THE ASTROPHYSICAL JOURNAL, 353:108–113, 1990 April 10

HIGH-RATE SPECTROSCOPIC ACTIVE GALACTIC NUCLEUS MONITORING AT THE WISE OBSERVATORY. II. NGC 5548

H. NETZER, D. MAOZ, A. LAOR, H. MENDELSON, N. BROSCH, E. LEIBOWITZ,
E. ALMOZNINO, S. BECK, AND T. MAZEH
School of Physics and Astronomy and the Wise Observatory,[1] Tel-Aviv University
Received 1989 June 5; accepted 1989 September 22

ABSTRACT

We present further results of the spectroscopic monitoring of AGNs, described in Paper I of this series, for the Seyfert galaxy NGC 5548. The high sampling rate (44 spectra during a 149 day period) and measurement accuracy (3%–4% in absolute flux) of our observations allow the resolution of a small pulse in Hα, Hβ, and the optical continuum in this object during May–June of 1988. Cross-correlation of the line and continuum light curves yields a very significant peak at a lag of 7 days in the emission line response to continuum variations. Using Monte-Carlo simulations, we estimate the size of the broad line region (BLR) in this galaxy to be 4–10 lt-days with a probability of 68%. Our results rule out, at the 95% significance level, a BLR 14 lt-days or larger for several different assumed gas distributions. This is an additional BLR size measurement discrepant by an order of magnitude with the predictions of "standard" photoionization theory. Several possible solutions to this problem are briefly discussed.

Subject headings: galaxies: individual (NGC 5548) — galaxies: nuclei — galaxies: photometry

I. INTRODUCTION

The study of continuum and emission-line variability is a potentially powerful tool for the understanding of active galactic nuclei (AGNs). In particular, measurement of the time lag in emission-line response to continuum variations may yield the size of the broad line region (BLR). Much observational effort has been dedicated to this purpose over the past decade (see Peterson 1988 and references therein).

In Paper I of this series (Maoz *et al.* 1990, hereafter Paper I) we presented first results of a monitoring project carried out at the Wise Observatory in an attempt to measure the size of the BLR in a sample of AGN. Our project is among the very few where systematic monitoring on a short enough time scale (3–4 days) has been attempted. This is crucial to the study of AGNs, since previous work along this line has suffered from severe undersampling. Our observing method and data reduction and analysis were described in detail in Paper I. There we studied the bright Seyfert galaxy Mrk 279 and found a lag of 12 ± 3 days in the Hα and Hβ response to changes in its optical continuum. This result is an order of magnitude shorter than predicted by "standard" photoionization models. In the present paper we present our results for the Seyfert galaxy NGC 5548.

NGC 5548 is a typical and relatively well-studied Seyfert 1. Various aspects of its variability have been studied by Gregory, Ptak, and Stoner (1982), Barr, Willis, and Wilson (1983), Wamsteker *et al.* (1986), Peterson and Ferland (1986), Chuvaev (1987), Reichert and Peterson (1988), Stirpe, van Groningen, and de Bruyn (1988), and Branduardi-Raymont (1989). Large-amplitude line and continuum variability have been observed, both in the optical and in the UV. Estimates of the BLR size based on variability have been given by Peterson and Gaskell (1986), Peterson (1987*a*, *b*), Peterson, Korista, and Cota (1987), and Wamsteker *et al.* (1990). According to these studies, the BLR in NGC 5548 has a size of order 30 lt-days or less and may be stratified or contain several components. None of these studies had the temporal resolution required to determine accurately the size of the BLR in this object. The aim of our project, including NGC 5548, was to achieve both the high temporal resolution and the measurement accuracy needed for this. Preliminary results of this work have been published by Maoz (1989) and Netzer *et al.* (1989).

In § II we describe our observations of NGC 5548 and in § III we present the line and continuum measurements, In § IV the results are analyzed, the size of the BLR of NGC 5548 is estimated, and the implications of these and other similar results are briefly discussed.

II. OBSERVATIONS

The observational setup and procedure are identical for all objects (11 Seyferts and three quasars) in our sample and were described in Paper I. For completeness, we repeat here the main points.

