

## NOAO Survey Program

George Jacoby

Up to 20% of the observing time available through NOAO may be allocated to Survey Programs (see: [www.noao.edu/gateway/surveys/](http://www.noao.edu/gateway/surveys/)). These surveys often have long-term impacts in ways that were never foreseen by their proposers, and the data are distributed through the NOAO Science Archive ([archive.noao.edu/nsa/](http://archive.noao.edu/nsa/)). Since 1999, a total of 22 surveys have been approved ([www.noao.edu/gateway/surveys/programs.html](http://www.noao.edu/gateway/surveys/programs.html)).

Currently, seven programs are underway, and representatives of the survey teams met at NOAO on October 15–16 to present progress reports. For one of these, The NEWFIRM Medium Band Survey (Principal Investigator [PI]: Pieter van Dokkum, Yale University), an overview was given in the June 2008 *NOAO/NSO Newsletter*. The PIs for four additional surveys describe their projects below.

### The NOAO DRaGONS Survey Andrew Connolly (University of Washington)

Andrew Connolly and 11 others have been using FLAMINGOS to image Distant Radio Galaxies Optically Non-detected in SDSS (DRaGONS). This is a K-band survey of 530 FIRST radio sources having  $S_{1.4\text{ GHz}} > 100$  mJy with no optical counterparts, spread over 5000 square degrees, representing a volume at  $z = 2$  of about  $6 \times 10^{10}$  Mpc<sup>3</sup>. These galaxies are very massive, providing signposts of clustering and rapid star formation in the early universe, out to  $z \sim 5$ , although the peak of the redshift distribution should be near  $z = 2$ .

With 60-minute integrations on-source, and about halfway through their analysis, results indicate a 75% detection rate ( $5\sigma$ ), with 64% of the galaxies consistent with being at  $z > 2$ , and 29% at  $z > 3$ . Figure 1 shows the K-band mag distribution. Figure 2 shows the density distribution as a function of apparent brightness. Of the 250 galaxies analyzed to date, about 10% of these are extremely red ( $r-K > 6.5$ ), and optical spectroscopic and imaging follow-up is underway at Keck, Gemini, and APO.

Sam Schmidt and Jeremy Brewer from the University of Pittsburgh have used data from this survey in their theses. The data will be made available to the public in early 2009.

### A NEWFIRM Survey of the NDWFS/SWFS Field Anthony Gonzalez (University of Florida)

A team led by Anthony Gonzalez is using NEWFIRM to obtain deep JHK<sub>s</sub> imaging of the Spitzer Deep Wide-Field Survey region (SDWFS, 8.3 sq. deg.), which corresponds to the NDWFS Boötes field. This program is designed to enable a broad variety of investigations—the combination of diverse data sets permits robust photometric redshifts for L\* galaxies to  $z > 3$ , as well as detection of galaxy clusters to

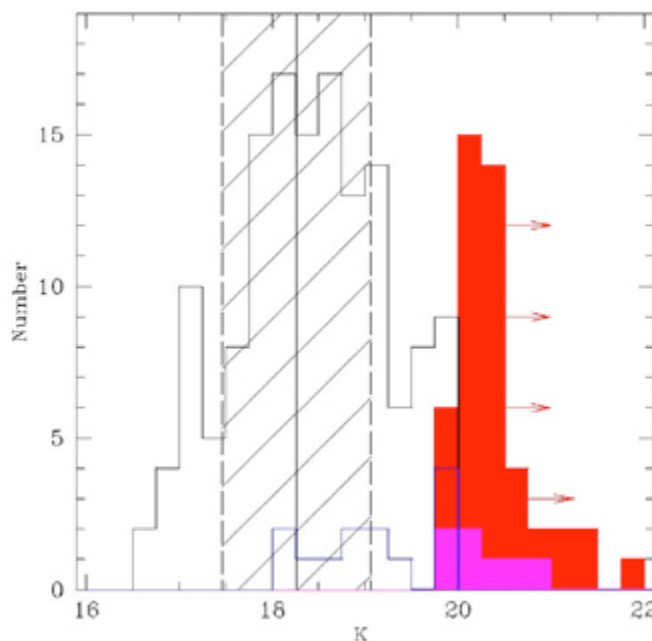


Figure 1: The K-band brightness distribution of recovered DRaGONS objects.

