New Prospects for Quasar Physics

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As a former undergraduate research assistant to Tom Armstrong (hereafter referred to as TPA), I am happy to reminisce about some of my experiences in 55 Malott Hall and comment on some of the scientific issues I've pursued since being introduced to research by TPA. My introduction to TPA occurred in 1983 after an advising session with Jack Davidson, our formidable and fascinating department chairman, who pointed out to me that I needn't scramble for improbable summer employment at national labs when research opportunities in physics existed close to home – in fact, in the subterranean recesses of Malott Hall. TPA informed me that, indeed, abundant opportunities existed for undergraduates within his group, and with the support of a summer Undergraduate Research Award, I was soon coming to terms with VMS and pondering the mysteries of IMP 8 data.

One of the pleasant features of working with TPA was the friendly environment to be found in the catacombs of the Space Plasma Physics Lab. As an undergraduate, I also enjoyed the novelty of actually having a desk and office of sorts. I shared space in the latter room with the coffee pot (used, in reality, to maintain a perpetual hot water supply as demanded by the tea-drinking habits of TPA and others) and a laboratory hood plastered with radioactivity signs. The fact that my office apparently doubled as a storage site for radioactive waste provided one of the few clouds in the skies of my halcyon summer. However, after some nervous inquiries and the assistance of a biochemist with a Geiger counter, I was reassured that the material in question (targets from the long-absented accelerator) posed little more radioactive hazard than did the limestone walls of Malott Hall.

The project TPA suggested I look into concerned whether the elemental composition of 2–4 MeV/nucleon interplanetary particles varies in any systematic way with solar cycle phase. Ultimately we found that H/He and He/CNO composition ratios do vary between solar minimum and maximum, particular when studied as a function of short-term flare and activity level. This study allowed me to participate in a small research endeavor from initial analysis, through presentation of results at a professional meeting, and ultimately publication in the *Journal of Geophysical Research.* The experience taught me a great deal about how decisions concerning data interpretation proceed, as well as about the mechanics of disseminating research results.

Undergraduates aren't necessarily the most efficient or productive people to have as research assistants, but TPA very patiently tolerated my simple-minded questions and mental woolgathering, while providing an occasional friendly prod to keep things moving. One pleasant distraction from work was provided by the various science-related magazines to which TPA subscribed and probably even read on the few occasions when his attention wasn't occupied by the demands of his research group. In particular, I recall reading with interest the review articles on astronomical topics that occasionally appeared in *Science* magazine. In one such article, reference was made to quasars, noting in particular that the standard paradigm for these objects assumes that they are powered by accretion onto a massive black hole. At the time, my knowledge of quasars was practically nonexistent and I found this description hard to digest. When I hesitantly asked TPA about this model, he confirmed that black holes figured into the picture, but suggested that in reality quasars were mysterious entities, and astronomers were probably fooling themselves if they thought they understood them.

TPA may consequently have rather mixed feelings about the fact that after leaving his fold, I've pursued dissertation research that focuses in large measure on quasars, or, more precisely, the diminutive form of this phenomenon seen in active galaxies. This line of work, like most other areas of astronomy and astrophysics, is certainly loosely constrained in comparison to interplanetary studies, which have the fundamental advantages offered by *in situ* measurement and high spatial resolution. Nonetheless, while deep mysteries concerning active galactic nuclei (AGN) persist, a surprising amount of information concerning the structure of their emission-line regions has been deduced. In the following paragraphs I will briefly describe a technique that is beginning to provide a much more detailed picture of AGN.

AGN are distinguished by prodigious energy generation within very compact regions. The radiative output of these sources appears to be nonstellar in origin, most strikingly in those cases that exhibit strong nonthermal radio and x-ray emission. The theoretical adoption of black hole accretion as the underlying power source has largely resulted from the failure to identify any competitive alternatives. However, evidence for the existence of massive black holes in the centers of some galaxies is mounting from measurements of the stellar dynamics in such regions (e.g., Kormendy 1988). Ultraviolet and optical spectra of AGN exhibit luminous permitted and forbidden emission lines from atomic species exhibiting a wide range of ionization. For one subset of these objects, the permitted lines are characterized by widths reflecting velocity distributions spanning several thousand km s^{-1}; the region giving rise to this emission is creatively referred to as the Broad Line Region (BLR). The gross aspects of the observed emission-line spectrum are surprisingly well duplicated by the spectrum predicted from simple models of slabs of gas irradiated by a power-law continuum. The absence of density-sensitive forbidden lines from the BLR apparently reflects a general trend of stratification such that emission-line clouds closer to the central source exhibit higher densities.

The compact nature of the AGN phenomenon is emphasized by strong variability in the continuum and broad-emission-line luminosities of some objects on timescales of less than a month. The strength of emission lines generally traces the ultraviolet and optical continuum brightness, although delayed in phase, consistent with photoionization of circumnuclear clouds by a central source responsible for the continuum radiation (e.g., Peterson 1988). Since the delay results from light travel-time requirements, measurement of the delay provides a constraint on the true physical extent of the BLR. Several attempts have been made in the past to spectroscopically monitor Seyfert galaxies in order to measure such time delays, though a general problem has been the acquisition of a data set of adequate duration and temporal sampling for this purpose. The best measurements to date have resulted from a recent coordinated campaign by a large group of observers utilizing the orbiting telescope on the *International Ultraviolet Explorer* and ground-based facilities to monitor NGC 5548 (Clavel *et al.* 1991; Peterson *et al.* 1991). To date, the NGC 5548 campaign has confirmed earlier suspicions that the BLR dimensions are considerably smaller than obtained in the early photoionization calculations. This finding has prompted a reassessment of the photoionization theory, leading to a revision of BLR model clouds to higher volume and column densities. This change has, in turn, removed an earlier inability of the photoionization models to reproduce high observed line strengths from Fe^+ and Ca^+ observed in some objects (Ferland and Persson 1989).

The accumulated data for NGC 5548 will permit a more detailed inquiry into the structure of the BLR. Blandford and McKee (1982) have elaborated a mathematical formalism for the interpretation of a time sequence of spectroscopic data, including consideration of variation as a function of velocity within the broad-line profiles. This technique, referred to as "reverberation mapping," can in principle be used to reconstruct the phase space distribution of emitting clouds in the BLR. Such an analysis has the potential to place new constraints on the geometry and possible coherent flows within the BLR. A realistic application of this method requires treatment of the photoionization process and its consequences for time response and anisotropies of line radiation. The detailed analysis of the NGC 5548 data in conjunction with a large existing photoionization code will be one focus of my future postdoctoral employment at Ohio State University.

A better understanding of physical conditions within the BLR might help us address the basic nature of BLR clouds and how they even manage to exist. The confinement of these apparently high density, low-filling-factor, irradiated clouds remains a persistent problem. Stronger constraints on the physical properties of the BLR might eventually make the associated plasma physics less ill-posed, and perhaps will make quasars seem slightly less mysterious and more tractable to investigators like TPA.

REFERENCES

Blandford, R.D., and McKee, C. F. 1982, *Astrophys. Journ.*, 255, 419.

Clavel, J., *et al.* 1991, *Astrophys. Journ.*, 366, 64.

Ferland, G.J., and Persson, S.E. 1989, *Astrophys. Journ.*, 347, 656.

Kormendy, J., 1988, *Astrophys. Journ.*, 325, 128.

Peterson, B.M., 1988, *Pub. Astr. Soc. Pac.*, 100, 18.

Peterson, B.M., *et al.* 1991, *Astrophys. Journ.*, 368, 119.