The observations were carried out at the Wise Observatory using the 1 m telescope with a Boller & Chivens spectrograph at the Cassegrain focus, and a thinned RCA 512 × 320 pixel CCD. A 300 line mm^{-1} grating yielded spectra between 4600 and 700 Å with a resolution of ~10 Å (2 pixels). The observing procedure was as follows:

1. An 8′ long and 20″ wide slit was used.
2. For each observation of NGC 5548, the slit was oriented so that the 14th mag field star 2′.5 south of the galaxy ("star 1" of Penston, Penston, and Sandage 1971), serving as a comparison standard, could be observed simultaneously.
3. Two consecutive 15 or 20 minute exposures were taken on each successful observing run.
4. To obtain wavelength calibration, He-Ar arc spectra were obtained several times each night.

The most important ingredient of this procedure is the simultaneous observation of the comparison star. As shown in Paper I, it yields a differential photometric accuracy of about 3%, even at high air mass and with adverse weather conditions.

[1] Of the Raymond and Beverly Sackler Faculty of Exact Sciences.

Four spectra of the comparison star were obtained on photometric nights together with standard stars (Stone 1977) and were calibrated independently. The flux measurements in several bands of these spectra are constant with a standard deviation of 4%. In addition, differential spectrophotometry of the comparison star was carried out using the comparison stars of the other galaxies in the sample during eight additional photometric nights. This gives the same limit on the variability of the comparison and is consistent with the assumption that it is constant.

The two consecutive exposures made each night give a check on the quality of the observation in terms of guiding accuracy and seeing effects. Data in which the ratio between the Galactic and comparison star spectrum was not identical to within 3% in the two exposures were discarded. The spectra from the two exposures were added if the ratio was the same.

We observed NGC 5548 on 48 nights during a 149 day period between 1988 February 20 and July 18. Three epochs were discarded for failing the criterion of identity between the two consecutive exposures, and one due to unacceptably low S/N (< seven per spectral element in the V continuum region). We thus have 44 successful observations, or an average sampling interval of 3.4 days. These dates are shown in Table 1. The average sampling interval during the second half of the observing period, when the most important variation took place (see § III below), is 2.5 days. No Seyfert galaxy has been observed with such frequency before.

The extraction of flux and wavelength calibrated spectra from the two-dimensional CCD images is identical to that described in Paper I and will not be repeated here.

TABLE 1

LINE AND CONTINUUM MEASUREMENTS OF NGC 5548 IN 1988

Date	Day	4710-4760A	5375-5575A	5950-6050A	6340-6440A	$H\beta$	$H\alpha$
Feb20	1	153±5	142±4	138±4	141±4	72±2	299± 9
Mar 8	17	150±7	136±5	132±5	142±7	68±6	324±13
Mar 9	18	146±5	138±4	137±4	139±4	73±3	291± 9
Mar11	20	139±4	135±4	127±4	131±4	71±2	293± 9
Mar12	21	142±4	133±4	129±4	134±4	60±2	279± 9
Mar14*	23	148±5	130±4	123±4	133±4	66±3	288± 8
Mar18	27	152±4	139±4	133±4	140±5	66±2	281± 9
Mar27*	36	159±4	141±4	133±4	137±4	70±2	305± 9
Mar31*	40	145±5	138±4	133±4	134±4	79±3	295± 9
Apr13	53	153±5	138±4	132±4	144±4	65±3	298± 9
Apr15	55	148±4	131±4	123±3	132±4	68±2	298± 9
Apr18	58	152±4	139±4	131±4	139±4	69±2	311± 9
May 1	71	131±6	131±5	127±4	116±4	66±4	301± 9
May 5	75	144±4	129±4	131±4	124±4	72±4	301± 9
May 6*	76	156±5	138±4	130±4	136±4	68±3	293± 9
May 7	77	138±5	131±4	128±4	127±4	68±4	279± 8
May 9	79	159±4	144±4	136±4	141±4	69±2	300± 9
May11*	81	166±5	145±4	141±4	144±4	68±2	296± 9
May14*	84	155±5	145±4	137±4	144±4	65±3	292± 9
May17	87	147±4	140±4	135±4	137±4	68±2	286± 8
May19	89	161±5	148±4	147±4	149±4	75±3	310± 9
May23*	93	163±5	145±4	139±4	144±4	70±3	304± 9
May26	96	154±5	146±4	143±4	139±4	79±3	307± 9
May27	97	157±5	140±4	135±4	138±4	74±2	295± 9
Jun 2	103	161±4	146±4	144±4	148±4	75±4	288± 9
Jun 3	104	159±5	153±5	137±4	143±5	74±3	320±10
Jun 4	105	150±5	147±4	141±4	139±4	78±3	319± 9
Jun 6*	107	163±5	146±4	141±4	149±4	74±3	336±10
Jun 7	108	157±5	145±4	136±4	142±4	77±3	309± 9
Jun 8*	109	160±5	147±4	140±4	141±4	80±3	310± 9
Jun10	111	166±5	151±4	145±4	144±4	73±3	319± 9
Jun11	112	163±5	144±4	143±5	149±5	65±6	319±10
Jun14	115	159±5	150±4	143±4	148±4	80±3	328±10
Jun16	117	145±5	141±4	133±4	133±4	80±4	314± 9
Jun19	120	147±4	136±4	128±4	133±4	79±3	296± 9
Jun20	121	146±4	143±4	137±4	137±4	86±3	309± 9
Jun23	124	143±5	131±4	130±4	135±4	69±3	299± 9
Jun26*	127	148±4	133±4	138±4	152±5	68±2	315±10
Jul 6	137	146±5	136±4	133±4	140±4	61±3	307± 9
Jul 7	138	146±5	138±4	138±4	141±4	75±3	310± 9
Jul11	142	139±5	135±4	134±4	136±4	71±3	290± 8
Jul12	143	158±5	140±4	132±4	136±4	61±3	303± 9
Jul17*	148	161±5	147±4	140±4	147±4	70±2	299± 9
Jul18*	149	168±5	148±4	143±4	148±4	60±2	291± 8