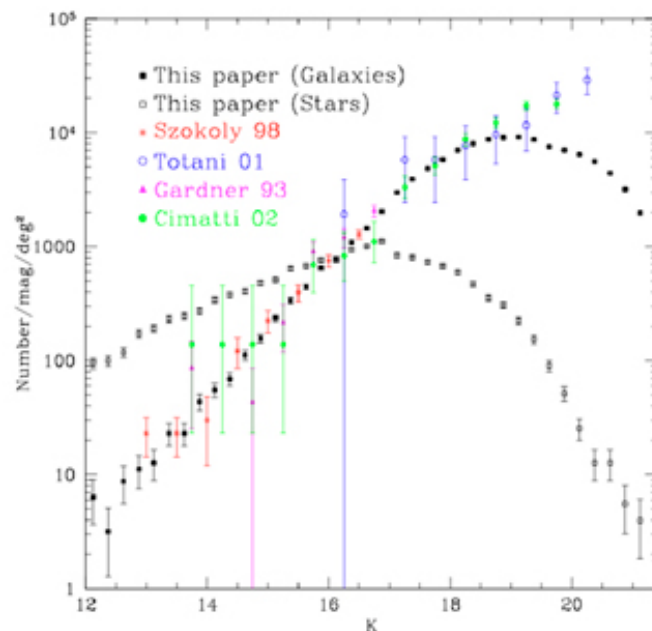


Figure 2: The number density of galaxies and stars identified in the DRaGONS survey as a function of K magnitude.

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$z > 2$ , quasars to  $z > 7$ , and brown dwarfs as cold as  $\sim 500$  K within 50 pc. The data will also facilitate measurement of the diffuse infrared background by CIBER, due to be launched in 2009.

The survey commenced in spring 2008 and will finish in spring 2009. The J imaging obtained during the first year is currently being used to confirm the most promising brown dwarf candidates arising from the SDWFS program. A composite J, 3.6  $\mu\text{m}$ , 4.5  $\mu\text{m}$  (BGR) color image of one candidate is shown in figure 3 (Eisenhardt et al., in prep). The image is one arcmin on a side, with the brown dwarf at the center. University of Florida graduate student David Vollbach is using the data for his master's thesis.

**The NOAO XCS**

*Christopher J. Miller (NOAO)*

The NOAO XMM Cluster Survey (NXS) is designed to optically image candidate galaxy clusters serendipitously detected with the XMM-Newton space telescope by the earlier XMM Cluster Survey (XCS) (Romer et al. 2001). Chris Miller and 15 team members are using Mosaic (north and south) imaging in two colors (SDSS r- and z-band) to measure the photometric redshifts of clusters to  $z \sim 1$ . In turn, the redshifts will be used in conjunction with the X-ray data to measure the cluster gas temperatures and/or luminosities.

For those clusters with enough X-ray counts to measure temperatures, the NXS will provide a comprehensive study of the galaxy cluster luminosity-temperature (L-T) relation between  $z = 0$  and  $z = 1$ . Understanding the L-T relationship is vital for the ultimate scientific goal of the NXS—to measure the cosmological parameters independent of the CMB or Type-Ia supernovae data. After all, temperature is one of the most accurate cluster mass proxies for galaxy clusters.

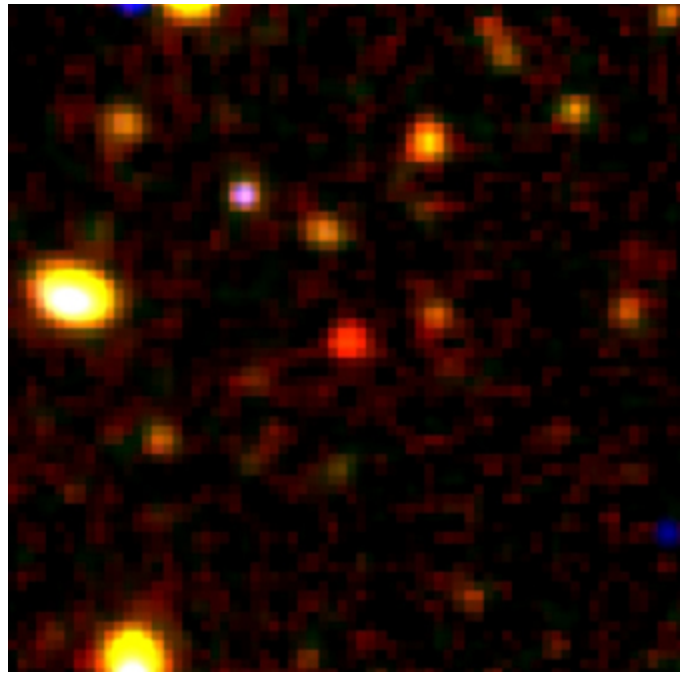


Figure 3: A promising brown dwarf candidate (center).

Based on cosmological models, it is the mass function of these cluster-sized matter halos, and their L-T evolution, that can be used to measure the cosmological parameters.

The NXS completed its main survey component of imaging over 300 clusters this past April 2008 (see figures 4 and 5 for an example). A final extension is scheduled for the 2009A semester. The first data

