THE FUTURE OF OBSERVATIONAL RESEARCH ON ACTIVE GALACTIC NUCLEI

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1. INTRODUCTION

Rather than conventional "summary" discussions, it was intended that the final presentations at this Symposium be used to anticipate the most exciting areas of AGN research in the few years to come. I viewed the opportunity to do this as an exciting one, and considered the papers presented primarily in context of what they promised for the future. The research areas discussed below, therefore, were all represented by various papers, either oral presentations or posters, and the results of these papers stimulated most of the suggestions I make for continued efforts. My charge is to consider the observational research, and I will describe observational problems that can be dealt with using existing telescopes. Although we all excitedly await the next round of space observatories and giant ground based facilities, this preview of coming astronomy is intended in large measure for young astronomers, and their careers cannot wait.

2. DYNAMICS OF THE NARROW LINE REGION

The last few years have seen major progress in coupling what happens in the small, central regions of AGN - the "engine" and the Broad Line Region - to what happens in the much more extended NLR. There have been convincing observational demonstrations of toroidal structures on various scales that prevent the isotropic escape of photons and energetic particles from the center into the NLR, as emphasized in M. Ward's paper. These studies illustrate how observations of the NLR can be used to deduce structures on much smaller scales. What impressed me at this Symposium was the way in which very conventional observations of bright emission lines in bright galactic nuclei still have much to teach us in terms of understanding why the NLR behaves as it does. R. Shaw, for example, is re-examining line profiles to determine if the gas is infalling or expanding. I had assumed the NLR to be expanding, and confirmation of Shaw's conclusion that this is wrong and that we are really seeing accreting gas would be quite

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interesting. The problem of interpreting line asymmetries is to understand whether obscuring dust is generally distributed throughout the NLR or distributed within individual clouds. By analyzing how the asymmetries change with ionization potential, this issue can be newly addressed.

In trying to understand the source of the kinetic energy in the NLR, M. Whittle correlated line widths with independent measures of gravitational potential determined by galaxy rotation curves. His correlations show that the NLR dynamics may generally be controlled by gravity in the same manner as stellar velocity dispersions, with the important exception of NLR containing radio jets which seem to provide extra kinematic stirring.

So here we have two studies that show new hope of major progress in understanding the NLR. Further results require only extensions of similar efforts to larger samples of objects. The key observational requirement is very high S/N line profile observations to obtain precise kinematic information.

3. MEASURING THE CONCENTRATED MASS IN AGN

Although all theoretical models for powering AGN discussed here rely upon the gravitational potential of a central, concentrated mass, the theorists readily admit, as H. Netzer summarized well, that this remains an assumption. Until the central mass is somehow measured, these models are fragile. Knowing the mass is not only imperative for understanding individual AGN, but it is also critical to issues concerning quasar evolution. Do low luminosity AGN have large masses but low accretion efficiences, or are the huge masses that must have powered high luminosity quasars in the early universe hiding somewhere else? As summarized by A. Dressler, looking for central masses in normal galaxies will remain a very difficult problem applicable to only a few nearby galaxies, even with Hubble Space Telescope. Active galaxies remain the only sources found in large numbers in which diagnostics of the mass are visible.

Measuring this mass would be straightforward observationally if a size scale could be determined for the BLR and if we were confident that the kinematics of the gas producing BLR emission lines is controlled by gravity. Even if the latter could not be established, an extra velocity component from non-gravitational sources would only cause the dynamically derived mass estimates to be upper limits - still very useful. The key objective for the present, therefore, is to determine size scales. There are three independent ways to attempt this: a. model the accretion disk using the "blue bump" luminosity (these models deduce central masses without needing kinematic information from the BLR); b. determine the ionization parameter in the BLR; c. compare ionizing continuum variability with emission line or dust shell variability. Consistent results among these approaches would be very encouraging.

Within the past few years, a great deal of effort went into the first two methods. But at this Symposium, what was most impressive

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were the many results concerning variability, most of which show the feasibility of using this method to obtain size scales successfully. Groups from France, the U.S., U.K., Israel, and South Africa all had impressive data. Discussions have begun to determine the optimum methodology for sampling variability data, an example being R. Edelson's presentation. A very large consortium is being set up to monitor NGC 5548 with the IUE and ground based telescopes. These various efforts are gaining momentum because it is now demonstrated that useful results can be obtained on time scales of a year. Extending these observational efforts to larger, carefully chosen samples is imperative.

It is not required to use the IUE to see the near-ultraviolet continuum, which is the most dramatically varying portion. There are bright quasars at adequate redshifts (about 2) to monitor the same spectral region from the ground. It is important in any case to have comparably sampled monitoring for AGN covering the widest possible range of luminosities. Samples should be chosen without prior knowledge of variability, to get the most objective statistics. Objects should be monitored for which size scales are also estimated using the accretion disk and ionization parameter methods. As soon as the VLBA is available for routine monitoring observations, samples of limited size must be agreed upon for joint optical/radio monitoring. It may not be the superluminal sources that are most important, but instead those AGN for which the VLBA can resolve compact cores on size scales of a parsec of less.