NOTES.—Units for specified bands: 10^{-16} ergs s^{-1} Å^{-1} cm^{-2}. Units for Hα and Hβ: 10^{-14} ergs s^{-1} cm^{-2}. Day 1 is JD 2,447,212. An asterisk indicates a photometric night.

III. LINE AND CONTINUUM MEASUREMENTS

In each reduced spectrum we measured the mean continuum flux density at four spectral bands: 4710–4760 Å, 5375–5575 Å, 5950–6050 Å, and 6340–6440 Å (rest wavelengths). The continuum underlying Hβ was assumed to be a straight line in F_λ between the first two bands, and the Hβ flux was found by integrating from 4810 Å to 4910 Å. This is not the total Hβ flux, as it excludes part of the wings of the line. Such an exclusion is necessary due to the noise that the inclusion of low-lying wings and improperly subtracted [O III] $\lambda\lambda$4959, 5007 residuals would introduce into the data. Nevertheless, the flux between 4810 and 4910 Å includes most (about 90%) of the line flux, which is what concerns us as we are foremost interested in the region which emits the bulk of the line.

The continuum underlying Hα was set by extrapolating that measured in the longest λ continuum band at a constant F_λ level. This is justified by the fact that, within our slit, the continuum appears constant in F_λ between the two sides of Hα, to within the uncertainties. Use of the small line-free continuum interval between the red wing of Hα and [S II] $\lambda\lambda$6716, 6732, or subtraction of the [S II] lines in order to set the continuum level would again needlessly introduce noise into the data. The Hα flux was integrated from 6470 to 6630 Å. Due to our low resolution, no attempt was made to remove the [N II] $\lambda\lambda$6548, 6583 and Fe II lines, or the narrow components from Hα and Hβ, nor the stellar contribution from the continuum. The [N II] lines contribute about 3% to the total Hα flux (Osterbrock 1977). The stellar continuum is about 0.65 of the total continuum flux density we observe at 5400 Å (Malkan and Filippenko 1983). The results of these measurements and their individual errors are shown in Table 1.

In Paper I, the error in our flux calibration was derived from our repeated observations of the Seyfert 2 galaxy Mrk 3, and of NGC 3516, a Seyfert 1 in our sample which did not vary. This error was found to be 3% (1 σ). We calculate our total measurement errors by combining this error with the error from counting statistics and the propagation of the error in setting the continuum level beneath the lines. The typical total error is 3%–4% for Hα and continuum measurements and 5% for Hβ.

