NASA grants through the Space Telescope Science Institute, operated by AURA, Inc., under NASA contract NAS5-26555.

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V. L. Sarajedini: University of Florida, Department of Astronomy, 211 Bryant Space Science Center, P.O. Box 112055, Gainesville, FL 32611 USA (vicki@astro.ufl.edu)

Science with the GTC 10-m Telescope (Granada, España, 5-8 febrero 2002)
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