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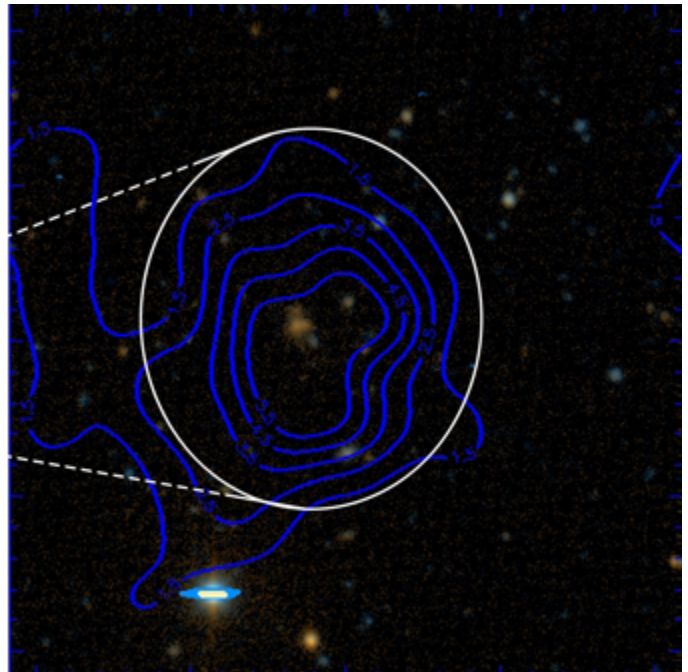
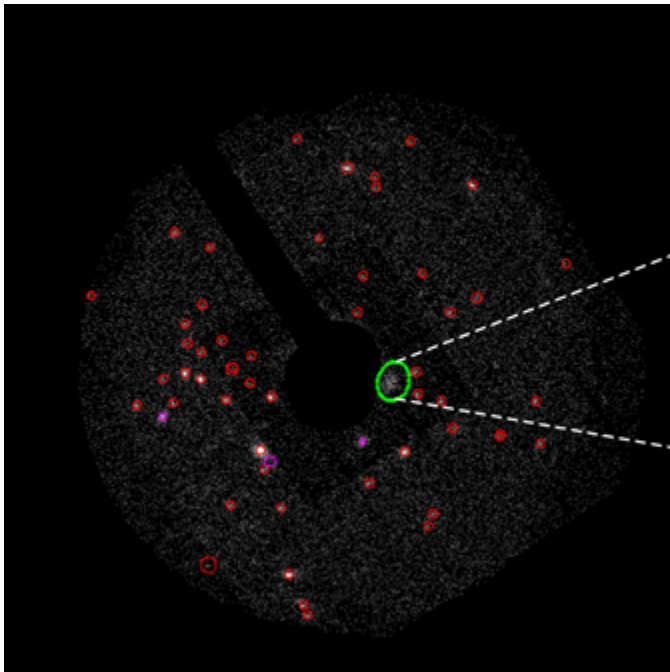


Figure 4: The XMM image and the detected sources (point sources in red and a cluster candidate in green ellipse) on the left. A close-up of the false color combined ground-based Mosaic imaging data for the cluster candidate is shown on the right. The contours indicate the X-ray data.

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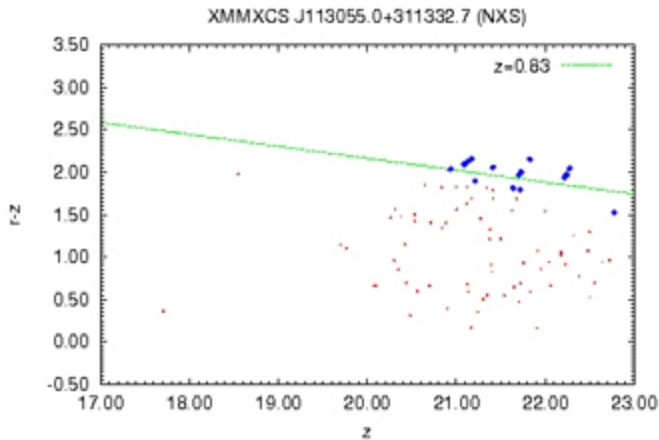


Figure 5: The color magnitude diagram for the galaxies in this cluster field. The blue diamonds are likely cluster members after a background subtraction technique is applied. A fit is then made to the galaxy cluster’s E/S0 ridgeline and the estimated redshift for this cluster is  $z = 0.83$ . The NXS can identify clusters and their redshifts to  $z \sim 1$ .

release of the raw and reduced imaging data will occur in January 2009. Over 100 XMM fields with deep SDSS r- and z-band imaging will be made available to the public through the NOAO Science Archive (reduced Mosaic stacks), as well as through the team’s data release Web site. Nicola Mehrrens (University of Sussex, UK) will be using these NXS data for her Ph.D. thesis under the guidance of the NXS PI and her thesis advisor, Kathy Romer (University of Sussex). While Nicola has led most of the observing runs (along with PI Miller and Co-Investigator Adam Stanford), three other Ph.D. students have participated in all aspects of the observing runs.

**The ChaMPlane Multi-wavelength Plane Survey (ChamPlane-II)**  
Maureen van den Berg (CFA, Harvard)

The goal of the Chandra Multi-Wavelength Plane (ChaMPlane) Survey (see Grindlay et al. 2005, ApJ 635, 920) is to constrain the space densities and Galactic distributions of low-luminosity ( $L_x \lesssim 10^{34}$  erg-s<sup>-1</sup>) accreting binaries, such as cataclysmic variables (CVs) and the quiescent low- and high-mass X-ray binaries containing neutron stars or black holes.