NGC 5548 was in a relatively quiescent state during the monitoring period, as seen in Figure 1, where the two line and the continuum light curves are shown. Nevertheless, the high accuracy of the measurements coupled with their high sampling rate reveal unmistakable structure. Most apparent in the continuum light curve is a month-long pulse of about 10% amplitude between mid-May and mid-June. Considering the stellar contribution to the continuum through the aperture we use (Malkan and Filippenko 1983) this corresponds to a 20%–30% variation of the nonstellar optical continuum. The Hβ light curve shows a gradual brightening of 15% at about the same time, followed by a sudden drop between June 20 and June 23. Hα also brightens, but only by about 6%, and gradually declines to its previous level.

Considering the small amplitude of these variations, it is important to verify their reality. An apparent overall brightening of the spectrum could be caused by a decrease in brightness of the comparison star. Inspection of the comparison star spectra taken on photometric nights shows no such anticorrelation with the galaxy's brightness; the mean comparison star flux density in several bands is the same to within 2% before and during the pulse. An additional check for this or other systematic effects is the [O III] λ5007 line which is generally accepted to be constant, at least on short time scales. The [O III] λ5007 fluxes in our spectra have a standard deviation of 4% with no correlation with the pulse. The average of 14 spectra before the continuum pulse (Feb 20 through May 5) and 17 spectra on the plateau of the pulse (May 9 through June 14; see Fig. 1) have the same [O III] λ5007 flux to within 2%.

The clear shape of the pulses allows us to estimate the BLR size in NGC 5548, as discussed in the next section.

IV. DISCUSSION

a) *Cross-Correlation Analysis*

To determine the lag in the emission-line response to changes in the continuum we linearly interpolated and cross-correlated the various light curves we obtained. Figure 2 shows the cross-correlation functions (CCFs) of Hβ and Hα with the continuum in the band indicated.

The CCF of Hβ versus the continuum has a sharp and symmetric peak at a small positive lag. A parabolic fit to the upper half of the CCF peak has a maximum of 0.62 at a lag of +7 days. Such a correlation is highly significant for this number of points. We have also calculated the discrete correlation function (DCF; Edelson and Krolik 1988) for the same data. This method does not introduce artificial (interpolated) data points into the correlation and is designed to account for correlated errors in lines and continuum by ignoring correlations between points taken at the same time. Its superiority to the CCF is, however, disputed (e.g., Rodríguez, Santos-Lleo, and Clavel 1989). Nonetheless, the DCF for these data has a very similar shape.

The CCF of Hα versus the continuum has two peaks of about 0.5, one at a negative lag of −45 days and the other between 0 and 30 days. The peak at negative lag results from a resemblance between the structure of the continuum pulse and the first, relatively badly sampled, 80 days of the Hα light curve. The detailed structure of the peak at positive lag is different in the CCF and the DCF. Part of this difference results from the low Hα measurement on day 103 which is preceded by a 6 day gap, thus introducing a series of decreasing interpolated points into the CCF; exclusion of the measurement on day 103 makes the positive lag peak flatter in both the CCF and the DCF and thus more similar in the two methods. In addition, use of a third correlation method, intermediate between these two in that it uses only some interpolated data points (Mazeh 1990, in preparation), also gives a noisy but flat-topped peak. We conclude that the detailed structure of the CCF peak is not significant in this case and use only the broad structure of the peak to derive the lag. A parabolic fit to it has a maximum of 0.45 at a lag of 16 days. Further discussion of the Hα and Hβ results follows below. We note here that due to the higher amplitude, relative to the measurement error, of the Hβ variation, leading to a less noisy and more highly peaked CCF, we consider the Hβ result as our main result.

To evaluate the significance of these results and the uncertainty in the BLR size they imply, we performed Monte Carlo simulations as described in Maoz and Netzer (1989) and in Paper I. A model light curve for the continuum of NGC 5548 was created by linearly interpolating our continuum light curve. The response of the emission lines to this continuum was calculated for a variety of BLR geometries assuming that the emission lines respond linearly to the continuum, each geometry giving a model emission-line light curve. The model

