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FINAL REPORT

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ABSTRACT

Large amounts of high quality UV and optical data have been obtained in massive multi-wavelength monitoring campaigns on a small number of active galactic nuclei, and these data are changing our understanding of the central engines in these sources in a fundamental way. Preliminary analyses have shown that more comprehensive approaches will be necessary to make full use of these data. We propose to undertake a complete set of photoionization equilibrium calculations with a state-of-the-art computer code in order to determine the radial structure of the broad-line region in a way that is consistent with the emission-line fluxes, profiles, and transfer functions.

Project Description

I. Introduction

The broad emission lines in the ultraviolet and optical spectra of AGNs provide an important probe of both the mass and radiated spectrum of the central engines in these luminous sources. Through analysis of the broad-line spectrum, it is possible to determine something about the nature of the otherwise unobservable spectrum shortward of the Lyman limit. Furthermore, the dynamics of the gas are almost certainly determined by some combination of radiation pressure and gravity. It is possible to determine the distribution and kinematics of the broad-line region (BLR) clouds by observing the response of the broad emission lines to continuum variations; the structure of the BLR can be unraveled by observing how the BLR "reverberates" in response to continuum variability (Blandford & McKee 1982). Measurement of the continuum and emission-line light curves consequently provides a tool of tremendous potential importance for probing the very central regions of AGNs. Indeed, determination of the size and kinematics of the BLR can result in unambiguous measurement of the mass of the central engine and lead to the identification of some of the most important physical processes in this region.

The structure and kinematics of the BLR can be solved for formally by inversion of the transfer equation

$$L(v,t) = \int_{-\infty}^{\infty} \Psi(v,\tau)C(t-\tau)d\tau, \tag{1}$$

where $C(t)$ is the continuum light curve, $L(v,t)$ is the emission-line flux at line-of-sight velocity v at time t, and Ψ is a geometry-dependent "transfer function" (Blandford & McKee 1982), which can be thought of as the response of the emission line to a δ-function continuum outburst as seen by external observer. The aim of reverberation mapping is to invert the transfer equation to solve for $\Psi(v,t)$ and thus infer the BLR geometry and velocity field. Obviously, successful inversion of the transfer equation requires accurate determination of $C(t)$ and $L(v,t)$. Even with modest amounts of data, it is possible to extract limited information about the transfer function by cross correlation of $C(t)$ and $L(t)$, since convolution of eq. (1) with $C(t)$ shows that the cross-correlation function is the convolution of the transfer function with the continuum autocorrelation function.

As described in our original proposal, our intent has been to carry out a more thorough analysis of existing variability data than has been undertaken to date. Our ultimate goal is to determine the nature and origin of the broad-line clouds, since this may well provide the key element in explaining the AGN phenomenon.

II. Project Summary

Virtually all of the funds requested through the ADP program were used to provide funding for a postdoctoral research associate (Dr. Ignaz Wanders) to work on analysis of the existing space-based and related ground-based data AGNs that have been monitored with *IUE*, *HST*, and other observatories.

The first major result of the project was determination of the C IV transfer function for NGC 5548 (Wanders et al. 1995). The transfer function is consistent with an anisotropic continuum source illuminating clouds in randomly inclined circular Keplerian orbits. Recognition that the continuum source might be beamed led to a full consideration of how different orientations might lead to a variety of different one-dimensional (i.e., velocity-independent) transfer functions and line profiles (Goad & Wanders 1996).

We then followed up on this work with a detailed study of emission-line profile variability (Wanders & Peterson 1996; Peterson et al. 1998). We have found that emission-line profile variations are unrelated to reverberation effects — profile variability is due to geometrical or physical changes in the BLR on time scales of several months (the dynamical time scale). We believe that the observed profile variations can be interpreted through the anisotropic continuum model: in this model, the profile variations are due to stochastic effects, specifically to individual emission-line clouds moving in and out of the beamed continuum. The argument for this is that profile changes seem to occur only rather rarely and a given profile state seems to persist for a long time, longer than the light travel-time across the BLR. However, when profile changes occur, they can occur fairly abruptly. The strongest argument against this scenario is that stochastic effects are unlikely to be responsible for profile variability if the number of clouds is very large, 10^{7-11} in various traditional estimates. However, we have argued earlier that these usual arguments about cloud numbers are generally specious (Peterson 1994). The *absence* of profile structure on small velocity scales ($500\,\mathrm{km\,s^{-1}}$ or less) indicates that the individual line-emitting clouds must have a supersonic component (such as a wind, perhaps), since the individual clouds must emit their radiation over a large line-of-sight velocity range, something like $10^3\,\mathrm{km\,s^{-1}}$ rather than the $10\,\mathrm{km\,s^{-1}}$ thermal width.

The work initiated under this grant is being continued and additional refereed publications describing more recent results are being prepared for submission under support for subsequent proposals.

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