The project analyzes serendipitous sources detected in Chandra/ACIS images to locate low  $L_x$  X-ray binaries from the center to the edges of our Galaxy. Using the Mosaic cameras on the NOAO Mayall and Blanco 4-m telescopes, we obtain deep VRIHa images of all our X-ray fields (144 as of late 2008, containing 15 000 sources) to look for optical counterparts. In the second phase of the survey, “ChaMPlane-II,” we use the Hydra multi-object spectrograph on the CTIO Blanco 4-m telescope to classify the candidate optical counterparts and the ISPI imager on the Blanco telescope to identify counterparts in heavily obscured bulge fields.

Thus far, 2800 ChaMPlane-II spectra have been obtained, and 1270 have been reduced and classified. Most are stars, but several new CVs, symbiotic stars, and background AGN have been identified. Figure 6 shows a newly discovered symbiotic binary (a white dwarf accreting from a late-type giant). Additional spectroscopic follow-up is obtained with other facilities including WIYN/Hydra and Magellan/IMACS. Many of our sources lie within a few degrees of the Galactic center, and we are able to map out the spatial distribution to obtain clues about the origin of the X-ray binary population. We are carrying out two other surveys to support this effort, namely our “Bulge Windows” and “Bulge Latitude” surveys. More information on these can be found on our Web site at [hea-www.harvard.edu/ChaMPlane](http://hea-www.harvard.edu/ChaMPlane).

Allen Rogel received his Ph.D. in 2005 from Indiana University using ChaMPlane data to study the anti-center fields, and Xavier Koenig’s (Harvard) thesis to study the Galactic Bulge fields is using survey data. ☉

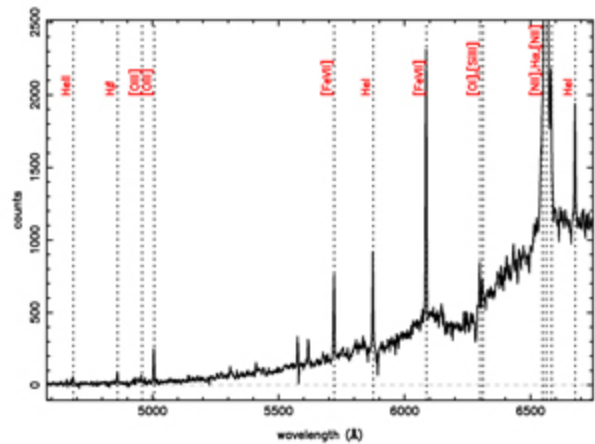


Figure 6: A symbiotic binary system newly discovered by the ChaMPlane-II survey.

# Properties of the Host Galaxies of Luminous Quasars

Marsha Wolf & Andrew Sheinis (University of Wisconsin)

**A** growing understanding of the connection between galaxies and their central black holes has emerged over the last decade. We now know that all galaxies with a bulge contain supermassive black holes at their centers (Kormendy 2004) and that the black hole mass correlates with the host galaxy's stellar velocity dispersion in the bulge (Gebhardt et al. 2000, Ferrarese et al. 2000, Tremaine et al. 2002).

A direct connection between the masses of a black hole and its host galaxy was a bit surprising, and suggests that the growth of the black hole and the galaxy bulge may be coupled. Furthermore, it has been speculated that energy from accreting black holes, or active galactic nuclei (AGN), may have a role in quenching star formation in galaxies, and thus stopping their growth. When an amount of energy equal to that expected from AGN feedback is included in semi-analytic galaxy formation models, the models can correctly reproduce the demographics and properties of galaxies observed in large surveys (Cattaneo et al. 2006, Dekel et al. 2006). Although the physical details of the AGN/galaxy interactions are not yet understood, the fact that these models form galaxies matching those that we observe is yet another clue toward an intimate relationship between the evolution of galaxies and their supermassive black holes.

One way of investigating this connection is to study the nature of galaxies that host AGN. Do AGN exist in galaxies with similar properties? Does something in the galaxy trigger the AGN activity? To better understand this connection, we are conducting an ongoing study of the properties of galaxies that host very luminous quasars ( $M_V < -23$ ), systems in which the black holes are actively accreting material from the surrounding galaxy at a high rate and growing. It is in these systems that we may have a better chance to understand the mechanisms in the galaxies that could trigger or stop the growth of both the black hole and the galaxy. Similar studies have been done on lower luminosity AGN where the light from the galaxy is comparable to that of the AGN. Various groups have reached different conclusions, but the consensus seems to be pointing toward AGN existing in a mix of morphological galaxy types, many of which show signs of some star formation in the last few hundred million years (e.g., Bahcall et al. 1997; McLure et al. 1999; Miller et al. 1996; Canalizo & Stockton 2000, 2001; Miller & Sheinis 2003).