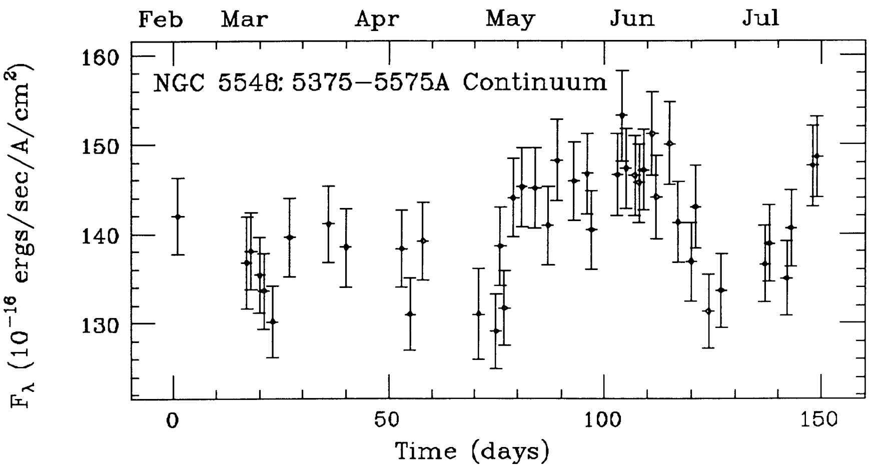

FIG. 1*a*

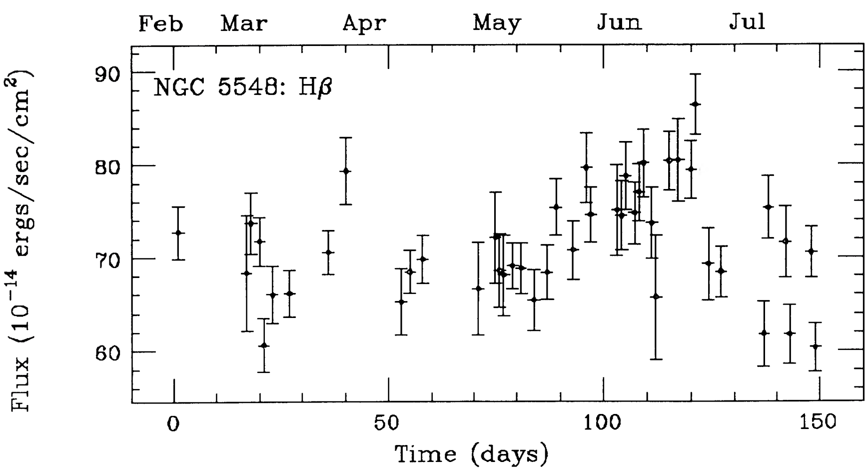

FIG. 1*b*

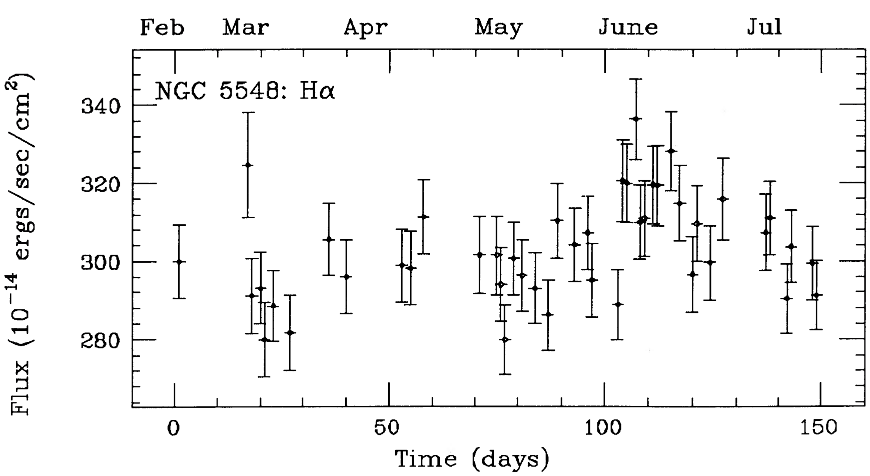

FIG. 1*c*

FIG. 1.—Line and continuum light curves of NGC 5548. (*a*) The 5375–5575Å continuum. Error bars denote the 1 σ uncertainty, as explained in text. (*b*) Hβ. (*c*) Hα.