While waiting for the various variability monitoring to pay off, larger statistical comparisons can continue. For example, further careful examination of correlations between luminosity and line width are needed. Much new information is available on luminosities because of improved X-ray, infrared, and millimeter data. High S/N line profile observations can be used to define consistent parameters of profile widths in many objects. There are differences in how line widths should scale with luminosities depending on the combination of mass and accretion efficiency that accounts for a given luminosity.

4. HIDDEN AGN

A long-standing question is that of how many galaxies contain hidden AGN which are not seen because of dust or gas obscuration. J. Miller's review showed the progress that has been made in disentangling Seyfert 1 and Seyfert 2 galaxies in this regard, but we now have a new category of possibly hidden AGN found in the IRAS samples. These mystery sources go by various names, a few imaginative ones being "Extremely Luminous Far Infrared Sources" (ELFs), "Ultraluminous Infrared Galaxies", and even "60 Micron Peakers". The fundamental issue at present for these objects is whether the hidden sources of their vast dust reradiated luminosities are non-thermal, like classical AGN, or are supersized starbursts. Results at this meeting, such as those of R. Norris, D. Sanders, and P. Vader, are inconclusive. The diagnostic that has been most used is emission line width, and many of these are comparable to Seyfert 2 galaxies. Norris began what I feel is a more meaningful probe by examining such objects with VLBI techniques. Most such infrared-luminous galaxies are radio sources on the spatial scales measurable by the VLA. But starburst galaxies are also radio sources on these scales. Finding compact cores is a much better indicator of true non-thermal activity, and this requires VLBI-scale resolution.

This topic provides a good excuse for reminding ourselves of the many uses of the VLBA for such examinations of AGN, hidden or otherwise visible. Many samples of radio-weak AGN are prime targets for VLBA surveys. We must keep in mind that at least one quasar, that in the nucleus of M81, has already had its non-thermal radio core resolved by VLBI, and that core is only 10 light days in diameter. Is this actually the BLR or within even the BLR? This AGN qualifies as the closest quasar, its low-luminosity quasar characteristics being again verified at this Symposium by W. Keel, A. Filippenko, and G. Fabbiano, but analogous VLBA studies will be extendable to other AGN. In the meantime, while waiting for the VLBA to become a routine instrument, optical and ground-based infrared observers must continue to compile well defined samples of the mystery galaxies within the IRAS catalog. Most of the work required is getting redshifts and beginning efforts to understand the morphologies on the basis of imagery at various wavelengths.

5. GALAXY MORPHOLOGIES

The products of one new technology began showing up in quantity at this meeting, that technology being the infrared array cameras, imaging primarily in the K band. Careful morphological studies of galaxies containing AGN still have much to teach us about what it takes to nurture a central engine. I. Shlosman, for example, convincingly demonstrated that bars are common in Seyfert galaxies, presumably providing dynamical help in allowing material to settle into the nucleus. Any demonstration that a gravitationally-controlled phenomenon in the outer regions of a galaxy influences the active nucleus is indirect support for the hypothesis that gravity controls the nucleus as well.

Although the near infrared images in some cases are dominated by very hot dust, they primarily are determined by the cooler stars in the galaxies. As these stars are more likely to be older and less massive than the bright blue stars which dominate a galaxy's morphology in visible light, the infrared images tend to show more the normal, underlying, fundamental stellar component of the galaxy. This is particularly important for galaxies with AGN, because so many such galaxies have irregular visible images caused by distorted distributions of ionized gas and hot stars. Such distortions are presumably caused by interactions, and they make the determination of intrinsic galaxy classifications very difficult. (G. de Vaucouleurs pointed out long ago that an automobile collision does not make a new kind of car; it just makes a wreck.)

By tracing the stars which more nearly represent the dominant mass of a galaxy, infrared imagery should allow better comparison of galaxies harboring AGN with normal galaxies (observers must be cautioned to accompany all studies of active galaxies with comparably sized control samples of galaxies thought to be normal). At present, the only limit to the amount of interesting work that can be done is telescope time. Even more exciting is the opportunity, for the first time, to compare nearby and distant galaxies without normalizing them through arbitrary assumptions about their spectra (the K-correction). In the near infrared, galaxies with redshifts of 1 to 2 can be observed at the same intrinsic wavelengths as nearby galaxies observed with CCD imagery. The most important project I can think of with an infrared array camera is to observe a selection of AGN at these redshifts and compare with objects at low redshifts having CCD imagery. Samples should be chosen on the basis only of the nuclear properties. Once and for all, it will be possible to determine if the galaxies containing AGN show luminosity evolution comparable to the evolution of the nuclei alone.

6. THE MANY USES OF QUASAR SURVEYS

The presence here of the small Armenian contingent, E. Khachikian and J. Stepanian, reminds us of Markarian's fundamental survey, to which many of us are greatly indebted. Although there were only about 1500 objects in this survey, more than twenty years were required to accumulate redshifts for all of them, and Markarian himself did not live to see this happen. The lesson is that those who accumulate survey data do so in large measure for the benefit of others to follow. It is not glamorous work with immediate gratifications, but to nurture research concerning AGN, continued surveys - particularly with Schmidt telescopes - are essential. The most productive such surveys for finding quasars are currently those using UK Schmidt plates searched with Automatic Plate Measuring techniques at Cambridge or Edinburgh. Such APM surveys were summarized by M. Smith in context of determining luminosity functions and evolution, and a poster paper on one APM survey was given by C. Foltz and colleagues.