It is much harder to observe host galaxies in systems where the central quasar outshines the surrounding galaxy by as much as 3.5 magnitudes. However, new observing and data reduction techniques have enabled us to successfully make such observations. Figure 1 shows the 10 quasar host galaxies that we have analyzed using off-nuclear spectra obtained with long-slit spectroscopy on the Keck 10-m telescope and with integral field spectroscopy using the SparsePak fiber bundle (Bershady et al. 2004, 2005) feeding the Bench Spectrograph on the WIYN 3.5-m telescope.

The SparsePak fibers are 5 arcsec in diameter, nearly the size of our entire host galaxy. If we centered the quasar on a fiber, the surrounding fibers would sample the host galaxy too far out in radius. Therefore, during setups on the objects, we offset the quasar toward the edge of one fiber, as shown in figure 1, to allow neighboring fibers to

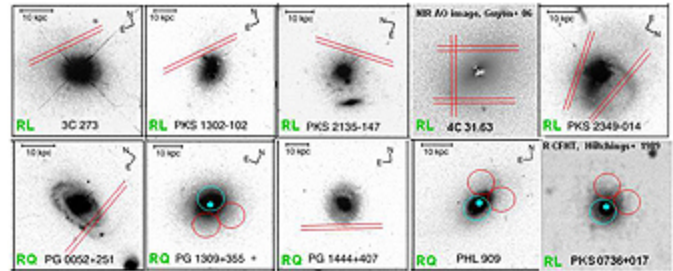


Figure 1: Observations of quasar host galaxies with long slits on the Keck 10-m telescope and with the SparsePak optical fiber bundle on the WIYN 3.5-m telescope. Each panel is  $23 \times 23$  arcsec. Fiber circles are 5 arcsec in diameter, and the dots inside them mark the approximate locations of the quasars. For clarity, only three of SparsePak's 82 fibers are shown. RL denotes radio-loud quasars and RQ denotes radio-quiet. Our sample is drawn primarily from the 20 nearby luminous quasars of Bahcall et al. (1997), from which the underlying images are taken unless otherwise noted.

sample the host galaxy closer in to the nucleus, while isolating most of the quasar light within the first fiber. This configuration, along with the fact that the fibers integrate over a larger portion of the galaxy than the long slits, allows us to obtain spectra with the WIYN telescope that have similar signal-to-noise ratios and less scattered quasar light than those obtained on the larger Keck telescope. This makes the SparsePak integral field unit a powerful tool in studying quasar host galaxies.

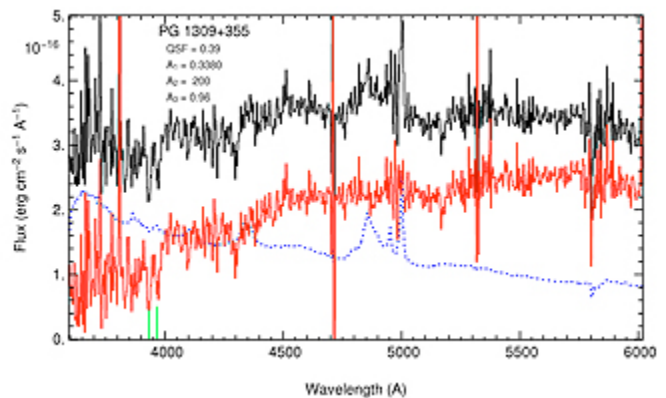


Figure 2: Subtraction of scattered quasar light from the host galaxy spectrum for PG 1309+355, observed on WIYN. The upper black spectrum is as observed in the off-nuclear location, the dotted blue line is the scaled quasar spectrum as observed independently by the fiber dedicated to the quasar, and the solid red spectrum is the host galaxy after scatter subtraction; all of these are presented in the rest frame. For this galaxy, 39% of the light in the observed spectrum was actually scattered quasar light.  $A_1$ ,  $A_2$ , and  $A_3$  are fitted coefficients to the scattering efficiency function,  $A_1 + A_2 \lambda^{-A_3}$ , that scales the quasar spectrum. The Ca H&K lines, that contribute to the 4000 Å break and are used to measure stellar velocity dispersion, are marked by vertical green lines near the lower left corner.

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*Properties of the Host Galaxies of Luminous Quasars continued*

Even with our careful setup procedures, 30–70% of the light in the observed off-nuclear spectrum can be scattered light from the quasar. We developed a technique to spectrally remove the scattered light by simultaneously fitting a spectrum of the quasar that is scaled by a wavelength-dependent scattering efficiency function, and fitting stellar population synthesis models to the residual galaxy spectrum. An example of this process is shown in figure 2.

Once our host galaxy spectrum is cleaned up, we measure the stellar velocity dispersion from the Ca II H&K lines at 3968 and 3934 Å (see Wolf & Sheinis (2008) for details). This parameter, combined with the galaxy’s effective radius and its average surface brightness (both obtained from 2-dimensional brightness profile fits to high-resolution images by Bahcall et al. 1997), allows us to compare the galaxy structural properties with other types of galaxies. Such comparisons are often done on the Fundamental Plane (FP), which is a projection of galaxy structural properties including the effective radius,  $R_e$ , the surface brightness,  $\mu_e$ , and the stellar velocity dispersion,  $\sigma_*$  (Djorgovski & Davis 1987, Faber & Jackson 1976). When a linear combination of  $\sigma_*$  and  $\mu_e$  are plotted against  $R_e$ , all early-type galaxies fall approximately on a plane.