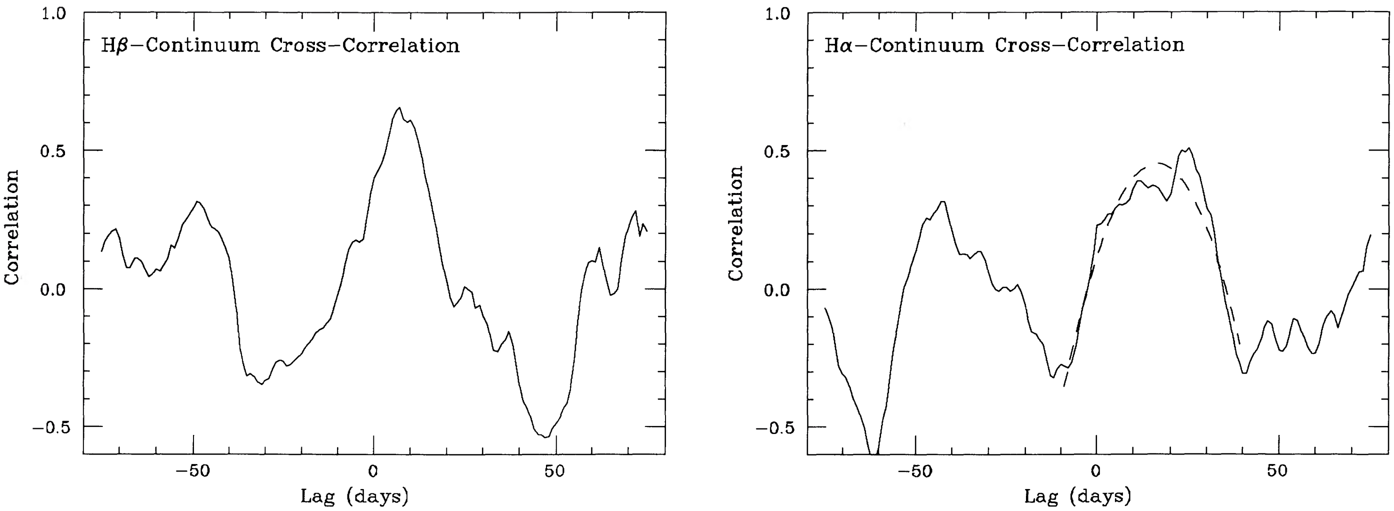

FIG. 2*a* FIG. 2*b*

FIG. 2.—Cross-correlation functions. (*a*) The cross-correlation function of Hβ vs. the 5375–5575 Å continuum. (*b*) Hα vs. the 5375–5575 Å continuum. Also shown (*dashed curve*) is a parabola fit to the peak of the CCF.

line and continuum light curves were then sampled at random on 44 epochs. A random "measurement error," typical of our measurement errors for NGC 5548 in terms of the ratio between the amplitude of the variation and the error, was added. The resulting light curves, each having the same number of points as the real data, were cross correlated, and the peak of the CCF found through a parabolic fit. The random sampling process was repeated 500 times to obtain the cross correlation peak distribution (CCPD; see Maoz and Netzer 1989) and determine the probability of obtaining a certain cross-correlation result given an assumed BLR geometry.

Based on the assumptions above, we find from the simulations that the Hβ results rule out at the 95% significance level, or better, the following BLR geometries (chosen to typify some common models) for NGC 5548:

1. Thin shells with radius 14 (lt-days) or larger, and thick shells of inner radius 14 lt-days or larger.
2. Thick shells of inner radius 4 lt-days and outer radius greater than 40 lt-days.
3. Nearly face-on rings of radius 11 lt-days or larger, rings with axis inclined by less than 45° and radius 12 lt-days or larger, and rings of any inclination with radius 14 lt-days or larger.
4. Thin disks inclined by 60° to the line of sight of inner radius 7 lt-days and outer radius larger than 30 lt-days.

These results alone, being of one season's length, cannot rule out much larger BLR models, as the observed line variation could be the reponse to a much earlier continuum event. However, such a scenario is not consistent with the previous variability studies of NGC 5548 (e.g., Peterson and Gaskell 1989; Wamsteker *et al.* 1990) carried out for periods of years, which show that the response time of the lines in this object is certainly less than a few months.

As explained by Maoz and Netzer (1989), the Monte Carlo simulations can also be used to estimate the equivalent of the 1 σ uncertainty (i.e., the 68% probability range) in our 7 day lag result. Our simulations show that if one assumes a thin shell geometry BLR of radius 7 lt-days and the observed continuum light curve then there is a 68% probability of obtaining a cross-correlation peak at a lag of 7 ± 3 days, assuming the emission-line response pulse has an amplitude of 3 times the typical individual measurement error (as in our Hβ data). Similarly, the 95% probability range is 7 ± 6 days. Alternatively, the CCF will peak at 7 ± 7 days for a 1.5 σ pulse, as in our Hα light curve. In such a case there is also a 15% probability of obtaining the CCF peak at a negative lag. Our observed results for both lines are therefore consistent with a BLR of 7 lt-days, although the Hα and Hβ-emitting radii neeed not be exactly the same.