By using both objective prism and multicolor search techniques, these surveys minimize selection effects. Just now, the most exciting problem which they are addressing is quasar evolution. Because quasars can be found in statistically meaningful numbers to z of 4, it is finally possible to trace the changes in the quasar luminosity function in detail in the crucial epoch of the universe when quasars (and galaxies) arise. A lot of effort is involved, both finding the candidates and obtaining follow-up spectra, but the only limitation to getting the answer is doing the work. Watching the evolution of AGN in the redshift interval from 2 to 4 is the only way of watching a component of the universe form and develop. This can never be done with normal galaxies, with any feasible instrument.

Another issue absolutely fundamental to cosmological understanding closely couples to accurate knowledge of quasar luminosity functions

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and evolution as seen in X-rays. This issue is disentangling the quasar contribution from the diffuse X-ray background, so that the residual cosmological component of that background can be specified. The extragalactic hard X-ray background (above 2 keV) is bright, analogous in surface brightness compared to discrete sources as the sky with a full moon seen by optical astronomers. As emphasized here by E. Boldt, the problem with this background is that it is too easy to account for all of it with evolving quasars; this cannot be the real explanation because the background spectrum is much flatter than quasar X-ray spectra. The background provides upper limits to quasar luminosity evolution, therefore. Even for people who do not care about quasars, correct accounting of them must be made to determine the residual cosmic background. In this case, the X-ray spectra of quasars are essential and any new results for such spectra, such as those given at this Symposium by K. Pounds, M. Urry and C. Canizares, are important for folding into optically derived luminosity functions.

Another use of increased samples of bright quasars is as back-lighting for probing otherwise undetectable material in the universe. There are three notable topics for which a great deal of further observing is needed. One is the continuing search for galactic disks at high redshifts using "damped Lyman α" absorption lines, as discussed here by H. Smith. These lines are characteristic of the amount of hydrogen in disks, and extensive surveys of quasar absorption line spectra are needed to locate many examples. It is imperative to compare counts of such features with direct imaging counts of faint galaxies whose spectra are not measureable. Similarly, the "Lyman α forest" has to be traced as a function of redshift because these weak absorption features show the smallest clouds of intergalactic gas that can be observed. Are these primordial, or did they come from galaxy mass loss? Is the universe really isotropic in the distribution of such material? A few enlightened people with large telescopes have been worrying about these problems for several years; there is room for many other observers when issues as fundamental as the cosmological principle are at stake. Finally, bright quasar samples are essential for searching out gravitational lenses.

Little was said about lensing at this Symposium, but what was here was important. S. Refsdal reminded us of the elegant confirmation of lensing models that account for the extraordinary configuration of a high redshift quasar found by J. Huchra in the very center of a low redshift galaxy. While such an observation might have rejuvenated support for non-cosmological redshifts, lensing models made a specific prediction. This was that the quasar image should actually have several components. After this prediction, these components were observed. This ability to make predictions which can be observationally tested accounts for the great appeal of lensing hypotheses compared to non-cosmological redshift suggestions when explaining improbable configurations of galaxies and quasars. New samples of quasars allow further searches for strange configurations that can test lensing models, simultaneously testing the universe for the presence of dark, massive objects. G. Meylan and S. Djorgovski are imaging newly discovered quasars to find possibly lensed examples. It is particularly

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important to image quasars discovered in Schmidt telescope surveys, as they are doing, because the spatial resolution of the discovery observations is usually insufficient to notice more than one component in the quasar image.

7. SUMMARY

I came to this Symposium to listen. After twenty years of intensive observing of AGN and frequent conferences on the topic, some of the old timers began to express concern that the early excitement had been mined out. That is not my current assessment. I have been impressed anew that we are still dealing with some of the most fundamental problems in astrophysics. Active Galactic Nuclei hold the key to basic questions of energy generation, radiation mechanisms, and cosmology. There are so many exciting problems; this causes a proliferation of relevant observations that may appear to some as a disorganized flood. But today's observers are an impressive lot, and what I saw and heard here proves that assaults on these basic problems are being very well planned.

DISCUSSION

WANDEL I strongly agree that we need to cross-correlate different methods of determining the masses of AGN. Actually, one step in this direction has already been done in this meeting. I am referring to my paper on the masses of AGNs which shows that the masses determined by the accretion-disk method agree with the masses found from broad emission-line dynamics. Such correlations could, however be treated with caution: in all three methods discussed, using variability, accretion disk, and emission lines, the mass increases with luminosity. Since we usually use magnitude-limited samples, it is not surprising that the masses calculated with different methods are correlated. One has to determine to what extent such correlations of different mass-estimations merely reflect a luminosity limited sample, or are more significant, suggesting a real intrinsic agreement.