Our hosts are compared to other galaxy samples on the FP in figure 3. Host galaxies from this work are indicated by the large numbered circles. The cloud of small cyan points represents normal early-type galaxies from the Sloan Digital Sky Survey (SDSS). The solid line is a fit to the FP of the SDSS galaxies. The open diamonds above the line are massive galaxies from the SDSS, analogous to giant ellipticals.

The first thing we see about our hosts is a dichotomy between the radio-loud quasars (green) and radio-quiet quasars (yellow). The hosts of radio-loud quasars lie at the upper extreme of the FP because of their higher velocity dispersions, larger effective radii, and lower surface brightness than normal early-type galaxies. Their structural properties are similar to giant elliptical galaxies. Our radio-quiet hosts lie on the FP and have structural properties similar to intermediate mass early-type galaxies. The triangles are radio-quiet quasar hosts from Dasyra et al. (2007). They were selected because their properties were similar to ultraluminous infrared galaxies (ULIRGs), which are thought to be merging galaxies in which a nuclear starburst is ongoing. Merger remnants are the last comparison sample on our FP plot (Rothberg & Joseph 2006), and are shown as squares. It is clear that merger remnant properties overlap those of the Dasyra et al. quasar hosts on the FP. The merger remnants also stretch down below the plane because galaxies with ongoing nuclear starbursts currently have high surface brightness (note that  $\mu_e$  is in magnitudes, so lower numbers are higher surface brightness). They are expected to fade up to the FP once this phase has ended.

Although we cannot make global claims with our currently small biased sample of nearby bright quasars, if we consider the structural properties of all the galaxy samples presented, there appear to be two populations. First, the hosts of radio-quiet quasars have properties similar to intermediate mass early-type galaxies, including those that formed from gas-rich mergers in which nuclear starbursts were triggered. The morphological classifications of these quasar host galaxies are mixed between ellipticals and spirals, as can be seen in figure 1.

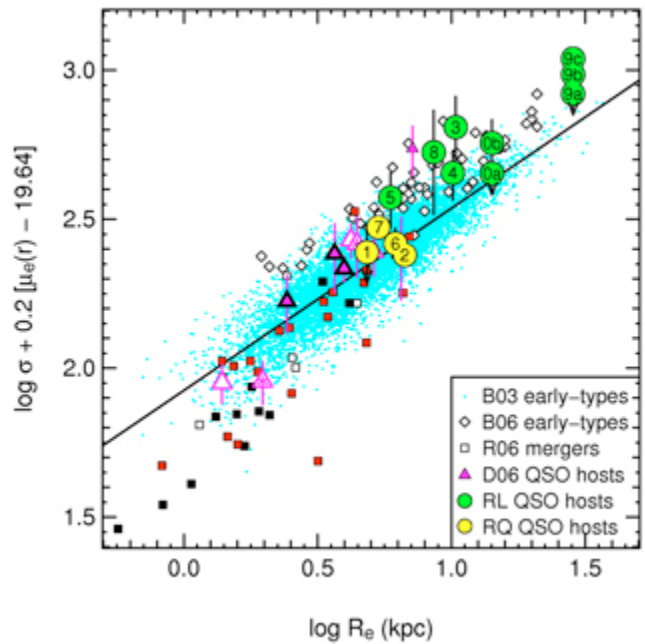


Figure 3: The Fundamental Plane of galaxies. Our quasar hosts are shown as large circles (yellow are radio-quiet, green are radio-loud). Comparison galaxies: small cyan points are early-type galaxies from SDSS (Bernardi et al. 2003), open diamonds are massive early-type galaxies (Bernardi et al. 2006), triangles are radio-quiet PG QSO hosts (Dasyra et al. 2007), and squares of all shades and colors are merger remnants (Rothberg & Joseph 2006). The solid line is the FP fit to early-type galaxies from Bernardi et al. (2006).

Second, the hosts of radio-loud quasars occur in massive galaxies with structural properties similar to giant ellipticals. Compared to normal early-type galaxies, they have higher stellar velocity dispersions, larger effective radii, and lower surface brightness. Their morphological classifications are ellipticals and interacting systems. Their low surface brightness indicates that no nuclear starburst is present. Perhaps these galaxies are the result of dry mergers between two massive ellipticals, rather than the gas-rich, lower-mass progenitors of the first population.

New observing and data reduction techniques have allowed us to probe the properties of the host galaxies of luminous quasars and directly measure stellar velocity dispersions. We continue to add to our sample with observations on the WIYN telescope. Our ongoing analyses include investigating whether these objects follow the same black hole mass/stellar velocity dispersion relation as lower luminosity AGN and quiescent galaxies. We are also estimating the stellar populations of the host galaxies from the entire observed spectral range. We see preliminary indications that populations as young as a few 100 Myr exist in these galaxies. Although the structural properties of the hosts of radio-loud quasars match those of giant ellipticals, five out of six in our sample have spectral features that do not suggest a purely old population. Ultimately, we hope to compare our local sample with one at higher redshift to look for evolution.