Our data thus indicate a BLR size of 7 ± 3 lt-days (68% significance) and 7 ± 6 lt-days (95% significance) for NGC 5548, assuming a thin shell geometry.

b) Comparison with Photoionization Theory

NGC 5548 has a typical Seyfert 1 spectrum. The size of its BLR can therefore be estimated within the framework of the "standard" photoionization model for AGNs (e.g., Davidson and Netzer 1979; Kwan and Krolik 1981; Mushotzky and Ferland 1984). Using a representative F_ν (1350 Å) from Wamsteker *et al.* (1990), we estimate

$$R_{\rm BLR} \sim 150\,(H_0/50)^{-1}(U/10^{-2})^{-0.5}(N_{10})^{-0.5}\ \text{lt-days}\,,$$

where H_0 is the Hubble constant in km s^{-1} Mpc^{-1}, U is the dimensionless ionization parameter, and N_{10} is the electron density in units of 10^{10} cm^{-3}. The commonly accepted values for these parameters of $U \sim 10^{-2}$, $N_{10} \sim 1$, and $H_0 = 50$ yield $R \sim 150$ lt-days. Our result, an order of magnitude smaller, conflicts with photoionization models for a spherical BLR with such values of U and N.

This discrepancy was first pointed out in general by Peterson *et al.* (1985) and Gaskell and Sparke (1986). NGC 5548 is the third Seyfert galaxy (following Mrk 279 (Paper I), and as of yet unpublished results for NGC 4151 (Clavel, Ulrich, and Wamsteker 1989) for which an accurate BLR size measurement is smaller by an order of magnitude than the standard model predictions. Akn 120 (Peterson and Gaskell 1989; Alloin, Boisson, and Pelat 1989) may probably be added to this list, although there is still need for homogeneous and systematic data on this object. In addition to these, Fairall 9, which changed from a bright quasar-like state to a fairly bright Seyfert over 2 years, shows a time lag of ~ 150 days in emission-line response (Clavel, Wamsteker, and Glass 1989). If one takes the bright phase to represent its "normal" luminosity, the lag in this object is also much less than expected.

The four or five reliable measurements of the BLR size all show it to be a factor of 3–10 times smaller than predicted by photoionization theory. If the theory is not to be rejected, then the product UN must be larger by a factor of 10–100 in order to explain the new observations. There have been several attempts to calculate such models (see review by Netzer 1989). Rees, Netzer, and Ferland (1989) investigated AGN models where very high density clouds at small radii contribute to the emission lines. Such models scaled to $U \sim 10^{-2}$ at the radius where $N_{10} \sim 1$ fail to reproduce the AGN spectrum if the BLR is truncated at a radius consistent with the new size measurements. Netzer (1987) and Ferland and Persson (1989) studied different aspects of large U models. Ferland and Persson showed that the C III 1909/C IV 1549 ratio in such models is much larger than previously calculated. Thus the carbon lines do not necessarily indicate $U \sim 10^{-2}$. Furthermore, much better agreement of the calculated high-ionization lines (Netzer 1987) with observations can be obtained by using a large U in disklike systems. Further discussion of these possibilities is given in Netzer (1989). Such models are promising and may lead to the solution of the small size BLR problem presented here.

We wish to thank Ezra Mashal and Sammy Ben-Guigui, of the Wise Observatory staff, for their dedicated assistance during this project. This work was supported by grant 85/00085 from the United States–Israel Binational Science Foundation (BSF), Jerusalem, Israel; by a grant from the Israel Academy of Sciences, and by a grant from the Israeli Ministry of Science and Development.

REFERENCES

Alloin, D., Boisson, C., and Pelat, D. 1989, preprint.
Barr, P., Willis, A. J., and Wilson, R. 1983, *M.N.R.A.S.*, **203**, 201.
Branduardi-Raymont, G. 1989, in *IAU Symposium 134, Active Galactic Nuclei*, ed. D. O. Osterbrock and J. S. Miller (Dordrecht: Kluwer), p. 177.
Chuvaev, K. K. 1987, in *Observational Evidence of Activity in Galaxies*, ed. E. Ye. Kachikian, K. J. Fricke, and J. Melnick (Dordrecht: Reidel), p. 203.
Clavel, J., Ulrich, M. H., and Wamsteker, W. 1989, *IAU Circ.*, No. 4721.
Clavel, J., Wamsteker, W., and Glass, I. S. 1989, *Ap. J.*, **337**, 236.
Davidson, K., and Netzer, H. 1979, *Rev. Mod. Phys.*, **51**, 715.
Edelson, R. A., and Krolik, J. H. 1988, *Ap. J.*, **333**, 646.
Ferland, G., and Persson, S. E. 1989, *Ap. J.*, **347**, 656.
Gaskell, C. M., and Sparke, L. S. 1986, *Ap. J.*, **305**, 175.
Gregory, S., Ptak, R., and Stoner, R. 1982, *Ap. J.*, **261**, 30.
Kwan, J., and Krolik, J. H. 1981, *Ap. J.*, **250**, 478.
Malkan, M. A., and Filippenko, A. V. 1983, *Ap. J.*, **275**, 477.
Maoz, D. 1989, in *IAU Symposium 134, Active Galactic Nuclei*, ed. D. O. Osterbrock and J. S. Miller (Dordrecht: Kluwer), p. 100.
Maoz, D., and Netzer, H. 1989, *M.N.R.A.S.*, **236**, 21.
Maoz, D., *et al.* 1990, *Ap. J.*, **350**, 75 (Paper I).
Mazeh, T. 1990, in preparation.
Mushotzky, R. F., and Ferland, G. J. 1984, *Ap. J.*, **278**, 558.
Netzer, H. 1987, *M.N.R.A.S.*, **225**, 55.
———. 1989, *Comments Ap.*, **14**, 137.
Netzer, H., *et al.* 1989, *IAU Circ.*, No. 4780.
Osterbrock, D. E. 1977, *Ap. J.*, **215**, 733.
Penston, M. V., Penston, M. J., and Sandage, A. 1971, *Pub. A.S.P.*, **83**, 783.
Peterson, B. M. 1987*a*, *Ap. J.*, **312**, 79.
———. 1987*b*, in *Emission Lines in Active Galactic Nuclei* (Proc. of the Sixth Rutherford Appleton Laboratory Workshop on Astronomy and Astrophysics), ed. P. Gondhalekar and H. Netzer, p. 195.
———. 1988, *Pub. A.S.P.*, **100**, 18.
Peterson, B. M., and Ferland G. J. 1986, *Nature*, **324**, 345.
Peterson, B. M., and Gaskell, C. M. 1989, preprint.
Peterson, B. M., Korista, K. T., and Cota, S. A. 1987, *Ap. J. (Letters)*, **312**, L1.
Peterson, B. M., Meyers, K. A., Capriotti, E. R., Foltz, C. B., Wilkes, B. J., and Miller, H. R. 1985, *Ap. J.*, **292**, 164.
Rees, M., Netzer, H., and Ferland, G. 1989, preprint.
Reichert, G. A., and Peterson, B. M. 1988, in *Proc. of the Georgia State University Conference on AGN*, ed. H. R. Miller and P. J. Miller (Berlin: Springer), p. 43.
Rodríguez, P. M., Santos-Lleo, M., and Clavel, J. 1989, *Astr. Ap.*, in press.
Stirpe, G. M., van Groningen, E., and de Bruyn, A. G. 1988, *Astr. Ap.*, **211**, 310.
Stone, R. P. 1977, *Ap. J.*, **218**, 767.
Wamsteker, W., *et al.* 1986, in *New Insights in Astrophysics: Eight Years of UV Astronomy with IUE*, ed. E. J. Rolfe (ESA Spec. Publ. ESA SP-263), p. 701.
Wamsteker, W., *et al.* 1990, *Ap. J.*, in press.

ELHANAN ALMOZNINO, SARA BECK, NOAH BROSCH, ARI LAOR, ELIA LEIBOWITZ, DAN MAOZ, TSEVI MAZEH, HAIM MENDELSON, and HAGAI NETZER: School of Physics and Astronomy and the Wise Observatory, Tel-Aviv University, Tel-Aviv 69978, Israel