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*Properties of the Host Galaxies of Luminous Quasars continued*

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# An Innovative Search for Elusive Ly $\alpha$ Blobs

*Moire Prescott (Steward Observatory), Arjun Dey & Buell Jannuzi (NOAO)*

**L**yman- $\alpha$  nebulae—or Ly $\alpha$  blobs—are giant clouds of gas (~100 kpc in diameter) emitting strongly in Ly $\alpha$ . These rare sources are likely sites of ongoing massive galaxy formation, as evidenced by their large Ly $\alpha$  luminosities (~ $10^{44}$  erg/s) and their association with star-forming galaxy populations such as Lyman Break Galaxies and Submillimeter Galaxies (e.g., Chapman et al. 2004, Dey et al. 2005, Geach et al. 2007).

Due to the internal complexity of these systems and the paucity of known examples, basic questions about Ly $\alpha$  blobs have been challenging to answer conclusively. First, what is the source of ionization? Are they powered by cooling radiation from gravitational infall, photoionized by hot young stars or AGN, or shock heated by starburst-driven superwinds (e.g., Nilsson et al. 2000, Dijkstra et al. 2006, Dey et al. 2005, Taniguchi & Shioya 2000)? Second, what determines their large extent? Are the 100-kpc diameters representative of their true size, or are we seeing the effects of strong resonant scattering of Ly $\alpha$  (e.g., Dijkstra et al. 2006)? Finally, what is the true space density of Ly $\alpha$  blobs? There is evidence that Ly $\alpha$  blobs are confined to the most overdense regions of the Universe (e.g., Steidel et al. 2000, Matsuda et al. 2004, Prescott et al. 2008a). However, the tally of large Ly $\alpha$  blobs remains small (~12 larger than 50 kpc), and many have been found by specifically targeting known galaxy overdensities.

To make progress in understanding the role Ly $\alpha$  blobs play in the galaxy formation process, we must answer fundamental questions about their prevalence and properties. What is needed is a systematic survey for moderate redshift Ly $\alpha$  blobs over a wide field, where their space density can be accurately measured and their properties investigated in detail. A large-volume survey will allow for unbiased study of the clustering properties of these sources and clarify the relationship between Ly $\alpha$  blobs and matter overdensities. In addition, a larger sample of individual Ly $\alpha$  blobs will provide the basis for the extensive multi-wavelength follow-up essential for building a coherent understanding of their internal structure and emission mechanisms.

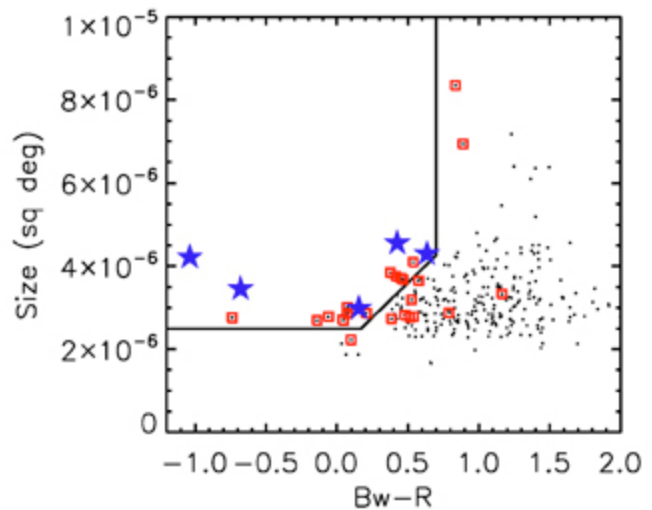


Figure 1: High-priority Ly $\alpha$  blob selection window in size-color space; morphological Ly $\alpha$  blob candidates (black points), spectroscopic targets (red squares), and confirmed Ly $\alpha$  sources (blue stars) are shown.

Numerous groups are now carrying out systematic Ly $\alpha$  blob surveys using narrowband filters in the hopes of measuring the true space density of these rare sources and providing new targets for follow-up study (e.g., Saito et al. 2006, Smith & Jarvis 2007, Yang et al. 2008). While these narrowband programs, covering 1–15 square degrees, are well-designed to find line-emitting sources, they require large quantities of observing time. This, combined with the narrow redshift span of the filters, puts a practical limit on the maximum co-moving volume that can be surveyed. Since covering large co-moving volumes is crucial for constraining the bright end of the Ly $\alpha$  blob luminosity function, we decided to take a complementary approach. Leveraging the power of deep broadband surveys, we have designed a systematic

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*Innovative Search for Elusive Ly $\alpha$  Blobs continued*

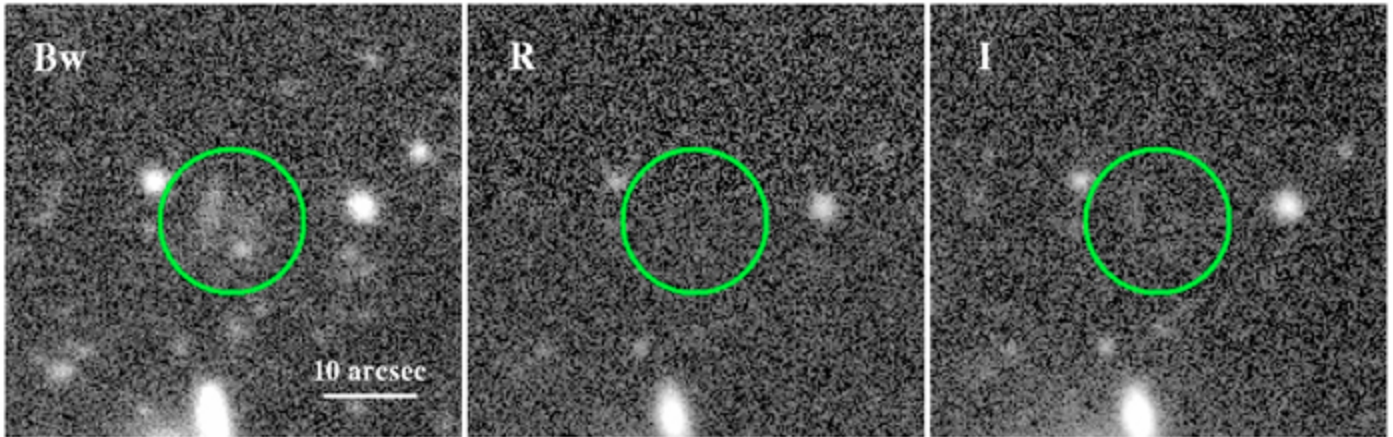


Figure 2: NDWFS  $B_w$ , R, and I imaging of a newly discovered 80-kpc Ly $\alpha$  blob at  $z \sim 2.3$ . This source was selected as a Ly $\alpha$  blob candidate because of the strong, diffuse Ly $\alpha$  emission dominating the flux in the  $B_w$  band.

search for the most luminous Ly $\alpha$  blobs using the archival NOAO Deep Wide-Field Survey (NDWFS) broadband optical imaging (Jannuzi & Dey 1999; NOAO Science Archive).

The inspiration for this unusual approach was the unexpected discovery of a large Ly $\alpha$  blob in the Boötes field at  $z \sim 2.7$  (Dey et al. 2005). Unlike many of the larger Ly $\alpha$  blobs, which were found in narrowband surveys targeting galaxy overdensities, this source came to light because of its very strong 24-micron emission and its diffuse, blue morphology in the NDWFS optical  $B_w$ -, R-, and I-band imaging. Thanks to the very dark sky in the blue, strong Ly $\alpha$  emission can dominate even the very broad  $B_w$  bandpass. The advantage is the enormous co-moving volume ( $\sim 10^8 h_{70}^{-3} \text{Mpc}^3$ ) that can be surveyed efficiently using publicly available archival data.

Our systematic search uses a wavelet-deconvolution algorithm to select large, diffuse sources from the  $B_w$  imaging, and we prioritize candidates with blue  $B_w$ -R colors (figure 1). As these systems can be quite complex, often with associated galaxies that contribute redder colors, we have chosen to keep our selection simple and fairly broad. Even so, we find only 17 high priority candidates over the entire nine-square-degree field. We carried out spectroscopic follow-up of our high priority candidate sample using the MMT and the Blue-Channel Spectrograph and confirmed five sources with Ly $\alpha$  emission, a success rate of roughly 30%. The details of the search will be discussed in an upcoming paper (Prescott et al. 2009, in preparation).

Due to the enormous volume surveyed, our innovative search provides the first lower limit on the space density of the most luminous Ly $\alpha$  blobs. The preliminary space density from this survey is  $N > 10^{-8} h_{70}^{-3} \text{Mpc}^{-3}$ , which is two orders of magnitude lower than other estimates from smaller volume surveys. With the search pipeline now

in place, we plan to expand our search to the NDWFS Cetus field and other deep imaging surveys.

In addition to putting constraints on the space density, this survey has uncovered lower redshift Ly $\alpha$  blobs that are ideal for detailed spectroscopic follow-up. For two cases in particular, all the standard emission lines out to H $\alpha$  will be accessible with optical and near-infrared spectroscopy. One is a 45-kpc Ly $\alpha$  blob at  $z \sim 1.7$  (Prescott et al. 2008b)—the lowest redshift Ly $\alpha$  blob known—and one is an 80-kpc Ly $\alpha$  blob at  $z \sim 2.3$  (figure 2). These low-redshift Ly $\alpha$  blobs present a crucial opportunity to study the physical conditions—temperatures, metallicities, and kinematics—of the gas within Ly $\alpha$  blobs and to better understand the role Ly $\alpha$  blobs play in the formation of the most massive galaxies.

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